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D. M. BEACH, *Editor*

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CERTIFICATE: By direction of the Commissioner of Public Roads, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

LIFE CHARACTERISTICS OF SURFACES CONSTRUCTED ON PRIMARY RURAL HIGHWAYS[1]

BY THE DIVISION OF CONTROL, PUBLIC ROADS ADMINISTRATION

Reported by ROBLEY WINFREY, Research Associate Professor, Iowa State College, and FRED B. FARRELL, Associate Highway Engineer-Economist, Public Roads Administration

Life characteristics of various surface types constructed on primary rural highways were determined from the analysis of construction and retirement mileage data obtained by several States in connection with the road-life study phase of the State-wide highway-planning surveys. Approximately 210,000 miles of construction up to January 1, 1937, of various surface types in 26 States were involved in the analyses of average service lives. In addition, an analysis was made of the disposition of mileage at the time of retirement, involving slightly over 56,000 miles of retired surfacing in 23 of the 26 States.

Estimates of average service lives were obtained from statistical analyses involving the use of survivor curves. Data were available for some types as early as 1903 and a continuous record of the miles remaining in service for each year's construction was available up to January 1, 1937. Each year's construction was analyzed separately, where possible. In general it was found that the average service life of the lower types decreased and the higher types increased during the period of 1910 to 1936.

The predominating limits of average service lives were as follows: Soil surfaced, 5 to 14 years; gravel or stone, 6 to 13 years; bituminous surface treated, 11 to 21 years; mixed bituminous, 14 to 22 years; bituminous penetration, 15 to 17 years; bituminous concrete, 13 to 20 years; portland cement concrete, 17 to 24 years; and brick or block, 18 to 21 years.

Retirement of a road surface is considered as being effected when (1) the wearing surface undergoes a resurfacing operation (other than a routine maintenance operation), (2) the surface is reconstructed, (3) the road is abandoned, (4) the road is transferred to another public authority for continued maintenance and reconstruction, or (5) the surface reverts to a lower type through lack of adequate maintenance. Approximately 12 percent of all retirements involved construction on new location.

The large annual increases in usage by the motor vehicle of the highways of the United States during the past few years have brought to the engineer, the legislator, and the general public the realization that there is no permanent type of highway facility. Many structures and roadways which were built to the most modern standards as recently as 10 years ago are rapidly becoming obsolete and in many instances consideration is already being given to their replacement or reconstruction.

In order to realize the maximum service from a highway, the highway engineer is obliged to design for conditions that he estimates will exist 10, 20, 30, and even 50 years in the future. It is obviously an economic waste to construct a road that will last 30 years from a structural standpoint, only to find that it must be abandoned within 10 years because of poor alinement or grades. Further, it is shortsighted policy to build a surface expected to last 20 years under existing traffic conditions if increases in traffic are anticipated that will immediately result in the structural failure of the road surface.

To evaluate the present status of the highway system and to formulate plans for orderly future development, it is necessary to estimate (1) the extent to which existing alinements and grades will be adequate for anticipated conditions in future years, and (2) how long the various types of surfaces, structures, and other appurtenances will afford satisfactory service before replacement is required.

Analyses of the service lives of roadway surfaces and other highway elements are necessary (1) to make available the facts concerning the service lives of the various types of highway construction and (2) so that estimates of revenue required for highway purposes can be prepared which are consistent with the probable kind and extent of necessary replacements. Studies of this character were first undertaken in 1934 at Iowa State College when a study of the street pavements in Des Moines, Iowa, was started.[2]

In January 1935, the studies of service lives of roadway surfaces were extended to State highway systems and other cities under a cooperative agreement between the Public Roads Administration (then the Bureau of Public Roads) and Iowa State College. Under this agreement, studies[3] were made in Buffalo, New York; Des Moines, Iowa; Wayne County, Michigan; Massachusetts; Rhode Island; New Hampshire; and Vermont.

Starting in the fall of 1935, these studies, designated as road-life studies, were incorporated as a phase of the State-wide highway-planning surveys inaugurated in the several States under the direction of the Public Roads Administration. Up to December 1940, 46 States had undertaken this phase of planning surveys.[4]

In addition to the compilation of data upon which to base calculations of average service lives of roadway surfaces, the road-life studies include tabulations and investigations of construction costs, salvage values of retired roadway elements, maintenance costs and the service lives of structures, traffic services, grading, right-of-way, etc. This work is being accomplished by State personnel in the individual States under the supervision of the Public Roads Administration. Involved in this phase of the highway planning survey are painstaking search and recording of the maintenance and construction records for each mile of primary State or Federal-Aid highways.

DATA OBTAINED FOR 9 ROAD SURFACE TYPES IN 26 STATES

This report is confined to an analysis of the data relative to the service life characteristics of various surface types compiled for the rural portions of the

[1] Paper presented at the Twentieth Annual Meeting of the Highway Research Board, December 1940.

[2] A Mortality Curve Study of the Actual Service Lives of Brick-on-Concrete Pavements, Des Moines, Iowa, 1909–1928, by Anson Marston. Proceedings Highway Research Board, Vol. 14, Pt. 1, pp. 49–58. 1934.

[3] Preliminary Studies of the Actual Service Lives of Pavements, by Robley Winfrey. Proceedings Highway Research Board, Vol. 15, Pt. 1, pp. 47–60. 1935.

[4] Some of the States have published or have available certain results and applications of the road-life studies, and other States are in the process of completing reports. Such information and reports, if available, may be obtained directly from the State highway department.

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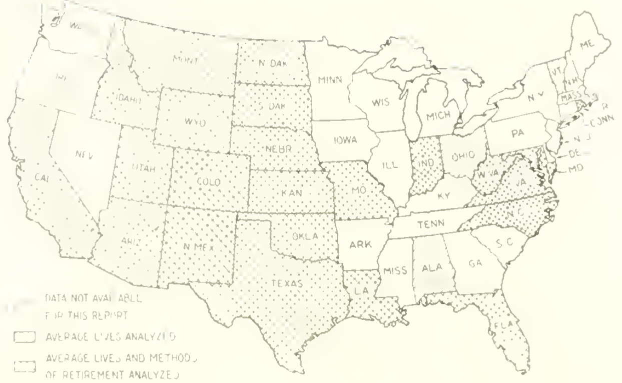

FIGURE 1.—STATES FOR WHICH ROAD-LIFE MILEAGE DATA ARE INCLUDED.

primary State or Federal-Aid systems of the following 26 States (fig. 1): [5]

Alabama.	Maryland.	Rhode Island.
Arizona.	Missouri.	South Dakota.
California.	Montana.	Texas.
Colorado.	Nebraska.	Utah.
Florida.	New Mexico.	Vermont.
Idaho.	North Carolina.	Virginia.
Indiana.	North Dakota.	West Virginia.
Kansas.	Ohio.	Wyoming.
Louisiana.	Oklahoma.	

The data compiled for the purposes of this report are those relating to constructed and retired mileages of surfacing from which the following basic summaries were obtained:

1. Miles constructed each year for each surface type (for 26 States).
2. Miles of each year's construction of each surface type remaining in service January 1 each year after construction (for 26 States).
3. Replacement surface types for miles of each surface type retired each year (for 23 States).
4. Method of retirement (resurfaced, reconstructed, abandoned, or transferred) for miles of each surface type retired each year (for 23 States).

Data for Alabama, Ohio, and Vermont were not available for the summaries prepared in connection with items 3 and 4 above.

There are nine major surface types for which individual summaries and analyses are presented:

1. Soil-surfaced roads.
2. Gravel or stone roads.
3. Bituminous surface-treated roads.
4. Mixed bituminous roads.
5. Bituminous penetration roads.
6. Bituminous concrete roads.
7. Portland cement concrete roads.
8. Brick or block roads.
9. Dual-type roads.

The following definitions used in all phases of the planning surveys are followed in determining the general type classification of the surfaces constructed in each individual State:

1. *Soil-surfaced road.*—A road of natural soil, the surface of which has been treated for purposes of stabilization by the addition of a course of mixed soil such as sand-clay, soft shale or topsoil, or an admixture such as bituminous material, portland cement, sodium chloride, or fine granular material (sand or similar material).

2. *Gravel or stone road.*—A road, the wearing course of which consists of gravel, broken stone, slag, chert, caliche, iron ore, hard shale, chats, disintegrated rock or granite, or other similar fragmental material coarser than sand.

3. *Bituminous surface-treated road.*—A graded and drained earth road, a soil-surfaced road, or a gravel or stone road, to which has been added by any process a surface mat of bituminous material and mineral aggregate less than 1 inch in compacted thickness.

4. *Mixed bituminous road.*—A road, the wearing course of which is 1 inch or more in compacted thickness, composed of gravel, stone, sand, or similar material, mixed with bituminous material under partial control as to grading and proportions.

5. *Bituminous penetration road.*—A road, the wearing course of which is 1 inch or more in compacted thickness, composed of gravel, stone, sand, or similar material, bound with bituminous material introduced by downward or upward penetration.

6. *Bituminous concrete road* (includes sheet asphalt and rock asphalt).—A road, the wearing course of which consists of gravel, stone, or sand, mixed with bituminous material in accordance with precise specifications defining gradation of the mineral aggregate and proportions of aggregate and bituminous cement 1 inch or more in compacted thickness, and laid on a base course of either rigid or nonrigid type.

7. *Portland cement concrete road.*—A road, the wearing course of which consists of portland cement concrete, with or without a bituminous mat less than 1 inch in compacted thickness.

8. *Brick or block road.*[6]—A road, the wearing course of which consists of vitrified paving brick, stone block, wood block, asphalt block, or other form of block, with or without a bituminous mat less than 1 inch in compacted thickness.

9. *Dual-type road.*—A road, the wearing course of which consists of two individual types constructed at the same time,[7] each of which has a width of at least 8 feet which may be in contiguous or divided strips, both individual types being of such character as to be classed logically as a part of the traffic-bearing road surface rather than as surfaced shoulders.

5 METHODS OF RETIRING ROAD SURFACES

Retirement of a road surface is considered as being effected when (1) the wearing surface undergoes a resurfacing operation (other than a routine maintenance operation), (2) the surface is reconstructed, (3) the road is abandoned, (4) the road is transferred to another public authority for continued maintenance and reconstruction, or (5) the surface reverts to a lower type through lack of adequate maintenance. With the exception of reversions, which are so few as not to warrant further consideration, retirements are generally considered as resulting from operations classified as construction. It is an accepted fact that a significant amount of construction work is done by maintenance forces in many States, and in the recording of the original data summarized in this report an attempt was made in each State to segregate construction from maintenance in a uniform manner regardless of the accounting classifications in effect in a particular State. The

[5] Acknowledgment is made to the personnel who compiled and reported the information in these States.

[6] In the highway planning surveys, vitrified paving brick roads are reported separately from other types of brick or block roads. Because of the small mileages involved, these two types are combined. Approximately 97 percent of the construction of these two types included in this report is vitrified paving brick.

[7] The qualification that both types comprising the dual-type road must be constructed at the same time does not apply to other phases of the highway planning survey. It is adopted in the road-life study because of the statistical procedures followed in analyzing construction having similar ages.

classifications of construction and maintenance operations generally followed in the road-life study are those included in the Tentative Draft of the Report to the 1938 Association Meeting by the Subcommittee on Accounting of the American Association of State Highway Officials.[8]

Mileage transferred off the State or Federal-Aid highway systems to the county or other local authority is classified throughout all mileage tables as a retirement. A transfer is not a retirement in the sense that the road has rendered its total service to the public from a structural standpoint, although quite frequently this is the case. A transfer is, however, a retirement in the sense that the road has rendered its complete service as a State or Federal-Aid highway. Retirements by transfer are generally the result of functional obsolescence involving alinements and grades which are unsatisfactory for existing traffic conditions. A new road is built on new alinement and improved grades, and the old road remains in service usually because of the necessity of providing for local traffic usage. After the new road is placed in service on the State or Federal-Aid highway system, the State frequently will no longer assume responsibility for the continued maintenance and reconstruction of the old road, and the county or other local authority generally takes over this responsibility; otherwise the old road may be entirely discontinued from service, in which case it is considered as an abandonment.

For most of the 26 States, the mileage data are for the primary rural State highway system. In two or three States, the data are for the rural Federal-Aid system. In general, all mileages in incorporated places having a population greater than 1,000 persons are excluded from the summaries. The data for all States are summarized only to January 1, 1937, since the information for more recent dates is complete for only a few States.

There are many miles of surfaces, primarily of the lower types, for which the date of retirement is known but for which there is no record of the date of initial construction or for which the date of initial construction cannot be closely estimated. The partial data in these cases are not included in the summaries for mileages constructed and remaining in service during the various years.

In general, the data for construction since 1920 are relatively complete for the 26 States. Prior to 1920, however, it is evident that the construction volume recorded in the tables is only a portion of that actually completed on roads which later became a part of the State or Federal-Aid highway systems. This results, primarily, from difficulty in locating records of early construction. In a few cases, the records were found in various field offices, but more frequently, records of such early construction could not be located.

Table 1 is a summary of the mileages involved in the analysis of the average service lives included in this report.

MILEAGES BUILT AND REMAINING IN SERVICE GIVEN FOR VARIOUS SURFACE TYPES

In tables 2, 3, and 4 are listed for each surface type the miles constructed each year, the miles retired each year, and the miles remaining in service on January 1 each year.

[8] Copies of this Tentative Draft were transmitted to all State highway departments under date of June 2, 1938, by **E. E. Hall**, Secretary, Subcommittee on Accounting, American Association of State Highway Officials.

TABLE 1.—*Total mileages in the 26 States used in the calculation of probable average service life*[1]

No.	Surface type	Miles constructed	Miles remaining in service on 1-1-37
1	Soil surfaced	8, 907	4, 321
2	Gravel or stone	79, 110	37, 187
3	Bituminous surface treated	30, 949	25, 139
4	Mixed bituminous	30, 581	28, 351
5	Bituminous penetration	14, 301	11, 901
6	Bituminous concrete	10, 283	8, 481
7	Portland cement concrete	32, 775	30, 602
8	Brick or block	2, 799	1, 927
9	Dual type	274	249

[1] Involves only mileage of each type for which: (1) Both the original construction date and the retirement date are known if the mileage was retired; and (2) the original construction date is known if the mileage is still in service.

The form in which the mileage data for each surface type were prepared by each State is similar to the arrangement of tables 5 to 13. The two left-hand columns show the year and mileage constructed, whereas the entries in the balance of the table indicate the mileage of each year's construction that remained in service on January 1 of each year after construction. Table 5, for example, records 450 miles of soil-surfaced roads constructed in 1929 by the 26 States included in these summaries. Of these 450 miles built in 1929, there were 435 miles remaining in service on January 1, 1930; 408 miles on January 1, 1931; 356 miles on January 1, 1932; and so forth up to January 1, 1937, when there were 289 miles remaining in service. The totals at the bottom of each year column of tables 5 to 13 represent the total miles in service on January 1 of each calendar year.

TABLE 2.—*Mileage of each surface type constructed each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Year of construction	Soil surfaced	Gravel or stone	Bituminous surface treated	Mixed bituminous	Bituminous penetration	Bituminous concrete	Portland cement concrete	Brick or block	Dual type
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1903		11							
1904		18							
1905		20							
1906		39							
1907		47	12					7	
1908	12	71	16		5			9	
1909	11	103	45	1	2			8	
1910	19	159	60	3	40		1	27	
1911	40	161	40		47			24	
1912	129	212	122	24	56		29	48	
1913	139	267	82	18	65	71	42	40	
1914	111	331	136		72	115	261	99	
1915	189	534	289	2	76	290	279	239	
1916	129	316	330	19	213	132	505	127	
1917	103	275	136	8	104	53	236	120	
1918	74	405	214	10	122	122	322	128	
1919	128	577	168	12	213	52	475	129	
1920	279	1, 273	260	136	312	213	561	143	
1921	334	2, 506	329	472	416	377	888	220	9
1922	499	3, 485	176	81	519	346	1, 113	261	41
1923	387	3, 657	438	182	555	545	1, 124	226	27
1924	421	4, 958	486	67	898	623	1, 922	112	3
1925	418	5, 659	996	77	794	471	1, 690	161	17
1926	200	5, 634	1, 567	197	546	476	2, 087	125	20
1927	218	4, 689	1, 770	375	458	718	1, 942	61	14
1928	279	5, 884	2, 108	1, 016	664	501	2, 238	78	8
1929	450	5, 168	2, 056	1, 162	873	682	1, 891	27	11
1930	532	5, 899	3, 747	2, 860	1, 184	514	3, 855	92	16
1931	475	6, 304	2, 631	3, 747	1, 411	606	3, 518	71	31
1932	498	5, 318	2, 169	5, 551	1, 096	590	2, 825	69	16
1933	548	4, 244	2, 444	3, 132	981	484	2, 039	28	6
1934	1, 021	4, 071	3, 042	5, 007	685	735	1, 110	57	22
1935	613	2, 856	2, 060	2, 686	944	514	828	35	20
1936	651	3, 959	3, 020	3, 736	950	1, 053	994	28	13
Total	8, 907	79, 110	30, 949	30, 581	14, 301	10, 283	32, 775	2, 799	274

TABLE 3.—*Mileage of each surface type retired each year* [1]

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Year of retirement	Soil surfaced	Gravel or stone	Bituminous surface treated	Mixed bituminous	Bituminous penetration	Bituminous concrete	Portland cement concrete	Brick or block	Dual type
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1911		1							
1912		7	3					1	
1913		2	7	1					
1914	4	13	25		1	1			
1915		30	13		5		8	4	
1916		89	16			5	6		
1917	4	39	14		7	6	7		
1918	9	109	31		5	3	21	7	
1919	45	57	43		1	9	18	6	
1920	30	189	37	4	8	27	24	6	
1921	15	638	110	8	22	12	57	7	
1922	12	235	49	5	28	100	35	3	
1923	45	371	51		36	59	53	8	
1924	154	401	59	12	38	32	16	13	
1925	276	573	29	3	45	40	38	41	
1926	379	783	83	10	37	61	71	17	
1927	435	806	71	17	43	81	85	26	
1928	350	2, 211	129	34	72	60	80	51	
1929	385	1, 939	157	45	133	117	143	53	1
1930	393	4, 736	439	97	225	133	202	75	1
1931	395	4, 813	795	172	264	112	135	111	2
1932	253	5, 789	822	222	263	178	234	114	2
1933	372	4, 432	527	271	223	172	205	39	9
1934	288	5, 033	919	336	202	189	191	80	4
1935	328	3, 337	608	441	219	108	163	57	
1936	414	5, 290	773	552	523	297	371	153	6
Total	4, 586	41, 923	5, 810	2, 230	2, 400	1, 802	2, 173	872	25

[1] Includes mileages which are retired as the result of being transferred from the rural State or Federal-Aid systems to the county or other authority for continued maintenance and reconstruction.

TABLE 4.—*Mileage of each surface type remaining in service on January 1 each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Year remaining in service	Soil surfaced	Gravel or stone	Bituminous surface treated	Mixed bituminous	Bituminous penetration	Bituminous concrete	Portland cement concrete	Brick or block	Dual type
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1904		11							
1905		29							
1906		49							
1907		88							
1908		135	12					7	
1909	12	206	28		5			16	
1910	23	309	73	1	7			24	
1911	42	468	133	4	47		1	51	
1912	82	628	173	4	94		1	75	
1913	211	833	292	28	150		30	122	
1914	350	1, 098	367	45	215	71	72	162	
1915	457	1, 416	478	45	286	185	333	261	
1916	646	1, 920	754	47	357	475	604	496	
1917	775	2, 147	1, 068	66	570	602	1, 103	623	
1918	874	2, 383	1, 190	74	667	649	1, 332	743	
1919	939	2, 679	1, 373	84	784	768	1, 633	864	
1920	1, 022	3, 199	1, 498	96	996	811	2, 090	987	
1921	1, 271	4, 283	1, 721	228	1, 300	997	2, 627	1, 124	
1922	1, 590	6, 151	1, 940	692	1, 694	1, 362	3, 458	1, 337	9
1923	2, 077	9, 401	2, 067	768	2, 185	1, 608	4, 536	1, 595	50
1924	2, 419	12, 687	2, 454	950	2, 704	2, 094	5, 607	1, 813	77
1925	2, 686	17, 244	2, 881	1, 005	3, 564	2, 685	7, 513	1, 912	80
1926	2, 828	22, 330	3, 848	1, 079	4, 313	3, 116	9, 165	2, 032	97
1927	2, 649	27, 181	5, 332	1, 266	4, 822	3, 531	11, 181	2, 140	117
1928	2, 432	31, 064	7, 031	1, 624	5, 237	4, 168	13, 038	2, 175	131
1929	2, 361	34, 737	9, 010	2, 606	5, 829	4, 609	15, 196	2, 202	139
1930	2, 426	37, 966	10, 909	3, 723	6, 569	5, 174	16, 944	2, 176	149
1931	2, 565	39, 129	14, 217	6, 486	7, 528	5, 155	20, 597	2, 193	164
1932	2, 645	40, 620	16, 053	10, 061	8, 675	6, 049	23, 970	2, 153	193
1933	2, 890	40, 149	17, 400	15, 390	9, 508	6, 461	26, 561	2, 108	207
1934	3, 066	39, 961	19, 317	18, 251	10, 266	6, 773	28, 395	2, 097	204
1935	3, 799	38, 999	21, 440	22, 922	10, 749	7, 319	29, 314	2, 074	222
1936	4, 084	38, 518	22, 892	25, 167	11, 474	7, 725	29, 979	2, 052	242
1937	4, 321	37, 187	25, 139	28, 351	11, 901	8, 481	30, 602	1, 927	249

For the purpose of calculating the average service lives, all mileages constructed during a given calendar year are considered to have been placed in service on July 1 of that year. Mileages remaining in service are thus ½ year of age on January 1 of the calendar year following the year of construction, 1½ years of age on January 1 of the second year after construction, etc. By the use of these ages and the mileages remaining in

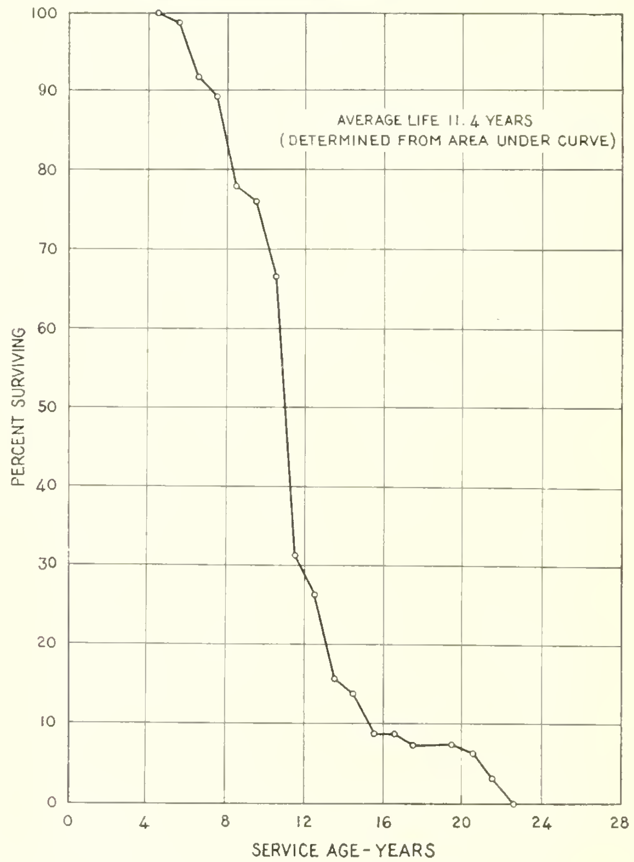

FIGURE 2.—SURVIVOR CURVE FOR 159 MILES OF GRAVEL OR STONE ROADS CONSTRUCTED IN 1910.

service as shown in tables 5 to 13 the probable average life of the construction for each year was calculated.

The mileages that remained in service on January 1 of each year after construction are expressed as percentages of the original construction mileage. These percentages at ages 0, ½, 1½, 2½, etc., years were plotted, using the percentage remaining in service as the ordinate, and the age in years as the abscissa. The plotted points were then connected with straight lines to form original survivor curves, illustrative examples of which are given in figures 2 to 9.

In the event that all mileage of a given surface type constructed during a particular year was retired prior to January 1, 1937, the survivor curve extends to zero percent remaining in service. In such cases (fig. 2) the construction rendered its complete service, the extent of which is measured by the area on the graph below the survivor curve.

AVERAGE SERVICE LIVES CALCULATED

In most instances (figs. 3 to 9), however, a portion of the mileage of a given surface type constructed during a particular year remained in service on January 1, 1937. Such a condition results in a "stub" survivor curve, the end point of which indicates the percentage of the original mileage remaining in service on January 1, 1937. In these cases the area below the stub survivor curve to the left of the ordinate erected at the end point represents the service realized prior to January 1, 1937, and it is necessary to extend the curve to zero percent surviving in order to estimate the average life of the entire original mileage.

TABLE 5.—*Soil-surfaced road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction		1910[1]	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
Year	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1908	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	0							
1909	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	0					
1910	19		19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	13	13	7	5	3	3	3	0				
1911	40			40	40	40	40	40	40	40	40	40	32	32	32	31	28	28	28	28	28	13	11	9	9	9	0		
1912	129				129	129	125	125	125	125	125	124	124	119	119	112	94	80	55	40	25	25	7	5	5	5	0		
1913	139					139	139	139	139	139	139	128	119	117	117	117	114	109	96	94	74	61	35	25	17	10	4	4	4
1914	111						111	111	111	111	111	111	111	106	104	100	86	75	72	53	41	35	19	18	18	14	8	7	0
1915	189							189	189	185	176	153	148	146	144	135	122	117	101	87	80	67	35	22	18	14	7	7	7
1916	129								129	129	129	121	121	121	113	113	107	88	88	81	71	54	22	19	19	15	12	12	12
1917	103									103	103	101	101	101	101	98	88	79	73	73	61	52	52	37	32	23	19	19	4
1918	74										74	74	74	74	74	74	74	65	57	52	37	30	24	15	10	7	4	4	4
1919	128											128	120	120	120	120	120	120	114	92	82	81	81	66	66	62	58	50	45
1920	279												279	278	278	271	228	183	142	118	107	101	101	101	101	98	96	80	69
1921	334													334	334	329	313	285	237	189	145	97	63	50	40	40	32	31	31
1922	499														499	498	470	409	294	205	160	143	110	101	74	67	48	43	38
1923	387															379	379	317	272	212	139	98	75	40	40	26	23	23	10
1924	421																421	419	383	310	278	188	170	161	153	140	119	114	89
1925	418																	418	401	350	325	255	238	225	216	202	200	198	193
1926	200																		200	200	183	182	147	103	83	69	69	67	60
1927	218																			218	218	218	218	209	186	179	169	169	153
1928	279																				279	277	260	247	245	245	240	234	213
1929	450																					435	408	356	352	348	320	306	289
1930	532																						475	359	320	271	258	257	242
1931	475																							474	388	349	299	292	279
1932	498																								498	333	298	287	278
1933	548																									540	506	412	383
1934	1,021																										1,010	875	736
1935	613																											593	556
1936	651																												626
Total	8,907	23	42	82	211	350	457	646	775	874	939	1,022	1,271	1,590	2,077	2,419	2,686	2,828	2,649	2,432	2,361	2,426	2,565	2,645	2,890	3,066	3,799	4,084	4,321

[1] No retirement of 1908–09 construction in earlier years.

TABLE 6.—*Gravel or stone road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction: Year	Construction: Miles	1910[1]	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1903	11	11	11	11	10	9	9	8	4	4	4	3	2	1	1	1	1	1	1	0									
1904	18	18	18	18	18	18	17	16	11	10	9	6	4	2	1	1	1	1	0										
1905	20	20	20	19	18	17	17	16	13	12	10	9	6	1	1	1	1	1	0										
1906	39	39	39	39	35	35	35	32	26	26	23	20	17	5	2	2	1	1	0										
1907	47	47	47	47	46	46	46	46	31	31	26	24	20	9	7	6	6	6	4	2	1	1	1	1	1	1	0		
1908	71	71	71	71	71	71	71	71	62	60	55	51	43	26	17	7	5	5	1	1	1	1	1	1	1	1	0		
1909	103	103	103	103	103	103	97	97	91	90	87	86	69	37	32	30	28	28	24	19	19	18	15	15	15	15	6	6	6
1910	159		159	159	159	159	159	157	146	142	124	121	106	50	42	25	22	14	14	12	12	12	10	5	0				
1911	161			161	161	161	155	151	140	138	138	126	90	35	19	11	11	10	10	9	9	6	6	4	4	4	1	1	0
1912	212				212	212	212	203	201	198	193	193	176	104	83	64	56	53	46	37	31	25	9	9	8	4	4	2	1
1913	267					267	267	264	259	256	254	244	217	140	128	101	99	97	73	54	51	40	32	23	13	3	3	2	1
1914	331						331	325	323	318	316	312	302	213	203	160	117	98	96	89	85	82	67	64	57	51	38	38	37
1915	534							534	525	508	453	448	443	365	324	258	216	180	163	127	113	89	75	75	71	64	63	59	55
1916	316								315	315	311	307	292	282	271	251	240	204	186	175	161	143	106	67	59	37	29	27	19
1917	275									275	271	271	269	246	230	210	198	152	123	106	99	93	50	25	10	5	0		
1918	405										405	405	389	354	352	346	319	292	258	247	228	207	175	138	84	72	66	56	51
1919	577											573	565	517	498	491	463	426	389	383	356	319	254	192	133	106	101	63	29
1920	1,273												1,273	1,269	1,229	1,202	1,190	1,167	1,070	1,017	911	811	664	560	437	345	316	298	223
1921	2,506													2,496	2,479	2,456	2,387	2,326	2,278	2,173	1,905	1,722	1,410	1,191	891	745	581	488	368
1922	3,485														3,482	3,432	3,340	3,228	3,088	2,979	2,639	2,407	2,029	1,659	1,258	986	800	701	458
1923	3,657															3,632	3,591	3,507	3,448	3,333	3,014	2,833	2,356	1,898	1,586	1,374	1,221	1,030	771
1924	4,958																4,952	4,877	4,745	4,644	4,315	3,962	3,387	2,784	2,282	1,971	1,670	1,467	1,199
1925	5,659																	5,656	5,541	5,408	4,979	4,807	4,244	3,841	3,266	2,978	2,653	2,496	2,100
1926	5,634																		5,623	5,579	5,359	5,056	4,210	3,656	3,103	2,794	2,518	2,312	1,955
1927	4,689																			4,670	4,583	4,421	3,902	3,557	3,062	2,807	2,470	2,296	1,974
1928	5,884																				5,866	5,800	5,368	4,897	4,348	3,876	3,405	3,150	2,726
1929	5,168																					5,111	4,914	4,367	3,702	3,244	2,891	2,675	2,367
1930	5,899																						5,814	5,477	5,067	4,617	4,158	3,877	3,506
1931	6,304																							6,114	5,626	4,993	4,449	4,177	3,764
1932	5,318																								5,065	4,724	4,218	3,951	3,569
1933	4,244																									4,144	3,558	3,256	2,821
1934	4,071																										3,780	3,419	3,139
1935	2,856																											2,671	2,301
1936	3,959																												3,747
Total	79,110	309	468	628	833	1,098	1,416	1,920	2,147	2,383	2,679	3,199	4,283	6,152	9,401	12,687	17,244	22,330	27,181	31,064	34,737	37,966	39,129	40,620	40,149	39,961	38,999	38,518	37,187

[1] No retirement of 1903–09 construction in earlier years.

TABLE 7.—*Bituminous surface-treated road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction		1910[1]	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
Year	Miles																												
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1907	12	12	12	12	12	11	9	6	0																				
1908	16	16	16	16	15	9	8	6	6	6	6	6	3	3	0														
1909	45	45	45	45	45	45	42	42	40	40	35	23	21	19	19	19	18	18	18	18	16	16	16	15	4	0			
1910	60		60	60	58	58	50	43	40	36	36	36	35	24	24	21	17	17	13	13	13	13	9	6	6	4	4	4	4
1911	40			40	40	40	31	30	29	28	28	28	24	16	15	12	10	10	10	10	7	7	4	4	4	4	4	4	4
1912	122				122	122	120	120	120	120	118	115	115	96	93	82	82	82	81	78	67	64	62	54	48	48	48	48	47
1913	82					82	82	82	80	77	68	58	58	47	37	32	29	26	24	24	20	17	12	10	8	8	7	7	6
1914	136						136	136	134	132	126	122	109	91	90	82	74	73	69	66	65	62	44	33	18	15	12	12	12
1915	289							289	289	285	281	275	269	256	246	240	236	235	228	227	226	216	186	169	148	145	134	131	125
1916	330								330	330	328	322	315	308	297	292	264	250	238	226	223	216	197	162	139	134	126	121	119
1917	136									136	133	132	131	116	116	116	113	109	109	106	104	100	90	74	65	62	60	60	57
1918	214										214	213	213	210	209	205	203	203	199	199	196	194	169	138	132	128	126	117	117
1919	168											168	168	167	164	164	161	161	148	147	143	142	122	111	101	101	94	81	63
1920	260												260	258	252	252	251	251	228	228	225	223	212	173	166	137	135	135	133
1921	329													329	329	325	325	320	315	305	297	285	270	240	215	210	192	187	187
1922	176														176	174	174	173	173	173	165	163	150	132	124	117	114	114	87
1923	438															438	438	438	438	438	419	408	390	369	356	350	344	328	284
1924	486																486	486	481	474	474	474	459	456	435	432	426	412	400
1925	996																	996	993	971	970	968	959	922	911	882	876	853	836
1926	1,567																		1,567	1,559	1,510	1,480	1,444	1,369	1,359	1,312	1,272	1,261	1,222
1927	1,770																			1,769	1,765	1,744	1,679	1,652	1,618	1,601	1,562	1,528	1,483
1928	2,108																				2,105	2,066	1,995	1,894	1,832	1,780	1,698	1,670	1,616
1929	2,056																					2,051	2,020	1,964	1,891	1,864	1,792	1,745	1,703
1930	3.747																						3,728	3,477	3,100	3,015	2,762	2,684	2,573
1931	2,631																							2,629	2,553	2,408	2,240	2,170	2,038
1932	2,169																								2,167	2,117	2,018	1,892	1,831
1933	2,444																									2,443	2,361	2,326	2,265
1934	3,042																										3,033	2,943	2,875
1935	2,060																											2,059	2,036
1936	3,020																												3,016
Total	30,949	73	133	173	292	367	478	754	1,068	1,190	1,373	1,498	1,721	1,940	2,067	2,454	2,881	3,848	5,332	7,031	9,010	10,909	14,217	16,053	17,400	19,317	21,440	22,892	25,139

[1] No retirement of 1907-09 construction in earlier years.

TABLE 8.—*Mixed bituminous road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction: Year	Construction: Miles	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1909	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0			
1910	3		3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1911																													
1912	24				24	24	24	24	24	24	24	24	23	22	22	22	20	18	11	10	8	6	5	5	5	4	4	4	4
1913	18					18	18	18	18	18	18	18	18	17	12	12	6	6	6	5	4	4	4	2	2	2	2	2	2
1914																													
1915	2							2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1916	19								19	19	19	19	16	16	16	16	16	16	16	16	15	15	15	15	15	13	13	11	11
1917	8									8	8	8	8	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1918	10										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1919	12											12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1920	136												136	136	136	136	135	135	135	123	122	119	119	118	116	109	109	109	109
1921	472													472	472	472	469	469	466	465	465	451	446	443	435	415	404	392	392
1922	81														81	81	81	81	81	81	81	81	81	76	71	67	67	67	67
1923	182															182	182	181	181	181	181	177	170	169	161	161	161	160	157
1924	67																67	67	67	67	67	67	67	67	63	50	35	35	35
1925	77																	77	77	75	75	75	75	75	69	59	58	58	58
1926	197																		197	197	168	156	144	136	120	110	102	96	75
1927	375																			375	375	372	346	336	328	314	301	299	293
1928	1,016																				1,016	1,011	983	948	897	836	780	742	677
1929	1,162																					1,160	1,142	1,133	1,097	1,052	1,016	997	963
1930	2,860																						2,860	2,764	2.733	2,681	2,597	2,552	2,485
1931	3,747																							3,745	3,706	3.692	3,652	3,548	3,408
1932	5,551																								5,543	5,528	5,468	5,301	5.220
1933	3,132																									3,130	3,122	3,094	3,058
1934	5,007																										5,003	4,986	4,902
1935	2,686																											2,686	2,671
1936	3,736																												3,736
Total	30,581	1	4	4	28	45	45	47	66	74	84	96	228	692	768	950	1,005	1,079	1,266	1,624	2,606	3,723	6,486	10,061	15,390	18,251	22,922	25,167	28,351

TABLE 9.—*Bituminous penetration road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction		1910 [1]	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
Year	Miles														
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1908	5	5	5	5	5	5	5	0							
1909	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1910	40		40	40	40	40	39	39	39	39	39	39	39	39	39
1911	47			47	47	47	47	47	47	47	47	47	47	47	46
1912	56				56	56	56	56	56	53	53	53	52	52	52
1913	65					65	65	65	65	65	65	65	64	59	55
1914	72						72	72	72	68	68	68	68	68	62
1915	76							76	76	76	75	74	74	72	70
1916	213								213	213	211	211	211	200	199
1917	104									104	102	102	102	101	101
1918	122										122	122	120	120	119
1919	213											213	209	208	202
1920	312												312	310	305
1921	416													416	416
1922	519														517
1923	555														
1924	898														
1925	794														
1926	546														
1927	458														
1928	664														
1929	873														
1930	1,184														
1931	1,411														
1932	1,096														
1933	981														
1934	685														
1935	944														
1936	950														
Total	14,301	7	47	94	150	215	286	357	570	667	784	996	1,300	1,694	2,185

Year	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1908														
1909	2	2	2	2	2	2	2	0						
1910	39	39	30	29	29	29	27	25	25	25	25	25	25	13
1911	45	45	35	35	35	32	22	15	6	6	6	5	4	4
1912	51	44	40	33	33	33	31	30	27	16	13	9	9	8
1913	46	45	45	45	45	42	23	19	17	17	15	15	10	6
1914	56	54	54	47	44	32	32	26	22	22	22	20	20	18
1915	68	68	62	60	59	54	52	38	29	25	25	25	25	25
1916	193	187	187	177	171	165	156	136	116	111	104	97	88	60
1917	96	94	91	85	77	76	74	73	62	51	50	46	44	44
1918	117	112	112	112	112	109	108	107	96	84	77	76	73	64
1919	200	200	200	200	194	191	186	181	164	144	131	122	118	108
1920	303	293	286	284	271	262	254	241	209	195	183	162	152	137
1921	416	416	416	415	415	410	400	389	343	295	277	257	233	213
1922	517	513	508	508	508	506	499	467	451	434	417	407	384	311
1923	555	554	554	554	549	541	536	510	485	471	456	441	441	389
1924		898	898	898	897	884	877	839	830	825	816	775	730	669
1925			793	793	793	791	790	774	766	759	750	741	723	661
1926				545	545	545	532	532	526	517	516	512	508	502
1927					458	458	452	447	442	431	431	417	411	400
1928						664	643	635	631	616	598	594	592	565
1929							873	862	858	841	833	815	791	753
1930								1,182	1,158	1,143	1,089	1,083	1,076	1,057
1931									1,409	1,391	1,380	1,366	1,362	1,333
1932										1,089	1,085	1,084	1,081	1,070
1933											967	967	967	953
1934												685	663	656
1935													944	939
1936														943
Total	2,704	3,564	4,313	4,822	5,237	5,829	6,569	7,528	8,675	9,508	10,266	10,749	11,471	11,901

[1] No retirement of 1908–09 construction in earlier years.

TABLE 10.—*Bituminous concrete road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction: Year	Construction: Miles	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1913	71	71	71	71	71	69	69	69	58	55	47	47	44	34	32	25	16	13	10	10	10	7	7	7	7
1914	115		114	114	109	106	103	103	99	93	79	73	73	71	63	62	61	56	39	31	31	31	30	28	23
1915	290			290	290	290	290	287	277	275	244	228	207	199	155	122	90	76	64	62	51	41	35	33	19
1916	132				132	131	131	131	129	129	102	87	87	83	83	83	79	73	72	71	70	56	50	48	44
1917	53					53	53	53	53	53	53	42	42	41	40	10	39	37	33	33	33	33	31	31	29
1918	122						122	116	116	115	98	93	93	93	93	91	89	71	64	62	58	51	51	43	28
1919	52							52	52	52	52	52	52	52	52	52	52	47	47	45	45	45	42	35	23
1920	213								213	213	210	204	196	196	195	180	178	174	159	153	141	136	130	116	102
1921	377									377	377	377	377	377	377	374	373	373	350	318	293	286	261	232	192
1922	346										346	346	346	331	327	321	320	319	311	296	259	247	225	221	216
1923	545											545	545	545	545	545	545	539	528	521	501	467	429	426	416
1924	623												623	623	623	623	619	585	584	571	536	535	514	507	474
1925	471													471	471	471	469	469	457	452	452	451	437	436	396
1926	476														475	475	474	473	473	473	458	456	439	436	431
1927	718															704	704	684	681	680	677	649	638	635	635
1928	501																501	500	496	496	483	480	480	473	467
1929	682																	682	673	655	655	641	637	636	620
1930	514																		514	514	512	505	503	499	470
1931	606																			606	606	588	586	584	571
1932	590																				590	588	581	581	581
1933	484																					480	478	470	468
1934	735																						735	734	729
1935	514																							514	506
1936	1,053																								1,034
Total	10,283	71	185	475	602	649	768	811	997	1,362	1,608	2,094	2,685	3,116	3,531	4,168	4,609	5,174	5,555	6,049	6,461	6,773	7,319	7,725	8,481

TABLE 11.—*Portland cement concrete road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction: Year	Construction: Miles	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1910	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1911																												
1912	29			29	29	29	29	29	29	29	29	29	28	28	25	25	25	21	21	15	14	14	14	13	13	13	13	13
1913	42				42	42	42	42	42	42	40	39	39	38	38	38	38	32	32	32	28	26	26	25	25	25	25	23
1914	261					261	261	261	258	258	255	255	254	252	252	250	246	217	201	189	180	175	170	144	139	128	124	89
1915	279						271	267	267	265	263	263	255	246	238	235	218	216	216	210	194	177	166	140	139	136	128	116
1916	505							503	500	490	479	461	418	411	402	400	393	391	357	346	335	308	292	258	235	219	201	182
1917	236								235	235	235	235	233	233	231	225	220	213	212	207	187	174	170	142	128	121	117	104
1918	322									313	313	310	310	303	292	291	290	289	282	273	264	227	217	207	193	167	162	137
1919	475										475	473	471	463	445	445	445	439	434	426	387	360	337	305	278	261	247	215
1920	561											561	561	560	558	556	554	554	541	533	518	507	490	473	448	429	420	378
1921	888												888	888	888	888	888	886	879	869	862	843	813	784	755	735	706	668
1922	1,113													1,113	1,113	1,113	1,111	1,104	1,104	1,102	1,101	1,088	1,079	1,076	1,057	1,034	1,015	951
1923	1,124														1,124	1,124	1,124	1,120	1,120	1,120	1,120	1,112	1,110	1,099	1,092	1,081	1,064	1,048
1924	1,922															1,922	1,922	1,921	1,920	1,919	1,919	1,909	1,900	1,897	1,877	1,863	1,857	1,831
1925	1,690																1,690	1,690	1,689	1,689	1,689	1,679	1,675	1,672	1,662	1,655	1,650	1,636
1926	2,087																	2,087	2,087	2,085	2,084	2,084	2,084	2,082	2,078	2,075	2,072	2,064
1927	1,942																		1,942	1,942	1,940	1,940	1,940	1,938	1,938	1,934	1,925	1,912
1928	2,238																			2,238	2,230	2,229	2,228	2,228	2,228	2,225	2,222	2,218
1929	1,891																				1,891	1,891	1,890	1,890	1,889	1,889	1,887	1,885
1930	3,855																					3,853	3,853	3,852	3,851	3,851	3,846	3,843
1931	3,518																						3,515	3,513	3,513	3,512	3,512	3,510
1932	2,825																							2,822	2,818	2,816	2,814	2,814
1933	2,039																								2,038	2,034	2,034	2,033
1934	1,110																									1,110	1,109	1,109
1935	828																										828	828
1936	994																											994
Total	32,775	1	1	30	72	333	604	1,103	1,332	1,633	2,090	2,627	3,458	4,536	5,607	7,513	9,165	11,181	13,038	15,196	16,944	20,597	23,970	26,561	28,395	29,314	29,979	30,602

TABLE 12.—*Brick or block road mileage remaining in service; mileage constructed each year and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction: Year	Construction: Miles	1910 [1]	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1907	7	7	7	7	6	6	6	3	3	3	1	1	1	1
1908	9	9	9	9	9	9	9	8	8	8	8	8	7	7
1909	8	8	8	8	8	8	8	8	8	8	8	8	8	7
1910	27		27	27	27	27	27	27	27	27	27	23	23	21
1911	24			24	24	24	24	24	24	24	24	24	22	22
1912	48				48	48	48	48	48	48	45	43	41	41
1913	40					40	40	40	40	40	40	40	40	40
1914	99						99	99	99	99	99	99	99	98
1915	239							239	239	239	239	239	239	238
1916	127								127	127	127	127	127	127
1917	120									120	119	119	118	118
1918	128										127	127	127	127
1919	129											129	129	127
1920	143												143	143
1921	220													220
1922	261													
1923	226													
1924	112													
1925	161													
1926	125													
1927	61													
1928	78													
1929	27													
1930	92													
1931	71													
1932	69													
1933	28													
1934	57													
1935	35													
1936	28													
Total	2,799	24	51	75	122	162	261	496	623	743	864	987	1,124	1,337

Construction: Year	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1907	1	1	1	1	1	1	1	1	1	1	1	1	1	0	
1908	7	7	7	6	5	4	4	4	4	4	3	3	3	3	1
1909	7	7	6	6	6	5	5	5	4	4	2	2	2	2	1
1910	18	17	17	17	14	14	14	14	9	8	7	7	7	6	5
1911	22	21	19	19	19	19	19	19	18	16	16	16	13	13	13
1912	41	40	37	37	34	34	30	27	18	17	13	11	11	10	10
1913	40	35	35	34	34	31	26	24	23	23	22	21	21	19	16
1914	98	98	98	98	98	98	96	96	91	71	67	62	55	47	37
1915	238	238	236	233	233	229	210	200	197	187	179	173	141	137	112
1916	127	127	127	114	114	114	109	108	102	100	80	74	71	69	61
1917	118	118	118	118	116	106	104	103	98	94	89	86	78	75	71
1918	127	127	126	122	122	122	122	122	114	99	87	87	85	84	73
1919	127	127	124	124	123	122	119	114	100	98	91	88	87	84	70
1920	143	143	142	125	120	120	120	102	98	85	81	79	75	70	69
1921	220	220	220	219	217	211	208	204	201	199	174	171	171	168	157
1922	261	261	261	261	261	261	261	257	252	233	218	215	204	192	169
1923		226	226	225	225	225	225	220	218	204	203	200	198	191	185
1924			112	112	112	112	111	111	111	111	111	109	103	99	87
1925				161	161	161	157	157	157	152	150	150	149	149	138
1926					125	125	122	122	120	120	119	119	119	119	114
1927						61	61	61	61	60	60	60	60	60	57
1928							78	78	77	77	77	77	77	77	76
1929								27	27	27	27	27	27	27	26
1930									92	92	91	91	91	91	91
1931										71	71	71	71	71	71
1932											69	69	69	69	69
1933												28	28	28	28
1934													57	57	57
1935														35	35
1936															28
Total	1,595	1,813	1,912	2,032	2,140	2,175	2,202	2,176	2,193	2,153	2,108	2,097	2,074	2,052	1,927

[1] No retirement of 1907–09 construction in earlier years.

TABLE 13.—*Dual-type road mileage remaining in service; mileage constructed each year, and mileage remaining in service on January 1 of each year*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction Year	Construction Miles	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
		Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
1921	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	7
1922	41		41	41	41	41	41	41	41	41	40	40	40	31	31	31	30
1923	27			27	27	27	27	27	27	26	26	25	23	23	19	19	16
1924	3				3	3	3	3	3	3	3	3	3	3	3	3	3
1925	17					17	17	17	17	17	17	17	17	17	17	17	17
1926	20						20	20	20	20	20	20	20	20	20	20	20
1927	14							14	14	14	14	14	14	14	14	14	14
1928	8								8	8	8	8	8	8	8	8	8
1929	11									11	11	11	11	11	11	11	11
1930	16										16	15	15	15	15	15	15
1931	31											31	31	31	31	31	31
1932	16												16	16	16	16	16
1933	6													6	6	6	6
1934	22														22	22	22
1935	20															20	20
1936	13																13
Total	274	9	50	77	80	97	117	131	139	149	164	193	207	204	222	242	249

Average service lives were determined in accordance with the particular conditions pertaining to each survivor curve. For the older construction, particularly for the lower types of surface, survivor curves that reach zero percent remaining in service were obtained in many instances, and hence the average service life is equal to the area below the survivor curve divided by 100. For the stub survivor curves generally obtained for the higher types of surface and for the more recent construction, it is necessary to estimate the future trend of the curves from the end point of the actual experience to zero percent remaining in order to obtain approximations of the total service to be expected from the mileage constructed. These future trends of stub survivor curves were estimated by one of the following two methods:

A. By projecting the stub survivor curve to zero percent remaining in accordance with the retirement trend reflected by the stub survivor curve as judged by visual inspection. This method was applied only to stub survivor curves of lengths sufficient to afford a reasonable and definite indication of the probable trend for the mileages remaining in service.

B. By matching the stub survivor curve with one of the 18 type survivor curves described in Bulletin 125 of the Iowa State College Engineering Experiment Station.[9] These 18 basic type survivor curves were developed as a result of a study of retirement trends for various types of industrial properties. The matching of a particular type curve with the stub survivor curve permits an estimate to be made of the probable future trend of mileages remaining in service.

For a survivor curve that reaches zero percent remaining for the reason that all the mileage was retired or that was extended to zero percent remaining in accordance with method A above, the probable average life was determined by dividing the area below the survivor curve by 100 percent. The total area below the survivor curve was obtained from a summation of the areas under the curve for each of the age intervals 0 to ½ year, ½ to 1½ years, 1½ to 2½ years, etc., to zero percent remaining. The area for each of these intervals is equal to the average percent surviving during the interval multiplied by the length of the interval which is 0.5 year for the 0 to ½ year age interval and 1.0 year for each succeeding interval (from ½ to 1½ years, 1½ to 2½ years, etc.). The average percent surviving during a given interval is assumed to be the arithmetic average of the percents surviving at the beginning and end of the interval.

For cases in which the type survivor curves were utilized as in method B, an estimate of the average service life was obtained directly by matching the stub survivor curve with the type survivor curve affording the best fit. When matching stub survivor curves with the type survivor curves in Bulletin 125 of the Iowa Engineering Experiment Station, it is obvious that the longer stub curves enable more reliable estimates to be made of the average service life. For short stub curves for which more than one type curve and average life satisfactorily match the stub curve, the type curve and average live selected were those consistent with indicated trends for other years of construction.

The general methods employed in determining the probable average service lives from survivor curves of various lengths are briefly described as follows:

Percent remaining at end point of survivor curve	*Usual method of determining probable average service life*
0	From the area under the survivor curve.
15 or less	From the area under the stub survivor curve and its projection to zero percent remaining by judgment based on the indicated trend.
15–40	Stub survivor curve matched with a type survivor curve from Bulletin 125 if a reasonable fit could be obtained; otherwise from the area under the stub survivor curve and its projection to zero percent remaining by judgment based on the indicated trend.
40–100	Stub survivor curve matched with a type survivor curve from Bulletin 125. In some cases construction for 2 or more consecutive years was combined into like age groups if the stub survivor curves for each of the individual years follows approximately the same trend.

SURVIVOR CURVES PLOTTED FOR VARIOUS SURFACE TYPES

Figures 2 to 9 represent examples of survivor curves from which the average service lives were determined in accordance with the foregoing methods for various surface types and years of construction. Figure 2 illustrates construction for which the survivor curve reaches zero percent remaining in service. The gravel or stone roads constructed in 1910 reached zero percent remaining on January 1, 1933, at an age of 22½ years. The average service life of 11.4 years was calculated from the area below the survivor curve.

[9] Statistical Analysis of Industrial Property Retirements, by Robley Winfrey, December 1935. See also Proc. Highway Research Board, Vol. 15, Pt. I, pp. 47 to 60, or a description of the matching process.

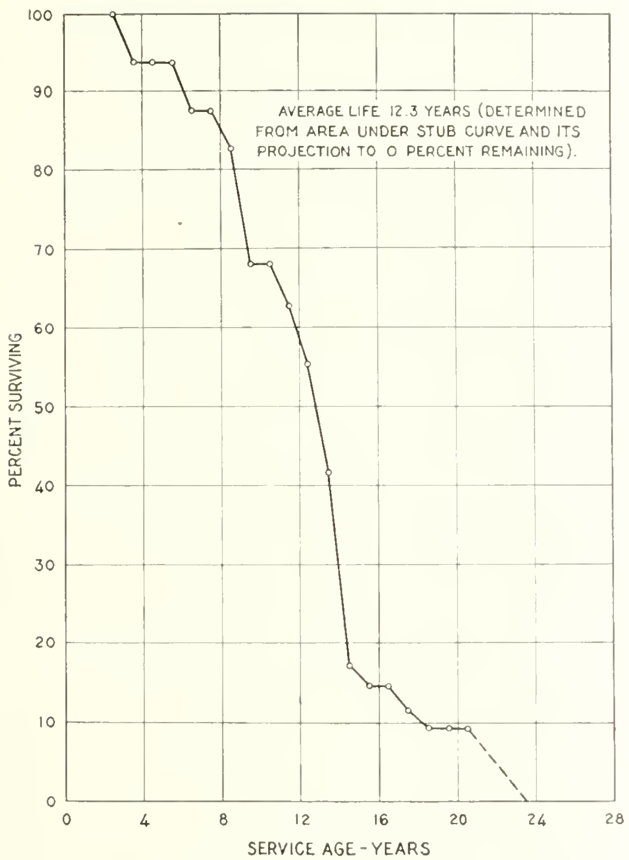

Figure 3.—Survivor Curve for 129 Miles of Soil-Surfaced Roads Constructed in 1916.

In figure 3 the stub survivor curve for soil-surfaced roads constructed in 1916 is shown as reaching 9 percent remaining in service at age 20½ years. In this instance the stub survivor curve was projected to zero percent remaining in service in accordance with judgment and the past trend. The probable average service life of 12.3 years was determined from the area below the stub curve and its projection to zero percent remaining in service.

Figures 4 and 5 illustrate alternate procedures used when the end points of the stub survivor curves are between 15 and 40 percent remaining in service. Figure 4 shows the stub survivor curve obtained for portland cement concrete surfaces built in 1914. The end point of the stub curve is 34 percent remaining at 22½ years of age. The trend of the stub survivor curve is such that the average service life of 20 years can be estimated by matching the stub curve with the type survivor curves. An S_2 type [10] survivor curve of 20 years average life was selected as the curve giving the best fit. Beyond the age represented by the end point of the stub survivor curve the percentages remaining in service in future years are presumed to follow the trend of the type survivor curve.

When matching type survivor curves with stub curves, no attempt was made to obtain type survivor curves that match the stub curve with the minimum

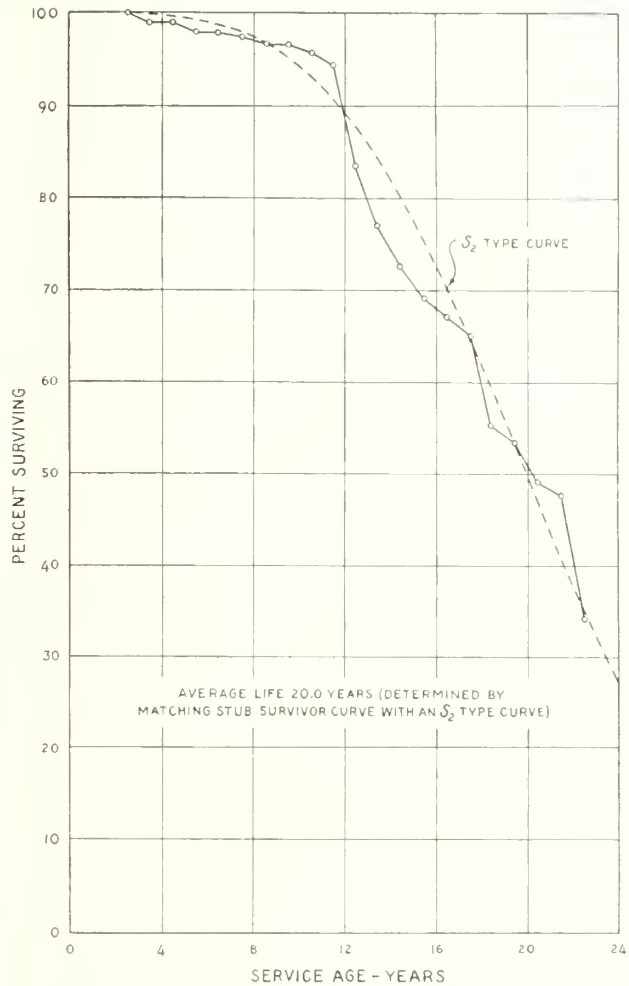

Figure 4.—Survivor Curve for 261 Miles of Portland Cement Concrete Roads Constructed in 1914.

mathematical deviation. When more than one type survivor curve and average life could be considered as satisfactorily matching the stub, care was taken to select the type curve and average life that were consistent with other years of construction. It was found through experience that undue refinement in matching is unwarranted in most cases. Approximate matching by visual methods in superimposing the stub curves on the various type survivor curves (drawn to the same scale) yields results as satisfactory from the standpoint of reliability as those obtained from more refined procedures involving precise mathematical adjustments. For purposes of comparison, figure 4 shows both the stub survivor curve for portland cement concrete roads constructed in 1914 and the S_2 type survivor curve visually selected as being the best matching curve.

On figure 5 is represented the stub survivor curve obtained for bituminous concrete roads constructed in 1916. At the end point (20½ years) of the stub curve, 33.3 percent remained in service. Because the trend of the stub curve is such that it cannot be satisfactorily matched with any of the type survivor curves, it was projected to zero percent remaining in service in accordance with the trend reflected by the stub curve with consideration being given both to the trends of the type survivor curves that most nearly match the

[10] The 18 type curves presented in Bulletin 125 are designated by their shape as indicated by both the modal age and modal frequency. The letters L, S, and R are given, respectively, to the types having their year of greatest retirement to the left of, coincident with, and to the right of the age corresponding to average life. Subscript numbers are added to the letters to show the relative percentage of retirement at the modal age, the larger number being used for the larger retirements or steeper survivor curves.

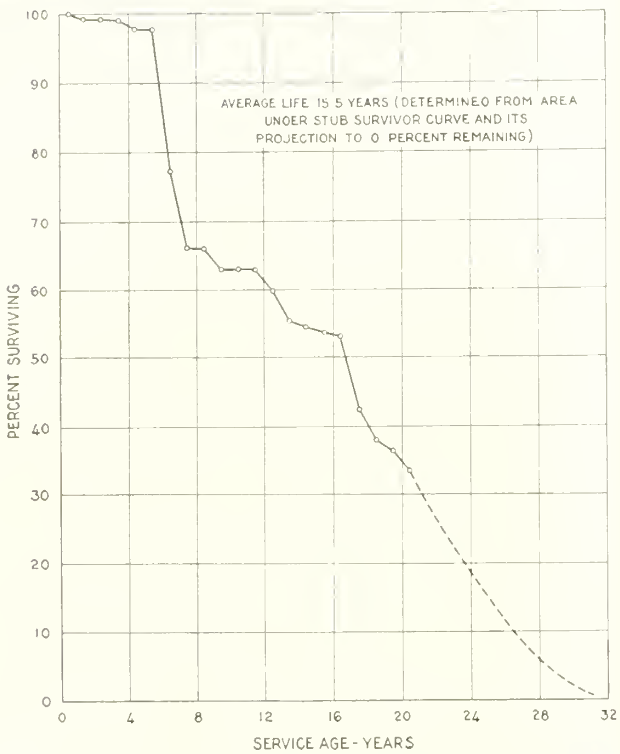

Figure 5.—Survivor Curve for 132 Miles of Bituminous Concrete Roads Constructed in 1916.

stub curve and to the trends for other years of construction. The probable average service life of 15.5 years was determined from the area below the stub curve and its projection to zero percent remaining in service.

Figure 6 shows the stub survivor curve obtained for bituminous penetration roads built in 1924. The end point of the stub curve is 75 percent remaining in service at 12½ years. The trend of the stub survivor curve is such that the probable average service life of 15 years can be estimated satisfactorily by matching the stub curve with the type survivor curves. An R_3 type curve of 15 years average life was selected by visual inspection as the curve giving the best fit. For purposes of comparison, figure 6 shows both the stub survivor curve and the type survivor curve.

Figure 7 illustrates an instance where type survivor curves from Bulletin 125 were matched with a stub curve whose end point is higher than 90 percent. The stub curve for portland cement concrete roads constructed in 1924 extends only to 95 percent remaining in service, and the matching type curve selected is an R_3 curve of 27 years average life.

On figure 8 are plotted the stub survivor curves for bituminous surface-treated roads built during 1919–23. It is apparent that the stub curves for the individual years follow approximately the same trend. When difficulty is experienced in obtaining satisfactory estimates for individual years of construction and the successive years of construction show close agreement with respect to survivor characteristics, the data for the individual years may be combined into like-age groups for purposes of analysis. This was done for the bituminous surface-treated roads constructed during 1919–23 and the composite stub survivor curve obtained from the grouping is shown in figure 9.

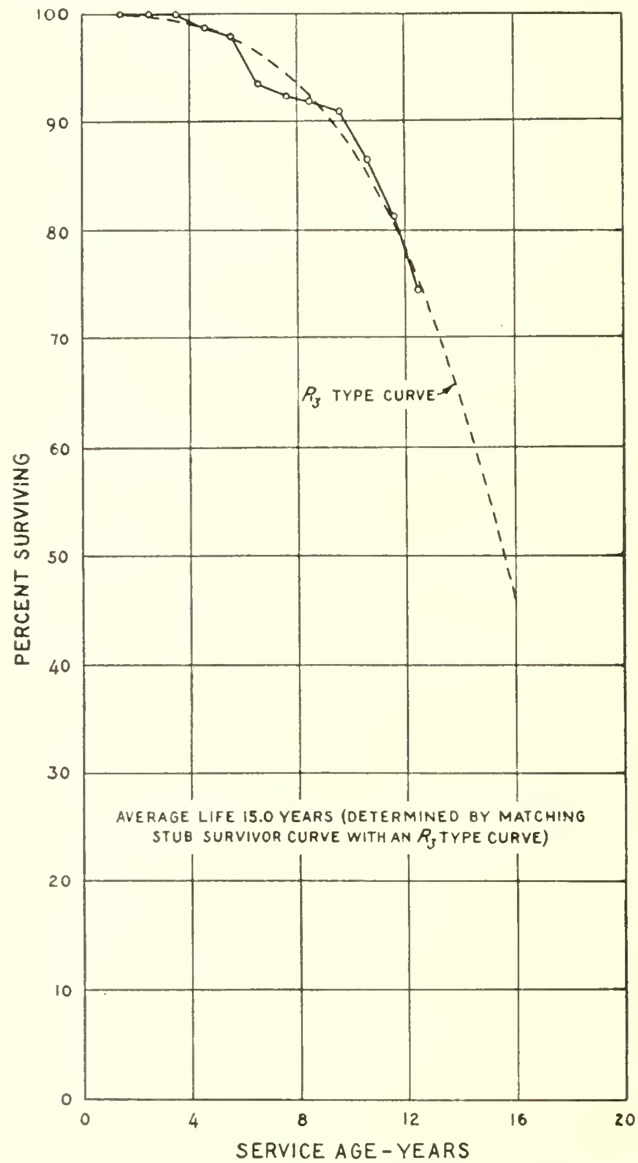

Figure 6.—Survivor Curve for 898 Miles of Bituminous Penetration Roads Constructed in 1924.

Table 14 shows the procedure for grouping the data for the individual years of construction in order to obtain a composite curve. The trend of the composite stub survivor curve thus obtained is such that the average service life of 15.5 years can be estimated by matching the stub curve with the type survivor curves. Type S_1 at 15.5 years average life was selected by visual inspection as the curve giving the best fit. For purposes of comparison, figure 9 shows both the composite stub survivor curve for these bituminous surface-treated roads and the S_1 type survivor curve.

Tables 15, 16, and 17 give in summarized form the probable average lives for the nine surface types and indicate the method used in arriving at the estimate. The estimates of average lives for the earlier years of construction of each type should be more reliable than those for the more recent years of construction. The reason for this is that the greater percentage of retirements from the early construction leaves less future life to be estimated. On the other hand the mileages of early construction are so limited that the resulting

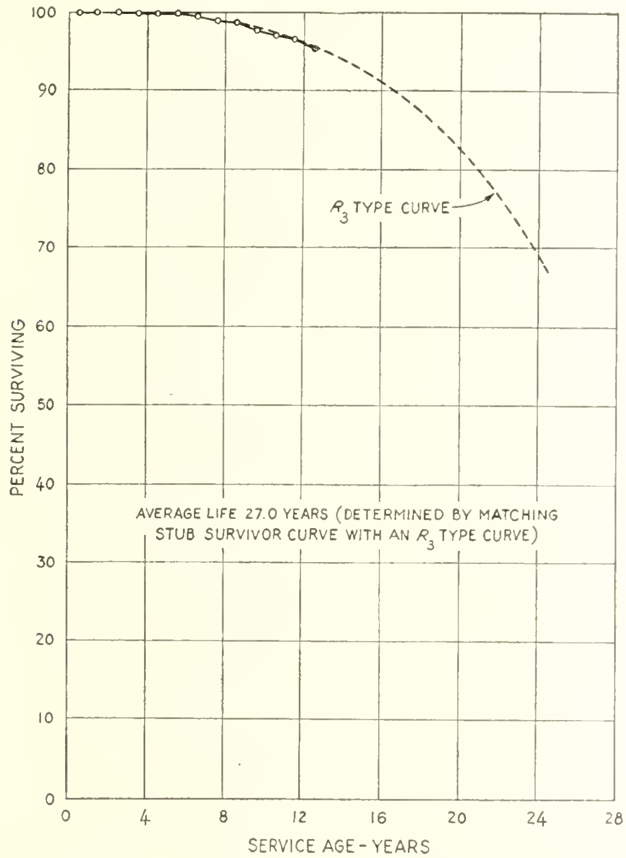

FIGURE 7.—SURVIVOR CURVE FOR 1,922 MILES OF PORTLAND CEMENT CONCRETE ROADS CONSTRUCTED IN 1924.

TABLE 14.—*Calculation of composite stub survivor curve for the 1919 to 1923 construction of bituminous surface-treated roads*

[Mileage data obtained from table 7]

Age, years	Remaining in service								
	Year of construction					A [1] Total	B [1]	C [1]	D [1]
	1919	1920	1921	1922	1923				
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Percent*	*Miles*	*Percent*
0	168	260	329	176	438	1,371	100.0		
½	168	260	329	176	438	1,371	100.0		
1½	168	258	329	174	438	1,367	99.7		
2½	167	252	325	174	438	1,356	98.9		
3½	164	252	325	173	438	1,352	98.6		
4½	164	251	320	173	438	1,346	98.2		
5½	161	251	315	173	419	1,319	96.2		
6½	161	228	305	165	408	1,267	92.4		
7½	148	228	297	163	390	1,226	89.4		
8½	147	225	285	150	369	1,176	85.8		
9½	143	223	270	132	356	1,124	82.0		
10½	142	212	240	124	350	1,068	77.9		
11½	122	173	215	117	344	971	70.8		
12½	111	166	210	114	328	929	67.8		
13½	101	137	192	114	284	828	60.4		
14½	101	135	187	87		510	56.6	544	93.8
15½	94	135	187			416	55.6	423	98.3
16½	81	133				214	51.9	229	93.4
17½	63					63	40.4	81	77.8

[1] The entries in columns A, B, C, and D for ages from 14½ years to 17½ years are obtained as follows:

Column A: The entry of 510 miles at the age of 14½ years is the summation of th mileages remaining for only 4 years of construction (1919 to 1922). The experience of the 1923 construction extends only to January 1, 1937, at 13½ years of age and must necessarily be omitted. Similarly, the entries in column A at ages of 15½, 16½, and 17½ years include 3, 2, and 1 year of construction, respectively.

Column C: The mileage entries in this column for ages from 14½ years to 17½ years represent the mileages existing 1 year prior to the corresponding mileage entries in column A. Thus, the entry of 544 miles at 14½ years of age is the sum of the mileages of 1919 to 1922 construction which existed at 13½ years of age.

Column D: The entries in this column represent the percentage of the mileage which remained in service throughout the preceding year, obtained by dividing the entries in column A by the entries in column C. Thus, of the mileage existing at 13½ years of age, there was 93.8 percent still in service at 14½ years of age (510 divided by 544).

Column B: Of the original construction of 1,371 miles there was 60.4 percent remaining in service at an age of 13½ years (828 divided by 1,371). Column D (for 4 of the 5 years of construction) indicates that 93.8 percent of mileage in service at an age of 13½ years was still in service at 14½ years of age. Thus, 0.604×0.938 or 56.6 percent of the original 100 percent may be considered as still in service at 14½ years of age. Similarly, 98.3 percent (from column D) of the mileage in service (or 56.6 percent) at an age of 14½ years was still in service at 15½ years of age. Therefore, 0.566×0.983 or 55.6 percent of the original 100 percent may be considered as still in service at 15½ years of age. This same procedure is followed for obtaining the stub survivor curve entries at 16½ and 17½ years of age in column B.

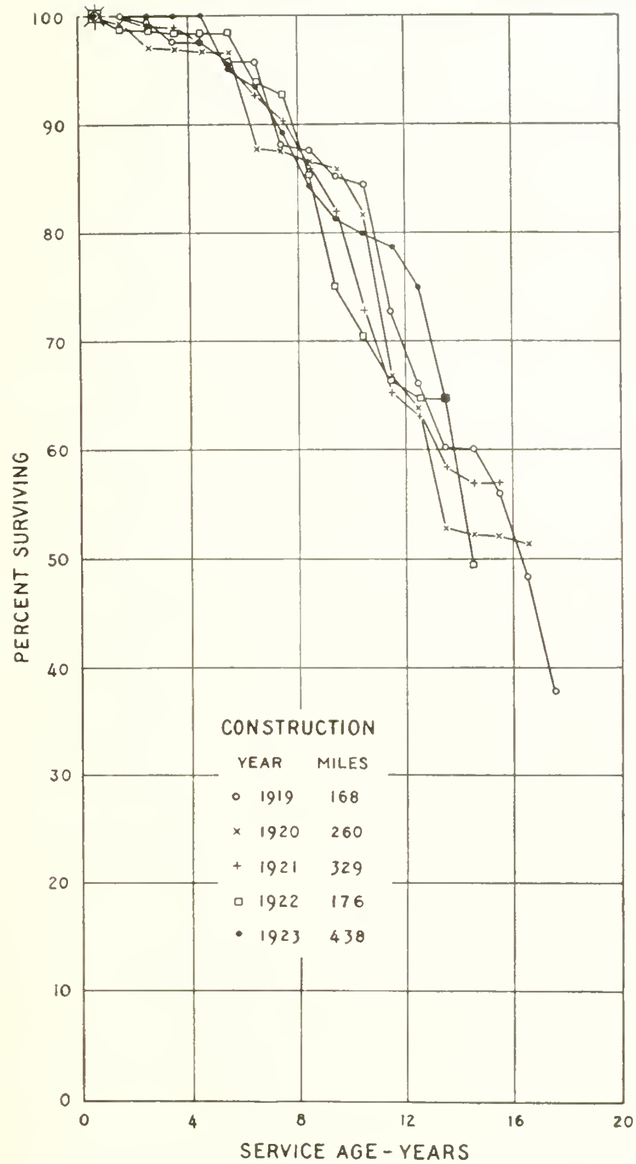

FIGURE 8.—SURVIVOR CURVES FOR 1,371 MILES OF BITUMINOUS SURFACE-TREATED ROADS CONSTRUCTED IN 1919–23.

survivor curves frequently follow erratic trends, as compared to the generally smooth curves obtained for the larger mileages of construction of later years. Estimates of average lives are given in tables 15, 16, and 17 only when the retirements were sufficient and the trend definite enough to warrant making the estimate. It will be noticed that generally no estimate is made unless the end point of the survivor curve is below 90 percent, and even for stub curves having end points between 85 and 95 percent, the probable error in the prediction may be large. An added degree of reliability is afforded, however, by giving consideration to the trend of probable average lives for the prior years.

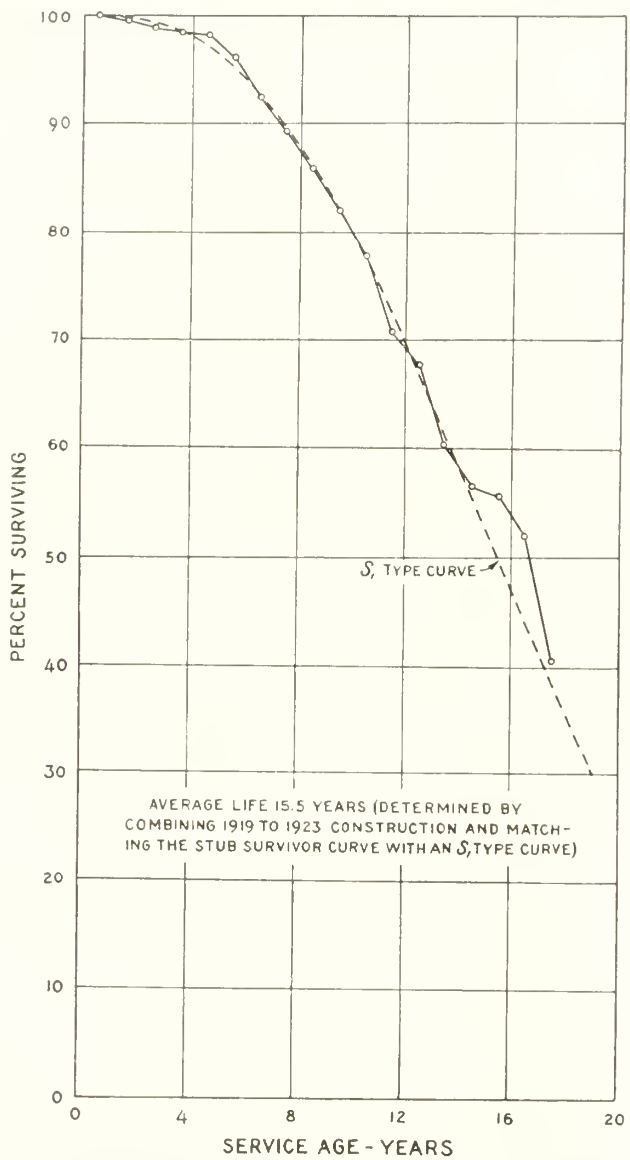

FIGURE 9.—COMPOSITE SURVIVOR CURVE FOR 1,371 MILES OF BITUMINOUS SURFACE-TREATED ROADS CONSTRUCTED 1919–23.

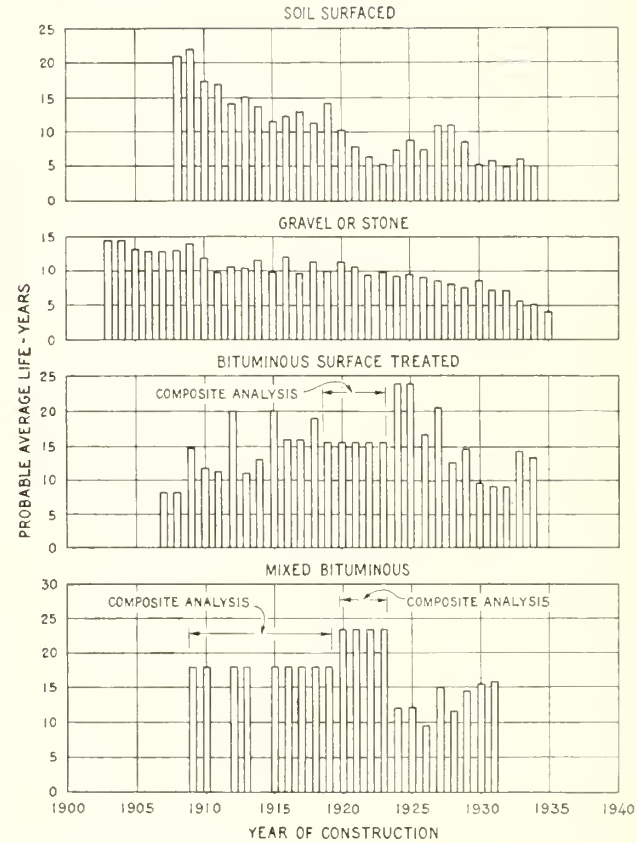

FIGURE 10.—PROBABLE AVERAGE LIVES FOR SEVERAL TYPES OF ROAD SURFACES CONSTRUCTED IN VARIOUS YEARS.

AVERAGE LIFE OF HIGH-TYPE SURFACES INCREASING

Figures 10 and 11 indicate the trends and show the irregularities of changes in average lives. Administrative policy has played a predominating part in the retirement of some types of surfacing. For example, the probable average service life of gravel or stone roads (the most extensive type of construction) has gradually been reduced to approximately 5 years for more recent construction, primarily as the result of a continually increasing practice of placing a bituminous surface on the gravel or stone within a limited time after construction. The conditions causing retirements of high-type surfaces are less influenced by changes of administrative policy than are those of low-type surfaces. Of interest, therefore, is the decrease in probable average service life of portland cement concrete constructed during the period 1916–20. This decrease probably results from the deteriorating effect of increases in volume and weight of traffic during and immediately following the World War period on those roads built under unfavorable conditions at that time.

For the purpose of obtaining definite indications, if any, of average service life trends, table 18 was prepared from tables 15, 16, and 17 by combining the individual construction years into six arbitrary construction-year groupings: 1903–10, 1911–15, 1916–20, 1921–25, 1926–30, and 1931–36. The averages were obtained by weighting the estimated average service life for a particular type during a given year with the mileage constructed during that year. The table indicates that the average service life of the lower types is decreasing, probably because of the administrative policy of keeping the lower type roads in serviceable condition by periodic resurfacing and reconstruction as well as by their gradual improvement to a higher type through stage construction. For the higher types, there is evidence that the average service life is increasing, probably because of substantial advances made in design standards, specifications, and construction methods.

In table 19 is recorded for each type of surface the average age of the miles remaining in service on January 1 of each year from 1920 to 1937. To calculate this average age each individual entry on tables 5 to 13 was multiplied by its particular age. Vertical totals of age-miles for each year were then divided by the corresponding miles remaining in service on January 1 to get the average ages. In general, the average ages increase from 1920 to 1937. Very heavy construction of a given type during a particular year either reduces the average age or slows up the increase during the same year for that type.

Tables 20 to 28 indicate the percentage distribution of retired mileages of each surface type according to

TABLE 15.—*Probable average service lives of each year's construction of soil-surfaced, gravel or stone, and bituminous surface-treated roads*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Year of construction	Soil-surfaced roads				Gravel or stone roads				Bituminous surface-treated roads			
	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]
1903					11	0	14.4	I				
1904					18	0	14.4	I				
1905					20	0	13.1	I				
1906					39	0	12.7	I				
1907					47	0	12.7	I	12	0	8.2	I
1908	12	0	21.0	I	71	0	12.8	I	16	0	8.3	I
1909	11	0	22.0	I	103	6	14.0	II	45	0	14.8	I
1910	19	0	17.5	I	159	0	11.4	I	60	7	11.8	II
1911	40	0	16.9	I	161	0	9.7	I	40	10	11.3	II
1912	129	0	14.1	I	212	0	11.0	I	122	39	20.0	L_1
1913	139	3	15.0	II	267	0	10.8	I	82	7	11.2	II
1914	111	0	13.8	I	331	11	11.4	II	136	9	12.9	II
1915	189	4	11.4	II	534	10	9.9	II	289	43	20.0	L_1
1916	129	9	12.3	II	316	6	12.0	II	330	36	16.0	S_0
1917	103	4	12.8	II	275	0	9.6	I	136	42		
1918	74	5	11.2	II	405	13	11.3	II	214	55	19.0	L_2
1919	128	35	14.0	S_0	577	5	10.1	II	168	38	15.5	S_1
1920	279	25	10.2	II	1,273	18	11.3	II	260	51		
1921	334	9	7.8	II	2,506	15	10.6	II	329	57		
1922	499	8	6.4	II	3,485	13	9.5	II	176	49		
1923	387	3	5.3	II	3,657	21	9.8	II	438	65		
1924	421	21	7.3	II	4,958	24	9.1	II	486	82	24.0	L_1
1925	418	46	8.7	II	5,659	37	9.5	II	996	84		
1926	200	30	7.3	II	5,634	35	9.1	II	1,567	78	17.0	R_1
1927	218	70	11.0	R_2	4,689	42	8.5	L_1	1,770	84	20.5	R_1
1928	279	76			5,884	46	8.0	L_1	2,108	77	12.5	R_1
1929	450	64	8.5	R_1	5,168	46	7.5	L_0	2,056	83	14.5	R_1
1930	532	45	5.2	II	5,899	59	8.5	L_0	3,747	69	9.5	L_0
1931	475	59	5.9	II	6,304	60	7.0	L_0	2,631	78	9.0	S_0
1932	498	56	5.0	II	5,318	67			2,169	84		
1933	548	70	6.0	L_0	4,244	67	5.5	L_0	2,444	93	14.0	R_1
1934	1,021	72	5.0	L_0	4,071	77	5.0	L_0	3,042	94	13.0	R_1
1935	613	91			2,856	80	4.0	L_0	2,060	99		
1936	651	96			3,959	95			3,020	100		

[1] The last entry in this column is the estimate for the most recent year for which the retirement experience is sufficient to enable a reasonable estimate of the average life to be made.

[2] Method I.—Average service life calculated from the area under the original survivor curve.

Method II.—Average service life calculated from the area under the stub survivor curve and its projection to 0 percent remaining by extension of past trend.

Method S_0, R_2, etc.—These designations indicate that an estimate of the average service life was obtained by matching the stub survivor curve with the type survivor curves in Bulletin 125.

TABLE 16.—*Probable average service lives of each year's construction of mixed bituminous, bituminous penetration, and bituminous concrete roads*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Year of construction	Mixed bituminous roads				Bituminous penetration roads				Bituminous concrete roads			
	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]
1908					5	0	7.0	I				
1909	1	0	18.1	II	2	0	21.0	I				
1910	3	67			40	33	23.5	II				
1911					47	9	18.3	II				
1912	24	17			56	14	17.7	II				
1913	18	11			65	9	15.8	II	71	10	13.1	II
1914					72	25	15.8	II	115	20	14.8	II
1915	2	100			76	33	16.4	II	290	7	12.6	II
1916	19	58			213	28	14.8	II	132	33	15.5	II
1917	8	25			104	42	16.0	R_2	53	55	18.5	S_0
1918	10	100			122	53	18.0	R_2	122	23	13.4	II
1919	12	100			213	51	16.5	R_2	52	44	17.0	S_4
1920	136	80	23.5	S_1	312	44	14.0	R_2	213	48	16.5	S_0
1921	472	83			416	51	14.5	S_3	377	51	15.0	S_3
1922	81	83			519	60	14.5	R_3	346	63	16.0	S_1
1923	182	86			555	70	15.0	R_3	545	76	15.0	S_3
1924	67	52	12.0	R_4	898	75	15.0	R_3	623	76	21.0	S_0
1925	77	75			794	83	16.5	R[illegible]	471	84	21.0	L_2
1926	197	38	9.5	L_0	546	92			476	91	20.0	L_2
1927	375	78	15.0	R_1	458	88	17.5	R_2	718	88		
1928	1,016	67	11.5	S_0	664	85	19.0	R_1	501	93		
1929	1,162	83	14.5	S_0	873	86	14.0	R_2	682	91		
1930	2,860	87	15.5	R_1	1,184	89	18.0	R_1	514	92		
1931	3,747	91	16.0	L_1	1,411	95			606	94		
1932	5,551	94			1,096	98			590	99		
1933	3,132	98			981	97			484	97		
1934	5,007	98			685	96			735	99		
1935	2,686	100			944	99			514	98		
1936	3,736	100			950	99			1,053	98		

[1] The last entry in this column is the estimate for the most recent year for which the retirement experience is sufficient to enable a reasonable estimate of the average life to be made.

[2] Method I.—Average service life calculated from the area under the original survivor curve.

Method II.—Average service life calculated from the area under the stub survivor curve and its projection to 0 percent remaining by extension of past trend.

Method S_0, R_2, etc.—These designations indicate that an estimate of the average service life was obtained by matching the stub survivor curve with the type survivor curves in Bulletin 125.

TABLE 17.—*Probable average service lives of each year's construction of portland cement concrete, brick or block, and dual-type roads*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Year of construction	Portland cement concrete roads				Brick or block roads				Dual-type roads			
	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]	Miles built	Percent remaining in service on 1-1-37	Estimated average service life in years [1]	Method of determination [2]
1907					7	0	11.3	I				
1908					9	11	20.4	II				
1909					8	13	21.1	II				
1910	1	100	27.0	(3)	27	19	18.5	II				
1911					24	54	25.5	S_1				
1912	29	45	20.0	S_2	48	21	17.8	II				
1913	42	55	22.5	S_1	40	40	21.3	II				
1914	261	34	20.0	S_2	99	37	21.1	II				
1915	279	42	19.0	S_0	239	47	21.0	S_3				
1916	505	36	16.5	R_1	127	48	19.5	S_2				
1917	236	44	16.5	R_3	120	59	21.5	S_1				
1918	322	43	16.5	R_2	128	57	19.5	S_2				
1919	475	45	16.5	S_1	129	54	19.0	S_1				
1920	561	67	17.5	R_3	143	48	15.5	S_0				
1921	888	75	20.0	S_2	220	71	20.0	S_1	9	78	16.5	S_6
1922	1,113	85	23.0	R_3	261	65	17.0	S_2	41	73	15.5	R_4
1923	1,124	93	25.0	R_3	226	82	17.5	R_3	27	59	14.0	S_3
1924	1,922	95	27.0	R_3	112	78	14.5	S_4	3	100		
1925	1,690	97			161	86	21.0	R_2	17	100		
1926	2,087	99			125	91			20	100		
1927	1,942	98			61	94			14	100		
1928	2,238	99			78	98			8	100		
1929	1,891	100			27	96			11	100		
1930	3,855	100			92	99			16	94		
1931	3,518	100			71	100			31	100		
1932	2,825	99			69	100			16	100		
1933	2,039	100			28	100			6	100		
1934	1,110	100			57	100			22	100		
1935	828	100			35	100			20	100		
1936	994	100			28	100			13	100		

[1] The last entry in this column is the estimate for the most recent year for which the retirement experience is sufficient to enable a reasonable estimate of the average life to be made.

[2] Method I.—Average service life calculated from the area under the original survivor curve.
Method II.—Average service life calculated from the area under the stub survivor curve and its projection to 0 percent remaining by extension of past trend.
Method S_0, R_2, etc.—These designations indicate that an estimate of the average service life was obtained by matching the stub survivor curve with the type survivor curves in Bulletin 125.

[3] Assumed.

TABLE 18.—*Weighted probable average service life for various construction year groupings for each surface type*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Construction-year grouping	Weighted probable average service life [1] of—								
	Soil surfaced	Gravel or stone	Bituminous surface-treated	Mixed bituminous	Bituminous penetration	Bituminous concrete	Portland cement concrete	Brick or block	Dual type
	Years	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
1903–1910	[2] 19.7	12.7	12.1	[2] 18.1	[2] 21.6		[2] 27.0	[2] 18.3	
1911–1915	13.6	10.5	17.0	[2] 18.1	16.7	13.2	19.7	20.9	
1916–1920	11.7	11.0	16.4	22.1	15.5	15.8	16.8	18.9	
1921–1925	7.1	9.6	20.7	21.6	15.2	17.9	[3] 24.4	18.2	[2, 4] 15.1
1926–1930	8.1	8.3	13.8	14.3	17.0	[5] 20.0			
1931–1936	[6] 5.4	[7] 6.0	[6] 11.4	[8] 16.0					

[1] Weighted in accordance with the constructed mileage and the estimates of average service life.

[2] Average service life computations based upon the experience of a very limited mileage of original construction.

[3] Average for 1921–24.
[4] Average for 1921–23.
[5] 1926 only.
[6] Average for 1931–34.
[7] Average for 1931–35.
[8] 1931 only.

method of retirement and replacement type. Retirements are summarized into year groupings as follows:

1. 1927 and prior.
2. 1928–30.
3. 1931–33.
4. 1934–36.
5. Total through 1936.

The methods of retirement are as follows:

1. *Resurfaced.*—Roads which are resurfaced or used as a base for the replacement type are so classified when the old surface is utilized more or less intact (with the exception of necessary scarifying, reshaping, or partial reworking of the surface) in the new construction which retires the old surface. Examples of this method are the retirement of a soil-surfaced road by surface treating, or the retirement of a gravel or stone road by utilizing it as a base or foundation for a mixed bituminous road or a bituminous penetration road, etc. For surfaces which are retired by this method, it is obvious that the new or replacement construction must

TABLE 19.—*Average age of surfaces existing on January 1 of each year, 1920–37*

[Compiled from data submitted by 26 States for rural State or Federal-Aid systems]

Surface type	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
	Years	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
Soil surfaced	4.6	4.5	3.8	4.2	4.4	4.6	4.8	5.4	5.9	6.0	5.6	5.0	4.9	5.0	5.2	4.5	4.9	5.1
Gravel or stone	4.4	3.8	2.7	2.4	2.5	2.6	2.7	3.0	3.5	3.7	4.1	4.3	4.5	4.7	5.1	5.4	6.0	6.3
Bituminous surface treated	3.9	4.2	4.3	4.8	4.8	4.8	4.4	3.9	3.8	3.8	4.0	3.7	3.9	4.4	4.7	5.0	5.5	5.8
Mixed bituminous	4.6	2.6	1.5	2.2	2.7	3.4	4.1	4.3	4.2	3.4	3.2	2.5	2.4	2.4	2.8	3.1	3.7	4.1
Bituminous penetration	3.6	3.6	3.6	3.6	3.7	3.6	3.8	4.3	4.8	5.2	5.4	5.3	5.3	5.5	5.9	6.4	6.8	7.0
Bituminous concrete	3.8	3.9	3.6	3.6	3.5	3.5	3.8	4.1	4.3	4.7	4.9	5.3	5.7	6.0	6.5	6.7	7.2	7.1
Portland cement concrete	2.8	3.2	3.2	3.3	3.5	3.5	3.7	3.9	4.2	4.5	4.9	4.8	5.0	5.4	5.9	6.6	7.3	8.0
Brick or block	3.9	4.3	4.5	4.7	5.0	5.6	6.1	6.7	7.5	8.1	9.0	9.5	10.0	10.5	11.3	11.7	12.4	13.0
Dual type			.6	.7	1.3	2.2	2.8	3.2	3.8	4.6	5.2	5.6	5.7	6.1	6.8	7.0	7.4	7.8
Total (weighted average)	3.9	3.8	3.3	3.3	3.3	3.4	3.5	3.7	4.0	4.2	4.5	4.5	4.6	4.7	5.1	5.4	6.0	6.3

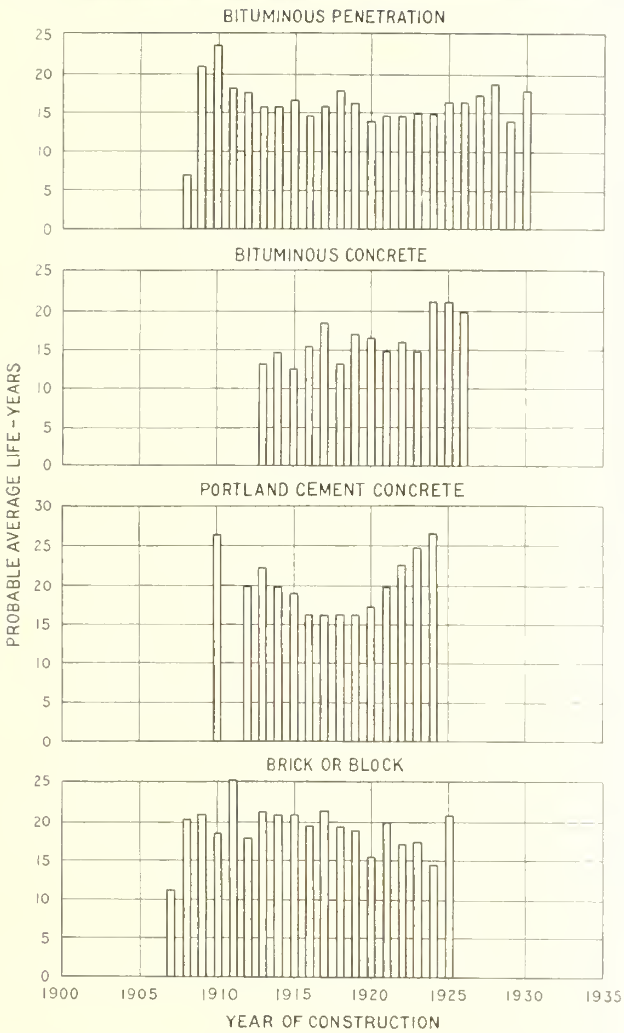

FIGURE 11.—PROBABLE AVERAGE LIVES FOR SEVERAL TYPES OF ROAD SURFACES CONSTRUCTED IN VARIOUS YEARS.

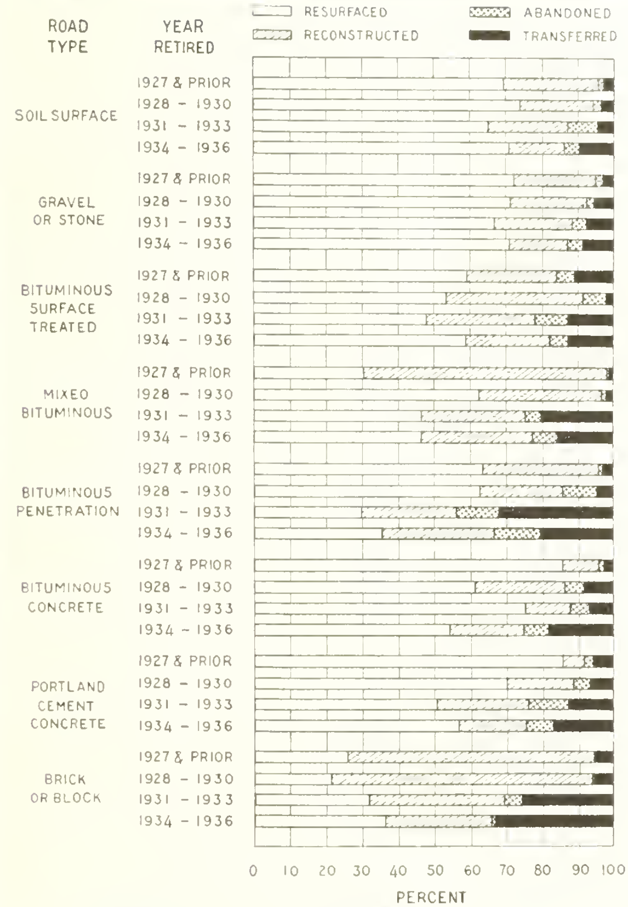

FIGURE 12.—METHODS OF RETIREMENT OF VARIOUS TYPES OF ROAD SURFACES FOR FOUR GROUPS OF YEARS.

necessarily be along the same alinement and practically the same grade.

2. *Reconstructed.*—When surfaces are retired by reconstruction there is little or no salvage of the old surface and base, if any, into the new type constructed.

TABLE 20.—*Soil-surfaced road retirements; percentage distribution of retired mileages of soil surfaced roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type [1]	1927 and prior, 1,295 miles retired					1928-30, 978 miles retired					1931-33, 1,012 miles retired					1934-36, 1,000 miles retired					Total through 1936, 4,285 miles retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
None [2]																			2.3	2.3				0.5	0.5
Graded and drained earth		3.0		0.2	3.2		3.5		2.5	6.0		1.1	3.4	3.3	7.8		2.3		5.2	7.5		2.5	0.8	2.6	5.9
Soil surfaced	3.6	1.6	0.2	.9	6.3	3.3	2.2			5.5	27.4	5.5			32.9	44.6	2.7		1.3	48.6	18.7	2.9	.1	.6	22.3
Gravel or stone	2.5	1.8	.4		4.7	3.0	1.8	0.9		5.7	5.4				5.4	5.8	1.2	1.0		8.0	4.0	1.2	.6		5.8
Bituminous surface treated	27.3	4.8	.3	1.4	33.8	44.4	9.1	1.7		55.2	20.1	4.2	.7		25.0	12.2	5.7	.8	.7	19.4	26.0	5.9	.8	.6	33.3
Mixed bituminous	.2				.2	5.4	.6			6.0	7.5	7.0	4.6		19.1	7.7	2.9	1.5	.3	12.4	4.9	2.5	1.4	.1	8.9
Bituminous penetration	.5		.5		1.0	1.3				1.3	2.1	.4			2.5	.5	.9	.1		1.5	1.0	.3	.2		1.5
Bituminous concrete	1.2	10.5			11.7	1.9	1.2			3.1	.4	2.8			3.2			.1		.1	.9	4.1			5.0
Portland cement concrete [3]	34.7	4.2		.2	39.1	14.8	2.2		.2	17.2	2.0	1.3		.8	4.1	.1			.1	.2	14.4	2.1		.3	16.8
Total	70.0	25.9	1.4	2.7	100.0	74.1	20.6	2.6	2.7	100.0	64.9	22.3	8.7	4.1	100.0	70.9	15.7	3.5	9.9	100.0	69.9	21.5	3.9	4.7	100.0

[1] No brick or block roads or dual-type roads were encountered which replaced soil-surfaced roads.

[2] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is transferred.

[3] The use of the term "resurfaced" in lieu of "reconstructed" as a method of retirement in the case of soil-surfaced roads which are replaced by portland cement concrete is not precise. An attempt, however, is made in the case of "resurfaced" to indicate the extent to which the retired soil-surfaced road is utilized as a base for the portland cement concrete. (This same qualification applies, in a lesser degree, to replacements by other types.)

TABLE 21.—*Gravel or stone road retirements; percentage distribution of retired mileages of gravel or stone roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type[1]	1927 and prior, 4,282 miles retired					1928-30, 7,725 miles retired					1931-33, 15,346 miles retired					1934-36, 13,609 miles retired					Total through 1936, 40,962 miles retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
None[2]				0.2	0.2			0.1	0.2	0.3			0.1	0.9	1.0			0.2	1.2	1.4			0.1	0.8	0.9
Graded and drained earth		1.3	0.3	.2	1.8		2.3	.4	1.4	4.1		2.6	1.1	1.8	5.5		4.3	1.2	4.1	9.6		3.0	.9	2.3	6.2
Soil surfaced		.5			.5							.1			.1	0.3	.1			.4	0.1	.1			.2
Gravel or stone	14.1	5.4	.7	1.2	21.4	11.6	1.6	.7	1.3	15.2	5.4	1.4	1.5	.9	9.2	5.7	2.9	1.0	.9	10.5	7.6	2.4	1.1	1.0	12.1
Bituminous surface treated	17.4	.2	.1	.1	17.8	20.7	.2			20.9	11.5	.1	.1		11.7	23.7	.8	.1	.1	24.7	17.8	.4	.1	.1	18.4
Mixed bituminous	26.3	.6	.1		27.0	26.8	1.1	.5	.2	28.6	43.0	1.9	.8	.6	46.3	35.6	4.0	1.7	.7	42.0	35.7	2.3	1.0	.5	39.5
Bituminous penetration	7.2	1.1	.1	.2	8.6	7.5	.2	.1	.1	7.9	5.6	.2	.3		6.1	3.9	.1	.3		4.3	5.6	.2	.2	.1	6.1
Bituminous concrete	5.5	2.2	.2		7.9	3.2				3.2	.8	.1			.9	1.5	.1	.1		1.7	2.0	.3	.1		2.4
Portland cement concrete[3]	1.7	11.7	.4	.9	14.7	1.5	16.2	.3	1.8	19.8	.6	15.1	.5	3.0	19.2	.3	3.6	.3	1.1	5.3	.8	11.1	.4	1.9	1.4
Brick or block	.1				.1												.1			.1					
Total	72.3	23.0	1.9	2.8	100.0	71.3	21.6	2.1	5.0	100.0	66.9	21.5	4.4	7.2	100.0	71.0	16.0	4.9	8.1	100.0	69.6	19.8	3.9	6.7	100.2

[1] No dual-type roads were encountered which replaced gravel or stone roads.
[2] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is abandoned or transferred.
[3] The use of the term "resurfaced" in lieu of "reconstructed" as a method of retirement in the case of gravel or stone roads which are replaced by portland cement concrete is not precise. An attempt, however, is made in the case of "resurfaced" to indicate the extent to which the retired gravel or stone road is utilized as a base for the portland cement concrete. (This same qualification applies, in a lesser degree, to replacements by other types.)

TABLE 22.—*Bituminous surface treated road retirements; percentage distribution of retired mileages of bituminous surface-treated roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type	1927 and prior, 148 miles retired					1928-30, 352 miles retired					1931-33, 1,085 miles retired					1934-36, 1,625 miles retired					Total through 1936, 3,210 miles retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
None[1]									0.1	0.1			0.2	2.6	2.8				3.5	3.5			0.1	2.6	2.7
Graded and drained earth							2.6	0.5		3.1		5.6	3.4	7.9	16.9		2.6	3.8	5.1	11.5		3.5	3.1	5.3	11.9
Soil surfaced		0.4			0.4												.3			.3		.2			.2
Gravel or stone		.1		0.5	.6		8.7	.3		9.0		4.2			4.2		9.1	.4	1.0	10.5		7.0	.2	.6	7.8
Bituminous surface treated[2]	36.8	.8			37.6	24.7	4.4	.6	.5	30.2	19.4	1.9	.6	.2	22.1	24.5	2.3	.5	1.1	28.4	23.4	2.3	.5	.7	26.9
Mixed bituminous	5.5				5.5	8.4	.5	3.3	.3	12.5	15.2	2.3	2.3		19.8	19.1	3.9		.1	23.1	16.0	2.8	1.1	.1	20.0
Bituminous penetration	9.2	10.6			19.8	9.1	5.3	1.4		15.8	5.6	2.0	.2		7.8	8.2	.6	.6		9.4	7.5	2.1	.5		10.1
Bituminous concrete	4.8	2.2	4.3	7.0	18.3	7.0	3.3			10.3	4.9	.5	.7		6.1	6.9	.4			7.3	6.1	.8	.4	.3	7.6
Portland cement concrete[3]	3.0	10.7	.9	3.1	17.7	3.8	13.6	1.6		19.0	2.7	13.8	1.8	2.0	20.3		4.2	.1	1.6	5.9	1.5	8.8	.9	1.6	12.8
Brick or block	.1				.1																				
Dual type																	.1			.1					
Total	59.4	24.8	5.2	10.6	100.0	53.0	38.4	7.7	.9	100.0	47.8	30.3	9.2	12.7	100.0	58.7	23.5	5.4	12.4	100.0	54.5	27.5	6.8	11.2	100.0

[1] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is abandoned or transferred.
[2] Because of the difficulties involved in the determination of the thickness of bituminous mats, it is probable that a portion of the large percentages of bituminous surface-treated roads which are resurfaced and indicated as being replaced by bituminous surface treated roads should in reality be indicated as being replaced by mixed bituminous roads. The data, however, are recorded as submitted.
[3] The use of the term "resurfaced" in lieu of "reconstructed" as a method of retirement in the case of bituminous surface-treated roads which are replaced by portland cement concrete is not precise. An attempt, however, is made in the case of "resurfaced" to indicate the extent to which the retired bituminous surface-treated road is utilized as a base for the portland cement concrete. (This same qualification applies, in a lesser degree, to replacements by other types.)

This classification includes old surfaces and bases that are torn up and not reused. Usually, for types that are retired by this method, the replacement type is built along the same general alinement involving only minor improvements in horizontal curvature and sight distance. Substantial improvements are usually made with respect to grades and vertical curves, however.

3. *Abandoned.*—For roads that are abandoned, the new construction is on new location. Sometimes, however, a road is dropped entirely from the system and there is no new construction that may be considered as replacing the mileage abandoned. In such cases, the replacement type is indicated as "none."

4. *Transferred.*—Retirement by transfer is similar to abandonment except that the road is continued in service after being dropped from the State or Federal-Aid system by being maintained and resurfaced or reconstructed, when necessary, by the county or other local authority.

It is obvious that a fine distinction between the various methods of retirement cannot be made. The classifications are general in character and should be so interpreted.

TYPES OF SURFACES BUILT TO REPLACE OLD SURFACES LISTED

The replacement type indicated on tables 20 to 28 is the surface type of the new road constructed to replace the surface of the old road. It is to be noted that the replacement type may be upon entirely new location or there may be no replacement type as men-

TABLE 23.—*Mixed bituminous road retirements; percentage distribution of retired mileages of mixed bituminous roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type [1]	1927 and prior, 64 miles retired					1928–30, 159 miles retired					1931–33, 617 miles retired					1934–36, 1,304 miles retired					Total through 1936, 2,144 miles retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
None [2]														0.1	0.1			0.3	0.8	1.1			0.2	0.5	0.7
Graded and drained earth		6.6			6.6							1.3	0.4	.1	1.8		1.1	.1	2.4	3.6		1.3	.1	1.5	2.9
Soil surfaced																	.5		.2	.7		.3		.1	.4
Gravel or stone		2.3			2.3		11.5			11.5		1.8	1.6	.2	3.6		2.8	2.2	1.2	6.2		3.1	1.8	.8	5.7
Bituminous surface treated		1.1			1.1		5.2	0.1		5.3		1.1			1.1		4.5	1.0		5.5		3.5	.6		4.1
Mixed bituminous	1.1		0.2		1.3	37.9	8.9	1.3		48.1	27.8	2.2	1.5	6.8	38.3	41.4	7.9	3.2	3.6	56.1	36.0	6.1	2.5	4.2	48.8
Bituminous penetration	19.8	8.6		1.1	29.5	6.1	1.6			7.7	3.9	1.2	.6		5.7	1.1	.1			1.2	2.8	.8	.2		3.8
Bituminous concrete	9.1	33.7			42.8	1.9	.4			2.3	10.5	.8		.3	11.6	3.8	1.8			5.6	5.7	2.4		.1	8.2
Portland cement concrete [3]		16.1	.3		16.4	16.2	7.0	.2	1.6	25.0	4.4	20.5	.4	12.5	37.8	.1	12.1	.5	7.0	19.7	2.5	14.2	.5	8.0	25.2
Dual type						.1				.1						.2	.1			.3	.1	.1			.2
Total	30.0	68.4	.5	1.1	100.0	62.2	34.6	1.6	1.6	100.0	46.6	28.9	4.5	20.0	100.0	46.6	30.9	7.3	15.2	100.0	47.1	31.8	5.9	15.2	100.0

[1] No brick or block roads were encountered which replaced mixed bituminous roads.

[2] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is abandoned or transferred.

[3] The use of the term "resurfaced" in lieu of "reconstructed" as a method of retirement in the case of mixed bituminous roads which are replaced by portland cement concrete is not precise. An attempt, however, is made in the case of "resurfaced" to indicate the extent to which the retired mixed bituminous road is utilized as a base for the portland cement concrete. (This same qualification applies, in a lesser degree, to replacements by other types.)

TABLE 24.—*Bituminous penetration road retirements; percentage distribution of retired mileages of bituminous penetration roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type	1927 and prior, 158 miles retired					1928–30, 299 miles retired					1931–33, 533 miles retired					1934–36, 878 miles retired					Total through 1936, 1,868 miles retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
None [1]				1.2	1.2								0.2	0.4	0.6			0.2	0.3	0.5			0.2	0.4	0.6
Graded and drained earth							0.2	1.0		1.2		0.5	2.6	10.2	13.3		1.5	5.4	11.5	18.4		0.9	3.4	8.3	12.6
Soil surfaced																	.3			.3		.1			.1
Gravel or stone		2.5		.4	2.9		2.7	1.3		4.0		4.8	.4	1.0	6.2		3.3	3.0	.8	7.1		3.6	1.7	.7	6.0
Bituminous surface treated							6.3	1.7		8.0		2.4	.3	.9	3.6		4.8	.1	2.5	7.4		3.9	.4	1.4	5.7
Mixed bituminous	4.0				4.0	7.8	.1		0.4	8.3	5.4	2.6	5.5	1.8	15.3	9.5	3.2			12.7	7.6	2.2	1.6	.6	12.0
Bituminous penetration	30.2	6.6	0.4	1.3	38.5	34.4	3.1	5.2	.1	42.8	18.5	1.7	1.6	5.3	27.1	16.0	12.8	3.6	1.8	34.2	20.9	7.5	3.0	2.4	33.8
Bituminous concrete	20.1	2.6			22.7	9.5	3.1	.9	.5	14.0	3.8	3.3			7.1	9.1	.7		.1	9.9	8.6	2.0	.2	.2	11.0
Portland cement concrete [2]	9.1	13.7	.9		23.7	10.4	8.0		3.1	21.5	1.6	11.2	1.4	12.4	26.6	.9	4.0	.6	3.4	8.9	3.3	7.5	.8	5.6	17.2
Brick or block		7.0			7.0							.1			.1		.2			.2		.7			.7
Dual type						.2				.2	.1				.1		.4			.4	.1	.2			.3
Total	63.4	32.4	1.3	2.9	100.0	62.3	23.5	10 1	4.1	100.0	29.4	26.6	12.0	32.0	100.0	35.5	31.2	12.9	20.4	100.0	40.5	28 6	11.3	19.6	100.0

[1] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is abandoned or transferred.

[2] The use of the term "resurfaced" in lieu of "reconstructed" as a method of retirement in the case of bituminous penetration roads which are replaced by portland cement concrete is not precise. An attempt, however, is made in the case of "resurfaced" to indicate the extent to which the retired bituminous penetration road is utilized as a base for the portland cement concrete. (This same qualification applies, in a lesser degree, to replacements by other types.)

tioned above under the classifications of abandoned and transferred. Table 20, for example, indicates that during the period 1931–33, there were 1,012 miles of soil-surfaced roads retired in the 23 States for which this series of tables is prepared. The entries indicate that 64.9 percent of the soil-surfaced roads retired from 1931 to 1933 were resurfaced, 22.3 percent were reconstructed, 8.7 percent were abandoned, and 4.1 percent were transferred to other authorities for continued maintenance and reconstruction. The distribution of each of these percentages according to the replacement type is also indicated. Of all retirements of soil-surfaced roads during 1931 to 1933, the maximum individual retirement entry is the 27.4 percent for soil-surfaced roads retired by being resurfaced with a soil-surface, and the next largest entry is 20.1 percent retired by being resurfaced by the addition of a bituminous mat less than 1 inch in compacted thickness.

Table 20 also indicates that for soil-surfaced roads retired during the years 1931 to 1933, 4.1 percent were replaced by portland cement concrete surfaces. The distribution of the 4.1 percent is as follows: 2.0 percent were resurfaced along the same line and grade, 1.3 percent were reconstructed along the same general alinement, and 0.8 percent were transferred to other authorities for continued maintenance and reconstruction. The new portland cement concrete roads which replaced the old soil-surfaced roads transferred were on new alinements.

Table 29 and figure 12 summarize the percentages retired by each method for each group of years for each surface type. Most of the indicated trends are not particularly significant, and there is considerable variation among the different types with respect to method of retirement. Resurfacing is an especially significant method of retirement since it affords an approximate measure of the relative extent to which the various types of surfacing construction are salvaged when they are retired.

TABLE 25.—*Bituminous concrete road retirements; percentage distribution of retired mileages of bituminous concrete roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type [1]	1927 and prior, 434 miles retired					1928-30, 305 miles retired					1931-33, 387 miles retired					1934-36, 549 miles retired					Total through 1936, 1,675 retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
None [2]																		0.1	5.3	5.4				1.8	1.8
Graded and drained earth		0.3			0.3		4.9		0.1	5.0		0.4	2.3	1.6	4.3		1.1	2.9	7.7	11.7		1.4	1.5	2.9	5.8
Gravel or stone		.3			.3		.5			.5		1.2	.1		1.3		3.2			3.2		1.5			1.5
Bituminous surface treated							.1	0.5		.6		1.5	.4		1.9		4.4	.1	.1	4.6		1.8	.2		2.0
Mixed bituminous						1.3		.3		1.6	1.8	.3			2.1	11.3	2.0	.7	.4	14.4	4.4	.7	.3	.1	5.5
Bituminous penetration	5.6	.5	0.6		6.7	2.6	.1	4.0		6.7	1.0	.1	.6	.1	1.8	3.3	.8			4.1	3.2	.4	1.0		4.6
Bituminous concrete	45.0	5.8		2.4	53.2	49.1	5.2		3.2	57.5	71.0	1.1	.1	2.4	74.6	38.9	2.5	.7	1.3	43.4	49.8	3.5	.3	2.2	55.8
Portland cement concrete [3]	30.4	3.4	.8		34.6	7.0	14.3	.5	5.1	26.9	1.3	8.2	2.2	2.2	13.9	.3	6.1	2.6	3.2	12.2	9.6	7.4	1.7	2.5	21.2
Brick or block												.1			.1										
Dual type	4.9				4.9	1.1	.1			1.2						.4	.6			1.0	1.6	.2			1.8
Total	85.9	10.3	1.4	2.4	100.0	61.1	25.2	5.3	8.4	100.0	75.1	12.9	5.7	6.3	100.0	54.2	20.7	7.1	18.0	100.0	68.6	16.9	5.0	9.5	100.0

[1] No soil-surfaced roads were encountered which replaced bituminous concrete roads.
[2] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is abandoned or transferred.
[3] The use of the term "resurfaced" in lieu of "reconstructed" as a method of retirement in the case of bituminous concrete roads which are replaced by portland cement concrete is not precise. An attempt, however, is made, in the case of "resurfaced" to indicate the extent to which the retired bituminous concrete road is utilized as a base for the portland cement concrete. (This qualification applies, in a lesser degree, to replacements by other types.)

TABLE 26.—*Portland cement concrete road retirements; percentage distribution of retired mileages of portland cement concrete roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type	1927 and prior, 418 miles retired					1928-30, 365 miles retired					1931-33, 484 miles retired					1934-36, 595 miles retired					Total through 1936, 1,862 miles retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
None [1]				0.2	0.2			0.1	2.7	2.8			1.0	1.8	2.8			0.2	2.6	2.8			0.3	1.9	2.2
Graded and drained earth		0.2			.2		2.9	1.4	.2	4.5			.4	2.4	2.8		0.4	.5	3.2	4.1		0.7	.5	1.7	2.9
Soil surfaced														.5	.5									.1	.1
Gravel or stone		3.2	0.2		3.4		1.3	.4	.1	1.8			.2	.2	.4		.3	.6	.4	1.3		1.1	.3	.2	1.6
Bituminous surface treated							.3	.2		.5		0.2	.1	.2	.5		.3	.1		.4		.2	.1		.3
Mixed bituminous	0.4	.1			.5	3.4	1.1			4.5	4.5	1.5	1.7		7.7	12.8	1.8	1.6	1.9	18.1	6.0	1.2	1.0	.6	8.8
Bituminous penetration	19.4	.6	1.9		21.9	19.4	3.1	.1	.2	22.8	9.4	.9	.1	.1	10.5	4.4	.1	.1		4.6	12.0	1.0	.5	.1	13.6
Bituminous concrete	52.5	.2		1.6	54.3	35.4	1.3			36.7	28.8	3.5	3.8	.1	36.2	29.9	3.9	.3	.3	34.4	35.7	2.5	1.1	.5	39.8
Portland cement concrete [2]	10.8	2.2	.6	3.5	17.1	11.5	8.5	2.4	3.3	25.7	5.4	19.3	3.6	7.6	35.9	5.0	11.9	4.0	8.4	29.3	7.7	11.0	2.8	6.1	27.6
Brick or block	.1				.1						.8				.8	1.9				1.9	.9				.9
Dual type	2.3				2.3	.7				.7	1.9				1.9	2.6	.3	.2		3.1	2.0	.1	.1		2.2
Total	85.5	6.5	2.7	5.3	100.0	70.4	18.5	4.6	6.5	100.0	50.8	25.4	10.9	12.9	100.0	56.6	19.0	7.6	16.8	100.0	64.3	17.8	6.7	11.2	100.0

[1] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is abandoned or transferred.
[2] Portland cement concrete roads which have been recapped by portland cement concrete are indicated as "resurfaced" opposite the entry for the portland cement concrete replacement type.

Table 30 was prepared to illustrate the approximate extent to which right-of-way was reused at the time the surfacing was retired. The mileages resurfaced or reconstructed were used as a measure of the extent to which right-of-way was salvaged at the time of retirement. The mileages of rights-of-way that were not salvaged insofar as the rural State or Federal-Aid systems were concerned were those that were abandoned or transferred. This table indicates a rather definite trend, both by surface types and years. In general, when the surfaces on roadways involving the higher types of surfaces are retired, there is less utilization of the original alinements than for roadways involving the lower types of surfaces. The yearly trend for all types is consistently toward less mileage resurfaced or reconstructed on existing alinement. This is evidenced by the decrease from 95 percent to 84 percent in utilizing in the replacement construction the alinements existing at the time of retirement for the periods of 1927 and prior and 1934 to 1936, respectively.

SUMMARY

The preparation of programs, particularly of long range estimates, of finance and construction for highway systems must involve consideration of the probable average life of existing construction.

While it is possible to determine the exact average life of construction already retired from service, the average life of existing construction cannot be determined with absolute certainty until it is retired. It follows then that the only analytical method of approach is to analyze the retirements to date to determine the average life of past construction. The facts and trends brought to light by such an analysis may then be used as a basis for arriving at reasonable estimates of the average lives of existing or future construction.

For certain studies in engineering and economics it would be most helpful to know the true average life of the recently completed construction, but because of

TABLE 27.—*Brick or block road retirements; percentage distribution of retired mileages of brick or block roads, according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Replacement type [1]	1927 and prior, 61 miles retired				1928–30, 62 miles retired					1931–33, 109 miles retired					1934–36, 68 miles retired					Total through 1936, 300 miles retired				
	Resurfaced	Reconstructed	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
None [2]																		5.0	5.0				1.1	1.1
Graded and drained earth																1.9	1.0	7.1	10.0		0.4	0.2	1.6	2.2
Gravel or stone								0.2	0.2			0.9		0.9				.4	.4			.3	.1	.4
Bituminous surface treated		21.3		21.3		20.2			20.2		0.9			.9		.4		.7	1.1		8.9		.2	9.1
Mixed bituminous	3.5			3.5						1.9	2.5			4.4	23.7			.3	24.0	6.8	.9		.1	7.8
Bituminous penetration	4.1	2.6		6.7														.3	.3	.8	.5		.1	1.4
Bituminous concrete	13.9	3.0		16.9	19.8	10.1			29.9	16.3	4.6			20.9	7.2	6.5		1.0	14.7	14.5	5.8		.2	20.5
Portland cement concrete [3]	2.1	33.5	5.7	41.3	1.8	34.0	0.6	5.0	41.4	12.9	29.3	4.4	25.0	71.6	3.2	13.4		16.9	33.5	6.2	27.5	1.8	15.2	50.7
Brick or block [3]	2.1	8.2		10.3		8.3			8.3		.4		.4	.8		.3		1.6	1.9	.4	3.6		.5	4.5
Dual type										.5				.5	2.2	6.9			9.1	.7	1.6			2.3
Total	25.7	68.6	5.7	100.0	21.6	72.6	.6	5.2	100.0	31.6	37.7	5.3	25.4	100.0	36.3	29.4	1.0	33.3	100.0	29.4	49.2	2.3	19.1	100.0

[1] No soil-surfaced roads were encountered which replaced brick or block roads.
[2] "None" indicates the mileage is dropped from the system and there is no new construction which may be considered as replacing the mileage which is transferred.
[3] Brick or block roads upon which have been placed a "second story" of portland cement concrete or brick or block are indicated as "resurfaced" opposite the entries for the portland cement concrete or brick or block replacement types.

TABLE 28.—*Dual type road retirements; percentage distribution of retired mileages of dual type roads according to method of retirement and replacement type*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems

Replacement type [1]	Total [2] through 1936, 26 miles retired				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Mixed bituminous	21.2	2.3			23.5
Bituminous penetration	18.1	1.2			19.3
Bituminous concrete	29.0	.4		5.0	34.4
Portland cement concrete	3.9	7.0	4.6	2.7	18.2
Dual type	1.5			3.1	4.6
Total	73.7	10.9	4.6	10.8	100.0

[1] The replacement types not listed were not encountered as replacing dual-type roads.
[2] Only the totals are shown for dual-type roads. The mileage retired during various years is too small to warrant distribution by year groups.

very few retirements, particularly from the higher types of surfaces, it becomes necessary to estimate these average lives on a basis of the trend of average life of prior construction. Such estimates will become fact or approach fact only as those forces that caused retirement in the past continue to act in the same relative magnitudes or continue to change at the same general rates. Standards of design and construction and traffic conditions have not changed materially enough in any short interval of time in the past to have caused any abrupt change in the trend of average lives of road surfaces, nor are they likely to do so in the future. The changes have been gradual in the past and are likely to continue to be gradual, but over a long period of years they have caused, and may again cause, significant changes in the average lives of roadway surfaces.

For other types of physical properties the survivor curve method of determining probable average lives is being used with increasing frequency and it should be equally advantageous when applied to highways. For human lives it has been successfully used for a hundred years. In contrast to human lives, however, physical properties are subjected to wide fluctuation in condi-

TABLE 29.—*Summary of retirements; percentages of retired mileages of each surface type according to method of retirement during various years*

[Compiled from data submitted by 23 States for rural State or Federal Aid systems]

Type retired	1927 and prior					1928–30					1931–33					1934–36					Total through 1936				
	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total	Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Soil surfaced	70.0	25.9	1.4	2.7	100.0	74.1	20.6	2.6	2.7	100.0	64.9	22.3	8.7	4.1	100.0	70.9	15.7	3.5	9.9	100.0	69.9	21.5	3.9	4.7	100.0
Gravel or stone	72.3	23.0	1.9	2.8	100.0	71.3	21.6	2.1	5.0	100.0	66.9	21.5	4.4	7.2	100.0	71.0	16.0	4.9	8.1	100.0	69.6	19.8	3.9	6.7	100.0
Bituminous surface treated	59.4	24.8	5.2	10.6	100.0	53.0	38.4	7.7	.9	100.0	47.8	30.3	9.2	12.7	100.0	58.7	23.5	5.4	12.4	100.0	54.5	27.5	6.8	11.2	100.0
Mixed bituminous	30.0	68.4	.5	1.1	100.0	62.2	34.6	1.6	1.6	100.0	46.6	28.9	4.5	20.0	100.0	46.6	30.9	7.3	15.2	100.0	47.1	31.8	5.9	15.2	100.0
Bituminous penetration	63.4	32.4	1.3	2.9	100.0	62.3	23.5	10.1	4.1	100.0	29.4	26.6	12.0	32.0	100.0	35.5	31.2	12.9	20.4	100.0	40.5	28.6	11.3	19.6	100.0
Bituminous concrete	85.9	10.3	1.4	2.4	100.0	61.1	25.2	5.3	8.4	100.0	75.1	12.9	5.7	6.3	100.0	54.2	20.7	7.1	18.0	100.0	68.6	16.9	5.0	9.5	100.0
Portland cement concrete	85.5	6.5	2.7	5.3	100.0	70.4	18.5	4.6	6.5	100.0	50.8	25.4	10.9	12.9	100.0	56.6	19.0	7.6	16.8	100.0	64.3	17.8	6.7	11.2	100.0
Brick or block	25.7	68.6		5.7	100.0	21.6	72.6	.6	5.2	100.0	31.6	37.7	5.3	25.4	100.0	36.3	29.4	1.0	33.3	100.0	29.4	49.2	2.3	19.1	100.0
Dual type [1]																					73.7	10.9	4.6	10.8	100.0
Total	72.2	22.8	1.9	3.1	100.0	69.9	22.6	2.7	4.8	100.0	63.7	22.4	5.2	8.7	100.0	65.8	18.5	5.5	10.2	100.0	66.6	21.1	4.5	7.8	100.0

[1] Only the totals are shown for dual-type roads. The mileage retired during various years is too small to warrant percentage distributions by year groups.

TABLE 30.—*Salvage of right-of-way at time of retirement of surfacing; percentages of surfaced mileage retired by resurfacing or reconstruction* [1] *used as a measure of the extent to which the right-of-way is utilized in the replacement construction*

[Compiled from data submitted by 23 States for rural State or Federal-Aid systems]

Type retired	1927 and prior			1928–30			1931–33			1934–36			Total through 1936		
	Total surfaced mileage retired	Amount resurfaced or reconstructed (right-of-way reused)		Total surfaced mileage retired	Amount resurfaced or reconstructed (right-of-way reused)		Total surfaced mileage retired	Amount resurfaced or reconstructed (right-of-way reused)		Total surfaced mileage retired	Amount resurfaced or reconstructed (right-of-way reused)		Total surfaced mileage retired	Amount resurfaced or reconstructed (right-of-way reused)	
	Miles	*Miles*	*Percent*	*Miles*	*Miles*	*Percent*	*Miles*	*Miles*	*Percent*	*Miles*	*Miles*	*Percent*	*Miles*	*Miles*	*Percent*
Soil surfaced	1, 295	1, 242	96	978	926	95	1, 012	883	87	1, 000	866	87	4, 285	3, 917	91
Gravel or stone	4, 282	4, 077	95	7, 725	7, 169	93	15, 346	13, 564	88	13, 609	11, 829	87	40, 962	36, 639	89
Bituminous surface treated	148	125	84	352	322	91	1, 085	848	78	1, 625	1, 337	82	3, 210	2, 632	82
Mixed bituminous	64	63	98	159	154	97	617	465	75	1, 304	1, 010	77	2, 144	1, 692	79
Bituminous penetration	158	152	96	299	256	86	533	299	56	878	585	67	1, 868	1, 292	69
Bituminous concrete	434	417	96	305	263	86	387	340	88	549	412	75	1, 675	1, 432	85
Portland cement concrete	418	384	92	365	324	89	484	369	76	595	450	76	1, 862	1, 527	82
Brick or block	61	58	95	62	58	94	109	75	69	68	45	66	300	236	79
Dual type	------	------	------	3	2	67	14	11	79	9	9	100	26	22	85
Total (approximate) [2]	6, 860	6, 518	95	10, 248	9, 474	92	19, 587	16, 854	86	19, 637	16, 543	84	56, 332	49, 389	88

[1] The terms "resurfacing" and "reconstruction" are limited to work done along the same alinement (or right-of-way) as the road which is retired or replaced. The differences between "Total surfaced mileage retired" and "Amount (miles) resurfaced or reconstructed" represent mileages which are abandoned or transferred at the time of retirement.

[2] The percentages indicated for the total are based upon the observed distribution and amounts of surfaced mileage retired as summarized directly from the data submitted by 23 States for rural State or Federal-Aid systems. The percentages are a lineal measure only; no adjustment is made for differences in right-of-way widths which may reasonably be expected between the lower and higher types of surfacing.

tions of service, in standards of design and construction, in economic and social forces surrounding their use, and in the policies of management. All of these combine to complicate the problem and to cast shadows of uncertainty upon predicted average lives of highway surfaces as well as upon other similar predictions. In spite of these uncertainties, much is to be gained by the type of analyses presented herein when the results are used within their limitations.

The estimated average lives shown in tables 15, 16, and 17 are probably within 10 percent of the ultimate values for the curves having end points of less than 70 percent surviving when the mileage constructed is 100 or more miles. For the shorter survivor curves, the amount of error is more uncertain, but where estimates of average lives are given for such short curves the mileage tables, 5 to 13, afford positive evidence upon which the estimates are based. Although many of the average life estimates are recorded to the nearest one-half year and still others to the nearest one-tenth year, it should not be assumed that they are accurate to this extent. These apparently precise estimates merely result from the method of calculation which permits relatively close determinations to be made on the basis of experience to date.

Closely related to the analysis of the probable average lives of roadway surfaces, but not considered in this report, are salvage value and economic life. Average lives presented herein relate solely to the period of time between the date of completion of the surface construction and the date of retirement without regard to the value or condition of the surface at the time it was retired. Salvage value, of course, is an important consideration when determining total life cost of a particular improvement or when making comparisons of the economies of two or more types of construction. Future annual maintenance cost, future salvage value, and the value of the services rendered are factors to consider when the economic life is sought. It is expected that future studies will include analyses of both salvage value and economic life in order that the full economic picture of roadway surfacings will be available for use in selection of design standards and for long-range planning.

While this report is restricted to road surfacing, the additional problems in connection with right-of-way, grading, and structures are being studied in the highway-planning surveys. The road-life studies also include roadway and bridge construction and maintenance cost studies. Eventually, data will be available for many specific analyses of highway costs, economic selection of projects, and other administrative and engineering problems, which in some way depend upon service lives for their solutions. The knowledge will be extended as additional States complete the compilations outlined in the original road-life studies and as they are continued and extended. Further, analyses by individual States will afford results of more specific application to the individual highway systems than can be obtained wholly by this analysis of the combined data from 26 States

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF FEBRUARY 28, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$4,065,913	$1,925,534	101.3	$5,299,705	$2,641,333	190.4	$954,074	$474,687	32.5	$3,282,072
Arizona	1,052,086	727,201	47.7	1,968,869	1,313,364	83.1	512,191	305,161	10.9	1,732,355
Arkansas	5,018,875	2,303,379	124.7	1,184,416	590,832	54.8	258,736	128,997	5.0	1,731,782
California	6,301,274	3,231,185	129.3	8,078,506	4,284,109	122.4	2,347,997	1,155,903	36.8	4,097,539
Colorado	2,171,951	1,178,824	188.7	2,045,647	1,189,802	81.4	858,796	484,017	89.1	3,314,637
Connecticut	1,936,006	938,685	16.2	1,187,936	580,855	11.3	699,855	338,145	7.5	1,313,013
Delaware	1,395,078	696,823	28.0	797,595	372,075	4.6	121,414	60,041	4.9	1,476,275
Florida	2,512,745	1,248,025	62.5	1,905,762	961,169	59.7	551,777	275,889	25.3	3,675,206
Georgia	3,050,650	1,517,589	184.8	7,191,776	3,596,388	282.4	1,598,960	799,480	74.7	6,926,356
Idaho	1,524,898	913,923	151.0	1,040,215	640,970	56.9	474,510	292,457	12.5	2,318,053
Illinois	6,590,396	3,248,367	149.7	7,228,876	3,615,023	143.4	2,329,000	1,164,500	74.4	5,281,660
Indiana	5,158,186	2,540,688	120.9	6,580,944	3,184,331	94.6	2,395,568	1,090,573	46.7	2,444,312
Iowa	5,493,005	2,572,928	193.0	3,831,595	1,716,859	115.0	1,154,048	470,600	66.9	2,550,989
Kansas	4,108,667	2,025,851	364.2	5,892,511	2,965,594	319.0	2,617,913	1,296,938	146.1	5,043,277
Kentucky	3,080,271	1,534,114	91.1	3,035,287	1,523,324	86.9	1,487,767	743,883	49.0	3,879,008
Louisiana	1,226,957	607,890	16.0	12,538,876	3,318,425	63.2	973,952	479,288	34.9	4,263,291
Maine	1,311,372	637,396	29.2	1,599,027	821,653	21.0	18,200	9,100	.6	1,042,591
Maryland	1,267,901	625,992	29.1	2,873,923	1,436,361	22.3	797,339	398,151	7.7	1,884,261
Massachusetts	1,835,469	914,828	22.9	2,214,791	1,117,056	13.0	61,470	30,705	.5	4,293,229
Michigan	6,119,174	2,871,853	215.0	8,248,810	4,111,805	198.8	775,610	387,805	24.3	3,026,032
Minnesota	6,111,975	2,967,938	459.5	4,162,539	2,077,887	232.8	2,102,852	1,050,496	91.7	4,914,777
Mississippi	2,846,806	1,220,612	120.0	6,274,674	2,916,847	327.9	2,168,000	1,061,250	133.6	2,280,445
Missouri	3,407,975	1,686,908	169.0	8,126,965	3,800,762	197.6	4,922,604	2,172,206	139.6	4,943,089
Montana	4,123,613	2,334,341	285.2	2,202,220	1,242,712	116.7	1,373,540	777,529	62.1	4,537,214
Nebraska	4,626,452	2,194,646	548.3	3,824,474	1,932,275	445.3	1,829,331	914,665	197.5	3,825,982
Nevada	1,553,216	1,325,261	80.0	1,055,321	918,973	43.5	630,806	511,815	37.2	1,514,532
New Hampshire	1,445,362	703,792	36.4	419,795	209,610	9.0				1,415,904
New Jersey	2,258,218	1,117,617	11.8	6,330,152	3,164,996	49.1	511,945	255,972	3.1	1,749,642
New Mexico	2,059,907	1,248,046	174.5	1,470,466	904,400	65.2	700,360	434,873	36.7	2,152,017
New York	11,443,080	5,610,806	198.8	11,258,818	5,601,260	137.8	629,727	313,109	12.0	4,956,428
North Carolina	4,320,050	2,158,272	232.3	4,887,632	2,429,130	209.0	905,578	452,250	37.5	3,129,479
North Dakota	1,919,089	1,029,145	191.2	2,560,588	1,454,119	197.4	2,585,944	1,330,890	218.5	4,602,432
Ohio	7,157,899	3,578,131	93.1	11,268,622	5,608,937	90.3	6,254,740	3,073,187	48.3	4,776,524
Oklahoma	2,668,030	1,414,276	120.4	2,830,634	1,457,547	88.1	1,890,676	984,512	77.2	5,522,902
Oregon	3,117,234	1,863,021	155.0	2,709,022	1,468,246	57.3	1,450,723	754,373	45.9	1,597,755
Pennsylvania	6,225,906	3,078,918	80.7	13,252,569	6,577,252	109.1	2,728,167	1,312,552	24.0	4,345,598
Rhode Island	1,294,668	644,176	13.3	928,546	463,642	7.9	4,760	2,380		1,256,946
South Carolina	1,950,769	945,285	138.1	2,114,797	997,575	116.8	1,894,510	805,760	67.8	2,669,868
South Dakota	3,125,094	1,755,269	530.4	3,953,863	2,489,603	479.3	989,980	578,360	151.3	3,416,623
Tennessee	2,438,087	1,210,168	57.1	3,686,120	1,843,060	127.8	1,825,138	912,569	39.4	4,734,453
Texas	7,763,471	3,768,775	464.1	10,987,670	5,430,351	507.2	3,933,059	1,901,655	137.6	8,710,135
Utah	993,637	714,180	73.1	993,347	742,959	41.6	463,353	234,850	11.5	1,672,217
Vermont	1,194,683	589,160	36.6	873,156	442,716	23.6	348,476	174,238	9.4	564,423
Virginia	2,568,018	1,197,907	72.5	3,636,400	1,722,190	66.8	959,243	457,774	12.3	2,658,908
Washington	3,305,203	1,687,958	86.5	3,065,148	1,628,349	28.1	15,022	6,900		1,900,971
West Virginia	1,986,952	989,890	74.2	3,489,084	1,738,340	73.9	932,236	462,685	9.6	1,926,530
Wisconsin	5,210,546	2,544,019	179.1	2,459,628	1,218,235	98.8	689,828	315,373	20.8	5,322,441
Wyoming	1,804,873	1,106,809	196.2	983,553	635,322	120.0	661,655	422,926	45.2	1,535,736
District of Columbia	513,511	256,756	5.1	602,937	269,909	.8	230,936	115,400	1.8	576,197
Hawaii	120,132	58,848	1.7	706,414	370,548	10.2	138,944	69,472	2.5	1,954,355
Puerto Rico	519,644	257,240	10.9	1,370,673	677,010	20.3	236,780	116,830	2.4	1,019,059
TOTALS	165,294,974	83,519,245	7,160.4	207,230,894	102,416,090	6,123.4	64,998,090	32,363,171	2,426.8	159,759,520

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF FEBRUARY 28, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 190,944	$ 95,263	9.4	$ 1,308,357	$ 654,158	60.7	$ 23,400	$ 11,700		$ 629,036
Arizona	233,227	152,258	23.6	142,651	105,759	.8				457,458
Arkansas	416,160	179,101	14.8	382,578	190,843	27.5	77,488	38,337	5.3	309,298
California	879,073	480,972	37.4	778,267	537,361	11.7	504,213	265,990	10.1	844,524
Colorado	45,873	25,854	1.6	252,726	141,919	5.3	66,893	37,701	10.8	392,826
Connecticut	370,531	179,413	4.6	105,456	49,907	1.8	194,675	87,585	4.3	186,667
Delaware	127,253	55,913	12.7	46,219	22,675	2.9				351,232
Florida	12,030	6,015		1,070,042	501,194	20.2	85,045	42,523	.2	329,157
Georgia	147,586	73,258	18.6	895,648	432,824	69.6	225,321	112,660	27.7	1,381,251
Idaho	152,006	93,357	24.0	166,859	99,425	6.7	145,090	46,001	7.2	283,587
Illinois	1,700,212	827,554	80.6	979,350	474,675	32.9	491,090	220,250	34.4	703,318
Indiana	476,372	229,757	31.0	163,864	87,389	8.1	219,571	109,785	10.0	1,230,526
Iowa	2,365,566	1,121,278	500.6	608,169	289,200	184.9	192,990	80,260	56.3	496,012
Kansas	321,450	160,409	49.0	913,408	459,612	46.8	175,115	87,558	51.8	1,573,986
Kentucky	792,145	268,935	65.5	569,227	138,095	18.2	373,349	106,751	21.6	552,479
Louisiana	105,321	52,661	10.9	192,608	96,249	14.9				718,740
Maine	298,852	142,635	17.0	40,606	20,303	1.5				157,657
Maryland	128,300	64,150	5.5	98,390	49,195	4.5	225,000	97,500	12.6	452,166
Massachusetts	456,347	225,862	10.3	244,546	138,203	3.6				678,018
Michigan	1,543,568	756,191	128.6	428,360	214,180	19.6	537,700	268,850	39.5	762,160
Minnesota	781,216	381,710	117.6	619,938	309,969	88.6	457,370	228,685	45.4	1,153,271
Mississippi	272,962	136,481	12.5	660,552	326,126	37.0	473,100	213,965	24.2	670,341
Missouri	735,526	363,972	96.5	134,298	67,149	12.7	357,996	157,860	34.6	1,093,519
Montana	641,506	362,577	80.3	131,028	73,938	9.3	301,938	170,675	60.9	804,353
Nebraska	546,969	262,583	99.7	603,128	301,342	67.4	62,260	31,130	17.3	546,655
Nevada	199,750	165,179	40.9	178,899	155,725	14.3				236,648
New Hampshire	143,639	68,883	3.4	71,533	34,946	3.6				220,624
New Jersey	319,476	159,633	10.6	347,262	188,145	11.4	117,660	58,830	.9	638,931
New Mexico	94,763	59,142	13.1	634,137	343,277	28.8	96,486	49,568	3.7	326,218
New York	2,027,620	970,482	67.9	1,347,060	673,530	40.0	172,260	62,297	.6	851,637
North Carolina	947,399	471,528	82.2	378,303	191,763	40.1	192,090	82,915	14.0	550,758
North Dakota	42,143	23,432	.3	169,224	90,702	3.6				1,279,920
Ohio	1,711,142	852,793	59.9	1,775,720	886,600	53.7	200,100	100,050	11.3	1,268,410
Oklahoma	667,352	353,621	47.8	261,280	138,008	17.4	259,900	136,802	13.4	1,171,889
Oregon	371,724	205,456	56.4	219,787	102,454	16.2	261,853	127,382	22.2	395,118
Pennsylvania	1,758,458	870,797	59.8	725,796	362,898	13.4	497,036	233,968	11.3	693,603
Rhode Island	249,118	122,207	3.6	90,306	47,016	.9	4,740	2,370		124,034
South Carolina	572,292	209,926	79.0	350,840	116,990	16.9	361,467	158,700	45.6	307,042
South Dakota				28,926	19,392	9.0				1,543,133
Tennessee	151,200	72,135	8.7	287,466	143,733	10.0				1,235,745
Texas	1,302,603	636,573	193.1	1,264,712	626,753	103.2	222,500	100,950	29.3	1,581,348
Utah	88,404	49,100	9.5	185,785	123,660	22.1	55,085	27,542	2.5	294,647
Vermont	335,084	108,809	13.1	193,984	56,235	7.6				97,260
Virginia	387,164	181,027	24.8	549,368	256,641	19.7				511,438
Washington	469,388	245,605	28.2	423,037	226,288	28.4	56,760	30,500	.5	368,988
West Virginia	338,127	168,327	18.5	90,300	45,150	2.4				621,964
Wisconsin	329,706	163,752	7.4	756,096	379,085	25.6	549,321	229,744	25.3	770,535
Wyoming	433,021	260,037	42.8	153,530	95,100	9.1	201,617	64,262	9.7	218,678
District of Columbia	112,164	56,082	1.4	2,192	1,096					115,944
Hawaii	264,732	132,578	8.6	1,096	1,096					250,559
Puerto Rico	143,800	70,400	6.4	213,613	104,380	9.7				157,407
TOTALS	27,201,264	13,375,663	2,339.7	22,236,527	11,192,353	1,264.3	8,438,479	3,881,646	664.5	32,600,715

U. S. GOVERNMENT PRINTING OFFICE: 1941

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

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No. 279MP. . Bibliography on Highway Lighting. 5 cents.

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The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF FEBRUARY 28, 1941

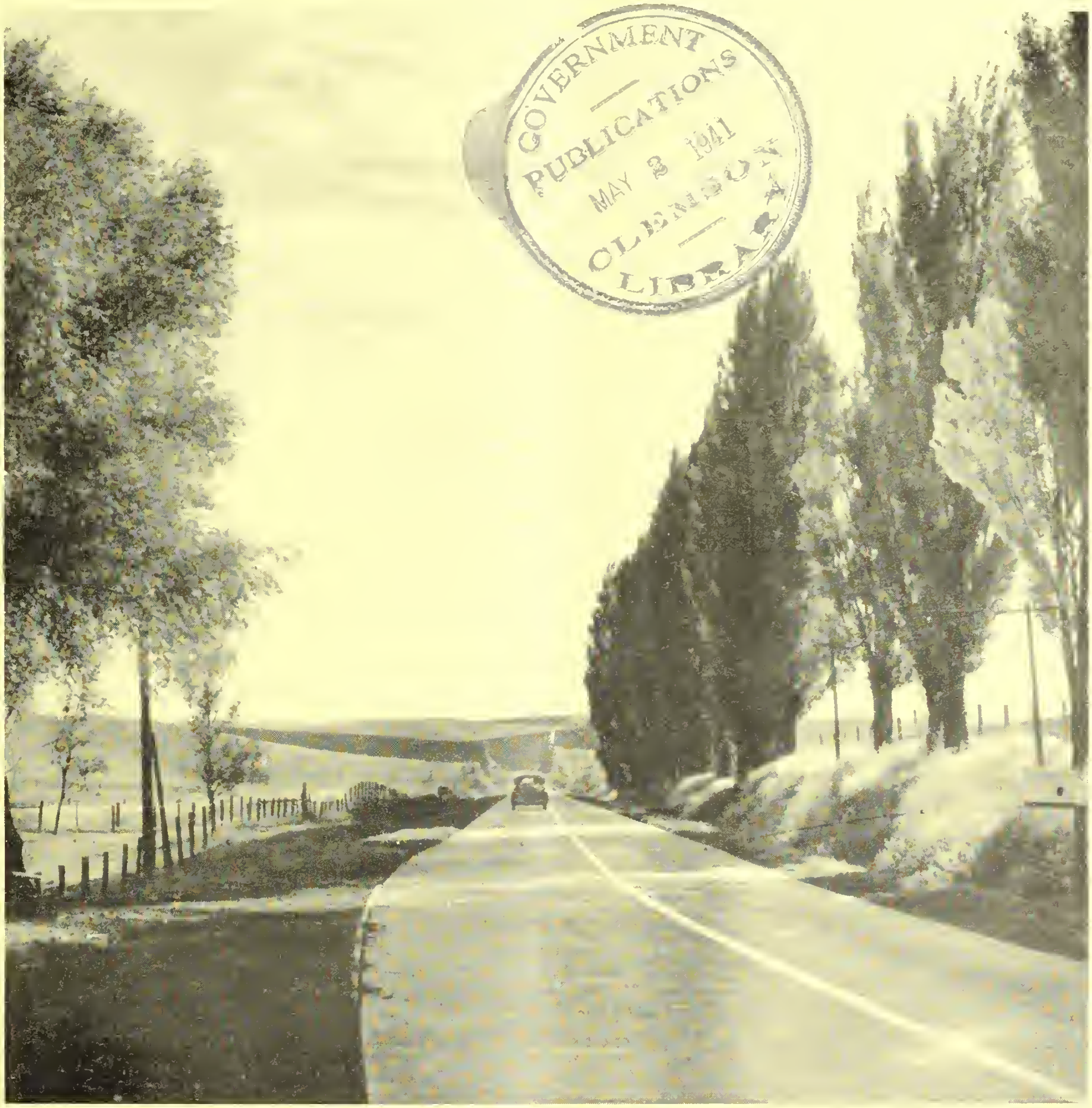
STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			
			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 282,122	$ 282,039	4		5	$ 508,001	$ 488,008	3	1	2	$ 191,232	$ 191,232	2		8	$ 1,116,926
Arizona	198,347	190,981	3		2	179,037	178,688	1			189,839	184,386	1	1	2	198,769
Arkansas	645,956	644,311	6	1	8	851,301	847,414	9		1	303,893	303,783	2		8	348,644
California	447,600	447,600	4		9	1,030,449	834,594	7	1		739,112	739,112	2		12	1,428,464
Colorado						293,434	293,434	1			354,284	354,284	2		4	814,905
Connecticut	622,002	611,366	5	1		166,222	165,415	2								614,980
Delaware	68,080	68,080			13	132,406	132,406	5		3	2,332	2,332			1	560,221
Florida	207,524	203,025	2		2	102,816	102,291	1	1		280,106	280,106	2		28	1,371,309
Georgia	209,905	209,810	4	2	13	1,109,967	1,109,967	10	6		198,161	198,161	1	1	6	2,166,934
Idaho	277,686	274,256	5		29	20,543	20,543			2	18,891	18,891			6	569,399
Illinois	1,733,149	1,662,161	9	1	54	1,337,696	1,109,847	4	1	85	157,823	149,729	1		24	2,913,933
Indiana	690,570	688,770	3	2	79	791,360	758,460	5	1	11	273,451	273,451	3		15	1,015,714
Iowa	478,263	452,373	4		82	157,729	129,472	2		12	360,860	359,546	3	2	12	1,402,280
Kansas	757,653	756,896	10		17	414,971	414,971	3	2	5	365,484	365,484	10		6	1,218,457
Kentucky	574,050	572,380	8		11	638,550	638,550	7		1	398,889	398,889	3		3	550,968
Louisiana	100,158	100,158	1			535,658	482,163	10			476,872	419,147	3		2	1,093,302
Maine	159,759	158,841	1	1	6	132,646	132,646	1	1							398,661
Maryland	180,996	180,993	1		2	485,009	453,216	2	2	7	60,550	60,550			12	920,364
Massachusetts	16,588	16,588		1		342,715	332,292	1			90,040	89,740	1			2,319,006
Michigan	1,159,449	1,116,537	8	1	36	1,428,735	1,428,735	2	5	1	149,807	149,807	2		6	1,146,756
Minnesota	1,186,763	1,178,364	12	2	15	893,686	893,686	5	4	4	567,617	567,617	3	2	3	1,126,220
Mississippi	263,360	263,360	3	1	1	595,634	595,634	8			86,900	86,900	1		3	803,304
Missouri	1,208,033	1,208,033	6	4	1	1,709,501	1,254,081	5	1		215,039	161,640		2		1,461,929
Montana	434,356	434,356	5		4	88,047	88,046	1			2,474	2,474			1	609,220
Nebraska	422,446	420,775	3	1	10	801,396	801,396	14	1	1	136,577	136,577	1		15	523,229
Nevada	72,617	72,617	1		20	70,501	70,501	1			71,448	71,448	1		5	154,921
New Hampshire	104,313	104,277	3		1	146,134	145,314	3			2,703	2,703			1	426,747
New Jersey	280,886	280,886	2		4	857,018	857,018	4	1		335,976	207,930	2		1	1,108,667
New Mexico	242,979	242,979	2		6	183,821	175,247	3								653,292
New York	1,207,716	1,173,326	7	5		3,490,433	3,438,462	7	15		417,145	412,645		2	8	3,550,675
North Carolina	558,278	558,215	8	2	22	642,749	642,509	6	4	5	205,760	205,760		2	38	1,193,284
North Dakota	428,578	427,126	5		22	385,790	385,790	4		1						893,676
Ohio	1,170,693	1,099,741	7	1	17	2,113,700	2,103,700	11	2		514,315	498,853	2			2,913,019
Oklahoma	528,698	526,324	9	1	36	446,582	443,166	4		7	140,173	140,173			45	2,265,740
Oregon	208,639	117,537	3			295,958	270,633	3			7,790	7,790			3	521,879
Pennsylvania	1,387,269	1,377,793	13	2		2,220,317	2,216,489	16			651,110	651,110	5			3,754,837
Rhode Island	8,222	7,406				206,703	206,703		1							175,628
South Carolina	447,320	446,917	4	3	21	136,359	136,359	1	1	1	211,296	211,296	2		32	1,094,416
South Dakota	129,470	129,470	2	1	4	568,364	567,504	16			104,420	88,470	2		1	1,017,637
Tennessee	244,886	241,169	2	2		225,803	216,803	1	3		98,647	98,647	2			2,010,411
Texas	1,343,917	1,331,759	12		10	1,483,380	1,470,800	15	1		373,840	372,350	4		1	2,351,474
Utah	40,529	40,318			12	104,696	103,954	2		37	95,436	95,436			35	307,129
Vermont	114,460	114,290		1	7	142,375	142,375		1	5	10,815	10,815			3	301,305
Virginia	205,954	204,508	2	2	7	679,025	678,805	5	2	2	133,882	133,882	1	1	8	866,757
Washington	268,532	265,581	4	1	7	536,503	535,003	3	4	3	11,529	11,529			4	450,708
West Virginia	9,310	9,310			2	442,862	437,242	5		1	173,910	173,910	2			1,026,333
Wisconsin	834,217	818,984	6	4	7	455,699	426,689	3		5	196,269	196,055	1		27	1,670,633
Wyoming	1,986	1,982				560,905	560,904	6			4,997	4,997			2	299,298
District of Columbia	56,868	56,868	1			2,193	2,193									275,206
Hawaii	5,292	5,017			1	199,451	199,444	2		1	272,046	210,000	2			179,852
Puerto Rico						584,007	579,336	11								582,439
TOTALS	22,226,444	21,796,453	200	43	605	31,928,837	30,698,898	241	62	203	9,653,740	9,299,637	69	13	391	56,739,857

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 22, NO. 2 APRIL 1941



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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

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FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 2 April 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

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THE PROPERTIES OF THE RESIDUES OF 50–60 AND 85–100 PENETRATION ASPHALTS FROM OVEN TESTS AND EXPOSURE [1]

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by R. H. LEWIS, Chemist, and J. Y. WELBORN, Assistant Highway Engineer

In recent years the value of the standard oven heat test for the prediction of the probable hardening of asphalts in the mixing and laying operations and under service conditions has been seriously questioned.

Many investigators have resorted to oxidation tests to study the hardening and weathering properties of asphalts. Specifications are now in use that limit the loss in penetration and ductility that an asphalt can undergo either in a laboratory mixing test or in a plant-prepared hot-mix surfacing sampled immediately after laying.

This report presents the results of tests on 50–60 and 85–100 penetration asphalts made on the residues from the standard oven test as well as on the residue from 50-gram samples exposed to the same conditions in films approximately ⅛ inch thick. Changes in the properties of 85–100 penetration asphalts after exposure in ⅛-inch films for 15 weeks during the hot summer months are also shown.

Although the residues from the standard oven test are not greatly altered, the residues from the ⅛-inch film oven tests, especially in the case of some 50–60 asphalts, are highly altered. Results of tests on the residues of 50–60 asphalts from the thin-film oven tests, when compared with the results of tests on bitumens extracted from both laboratory-prepared mixtures and from mixtures from commercial paving plants, indicate that the ⅛-inch film oven test produces alterations in the asphalts similar to the changes in properties that occur during the mixing process. It is believed, therefore, that a thin-film oven heat test may prove of value in predicting the probable behavior of asphalts under processing and service conditions.

THIS REPORT describes a continuation of studies previously reported, (*11*) [2] together with the results of tests on other asphalts before and after their incorporation in hot paving mixtures prepared in laboratory and plant mixers.

Since the early days of the asphalt paving industry some form of laboratory heat test has been used in specifications for asphalt cements to indicate the probable hardening of the asphaltic binder when subjected to high temperatures and to exposure in service. In 1897 Allen W. Dow enumerated essential characteristics that asphalts should have to insure satisfactory pavements. Among the many desirable properties, he included stability when exposed to high temperatures for appreciable periods of time. Although at that time there were no standard tests for asphalt cements, Dow suggested the following methods for determining the stability of asphalts at high temperatures.

Method 1.—Weigh 20 grams of asphalt into a 2-ounce glass retort and place this in an air bath at a temperature of 400° F. for 30 hours. Determine the loss of weight and measure the consistency of the residue with a penetrometer.

Based on this method, the specifications of the District of Columbia for 50 to 120 penetration asphalts required that the loss of heating should be not more than 8 percent and that the percentage of original penetration retained should be not less than 75. The relatively high loss permitted was, no doubt, due to the use of fluxing oils in the preparation of asphalt cements from hard native asphalts.

Method 2.—Mix the asphalt and sand, in the proportions to be used, at a temperature of 300° F. Divide the finished mix into two parts. Allow one part to cool to room temperature, and hold the other part at 300° F. for 30 minutes and then allow it to cool. Extract the asphalt from the two mixtures with carbon disulfide and recover the asphalt by distilling to a maximum temperature at 300° F. Determine the hardening of the asphalt by comparing the penetrations of the two recovered residues.

Although there is no record of this method having been used in specification requirements, it is of interest because so many present-day investigators have resorted to similar types of tests to study the behavior of asphalts in the processing of hot-mix pavements.

VALUE OF STANDARD LOSS ON HEATING TEST QUESTIONED

Before 1911 many different methods were used to determine the loss on heating and the drop in penetration. Temperatures, time of heating, size of containers, and methods of heating varied considerably. In 1911 the American Society for Testing Materials issued a provisional method for the determination of the loss on heating of oil and asphaltic compounds, in which a 20-gram sample was placed in a flat-bottomed tin 6 centimeters in diameter and 2 centimeters deep, and heated for 5 hours at 163° C. (325° F.).

In 1916 the loss on heating test was made A. S. T. M. Standard Test Method D6–16. The size of the sample tested was increased to 50 grams, and the 3-ounce tin in use today was specified. The oven temperature and time of heating were unchanged, being respectively 163° C. (325° F.) and 5 hours. Although there have been refinements in the testing oven from time to time, the basic conditions of the test method (D6–16) have not been altered. The present A. S. T. M. designation for this test is D6–39T.

In recent years the value of the standard oven test for predicting the probable hardening of asphalts in the mixing and laying operations and under service conditions has been seriously questioned. Victor Nicholson (*14*) has stated that use of the 50-gram sample does not give as sharp a differentiation in the hardening properties of asphalts as the 20-gram sample did. He has also stated that the properties of asphalts recovered from pavements cannot be correlated with the test for loss on heating and that the test is retained in the specifications of the City of Chicago merely to check the

[1] Paper presented at the meeting of the Association of Asphalt Paving Technologists, Dallas, Texas, December 9–13, 1940.
[2] Italic figures in parentheses refer to bibliography, p. 46.

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hardening action of heat on the asphalt in the storage kettle at the paving plant.

Rasehig and Doyle (*17*) concluded, after examination of the extracted bitumens from paving mixtures immediately after mixing and after various periods of service, that an asphalt that showed an excessive drop in penetration after the standard loss on heating test would probably have an unsatisfactory service record.

In the previous report (*11*) it was noted that all the asphalts of both the 50–60 and 85–100 grades had lower percentages of loss in the standard oven test and retained greater percentages of their original penetration than were required by the most stringent specification. The range in the percentage of loss on heating and the drop in penetration was too narrow to evaluate adequately the probable hardening properties of the various asphalts.

The inability of the present test for loss on heating to furnish adequate indications of the hardening of asphalts in the mixing operation and in service has led to numerous investigations of this problem by laboratory mixing methods, oxidation tests, and the study of mixtures freshly laid and after service in the pavement. An excellent bibliography on the behavior of asphalts during the processing of mixtures and in service is appended to a report by J. R. Benson (*3*). The work of F. C. Lang and T. W. Thomas (*6*), C. L. Shattuck (*19*), and the reports by H. A. Juhlin (*5*), E. B. Tucker (*21*), R. Vokac (*22*), J. G. Schaub and W. K. Parr (*18*) are additional evidence of the interest in this particular subject.

Steinbaugh and Brown (*20*), in enumerating the major causes for the cracking of asphalt pavements, concluded that the failure of surfaces because of excessive oxidation or "loss of life" of the asphaltic binder was difficult to control or to predict. They added that the changes in the asphalt residue from the oven heating test may approach the changes that take place during mixing and laying; but they doubted whether the oxidation of the mass of asphalt in the test sample is similar to that occurring in a paving mixture, with the asphalt in the film stage. For this reason, they concluded that it must be demonstrated that an oven heat test can give significant results.

RESIDUES FROM STANDARD AND THIN-FILM OVEN TESTS COMPARED

The information obtained from the standard oven test has been limited to loss of volatile matter and drop in penetration. This study was undertaken to determine if a better evaluation of the relative durability of asphalts might be made with other tests on the residues from the standard oven test or on the residues from an oven test so modified as to accelerate the changes that occur.

The study was made with the same asphalt cements of the 50–60 and 85–100 penetration grades that were included in the previous investigation (*11*). The sample identification numbers used in this report are the same as those used in the previous report and these numbers, together with the designated grade, will be used to identify the various asphalt cements.

This investigation included tests on the residues obtained from the standard test for loss on heating (A. S. T. M. Method D6–39T) and from oven tests made with the asphaltic material exposed in a film ⅛-inch thick. Tests on the residues of the 85–100 penetration asphalts after exposure to light, heat, and air, were also made. Throughout this report the above tests will be referred to, respectively, as the standard oven test, the thin-film oven test, and the exposure test. Comparative data on the physical properties of other asphalts before and after subjection to the thin-film oven test and after extraction from mixtures from hot-mix pavements and from laboratory mixtures prepared by the Shattuck method (*19*) will be presented.

The test procedure used in making the thin-film oven tests was as follows:

Fifty milliliters of the asphalt to be tested were weighed into a flat-bottomed aluminum container, 5.5 inches in inside diameter and ⅜ inch deep. This volume gave a film thickness of approximately ⅛ inch. A special rotating shelf was installed in the oven to carry four of these 5.5-inch containers. In other particulars the testing procedure of the standard oven test was followed.

In order further to accelerate the effects of exposure to high temperature, the thin-film test was modified in some cases by using aluminum containers 7.78 and 11.0 inches in diameter, in which 50 milliliters of asphalt gave film thicknesses of approximately 1/16 and 1/32 inch, respectively. The larger containers were placed on a special stationary shelf immediately below the rotating shelf.

In order to determine the effects of outdoor exposure on asphalt cements, the 85–100 penetration asphalts used in this investigation, with the exception of sample 40, were exposed out of doors, under glass, to the action of sunlight, heat, and air, under conditions similar to those of previous investigations that have been reported (*7, 8, 9, 10*). The asphalts were exposed in ⅛-inch films in containers 5½ inches in diameter for a period of 15 weeks during the summer months.

The temperatures of the air and asphalt within the exposure boxes were recorded continuously during the entire 15 weeks by means of automatic temperature recorders. One element of the recorder was placed in the air and the other element was immersed in a container of asphalt. The range and average in maximum and minimum daily temperatures for both the air and asphalt are given in table 1. As determined from United States Weather Bureau reports, the asphalts were subjected to 875 hours of sunlight during the 15-week period.

TABLE 1.—*Range of and average daily maximum and minimum temperatures during exposure of 85–100 penetration asphalts*

	Maximum temperature		Minimum temperature	
	Air [1]	Asphalt [2]	Air	Asphalt
	°F.	*°F.*	*°F.*	*°F.*
Maximum	195	210	75	75
Minimum	70	70	40	45
Average	168.2	175.6	60.1	62.4

[1] Recorder placed in air inside exposure box.
[2] Recorder placed in asphalt inside exposure box.

DROP IN PENETRATION IN OVEN TEST NOT DUE TO VOLATILITY

Steinbaugh and Brown (*20*) have shown the effect of the mixing operation on the penetration and ductility of asphalts, and Shattuck (*19*) has included the determination of the softening point in his investigation. These tests, as well as the determination of organic matter insoluble in 86° B. naphtha, were made on the residues from both the standard and thin-film oven tests and on the residues from exposure. The exposure residues were also tested for penetration at 95° F. (35° C.), organic matter insoluble in carbon tetrachloride, and the reaction to the Oliensis test, including the determination of the xylene equivalent.

The physical properties of the 50–60 and 85–100 penetration asphalts before and after the oven tests are given in tables 2 and 3, respectively. The results of tests on the 85–100 penetration asphalts after exposure, as well as the results of special tests made on the original materials, are shown in table 4.

In order to indicate the extent of the alterations in test characteristics that occurred in the asphalts during the oven and exposure tests, the test results given in tables 2 to 4 have been expressed as percentages of the test results for the original materials. These percentages for penetration, softening point, ductility, and insolubility in 86° B. naphtha are shown for the 50–60 asphalts in table 5 and for the 85–100 penetration asphalts in table 6.

In figures 1 to 6, the percentage of original penetration, the softening point, and ductility values are shown by bar diagrams. The figures give a graphical presentation of the relative behavior of asphalts from each source. Figures 1 to 3 show the source of the base petroleum in relation to the effect of the oven tests on the penetration, softening point, and ductility of the 50–60 penetration asphalts. Figures 4 to 6 show the same data for the 85–100 penetration asphalts, as well as the same test data on the exposure residues. Average values for each test for the asphalts as a group are indicated for each condition of test.

The test results given in tables 5 and 6 show that the loss by volatilization in the standard oven test was very low. Only one asphalt, sample 40 of the 50–60 and 85–100 grades, had a loss of more than 0.25. The loss by volatilization during the thin-film oven test was not much greater in many cases than the loss in the standard oven test. There were 17 asphalts of the 50–60 grade that had lower losses in the thin-film oven test than in the standard oven test, and the residues of 9 asphalts increased in weight during the testing period. For the 85–100 penetration grade, 14 asphalts had lower thin-film oven losses than were obtained in the standard test and 11 of these gained in weight in the oven. Those asphalts of both grades that gained in weight when exposed in thin films had low losses in the standard oven test. Those asphalts with relatively high losses in the standard oven test had still higher losses in the thin-film oven test. Considering the penetration drop under both tests, it is apparent that for petroleum asphalts the relative hardening of the asphalts cannot be correlated with the volatility of the materials in the oven heat tests.

As shown in table 5 and figure 1, the percentage of original penetration retained by the residues of the 50–60 asphalts in the standard oven test varied from 70 to 94 with an average of 85. The residues from the thin-film oven test retained from 38 to 73 percent, with an average of 62 percent, of the original penetration.

Table 2.—*Effect of the standard and thin-film oven tests on the 50–60 penetration asphalts*

Identification No.	Original asphalt: Penetration at 77° F., 100 gm., 5 sec.	Original asphalt: Softening point	Original asphalt: Ductility at 77° F., 5 cm. per min.	Original asphalt: Organic matter insoluble in 86° B. naphtha	Standard oven test: Change in weight	Standard oven test, tests on the residue: Penetration at 77° F., 100 gm., 5 sec.	Standard oven test, tests on the residue: Softening point	Standard oven test, tests on the residue: Ductility at 77° F., 5 cm. per min.	Standard oven test, tests on the residue: Organic matter insoluble in 86° B. naphtha	Thin-film oven test: Change in weight	Thin-film oven test, tests on the residue: Penetration at 77° F., 100 gm., 5 sec.	Thin-film oven test, tests on the residue: Softening point	Thin-film oven test, tests on the residue: Ductility at 77° F., 5 cm. per min.	Thin-film oven test, tests on the residue: Organic matter insoluble in 86° B. naphtha
		°F.	Cm.	Percent	Percent		°F.	Cm.	Percent	Percent		°F.	Cm.	Percent
1	57	119	250+	10.7	−0.13	48	120	250+	11.5	−0.40	33	125	250+	14.5
2	61	118	250+	10.6	−.05	50	120	250+	11.8	−.04	36	126	250+	14.3
3	61	118	250+	10.0	−.05	50	121	250+	14.3	+.01	39	125	250+	14.0
4	60	118	250+	11.8	−.06	50	120	250+	12.7	−.08	38	125	250+	15.2
5	58	120	250+	12.6	−.07	46	122	250+	14.2	−.06	31	129	250+	17.4
6	52	126	250+	18.1	−.06	46	130	250+	19.5	−.00	35	137	129	21.5
7	58	132	197	28.2	−.07	49	134	235	29.8	−.26	38	141	73	29.0
8	56	130	68	30.9	−.11	46	139	19	32.0	−.22	34	152	8	35.2
9	53	132	218	29.3	−.08	46	139	175	31.5	−.20	35	145	98	31.7
10	56	131	215	28.8	−.12	45	139	200	30.1	−.34	33	145	70	32.2
11	54	132	180	28.1	−.11	44	137	140	31.1	−.26	30	146	52	34.1
12	55	132	250+	28.0	−.06	46	135	140	29.8	−.17	34	144	118	31.4
13	51	132	140	27.5	−.11	44	139	23	29.8	−.24	31	152	8	30.7
14	52	126	250+	21.7	+.01	46	130	250+	23.2	+.09	33	135	200	24.9
15	52	126	181	24.8	−.02	47	132	97	25.8	−.00	27	140	30	28.4
16	48	132	57	25.6	−.03	41	139	24	26.8	−.03	31	148	10	28.8
17	48	128	250+	22.9	−.02	43	133	160	23.6	−.02	34	140	92	23.8
18	51	129	250+	24.8	−.05	46	132	140	25.9	−.06	34	140	68	28.1
19	57	125	220	19.7	−.00	49	129	250+	20.6	+.10	39	133	240	22.3
20	58	137	36	30.8	−.12	53	140	22	27.8	−.46	39	146	8	29.8
21	57	130	232	24.2	−.02	50	131	160	24.3	+.05	40	138	41	25.4
22	57	137	96	27.9	−.04	48	138	41	27.5	−.00	40	145	18	29.1
23	60	120	202	21.6	−.10	42	128	24	24.4	−.21	30	142	8	24.0
24	54	131	84	20.4	−.04	48	137	29	21.1	−.01	38	144	12	22.7
25	58	127	116	17.3	−.07	49	135	84	18.6	−.00	38	137	38	18.7
26	53	129	78	25.4	−.09	44	137	23	26.4	−.20	33	143	11	25.4
27	49	131	226	19.3	−.03	43	136	112	21.0	+.03	32	141	32	21.1
28	58	126	244	23.0	−.12	45	132	90	25.1	−.36	31	138	19	24.3
30	48	131	170	23.3	−.03	45	135	58	23.6	+.05	34	138	28	26.3
31	59	133	41	30.2	−.08	51	140	22	31.9	−.25	34	152	8	32.5
32	49	128	159	21.4	−.05	44	135	44	22.3	+.08	33	137	24	23.8
33	46	127	27	24.5	−.04	40	140	8	27.8	+.05	33	152	6	27.1
34	58	128	112	28.5	−.05	46	136	53	30.2	−.04	32	148	11	32.5
35	57	123	219	19.1	−.06	52	126	230	19.4	−.10	41	129	165	20.9
36	55	125	190	20.9	−.07	50	129	131	19.6	+.02	40	136	61	22.1
37	52	132	137	27.0	−.06	44	139	58	29.2	−.13	31	146	25	30.2
38	55	132	120	25.7	−.08	46	140	20	27.6	−.20	36	146	11	29.3
39	47	129	121	23.0	−.05	44	130	160	24.9	−.07	23	141	19	27.0
40	50	123	250+	31.9	−.48	37	135	92	31.9	−2.09	19	153	6	31.4

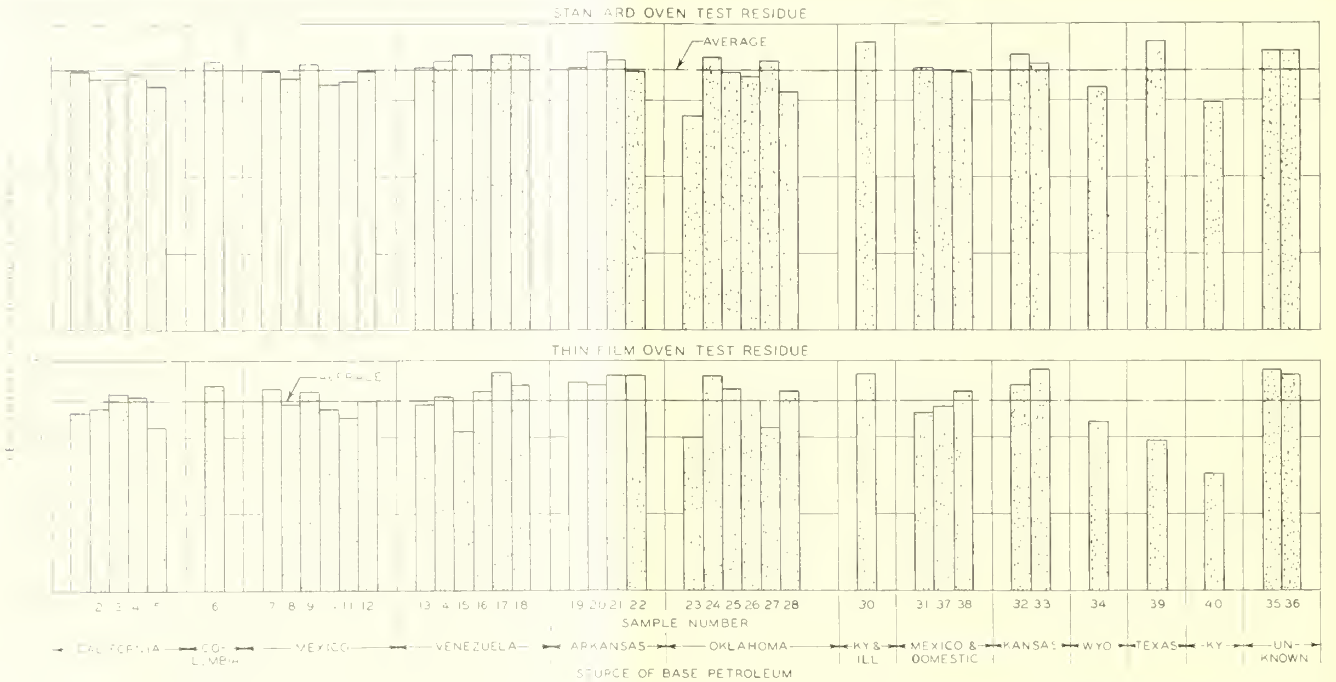

FIGURE 1.—SOURCE OF THE BASE PETROLEUM IN RELATION TO THE EFFECT OF OVEN HEAT TESTS ON THE PENETRATION OF THE 50–60 PENETRATION ASPHALTS.

TABLE 3.—*Effect of the standard and thin-film oven tests on the 85–100 penetration asphalts*

Identification No.	Original asphalt				Standard oven test					Thin-film oven test				
					Change in weight	Tests on the residue				Change in weight	Tests on the residue			
	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha		Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha		Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per min.	Organic matter insoluble in 86° B. naphtha
		° F.	*Cm.*	*Percent*	*Percent*		*° F.*	*Cm.*	*Percent*	*Percent*		*° F.*	*Cm.*	*Percent*
1	85	113	223	10.5	−0.16	69	114	250+	11.8	−0.55	48	121	250+	13.2
2	96	111	193	10.1	−.07	79	113	240	13.0	−.17	54	119	215	13.7
3	95	112	201	9.9	−.07	80	113	190	13.2	−.14	56	119	244	13.8
4	92	112	227	11.5	−.08	75	115	250+	13.6	−.21	55	120	250+	14.7
5	91	113	197	14.7	−.08	74	116	245	16.7	−.15	47	123	250+	19.7
6	92	117	185	14.3	−.05	73	120	250+	17.5	+.04	58	124	210	17.6
7	96	120	220	26.4	−.10	76	124	160	29.4	−.44	55	133	132	30.0
8	96	121	102	28.0	−.21	66	129	50	31.1	−.46	43	144	11	33.0
9	96	121	230	26.2	−.13	75	125	182	29.7	−.55	51	135	106	30.3
10	95	121	192	26.4	−.19	70	126	162	29.7	−.68	49	136	125	32.3
11	97	119	209	26.4	−.12	75	124	193	29.7	−.41	51	134	143	31.0
12	97	119	242	25.5	−.13	74	124	240	29.7	−.45	52	132	130	30.9
13	94	117	192	23.1	−.05	70	123	220	26.1	−.11	47	133	34	27.8
14	95	115	192	20.4	−.01	73	119	205	22.3	+.08	56	124	212	23.0
15	92	115	187	21.7	−.04	71	121	245	25.2	+.01	52	126	205	25.4
16	94	117	107	22.0	−.03	72	123	65	24.7	−.00	55	128	53	25.8
17	92	118	191	18.0	−.04	72	121	190	22.7	−.04	57	127	252	22.6
18	85	123	196	24.6	−.17	65	126	176	28.7	−.51	47	134	108	29.8
19	90	116	179	19.0	−.02	74	120	215	25.9	+.09	61	124	235	21.1
20	90	121	139	25.4	−.15	79	126	131	26.8	−.59	61	132	36	27.2
21	97	115	178	20.2	−.05	78	121	191	22.1	−.02	62	124	225	22.7
22	96	117	211	21.4	−.03	79	123	203	24.7	+.03	64	126	173	27.2
23	91	112	223	15.9	−.04	62	120	180	21.6	−.05	42	128	42	21.2
24	94	118	162	16.6	−.04	74	122	120	19.1	−.13	52	132	60	21.1
25	94	118	152	12.7	−.08	76	122	176	14.9	−.01	61	126	130	14.5
26	84	119	172	18.2	−.08	65	123	148	21.1	−.16	53	129	76	21.6
27	93	116	164	13.2	−.02	75	119	158	14.9	+.07	60	122	225	17.6
28	92	115	184	15.1	−.06	73	118	237	17.8	−.09	54	123	250+	18.7
29	92	113	200	18.5	−.10	60	120	250+	23.4	−.13	40	129	52	25.7
30	90	116	163	18.3	−.03	77	122	180	20.5	+.08	62	129	145	23.1
31	93	120	101	27.7	−.08	70	130	55	29.3	−.26	51	141	20	31.9
32	85	119	173	18.9	−.02	64	126	150	21.6	+.09	53	132	66	22.9
33	83	119	125	22.5	−.04	54	133	15	25.1	+.06	50	139	10	26.2
34	94	116	170	26.3	−.02	68	125	192	27.9	+.04	49	133	95	29.4
35	96	116	186	18.7	−.07	80	120	180	20.1	−.14	65	124	198	22.0
36	92	121	115	21.2	−.03	74	127	32	22.4	+.02	59	136	18	23.4
37	96	118	193	24.7	−.07	75	126	200	27.0	−.12	56	134	66	28.3
38	95	121	120	23.6	−.13	76	128	86	25.0	−.37	58	137	29	26.2
39	86	116	141	19.9	−.14	65	122	203	21.7	−.15	48	128	165	23.6
40	87	113	250+	25.8	−.53	61	124	250+	27.1	−2.17	28	139	24	29.2

TABLE 4.—*Effect of outdoor exposure on the characteristics of asphalts of the 85–100 penetration grade*

Identification No.	Change in weight	Tests on the exposure residue: Penetration 100 gm.; 5 sec. At 77° F.	At 95° F.	Slope of the log-penetration temperature curve	Softening point	Ductility at 77° F. 5 cm. per min.	Organic matter insoluble in CCl₄	Organic matter insoluble in 86° B. naphtha	Oliensis test: Character of spot	Xylene equivalent	Additional tests on the original asphalt: Slope of the log-penetration temperature curve	Organic matter insoluble in CCl₄	Oliensis test: Character of spot	Xylene equivalent
	Percent				°F.	Cm.	Percent	Percent				Percent		
1	+0.5	23	75	0.0285	134	79.0	0.29	19.5	Positive	0-2	0.0323	0.05	Negative	
2	+1.2	19	56	.0261	139	100.0	.16	22.8	Negative		.0314	.07	do	
3	+.9	19	54	.0252	140	78.0	.15	22.7	Positive	0-2	.0324	.07	do	
4	+.9	20	56	.0248	140	110+	.14	24.1	do	12-16	.0315	.08	do	
5	+1.0	17	44	.0229	146	14.0	.30	27.7	do	12-16	.0313	.08	Positive	0-2
6	+.9	24	57	.0209	146	12.0	.13	22.8	Negative		.0267	.12	Negative	
7	+.5	40	83	.0176	145	15.0	.24	32.5	do		.0219	.06	do	
8	+.7	25	41	.0119	172	4.0	.31	37.3	Positive	28-32	.0211	.07	Positive	24-28
9	+.4	35	79	.0196	147	19.0	.36	33.0	Negative		.0217	.05	Negative	
10	+.3	38	77	.0170	147	13.0	.37	33.0	do		.0220	.07	do	
11	+.6	34	67	.0164	151	15.0	.39	34.6	do		.0219	.06	do	
12	+.5	34	71	.0178	149	13.0	.42	33.8	do		.0219	.05	do	
13	+.9	27	52	.0158	158	5.5	.29	32.8	Positive	12-16	.0221	.10	Positive	2-4
14	+1.1	21	47	.0194	153	6.0	.34	30.8	do	12-16	.0248	.05	Negative	
15	+.8	19	46	.0213	153	7.0	.24	31.8	do	20-24	.0248	.05	Positive	2-4
16	+.8	25	51	.0172	154	7.0	.34	31.6	do	12-16	.0236	.07	do	2-4
17	+.9	22	52	.0208	153	7.5	.25	29.3	do	0-2	.0246	.09	Negative	
18	+.4	29	65	.0195	151	13.5	.41	34.4	do	0-2	.0226	.10	do	
19	+1.0	27	64	.0208	146	9.5	.24	28.3	Negative		.0235	.11	Positive	0-2
20	+.4	37	77	.0177	148	7.5	.15	30.1	do		.0189	.09	Negative	
21	+1.0	27	56	.0176	146	9.5	.20	29.2	do		.0230	.15	do	
22	+.9	33	66	.0167	148	9.5	.16	30.2	do		.0214	.17	do	
23	+.7	29	62	.0183	142	8.0	.48	24.5	Positive	72-76	.0277	.08	Positive	44-48
24	+1.1	31	63	.0171	150	6.5	.37	23.1	Negative		.0226	.20	Negative	
25	+.7	31	75	.0213	143	14.0	.33	19.5	do		.0228	.29	do	
26	+.8	27	57	.0180	150	6.8	.51	25.6	Positive	4-8	.0231	.22	Positive	2-4
27	+1.0	27	63	.0204	142	18.5	.11	20.2	Negative		.0256	.05	Negative	
28	+.6	25	63	.0223	141	17.5	.27	23.0	Positive	8-12	.0272	.12	Positive	4-8
29	+.4	28	62	.0192	141	11.0	.42	25.7	do	100+	.0266	.15	do	[1] 56-60
30	+.8	33	71	.0185	142	15.8	.14	23.1	Negative		.0245	.07	Negative	
31	+.7	31	54	.0134	160	4.8	.42	34.9	Positive	4-8	.0205	.06	do	
32	+.9	30	61	.0171	147	9.0	.20	24.9	Negative		.0225	.11	do	
33	+.6	33	67	.0171	195	4.0	.75	29.4	Positive	100+	.0219	.42	Positive	[1] 60-64
34	+1.1	26	42	.0116	159	5.0	.19	35.1	do	32-36	.0227	.04	do	12-16
35	+.6	37	75	.0170	141	11.5	.11	25.0	Negative		.0224	.18	Negative	
36	+.8	34	57	.0125	158	5.0	.26	27.0	do		.0192	.16	Positive	0-2
37	+.4	37	77	.0177	146	9.0	.30	30.3	Positive	0-2	.0200	.03	Negative	
38	+.7	33	55	.0123	141	5.0	.35	30.5	do	2-4	.0188	.08	do	
39	+.7	23	49	.0182	148	10.0	.26	28.6	do	36-40	.0277	.07	Positive	16-20
40											.0261	.38	do	80-84

[1] Maximum value same as spot with 100 percent xylene.

TABLE 5.—*Changes in test characteristics of 50–60 penetration asphalts after oven tests*

Identification No.	Change in weight: Standard oven test	Change in weight: Thin-film oven test	Penetration at 77 degrees F., 100 gm., 5 sec.: Standard oven test	Penetration: Thin-film oven test	Softening Point: Standard oven test	Softening Point: Thin-film oven test	Ductility at 77 degrees F., 5 cm. per min.: Standard oven test	Ductility: Thin-film oven test	Organic matter insoluble in 86 degree B. naphtha: Standard oven test	Organic matter: Thin-film oven test
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
1	-0.13	-0.40	84	58	101	105	100±	100±	107	136
2	-.05	-.04	82	59	103	107	100±	100±	111	135
3	-.05	+.01	82	64	103	107	100±	100±	118	140
4	-.06	-.08	83	63	103	107	100±	100±	108	129
5	-.07	-.06	79	53	102	108	100±	100±	113	138
6	-.06	00	88	67	103	109	100±	52-	108	119
7	-.07	-.26	84	66	102	107	119	37	106	103
8	-.11	-.22	82	61	107	117	28	12	104	114
9	-.08	-.20	87	66	105	110	83	47	108	108
10	-.12	-.34	80	60	106	111	93	33	105	112
11	-.11	-.26	81	56	104	111	78	29	111	121
12	-.06	-.17	84	62	102	109	56-	47-	106	112
13	-.11	-.24	86	61	105	115	16	6	108	112
14	+.01	+.09	88	63	103	107	100±	80-	107	115
15	-.02	00	90	52	105	111	54	17	104	115
16	-.03	-.03	85	65	105	112	42	18	105	113
17	-.02	-.02	90	71	104	109	64-	37-	103	104
18	-.05	-.06	90	67	102	109	56-	27-	104	113
19	00	+.10	86	68	103	106	114+	109	105	113
20	-.12	-.46	91	67	102	107	55	20	90	97
21	-.02	+.05	88	70	101	106	80	21	100	105
22	-.04	00	84	70	101	106	43	19	104	104
23	-.10	-.21	70	50	107	118	12	4	113	111
24	-.04	-.01	89	70	105	110	35	14	103	111
25	-.07	00	84	66	106	108	72	33	108	108
26	-.09	-.20	83	62	106	111	30	14	104	100
27	-.03	+.03	88	53	104	108	51	15	109	109
28	-.12	-.36	78	65	105	110	40	8	109	106
30	-.03	+.05	94	71	103	105	34	16	101	113
31	-.08	-.25	86	58	105	114	54	20	106	108
32	-.05	+.08	90	67	105	107	26	14	104	111
33	-.04	+.05	87	72	110	120	32	24	113	111
34	-.05	-.04	79	55	106	116	47	10	106	114
35	-.06	-.10	91	72	102	105	105	75	102	109
36	-.07	+.02	91	73	104	109	69	32	94	106
37	-.06	-.13	85	60	105	111	42	18	108	112
38	-.08	-.20	84	65	106	111	17	9	107	114
39	-.05	-.07	94	49	101	109	132	16	108	117
40	-.48	-2.09	74	38	110	124	37-	2-	100	98

(Test values for penetration, softening point, ductility and organic matter are expressed as a percentage of test values on original materials.)

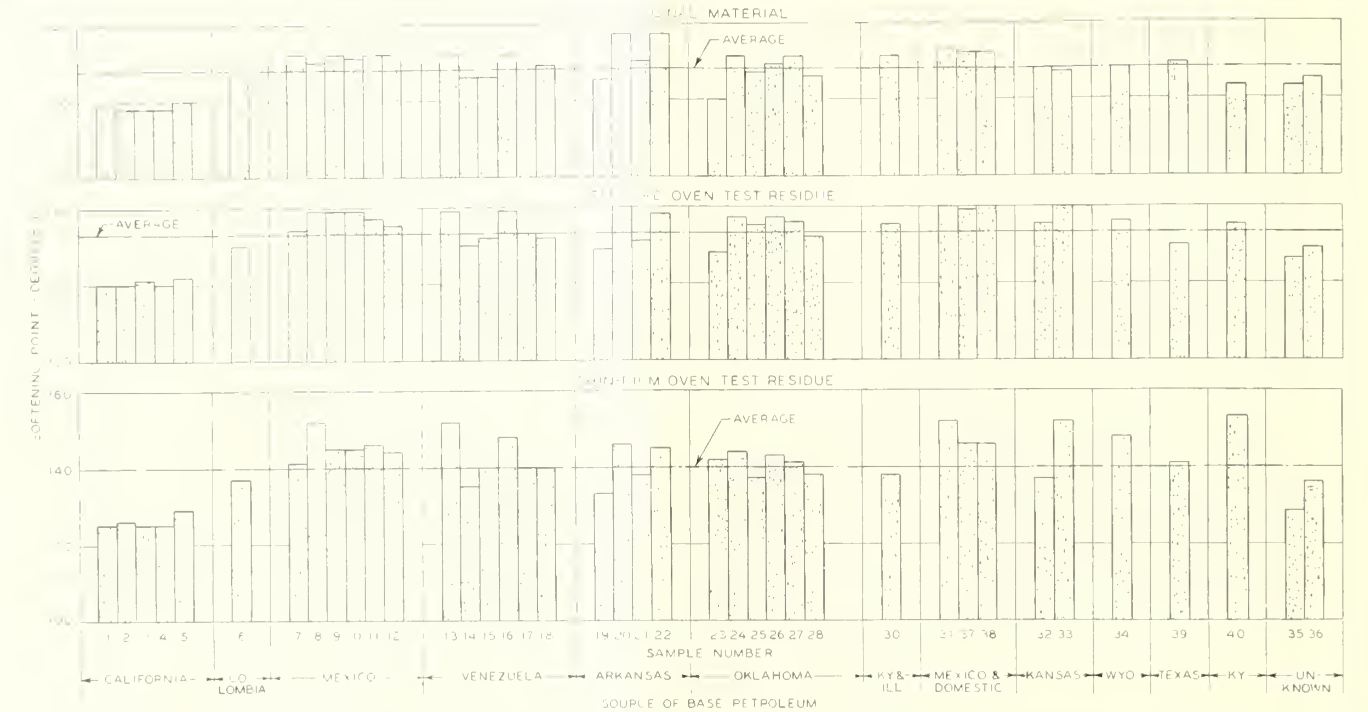

Figure 2.—Source of the Base Petroleum in Relation to the Effect of Oven Heat Tests on the Softening Point of the 50–60 Penetration Asphalts.

Table 6.—*Changes in test characteristics of 85–100 penetration asphalts after oven and exposure tests*

Identification No.	Change in weight			Test values expressed as a percentage of test values on original materials: Penetration at 77° F. 100 gm., 5 seconds			Softening point			Ductility at 77° F., 5 cm. per minute			Organic matter insoluble in 86° B. naphtha		
	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test	Standard oven test	Thin-film oven test	Exposure test
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	−0.16	−0.55	+0.50	81	56	27	101	107	119	112+	112+	35.4	112	126	186
2	−.07	−.17	+1.20	82	56	20	102	107	125	124	111	51.8	129	136	226
3	−.07	−.14	+.9	84	59	20	102	107	126	93	120	38.2	133	139	229
4	−.08	−.21	+.9	82	60	22	104	108	126	110+	110+	48.5	118	128	210
5	−.08	−.15	+1.0	81	52	19	103	109	129	125	127+	7.1	115	134	188
6	−.05	+.04	+.9	79	63	26	103	106	125	135+	114	6.5	122	123	159
7	−.10	−.44	+.5	79	57	42	103	111	121	73	60	6.8	111	114	123
8	−.21	−.46	+.7	69	45	26	107	119	142	49	11	3.9	111	118	133
9	−.13	−.55	+.4	78	53	36	103	112	122	79	46	8.3	113	116	126
10	−.19	−.68	+.3	74	55	40	104	112	122	84	65	6.8	112	122	125
11	−.12	−.41	+.6	77	53	35	104	113	127	92	68	7.2	112	117	131
12	−.13	−.45	+.5	76	54	35	104	111	125	99	54	5.4	116	121	133
13	−.05	−.11	+.9	74	50	29	105	114	135	115	18	2.9	113	120	142
14	−.01	+.05	+1.1	77	59	22	103	113	133	107	110	3.1	109	113	151
15	−.04	+.01	+.8	77	57	21	105	115	133	131	110	3.7	116	117	147
16	−.03	0	+.8	77	59	27	105	114	132	61	50	6.5	112	117	144
17	−.04	−.04	+.9	78	62	24	103	112	130	100	134	3.9	126	126	163
18	−.17	−.51	+.4	76	55	34	103	109	123	90	55	6.9	117	121	140
19	−.02	+.09	+1.0	82	68	30	104	108	127	120	131	5.3	110	111	149
20	−.15	−.59	+.4	88	68	41	104	109	122	94	26	5.4	106	107	119
21	−.05	−.02	+1.0	80	64	28	105	108	127	107	126	5.3	109	112	145
22	−.03	+.03	+.9	82	67	34	105	108	127	96	82	4.5	115	127	141
23	−.04	−.05	+.7	68	46	32	107	114	127	81	19	3.6	136	133	154
24	−.04	−.13	+1.1	79	55	33	104	112	127	74	37	4.0	115	127	139
25	−.08	−.01	+.7	81	65	33	104	107	121	116	86	9.2	117	114	154
26	−.08	−.16	+.8	77	63	32	104	108	126	86	44	3.9	116	119	141
27	−.02	+.07	+1.0	81	65	29	103	105	123	96	137	11.3	113	133	153
28	−.06	−.09	+.6	79	59	27	103	107	123	129	136+	9.5	118	124	152
29	−.10	−.13	+.4	65	43	30	106	114	125	125+	26	5.5	126	139	139
30	−.03	+.08	+.8	86	69	37	105	111	122	110	89	9.8	112	126	126
31	−.08	−.26	+.7	75	55	33	107	117	132	54	20	4.7	106	115	126
32	−.02	+.09	+.9	75	62	35	106	111	124	87	38	5.2	114	121	132
33	−.04	+.06	+.6	65	60	40	112	117	164	12	8	3.2	112	116	131
34	−.02	+.04	+1.1	72	52	28	108	115	137	113	56	2.9	106	112	133
35	−.07	−.14	+.6	83	68	39	103	107	121	97	107	6.2	107	118	134
36	−.03	+.02	+.8	80	64	37	105	112	131	28	16	4.4	106	110	127
37	−.07	−.12	+.4	78	58	39	107	114	124	104	34	4.7	109	115	123
38	−.13	−.37	+.7	80	61	35	106	113	117	72	24	4.2	106	111	129
39	−.14	−.15	+.7	76	56	27	105	110	128	144	117	7.1	109	119	144
40	−.53	−2.17		70	32		110	123		100±	10		105	113	

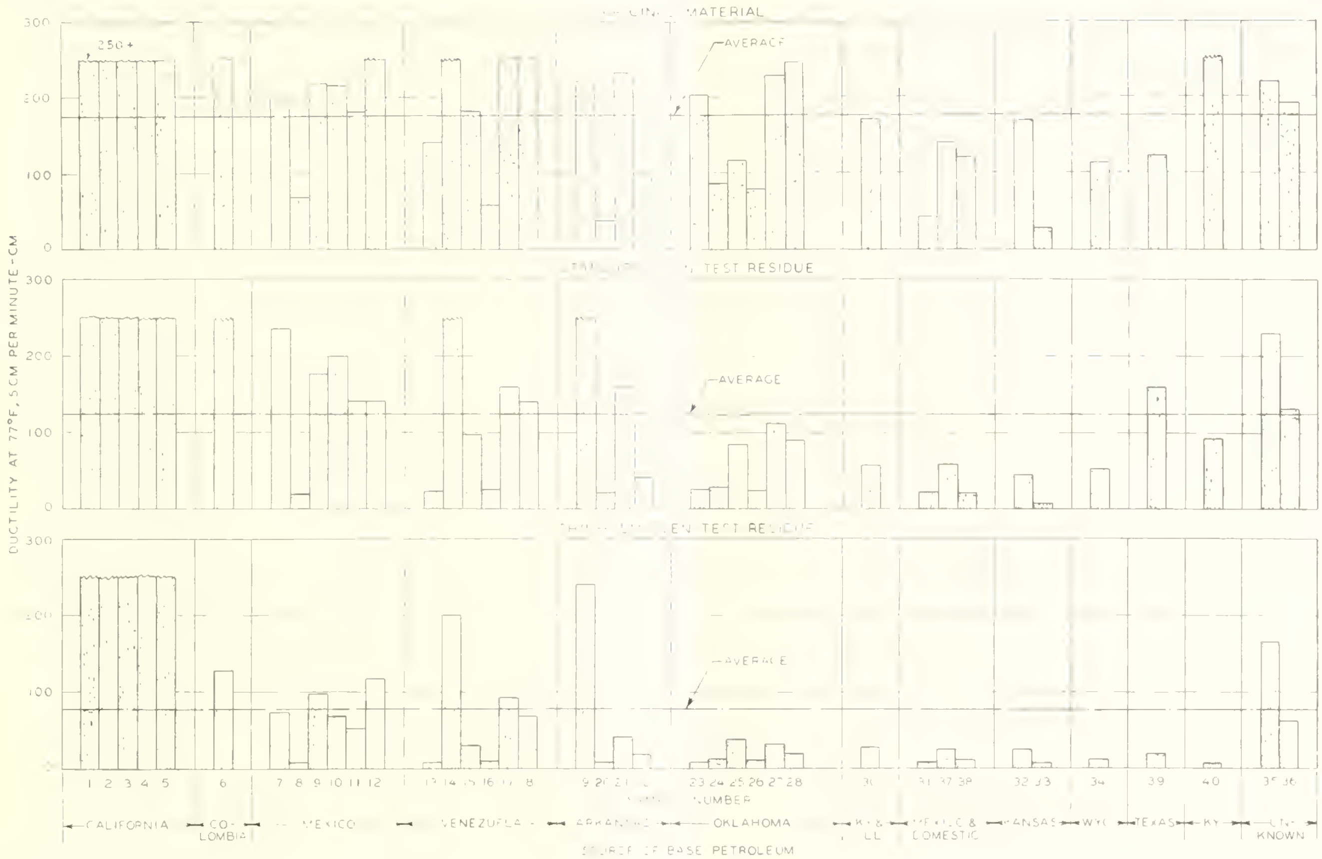

FIGURE 3.—SOURCE OF THE BASE PETROLEUM IN RELATION TO THE EFFECT OF OVEN HEAT TESTS ON THE DUCTILITY OF THE 50–60 PENETRATION ASPHALTS.

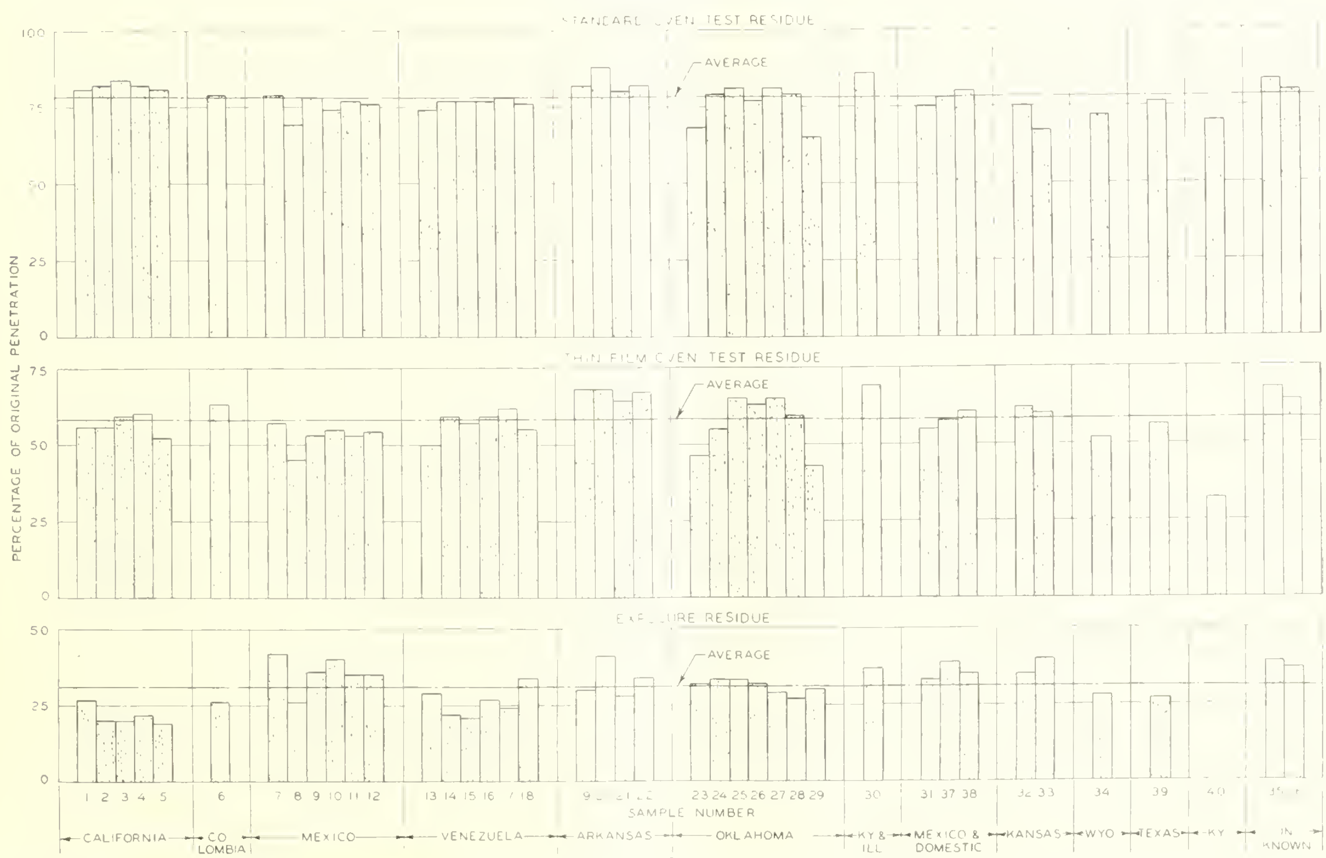

FIGURE 4.—SOURCE OF THE BASE PETROLEUM IN RELATION TO THE EFFECT OF OVEN HEAT AND EXPOSURE TESTS ON THE PENETRATION OF THE 85–100 PENETRATION ASPHALTS.

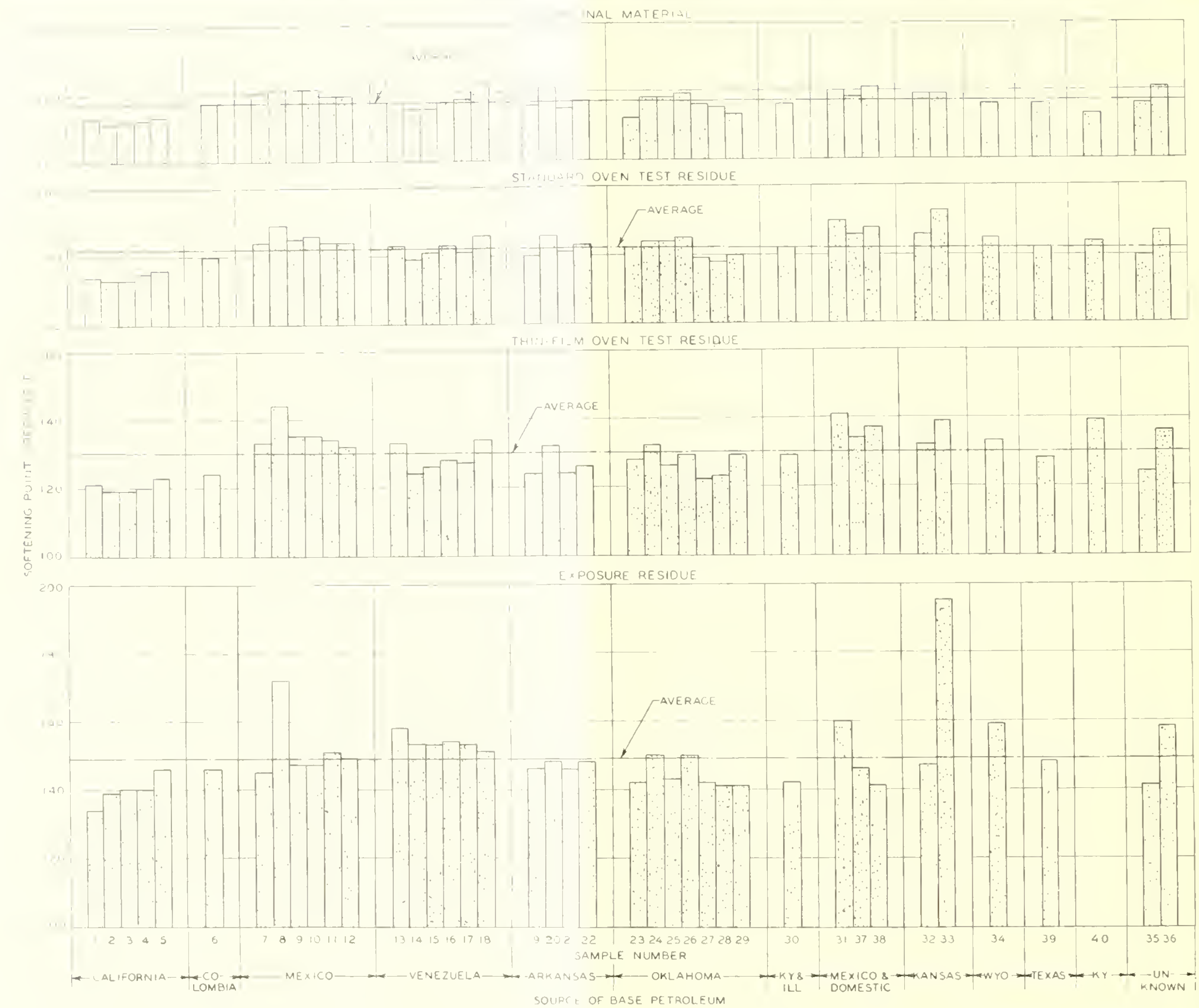

Figure 5.—Source of the Base Petroleum in Relation to the Effect of Oven Heat and Exposure Tests on the Softening Point of the 85–100 Penetration Asphalts.

The percentage of original penetration for the 85–100 penetration asphalts, as shown in table 6 and figure 4, varied from 65 to 88 with an average of 78 for the standard oven test and from 32 to 69 with an average of 58 for the thin-film residues. The range in percentage of original penetration retained by the exposure residues was from 19 to 42, with an average of 31. Only two asphalts of the 50–60 grade and four of the 85–100 grade retained less than 50 percent of their original penetration after the 5-hour heating in thin films.

THIN-FILM OVEN TESTS GREATLY REDUCED THE DUCTILITY OF SOME ASPHALTS

The range in the values for retention of original penetration for both grades of asphalt is greater for residues from the thin-film test than for the residues from the standard oven test, indicating that the thin-film oven test provides a somewhat sharper differentiation between the various asphalts with respect to resistance to hardening. The difference between maximum and minimum values for percentage of original penetration is greater for the thin-film residues of 85–100 penetration asphalts than for the residues from the exposure test.

The softening point values shown in tables 2 and 3 and in figures 2 and 5 indicate that the range in values is somewhat greater for the residues from the thin-film oven test than for the residues from the standard oven test, further indicating that the thin-film oven test provides a sharper differentiation between the asphalts with respect to their resistance to hardening. As compared to the residues from the thin-film oven test, the range in penetration of the exposure residues was reduced, while the range in softening point has increased considerably. This indicates that continued exposure produces changes that affect the softening point values to a greater extent than the consistency as measured by penetration. For instance, the exposure residues of samples 8 and 33 had penetrations slightly under and over the average for all the asphalts, respectively, but these two materials developed residues having the highest softening points.

Figures 3 and 6 show the effects of the oven and exposure tests on the ductility of the 50–60 and 85–100 penetration asphalts. These figures show that the ductilities of many of the asphalts were greatly changed in these tests. Although the average ductility of the

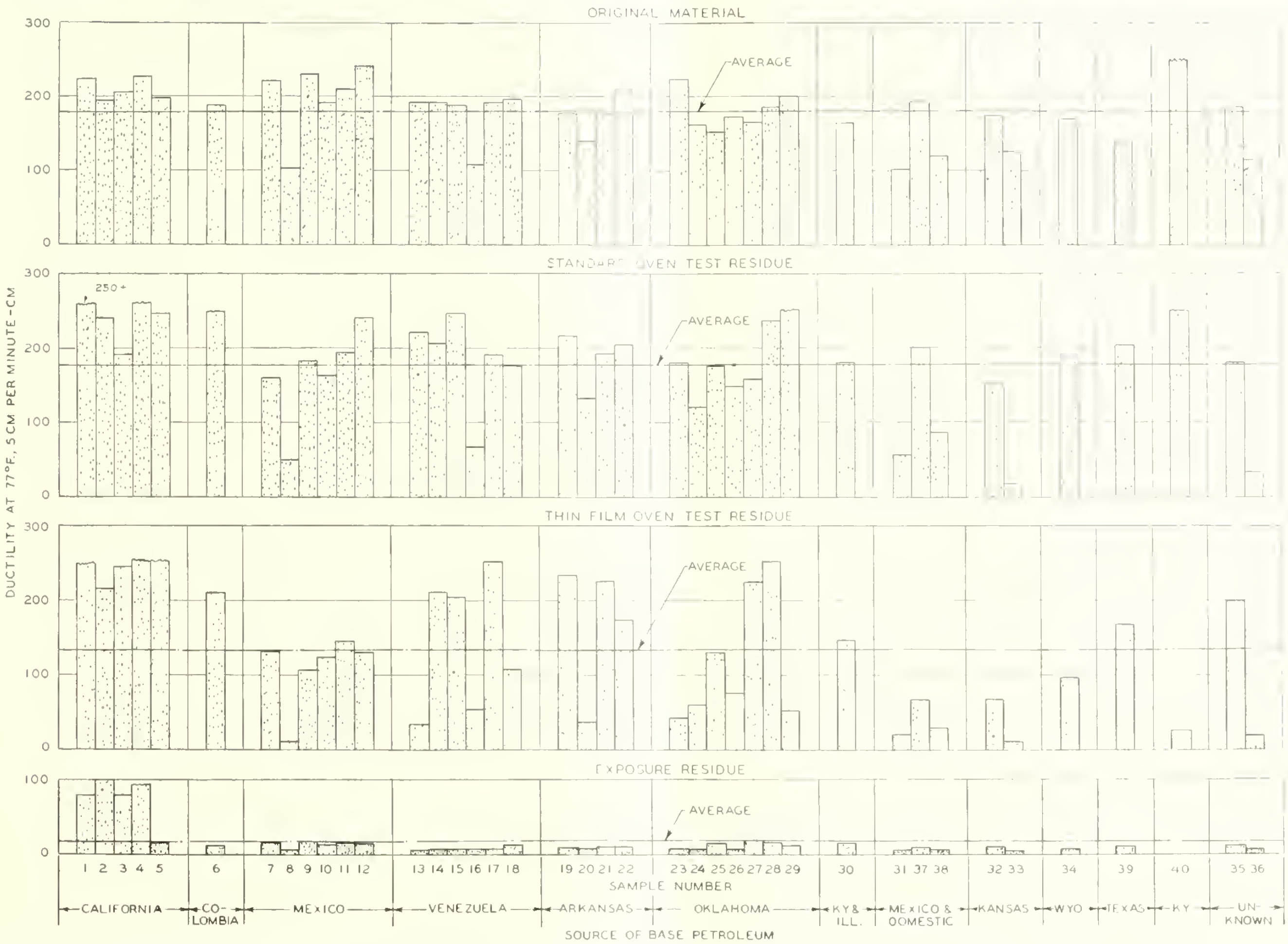

Figure 6.—Source of the Base Petroleum in Relation to the Effect of Oven Heat and Exposure Tests on the Ductility of the 85–100 Penetration Asphalts.

original 50–60 and 85–100 penetration asphalts was nearly the same (176 and 180 centimeters, respectively) the reduction in ductility was greater for the 50–60 penetration asphalts than for the 85–100 penetration asphalts. The average ductility of residues of the 50–60 asphalts from the standard oven test dropped to 123 centimeters, but the average ductility of the 85–100 residues was practically unchanged, being 177 centimeters.

This low reduction in the average ductility for the asphalts of the 85–100 grade after heating indicates that many of the original asphalts were of too soft a consistency at 77° F, to develop their maximum ductility, and the additional hardening made the residues more ductile at 77° F. than the original asphalts. In the thin-film oven test the average ductilities of the 50–60 and 85–100 penetration residues were 77 and 132 centimeters, respectively. Although the average ductility for the 85–100 penetration asphalts had been materially reduced, many of these residues still had higher ductilities than the original asphalt. The ductilities of all the exposure residues of the 85–100 penetration asphalts were greatly reduced. The average ductility was 18 centimeters, and 33 of the 39 asphalts tested had ductilities under the average. Only six asphalts representing four of the five materials produced from California petroleums, one from Mexico and one from Oklahoma, had ductilities higher than the average.

Tables 5 and 6 show the percentage of increase in organic matter insoluble in 86° B. naphtha due to alterations occurring in the oven and exposure tests. With the exception of samples 20, 36, and 40 of the 50–60 grade, all the residues had the same or greater amounts of insoluble material than the original asphalts. The average percentage of increase for residues from oven tests was greater for the 85–100 penetration grade. Figure 7 shows the relation between the amount of organic matter insoluble in the original material and the percentage of change in the insoluble matter in the oven and exposure residues for the 85–100 penetration asphalts. This figure indicates that there is a tendency for the insolubility of the residues from those asphalts with an initial low insolubility to increase more than in the case of asphalts containing higher percentages of insolube matter. The difference between maximum and minimum values for the naphtha-insoluble matter of the original materials and the oven and exposure residues remains practically the same.

OXIDATION RESPONSIBLE FOR ALTERATIONS IN ASPHALTS ON EXPOSURE

Table 4 shows the slope of the log-penetration temperature curves for the 85–100 penetration asphalts before and after exposure. The values for the slope of the curves are of interest in evaluating the alterations that occurred during the exposure not only in the case of the individual asphalts but for the asphalts as a group.

J. P. Pfeiffer and P. M. Van Doormal (*15, 16*) proposed the penetration index for the classification of

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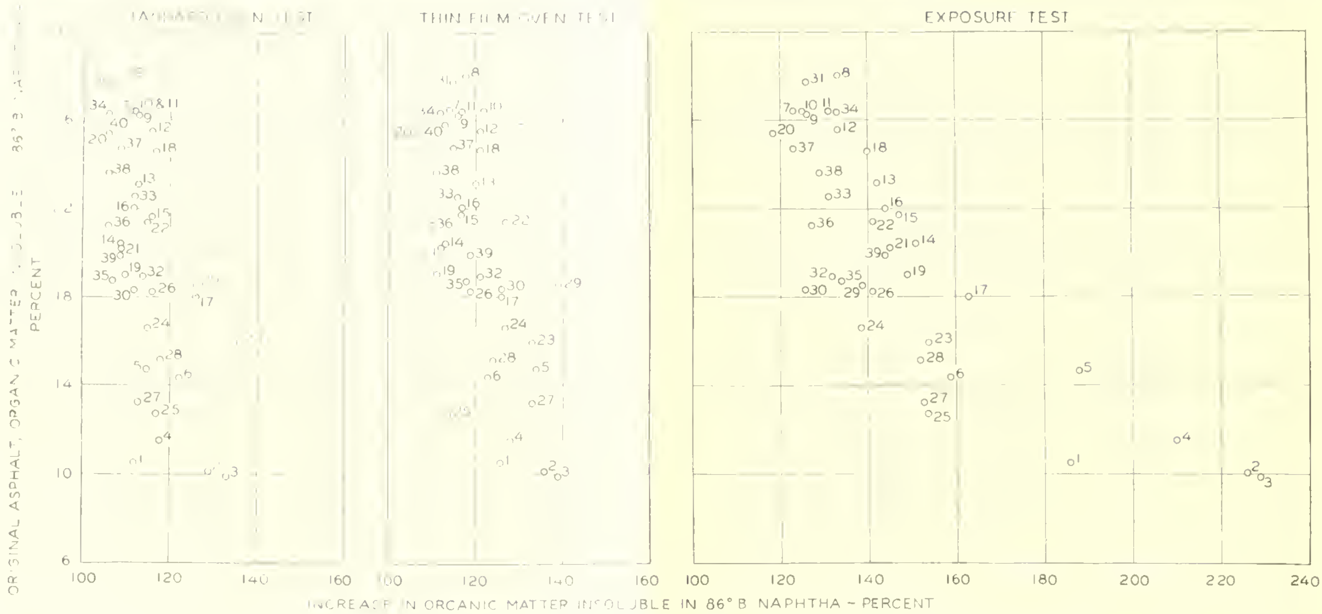

FIGURE 7.—EFFECT OF 86° B. NAPHTHA INSOLUBLE MATTER IN THE ORIGINAL 85–100 PENETRATION ASPHALTS ON THE INCREASE OF 86°B. NAPHTHA INSOLUBLE MATTER DUE TO OVEN AND EXPOSURE TESTS.

asphalts according to their susceptibility to change in consistency with change in temperature. They stated that an asphalt with a penetration index of from −1.0 to +1.0 has normal susceptibility (N type). Asphalts with penetration indexes of less than −1.0 or of more than +1.0 have high susceptibility (Z type) or low susceptibility (blown or R type), respectively. The slope of the log-penetration temperature curve can be used to calculate the true penetration index which differs slightly from the one calculated by the Pfeiffer and Van Doormal formula (*11*). Using the values proposed by Pfeiffer and Van Doormal for asphalts of different susceptibilities, a slope of more than 0.0259 indicates high susceptibility, from 0.0259 to 0.0192 normal susceptibility, and of less than 0.0192 low susceptibility.

As indicated in table 4, the slope of the curves for all the asphalts was reduced by the exposure. The residues became less susceptible to change in consistency as a result of the exposure. The extent of the reduction in slope may be considered as a measure of the resistance of the various asphalts to oxidation.

Considering the values for the slopes of the curves and the Pfeiffer and Van Doormal classification (*15, 16*), it will be noted that 10 of the 39 asphalts exposed were originally of the Z (high susceptibility) type, 27 were of the N (normal) type and 2 were of the R (blown) type. After 15 weeks of exposure, 2 were of the Z type, 14 of the N type, and 23 of the R type. These changes tend to substantiate the conclusion that oxidation is responsible for the alterations occurring in asphaltic materials under exposure conditions.

As compared with the original materials, with few exceptions, the exposure residues from the 85–100 penetration asphalts showed some increase in the amount of organic matter insoluble in carbon tetrachloride. However, the extensive carbonization that has been observed previously in similar tests on slow-curing oils (*7, 8*), having approximately the same initial insolubility in carbon tetrachloride, did not take place in these semisolid asphalts.

In table 4 the results of the Oliensis spot test on the asphalts before and after exposure are given. Fourteen of the 39 asphalts gave positive spots before exposure. Two of the asphalts, samples 19 and 36, with xylene equivalents of 0–2, gave positive spots before exposure but had negative spots after exposure. Samples 29 and 33 gave positive spots in 100 percent xylene under both conditions. The xylene equivalents of the exposure residues that gave positive spots were higher than those of the original materials but there does not appear to be any relationship between the initial xylene equivalent and the increase shown in the exposure residues. In previous work with all types of liquid asphaltic materials (*8*), residues of all materials that were originally negative gave positive spots after only 5 weeks of exposure. The greater resistance of these semisolid asphalts to changes that are indicated by their reaction to the Oliensis test is shown by the fact that 16 of them gave negative spots both before and after exposure. This emphasizes the lower durability of fluid asphaltic materials.

It is evident from the study of the data presented that even though additional tests, such as ductility and softening point, were made specification requirements for the residues from the standard oven test, no sharp differentiation in the hardening properties of the various asphalts is possible. Tests on the residues from the thin-film oven test, however, do show wide differences in resistance to change in original characteristics.

ALTERATIONS IN RESIDUES GREATLY AFFECTED BY TIME OF HEATING

In order to study more thoroughly the effect of the thin-film oven test on the characteristics of the asphalts used in this investigation, 16 asphalts of the 50–60 penetration grade were selected for further study. These asphalts represented materials from a majority of the sources of base petroleums covered by this investigation. In cases where two or more asphalts from the same source showed considerable difference in behavior in the 5-hour thin-film tests, two materials from the same source were selected.

These 16 samples were heated in ⅛-inch films at 325° F. for various periods of time up to 10 hours or until the ductility of the residue was reduced to a relatively low value. Those materials that did not show an appreciable reduction in ductility at the end of 7- or 10-hour test periods were heated, in a few instances, in 1/16- or 1/32-inch films for periods of 7 hours. The results of tests on the residues of the 16 selected asphalts for various periods of heating and thickness of film are given in table 7. Values for the penetration at 77° F., ductility at 77° F., and softening point,

TABLE 7.—*Effect of heating typical 50–60 penetration asphalts in thin films for various periods of time and film thicknesses*

Identification No.	Source of base petroleum	Time in oven at 325° F.	Film thickness	Tests on residue: Penetration at 77° F., 100 gm.; 5 sec.	Tests on residue: Ductility at 77° F., 5 cm. per min.	Tests on residue: Softening point
		Hours	*Inches*		*Cm.*	*°F.*
3	California	0	------	61	250+	118.0
		5	⅛	39	250+	125.0
		7	⅛	30	250+	131.9
		10	⅛	24	250+	135.5
		7	1/16	20	250+	136.7
		7	1/32	16	27.5	142.8
6	Colombia	0	------	52	250+	126.0
		2	⅛	40	240	132.0
		5	⅛	35	129	137.0
		7	⅛	33	88	141.5
		10	⅛	27	24	146.0
		7	1/16	25	10	151.5
8	Mexico	0	------	56	68	130.0
		2	⅛	43	22	141.2
		5	⅛	34	8	152.0
		7	⅛	29	5.3	160.8
		10	⅛	25	4.3	169.3
9	do	0	------	53	218	132.0
		2	⅛	44	195	137.0
		5	⅛	35	98	145.0
		7	⅛	30	30	149.3
		7	1/16	23	9.5	163.7
13	Venezuela	0	------	51	140	132.0
		2	⅛	40	20.5	144.6
		5	⅛	31	8	152.0
		7	⅛	28	5.5	162.5
		10	⅛	24	4.3	172.8
14	do	0	------	52	250+	126.0
		5	⅛	33	200	135.0
		7	⅛	31	95	139.9
		7	1/16	22	9	149.8
19	Arkansas	0	------	57	220	125.0
		2	⅛	43	250+	130.9
		5	⅛	39	240	133.0
		7	⅛	33	128	139.0
		10	⅛	31	48	141.0
		7	1/16	29	18	146.8
20	do	0	------	58	36	137.0
		2	⅛	49	16	142.8
		5	⅛	39	8	146.0
		7	⅛	38	6.3	155.5
23	Oklahoma	0	------	60	202	120.0
		1	⅛	37	26.5	131.0
		2	⅛	34	13	135.4
		5	⅛	30	8	142.0
		10	⅛	27	4	161.8
27	do	0	------	49	226	131.0
		2	⅛	41	173	134.7
		5	⅛	32	32	141.0
		7	⅛	31	23	145.5
30	Kentucky and Illinois	0	------	48	170	131.0
		2	⅛	43	90	136.6
		5	⅛	34	28	138.0
		7	⅛	35	27	145.3
32	Kansas	0	------	49	159	128.0
		2	⅛	44	69	134.3
		5	⅛	33	24	137.0
		7	⅛	32	15	145.2
3	do	0	------	46	27	127.0
		2	⅛	42	12	134.9
		5	⅛	33	6	152.0
35	Unknown	0	------	57	219	123.0
		5	⅛	41	165	129.0
		7	⅛	38	65	134.2
		10	⅛	35	46	137.8
36	do	0	------	55	190	125.0
		2	⅛	46	170	132.2
		5	⅛	40	61	135.9
		7	⅛	37	26	139.0
		10	⅛	33	21	141.5
37	Mexico and domestic Gulf coast.	0	------	52	137	132.0
		2	⅛	43	91	138.8
		5	⅛	31	25	146.0
		7	⅛	30	11	151.9

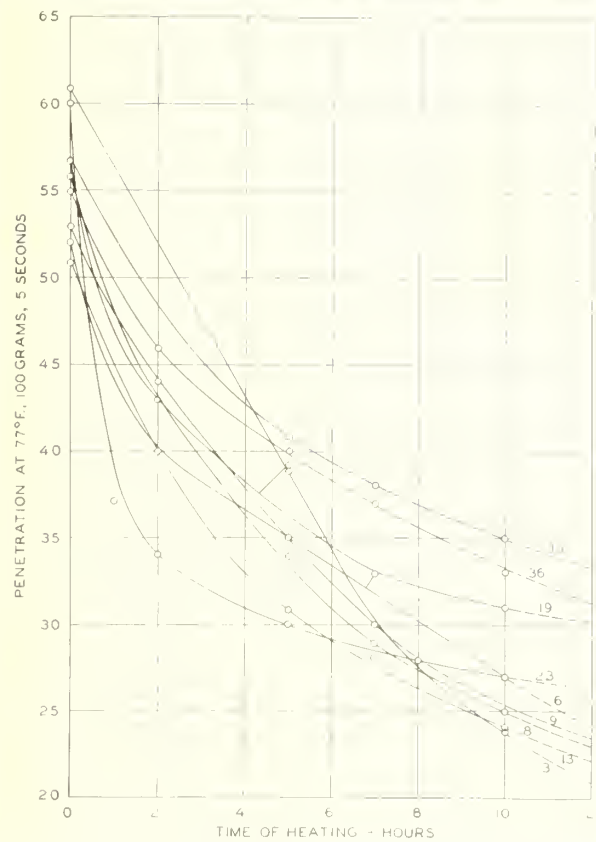

FIGURE 8.—EFFECT OF TIME OF HEATING IN ⅛-INCH FILMS ON THE PENETRATION OF TYPICAL 50–60 PENETRATION ASPHALTS.

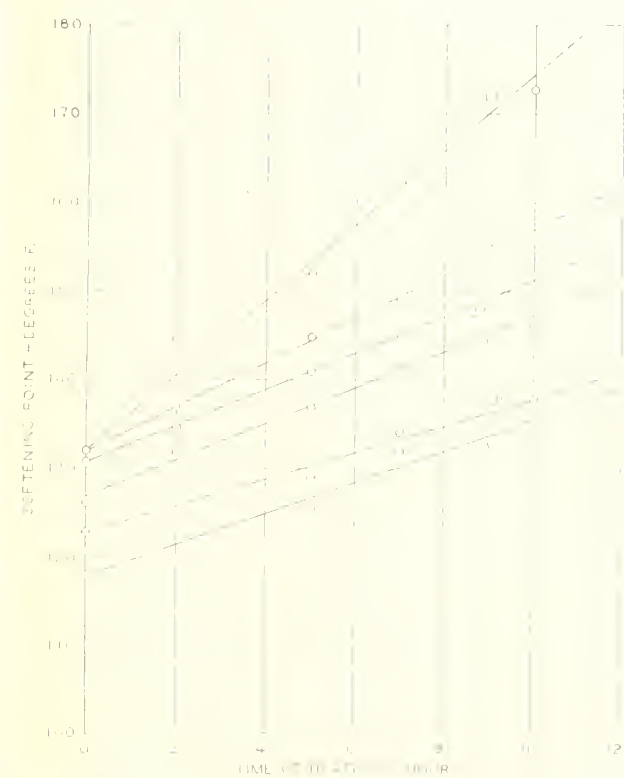

FIGURE 9.—EFFECT OF TIME OF HEATING IN ⅛-INCH FILMS ON THE SOFTENING POINT OF TYPICAL 50–60 PENETRATION ASPHALTS.

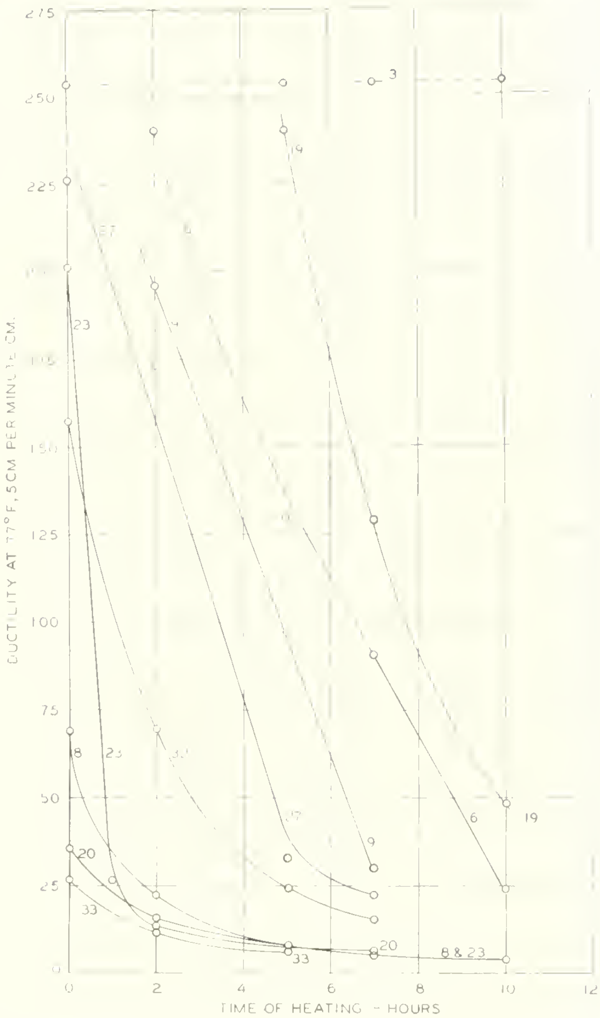

Figure 10.—Effect of Time of Heating in ⅛-Inch Films on the Ductility of Typical 50–60 Penetration Asphalts.

are given for the original materials and for the residues. The effects of time of heating in ⅛-inch films on the properties of some of these asphalts are given in figures 8, 9, and 10.

In figure 8, the results on nine of the asphalts are used to illustrate the effect of time of heating on the penetration of the residues. The time-penetration curves for the other asphalts, with the exception of sample 33, are between the upper and lower curves shown. All the curves indicate that the asphalts had a high initial drop in penetration and, as the time of heating increased, the rate of drop in penetration decreased. Sample 23 had a very high initial drop in penetration up to 2 hours and then a more gradual drop up to 10 hours. The California asphalt (sample 3) showed a uniform rate of hardening up to 7 hours and then a decreased rate. In general, the difference between the high and low values of penetration, for any given time of heating, are approximately the same throughout the range of time covered by these tests. These curves are similar to curves showing the penetration versus time of mixing, one of which for bituminous concrete is charted in the report by Schaub and Parr (*18*) on changes in physical characteristics of paving asphalt cements and their relation to service behavior. In this case, an 85–100 penetration asphalt showed a 27 point decrease in penetration in the first 30 seconds of mixing and a decrease of only 10 points in the next 150 seconds.

In figure 9 are representative curves showing the relation between softening point and time of heating in the thin-film test. The plotted points for these asphalts, and the others of table 7, fall approximately on straight lines.

In figure 10 are representative curves showing the relation between time of heating in the thin-film test and ductility at 77° F. It is apparent that the time of heating has a much more variable effect on ductility than on softening point or penetration. Sample 3 (California) retained a ductility of more than 250 centimeters over the whole 10-hour period while all the other samples showed a large reduction in ductility during this period. Sample 6 (Columbia) lost ductility at a fairly constant rate with increase in time of heating, while the ductility of sample 23 (Oklahoma) dropped from 202 to 26.5 centimeters in 1 hour and from 26.5 to 4 centimeters in the succeding 9 hours. Table 7 shows that samples 8, 13, 20, 23, and 33, with initial ductilities of 27 to 202 centimeters, had ductilities of 8 ticenmeters or less after heating for 5 hours in ⅛-inch films.

In order to show the effect of the thin-film oven test on the ductility-penetration relationship, some of the data given in table 7 have been plotted in figure 11. If the penetrations are plotted against the corresponding log ductility for the residues after various periods of heating, a straight line can be drawn that will pass approximately through the points, except for the higher values of ductility. The data for the majority of 16 selected asphalts can be plotted to show a straight line relationship between penetration and logarithm of ductility when the ductility had been reduced below 100 centimeters. The penetration-ductility curves for the other asphalts are distributed between the extremes shown in figure 11. This figure and the data given in table 7 show that the conditions of the thin-film oven test produced wide differences in the penetration log-ductility relationships of these typical 50–60 penetration asphalts.

EFFECT OF MIXING ON CHARACTERISTICS OF ASPHALTS INVESTIGATED

The relation between the penetration and softening point of the various thin-film residues, data for which are given in table 7, is also of interest in showing the difference in behavior that occurred when these materials were heated under comparable conditions. In figure 12 the softening points of the various residues have been plotted against the logarithms of the corresponding penetrations and the points connected by smooth curves. Several asphalts, of which sample 23 is one, show a uniform rate of change in the earlier periods of heating, but when reduced to a certain penetration the curve breaks, and thereafter shows a greater increase in softening point for a given drop in penetration. Of the materials that show a uniform rate of change, sample 3 shows a very much lower increase in softening point for a corresponding drop in penetration than does sample 20 or sample 33. The curve for the latter is not shown in this figure. In general, the data indicate that asphalts having a low rate of increase in softening point with decrease in penetration retain a high ductility when reduced to low penetrations, but those that increase rapidly in softening point with decrease in penetration do not retain their ductility as well.

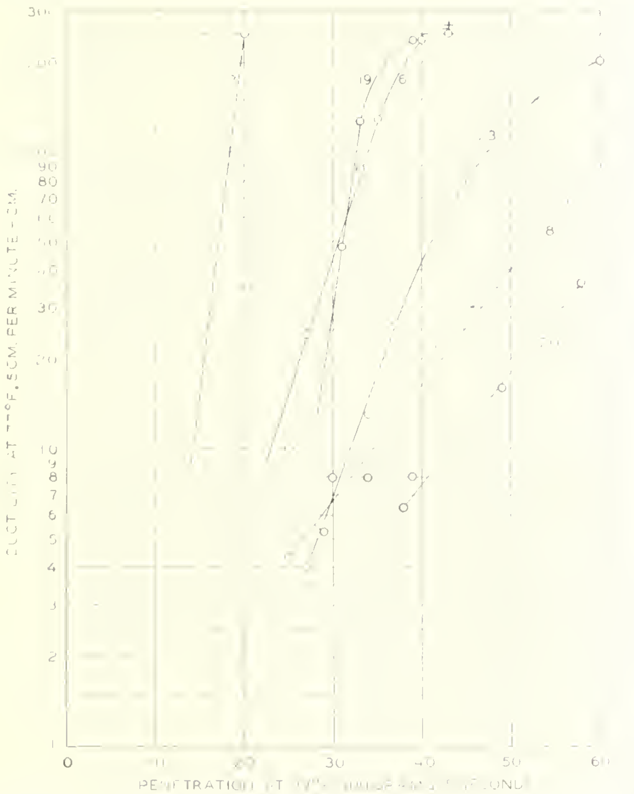

Figure 11.—Relation Between Penetration and Ductility of Typical 50–60 Penetration Asphalts When Heated in Thin Films at 325° F. for Various Periods of Time.

Figure 12.—Relation Between Softening Point and Penetration of Typical 50–60 Penetration Asphalts When Heated in Thin Films at 325° F., for Various Periods of Time.

Bateman and Delp (*1*) and Bateman and Lehmann (*2*) have shown the effect of the mixing process on the physical properties of the asphalt and the effect of the mixing temperatures on the penetration, the softening point, and the ductility of the asphalt extracted from the mixtures with carbon disulfide and recovered by a vacuum distillation. This work was confined to one type of asphalt and they concluded that penetration and ductility of the asphalt were decreased and the softening point was increased by the mixing operation and that these changes were affected by the mixing temperature. In recent years, with improvement in the technique of recovering the bitumens from solutions, investigations of asphalt from laboratory and plant mixes and from pavements have been made. Many of these investigations have been confined to the determination of drop in penetration only. Steinbaugh and Brown (*20*) included ductility determinations, and Shattuck (*19*) made softening point determinations on the recovered bitumen, as well as ductility and penetration tests.

The work of Steinbaugh and Brown led to the adoption by the Michigan Highway Department of a specification requirement that the penetration of the bitumen extracted from a pavement immediately after laying shall be not less than 50 percent of the original and that the ductility shall be not less than 40 centimeters.

A specification requirement of this type appears to be logical. Its use, however, introduces a practical difficulty that has been quite generally recognized. The responsibility for compliance with the test requirement is divided between the producer who furnishes the asphalt and the contractor who uses it. Shattuck (*19*) has developed a laboratory mixing test in which the probable loss in penetration and ductility of the asphalt to be furnished during the mixing and laying operations can be predetermined. Shattuck stated that an asphalt that failed to meet a specified drop in penetration and ductility when subjected to his laboratory mixing test would not meet the requirement outlined in some specifications for the ductility and penetration of bitumen extracted from the pavement after laying.

In the Shattuck mixing test (*19*) a 2,000-gram mixture, containing 94 percent of standard Ottawa sand and 6 percent of the asphalt to be tested, is mixed for 1 minute in a small laboratory rotary mixer, 6 inches in diameter and approximately 10 inches long. The air temperature of the mixer is brought to 275° to 300° F. The sand and asphalt are brought to temperatures of 400° and 300° F., respectively, before placing in the mixer. After mixing, the asphalt mixture is placed in a shallow pan, 7 by 11 by 1¼ inches, and is held in a constant-temperature oven at 350° F. for 30 minutes. After cooling to room temperature the bitumen is extracted and recovered by the Abson method. The recovered bitumen is tested for penetration, ductility, and softening point. Bituminous mixes, using proportions of aggregate, dust, and asphalt specified for the particular project, may also be tested in the same manner. Bituminous concrete containing aggregate from 1 inch to dust has been handled satisfactorily in this mixer.

The Public Roads Administration cooperated with Shattuck in the investigation (*19*) of his laboratory mixing test. Comparison was made of the properties of the residues from the thin-film oven tests with those of the asphalts recovered from the Ottawa sand and sheet asphalt sand mixtures used in the Shattuck test. Eight asphalts were selected from those used in Shattuck's work. The characteristics of these asphalts after

TABLE 8.—*Test characteristics of asphalts after exposure to Shattuck's mixing test and thin-film oven tests*

Identification No.	Source of base petroleum	Tested by laboratory	Penetration at 77° F., 100 gm., 5 sec.					Ductility at 77° F., 5 cm. per min.					Softening point				
			Original asphalt	Recovered bitumen		Residue from thin-film oven tests		Original asphalt	Recovered bitumen		Residue from thin-film oven tests		Original asphalt	Recovered bitumen		Residue from thin-film oven tests	
				Ottawa sand mix	Sheet asphalt mix	5 hours	7 hours		Ottawa sand mix	Sheet asphalt mix	5 hours	7 hours		Ottawa sand mix	Sheet asphalt mix	5 hours	7 hours
								Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*
3	California	A	53	25	38	--	--	110+	110+	110+	--	--	124	135	130	--	--
		B	54	25	36	34	30	250+	250+	250+	250+	250+	119.6	134.5	128.1	129.3	130.8
4	West Texas	A	51	26	31	--	--	110+	7	13.5	--	--	128	141	133.1	--	--
		B	52	36	38	37	34	250+	66	193	77	40.5	126	137.8	133.6	137.5	140.3
6	Colombia	A	51	25	31	--	--	110+	13	32.5	--	--	126.1	146	141.8	--	--
		B	56	30	36	35	30	250+	20.5	137	105	61	126.8	145.3	139.0	141.0	144.5
6-A	Venezuela	A	52	26	32	--	--	110+	15.5 16.5	25 35	--	--	126	146.2	143	--	--
		B	54	27	33	35	32	250+	19.5	58	145	126	127.5	149.8	142.7	141.3	143.1
8	East Texas	A	51	29	34	--	--	107	7 10	10.5 12	--	--	136	160	153.3	--	--
		B	51	34	36	33	30	99	16.5	16.5	15	10.5	136	150.8	148.5	154.0	155.0
10-A	Venezuela	A	54	23	37	--	--	110+	7.5 8	39 40	--	--	131.1	159	142	--	--
		B	58	22	30	33	30	250+	7	20	62	22	127.4	158.3	148.4	146.0	147.0
12	Unknown	A	50	32	38	--	--	74	5	11 15	--	--	139.1	153.2	147.2	--	--
		B	51	34	42	36	33	84	7	23	10	8	135.9	153.1	141.5	150.0	154.0
12-B	do	A	50	35	37	--	--	110+	110+	110+	--	--	120.4	126	124	--	--
		B	51	29	34	34	31	250+	222	250+	250+	250+	120.5	130	125	127.8	130.5

making the mixing test and thin-film oven test are given in table 8. Test results for penetration, ductility, and softening point are shown for the original asphalt and the bitumen recovered from the Ottawa sand and sheet asphalt mixes, as determined in both laboratories, and for the residue from the thin-film oven tests for 5- and 7-hour periods as determined in the Public Roads laboratory.

THIN-FILM OVEN TEST FURNISHES INDICATION OF ASPHALT BEHAVIOR IN MIXING OPERATIONS

In general, the penetrations and softening points of the residues from the oven tests are approximately comparable to the penetrations and softening points of the bitumens recovered from the mixes. Except for sample 6-A, the ductilites of the thin-film residues are also generally comparable to the ductilites of the bitumens recovered from the mixes. The similarity of the reduction in penetration and ductility and the increase in softening point that occurred in these tests are better shown in figures 13 and 14 for 2 of the 8 asphalts (samples 6 and 12) tested in this manner.

In figure 13 the penetration of the asphalt recovered by both laboratories and the penetration of the residues from the 5- and 7-hour thin-film oven tests are plotted against the logarithms of their ductilities. The majority of these points for each asphalt fall closely along a straight line similar to those shown in figure 11 where the relationship is shown for residues from the thin-film tests only.

Figure 14 shows the relationship between softening point and penetration of samples 6 and 12 when subjected to the Shattuck mixing tests and the thin-film oven test. This figure shows the similarity between the reduction in penetration and increase in softening point that occurred under both testing conditions.

During 1935 and 1936 test sections of sheet asphalt pavement were constructed in Washington, D. C. Tests were made to determine the alterations in the physical properties of the asphalt during the mixing, laying and service of the paving mixture. The behavior of the asphalt in the thin-film oven tests also was determined. Samples were taken immediately after the hot mix was laid and compacted. Following construction, samples were taken at the end of 12, 18, 24, and 30 months of service. These samples were extracted and the asphalt recovered by the Abson method. The original asphalts were heated at 325° F. in ⅛-, ¹⁄₁₆-, and ¹⁄₃₂-inch films for 2, 5, and 7 hours. The asphalts recovered from the pavement and the residues from the thin-film oven tests were tested for penetration, ductility, and softening point. The results of these tests, as well as the tests on the original asphalt, are given in table 9.

The relations between the penetration and ductility of the original asphalt, the bitumens from the pavement, and the residues from the thin-film oven test, are shown in figure 15. A majority of the points for the thin-film tests fall close to or on the line drawn. The points for the asphalts recovered from the pavement are approximately along the same line as the points for the thin-film residues. The reduction in penetration and ductility of the ⅛-inch film residue, heated for 5 hours, was approximately the same as the reduction that occurred during mixing and laying. While there was no uniform reduction in penetration and ductility with increased age in the pavement, two samples from the 24-month period had considerable decreases. Schaub and Parr (*18*) noted the difficulty of determining the progressive hardening of asphalt in sheet asphalt pavements on city streets because of the great possibility of contamination in these areas.

Figure 16 shows the relation between softening point and penetration of the bitumen recovered from the pavement and the residues from the thin-film oven test. This figure furnishes additional evidence of the similarity of the behavior of asphalts when heated at 325° F. in thin films and their behavior during the mixing and laying operations and in service.

On the basis of data obtained from tests of freshly laid sheet asphalts from other projects, and from the Shattuck mixing tests, it is believed that the alterations in penetration, ductility, and softening point that occur in 50–60 penetration asphalt cements during the processing and laying of sheet asphalt pavements in accordance with present standard practice can be predicted from tests made on the residues from the thin-film oven test. It has been noted that when some asphalts are merely dissolved in benzene and recovered by the Abson method a marked reduction in ductility occurs, even though the asphalt has not been exposed to the mixing operation or to service, indicating that the Abson recovery method itself may change the asphalt. It is therefore believed that the thin-film oven test may be more generally indicative of the actual alterations that occur than is the Shattuck test.

Table 9.—*Test characteristics of an asphalt before and after thin-film oven tests and of the same asphalt recovered from the pavement after various periods of service*

TESTS ON ORIGINAL ASPHALT

Sample	Penetration at 77° F., 100 gm., 5 sec.	Ductility at 77° F., 5 cm. per min.	Softening point
		Cm.	*°F.*
A	57	250+	126.0
B	56	205	126.0
C	56	226	127.0

THIN-FILM OVEN TESTS ON RESIDUE

Film thickness	Time of heating at 325° F.	Penetration at 77° F., 100 gm., 5 sec.	Ductility at 77° F., 5 cm. per min.	Softening point
Inches	*Hours*		*Cm.*	*°F.*
⅛	2	42	118.0	136.4
	5	32	28.5	144.9
	7	28	14.0	150.9
1/16	2	37	63.0	141.0
	5	26	8.0	155.0
	7	21	6.0	163.4
1/32	2	30	15.0	149.8
	5	18	4.0	175.6
	7	16	3.3	185.0

TESTS ON RECOVERED BITUMEN FROM PAVEMENT SAMPLES

Age of pavement	Penetration at 77° F., 100 gm., 5 sec.	Ductility at 77° F. 5 cm. per min.	Softening point
Months		*Cm.*	*°F.*
0	31	29	143
	34	40	143
	33	80	141
	33	36	145
	33	35	144
	36	39	142
	32	33	145
12	35	85	141
	32	41	145
	34	51	143
	36	48	141
	31	27	146
18	34	30	144
	34	57	142
24	29	30	145
	26	12	151
	29	28	145
	30	36	146
	26	14	150
30	32	26	144
	38	100	139

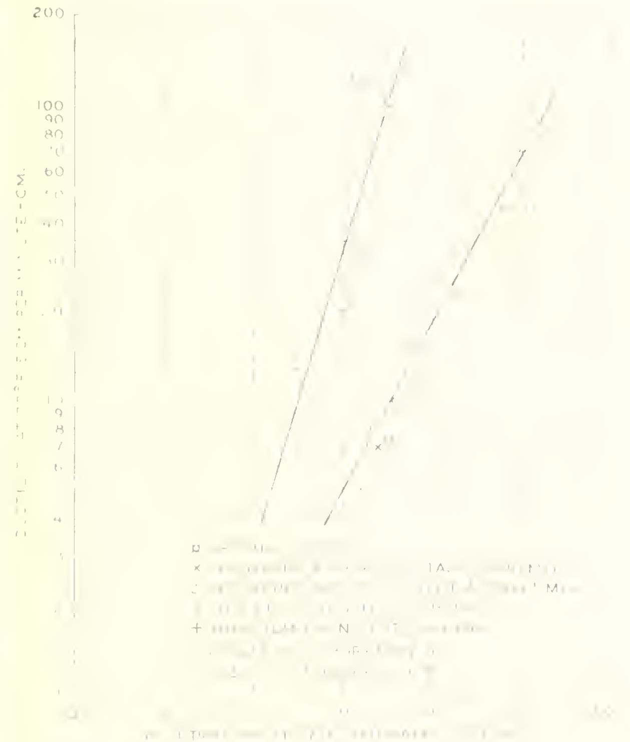

Figure 13.—Relation Between Penetration and Ductility of Asphalts Subjected to the Shattuck Test and Thin-Film Oven Test.

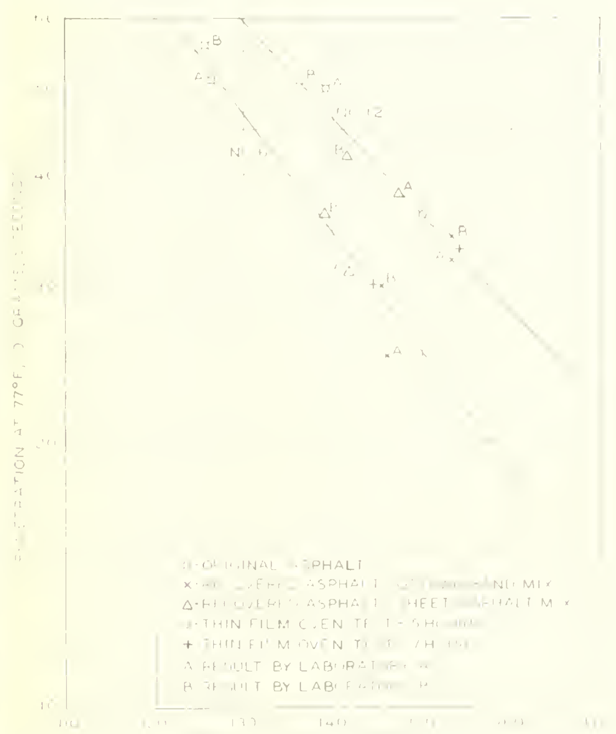

Figure 14.—Relation Between Softening Point and Penetration of Asphalts Subjected to the Shattuck Mixing Test and Thin-Film Oven Tests.

REQUIREMENTS FOR 50-60 PENETRATION ASPHALTS MAY NOT BE APPLICABLE TO OTHER GRADES

The 5-hour, ⅛-inch film test appears to have possibilities for predicting the resistance of asphalts to the hardening and oxidizing influence of heat during the normal mixing process, thus providing essential information for the adjustment of temperature or construction features that tend to destroy ultimately the life of pavements containing highly susceptible materials. The test results given in table 10 and plotted in figure 17, for a series of Mexican asphalts, show, however, that any specification requirement based on the behavior of 50–60 penetration asphalts may not be applicable to those of other consistency grades. Figure 17 shows the percentage loss in penetration and ductility and percentage gain in softening point produced by the 5-hour thin-film oven test, plotted against the con-

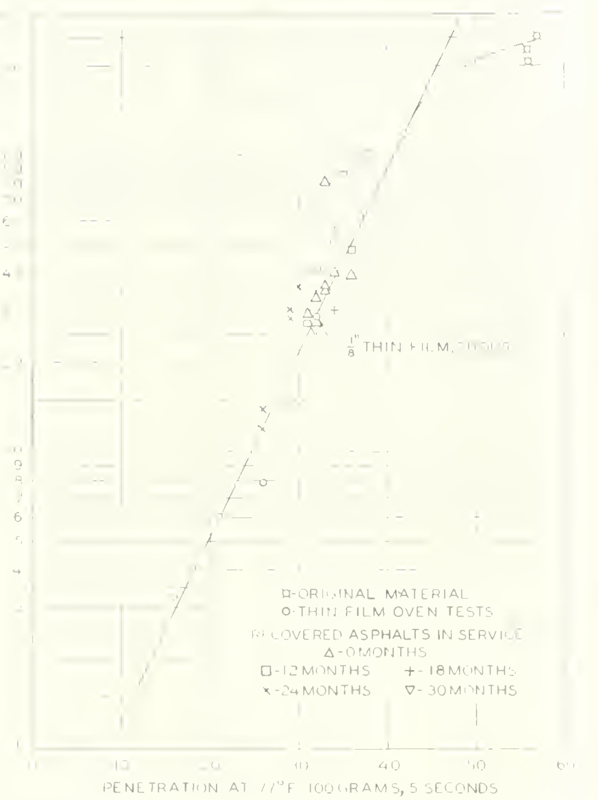

Figure 15.—Relation Between Penetration and Ductility of Bitumen Recovered From the Pavement and the Same Asphalt Heated in Thin Films at 325° F.

sistency of the original asphalt. The percentage loss in penetration and gain in softening point increases, but the percentage loss in ductility decreases, as the penetration of the original asphalt increases. The ductilities of the 150–180 and 180–200 grades are more than the ductilities of the original asphalts and are indicated by the negative values.

Table 10.—*Effect of thin-film oven tests on the characteristics of various grades of Mexican asphalt*

Penetration grade	Material tested	Penetration at 77° F. 100 gm. 5 sec.	Ductility at 77° F. 5 cm. per min.	Softening point	Loss in penetration by heating	Loss in ductility by heating	Gain in softening point by heating
			Cm.	*°F.*	*Percent*	*Percent*	*Percent*
30-40	Original asphalt	38	194	139.0			
	Residue from 5-hour test	21	25	153.5	36.8	87.1	10.1
50-60	Original asphalt	55	215	131.0			
	Residue from 5-hour test	33	70	145.0	40.0	67.1	10.7
70-80	Original asphalt	74	197	126.2			
	Residue from 5-hour test	42	81	140.3	13.2	58.9	11.2
85-100	Original asphalt	89	192	121.0			
	Residue from 5-hour test	49	125	135.9	41.9	34.9	12.3
120-150	Original asphalt	135	153	113.6			
	Residue from 5-hour test	66	132	132.2	51.1	13.7	16.4
150-180	Original asphalt	160	135	110.4			
	Residue from 5-hour test	71	137	131.2	55.6	[1] −1.5	18.8
180-200	Original asphalt	182	134	108.8			
	Residue from 5-hour test	78	135	128.3	57.1	[1] −0.7	17.9

[1] Ductility greater than original.

A recent project in which the Public Roads Administration was interested involved an asphaltic concrete mixture graded from ¾-inch to dust and containing approximately 6 percent asphalt cement of 120–150 penetration grade. The specification required that the extracted bitumen from a sample of the mixture taken from the finished pavement within 24 hours should have a penetration of not less than 50 percent of the penetration of the original material and a ductility of not less than 100 centimeters. The data given in tables 11 and 12 show that neither the Shattuck mixing test with Ottawa sand nor with the aggregate specified, when run with the standard temperatures for this test, namely, 400° F. for the aggregate, 300° F. for the asphalt, and 350° F. for the oven, nor the ⅛-inch film test, gave an approximate indication of the hardening that occurred. Although the plant mix was made with the asphalt and aggregate at approximately 275° F., the bitumens recovered from the pavement samples had penetrations approximately the same as the asphalt recovered from the mixture made in the Shattuck test, in which the temperature of the asphalt, aggregate, and curing oven were at a temperature of 200° F.

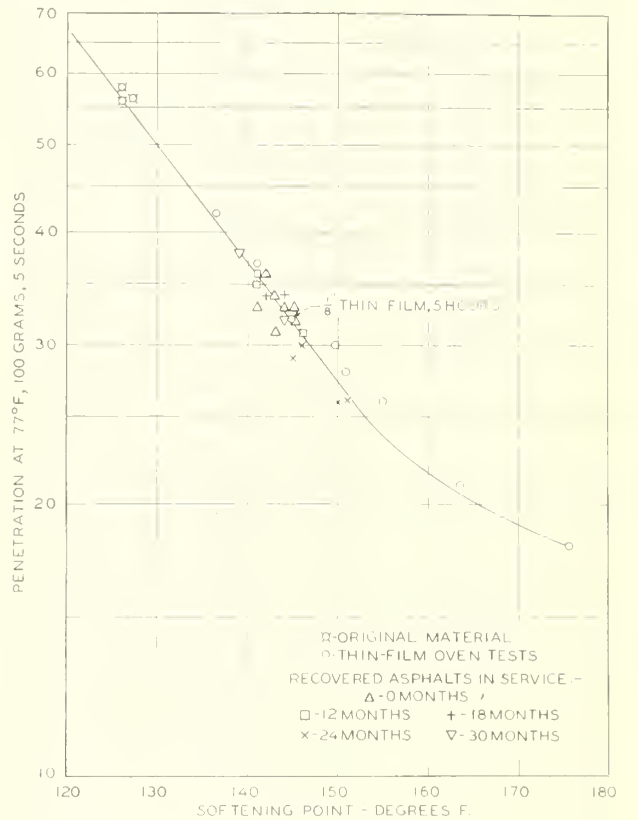

Figure 16.—Relation Between Softening Point and Penetration of Bitumen Recovered From the Pavement and the Same Asphalt Heated in Thin Films at 325° F.

ABILITY TO RETAIN ORIGINAL CHARACTERISTICS CONSIDERED A MEASURE OF DURABILITY

It should be noted that the extracted bitumen of the lower penetrations had much higher ductility than those of higher penetration. It has been shown that if there has been no great change in susceptibility, the softer grades of asphalt will have lower ductilities than the harder grades. For most asphalts, the maximum ductility is obtained when the penetration is considerably below 100 (*11*). Accordingly, it may be quite difficult to set satisfactory limits for the ductility of

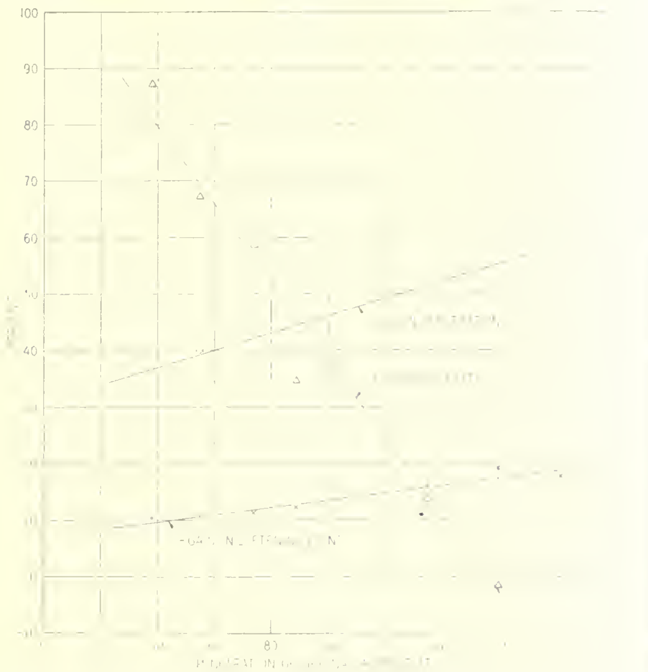

FIGURE 17.—EFFECT OF THE ORIGINAL CONSISTENCY OF VARIOUS GRADES OF MEXICAN ASPHALT ON THE CHANGES IN TEST CHARACTERISTICS PRODUCED BY THE 5-HOUR THIN-FILM OVEN TEST.

TABLE 11.—*Properties of 120–150 penetration asphalt after thin-film oven tests and after plant and laboratory mixing*

Identification No.	Source of material for tests	Tests on residue: Penetration at 77° F. 100 gm. 5 sec.	Ductility at 77° F. 5 cm. per min.	Softening point
			Cm.	*° F.*
	Original asphalt	134	134	104.2
R-1	Recovered from pavement immediately after laying [1]	126	160	108.5
R-2	....do	129	131	107.5
M-1	Recovered from laboratory mixes [2]	126	138	108.4
M-2	....do	121	138	107.2
M-3	....do	58	250+	120.9
M-4	....do	45	190	125.5
TF-1	Thin-film oven test, ⅛ inch film, 5 hours	77	203	116.6
TF-2	Thin-film oven test, 1/16-inch film, 5 hours	49	250+	123.5
TF-3	Thin-film oven test, 1/32-inch film, 5 hours	39	250+	128.0

[1] Recovered by Abson's method.
[2] Prepared by Shattuck's method; data on mixes given in table 12.

TABLE 12.—*Data on laboratory mixes prepared by Shattuck's method*

Identification No.	Temperature of aggregate	Temperature of asphalt	Temperature of oven	Aggregate used
	° *F.*	° *F.*	° *F.*	
M-1	200	200	200	¾ inch to dust [1]
M-2	250	250	250	Do.
M-3	400	300	350	Do.
M-4	400	300	350	Ottawa sand.

[1] Approximately same grading as used on construction.

the extracted bitumen, if the softer grades of asphalt cements are used in hot-mix pavements.

The examination of pavements by Shattuck (*19*) and by Vokac (*22*) show that the extracted bitumens in the pavements that have failed through cracking have lower penetrations, lower ductilities, and higher soften-

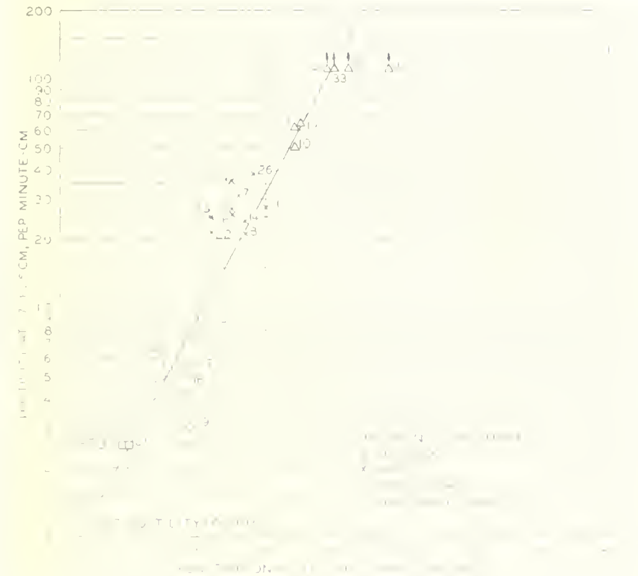

FIGURE 18.—RELATION BETWEEN PENETRATION AND DUCTILITY OF RECOVERED BITUMENS COMPARED WITH CONDITION OF DETROIT PAVEMENTS.

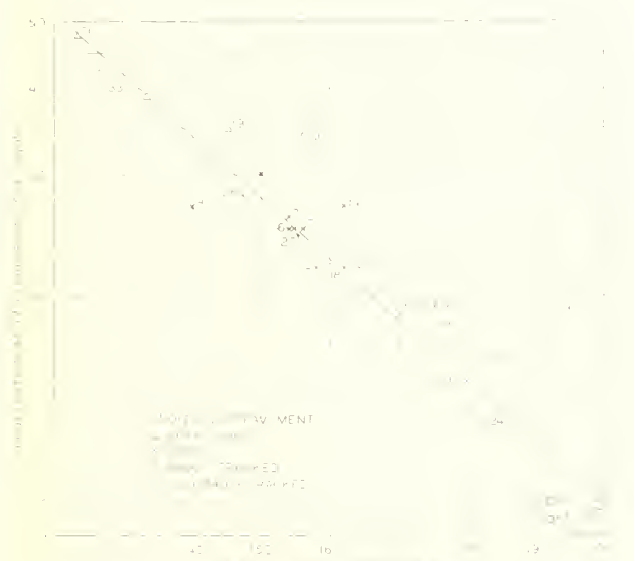

FIGURE 19.—RELATION BETWEEN SOFTENING POINT AND PENETRATION OF RECOVERED BITUMEN COMPARED WITH CONDITION OF DETROIT PAVEMENTS.

ing points than the bitumens in pavements that are satisfactory. The data given in table 1 of Shattuck's report on sheet asphalt pavements prepared with 40–45 and 50–55 penetration asphalts have been plotted in figures 18 and 19 to show the penetration-ductility and penetration-softening point relationships of the extracted bitumen. The condition of the pavement from which the asphalt was recovered is indicated. It will be seen that the majority of the points fall close to the average line. These figures show that not only the penetration but also the softening point and ductility can be closely correlated with the condition of the pavement.

The correlation of pavement condition, as shown in these figures, with the test characteristics of the extracted bitumen is in substantial agreement with the conclusions by Vokac (*22*) relative to penetration and ductility but not to softening point. Vokac stated that when the penetration of the extracted bitumen is less than 25, the ductility is less than 24 centimeters and the softening point is more than 160° F., the pavement containing asphalt of this character is of the cracking type. He also concluded that a softening point of less than 146° F. on the extracted bitumen is indicative of pavement that may shove. Shattucks' report *(19)* does not note this type of failure.

It has been demonstrated by many investigators that a major portion of the alterations that occur in the asphalt of hot-mix pavements that show a tendency to early cracking in service, occurs during the fabrication of the pavement. Accordingly, since it is indicated by the data presented that the thin-film oven tests develop residues with properties similar to those of the bitumens extracted from both laboratory and plant mixtures, a requirement limiting the loss in penetration and ductility could readily be applied to the residues from the thin-film oven test. A requirement of this sort would be of value in preventing the use of materials that are seriously impaired in the normal mixing operations, or it would serve as a warning that less damaging temperatures or more efficient plant design are necessary successfully to employ the particular material.

Lang and Thomas *(6)* and E. B. Tucker *(21)* have recently emphasized the necessity for considering the viscosity of asphalts at the mixing temperatures in general use for hot-mix pavements. Lang and Thomas showed, in a series of laboratory mixing tests on asphalts typical of those in use throughout the country, that the alterations that occurred in the highly susceptible asphalts when a constant mixing temperature was employed, were materially reduced when the mixing temperatures were adjusted to provide a uniform viscosity for all the asphalts during the tests. Specification requirements for hot-mix pavements should be drawn so that the particular asphalt to be used can be handled efficiently with as little change in original properties as possible.

In the previous report *(11)* the failure of these 50–60 and 85–100 penetration asphalts to pass many of the special test requirements that have been proposed for adequate control was discussed. The conclusion was drawn that these special tests were essentially tests that assist in the identification of source or the method of processing or that they were measures of special qualities. The opinion was expressed that they were not true measures of quality or durability. The term quality or durability was not defined. But on the basis of the data presented in this report and the work of other investigators, the ability of asphalts to retain their original characteristics in the fabrication of hot-mix pavements and in subsequent service may reasonably be considered as one measure of quality.

As previously noted, the specifications of the Michigan Highway Department require that the bitumen recovered from freshly laid pavements shall have a ductility of not less than 40 centimeters and a penetration of not less than 50 percent of that of the original asphalt. Hubbard and Gollomb *(4)* have concluded that for satisfactory hot-mix pavements the penetration of the recovered bitumen should be not less than 30. Miller, Hayden and Vokac *(13)* have used 29 and Vokac *(22)* later used 25 as the minimum satisfactory penetration.

Shattuck's investigation, the results of which are shown in figures 18 and 19, indicates that in the best pavements the ductility is greater than 40 centimeters and the penetration is more than 30. In general, these figures apply to hot-mix construction with asphalt having an initial penetration of 40–60. Therefore, it appears that an indication of the probable satisfactory performance of 50–60 penetration asphalts would be obtained by requiring that the residue from the thin-film oven test (⅛-inch film, 5-hour heating at 325° F.) should have a ductility of not less than 40 centimeters and a penetration not less than 50 percent of the original penetration. Concerning the desirable characteristics of the thin-film residues from 85–100 penetration asphalts very little is known, but for the time being it is suggested that it would not be unreasonable to adopt the same limit for loss in penetration as for asphalts of the 50–60 penetration grade and to require that the ductility of the residue should be not less than 100 centimeters. It will be of interest to observe the effect of such requirements on the 50–60 and 85–100 penetration asphalts included in this investigation.

ALTERATIONS IN ASPHALT IN HOT-MIX PROCESSES NOT PREDICTABLE FROM USUAL TESTS

In table 13 is listed the number of special tests, listed in table 14, that each asphalt failed to meet, and the number that would not meet the requirements proposed for the residues from the thin-film oven test. Eighteen of the 50–60 and 24 of the 85–100 penetration asphalts, failing from 1 to 11 and from 0 to 7 of the special tests, respectively, met the requirements stipulated for the thin-film oven test. Only 2 samples of the 50–60 grade and 4 samples of the 85–100 grade failed to meet the penetration requirement and these also failed to meet the ductility requirements. Twenty-one asphalts of the 50-60 grade and 16 asphalts of the 85–100 penetration grade failed to meet the ductility requirements indicating that these requirements are more severe than those for penetration and that the requirement of a minimum ductility of 40 centimeters for the 50–60 penetration grade is more severe than the minimum of 100 centimeters for the 85–100 penetration grade. Except for sample 29, which was not represented in the 50–60 grade, there was only one asphalt (sample 36) that failed in the 85–100 grade but did not fail in the 50–60 grade.

In table 14 the special tests and the usual specification requirements proposed for them are given. The number of samples failing or passing the thin-film oven tests and the number failing or passing each individual special test are indicated. The results of the Oliensis test appear to give the most consistent indication of the probable behavior in the thin-film oven test. There were 13 of 14 asphalts of the 50–60 grade and 10 of 15 asphalts of the 85–100 penetration grade that failed to pass the Oliensis test and also failed to meet the penetration and ductility requirements for the thin-film residues. Twenty-five asphalts of each grade passed the Oliensis test and of these 17 of the 50–60 grade and 19 of the 85–100 grade also passed the requirements for the thin-film test.

If the alterations occurring in these thin films are accepted as indications of the changes occurring in asphalts during fabrication of hot-mix pavements, it can be seen that the use, as specification requirements, of the special tests listed in table 14 will not entirely

TABLE 13.—*Comparison of samples failing special test requirements and those failing the thin-film oven test*

Identification No.	50–60 grade: Number of special tests each sample fails to pass	50–60 grade: Samples failing to pass thin-film oven test requirement for— Penetration 50+ percent	50–60 grade: Samples failing to pass thin-film oven test requirement for— Ductility 40+ cm.	85–100 grade: Number of special tests each sample fails to pass	85–100 grade: Samples failing to pass thin-film oven test requirement for— Penetration 50+ percent	85–100 grade: Samples failing to pass thin-film oven test requirement for— Ductility 100+ cm.
1	11			7		
2	11			5		
3	11			6		
4	11			6		
5	9			7		
6	6			5		
7	2			0		
8	7		X	5	X	X
9	3			1		
10	2			1		
11	2			1		
12	1			1		
13	4		X	4		X
14	5			3		
15	6		X	3		
16	5		X	4		X
17	4			3		
18	3			1		
19	5			5		
20	5		X	4		X
21	5			2		
22	3		X	2		
23	10		X	8	X	X
24	6		X	5		X
25	7		X	7		
26	8		X	5		X
27	6		X	5		
28	7		X	6		
29				9	X	X
30	4		X	5		
31	5		X	4		X
32	7		X	5		X
33	9		X	8		X
34	5		X	5		X
35	7			3		
36	7			7		X
37	3		X	4		X
38	4		X	5		X
39	9	X	X	6		
40	10	X	X	5	X	X

TABLE 14.—*Number of asphalts that pass or fail the thin-film oven test compared to the number that pass or fail the various special tests*

Special test	Proposed test requirement	Penetration grade	Fail thin-film requirement: Fail special test	Fail thin-film requirement: Pass special test	Pass thin-film requirement: Fail special test	Pass thin-film requirement: Pass special test
Fluidity factor	140+	50–60	12	9	10	8
		85–100	16	0	18	6
Float test index	90+	50–60	12	9	12	6
		85–100	0	16	1	23
Pen. 39.2° F., 200 gm., 60 sec. / Pen. 77° F., 100 gm., 5 sec.	30+ percent	50–60	0	21	4	14
		85–100	2	14	7	17
Pen. 115° F., 50 gm., 5 sec.—Pen. 32° F., 200 gm., 60 sec. / Pen. 77° F., 100 gm., 5 sec.	4.2—	50–60	11	10	16	2
		85–100	-----	-----	-----	-----
Ductility, 39.2° F., ¼ cm. per min.	1/10 pen. at 77° F.	50–60	5	16	0	18
		85–100	3	13	0	24
Ductility 32° F., ¼ cm. per min.	1/10 pen. at 77° F.-1.	50–60	14	7	8	10
		85–100	11	5	3	21
Do	1/10 pen. at 77° F.	50–60	21	0	12	6
		85–100	13	3	5	19
Ductility 39.2° F., 5 cm. per min.	1/10 pen. at 77° F.	50–60	21	0	18	0
		85–100	15	0	23	1
Toughness test	10+	50–60	3	18	6	12
		85–100	1	15	4	20
Organic matter insoluble in 86° B. naphtha.	15–29 percent	50–60	4	17	6	12
		85–100	0	16	8	16
Fixed carbon	8–17 percent	50–60	0	21	4	14
		85–100	0	16	4	20
Sulfur	3+ percent	50–60	11	10	8	10
		85–100	12	4	13	11
Film test	Shall not coagulate.	50–60	3	18	0	18
		85–100	4	12	0	24
Oliensis test	Shall be negative.	50–60	13	8	1	17
		85–100	10	6	5	19

insure asphalt of good durability. For instance, C. L. McKesson (*12*) concludes that sulfur probably contributes to early hardening and loss of ductility in asphaltic binders. Table 14 indicates that the sulfur content alone is not a true indication of the probable behavior of asphaltic materials. Of the 18 asphalts of the 50–60 grade that met the requirements of the thin-film test, 10 contained more than 3 percent of sulfur and of the 24 asphalts of the 85–100 grade that passed the thin-film test, 11 contained more than 3 percent of sulfur.

It is interesting to note that the asphalts that were the least susceptible to temperature change, as determined by the slope of the log penetration-temperature curve (*11*), consistently failed to pass the requirements proposed for the residue from the thin-film oven test. There were 10 asphalts of the 50-60 grade and 5 of the 85–100 grade that had slope values less than 0.021 and these all failed to pass the proposed limits set for the residue from the thin-film oven test.

Undoubtedly, under service conditions asphalts continue to show varying resistance to alterations depending on the character of service and the type of pavement. Asphalt technologists have centered their interest on changes in characteristics of asphalts chiefly in relation to the durability of hot-mix, dense-graded pavements, although the initial properties and the changes in properties of asphalt used in such pavements as penetration macadam and liquefier-type bituminous concrete probably contribute to the ultimate failure of these types of pavements. The data in this report and the facts generally known indicate that asphalts have different resistances to change. There is the possibility that those asphalts that are highly susceptible to the action of heat can be handled at such temperatures and in such manner that they reach the finished pavement with a minimum change in their original properties. This is a problem that the producer and the user dependent on such material must eventually meet.

CONCLUSIONS

1. The present standard test for loss on heating and degree of hardening does not furnish adequate information concerning the probable behavior of asphalts for use in hot-mix paving.

2. The relations between penetration and ductility and penetration and softening point determined from oven tests with thin films appear to be of value for predicting the changes in characteristics of asphalts that take place during mixing and after exposure to service conditions.

3. The changes that occur during the thin-film oven test (5 hours, ⅛-inch films) in asphalts of the 50–60 grade are comparable to the changes that may be expected to occur in bitumen recovered from mixtures prepared in paving plants or from laboratory mixes prepared to duplicate paving plant practice.

4. The ability of asphalts to retain their original characteristics as measured by tests for penetration, ductility, and softening point, after the 5-hour, ⅛-inch film oven tests, offers a means of evaluating their relative durability.

5. A specification requirement based on the decrease in penetration and ductility and the increase in softening point that occurs during the 5-hour, ⅛-inch film oven test should prevent the use of asphalts that are

injured by normal mixing temperatures, or should indicate the need for more moderate temperatures or better equipment to permit the asphalt to be incorporated in the pavement with a minimum of change.

6. Many of the special test requirements that have been proposed by various agencies for control of asphalt cement are not adequate measures of durability.

7. Lower mixing temperatures and improvement in equipment will prevent undue alterations occurring in those asphalts highly susceptible to change in the mixing operation.

8. Most of the producers furnished asphalt having high ductility but, in many cases, the ductile properties were materially reduced in both the thin-film residues and in the bitumen recovered from mixes.

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HIGHWAY CONSTRUCTION SPECIFICATIONS AVAILABLE

Specifications for construction of main highways through national parks and forests are now available in printed form from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. The price is $1.00 per copy—there is no free supply.

This 500-page publication is arranged in three parts. The first part contains general requirements on bidding, responsibility to the public, patents, liquidated damages, payments, etc.

The second part on construction details lists 27 items under earthwork; 12 under base courses; 18 under surface courses and pavements; 27 under structures, such as bridges, culverts, and retaining walls; and 38 under incidental construction, such as piling, curb and gutter, riprap, and sidewalks. No specifications are given for concrete road surfaces. Some of the listed items are preferred in all construction; others were included to meet local conditions and needs.

The third part is a sample bid schedule.

Issued by the Public Roads Administration, Federal Works Agency, the publication is titled, Specifications for Construction of Roads and Bridges in National Forests and National Parks.

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STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF MARCH 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			
			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 282,122	$ 282,039	4		5	$ 655,601	$ 635,608	5	1	2	$ 45,132	$ 45,132			8	$ 1,114,605
Arizona	203,065	195,699	3		2	333,076	327,274	2			31,082	31,082		1	2	217,126
Arkansas	656,196	654,552	6	1	11	985,421	981,479	10		1	158,875	158,820	1		5	349,302
California	463,251	463,251	4		11	1,019,517	825,141	7	1		700,713	700,713	2		15	1,462,144
Colorado	2,410	2,410			1	296,835	296,835	1		1	469,151	469,151	3		2	694,227
Connecticut	622,002	611,366	5	1		166,222	165,415	2								615,261
Delaware	77,997	77,997	4		13	122,489	122,489	1		3	2,332	2,332			1	560,221
Florida	217,540	213,042	2		3	102,816	102,291	1	1		277,706	277,706	2		28	1,363,692
Georgia	209,905	209,810	4	2	13	1,278,713	1,278,713	11	7		27,484	27,484			6	2,168,865
Idaho	286,450	283,021	5		32	14,943	14,943				15,726	15,726			5	569,399
Illinois	1,770,151	1,688,952	9	1	63	1,321,951	1,096,496	4	1	81	419,181	397,155	2		41	2,653,066
Indiana	712,640	710,840	3	2	85	1,003,159	976,359	8	1	9	48,153	48,153			15	1,001,043
Iowa	492,562	467,338	4		87	370,426	342,594	4	1	11	174,811	173,876	1	1	17	1,363,796
Kansas	765,493	762,083	10		16	384,623	384,623	3	2	3	353,603	353,603	10		6	1,255,500
Kentucky	576,713	574,909	8		12	973,054	973,054	9			162,066	157,343	2		3	456,303
Louisiana	100,158	100,158	1			535,658	482,163	6			601,158	543,433	5		2	969,016
Maine	159,988	159,070	1	1	6	132,646	132,646	1	1							393,580
Maryland	180,997	180,993	1		2	485,009	453,216	2	2	7	60,550	60,550			12	920,364
Massachusetts	16,588	16,588		1		342,715	332,292	1			90,040	89,740	1			2,319,006
Michigan	1,156,339	1,113,193	8	1	36	1,447,042	1,447,042	2	5	3	338,600	338,600	2		4	942,999
Minnesota	1,443,430	1,433,048	12	2	19	621,477	621,477	4	4	1	658,018	658,018	3	3	2	1,053,609
Mississippi	263,360	263,360	3	1	1	674,834	674,834	9			62,999	62,999	1	1	5	759,480
Missouri	1,207,495	1,207,495	6	4	1	1,764,741	1,309,321	5	2		159,799	106,400		1		1,462,467
Montana	434,356	434,356	5		4	88,047	88,046	1			2,474	2,474			1	609,220
Nebraska	421,252	418,758	3	1	10	889,429	889,429	15	1	3	64,196	64,196	1		14	509,952
Nevada	72,617	72,617	1		20	70,501	70,501	1			71,448	71,448	1		5	154,921
New Hamnshire	104,313	104,277	3		1	146,134	145,314	3			2,703	2,703			1	426,747
New Jersey	280,886	280,886	2		4	857,018	857,018	4	1		335,976	207,931	2		1	1,108,667
New Mexico	242,979	242,979	2		6	183,821	175,247	3			159,723	159,723	1			493,568
New York	1,229,561	1,186,966	7	5	8	3,712,833	3,656,862	7	16		172,900	172,400		1		3,559,087
North Carolina	578,938	578,875	8	3	25	632,989	632,749	6	3	6	198,385	198,385		3	34	1,200,318
North Dakota	426,458	424,555	5		22	390,220	390,220	4		1	78,223	78,223	1			813,593
Ohio	1,170,693	1,099,741	7	1	17	2,420,125	2,396,650	12	2		512,977	505,840	2			2,621,961
Oklahoma	613,845	611,471	10	1	38	390,096	386,680	3		12	196,054	196,054	1		42	2,181,198
Oregon	208,639	117,537	3			295,958	270,633	3			43,497	43,497	1		4	486,172
Pennsylvania	1,387,269	1,377,793	13	2		2,236,683	2,232,855	16			1,848,997	1,731,097	8			2,658,484
Rhode Island	8,220	7,406				206,703	206,703		1							177,279
South Carolina	447,320	446,917	4	3	21	201,460	201,460	3	1	2	274,995	257,395	1	1	31	983,216
South Dakota	136,127	133,502	2	1	4	564,332	563,472	16			104,420	88,470	2		1	1,017,636
Tennessee	245,718	241,009	2	2		225,803	216,803	1	3		235,009	235,009	3			1,874,209
Texas	1,480,753	1,474,324	12	1	10	1,336,470	1,323,890	15			557,950	556,460	5		1	2,172,328
Utah	87,141	86,930			32	72,826	72,084	2		22	84,753	84,753			31	304,788
Vermont	117,101	116,931		1	8	139,735	139,735		1	4	16,478	16,478			4	295,642
Virginia	205,954	204,508	2	2	7	741,175	740,955	6	2	5	69,632	69,632		1	5	869,365
Washington	363,183	361,168	4	2	10	438,515	438,515	3	3		11,529	11,529			4	451,739
West Virginia	12,130	12,130			3	532,452	526,832	5			116,160	116,160	2		4	991,751
Wisconsin	825,078	809,586	6	4	7	455,699	426,689	3		5	631,809	554,140	2	2	38	1,321,946
Wyoming	6,984	6,979			2	560,904	560,904	6			2,158	2,158			1	297,140
District of Columbia	56,868	56,868	1			2,193	2,193									275,206
Hawaii	8,416	8,141			2	194,767	194,759	2			272,046	210,000	2			181,413
Puerto Rico						584,007	579,336	11			133,350	132,170	2			450,269
TOTALS	23,039,651	22,588,424	205	46	680	33,603,863	32,362,839	249	63	182	11,055,021	10,486,341	72	15	401	53,152,886

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF MARCH 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 190,944	$ 95,263	9.4	$ 1,331,757	$ 665,858	60.8				$ 630,254
Arizona	240,851	169,479	23.6	198,250	119,359	5.4				426,637
Arkansas	416,160	179,101	14.8	460,066	229,180	32.8				309,298
California	894,281	488,989	38.0	1,022,836	705,275	13.6	$ 364,076	$ 191,240	7.9	743,343
Colorado	65,231	36,764	5.7	284,457	159,802	8.2	11,736	6,614	3.8	395,119
Connecticut	370,531	179,413	4.6	225,884	103,652	4.3	74,247	33,840	1.7	186,667
Delaware	127,253	55,913	12.7	46,219	22,675	2.8	82,663	37,626	6.9	313,605
Florida	63,276	31,230	1.6	1,022,611	478,979	18.7	85,045	42,523	.2	326,157
Georgia	147,024	72,610	18.6	954,275	462,138	76.2	166,693	83,347	21.1	1,384,580
Idaho	154,346	91,644	24.0	227,701	137,044	10.3	72,833	4,293	3.5	289,389
Illinois	1,743,814	823,679	80.6	1,017,450	493,725	35.4	448,990	203,400	31.9	704,993
Indiana	470,402	224,327	31.0	286,764	148,839	15.9	285,410	142,635	14.0	1,141,656
Iowa	2,364,931	1,120,985	500.6	608,169	289,200	184.9	192,990	80,260	56.3	496,305
Kansas	321,133	160,232	49.0	916,584	464,112	46.8	194,188	97,094	53.0	1,560,127
Kentucky	797,730	268,935	65.5	688,737	185,095	21.6	275,661	72,251	20.7	539,979
Louisiana	105,321	52,661	10.9	192,608	96,249	14.9				718,901
Maine	303,299	142,929	17.0	40,606	20,303	1.5				157,363
Maryland	128,300	64,150	5.5	98,390	49,195	4.5	225,000	97,500	12.6	452,165
Massachusetts	456,347	225,862	10.3	244,546	138,203	3.6	40,000	20,000	.7	658,018
Michigan	1,543,568	756,191	128.6	531,712	277,930	23.8	378,700	189,350	39.5	777,910
Minnesota	780,978	381,051	117.6	665,386	332,693	88.7	423,082	211,541	45.4	1,148,350
Mississippi	270,229	133,851	12.5	776,452	373,126	42.1	357,200	166,965	19.2	673,023
Missouri	733,428	362,715	96.5	136,270	68,135	13.4	542,988	232,778	50.5	1,018,872
Montana	641,506	362,577	80.3	131,028	73,938	9.3	430,412	243,726	78.0	731,303
Nebraska	575,564	276,209	107.0	573,693	286,624	60.1	198,900	99,098	25.1	479,779
Nevada	199,750	165,179	40.9	178,899	155,725	14.3				236,648
New Hampshire	143,639	68,883	3.4	71,533	34,946	3.6				223,280
New Jersey	389,276	194,533	15.3	287,722	160,375	6.7	346,390	173,195	6.8	517,436
New Mexico	180,724	95,310	20.0	644,662	356,677	25.5				326,218
New York	2,027,020	964,858	67.9	1,399,674	726,144	40.0	172,260	62,297	.6	804,647
North Carolina	946,814	471,235	82.2	427,713	216,468	42.5	260,344	99,325	16.5	509,936
North Dakota	42,143	23,432	.3	172,658	94,136	3.6				1,276,486
Ohio	1,711,142	852,793	59.8	1,775,720	886,600	53.7	200,100	100,050	11.3	1,268,410
Oklahoma	791,152	419,012	57.1	232,076	122,583	14.1	183,600	96,969	12.4	1,161,756
Oregon	371,724	205,456	56.4	300,440	151,654	24.5	240,849	111,122	21.0	362,178
Pennsylvania	1,741,032	856,391	59.9	747,296	373,648	13.4	1,281,082	638,911	30.6	292,316
Rhode Island	262,488	120,687	3.6	93,806	50,516	.9	4,740	2,370		122,054
South Carolina	572,292	209,926	79.0	485,240	170,890	37.6	395,667	174,800	35.9	237,042
South Dakota	3,714	3,624		25,302	15,768	9.0				1,543,134
Tennessee	150,956	72,135	8.7	287,466	143,733	10.0	97,118	48,559	3.2	1,187,186
Texas	1,415,529	693,036	193.1	1,196,786	592,790	108.3	193,830	86,630	24.2	1,573,168
Utah	88,404	49,100	9.5	185,785	123,660	22.1	193,545	72,831	12.1	249,359
Vermont	331,430	111,393	13.1	193,984	56,234	7.6				94,677
Virginia	387,164	181,027	24.8	549,368	256,641	19.7				511,438
Washington	609,592	320,705	31.0	343,673	212,028	25.6	56,751	30,400	.5	308,248
West Virginia	338,126	168,327	18.5	90,300	45,150	2.4	26,300	13,150		608,814
Wisconsin	328,957	163,259	7.4	768,024	391,013	25.5	588,597	271,260	28.4	717,583
Wyoming	433,021	260,037	42.8	259,381	139,362	12.2	95,766	20,000	6.6	218,678
District of Columbia	112,164	56,082	1.4	2,192	1,096		62,564	24,737	.6	91,208
Hawaii	264,732	132,578	8.6	1,096	1,096					250,559
Puerto Rico	143,800	70,400	6.4	213,613	104,380	9.7				167,407
TOTALS	27,893,232	13,686,158	2,377.0	23,616,860	11,964,642	1,332.1	9,250,317	4,282,687	702.7	31,123,659

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TECHNICAL BULLETINS

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House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF MARCH 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 4,061,349	$ 1,917,944	101.2	$ 5,314,223	$ 2,648,070	190.4	$ 1,653,060	$ 821,650	60.7	$ 2,942,093
Arizona	1,266,080	880,867	53.5	1,836,963	1,212,237	78.6	428,157	266,227	9.7	1,718,750
Arkansas	5,068,643	2,323,583	125.2	1,280,844	638,716	56.3	126,384	63,151	3.0	1,729,539
California	6,922,594	3,534,472	132.8	8,118,332	4,298,692	125.2	1,865,238	972,433	30.4	3,963,139
Colorado	2,220,542	1,194,180	189.1	2,104,392	1,223,566	91.9	1,141,972	643,812	92.2	3,057,843
Connecticut	1,936,006	938,685	16.2	1,187,936	580,855	11.3	699,854	338,145	7.5	1,327,326
Delaware	1,854,252	926,347	28.3	338,421	142,552	4.2	363,173	177,192	11.8	1,359,124
Florida	2,512,745	1,248,025	62.5	2,017,139	1,029,357	72.6	600,927	300,463	12.9	3,589,656
Georgia	2,979,846	1,442,934	184.8	7,191,776	3,596,388	282.4	1,598,960	799,480	74.7	7,034,729
Idaho	1,560,205	924,308	151.0	1,040,215	640,970	56.9	698,728	424,829	19.1	2,175,303
Illinois	6,630,811	3,252,337	152.0	7,441,576	3,721,373	144.5	2,608,600	1,304,300	78.2	5,040,682
Indiana	5,154,984	2,534,678	120.9	7,452,303	3,619,933	108.7	1,835,833	761,433	36.4	2,345,244
Iowa	5,488,199	2,572,928	193.0	4,139,791	1,805,341	129.9	1,111,874	522,900	57.4	2,410,406
Kansas	4,503,844	2,202,666	385.9	5,561,032	2,822,183	304.9	2,391,248	1,183,590	134.6	5,123,646
Kentucky	3,044,711	1,513,679	91.1	3,057,383	1,539,372	86.9	3,437,784	1,718,892	110.1	2,913,214
Louisiana	1,270,088	629,985	16.1	12,582,422	3,[illegible]40,138	64.9	930,859	457,742	33.1	4,240,969
Maine	1,297,724	633,944	29.2	1,599,027	821,653	21.0	18,200	9,100	.6	1,046,043
Maryland	1,270,568	623,817	29.1	3,296,959	1,647,361	25.9	374,303	187,151	4.0	1,889,340
Massachusetts	1,835,469	914,828	22.9	2,237,791	1,140,056	13.1	451,920	225,930	2.8	4,079,708
Michigan	6,151,906	2,871,499	215.0	8,385,010	4,179,905	198.9	1,891,210	945,605	32.5	2,400,486
Minnesota	6,032,441	2,918,243	459.5	4,174,545	2,083,890	232.9	3,207,795	1,602,835	154.8	4,408,545
Mississippi	2,954,906	1,274,662	124.5	6,755,974	3,157,497	378.4	1,835,120	894,760	101.5	2,152,235
Missouri	3,393,135	1,679,332	169.2	8,959,755	4,205,807	223.7	4,814,220	1,996,662	150.5	4,724,478
Montana	4,123,613	2,334,341	285.2	2,510,524	1,416,687	129.6	1,104,081	625,657	49.7	4,515,111
Nebraska	4,684,818	2,214,912	549.5	4,159,522	2,099,799	463.2	2,543,430	1,271,715	251.7	3,281,142
Nevada	1,568,973	1,338,924	80.0	1,469,766	1,279,599	73.2	515,124	392,001	20.6	1,260,057
New Hampshire	1,436,947	705,498	36.4	416,295	206,110	9.0	118,536	59,125	.7	1,358,573
New Jersey	2,277,954	1,117,617	11.8	6,832,152	3,415,996	52.2	9,945	4,972		1,750,074
New Mexico	2,316,417	1,401,463	188.5	1,528,856	939,597	62.2	323,691	209,299	25.9	2,188,977
New York	11,495,431	5,564,413	199.0	11,176,318	5,562,460	137.6	629,727	313,109	12.0	5,051,912
North Carolina	4,350,900	2,173,697	233.2	4,920,122	2,445,935	210.8	948,838	473,485	37.0	3,076,451
North Dakota	1,869,206	996,382	191.9	2,595,236	1,488,768	197.4	2,836,094	1,455,965	232.5	4,475,472
Ohio	7,207,318	3,602,840	93.1	12,396,990	6,171,616	99.0	6,849,493	3,279,090	53.7	3,987,081
Oklahoma	3,029,510	1,605,209	134.0	2,790,654	1,436,429	84.1	1,977,200	1,029,825	101.0	5,307,772
Oregon	3,277,276	1,959,171	155.9	2,818,825	1,506,569	73.2	1,523,137	866,020	45.3	1,363,609
Pennsylvania	6,241,430	3,082,407	80.7	13,341,298	6,621,635	109.1	3,927,165	1,850,054	40.4	3,784,215
Rhode Island	1,294,668	644,176	13.2	928,546	463,642	7.9	67,790	33,895	.6	1,225,431
South Carolina	1,984,214	955,732	143.1	2,900,697	1,374,625	126.8	1,080,910	476,143	53.8	2,612,659
South Dakota	3,134,346	1,771,172	530.9	3,930,873	2,466,093	479.3	1,219,600	707,480	176.4	3,295,110
Tennessee	2,706,986	1,342,667	58.1	4,176,138	2,088,069	146.5	1,535,736	767,868	22.4	4,501,646
Texas	8,322,487	4,033,525	479.4	11,525,132	5,693,599	536.3	3,770,243	1,836,360	149.0	8,247,432
Utah	997,642	709,126	73.1	1,097,600	822,629	46.0	359,100	155,180	7.0	1,677,271
Vermont	1,194,683	560,795	36.6	873,155	442,716	23.7	348,476	174,238	9.4	592,788
Virginia	2,568,018	1,197,907	72.5	4,376,798	2,073,975	74.6	398,487	152,208	4.7	2,619,036
Washington	3,308,178	1,693,052	86.8	3,052,642	1,621,649	27.8	15,022	6,900		1,902,577
West Virginia	2,133,911	1,063,369	75.7	3,385,934	1,686,765	73.0	939,976	465,890	8.8	1,901,516
Wisconsin	5,254,548	2,563,710	182.5	2,621,338	1,299,038	98.6	1,551,132	718,390	49.3	4,818,930
Wyoming	1,801,984	1,106,448	196.2	1,184,199	763,574	137.3	585,584	374,955	37.7	1,455,838
District of Columbia	498,667	249,021	5.1	603,588	301,209	.8	224,623	112,300	1.8	555,731
Hawaii	236,412	115,318	4.1	590,134	314,078	7.8	138,944	69,472	2.5	1,954,355
Puerto Rico	519,644	257,240	10.9	1,520,252	750,590	22.2	259,640	128,190	2.6	934,119
TOTALS	169,247,229	85,314,075	7,260.4	215,797,393	106,849,423	6,412.7	69,887,143	34,628,068	2,615.0	151,367,383

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 22, NO. 3 MAY 1941

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PUBLIC ROADS ▸ ▸ ▹ *A Journal of Highway Research*

Issued by the

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PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 3 May 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

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CERTIFICATE: By direction of the Commissioner of Public Roads, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

PROGRESS IN EXPERIMENTS WITH CONTINUOUS REINFORCEMENT IN CONCRETE PAVEMENTS[1]

Reported by HARRY D. CASHELL, Assistant Highway Engineer, Public Roads Administration, and SANFORD W. BENHAM, Research Engineer, Indiana Highway Commission

This report contains data obtained during the first 2 years of observation of continuously reinforced concrete pavement sections.

Changes in pavement elevation have been small and there is nothing to indicate that these changes have affected the structural condition of the various sections.

The annual cycle of length change of the various sections shows that those approximately 150 feet long move with as much freedom as the very short sections. The movement of sections greater than 150 feet long is apparently restrained by the subgrade and this restraint is progressively greater as the section length is increased.

In the long, heavily reinforced sections many fine cracks have developed in the central areas. In the sections of intermediate length containing ½-inch steel bars a moderate amount of cracking has developed, while only a very limited amount of cracking has occurred in the short sections containing welded wire fabric. Although the width of the cracks is slightly greater in the sections containing the smaller amounts of longitudinal steel there is no evidence of spalling, raveling, disintegration, steel failure, or other structural weakness at any of the cracks. A relation between the length of the section as constructed and the average slab length (or the distance between transverse cracks) appears to exist. So far, no relation has been found between the average slab length and either the type or the amount of longitudinal steel.

Relative roughness determinations over the various sections show that the surface of the sections was very smooth after about 18 months of service.

THIS is the second report describing an experimental reinforced concrete pavement investigation that is being conducted by the Public Roads Administration and the Indiana State Highway Commission. In the first report[2] the scope of the study was outlined in detail and the construction of the experimental pavement was described. The present report contains a general discussion of the current condition of the pavement, with data showing the more important developments and trends that have become evident during its 2-year life. The purpose of this report is not to draw definite conclusions regarding the relative merits of the various sections, but to present data that will show the observed behavior to date.

To enable a better understanding of the data, certain essential details of design that were presented in the first report will be repeated here. The number and length of the sections and the amount and type of reinforcement used in each are given in tables 1, 2, and 3.[3] It will be noted that the values of the calculated maximum steel stresses are such as to permit direct comparison between sections containing different types as well as different percentages of longitudinal steel. The average unit tensile strength of each of the different types and sizes of steel reinforcement as found by tests is given in table 4. It is apparent from these data that the yield points of both the billet and rail steel bars are appreciably higher than the calculated maximum stresses shown in tables 2 and 3.

In addition to the regular sections, four other sections were included in which special joint designs and different methods of reinforcing were employed. The essential common features of these four sections are: (1) Each section is 500 feet long; (2) weakened-plane joints were placed at 10-foot intervals in each; (3) reinforcement consisted of welded fabric placed continuously through the weakened-plane joint; (4) the bond between the steel and the concrete was broken for a distance of 18 inches on each side of each weakened-plane joint by omitting the transverse steel at this point and by greasing; and (5) dowel bars for load transfer were placed across one-half of the weakened-plane joints of each section.

The distinguishing features of the four sections are as follows:

No. 1. Weakened-plane joints are of the submerged type and the welded fabric reinforcement weighs 91 pounds per square.

No. 2. This section is the same as No. 1, except that it is reinforced with a 45-pound welded fabric.

No. 3. Weakened-plane joints are of the surface groove type and the reinforcement weighs 91 pounds per square.

No. 4. The section is the same as No. 3, except that it is reinforced with a 45-pound welded fabric.

The amount of longitudinal steel in the 91-pound welded fabric is 77 pounds per square; that in the 45-pound welded fabric is 35 pounds per square.

The strength of the concrete was determined by compression tests on drilled cores at the age of 6 months. The average strength was found to be 6,360 pounds per square inch. The average density of the concrete was 154 pounds per cubic foot.

The experimental pavement was constructed during September and October 1938 as a regular Federal-aid project, being a part of the transcontinental highway U S 40. Approximately 1½ miles of this 6-mile experimental pavement has been subject to heavy truck and passenger-car traffic for nearly 2 years, while the remaining 4½ miles has been under the same traffic for 1½ years.

The schedule of observations described in the first report has been adhered to, and for detailed information concerning this program the reader is referred to the first report. Briefly, the schedule comprises:

1. Measurement of changes in pavement elevation.
2. Measurement of changes in length of the experimental sections.
3. Condition and crack surveys.

[1] Paper presented at the Twentieth Annual Meeting of the Highway Research Board, December 1940.

[2] Experiments with Continuous Reinforcement in Concrete Pavements, by Earl C. Sutherland and Sanford W. Benham. Proceedings of the Highway Research Board, vol. 19, 1939; also PUBLIC ROADS, vol. 20, No. 11, January 1940.

[3] The lengths of sections given in these tables are nominal lengths and may be either 5 feet or 10 feet greater than the actual length as laid in cases where the type I or type II expansion joints were installed.

311162—41——1

TABLE 1. *Details of steel reinforcement in experimental reinforced concrete pavement;* [1] *cold drawn wire (welded fabric)*

Number of sections	Length of each section	Calculated maximum stress in steel	Reinforcement size and spacing: Longitudinal	Reinforcement size and spacing: Transverse	Weight of longitudinal steel
149-POUND					
	Feet	*Pounds per square inch*			*Pounds per 100 square feet*
6	140	25,000	No. 4-0; d=0.3938 inch; 4 inches center to center.	No. 3; 12 inches center to center.	132
6	190	35,000			
6	250	45,000			
6	310	55,000			
107-POUND					
6	90	25,000	No. 4-0; d=0.3938 inch; 6 inches center to center.	No. 3; 12 inches center to center.	91
6	130	35,000			
6	170	45,000			
6	200	55,000			
91-POUND					
6	80	25,000	No. 3-0; d=0.3625 inch; 6 inches center to center.	No. 4; 12 inches center to center.	77
6	110	35,000			
6	140	45,000			
6	170	55,000			
65-POUND					
6	60	25,000	No. 0; d=0.3065 inch; 6 inches center to center.	No. 6; 12 inches center to center.	55
6	80	35,000			
6	100	45,000			
6	120	55,000			
45-POUND					
6	30	25,000	No. 3; d=0.2437 inch; 6 inches center to center.	No. 6; 12 inches center to center.	35
6	50	35,000			
6	60	45,000			
6	80	55,000			
32-POUND					
6	20	25,000	No. 6; d=0.1920 inch; 6 inches center to center.	No. 6; 12 inches center to center.	22
6	30	35,000			
6	40	45,000			
6	50	55,000			

[1] Sections are 10 feet wide.

In addition to these observations, during the past year measurements were made of the relative surface roughness of the various sections. The results of all of these various studies are presented in this report.

PAVEMENT ELEVATIONS DETERMINED PERIODICALLY

In connection with the presentation of the pavement elevation data certain pertinent physical characteristics and moisture determinations of the subgrade are given in table 5. The soil samples were taken from the finished subgrade at the depths indicated.

The first set of elevation measurements to establish the normal elevation of the pavement was started as soon as possible after the necessary bench marks had been established and the measuring points installed in the pavement.

Unfortunately, the first set of elevation measurements had been completed on only about 1½ miles of the experimental pavement before the first freezing weather occurred, so it cannot be certain that the remaining portion was entirely undisturbed at the time of the first measurements. However, the winter of 1938–39 was generally mild in this area and frost did not penetrate more than a few inches at any time.

TABLE 2.—*Details of steel reinforcement in experimental reinforced concrete pavement;* [1] *billet steel bars (intermediate grade—deformed)*

Number of sections	Length of each section	Calculated maximum stress in steel	Reinforcement size and spacing: Longitudinal	Reinforcement size and spacing: Transverse	Weight of longitudinal steel
	Feet	*Pounds per square inch*			*Pounds per 100 square feet*
2	360	15,000	1-inch round bars; 6 inches center to center.	½-inch round bars; 24 inches center to center.	534
2	600	25,000			
2	840	35,000			
2	1,080	45,000			
4	200	15,000	¾-inch round bars; 6 inches center to center.	½-inch round bars; 24 inches center to center.	300
4	340	25,000			
4	470	35,000			
4	610	45,000			
4	90	15,000	½-inch round bars; 6 inches center to center.	½-inch round bars; 24 inches center to center.	134
4	150	25,000			
4	210	35,000			
4	270	45,000			
6	50	15,000	⅜-inch round bars; 6 inches center to center.	⅜-inch round bars; 24 inches center to center.	75
6	80	25,000			
6	120	35,000			
6	150	45,000			
6	20	15,000	¼-inch round bars; 6 inches center to center.	¼-inch round bars; 12 inches center to center.	33
6	40	25,000			
6	50	35,000			
6	60	45,000			

[1] Sections are 10 feet wide.

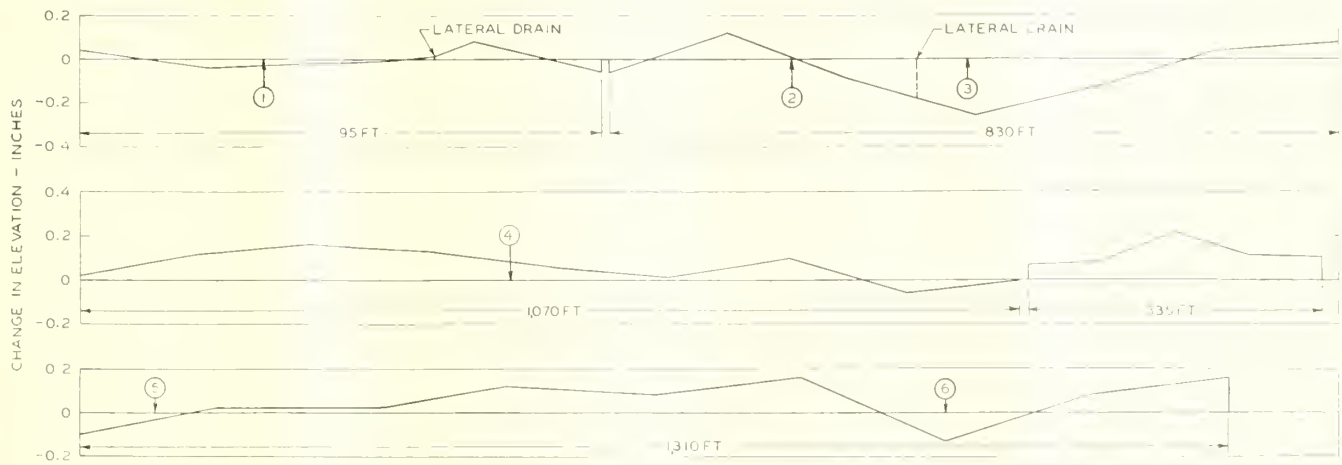
TABLE 3.—*Details of steel reinforcement in experimental reinforced concrete pavement;* [1] *rail steel bars (deformed)*

Number of sections	Length of each section	Calculated maximum stress in steel	Reinforcement size and spacing: Longitudinal	Reinforcement size and spacing: Transverse	Weight of longitudinal steel
	Feet	*Pounds per square inch*			*Pounds per 100 square feet*
2	600	25,000	1-inch round bars; 6 inches center to center.	½-inch round bars; 24 inches center to center.	534
2	840	35,000			
2	1,080	45,000			
2	1,320	55,000			
4	340	25,000	¾-inch round bars; 6 inches center to center.	½-inch round bars; 24 inches center to center.	300
4	470	35,000			
4	610	45,000			
4	740	55,000			
4	150	25,000	½-inch round bars; 6 inches center to center.	½-inch round bars; 24 inches center to center.	134
4	210	35,000			
4	270	45,000			
4	330	55,000			
6	80	25,000	⅜-inch round bars; 6 inches center to center.	⅜-inch round bars; 24 inches center to center.	75
6	120	35,000			
6	150	45,000			
6	180	55,000			
6	40	25,000	¼-inch round bars; 6 inches center to center.	¼-inch round bars; 12 inches center to center.	33
6	50	35,000			
6	60	45,000			
6	80	55,000			

[1] Sections are 10 feet wide.

The second set of elevation measurements over the full length of the experimental sections was made during October 1939, the pavement then being about 1 year old. It is believed that by this time the subgrade had attained a normal moisture condition throughout and the pavement slab was at an elevation normal for the season.

The third set of elevation measurements over the full length of the experimental sections was made in January 1940. This was a severe winter and frost had penetrated to a depth of about 20 inches at the time of the measurements.



SOIL SAMPLE NO.	1	2	3	4	5	6
	PERCENT					
SILT	58	63	39	54	46	43
CLAY	18	13	12	23	19	18
LIQUID LIMIT	37	43	28	39	35	29
PLASTICITY INDEX	12	19	11	16	14	11

SOIL SAMPLE NO	1	2	3	4	5	6
	PERCENT					
MOISTURE CONTENT: 0 - 3 INCH DEPTH	11.5	12.9	9.2	17.0	16.8	9.8
3 - 12 INCH DEPTH	14.6	15.8	13.5	21.4	18.7	15.7
12 - 24 INCH DEPTH	13.1	20.9	13.5	21.2	19.6	12.8

FIGURE 1.—CHANGES IN ELEVATION OF CERTAIN SECTIONS OF PAVEMENT AT END OF FIRST YEAR, AND PHYSICAL CHARACTERISTICS OF SUBGRADE SOIL.

TABLE 4.—*Tensile strength of steel reinforcement*

WELDED FABRIC

Weight	Average tensile strength	
	Longitudinal wires	Transverse wires
Lb. per sq.	*Lb. per sq. in.*	*Lb. per sq. in.*
32	88,700	84,767
45	81,000	87,000
65	83,700	87,800
91	89,100	88,867
107	80,250	86,150
149	81,820	81,820

BILLET STEEL BARS

Diameter	Average tensile strength	
	Yield point	Ultimate
Inch	*Lb. per sq. in.*	*Lb. per sq. in.*
¼	56,850	77,300
⅜	55,480	81,940
½	51,433	78,567
¾	49,132	78,468
1	46,943	78,033

RAIL STEEL BARS

¼	60,250	84,600
⅜	66,650	93,625
½	68,768	115,312
¾	64,428	113,255
1	63,342	113,202

Other measurements of the elevation of certain selected sections of the pavement have been made from time to time.

In figure 1 are shown the changes in pavement elevation that had occurred on typical sections at the end of the first year of pavement life, using the elevations determined in the fall of 1938 as a base. The moisture condition and other subgrade soil data at the time the pavement was placed are shown also in this figure. Although no moisture determinations were made at the time the second set of elevation data was obtained, it is only reasonable to expect that changes had occurred during the year since the concrete was placed. It is believed that the changes in pavement elevation that had developed during this period were caused by changes in the physical state of the subgrade soil.

TABLE 5.—*Subgrade soil data*

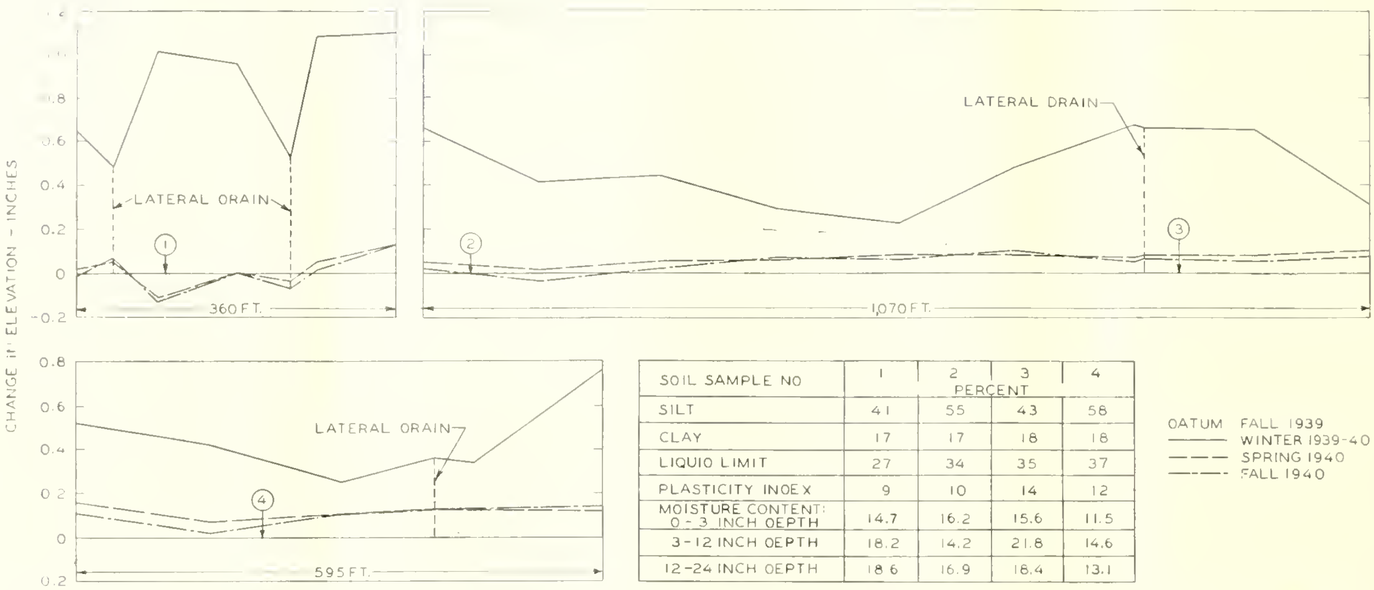
	Silt	Clay	Liquid limit	Plasticity index	Moisture content		
					0-3 inches below surface	3-12 inches below surface	12-24 inches below surface
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Maximum	65	[1] 26	52	26	22.6	24.0	27.5
Minimum	20	7	19	4	6.1	8.9	8.1
Average	48	17	33	12	12.8	15.5	17.1

[1] This maximum percentage was exceeded in two instances; however, these cases were not considered as representative of the entire project.

It will be noted that little change occurred at any point in the 595-foot section. In the 830-foot section the most noticeable change was a settlement of 0.2 inch near the center. It was observed that the subgrade in this area was somewhat spongy at the time the concrete was placed. Figure 1 shows that over much of the length of both the 335-foot and the 1,070-foot sections the elevation increased 0.1 to 0.2 inch, while on the 1,310-foot section slight increases and slight decreases developed in certain areas during the first year.

The data in figure 1 give a fair indication of the general order of the changes in elevation that were observed at the end of the first year. Over the entire length of the experimental sections no change in elevation of more than 0.5 inch was found at this time.

Using as a datum the elevations measured on the pavement surface in October 1939, when presumably the sections had stabilized at their normal position for this season of the year, the positions of certain selected sections are shown in figures 2, 3, and 4 as they were found to be: (1) In January 1940 with the subgrade frozen deeply; (2) in May 1940 after thawing was complete; and (3) in October 1940 after the annual cycle of change was again completed.



SOIL SAMPLE NO	1	2	3	4
	PERCENT			
SILT	41	55	43	58
CLAY	17	17	18	18
LIQUID LIMIT	27	34	35	37
PLASTICITY INDEX	9	10	14	12
MOISTURE CONTENT: 0 - 3 INCH DEPTH	14.7	16.2	15.6	11.5
3 - 12 INCH DEPTH	18.2	14.2	21.8	14.6
12 - 24 INCH DEPTH	18.6	16.9	18.4	13.1

FIGURE 2.—SEASONAL CHANGES IN ELEVATION OF SELECTED SECTIONS DURING THE SECOND YEAR, AND PHYSICAL CHARACTERISTICS OF SUBGRADE SOIL.

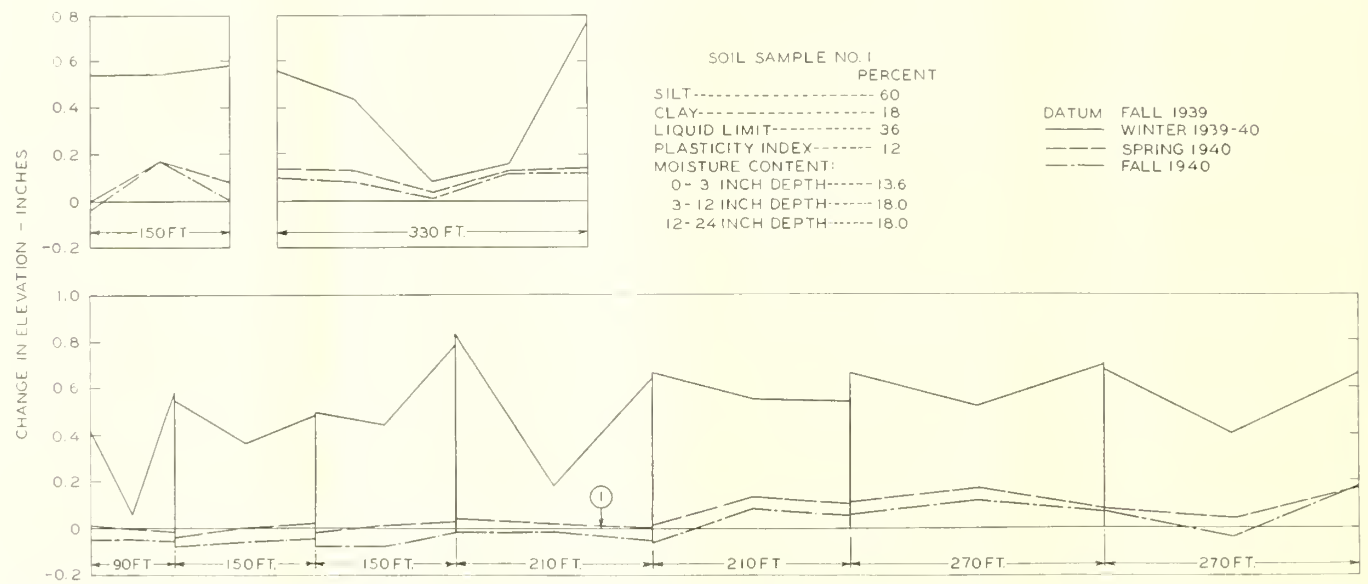


FIGURE 3.—SEASONAL CHANGES IN ELEVATION OF SELECTED SECTIONS DURING THE SECOND YEAR, AND PHYSICAL CHARACTERISTICS OF SUBGRADE SOIL.

In these figures the data are divided into three groups on the basis of the amount of longitudinal reinforcement present (and indirectly the general length of the sections). In figure 2 are shown data for sections containing 1-inch diameter bars and of considerable length; in figure 3 are data for those containing ½-inch diameter bars and of intermediate section length; while in figure 4 are data for relatively short sections reinforced with welded wire fabric.

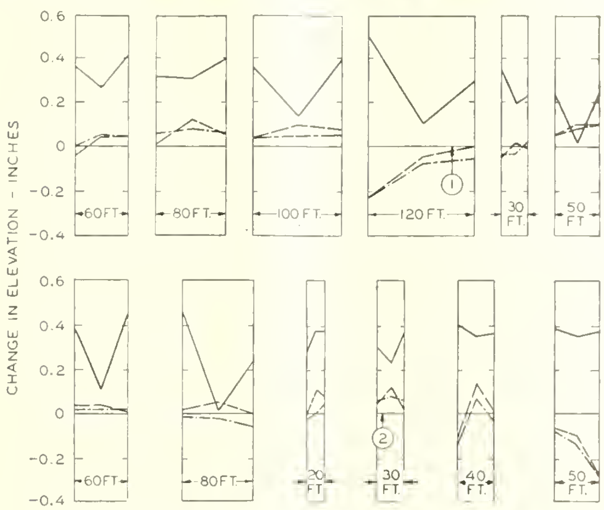
It is of interest to note that the changes in elevation caused by freezing are (1) of relatively small magnitude; (2) not uniform; and (3) frequently greater at the expansion joints than elsewhere in the sections.

Figure 5 contains similar data showing changes in elevation caused by freezing at six joints in the central area of each of the four 500-foot sections, which have warping joints at 10-foot intervals. The same general order and nonuniformity of heaving is evident in these sections. It appears, however, that the warping joints were better sealed and did not aggravate the frost heaving, in contrast to the expansion joints in the longer sections.

In spite of the deep freezing the magnitude of the frost heaving is not large, being generally within the range 0.2 to 1.0 inch. It is not uniform, varying probably with the physical characteristics and condition of the subgrade soil. In this connection it is of interest to note that at places where lateral drains were placed under the 360-foot section the magnitude of the frost heaving was less than at any other point.

It is believed that the flexure caused by the nonuniformity of the frost heaving was not sufficient to fracture the sections and the condition surveys confirm this.

After the soil had competely thawed, the elevation of the pavement was, in general, slightly greater than before freezing occurred. Between May 1940 and October 1940 little or no change in pavement elevation developed.



SOIL SAMPLE NO.	1	2
	PERCENT	
SILT	43	38
CLAY	18	16
LIQUID LIMIT	34	32
PLASTICITY INDEX	11	14
MOISTURE CONTENT: 0 - 3 INCH DEPTH	11.0	16.0
3 - 12 INCH DEPTH	13.0	18.0
12 - 24 INCH DEPTH	19.0	18.0

DATUM FALL 1939
——— WINTER 1939-40
— — — SPRING 1940
—·—·— FALL 1940

Figure 4.—Seasonal Changes in Elevation of Selected Sections During the Second Year, and Physical Characteristics of Subgrade Soil.

These data emphasize the importance of subgrade uniformity and of tightly sealed joints as aids in maintaining the structural integrity of concrete pavements exposed to freezing conditions.

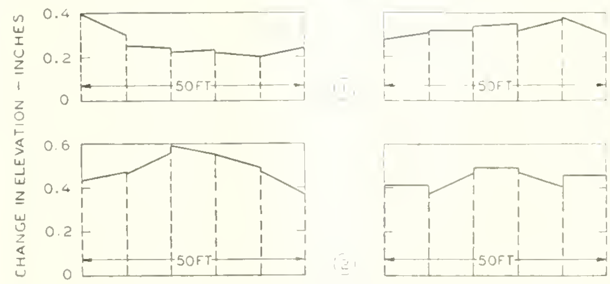
DAILY AND ANNUAL CHANGES IN SECTION LENGTH OBSERVED

As a part of the regular schedule, measurements are made of the daily and annual changes in section length[4] of a number of representative sections. The daily change in length is primarily that caused by the temperature change, but the annual change combines the length changes caused by temperature and moisture changes with any permanent change in length from other causes. In the present report only the annual change in length will be discussed. Measurements of this movement are made at the expansion joints of 1 section of each length for each of 3 types of reinforcement, a total of 64 sections.

In figure 6 are shown the average maximum changes in length observed for sections of different length during the first and the second years of pavement life. The changes in average pavement temperature accompanying these changes in length were 63° F. for the first year and 87° F. for the second year. For clarity in presentation, the points representing observed values for the first year are omitted from the graph. The two light straight lines, that appear to be tangent to the lower portion of the two curves, were drawn through the points for the shorter sections and thus represent the relation for short sections that are comparatively free to expand and contract.

The type of reinforcement used in the various sections is denoted by the character of symbol and it is apparent that type of reinforcement exercises no significant

[4] The term "annual change in section length," as used in this report, refers to the observed changes in length that occur between midwinter and midsummer. The values given are, therefore, approximately the maximum for the annual cycle.



SOIL SAMPLE NO.	1	2
	PERCENT	
SILT	47	43
CLAY	15	18
LIQUID LIMIT	44	33
PLASTICITY INDEX	14	12
MOISTURE CONTENT: 0 - 3 INCH DEPTH	21.0	18.0
3 - 12 INCH DEPTH	24.0	18.0
12 - 24 INCH DEPTH	19.0	17.0

Figure 5.—Increase in Elevation of Sections Containing 10-foot Slabs Caused by Freezing of Subgrade to a Depth of 20 Inches.

influence on the magnitude of the length changes thus far observed.

The two curves in figure 6 represent length changes that accompanied temperature changes of quite different magnitude. When the two sets of data are reduced to a common temperature base, it is found that the length changes observed during the second year, for sections exceeding 600 feet in length, are appreciably greater than those during the first year. For example, take the extreme case of the 1,310-foot section. During the first year the observed change in its length was 1.64 inches. Multiplying this by the temperature ratio 87/63 gives 2.27 inches, the change in length that might be expected with an 87° change in temperature. During the second year, however, a change in length of 2.72 inches was observed. Thus, it appears that the change in length was affected by temperature and also by other influences. It seems possible that the restraint offered by the subgrade may have been less after the pavement had been through an annual cycle of moisture and temperature change.

The difference in restraint increases with section length up to lengths of about 1,000 feet, after which it is practically constant, indicating that it is more probably the result of changes in soil resistance than of other causes.

When the changes in length observed during the two annual cycles are reduced to unit values per degree temperature change and related to the corresponding section lengths, the curves shown in figure 7 result. This figure is of interest in showing how the magnitude of the annual length change varies with the length of the section. The unit length change, although expressed in terms of temperature, is not actually a coefficient of thermal change alone but rather a coefficient of length change that involves temperature, moisture, and perhaps other influences. The relation is useful in indicating the order of movement to be expected at the ends of pavement slabs of various lengths. It appears from this figure that for sections up to 150 feet in length the coefficient has a value of about 0.000004. As the length of section is increased to about 600 feet, the value of the coefficient is reduced to about 75 percent of that for short sections; while for sections

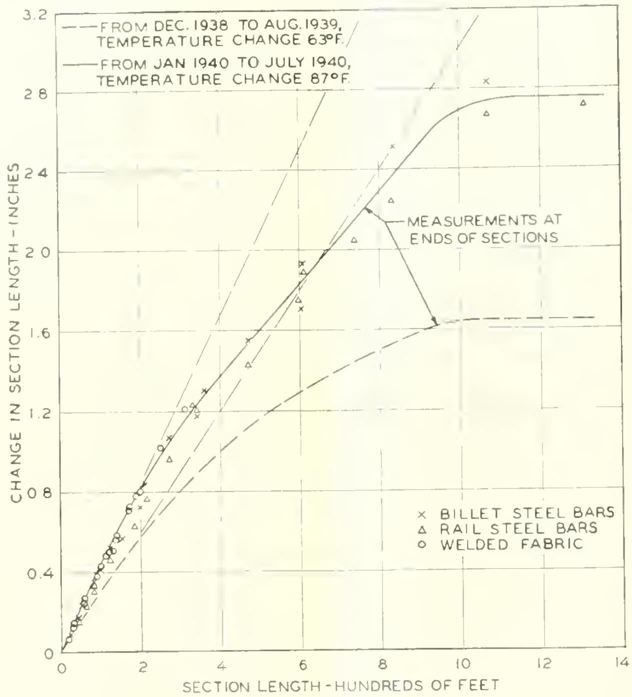


FIGURE 6.—RELATION BETWEEN SECTION LENGTH AND ANNUAL CHANGE IN LENGTH.

1,200 to 1,300 feet in length it is reduced to about 50 percent.

In the discussion of figure 6 it was pointed out that for long sections the changes in length that accompanied a given temperature change were greater during the second year than during the first year. This is shown perhaps more clearly in figure 7.

The annual longitudinal movements observed at the center, quarter-points, and ends of the 1,310-foot section are shown for each of the two years in figure 8. The value shown for the quarter-point and that shown for the end is in each case the average of the measurements at both quarter-points and at both ends of this section. In this graph are shown also straight-line relationships between movement and section length as observed on the short and relatively unrestrained slabs during each annual period.

During the first year the movement at the quarter-points was about 10 percent and at the ends about 40 percent of that which would be expected in a free slab of this length. During the second cycle the movement at the quarter-points was about 33 percent and at the ends about 54 percent of that of the hypothetical unrestrained section. This is added evidence that less restraint to longitudinal movement was present during the second cycle of length change.

NUMEROUS CRACKS FORMED IN LONG, HEAVILY REINFORCED SECTIONS

Figures 9, 10, and 11 are typical crack survey sheets, including data obtained in the six surveys made up to this time. These surveys were made during the various seasons of each of the 2 years of the service life of the pavement. Figure 9 shows the location of cracks in a 1,070-foot section reinforced with 1-inch diameter billet steel bars; figure 10 shows data for sections 90, 150, and 330 feet in length reinforced with ½-inch diameter steel bars; and figure 11 shows data for sections 20, 30, 40, 50, 60, 80, 100, and 120 feet in length

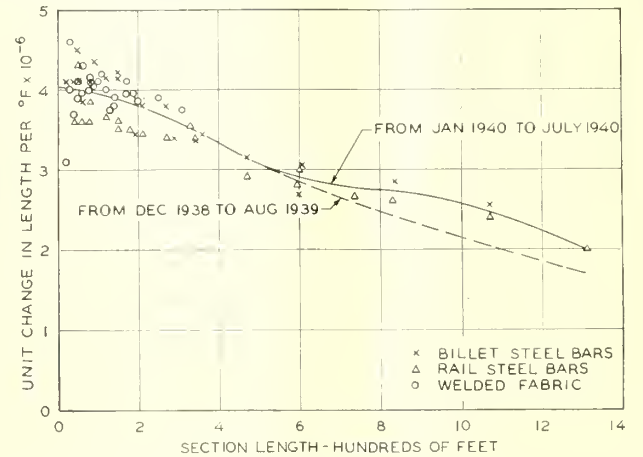


FIGURE 7.—RELATION BETWEEN SECTION LENGTH AND ANNUAL EXPANSION.

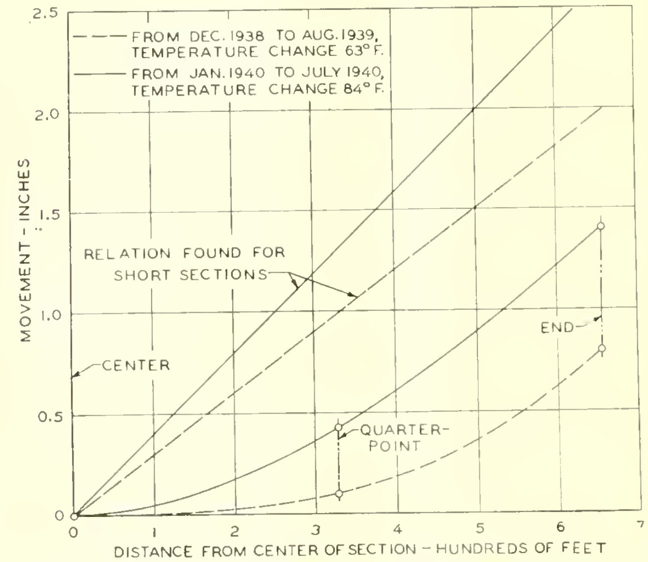


FIGURE 8.—ANNUAL MOVEMENT AT THE CENTER, QUARTER-POINT, AND END OF A 1,310-FOOT SECTION.

containing three different weights of welded wire fabric reinforcement as noted.

Referring to figure 9, it will be noted that numerous cracks have formed in the central area of this long, heavily reinforced section. In this area cracks are frequently less than 2 feet apart, but near the ends the spacing gradually becomes much greater. This manner of cracking was anticipated. The cracks are barely visible even on very close inspection and none has opened sufficiently to indicate an inelastic elongation of the steel. At this time there is no spalling or disintegration and the section is structurally intact. Figure 12–A is a recent photograph of a crack typical of those that formed early in the life of this section.

In the intermediate-length sections shown in figure 10 containing much less reinforcement, the number of cracks that have formed in a given length is much smaller than that found in the longer, more heavily reinforced sections. Of the three sections represented in figure 10, only the 330-foot section has an appreciable number of cracks discernible at this time. In the 150-foot section only one crack has formed and the 90-foot section contains no full length cracks. The cracks in

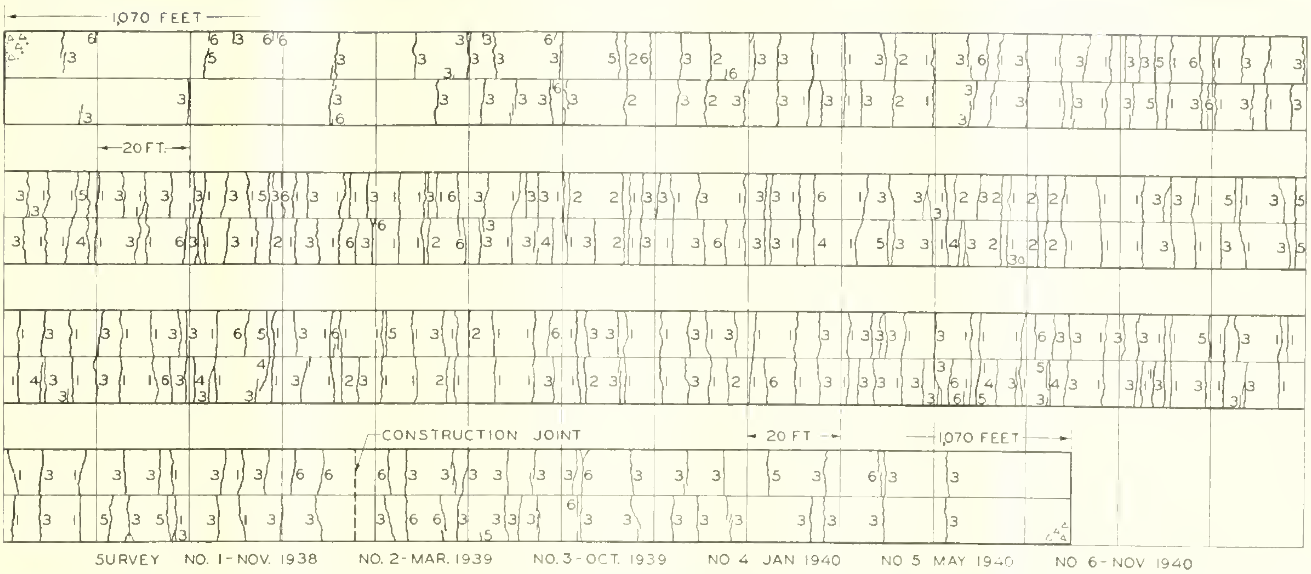


FIGURE 9.—TYPICAL CRACK SURVEY SHEET FOR LONG SECTIONS REINFORCED WITH 1-INCH DIAMETER STEEL; SECTIONS PLACED SEPTEMBER-OCTOBER, 1938.

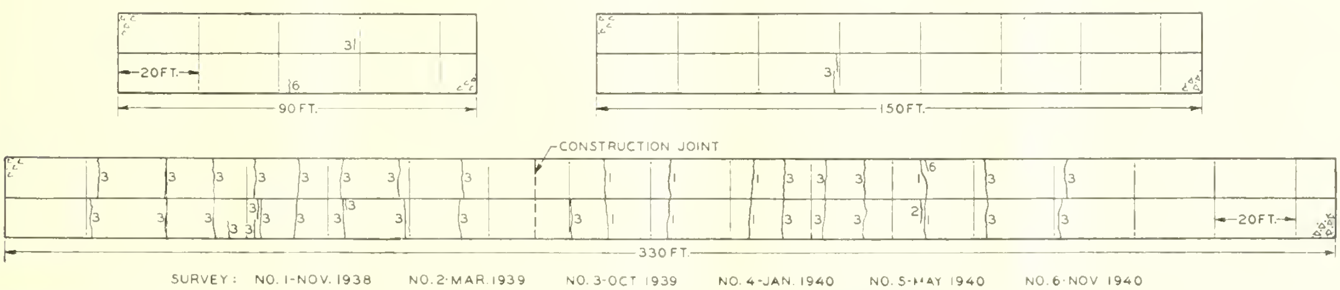


FIGURE 10.—TYPICAL CRACK SURVEY SHEET FOR INTERMEDIATE-LENGTH SECTIONS REINFORCED WITH ½-INCH DIAMETER STEEL; SECTIONS PLACED SEPTEMBER-OCTOBER, 1938.

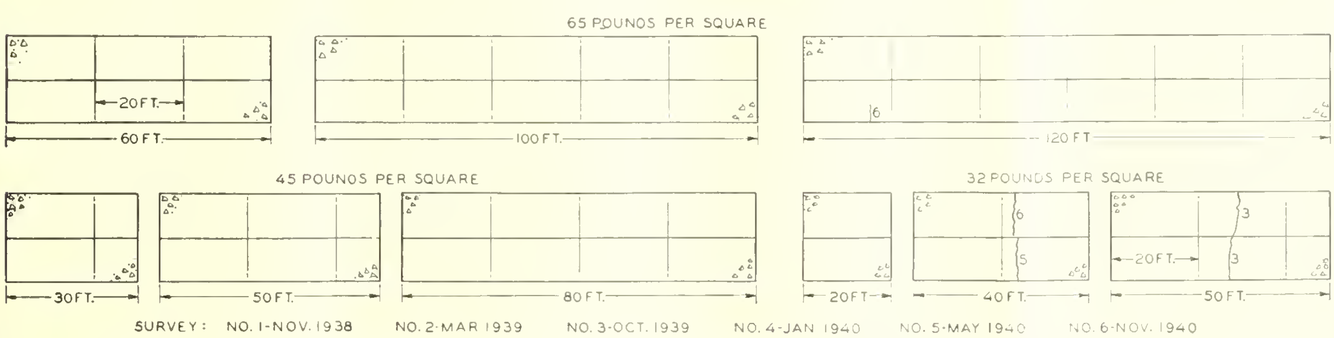


FIGURE 11.—TYPICAL CRACK SURVEY SHEET FOR SHORT SECTIONS REINFORCED WITH WELDED FABRIC; SECTIONS PLACED SEPTEMBER-OCTOBER, 1938.

the intermediate-length sections appear to be slightly more open than those in the more heavily reinforced sections, but the difference is slight and no quantitative data are available at this time. There is no spalling, disintegration, or evidence of inelastic deformation of the steel in these sections. Figure 12–B shows the present appearance of a typical crack in this part of the pavement.

As will be noted from figure 11, little or no cracking has occurred to date in the shorter sections reinforced with welded wire fabric. Of the nine sections represented in this figure only two have cracked across the full width of the slab. These are the 40- and 50-foot sections reinforced with the 32-pound fabric, the lightest weight used. Figure 12–C shows the present appearance of one of these cracks. The cracks are open slightly but there is no spalling, disintegration, or evidence of steel failure.

Comparison of figures 9, 10, and 11 indicates the existence of a relationship between the average slab length, or number of cracks, and the length of the sections, or amount of longitudinal reinforcement. A study has been made of this relationship and in figure 13 is shown the relation between length of section and the average slab length as found in March 1939 and again in November 1940. The sections represented

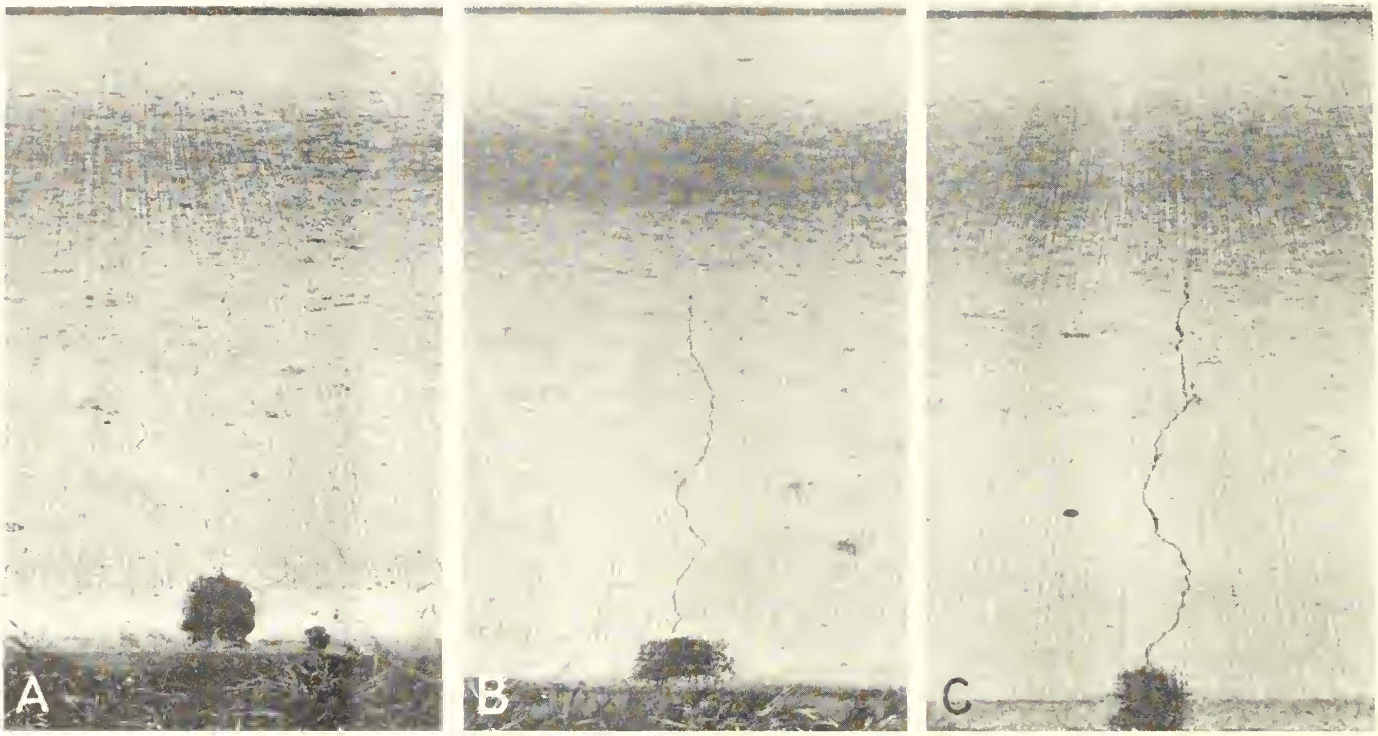


FIGURE 12.—TYPICAL CRACKS IN: A, LONG SECTION REINFORCED WITH 1-INCH DIAMETER BARS; B, INTERMEDIATE-LENGTH SECTION REINFORCED WITH ½-INCH DIAMETER BARS; AND C, 30-FOOT SECTION REINFORCED WITH 32-POUND WIRE FABRIC.

in this graph include three sizes of bar reinforcement and several weights of welded wire fabric. As in other figures, the points for the first survey have been omitted for the sake of clarity.

At the time of the March 1939 survey little or no cracking was found in sections having lengths of 210 feet or less. In sections longer than 210 feet cracking occurred and the frequency, as indicated by the average slab length, increased rapidly with increase in section length. For example, at the time of this survey the average uncracked slab length of the 250-foot sections was approximately 120 feet, that for the 600-foot sections was about 16 feet, and that for the 1,070-foot sections was about 13 feet.

By November 1940 a considerable change had occurred. The average length of the uncracked slabs had been reduced to about 130 feet. The average slab length of the 250-foot sections had been reduced to about 23 feet, the 600-foot sections to about 10 feet, and the 1,070-foot sections to about 6 feet.

While it might be inferred from figure 13 that the average slab length is not influenced by the amount of longitudinal steel present, it is believed desirable to await further developments before attempting to draw any conclusion regarding this point.

SUBGRADE RESISTANCE CAUSED CRACKING IN LONG SECTIONS

Figure 14 shows the manner in which the cracking developed in the sections of various lengths with respect to time of year. The long sections shown are reinforced longitudinally with 1-inch diameter bars, the intermediate sections with ½-inch diameter bars, while the short sections contain the three lighter weights of welded fabric (32, 45, and 65 pounds per square). The condition at the time of each of the six surveys is shown. The first survey was made after the completion of the curing period and within about 1 month after the section was laid. At this time about 40 percent of the cracking that now exists was present in the long sections and about 20 percent in the intermediate-length sections. By March 1939 there had been but little change although the pavement had passed through a winter.

The survey in October 1939 showed a very great change in all groups. Since October 1939 there has been only a gradual increase in the number of cracks in all of the sections. The rate of cracking during this period has been greater for the shorter sections, although so few cracks have occurred that this is probably not significant. Figure 14 indicates that the severe freezing of December 1939 and January 1940 had no noticeable influence on the rate of cracking.

The tensile stress in the concrete caused by the resistance offered by the subgrade is apparently responsible for most of the cracking that has occurred in the longer sections. This is indicated by the fact that comparatively little cracking has developed thus far in either the shorter sections or in the ends of the longer sections. In long slabs reinforced with continuously bonded longitudinal steel, the tensile stresses in the concrete caused by subgrade resistance are relieved when a crack or rupture occurs. The forces that caused the stresses are transmitted across the rupture plane by the steel and are transferred back to the concrete by the bond between it and the steel. The distance required for this transfer depends upon the magnitude of the force and the quality of the bond available. This explains why cracks have formed at such close intervals in the long sections with large amounts of reinforcement and at greater intervals in the shorter sections containing relatively small amounts of reinforcement.

Because the pavement was laid in the fall of the year, it might be expected that, in the long sections that are restrained, there would be a residual compressive stress during the summer when the temperature rises above

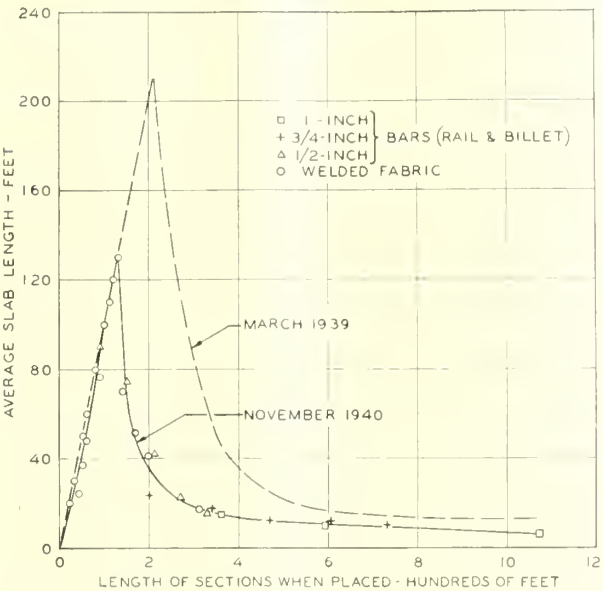


FIGURE 13.—RELATION BETWEEN LENGTH OF SECTION AND AVERAGE SLAB LENGTH.

that at which the concrete was placed and a corresponding residual tensile stress when the temperature falls below that point during the winter. This being the case, it is natural to expect that cracking from subgrade restraint would develop during the winter. It was shown by figure 14 that the greater part of the cracking was found after the hot weather of summer, rather than after the cold weather of winter as might have been expected. It is possible that incipient cracks started during the winter do not become discernible for some months. Whether or not this is true has not been established. It is possible that the residual stresses mentioned above would be relieved by plastic flow. If this happened, the highest tensile stresses would probably be the combined stresses that develop during the daily temperature cycle in the summer months.

The occasional cracking that has developed in the shorter sections and in the end areas is probably the result of combined load and warping stresses, as the restraint of the subgrade could not produce critical tensile stress in sections of such length. Also the cracking in the shorter sections apparently occurred during the summer when warping stresses are high.

SPECIAL STUDY MADE OF SECTIONS CONTAINING PLANE-OF-WEAKNESS JOINTS

In connection with the study of cracking of the various sections of the experimental pavement, an opportunity has been afforded to observe the influence of traffic on the development and condition of the cracks. This 2-lane pavement is one-half of a dual highway; consequently, the right-hand lane carries the greater number of vehicles and practically all of the heavy trucks, the left-hand lane being used largely for passing. While it might be argued that the two slabs are tied together at the center joint and thus cannot act independently, still it would be expected that if heavy traffic played an important part in the development of the transverse cracking, some difference in the condition of the two lanes would exist. None has been found.

It will be recalled that in the experimental pavement were four sections each 500 feet in length, in which

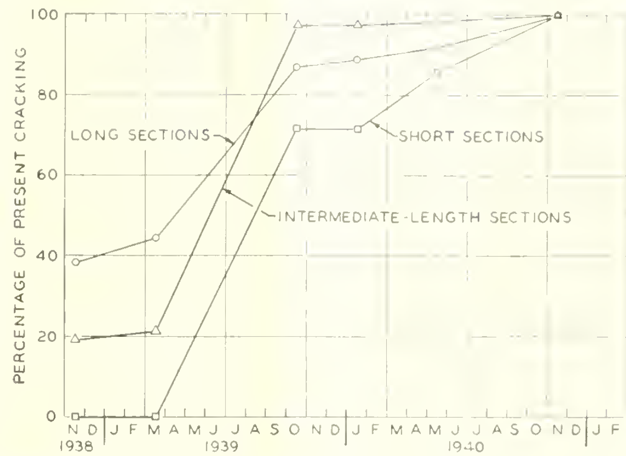


FIGURE 14.—RATE OF CRACK DEVELOPMENT IN PAVEMENT SECTIONS.

contraction or warping joints were placed at 10-foot intervals. Two of these sections contained 45-pound wire fabric; the other two contained 91-pound fabric. The fabric was continuous through the warping joints although the bond was broken for 36 inches. These joints were planes of weakness formed by grooves in the bottom of the pavement in two sections and in the upper surface in the other two sections.

A record was kept of the time at which the cracks appeared over the grooves that had been formed in the bottom of the pavement, and this record is shown in figure 15. It is noted that only two cracks were found at the time of the removal of the burlap and only two more during the remainder of the curing period. The others occurred gradually until by the end of the first year fractures had developed at all of the joints.

Measurements are being made periodically of the changes in width that take place, both at the expansion joints and at the warping joints, in these 500-foot sections. From these measurements certain trends have been observed.

1. The weakened-plane joints near the center of the section open and close slightly with temperature changes but there appears to be no tendency for progressive increase in width.
2. The weakened-plane joints near the ends of the sections show a tendency toward a progressive increase in width. This tendency seems to be greater in the sections with the groove in the lower surface of the pavement than in those that have the grooves in the upper surface.
3. There seems to be a tendency toward a progressive closing of the expansion joints. This tendency is apparently more pronounced in the sections containing the lighter reinforcement.

The changes in length of each of the four 500-foot sections as measured at the ends for the two annual cycles are given in table 6.

The changes in length are not caused entirely by variation in temperature and moisture because, as stated, there has been a slight progressive opening of some of the plane-of-weakness joints. It will be noted in this table that the change in temperature during the first year was smaller than that during the second and that there is a difference in the length changes of the same general order. Using the coefficient of 0.000004, as explained earlier, the observed changes in length of these 500-foot sections indicate that a certain amount

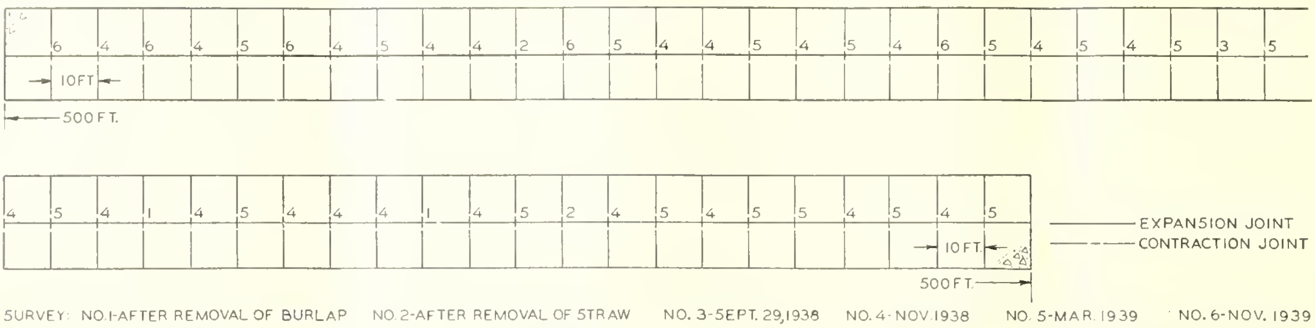


FIGURE 15.—PROGRESSIVE CRACKING OF SUBMERGED PLANE-OF-WEAKNESS CONTRACTION JOINTS; SECTION PLACED SEPTEMBER 8, 1938.

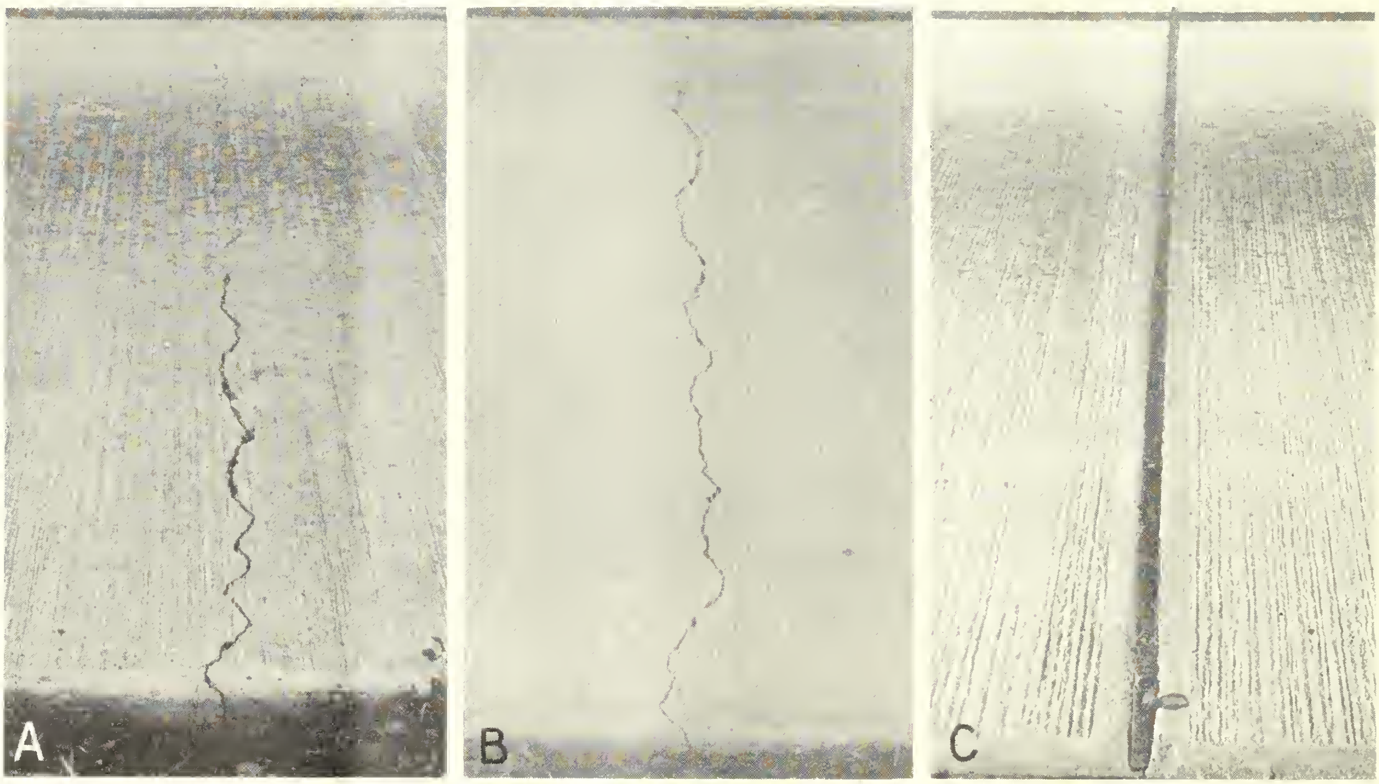


FIGURE 16.—A, TYPICAL CRACK OVER SUBMERGED PARTING STRIP IN LANE CARRYING HEAVY TRAFFIC; B, TYPICAL CRACK OVER SUBMERGED PARTING STRIP IN LANE CARRYING LIGHT TRAFFIC; C, PRESENT CONDITION OF TYPICAL WEAKENED-PLANE JOINT WITH SURFACE GROOVE.

of restraint was present during expansion and contraction.

Figure 16 shows the appearance of cracks over the submerged grooves in the right-hand and the left-hand lanes. These cracks have opened slightly and the edges have become slightly rounded. This condition is more noticeable in the right-hand lane.

Those weakened-plane joints formed under a groove in the upper surface appear to be in perfect condition at this time. Figure 16-C shows the present condition of one of these joints.

TABLE 6.—*Annual changes in length of 500-foot sections with weakened-plane joints at 10-foot intervals*

Section No.	Weight of reinforcement	Type of weakened-plane joint	Time of observation		Temperature difference	Change in length
			Winter	Summer		
	Lb. per sq.				*°F.*	*Inches*
1	91	Submerged	1938–1939	1939	60	1.10
			1939–1940	1940	84	1.47
2	45	do	1938–1939	1939	60	1.33
			1939–1940	1940	84	1.41
3	91	Surface	1938–1939	1939	60	.74
			1939–1940	1940	84	1.23
4	45	do	1938–1939	1939	60	.83
			1939–1940	1940	84	1.05

SURFACE ROUGHNESS OF THE SECTIONS COMPARED

Recently a new instrument for indicating the relative roughness of road surfaces has been developed by the Public Roads Administration. The roughness of the surface is indicated by an index expressed in inches per mile of pavement length. With this apparatus it is possible to compare the surface roughness of sections of various lengths. The device was described in the February 1941 issue of PUBLIC ROADS.

The relative roughness index of the heavily traveled lane as determined during August 1940 for the various

(*Continued on p. 65*)

THE APPLICATION OF ROAD-USE SURVEY METHODS IN TRAFFIC ORIGIN AND DESTINATION ANALYSIS

BY THE DIVISION OF CONTROL, PUBLIC ROADS ADMINISTRATION [1]

Reported by T. M. C. MARTIN, Assistant Highway Engineer-Economist, and HOMER L. BAKER, Assistant Transportation Economist

DATA relative to motor-vehicle travel are in general procured in two ways. The first is that method to which the name "traffic survey" has been applied. The second method is that which has come to be designated by the term "road-use survey."

Traffic surveys embody many ramifications but there is one characteristic which differentiates them from the second method of evaluating motor-vehicle travel. Traffic surveys involve the actual observance of the vehicles at some point of their travel on a given trip, whereas the road-use surveys depend upon interviews with the owners of motor vehicles. In the traffic survey the observance of the vehicle at one or more points in a particular trip may be supplemented by questioning the driver concerning that particular trip. The road-use surveys depend upon interviews with the owners of motor vehicles during which a complete enumeration is made of all or a large part of the travel performed in the vehicles of the interviewed owners throughout a specified period of time, usually 12 months.

Most early traffic studies were made by observing the movement of vehicles past a station located usually at the junction of two or more highways. Traffic surveys have grown in scope and many corollary types of information are now collected. The gathering of some of these data necessitates the stopping of vehicles. This is necessary, for example, where the physical dimensions and weights of commercial vehicles and the nature of the commodities transported are subjects of inquiry. Lately another type of information pertaining to vehicle movement has been found useful in traffic analyses. This information concerns the origin and destination of individual trips by vehicles engaged in both private and commercial transportation, and likewise requires the stopping of traffic. Special origin-and-destination surveys have also been made by most of the States participating in the highway-planning surveys. These studies have usually been localized to a relatively restricted section of highway and have yielded information relating only to the travel of vehicles over the specified section of highway or within a limited area.

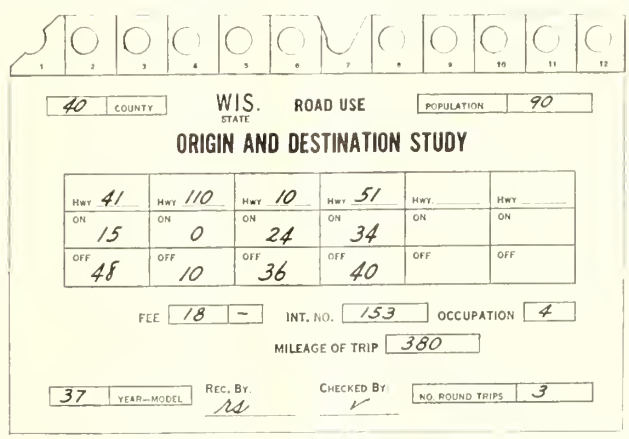
The road-use survey embodies certain features which suggest the possibility of using the data obtained in interviews to make State-wide origin-and-destination travel analyses. Actually, the origins and destinations of as many as possible of the trips made by a selected sample of motor-vehicle owners are determined and recorded in the road-use survey. The road-use survey interview form provided for the recording of a complete description of each type of trip made during the year, including the routes followed, the destinations reached, and the mileage traveled.

One of the earliest attempts to obtain travel data by questioning drivers concerning the number and extent of their trips was made in Wisconsin about 1916 under the direction of A. R. Hirst, State highway engineer. A reference to this work was made in the Third Biennial Report of the Wisconsin Highway Commission, 1916, as follows:

> A careful inquiry (through written question sheets) among automobile owners indicates that the average distance traveled by each automobile is at least 3,500 miles per year on roads outside the limits of incorporated cities and villages. If we estimate 140,000 pleasure cars in use in Wisconsin next year, which seems conservative, and each travels this number of miles, the motor travel on Wisconsin rural highways will be 490,000,000 miles. This does not take into consideration the travel of automobiles from other States.

ROAD-USE SURVEYS HAVE BEEN MADE IN 44 STATES DURING RECENT YEARS

Since 1930, road-use surveys have been made in 44 States, the majority having been conducted between 1936 and 1940. Two methods of obtaining the driver interviews were used in these surveys. The first of these methods employed parties of full-time salaried interviewers; while the second method was based upon the collection of interviews through the public schools. In the latter method, high school pupils were instructed in the procedure used to obtain driver interviews. The usual practice was to have each student obtain an interview based upon the travel of the family automobile and if possible an extra interview from a friend or neighbor. Excellent results were obtained with both methods.


40 COUNTY | WIS. STATE | ROAD USE | POPULATION 90

ORIGIN AND DESTINATION STUDY

HWY 41	HWY 110	HWY 10	HWY 51	HWY	HWY
ON 15	ON 0	ON 24	ON 34	ON	ON
OFF 48	OFF 10	OFF 36	OFF 40	OFF	OFF

FEE 18 – | INT. NO. 153 | OCCUPATION 4

MILEAGE OF TRIP 380

37 YEAR—MODEL | REC. BY. | CHECKED BY | NO. ROUND TRIPS 3

FIGURE 1.—TABULATING CARD USED TO RECORD INDIVIDUAL TRIP DATA.

The results of these surveys have been published by many of the States in complete form while others have used the road-use data in preparing special reports including other related data.

In order to investigate the potentialities of road-use methods for origin-and-destination analyses, a special study was instituted using data collected by the Wis-

[1] Acknowledgment is made to the personnel of the Wisconsin Highway Planning Survey for their cooperation in supplying data for this report.

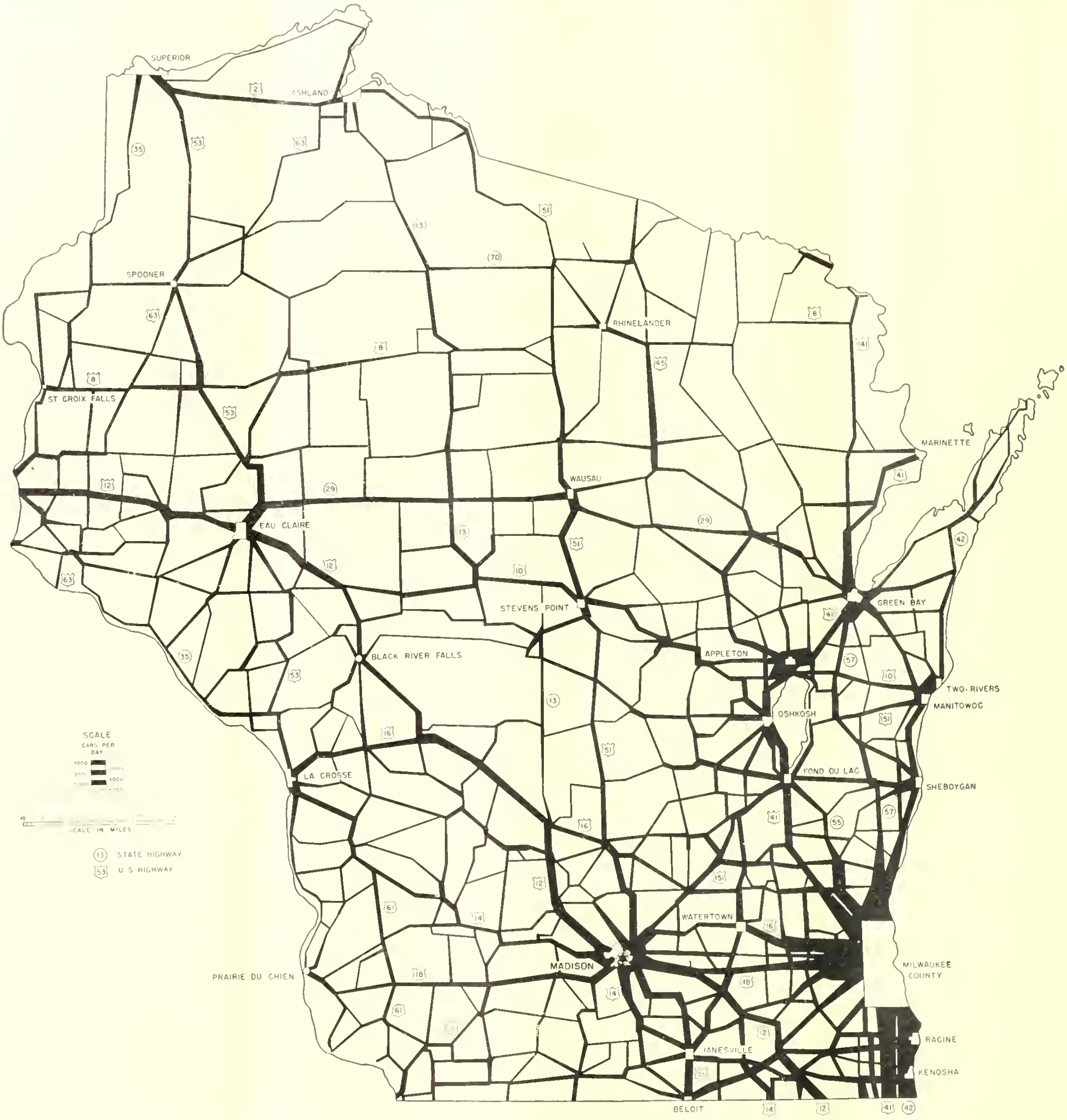


Figure 2.—Average Daily Passenger-Car Traffic on Wisconsin State Trunk Highways.

consin State-Wide Highway Planning Survey in 1936. The scope of this particular inquiry was limited to cover the destination of passenger-car travel performed on State highways by owners resident within the corporate limits of the City of Milwaukee. The analysis was made of only those trips which extended beyond the limits of Milwaukee County. The boundaries of Milwaukee County are slightly outside those of the City on the north, south, and west. On the east the two share Lake Michigan as a common boundary.

The areas contiguous to the city within the county have become generally urban in character, and the travel upon State highways in these areas has assumed many of the characteristics of city travel, including among other attributes a certain amount of indefiniteness. This may be illustrated by the large number of pleasure trips that involve the use of State highway route 100 which in reality is a county belt highway located outside the city but passing entirely around it and connecting all radial routes, both State and local.

By excluding travel within Milwaukee County, it was possible to eliminate virtually all trips that were sparingly described, such as, "Sunday afternoon drive—Doctors' Park, River Hills, Pewaukee, Club Madrid, etc., 40 miles." The trips on the primary system which were tabulated in this study were all definite in the sense that they (1) originated within the City of Mil-

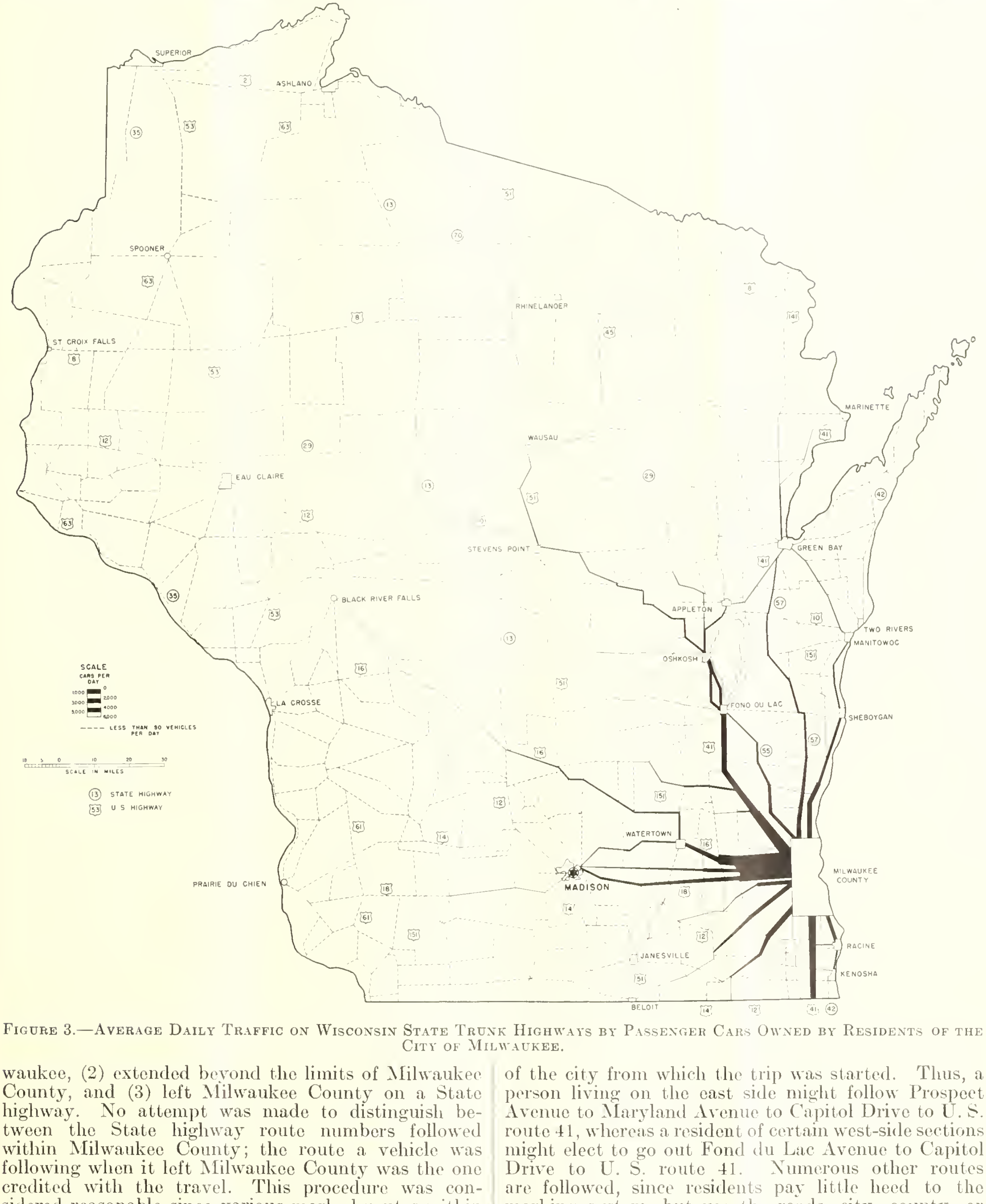


Figure 3.—Average Daily Traffic on Wisconsin State Trunk Highways by Passenger Cars Owned by Residents of the City of Milwaukee.

waukee, (2) extended beyond the limits of Milwaukee County, and (3) left Milwaukee County on a State highway. No attempt was made to distinguish between the State highway route numbers followed within Milwaukee County; the route a vehicle was following when it left Milwaukee County was the one credited with the travel. This procedure was considered reasonable since various marked routes within the City of Milwaukee would be used. The particular streets which could be used by persons traveling from Milwaukee to Fond du Lac on U. S. route 41, for example, would depend largely upon the particular part of the city from which the trip was started. Thus, a person living on the east side might follow Prospect Avenue to Maryland Avenue to Capitol Drive to U. S. route 41, whereas a resident of certain west-side sections might elect to go out Fond du Lac Avenue to Capitol Drive to U. S. route 41. Numerous other routes are followed, since residents pay little heed to the marking system, but use the roads, city, county, or State, which provide the most direct egress from the county.

In order to facilitate the tabulation of the required information from the original road-use forms used in the planning survey, a special tabulating card was designed. This card, which is illustrated in figure 1, provided for a codified recording of the essential data pertaining to each type of trip performed by Milwaukee vehicle owners. A log was prepared of each State highway in Wisconsin, and all junctions of both State and county roads with each State route were numbered to provide a code for the recording of the junctions passed on a given trip. Thus, a trip from Milwaukee to Wausau, Wisconsin, via U. S. route 41 to Oshkosh, thence U. S. route 110 to Fremont, thence U. S. route 10 to Stevens Point and U. S. route 51 to destination would be recorded as shown in figure 1. Since the junctions were numbered starting from the south and east, this would mean merely that Milwaukee was the 15th junction on U. S. route 41, Oshkosh the 48th junction on U. S. route 41 and the zero junction on U. S. route 110, Fremont the 10th junction on U. S. route 110 and the 24th on U. S. route 10, Stevens Point was the 36th junction on U. S. route 10 and the 34th on U. S. route 51, while Wausau was the 40th junction on U. S. route 51.

ANALYSIS INDICATES EXTENSIVE USE OF ALL STATE ROUTES BY MILWAUKEE RESIDENTS

The recording of information regarding route junctions in this manner greatly facilitated the operations necessary in making trip origin-and-destination analyses. All that was required following the recording of trip information on these cards was an orderly sorting and tabulating procedure whereby the number of trips performed over various sections of the State highway system could be ascertained. In this particular analysis, only the travel on the State system was the subject of inquiry and consequently the "destination" was the point at which the route followed departed from the State highway system either to city streets or to local rural roads.

The Milwaukee road-use survey included in its passenger-car sample reports from 2,387 vehicles. The total number of passenger vehicles registered in the city at the corresponding period was 113,342. The method of expanding the trip information obtained from the sample involved the application of the following formula:

$$\text{Number of trips (from sample)} \times \frac{\text{total passenger car registration}}{\text{passenger cars in sample}} = \text{estimated total trips for complete passenger-car registration.}$$

Two maps have been prepared to illustrate the data obtainable from this type of analysis. The first map, figure 2, is based upon the regular traffic volume studies conducted by the Wisconsin highway-planning survey. The map shown in figure 3 was prepared from trip-destination data from the special road-use tabular cards described above. The first map represents the use of Wisconsin State highways by all passenger cars, both of Wisconsin and foreign registration, and without regard to their owners' residential classification. The second map represents the travel upon the same State highways by passenger cars having Wisconsin registration and owned by residents of the City of Milwaukee.

Many of the roads shown in the second map carried less traffic than could be accurately shown at a scale in keeping with permissible over-all dimensions. It was necessary to distinguish, therefore, the point at which the traffic became so small that the width of the line prevented accurate graphical representation. This was taken to be a volume of 50 cars per 24 hours. Consequently, the dotted lines represent average annual 24-hour traffic of less than 50 passenger cars.

These maps illustrate the extensive use of the State highway system and emphasize the intensive use of those roads lying within a comparatively short distance of Milwaukee. The extensive use of the entire primary system by residents of Milwaukee indicates the widespread distribution of points of interest for trips originating in Milwaukee. The location of many urban centers of varying importance to Milwaukee residents within a radius of 85 miles tends to make the highways within that distance of more importance to Milwaukee drivers than those highways which lie at greater distances from the city. Cities of major importance to Milwaukee drivers which lie near the extremities of this 85-mile radius are Chicago, on U. S. route 41, Madison, on U. S. route 18, and Oshkosh on U. S. route 41. Figure 3 indicates that Milwaukee drivers make extensive use of these routes to reach these cities.

While travel to these larger cities accounts for a large proportion of the total use of the primary system, the number of trips to these places is far exceeded by the number of trips to points relatively close to Milwaukee. Figure 4, which is an enlargement of the area lying within a 50 mile radius of Milwaukee and based on figure 3, illustrates the intensive use of the State highways within a 30-mile radius of the City and the rapid decrease in the volume of Milwaukee passenger cars using these highways at points more than 30 miles from the City.

Figure 5, is an enlargement of the area lying within a 50-mile radius of Milwaukee, and is based upon the total passenger-car traffic on State trunk highways.

STUDY INDICATES THAT LARGE PROPORTION OF ANNUAL TRAVEL CONSISTS OF RELATIVELY SHORT TRIPS

Several recreational areas within a 40-mile radius of Milwaukee are visited frequently by residents of that city. The proximity of numerous lakes is an important factor in the use of rural highways in the vicinity of Milwaukee. Many Milwaukee residents have established summer homes in this lake region, which lies within 30 miles of the city. A large proportion of travel to nearby points is occasioned by trips to these summer residences and by evening and week-end trips to resorts. The influence of these factors is illustrated by the rapid decline in the amount of traffic on the principal routes at points 20 to 30 miles from the city. These factors exert the greatest influence on travel on routes leading to the area lying west and southwest of Milwaukee.

Travel to Chicago by Milwaukee residents probably accounts for the relatively uniform use of U. S. route 41 from Milwaukee to the State line. Similarly, this same route leading to Fond du Lac and Oshkosh north of Milwaukee does not show a rapid decline in the volume of traffic at points close to the city. This is the principal route leading to these important cities and it also carries a large volume of traffic to the recreational areas in the northern lake region.

Figure 3 presents a reasonably accurate picture of the use of the State primary system by Milwaukee residents. A comparison of this map with figure 2

(Continued on p. 66)

METHOD OF COMPUTING THE INTERSECTION OF A LINE WITH A SPIRAL AND ANY CURVES PARALLEL TO THE SPIRAL

Reported by M. C. KOEHLER, Senior Engineer Inspector Foreman, District 1, Public Roads Administration

SINCE the adoption of the spiral or easement curve in highway design and construction, the problem of computing the intersection of a line with such a curve, and its parallel right-of-way lines, has persistently presented itself in the computation of property line ties preparatory to the preparation of right-of-way descriptions. Various approximate methods have been proposed from time to time, but like all approximate methods are unsatisfactory if an exact solution is possible.

Although the solution presented in the following paragraphs is not exact in a strictly theoretical concept, it is an exact solution from a practical standpoint since the results are within the limits of measurement possible with standard engineering instruments.

In figure 1, assume CA to be a property line intersecting a talbot spiral BD, the intersection occurring at point A. The solution is then of triangle ABC of which the following is known:

Distance CB which has been determined by the coordinates shown or 776.68 feet.

Angle α which is determined from the bearings of line CA and CB or 7°09.5′.

Now scale chord BA attempting to choose the length to the nearest foot just short of the exact length. In this case try 228 feet.

Since the chord length has been assumed, and knowing the characterstics of the spiral shown in figure 1, now compute angle ϕ which is 25°03.3′.

By the law of sines:

$$BA=\frac{776.68\times \sin 7°09.5'}{\sin 25°03.3'}=228.55>228.$$

Now try the chord 229 feet.

$$BA=\frac{776.68\times \sin 7°09.5'}{\sin 25°03.9'}=228.47<229.$$

These results are shown in table 1, together with values found for chords 227 and 230 feet.

It is thus found that the true chord length is something between 228 and 229 feet and always occurs between the two chords where the difference between the assumed chord and the computed chord changes sign. It should also be noted that even though the assumed chord were scaled several feet from its true value, the computed chord always calculates within a few tenths of the true value, materially reducing the number of trials to be made in isolating the true length within a foot.

TABLE 1.—*Differences between assumed and computed chords*

Assumed chord	Computed chord	Difference
227	228.64	+1.64
228	228.55	+0.55
229	228.47	−0.53
230	228.38	−1.62

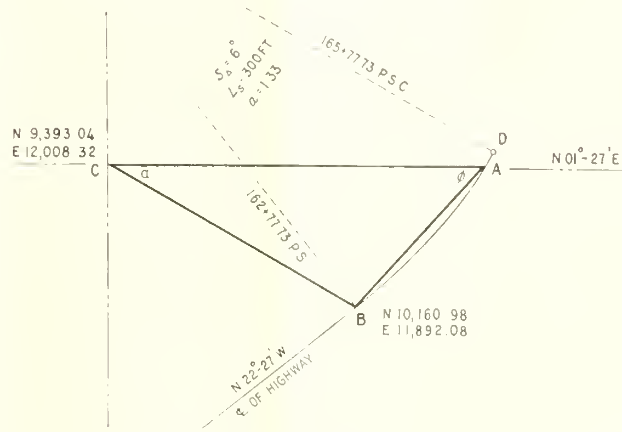


FIGURE 1.—INTERSECTION OF A LINE WITH A SPIRAL CURVE.

By interpolation, it is possible to compute the true chord which will close triangle ABC.

$$228+\frac{0.55}{0.55+0.53}=228.51.$$

Proof:

$$BA=\frac{776.68\times \sin 7°09.5'}{\sin 25°03.6'}=228.51.$$

The further solution of triangle ABC gives:

$$CA=\frac{776.68\times \sin 32°13.1'}{\sin 25°03.6'}=977.61.$$

From any table of spiral data it is found that the arc distance is 0.04 foot longer than the chord 228.51.

Therefore 228.51+0.04=228.55 feet and the station of intersection is:

P. S. 162+77.73+228.55=165+06.28 and bears N 01°27′ E a distance of 977.61 feet from the property corner.

INTERSECTION WITH CURVES PARALLEL TO SPIRAL COMPUTED

In figure 2, assume an inside right-of-way line, always 50 feet from and parallel to the talbot spiral, intersecting the property line at point C. In triangle ABC the distance CB, which is 50 feet, is known.

As before scale chord BA using 103 feet for the first trial.

Now 228.55−103.00=125.55 feet which is assumed to be the chord from the P. S. (point of spiral) to point B. From this chord compute the bearing of the local tangent at point B and then compute the bearing of the normal to this tangent which is CB. Taking the difference in bearings of CB and CA, angle α is found to be 65°03.0′.

By the method of computing the deflection from any point on a spiral to any other point on the spiral, compute the bearing of BA. Taking the difference in bearings between BA and CA angle ϕ is found to be 26°03.0′.

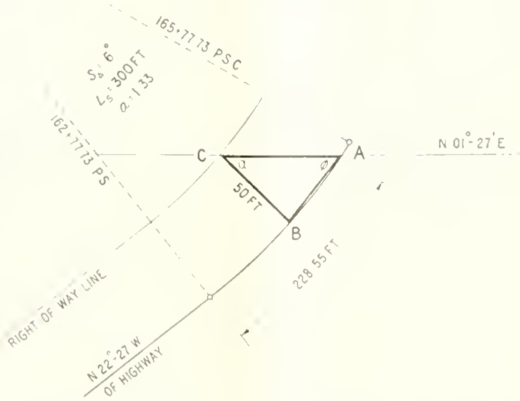


FIGURE 2.—INTERSECTION OF A LINE WITH A CURVE INSIDE AND PARALLEL TO A SPIRAL CURVE.

By the law of sines:

$$AB=\frac{50\times \sin 65°03.0'}{\sin 26°03.0'}=103.23>103.$$

Now try the chord 104.

$$AB=\frac{50\times \sin 65°03.5'}{\sin 26°02.7'}=103.26<104.$$

By interpolation the chord which will close triangle ABC is found to be 103.24.

$$\text{Proof:}\quad AB=\frac{50\times \sin 65°03.2'}{\sin 26°02.8'}=103.24.$$

The further solution of triangle ABC gives:

$$CA=\frac{103.24\times \sin 88°54.0'}{\sin 65°03.2'}=113.84.$$

Therefore 977.61−113.84=863.77 feet from the property corner and is 50 feet at right angles from centerline station 164+03.05.

Figure 3 shows the outside right-of-way line which intersects the property line at point D. It is evident that this intersection is not on the parallel spiral but occurs on the parallel simple curve and the solution is by coordinates and triangulation, resulting in the solution of triangle COD by the following method:

Starting with the coordinates of point B compute the coordinates of point E and then point O, which is the center of the simple curve. From the coordinates of point O and C, OC is found to bear N 74°12.2′ W and is 1,317.02 feet long, making angle α 75°39.2′.

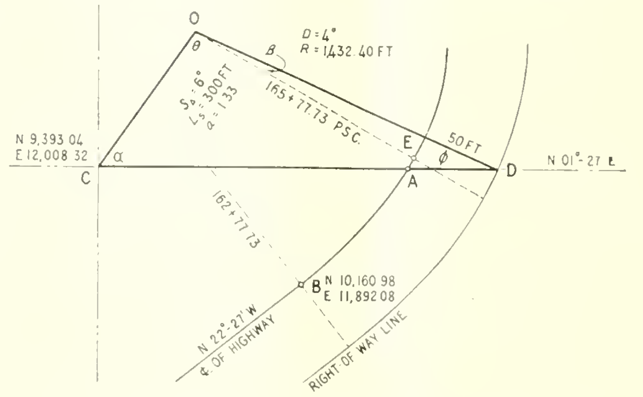


FIGURE 3.—INTERSECTION OF A LINE WITH A CURVE OUTSIDE AND PARALLEL TO A SPIRAL CURVE.

Side OD is equal to the radius of the simple curve (1,432.40) plus 50 feet or 1,482.40 feet, and by the law of sines angle ϕ is 59°23.9′ and angle θ is 44°56.9′.

$$\text{Therefore } CD=\frac{\sin 44°56.9'\times 1317.02}{\sin 59°23.9'}=1{,}080.98 \text{ feet}$$

which is the distance from the property corner C to point D on the right-of-way line. From the bearings of OE and OG angle β is found to be 0°42.1′ which subtends 17.54 feet on the arc of the 4° simple curve and point D is 50 feet at right angles from centerline station 165+95.27.

In these computations it will be noted that all angles have been carried out to tenths of a minute. This has been found necessary to make all lineal distances calculate to the nearest one hundredth of a foot.

There are many other combinations of property lines intersecting spirals which are not presented in the above problem, but all are solvable by the method outlined. One point should be borne in mind; always choose a triangle in such a manner that one side is a chord of the centerline spiral, since the characteristics of that curve are known. Distances and angles may be computed to any point on the parallel spiral, but the exact characteristics of the parallel spiral itself are still open to solution.

NATURAL-COLOR SLIDES OF MERRITT PARKWAY AVAILABLE

A film book composed of natural-color slides of aerial pictures and script covering the story of the Merritt Parkway, including its connection down to New York through the West Side Highway, has recently been completed. Prepared by the Yale University Bureau for Street Traffic Research in cooperation with the Connecticut Highway Department, the film book is called "Roads Leading North."

In addition to the 84 2- by 2-inch slides with accompanying script, there is a technical trailer consisting of over 20 slides and script dealing with enginering detail, accident experience, and the volume and speed of vehicles. The slides may be shown on any 2- by 2-inch projector.

"Roads Leading North" is available on loan without charge other than transportation from and to Yale University or nearby depository, to any highway department, highway commission, traffic engineering department, or similar organization dealing with highway problems. Requests for the film book should be addressed to: Bryant Burkhard, Yale Bureau for Street Traffic Research, Strathcona Hall, Yale University, New Haven, Conn.

(Continued from p. 58)

sections of the experimental reinforced pavement is shown in figure 17, plotted with respect to section length. The pavement at this time was nearly 2 years old. It will be noted that in this graph different symbols are used to distinguish between sections reinforced with the different types of steel. A study of this figure indicates that:

1. The pavement as a whole is smooth (with this apparatus, index values of the order of 80 to 120 represent smooth surfaces, 200 and above indicate rough surfaces).
2. The different types and weights of reinforcement have had no noticeable influence on the relative roughness of the various sections.
3. With modern methods of construction and proper care, the number or spacing of joints in a concrete pavement apparently need not affect its surface roughness.

The roughness index for the four special sections with weakened-plane joints at 10-foot intervals is shown on the graph as a section length of 500 feet (the distance between expansion joints). Two points are shown, one for the two sections with submerged joints and one for the two with surface joints. These sections appear to be no rougher than sections of equal length having no intermediate joints. In fact, their surface roughness appears to be about the average for the experimental pavement as a whole.

It should be pointed out that any effect of the design of the various sections on their smoothness will probably become more evident as time passes. The data presented in figure 17 are intended to furnish a basis for future comparisons.

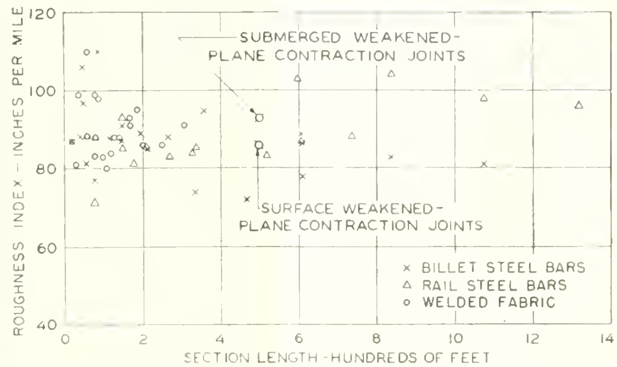


Figure 17.—Relative Roughness of Various Sections of Pavement.

SUMMARY

In the course of this progress report the data that have been obtained in the several detailed surveys made during the 2 years of service life of the experimental pavement have been presented and discussed and certain trends have been pointed out.

It has been shown that in the long, heavily reinforced sections many fine transverse cracks have developed in the central area. Frequently, these cracks are no more than 2 feet apart. At all times and in all cases the cracks have remained tightly closed and no spalling, raveling, or disintegration has yet appeared at any of them.

In the sections of intermediate length containing the ½-inch diameter bars a moderate amount of transverse cracking has developed in the longer sections, and but relatively little has developed in the shorter sections. In this group of sections the cracks are open slightly more than those in the sections containing the ¾-inch and 1-inch diameter bars, but there is as yet no sign of spalling, raveling, disintegration, or of inelastic deformation of the steel.

Only a limited amount of transverse cracking has occurred in the sections containing the welded wire fabric. The cracks that are present are open slightly more than those in the more heavily reinforced sections but here also no evidence of spalling, raveling, disintegration, or structural weakness has been found.

There appears to be a relationship between the length of the section as constructed and the average slab length (or distance between transverse cracks). So far there appears to be no relation between the average slab length and either the type or the amount of longitudinal steel.

The amount of change in elevation observed from season to season has been small (less than 1 inch) and has not been uniform. There is nothing to indicate that it has affected the structural integrity of the various sections.

In the four special 500-foot sections containing 10-foot slabs separated by plane-of-weakness joints, the sections as a whole are in excellent condition. The joints in which the surface groove was used are apparently perfect; those formed by a submerged parting strip have opened and raveled slightly.

Relative roughness determinations over the experimental pavement show that the surfaces of the sections were very smooth after about 18 months of service. The sections containing planes of weakness at 10-foot intervals were as smooth as those in which the joints were 1,000 feet or more apart.

(Continued from p. 62)

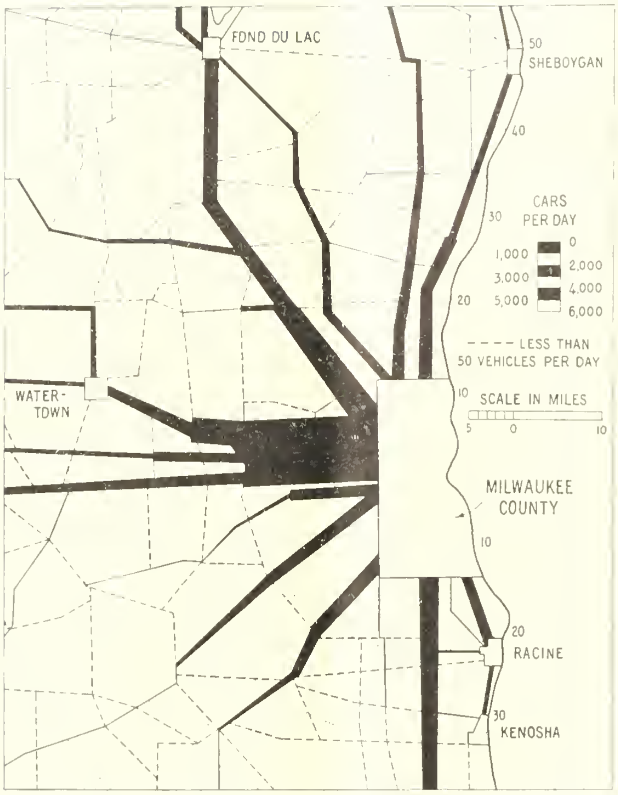


FIGURE 4.—AVERAGE DAILY TRAFFIC ON WISCONSIN STATE TRUNK HIGHWAYS IN THE VICINITY OF MILWAUKEE BY PASSENGER CARS OWNED BY RESIDENTS OF THAT CITY.

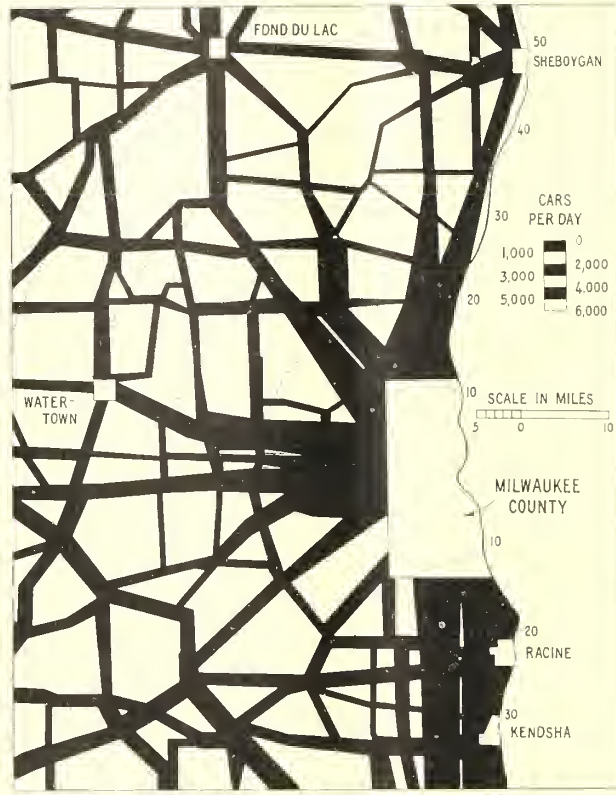


FIGURE 5.—AVERAGE DAILY PASSENGER-CAR TRAFFIC ON WISCONSIN STATE TRUNK HIGHWAYS IN THE VICINITY OF MILWAUKEE.

indicates the importance of the travel of Milwaukee residents in relation to the total travel upon the State system. The assembly of similar origin-and-destination data for all travel on the primary system on a State-wide basis would be valuable in highway administration. A study of this type would not, however, replace the special origin-and-destination studies which are necessary whenever a construction program is under consideration.

A State-wide survey made by road-use survey procedures should be looked upon as an adjunct to the special origin-and-destination study. This method would provide a qualitative approach to the problem and, if it were found desirable to obtain quantitative data, a special study could be made. The chief advantage of the State-wide method is in its comparative economy, for it is doubtful if so large a volume of useful data on travel habits could be assembled as economically in any other way. The development and use on a State-wide basis of such methods should result in a more efficient expenditure of funds for special studies since they could be planned and operated more efficiently if fairly accurate preliminary data were readily available.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF APRIL 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 4,103,569	$ 1,939,044	101.8	$ 5,467,643	$ 2,721,955	198.4	$ 2,281,660	$ 1,131,100	76.5	$ 2,537,658
Arizona	1,266,146	880,844	53.6	2,016,544	1,341,439	86.6	375,679	249,349	8.2	1,608,838
Arkansas	5,130,207	2,347,985	130.2	1,360,465	678,588	53.6	464,290	231,807	31.9	1,496,610
California	7,166,538	3,603,909	133.6	8,163,882	4,379,995	125.0	1,965,747	1,026,876	29.6	3,757,957
Colorado	2,241,641	1,209,449	189.1	2,640,143	1,529,636	115.1	694,436	387,979	69.1	2,992,414
Connecticut	1,936,006	938,685	16.2	1,585,521	770,582	16.9	454,236	223,220	7.0	1,252,523
Delaware	1,927,922	963,182	30.5	276,173	137,936	2.1	658,560	296,100	24.3	1,207,996
Florida	2,851,020	1,417,163	67.9	1,678,863	860,220	67.2	600,927	300,463	12.9	3,587,269
Georgia	3,413,741	1,652,691	199.5	6,959,190	3,489,845	277.9	1,742,340	871,170	84.0	6,859,825
Idaho	1,558,471	918,204	151.0	1,441,228	888,118	64.7	313,789	187,620	11.4	2,171,468
Illinois	6,613,731	3,229,261	152.0	7,897,176	3,949,173	163.7	3,004,000	1,502,000	63.1	4,648,827
Indiana	5,428,900	2,655,476	124.8	7,748,568	3,768,143	120.3	1,642,464	627,428	27.3	2,217,941
Iowa	5,643,387	2,660,020	198.2	4,435,973	1,944,641	145.6	1,620,134	773,850	91.2	1,933,064
Kansas	5,089,827	2,470,023	457.9	5,370,842	2,727,088	268.0	2,388,402	1,182,168	143.6	4,952,806
Kentucky	3,068,125	1,524,477	91.1	3,659,951	1,840,655	112.4	3,478,566	1,609,840	96.2	2,710,183
Louisiana	11,220,869	2,653,883	21.5	2,840,049	1,420,003	65.6	1,462,134	722,646	45.9	3,872,361
Maine	1,298,981	633,369	29.2	1,599,027	821,653	21.0	26,700	11,100	.6	1,044,618
Maryland	1,270,568	623,817	29.1	3,671,262	1,834,513	29.9	30,000	15,000		1,874,340
Massachusetts	1,835,469	914,827	22.9	2,237,791	1,140,056	13.1	2,101,000	1,049,310	18.8	3,256,329
Michigan	6,148,061	2,834,997	215.0	9,089,320	4,532,060	218.0	1,190,000	595,000	14.2	2,435,438
Minnesota	5,986,527	2,890,482	459.2	4,876,986	2,428,672	278.4	3,716,277	1,856,842	205.0	3,837,518
Mississippi	3,185,667	1,389,993	134.7	7,440,174	3,499,597	411.8	1,402,808	678,654	89.7	1,808,366
Missouri	3,489,129	1,724,918	172.4	10,305,349	4,769,948	254.0	5,854,280	2,168,349	161.9	3,943,064
Montana	4,123,613	2,334,341	283.4	3,298,550	1,863,176	172.7	466,981	254,505	16.5	4,439,774
Nebraska	4,724,995	2,215,968	551.5	4,438,469	2,239,272	470.7	2,910,575	1,455,287	304.7	2,963,205
Nevada	1,561,286	1,322,070	76.6	1,469,765	1,279,599	73.2	666,810	524,456	23.4	1,144,456
New Hampshire	1,420,775	698,400	36.4	416,295	206,110	9.0	682,767	338,757	9.1	1,086,039
New Jersey	2,277,954	1,117,617	11.8	6,832,152	3,415,996	52.2	8,930	4,465		1,750,582
New Mexico	2,770,691	1,704,134	207.6	1,288,486	786,870	59.6	117,614	76,049	17.8	2,172,283
New York	11,454,784	5,529,723	199.0	11,652,445	5,797,487	147.1	379,305	158,800	5.9	5,006,110
North Carolina	4,356,736	2,175,743	233.1	5,427,752	2,699,750	231.6	752,782	364,345	26.6	2,948,948
North Dakota	1,838,668	977,429	191.9	2,909,164	1,667,024	242.1	2,711,860	1,373,768	213.0	4,398,366
Ohio	7,194,741	3,596,155	93.1	13,162,955	6,554,256	108.7	6,406,928	3,058,150	47.7	3,832,067
Oklahoma	3,168,398	1,675,105	141.9	2,834,704	1,459,696	87.7	2,460,560	1,265,812	107.2	4,987,628
Oregon	3,359,560	2,007,681	157.6	2,968,880	1,616,886	86.5	1,502,916	816,910	34.4	1,253,892
Pennsylvania	6,217,994	3,061,207	80.7	13,414,867	6,657,939	110.2	4,016,861	1,881,393	41.6	3,800,676
Rhode Island	1,313,964	642,140	13.3	928,546	463,642	7.9	224,982	112,485	2.6	1,148,877
South Carolina	2,124,454	1,025,792	162.5	3,612,057	1,700,065	143.5	1,269,792	352,008	42.9	2,341,294
South Dakota	3,110,156	1,757,293	530.3	4,099,013	2,560,373	504.8	1,378,170	807,120	210.8	3,115,069
Tennessee	2,904,745	1,437,397	65.7	3,960,674	1,980,337	138.8	2,747,316	1,373,441	34.6	3,909,075
Texas	8,505,414	4,116,472	494.3	13,671,982	6,761,799	582.6	3,032,920	1,377,895	164.8	7,556,305
Utah	995,824	707,521	73.1	1,203,655	892,909	47.9	766,825	442,801	13.0	1,320,975
Vermont	1,181,139	560,724	36.6	1,219,127	615,702	32.7	49,101	24,550	.8	569,561
Virginia	2,947,748	1,387,772	73.9	3,997,368	1,884,260	73.1	893,501	391,495	13.7	2,421,500
Washington	4,338,626	2,229,972	91.3	2,019,928	1,078,949	23.3	522,818	276,815	4.6	1,645,391
West Virginia	2,205,010	1,095,169	76.4	4,072,160	2,029,598	79.8	202,850	101,358	1.4	1,891,416
Wisconsin	5,192,364	2,549,927	182.5	2,674,043	1,325,338	98.8	1,573,625	746,330	54.5	4,778,472
Wyoming	1,802,292	1,106,448	196.2	1,579,199	1,029,406	161.7	521,848	312,290	39.3	1,252,671
District of Columbia	498,667	249,021	5.1	828,211	413,509	2.6	281,531	135,481	1.1	420,250
Hawaii	236,412	115,318	4.1	590,134	314,078	7.8	138,944	69,472	2.5	1,954,355
Puerto Rico	519,644	257,240	10.9	1,567,632	773,930	22.7	217,350	107,320	2.1	931,649
TOTALS	184,221,156	89,730,478	7,462.2	218,900,333	111,542,472	6,888.6	74,374,891	35,901,489	2,749.0	141,048,899

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF APRIL 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 190,944	$ 95,263	9.3	$ 1,333,057	$ 667,758	60.8				$ 628,354
Arizona	240,851	169,480	23.6	202,398	149,241	5.3				396,754
Arkansas	416,160	179,101	14.8	460,066	229,180	32.8				309,298
California	953,657	512,724	38.2	1,049,656	750,475	13.4	$ 595,573	$ 315,639	14.9	550,009
Colorado	276,356	154,558	9.8	179,854	100,942	26.7				342,799
Connecticut	370,531	179,413	4.6	298,035	136,331	6.1				187,829
Delaware	127,253	55,914	12.7	46,219	22,675	2.9	258,290	118,835	12.3	232,397
Florida	63,276	31,230	1.6	1,039,527	519,314	18.7	85,045	42,523	.2	285,907
Georgia	260,943	129,353	24.4	948,290	512,895	70.4	346,524	173,262	34.2	1,187,165
Idaho	154,346	91,644	24.0	300,535	141,337	13.8				289,389
Illinois	1,746,582	821,040	80.6	1,158,850	564,425	46.3	610,290	284,050	35.1	556,282
Indiana	470,654	223,984	31.0	286,764	148,839	15.9	801,010	400,435	37.4	884,199
Iowa	2,403,069	1,141,236	524.6	678,813	317,385	194.0	60,708	28,850	23.1	499,687
Kansas	395,077	196,627	50.2	846,651	430,896	45.6	665,965	334,483	74.9	1,319,560
Kentucky	799,718	268,935	65.5	762,283	214,927	26.7	491,720	137,761	38.0	444,637
Louisiana	105,321	52,661	10.9	192,608	96,249	14.9				718,901
Maine	303,854	139,080	17.0	40,606	20,303	1.5				161,212
Maryland	128,300	64,150	5.5	242,390	121,195	10.6	213,000	96,000	8.9	381,665
Massachusetts	456,347	225,862	10.3	244,546	138,203	3.6	139,610	69,185	4.4	609,968
Michigan	1,582,553	742,776	128.6	732,660	366,330	27.9	411,300	205,650	44.4	686,625
Minnesota	799,202	387,394	122.5	946,992	473,496	114.9	598,120	267,049	72.5	945,695
Mississippi	270,229	133,851	12.5	789,152	395,926	42.1	353,700	165,315	19.2	651,872
Missouri	763,578	377,428	103.9	139,850	68,817	11.9	649,898	270,071	62.6	966,184
Montana	641,506	362,577	80.3	369,820	209,264	46.1	303,929	150,908	49.5	688,794
Nebraska	747,748	354,714	119.3	402,486	206,521	47.9	305,015	152,156	34.3	428,320
Nevada	202,910	164,689	40.9	178,899	155,725	14.3	108,993	94,713	9.7	142,425
New Hampshire	143,639	68,883	3.4	71,533	34,946	3.6	85,410	42,457	1.1	180,822
New Jersey	386,996	191,060	15.3	336,342	187,135	7.4	340,610	170,305	6.1	496,989
New Mexico	439,327	222,320	25.8	386,059	229,667	19.7	16,312	10,074	2.2	316,144
New York	2,022,102	951,565	67.9	1,571,934	788,441	40.5				817,940
North Carolina	1,001,434	498,422	89.4	370,113	187,668	35.4	281,884	123,225	22.6	487,649
North Dakota	80,071	42,652	.3	136,016	74,496	3.5				1,276,906
Ohio	1,710,388	848,861	59.9	1,872,630	983,510	53.7	283,920	141,960	12.5	1,131,333
Oklahoma	795,576	416,089	57.1	301,276	159,134	14.8	385,480	203,548	38.4	1,021,808
Oregon	371,724	205,456	56.4	348,981	172,086	26.6	257,504	126,050	21.8	327,926
Pennsylvania	1,728,851	846,811	59.8	747,296	373,648	13.4	1,626,098	782,319	34.2	167,279
Rhode Island	262,488	120,687	3.6	93,806	50,516	.9	142,588	71,080	1.6	53,344
South Carolina	635,993	238,916	90.4	422,540	139,540	26.1	606,517	248,108	35.9	168,691
South Dakota	3,714	3,624		25,302	15,768	9.0	9,240	5,190	6.2	1,537,944
Tennessee	150,805	71,863	8.7	287,466	143,733	10.0	779,488	389,744	25.4	846,273
Texas	1,471,227	720,149	198.4	1,139,186	564,340	103.1	276,630	125,480	39.1	1,535,654
Utah	154,224	91,100	18.3	272,630	163,121	22.9	62,304	31,611	2.5	209,119
Vermont	334,397	116,366	13.5	193,984	56,234	7.6				89,704
Virginia	498,464	236,677	25.2	438,068	200,991	19.4				516,836
Washington	631,616	320,705	31.0	350,274	218,628	25.6	156,583	70,600	2.4	261,448
West Virginia	335,788	166,996	18.5	90,300	45,150	2.4	233,650	116,825	7.8	506,470
Wisconsin	328,957	163,259	7.4	868,937	441,443	28.0	585,173	253,672	27.6	684,741
Wyoming	432,361	260,037	42.8	369,790	159,928	18.8				218,112
District of Columbia	112,164	56,082	1.4	2,192	1,096		62,564	24,737	.6	91,208
Hawaii	264,732	132,578	8.6	1,096	1,096					250,559
Puerto Rico	143,800	70,400	6.4	213,613	104,380	9.7	76,932	37,455	3.1	129,952
TOTALS	29,311,803	14,317,242	2,476.1	24,782,371	12,655,394	1,417.2	13,267,577	6,281,325	866.7	27,820,778

U. S. GOVERNMENT PRINTING OFFICE: 1941

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . Case Histories of Fatal Highway Accidents. 10 cents.

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No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP . . Construction of Private Driveways. 10 cents.

No. 279MP . . Bibliography on Highway Lighting. 5 cents.

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The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

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DEPARTMENT BULLETINS

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MISCELLANEOUS PUBLICATIONS

No. 296MP . . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF APRIL 30, 1941

STATE	Completed During Current Fiscal Year: Estimated Total Cost	Completed: Federal Aid	Completed: Number — Grade Crossings Eliminated by Separation or Relocation	Completed: Number — Grade Crossing Structures Reconstructed	Completed: Number — Grade Crossings Protected by Signals or Otherwise	Under Construction: Estimated Total Cost	Under Construction: Federal Aid	Under Construction: Number — Grade Crossings Eliminated by Separation or Relocation	Under Construction: Number — Grade Crossing Structures Reconstructed	Under Construction: Number — Grade Crossings Protected by Signals or Otherwise	Approved for Construction: Estimated Total Cost	Approved for Construction: Federal Aid	Approved for Construction: Number — Grade Crossings Eliminated by Separation or Relocation	Approved for Construction: Number — Grade Crossing Structures Reconstructed	Approved for Construction: Number — Grade Crossings Protected by Signals or Otherwise	Balance of Funds Available for Programmed Projects
Alabama	$ 282,122	$ 282,039	4		5	$ 652,503	$ 632,450	5	1	3	$ 95,990	$ 95,990	2		7	$ 1,066,905
Arizona	203,065	195,699	3		2	339,710	339,362	2			29,350	29,350		1	2	206,818
Arkansas	701,648	699,956	7	1	14	951,048	947,106	9		1	147,844	147,789	1		2	349,302
California	461,045	458,655	4		11	1,019,517	838,918	7	1		700,711	700,711	2		15	1,467,134
Colorado	7,698	7,698			3	414,112	414,112	2			374,981	374,981	3		1	665,832
Connecticut	622,002	611,366	5	1		166,222	165,415	2			55,869	54,784		1		563,322
Delaware	108,682	108,682	4		17	94,135	94,135	1			4,380	4,380			1	555,841
Florida	221,540	217,042	2		4	225,190	223,676	3	1	1	293,834	293,834	1		27	1,222,179
Georgia	257,207	255,447	5	2	13	1,242,104	1,242,104	10	7	2	94,197	94,197		1	6	2,093,193
Idaho	286,450	283,021	5		32	17,981	17,981			1	111,151	111,151	1		4	470,937
Illinois	1,800,577	1,723,632	10		76	1,503,859	1,283,089	5	1	72	435,533	413,507	3		37	2,415,442
Indiana	710,535	702,420	3	2	83	1,006,391	979,591	8	1	10	78,205	60,009			24	994,278
Iowa	524,629	498,666	4		96	461,844	448,810	6	2	3	551,382	549,640	3		30	852,840
Kansas	771,850	765,622	10		18	617,231	617,231	10	2	2	98,301	98,301	3		6	1,276,947
Kentucky	575,873	574,001	8		11	982,133	982,133	9		1	271,942	226,103	4		1	379,372
Louisiana	100,158	100,158	1			535,658	482,163	6			604,443	546,718	5		3	965,731
Maine	159,988	159,070	1	1	6	132,646	132,646	1	1							393,580
Maryland	183,547	183,543	1		3	482,459	450,666	2	2	6	60,550	60,550			12	920,364
Massachusetts	16,588	16,588		1		426,750	416,111	2			112,050	111,130	1			2,213,796
Michigan	1,170,876	1,116,186	8	1	39	1,440,835	1,440,835	2	5	1	422,650	422,650	2		4	862,164
Minnesota	1,447,977	1,436,701	12	2	20	1,057,558	1,057,558	8	5		219,210	219,210		2	2	1,052,684
Mississippi	263,360	263,360	3	1	1	674,834	674,834	9			74,999	74,999	1	1	9	747,725
Missouri	1,206,786	1,206,785	6	4	1	1,890,768	1,389,321	5	3		156,492	126,400	1			1,363,177
Montana	434,356	434,356	5		4	88,047	88,046	1			103,112	103,112	1		3	508,581
Nebraska	435,090	432,596	3	1	13	896,294	896,294	15	1	2	83,378	83,378	1		20	479,243
Nevada	72,617	72,617	1		20	70,501	70,501	1			121,412	121,412	3		5	104,964
New Hampshire	104,313	104,277	3		1	146,134	145,314	3			2,703	2,703			1	426,747
New Jersey	278,937	278,937	2		4	1,188,458	1,062,908	6	1		63,056	63,056		1	1	1,049,600
New Mexico	242,979	237,896	2		6	183,821	175,247	3			159,441	159,441	1			498,988
New York	1,229,561	1,186,966	7	5	8	3,885,733	3,829,262	7	17		208,090	160,000		1		3,399,087
North Carolina	589,190	589,122	8	3	29	721,274	721,034	6	6	10	236,886	236,886		2	28	1,063,285
North Dakota	417,276	415,284	5		22	468,443	468,443	5		1						844,173
Ohio	1,168,483	1,097,531	7	1	17	2,420,125	2,396,650	12	2		1,892,307	1,835,170	7		1	1,296,024
Oklahoma	653,264	650,890	10	1	52	372,241	368,825	3		5	185,524	185,524	1		38	2,170,164
Oregon	208,639	117,537	3			411,078	345,633	4			8,523	8,523			4	446,147
Pennsylvania	1,387,269	1,377,793	13	2		2,381,629	2,377,801	19			1,892,765	1,774,865	6			2,472,159
Rhode Island	8,222	7,406				206,703	206,703		1							178,256
South Carolina	465,665	465,051	4	3	23	192,164	192,164	3	1	1	271,754	254,154	1	1	31	977,867
South Dakota	136,032	133,406	2	1	4	564,332	563,472	16			176,220	160,270	3		1	945,932
Tennessee	244,480	231,146	2	2		225,803	216,803	1	3		684,903	684,903	4	1		1,434,178
Texas	1,472,823	1,454,812	11	1	9	1,522,470	1,508,690	17			477,600	430,030	4		1	2,138,008
Utah	116,959	116,748			44	58,673	57,931	2		16	140,518	140,518	1		37	236,899
Vermont	122,393	122,154		1	9	137,064	137,064		1	3	16,478	16,478			4	293,090
Virginia	234,842	232,573	2	2	12	764,850	764,630	6	3	1	114,632	80,772	1	1	4	807,771
Washington	362,767	357,785	4	2	10	440,794	440,794	3	3	1	9,250	9,250			3	455,123
West Virginia	119,730	119,730	1		3	530,502	524,882	6			16,830	16,830			6	985,431
Wisconsin	825,078	809,586	6	4	7	553,004	523,781	4		8	585,860	584,731	2	2	43	1,194,263
Wyoming	6,983	6,979			2	560,904	560,904	6								299,298
District of Columbia	56,868	56,868	1			2,193	2,193				284,230	280,270	4			275,206
Hawaii	8,416	8,141			2	194,767	194,759	2			210,515	210,000	2			181,412
Puerto Rico						584,007	579,336	11								302,169
TOTALS	23,487,435	22,984,524	208	45	756	36,107,496	34,690,311	276	71	151	12,940,051	12,418,660	75	15	424	48,563,628

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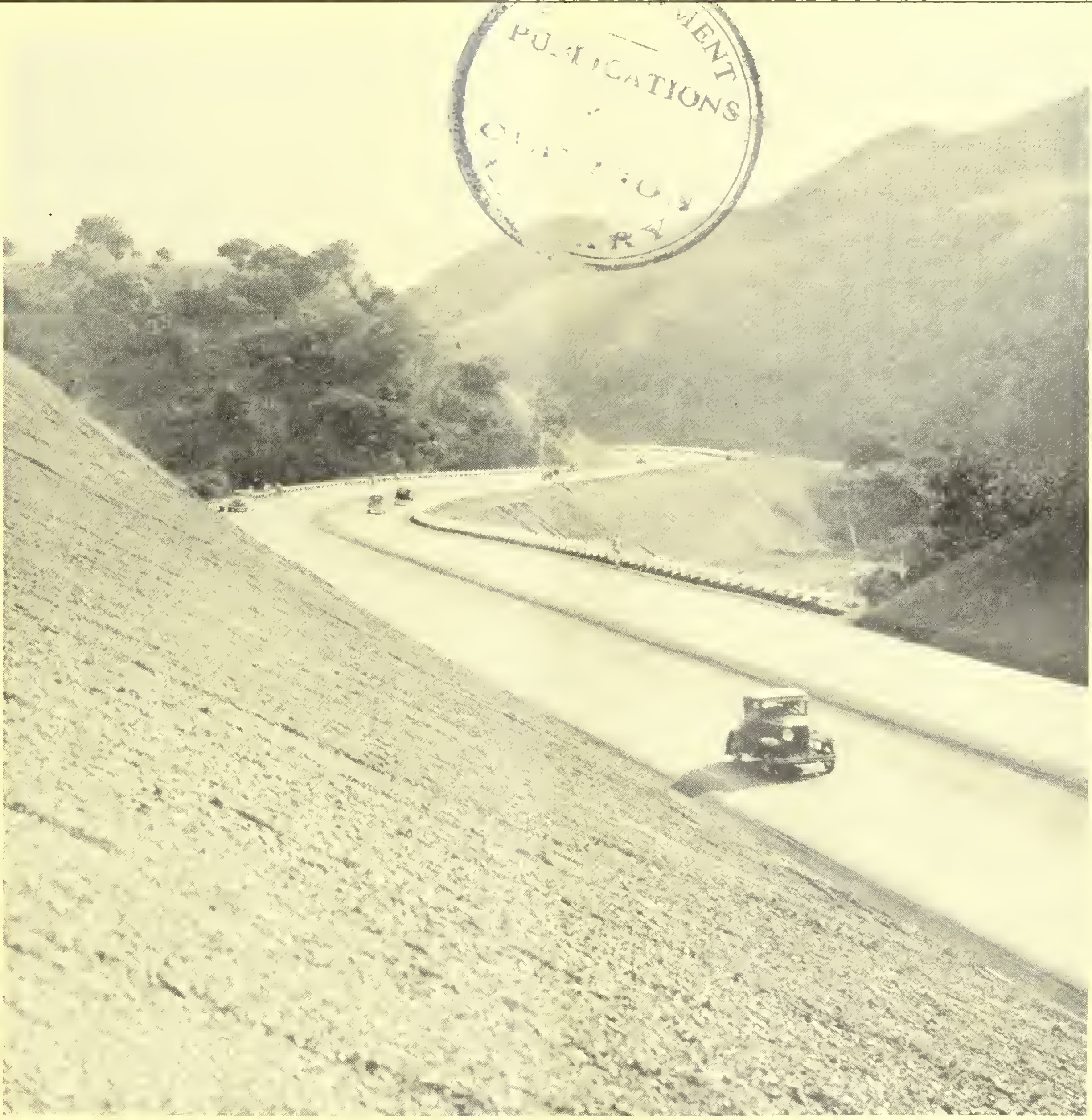
VOL. 22, NO. 4 JUNE 1941



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PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 4 June 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Commissioner of Public Roads, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

PLANNING THE INTERREGIONAL HIGHWAY SYSTEM[1]

BY THE DIVISION OF HIGHWAY TRANSPORT, PUBLIC ROADS ADMINISTRATION

Reported by H. E. HILTS, Assistant Chief, Division of Highway Transport

Interregional highways have been built in this country from its earliest days. Their character and extent have always been limited by available funds, which, in turn, have depended upon the economic importance of the mode of transport that has used them.

The present need of a balanced interregional system of free highways to serve the respective needs of the regions traversed as well as the needs for longer interregional movements is apparent. This system should mainly be made up of the most direct routes between the major centers of population and the belts of heaviest population.

A tentatively defined interregional system is located and the needs of the system are discussed. Design standards are given and cost estimates on both a long-term program and an emergency program are quoted. The distribution of the system in geographic regions is analyzed and preliminary indications of the use, cost of operating, and the earning capacity of the system are developed.

THE concept of an interregional highway system is no startling innovation to the highway builders of this country. Since the first settlers landed on American shores, people have been dreaming of it and building it.

The construction of routes that form the basic outline of the interregional system (fig. 1) has been quickened by the advent of gas-driven vehicles whose owners have been farsighted enough to join in reasonable cooperation in financing by public investment the highway plant that is now one of the world's wonders. To those who have lived in this era the highway plant has seemed to grow at an uncommonly leisurely pace largely because Americans are, in the main, a restless, creative people.

Now the main highway network is practically all surfaced and, in order to attain major benefits promptly for both civil and military requirements, it seems logical to plan and carry out a program of betterments and new construction on routes carrying large volumes of swiftly moving traffic between the country's main population centers. This was probably the impelling reason when the Congress included in the Federal Highway Act of 1938 a provision, section 13, which directed the Chief of the Bureau of Public Roads to investigate and to report to the Congress on the feasibility of building and operating as toll roads six express highways.

The results of the investigation undertaken pursuant to this instruction were published in Toll Roads and Free Roads, House Document No. 272, 76th Congress, First Session. From the discussion in that report there emerged a general outline of what was called A Master Plan for Free Highway Development. The consummation of this plan calls for the full cooperation of the Federal and State Governments. The program outlined in that report includes the following five points:

1. The construction of a special, tentatively defined system of direct interregional highways, with all necessary connections through and around cities, designed to meet the requirements of the national defense in time of war and the needs of a growing peacetime traffic of longer range.
2. The modernization of the Federal-aid highway system.
3. The elimination of hazards at railroad grade crossings.
4. An improvement of secondary and feeder roads, properly integrated with land-use programs.
5. The creation of a Federal Land Authority empowered to acquire, hold, sell, and lease lands needed for public purposes and to acquire and sell excess lands for the purpose of recoupment.

This paper deals with the general problems encountered in a tentative study of the first point together with some remarks on an emergency modernization of the tentatively defined interregional system and the elimination of hazards at grade crossings on the system.

29,330 MILES INCLUDED IN INTERREGIONAL SYSTEM

The system shown in figure 1 and tentatively selected after close cooperation with State and Federal agencies includes substantially all of the major interregional lines of travel. The system is 29,330 miles in length, of which 25,554 miles are rural in character and 3,776 miles are in urban territory. Figure 2 shows that it serves substantially all of the major population centers and the belts of heaviest population.

Traffic maps of the routes to be improved, given in figures 3 and 4, show the routes as the most heavily traveled, on the whole, of all the routes in the U. S. numbered system of highways. Improved as a system of largely limited-access free roads, it will attract traffic and generate new activities. To show how the traffic builds up in cities, the traffic flow has been plotted vertically in profile form and is shown in figure 5.

The existing rural routes most nearly conforming to the direct routes of the interregional system (figs. 6 and 7) now serve almost 11 percent of the total vehicle-miles of travel on all rural highways. Although their length represents only about 1 percent of the total rural highway mileage of the country, it is estimated that the completed system would unquestionably accommodate at least 12.5 percent of the total rural vehicle mileage. By providing ample capacity and up-to-date safety devices these free roads would effect a material reduction in the highway accident rate.

In the data submitted in this paper the direct routes follow the alinement and incorporate the improvements of existing highways with deviations from direct routes between population concentrations in limited degree only to accommodate the largest intermediate towns.

The routes are assumed to join facilities that will promote free movement of traffic to and through the centers of the cities. At large cities, wherever necessary, limited-access belt lines will have to be provided. All small communities are assumed to be bypassed. The two conditions cited are premised upon whether the city or town contributes either (1) the larger, or

[1] Paper presented at the Twentieth Annual Meeting of the Highway Research Board, December 1940.

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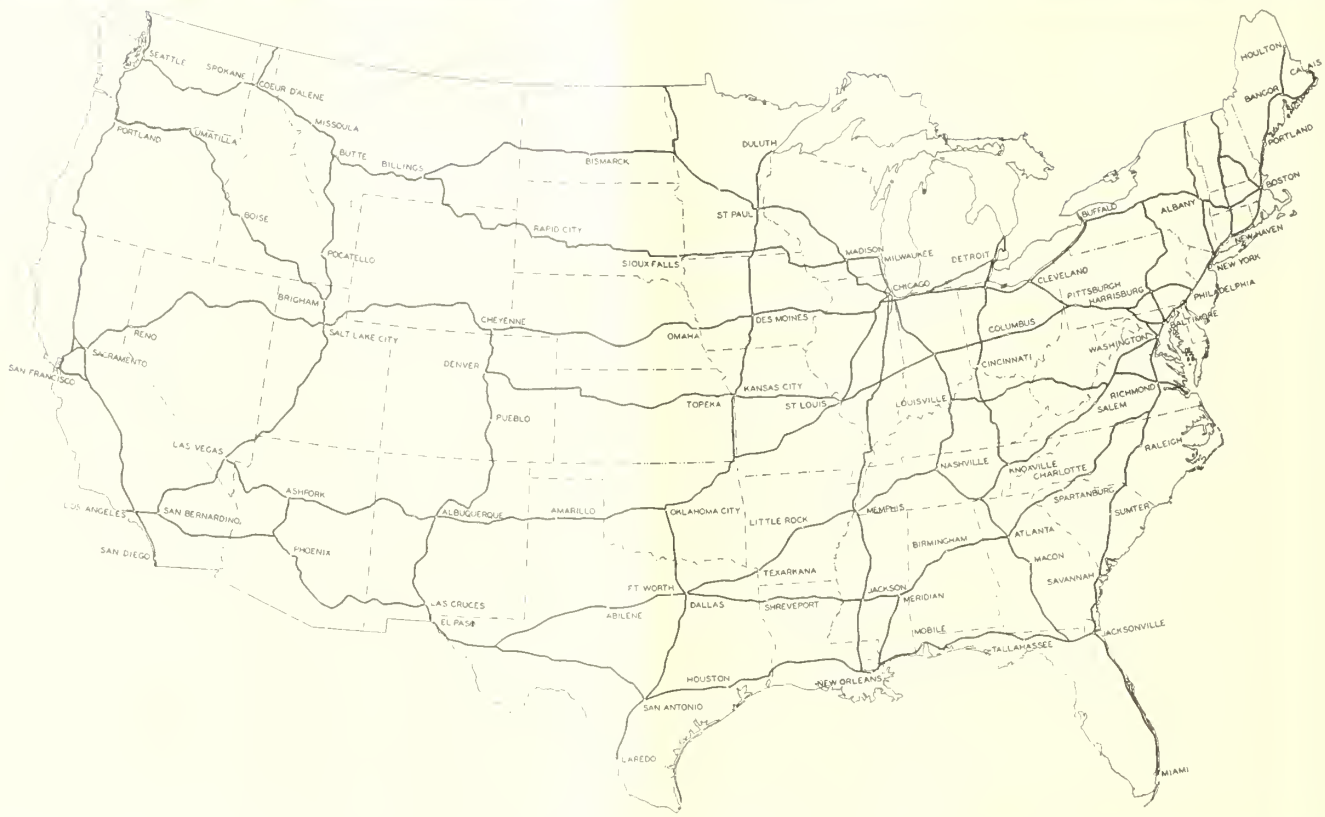

FIGURE 1.—EXISTING HIGHWAYS FOLLOWING THE APPROXIMATE ALINEMENT OF THE TENTATIVELY SELECTED INTERREGIONAL HIGHWAY SYSTEM.

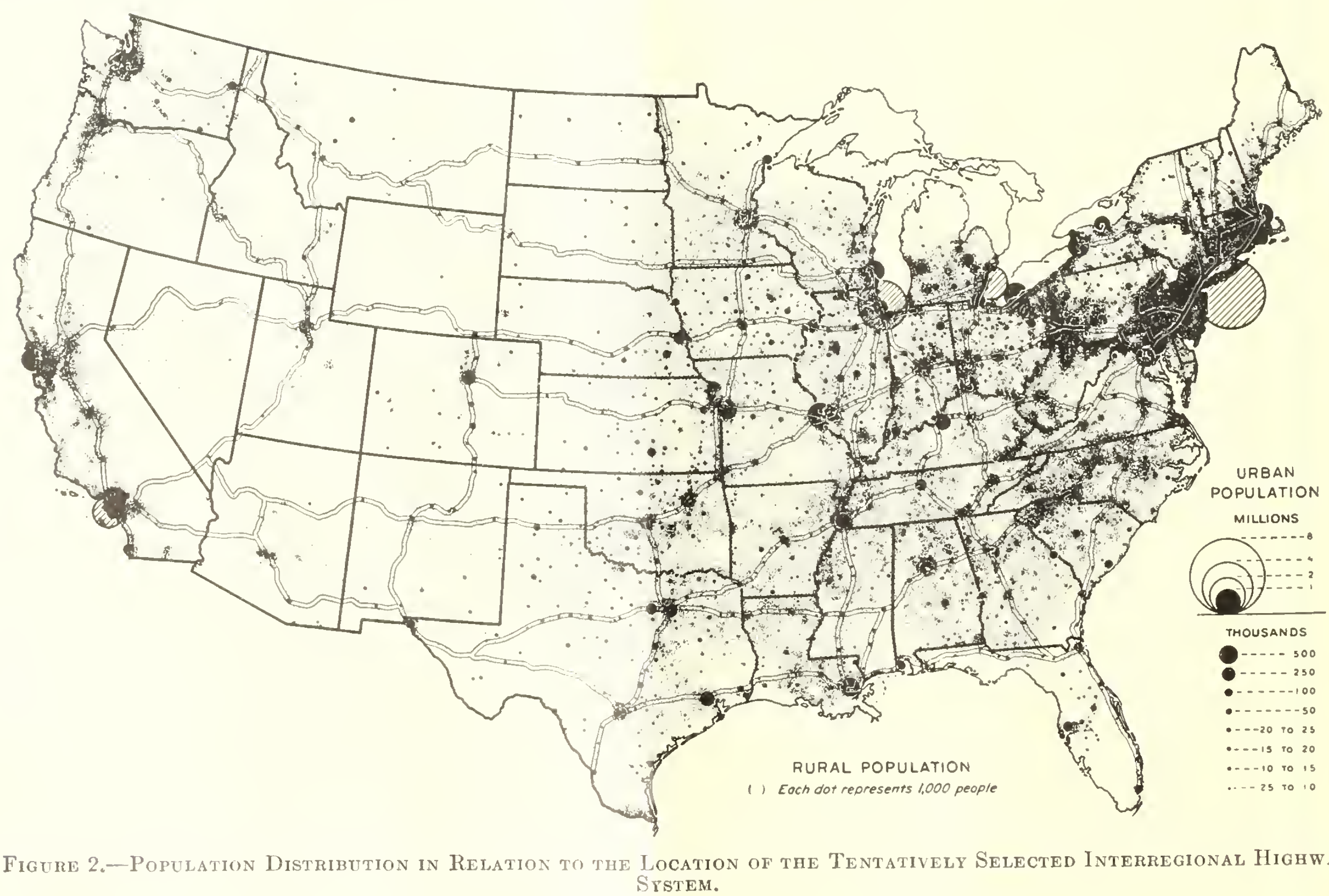

FIGURE 2.—POPULATION DISTRIBUTION IN RELATION TO THE LOCATION OF THE TENTATIVELY SELECTED INTERREGIONAL HIGHWAY SYSTEM.

Figure 3.—Comparison Between the Average Daily Passenger-Car Traffic on the Tentatively Selected Interregional Highway System and That on Other Important Routes, 1937 Data.

FIGURE 4.—COMPARISON BETWEEN THE AVERAGE DAILY TRUCK AND BUS TRAFFIC ON THE TENTATIVELY SELECTED INTERREGIONAL HIGHWAY SYSTEM AND THAT ON OTHER IMPORTANT ROUTES, 1938 DATA.

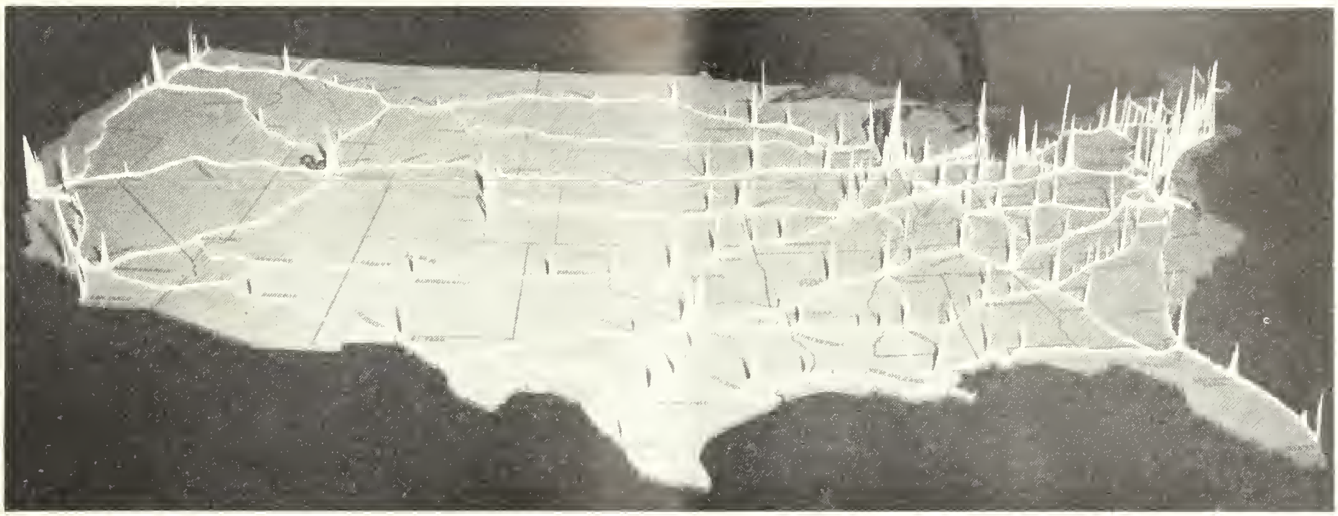

FIGURE 5.—TRAFFIC FLOW PROFILE OF THE TENTATIVE INTERREGIONAL HIGHWAY SYSTEM, 1937 DATA.

(2), the smaller part of the expected traffic on the route at its boundaries.

In general, the main rural highways of the Nation, beyond the immediate vicinity of the cities, are of sufficient capacity to discharge the flow of present traffic.

If a slight restriction of absolute freedom of movement is accepted, which is to be expected on the rural highways during short periods of maximum hourly traffic volume that occur in the course of a year, an average daily volume of 3,000 vehicles may be considered as within the reasonably convenient discharge capacity of a 2-lane highway.

On this basis, figure 8 shows the portions of the interregional system now having only two lanes which should be widened. Sections now having four or more lanes are also shown in figure 8. To emphasize the contrast, figure 9 has been prepared to show only the existing sections having four or more lanes. These data were obtained by analysis of diagrams that will be discussed later. They have been prepared for the entire tentative interregional system, first, between route intersections, and second, as continuous routes between main city termini. These diagrams show the main physical and operating characteristics of the entire system. An analysis of these diagrams (table 1) shows that on the tentative system, 1,230 miles of more than 2-lane width are within 25 miles of municipalities having populations exceeding 100,000, of which 500 miles are 3-lane width and 730 miles are 4-lane width. The traffic data (table 2) show that to provide adequate traffic facilities, 1,770 additional miles of more than 2-lane width should be constructed within 25 miles of the larger municipalities, and 1,230 additional miles should be constructed on the remaining part of the rural interregional system.

The traffic standards suggested above contemplate the construction of roads greater than two lanes in width when the present average daily traffic volume exceeds 3,000 vehicles. For the purpose of this discussion it is assumed that 4-lane divided highways will be built at locations having present average traffic volumes of from 3,000 to 10,000 vehicles per day. Should the present average volume exceed 10,000 vehicles per day, it might be that special conditions would require still wider pavements, but such requirements should be determined by analysis of each case rather than by resort to a general standard.

TABLE 1.—*Present lengths of sections of the tentative interregional highway system having more than 2 lanes, located within 25 miles of cities of more than 100,000 population*

Geographic division	Lengths having 3 lanes	Lengths having 4 lanes or more	Total
	Miles	*Miles*	*Miles*
New England	80	90	170
Middle Atlantic	140	130	270
East North Central	80	150	230
West North Central	30	70	100
South Atlantic	70	90	160
East South Central	10	30	40
West South Central	10	60	70
Mountain		10	10
Pacific	80	100	180
United States	500	730	1, 230

TABLE 2.—*A comparison between the length of sections of the tentative interregional highway system requiring widths in excess of 2 lanes and the length of the existing sections having more than 2 lanes* [1]

Geographic division	Length of sections requiring more than 2 lanes		Length of sections both requiring and now having more than 2 lanes [2]		Length of sections requiring widening	
	Located within 25 miles of cities	Located beyond 25 miles of cities	Located within 25 miles of cities	Located beyond 25 miles of cities	Located within 25 miles of cities	Located beyond 25 miles of cities
New England	390	180	170	70	220	110
Middle Atlantic	560	450	260	160	300	290
East North Central	540	280	200	100	340	180
West North Central	210	80	40	80	170	
South Atlantic	430	240	150	160	280	80
East South Central	100	30	10		90	30
West South Central	220	190	40	30	180	160
Mountain	90	60	10	40	80	20
Pacific	270	610	160	250	110	360
United States	2, 810	2, 120	1, 040	890	1, 770	1, 230

[1] The determination of need is based on the assumption that routes carrying in excess of 3,000 vehicles per day should be wider than 2 lanes.
[2] Length of sections now having more than 2 lanes and carrying more than 3,000 vehicles per day.

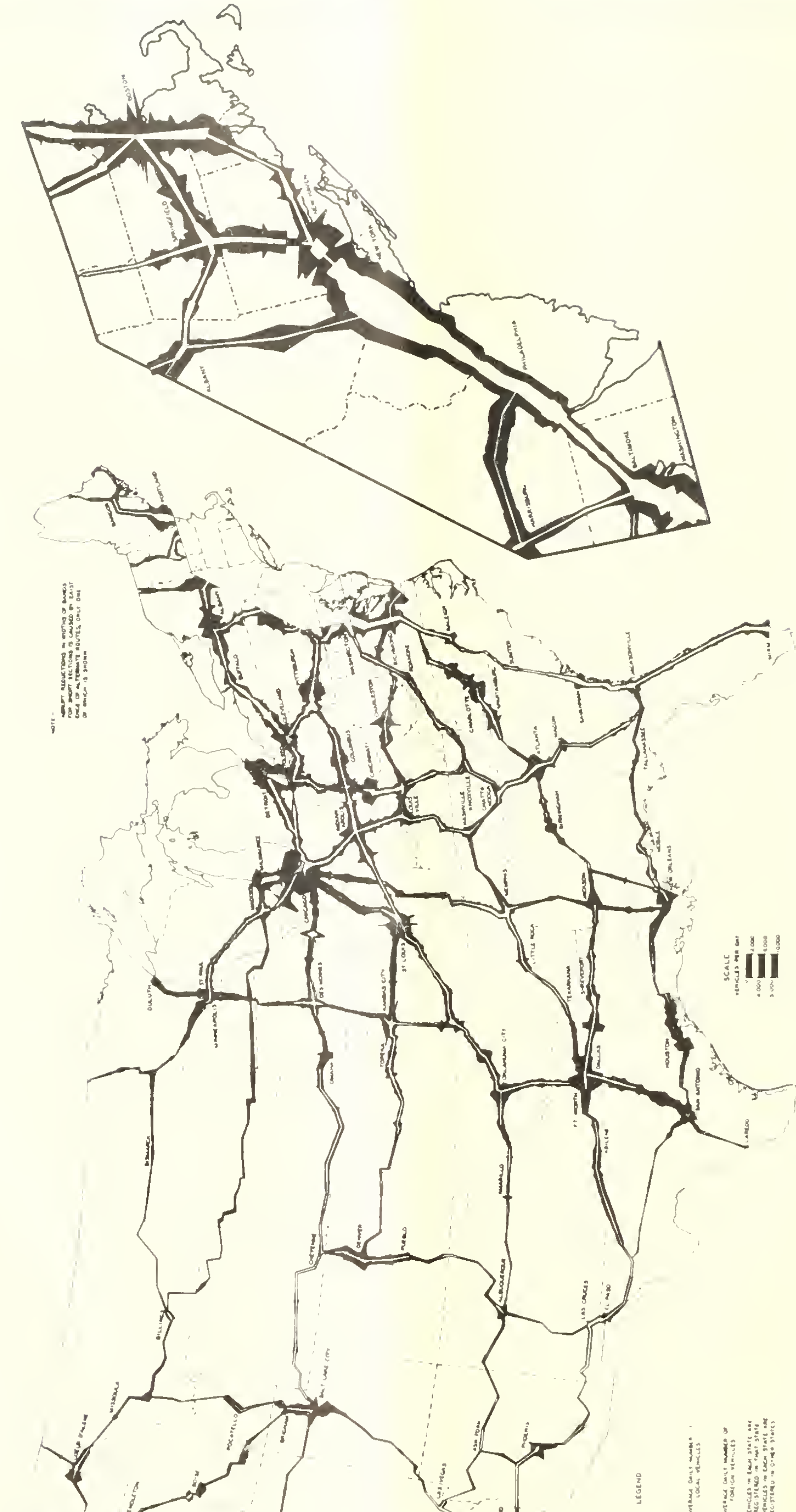

FIGURE 6.—THE AVERAGE DAILY PASSENGER-CAR TRAFFIC ON THE TENTATIVELY SELECTED INTERREGIONAL HIGHWAY SYSTEM, 1937 DATA.

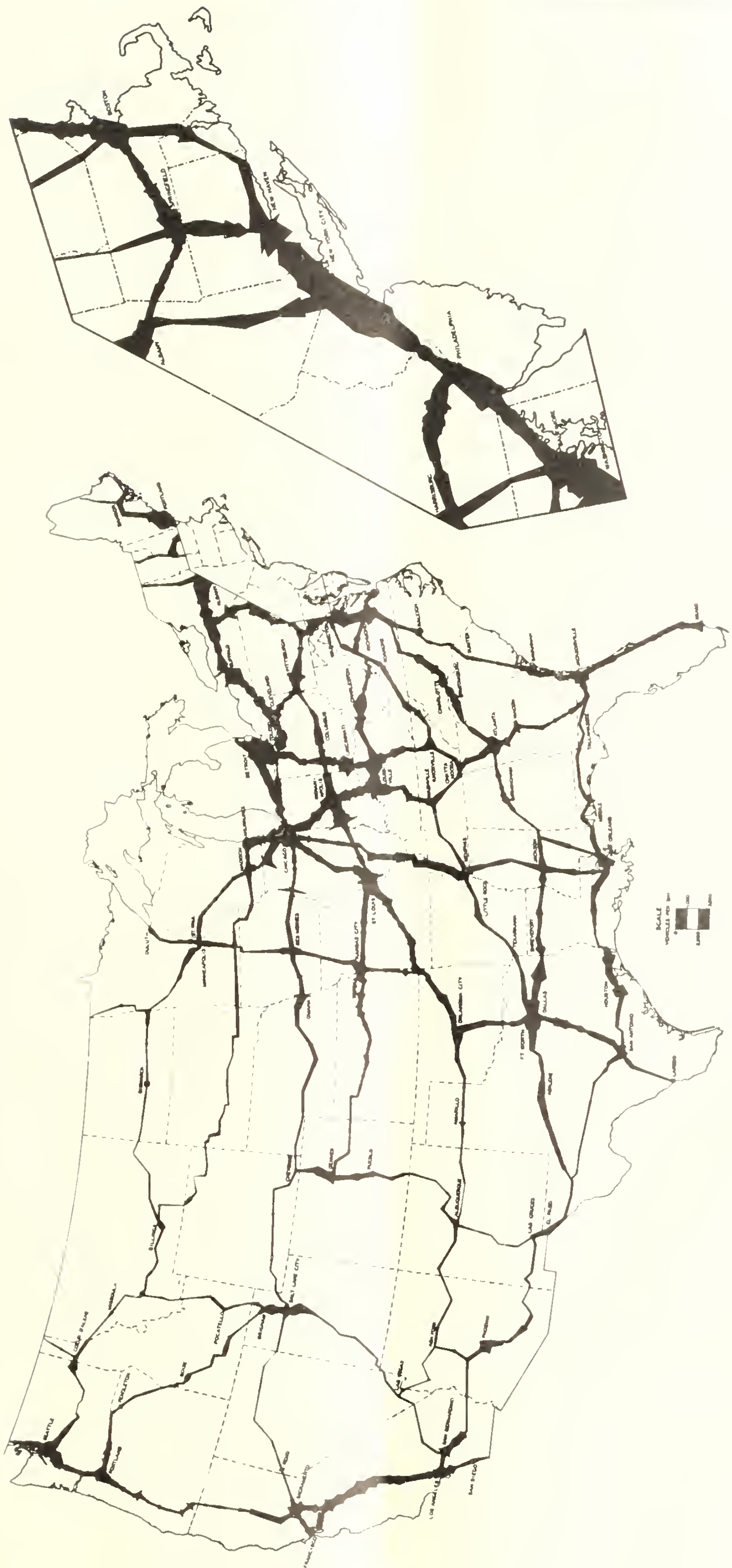

Figure 7.—The Average Daily Truck and Bus Traffic on the Tentatively Selected Interregional Highway System, 1937 Data.

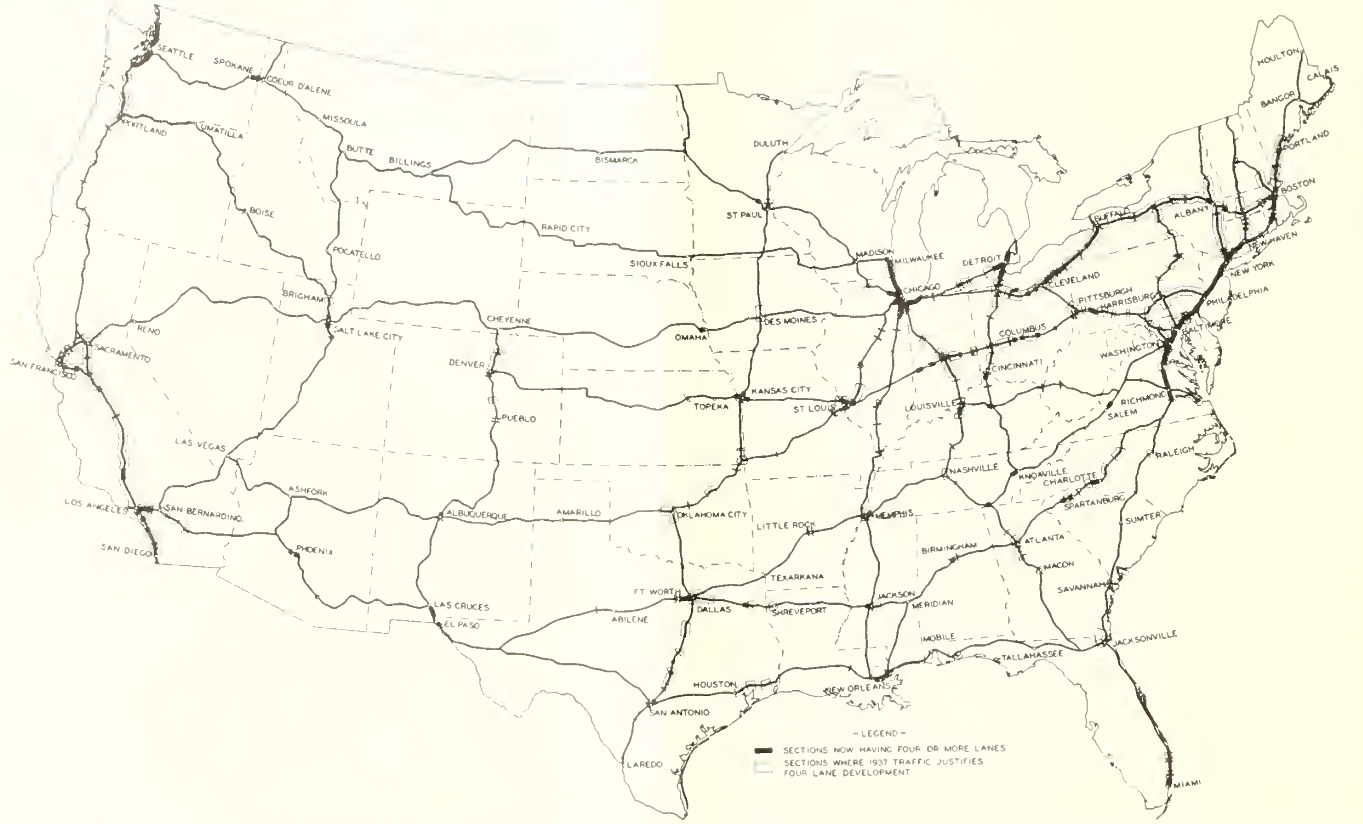

Figure 8.—Location of Sections of the Tentatively Selected Interregional Highway System Having Four or More Lanes, and Other Sections Where 1937 Traffic Data Indicate the Need of Improvement to Four-Lane Standards.

PEAK TRAFFIC GREATLY EXCEEDS AVERAGE TRAFFIC VOLUME

By correlating the analysis of the complete records of 89 fixed-type automatic traffic counters, selected from a total of some 500 now in operation, with the analysis of speed and passing distance studies made on 28 sections of 2-lane highway in Virginia, Maryland, Massachusetts, New York, Connecticut, and Illinois, and on 8 sections of 4-lane undivided highway and 5 sections of 4-lane divided highway in Massachusetts, New York, and Illinois, the following present general résumé appears reasonable. During certain periods of the year, and particularly on weekends, the daily traffic will far exceed the average. On roads with an average daily volume of 3,000 vehicles it may be expected that on 1 day each year the volume will reach 7,300 vehicles, and that on the 10 days of heaviest traffic the daily volume will exceed 5,700 vehicles. This latter figure corresponds to what might be expected on a normal summer Sunday.

On the average road carrying an average daily volume of 10,000 vehicles, the maximum daily volume will probably reach 18,500 vehicles, and on the tenth highest day, or the summer Sunday condition, the daily volume may be expected to be 15,000 vehicles. That volumes in this range require special analysis is shown by the fact that on one road, a modern 4-lane divided highway corresponding to the design proposed for the interregional system, an average traffic of 10,000 vehicles per day resulted in a peak day's flow of 24,000 vehicles, and on the 10 days of highest traffic volume, the daily flow exceeded 19,000 vehicles. Either special conditions induced these larger peaks, or the road's design permitted a traffic movement more nearly corresponding to the desires of the traveling public. The latter explanation is quite reasonable when it is considered that the peaks on this road are in the same proportion to the average daily flow of 10,000 as they are on the other roads with but 3,000 vehicles per day. Undoubtedly, congestion caused by poor alinement, intersections, and other restrictive features deters some travel and tends to lengthen the peak periods and thus to lower the peaks.

The significance of these figures is emphasized by translating them to terms of hourly traffic density and measures of congestion. On the average highway carrying an average daily volume of 3,000 vehicles, it may be expected that during 1 hour of the year the volume will be 750 vehicles, and during the 10 hours of heaviest flow the volume will exceed 550 vehicles per hour. As a result of studies on selected average 4-lane roads it is estimated that with an average traffic of 10,000 vehicles per day, the maximum volume in any 1 hour during the year will be 1,750 vehicles, and for 10 hours the flow will exceed 1,450 vehicles per hour.

On the more modern road with its sharper traffic peaks, the hourly volume will reach 2,500 vehicles, and for 10 hours the flow will exceed 1,800 per hour. Since the 4-lane roads will be divided, however, the traffic in each direction will be of greater importance than the total. For an entire day the traffic in one direction will nearly equal that in the other. For individual hours, however, as much as 70 percent of the total may be in one direction. Average roads, with average traffic of 10,000 vehicles per day, thus will carry some 1,200 vehicles in one direction during the heaviest hour, while the road permitting free travel will be required to accommodate 1,750 vehicles in one direction during 1 hour of the year. With these traffic standards, vehicles will be able to move with very little

FIGURE 9.—LOCATION OF SECTIONS OF THE TENTATIVELY SELECTED INTERREGIONAL HIGHWAY SYSTEM HAVING FOUR OR MORE LANES.

restriction to speed even during the hour of heaviest flow.

Studies have been made on 12 sections of 2-lane road tangents with only minor restrictions in alinement and grade beyond the limits of the sections under study in Massachusetts, New York, and Illinois. According to records obtained on the best of these sections, vehicle speeds in the periods of lightest traffic will generally average between 42 and 45 miles per hour, with 10 percent of the vehicles traveling at 52 to 54 miles per hour or faster. With an hourly rate of 750 vehicles, the worst condition that may be expected on 2-lane roads, the average speeds will range from 39 to 42 miles per hour, with 10 percent of the vehicles moving at 48 to 50 miles per hour or faster. The average difference in speed between successive vehicles (designated herein as the congestion index), which is a measure of the freedom of movement, decreases from around 8 miles per hour in the lightest traffic to 5 or less at a rate of 750 vehicles per hour. Shifting from a 2-lane to a 4-lane divided road at this volume of 750 vehicles per hour, corresponding to 3,000 vehicles per day, the average speed increases to 47 miles per hour or faster, with 10 percent of the vehicles moving at 58 miles per hour or faster; and the congestion index shows a speed difference between vehicles of about 8 miles per hour.

Studies made on the best of four sections of road in two States indicate that as the average volume increases to 10,000 vehicles per day on an undivided 4-lane road on which the traffic is not retarded by intersections and roadside establishments, the maximum anticipated hourly volume of 1,200 vehicles in one direction would move at an average speed of 40 miles per hour, with 10 percent exceeding 54 miles per hour and the congestion index would become about 7 miles per hour. On modern 4-lane divided highways on which the sharper peaks will be expected, the maximum hourly rate in one direction may reach 1,750 vehicles per hour, but it is likely that the speeds will equal or exceed the values listed above for 1,200 vehicles per hour.

CHARTS SHOW PHYSICAL CONDITION OF SYSTEM

Figure 10 shows a portion of the interregional system from near Los Angeles to Sacramento, California, Distance on the diagram is represented by a very small scale. Beginning at the top, 1937 traffic density for the route is shown in terms of annual average 24-hour volume classified as total traffic, total trucks and busses, and that portion of the total that is classified as foreign (carrying out-of-State registration tags). Below traffic are shown the number of fatal accidents per mile and their location to the nearest mile. Below fatal accidents the number of restricted sight distances are given per individual mile classified as permanent or temporary. The number of sight distances shown are those in each individual mile that are shorter than desirable limits of 1,000 feet and 650 feet in non-mountainous and mountainous areas, respectively. Below sight distance data are shown the number of grades longer than 500 feet in each individual mile exceeding 5 percent in non-mountainous areas and 8 percent in mountainous areas, considered generally as desirable maximum limits.

Below grade data are represented to the indicated scale the number of curves in each individual mile of the highway that in 1937 were sharper than certain indicated desirable standards, generally 6 degrees in non-mountainous areas and 14 degrees in mountainous areas.

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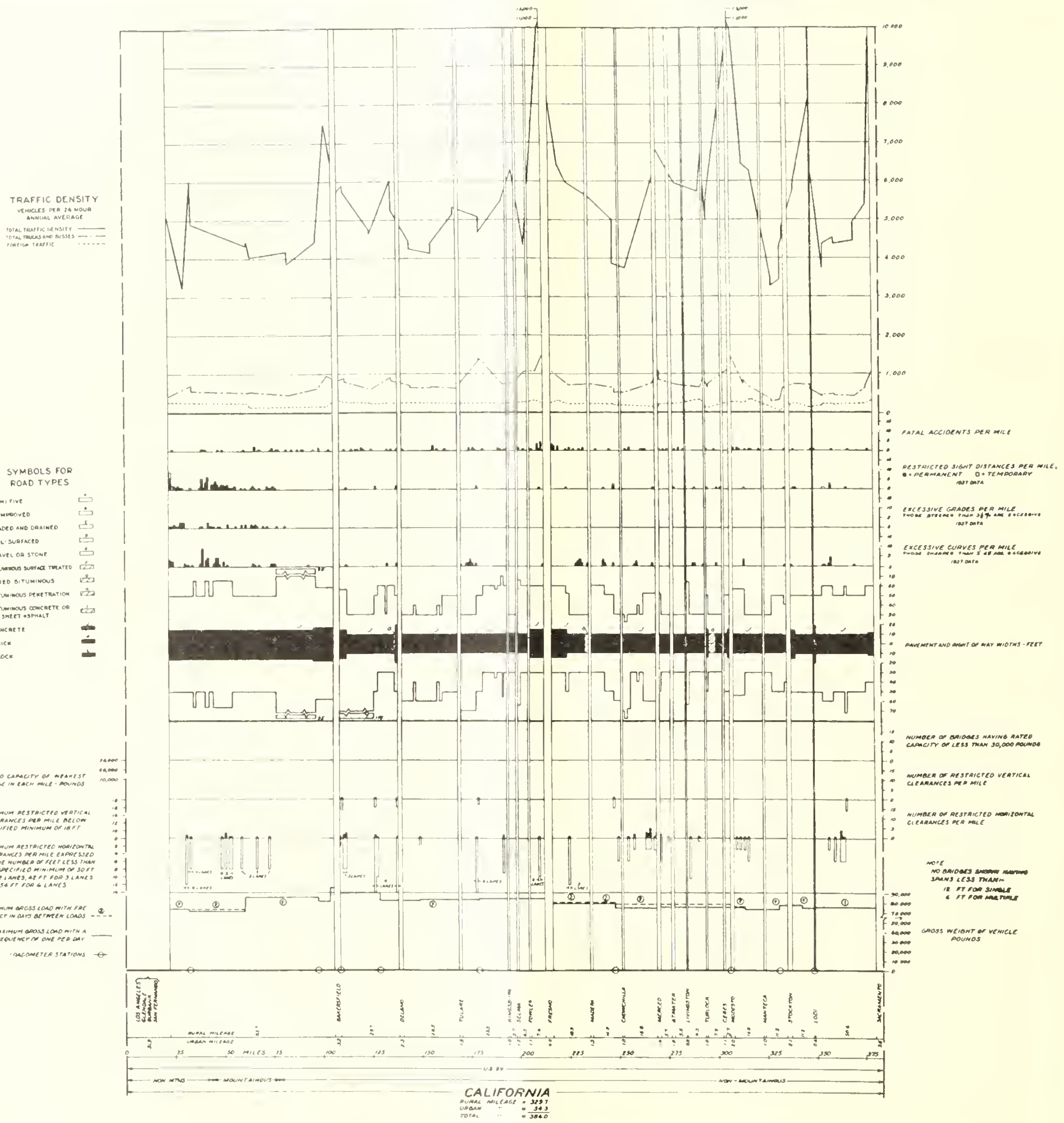

Figure 10.—Traffic Profiles, Limiting Physical Components of the Road, and Limiting Features of Bridges for a Section of the Tentatively Selected Interregional Highway System.

Below the curve data are shown pavement and right-of-way widths in feet. The character of the highway surface is represented by the shading or hatching within the broad bands extending across the diagram. The width of the pavement or surface on each mile is represented to the indicated scale by the width of the hatched band. The right-of-way width is shown to the same scale.

Below pavement and right-of-way width follow data on the number per mile of bridges having rated capacities of less than 30,000 pounds, and the rated capacity of the weakest bridge in each mile; the number per mile of restricted vertical clearances less than 18 feet, and the minimum vertical clearance in the mile; the number of restricted horizontal clearances per mile, and the minimum horizontal clearances per mile expressed as the number of feet less than the specified base width of 30 feet for 2 lanes, 42 feet for 3 lanes, and 54 feet for 4 lanes. The lowest data on the diagram show the maximum gross loads in pounds for the sections involved, based on the data for the loadometer stations located as shown by the circles on the lowest line. The maximum gross loads are shown for 1-day frequency by a solid line and for frequency in the number of days as

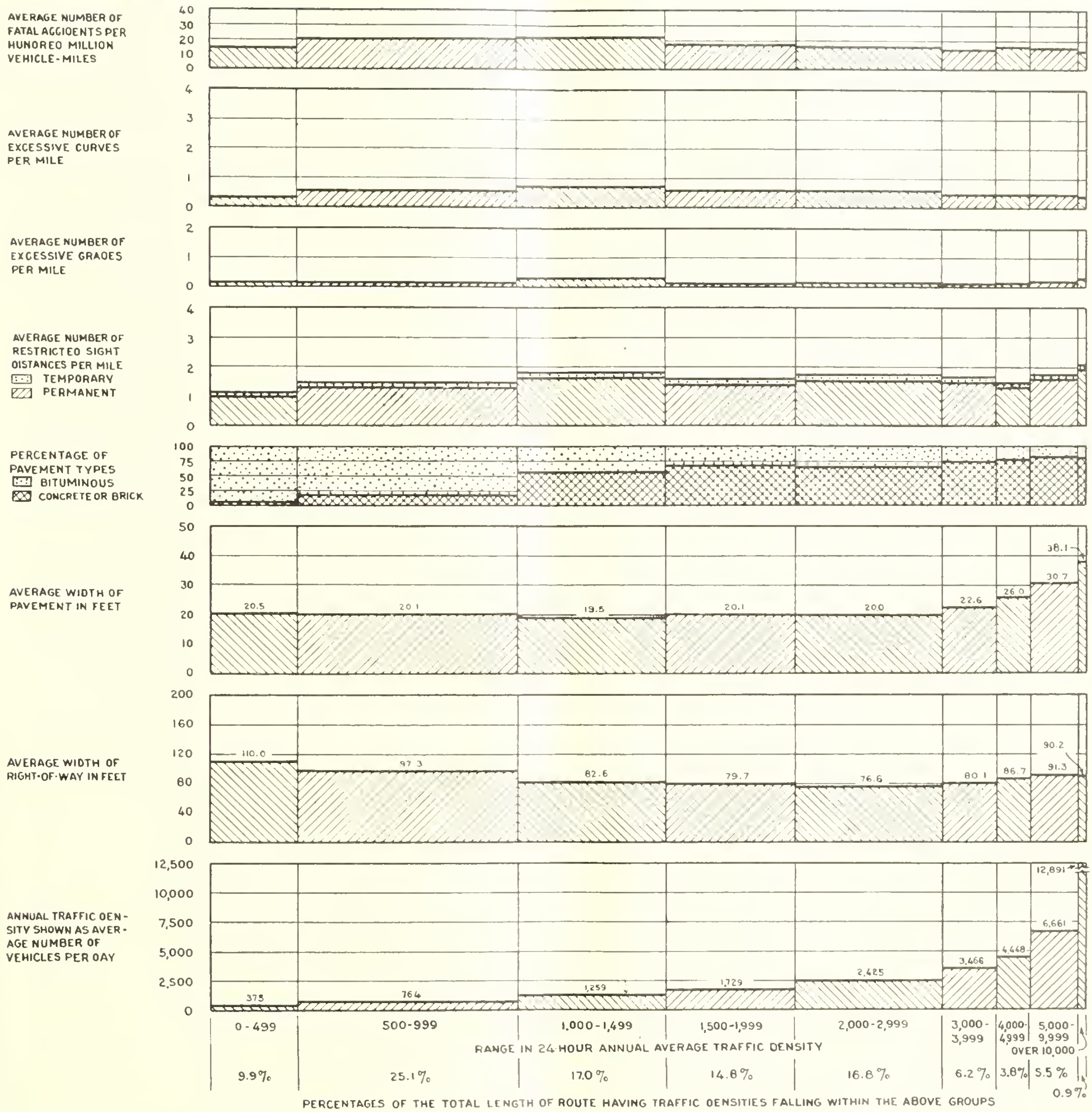

Figure 11.—Summary of Physical Conditions on Rural Sections of the Tentatively Selected Interregional Highway System Arranged in Traffic Volume Groups.

indicated by the number within the circle by a broken line.

Below the diagram are shown the rural mileage, the urban mileage, a mileage scale, the U. S. route number, and the classification of the route into mountainous and non-mountainous.

Figure 11 is a summary of all the physical conditions on the existing mileage of rural sections of the tentative interregional system arranged in traffic-volume groups. This chart shows that 9.9 percent of the total rural mileage carries less than 500 vehicles per day, 25.1 percent carries between 500 to 999 vehicles per day, etc. The horizontal width of the space for showing features within each of the various density groups is proportional to these percentages.

In the lowest space of the chart the average number of vehicles per day for all sections falling within each traffic-density group is plotted. Next above this is plotted the average width of right-of-way for all sections falling within each group. Other conditions are shown graphically in the same manner in the other spaces.

On those sections carrying less than 500 vehicles per day are found the widest right-of-way, a relatively wide pavement, the lowest percentage of concrete or brick pavement, the fewest restricted sight distances per mile, relatively few excessive grades per mile, the fewest excessive curves per mile, and a relatively low rate of occurrence of fatal accidents. In sharp contrast are those sections carrying from 1,000 to 1,499 vehicles per day where there are found a relatively narrow right-of-way, the narrowest pavement, slightly more than 50 percent of the concrete or brick pavement, a relatively large number of restricted sight distances, the greatest number of excessive grades per mile, the greatest number of excessive curves per mile, and the most frequent rate of occurrence of fatal accidents.

Many significant relationships are shown in figure 11. The narrowest right-of-way is found to exist for highway sections carrying 2,000 to 2,999 vehicles per day, the narrowest pavement for sections carrying 1,000 to 1,499 vehicles per day, the greatest percentage of concrete or brick pavement for sections carrying 5,000 to 9,999 vehicles per day, the greatest number of restricted sight distances for sections carrying more than 10,000 vehicles per day, the greatest number of excessive grades per mile for sections carrying 1,000 to 1,499 vehicles per day (but only slightly more than the number occurring on sections carrying more than 10,000 vehicles per day), the greatest number of excessive curves per mile for sections carrying 1,000 to 1,499 vehicles per day, and the greatest number of fatal accidents per hundred million vehicle-miles for sections carrying 1,000 to 1,499 vehicles per day. The safest sections are those carrying more than 10,000 vehicles per day. They are by far the most congested, carrying 340 vehicles per day per foot of width. The sections which rank second in safety are those carrying less than 500 vehicles per day, or only 18 vehicles per day per foot of width.

Charts of similar form have been prepared for each of the 20 longer routes of the system. Their comparison with the summary chart for the entire system indicates, in general, that routes in the southern part of the country are more dangerous than northern routes.

From available data, it is not possible to compare the accident rate on the rural interregional system with that for all rural highways. The accident figures shown have been expressed in terms of the number of fatal accidents per 100 million vehicle-miles of travel on the system in 1937. On the rural interregional system there were 16.04 fatal accidents per 100 million vehicle-miles. It has been estimated that about 1.2 persons were killed in each fatal rural highway accident in 1937. Assuming that this rate applies to the rural interregional system, it implies a death rate of about 19.2 per 100 million vehicle-miles during 1937. The National Safety Council reports that in 1937 there were 15.8 deaths per 100 million vehicle-miles on all rural roads and urban streets.

PAVEMENT AND RIGHT-OF-WAY WIDTHS INADEQUATE

Figure 12 is a summary chart showing the accumulative distribution of right-of-way widths by traffic density groups. From it there can be read directly the percentage of the aggregate length of all rural sections which carry less than any chosen number of vehicles per day and which have right-of-way widths less than any chosen width. For example, if it is assumed that a right-of-way width of 160 feet is desired for all rural sections of the system carrying less than 3,000 vehicles per day, the length of the system requiring additional right-of-way is shown to be 79.5 percent of the aggregate length of all rural sections.

Similarly, figure 13 shows the cumulative distribution of pavement widths. If it is assumed that a pavement width of 22 feet is desired for all rural sections of the system carrying less than 1,000 vehicles per day (this is a liberal assumption for those roads that now carry less than 600 vehicles per day), the length of the system requiring additional pavement width is shown to be 30.1 percent of the aggregate length of all rural sections. If it is assumed that a pavement width of 24 feet is desired for all rural sections carrying less than 3,000 but more than 1,000 vehicles per day, the length requiring additional pavement width may be obtained by reading, on the vertical bar representing 24 feet, the intercept between the lines representing 1,000 and 3,000 vehicles per day. The length is shown to be 44.8 percent of the aggregate rural length.

A less direct use of figures 12 and 13 is the determination of the deficiency in the area of right-of-way or pavement for any desirable width for any traffic volume group. The area between the limits of the traffic volume group and to the left of the desired width is the deficient area which may easily be converted to acres or square yards.

There is no doubt that, as measured by the diagrams, unsatisfactory conditions with respect to sight distance, curvature, and gradient, are common. There is no doubt that present rights-of-way are largely inadequate. There seems to be generally a reasonable accord between traffic volume and the number of pavement lanes, the amount and character of the traffic, and the kind of pavement or surface in place, but there is inadequate width of pavement lanes on a considerable mileage, usually near cities. These inadequacies are the concomitant of construction operations carried on for more than 20 years, during which period top vehicle speeds have increased from 30 to well above 60 miles per hour. Then, too, when the oldest of the existing pavements were built there were only 2 or 3 million motor vehicles and there was a strong demand for hard surfaced roads to get the traffic through.

These conditions account for the present need for correction of sharp curvature, steep grades, and narrow surfaces and rights-of-way by reconstruction or by abandonment of such obsolete sections and relocating the highway.

The present need is to bring all of these interregional routes gradually up to a higher degree of usefulness by the reduction of excessive curvature, the easing of steep grades, the opening up of longer sight distances, the general widening of pavement lanes and the construction of additional lanes, the separation of opposing traffic on heavily traveled sections, arrangements for the accommodation of slow-moving traffic on steep grades, the separation of grades at railroad grade crossings and important highway intersections and the installation of protective cross traffic controls at others, the abatement of dangerous roadside conditions of all sorts, relocations for directness of travel between important objectives for serving the movements of longer range, and finally, the acquisition of new right-of-way of sufficient width to make all of these improvements possible.

During the next 20 years planning technique will be greatly improved. The determination of the required number of traffic lanes will probably not be determined on the basis of traffic density, but on the basis of some measures of traffic congestion, which will take into account the magnitude, duration, and frequency of occurrence of peak traffic loads, differences in speed of

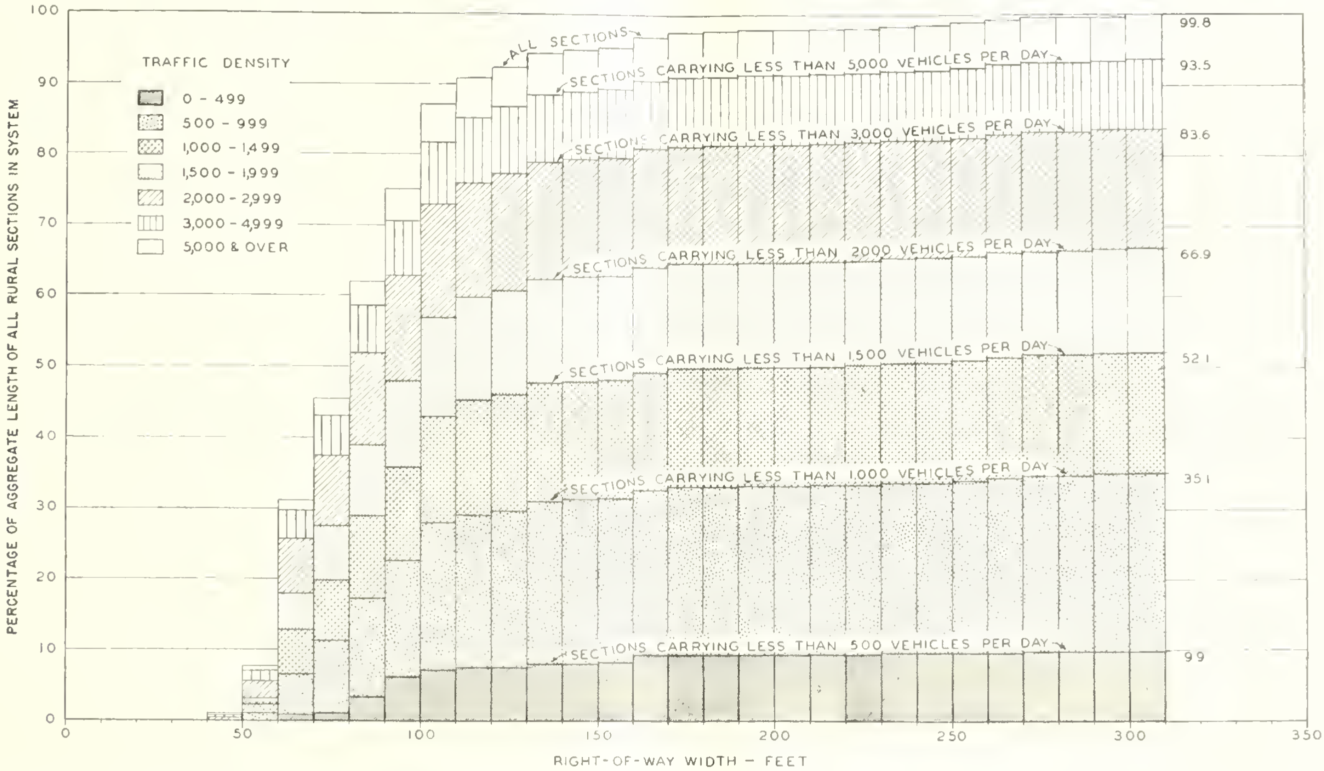

Figure 12.—Cumulative Distribution of Lengths of Rural Sections of the Tentatively Selected Interregional Highway System Having Various Right-of-Way Widths and Traffic Densities.

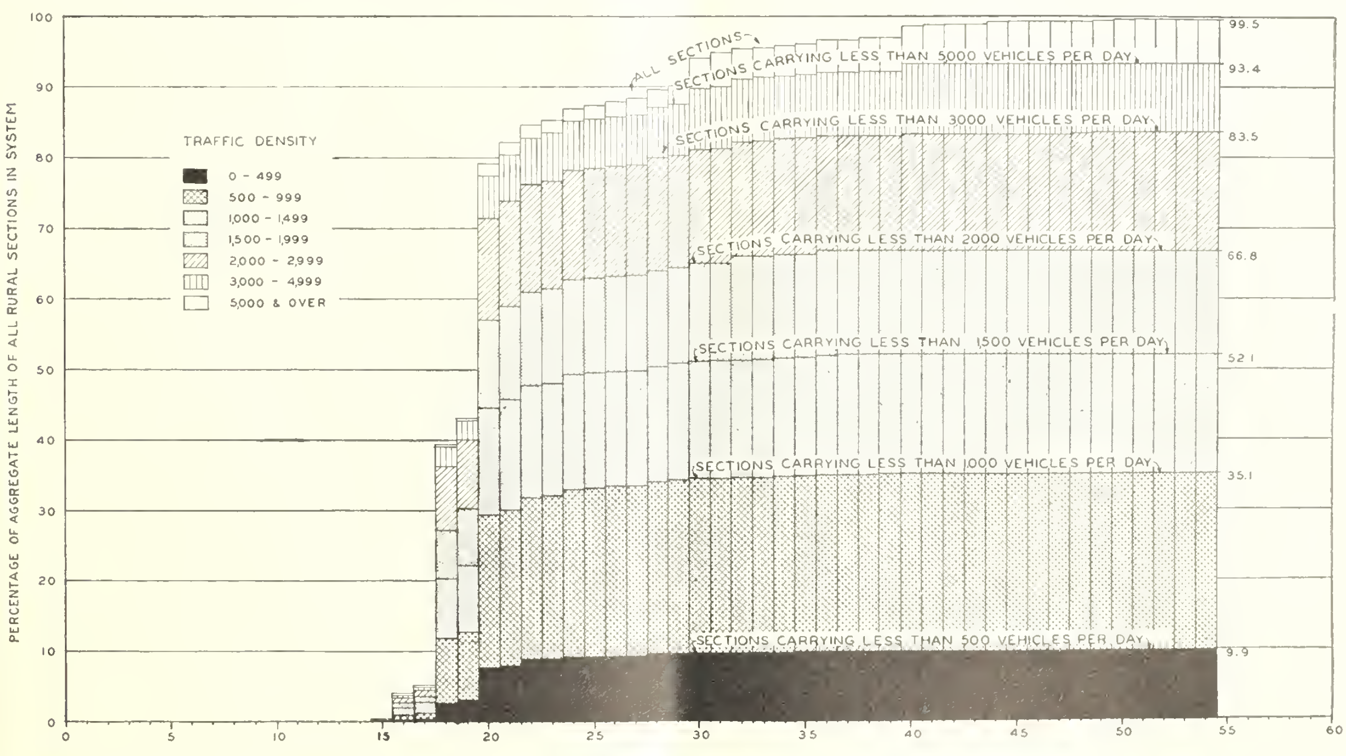

Figure 13.—Cumulative Distribution of Lengths of Rural Sections of the Tentatively Selected Interregional Highway System Having Various Pavement Widths and Traffic Densities.

travel, etc. Until uses of these measures of traffic congestion are perfected, the best basis for classification applicable to present available information is traffic density.

SECTIONS CLASSIFIED BY DAILY TRAFFIC VOLUME

For immediate planning purposes, all rural sections of the interregional system are classified into six groups as follows:

- Group I—Sections carrying less than 1,000 vehicles per day.
- Group II—Sections carrying 1,000 to 1,999 vehicles per day.
- Group III—Sections carrying 2,000 to 2,999 vehicles per day.
- Group IV—Sections carrying 3,000 to 4,999 vehicles per day.
- Group V—Sections carrying 5,000 to 9,999 vehicles per day.
- Group VI—Sections carrying 10,000 or more vehicles per day.

Design standards considered in this study of the interregional system are shown in table 3, and are based on the above classification of rural sections. The "present average daily traffic density" is considered to be the volume of traffic which follows the existing road immediately before the improvement is undertaken, plus the existing traffic then following other routes which would logically be diverted to the interregional road if the improvement were made. It does not include "generated traffic" which is generally defined as that traffic which results from a new desire for travel on the part of certain people who would not care to perform the same travel in the absence of the improved facility.

Groups I and II (traffic density 0–1,999) contain sections which cannot be expected to carry sufficient traffic to warrant construction to more than 2 lanes during the life of the new surface. The only difference in standards for sections in group I and those in group II is that a wider right-of-way is specified for the latter group. This additional right-of-way is justified by the improved protection to traffic and by the fact that high right-of-way costs can be avoided on those sections which will become inadequate from the standpoint of service in the shortest time, thus placing them in line for widening when the new surface must be replaced.

Practically all of the sections in group III (traffic density 2,000–2,999) will be due for construction as 4-lane divided highways when the life of the new surface has expired. Some of them will be ready for this higher type of construction before that time. The same right-of-way widths are specified for this group of sections as are specified for sections in group II.

All of the sections in group IV (traffic density 3,000–4,999) are assumed to carry sufficient traffic to warrant their construction as 4-lane divided highways.

Four-lane divided highway construction is also specified for sections in group V (traffic density 5,000–9,999), but greater cost allowances are provided for the attainment of the desirable standards, and more rigid limits are specified for the permissible standards. Many of these sections may require widening before the new surface needs replacement.

Sections in group VI (traffic density in excess of 10,000) are assumed to require special design, usually requiring more than a 4-lane divided highway.

The design standards marked "desirable" in table 3 apply wherever the average cost per mile for a section of any considerable length, exclusive of the costs of right-of-way, property damage, large bridges, and railroad and highway grade separation structures, does not exceed the amounts shown in column 4 headed "cost limitation, desirable standards." In order to provide flexibility in these standards, three subclassifications, based on topography of the terrain traversed, are

TABLE 3.—*Interregional highway standards*

Classification of section	Present average daily traffic density	Type of topography	Cost limitation, desirable standards	Right-of-way width[1]: Minimum, Without border control	Right-of-way width[1]: Minimum, With border control	Right-of-way width[1]: Desirable, Without border control	Right-of-way width[1]: Desirable, With border control	Pavement widths[2]	Shoulder widths[3]: On embankments[4], Minimum permissible	Shoulder widths[3]: On embankments[4], Minimum desirable	Shoulder widths[3]: In excavation,[5] outside of curve or on tangent, Minimum permissible	Shoulder widths[3]: In excavation,[5] outside of curve or on tangent, Minimum desirable	Width of normal median strip[3]: Minimum permissible, Rural humid areas	Width of normal median strip[3]: Minimum permissible, Rural arid areas	Width of normal median strip[3]: Minimum permissible, Suburban areas	Width of normal median strip[3]: Minimum desirable	Curvature[6]: Maximum permissible	Curvature[6]: Maximum desirable	Grades: Maximum permissible	Grades: Maximum desirable
			Dollars	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Degree*	*Degree*	*Percent*	*Percent*
I	Less than 1,000	Relatively level	30,000	200	100	300	100	1–22	8	10	8	8					3	3	3	3
		Rolling	40,000	200	100	300	100	1–22	4	10	4	8					7	3	4.5	3
		Mountainous	60,000	200	100	300	100	1–22	4	10	4	8					10	3	6	3
II	1,000–1,999	Relatively level	40,000	200	[7] 160	300	[7] 160	1–24	8	10	8	8					3	3	3	3
		Rolling	60,000	200	[7] 160	300	[7] 160	1–24	4	10	4	8					7	3	4.5	3
		Mountainous	80,000	200	160	300	160	1–24	4	10	4	8					10	3	6	3
III	2,000–2,999	Relatively level	40,000	200	[7] 160	300	[7] 160	1–24	8	10	8	10					3	3	3	3
		Rolling	60,000	200	[7] 160	300	[7] 160	1–24	4	10	4	8					6	3	4	3
		Mountainous	80,000	200	160	300	160	1–24	4	10	4	8					8	3	5	3
IV	3,000–4,999	Relatively level	100,000	240	240	300	240	2–24	8	10	8	10	32	32	12	43	3	3	3	3
		Rolling	150,000	240	240	300	240	2–24	4	10	4	8	12	6	12	32	6	3	4	3
		Mountainous	200,000	240	240	300	240	2–24	4	10	4	8	6	6	6	25	8	3	5	3
V	5,000–9,999	Relatively level	225,000	240	240	300	240	2–24	8	10	8	10	32	32	12	43	3	3	3	
		Rolling	250,000	240	240	300	240	2–24	8	10	8	10	12	6	12	32	4	3	4	
		Mountainous	300,000	240	240	300	240	2–24	8	10	8	10	6	6	6	25	5	3	5	
VI	10,000 or more	Relatively level	(8)	(8)	(8)	(8)	(8)	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)	3	3	3	
		Rolling															4	3	4	
		Mountainous															5	3	5	

[1] Additional right-of-way to be provided where required to accommodate grading. Border control consists of State control of development of strip of land adjacent to the right-of-way for the purpose of eliminating objectionable features without necessarily preventing cultivation of arable land.
[2] Number and width of individual 2-lane pavements. All multiple parallel 2-lane pavements shall be separated by a median or dividing strip of land
[3] Design of shoulders and median or dividing strips shall be consistent with recommendations contained in A Policy on Highway Types, 1940.
[4] Exclusive of widening for guardrail.
[5] Inside of curves, maintain a uniform distance of 24 feet from centerline of 2-lane highway to toe of cut slope at ditch bottom, except unwidened curves on grade tangents where 22 feet will be permitted. Carry uniform slope from pavement edge to bottom of ditch. Provide comparable widths for 4-lane divided highways. Provide adequate foundation and stabilized surface for all shoulders.
[6] Vertical curves are to be designed as specified in the appendix.
[7] In relatively level and rolling terrain, 100 feet of this width should run continuously on 1 side of centerline.
[8] Special design.
[9] Not specified.

introduced, each carrying a specific cost limitation. These are designated "relatively level," "rolling," and "mountainous."

Wherever construction to desirable standards would exceed these amounts, the standards to be applied are relaxed, but not further than indicated in the column headed "maximum" or "minimum," except in rare instances.

DESIGN STANDARDS DESCRIBED IN DETAIL

Right-of-way widths.—The desirable width of right-of-way for all rural sections is shown to be 300 feet, except where the principles of border control can be employed. Border control consists of State control of development of a strip of land adjacent to the right-of-way for the purpose of eliminating objectionable features without necessarily preventing cultivation of arable land. Agreements for such control may even include an option to buy the adjacent strips at some future time. Where border control can be obtained, the sum of the right-of-way width and the controlled width should be equal to the right-of-way widths shown in the columns headed "without border control." It should be noted that for 2-lane highways, the border control principle will permit reductions in required right-of-way widths to as little as one-third to one-half the width otherwise required, and on such highways, where old alinements are followed, the additional right-of-way width required would often be small.

Where right-of-way costs are abnormally high and border control principles cannot be employed, minimum widths are specified, consisting of 200 feet for 2-lane highways, and 240 feet for 4-lane divided highways.

Pavement widths.—Pavement widths are shown to be 22 feet for traffic densities of less than 1,000 vehicles per day, and 24 feet for traffic densities of 1,000 to 2,999. Divided highways having two roadways each 24 feet in width are specified for traffic densities of 3,000 to 9,999 vehicles per day.

Shoulder and median strip widths.—Shoulder widths of 8 feet in cut and 10 feet in fill are generally specified as desirable. Minimum requirements permit widths of 8 feet in terrain classified as relatively level, and 4 feet in terrain classified as rolling or mountainous.

The design of shoulders and median strips is to be consistent with recommendations contained in A Policy on Highway Types, published by the American Association of State Highway Officials.

Curvature and grades.—Curves of 3 degrees and grades of 3 percent are specified as desirable for all topography and all groups of highway sections and should control the design wherever the estimated cost is less than the limitations appearing in column 4 of table 3. In topography classified as relatively level, no departure from this requirement is permitted, even though the cost should exceed the limitation. For sections carrying less than 1,000 vehicles per day and located in mountainous country, 10-degree curves and 6-percent grades are specified. The standards become increasingly severe for more heavily traveled routes, reaching limits of 5 degrees and 5 percent for mountainous sections carrying more than 5,000 vehicles per day.

Sight distances.—The main controllable features of the highway which restrict sight distances may be classified as cut banks on horizontal curves, and hill crests. At night, sight distance is also limited by the rate of change of the profile elevations in sags, which affects the point at which headlamp rays strike the road surface. At the present time, specifications for lengths of vertical curves in sags are incomplete.

The limiting degree of horizontal curvature must usually be selected on the basis of a number of economic considerations, only one of which is the extent to which desirable sight distances can be provided. Once the specifications for horizontal alinement and cross sections are settled, the sight distances limited by cut banks on horizontal curves are fixed. Obviously, no advantage to the traveling public can be gained by increasing lengths of vertical curves occurring on horizontal curves beyond those lengths required to provide sight distance equal to that afforded by the horizontal curve. There is, therefore, no justification for construction expenditures for this purpose. For sections of the highway located on tangent and short horizontal curves where sight distance is not restricted by cut banks but by hill crests, vertical curves should be designed as described in the Appendix, page 95.

INTERREGIONAL STANDARDS COMPARED WITH EMERGENCY MILITARY STANDARDS

Highway grade separations are to be designed to conform with the recommendations contained in A Policy on Highway Types published by the American Association of State Highway Officials in 1940. For sections of the interregional highway carrying less than 3,000 vehicles per day and designed with two traffic lanes, grade separations are specified for all intersecting highways carrying more than 500 vehicles per day. Grade separations are also to be used at all railroad crossings. Intersecting roads carrying between 200 and 500 vehicles per day at the time the interregional improvement is constructed will cross at grade employing the design principles contained in A Policy on Highway Types and A Policy on Intersections at Grade.

For sections of the interregional system carrying between 3,000 and 10,000 vehicles per day and where a 4-lane divided highway is specified, grade separations are specified at all railroad intersections and at all intersecting highways carrying more than 200 vehicles per day. Intersecting roads carrying less than 200 vehicles per day will cross the interregional road at grade by means of special designs conforming to the recommendations contained in A Policy on Highway Types. For sections of the interregional system carrying more than 10,000 vehicles per day, grade separations are assumed for all railroad intersections and all intersecting highways left open for public use. Minor intersecting roads are to be closed to public use unless more than 200 vehicle-miles per day of additional travel are required for existing traffic to use an adjacent grade separation structure.

The foregoing discussion relates entirely to design standards for complete modernization of the interregional system. It will be interesting to compare these standards with the standards recently specified for emergency conditioning of principal routes of military importance. In these recent emergency standards provision is made for strengthening of weak bridges having ratings of less than H–15, widening of the narrowest bridges having horizontal clearance of less than 18 feet, increasing the vertical clearances of structures now having less than 12½ feet vertical clearance, widening pavements having surfaces less than 18 feet wide, widening shoulders to 8- or 10-foot widths wherever practical and improving surfaces which are not all-weather, dustless, or designed in accordance with present practice of individual States for repeated application of the 9,000-pound pneumatic wheel load.

The emergency standards provide for the improvement of all weak bridges to withstand H–15 loadings in rural areas and H–20 loadings in metropolitan areas. They provide for the increase of all vertical clearances less than 12½ feet to a minimum of 14 feet. Where pavement widening is necessary, specified new pavement widths are 20 feet for sections carrying less than 600 vehicles per day, 22 feet for sections carrying 1,600 to 1,799 vehicles per day, and 24 feet for sections carrying more than 1,800 vehicles per day. Where horizontal clearances on bridges are less than 18 feet, the standards specify their widening to a minimum of 4 feet in excess of the pavement widths specified, and preferably 6 feet in excess of these widths. Where horizontal clearances at underpasses are less than 18 feet, the standards specify their widening to a minimum of 30 feet, and preferably to a width equal to the new pavement widths specified plus shoulder widths.

Except in mountainous terrain where heavy grading is encountered, the standards specify the widening of all shoulders that are now less than 8 feet to a minimum width of 8 feet, and preferably to a width of 10 feet, wherever widening of shoulders can be undertaken economically. Where such widening is financially impractical or where sufficient right-of-way cannot be obtained without difficulty, the standards specify as a minimum requirement that 8- to 10-foot shoulders about 2,000 feet long be provided at 4-mile intervals on the same side of the highway. It is recommended in the standards that such intermittent shoulders be staggered on both sides in order to make emergency parking spaces available in one direction or the other at 2-mile intervals.

COST ESTIMATE BASED ON CLASSIFICATION OF SECTIONS IN ACCORDANCE WITH 1937 TRAFFIC DENSITY

For economic development, the improvement of the system must extend over a period of many years. Many existing sections improved to modern standards provide reasonably adequate service. The wisest course to follow is to improve each section to the interregional standards at the time when it can no longer continue to provide reasonably adequate service. On this basis, the worst sections will be improved first; therefore, sections in low traffic density groups as well as those in high traffic density groups will be placed under construction during the same year.

As the traffic density increases from year to year, the sections will progress from one traffic density group to another. An estimate of cost, therefore, based on a classification of sections in accordance with present-day traffic densities would be low as compared with one which must be developed to represent the actual expenditures required over a period of years. Nevertheless, for planning purposes, an estimate based upon traffic density classifications for a selected year has considerable value in that it can be subdivided by economic regions to show the relative cost, by regions (fig. 14), of the development proposed. These regional costs can be compared with various economic indices to test the soundness of the proposal, and particularly the distribution of the proposed work among the various regions.

FIGURE 14.—CENSUS REGIONS OF THE UNITED STATES.

The cost of improving the rural sections of the interregional system to the design standards recommended, based upon a classification of sections in accordance with 1937 traffic densities, is shown in table 4. Grouped together are all rural sections in each geographic division for which the same number of traffic lanes are recommended. The estimated length of 2-lane sections is 21,237.3 miles, and the estimated construction cost is $1,149,404,000, or $54,100 per mile. The estimated length of 4-lane sections is 4,048.3 miles, and the estimated construction cost is $741,447,000, or $183,100 per mile. The estimated length of sections requiring special designs with more than 4 lanes is 268.6 miles, and the estimated construction cost is $117,887,000, or $438,900 per mile. Right-of-way

TABLE 4.—*Estimated cost of improving rural sections of the interregional system*

Geographic division	Less than 3,000 vehicles per day			3,000 to 10,000 vehicles per day			More than 10,000 vehicles per day			Total length	Total construction cost	15 percent allowance for engineering and contingencies	7.5 percent allowance for right-of-way	Total cost	Total cost per mile
	Length	Cost per mile	Estimated construction cost	Length	Cost per mile	Estimated construction cost	Length	Cost per mile	Estimated construction cost						
	Miles	*1,000 dollars*	*1,000 dollars*	*Miles*	*1,000 dollars*	*1,000 dollars*	*Miles*	*1,000 dollars*	*1,000 dollars*	*Miles*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New England	662. 2	70	46, 354	337. 2	192	64, 742	70. 3	464	32, 619	1, 069. 7	143, 715	21, 557	10, 779	176, 051	165
Middle Atlantic	383. 0	70	26, 810	699. 6	270	188, 892	102. 6	540	55, 404	1, 185. 2	271, 106	40, 666	20, 333	332, 105	280
East North Central	2, 072. 8	60	124, 368	720. 4	173	124, 629	4. 1	433	1, 775	2, 797. 3	250, 772	37, 616	18, 808	307, 196	110
West North Central	3, 516. 6	50	175, 830	233. 4	151	35, 243	4. 3	250	1, 075	3, 754. 3	212, 148	31, 822	15, 911	259, 881	69
South Atlantic	2, 442. 3	55	134, 326	541. 7	162	87, 755	45. 2	350	15, 820	3, 029. 2	237, 901	35, 685	17, 843	291, 429	96
East South Central	1, 873. 1	50	93, 655	128. 9	161	20, 753				2, 002. 0	114, 408	17, 161	8. 581	140, 150	70
West South Central	3, 035. 6	50	151, 780	403. 2	130	52, 416	6. 2	300	1, 860	3, 445. 0	206, 056	30. 909	15, 454	252, 419	73
Mountain	5, 566. 9	50	278, 345	143. 0	133	19, 019				5, 709. 9	297. 364	44, 605	22, 302	364. 271	64
Pacific	1, 684. 8	70	117, 936	840. 9	176	147, 998	35. 9	260	9, 334	2, 561. 6	275, 268	41, 290	20, 645	337. 203	132
United States	21, 237. 3	54	1, 149, 404	4, 048. 3	183	741, 447	268. 6	439	117, 887	25, 554. 2	2. 008. 738	301, 311	150. 656	2, 460. 705	96

TABLE 5.—*Estimated cost of improving urban sections of the interregional system*

Geographic division	Length	Construction cost per mile	Estimated construction cost	15 percent allowance for engineering and contingencies	25 percent allowance for right-of-way	Total cost	Total cost per mile
	Miles	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New England	227.0	807	183,189	27,478	45,797	256,464	1,130
Middle Atlantic	407.1	1,052	428,269	64,240	107,067	599,576	1,473
East North Central	628.4	537	337,451	50,618	84,363	472,432	752
West North Central	452.5	385	174,212	26,132	43,553	243,897	539
South Atlantic	549.9	385	211,712	31.757	52,928	296,397	539
East South Central	320.9	365	117,128	17,569	29,282	163,979	511
West South Central	437.6	319	139,594	20,939	34,898	195,431	447
Mountain	371.5	275	102,162	15,324	25,541	143,027	385
Pacific	381.6	548	209,117	31,368	52,279	292,764	767
United States	3,776.5	504	1,902,834	285,425	475,708	2,663,967	705

costs for rural sections are estimated to be 7.5 percent of the construction costs, and an allowance for engineering and contingencies equal to 15 percent of the construction cost is made.

The estimated cost of improving urban sections is shown in table 5. There are 3,776.5 miles of urban sections, representing 12.9 percent of the total length of the system The estimated construction cost is $1,902,834,000, or $503,900 per mile. Right-of-way costs are estimated to be 25 percent of this amount, and a further allowance of 15 percent of the construction cost is made for engineering and contingencies.

The estimated costs of urban sections are not sufficient to permit construction to theoretically ideal standards, but they are thought to be reasonable estimates of probable costs which would result from a general program aimed toward providing facilities as nearly approaching the ideal standards as practical, after reasonable compromises had been made. As one test of the consistency of the estimates for individual cities, the costs were reduced to a per capita basis. The estimates showed that per capita costs in large cities were lower than those in small cities. That this should be so is obvious when it is considered that the service rendered to a city by merely projecting the routes of the interregional system through it varies inversely with the population. This condition implies that attention should be directed to the need for extensive city development, which can be accomplished only in small part by the construction of the transcity connections of the interregional system. It emphasizes the fact that the larger the area of local congestion, the less is the amount of relief to be obtained merely by development of the system.

Even though the urban cost, including an allowance for right-of-way, exceeds the rural cost, this urban cost is estimated to be only about one-fifth of the expenditure which must be made to modernize completely all the main connecting thoroughfares in the cities traversed. Unless these additional and greater expenditures are made, the investment in the interregional route is threatened by the rapid obsolescence of urban portions of improved interregional routes which may be anticipated as a result of their attracting a disproportionately large share of traffic. This would probably lead to the outward development of the city further than would prove most economical to its interests. Only by construction of comparable facilities in other directions can the economic growth of cities, and the success of the interregional system itself, be assured.

In sharp contrast to the cost estimates for the improvement of the interregional system to recommended standards is the cost estimate for its improvement to the standards recently specified for the emergency improvement of principal routes of military importance. Table 6 shows that the estimated cost of improving rural sections to recommended standards is about six times the cost of improvement to emergency standards. Although a cost estimate on the latter basis was not prepared for urban sections, it would not seem unreasonable to assume that the same relationship would exist between estimates prepared for the urban sections as is shown for the rural sections.

DISTRIBUTION OF SYSTEM COMPARED WITH VARIOUS ECONOMIC INDICES

The report Toll Roads and Free Roads suggests that the routes of the system be selected "without specific limitation in each State." Although the system described in this paper was selected on the basis of present traffic service to population concentrations and with particular reference to interregional coverage, it may be well to present certain economic facts and see how the selected tentative system measures up to these facts.

TABLE 6.—*A comparison of the estimated cost of emergency work with the estimated cost of improvement to recommended long-range standards for rural sections of the interregional system*

Geographic division	Length of rural sections	Estimated construction cost of improving interregional system		Ratio of cost of emergency work to the cost based on long-range standards
		Using recommended long-range standards	Using standards recommended for emergency work	
	Miles	*1,000 dollars*	*1,000 dollars*	*Percent*
New England	1,069.7	143,715	21,799	15.2
Middle Atlantic	1,185.2	271,106	18,548	6.8
East North Central	2,797.3	250,772	25,690	10.2
West North Central	3,754.3	212,148	52,206	24.6
South Atlantic	3,029.2	237,901	57,170	24.0
East South Central	2,002.0	114,408	33,220	29.0
West South Central	3,445.0	206,056	54,351	26.4
Mountain	5,709.9	297,364	66,116	22.2
Pacific	2,561.6	275,268	36,557	13.3
United States	25,554.2	2,008,738	365,657	18.2

Table 7 shows the population, area, national wealth, national income, cash farm income, value of manufactures, and value of mineral production, distributed by geographic divisions. Table 8 shows these same values expressed in terms of the percentage falling in each of the geographic divisions. Columns are included showing the portion of the length and the cost of the interregional system within each geographic division. The distribution is made on the basis of the rural sections, the urban sections, and also on the

TABLE 7.—*Selected economic data by geographic divisions*

Geographic division	Population 1940 [1]	Area 1930 [2]	National wealth 1936 [3]	National income 1937 [3]	Cash farm income 1939 [4]	Value of manufactures 1937 [5]	Value of mineral production 1937 [6]
		Square miles	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
New England	8, 426, 566	61, 976	22, 615, 000	5, 459, 000	246, 500	5, 109, 927	24, 757
Middle Atlantic	27, 419, 893	100, 000	87, 613, 000	19, 209, 000	672, 600	16, 596, 004	708, 951
East North Central	26, 550, 823	245, 564	64, 841, 000	15, 978, 000	1, 540, 900	19, 971, 022	453, 745
West North Central	13, 490, 492	510, 804	29, 341, 000	6, 071, 000	1, 841, 000	4, 091, 727	417, 055
South Atlantic	17, 771, 099	269, 073	27, 049, 000	6, 979, 000	789, 600	5, 403, 450	406, 084
East South Central	10, 762, 967	179, 509	11, 479, 000	2, 858, 000	471, 800	1, 977, 318	220, 658
West South Central	13, 052, 218	429, 746	17, 363, 000	4, 569, 000	847, 200	2, 693, 027	1, 388, 412
Mountain	4, 128, 042	859, 009	10, 663, 000	1, 974, 000	506, 300	928, 951	543, 091
Pacific	9, 682, 781	318, 095	23, 517, 000	6, 322, 000	795, 100	3, 938, 627	510, 243
United States	131, 409, 881	2, 973, 776	294, 481, 000	69, 419, 000	7, 711, 000	60, 710, 053	4, 672, 996

[1] Preliminary figures issued by the United States Bureau of the Census, total includes 125,000 undistributed.
[2] Figures issued by the United States Bureau of the Census.
[3] National Industrial Conference Board Studies in Enterprise and Social Progress, pp. 62, 117.
[4] Crops and Markets, January 1940.
[5] United States Department of Commerce, report dated Jan. 31, 1940.
[6] Minerals Yearbook, 1939, p. 9.

TABLE 8.—*Geographical distribution of the length and estimated cost of the interregional system in relation to various economic indices*

Geographic division	Population 1940 [1]	Area 1930 [2]	National wealth 1936 [3]	National income 1937 [3]	Cash farm income 1939 [4]	Value of manufactures 1937 [5]	Value of mineral production 1937 [6]	Length of interregional system			Estimated cost of interregional system			Estimated cost of improving rural sections of system to "emergency" standards
								Rural sections	Urban sections	All sections	Rural sections	Urban sections	All sections	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
New England	6. 4	2. 1	7. 7	7. 9	3. 2	8. 4	0. 6	4. 2	6. 0	4. 4	7. 1	9. 6	8. 5	5. 9
Middle Atlantic	20. 9	3. 4	29. 7	27. 7	8. 7	27. 3	15. 2	4. 6	10. 8	5. 4	13. 5	22. 5	18. 2	5. 1
East North Central	20. 2	8. 2	22. 0	23. 0	20. 0	32. 9	9. 7	11. 0	16. 6	11. 7	12. 5	17. 7	15. 2	7. 0
West North Central	10. 3	17. 2	10. 0	8. 7	23. 9	6. 8	8. 9	14. 7	12. 0	14. 4	10. 6	9. 2	9. 8	14. 3
South Atlantic	13. 5	9. 0	9. 2	10. 1	10. 2	8. 9	8. 7	11. 9	14. 6	12. 2	11. 8	11. 1	11. 5	15. 6
East South Central	8. 2	6. 0	3. 9	4. 1	6. 1	3. 3	4. 7	7. 8	8. 5	7. 9	5. 7	6. 2	5. 9	9. 1
West South Central	9. 9	14. 5	5. 9	6. 6	11. 0	4. 4	29. 7	13. 5	11. 6	13. 2	10. 3	7. 3	8. 7	14. 9
Mountain	3. 2	28. 9	3. 6	2. 8	6. 6	1. 5	11. 6	22. 3	9. 8	20. 7	14. 8	5. 4	9. 9	18. 1
Pacific	7. 4	10. 7	8. 0	9. 1	10. 3	6. 5	10. 9	10. 0	10. 1	10. 1	13. 7	11. 0	12. 3	10. 0
United States	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0

[1] Preliminary figures issued by the United States Bureau of the Census.
[2] Figures issued by the United States Bureau of the Census.
[3] National Industrial Conference Board Studies in Enterprise and Social Progress, pp. 62, 117.
[4] Crops and Markets, January 1940.
[5] United States Department of Commerce, report dated Jan. 31, 1940.
[6] Minerals Yearbook, 1939, p. 9.

basis of the rural and urban sections combined. For purposes of comparing the cost of the work that would be done in each region following the long-range recommended standards with the cost of the work that would be done following the emergency standards, the column on the extreme right has also been added which shows the distribution of the costs of the emergency work.

Figure 15 shows this same comparison graphically. To the left of the group of plotted values for each geographic division, the general economic indices are grouped. The value plotted to the extreme left is the percentage of the United States population that falls within the geographic division; next is the percentage of the area; third, the percentage of the national wealth; fourth, the percentage of the national income; fifth, the percentage of the national cash farm income, sixth, the percentage of the national value of manufactures, and finally, the percentage of the national value of mineral production. The next group of plotted values shows the percentage of the length of the interregional system falling within the geographic division. In this group, the value to the left represents the percentage of the length of all rural sections, and the one on the right represents the percentage of the total length including both rural and urban sections, and the mid-section represents the percentage of all urban sections. The third group of plottings shows the percentage of the estimated cost of the interregional system falling within the geographic division. The value to the left shows the percentage of the cost of all rural sections, and one on the right shows the percentage of the total cost including both rural and urban sections. The single value plotted on the extreme right for each geographic division represents the percentage of the estimated total cost of improvement of rural sections to emergency standards.

It will be noted that the distribution of mileage does not always compare favorably with the various economic indices. However, the distribution of costs of construction to long-range standards in all such cases tends to correct this condition. The level of the plotted values for rural costs alone is usually nearer the level of the economic indices, and the level of the plotted values for total costs is still nearer. The conclusion may be drawn that the system selected on the basis of present traffic service to population concentrations is well distributed on a general economic basis.

The levels of the plotted values representing the percentage distribution of the estimated cost of improvement of rural sections to emergency standards, when compared with the levels of the economic indices, is not so favorable. This is caused by the fact that in working to emergency standards, the same degree of improved service cannot be afforded throughout the country. Only the worst conditions can be remedied.

Table 9 shows the distribution to geographic divisions

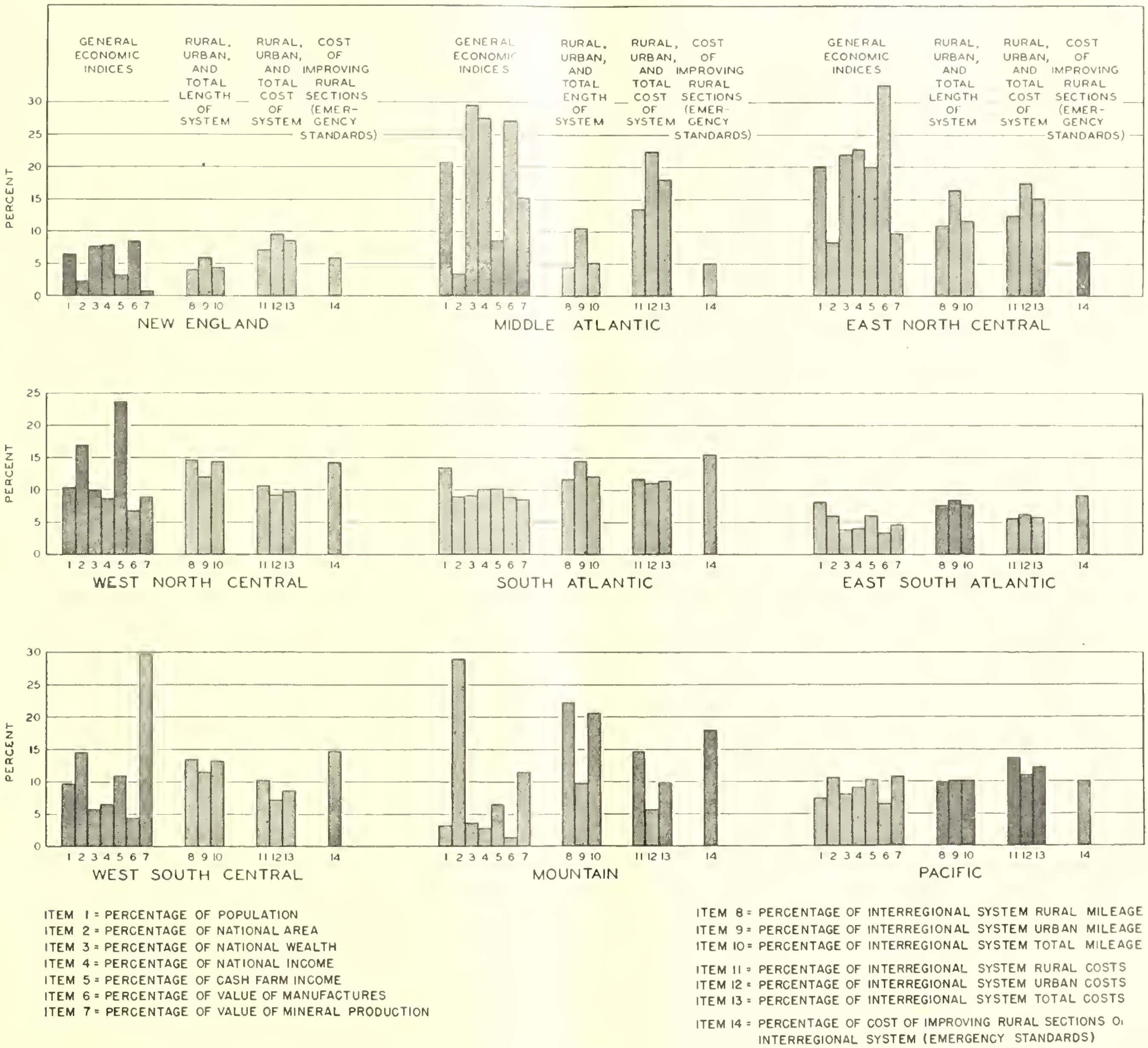

FIGURE 15.—GEOGRAPHICAL DISTRIBUTION OF THE LENGTH AND ESTIMATED COST OF THE TENTATIVELY SELECTED INTERREGIONAL HIGHWAY SYSTEM IN RELATION TO VARIOUS ECONOMIC INDICES.

TABLE 9.—*Pertinent highway facts and figures by geographic divisions*

Geographic division	Federal-aid apportionments 1941	Mileage of rural highways[1]	Mileage of urban streets and alleys [2]	Total mileage of roads, streets and alleys	Motor-vehicle registrations 1939 [3]	State highway income 1939 [4]
	1,000 dollars	*Miles*	*Miles*	*Miles*	*Vehicles*	*1,000 dollars*
New England	7, 134	82, 364	14, 591	96, 955	1, 944, 510	91, 450
Middle Atlantic	17, 781	187, 494	47, 802	235, 296	5, 813, 487	187, 911
East North Central	25, 364	438, 311	67, 033	505, 344	7, 078, 336	195, 464
West North Central	25, 390	765, 604	49, 706	815, 310	3, 862, 461	115, 000
South Atlantic	19, 754	333, 472	33, 288	366, 760	3, 274, 027	185, 365
East South Central	12, 190	238, 832	16, 758	255, 590	1, 458, 731	94, 041
West South Central	18, 486	380, 273	34, 128	414, 401	2, 800, 053	118, 104
Mountain	17, 253	333, 050	14, 178	347, 228	1, 210, 838	66, 260
Pacific	11, 010	194, 967	26, 336	221, 303	3, 565, 177	90, 469
United States	154, 362	2, 954, 367	303, 820	3, 258, 187	31, 007, 620	1, 144, 064

[1] Figures compiled in January 1941 by Public Roads Administration and based on latest inventory data or estimates furnished by the State-wide Highway Planning Surveys.

[2] Estimates compiled in January 1941 by Public Roads Administration from fiscal data collected by the State-wide Highway Planning Surveys.

[3] Figures include publicly owned, private and commercial motor vehicles. Figures do not include trailers, semitrailers, or motorcycles, nor 2,250 motor vehicles publicly owned and not registered in any State, compiled from reports of State authorities.

[4] Figures include transactions relating to debt service, operations of special bridge and grade separation authorities, expenditures of local authorities on State highways, and similar transactions.

TABLE 10.—*Geographical distribution of the length and estimated cost of the interregional system in relation to various highway factors*

Geographic division	Federal-aid apportionments 1941	Mileage of rural highways [1]	Mileage of urban streets and alleys [2]	Total mileage of roads, streets and alleys	Motor-vehicle registrations 1939 [3]	State highway income 1939 [4]	Length of interregional system			Estimated cost of interregional system			Estimated cost of improving rural sections of system to "emergency" standards
							Rural sections	Urban sections	All sections	Rural sections	Urban sections	All sections	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
New England	4.6	2.8	4.8	3.0	6.3	8.0	4.2	6.0	4.4	7.1	9.6	8.5	5.9
Middle Atlantic	11.5	6.3	15.7	7.2	18.7	16.4	4.6	10.8	5.4	13.5	22.5	18.2	5.1
East North Central	16.4	14.8	22.0	15.5	22.8	17.1	11.0	16.6	11.7	12.5	17.7	15.2	7.0
West North Central	16.5	25.9	16.4	25.0	12.5	10.1	14.7	12.0	14.4	10.6	9.2	9.8	14.3
South Atlantic	12.8	11.3	11.0	11.3	10.6	16.2	11.9	14.6	12.2	11.8	11.1	11.5	15.6
East South Central	7.9	8.1	5.5	7.8	4.7	8.2	7.8	8.5	7.9	5.7	6.2	5.9	9.1
West South Central	12.0	12.9	11.2	12.7	9.0	10.3	13.5	11.6	13.2	10.3	7.3	8.7	14.9
Mountain	11.2	11.3	4.7	10.7	3.9	5.8	22.3	9.8	20.7	14.8	5.4	9.9	18.1
Pacific	7.1	6.6	8.7	6.8	11.5	7.9	10.0	10.1	10.1	13.7	11.0	12.3	10.0
United States	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Figures compiled in January 1941 by Public Roads Administration and based on latest inventory data or estimates furnished by the State-wide Highway Planning Surveys.
[2] Estimates compiled in January 1941 by Public Roads Administration from fiscal data collected by the State-wide Highway Planning Surveys.
[3] Figures include publicly owned, private, and commercial motor vehicles. Figures do not include trailers, semitrailers, motorcycles, or 2,250 motor vehicles publicly owned and not registered in any State, compiled from reports of State authorities.
[4] Figures include transactions relating to debt service, operations of special bridge and grade separation authorities, expenditures of local authorities on State highways and similar transactions.

of highway factors. These items include the 1941 Federal-aid apportionments, the total rural highway mileage, the mileage of urban streets and alleys, the total mileage of roads, streets, and alleys, the 1939 motor vehicle registrations, and the State highway departments' income in 1939. In table 10 these items are expressed in terms of the percentage which falls in each geographic division, and are compared with the portions of the length and the cost of the interregional system falling within each division. Figure 16 shows these same relationships graphically.

BOTH FREIGHT AND PASSENGER VEHICLES MAKE EXTENSIVE USE OF SYSTEM

Freight vehicles.—Close estimates of the use of the rural interregional highways by commercial freight vehicles and the tonnage hauled may be obtained for each State from the average daily commercial traffic per mile, the mileage of the system, the average load carried by commercial vehicles, and the percentage of total commercial vehicles that were loaded. All of these data are produced by the highway planning surveys.

Table 11 shows the mileage of rural interregional highways and the average daily ton-mileage of goods carried by commercial vehicles for each region. The commercial vehicle-mileage of loaded vehicles by States multiplied by average carried load is the basis of these estimates.

The relative use of rural interregional highways varies widely between regions of the country. In the Mountain Region average daily ton-miles per mile of highway are 314, as compared with 840 ton-miles per mile for the country as a whole. Vehicle loadings in the Mountain Region are not below average, but the number of commerical vehicles per mile is lower than in any other region.

In the West South Central Region (Arkansas, Louisiana, Oklahoma, and Texas) the average vehicle load is less than in the Mountain Region, but because the average number of commerical vehicles using the highways in the West South Central Region is higher, the average daily ton-miles per mile is larger than in the Mountain Region.

Ton-miles per mile are greatest in the East North Central Region (Ohio, Indiana, Illinois, Michigan, and Wisconsin). In this region the average number of commercial vehicles is high, and the average carried load per vehicle exceeds that in any other region.

TABLE 11.—*Estimated average daily ton-miles and ton-miles per mile on the tentative rural interregional system in 1938*

Geographic division	Miles	Average daily ton-miles	Daily ton-miles per mile
New England	1,070	1,300,595	1,215
Middle Atlantic	1,185	1,502,850	1,268
East North Central	2,797	4,232,944	1,513
West North Central	3,754	2,534,761	675
South Atlantic	3,029	3,696,614	1,220
East South Central	2,002	1,459,229	728
West South Central	3,445	2,004,491	581
Mountain	5,710	1,794,613	314
Pacific	2,562	2,930,045	1,144
United States	25,554	21,456,142	840

The average daily ton-miles for the country carried by motor vehicles on the tentative rural interregional system totals 21,456,000; on an annual basis the system is estimated to carry 7,831,000,000 ton-miles. Total truck ton-miles of carried load for all rural highways, exclusive of purely local haulage, are estimated at approximately 57 billion in 1939.[2] Thus, the rural interregional highway system, comprising 25,554 miles or less than 1 percent of the rural highway mileage of the United States, carries approximately 14 percent of the total truck ton-miles of carried load generated upon all rural highways.

Passenger cars.—Estimates of the use of the rural interregional highways by passenger cars are obtained from the highway planning surveys. These data are presented in table 12, together with a compilation of the passenger-car miles per mile.

As in the case of freight vehicles, the use of the tentative rural interregional system by passenger cars varies widely by regions; in fact, the variation between regions is much wider than in the case of freight vehicles. In the South Atlantic Region, for example, freight-

[2] Estimated from data furnished by the highway planning surveys.

FIGURE 16.—GEOGRAPHICAL DISTRIBUTION OF THE LENGTH AND ESTIMATED COST OF THE TENTATIVELY SELECTED INTERREGIONAL HIGHWAY SYSTEM IN RELATION TO THE GEOGRAPHICAL DISTRIBUTION OF VARIOUS HIGHWAY FACTORS.

vehicle use per mile of the interregional system is 45 percent more than the average for the United States, while passenger-car use per mile in the South Atlantic Region is but 13 percent more than the average for the United States.

Again, in the Middle Atlantic Region the passenger-car use per mile exceeds the average for the Nation by 154 percent, while freight-vehicle use per mile exceeds the average for the Nation by but 51 percent.

Thus, the road use by freight vehicles, although the range is considerable, tends to be much more uniformly distributed by regions than is the case in passenger-car use.

Total passenger-car miles in 1938 for all rural roads in the United States, derived from the road-use surveys, are estimated at 146 billion. Passenger-car use of the interregional system, from table 12, is 14,948 million passenger-car miles, or approximately 10 percent of passenger-car use of all rural roads of the country.

TABLE 12.—*Estimated average daily passenger-ear miles and passenger-ear miles per mile on the tentative rural interregional highway system in 1938*

Geographic division	Miles	Average daily passenger-car miles	Passenger-car miles per mile [1]
New England	1,070	3,024,787	2,827
Middle Atlantic	1,185	4,833,445	4,079
East North Central	2,797	5,655,758	2,022
West North Central	3,754	4,594,484	1,224
South Atlantic	3,029	5,485,726	1,811
East South Central	2,002	2,461,876	1,230
West South Central	3,445	4,844,882	1,406
Mountain	5,710	4,073,109	713
Pacific	2,562	5,979,161	2,334
United States	25,554	40,953,228	1,603

[1] Does not include busses. Variation in bus loading and the fact that busses are less than 1 percent of all vehicles make estimates of bus-miles impractical.

TABLE 13.—*Motor-vehicle taxes and other highway-user costs, 1934–39* [1]

Year	Net total motor-fuel tax receipts [2]	Motor-vehicle registration receipts [3]	Motor-carrier tax receipts [4]	Federal excise taxes paid by highway users [5]	Bridge and tunnel tolls [6]	Ferry tolls [6]	Total [7]
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
1934	566, 642	307, 260	9, 402	235, 743	46, 693	15, 151	1, 180, 891
1935	619, 677	322, 974	12, 421	256, 671	49, 375	16, 021	1, 277, 139
1936	691, 420	359, 783	15, 137	297, 142	53, 600	17, 392	1, 434, 474
1937	761, 998	399, 613	16, 216	326, 515	57, 082	18, 522	1, 579, 946
1938	771, 764	388, 825	16, 421	267, 959	57, 424	18, 633	1, 521, 026
1939	821, 656	412, 494	18, 055	320, 373	60, 621	19, 670	1, 652, 869

[1] Compiled by Public Roads Administration.
[2] Figures include distributors' and dealers' licenses, inspection fees, fines and penalties, and otber similar miscellaneous receipts.
[3] Figures include motor-vehicle registration fces, dealers' license plates, operators' and cbauffeurs' permits, certificates of title, special titling taxes, fines and penalties, transfers or registration fees, and otber similar miscellaneous receipts.
[4] Figures include receipts from gross receipt taxes; mileage, ton-mile and passenger-mile taxes; weigbt, capacity or flat-rate taxes, certificate or permit fees, caravan taxes, and other similar miscellaneous receipts.
[5] Figures include the estimated portion of taxes on gasoline paid by bighway users (90.5 percent), the estimated portion of taxes on lubricating oil paid by highway users (58.0 percent) and the taxes collected on tires, tubes, automobiles, motorcycles, trucks, parts, and accessories.
[6] Figures compiled for year of 1937 and estimates for previous and later years made on the basis of the relative values of gasoline consumption and motor-vebicle registration for these years.
[7] Totals do not include road tolls, municipal or county fees or licenses applicable to motor vebicles, or personal property taxes on motor vehicles. Reliable estimates of tbese figures were not available.

TABLE 14.—*Percentage of motor-vehicle taxes and other highway user costs for 1934 to 1939 from each source* [1]

Year	Net total motor-fuel tax receipts [2]	Motor-vehicle registration receipts [3]	Motor-carrier tax receipts [4]	Federal excise taxes paid by highway users [5]	Bridge and tunnel tolls [6]	Ferry tolls [6]	Total [7]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1934	48. 0	26. 0	0. 8	20. 0	4. 0	1. 2	100. 0
1935	48. 5	25. 3	1. 0	20. 0	3. 9	1. 3	100. 0
1936	48. 2	25. 1	1. 1	20. 7	3. 7	1. 2	100. 0
1937	48. 2	25. 3	1. 0	20. 7	3. 6	1. 2	100. 0
1938	50. 7	25. 6	1. 1	17. 6	3. 8	1. 2	100. 0
1939	49. 7	24. 9	1. 1	19. 4	3. 7	1. 2	100. 0
Average	49. 0	25. 3	1. 0	19. 7	3. 8	1. 2	100. 0

[1] Compiled by Public Roads Administration.
[2] Figures include distributors' and dealers' licenses, inspection fees, fines, and penalties, and other similar miscellaneous receipts.
[3] Figures include motor-vehicle registration fees, dealers' license plates, operators' and cbauffeurs' permits, certificates of title, special titling taxes, fines and penalties, transfers or registration fees, and other similar miscellaneous receipts.
[4] Figures include receipts from gross receipt taxes; mileage, ton-mile and passenger-mile taxes; weight, capacity or flat-rate taxes; certificate or permit fees; caravan taxes; and other similar miscellaneous receipts.
[5] Figures include the estimated portion of taxes on gasoline paid by highway users (90.5 percent), the estimated portion of taxes on lubricating oil paid by bighway users (58.0 percent) and the taxes collected on tires, tubes, automobiles, motorcycles, truck, parts, and accessories.
[6] Figures compiled for year of 1937 and estimates for previous and later years made on the basis of the relative values of gasoline consumption and motor-vebicle registration for these years.
[7] Totals do not include road tolls, municipal or county fees or licenses applicable to motor vehicles, or personal property taxes on motor vehicles. Reliable estimates of these figures were not available.

MOTOR-VEHICLE TAXES AMOUNT TO 0.582 CENTS PER VEHICLE-MILE

A highway, like an automobile, earns nothing except when used for transportation service. The more the road is used, the greater are its earnings. These earnings come from various highway-user charges, the more important of which are the motor-fuel taxes, registration fees, and Federal excise taxes. Motor-carrier taxes and tolls comprise a small portion of the cost of operating motor vehicles over the highways. Tables 13 and 14 show these data for the years 1934 to 1939, inclusive.

While the data contained in these two tables are useful for the country as a whole, there is no published information showing the earning power of individual roads. Such information must be calculated from various data such as the vehicle-miles of travel on the road, gallons of gasoline consumed, the rate of gasoline taxes, and the relation between gasoline taxes and other motor-vehicle taxes.

The Public Roads Administration has estimated that in 1939 there was a total of 287,747.5 million vehicle-miles of travel by all kinds of motor vehicles, and that the gasoline consumed amounted to 22,685,056,000 gallons, of which motor vehicles utilized 91.40 percent, or 20,735,120,000 gallons. On this basis a motor vehicle traveled on the average 13.88 miles while consuming 1 gallon of gasoline. This mileage figure represents a weighted average of gasoline consumption by all kinds of motor vehicles used on city streets and on highways.

From table 14 it is shown that the average of the gasoline tax during the 6 years, 1934–39, constituted 49.0 percent of all motor-vehicle taxes for those years. The Public Roads Administration has also calculated that the weighted average State gasoline tax for the country in 1939 was 3.96 cents per gallon. On this basis the total motor-vehicle taxes collected on a motor vehicle while consuming 1 gallon of gasoline amount to 8.08 cents. By dividing the total taxes collected on a motor vehicle while consuming 1 gallon of gasoline by the total distance traveled, the total tax burden on a motor vehicle per mile is obtained. This amounts to 0.582 cent.

Table 15 shows the annual earnings of rural sections of the tentative interregional system grouped in accordance with geographic divisions and 1937 traffic densities, based upon this rate of 0.582 cent per vehicle-mile. A more detailed study of tax rates by regions would make possible some refinement of the regional earnings.

The earnings have been reduced to a per mile basis in order to compare later the annual cost of each section with its earning capacity.

The annual earnings during the lifetime of an im-

TABLE 15.—*Approximate earnings*[1] *of rural sections of the interregional highway system for the year 1937*

Geographic division	Sections carrying less than 3,000 vehicles per day				Sections carrying more than 3,000 vehicles but less than 10,000 vehicles per day				Sections carrying 10,000 or more vehicles per day				All sections			
	Length	Daily traffic	Annual earnings		Length	Daily traffic	Annual earnings		Length	Daily traffic	Annual earnings		Length	Daily traffic	Annual earnings	
			Total	Per mile			Total	Per mile			Total	Per mile			Total	Per mile
	Miles	*1,000 vehicle-miles*	*1,000 dollars*	*Dollars*	*Miles*	*1,000 vehicle-miles*	*1,000 dollars*	*Dollars*	*Miles*	*1,000 vehicle-miles*	*1,000 dollars*	*Dollars*	*Miles*	*1,000 vehicle-miles*	*1,000 dollars*	*Dollars*
New England	662.2	690	1,466	2,210	337.2	2 038	4,329	12,840	70.3	1,103	2,343	33,330	1,069.7	3,831	8,138	7,610
Middle Atlantic	383.0	808	1,716	4,480	699.6	3,682	7,822	11,180	102.6	1,205	2,560	24,950	1,185.2	5,695	12,098	10,210
East North Central	2,072.8	3,915	8,317	4,010	720.4	3,193	6,783	9,420	4.1	45	96	23,410	2,797.3	7,153	15,196	5,430
West North Central	3,516.6	4,761	10,114	2,880	233.4	1,047	2,224	9,530	4.3	53	113	26,280	3,754.3	5,861	12,451	3,320
South Atlantic	2,442.3	3,848	8,174	3,350	541.7	2,579	5,479	10,110	45.2	630	1,338	29,600	3,029.2	7,057	14,991	4,950
East South Central	1,873.1	2,729	5,797	3,090	128.9	541	1,149	8,910	-------	-------	-------	-------	2,002.0	3,270	6,946	3,470
West South Central	3,035.6	4,489	9,536	3,140	403.2	1,667	3,541	8,780	6.2	66	140	22,580	3,445.0	6,222	13,217	3,840
Mountain	5,566.9	4,494	9,547	1,710	143.0	600	1,275	8,920	-------	-------	-------	-------	5,709.9	5,094	10,822	1,900
Pacific	1,684.8	2,334	4,958	2,940	840.9	4,344	9,228	10,970	35.9	396	841	23,430	2,561.6	7,074	15,027	5,870
United States	21,237.3	28,068	59,625	2,810	4,048.3	19,691	41,830	10,330	268.6	3,498	7,431	27,670	25,554.2	51,257	108,886	4,260

[1] The earnings are based on a rate of 0.582 cent per vehicle-mile, which is the estimated rate for the period 1934–39.

provement greatly exceed the present earnings of an existing highway because of diverted traffic, generated traffic, and the normal rate of increase in traffic. The extent of the influence of each of these three factors will vary considerably with the region, the proximity to urban areas, the type of service rendered, etc. Such variations must be ignored in this paper, and general assumptions must be made for the country as a whole. It seems conservative to estimate that at the time an average rural section is improved to rural standards, the increase in traffic resulting from diversion would be approximately 10 percent, and generated traffic would be approximately 5 percent of the existing traffic. During the lifetime of the improvement, assuming an average life of 30 years, the normal rate of increase in traffic should be such that the average traffic during the entire period should be at least 50 percent greater than the traffic using it during the first year the improved facility is in operation. The average traffic during the lifetime of the improvement would, on the basis of these assumptions, be equal to 150 percent times 110 percent times 105 percent of the traffic using the existing highway, or approximately 173 percent.

The design standards to be applied are controlled by the traffic density of the particular section, adjusted to include traffic which will be diverted to the improvement. The improvements on the system are to extend over a period of years, and the distribution of the rural sections among the various traffic-density groups will shift materially by the time reconstruction of all sections has taken place. Some of the sections constructed in later years would still have earnings comparable with improvement costs after the life of some of the first sections had expired. For these reasons, the total earning capacity of the system would have to be estimated on a very complicated basis, requiring many assumptions. However, the total earning capacity of the system need not be known in comparing the costs with the earnings. If it can be shown that there is a favorable ratio of earnings to costs for any section regardless of which traffic density group it may happen to fall in at the time of its improvement, the ratio of earnings to costs for the system would also have to be favorable.

For a section falling within any one of three major traffic density groups, when classified on the basis of its traffic density, adjusted to include diverted traffic, the average annual earnings per mile and per vehicle-mile during the lifetime of the improvement are shown in table 16, it being assumed that the influence of generated traffic and the normal rate of increase combined would be equal to 105 percent times 150 percent or 157 percent. In this same table there is also shown the amount to which these earnings would accumulate during a period of 30 years, which is assumed to be the average life of the improvements. These earnings per mile would, of course, shift to higher or lower levels if the improvement program were carried on in such a manner that the average adjusted initial traffic density of all sections selected for improvement within any density group were allowed to depart from the 1937 determined average traffic density of that group. An increase can hardly be avoided for the lower traffic density group, but, theoretically, the levels for the intermediate and high traffic density groups could be maintained. Difficulties arising from shifts in levels can be avoided by confining appraisals of earnings to a vehicle-mile basis. The vehicle-mile basis also applies just as well to one geographic division as to another, whereas the earnings per mile within any density group for a geographic division and for the 30-year period following improvement cannot be estimated reliably without exhaustive study.

TABLE 16.—*Average earnings of rural sections of the tentative interregional highway system*[1]

Initial traffic density adjusted to include traffic which would be attracted by the improvement	Annual earnings for adjusted initial traffic density		Average annual earnings for 30-year period after improvement		Total earnings for 30-year period after improvement	
	Per mile	Per 1,000 vehicle-miles	Per mile	Per 1,000 vehicle-miles	Per mile	Per 1,000 vehicle-miles
Less than 3,000	$2,810	$5.82	$4,410	$5.82	$132,300	$5.82
3,000–9,999	10,330	5.82	16,220	5.82	486,600	5.82
10,000 and over	27,670	5.82	43,440	5.82	1,303,200	5.82

[1] It is assumed that the average traffic density for the 30-year period will be 157 percent of the initial traffic density adjusted to include traffic which would be attracted by the improvement.

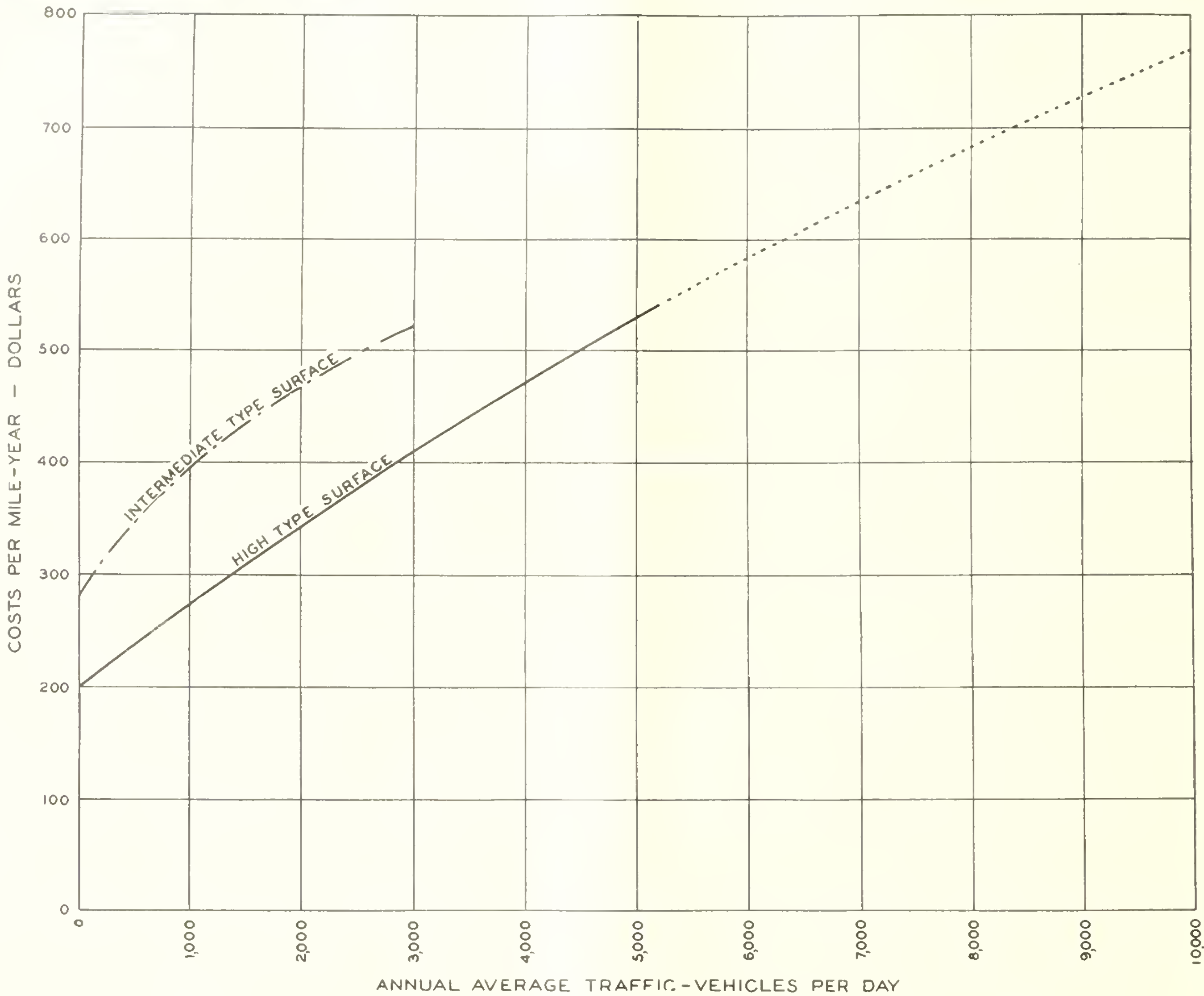

FIGURE 17.—AVERAGE MAINTENANCE COSTS PER MILE FOR VARIOUS TRAFFIC DENSITIES.

IMPROVEMENT, MAINTENANCE, AND OPERATION COSTS DISCUSSED

The estimated cost of improving and operating the system must include suitable allowances for administration, maintenance, operation, and policing, in addition to the cost of the improvements. The cost of improvements actually includes the initial cost, the cost of emergency reconstruction caused by floods, slides, etc., the cost of widening some of the sections where the rate of traffic increase is abnormally high, etc. Allowances for these various classes of construction may be made either in a direct manner or they may be made by considering the average life of the improvements to be a little shorter than the anticipated life of those sections not requiring any reconstruction. The latter basis is preferred, and it is assumed that an average life of 30 years for sections built to the recommended standards is reasonable for the shortened life.

Estimated maintenance costs are based on the unit costs shown in figures 17 and 18. These curves were drawn through the field of points obtained by plotting the maintenance cost data reported in Public Aids to Transportation, Volume IV.[3] The curves for the intermediate-type roads were carried no further than the 3,000 average traffic density ordinate, because it is assumed that any intermediate type surfaces would not be placed on sections carrying more than this number of vehicles. The portion of the curves for the high-type surfaces shown by means of dashed lines was projected for high-traffic densities beyond the range of the plotted points.

The curves should not be considered applicable to 4-lane highways but merely as indicative of the extent to which maintenance costs on 2-lane highways vary with traffic densities up to 5,500 vehicles per day. Beyond this traffic density the dashed curves should be regarded as theoretical projections of the trend in the maintenance costs which might logically be used as a measure of the rate of change in maintenance costs on 4-lane divided highways. The 4-lane highway maintenance costs would obviously be at some higher level. Considering the fact that most of the heavier traveled sections requiring 4-lane treatment will be located where more than usual attention must be paid

[3] Published by Section of Research, Federal Coordinator of Transportation, 1940.

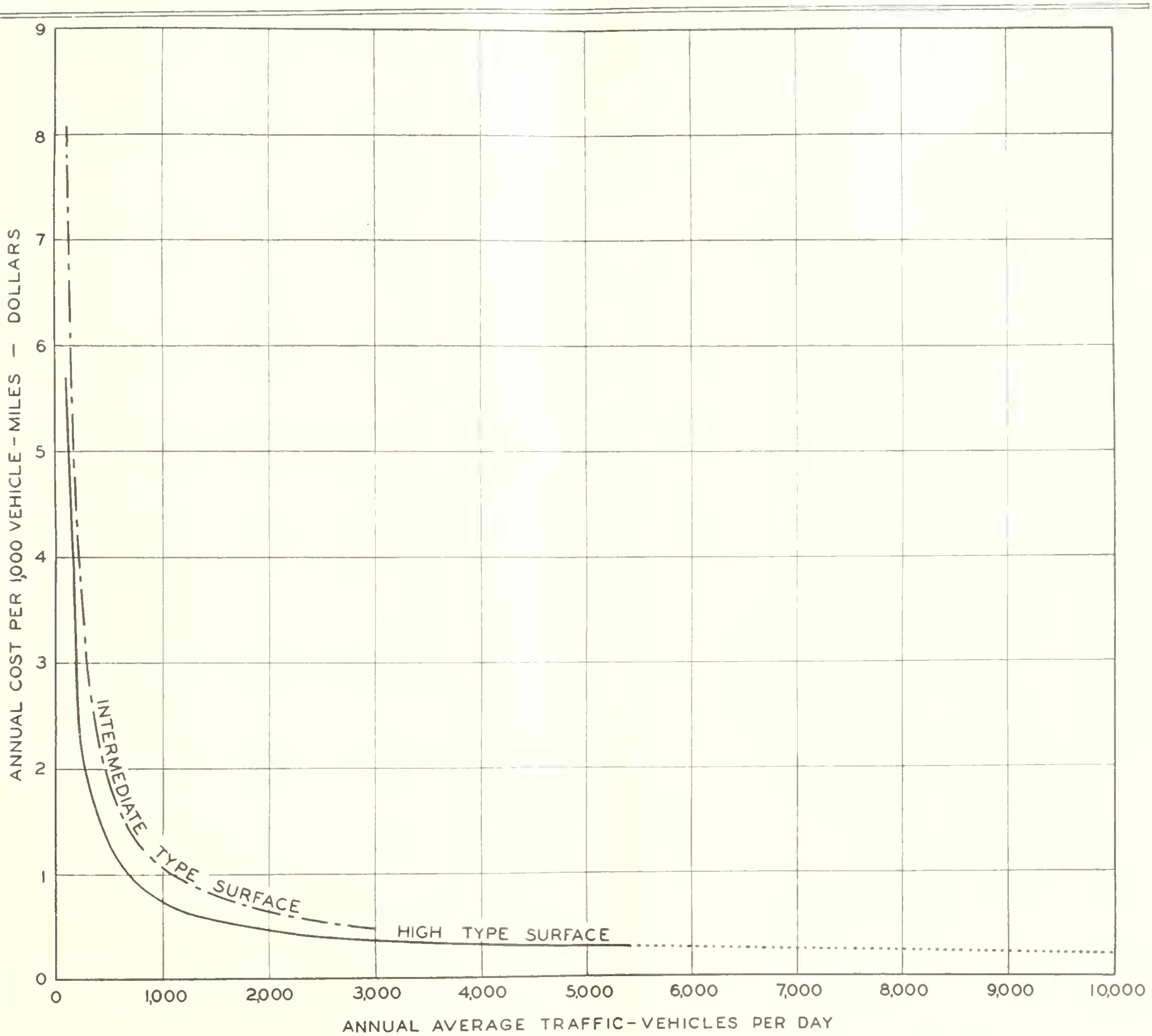

Figure 18.—Average Maintenance Costs Per Vehicle-Mile for Various Traffic Densities.

to landscaping, it has been assumed that the amounts indicated by the curves based on 2-lane maintenance costs should be doubled. For highway sections carrying more than 10,000 vehicles per day where special design is recommended, amounts equal to two and one-half times those indicated by curves based on 2-lane maintenance costs have been assumed.

In selecting from the curves a value that is applicable for the life of an improvement, it is necessary to select the value corresponding with the average traffic density during the period of service and not the value for the traffic density at the time of the improvement. In accordance with assumptions made in the calculation of the earning power of the system, the traffic density controlling the selection of the maintenance cost should be 157 percent of the initial traffic density adjusted to include divertable traffic. For values selected for traffic densities of less than 3,000, a point lying somewhere between the two curves should be selected.

Table 17 shows the estimated maintenance and operation cost during the life of the improvement based upon values obtained from the curves shown in figures 17 and 18. An allowance for policing equal to 15 percent of the maintenance and operation cost is made and an allowance of 5 percent of the total construction and maintenance expenditures is made for administration and overhead.

For a section falling within any one of three major traffic density groups, when classified on the basis of its traffic density adjusted to include diverted traffic, the cost per 1,000 vehicle-miles and the average annual and total costs per mile during the lifetime of the improvement are shown in table 18. As in the case of the earnings similarly shown in a previous table, the costs per vehicle-mile would shift to higher or lower levels if the improvement program were carried on in such a manner that the average initial traffic density of all sections selected for improvement within any density group were to depart from the 1937 determined average traffic density of that group. However, in contrast to the tendency for the earnings per mile to increase, a decrease can hardly be avoided in the costs per vehicle-mile for the lower traffic density groups, but it would be possible to maintain the levels in the other groups. The effect of any probable change of levels will always be to improve the relationship between earnings and costs, as can be shown by comparison of the estimated earnings and the estimated costs shown in this paper.

TABLE 17.—*Average costs of improving and operating rural sections of the tentative interregional system*

Initial traffic density adjusted to include traffic which would be attracted by the improvement	Initial cost [1] of of the improvement per 1,000 vehicle-miles of travel during the 30-year period	Maintenance and operation costs, including policing, per 1,000 vehicle-miles of travel during the 30-year period	Administration costs per 1,000 vehicle-miles of travel during the 30-year period	Average annual cost of improvement and operation during the 30-year period		Total cost of improvement and operation during the 30-year period	
				Per mile	Per 1,000 vehicle-miles	Per mile	Per 1,000 vehicle-miles
Less than 3,000	$2.92	$0.55	$0.17	$2,760	$3.64	$82,800	$3.64
3,000–9,999	2.68	.55	.16	9,460	3.39	283,800	3.39
10,000 and over	2.40	.39	.14	21,900	2.93	657,000	2.93

[1] Includes allowances for right-of-way engineering, and contingencies.

TABLE 18.—*Estimated maintenance and operation costs for rural sections of the tentative interregional system* [1]

Initial traffic density adjusted to include traffic which would be attracted by the improvement	Annual costs for adjusted initial traffic density		Average annual costs during 30-year period after improvement		Total costs during 30-year period after improvement	
	Per mile	Per 1,000 vehicle-miles	Per mile	Per 1,000 vehicle-miles	Per mile	Per 1,000 vehicle-miles
	Dollars	*Cents*	*Dollars*	*Cents*	*Dollars*	*Cents*
Less than 3,000	320	66.336	362	47.798	10,860	47.798
3,000–9,999	1,040	58.580	1,330	47.716	39,900	47.716
10,000 and over	2,150	45.227	2,550	34.167	76,500	34.167

[1] It is assumed that the average traffic density for the 30-year period will be 157 percent of the initial traffic density adjusted to include traffic which would be attracted by the improvement.

SUMMARY

Table 19 shows a comparison of the estimated earnings during a 30-year period with the total estimated costs during a 30-year period, which is assumed to be the average life of a section improved to the recommended standards. This is the picture that is obtained when improvements are financed on a "pay as you go" basis, from current revenues, and are undertaken after the present improvement has paid for itself and is due for reconstruction. Obviously, other relationships would exist if new improvements were to be financed by other methods or if new improvements were to be undertaken before the present improvements had served their economic life. If the whole program were to be undertaken at once, financing charges would have to be included in the costs, and earnings required to liquidate the unretired balance of the investments in existing improvements would have to be subtracted from the earnings. These two operations would narrow or possibly wipe out the excess earnings of the system.

Before these excess earnings, shown in table 19, excite too much enthusiasm for the interregional highway system proposal, and before they invite false conclusions as to the advisability of proceeding immediately with a great portion of the work financed by borrowed money, careful consideration must be given to their true meaning.

TABLE 19.—*Comparison of costs and earnings of rural sections of the tentative interregional system*

Initial traffic density adjusted to include traffic which would be attracted by the improvement	Total cost of improvement and operation during the 30-year period		Total earnings during the 30-year period		Excess of earnings over costs during the 30-year period		Ratio of costs to earnings during the 30-year period
	Per mile	Per 1,000 vehicle miles	Per mile	Per 1,000 vehicle miles	Per mile	Per 1,000 vehicle miles	
							Percent
Less than 3,000	$82,800	$3.64	$132,300	$5.89	$49,500	$2.25	63
3,000–9,999	283,800	3.39	486,600	5.89	202,800	2.50	58
10,000 and over	657,000	2.93	1,303,200	5.89	646,200	2.96	50

Present practice does not consist of financing highways of a single class with funds earned by that class. If costs and earnings were balanced for each class of highways, lightly traveled routes could seldom be improved with available funds to the minimum standard satisfactory to the highway users. The construction of lightly traveled secondary and local roads must be subsidized from excess earnings of heavily traveled routes. Unless this practice were followed, lightly traveled routes could not be developed unless additional funds from a new source were made available. Unless lightly traveled or feeder routes, which provide access to widely scattered points, were developed, the main highways would be less heavily traveled and the earning capacity of the main traveled routes would be reduced.

The interregional highway system tentatively selected is the most heavily traveled integrated national system that it has been possible to select. The routes in each State are invariably the greatest, or at least among the greatest, revenue producing routes. It would seem that even a lower percentage of their total earnings should be applied to the development and operation of the system than is applied to the remaining heavily traveled routes of the State highway systems, if equilibrium is to be maintained amongst the various systems.

It is interesting to note that even within the interregional system, table 19 shows that the total earnings during the 30-year period following improvement would exceed the total costs during the 30-year period by greater amounts for the more heavily traveled sections than for the more lightly traveled sections. The percentage of the earnings required for expenses over a 30-year period on sections having adjusted initial traffic densities of less than 3,000 vehicles is shown to be 63 percent. For sections falling within the intermediate traffic density group where 4-lane highway design is recommended, the percentage of the earnings required for expenses drops to 58; and for sections falling within the highest traffic density group, the percentage drops to 50.

These relationships are only preliminary indications. The main problem still lies ahead in refining the analysis by substituting facts and field determinations for present assumptions and estimates. The present analysis must be extended to include various methods of financing and complete studies must be made by regions and by States. Coincident with these studies, studies must be made of the amount that local roads must be subsidized from excess earnings of the more heavily traveled systems. In fact, analyses similar to this interregional system analysis must be applied to all systems. Standards for all systems must be adjusted to levels that can be afforded. These refinements and extensions of the analysis of the rural sections will require a great deal of work, but the larger and more significant job ahead is planning the improvement of urban sections.

The best preliminary estimate shows that the cost of urban sections of the tentative interregional system is only about one-fifth of the expenditure that must be made to modernize highway and street facilities in the cities traversed. The modernization of only the interregional system in the vicinity of cities would be but a palliative because the system would soon be overloaded by traffic attracted to its superior facilities. Only by construction of comparable facilities in other directions on the cities' street networks can the economic growth of cities and the success of the interregional system itself be assured.

APPENDIX

In the discussion of design standards it was stated that:

> The limiting degree of horizontal curvature must usually be selected on the basis of a number of economic considerations, only one of which is the extent to which desirable sight distances can be provided. Once the specifications for horizontal alinement and cross sections are settled, the sight distances limited by cut banks on horizontal curves are fixed. Obviously, no advantage to the traveling public can be gained by increasing lengths of vertical curves occurring on horizontal curves beyond those lengths required to provide sight distance equal to that afforded by the horizontal curve. There is, therefore, no justification for construction expenditures for this purpose.

On horizontal curves having sufficient length for the view between vehicles on the curve to be restricted by the cut bank, there is a constant, for any distance between the centerline of the highway and the cut bank, which, when divided by the degree of curvature may be multiplied by the algebraic difference in grades to give the length of vertical curve whose crest will limit sight distance to the same extent as the cut bank will limit it. Such a constant is specified for the interregional system and its value for the interregional highway cross section is 700.

For sections of the highway located on tangent, and on short horizontal curves where sight distance is not restricted by cut banks but by crests in vertical alinement, constants shown in table A are specified. These constants, when multiplied by the algebraic difference in grades, give lengths of vertical curves which will provide sight distances as great as can be afforded and yet maintain equilibrium between this feature of design and the other features. It will be noted that shorter vertical curves, and correspondingly shorter sight distances, are specified for 4-lane divided highways than are specified for 2-lane highways. This is done because the chief advantage in increasing the sight distance on 4-lane divided highways is that safe stopping distances for higher speeds of travel are provided; but on 2-lane highways, the further advantage is gained that vehicles traveling in the same direction may pass one another at higher speeds without increasing the hazard of meeting an oncoming car before completing the passing maneuver. This hazard obviously does not exist on 4-lane divided highways.

For the various classifications of 4-lane highway sections, the speeds for which adequate sight distances on vertical curves are provided are related to the speeds at which horizontal curves of the maximum degree may be negotiated safely, because the economic limits of both the degree of horizontal curvature and the length of vertical curve for various classification of highways are determined by the type of topography and the traffic service. Also, in terrain where drivers are required to reduce their speeds in order to negotiate the horizontal curves, relatively short vertical curves should not be found as objectionable as they are in flatter terrain. Careful consideration of the rate that excavation quantities increase with lengths of vertical curves has led to the conclusion that the greatest speed for which sight distances on crests in vertical alinement can be made equal to safe stopping distances, without excessive expenditures, is the maximum speed that can be traveled around horizontal curves of one-half the maximum degree (twice the minimum radius) specified for the particular classification of the highway section. This criterion has been selected because (1) most of the horizontal curves occurring on any section have shorter radii than the radius of a curve of half the maximum specified degree, which means that drivers of vehicles will generally be accustomed to reducing speeds below this critical speed on most of the horizontal curves, and (2) an examination of resulting speeds indicates that they are reasonable in relation to other factors.

TABLE A.—*Values of K [1] for computing length of vertical curves on horizontal tangents and short horizontal curves [2]*

Classification of section	Present average daily traffic density	Type of topography	Values of K	
			Minimum permissible	Maximum desirable
I	Less than 1,000	Relatively level	1,070	1,070
		Rolling	550	550
		Mountainous	260	260
II	1,000–1,999	Relatively level	1,070	1,070
		Rolling	550	550
		Mountainous	260	260
III	2,000–2,999	Relatively level	1,070	1,070
		Rolling	550	550
		Mountainous	260	260
IV	3,000–4,999	Relatively level	465	465
		Rolling	233	465
		Mountainous	175	465
V	5,000–9,999	Relatively level	465	465
		Rolling	350	465
		Mountainous	280	465
VI	10,000 or more	Relatively level	465	465
		Rolling	350	465
		Mountainous	280	465

[1] Length of vertical curve = algebraic difference of grades $\times K$. For use only where sight distance is restricted by vertical curve.

[2] For computing lengths of vertical curves occurring on long horizontal curves where sight distance is restricted by cut bauk, use formula $K = \frac{700}{D}$ in all traffic classifications and on all horizontal curves whose lengths are in excess of the following values:

	Feet		Feet
1° curve	1,060	6° curve	440
2° curve	750	7° curve	410
3° curve	620	8° curve	380
4° curve	530	9° curve	360
5° curve	480	10° curve	350

Maximum lengths of vertical curves in relatively level topography shall be 4,000 feet, in rolling topography 3,000 feet, and in mountainous topography 2,000 feet.

Values of the constants for computing lengths of vertical curves occurring at crests on 2-lane highways are based on providing sight distances permitting passing maneuvers (1) in relatively level topography when the passing and oncoming vehicles travel 60 miles per hour and the passed vehicle travels 50 miles per hour, (2) in rolling topography when the passing and oncoming vehicles travel 50 miles per hour and the passed vehicle travels 40 miles per hour, and (3) in mountainous topography when the passing and oncoming vehicles travel 40 miles per hour and the passed vehicle travels 30 miles per hour. Actually, passings can probably take place safely at higher speeds than these because the calculations are based on existing passing maneuver theory which appears to be on the conservative side. In cases where maximum algebraic differences in grades are approached, the standards specify reduced lengths of vertical curves below the values obtained by the use of the constants. These reduced lengths are necessary because of topographical difficulties and should be accepted even though the speeds at which passing maneuvers may take place are lowered by about 10 percent.

The maximum safe speeds of travel at any point where the sight distance is limited by any feature of the design are shown in table B.

TABLE B.—*Maximum safe speeds permitted by limiting vertical curves*[1] *suggested for interregional highways*

Classification of section	Present average daily traffic density	Type of topography	Speeds permitted on vertical curves occurring on long horizontal curves when sight distance is restricted by cut bank				Speeds permitted on vertical curves occurring on horizontal tangents or short horizontal curves			
			Minimum permissible length of vertical curve		Minimum desirable length of vertical curve		Minimum permissible length of vertical curve		Minimum desirable length of vertical curve	
			Lowest maximum safe speed[2]	Lowest maximum passing speed[3]	Lowest maximum safe speed[2]	Lowest maximum passing speed[3]	Lowest maximum safe speed[2]	Lowest maximum passing speed[3]	Lowest maximum safe speed[2]	Lowest maximum passing speed[3]
			M. p. h.	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*
I	Less than 1,000	Relatively level	68	28	68	28	80+	[4] 53-60	80+	[4] 53-60
		Rolling	53	20	68	28	[4] 76-80+	[4] 44-50	80+	50
		Mountainous	47	17	68	28	[4] 61-70	[4] 35-40	80+	40
II	1,000-1,999	Relatively level	68	28	68	28	80+	[4] 53-60	80+	[4] 53-60
		Rolling	53	20	68	28	[4] 76-80+	[4] 44-50	80+	50
		Mountainous	47	17	68	28	[4] 61-70	[4] 35-40	80+	40
III	2,000-2,999	Relatively level	68	28	68	28	80+	[4] 53-60	80+	[4] 53-60
		Rolling	56	20	68	28	79-80+	[4] 44-50	80+	50
		Mountainous	52	18	68	28	[4] 64-70	[4] 35-40	80+	40
IV	3,000-4,999	Relatively level	68	68	68	68	80+	80+	80+	80+
		Rolling	56	56	68	68	70	70	80+	80+
		Mountainous	52	52	68	68	64	64	80+	80+
V	5,000-9,999	Relatively level	68	68	68	68	80+	80+	80+	80+
		Rolling	63	63	68	68	78	78	80+	80+
		Mountainous	59	59	68	68	73	73	80+	80+
VI	10,000 or more	Relatively level	68	68	68	68	80+	80+	80+	80+
		Rolling	63	63	68	68	78	78	80+	80+
		Mountainous	59	59	68	68	73	73	80+	80+

[1] When sight distance is restricted by cut banks on horizontal curves, vertical curves have been selected which provide the same sight distances as do the horizontal curves. Therefore, lengthening of vertical curves would not make higher safe speeds possible.

[2] Lowest maximum safe speed is the maximum speed which vehicles can travel and yet stop safely within the sight distance provided on the shortest vertical curve permitted for the indicated classification of highway.

[3] Lowest maximum passing speed is the maximum speed which passing and oncoming vehicles may travel and yet complete a passing maneuver when the passed vehicle is traveling 10 miles per hour slower on the shortest vertical curve permitted for the indicated classification of highway.

[4] The lower speed applies when the algebraic difference in grades is the maximum permitted; the higher speed applies when the algebraic difference in grades is less than two-thirds of the maximum allowable.

MOTOR-FUEL CONSUMPTION-1940

COMPILED FOR CALENDAR [illegible] FROM REPORTS OF STATE AUTHORITIES 1/

TABLE C-2, 1940
ISSUED MAY 1941

STATE	TAX RATE PER GALLON ON DECEMBER 31	GROSS AMOUNT REPORTED 2/	AMOUNT EXEMPTED FROM PAYMENT OF TAX 3/	GROSS AMOUNT ASSESSED FOR TAXATION	AMOUNT SUBJECT TO REFUND OF ENTIRE TAX	NET AMOUNT TAXED				AMOUNT TAXED AT PREVAILING RATE DURING 1939	INCREASE DURING 1940		STATE
						TOTAL	AT PREVAILING RATE	AT OTHER RATES			AMOUNT	PER-CENT-AGE	
								RATE PER GALLON	AMOUNT				
	CENTS	1,000 GALLONS	1,000 GALLONS	1,000 GALLONS	1,000 GALLONS	1,000 GALLONS	1,000 GALLONS	CENTS	1,000 GALLONS	1,000 GALLONS	1,000 GALLONS		
ALABAMA	6	259,915	-	259,915	-	259,915	259,915	-	-	241,375	18,540	7.7	ALABAMA
ARIZONA	5	113,435	4,575	108,860	13,153	95,707	95,707	-	-	89,939	5,768	6.4	ARIZONA
ARKANSAS	6.5	191,421	7,620	183,801	-	183,801	162,328	(4/)	21,473	155,709	6,619	4.3	ARKANSAS
CALIFORNIA	3	1,948,880	37,198	1,911,682	153,356	1,758,326	1,758,326	-	-	1,673,780	84,546	5.1	CALIFORNIA
COLORADO	4	251,877	8,645	243,232	36,490	206,742	206,742	-	-	196,147	10,595	5.4	COLORADO
CONNECTICUT	3	380,375	7,567	372,808	8,214	364,594	364,594	-	-	335,146	29,448	8.8	CONNECTICUT
DELAWARE	4	63,920	1,498	62,422	4,025	58,397	58,397	-	-	54,410	3,987	7.3	DELAWARE
FLORIDA	7	408,124	19,407	388,717	-	388,717	388,717	-	-	350,089	38,628	11.0	FLORIDA
GEORGIA	6	400,296	13,449	386,847	-	386,847	386,847	-	-	352,862	33,985	9.6	GEORGIA
IDAHO	5.1	107,644	3,677	103,967	-	103,967	94,565	(5/)	9,402	6/ 88,444	6,121	6.9	IDAHO
ILLINOIS	3	1,540,441	-	1,540,441	129,474	1,410,967	1,410,967	-	-	1,336,233	74,734	5.6	ILLINOIS
INDIANA	4	700,360	2,263	698,097	56,933	641,164	641,164	-	-	598,734	42,430	7.1	INDIANA
IOWA	3	572,720	-	572,720	86,725	485,995	485,995	-	-	469,102	16,893	3.6	IOWA
KANSAS	3	503,586	156,866	346,720	-	346,720	346,720	-	-	334,577	12,143	3.6	KANSAS
KENTUCKY	5	305,334	10,129	295,205	-	295,205	295,205	-	-	275,107	20,098	7.3	KENTUCKY
LOUISIANA	7	278,083	5,855	272,228	4	272,224	264,057	2	7/ 8,167	247,419	16,638	6.7	LOUISIANA
MAINE	4	157,361	957	156,404	-	156,404	149,130	1	8/ 7,274	141,850	7,280	5.1	MAINE
MARYLAND	4	314,606	4,854	309,752	20,107	289,645	286,636	3	9/ 3,009	265,548	21,088	7.9	MARYLAND
MASSACHUSETTS	3	747,204	2,941	744,263	30,905	713,358	713,358	-	-	683,733	29,625	10.4	MASSACHUSETTS
MICHIGAN	3	1,253,535	116,333	1,137,202	54,819	1,082,383	1,082,006	1.5	10/ 377	994,058	87,948	8.8	MICHIGAN
MINNESOTA	11/ 3	593,842	29,563	564,279	66,723	497,556	497,556	-	-	469,578	27,978	6.0	MINNESOTA
MISSISSIPPI	6	214,538	9,171	205,367	-	205,367	197,570	1	12/ 7,797	188,426	9,144	4.9	MISSISSIPPI
MISSOURI	2	697,545	-	697,545	39,224	658,321	658,321	-	-	620,791	37,530	6.0	MISSOURI
MONTANA	5	137,639	7,061	130,578	26,127	104,451	104,451	-	-	98,919	5,532	5.6	MONTANA
NEBRASKA	5	244,354	10,697	233,657	4	233,653	233,438	1	13/ 215	232,119	1,319	0.6	NEBRASKA
NEVADA	4	42,788	2,663	40,125	2,602	37,523	35,717	5	14/ 1,806	33,618	2,099	6.2	NEVADA
NEW HAMPSHIRE	4	95,827	653	95,174	4,352	90,822	90,822	-	-	88,448	2,374	2.7	NEW HAMPSHIRE
NEW JERSEY	3	898,684	2,978	895,706	73,280	822,426	822,426	-	-	773,346	49,080	6.3	NEW JERSEY
NEW MEXICO	5	110,917	5,569	105,348	11,152	94,196	94,196	-	-	86,374	7,822	9.1	NEW MEXICO
NEW YORK	4	1,970,555	76,621	1,893,934	56,957	1,836,977	1,836,977	-	-	1,768,288	68,689	3.9	NEW YORK
NORTH CAROLINA	6	463,498	9,786	453,712	-	453,712	440,548	1	12/ 13,164	410,340	30,208	7.4	NORTH CAROLINA
NORTH DAKOTA	4	147,246	61,466	85,780	-	85,780	85,780	-	-	15/ 82,694	3,086	3.7	NORTH DAKOTA
OHIO 16/	4	1,473,856	73,094	1,400,762	12,958	1,387,804	1,320,885	1	8/ 66,919	1,231,223	89,662	7.3	OHIO 16/
OKLAHOMA	4	441,161	62,316	378,845	570	378,275	378,275	-	-	365,735	12,540	3.4	OKLAHOMA
OREGON	5	264,672	5,017	259,655	29,816	229,839	228,396	1	17/ 1,443	212,609	15,787	7.4	OREGON
PENNSYLVANIA	4	1,581,975	6,897	1,575,078	-	1,575,078	1,575,078	-	-	1,476,077	99,001	6.7	PENNSYLVANIA
RHODE ISLAND	3	133,963	1,271	132,692	1,134	131,558	131,558	-	-	126,695	4,863	3.8	RHODE ISLAND
SOUTH CAROLINA	6	234,307	-	234,307	4,909	229,398	229,398	-	-	206,953	22,445	10.8	SOUTH CAROLINA
SOUTH DAKOTA	4	145,713	2,836	142,877	29,218	113,659	113,659	-	-	18 103,987	9,672	9.3	SOUTH DAKOTA
TENNESSEE	7	327,055	21,201	305,854	1,812	304,042	304,042	-	-	270,222	33,820	12.5	TENNESSEE
TEXAS	4	1,414,932	18,024	1,396,908	201,214	1,195,694	1,195,694	-	-	1,140,442	55,252	4.8	TEXAS
UTAH	4	107,194	4,769	102,425	-	102,425	102,425	-	-	94,349	8,076	8.6	UTAH
VERMONT	4	70,806	880	69,926	-	69,926	69,926	-	-	67,137	2,789	4.2	VERMONT
VIRGINIA	5	417,599	-	417,599	24,669	392,930	392,386	3	19/ 544	358,541	33,845	9.4	VIRGINIA
WASHINGTON	5	386,348	10,776	375,572	27,700	347,872	347,872	-	-	320,941	26,931	8.4	WASHINGTON
WEST VIRGINIA	5	221,005	-	221,005	6,022	214,983	214,983	-	-	18 201,640	13,343	6.6	WEST VIRGINIA
WISCONSIN	4	589,789	17,670	572,119	42,386	529,733	529,733	-	-	507,776	21,957	4.3	WISCONSIN
WYOMING	4	70,753	1,754	68,999	-	68,999	68,999	-	-	65,673	3,326	5.1	WYOMING
DISTRICT OF COLUMBIA	2	169,512	7,441	162,071	1,117	160,954	160,954	-	-	142,776	18,178	12.7	DISTRICT OF COLUMBIA
TOTAL	20/ 3.96	24,167,190	854,008	23,313,182	1,258,151	22,055,031	21,913,441	-	141,590	20,629,979	1,283,462	6.2	TOTAL

1/ AN ANALYSIS OF MOTOR-FUEL USAGE WILL BE GIVEN IN TABLE G-21, TO BE PUBLISHED LATER.

2/ EXPORT SALES AND OTHER AMOUNTS NOT REPRESENTING CONSUMPTION IN STATE HAVE BEEN ELIMINATED AS FAR AS POSSIBLE. IN CASES WHERE STATES FAILED TO REPORT AMOUNTS EXEMPTED FROM TAXATION, THE GROSS AMOUNT TAXED IS SHOWN IN THIS COLUMN.

3/ INCLUDES ALLOWANCES FOR EVAPORATION AND OTHER LOSSES, FEDERAL USE, OTHER PUBLIC USE, AND NONHIGHWAY USE, WHERE INITIAL EXEMPTIONS RATHER THAN REFUNDS ARE MADE.

4/ WITHIN 300 FEET OF BORDER, TAX IS REDUCED TO THAT OF ADJACENT STATE. GALLONS TAXED AT 2 CENTS, 5,366,000; AT 4 CENTS, 16,107,000.

5/ AVIATION FUEL TAXED AT 2.5 CENTS, 349,000 GALLONS; MOTOR FUEL TAXED AT 0.1 CENT (5 CENTS REFUNDED ON NONHIGHWAY USE), 9,053,000 GALLONS.

6/ GALLONS TAXED AT 5 CENTS, 3,003,000; AT 5.1 CENTS, 85,441,000.

7/ REPRESENTS EVAPORATION OR LOSS ALLOWANCE UNDER 5-CENT TAX NOT ALLOWED UNDER ADDITIONAL 2-CENT TAX, WHICH IS ADMINISTERED UNDER A SEPARATE LAW.

8/ THREE CENTS PER GALLON REFUNDED ON NONHIGHWAY USES.

9/ ONE CENT PER GALLON REFUNDED ON MOTOR FUEL USED IN VEHICLES LICENSED TO OPERATE EXCLUSIVELY IN CITIES.

10/ ONE AND ONE-HALF CENTS PER GALLON REFUNDED ON MOTOR FUEL USED IN INTERSTATE AVIATION.

11/ RATE CHANGED FROM 4 CENTS TO 3 CENTS SEPTEMBER 1.

12/ FIVE CENTS PER GALLON REFUNDED ON NONHIGHWAY USES.

13/ AVIATION FUEL USED IN FLYING INSTRUCTION.

14/ DIESEL FUEL, 1,749,000 GALLONS; AND BUTANE, 57,000 GALLONS.

15/ GALLONS TAXED AT 3 CENTS, 35,693,000; AT 4 CENTS, 47,001,000.

16/ AMOUNTS GIVEN DO NOT INCLUDE 65,204,000 GALLONS OF LIQUID FUEL (KEROSENE, FUEL OIL, ETC.) TAXED AT 1 CENT PER GALLON BUT NOT SUBJECT TO THE 3-CENT TAX ON MOTOR-VEHICLE FUEL.

17/ FOUR CENTS PER GALLON REFUNDED ON MOTOR FUEL USED IN AVIATION.

18/ REVISED SINCE PUBLICATION OF TABLE C-2, 1939.

19/ TWO CENTS PER GALLON REFUNDED ON MOTOR FUEL USED IN INTRASTATE AVIATION.

20/ WEIGHTED AVERAGE RATE.

STATE MOTOR-FUEL TAX RECEIPTS - 1940

COMPILED FOR CALENDAR YEAR FROM REPORTS OF STATE AUTHORITIES

TABLE G-1, 1940
ISSUED MAY 1941

STATE	TAX RATE PER GALLON ON DECEMBER 31	RECEIPTS FROM TAXATION OF MOTOR FUEL: GROSS TAX COLLECTIONS	DEDUCTIONS BY DISTRIBUTORS FOR EXPENSES 1/	GROSS RECEIPTS BY STATE	REFUNDS PAID	NET RECEIPTS BY STATE	OTHER RECEIPTS IN CONNECTION WITH MOTOR-FUEL TAX 2/: DISTRIBUTORS AND DEALERS LICENSES	INSPECTION FEES 3/	FINES AND PENALTIES	MISCELLANEOUS RECEIPTS	TOTAL	NET TOTAL RECEIPTS	LESS TAX ON AVIATION GASOLINE	ADJUSTED NET TOTAL RECEIPTS	STATE
	CENTS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	
ALABAMA	6	15,470	-	15,470	-	15,470	-	65	-	-	65	15,535	-	15,535	ALABAMA
ARIZONA	5	5,556	-	5,556	789	4,767	*	-	2	-	2	4,769	-	4,769	ARIZONA
ARKANSAS	6.5	11,312	-	11,312	-	11,312	-	100	*	-	100	11,412	-	11,412	ARKANSAS
CALIFORNIA	3	56,561	-	56,561	4,601	51,960	17	-	-	1	18	51,978	-	51,978	CALIFORNIA
COLORADO	4	9,632	-	9,632	1,341	8,291	-	-	-	-	-	8,291	-	8,291	COLORADO
CONNECTICUT	3	11,392	114	11,278	246	11,032	51	-	1	-	52	11,084	-	11,084	CONNECTICUT
DELAWARE	4	2,483	-	2,483	161	2,322	3	-	-	-	3	2,325	-	2,325	DELAWARE
FLORIDA	7	26,929	-	26,929	-	26,929	39	480	-	-	519	27,448	-	27,448	FLORIDA
GEORGIA	6	23,039	230	22,809	-	22,809	32	-	-	-	32	22,841	-	22,841	GEORGIA
IDAHO	5.1	5,281	-	5,281	459	4,822	1	-	-	2	3	4,825	8	4,817	IDAHO
ILLINOIS	3	46,191	924	45,267	3,907	41,360	-	463	1	-	464	41,824	-	41,824	ILLINOIS
INDIANA	4	27,787	-	27,787	2,293	25,494	*	573	-	1	574	26,068	-	26,068	INDIANA
IOWA	3	17,190	-	17,190	2,598	14,592	63	-	-	-	63	14,655	-	14,655	IOWA
KANSAS	3	10,402	-	10,402	-	10,402	15	110	-	35	160	10,562	-	10,562	KANSAS
KENTUCKY	5	14,861	148	14,713	-	14,713	-	-	4	-	4	14,717	-	14,717	KENTUCKY
LOUISIANA	7	18,584	-	18,584	-	18,584	-	87	*	-	87	18,671	-	18,671	LOUISIANA
MAINE	4	6,158	-	6,158	218	5,940	-	-	*	-	*	5,940	11	5,929	MAINE
MARYLAND	4	12,282	-	12,282	834	11,448	-	-	-	-	-	11,448	-	11,448	MARYLAND
MASSACHUSETTS	3	22,328	-	22,328	927	21,401	53	-	*	-	53	21,454	-	21,454	MASSACHUSETTS
MICHIGAN	3	34,116	-	34,116	1,650	32,466	5	-	8	-	13	32,479	81	32,398	MICHIGAN
MINNESOTA	4/ 3	20,933	-	20,933	2,588	18,345	1	174	1	5	181	18,526	-	18,526	MINNESOTA
MISSISSIPPI 5/	6	12,337	-	12,337	406	11,931	-	-	-	-	-	11,931	-	11,931	MISSISSIPPI 5/
MISSOURI	2	13,893	-	13,893	592	13,301	-	143	11	-	154	13,455	-	13,455	MISSOURI
MONTANA	5	6,378	-	6,378	1,310	5,068	-	6	-	-	6	5,074	-	5,074	MONTANA
NEBRASKA	5	12,133	91	12,042	300	11,742	10	120	-	29	159	11,901	73	11,828	NEBRASKA
NEVADA	4	1,620	31	1,589	104	1,485	*	21	1	-	22	1,507	-	1,507	NEVADA
NEW HAMPSHIRE	4	3,790	-	3,790	174	3,616	-	-	1	-	1	3,617	-	3,617	NEW HAMPSHIRE
NEW JERSEY	3	26,546	-	26,546	2,320	24,226	93	-	1	17	111	24,337	-	24,337	NEW JERSEY
NEW MEXICO	5	5,245	-	5,245	569	4,676	23	-	-	-	23	4,699	-	4,699	NEW MEXICO
NEW YORK	4	76,062	761	75,301	2,246	73,055	61	-	-	*	61	73,116	-	73,116	NEW YORK
NORTH CAROLINA	6	26,932	-	26,932	658	26,274	-	1,089	-	9	1,098	27,372	-	27,372	NORTH CAROLINA
NORTH DAKOTA	4	3,464	52	3,412	61	3,351	*	77	-	24	101	3,452	-	3,452	NORTH DAKOTA
OHIO	4	6/ 53,374	-	53,374	2,585	50,789	-	-	-	-	-	50,789	-	50,789	OHIO
OKLAHOMA	4	15,174	379	14,795	24	14,771	-	296	-	-	296	15,067	-	15,067	OKLAHOMA
OREGON	5	12,931	-	12,931	1,572	11,359	-	-	*	-	*	11,359	14	11,345	OREGON
PENNSYLVANIA	4	63,197	710	62,487	-	62,487	-	-	8	-	8	62,495	-	62,495	PENNSYLVANIA
RHODE ISLAND	3	4,277	-	4,277	336	3,941	4	-	-	-	4	3,945	-	3,945	RHODE ISLAND
SOUTH CAROLINA	6	13,899	-	13,899	277	13,622	-	288	-	-	288	13,910	73	13,837	SOUTH CAROLINA
SOUTH DAKOTA	4	5,827	205	5,622	1,169	4,453	-	74	-	-	74	4,527	16	4,511	SOUTH DAKOTA
TENNESSEE	7	21,245	-	21,245	133	21,112	-	1,146	-	62	1,208	22,320	142	22,178	TENNESSEE
TEXAS	4	55,903	557	55,346	7,828	47,518	-	-	-	12	12	47,530	-	47,530	TEXAS
UTAH	4	4,117	62	4,055	-	4,055	*	-	1	*	1	4,056	68	3,988	UTAH
VERMONT	4	2,781	-	2,781	-	2,781	-	-	*	-	*	2,781	-	2,781	VERMONT
VIRGINIA	5	20,645	-	20,645	1,241	19,404	1	-	4	1	6	19,410	16	19,394	VIRGINIA
WASHINGTON	5	18,732	94	18,638	1,466	17,172	3	-	-	10	13	17,185	-	17,185	WASHINGTON
WEST VIRGINIA	5	10,981	-	10,981	301	10,680	11	-	-	-	11	10,691	-	10,691	WEST VIRGINIA
WISCONSIN	4	22,861	-	22,861	1,711	21,150	-	161	-	-	161	21,311	-	21,311	WISCONSIN
WYOMING	4	2,772	-	2,772	-	2,772	2	-	-	-	2	2,774	54	2,720	WYOMING
DISTRICT OF COLUMBIA	2	3,244	-	3,244	22	3,222	7	-	-	-	7	3,229	-	3,229	DISTRICT OF COLUMBIA
TOTAL	7/ 3.96	918,847	4,358	914,489	50,017	864,472	495	5,473	44	208	6,220	870,692	556	870,136	TOTAL

1/ THE STATES FOR WHICH AMOUNTS ARE SHOWN MAKE ALLOWANCES TO DISTRIBUTORS FOR EXPENSE OF COLLECTING THE TAX. IN KENTUCKY, SOUTH DAKOTA, UTAH, AND WASHINGTON ALLOWANCES OF 2 1/4, 4, 3, AND 1 PERCENT, RESPECTIVELY, OF THE TAX OTHERWISE DUE ARE MADE IN CONSIDERATION OF BOTH EXPENSE OF COLLECTION AND GALLONAGE LOSSES IN HANDLING. IN THESE STATES THE ALLOWANCES FOR EXPENSES ONLY HAVE BEEN ESTIMATED AS 1, 3½, 1½, AND ½ PERCENT, RESPECTIVELY.

2/ STARS INDICATE AMOUNTS LESS THAN $500.

3/ FEES FOR INSPECTION OF MOTOR-VEHICLE FUEL. WHEREVER POSSIBLE, FEES FOR INSPECTION OF KEROSENE AND OTHER NON-MOTOR-VEHICLE FUELS HAVE BEEN ELIMINATED.

4/ RATE CHANGED FROM 4 CENTS TO 3 CENTS SEPTEMBER 1.

5/ SPECIAL COUNTY TAXES OF 3 CENTS PER GALLON IN HANCOCK COUNTY AND 2 CENTS PER GALLON IN HARRISON AND JACKSON COUNTIES, AMOUNTING TO $197,000 IN 1940, ARE IMPOSED FOR SEAWALL PROTECTION AND ARE NOT INCLUDED IN THIS TABLE.

6/ OHIO IMPOSES A 3-CENT TAX ON MOTOR-VEHICLE FUEL AND A 1-CENT TAX ON ALL LIQUID FUELS. THE RECEIPTS FROM THE 1-CENT TAX APPLICABLE TO NON-MOTOR-VEHICLE FUELS (KEROSENE, FUEL OIL, ETC.) WERE $638,000. THESE RECEIPTS HAVE BEEN ELIMINATED FROM THE TOTAL GIVEN, WHICH REPRESENTS A 4-CENT TAX ON MOTOR-VEHICLE FUEL.

7/ WEIGHTED AVERAGE RATE.

STATE MOTOR-VEHICLE REGISTRATIONS-1940

COMPILED FOR CALENDAR YEAR FROM REPORTS OF STATE AUTHORITIES 1/

TABLE MV-1, 1940
ISSUED MAY 1941

STATE	MOTOR VEHICLES									TRAILERS AND SEMITRAILERS				MOTORCYCLES				DEALERS REGISTRATIONS 7/		1939 TOTAL REGIS-TERED MOTOR VEHICLES	YEAR'S CHANGE IN MOTOR-VEHICLE REGISTRATIONS		STATE
	TOTAL	PRIVATE AND COMMERCIAL 2/					PUBLICLY OWNED			TOTAL	PRIVATE AND COMMER-CIAL 6/	PUBLICLY OWNED		TOTAL	PRIVATE AND COMMER-CIAL 2/	PUBLICLY OWNED		REGULAR	EXTRA PLATES		INCREASE OR DECREASE	PER-CENT-AGE CHANGE	
		TOTAL	PASSENGER VEHICLES 3/			TRUCKS AND TRACTOR TRUCKS	TOTAL	FEDERAL 4/	STATE, COUNTY, AND MUNICIPAL 5/			FEDERAL 4/	STATE, COUNTY, AND MUNICIPAL 5/			FEDERAL 4/	STATE, COUNTY, AND MUNICIPAL 5/						
			TOTAL	AUTOMOBILES (INCLUDING TAXICABS)	BUSSES																		
ALABAMA	347,123	339,853	277,006	273,114	3,892	62,847	7,270	2,514	4,756	5,323	5,263	60	-	1,069	1,012	57		3,292	-	331,742	15,381	4.6	ALABAMA
ARIZONA	143,451	138,403	113,295	112,945	350	25,108	5,048	2,806	2,242	5,323	5,000	102	221	586	513	37	36	320	1,484	136,037	7,414	5.4	ARIZONA
ARKANSAS	261,997	257,177	191,019	190,589	430	66,158	4,820	2,370	2,450	11,621	11,519	46	56	642	625	11	6	696	2,004	245,707	16,290	6.6	ARKANSAS
CALIFORNIA	2,810,566	2,773,659	2,453,958	2,453,958	(8/)	319,701	36,907	9,959	26,948	170,286	167,929	475	1,882	17,177	15,901	133	1,143	4,714		2,642,006	168,560	6.4	CALIFORNIA
COLORADO	355,309	352,110	293,792	292,626	1,166	58,318	3,199	3,199	-	1,740	1,703	37	-	1,392	1,379	13	-	4,250	-	345,884	9,425	2.7	COLORADO
CONNECTICUT	498,463	493,667	417,828	416,656	1,172	75,839	4,796	829	3,967	6,918	6,693	18	207	2,370	2,061	18	291	3,061	9,039	465,346	33,117	7.1	CONNECTICUT
DELAWARE	72,973	71,763	60,209	60,209	(8/)	11,554	1,210	427	783	3,417	3,375	9	33	359	300	5	54	882		69,109	3,864	5.6	DELAWARE
FLORIDA	503,678	495,210	415,420	413,723	1,697	79,790	8,468	2,380	6,088	20,803	20,360	46	397	1,966	1,736	49	181	2,137		458,615	45,063	9.8	FLORIDA
GEORGIA	513,097	502,603	415,421	412,439	2,982	87,182	10,494	4,992	5,502	15,288	14,926	279	83	2,242	1,668	440	134	444	2,555	477,713	35,384	7.4	GEORGIA
IDAHO	167,066	163,340	129,582	129,454	128	33,758	3,726	1,936	1,790	22,312	22,134	50	128	665	649	3	13	414	-	156,820	10,246	6.5	IDAHO
ILLINOIS	1,941,206	1,925,814	1,706,639	1,706,639	(8/)	219,175	15,392	4,805	10,587	29,504	28,962	155	387	7,841	7,116	99	626	4,679	-	1,863,486	77,720	4.2	ILLINOIS
INDIANA	1,003,240	994,006	857,849	856,528	1,321	136,157	9,234	2,061	7,173	75,077	75,005	72	-	5,583	5,338	30	215	2,669	-	969,593	33,647	3.5	INDIANA
IOWA	802,885	793,969	691,257	691,257	(8/)	102,712	8,916	1,915	7,001	96,732	96,102	102	528	2,977	2,874	35	68	1,989	4,766	774,227	28,658	3.7	IOWA
KANSAS	584,380	582,668	480,235	480,002	233	102,433	1,712	1,712	-	5,632	5,589	43	-	1,320	1,262	58	-	2,191	-	575,980	8,400	1.5	KANSAS
KENTUCKY	470,825	463,727	387,836	387,068	768	75,891	7,098	2,393	4,705	158	(9/)	158	-	1,629	1,258	371	-	883	-	444,218	26,607	6.0	KENTUCKY
LOUISIANA	372,830	365,429	283,636	280,663	2,973	81,793	7,401	2,421	4,980	14,367	13,939	93	335	1,432	1,342	24	66	342	-	346,820	26,010	7.5	LOUISIANA
MAINE	208,595	205,896	161,982	161,792	190	10/ 43,914	2,699	693	2,006	11,202	10/ 10,990	23	189	849	807	11	31	556	3,569	203,793	4,802	2.4	MAINE
MARYLAND	450,169	444,532	385,110	383,974	1,136	59,422	5,637	3,434	2,203	5,670	5,448	150	72	1,901	1,813	54	34	10,281	-	430,095	20,074	4.7	MARYLAND
MASSACHUSETTS	907,862	11/ 903,843	795,201	790,312	4,889	108,642	4,019	4,019	(11/)	16,281	16,092	189	-	1,065	970	95	(11/)	2,907	20,360	874,932	32,930	3.8	MASSACHUSETTS
MICHIGAN	1,556,571	1,552,561	1,401,686	12/ 1,400,838	848	12/ 150,875	4,010	4,010	-	161,008	160,762	246	-	4,920	4,773	147	-	2,043	2,043	1,475,616	80,955	5.5	MICHIGAN
MINNESOTA	879,862	871,351	746,888	746,289	599	124,463	8,511	3,126	5,385	90,522	90,168	135	219	2,641	2,437	58	146	3,570	-	848,572	31,290	3.[illegible]	MINNESOTA
MISSISSIPPI	264,439	259,013	198,086	196,478	1,608	60,927	5,426	1,385	4,441	5,384	5,323	61	-	403	380	7	16	2,747	-	248,789	15,650	6.[illegible]	MISSISSIPPI
MISSOURI	926,715	921,800	771,774	768,345	3,429	150,026	4,915	2,647	2,268	38,718	38,632	52	34	2,457	2,421	12	24	2,537	3,290	881,946	44,769	5.1	MISSOURI
MONTANA	196,116	191,032	143,068	143,068	(8/)	47,964	5,084	2,394	2,690	6,240	6,171	69	-	536	534	2	-	1,003	-	185,327	10,789	5.8	MONTANA
NEBRASKA	417,827	412,116	347,627	347,317	310	64,489	5,711	1,751	3,960	45,362	45,007	49	306	1,374	1,265	46	63	1,603	2,193	411,464	6,363	1.5	NEBRASKA
NEVADA	45,708	44,108	35,373	35,264	109	8,735	1,600	884	716	1,572	1,512	15	45	147	139	5	3	71	284	42,296	3,412	8.1	NEVADA
NEW HAMPSHIRE	136,109	135,384	105,322	105,034	288	30,062	725	725	-	6,130	6,096	34	-	704	700	4	-	587	-	131,963	4,146	3.1	NEW HAMPSHIRE
NEW JERSEY	1,101,213	1,086,966	949,840	944,630	5,210	137,126	14,247	3,490	10,757	8,371	8,218	153	-	5,535	4,973	48	514	3,046	18,620	1,041,337	59,876	5.7	NEW JERSEY
NEW MEXICO	128,159	125,056	95,795	94,534	1,261	29,261	3,103	1,839	1,264	2,929	2,853	76	-	439	409	4	26	156	92	123,549	4,610	3.7	NEW MEXICO
NEW YORK	2,778,312	2,743,014	2,407,253	2,399,496	7,757	335,761	35,298	7,315	27,983	52,622	51,251	331	1,040	12,229	10,846	223	1,160	5,388	-	2,689,288	89,024	3.3	NEW YORK
NORTH CAROLINA	610,121	591,946	504,489	503,494	995	87,457	18,175	4,725	13,450	44,670	44,386	284	-	1,967	1,862	105		9,739	-	587,832	22,289	3.8	NORTH CAROLINA
NORTH DAKOTA	184,016	182,287	145,903	145,746	157	36,384	1,729	924	805	1,185	1,162	23	-	271	269	2	-	589	436	178,161	5,855	3.3	NORTH DAKOTA
OHIO	1,942,639	1,918,929	1,728,275	1,728,275	(8/)	190,654	23,710	3,252	20,458	139,411	138,070	127	1,214	11,922	11,426	74	422	4,626	21,003	1,910,468	32,171	1.7	OHIO
OKLAHOMA	585,052	574,719	469,891	467,099	2,792	104,828	10,333	2,710	7,623	7,740	7,589	151	-	1,271	1,250	21	-	3,890	-	565,864	19,188	3.4	OKLAHOMA
OREGON	401,328	393,578	325,822	325,130	692	13/ 67,756	7,750	3,348	4,402	185	(13/)	185	-	1,847	1,833	14	-	695	818	376,736	24,592	6.5	OREGON
PENNSYLVANIA	2,169,702	2,145,849	1,883,094	1,877,495	5,599	262,755	23,853	4,406	19,447	33,559	32,840	170	549	12,180	11,268	76	836	34,321	-	2,082,862	86,840	4.2	PENNSYLVANIA
RHODE ISLAND	189,717	187,509	166,792	166,341	451	20,717	2,208	664	1,544	1,210	1,168	32	10	875	768	9	98	398	-	177,069	12,648	7.1	RHODE ISLAND
SOUTH CAROLINA	343,688	336,772	290,366	289,088	1,278	46,406	6,916	1,875	5,041	5,887	5,799	88	-	1,062	948	36	78	1,124	2,242	321,235	22,453	7.0	SOUTH CAROLINA
SOUTH DAKOTA	198,615	195,667	163,369	163,252	117	32,298	2,948	1,535	1,413	23,586	23,395	56	135	586	469	106	11	798	-	192,111	6,504	3.4	SOUTH DAKOTA
TENNESSEE	459,170	447,983	377,316	377,316	-	13/ 70,667	11,187	3,025	8,162	65	(13/)	65	-	1,651	1,641	10	-	580	-	433,982	25,188	5.8	TENNESSEE
TEXAS	1,719,313	1,694,113	1,343,673	1,342,861	812	350,440	25,200	7,313	17,887	56,913	55,666	456	791	5,505	4,774	346	385	3,396	-	1,641,662	77,651	4.7	TEXAS
UTAH	143,634	139,921	117,687	117,026	661	22,234	3,713	2,099	1,614	726	610	47	69	602	540	23	39	545	1,008	135,935	7,699	5.7	UTAH
VERMONT	94,472	93,645	84,017	14/ 83,922	95	14/ 9,628	827	827	-	2,362	2,315	47	-	450	433	17	-	634	-	91,407	3,065	3.4	VERMONT
VIRGINIA	509,191	498,838	422,591	422,591	-	76,247	10,353	4,362	5,991	13,003	12,630	222	151	2,505	2,246	122	137	6,286	-	469,518	39,673	8.4	VIRGINIA
WASHINGTON	576,248	562,495	474,261	473,048	1,213	88,234	13,753	5,991	7,762	24,535	23,859	304	372	2,732	2,407	210	115	1,644	3,405	546,435	29,813	5.5	WASHINGTON
WEST VIRGINIA	309,361	302,558	251,038	250,294	744	51,520	6,803	1,271	5,532	3,902	3,715	27	160	1,424	1,351	2	71	12,767	-	292,484	16,877	5.8	WEST VIRGINIA
WISCONSIN	913,055	900,915	751,664	750,953	711	149,251	12,140	2,983	9,157	7,383	7,019	113	251	3,826	3,531	19	276	-		859,173	53,882	6.3	WISCONSIN
WYOMING	88,166	85,657	66,758	66,613	145	18,899	2,509	1,567	942	10,524	10,313	125	86	380	297	83	-	385	-	84,990	3,176	3.7	WYOMING
DIST. OF COL.	165,220	161,914	147,986	146,612	1,374	13,928	3,306	1,860	15/ 1,446	1,092	929	35	128	818	658	55	105	210	2,672	167,426	-2,206	-1.3	DIST. OF COL.
AT LARGE	3,407	-	-	-	-	-	3,407	3,407	-	91	-	91	-	18	-	18	-	-	-	2,250	1,157	51.4	AT LARGE
TOTAL	32,452,861	32,025,365	27,434,979	27,372,397	62,582	4,590,386	427,496	143,175	284,321	1,314,547	1,298,487	5,982	10,078	136,402	125,532	3,447	7,423	152,085	101,883	31,009,870	1,442,991	4.7	TOTAL

1/ REGISTRATION PERIODS ENDING NOT EARLIER THAN NOVEMBER 30 AND NOT LATER THAN JANUARY 31 ARE CONSIDERED CALENDAR-YEAR PERIODS. IN THOSE STATES WHERE THE REGISTRATION PERIOD IS DEFINITELY REMOVED FROM THE CALENDAR YEAR, REGISTRATION FIGURES WERE OBTAINED FOR THE CALENDAR-YEAR PERIOD.

2/ WHEREVER POSSIBLE PUBLICLY OWNED VEHICLES AND VEHICLES NOT FOR HIGHWAY USE HAVE BEEN ELIMINATED FROM THESE COLUMNS.

3/ A COMPLETE SEGREGATION OF BUSSES FROM OTHER VEHICLES IS NOT AVAILABLE. THE BUS FIGURES GIVEN REPRESENT COMMERCIAL BUSSES IN MOST CASES, ALTHOUGH IN SOME STATES CONTRACT SCHOOL BUSSES ARE INCLUDED. WHERE NO BUSSES ARE TABULATED, THEY ARE INCLUDED WITH AUTOMOBILES, UNLESS OTHERWISE NOTED.

4/ DATA ON FEDERAL VEHICLES OBTAINED THROUGH AGENCY OF PROCUREMENT DIVISION, DEPARTMENT OF THE TREASURY.

5/ STATE, COUNTY, AND MUNICIPAL VEHICLES ARE INCLUDED WITH PRIVATE AND COMMERCIAL REGISTRATIONS IN COLORADO, KANSAS, MICHIGAN, NEW HAMPSHIRE, AND VERMONT. A SMALL NUMBER OF FEDERAL VEHICLES ARE INCLUDED IN THE FIGURES FOR INDIANA, KENTUCKY, LOUISIANA, MONTANA, NEW YORK, PENNSYLVANIA, AND VIRGINIA.

6/ FIGURES FOR TRAILERS AND SEMITRAILERS ARE AS REPORTED. APPARENT INCONSISTENCIES ARE DUE TO THE FACT THAT SOME STATES REQUIRE THE REGISTRATION OF TOURIST TRAILERS, LIGHT WORK TRAILERS, AND SIMILAR VEHICLES, WHEREAS OTHER STATES REGISTER ONLY FREIGHT-CARRYING TRAILERS AND SEMITRAILERS. WHEREVER POSSIBLE PUBLICLY OWNED VEHICLES AND VEHICLES NOT FOR HIGHWAY USE HAVE BEEN ELIMINATED FROM THIS COLUMN.

7/ FIGURES INCLUDE NEW-CAR, USED-CAR, AND MOTORCYCLE DEALERS REGISTRATIONS AND SOME WRECKER AND REPAIRER REGISTRATIONS. DATA ON DEALERS EXTRA PLATES ARE INCOMPLETE, ALTHOUGH THEY ARE INCLUDED WITH DEALERS REGISTRATIONS IN SOME STATES.

8/ INCLUDED WITH TRUCKS.

9/ TRAILERS OF 1,000 POUNDS CAPACITY OR MORE PROHIBITED ON HIGHWAYS, ALTHOUGH PERMITTED IN CITIES UNDER CITY LICENSES. TRACTOR-SEMITRAILERS REGISTERED AS TRUCKS. LIGHT TRAILERS PERMITTED BUT NOT REGISTERED.

10/ COMMERCIAL FULL TRAILERS INCLUDED WITH TRUCKS.

11/ APPROXIMATELY 7,500 PUBLICLY OWNED MOTOR VEHICLES AND 200 PUBLICLY OWNED MOTORCYCLES ARE INCLUDED WITH PRIVATE AND COMMERCIAL REGISTRATIONS.

12/ TAXICABS INCLUDED WITH TRUCKS.

13/ TRAILERS INCLUDED WITH TRUCKS.

14/ TRUCKS UNDER 1,500 POUNDS CAPACITY INCLUDED WITH PASSENGER CARS.

15/ INCLUDES 456 AUTOMOBILES OF THE DIPLOMATIC CORPS.

STATE MOTOR-VEHICLE RECEIPTS - 1940

COMPILED FOR CALENDAR YEAR FROM REPORTS OF STATE AUTHORITIES 1/

TABLE MV-2, 1940
ISSUED MAY 1941

STATE	TOTAL RECEIPTS	REGISTRATION FEES 2/: MOTOR VEHICLES: PASSENGER VEHICLES 3/: AUTOMOBILES (INCLUDING TAXICABS)	BUSSES	TOTAL	TRUCKS AND TRACTOR-TRUCKS	TOTAL	OTHER VEHICLES: TRAILERS	MOTORCYCLES	TOTAL	MISCELLANEOUS RECEIPTS: DEALERS LICENSES	OPERATORS AND CHAUFFEURS PERMITS	CERTIFICATE OF TITLE FEES	SPECIAL TITLING TAXES 4/	FINES AND PENALTIES	TRANSFER OR REREGISTRATION FEES	ESTIMATED SERVICE CHARGES, LOCAL COLLECTORS 5/	OTHER RECEIPTS LESS UNCLASSIFIED REFUNDS	TOTAL	STATE
	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	
ALABAMA	4,548	-	-	-	-	4,244	-	-	4,244	3	125	-	-	170	-	-	6	304	ALABAMA
ARIZONA	1,225	383	27	410	460	870	92	2	964	6	25	80	-	9	14	-	127	261	ARIZONA
ARKANSAS	3,399	1,834	80	1,914	1,015	2,929	176	2	3,107	73	206	-		2	9	-	2	292	ARKANSAS
CALIFORNIA 6/	27,914	19,751	(7/)	19,751	4,747	24,498	1,188	79	25,765	81	140	-	-	197	1,522	-	209	2,149	CALIFORNIA 6/
COLORADO	2,797	8/ 1,689	-	1,689	8/ 481	2,170	39	2	2,211	32	176	176	-	53	87	-	62	586	COLORADO
CONNECTICUT	7,385	3,031	132	3,163	1,599	4,762	23	6	4,791	114	1,874	-		163	161	-	282	2,594	CONNECTICUT
DELAWARE	1,252	583	(7/)	583	316	899	44	1	944	8	107	62	-	93	29	-	9	308	DELAWARE
FLORIDA	8,002	4,507	211	4,718	2,059	6,777	359	9	7,145	25	419	260	-	-	1	129	23	857	FLORIDA
GEORGIA	2,768	1,059	134	1,193	554	1,747	246	2	1,995	14	723	-	-	-	10	-	26	773	GEORGIA
IDAHO	1,401	648	9	657	535	1,192	74	2	1,268	24	45	49	-	-	-		15	133	IDAHO
ILLINOIS	24,760	15,631	(7/)	15,631	6,771	22,402	235	19	22,656	102	567	646	-	39	535	-	215	2,104	ILLINOIS
INDIANA	10,596	6,490	92	6,582	1,791	8,373	381	10	8,764	52	770	386	-	36	382	271	-65	1,832	INDIANA
IOWA	12,987	9,208	(7/)	9,208	3,146	12,354	212	11	12,577	75	189	-	-	-	226	-	-80	410	IOWA
KANSAS	4,012	2,676	(7/)	2,676	879	3,555	69	5	3,629	32	48	87	-	196	16	-	4	383	KANSAS
KENTUCKY	5,509	1,829	107	1,936	1.292	3,228	(9/)	3	3,231	25	564	-	1,428	7	223	-	31	2,278	KENTUCKY
LOUISIANA	5,392	3,235	107	3,342	1,293	4,635	701	6	5,342	11	105	-	-	-	-	-	-66	50	LOUISIANA
MAINE	4,162	2,249	13	2,262	10/ 889	3,151	11/ 29	4	3,184	78	533	175	-	24	102	-	66	978	MAINE
MARYLAND	6,698	3,196	188	3,384	666	4,050	160	4	4,214	53	326	237	1,335	392	147	-	-6	2,484	MARYLAND
MASSACHUSETTS	7,319	2,851	150	3,001	1,487	4,488	21	2	4,511	70	2,728	-	-	2	-	-	8	2,808	MASSACHUSETTS
MICHIGAN	24,115	12/ 14,213	(7/)	14,213	5,788	20,001	1,290	18	21,309	99	1,168	920	-	-	356	-	263	2,806	MICHIGAN
MINNESOTA	10,305	7,230	105	7,335	2,081	9,416	373	8	9,797	59	160	-	-	140	-	-	149	508	MINNESOTA
MISSISSIPPI	3,009	-	-	-	-	2,951	-	-	2,951	3	-	-	-	48	-	-	7	58	MISSISSIPPI
MISSOURI	10,750	7,645	(7/)	7,645	1,514	9,159	177	13	9,349	95	390	505	-	3	383	-	25	1,401	MISSOURI
MONTANA 13/	1,721	937	(7/)	937	370	1,307	27	1	1,335	19	185	64	-	63	49	-	6	386	MONTANA 13/
NEBRASKA	2,839	1,301	25	1,326	985	2,311	62	2	2,375	36	138	177	-	-	77	-	36	464	NEBRASKA
NEVADA	313	176	1	177	108	285	7	1	293	2	-	-	-	2	15	-	1	20	NEVADA
NEW HAMPSHIRE	3,052	-	-	-	-	2,529	-	4	2,533	24	376	-	-	67	-	-	52	519	NEW HAMPSHIRE
NEW JERSEY	22,562	10,813	304	11,117	4.297	15,414	384	10	15,808	78	4,026	695	-	232	303	-	1,420	6,754	NEW JERSEY
NEW MEXICO	1,994	989	63	1,052	591	1,643	56	1	1,700	10	179	30	-	1	-	-	74	294	NEW MEXICO
NEW YORK	55,944	33,977	-	33,977	12,339	46,316	736	47	47,099	209	6,464	-	-	566	1,227	-	379	8,845	NEW YORK
NORTH CAROLINA	8,174	4,674	75	4,749	2,567	7,316	450	7	7,773	36	141	187	-	59	-	-	-22	401	NORTH CAROLINA
NORTH DAKOTA	1,661	1,165	14	1,179	345	1,524	5	1	1,530	21	22	63	22	-	-	-	3	131	NORTH DAKOTA
OHIO	30,376	15,831	(7/)	15,831	8,507	24,338	1,451	44	25,833	272	813	610	-	115	819	1,874	40	4,543	OHIO
OKLAHOMA	6,435	2,584	235	2,819	1,514	4,333	648	6	4,987	52	496	288	-	-	-	378	234	1,448	OKLAHOMA
OREGON	3,346	1,626	43	1,669	14/ 1,283	2,952	(7/)	5	2,957	26	81	215	-	30	-	-	37	389	OREGON
PENNSYLVANIA	38,891	20,544	601	21,145	9,150	30,295	578	33	30,906	409	3,301	2,301	-	12	1,671	-	291	7,985	PENNSYLVANIA
RHODE ISLAND	3,218	1,920	46	1,966	543	2,509	8	3	2,520	18	463	-	-	-	95	-	122	698	RHODE ISLAND
SOUTH CAROLINA	2,104	881	39	920	693	1,613	182	1	1,796	27	214	-	-	33	29	-	5	308	SOUTH CAROLINA
SOUTH DAKOTA	1,794	1,434	4	1,438	253	1,691	41	1	1,733	20	-	32	-	-	-	-	9	61	SOUTH DAKOTA
TENNESSEE	5,330	-	-	-	-	4,969	-	-	4,969	(15/)	59	-	-	156	-	-	146	361	TENNESSEE
TEXAS	22,422	13,258	154	13,412	7,130	20,542	627	21	21,190	43	368	387	-	-	294	-	140	1,232	TEXAS
UTAH	1,227	560	(7/)	560	16/ 511	1,071	(7/)	1	1,072	20	29	79	-	1	26	-	-	155	UTAH
VERMONT	2,625	17/ 1,529	13	1,542	17/ 647	2,189	42	3	2,234	28	299	-	-	-	58	-	6	391	VERMONT
VIRGINIA	7,159	4,711	-	4,711	1,521	6,232	170	7	6,409	69	97	322	-	-	210	-	52	750	VIRGINIA
WASHINGTON	3,728	1,427	68	1,495	1,237	2,732	310	7	3,049	15	170	150	-	48	104	175	17	679	WASHINGTON
WEST VIRGINIA	6,529	3,883	27	3,910	1,108	5,018	71	6	5,095	49	319	170	820	-	69	-	7	1,434	WEST VIRGINIA
WISCONSIN	13,075	9,739	168	9,907	2,543	12,450	288	16	12,754	27	38	7	-	-	239	-	10	321	WISCONSIN
WYOMING	603	324	-	324	220	544	46	1	591	8	-	-	-	-	3	-	1	12	WYOMING
DISTRICT OF COLUMBIA	1,751	780	16	796	461	1,257	22	3	1,282	16	232	88	-	-	34	-	99	469	DISTRICT OF COLUMBIA
PARTIAL TOTALS 18/	-	245,001	3,251	248,252	98,286	-	12,100	440	-	-	-	-	-	-	-	-	-	-	PARTIAL TOTALS 18/
FULL TOTALS	439,178	-	-	-	-	361,231	-	-	373,771	2,668	29,898	9,448	3,605	2,959	9,525	2,827	4,477	65,407	FULL TOTALS

1/ RECEIPTS FOR REGISTRATION PERIODS ENDING NOT EARLIER THAN NOVEMBER 30 AND NOT LATER THAN JANUARY 31 ARE CONSIDERED CALENDAR-YEAR RECEIPTS. IN THOSE STATES WHERE THE REGISTRATION PERIOD IS DEFINITELY REMOVED FROM THE CALENDAR YEAR, REGISTRATION RECEIPTS WERE OBTAINED FOR THE CALENDAR-YEAR PERIOD.

2/ SEGREGATION OF REGISTRATION FEES BY TYPE OF VEHICLE NOT AVAILABLE FOR ALABAMA, MISSISSIPPI, NEW HAMPSHIRE, AND TENNESSEE. TOTAL MOTOR-VEHICLE REGISTRATION FEES IN THOSE STATES INCLUDE TRAILER AND MOTORCYCLE FEES, EXCEPT IN NEW HAMPSHIRE, FOR WHICH MOTORCYCLE FEES WERE REPORTED SEPARATELY. DEALERS LICENSE FEES IN TENNESSEE ARE ALSO INCLUDED WITH MOTOR-VEHICLE REGISTRATION FEES.

3/ THE BUS REGISTRATION FEES ARE INCOMPLETE (SEE TABLE MV-1, 1940, NOTE 3). WHERE NO FEES ARE TABULATED, THE FEES OF BUSSES ARE INCLUDED WITH THOSE OF AUTOMOBILES, UNLESS OTHERWISE NOTED.

4/ THE PROCEEDS OF SPECIAL EXCISE AND PRIVILEGE TAXES ON NEW CAR SALES HAVE BEEN SEGREGATED AND ENTERED IN THIS COLUMN. RECEIPTS FROM A 2-PERCENT TAX IN OKLAHOMA AND A 3-PERCENT TAX IN SOUTH DAKOTA, EACH IMPOSED AS PART OF A GENERAL SALES TAX, WERE $1,413,950, AND $497,718, RESPECTIVELY.

5/ IN MANY STATES COUNTY OR LOCAL OFFICERS ARE ALLOWED SERVICE CHARGES FOR ISSUING REGISTRATIONS, OPERATORS LICENSES, ETC. IN THE MAJORITY OF CASES THESE CHARGES ARE INCLUDED IN REGISTRATION AND OTHER FEES. THE AMOUNTS SHOWN IN THIS COLUMN ARE ESTIMATES OF SERVICE CHARGES COLLECTED AND RETAINED BY LOCAL OFFICIALS AND NOT REPORTED ELSEWHERE IN THE TABLE.

6/ REGISTRATION FEES INCLUDE PROCEEDS OF STATE "VEHICLE LICENSE FEES", $13,117,816, IMPOSED IN ADDITION TO THE REGULAR REGISTRATION FEES OF $12,646,756.

7/ INCLUDED WITH TRUCK FEES.

8/ FEES OF 28,018 LIGHT TRUCKS INCLUDED WITH THOSE OF PASSENGER VEHICLES.

9/ TRAILERS OF 1,000 POUNDS CAPACITY OR MORE PROHIBITED ON HIGHWAYS, ALTHOUGH PERMITTED IN CITIES UNDER CITY LICENSES. TRACTOR-SEMITRAILERS REGISTERED AS TRUCKS. LIGHT TRAILERS PERMITTED BUT NOT REGISTERED.

10/ INCLUDES FEES OF COMMERCIAL FULL TRAILERS.

11/ FEES OF LIGHT TRAILERS AND COMMERCIAL SEMITRAILERS ONLY. FEES OF COMMERCIAL FULL TRAILERS INCLUDED WITH THOSE OF TRUCKS.

12/ TAXICAB FEES INCLUDED WITH THOSE OF TRUCKS.

13/ REGISTRATION FEES ARE COLLECTED BY COUNTIES AND STATE DOES NOT MAINTAIN COMPLETE RECORD. FIGURES GIVEN ARE ESTIMATES SUPPLIED BY STATE.

14/ INCLUDES TRAILER FEES.

15/ INCLUDED WITH REGISTRATION FEES.

16/ INCLUDES FEES OF BUSSES AND TRAILERS.

17/ FEES OF TRUCKS UNDER 1,500 POUNDS CAPACITY INCLUDED WITH THOSE OF PASSENGER CARS.

18/ TOTALS OF COLUMNS FOR WHICH FULLY CLASSIFIED DATA WERE NOT AVAILABLE FOR ALL STATES.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF MAY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 4,532,129	$ 2,119,682	105.9	$ 6,463,196	$ 3,214,205	237.0	$ 1,790,100	$ 887,150	57.4	$ 2,108,720
Arizona	1,658,892	1,117,267	62.2	1,704,502	1,168,485	79.0	238,615	158,349	1.7	1,636,480
Arkansas	5,130,207	2,347,985	130.2	1,366,943	681,786	54.3	676,098	337,595	37.8	1,387,624
California	7,182,005	3,603,909	133.6	8,670,313	4,675,226	125.2	2,103,539	1,096,376	41.7	3,394,309
Colorado	2,529,042	1,364,397	199.2	2,344,465	1,363,086	104.9	778,156	430,911	69.8	2,961,086
Connecticut	1,952,321	945,967	16.2	1,784,135	868,069	18.1	575,967	280,284	9.0	1,090,689
Delaware	1,927,921	963,182	30.5	361,405	180,552	4.5	639,356	276,669	22.6	1,184,811
Florida	3,652,499	1,813,691	85.2	887,632	474,716	49.9	656,518	328,008	13.7	3,548,700
Georgia	3,413,741	1,652,691	199.5	7,068,427	3,544,463	278.1	2,282,339	1,141,170	109.1	6,535,207
Idaho	2,047,494	1,155,675	151.2	1,434,790	884,183	64.7	827,892	395,842	42.9	1,729,709
Illinois	7,171,478	3,504,867	157.9	8,554,046	4,277,773	180.6	1,900,052	949,470	41.0	4,597,913
Indiana	5,761,799	2,814,994	127.2	8,054,056	3,828,537	128.8	993,166	417,933	16.2	2,209,436
Iowa	5,641,075	2,660,020	198.2	4,749,139	2,268,158	161.1	1,693,942	809,050	90.2	1,574,347
Kansas	5,131,145	2,480,080	470.5	5,485,031	2,784,583	280.9	3,920,992	1,942,461	216.3	4,124,962
Kentucky	3,068,125	1,492,936	91.1	3,731,523	1,876,442	112.8	4,947,660	2,297,595	121.0	2,028,201
Louisiana	11,856,522	2,970,570	39.4	2,375,813	1,187,148	55.2	1,566,035	773,850	38.9	3,737,326
Maine	1,385,161	676,459	31.0	1,539,547	791,913	19.8	966,842	483,005	20.6	559,363
Maryland	1,270,568	623,817	29.1	3,665,235	1,831,513	29.9	430,900	135,000	2.3	1,759,504
Massachusetts	1,835,469	914,828	22.9	2,758,736	1,400,529	19.7	2,059,810	1,025,825	15.0	3,019,341
Michigan	6,385,064	2,922,971	224.1	9,406,920	4,690,860	214.0	589,400	294,700	9.1	2,490,398
Minnesota	6,455,327	3,113,854	531.9	5,458,736	2,719,077	286.6	4,195,944	2,080,657	232.8	3,099,925
Mississippi	3,350,021	1,550,947	139.5	7,982,716	3,910,558	453.6	853,700	425,100	49.4	1,247,006
Missouri	3,619,467	1,783,975	179.9	10,383,487	4,929,023	255.8	5,900,076	2,271,030	163.0	3,622,252
Montana	4,631,688	2,621,088	328.8	2,921,800	1,652,125	133.4	1,007,547	572,891	57.2	4,045,692
Nebraska	4,900,669	2,298,927	578.4	4,431,382	2,235,729	472.1	3,085,103	1,541,489	294.5	2,797,588
Nevada	1,585,633	1,342,400	80.0	1,761,074	1,478,267	79.2	1,010,137	794,058	47.4	658,339
New Hampshire	1,639,811	806,655	42.1	426,398	211,890	8.4	545,446	271,374	5.3	1,039,387
New Jersey	2,564,349	1,266,942	13.3	6,533,502	3,266,671	50.7	27,110	13,555		1,741,492
New Mexico	2,933,097	1,803,575	215.6	1,109,838	679,182	51.4	504,907	326,473	46.3	1,930,106
New York	11,435,832	5,519,494	199.0	11,987,960	5,966,392	153.0	1,356,945	534,522	16.6	4,471,711
North Carolina	4,406,245	2,200,608	235.0	5,802,434	2,894,170	244.6	747,530	356,595	32.4	2,738,306
North Dakota	2,084,039	1,101,526	212.6	3,688,594	2,058,721	292.6	1,839,060	929,613	154.4	4,326,726
Ohio	7,228,202	3,600,519	93.4	14,856,305	7,406,088	123.9	5,293,648	2,401,685	37.8	3,632,335
Oklahoma	3,363,644	1,778,855	151.5	2,998,424	1,545,424	98.0	2,342,140	1,213,896	89.8	4,850,065
Oregon	3,480,704	2,078,861	160.4	3,830,842	2,063,246	111.8	1,199,063	671,410	10.6	881,852
Pennsylvania	8,126,306	3,999,124	100.5	14,057,274	6,923,640	118.3	1,948,908	963,900	19.9	3,546,750
Rhode Island	1,313,964	642,140	13.2	1,102,946	550,832	9.9	197,310	98,655	1.6	1,075,517
South Carolina	2,510,834	1,211,198	190.0	4,073,447	1,903,387	135.4	418,810	171,057	23.6	2,133,518
South Dakota	3,232,680	1,824,453	544.6	4,454,883	2,770,573	543.9	1,131,370	659,700	181.1	2,985,129
Tennessee	3,421,603	1,694,964	75.1	5,192,596	2,596,298	152.9	1,543,892	771,946	19.8	3,637,042
Texas	8,970,044	4,347,317	520.0	14,009,871	6,919,759	603.9	3,077,165	1,432,470	145.8	7,112,925
Utah	1,078,435	768,501	75.0	1,731,476	1,302,473	56.9	635,822	393,059	20.7	900,173
Vermont	1,308,660	624,484	37.6	1,092,828	552,552	31.8	387,654	189,176	6.1	404,325
Virginia	3,118,810	1,476,053	80.0	4,544,042	2,127,804	75.8	1,337,692	589,542	30.7	1,920,472
Washington	4,443,677	2,283,267	91.4	2,011,112	1,074,049	23.8	443,358	235,015	4.0	1,638,797
West Virginia	2,188,728	1,083,857	76.4	4,175,160	2,080,547	80.1	364,570	182,218	5.2	1,770,918
Wisconsin	5,707,254	2,801,205	201.7	3,322,886	1,652,288	123.1	683,992	318,740	20.3	4,627,835
Wyoming	1,820,709	1,111,594	196.3	1,843,380	1,199,056	180.7	275,927	154,376	20.2	1,235,788
District of Columbia	498,667	249,021	5.1	828,211	413,509	2.6	271,446	135,481	1.1	420,250
Hawaii	338,503	167,392	6.0	546,698	292,545	7.8	38,944	19,472	.3	1,973,814
Puerto Rico	709,534	351,220	15.4	1,583,127	781,640	20.3	267,936	131,600	2.1	805,679
TOTALS	195,999,793	95,650,004	7,894.8	231,149,283	118,149,742	7,200.8	72,570,531	35,311,998	2,716.3	128,949,840

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF MAY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 190,944	$ 95,263	9.3	$ 1,333,057	$ 667,758	60.8	$ 41,700	$ 20,850	0.1	$ 607,504
Arizona	240,302	168,815	23.6	202,398	149,242	5.3	50,713	31,527	8.7	365,891
Arkansas	463,572	202,807	14.9	412,654	205,474	32.6				309,298
California	1,056,411	564,761	40.5	1,177,912	850,598	13.8	429,723	226,939	12.1	486,549
Colorado	276,356	154,551	9.8	175,652	98,569	26.7				345,179
Connecticut	370,531	179,413	4.6	298,035	136,331	6.1				187,829
Delaware	127,253	63,627	12.7	46,219	22,675	2.9	258,291	118,835	12.3	224,684
Florida	91,270	45,227	8.7	1,096,579	547,839	11.7				285,907
Georgia	296,304	147,033	26.9	940,929	520,815	67.8	346,525	173,262	34.2	1,161,565
Idaho	154,346	91,644	24.0	289,104	174,459	13.8	18,414	9,252	5.5	247,016
Illinois	1,766,825	829,343	80.6	1,193,850	581,925	52.0	818,290	388,050	34.2	426,478
Indiana	471,760	222,327	31.0	352,964	181,939	18.9	1,465,471	652,716	69.9	600,475
Iowa	2,441,922	1,160,111	544.0	648,074	302,785	179.2	143,140	56,062	31.2	468,200
Kansas	396,841	197,497	50.2	846,651	430,896	45.6	1,268,141	635,170	133.5	1,018,002
Kentucky	799,718	268,935	65.5	762,283	214,927	26.7	1,035,400	253,911	74.1	328,487
Louisiana	112,966	52,661	10.9	564,708	230,289	20.2	168,715	84,358	14.6	500,503
Maine	303,854	139,080	17.0	40,606	20,303	1.5				161,212
Maryland	128,300	64,150	5.5	451,390	222,695	17.3	117,500	47,000	4.2	330,351
Massachusetts	523,320	259,348	10.5	177,572	104,717	3.4	605,103	301,067	10.8	378,087
Michigan	1,582,408	738,209	128.6	805,460	402,730	37.2	513,900	256,950	40.1	604,654
Minnesota	793,611	382,232	122.5	1,133,595	571,047	139.0	423,498	179,368	51.7	940,987
Mississippi	278,087	137,780	12.5	925,194	463,947	51.9	209,800	93,365	9.3	651,872
Missouri	762,270	376,672	103.9	326,112	157,075	25.0	668,366	279,656	75.1	869,097
Montana	712,410	402,588	98.0	389,844	220,819	38.2	279,332	158,599	54.5	629,537
Nebraska	751,855	356,768	119.3	423,696	217,126	48.3	357,828	178,562	45.6	389,255
Nevada	206,236	167,549	40.9	186,061	161,978	19.6	97,767	84,959	4.5	143,066
New Hampshire	143,639	68,883	3.4	71,533	34,946	3.6	83,573	41,587	1.1	181,693
New Jersey	390,996	195,060	15.3	337,342	188,185	7.5	436,810	218,405	12.7	443,889
New Mexico	445,310	225,926	25.8	395,008	235,715	21.9	150,634	96,358	26.6	220,206
New York	2,357,156	1,117,810	77.9	1,239,034	621,991	30.5				818,145
North Carolina	1,001,149	497,279	89.4	604,099	304,628	51.8	102,240	51,120	15.3	443,937
North Dakota	80,071	42,652	.3	136,016	74,496	3.5				1,276,906
Ohio	1,710,388	848,861	59.8	2,064,770	1,079,580	64.9	450,180	223,915	5.3	953,308
Oklahoma	795,576	416,089	57.1	301,276	159,134	14.8	488,330	257,767	47.3	967,589
Oregon	407,563	227,326	61.3	370,544	167,124	27.2	176,886	100,050	16.4	337,018
Pennsylvania	1,728,851	846,811	59.9	1,632,189	815,164	34.4	792,210	385,969	13.3	122,113
Rhode Island	262,488	120,687	3.6	93,806	50,516	.9	121,212	60,435	1.7	63,989
South Carolina	647,847	238,916	90.4	668,457	256,366	51.0	377,700	140,124	11.5	159,848
South Dakota	3,714	3,624		25,302	15,768	9.0	9,240	5,190	6.2	1,537,944
Tennessee	150,805	71,863	8.7	287,466	143,733	10.0	1,355,580	677,790	48.2	558,227
Texas	1,517,781	742,578	202.0	1,188,396	587,563	111.5	325,220	149,900	39.3	1,465,584
Utah	181,542	110,320	23.9	236,725	156,443	13.8	32,539	16,780	9.4	211,407
Vermont	323,296	116,366	13.1	193,984	56,234	7.6				89,704
Virginia	522,235	244,363	28.1	414,868	192,991	16.4	319,464	136,740	3.9	380,410
Washington	631,616	320,705	31.0	504,263	287,828	28.0				262,848
West Virginia	334,392	165,602	18.5	285,050	142,525	7.9	438,997	218,945	18.3	310,650
Wisconsin	328,957	163,259	7.4	950,433	482,153	32.6	819,984	342,962	35.6	554,741
Wyoming	431,815	260,037	42.8	369,790	159,928	18.8	38,360	17,300	9.1	200,812
District of Columbia	112,164	56,082	1.4	58,203	29,096	.6	30,529	14,750	.3	73,194
Hawaii	264,732	132,578	8.6	1,096	1,096					250,559
Puerto Rico	193,690	94,735	8.7	231,364	112,855	10.6				134,597
TOTALS	30,267,445	14,796,803	2,554.3	27,861,813	14,215,016	1,544.3	15,867,305	7,386,545	1,047.7	24,681,003

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

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Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

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Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

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No. 191MP. . Roadside Improvement. 10 cents.

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No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

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No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP . . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF MAY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 288,272	$ 288,189	4		7	$ 649,253	$ 629,200	5	1	2	$ 145,390	$ 145,390	2	2	6	$ 1,014,605
Arizona	202,308	194,942	3		2	339,710	339,362	2			29,350	29,350		1	2	207,575
Arkansas	1,200,084	1,194,779	11	1	15	454,968	454,639	5		1	150,877	150,822	1		3	344,619
California	474,671	472,281	4		19	1,031,503	850,904	7	1		684,027	684,027	2		7	1,458,206
Colorado	18,386	18,386			3	380,953	380,953	2			447,032	439,799	4		1	623,485
Connecticut	622,002	611,366	5	1		166,222	165,415	2			55,869	54,783		1		563,322
Delaware	108,682	108,682	4		17	94,135	94,135	1			176,448	175,348	1		1	384,873
Florida	228,495	223,997	2		5	366,897	365,383	4	1	2	188,859	188,859	1		25	1,183,217
Georgia	256,047	254,148	5	2	13	1,242,104	1,242,104	10	7	2	217,434	217,434	1	1	15	1,974,385
Idaho	302,149	291,486	5		35	14,943	14,943				95,098	95,098	1		3	481,562
Illinois	1,815,943	1,681,006	10		80	1,477,555	1,251,765	5	1	77	1,041,144	1,012,138	6		28	1,890,761
Indiana	785,008	776,856	4	2	87	946,240	906,953	7	1	10	101,550	95,841			26	956,891
Iowa	528,992	506,257	4		98	477,490	456,245	6	2	2	592,469	590,415	3		42	797,573
Kansas	846,646	839,306	11		18	54[illegible],768	544,768	9	2	3	95,752	95,752	3		5	1,278,276
Kentucky	579,583	551,568	8		12	1,036,397	1,035,397	9			218,085	218,085	3	1	1	358,480
Louisiana	436,153	422,870	3		1	202,163	202,163	4			553,700	553,694	6		2	916,044
Maine	159,988	159,070	1	1	6	132,646	132,646	1	1							393,580
Maryland	183,547	183,543	1		3	482,459	450,666	2	2	6	393,550	180,550	1		12	800,364
Massachusetts	16,588	16,588		1		426,750	416,112	2			505,452	504,322	3	1		1,820,605
Michigan	1,169,498	1,112,969	8	1	40	1,544,745	1,544,745	4	5		305,600	305,600			4	878,520
Minnesota	1,443,347	1,432,956	12	2	20	1,065,804	1,065,804	8	5		276,580	276,580	1	2	2	990,812
Mississippi	308,819	308,819	4	1	1	664,475	664,475	9			142,499	142,499	1	1	9	645.125
Missouri	1,207,124	1,206,565	6	4	1	1,921,553	1,466,133	5	4		181,880	159,161	1	1		1,253,824
Montana	434,356	434,356	5		4	90,520	90,520	1		1	96,536	96,536	1		2	512,684
Nebraska	438,949	436,440	3	1	14	894,621	894,621	15	1	2	389,818	389,818	8		24	183,237
Nevada	75,015	74,810	1		20	118,272	118,272	3			71,448	71,448	1		5	106,425
New Hampshire	104,313	104,277	3		1	148,837	148,017	3		1	131,062	82,451	1	1		344,297
New Jersey	278,937	278,937	2		4	1,192,373	1,066,823	6	1	1	59,140	59,140		1		1,049,600
New Mexico	348,049	339,475	4		6	73,664	73,664	1			159,441	159,441	1			498,993
New York	1,534,851	1,491,256	9	6	8	3,580,443	3,524,972	5	16		666,950	518,000		2		3,041,087
North Carolina	768,045	767,977	10	3	33	630,009	629,769	4	7	10	162,196	162,196		1	26	1,050,385
North Dakota	417,276	415,284	5		22	470,440	457,503	5		1	200,750	128,500	4			726,613
Ohio	1,372,166	1,300,972	7	2	17	2,404,847	2,373,804	13	1		1,706,340	1,656,340	6		3	1,294,259
Oklahoma	785,879	780,074	11	1	58	266,622	263,206	2		6	789,479	730,952	6		33	1,601,171
Oregon	208,640	159,119	3			411,078	347,465	4			18,280	18,280	1		4	392,976
Pennsylvania	1,387,269	1,377,793	13	2		2,671,627	2,667,799	20			1,578,372	1,459,925	5			2,513,593
Rhode Island	8,222	7,406				206,703	206,703		1							178,256
South Carolina	474,196	473,546	4	3	25	206,011	206,011	3	1	3	553,412	466,625	3	3	27	743,454
South Dakota	136,032	133,406	2	1	4	564,332	563,472	16			253,413	237,463	5		9	868,739
Tennessee	244,480	231,146	2	2		300,646	291,646	3	3		1,118,708	1,118,708	6	1		925,530
Texas	1,630,991	1,609,827	12	1	9	1,792,268	1,776,081	19		1	622,116	566,789	6			1,578,844
Utah	133,708	133,399			51	83,515	82,772	3		12	96,722	96,722			35	248,062
Vermont	143,924	143,684		1	12	115,533	115,533		1		16,478	16,478			4	293,090
Virginia	322,483	319,995	3	2	14	681,709	681,709	5	3		385,248	309,869	2	2	3	583,843
Washington	362,481	357,499	4	2	10	440,794	440,794	3	3	1	9,250	9,250			3	455,408
West Virginia	119,730	119,730	1		3	530,502	524,882	6			366,430	362,566	4	1	6	639,695
Wisconsin	825,078	809,586	6	4	7	553,004	523,781	4		8	621,505	620,731	2	2	43	1,159,122
Wyoming	91,384	91,379	1		2	481,657	481,656	6			2,258	2,258			4	291,888
District of Columbia	56,868	56,868	1			2,193	2,193				298,213	273,744		1		1,462
Hawaii	8,416	8,141			2	405,282	404,759	4								181,412
Puerto Rico	90,290	89,720	5			612,557	607,666	8			130,412	127,830	2			336,559
TOTALS	25,984,360	25,402,731	23[illegible]	47	809	35,593,792	34,241,003	271	71	152	17,102,622	16,057,607	105	26	425	43,017,388

[illegible] GOVERNMENT PRINTING OFFICE: 1941

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 22, NO. 5 ▽ JULY 1941

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ATTRACTIVE PARKING LOT IN WASHINGTON, D. C.

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

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FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 5 July 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

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THE PROBLEM OF PARKING FACILITIES

REPORT OF THE DEPARTMENT OF FINANCE, HIGHWAY RESEARCH BOARD,[1] THOMAS H. MacDONALD, CHAIRMAN, COMMISSIONER, PUBLIC ROADS ADMINISTRATION

The off-street parking problem is a significant factor in highway finance because of its relation to urban congestion and to the provision of express roads into cities designed to furnish more convenient access to central business districts. Yet today efforts to meet this problem by providing adequate low-cost parking facilities have been generally feeble and ineffective. In most cases the American city has done nothing to help itself, and in many cases it has adopted policies which constitute a definite hindrance to any sane solution.

The parking problem is discussed in terms of the general problem of providing a complete highway transportation service, and in relation to the general transportation problem of urban areas and the general problem of city planning. Three types of parking facilities are described: commercial, private, and municipal. Cost conditions are described for each of these types of operation and consideration is given to methods of equitable payment. It is found that there are numerous inadequacies in current provision of terminal accommodations by private initiative and in view of these, the following means are suggested by which government may assume its proper responsibility.

1. Municipal governments might encourage private operators by eliminating license fees on parking lots, by lowering property assessments on land used for parking, or by the abatement of taxes on such property. These concessions would result in the reduction of parking costs, on the principle that the benefit of parking facilities would increase surrounding land values and help to rehabilitate the city.

2. Cities might also assist private enterprise by furnishing adequate street approaches, by enforcing street parking restrictions, by leasing public lands to private operators, and by planning the most desirable locations and designs for future parking facilities. Enactment of building codes requiring the provision of off-street facilities for new buildings should be extended.

3. The success and growth of municipal parking accommodations suggests further development of public ownership and operation and the passage of necessary legislation to permit the acquisition and financing of land for this purpose.

4. State governments might contribute to a solution by permitting the use of revenue bonds for parking facilities and the servicing of these with shares of State motor-vehicle revenues at present being made available for municipal streets.

5. The Federal Government might assist in furnishing land by R. F. C. loans or the demolition of condemned buildings through W. P. A., and by sponsoring adequate surveys and planning of parking needs.

During the early road-building era, efforts to provide highway transportation service were directed exclusively to the vehicle in motion on the assumption that the vehicle at rest could take care of itself. This assumption at one time was generally valid, for parking at the curb furnished adequate terminal facilities for the motor vehicle, as it had for the horse. Today, however, the growth and concentration of motor-vehicle ownership and use have reduced curb space to relative insignificance in relation to the demand for parking accommodations in downtown areas, leading to the necessity of furnishing this service off the street. Failure to recognize the need for off-street terminals in conjunction with the urban highway system, and inability or unwillingness on the part of cities to adopt bold measures for alleviating this problem, have long been a source of inconvenience and a barrier to efficient motor-vehicle use.

It would hardly be possible to convey the eloquence of previous testimony that parking is a serious problem. Elaborate surveys conducted in many cities already seem to have proved that further street parking is a mathematical impossibility. Yet the counting and recounting of potential parkers and available parking accommodations have generally led to only superficial recommendations affording little relief, with the result that the city and the motorist have accepted their predicament as a matter of course. A recent trip through the United States, for example, revealed that municipal governments have generally done little of real significance to alleviate parking difficulties, and instead have sponsored policies which are a definite hindrance to any sane solution. Municipal interest in some cases seemed to be limited to the apprehension of illegal parkers and the revenue possibilities of parking meters, while in others the inability to cope with parking difficulties has created the attitude that effective measures are no longer possible. Yet in view of the importance of the problem the wonder is not so much how it can be solved as how it has so long escaped solution. In one city, for example, a survey of the downtown area revealed that 93 percent of all vehicles in the district were parked and only 7 percent moving on the streets.

Two years ago a report was transmitted to the Congress by the President of the United States containing a master plan for highway development (*25*).[2] This report outlined the need for express highways into the cities to permit easier access to the central districts, which are the ultimate destinations of most main line traffic entering the urban areas. The present report is an attempt to supplement these plans by discussion of the simultaneous need of accommodating the vehicle after its city terminus has been reached, and of removing to off-street facilities all vehicles parked at the curb where they interfere with the efficient movement of traffic. The magnitude of this task and a growing recognition of public responsibility for its performance have suggested a review of the nature of the problem and its solution as they concern the problems of highway finance.

PARKING AN ESSENTIAL PART OF COMPLETE TRANSPORTATION SERVICE

It is not a new idea, but an important one, that highway transportation constitutes not merely the movement of vehicles but the function of getting from one place to another. The provision of motor highways must, therefore, comprehend this over-all service from origin to destination, since exclusive concern with the ability of the automobile to go and not to stop makes impossible a full realization of the speed, economy, and convenience of efficient highway service. For example, economy is greatly reduced when high terminal fees are added to vehicle operating costs, or when extra distance must be traveled to a parking space; likewise

[1] Prepared for the Department by Wilfred Owen.

[2] Italic figures in parenthesis refer to bibliography, p. 118.

in terms of total highway transportation cost it is uneconomical to provide storage space on expensive street pavement when such use results in traffic congestion, or to widen pavements and then permit parked vehicles to reduce effective width. Parking on the street is expensive. In fact it has been estimated that the cost to the city of providing curb space for one vehicle on Fifth Avenue, New York, is approximately $142 per month, or about 10 times the cost of parking in a modern garage (*8*).

With regard to over-all speed of motor-vehicle service, the time spent in locating a place to park and walking to and from it considerably reduces the swiftness of automobile travel; and the task of finding terminal accommodations within reasonable reach of the motorist's destination renders motor-vehicle service in many urban communities irksome rather than convenient. As an illustration of the time-consuming process of urban motoring, tests made of the progress of a commuter from a suburb of Washington, D. C., to the downtown district revealed that average running speed for the automobile was 14 miles per hour from origin to destination; that after the driver had found a place to park, the speed had been reduced to 9.9 miles per hour; and that accounting for the time spent in walking back to the office, the over-all average speed was further reduced to 7.3 miles per hour, or approximately half the actual running speed (*9*).

The point to be emphasized, therefore, is that parking is not an isolated issue, but an intimate part of providing fast, cheap, and convenient highway transportation service. Failure of the street itself to provide complete service in terms of adequate parking as well as traffic movement has not altered this fact, but has merely necessitated the dedication of additional facilities off the street. The problem of financing these facilities is therefore closely allied to the whole question of highway finance, just as rail service involves the railroad terminal, or as airports and docks must be furnished in providing transportation by air and water.

In addition to this consideration, the highway problem is part of the general problem of providing transportation in urban areas, for the planning of urban highway service through provision of motorways and parking facilities cannot achieve the optimum result unless decisions are made in conjunction with possible alternative improvements in transit facilities. Important factors in this choice are the relative costs of individual and mass transportation and the convenience and efficiency of each in terms of serving the peculiar needs of a particular urban area. It is also significant, moreover, that transportation is not an end in itself but only a means of implementing some other objective, so that the parking problem, as part of the transportation problem, cannot be viewed completely without reference to the broader problems and policies of the whole city in terms of land use, urban finance, and the pattern of municipal development.

CITY TRAFFIC PROBLEMS NOT SOLVED BY FLIGHT TO SUBURBS

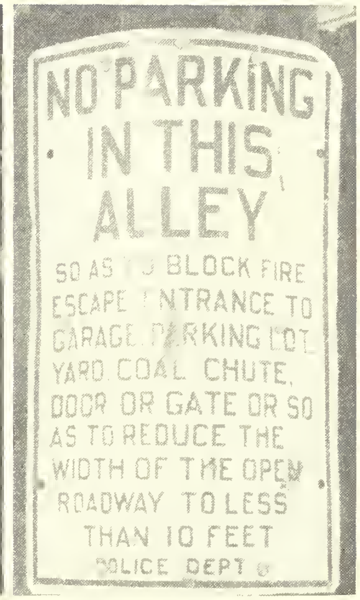
This intimate connection between transportation methods and municipal patterns is illustrated by the history of urban growth. In the days of horses and pedestrians the city remained small in size because its radius was determined primarily by the time it took to commute. The streetcar later increased this radius, and by permitting mass movements of commuters it encouraged vertical development of the downtown area. Finally came the automobile with its much greater travel possibilities, extending the area of urban influence many times and making it possible to escape the old city area made distasteful by unintelligent land use and planless growth (*4*).

The problems raised by these trends in urban development are of grave concern to most large cities, and considerable effort will be required to determine proper steps to halt their disastrous consequences. For disintegration of the city appears to be not merely the temporary effect of a readjustment in the urban pattern, but a more permanent malady which spreads with attempts to escape it. Thus the trend began with the gradual abandonment of congested and run-down areas, as evidenced in the city by slums and vacant lots, and in the suburbs by an outcrop of new business establishments and satellite communities. With the costs of public services remaining high even in decadent areas, other more productive districts were called upon through higher tax burdens to subsidize those parts of the city no longer self-supporting. In St. Louis, for example, taxes levied in slum districts amount to only about 40 percent of the costs of municipal services furnished these districts, and a large percentage of these levies are delinquent. On the other hand, the central downtown district pays two and one-half times as much in taxes as it receives in the cost of municipal services rendered (*21*). This situation, typical of our large cities, has led to further withdrawal of business from expanding areas of high-tax property, with consequent extension of blight, a need for further subsidy, and the movement of taxable values beyond the jurisdiction of the city.[3]

Abandoning the city for the suburbs, however, does not long afford relief from urban troubles. For as the plight of the downtown district produces increasing outward movement, those who previously sought the city limits find that the edge of the city has itself moved farther outward, and that most of the mistakes which led to the original exodus from the downtown area are committed again in the suburbs. Absence of zoning regulations or lack of zoning enforcement permit business to encroach upon residential areas, causing further population movement and depressing residential real estate values. Failure to protect new highways from harmful uses of abutting land and neglect of necessary parking accommodations render the outlying shopping district as inaccessible as the central area it sought to replace. Indiscriminate and scattered development of real estate over wide areas makes unit costs for public services unnecessarily high, and because there is often no way of furnishing satisfactory mass transportation for the dispersed populace, commuting to the central business district must be accomplished largely by automobiles, with consequent multiplication of street congestion and parking difficulties.

The question naturally suggested by consideration of the urban problem is how this diseased condition has been permitted to thrive in American municipalities. One answer seems to be that in spite of the preponderant role of our cities in the national economy, public concern in this country has always been directed chiefly toward farm and rural problems, as demonstrated in transportation by traditional emphasis upon rural highways and intercity traffic, and by the comparative neglect of terminal problems, municipal street facilities

[3] For an enumeration of the causes of urban decentralization, see the preliminary report on "Decentralization" by the Urban Land Institute, Chicago, April 1940.



Photos by American Automobile Association

In Large Cities, Even Parking Space in Alleys is at a Premium.

and mass transportation. The failure of cities to take appropriate measures in their own behalf has resulted in large part from the fact that our Federal and State governments were inaugurated at a time when no urban places of importance existed. Today, therefore, the city finds itself "almost completely disfranchised by our constitutional system," with many major programs in transportation as well as in other fields "throttled from sheer fear on the part of city officials who know from bitter experience that that city's governmental powers are not commensurate with its growing functions and responsibilities" (*11*). It is these conditions which constitute the setting in which the parking problem has emerged. Any solution of that problem must therefore take into account over-all needs for solving the whole urban dilemma.

PARKING NOW BEING FINANCED BY SEVERAL MEANS

Types of operation.—Payment for off-street parking in the central city varies considerably with the methods used to provide facilities, of which there are three general categories: Private facilities, privately operated public facilities, and public facilities. Today the second category, the privately operated public facility, which may be either a parking lot or a garage, is providing the major parking capacity in our downtown areas. Payment for these commercial facilities is assessed entirely against the motorist through direct cash charges, except where payments are made by stores to provide their customers a period of free parking. In the case of private accommodations operated in connection with retail stores, hotels, or other business establishments, there is no universal means of exacting payment. In some cases the motorist pays directly for the service, while in others the whole cost may be absorbed by the business establishment, or there may be some sharing of responsibility by the vehicle user and the business. Finally, parking may be a municipal operation, with facilities furnished free to the motorist or at low rates made possible through sharing of the bill by property owners or general taxpayers.

This variety of responsibilities established in paying the parking bill is not unlike that encountered in providing the streets themselves. For just as the motorist, the property owner, and the city share in the provision of adequate pavements for moving traffic, so also the necessity of furnishing terminal space suggests that access to the downtown area is of advantage not only to the motorist, but to the property owner, the merchant, and the city itself. Decision as to how the bill should be paid depends not only upon the financial condition of the individual city, but upon the manner in which facilities are provided, since conditions of cost and possible methods of financing differ with each operating category.

Varying cost conditions.—Under private operation of public lots the land used for parking is generally leased for an amount sufficient to pay taxes. In addition to this payment of rent, additional cost items include a return to compensate for private initiative in managing the enterprise, and generally a license fee payable to the city. Analysis of the cost per car of providing privately owned parking lot facilities has revealed that 36.3 cents out of every dollar represent return on investment, and that property taxes and license fees constitute another 10 cents.

Under municipal operation, however, cost conditions may be entirely different. Parking may be provided on land which has long been in the possession of the city, involving no cash outlay. Appropriate sites are often available on land which has become public property through tax delinquency, or on remnants left from some previous public project. Removal of a public building may also provide usable property, or land may be acquired as a gift. In the event that a municipality should acquire land directly for parking facilities, however, total costs incurred would still be lower than under private ownership. For on the theory that the whole city would benefit, taxes and return on investment might be foregone, and operating costs for municipal facilities have generally been kept at a minimum.

Private parking accommodations present still further variations in cost, for parking facilities may be provided as part of the building, or on adjacent property previously available or acquired specifically for that purpose. Cost figures for merchant-owned parking facilities are in general much lower than those for privately owned public facilities, not only because of the possibility of providing them in conjunction with existing property and business organization, but because a direct return on the investment may be foregone in view of the profits from increased sales.

Private vs. public operation.—The problem of how parking should be financed, therefore, leads inevitably to the question of whether operation should be private or whether some degree of municipal action is necessary. Traditionally, American enterprise has been conducted on a private basis, with government performing only those functions which private endeavor has been unable successfully to provide. In other words, our economy is the joint product of private and public action, based upon the belief that each function should be assigned to whichever type of enterprise can do the best job. Obviously this arrangement comprehends certain realms of activity which are difficult to classify in one sphere or the other, but a satisfactory decision is not impossible if a thoughtful evaluation is made of the alternative methods. The following critique of existing private parking facilities is intended to point out some of the reasons why private initiative has failed to solve the problem, including not only those weaknesses which are believed to be inherent in the private operation of parking facilities, but other factors which may be susceptible to correction.

REASONABLE FEES AND CONVENIENT LOCATION REQUIRED

Trend in commercial facilities.—In the absence of municipal action there has been little reluctance among private interests to establish parking stations. The rate at which this responsibility has been assumed is illustrated by Los Angeles, where the number of off-street parking facilities increased from 50 in 1922 to 920 in 1938, with capacity expanding from 4,000 automobiles to 65,000. Chicago had 60 off-street facilities in 1927 and 237 in 1938, and today one-fourth of the Chicago downtown area, excluding streets and railroad properties, is used for open parking lots. Similar trends are reported from every large city. Philadelphia had 100 lots in 1931 and 800 in 1938; Cincinnati nearly doubled its parking lot space in the period from 1932 to 1936, and Detroit lots could accommodate three times as many cars in 1937 as in 1927.

Unfortunately, however, solution of the parking problem involves not merely the provision of space, but of space properly located and attractively priced. These qualifications were recognized 17 years ago at the National Conference on City Planning, where it was stated that parking rates must not be "too high to be popular," nor parking locations "haphazard and illogical" (*27*). The fact that current efforts by private enterprise often fail to comply with these specifications, however, is suggested by figures describing the use of off-street facilities. In New York City a survey of parkers conducted in a congested downtown district revealed that while 15,000 cars were parked at the curb, only one-third of available off-street space was being used, leaving 12,000 spaces empty (*6*). In Detroit the situation was much the same. Within four-tenths of a mile of the central district there are 32,000 off-street parking spaces, yet a count conducted at the peak hour, 2:30 p. m., revealed that only 37 percent of this space was occupied. "It would seem futile," therefore, "to increase the number of berths unless at low rates and convenient locations" (*10*).

Parking lots.—As a result of the rapid increase in privately operated public parking lots during recent years, these facilities are now the most prevalent type of off-street parking accommodations. In the average city contacted by the American Automobile Association for its report on terminal facilities, the parking lot was found to constitute 58 percent of total off-street parking space and it did 78 percent of the business (*1*). These figures, however, are more an expression of the plight of the motorist than of the popularity of the average parking lot. Over-crowded, over-priced and ill-designed, these unattractive properties resemble more closely the scars of mass bombings than utilities performing a public service. Among the specific charges which have been brought against them are the following:

1. Location of the parking lot is generally dependent upon the location of vacant property which cannot return sufficient earnings in any other use, rather than being governed in accordance with studies of traffic origin and destination, the effects of terminal location upon street use, and the relation of these factors to the general urban problem.
2. The size of lots is likewise determined by the fortuitous circumstances governing their location, in spite of the fact that demand conditions as well as the relation of terminal size to street congestion should regulate.
3. Land for parking is furnished on a temporary speculative basis with the intention of later conversion to more profitable use. The dilemma thus arises that if greater accessibility created by parking facilities should restore values in the business district, land now used for parking would probably be withdrawn for building construction.
4. The temporary nature of parking lots, many of which are operated on one-year leases, makes improvement of the property uneconomical, with the result that the benefit of parking facilities in terms of transportation service may be offset by the depressing effect of unsightly property upon surrounding land values.
5. The whole cost of parking is charged to the motorist, in spite of the fact that the accrual of benefits to merchants, adjacent property and the city may suggest a more equitable cost allocation.
6. Rates must be charged to cover all costs in connection with the operation of the lot, whereas the broad interests involved in the availability of parking facilities suggest that these properties, like the streets themselves, should be operated on a noncommercial basis in terms of profit to the community as a whole.
7. Because of the compulsion to produce an optimum return, parking lot charges, particularly for short-time parking, are often considered unreasonable, and the desire to operate at capacity often results in irresponsible handling of vehicles, illegal use of surrounding streets, crowding and inconvenience to the motorist.

COST OF GARAGE PARKING LOWERED BY NEW DESIGN

Garages.—In the survey of the American Automobile Association, approximately 42 percent of the total off-street parking space in the average city contacted was furnished by garages, but these performed only 22 percent of the total business. Many of the criticisms of private operation cited in connection with the parking lot are likewise applicable to the garage, but the latter,

Photos by American Automobile Association

OVER-CROWDED, OVER-PRICED, AND ILL-DESIGNED PARKING LOTS. USE OF SUCH MAKESHIFT PARKING LOTS OFTEN RESULTS IN IRRESPONSIBLE HANDLING OF VEHICLES, ILLEGAL USE OF SURROUNDING STREETS, CROWDING, AND INCONVENIENCE TO THE MOTORIST.

representing a relatively permanent type of facility which has generally been in operation for a number of years, introduces additional factors:

1. The early establishment of many garages has frequently resulted in their being poorly located with respect to current motor-vehicle terminal needs.

2. Garages were first built when there was no lack of street space available for parking, but when enclosed parking was a luxury service to protect the vehicle from the elements. These buildings were accordingly of ornate design, hence high cost, in keeping with the type of patronage. Today, however, technical improvements in the motor vehicle have eliminated the need for escaping the weather, and the lack of street space has made off-street facilities a necessity rather than a luxury.

3. The extra cost of pretentious garage structures, their inefficient use of space and the high labor costs required in operating them are reflected in rates which most motorists are unwilling or unable to pay.

Garage design has undergone very considerable revision in recent years, however, and the new open-wall garage is now a demonstrated possibility for the future. This parking structure embodies the old garage principle of multiple-level parking, but is designed specifically for storing cars at low cost by incorporating certain construction economies. The omission of walls makes ventilation and sprinkler equipment unnecessary, and ramps are provided for quick and easy movement of vehicles between floors. Low-studded construction and all possible utilization of space, including the roof, are also distinguishing characteristics of the open ramp structure. The combined effect of low first cost and a minimum of operating expense results in total costs from one-third to one-half those of the old enclosed garage.[4] Thus far these structures have generally been established for private provision of parking service by department stores, although their use for privately operated public parking is now established in several cities, including Boston, St. Louis, and Washington. Under the latter type of operation there appear to have been no large price reductions passed on to the motorist, but several cities have recently been considering plans for municipal operation of open-wall garages at lower figures.

Merchant facilities.—In the past several years there has been a considerable extension of shopper garages and lots provided in conjunction with retail stores. Much of this activity has been in suburban areas where land may be cheaper or where stores have been newly located, but in the downtown area there have also been outstanding successes in merchant operations, both individual and cooperative. Indeed, the downtown merchant has generally been far more alert to the consequences of inadequate access to the city than has the city itself.

MERCHANT'S COOPERATIVE PARKING PLAN SUCCESSFUL

A recent survey of customer parking facilities offers interesting information concerning the extent of merchant attempts to provide for the shopper (*15*). Data from 118 stores in 75 cities located in 31 States revealed that 53 stores, or 45 percent of the total, offered parking facilities of some kind. The same number had no parking arrangements whatsoever, while the remaining 12 stores, or 10 percent of the total, had formerly provided parking services but had discontinued them. As to the type of facility used, 10 of the 53 stores providing parking service had their own garages, 8 provided garage parking through arrangements with a public garage, 14 parked cars on a lot which they owned or leased, and 17 had arrangements with a commercial lot. Four stores had more than one type of service.

To cite some of the most successful ventures in merchant provision of parking facilities, in St. Louis a combined garage and bus service has been established for the use of shoppers patronizing any of 130 stores and offices in the downtown section. Each time a purchase is made in a member store ten cents is deducted from the total parking fee. These deductions are applied to reduce the regular rates of 10 cents for the first hour, 20 cents for two hours, 30 cents for three to five hours, and 35 cents for all day. In addition, frequent bus service is provided without charge along a route close to member stores. The success of this "Park-N-Shop" plan is measured by the fact that patronage in 1940 increased from 7,000 shoppers in January to 17,000 in April and 30,000 in August.

Another successful merchant venture is the Oakland, Calif., experiment started in 1929, known as the Downtown Merchants Parking Association. This organization, now comprising 164 members, has acquired a number of strategically situated low-income properties for parking lots designed to anchor the business district. Land is acquired either by purchase or by lease, with a 10-year minimum term for leased property and an average rental of 1½ cents per month per square foot. The rate for parking in the Oakland lots is 10 cents per hour, but the motorist can park free for 2 hours by having his parking check validated in a member store, regardless of whether a purchase is made.

At the end of each month the Parking Association subtracts from its total costs the cash receipts received from nonvalidated or overtime parking, or from night parking, which is provided for 15 cents without validations. This cash income amounts to about 40 percent of total costs. The number of validated checks is then divided into this net cost figure to obtain the unit parking cost per validated ticket, now about 4 cents per car and 50 percent lower than when the organization began operations. The number of checks validated by each store is then multiplied by 4 cents to obtain the total charge per store. One member, a large market, pays as much as $1,000 per month to park its motoring customers.

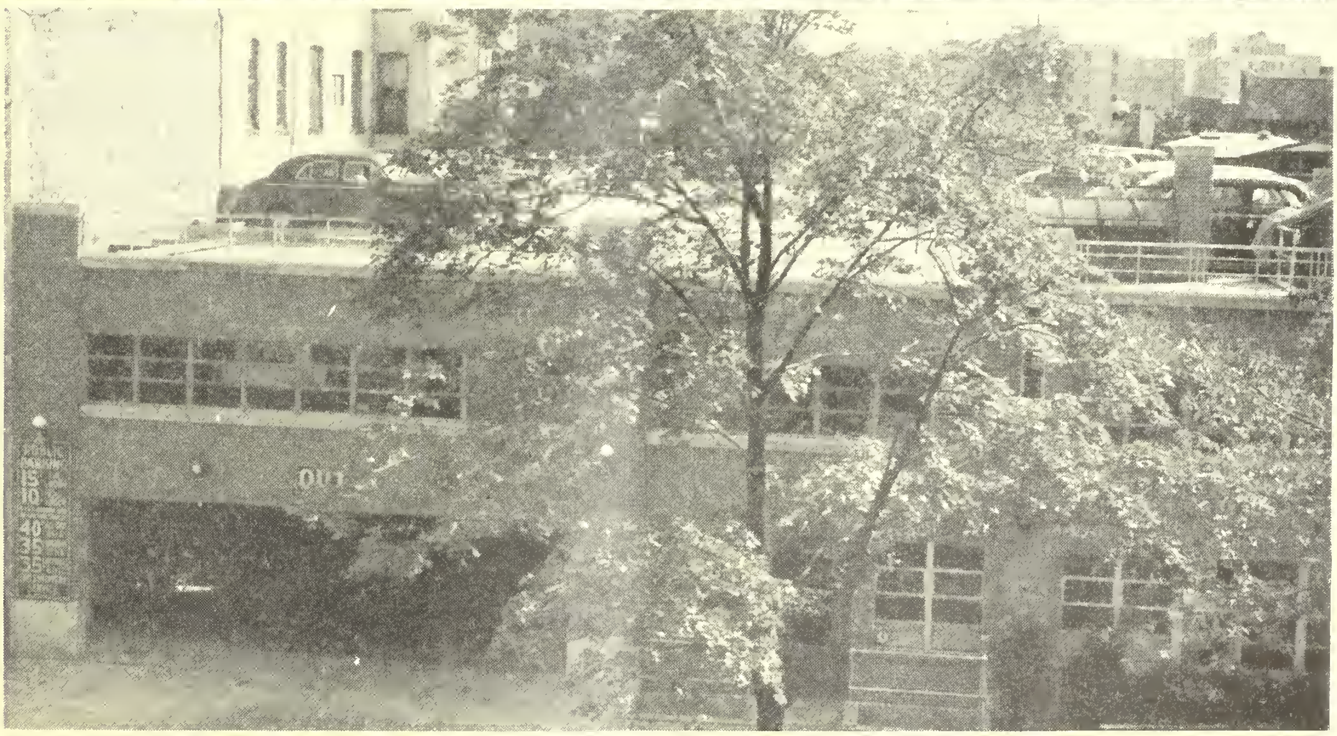
An important observation from the Oakland experience is that stores which joined the Parking Association rather than operating through established commercial lots have lowered their parking costs about 25 percent.[5] In addition, there is a tendency among members to consider that such parking costs are actually chargeable to advertising, since the payment of 4 cents is guaranteed to bring a customer into their stores. Over a million and a quarter cars have been accommodated during 1940, and Oakland merchants have made the provision of parking facilities in the downtown area almost unprofitable for independent operators. This experiment has been an excellent demonstration of the possibilities of cheap nonprofit parking in downtown areas. With cost concessions possible under municipal operation, parking rates could be made even lower.

In contrast to well publicized successes, however, there are numerous instances where stores are losing heavily on parking arrangements, or where free parking privileges have been abused or abandoned. Moreover, most stores are not large enough to provide their own accommodations, and where arrangements must be made with a commercial lot or garage the cost is often a considerable burden. On the other hand, an association of merchants formed to provide joint parking accommodations has this defect; that after costs have been lowered beyond a certain point there may be a desire on the part of member stores to maintain their competitive advantage by restricting entrance into the organization. Thus a serious obstacle is placed in the way of eventually extending the benefits of low-cost parking to the whole city. The fact remains, moreover, that the short-time shopper does not constitute the whole parking problem, nor can the premise be accepted that downtown merchants should shoulder the parking burden alone, while the city, which is largely dependent upon the success of business, does nothing.

Existing facilities.—Failure of private enterprise to produce a satisfactory solution to the parking problem has led in a number of cities to the adoption of municipally owned and operated facilities as a public responsibility. Public action in this field has now been established 15

[4] The so-called "cage" parking structure established in Boston in 1934 can be constructed at 10 cents per cubic foot instead of the usual 25 to 35 cents for the ordinary garage, according to the patent holder, Mr. Samuel Eliot.

[5] According to the American Automobile Association, merchants having their own facilities reported a cost of 6.9 cents per car parked, while those having arrangements with a private operator paid 14.2 cents.



Photos by American Automobile Association

Two Means of Alleviating the City Parking Problem. Above, Shopping Center Which Provides Off-Street Parking for Patrons; Below, Modern Parking Garage of Open Ramp Construction and with Parking on Roof.

years or more, with the past few years witnessing the largest increase in such accommodations despite expressions of concern over the encroachment of government upon the garage business.

Among the cities displaying initiative in this field at an early date was Flint, Mich., which established a municipal lot in 1924, followed soon after by Bay City, Mich.; Mitchell, S. Dak.; and Racine, Wis. At this time publicly owned land was also being used for parking in both Cleveland and Chicago, (*13*) and in 1926 the city council of Lafayette, Ind., authorized a bond issue of $52,000 to acquire lands for this purpose. The attorneys for the successful bidders at the bond sale advised against the purchase because there was no court decision in the State establishing the fact that a municipal parking ground constituted a public use. To overcome this objection, the city secured enactment of a State law which authorizes municipalities to establish municipal parking grounds for vehicles; to acquire necessary lands by gift, lease, purchase, or condemnation; and to raise funds by donation, appropriation, taxation, or sale of bonds. The act also ratifies action previously taken by any city for the establishment of parking grounds (*20*).[6]

Kansas City sought in 1936 to condemn lands for public off-street parking facilities by passing an ordi-

[6] For State law see ch. 15, Acts of Indiana, 1927, or Baldwin's Indiana Statutes, 1934, secs. 11815–11816.

nance for that purpose. Several landowners contested the action, and the State court held that under the then existing laws the city could not condemn lands for parking lots.[7] Attempting to solve the problem, the Kansas Legislature enacted a law which authorized first-class cities having a population of 120,000 or more to establish public parking stations. The validity of this law was questioned, and the State court held that it was unconstitutional because it was a "special law," applying only to Kansas City.[8] The court did not consider the other questions presented in the case. The State legislature, in the meantime, enacted a law which authorizes cities having a population between 60,000 and 100,000 to acquire lands for public parking stations.[9]

The city of Cleveland, Ohio, was enjoined several years ago from using its underground exhibition hall as a public garage. The court held that the city could use the premises for its own vehicles, for those of its officers and employees, or for any other purely public purpose, but that it could not operate a garage as a purely private business in competition with privately owned garages.[10]

Unquestionably, there is an urgent need for legislation in many of the States to provide means by which municipalities can solve their parking problems. Other States which already have some provision in their general laws for municipally owned parking facilities are California, Massachusetts, Michigan, Pennsylvania, and West Virginia.

MUNICIPAL INTEREST IN PARKING PROBLEM INCREASING

Information concerning the extent of municipal parking activity is not available, but several indications are available in recent reports. When the Public Administration Service made its parking survey in 1938, one-fourth of the cities studied had established municipal parking facilities, and one-third of these had been developed within the preceding 3 years (*16*). In a recent report of the New York State Bureau of Municipal Information 53 municipalities in the State were reported to be providing parking lots in their central business districts. The Regional Plan Association of New York has likewise investigated the progress of municipal parking provisions in the New York metropolitan area, where 18 communities of the 54 visited had by 1936 established municipal parking areas for general use (*23*). Among the 34 municipal lots described in the Public Administration Service report, the largest accommodations were reported in Chicago with 3,500 spaces, Memphis with 3,000, and Quincy, Massachusetts with 1,650.

In New England, reports received by the Regional Planning Commission from localities in that area indicate an expanding municipal interest in parking remedies (*14*). Among the developments noted are the following:

Derry, New Hampshire—An article was passed at the town meeting in March appropriating money for a municipally owned parking lot.

Exeter, New Hampshire—A generous citizen purchased a useless house close to the center of the village and presented the lot to the town on condition that it be made a municipal parking facility.

Falmouth, Massachusetts—All land owned by the town has been used for parking space where feasible.

Lowell, Massachusetts—Whenever the city has acquired slum property in the downtown section for nonpayment of taxes, its suitability for public parking is considered. If it can be so used, it is graded and lined.

Middleboro, Massachusetts—The town has just appropriated funds to lease land for additional municipal parking space.

Quincy, Massachusetts—The parking problem has to a large extent been solved. A tract of land was taken by eminent domain, immediately in the rear of the business center. It is reported that since these facilities were established in Quincy, half the trade has come from outside communities. Property on the side of the main business street immediately adjacent to the parking area has jumped in value and is now worth 50 percent more than the property on the other side of the street. Quincy merchants estimate that if the free parking plan should be abandoned their sales would drop 25 percent overnight (*7*).

Salem, Massachusetts—Central parking space of large size owned by city.

Waltham, Massachusetts—Considering large parking area to be financed mostly by merchants and property owners over a 10-year period, with the city abating taxes.

New Britain, Connecticut—A W. P. A. project has been approved to build a large parking garage, with bus terminal on ground floor.

Although the efforts of municipalities to aid in solving the parking problem have generally been more successful in smaller communities, a number of large cities are giving consideration to similar possibilities. In Boston, the Mayor's Committee on off-street parking has reported that effective alleviation of traffic congestion in the downtown business district necessitates the immediate doubling of available off-street parking space, and that this must be accomplished by the city (*12*). It was decided that the most economical approach to providing cheap parking would be for the city to acquire through a private operator strategically located properties upon which would be constructed multiple-level parking structures of low-cost ramp design. Land and buildings would be financed by means of 20-year bonds. It was believed that a large saving in purchase price could be realized by avoiding eminent domain proceedings and by taking advantage of low municipal interest rates. The Boston report suggested that these properties be leased for private operation, which it is claimed would be cheaper than municipal operation due to civil service requirements. "Such private operations," this document is careful to state, "will also avoid competition between the municipality and other privately operated facilities." [11] The plan represents an investment of $6,700,000 and would be spread over a 6-year period.

Milwaukee is another city with plans for providing municipal parking areas as part of a program for rehabilitating the downtown section (*26*). A report on this subject states that between 6 a. m. and 6 p. m., motorists pay an annual sum of one and a quarter million dollars in Milwaukee for parking on private property. In other words, while toll gates on the highways have been eliminated, now that increasing volumes of traffic have rendered street space inadequate, "many people have seized the opportunity of collecting

[7] *Barker* v. *Kansas City*, 70 Pac. (2d) 5.

[8] *Barker* v. *Kansas City*, 88 Pac. (2d) 1071. For law held unconstitutional, see 1939 supplement to Kansas General Statutes, 1935, secs. 13-1366 and 13-1367.

[9] See ch. 124, Laws of Kansas 1939, or 1939 supplement to Kansas General Statutes, 1935, sec. 13-1368.

[10] *Cleveland* v. *Ruple*, 130 Ohio St. 165, 200 N. E. 507, 103 A. L. R. 853.

[11] The city could not make this transfer to private operators without authority from the legislature

toll privately for parking." The Board of Public Land Commissioners accordingly requested that $125,000 be appropriated annually for the gradual renovation of Milwaukee, "and to provide efficient use of automobile transportation—with convenient parking facilites." Another large city in the East has prepared extensive plans for the construction of multiple-deck open parking garages on available city-owned property, these garages to be municipally owned and operated as a demonstration project to attract private capital into further provision of similar facilities. For this reason all costs were to be computed as if the properties were privately owned, with the result that the cost advantages possible under municipal operation would thereby be cancelled. In view of the magnitude of the problem confronting this city, the plan appears to be somewhat overcautious.

CITIES CAN FINANCE PARKING IN SEVERAL WAYS

Methods of finance.—As previous examples have indicated, land used for municipal parking facilities is often already available to the city and does not have to be acquired specifically for that purpose. This was true in most cases studied by the Public Administration Service, which found appropriate sites supplied through tax delinquencies, by gift-taking, by the removal of public buildings, or where remnants had been left from some previous public project. The demolition of public buildings by W. P. A. or of private dwellings in conjunction with slum clearance projects, offers the city an opportunity to obtain desirable sites for municipal parking facilities. When land is obtained by any of these devices, the problem of financing parking is generally negligible. In many instances, however, the city does not own satisfactory sites, making it necessary to purchase, condemn or lease. The problem of financing may then be solved in a number of ways, including general obligation or public revenue bonds,[12] special assessments, general fund appropriations of motor vehicle contributions. For example, Kalamazoo, Mich., has financed a municipal "shoppers parking lot" for free 2-hour parking by charging the cost of the land and improvements to business property through special assessment districts. Instead of a bond issue, money was borrowed from the city cemetery perpetual care fund at 3 percent interest. The city expects to cover operating costs in part at least from cash fees collected for overtime parking (*2*).

Another interesting plan was developed in 1936 by Garden City, N. Y., which rejected the idea of a common parking lot serving a considerable area and adopted instead the principle of locating facilities in the rear of properties served. The objectives sought were convenient access, the minimizing of property depreciation, and cost reduction by acquiring rearage instead of high value frontage. (*18*) To finance this $197,000 parking project, 75 percent of the cost was assessed on a 10-year basis to commercial houses benefiting, while the improvements, amounting to $46,000, were absorbed in general village expense. No fee is charged the motorist (*19*).

Although the cost of municipal parking is not generally charged to the motorist directly, wherever this practice has been followed remittance has been made in cash, as in the case of commercial facilities. Under municipal operation, however, there are two unexplored alternatives which appear to have merit. One is the issuance of identification plates for a designated annual sum, which would admit the motorist to any municipal lot during the year. Proceeds from the sale of these plates would be used to finance such properties, which might be supplied in conjunction with special urban express roads. The second suggested method would be to amend State laws for the distribution of motor-vehicle revenues to permit cities to use their allotments for the purpose of providing off-street parking. In other words, the meaning of the term "highway purposes" would be extended to include terminal facilities.

Objections to municipal operation.—Many city officials have expressed the belief that municipal operation is to be avoided because the city should not compete with private garages and parking lots. Obviously the city already competes with private business, however, when it permits free parking on the streets, or when parking meters take the cream of the traffic—the short-time parker—away from private off-street facilities. This argument against public ownership, moreover, is hardly important, since the business of parking cars on lots does not involve a long-term investment or a permanent enterprise so that the transition from private operation would create little hardship. Even in the case of garages, which involve a more permanent investment, the fact that such operations have been generally unprofitable for many years and that most garages are now being rendered obsolete by new designs appear to minimize the effect of a shift to municipal parking operation.

Decision concerning the advisability of private or public operation of parking facilities, therefore, should not be influenced by the desire to preserve existing values. The real issue is simply whether public operation makes possible a better and cheaper service, and judging from the results of private efforts, it appears that such would almost have to be the case. As one writer has commented, private attempts to solve the parking problem "have not anywhere near succeeded in bringing about even reasonable conditions" (*24*). In spite of the familiar argument that private initiative must be preserved in the parking industry, therefore, it is concluded from the very nature of the problem that "only through public ownership can continued operation and relative permanency of necessary off-street parking terminals be assured" (*22*).

Development of mass transport.—The apparent logic of considering parking facilities an integral part of highway service, hence a public responsibility, does not imply that municipal operation of off-street terminals is the only solution to parking troubles, for the problem might be attacked by reducing the demand for parking space as well as by providing an adequate supply. This approach introduces the possibilities of mass transportation. In spite of the phenomenal growth in motor vehicle traffic during the past two decades, transit facilities still provide the major transportation capacity in most large cities. An illustration of this fact is afforded by surveys of the methods used in entering and leaving downtown Boston on a typical weekday between 7 a. m. and midnight in the years 1927 and 1938 (*5*). This study shows that despite the rapid shift from mass transportation, particularly by railroad and surface streetcar, to individual transportation by automobile, over half of all the persons entering and leaving downtown Boston still utilize some form of mass transportation. It is reported that 90 percent of New York commuters travel on public carriers, and that in Chicago despite a loss of 20 to 25 percent in mass transportation patronage in the period from 1926 to 1938, and a 44 percent increase

[12] Michigan has a State law which permits municipalities to issue revenue bonds to finance parking facilities.

in passenger-car traffic, less than one-fourth of all commuters travel by automobile. Finally, even in such cities as Los Angeles and Washington, where automobile use has been so highly developed, fully 38 percent of commuting is still accomplished by mass facilities. Lack of highway and parking facilities has obviously been a factor in this high degree of transit patronage.

IMPROVED MASS TRANSPORTATION SERVICE A PARTIAL SOLUTION OF PROBLEM

In spite of the need for more satisfactory automobile accommodations in our cities, therefore, it must be remembered that motor-vehicle traffic constitutes but a part of the urban transportation problem. Accordingly, emphasis placed upon this single phase of the problem should not lead to neglect of the needs of a large percentage of the population for better facilities of mass transportation. It is possible that, if the equipment and service supplied by these mass transportation facilities were improved, they would be patronized by many who now use their own automobiles.[13] The result of thus attracting a larger percentage of commuters to mass transportation media might be highly salutary to the downtown district, not only because it would lessen the required amount of parking space, but because street capacity would thereby be enhanced. The American Transit Association has illustrated this latter point with the example of a 60-foot street carrying three lanes of traffic in each direction with no parking. Such an artery would move 3,700 persons per hour if automobiles were used exclusively, assuming an average of 1.75 persons per car. The same street used by both automobiles and busses, however, would move 2,130 persons by automobile, 7,200 seated bus passengers, and 1,800 standing bus passengers, or a total of 11,130 persons per hour. Finally, using this artery for automobiles and streetcars, it will have a capacity of 2,130 automobile passengers, 9,000 persons seated in streetcars, and 4,500 standing, or a total of 15,630 people per hour (*3*).

These data admittedly demonstrate the superior capacity of mass transportation facilities. It is somewhat ironical, however, that the Transit Association, in computing how many persons could be herded into the aisles, has unwittingly answered the question of why, if transit facilities are more economical, those who are able prefer not to use them. In other words, while mass movement has tremendous possibilities in the solution of urban transport problems, including the parking problem, until more emphasis is placed upon the service factor and less on cost the consumer will exercise his right of free choice.

Municipal subsidy and regulation.—Because of the realization that considerable time may elapse before the city acts to make possible attractive mass transportation and adequate municipal parking facilities, certain interim aids are suggested which might afford a measure of immediate relief. Municipal governments might subsidize private operation of parking lots by lowering the assessment of land so used on the theory that parking facilities constitute a public utility. Costs might also be lowered by tax abatement or the elimination of license fees, and the advantage passed on to the motorist by municipal regulation of parking rates. Reduction of parking costs effected by such subsidies would be justified on the grounds that adequate parking at low rates would improve accessibility to the downtown district and thereby bolster surrounding land values. Cities might also bring about an improvement in private efforts by furnishing adequate street approaches to parking lots, by enforcing curb parking ordinances, by leasing public land to private operators and by exacting strict requirements concerning the appearance of lots, the handling of cars, financial responsibility, and the use of abutting streets.

[13] For a discussion of possible transit improvements, see Proceedings, American Society of Planning Officials, 1940, "Highways and Transportation," p. 54.

Among the steps which a municipality might take to provide for better parking conditions in the future are two which suggest immediate action. The first concerns establishment of an adequate parking plan through intelligent study of the peculiar needs of each individual city. The parking study now being conducted as a phase of the District of Columbia Highway Planning Survey, in which the Public Roads Administration and the District of Columbia Department of Highways are cooperating, is an example of the comprehensive approach required. The Washington survey is unique in that it proposes to determine the actual and potential demand for parking facilities generated by varying urban land uses. Data are obtained by means of carefully devised questionnaires directed to the parking habits of the motorist, supplemented by descriptive material concerning the travel habits of 200,000 government and business employees. It is this type of transportation study rather than the meaningless enumeration of motor-vehicle traffic which must indicate proper plans for reducing urban congestion.

A second step having long-range implications is the enactment of building codes and zoning ordinances. A dozen years ago a Detroit engineer issued this warning to constructors: "Take care of the parking demand created, or your building will be obsolete before it is up" (*17*). Not only are buildings unsatisfactory without parking facilities, but street congestion resulting from new apartments and theaters has been such as to impel many communities to adopt ordinances requiring off-street parking space in connection with certain types of building construction. The American Society of Planning Officials recently issued a selected list of zoning ordinances of this nature in 34 cities. Los Angeles requires that in certain zones "in connection with each and every duplex, double dwelling, multiple dwelling, apartment house, bungalow court, or other multiple family use of a lot, there shall be provided on such lot garage space in a building for at least one automobile for each family unit or apartment contained on such lot."

Hotels are also included in the regulations of some cities, Southampton, N. Y., specifying that "for each sleeping room there shall be a paved or gravel parking space not less than 300 square feet, either on the same lot or within 200 feet of such lot and also on private property." In the case of theaters, Detroit has proposed that 200 square feet of off-street parking space be furnished for every 10 seats, and San Merino, Calif., requires parking facilities for 1 car for every 2 theater seats. Stores are also included in some regulations, Du Page County, Ill., specifying that "no building or structure shall be erected or structurally altered or land used for any purpose which will cause customers, employees, or residents to park their vehicles of transportation for 1 hour or longer unless space for such parking is provided and maintained in the lot or tract of land used." In Los Angeles there is no law to this effect, but merchants are encouraged by the planning depart-

(Continued on page 118)

SOME LEGAL ASPECTS OF MUNICIPALLY OPERATED PARKING FACILITIES

BY THE DIVISION OF HIGHWAY LAWS AND CONTRACTS, PUBLIC ROADS ADMINISTRATION

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THE MOTORIST is finding it increasingly difficult to find a parking place for his vehicle at the street curb in urban areas. Privately operated off-street parking enterprises do not provide sufficient accommodations at reasonable prices to alleviate this condition. Consequently, there is serious traffic congestion in business and industrial districts with constant hazard and inconvenience to both pedestrian and vehicular traffic. The involved complexities of this problem have become a matter of real concern to local planning officials. Probably the most plausible solution lies in a further development of the already growing trend toward publicly owned and operated parking facilities. It therefore is believed that a presentation of some of the legal phases of the question would be timely.

Efforts to solve the parking problem through municipally operated facilities have met with varied success. In some instances existing laws have not granted adequate authority for such operations. Some State legislatures have recognized the inadequacy of existing laws and have enacted legislation to make municipal operation of parking facilities possible. Other State legislatures are now considering such legislation.

Proper planning and action by municipal bodies is necessary to establish legislative and judicial recognition of the public nature which the automobile parking facility has assumed, if public efforts to solve the parking problem are to be effective.

This discussion does not purport to be a comprehensive technical dissertation; nor does it attempt to answer all the queries of a legal nature which may arise in any particular community. The varied constitutional and statutory provisions of the several States, the dearth of reported court decisions, and the multiplicity of municipal charters and ordinances make it impossible without careful study to express any opinion as to what might happen under a given set of circumstances. This article merely intends (1) to show the general laws that some of the States have enacted on this subject; (2) to indicate where those laws may be found; (3) to point out hindrances that several municipalities have encountered in this field; (4) to discuss the "public use" question involved; and (5) to emphasize the need for legislation in many of the States, and for proper preliminary action by local officials, if the solution of the urban traffic problem is to be substantially helped through municipally owned and operated parking facilities.

10 STATES HAVE LAWS RELATING TO MUNICIPAL PARKING FACILITIES

At least 10 States have made some provision in their general laws for public undertakings in this field. Seven of these States—California, Indiana, Kansas, Maine, Massachusetts, New Hampshire, and West Virginia—merely authorize their municipalities to establish parking places. The other three—Iowa, Michigan, and Pennsylvania—not only empower municipalities to establish such facilities but also expressly authorize them to collect fees for use thereof.

One provision of the California law confers upon municipal corporations of the sixth class (those having a population not exceeding 3,000) the following authority:[1]

> To acquire property required for the parking of motor vehicles and for the opening and laying out of any street, alley, lane or tunnel from the point where the continuity of such street, alley, lane or tunnel ceases, to the point where such street, alley, lane or tunnel again commences; to lay out and improve said street, alley, lane or tunnel; and to pay the cost and expense incurred in the acquisition of the required property out of the general fund of the city.

Another provision of the California law is as follows:[2]

> Whenever the public interest or convenience may require, the city council of any municipality shall have full power and authority to order the laying out, opening, extending, widening, straightening, establishment or change of grade, in whole or in part, of any one or more of any public streets, parking places, squares, lanes, alleys, courts or places within such municipality, and to acquire by condemnation any and all property necessary or convenient for that purpose or any interest therein including an easement or easements for the construction and maintenance of any one or more of any public streets or walks, parking places, passages or ways upon the surface of the earth or in any designated level or levels or slope or slopes, above or below such surface together with a sufficient clearance height thereabove which height shall be conclusively determined and designated by the city council of such municipality and the leaving to the owner or owners the right to maintain or construct and maintain any building or buildings or other structure or structures above or below, or above and below such street or streets, walk or walks, parking place or parking places, passage or passages, way or ways, and the clearance height therefor so acquired by such municipality.

An alternative procedure which cities in California may follow in developing publicly owned parking facilities, involving the establishment of improvement districts for such purposes, is provided in a recent enactment of the State legislature.[3]

LAFAYETTE, INDIANA, EXPERIENCE CITED

The law in Indiana on this subject has an interesting background. In 1926, the city council of Lafayette, Ind., authorized a bond issue of $52,000 to cover the purchase of land and equipment for a free public parking space for long-time parking. The detailed plan in connection with the parking ground involved a building with sanitary facilities, as well as a free checking room; and the entire parking area was to be encircled by a fence. A custodian was to be placed in charge of the

[1] Deering's General Laws of California, 1937, sec. 862.6 of act No. 5233. (Section last amended by Statutes of California, 1937, ch. 659, sec. 5.)

[2] Deering's General Laws of California, 1937, sec. 1 of act No. 8198. (Section last amended by Statutes of California, 1937, ch. 244, sec. 2.) Procedural provisions for operation of this section may be found in the rest of act No. 8198.

[3] California Statutes of 1941, ch. 246, approved May 13, 1941. Detailed provisions can be found in the law.

property to serve as an attendant and as a guard against automobile thefts. The municipal officials acted under a law passed in 1905, which apparently is still in force and reads in part as follows:[4]

The board of public works shall have power: First, to condemn, rent, or purchase any real estate or personal property needed by any such city for any public use, except when a different provision for purchase is made by this act; *Provided*, That when a sum of more than two thousand dollars is required to be paid for condemnation, rent, or purchase of any real estate or personal property, the same shall not take place unless the condemnation, rent, or purchase is specifically authorized by ordinance.

It was contended by the local officials that "it would be difficult to conceive of anything that could be more clearly established as constituting a public use than this plan of providing a parking ground for a number of automobiles." However, the attorneys for the successful bidders when the bonds were offered for sale advised against the purchase because there was no court decision in the State holding that a municipal parking ground constituted a public use. The State law at that time did not specifically authorize municipalities to construct or maintain public parking lots. To overcome this objection, the city secured enactment of a State law which reads as follows:[5]

In addition to any and all other powers conferred by law, any city of this State is hereby authorized and empowered to acquire, establish, improve, maintain and operate municipal parking grounds for vehicles. Any real estate or personal property, or any interest therein, needed by any city to establish, improve, maintain or operate such municipal parking grounds may be acquired by such city by gift, lease, purchase or condemnation. Funds for purposes of this act may be accepted as a donation, or may be appropriated from the general fund, or may be raised by taxation, or by the issue and sale of the bonds of the municipality, or by any or all of such methods. Bonds may be issued and sold by any such city, as bonds are now issued and sold for the purpose of procuring money to be used in the legitimate exercise of the corporate powers of such city. Any city of the State of Indiana is hereby authorized through its proper officers, from time to time, to make such levies as may be necessary to produce a fund for any or all purposes of this act, including the payment and retirement of any bonds therefor issued and sold, and the payment of the interest thereon, and to collect the same as other taxes are collected.

Although the city of Lafayette had a population of only about 25,000 in 1926, the program undertaken by the local officials at that time clearly indicates the farsightedness with which they acted.

KANSAS LAW HELD UNCONSTITUTIONAL

Ten years later, the city of Kansas City, Kans., had a more difficult problem. The city council sought in 1936 to condemn lands for five public off-street free-parking facilities in the business section of the city by passing an ordinance for that purpose. The action was contested in court by several landowners who raised a number of objections to the measure. Some of these objections, local or procedural in nature, are not covered in this report. However, the case should be of interest to planning officials of other cities because they may find that the facts in it are very similar to those in their own communities. The pertinent points of the case to be considered here are the landowners' contentions (1) that the city had no statutory authority to condemn property for free-parking places; and (2) that the city was attempting, by eminent domain, to take private property for the benefit of private parties—the businessmen—and not for the benefit of the city at large. The city in reply to these objections relied on a State law which reads as follows:[6]

Whenever it shall be deemed necessary by any governing body of any city to appropriate private property for the opening, widening, or extending any street or alley, or to condemn private property or easement therein for the use of the city for any purpose whatsoever, the governing body shall cause a survey and description of the land or easement so required to be made by some competent engineer and file with the city clerk. And thereupon the governing body shall make an order setting forth such condemnation and for what purpose the same is to be used. If in the opinion of the governing body any property is specially benefited by the proposed improvement such property shall be designated as the benefit district and the same shall be fixed by ordinance. The governing body, as soon as practicable after making the order declaring the appropriation of such land necessary and the fixing of the benefit district, if any is fixed, shall present a written application to the judge of the district court of the county in which said land is situated describing the land sought to be taken and setting forth the land necessary for the use of the city and setting out the benefit district in full and praying for the appointment of three commissioners to make an appraisement and assessment of the damages therefor.

In considering the first objection and construing the words "for any purpose whatsoever," the Supreme Court of Kansas said:[7]

This is a procedural statute. It is not one designating purposes for which private property may be taken by eminent domain. By the use of this phrase the Legislature never intended to do away with the well-settled rule that the Government takes private property by eminent domain only for a public use. The phrase should be interpreted as though it read, "for any purpose whatsoever for which a city is authorized to take private property for public use." We are cited to no statute, and our own research discloses none, which specifically, or by necessary implication, authorizes the city to condemn lots or blocks for automobile parking places.

In discussing the second objection, the court added:

The commissioners appointed by the court found that the city at large was not benefited by the establishment of these parking places, and this report was approved by the city commissioners. * * * This gives color and force to the plaintiffs' allegations that the project was for the benefit of private parties and that it never was regarded by the defendant city or its officers as of a public necessity.

The city lost all issues raised in the case.

A short time before the court ruled on this case, the Kansas Legislature enacted a law which authorized cities of the first class having a population of 120,000 or more, to acquire by purchase, gift, or condemnation, lands for parking stations in or near commercial or industrial districts in such cities. The original act provided that no bonds could be issued for said purposes after January 1, 1940.[8] In a case decided April 8, 1939, the court held that said law was unconstitutional because it conferred special corporate powers, being applicable to only Kansas City. The court, having found a basis on which it could declare the law invalid, did not discuss other matters presented in the briefs.[9] This law was subsequently repealed.

COST OF PARKING FACILITIES ASSESSED TO BENEFIT DISTRICTS

The Kansas Legislature later enacted a law which authorized cities having a population between 60,000 and 100,000, in the discretion of the governing body, to acquire by purchase, gift, or condemnation, lands for public parking stations in or near commercial districts

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[4] Baldwin's Indiana Statutes, Annotated, 1934, sec. 11472.

[5] Baldwin's Indiana Statutes, Annotated, 1934, sec. 11815. (Laws of 1927, ch. 15.) Sec. 11816 (sec. 2 of enactment) ratifies action previously taken by municipalities for public parking lots. For discussion of question see "Lafayette's Successful Efforts to Provide Free Municipal Parking Space," by A. R. Ross, The American City, May 1927, p. 631.

[6] General Statutes of Kansas, 1935, sec. 26-201.

[7] *Barker* v. *Kansas City*, 146 Kans. 347, 70 Pac. (2d) 5.

[8] 1939 Supplement to General Statutes of Kansas, 1935, sec. 13-1366 and 13-1367. (Laws of 1937, ch. 152; Laws of 1938, ch. 35; time limit repealed by Laws of 1939, ch. 108.)

[9] *Barker* v. *Kansas City*, 149 Kans. 696, 88 Pac. (2d) 1071.

of such cities, and to improve the same for such public parking stations.[10] It recently repealed this law and enacted a similar law affecting cities of the first class.[11]

The present Kansas law authorizes the establishment of benefit districts by ordinance and permits establishment of several parking stations in each benefit district. Not less than 75 percent nor more than 90 percent of the costs of the parking facilities are assessable to the benefit district in which said facilities are located. Costs of the improvement may be levied and assessed in not to exceed 10 installments, with interest on the amount remaining due and unpaid each year accruing at the rate of not exceeding 5 percent per annum. Landowners may pay the entire costs chargeable to their property within 30 days after the assessment ordinance is passed.

The governing body of the city is authorized to assess the pro rata cost of the condemnation and the improvement of the facilities against the privately owned property in the benefit district, and to levy the rest of the cost by a general tax on all the property in such city. Suits contesting the action taken by the city must be instituted and the summons served within 30 days from the publication of the ordinance levying the assessment. Municipal bonds may be issued and sold to pay the costs of such improvements. The bonds are payable in 10 equal annual installments and are to bear interest at not to exceed 5 percent per annum. Other features of this law are not pertinent to the present discussion.

The State of Maine has revised certain sections of its general laws to authorize municipal expenditures for public parking places. The sections, as amended, read as follows: [12]

Purposes for which money may be raised: The voters, at a legal town meeting, may raise the necessary sums for the support of schools and the poor; making and repairing highways, town ways, and bridges; and sprinkling streets; acquiring, improving and repairing land for use as public parking places for motor and other vehicles; acquiring by purchase or otherwise suitable sites, or suitable sites and buildings, or erecting buildings for free public libraries; repairing and constructing buildings for academies, seminaries or institutes with which the town has a contract as provided in section 92 of chapter 19; purchasing and fencing burying-grounds; maintaining private burying-grounds established before 1880; purchasing or building and repairing a hearse and hearse-house for the exclusive use of its citizens; and for other necessary town charges.

Towns may lay out land for public parking places; provision as to assessment of damages: Towns may lay out land within their corporate limits for use as public parking places for motor and other vehicles and may alter or discontinue such use. All procedure including assessment of damages and appeal therefrom shall be the same as is provided by general law for laying out, altering and discontinuing town ways. The words "town" and "towns" as used in this act shall include cities.

LEGAL AUTHORITY IN SEVERAL STATES OUTLINED

The State of Massachusetts has a law which reads, in part, as follows: [13]

A town may at any town meeting appropriate money for the following purposes: (33) For acquiring land for public parking places and maintaining the same.

The State of New Hampshire recently amended its laws to provide for public parking areas. The law in question now reads, in part, as follows: [14]

Towns may at any legal meeting grant and vote such sums of money as they shall judge necessary for the following purposes: III. Highways. To lay out, build and repair highways, sidewalks, bridges and public parking places.

The provision of the West Virginia law on this subject is as follows: [15]

A city shall have power: (4) To establish, construct, maintain and operate markets, parks, recreation grounds, municipal camps, and parking lots, and upon the discontinuance thereof to sell and convey the same.

The Iowa law authorizes cities and towns to acquire by purchase, lease, or condemnation, real estate for parking purposes, and to pay the costs thereof either from the general fund or, if general funds are not available, from a parking lot tax fund which may be raised by taxation at the rate of not to exceed one-half mill in any fiscal year. The city council of any city is empowered to establish, maintain, and collect just and equitable charges for use of the parking lands; and the proceeds are to be used for the acquisition of other lands for the same purposes, while any surplus proceeds may be transferred to the general fund of the city. Authority to sell gasoline, oil, motor vehicle supplies, or other merchandise is expressly denied. The city may lease the enterprises to individuals or corporations for terms not exceeding 5 years, and under regulations determining the parking fees to be charged, or it may sell its interests in the property in such manner and under such terms as the council shall direct.[16]

The laws of the remaining two States—Michigan and Pennsylvania—authorize municipalities to engage in a large number of revenue-producing enterprises. The Michigan law, section 1, reads as follows:[17]

Any county, city, incorporated village, township, school district, port district, or metropolitan district, of the State of Michigan, is authorized to purchase, acquire or construct housing facilities, garbage, rubbish and/or sewage disposal plants and systems, water supply and/or water supply systems, incinerators, automobile parking facilities, public markets and storage facilities, merchandise marts, industrial marts, commercial marts, yacht basins, harbors, docks, wharves, terminal facilities, bridges over, tunnels under, ferries across rivers, streams and/or channels within or bounding such unit, community buildings, stadiums, convention halls and auditoriums, dormitories, hospitals, buildings devoted to public use, parks and recreational facilities, reforestation projects, aeronautic facilities and marine railways, either within or without the limits of such county, city, incorporated village, township, school district, port district or metropolitan district, and in furtherance thereof to purchase or construct any necessary part of any such project either within or without the limits of such county, city, incorporated village, township, school district, port district or metropolitan district, of the State of Michigan, which may now or hereafter own or operate any such project, is authorized to improve, enlarge, extend or repair the same: *Provided*, That nothing in this act shall be construed to authorize any county, city, incorporated village, township, school district, port district or metropolitan district to establish warehouses under the terms of this act for the purpose of storing or dispensing alcoholic beverages.

This law further provides that municipalities may operate these enterprises on a revenue-producing basis; and that they may issue bonds payable solely, both principal and interest, from the revenues derived.

In actual operation, the Pennsylvania law differs from the one in Michigan. It authorizes any county,

[10] 1939 Supplement to General Statutes of Kansas, 1935, sec. 13-1368. (Laws of 1939, ch. 124.)
[11] Senate Bill No. 227, approved April 1, 1941, effective April 3, 1941.
[12] Public Laws of Maine, 1941, ch. 149, approved April 4, 1941 (first paragraph amends ch. 5, sec. 78, and second paragraph adds sec. 24-A to ch. 27, of Revised Statutes of Maine, 1930).
[13] General Laws of Massachusetts 1932, ch. 40, sec. 5 (33). (Acts of 1926, ch. 116.)
[14] Public Laws of New Hampshire, 1926, ch. 42, sec. 4 (III), as amended by House Bill No. 52, Public Acts of New Hampshire, 1941, approved April 16, 1941, effective upon passage.
[15] Michie's West Virginia Code of 1937, sec. 591 (85). See Acts of West Virginia, 1937, ch. 56, for details.
[16] Senate Bill No. 293, Public Acts of Iowa, 1941, approved April 3, 1941.
[17] Public Acts of Michigan, 1933, Act No. 94, as amended by Public Acts of Michigan 1939, Acts Nos. 2 and 34.

city, town, borough, or township, individually or jointly with another municipality, to create by resolution or ordinance an authority for construction of, among other things, parking spaces. Said authority has a corporate existence for 50 years. It can sue and be sued; it can acquire property by lease, purchase, or condemnation; it can use said property to construct, improve, maintain, repair, and operate facilities; it can fix, alter, charge, and collect rates for use of its facilities; and it can borrow money and issue bonds to finance its operations. When any authority shall have paid all its obligations, it may convey all its property to the municipality and terminate its existence.[18]

SEVERAL BILLS CONCERNING PARKING BEING CONSIDERED BY STATE LEGISLATURES

Legislation on this question was introduced this year in Idaho [19] and New Mexico [20] but failed of enactment. At the time this report was prepared, five bills on this subject were being considered by the Illinois Legislature [21] and one by the Massachusetts Legislature.[22]

The bills before the Illinois Legislature vary in scope. Senate Bill No. 181 would authorize cities having a population of 150,000 or more, upon approval of the electorate, to establish parking places for motor vehicles within 400 feet of a municipal airport and to finance the same by revenue bonds. House Bill No. 337 would authorize all cities and towns, individually or jointly, to establish parking lots within or without their corporate limits. It also would authorize financing by sale of revenue bonds.

Senate Bill No. 580 would authorize park districts to acquire by gift, lease, or permit, land for use as parking lots, and to place permanent structures thereon. Senate Bill No. 581 would permit any city having a population between 5,000 and 100,000 to expend not to exceed 20 percent of a special tax fund for leasing, improving, and maintaining tracts of land and town lots as parking lots. House Bill No. 69 would authorize the creation of highway authorities, in counties with a population exceeding 300,000, which would be granted broad powers in the construction and operation of toll highway facilities, including "any facility intended for the accommodation of parking vehicles." This bill also contains a legislative declaration of public interest.

The Massachusetts bill would give the mayor of Boston broad powers for use in solving that municipality's parking problems. It would authorize him to appoint a department, board, commission, or official as an authority to exercise, subject to the approval of the mayor, the powers granted under the act. The authority would be empowered to purchase, condemn, or otherwise acquire land for parking facilities; to operate the same, or to license or lease them to individuals; to establish the rates to be charged for use of the facilities; to revise the rates whenever necessary so that the lowest possible charge would cover the cost of operation, maintenance, and administration, as well as meet the payment of principal and interest of any debt incurred by the city for such enterprises.

The bill would also authorize rate differentials due to such causes as the location of the facility and the size of the space occupied. The city treasurer, subject to the approval of the mayor, would be authorized to issue and sell at public or private sale serial bonds of the city to an amount not exceeding $6,000,000 in aggregate principal; said indebtedness would be outside the statutory limit of indebtedness of such city, and payment of the bonds would be made within 20 years.

Although some of the detailed provisions of this bill, particularly the one relating to the financing of these enterprises, apparently would not meet the constitutional inhibitions on municipal corporations in other States, the proposed measure is of utmost importance in this field because it contains a provision which, if enacted, would establish legislative recognition of the automobile parking facility as a public use. That provision, found in section 1 of bill, reads as follows:

> It is hereby declared that the free circulation of traffic of all kinds through the streets of the city of Boston is necessary to the health, safety, and general welfare of the public, whether residing in said city or travelling to, through or from said city in the course of lawful pursuits; that in recent years the greatly increased use by the public of motor vehicles of all kinds has caused serious traffic congestion in the streets of the city of Boston; that the parking of motor vehicles in the streets of the city of Boston has contributed to this congestion to such an extent as to constitute at the present time a public nuisance; that such parking prevents the free circulation of traffic in, through, and from said city, impedes the rapid and effective fighting of fires and disposition of police forces in said city, threatens irreparable loss in valuations of city property which can no longer be readily reached by vehicular traffic, and endangers the health, safety, and welfare of the general public; that this parking nuisance is not capable of being adequately abated except by provision of sufficient off-street parking facilities, conveniently located in the several commercial and residential districts of the city; that adequate off-street parking facilities have not been provided by private capital and private parking spaces now existing must be forthwith supplemented by off-street parking facilities provided by public undertaking; and that the enactment of sections two to eight of this act, inclusive is hereby declared to be a public necessity.

MUNICIPAL PARKING FACILITIES MUST COME WITHIN CONCEPT OF A PUBLIC USE

Developments in Cleveland, Ohio, several years ago seem to have some significance with respect to this question. It appears that between June 1933 and January 1935, excepting for a total of about 3 months time when the property was used for 11 major events or exhibits, the city had used an underground exhibition hall in its civic center as a garage in competition with private garages, and had permitted the parking and storing of automobiles for the general public. A neighboring garageman filed suit to enjoin the city from operating the exhibition hall as a garage. In referring to a municipal ordinance and the provisions of a lease between the city and the Cuyahoga County Commissioners relating to the intended use of this property, the Ohio Supreme Court said:[23]

> In the instant case the municipal legislation for acquiring the land and erecting the underground structure expressly provides that the purpose is to be a public one, and that the space is to be used for "storage, garage or other public purpose, and for all uses incidental thereto." Manifestly had the express purpose been to maintain and operate a private competitive garage, the proposal would have been extra-legal from the beginning. To engage in private, competitive business is to go beyond the purpose for which the underground exhibition hall was constructed, as expressed in the legislation therefor.
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> It is true that in many instances it has been held that public buildings may be temporarily let for a consideration, but in our judgment the present case does not present a situation of that character. Here we are concerned not with a temporary leasing of a public building, but with one which is used at times for purely public functions and at other times, and by far the

[18] Laws of Pennsylvania, 1935, Act No. 191 (Purdon's Pennsylvania Statutes, 1936, Title 53, secs. 2900f to 2900w), as amended by Laws of 1937, Act No. 200, and Laws of 1939, Act No. 85.

[19] Idaho, 1941, House Bill No. 111.

[20] New Mexico, 1941, House Bill No. 150.

[21] Illinois, 1941, House Bills Nos. 69, and 337, and Senate Bills Nos. 181 (a substitute for Senate Bill No. 121), 580, and 581.

[22] Massachusetts, 1941, House Bill No. 1636.

[23] *Cleveland* v. *Ruple*, 130 Ohio St. 465, 200 N. E. 507, 103 A. L. R. 853.

larger part of the time, for engaging in a private garage business in direct competition with privately owned and operated garages in the vicinity, including that which plaintiff below operated as receiver.

The court held:

The building may be operated as a garage so far as in doing so there is involved a public function. * * * To be specific, whenever the public buildings of entertainment located in the civic center, to wit, the underground exhibition hall itself, the public hall, or the stadium, are used properly and lawfully for public gatherings, patrons in attendance thereat may use the underground exhibition hall for parking or storing automobiles, for hire or otherwise. The city may permit its officers and employees to park or store their automobiles in the underground exhibition hall while they are engaged in the performance of duties as such officers and employees, but subject to the terms prescribed by the city. The city of Cleveland may use the premises for the parking, storing, washing, oiling, lubricating, repairing, and otherwise servicing its own automobiles, trucks, busses and other vehicles. Should any purely public purpose for which the building may be used arise in the future, such a use is not prohibited.

On the other hand, the defendants in the court below are enjoined from operating the garage as a purely private business in competition with privately owned garages.

Municipalities planning to establish public parking facilities may find it very helpful if they would carefully check the sources of their power before condemning or purchasing the desired lands, or before converting lands acquired by tax delinquencies or for other public uses into public parking places. Although these sources of power vary in the different States, they may be found in the State constitutions, municipal charters, and the general or special acts of the State legislature. It should be remembered when these studies are made that courts are inclined to construe grants of power strictly against the municipality, and that they limit implied powers to only those which are necessarily incidental to an express power. In other words, the courts in construing a State law authorizing its municipalities only to construct a public parking lot would not necessarily imply that they could charge fees for use of the same, or that they could issue bonds to finance the construction costs.

It might be well to review the decisions of the local courts interpreting these grants of municipal power, or the decisions of the courts of other States interpreting similar provisions of law. In the event that a municipality has no express power under which it can undertake the program that its planning officials desire, it should secure enactment of a State law to cover the situation. A general law, enacted at the request of a number of communities which base their recommendations upon the reports of their planning officials showing the urgent need for remedial measures, would prove most desirable. The detailed provisions should be expressly stated in the law.

LEGISLATIVE RECOGNITION AND ACTION NEEDED TO SOLVE PROBLEM

The city-owned parking facility question has not been reviewed by the courts to any great extent because the trend toward such enterprises is a very recent development. Since many of the municipal undertakings currently operating in a number of cities throughout the country require only small cash outlays from public funds and are on lands which have been acquired by means other than through condemnation proceedings, the interests of the taxpayer, and of the owner of property sought to be condemned, have not yet been aroused sufficiently to have the program subjected to judicial scrutiny. Therefore, the real issue—the public nature of the automobile parking facility—is still a moot question which only the courts can answer. Each case in which this issue is raised, of course, will be decided on its own merits.

This question is of utmost importance, particularly since (1) the most suitable locations in many cities for public parking facilities often can be acquired by the municipality at a reasonable cost only by the exercise of eminent domain powers; (2) private property may not be taken from the owner against his will for other than a public use; and (3) public funds may not be expended for private purposes.

City planning officials can do much to strengthen their claim of public necessity for municipally owned and operated enterprises in this field by careful planning of the entire record on which they base their claims. They can go beyond enactment of a State law which merely authorizes them, among other things, to condemn lands for such purposes. Such a law may prove inadequate when the case testing their action is heard in court. Measures far more effective than the mere enactment of a law can be taken. They are, of course, detailed steps which the various municipalities of a State interested in the movement should consider before any one of them seeks State legislation on the question. A municipality of a State which can enact special laws may desire to present its own problems to the State legislature and request enactment of a law which would apply only to that one city.

Properly prepared reports showing analogous conditions in several communities within the same State, or within one community of a State in which special legislation is constitutionally proper, and used as the basis for State legislation, can provide means by which the legislature may make findings relating to existent urban traffic conditions as well as the determination of public necessity for municipally owned parking facilities. Such findings and the determination of public necessity are proposed specifically for municipally owned parking places in the bill being considered by the Massachusetts legislature. Since these findings and determinations relate to public conditions concerning which the State legislature by necessity and duty must know, they are usually given great respect by the courts, even though the courts are not required to accept them as conclusive.

The record can be so developed that it may be possible for a municipality to allege in its court pleadings all the conditions adverted to by the legislature, and actually to prove the existence of those conditions during the trial. The added weight of the legislative findings and the determination of public necessity, coupled with the allegation and proof of the existent conditions, may be sufficient to sway an otherwise doubtful court toward the favorable side of the continuously growing public concept that an automobile parking facility is a "public use."

The developments which already have taken place in the form of State legislation and municipal action definitely show a tendency on the part of the legislative and executive branches of State and local governmental units to recognize the automobile parking facility as a public use. The increased interest in this field which may be expected throughout the country within the next few years will further strengthen the public use concept of such enterprise. This trend should help to obtain favorable court decisions on the issues of properly developed cases. In the meantime, municipal planners should recognize that the legal phases of the publicly owned parking facility are no less important than plans for the physical layout and financing. The groundwork laid today will influence the judicial determinations of tomorrow.

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ment to provide such facilities for self-preservation, and most large stores now generally insist upon parking space at least equal to total floor space.

Other means of relieving urban street congestion are zoning ordinances which designate permissible land uses or which limit the intensity of land use by fixing the maximum height and bulk of buildings.[14] Employment of these instruments of planning, it is true, may not yield any immediate relief in downtown areas, but the fact that cities are practically rebuilt every generation suggests the merit of planning now for a wise reconstruction.

CONCLUSIONS

Consideration of the parking requirements of the automobile and of the issues they involve has led to the conclusion that off-street parking facilities constitute an essential part of urban highway transportation service. This fact, together with the inability of private enterprise to supply a satisfactory solution, has established parking as a public responsibility and introduced into the field of highway finance extensive new factors involving the whole city problem. In view of the utter inadequacy of urban transportation in the United States at the present time, it is inconceivable that public officials can long continue to deny this responsibility.

Today the favorable cost conditions and financial methods possible under municipal operation of parking facilities are being realized in an increasing number of cities, and the growing magnitude of urban congestion is creating widespread interest in further municipal experiments. It is suggested that Federal assistance might be offered in the planning of parking facilities in connection with the highway program, and that actual sites might be made available through building demolitions by the Work Projects Administration. Financial aid in the provision of the new facilities or loans for land acquisitions are also possibilities for the future. At the same time there appears to be no logical objection to the broadening of the legal interpretation of highway service to permit the cities to use their allotments of State motor-vehicle tax revenues to finance off-street parking facilities. Intelligent surveys and enabling legislation, however, appear to be the most essential immediate steps, so that eventual return to a peacetime economy may find in readiness bold plans for a large-scale program of public works designed to rescue the city from its present plight.

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BULLETIN ON SOIL MECHANICS AVAILABLE

"Plane Strain Distribution of Stress in Elastic Media" has recently been published as Iowa State College Bulletin No. 148.

This 56-page bulletin presents an analysis of stresses and displacements in a semi-infinite elastic medium. Its practical application is in soil mechanics. The analysis approximates the condition present when an earth fill or highway embankment is placed on level or sloping ground.

A limited number of copies of Bulletin 148 are available for free distribution and may be obtained from the Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa.

CORRECTION

In figure 16, page 89, of the June 1941 issue of PUBLIC ROADS, Item 1 should read "Percentage of Federal-aid Apportionments, 1941." It was incorrectly labeled "Percentage of total area."

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF JUNE 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 4,827,329	$ 2,266,382	122.1	$ 6,370,806	$ 3,161,345	221.9	$ 2,188,500	$ 1,088,350	60.1	$ 1,813,680
Arizona	1,776,383	1,216,648	70.0	1,604,155	1,119,247	71.3	386,532	265,870	8.6	1,478,816
Arkansas	5,246,519	2,403,405	137.2	1,423,438	709,959	57.9	562,452	281,069	26.9	1,360,557
California	7,669,676	3,862,136	143.8	8,754,616	4,723,774	122.8	2,851,722	1,489,096	56.6	2,694,814
Colorado	2,822,156	1,532,734	220.0	2,375,049	1,376,969	95.4	921,087	519,852	69.5	2,690,469
Connecticut	1,952,321	945,967	16.2	2,032,068	990,677	23.9	564,172	275,308	8.1	973,057
Delaware	2,010,443	1,004,442	32.5	328,389	163,920	5.0	817,812	400,879	23.4	1,035,973
Florida	3,691,978	1,833,430	85.5	1,115,428	585,805	57.8	1,956,762	946,540	16.6	2,799,339
Georgia	3,703,811	1,797,726	212.7	7,105,429	3,562,964	270.0	5,248,992	2,624,496	226.2	4,888,345
Idaho	2,296,691	1,303,593	161.7	1,686,903	1,018,103	81.7	532,633	284,944	26.8	1,558,916
Illinois	8,234,811	4,022,451	188.9	8,183,346	4,092,423	165.3	2,752,252	1,375,570	30.1	3,818,477
Indiana	6,351,009	3,125,356	136.6	8,345,719	3,910,725	134.8	152,766	43,183	1.5	2,191,636
Iowa	7,530,985	3,555,970	260.1	3,602,738	1,732,208	133.1	3,208,052	1,517,750	116.4	505,647
Kansas	6,483,589	3,079,023	530.9	5,596,548	2,840,341	287.2	3,175,123	1,576,487	167.5	3,836,234
Kentucky	3,384,253	1,666,719	101.9	4,923,180	2,396,687	121.4	4,453,360	2,133,989	129.8	1,497,778
Louisiana	11,859,995	2,970,570	39.4	2,375,813	1,187,148	55.2	3,023,507	1,478,882	63.1	3,032,294
Maine	1,408,282	688,019	31.8	1,680,458	861,953	23.0	917,540	458,770	18.5	501,998
Maryland	1,495,568	736,317	31.0	3,740,235	1,859,013	28.1	1,058,128	456,665	6.2	1,297,839
Massachusetts	1,835,469	914,827	22.9	3,603,415	1,822,083	24.3	1,631,409	811,216	12.9	2,812,396
Michigan	7,684,964	3,572,921	267.4	8,357,520	4,166,160	177.0	745,000	372,500	12.0	2,287,348
Minnesota	6,542,656	3,149,718	542.3	7,592,677	3,779,119	396.3	4,146,620	2,049,484	219.2	2,035,192
Mississippi	3,678,421	1,744,146	163.0	8,069,112	3,969,706	452.1	530,100	263,300	27.4	949,308
Missouri	4,700,060	2,236,509	229.3	10,458,355	5,059,081	241.6	5,718,000	2,117,611	134.0	3,193,079
Montana	5,022,372	2,841,537	337.9	3,210,474	1,817,945	154.9	286,871	163,115	26.6	4,069,200
Nebraska	4,942,017	2,303,138	585.8	4,739,531	2,389,803	525.0	3,048,518	1,524,259	258.5	2,656,533
Nevada	1,589,675	1,339,934	79.6	2,226,708	1,937,148	102.9	571,653	413,018	23.6	582,964
New Hampshire	1,712,063	842,469	43.5	771,073	384,261	11.1	449,656	216,604	6.0	885,973
New Jersey	3,209,169	1,589,352	21.3	5,888,682	2,944,261	42.8	27,110	13,555		1,741,492
New Mexico	2,933,097	1,803,575	215.6	1,221,885	751,631	51.5	513,106	331,774	54.4	1,852,356
New York	11,945,473	5,775,856	204.9	12,217,502	6,081,600	155.6	900,080	399,390	11.7	4,235,274
North Carolina	5,988,295	2,991,393	294.7	4,609,934	2,300,755	195.4	552,500	268,740	26.4	2,629,185
North Dakota	2,530,261	1,333,272	255.0	3,949,940	2,185,535	314.5	3,548,120	1,782,737	308.4	3,115,042
Ohio	7,744,295	3,844,249	95.1	17,458,700	8,577,798	143.5	2,489,722	1,051,230	19.6	3,567,350
Oklahoma	3,603,840	1,903,220	170.6	3,423,074	1,769,597	105.2	2,834,320	1,451,657	95.8	4,263,768
Oregon	3,701,576	2,213,601	168.2	4,128,063	2,226,236	106.5	922,275	512,240	13.1	743,292
Pennsylvania	8,950,104	4,410,982	106.6	13,624,954	6,706,878	116.3	2,884,024	1,392,419	27.9	2,923,134
Rhode Island	1,377,507	673,905	13.4	1,117,614	558,172	10.3	230,390	115,195	1.6	1,019,872
South Carolina	2,664,734	1,288,098	190.2	4,337,147	1,992,844	158.7	419,263	170,226	19.1	1,967,991
South Dakota	3,689,420	2,084,433	638.6	4,467,683	2,785,223	521.2	1,137,360	652,140	136.9	2,718,059
Tennessee	4,131,091	2,049,708	102.0	5,523,448	2,761,724	133.9	922,208	461,104	14.4	3,427,714
Texas	10,045,404	4,881,747	570.0	14,682,580	7,255,994	635.8	2,964,778	1,413,775	121.7	6,260,955
Utah	1,275,905	913,601	82.3	2,125,922	1,550,123	61.1	398,236	259,439	15.3	641,043
Vermont	1,489,949	709,384	44.8	911,538	462,046	24.6	809,403	400,051	13.8	199,057
Virginia	3,292,235	1,561,634	84.2	4,435,323	2,072,998	71.5	1,527,926	715,603	36.9	1,770,935
Washington	4,502,460	2,313,802	91.4	1,954,491	1,043,494	23.8	1,492,118	756,985	26.2	1,116,847
West Virginia	2,607,727	1,291,446	94.3	3,822,330	1,905,976	62.8	550,400	273,385	9.6	1,646,733
Wisconsin	5,837,466	2,864,625	204.2	3,556,123	1,766,988	130.2	1,581,567	727,820	65.5	4,040,635
Wyoming	2,192,003	1,350,061	235.9	1,452,036	948,842	141.1	353,677	204,368	31.0	1,197,638
District of Columbia	674,267	336,821	6.0	789,420	393,940	2.2	134,637	67,250	.5	420,250
Hawaii	338,503	167,392	6.0	546,698	292,545	7.8	296,658	277,186	3.2	1,716,101
Puerto Rico	865,208	412,985	19.4	1,456,652	719,875	16.2	267,936	131,600	2.1	805,679
TOTALS	216,043,485	105,721,229	8,708.7	237,974,922	121,673,642	7,273.5	79,657,033	38,978,676	2,831.2	111,468,264

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF JUNE 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 201,544	$ 100,563	10.3	$ 1,322,457	$ 662,458	59.8	$ 438,900	$ 213,730	29.0	$ 414,624
Arizona	239,793	167,992	23.6	202,398	149,241	5.3	53,969	39,230	8.7	359,011
Arkansas	463,572	202,807	14.9	412,654	205,474	32.6				309,298
California	1,080,315	587,266	40.5	1,431,118	966,148	21.5	182,486	102,820	4.4	472,613
Colorado	354,364	198,516	17.7	151,590	75,247	20.7	67,508	14,516	1.9	310,021
Connecticut	370,531	179,413	4.6	298,035	136,331	6.1	249,242	109,263	4.8	78,566
Delaware	167,624	83,378	15.5	89,307	44,179	.4	319,569	143,826	15.8	158,438
Florida	118,332	58,758	10.0	1,077,958	538,529	10.5	67,314	33,657	1.3	248,030
Georgia	347,056	172,409	39.6	934,746	517,723	59.3	1,050,897	525,448	102.6	787,094
Idaho	171,420	101,343	24.2	290,633	175,671	19.2	40,937	7,402	1.2	237,955
Illinois	1,909,326	884,983	81.9	1,380,450	669,625	63.6	516,900	258,450	24.1	412,738
Indiana	471,760	222,327	31.0	865,164	438,039	52.5	868,200	392,316	34.0	604,775
Iowa	2,585,177	1,229,520	596.5	545,667	246,923	136.8	121,203	44,025	21.1	466,690
Kansas	489,957	244,055	58.9	1,038,939	526,640	49.1	1,632,975	813,992	167.5	696,878
Kentucky	934,509	303,935	69.6	677,428	199,427	29.2	1,080,987	266,885	78.2	296,013
Louisiana	112,966	52,661	10.9	564,708	230,289	20.6	289,362	138,761	21.5	446,100
Maine	330,551	152,283	17.7	14,200	7,100	.8				161,212
Maryland	128,300	64,150	5.5	449,390	224,695	17.3	352,610	176,130	5.2	199,221
Massachusetts	537,358	266,367	10.5	326,366	178,602	7.8	464,750	231,510	6.4	366,739
Michigan	1,621,562	756,518	134.9	1,116,860	558,430	61.0	487,300	243,650	30.7	443,946
Minnesota	1,065,399	517,902	161.3	1,067,230	542,865	118.1	741,473	369,294	102.8	643,574
Mississippi	278,087	137,780	12.5	1,134,994	557,312	61.3	233,261	116,631	7.9	535,242
Missouri	871,518	431,253	115.6	461,040	217,937	30.8	475,672	190,553	66.6	842,757
Montana	908,856	513,440	129.7	362,875	206,169	37.8	103,169	58,594	23.2	633,341
Nebraska	757,643	361,916	122.8	610,265	310,410	59.8	170,793	85,397	30.6	383,988
Nevada	269,855	223,012	47.7	122,442	106,515	12.8	126,764	110,157	9.5	117,868
New Hampshire	143,639	68,883	3.4	155,106	76,532	4.7	187,417	92,808	3.5	88,885
New Jersey	402,862	203,795	15.3	366,642	194,835	7.8	604,560	298,145	20.6	348,764
New Mexico	565,083	289,531	31.8	426,456	268,847	42.6				219,827
New York	2,471,956	1,175,210	80.5	1,124,234	585,815	27.9	335,000	146,500	4.9	650,421
North Carolina	1,134,809	564,109	105.7	521,179	265,168	41.7	261,048	98,960	22.1	368,727
North Dakota	163,101	87,156	1.4	52,986	29,992	2.4	808,050	793,860	42.7	483,046
Ohio	1,911,776	948,811	66.2	1,864,110	979,630	58.6	525,400	250,125	6.1	927,098
Oklahoma	795,576	416,089	57.1	362,826	191,561	21.6	856,486	452,224	64.6	740,704
Oregon	435,623	244,446	64.1	434,258	211,893	33.4	248,573	148,200	25.2	226,979
Pennsylvania	1,806,155	885,463	62.5	2,347,095	1,162,481	45.1	162,000	81,000	2.9	41,113
Rhode Island	262,488	120,687	3.6	211,098	108,991	2.6	3,920	1,960		63,989
South Carolina	671,637	246,116	97.8	644,667	249,166	43.6	365,200	140,124	11.5	159,848
South Dakota	3,714	3,624		25,302	15,768	9.0	1,153,880	1,053,460	123.6	489,674
Tennessee	150,805	71,863	8.7	551,006	275,503	17.7	1,333,078	666,539	46.9	437,708
Texas	1,644,276	804,137	214.4	1,153,216	563,173	113.9	457,105	215,875	41.0	1,362,440
Utah	207,897	130,260	27.6	231,700	147,199	15.8	17,494	8,984	3.7	208,507
Vermont	477,095	152,849	19.4	36,219	18,109	1.2				91,346
Virginia	528,246	248,088	28.3	505,941	241,352	17.6	202,000	82,152	2.5	383,586
Washington	715,902	365,694	38.7	420,865	244,139	20.3	88,447	9,000	1.1	252,548
West Virginia	334,593	165,602	18.5	537,890	268,945	20.3	166,434	82,604	5.8	320,571
Wisconsin	454,409	225,949	10.0	1,080,995	546,013	44.8	991,668	413,110	38.3	358,043
Wyoming	431,815	260,037	42.8	369,790	159,928	18.8	214,231	68,100	20.0	150,012
District of Columbia	112,164	56,082	1.4	58,203	29,096	.6	30,529	14,750	.3	73,194
Hawaii	264,732	132,578	8.6	1,096	1,096					250,559
Puerto Rico	193,690	94,735	8.7	231,364	112,855	10.6				134,597
TOTALS	33,071,418	16,176,341	2,824.4	30,663,158	15,640,066	1,617.3	19,148,761	9,804,717	1,286.3	19,458,918

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

Work of the Public Roads Administration, 1940.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

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No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP. . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

Specifications for Construction of Roads and Bridges in National Forests and National Parks. 1 dollar.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

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No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washungton, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF JUNE 30, 1941

STATE	Completed During Current Fiscal Year: Estimated Total Cost	Completed: Federal Aid	Completed: Number: Grade Crossings Eliminated by Separation or Relocation	Completed: Number: Grade Crossing Structures Reconstructed	Completed: Number: Grade Crossings Protected by Signals or Otherwise	Under Construction: Estimated Total Cost	Under Construction: Federal Aid	Under Construction: Number: Grade Crossings Eliminated by Separation or Relocation	Under Construction: Number: Grade Crossing Structures Reconstructed	Under Construction: Number: Grade Crossings Protected by Signals or Otherwise	Approved for Construction: Estimated Total Cost	Approved for Construction: Federal Aid	Approved: Number: Grade Crossings Eliminated by Separation or Relocation	Approved: Number: Grade Crossing Structures Reconstructed	Approved: Number: Grade Crossings Protected by Signals or Otherwise	Balance of Funds Available for Programmed Projects
Alabama	$ 807,825	$ 787,689	7		7	$ 158,039	$ 156,239	3	1	3	$ 335,673	$ 335,451	5	4	5	$ 300,717
Arizona	373,753	366,038	4		2	168,266	168,266	1			29,350	29,350		1	2	207,575
Arkansas	1,191,435	1,184,682	11	1	16	452,612	452,283	5			173,273	171,563	1		4	336,331
California	474,671	472,281	4		19	1,449,884	1,258,196	9	1		259,334	259,334	1		7	1,475,608
Colorado	299,792	299,792	1		4	143,040	143,040	2			407,329	400,096	3			619,695
Connecticut	622,002	611,366	5	1		166,222	165,415	2			293,086	283,416		2		334,689
Delaware	108,682	108,682	4		17	94,135	94,135	1			697,074	508,721	3	1	1	51,500
Florida	351,276	346,252	3	1	5	279,548	278,559	3		4	626,585	622,329	5		35	709,591
Georgia	255,273	253,240	5	2	13	1,249,432	1,249,432	10	7	2	1,013,911	1,013,911	4	5	21	1,171,488
Idaho	304,809	293,297	5		36	14,943	14,943				325,787	309,720	5	1	4	265,130
Illinois	1,937,272	1,820,332	13		101	1,791,514	1,583,915	6	1	60	510,722	493,716	4		25	1,937,707
Indiana	956,658	948,442	5	2	91	782,193	769,706	6	1	8	137,796	132,087			35	886,306
Iowa	550,420	532,395	6		98	879,547	661,727	7	2	1	655,431	626,332	2		57	530,721
Kansas	1,005,495	997,541	12	2	20	383,757	383,757	8		2	435,188	434,873	2	1	9	941,930
Kentucky	614,326	586,272	10		12	1,083,812	1,082,812	8	1		147,955	141,842	2		1	352,604
Louisiana	438,543	425,254	3		2	202,163	202,163	4			702,474	701,306	7		1	766,048
Maine	179,563	178,645	1	2	6	113,072	113,072	1			278,011	278,011	1		1	115,569
Maryland	183,547	183,543	1		3	482,459	450,666	2	2	6	749,953	749,475	3		16	231,439
Massachusetts	16,588	16,588		1		435,901	425,263	2			1,408,925	1,407,670	6	3		908,106
Michigan	1,462,976	1,406,448	9	2	40	1,250,755	1,250,755	3	4	1	320,323	320,323			5	864,308
Minnesota	1,496,156	1,485,600	14	3	21	1,023,080	1,023,080	6	4		483,266	483,266	1	4	1	774,206
Mississippi	327,019	327,019	5	1	1	743,375	743,375	9			50,399	50,399		1	11	640,125
Missouri	1,164,344	1,163,785	6	4	1	2,034,922	1,579,502	6	4		59,161	59,161		1		1,283,235
Montana	440,750	440,748	5		5	174,019	174,019	2			6,645	6,645			2	512,684
Nebraska	447,821	445,313	3	1	17	912,016	912,016	15	1	6	391,610	391,610	8		19	156,242
Nevada	75,015	74,810	1		20	120,830	120,830	3			71,448	71,448	1		5	103,867
New Hampshire	107,016	106,980	3		2	207,780	206,960	3	1		158,429	158,129	3	1		206,973
New Jersey	278,937	278,937	2		4	1,192,373	1,066,823	6	1	1	336,030	296,075	1	2		812,665
New Mexico	421,713	413,138	5		6	2,560	2,560				259,103	252,068	3		1	403,805
New York	1,534,851	1,491,256	9	6	8	3,844,164	3,788,193	5	17		633,245	539,285		2		2,756,581
North Carolina	937,210	936,902	12	4	42	531,723	531,723	2	7	1	220,243	220,243	1		26	921,459
North Dakota	417,947	415,903	5		23	468,470	455,533	5			300,900	300,900	5			555,963
Ohio	1,676,506	1,605,312	10	2	17	2,398,317	2,367,274	11	1		1,366,530	1,316,530	5		3	1,336,259
Oklahoma	963,354	957,549	12	1	63	156,982	152,076	2		4	1,220,467	1,160,510	8		31	1,105,268
Oregon	208,640	159,119	3			411,078	347,465	4			18,280	18,280	1		4	392,976
Pennsylvania	1,484,274	1,474,798	14	2		3,144,763	3,110,554	21			1,218,306	1,213,759	5			2,219,999
Rhode Island	8,222	7,406				206,703	206,703		1							178,256
South Carolina	541,470	540,820	5	3	27	195,235	185,135	3	1	4	570,001	437,427	5	3	27	726,254
South Dakota	179,106	175,621	3	1	5	517,332	517,332	15			481,323	465,373	8		9	644,755
Tennessee	244,480	231,146	2	2		490,316	481,316	4	3		929,038	929,038	5	1		925,530
Texas	1,628,473	1,612,149	12	1	10	1,789,368	1,773,181	19			622,016	570,009	6		2	1,576,201
Utah	149,862	149,545			56	67,432	66,690	3		7	109,004	109,004			38	237,069
Vermont	257,264	257,024		2	12	5,967	5,967			1	255,316	255,316	2		3	50,478
Virginia	457,084	454,594	4	2	14	616,419	616,419	4	5		259,348	239,388	2		3	585,543
Washington	422,323	417,341	4	3	11	379,654	379,654	3	2		9,250	9,250			3	456,706
West Virginia	232,330	232,330	2		3	440,682	435,062	5		2	469,800	469,800	4	1	6	509,681
Wisconsin	948,394	934,965	7	4	12	802,619	772,758	4	1	5	251,283	251,161	1	1	42	1,160,467
Wyoming	91,384	91,379	1		2	480,106	480,104	6			5,322	5,322			5	290,375
District of Columbia	56,868	56,868	1			2,193	2,193				298,213	273,744		1		1,462
Hawaii	8,416	8,141			2	405,282	404,759	4								181,412
Puerto Rico	90,290	89,720	5			742,969	735,496	10								337,988
TOTALS	29,432,425	28,854,997	264	56	876	36,090,023	34,549,096	263	69	118	20,562,156	19,772,666	129	36	470	35,551,546

PUBLIC ROADS

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FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 22, NO. 6 AUGUST 1941

CUTTING A SAMPLE OF ASPHALTIC CONCRETE PAVEMENT IN OHIO

PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

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PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 6 August 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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ACCIDENT HAZARD AT GRADE CROSSINGS

A RATING BASED UPON RAILWAY AND HIGHWAY TRAFFIC, TYPE OF PROTECTION, AND PHYSICAL CHARACTERISTICS OF THE CROSSING

BY THE DIVISION OF HIGHWAY TRANSPORT, PUBLIC ROADS ADMINISTRATION

Reported by L. E. PEABODY, Senior Highway Economist, and T. B. DIMMICK, Associate Highway Engineer-Economist

HIGHWAY ENGINEERS have been attempting for some time to develop a method of measuring the need for railroad-highway grade crossing separation or protection, and of stating this need in the form of a numerical rating. Many plans, founded on studies of the various basic relationships, have been proposed. Generally, the rating has been reached by assigning coefficients to various factors connected with the individual crossing and inserting these coefficients in a formula. Because the coefficients chosen were frequently the result of estimates, the ratings have often lacked uniformity and were sometimes thought to be biased.

Methods of measuring the need for highway-railroad grade crossing separation or protection have long been sought by highway engineers. Formulas have been advanced in which coefficients have been assigned to various factors connected with the individual crossing.

A large amount of information, collected by the various highway planning surveys in all sections of the country concerning rural grade crossings at which accidents had occurred, was used (1) in calculating protection coefficients for various types of crossing protection, and (2) in evaluating the relative accident hazard at crossings.

Hazard ratings are particularly valuable in obtaining the maximum of hazard reduction, either through crossing protection or elimination, for a given expenditure. They may be quickly calculated by graphical methods; and the hazard rating is a valuable means of selecting crossings that should receive priority in treatment. Local conditions at the crossing are shown to be of considerable importance.

Elimination or protection of railroad grade crossings should not depend solely upon the inherent hazard of the crossing itself. A priority program made up on such a basis, even if perfect ratings of inherent hazard were available, might result in exhaustion of funds with the separation of a few very dangerous crossings. A wiser distribution of the funds might permit the separation, or protection, of a much larger number of crossings and with an aggregate hazard elimination much in excess of that resulting from the first program. The more valuable measure would be based upon the cost per unit of hazard reduction, and the objective should be the maximum of hazard elimination with a given sum of money.

The total cost of elimination depends in part upon the cost of any adjacent lands that must be acquired, as well as upon the construction expenditures necessitated by the physical layout at the individual crossing. The cost of one separation at a location where land values are high, if distributed over several locations where construction expenditures are smaller and land values are lower, might result in the elimination of a total of many times as much hazard.

RATINGS BASED ON HAZARD TO LIFE AND TIME LOSS

Another factor to be considered in the setting up of such a program is the amount of delay to highway traffic, and resulting economic loss, at a crossing. Where hazard ratings are approximately equal, the crossings used by the larger number of motor vehicles should be selected for elimination, since this will result in a minimum of economic loss due to delay.

The evaluation of objectionable grade crossing features is usually based on one or both of two considerations—the relative potential danger to human life, or the relative loss of time. In considering rural grade crossings it is believed that the hazard to life is more important than the time factor. In rural areas trains move faster and the time loss at crossings will not be as serious a matter generally, although it may be a source of annoyance. The method discussed in this paper deals with the measurement of the hazard at the grade crossings as one means of evaluating the need of separation or protection.

In order to calculate the hazard that exists at any crossing, a large amount of information was collected by the various highway planning surveys in all sections of the country concerning rural crossings at which accidents had occurred. Data concerning 3,563 such crossings were furnished by the planning survey organizations of 29 States. This information consisted of a description or sketch of the crossing, a statement of the highway and railway traffic using the crossing, and a description of the accidents that had occurred in a 5-year period.

The description of the crossing included the clear view distances measured along the tracks from points on the highway 300 feet from the crossing, the gradient of the highway on either side of the crossing, the alinement of the highway at the crossing, the surface type, the number of tracks crossed, the angle of intersection of the highway with the railway, and other special features that might affect the safety of the crossing. Any type of protection that had been installed at the individual locations was described. Data concerning the average daily highway and train traffic were generally subdivided to show the division between passenger-car and commercial traffic on the highways and the division between high-speed, medium-speed, and standing or switching trains, on the railroads. Finally the number of accidents, including the number of persons killed and the number injured, were given and the accident causes which could be determined were reported. This information covered a period of 5 years, generally from 1932 to 1936 inclusive, and furnished a basis for determining the relations between the number of accidents and some of the factors contributing to these accidents.

Several deficiencies in existing accident reports condition the results of this study and should be stated to insure a complete understanding by the reader. Some writers of accident reports ascribed similar causes to accidents which were very different in nature. For example, the reports of one division superintendent stated, with almost flawless uniformity, that the accident resulted from "car stalled on crossing." Other more careful reporters used the same phrase, but differentiated between the motor-vehicle operator who rounds a sharp curve or comes from a sector with short sight distance and is surprised to find a train a short distance away, and other cases to be cited. This operator, in panic, kills his motor and does stall his car directly before the approaching train—often with fatal results. Other accidents, generally described as "car stalled on crossing," include cases of drunken drivers who have left their vehicles standing on the crossing, drivers of stolen cars who have abandoned the stalled cars because of fear of apprehension, and the driver who leaves the car standing on the crossing while he goes for assistance to remove it. The case first cited differs fundamentally from the three others. All have actually been found, some frequently, in the accidents reported.

The first case is a true "accident" in the generally accepted meaning of the word. The drunken driver's "accident" is self-induced; the driver of the stolen car suffers no economic penalty from his "accident" and may be indifferent to the possibility of injury or death to those in the train; the driver who leaves the car while he goes for help may either be exercising poor judgment or may actually be unable to push the car alone. However, if the accident reporter records them all as due to "car stalled on crossing" and gives no further detail, the true hazard rating of the crossing is obscured. Failure to differentiate in these cases is not uncommon and has serious unmeasurable effects upon the results of an accident relation study. Other and relatively infrequent causes such as the case of the driver who is convinced he can beat the train over the crossing and shoves down the accelerator, while his passenger is equally convinced that it can't be done and grabs the brake, must be dealt with in the analysis.

There are other difficulties in arriving at the true hazard rating of a crossing. For example, some crossings have been given "over protection" in the sense that the true hazard rating would not justify the kind of protection that has been installed. These cases often result from public demands after some particularly spectacular accident which may have occurred during Christmas holidays or which was accompanied by a fire, as when a gasoline truck is hit. These more or less isolated accidents provoke widespread discussion and criticism and, because of their spectacular nature, often result in the crossing being given a higher type of protection than would generally be thought necessary.

LOCAL CONDITIONS SHOULD TEMPER USE OF FORMULA

The formula for the rating of crossings derived herein is general and does not take completely into account special local conditions that greatly affect the true hazards at a given crossing. It has the advantage of objectivity but does not take into account the effects of some of the specific conditions peculiar to the individual crossing. For example, there are crossings where every train movement is guarded by brakemen who serve as flagmen. These crossings show a statistical movement of a certain number of trains per day; while from the standpoint of true hazard (because of the protection given each train movement), there are actually no trains per day. A crossing of U. S. Route 1 near Laurel, Md., and another crossing of U. S. Route 1 near the Washington Airport between Washington, D. C., and Alexandria, Virginia, are examples of such cases.

Any formula arrived at through use of accident experience must be general in application because of the wide variety of conditions to be met. Nevertheless, a rating of crossings upon a basis of knowledge of local conditions alone is subjective, and suffers from failure to take accurately into account the effect upon the hazard of the amount and type of highway and railway traffic, the protective devices in operation at the crossing, and the physical characteristics of the crossing and its approaches, such as angle of vision, sight distance, number of tracks, grade of approach highways, etc.

Because of the conditions just cited it would seem best to use any formula in conjunction with a knowledge of peculiar local conditions. To be sure, it is difficult to know how much to modify the formula for hazard rating by consideration of local conditions such as those described in detail above. However, a rating of the crossings of a State made upon the basis of the formula may be compared with ratings made independently by several individuals who are well acquainted with local conditions surrounding individual crossings. Priority lists for elimination or protection of crossings arrived at in such fashion will combine the best features of both methods.

Another major problem involved in the derivation of a formula for hazard rating is whether to include or exclude in the analysis, crossings for which no accidents were reported during the period covered by the study. It is possible that at these crossings there may have been an accident, very soon after the close of the period under observation, or there may have been an accident in the period just prior to that for which data were reported. Five years, the period used in the study covered by this report, is a rather short time for the establishment of true accident ratings, and a rating of 0.2 on the basis of 5 years' experience might become a rating of 0.8 on 25 years' experience. Because of this relatively high variability, and the relative shortness of the experience, it was decided to omit from consideration altogether data for crossings at which no accidents were reported within the 5 years studied.

A study was first made of the data submitted to determine the accident trend caused by variations of the various items concerning the crossings. Several of these items are qualitative and suitable preliminary coefficients were determined on a basis of traffic per accident. This study indicated that considering traffic, both highway and train, and type of protection, a definite trend was easily obtainable. Other items, although they probably influenced the safety or hazard at individual crossings, when considered in combination indicated no average trend or one too indefinite to make its use practicable. The results of this preliminary study indicated, therefore, that traffic and protection were the only factors that could be depended upon to rate the crossings on an average accident basis.

Before calculating the preliminary coefficients, all data concerning accidents of the "scratch" type—those resulting from intoxication, and certain of the "car stalled on crossing" type, as previously described, were eliminated. Accidents such as "striking gates" or "running off crossing plank" were thought to be of minor importance and were excluded from the study being made. The accidents due to drunkenness were eliminated because it was assumed that drivers in that condition were unfit to handle their vehicles and would possibly have had an accident with passing traffic or at some obstacle along the roadside if they had not happened to have the accident at the crossing. A few other accidents of a miscellaneous nature, which were not connected with a train movement, were also eliminated from the study.

PROTECTION COEFFICIENTS CALCULATED FOR VARIOUS TYPES OF CROSSING PROTECTION

As stated above, preliminary coefficients were determined for the various common types of protection by determining the average number of "exposure units" which passed over all crossings of each type of protection for each accident which had occurred at those crossings. The exposure units were obtained by multiplying the average daily highway traffic by the average daily train traffic. These products were divided by 100 to reduce the size of the figure. The equation used in determining the coefficient for each type of protection was as follows:

$$P=\frac{1}{N}\sum\left(\frac{H\times T}{100\,A}\right)=\frac{1}{100\,N}\sum\left(\frac{H\times T}{A}\right) \qquad (1)$$

where
- P=the protection coefficient for a type of protection,
- N=the number of crossings in a type group,
- H=the highway traffic at each crossing,
- T=train traffic at each crossing, and
- A=number of accidents.

Using the above formula the following preliminary protection coefficients were determined:

Type of protection:	*Preliminary protection coefficient*
Signs	19
Bells	29
Wigwag	56
Wigwag and bells	63
Flashing lights	96
Flashing lights and bells	114
Wigwag and flashing lights	121
Wigwag, flashing lights, and bells	147
Watchman, 8 hours	119
Watchman, 16 hours	180
Watchman, 24 hours	228
Gates, 24 hours	241
Gates, automatic	333

Study of the coefficients listed above reveals several interesting comparisons. It will be noted that bells were approximately one and one-half times as effective in preventing accidents as the signs alone. It is likewise shown that wigwags were more effective than bells, and flashing lights were more effective than wigwags. It is also interesting to note that a combination of any two of these types of protection was more effective than either type alone, although in all cases the index for the combination was less than the sum of the individual indices.

A sufficient sample was not available to permit the calculation of a coefficient for gates operated less than 24 hours. The signs included both plain painted signs and those equipped with reflector buttons. No attempt was made to determine the effectiveness of one wigwag compared with two wigwags at a crossing, or to measure the protection of these types with signs as compared with the mechanical equipment without signs. While all of the figures are approximate and might be different for another sample of crossings, it is believed that the sample used was entirely sufficient and that the relations expressed between the various types of protection are logical and sufficiently accurate for use in the study which was made.

These coefficients are of particular value when circumstances indicate that the maximum of hazard reduction will result from improvement of the protective devices at a large number of crossings rather than from the same expenditure for the elimination of a few crossings.

Using the highway traffic, the train traffic, and the protection coefficient as independent variables and the number of accidents as the dependent variable, a correlation was made of the data using the following equation:

$$I=C\frac{H^a\times T^b}{P^c}+K \qquad (2)$$

where
- I=probable number of accidents in a 5-year period (this figure to be used as the hazard rating),
- H=highway traffic—average daily number of vehicles,
- T=train traffic—trains per day,
- P=protection type coefficient,
- C=constant,
- K=additional parameter, and
- a, b, and c=fractional exponents.

PROBABLE NUMBER OF ACCIDENTS IN 5 YEARS USED AS INDEX OF HAZARD

The probable number of accidents which would occur at a crossing in a 5-year period was assumed to be a sufficient index of the hazard at a crossing. From the correlation that was made it was found that the index could be calculated from the following equation:

$$I=1.28\frac{H^{0.170}\times T^{0.151}}{P^{0.171}}+K \qquad (3)$$

As an aid in calculating the hazard rating, curves were plotted showing the relationships between the hazard and the highway traffic (fig. 1), the train traffic (fig. 2), and the type of protection (fig. 3). From these data the hazard values for each contributing item considered may be determined, that is H^a, T^b, and P^c, and these inserted in equation 2. When these factors are inserted, the formula may be reduced to the following:

$$I=I_u+K \qquad (4)$$

where
- I=probable number of accidents in a 5-year period (the hazard rating),
- I_u=an unbalanced rating, and
- K=an additional parameter.

The factor K can be obtained from figure 4 which gives the variation of this factor for values of the unbalanced rating I_u. The product of H^a, T^b, and C divided by P^c, plus K, gives the probable number of accidents which will occur in a period of 5 years and a figure which is used in this study as the hazard rating.

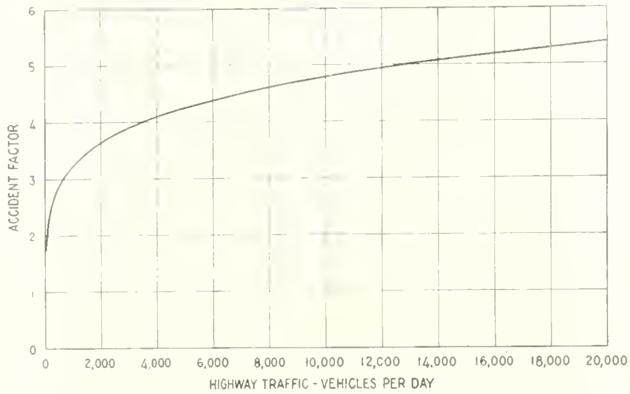

FIGURE 1.—RELATION BETWEEN HIGHWAY TRAFFIC AND ACCIDENTS, H^a.

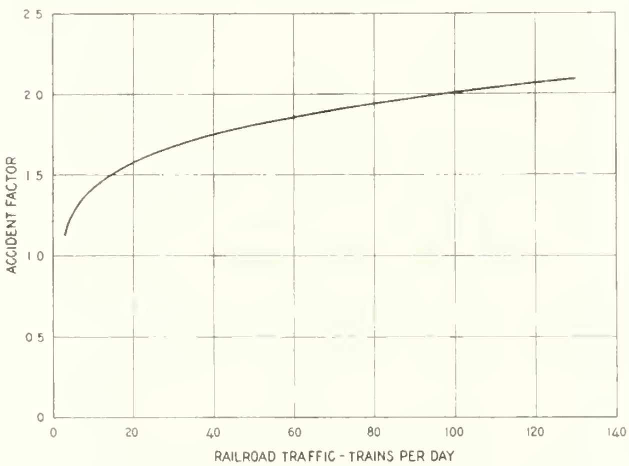

FIGURE 2.—RELATION BETWEEN RAILROAD TRAFFIC AND ACCIDENTS, T^b.

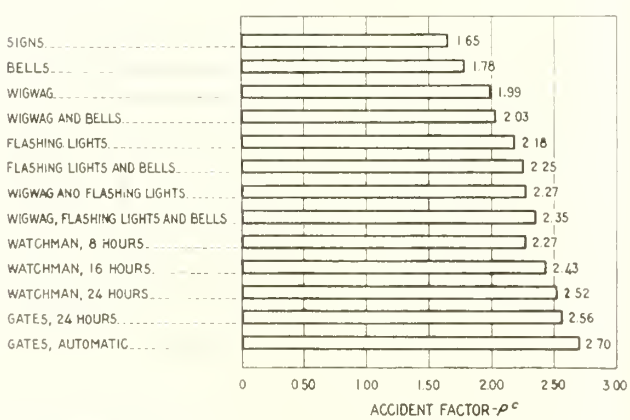

FIGURE 3.—ACCIDENT FACTORS, P^c, FOR VARIOUS TYPES OF PROTECTION.

Use of this formula is illustrated using data for two rural crossings in Oregon. The first crossing is in Clackamas County at milepost 13.27 on road 160. The average daily highway traffic is 3,442 vehicles; the average train traffic is 22 trains each day. The crossing is protected by wigwags. From figure 1, the hazard factor due to highway traffic of 3,442 vehicles per day is found to be 3.99. From figure 2 the factor due to train traffic of 22 trains per day is found to be 1.59; and from figure 3 the factor for a wigwag type of protection is found to be 1.99. Substituting these figures in equation 2, it is found that the hazard index

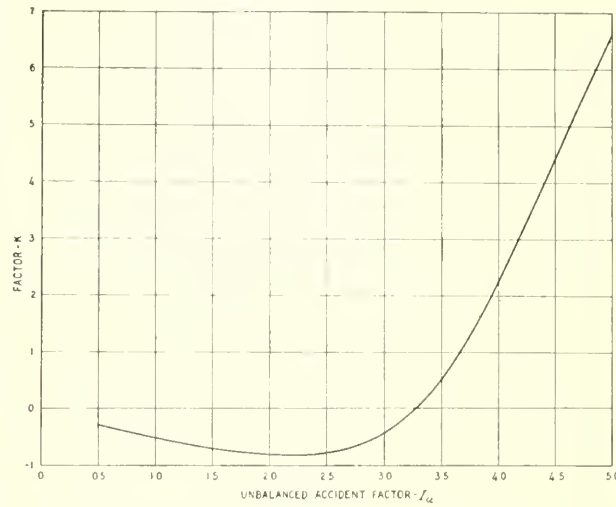

FIGURE 4.—RELATION BETWEEN UNBALANCED ACCIDENT FACTOR, COMPUTED FROM FORMULA $I_u=C\frac{H^a \times T^b}{P^c}$, AS COMPARED TO SMOOTHING FACTOR.

is equal to $1.28\frac{3.99\times 1.59}{1.99}+K$ or equal to $4.08+K$. From figure 4, K is determined to be +2.58 for a value of I_u of 4.08 and, with this figure for the parameter, the hazard index is 6.66.

The second crossing for which an index is calculated is in Yamhill County on route 32 at milepost 35.75. The average daily highway traffic at this crossing is 1,848 vehicles in a 24-hour day; the average train traffic is 4 trains each day. The protection consists of signs (approach signs and cross-bucks). Referring to figures 1, 2, and 3, the hazard factors due to highway traffic, train traffic, and to the signs as a type of protection are found to be 3.59, 1.20, and 1.65, respectively. When these figures are inserted in equation 2 it is found that I_u is 3.34 and, with this figure, K is determined to be +0.06 and the hazard index is 3.40.

To test the reliability of the formula, 123 crossings, the data concerning which were not used in the derivation of the formula, were rated by means of the formula. A large majority of these crossings were relatively safe, having had no more than three accidents recorded in the 5 years during which the accidents were reported. Some of them were at locations at which from six to eight accidents had occurred. The estimated number of accidents is compared with the actual number of accidents recorded at these 123 locations in table 1. The ranges of these figures are illustrated in figure 5.

TABLE 1.—*Average computed number of accidents using formula at 123 crossings in 10 States* [1] *compared to actual number of accidents recorded at those crossings*

Number of crossings	Actual number of accidents	Average computed accidents
15	1	1.21
47	2	1.84
39	3	3.05
11	4	3.69
3	5	5.20
5	6	6.18
1	7	7.36
2	8	8.37

[1] States included are as follows: Indiana, Iowa, Kentucky, Nevada, New Hampshire, Montana, Rhode Island, Utah, Wisconsin, and Wyoming.

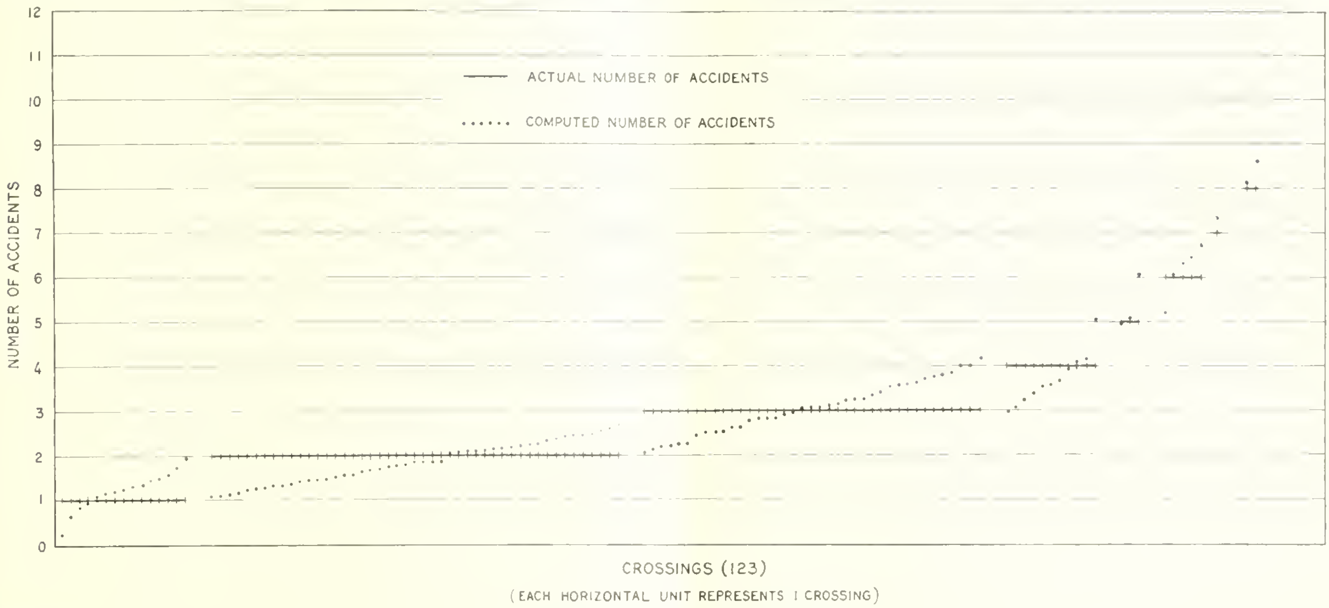

FIGURE 5.—COMPUTED NUMBER OF ACCIDENTS COMPARED TO ACTUAL NUMBER OF ACCIDENTS AT 123 CROSSINGS IN INDIANA, IOWA, KENTUCKY, NEVADA, NEW HAMPSHIRE, MONTANA, RHODE ISLAND, UTAH, WISCONSIN, AND WYOMING.

These data indicate that the computed number of accidents is generally in excess of the actual number of accidents at the low-accident crossings. These differences are not of great importance because priority information will ordinarily be of most value at a few of the most dangerous crossings. For instance, it is of little importance if a crossing which has had 1 accident is rated at 1.25, while one that has had 2 accidents is rated 2.19. In this case the latter is clearly more dangerous from a hazard standpoint. Neither is as dangerous as one rated 6.50. Although the sample of the high-accident crossings is small, a fairly consistent trend is noticeable.

The study of the various factors which might affect the hazard at a crossing indicated that several of these items exerted little influence on the calculation of the number of accidents at the locations and, therefore, were of little value in measuring the hazard. Although the effect of the physical factors was not sufficient to merit their inclusion in the hazard rating formula, these data should be considered in the assignment of priorities within groups of crossings of the same rating. The formula may be used to calculate the hazard rating of all the crossings, and then crossings with approximately the same hazard rating may be grouped and tabulated together with the physical factors (grade of approaches, angle of intersection, sight distance, etc.). Priorities within these groups may then be established on the basis of the relative hazard of physical factors. The relative importance of each physical factor, or combinations of these factors, must be determined.

ACCIDENT PROBABILITY AFFECTED BY OTHER FACTORS NOT CONSIDERED IN FORMULA

The probable number of accidents which will occur at any crossing cannot be obtained by means of this formula with a high degree of accuracy. While the factors used account for a large part of the variation in the accident probability, there are other variables that were not reported but probably have a definite influence. Probably there are also psychological factors that in many cases greatly affect the safety or danger of crossings but which cannot be measured numerically. The index rating, therefore, is no more than an indication of the variation of the number of accidents in conjunction with the variation of the factors considered and other items must be weighed before any set of crossings can be assigned rating numbers.

A portion of the probable error in the calculated accident record, or hazard index, may be due to the use of average daily figures for traffic. Inasmuch as large variations in these figures are apt to occur, it is probable that few of the accidents occurred at times when any of the conditions were as assumed by the measuring data. The peak highway traffic is generally found in the months of July and August, but the largest portion of the accidents occurs in November and December.

This variation between average daily traffic and the frequency of crossing accidents is illustrated in figure 6. From the two curves plotted on this figure it will be noted that the high points of traffic on the average section of highway are in July and August. The accident curve, however, indicates that in July and August the frequency of accidents is at a low point for the year and the high point is found to occur in November and December. Almost as many accidents occur in the night hours as during the day hours although the hourly traffic is less at night than during the day. The greatest frequency of accidents is usually found between 11 p. m. and midnight, when traffic is comparatively light. Likewise, train traffic may vary considerably from year to year, and train speed will vary from the average figures reported. Cases where the protection was changed during the 5-year period were omitted from consideration. It is believed that the protection coefficients are relatively constant for each type of protection listed. It is probable, however, that accident factors for highway traffic and train traffic would be changed somewhat if true values at the time of the accident could be obtained.

It is possible that traffic laws in the various States have some effect on the number of accidents which oc-

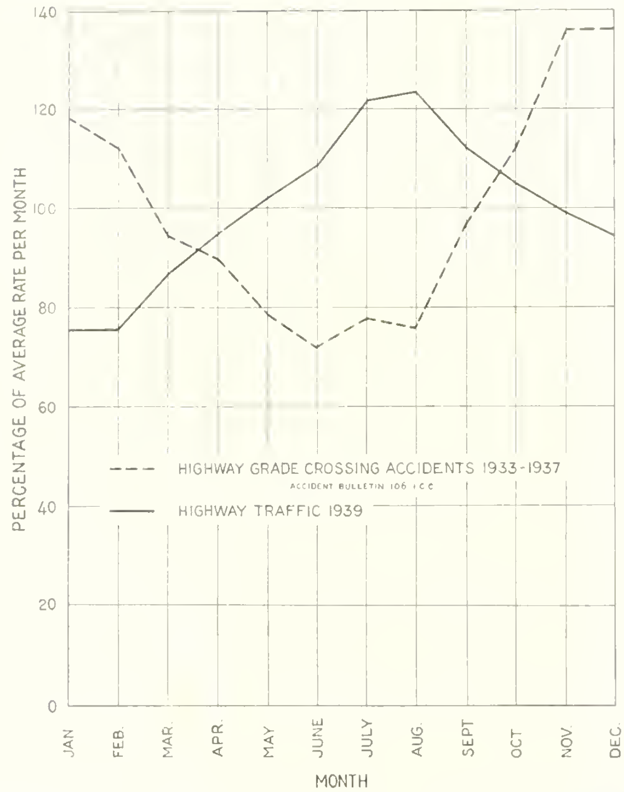

Figure 6.—Variation of Highway Traffic by Months in 1939 and Variation of Grade Crossing Accidents by Months from 1933 to 1937, Inclusive.

cur at crossings on the highways of those States. The large variation in the grade-crossing accident record of the States must be due to causes other than chance; and, since States with high or low traffic volumes are found to have good and bad accident records indiscriminately, it appears that the traffic regulation may have some bearing on the variation in these figures. Data collected by the Interstate Commerce Commission for 1937 illustrate this. In their accident bulletin No. 106 it is shown that during 1937 the States of Rhode Island, Wyoming, Connecticut, Massachusetts, Maine, Nevada, New Jersey, New York, and New Hampshire had the best records while the States of Alabama, Illinois, Louisiana, Georgia, South Carolina, Mississippi, Kansas, Arkansas, and Indiana had the poorest records. The States having the poorer records had approximately 10 times the number of casualties per 10,000 vehicles registered as those more fortunate States whose accident records were better.

Another important fact to be considered is that the number of accidents that occur at any crossing in a 5-year period is comparatively small. Public opinion has forced most of the States to eliminate those crossings that were obviously the most undesirable or at which an excessive number of accidents occurred. Only one accident had occurred at most of the crossings for which the data were submitted, and for only a few of the crossings were five or more accidents reported.

Information could be gathered for a longer period of time and thus a greater number of accidents recorded but, if this were done, it is probable that traffic volumes and physical features at the crossing would have changed to such a degree that the data for the longer period would be little better from a statistical point of view.

MARYLAND CROSSINGS RATED ACCORDING TO RELATIVE HAZARD

Many of the highway planning survey organizations and others interested in this phase of highway planning have developed formulas for rating all grade crossings in which the coefficients are based on judgment. These formulas are approximate and probably do not give a complete and unbiased evaluation of the hazard. It is obviously impossible to assign numerical values to all situations and combinations of conditions with the assurance that these values are even approximately correct. However, when data are uniformly applied through one of these formulas, valuable relative information can be obtained. Several of the planning surveys have been able to collect more detailed information than was generally collected and have utilized this detailed knowledge in their evaluation formulas. The inclusion of the additional information has greatly aided in development of priority lists that coincided with the best public and engineering opinion.

Grade crossings in Maryland were independently rated by a committee of several individuals well acquainted with conditions throughout the State and competent to judge the relative hazards. These men were furnished with complete information with respect to all crossings in the State, this information consisting of tabulated data concerning the average daily highway traffic, the average daily railroad traffic, the physical characteristics of the crossing, and other pertinent information. The most dangerous crossings were put into five priority groups by State engineers, Federal engineers, and engineers of the railroads operating within the State. The ratings of crossings listed in table 2 represent the consensus of these men as to the relative hazard by groups. No attempt was made to arrange the crossings within any one priority group in order of their hazard.

The hazard formula has been applied to these 25 crossings and the results are also tabulated in table 2. From this table it will be noted that the sum of the hazard ratings calculated for the five crossings that were assigned first priority is greater than the total of the hazard ratings for any other group. Likewise, the sum of the hazard indices of the crossings in the second priority group is greater than the total hazard in those following this group. These totals decrease in a fairly uniform manner as follows:

Priority group:	*Total calculated hazard*
1	20. 54
2	17. 03
3	15. 13
4	13. 80
5	11. 42

This indicates that the committee made a very good distribution of the crossings into the priority groups when judged by equation 4. While a rating on a hazard basis would change the priority rating of several crossings in the list, a study of the physical characteristics and local conditions, in combination with the hazard rating, might easily justify the priority groupings of these crossings.

A study of the priority ratings assigned by the committee of engineers, and the hazard ratings calculated by the formula, with respect to the individual crossings, indicated that insufficient credit was given by the committee to the effectiveness of gates and

(Continued on p. 142)

A STUDY OF BITUMINOUS CONCRETE PAVEMENTS IN OHIO

BY THE BUREAU OF TESTS OF THE OHIO DEPARTMENT OF HIGHWAYS, AND THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION [1]

During the 6 years prior to 1935, the Ohio Department of Highways carried on an extensive resurfacing program on the principal highways of the State using bituminous concrete over such old surfaces as portland cement concrete, brick, bituminous macadam, and surface-treated, water-bound macadam.

Evolving from a modified Topeka, containing mineral dust and requiring a seal coat, the resurfacing mixture used in most of the program was characterized by its small maximum size which facilitated laying and finishing with mechanical equipment and by the absence of any stone dust other than that naturally contained in the aggregates used. Seal coats were found to be unnecessary.

While these resurfacing mixtures proved to have excellent stability, good riding qualities, and generally good durability, they often developed considerable cracking. There were no definite failures but, in some cases, spalling occurred along the cracks and at the pavement edges and there were occasional instances of slight, though definite, surface raveling.

Following the construction season of 1936 and continuing through 1937, the Ohio Department of Highways and the Public Roads Administration collaborated in a program of sampling, testing, and study of selected areas representing all pavement conditions. Some modifications were made in the specifications and production methods for current work as the study progressed and these and further possible modifications are discussed.

The tests indicated that drastic changes in the asphalt, resulting from normal mixing operations, probably resulted in the loss of many months of satisfactory pavement service.

Alterations in the asphalt caused by mixing appeared to depend on the susceptibility of the asphalt to alteration and the conditions and time involved in the mixing operation.

The field is open for revisions in specifications to assure that the asphalt, as delivered, is resistant to alteration and that it is not unduly altered during mixing and placing.

THE Ohio Department of Highways began the development of its present specifications for hot-mixed, hot-laid asphaltic concrete surfacing in 1929. Starting with a modified Topeka mix employing lake sand and mineral filler and requiring a seal coat, the present specification, known as item T–50, hot-mixed, hot-laid asphaltic concrete, was developed permitting the use of local sand without the addition of mineral filler and dispensing with the seal coat. The specification was designed to provide mixtures of high density through the special grading of the aggregate rather than by the use of dust so that, when properly placed in the pavement, they would not only be dense and well sealed against surface moisture, but would also retain a nonskid surface texture. During recent years several hundred miles of this type of pavement have been constructed throughout the State.

In 1935, under the direction of the Ohio State Highway Testing Laboratory, a study was instituted to determine the factors affecting the durability of this type of surfacing. During the winter of that year samples were cut from 16 pavements that had been in service up to 5 years. The samples were selected from pavements ranging in condition from excellent to very poor. These samples were examined for density, crushing of aggregate, and condition of the recovered asphalt. A number of samples were also taken of freshly prepared mixtures and of pavements that had just been completed. The results of the tests on the recovered asphalt from these samples, as reported by T. W. Brannan,[2] indicated the need for a more intensive study of the problem.

In October 1936 arrangements were made to conduct a more detailed and comprehensive study of hot-mixed, hot-laid, asphaltic concrete pavements throughout the State in cooperation with the Public Roads Administration. A carefully planned investigation was outlined, and the taking and testing of additional samples was started immediately.

FACTORS AFFECTING SERVICE RECORD AND CURRENT CONDITION INVESTIGATED

The purpose of the cooperative investigation was to ascertain whether the service record and current condition of these asphaltic concrete pavements, which had been in service, could be correlated with such factors as changes in the consistency of the bitumen, degree of heterogeneity of the bitumen, or other factors that might be susceptible to satisfactory analysis.

Obviously, a great number of possible factors influenced the behavior of the pavements. Asphaltic materials from numerous sources and prepared by several processes of manufacture had been used. Construction procedure, drainage conditions, type and condition of base structure, age, and probably other factors had their effect. Consequently, a rather broad plan of study was necessary in order to obtain sufficient data to isolate the effects of the major variables. The procedure decided upon consisted of:

1. A general survey of the bituminous pavements of the State and selection of sections to be sampled.
2. Inspection and photographic recording of the general condition of the pavement surface near each selected sample location.
3. The taking of a large sample of the pavement surface course at each selected location.
4. Inspection and photographic recording of the type and condition of the base structure after removal of the sample.
5. Careful inspection of samples in the laboratory to note any peculiar appearance or condition.
6. Laboratory tests to determine the pavement density, the amount of asphalt contained in the mixture, and the specific gravity, grading, and compactibility of the extracted aggregate.

[1] The following employees of the Ohio Department of Highways participated in planning and directing this investigation: R. R. Litehiser, Chief Engineer of Tests T. W. Brannan, previously Assistant Engineer; J. H. Goshorn, Assistant Engineer, and T. F. Spencer, previously Assistant Engineer.
[2] Civil Engineering, vol. 7, No. 4, April 1937, page 291.

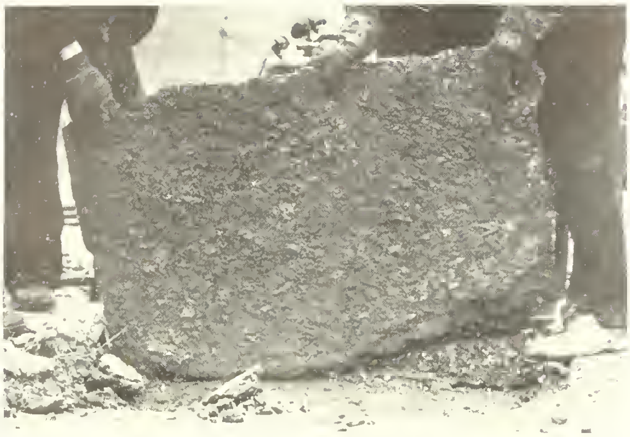

Figure 1.—A Typical Field Sample of Bituminous Concrete Surfacing.

7. Laboratory tests on the extracted asphalt recovered from solution by distillation.

In the tests made by the Public Roads laboratory, the asphalt was extracted by means of Rotarex extractors and, while in solution, was passed through a supercentrifuge to eliminate suspended dust. It was recovered from solution by Bussow's method as described in the Proceedings of the technical session of the Association of Asphalt Paving Technologists, January 23, 1936, page 160.

In the tests made by the State, the dust was removed by filtering through fuller's earth and the asphalt was then recovered by Abson's method as described in A. S. T. M. Proceedings, vol. 33, 1933, part II. Technical papers, page 704.

8. Comparison of the new test data with data obtained on the materials at the time of construction.

9. Roller stability tests on sawed specimens from a limited number of the samples.[3] These tests were made by the Public Roads laboratory only.

10. Analysis of the test data to evaluate the relative effect of various factors on the asphalt and on the behavior of the pavement. The data from the preliminary survey of 1935 were included in this analysis.

TESTS SHOW NEED FOR SOFTER ASPHALTS IN SURFACE COURSES

This report deals with test results on about 80 samples of Ohio T–50 asphaltic concrete containing 50–60 penetration petroleum asphalt. Forty-seven pavement sections are represented by these samples. About half of them were taken and tested in the preliminary study of 1935 and the rest during 1936 and 1937. All samples were tested by the State laboratory and 22 of the 1936–37 samples were divided and also tested in the Public Roads laboratory. Large samples were taken in order to provide adequate material for all tests required and any check tests that might be desired. A typical field sample is shown in figure 1.

In general, the paving mixtures were composed of from 45 to 55 percent of coarse aggregate, 30 to 48.5 percent of sand, and 6.5 to 10 percent of asphaltic cement. They were prepared at temperatures ranging between 275° and 375° F. The specifications for T–50 bituminous concrete surface-course mixtures, in effect at the time of this inspection and requiring the use of 50–60 penetration asphalt, are given in table 1 and the specified mixing and laying temperatures are shown in table 2. As a result of the information obtained through this investigation, softer asphalts (60–70, 70–80, and 85–100 penetration) are now being specified for asphaltic concrete surface courses.

[3] The test specimens were 4 inches wide, 8 inches long, and 2¼ inches deep. The procedure for making the roller stability tests is given in PUBLIC ROADS, vol. 16, No. 7, September 1935.

Table 1.—*Composition of T–50 wearing courses, types B and C, as required in present Ohio specifications*

Sieve sizes		T–50, Type B		T–50, Type C	
Passing sieve—	Retained on sieve—	Minimum	Maximum	Minimum	Maximum
		Percent	*Percent*	*Percent*	*Percent*
1½-inch	3/8-inch	0	15	--	--
3/8-inch	1/4-inch	30	45	0	5
1/4-inch	No. 4			20	40
No. 4	No. 6	0	8	0	30
No. 6	No. 8	0	10	0	10
No. 8	No. 16	5	20	5	20
No. 16	No. 50	10	30	8	30
No. 50	No. 100	1	18	1	15
No. 100	No. 200	1	5	1	5
No. 200		0	3	0	3
Bitumen [1]		6.5	8.5	7	10
Total retained on No. 6 sieve		45	55	45	55

[1] Asphalt of 50–60 penetration was specified until Mar. 1, 1939, when the requirement was changed to 50–70 penetration with the provision that the laboratory shall designate the grade (50–60 or 60–70) to be used on each project.

Table 2.—*Mixing and laying temperatures required in present Ohio specifications for T–50 surfacing*

Plant temperatures						Road or street temperatures		
Aggregate		Asphalt		Mixture		Minimum	Ideal	Maximum
Min.	Max.	Min.	Max.	Min.	Max.			
°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
300	375	250	350	275	375	275	310–325	375

The data resulting from tests on the materials used in the pavements, the field inspection, and tests on the plant and pavement samples are given in tables 3 to 9 inclusive. The test data in tables 3, 4, 5, and 6 were obtained in the Ohio laboratory and those in tables 7, 8, and 9 in the Public Roads laboratory. In most cases, the test results on original asphalts reported by Ohio represent the individual cars of material that were used. When it was not possible to determine where particular cars of material had been used on the job, the average test values for the entire project are presented. Test results on recovered asphalts reported by Ohio are generally averages obtained by recovering and testing three separate samples of asphalt from each pavement sample. The test results reported by the Public Roads laboratory are not averages but represent individual tests.

In general, the results of the tests made on portions of individual pavement samples by the two laboratories were in good agreement. As was to be expected, there were a few instances of nonagreement because of nonuniformity of the samples or because of differences in the method of recovering the asphalt. These differences, however, caused no material disagreement in the conclusions reached by the two agencies. The conclusions in this report are therefore based on the work of both laboratories.

TABLE 3.—*Results of condition survey and data available at time of survey*

Sample No.	Project designation	County	Type of surfacing	Asphalt (tests made at time of construction)			Age of surfacing when sampled	Condition at time of sampling		
				Specific gravity	Penetration at 77° F.	Ductility at 77° F.		Base	Surface	Surface cracked more than base
						Cm.	*Months*			
1-A	2	Licking	T-50-A	1.015	52.9	97	67	Good	Very poor	Yes.
1-B	3	Ashtabula	T-50-B	1.018	53.0	100+	37			
1-B-1	3	do	T-50-B	1.018	53.0	100+	52	Good	Fair	Yes.
2-B	4	do	T-50-B	1.054	49.2	93	52			
2-B-1	4	do	T-50-B	1.054	49.2	93	66	Good	Very poor	Yes.
3-B	5	Greene	T-50-B	1.019	49.8	100+	62	Excellent	Good	No.
4-B	6	do	T-50-B	1.023	51.7	100+	61	do	do	No.
5-B	7	Clinton	T-50-B	1.005	54.0	100+	42	do	do	No.
6-B	8	do	T-50-B	1.016	53.0	100+	35	do	do	No.
8-B	9	Portage	T-50-B	1.043	55.8	100+	52	Very poor	Very poor	Yes.
9-B	10	Mahoning	T-50-B	1.019	52.4	100+	51	Fair	Poor	No.
10-B	11	Lake	T-50-B	1.022	54.2	100+	54	Good	Very poor	No.
11-B	12	Allen	T-50-B	1.034	54.1	100+	18	Excellent	Excellent	No
12-B	13	Allen and Hardin	T-50-B	1.017	52.8	100+	53	Good	Poor	Yes.
12-B-1	13	do	T-50-B	1.017	52.8	100+	50	do	do	Yes.
13-B	14	Marion	T-50-B	1.005	53.8	100+	49	Excellent	Good	No.
14-B	15	Ashtabula	T-50-B	1.001	55.0	100+	8	do	Excellent	No.
15-B	16	do	T-50-B	1.004	52.5	100+	39	Good	Good	No.
16-B	17	do	T-50-B	1.000	56.8	100+	19	do	do	No.
17-B	18	do	T-50-B	1.013	53.0	100+	51	Very poor	Poor	Yes.
18-B	19	Clermont	T-50-B	1.004	53.2	100+	41	Good	Very poor	Yes.
19-B	20	Brown	T-50-B	1.002	53.4	100+	28	do	Good	No.
1-C	21	Harrison	T-50-C	.999	55.7	100+	0			
1-C-1	21	do	T-50-C	.999	55.7	100+	16	Good	Excellent	No.
2-C	22	Delaware	T-50-C	.997	54.4	100+	6			
2-C-1	22	do	T-50-C	.997	54.4	100+	20	Fair	Excellent	No.
3-C	23	Lucas	T-50-C	1.019	56.7	100+	18			
3-C-1	23	do	T-50-C	1.019	56.7	100+	32	Good	Good	No.
4-C	24	Harrison	T-50-C	1.015	55.8	100+	28			
4-C-1	24	do	T-50-C	1.015	55.8	100+	43	Very poor	Very poor	Yes.
5-C	25	Jefferson	T-50-C	1.016	54.0	100+	30			
5-C-1	25	do	T-50-C	1.016	54.0	100+	45	Good	Fair	No.
6-C	26	Tuscarawas	T-50-C	1.014	52.0	100+	30			
6-C-1	26	do	T-50-C	1.014	52.0	100+	46	Poor	Very poor	Yes.
7-C	27	Lake	T-50-C	1.015	54.3	100+	17			
7-C-1	27	do	T-50-C	1.015	54.3	100+	31	Good	Good	No.
8-C	28	Lorain	T-50-C	1.015	52.7	100+	26			
8-C-1[1]	28	do	T-50-C	1.015	52.7	100+	40	Fair	Poor	No.
9-C	29	Richland	T-50-C	1.011	54.8	100+	29			
9-C-1	29	do	T-50-C	1.011	54.8	100+	42	Good	Good	No.
10-C	30	Ashtabula	T-50-C	1.019	55.7	100+	28			
10-C-1	30	do	T-50-C	1.019	55.7	100+	42	Poor	Poor	No.
11-C	31	Clinton	T-50-C	.998	56.0	100+	4			
11-C-1	31	do	T-50-C	.998	56.0	100+	18	Good	Excellent	No.
12-C	32	Morgan	T-50-C	.998	56.0	100+	5			
12-C-1	32	do	T-50-C	.998	56.0	100+	20	Fair	Excellent	No.
13-C	33	Muskingum	T-50-C	1.007	53.0	100+	18			
13-C-1	33	do	T-50-C	1.007	53.0	100+	32	Excellent	Excellent	No.
14-C	34	Franklin	T-50-C	1.009	56.0	100+	17			
14-C-1	34	do	T-50-C	1.009	56.0	100+	30	Good	Good	No.
15-C	35	Cuyahoga	T-50-C	1.017	54.2	100+	55	do	do	No.
16-C	36	Clermont	T-50-C	1.001	55.2	100+	15	Excellent	do	No.

[1] Data on this sample not included in table 5 and following analyses because results of individual tests by Ohio showed excessive variation.

The data resulting from the condition survey, together with such laboratory data on the materials used in the construction as were available before the survey was started, are presented in table 3. With one exception, all these samples, representing 35 paving projects, were taken from pavements that had been subjected to service.

The results of the condition survey, as given descriptively in the last three columns of table 3, represent the personal opinions of the observers as to the comparative condition of the surface and base on each section at the time of sampling and in the immediate vicinity of the area sampled. In selecting sections to be sampled an effort was made to find, wherever possible, areas in which damage to the surfacing could not be attributed in major part to failure of the base or subgrade; but in several cases it was found, when the base was uncovered by removal of the sample, that poor base conditions had contributed largely to damage sustained by the surface.

Pavements that are described as "very poor" were cracked extensively and the surfacing mixture showed spalling and raveling along the cracks and pavement edges, although none of the pavements showed complete failure. In some cases the surface was pot-holed to some extent but generally the riding quality was not seriously impaired. Straight longitudinal or transverse cracks that were obviously caused by joints in the base were not considered evidence of weakness in either the surface or the base. A general view of a pavement section typical of those classified as very poor is shown in figure 2 A. Figure 2 B is a close-up view of the same surface and shows in more detail the extensive irregular cracking and also the spalling and raveling.

Pavements that are described as "excellent" were, so far as could be detected by examination, in perfect condition. They showed no irregular cracking even on very close examination, and no raveling or edge spalling. Figure 3 A shows a general view of an excellent pavement with the patch replacing sample 11-C-1 in the right foreground. Figure 3 B is a detail view of the good water-bound macadam base on which the surface was constructed.

Ranging upward from very poor to excellent were the other three classifications—"poor," "fair" (or average), and "good." Naturally, these various intermedi-

TABLE 4.—*Results of Ohio laboratory tests on samples of freshly prepared mixtures and newly constructed surfacing containing negative-spot asphalt*

Field identification	Project No.	Source of sample[1]	Mixing temperature	Mixing time	Penetration of asphalt			Asphalt producer No.	Mixing plant No.
					Original	Recovered[2]	Portion retained		
			° F.	Minutes			Percent		
B-1	38	Truck	375	1	60	49	82	4	9
B-2	38	do	275	1	60	49	82	4	9
B-3	39	do	375	1	51	41	80	4	12
B-4	39	do	280	1	51	44	86	4	12
B-5	40	do	375	1	59	40	68	4	17
B-6	40	do	275	1	59	44	75	4	17
C-1	41	do	250	1	48	40	83	2	2
C-2	41	do	250	1	48	41	85	2	2
C-3	42	do	375	1	54	39	72	2	1
C-4	42	do	360	5	54	35	65	2	1
C-5	42	do	275	1	54	42	78	2	1
C-6	43	do	355	1	58	39	67	6	20
C-7	43	do	340	5	58	39	67	6	20
C-8	43	do	275	1	58	43	74	6	20
Average of truck samples							76		
1-X	44	Pavement		1	55	50	91	5	11
2-X	44	do		1	55	42	76	5	11
3-X	44	do		1	55	39	71	5	11
4-X	36	do		1	55	44	80	5	7
5-X	36	do		1	55	44	80	5	7
6-X	45	do		1	57	46	81	4	15
7-X	45	do		1	57	41	72	4	15
8-X	46	do		1	57	45	79	2	14
9-X	47	do		1	53	41	77	4	5
10-X	48	do		1	52	41	79	4	4
11-X	21	do		1	56	43	77	2-4	20
12-X	21	do		1	56	43	77	2-4	20
13-X	21	do		1	56	40	71	2-4	20
14-X	49	do		1	57	41	72	2	17
15-X	49	do		1	57	40	70	2	17
16-X	49	do		1	57	40	70	2	17
1 C	21	do		1	56	41	73	2-4	20
Average of pavement samples							76		

[1] All truck samples taken at the plant immediately after mixing.
[2] Asphalt recovered by Abson's method.

TABLE 5.—*Results of laboratory tests on field samples and correlation with field survey data*

Sample No.	Thickness surface and binder	Surface condition	Base condition	Voids data[1]			Penetration of the asphalt 77° F. 100 g., 5 sec.			Ductility of asphalt 77° F., 5 cm., per min.		Age of surface course	Oliensis spot test on recovered asphalt
				Voids in aggregate	Voids in pavement	Aggregate voids filled	Original (before mixing)	Recovered by Abson's method	Portion retained	Original (before mixing)	Recovered by Abson's method		
	Inches			Percent	Percent	Percent			Percent	Cm.	Cm.	Months	
1-A	2.5	Very poor	Good	15.7	3.5	78	52.9	22.3	42	97	5.7	67	Negative.
1-B							53.0	32.5	61	100+		37	Do.
1-B-1	1.7	Fair	Good	14.5	.8	94	53.0	30.0	57	100+	9.6	52	Do.
2-B							49.2	10.0	20	93		52	Positive.
2-B-1	2.4	Very poor	Good	16.9	6.7	60	49.2	11.5	23	93	4.2	66	Do.
3-B	4.4	Good	Excellent	25.0	9.7	61	49.8	17.0	34	100+	4.0	62	Negative.
4-B	2.5	do	do	21.3	2.5	88	51.7	23.5	45	100+	11.5	61	Do.
5-B	2.0	do	do	18.9	2.4	87	54.0	28.0	52	100+	14.0	42	Do.
6-B	1.8	do	do	20.9	3.5	83	53.0	23.5	44	100+	5.3	35	Positive.
8-B	1.0	Very poor	Very poor	20.8	6.4	69	55.8	17.5	31	100+	4.3	52	Do.
9-B	2.8	Poor	Fair	16.3	1.7	90	52.4	28.7	55	100+	10.3	51	Negative.
10-B	2.8	Very poor	Good	18.1	4.5	75	54.2	23.0	42	100+	5.9	54	Do.
11-B	2.0	Excellent	Excellent	16.1	1.1	93	54.1	34.0	63	100+	34.0	18	Positive.
12-B	2.4	Poor	Good	17.1	1.7	90	52.8	22.5	43	100+	6.2	[2] 53	Do.
12-B-1	2.5	do	do	18.7	1.5	92	52.8	29.0	55	100+	13.0	[2] 50	Do.
13-B	2.0	Good	Excellent	17.5	1.5	91	53.8	31.5	59	100+	13.8	49	Negative.
14-B	2.6	Excellent	do	16.8	1.9	89	55.0	50.0	91	100+	100+	8	Do.
15-B	2.5	Good	Good	15.6	1.8	88	52.5	47.0	90	100+	100+	39	Do.
16-B	2.0	do	do	15.0	.4	97	56.8	52.0	92	100+	100+	19	Do.
17-B	1.5	Poor	Very poor	16.7	2.1	87	53.0	36.5	69	100+	28.7	51	Do.
18-B	1.1	Very poor	Good	21.4	4.9	77	53.2	19.5	37	100+	4.9	41	Do.
19-B	2.3	Good	do	23.9	6.6	72	53.4	26.0	49	100+	21.4	28	Do.
1-C							55.7	41.0	74			0	Do.
1-C-1	1.1	Excellent	Good	23.3	5.6	76	55.7	32.0	57	100+	37.1	16	Do.
2-C							54.4	48.0	88			6	Do.
2-C-1	2.2	Excellent	Fair	16.6	0	100	54.4	54.0	99	100+	100+	20	Do.
3-C							56.7	27.0	48			18	Positive.
3-C-1	3.3	Good	Good	20.3	2.1	90	56.7	21.5	38	100+	6.0	32	Do.
4-C							55.8	19.0	34			28	Do.
4-C-1	1.7	Very poor	Very poor	21.0	5.9	72	55.8	22.0	39	100+	4.8	43	Do.
5-C							54.0	30.0	56			30	Do.
5-C-1	3.0	Fair	Good	19.8	6.7	66	54.0	23.0	43	100+	6.5	45	Do.
6-C							52.0	24.0	46			30	Do.
6-C-1	2.2	Very poor	Poor	18.0	2.5	86	52.0	21.5	41	100+	6.0	46	Do.
7-C							54.3	29.0	53			17	Do.
7-C-1	2.0	Good	Good	15.5	.8	95	54.3	32.0	59	100+	7.9	31	Slightly positive.
8-C							52.7	39.5	75			26	Positive.
9-C							54.8	29.5	54			29	Negative.
9-C-1	1.4	Good	Good	18.8	2.7	86	54.8	21.5	39	100+	5.6	42	Slightly positive.
10-C							55.7	29.0	52			28	Positive.

[1] The voids were computed from densities determined by immersion in water. The densities were determined on the combined top and binder courses.
[2] Difference in age accounted for by time interval between laying first and last parts of section.

TABLE 5.—*Results of laboratory tests on field samples and correlation with field survey data*—Continued

Sample No.	Thickness surface and binder	Surface condition	Base condition	Voids data [1]			Penetration of the asphalt 77° F. 100 g., 5 sec.			Ductility of asphalt 77° F., 5 cm., per min.		Age of surface course	Oliensis spot test on recovered asphalt
				Voids in aggregate	Voids in pavement	Aggregate voids filled	Original (before mixing)	Recovered by Abson's method	Portion retained	Original (before mixing)	Recovered by Abson's method		
	Inches			*Percent*	*Percent*	*Percent*			*Percent*	*Cm.*	*Cm.*	*Months*	
10-C-1	2.2	Poor	Poor	16.7	1.3	92	55.7	32.0	57	100+	11.1	42	Negative.
11-C							56.0	38.0	68			4	Do.
11-C-1	3.0	Excellent	Good	19.9	5.9	70	56.0	35.0	63	100+	36.0	18	Do.
12-C							56.0	48.5	87			5	Do.
12-C-1	2.8	Excellent	Fair	15.0	1.2	92	56.0	43.0	77	100+	58.0	20	Do.
13-C							53.0	42.0	79			18	Do.
13-C-1	2.4	Excellent	Excellent	15.8	.5	97	53.0	45.0	85	100+	100+	32	Do.
14-C							56.0	43.0	77			17	Do.
14-C-1	1.6	Good	Good	17.6	0	100	56.0	41.0	73	100+	23.0	30	Do.
15-C	1.6	do	do	16.9	3.4	80	54.2	20.5	38	100+	4.9	55	Positive.
16-C	2.7	do	Excellent	21.3	5.4	75	55.2	31.0	56	100+	62.0	15	Negative.

TABLE 6.—*Summary of data on condition of pavement as reloted to hardening of the asphalt* [1]

Condition of surface	Number of samples	Penetration of asphalt recovered by Abson's method			Portion of original penetration retained		
		Minimum	Maximum	Average	Minimum	Maximum	Average
NEGATIVE-SPOT ASPHALTS							
					Percent	*Percent*	*Percent*
Very poor	3	19.5	23.0	21.6	37	42	40
Poor	1	28.7	28.7	28.7	55	55	55
Fair	1	30.0	30.0	30.0	57	57	57
Good	9	17.0	52.0	33.0	34	92	61
Excellent	6	32.0	54.0	43.2	57	99	79
POSITIVE-SPOT ASPHALTS							
Very poor	1	11.5	11.5	11.5	23	23	23
Poor	2	22.5	29.0	25.8	43	55	49
Fair	1	23.0	23.0	23.0	43	43	43
Good	5	20.5	32.0	23.8	38	59	44
Excellent	1	34.0	34.0	34.0	63	63	63
ALL ASPHALTS							
Very poor	4	11.5	23.0	19.1	23	42	36
Poor	3	22.5	29.0	26.7	43	55	51
Fair	2	23.0	30.0	26.5	43	57	50
Good	14	17.0	52.0	29.7	34	92	55
Excellent	7	32.0	54.0	42.0	57	99	76

[1] No test results included for samples taken where the base was in poor or very poor condition.

ate classifications could not be made with mathematical precision, but in most cases the classification used represented the judgment of at least two observers. None of the pavements examined showed any evidence of lack of stability of the surfacing mixture such as would have been indicated by shoving, corrugations, or rutting.

MIXING OPERATIONS CAUSED DETRIMENTAL CHANGES IN ASPHALT

Classification of the bases was made by observing the amount of cracking and vertical misalinement revealed by removal of the surfacing sample and the soil and drainage conditions as evidenced by the presence or absence of excessive moisture or mud in the base. The slope and character of the land along the right-of-way and the presence or absence of adequate surface drainage features were also taken into account. The appearance of some typical bases exposed by removal of the surfacing samples is shown in figure 4.

FIGURE 2.—A, GENERAL VIEW, AND B, SURFACE DETAIL OF A PAVEMENT THAT WAS RATED VERY POOR. NOTE THE SPALLING ALONG THE CRACKS AND THE RAVELED CONDITION OVER A LARGE PORTION OF THE PAVEMENT. SAMPLE 8-B WAS TAKEN AT THIS LOCATION. THE PATCHED SAMPLE HOLE CAN BE SEEN IN THE RIGHT CENTER OF THE UPPER PICTURE.

No record was made of the condition of the pavements represented by the samples taken during the preliminary study in 1935 by the State alone. These are the samples numbered 1-B and 2-B and 1-C to 14-C, inclusive. However, when these sections of pavement were again sampled in 1936 as a part of the enlarged study program, their condition was noted. These later samples are numbered 1-B-1, 1-C-1, etc., the notation (-1) being added to distinguish them from the earlier ones. They were not necessarily taken in the same areas of the various projects as those of the first series, and for this reason direct comparisons be-

TABLE 7.—*Correlation of pavement performance with the results of tests on surfacing samples by the Public Roads Administration laboratory*

SATISFACTORY PAVEMENTS

Sample No.	Age of surface	Condition of base	Characteristics associated with satisfactory performance: Roller stability less than 100	Asphalt recovered by Bussow's method: Penetration retained more than 55 percent	Asphalt recovered by Bussow's method: Ductility retained more than 10	Asphalt recovered by Bussow's method: Spot test negative	Characteristics associated with unsatisfactory performance: Roller stability more than 100	Asphalt recovered by Bussow's method: Penetration retained not more than 55 percent	Asphalt recovered by Bussow's method: Ductility retained less than 10	Asphalt recovered by Bussow's method: Spot test positive (xylene equivalent)	Condition of surface
	Months			*Percent*				*Percent*			
11-B	18	Excellent	47	57	32					24-28	Excellent.
11-C-1	18	Good		63	36	Yes					Do.
12-C-1	20	Fair	44	71	55	Yes					Do.
13-C-1	32	Excellent	16								Do.
3-B	62	do.				Yes		48	5		Good.
4-B	61	do.		56	13	Yes					Do.
5-B	42	do.		63	23	Yes					Do.
6-B	35	do.									Do.
13-B	49	do.	84	63	14	Yes					Do.
15-B	39	Good	44								Do.
19-B	28	do.	89	60	52	Yes					Do.
14-C-1	30	do.	12	79	21					4-8	Do.
15-C	55	do.	51					39	4	16-20	Do.

UNSATISFACTORY PAVEMENTS

Sample No.	Age of surface	Condition of base	Roller stability less than 100	Penetration retained more than 55 percent	Ductility retained more than 10	Spot test negative	Roller stability more than 100	Penetration retained not more than 55 percent	Ductility retained less than 10	Spot test positive (xylene equivalent)	Condition of surface
12-B	53	Good									Poor.
12-B-1	50	do.	4					45	6	24-28	Do.
8-C-1	40	Fair						55	8	20-24	Do.
1-A	67	Good					170				Very poor.
2-B-1	66	do.					478	28	4	12-16	Do.
8-B	52	Very poor					109	36	4	4-8	Do.
18-B	41	Good				Yes	290	47	6		Do.
4-C-1	43	Very poor						39	5	12-16	Do.
6-C-1	46	Poor					225	48	7	16-20	Do.

FIGURE 3. A, GENERAL VIEW OF AN EXCELLENT PAVEMENT, AND B, DETAIL OF THE GOOD WATER-BOUND MACADAM BASE EXPOSED BY REMOVAL OF THE SAMPLE. THE DARK SPOT IN THE RIGHT FOREGROUND IN A IS THE PATCH THAT WAS PLACED AFTER THE REMOVAL OF SAMPLE 11-C-1.

tween the earlier and later samples from individual projects were not particularly satisfactory.

The field and laboratory data pertaining to the 31 samples obtained either at the plant or from the freshly laid pavement on 14 projects during construction in 1935, are given in table 4 and the results of laboratory tests on the samples from the pavements in service (those of table 3) are shown in table 5.

As shown in table 4, the amount of hardening or loss of penetration caused by the mixing operation alone was generally quite extensive, averaging 24 percent and ranging from 14 to 35 percent for the 14 samples of freshly prepared surfacing mixture tested. The average penetration loss for the 17 samples of newly laid pavement was exactly the same as for the 14 samples of freshly prepared mixture, namely, 24 percent, while the minimum and maximum losses were 9 and 30 percent, respectively. While these data cannot be said to furnish conclusive proof that no hardening occurs during handling and laying operations because the mixtures sampled at the plant were not the same as those sampled from the newly laid pavement, these as well as data obtained in other investigations by the Public Roads Administration do indicate that such hardening is relatively unimportant as compared to that sustained during the mixing operation.

TABLE 8.—*Comparison of the characteristics of the extracted bitumens from top and binder courses* [1]

Sample No.	Hardening (loss of penetration): Original penetration of asphalt, top and binder	Penetration of recovered asphalt: Top	Penetration of recovered asphalt: Binder	Decrease in penetration [2]: Top	Decrease in penetration [2]: Binder	Decrease in ductility: Top	Decrease in ductility: Binder	Oliensis spot test on recovered asphalt, xylene equivalent: Top	Oliensis spot test: Binder
				Percent	*Percent*	*Percent*	*Percent*		
4-B	52	29	32	44	38	87+	80+	0	0
15-C	54	21	26	61	52	96+	94+	16-20	16-20
12-B-1	53	24	33	55	38	94+	91+	24-28	40-44
8-C-1	53	29	31	45	42	92+	92+	20-24	20-24

[1] Asphalt recovered by Bussow's method.
[2] 100 minus percentage of original penetration retained.

TABLE 9.—*Relation of pavement and aggregate density to grading of the aggregate*

Sample No.	Results of tests of surfacing samples		Compaction tests on extracted aggregate		Mechanical analysis of extracted aggregate (total aggregate passing)				
	Density (grams per cc.)	Computed aggregate density [1]	Aggregate density [2] (vibrated)	Aggregate voids overfilled [3]	3/4-inch sieve	3/8-inch sieve	No. 4 sieve	No. 8 sieve	No. 200 sieve
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1-A	2.361				100	84.7	60.6	45.1	3.0
2-B-1	2.237	81	88	0	95	85.0	48.9	35.9	3.6
3-B	2.256	77	83	.8	100	93.0	64.2	47.0	4.5
4-B	2.316	78	81	0	100	93.0	70.7	60.0	6.0
5-B	2.343	79	85	2.7	100	93.0	62.3	54.0	6.3
6-B	2.290	77	82	.7	100	93.0	65.6	55.0	6.6
8-B			89	3.0	100	90.6	48.4	38.2	4.7
11-B	2.375	82	89	2.8	100	84.1	49.2	40.5	4.2
12-B	2.356	81	86	2.2	100	96.3	60.0	50.4	3.4
12-B-1	2.360	80	90	4.5	100	95.6	61.0	45.8	4.8
13-B	2.340	81	88	2.9	100	96.1	64.5	53.1	6.7
15-B	2.385	84	88	2.3	100	97.3	60.7	42.0	3.2
18-B	2.103	77	82	0	100	86.9	63.6	51.9	3.8
19-B	2.051	74	86	3.0	100	77.3	52.2	43.8	4.1
4-C-1	2.175	77	87	2.6	100	97.7	69.4	44.8	4.7
6-C-1	2.247	79	87	2.5	100	93.4	78.2	45.6	3.0
8-C-1	2.229					100.0	65.1	42.2	2.5
11-C-1	2.115	76	81	[4] −1.2	100	82.2	57.0	46.8	4.1
12-C-1	2.359	82	86	1.3		100.0	84.0	50.1	4.7
13-C-1	2.278	81	87	2.7	100	97.0	70.2	44.5	3.8
14-C-1			90	4.6		100.0	74.0	40.0	7.2
15-C	2.282	81	87	1.2	100	97.6	60.2	37.9	3.3

[1] Percentage of aggregate volume per unit of total volume in the sample of field-compacted surfacing.
[2] Percentage of aggregate volume per unit of total volume in the sample of extracted aggregate compacted by vibration.
[3] Difference between actual asphalt content of the field sample and the asphalt capacity of the extracted aggregate compacted by vibration. (Percentages based on dry weight of aggregate.)
[4] As indicated by the minus sign, this mixture was underfilled.

The ductility of the asphalt before and after mixing was 100+ for all 14 of the freshly prepared surfacing mixtures. Initial ductilities for the asphalts contained in the 17 samples of newly laid pavement were also 100+ but the ductility test was made on the recovered asphalt for only 3 of the 17 samples. Two of these had a ductility of 100+ and the other, 90.

None of these data are included in table 4 because they fail to give a true picture of the effect of mixing on the ductility. Certainly, they cannot be considered to show that no change occurred in ductility because the machine available for making the test, being only 100 centimeters long, was not capable of measuring the full ductility either of the original materials or any but one of the recovered asphalts on which the test was made. Tests with the 250-centimeter ductility machine of the Public Roads laboratory have shown that ductilities of 200 centimeters are not uncommon for 50–60 asphalts and some samples have been found to have ductilities of 250+. Thus the initial ductilities reported by the laboratory but omitted from table 4 and most of those reported in table 5 for the pavements in service fail to represent the true ductilities.

Some data are given in table 4 on the effect of variations in mixing temperature and mixing time on the hardening of the asphalt. Although limited in number, the tests show quite definitely that 375° F., the highest mixing temperature permitted under the T 50 specification, is considerably more detrimental to the asphalt than the minimum specified temperature of 275° F. The comparisons were made at six different mixing plants as shown in the right-hand column of table 4.

At plant No. 9 no difference was found in the amount of hardening caused by mixing temperatures of 375° F. and 275° F. At plant No. 12 the percentage of the original penetration retained after 1 minute of mixing at 375° F. was 80 and at 280° F. it was 86, the difference in percentage being 6 for a temperature difference of 95° F. or 6.3 when estimated for a temperature difference of 100° F. The estimated or actual difference for the other plants on the basis of a temperature difference of 100° F. was 7 for plant No. 17, 6 for plant No. 1, and 10 for plant No. 20. The average difference for these five plants where the temperature was varied was 5.9.

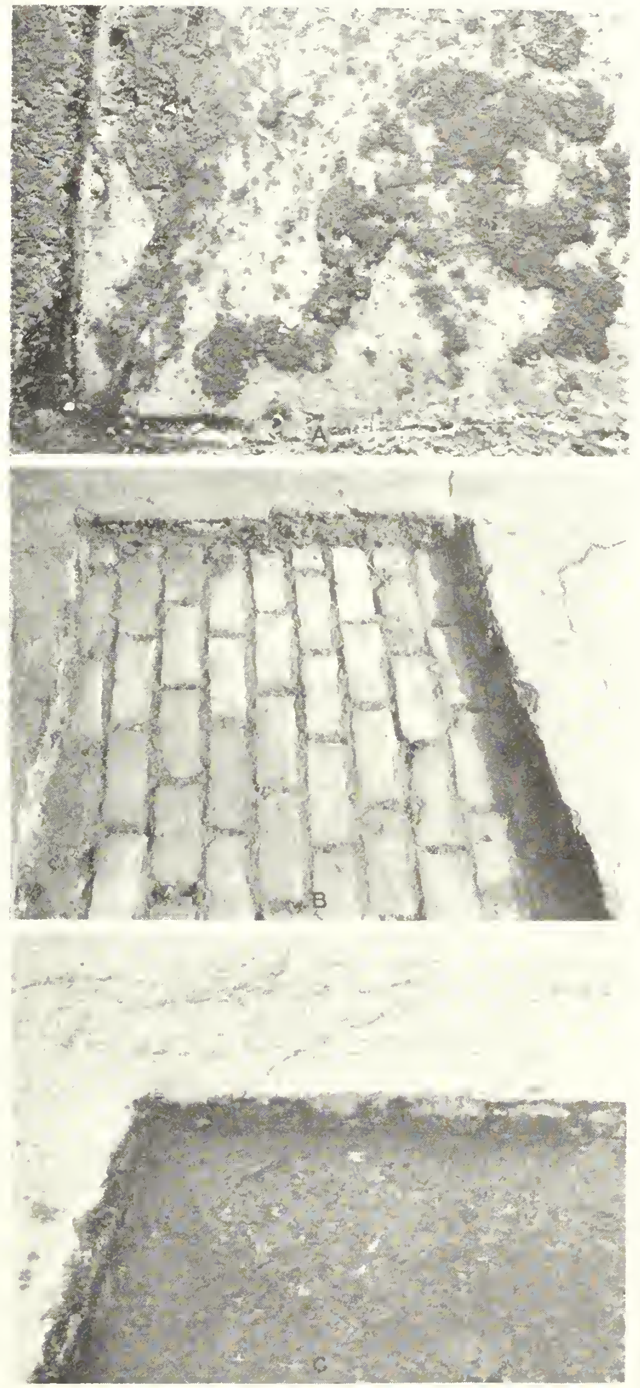

FIGURE 4.—TYPICAL BASES EXPOSED BY REMOVAL OF SAMPLES. A, CONCRETE BASE SHOWING SHATTERING AND SCALING (EXTREME LEFT OF PICTURE); B, BRICK BASE WHICH SHOWED SOME MOVEMENTS AS EVIDENCED BY THE CRACK IN THE GROUT FILLER (EXTREME RIGHT OF PICTURE); C, SURFACE-TREATED, WATER-BOUND MACADAM BASE IN GOOD CONDITION.

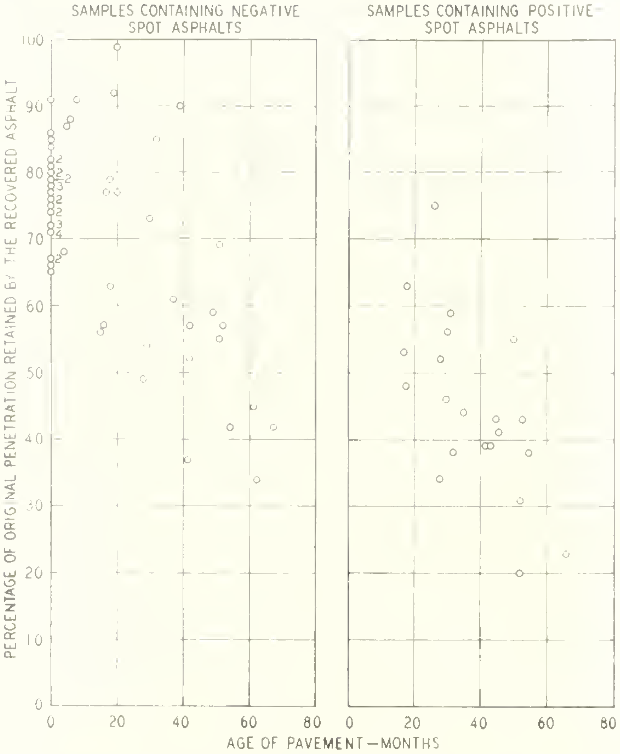

Figure 5.—Relation of Percentage of Original Penetration Retained by the Recovered Asphalt to the Age of the Pavement. (Points Shown on Zero Age Line for Negative-Spot Group Represent 31 Samples of Freshly Prepared or Newly Laid Paving Mixture; Numerals Beside Some of These Points Indicate That 2, 3, or 4 Samples Are Represented by These Points.)

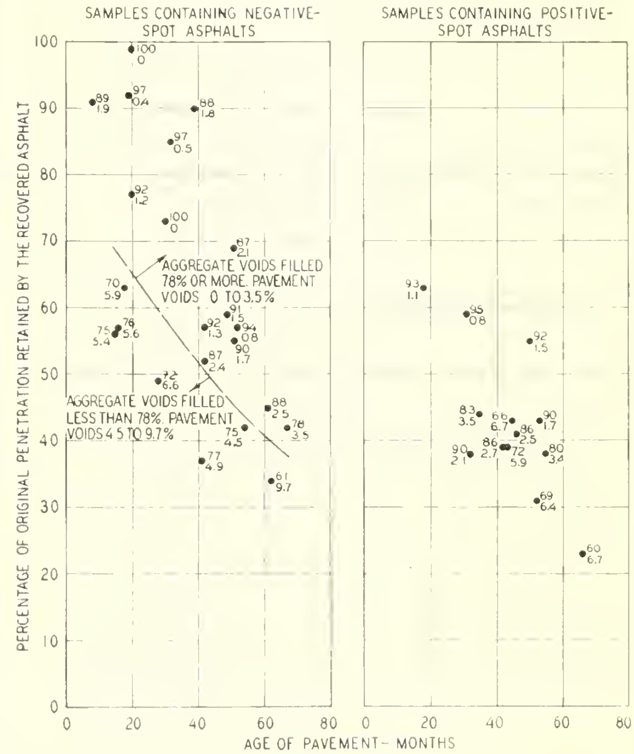

Figure 6.—Effect of Void Content and Percentage of Aggregate Voids Filled With Asphalt on Hardening of the Asphalt With Age. (Upper Number Beside Each Point Represents Percentage of Aggregate Voids Filled With Asphalt; Lower Number Represents Percentage of Air-Filled Voids in Pavement Sample.)

In other words, the loss in penetration was indicated to be about 6 percent greater for a mixing temperature of 375° F. than for a temperature of 275° F.

Comparison of sample C–3 with sample C–4 and sample C–6 with sample C–7, table 4, shows the effect of varying the mixing time with the temperature maintained approximately constant. On the basis of the temperatures actually maintained, lengthening the mixing time to 5 minutes as compared to the normal 1 minute, increased the amount of hardening by a percentage difference of 7 in one case and did not appear to affect the amount of hardening in the other.

AGING IN PAVEMENT APPARENTLY CAUSED DETRIMENTAL CHANGES IN THE ASPHALT

The results of tests on the asphalts recovered from pavements in service, table 5, indicate that important changes continued to develop after the paving mixtures were laid and placed in service.

The effect of aging in service on the penetration of the asphalt is shown graphically in figure 5. This effect appears to differ somewhat for the negative-spot and the positive-spot asphalts and is, therefore, shown separately for the two respective groups of samples in the left and right portions of the figure. For both classes of material, a definite tendency is shown for penetration to fall off as the age of the pavement increases but the wide range of values of retained penetration for any particular age makes it impractical to present curves to show mean rates of hardening or to attempt to predict for any given set of materials and conditions what rate of hardening should be expected. It is believed, however, that the data are sufficiently indicative when considered in relation to the losses at the mixing plant to show (1) that the very serious losses that occur at the plant injure the asphalt as much as would several years of service, and (2) that reasonable measures that might tend to reduce penetration losses, both at the plant and in the pavement, should be investigated.

The wide dispersion of the points in both parts of figure 5 from any conceivable mean rate of hardening indicate that there may be several factors capable of greatly modifying the effect of age on the amount of hardening shown by the asphalt in the pavement.

One of these factors is the susceptibility of the asphalt itself to weathering and this susceptibility doubtless varies with the source of the crude oil, the method of manufacture, and perhaps other considerations. The fact that, as a group, the recovered asphalts that reacted negatively to the spot test differed materially in the amount of hardening shown at a given age from those that gave positive spots (see fig. 5) is indicative of this.

A second factor that appears from the data to have a marked effect on the rate of hardening and to account, therefore, for a considerable part of the dispersion of points, particularly those representing negative-spot asphalts, is the denseness of the finished pavement as reflected in the percentage of the aggregate voids in the compacted pavement filled with asphalt and the corresponding percentage of air-filled or pavement voids.

The relation of this factor of pavement density to the amount of hardening of the asphalt in the pavement is shown in figure 6. This figure is a repetition of figure 5 with all samples of zero age and all samples for which density figures were lacking omitted. The percentages of aggregate voids filled with asphalt are shown as whole numbers beside the individual points and the percentages of pavement voids, these being less than 10 in all cases, are also shown.

In the case of the samples containing negative-spot asphalt, it happened that most of those showing extremely high or extremely low retained penetration were taken after 1935. Hence, the test data included their densities. The ones having 78 to 100 percent of their aggregate voids filled with asphalt and having corresponding pavement voids of 3.5 to 0 percent contained asphalts that, at equal ages, had retained higher percentages of their original penetration than those having less than 78 percent of their aggregate voids filled and having corresponding pavement voids of 4.5 to 9.7 percent. This suggests that about 4 percent may be a critical void content from the standpoint of weathering for this type of mixture.

Thorough filling of the aggregate voids may be accomplished, without undue compaction effort but at the possible expense of skid resistance, by the use of extremely rich mixtures. It may also be accomplished on relatively leaner mixtures by the expenditure of greater compaction effort but at the expense, in extreme cases, of detrimental crushing of the aggregate. Within reasonable limits, either means may be selected as the primary design consideration depending upon the purpose for which the mixture is intended and whether high stability or great flexibility is desired.

Several of the samples containing positive-spot asphalt and showing extreme variations in loss of penetration (see fig. 5) were among the group taken in 1935 for which density figures are not available. The relation between pavement voids and loss of penetration through aging, shown by the remaining 13 samples of known density (see fig. 6) is neither as marked nor as consistent as was the case for the negative-spot samples. However, there is some indication that the hardening shown by the positive-spot asphalts was also affected by the void contents of the pavements.

While the data on the plant samples and those from the newly laid pavement failed, as previously noted, to give any indication of ductility losses incident to mixing because of the lack of information concerning the true initial or final ductilities involved, the samples from the pavements in service furnished at least partially satisfactory information on the loss of ductility with aging. Again, as in the case of the plant samples, the true initial ductilities are not known but even with the reported initial ductilities as a starting point, these being 100+ in all but three cases (see table 5), the loss of ductility during service in the pavement was generally very extensive and furnished further evidence of the very definite and presumably detrimental changes that were induced in the asphalt by the conditions of service.

The relation of retained ductility to pavement age is shown in figure 7. The data for the samples containing negative-spot asphalts are plotted in the left panel while the data for the positive-spot samples are at the right. Although, as in the case of penetrations (fig. 5) it is impractical to attempt to draw curves to show the average rate of ductility loss, it is quite apparent that there is a general trend for ductility to decrease rather rapidly with increasing age. It is also apparent that as a group and for comparable ages, the positive-spot

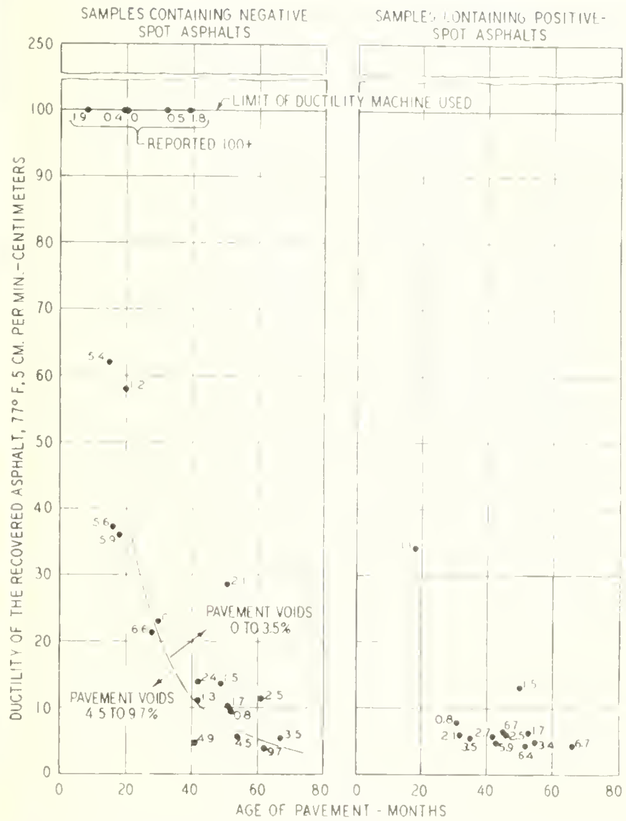

FIGURE 7.—RELATION OF PAVEMENT AGE AND PAVEMENT VOIDS TO DUCTILITY OF THE RECOVERED ASPHALT. (FIGURES BESIDE INDIVIDUAL POINTS REPRESENT PERCENTAGES OF VOIDS IN THE PAVEMENT SAMPLES.)

asphalts retained somewhat lower residual ductilities than the negative-spot materials.

The void contents of the pavement samples are again shown beside the individual points as in figure 6. Here, as in figure 6, where loss of penetration was considered, it is apparent that the void content of the pavement had a consistent and fairly important effect on the amount of alteration or weathering shown by the negative-spot asphalts. Those from samples having void contents of 3.5 percent or less showed consistently higher residual ductilities than those from pavements of comparable age having void contents of 4.5 percent or more. From the data available, however, the ductilities of the positive-spot asphalts appear to have been little affected by the void contents of the pavements (see fig. 7).

TEST RESULTS CORRELATED WITH SERVICE BEHAVIOR

So far, the discussion has been confined primarily to the changes that took place in the asphalt as a result of the mixing process and subsequent exposure and an effort has been made to show how various factors affected these changes.

In the following graphs and discussion, the various factors for which data have been presented, will be considered with respect to the condition of the pavement at the time of sampling.

Figure 8 shows the relation of surface condition to base condition. There is, as would be expected, a general tendency for good base conditions to be reflected in good surface conditions. All of the fair (average) and good surfaces and all but two of the excellent surfaces were found on bases that were in good or excellent

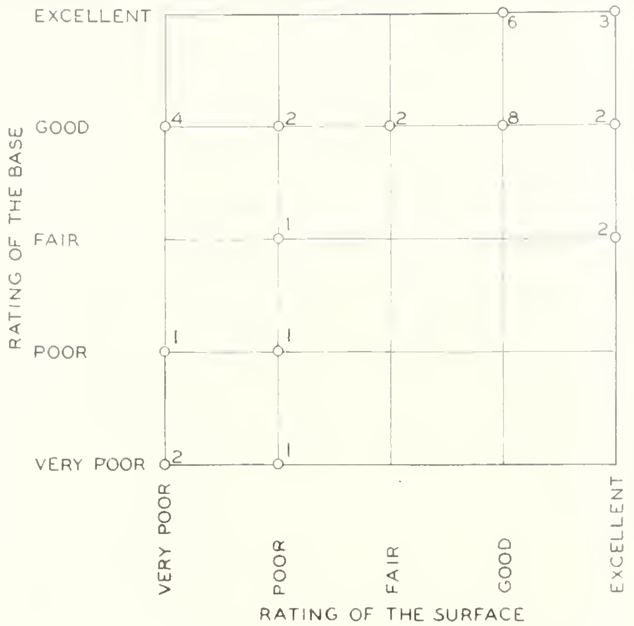

FIGURE 8.—RELATION OF SURFACE CONDITION TO BASE CONDITION. (NUMERALS INDICATE NUMBER OF SECTIONS.)

condition. The other two excellent surfaces were on fair (average) bases. However, the fact that very poor and poor surfaces were found on several good bases indicates that other factors than base condition must be taken into consideration to account for all surface conditions. In order that unsatisfactory surface conditions that are properly attributable to base conditions may not be charged improperly against the quality of the surfacing mixtures or their constituent materials, the data to be used in the following analyses and graphs in the study of these other factors will be only those obtained from samples taken where the base was rated average or better.

Figures 9 and 10, which were plotted from data in table 5, show the relation of surface condition to the amount of hardening developed in the asphalt. In figure 9, the comparison is made on the basis of the actual penetrations as determined on the samples of recovered asphalt, while in figure 10 these residual penetrations have been converted to percentages of the original penetrations as determined at the time of construction. The relations of figures 9 and 10 are also shown in table 6 which is a summary of the hardening data in table 5.

From the relations shown in table 6 and figures 9 and 10, the effect of hardening on the behavior of the pavement is clearly apparent. For the asphalts in very poor pavements, the retained penetration was in no case more than 42 percent of the original. In the poor and fair (average) pavements, the maximum retained penetrations were respectively 55 percent and 57 percent.

In contrast to the pavements classified as average or poor, the asphalts in the excellent pavements had retained from 57 to 99 percent of their original penetration.

Of the asphalts from good pavements, five had retained more than 57 percent and nine had retained less than 57 percent of their original penetration.

The foregoing analysis, which is confined entirely to cases where the bases were average or better, indicates that asphaltic concrete surfaces of the type studied can

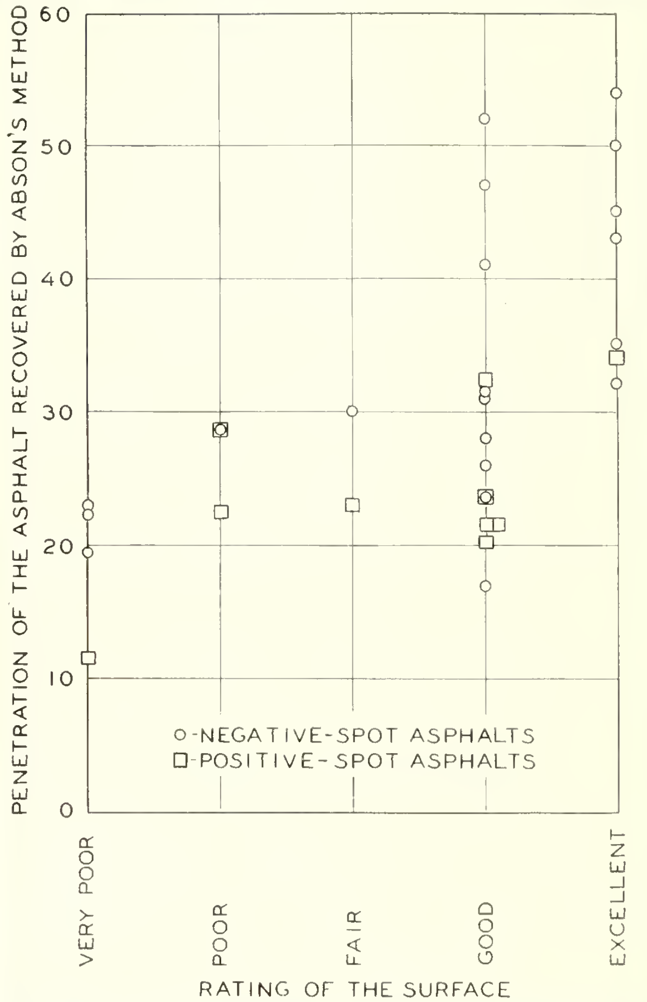

FIGURE 9.—RELATION OF SURFACE CONDITION TO PENETRATION OF THE RECOVERED ASPHALT. (ALL SAMPLES TAKEN WHERE THE BASE WAS POOR OR VERY POOR HAVE BEEN OMITTED.)

reasonably be expected to remain in good to excellent condition as long as the 50–60 penetration asphalt used retains as much as 57 or perhaps 60 percent of its original penetration. This corresponds to an actual penetration of about 30 on the recovered asphalt (see fig. 9).

It does not follow that unsatisfactory pavement conditions will result as soon as the retained penetration falls below 57 percent because nine of the pavements classified as good ranged from 34 to 56 percent in retained penetration, indicating the influence of other favorable factors; but it seems safe to say that unsatisfactory surface conditions are more than likely to develop when the retained penetration of the grade of asphalt used in these pavements falls to the vicinity of 40 percent or to an actual penetration of perhaps 20 to 22.

Figure 11 shows the relation of surface condition to the ductility of the recovered asphalt. The grouping of the points in the various condition classes is very similar to that shown in the previous figure although the numerical values are, of course, different. Reference to this figure shows that only good or excellent surface conditions were observed on pavements in which the ductility of the recovered asphalt proved to be 13 centimeters or more, provided the base conditions were average or better, and that only one unsatisfactory

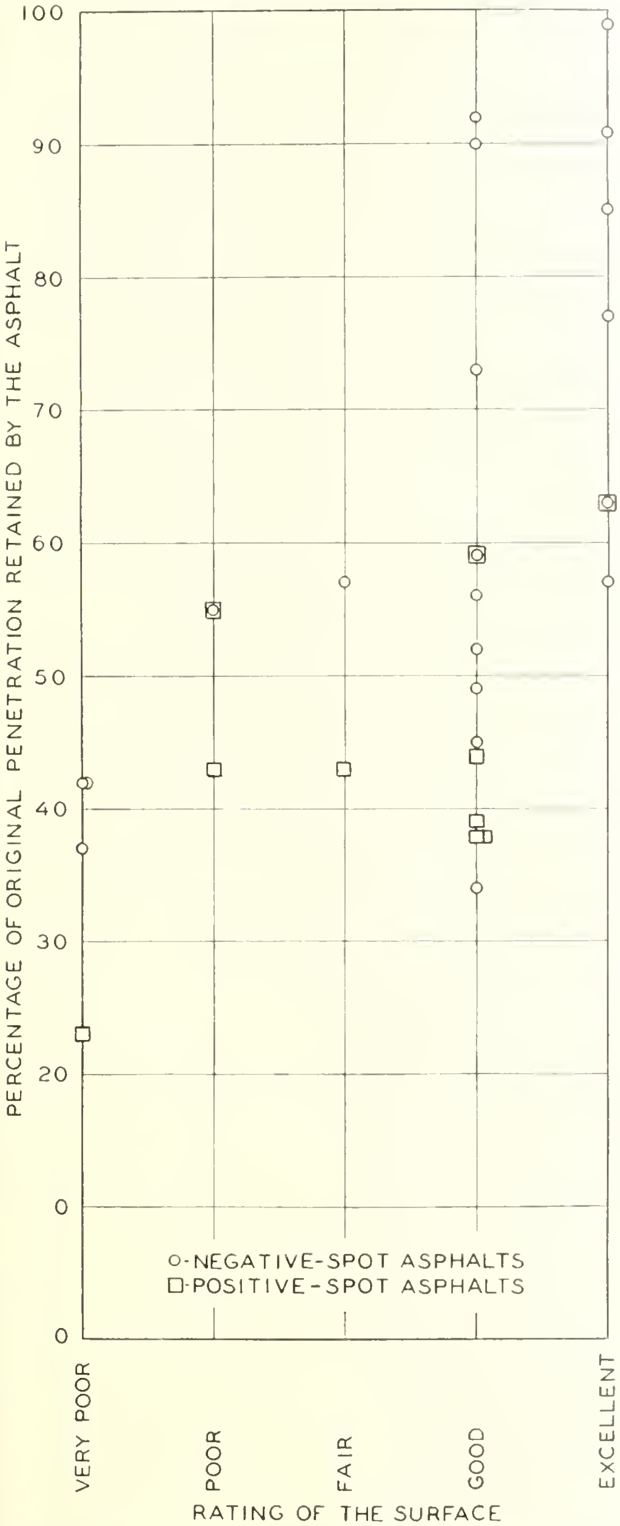

FIGURE 10.—RELATION OF SURFACE CONDITION TO PERCENTAGE OF ORIGINAL PENETRATION RETAINED BY THE ASPHALT. (ALL SAMPLES TAKEN WHERE THE BASE WAS POOR OR VERY POOR HAVE BEEN OMITTED.)

pavement was found in which the retained ductility was appreciably more than 10 centimeters. On the other hand, more than half the pavements in which the ductility of the recovered asphalt was 10 or less were in very poor to fair (average) condition.

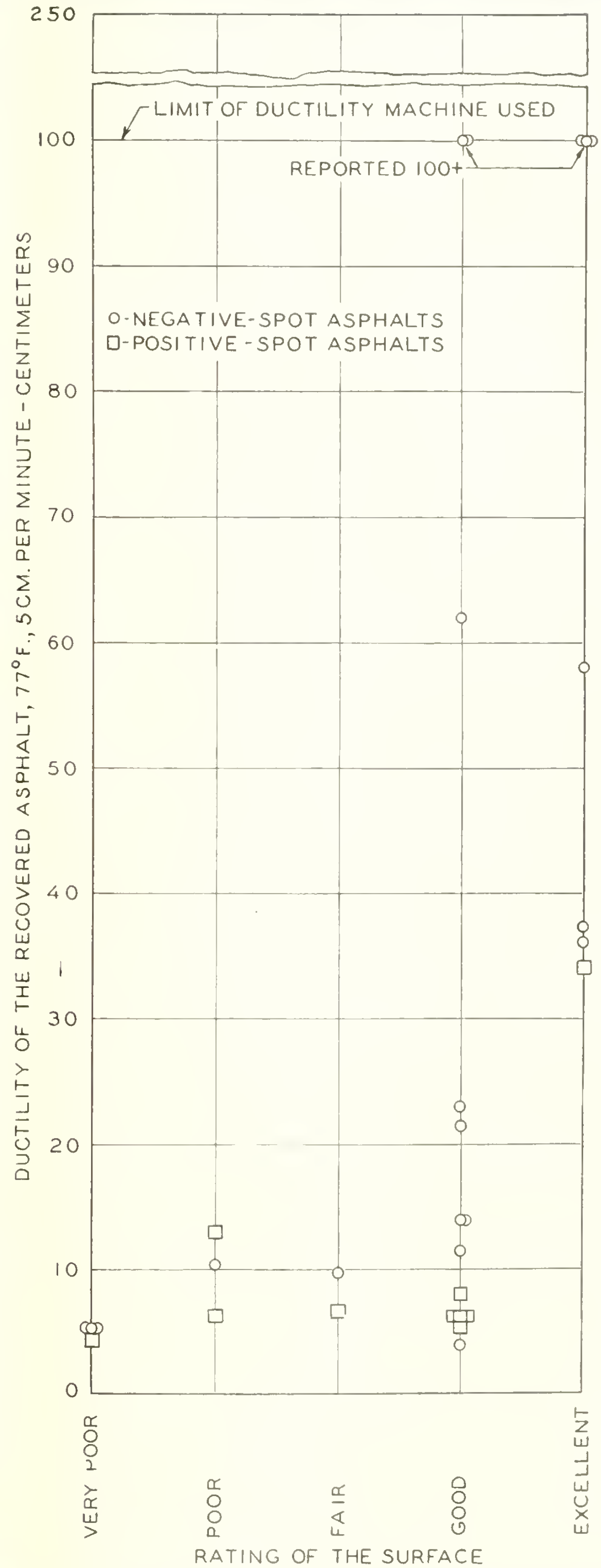

FIGURE 11.—RELATION OF SURFACE CONDITION TO DUCTILITY OF THE RECOVERED ASPHALT. (ALL SAMPLES TAKEN WHERE THE BASE WAS POOR OR VERY POOR HAVE BEEN OMITTED.)

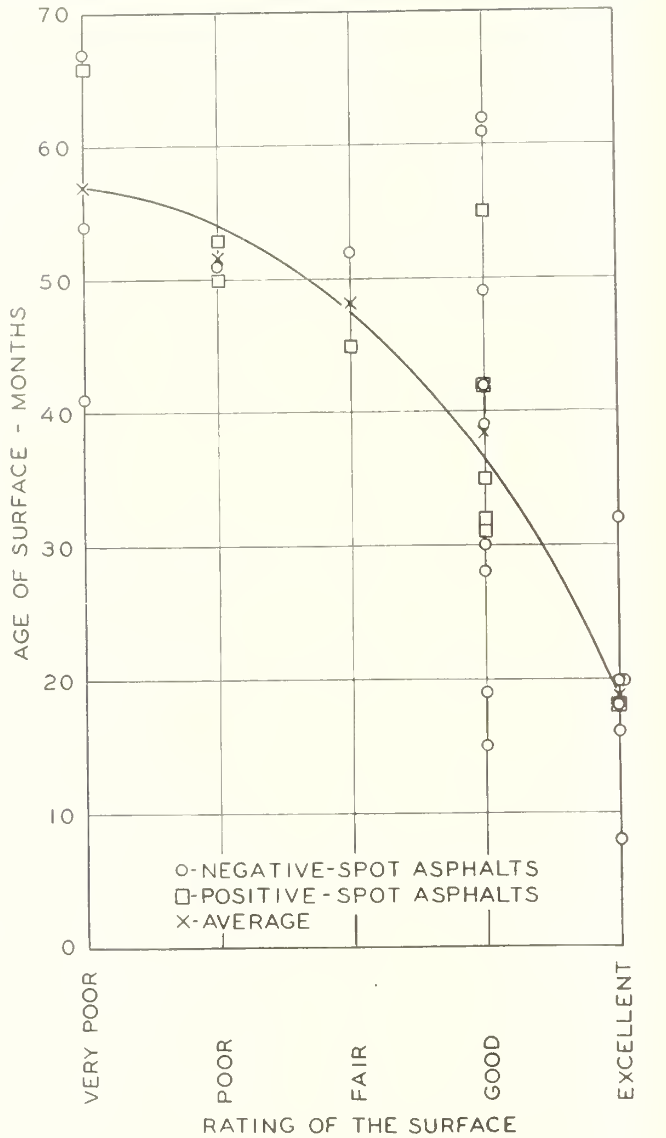

Figure 12.—Relation of Surface Condition to Age. (All Samples Taken Where the Base Was Poor or Very Poor Have Been Omitted.)

BETTER SECTIONS HAD HIGHER RETENTION OF ORIGINAL PENETRATION AND DUCTILITY

In the analysis based on the limited number of tests made by the Public Roads laboratory (see table 7) the good and excellent surfaces were grouped together as satisfactory pavements and the poor and very poor were grouped as unsatisfactory. No samples from intermediate, or fair, surfaces were tested by this laboratory. On the basis of percentage of penetration retained, these two groups are clearly divided at 55 percent. Of the samples for which the penetration of the recovered asphalt was determined, all but two of those representing satisfactory surfaces contained asphalts that had retained more than 55 percent of their original penetration and all those that represented unsatisfactory surfaces showed retentions ranging downward from 55 percent. On the basis of residual ductility, a fairly good separation was obtained at a ductility of 10 centimeters. Eight out of ten samples from satisfactory surfaces contained asphalts having ductilities above 10 centimeters and all the asphalts tested from unsatisfactory pavements had ductilities of less than 10 centimeters.

Tests were made on the asphalt from both the surfacing and binder course of four samples to determine whether the character of the asphalt showed more alteration near the exposed surface than at a deeper level. The results of these tests are shown in table 8. As would be expected, these asphalts showed consistently greater changes in the wearing course than in the binder course. The amount of hardening at the higher level was the greater in all cases and the loss of ductility was greater for three out of the four samples for which the comparison was made.

The factor of age naturally had an important effect on the condition of the wearing courses. The relation of surface condition to age is shown in figure 12. None of the poor or very poor surfaces were less than 40 months old and only one of the excellent pavements was as much as 32 months old. However, the age of the surfaces described as good ranged from 15 to 62 months, another indication that no one factor could be used to account for the condition of the pavement.

The roller stability test, although made on only a limited number of samples (see table 7) produced valuable information. The roller stability values for eight samples of satisfactory pavement ranged from 12 to 89, indicating that the mixtures were still plastic.

The values for five out of six samples of unsatisfactory pavement ranged from 109 upward to 478, indicating that the pavements were becoming hard and showing a tendency toward brittleness. The other one of these six samples showed the extremely low stability of 4, indicating a very soft plastic condition. Although this pavement had not actually developed any rutting or corrugation, it is believed that its stability was dangerously low. Two samples from unsatisfactory pavements were too brittle and badly cracked to permit the sawing of specimens for the roller stability test.

It is believed that the magnitude of the roller stability values, indicating the dividing line between satisfactory and unsatisfactory pavements, may vary considerably for various types of surfacing mixtures and that, because of this probable variation, the figures given should be considered as applicable only to these or similar bituminous concrete wearing course mixtures containing little or no mineral filler.

EFFECT OF AGGREGATE GRADING STUDIED

Although this investigation was primarily concerned with the behavior of the asphalt rather than the aggregate, sieve analyses were made on the extracted aggregates from all the samples tested in the Public Roads laboratory, and vibratory compaction tests[4] were made on all but two of the aggregates. The results of these tests are shown in table 9.

The vibratory compaction tests indicated that all but 1 of the 20 mixtures tested contained sufficient or more than sufficient asphalt to fill the aggregate voids if the aggregate were compacted to its maximum obtainable density. The use of such an amount of asphalt as to produce up to 4½ percent of overfilling on the basis of the vibratory compaction tests (table 9) did not impair the stability of the surfaces as evidenced by their freedom from ruts or corrugations. It is, therefore, believed that in cases where little or no overfilling was indicated by the vibratory compaction tests some additional asphalt would not have impaired the

[4] Apparatus and method of test described by J. T. Pauls and J. F. Goode in Public Roads, Vol. 20, No. 3, May 1939, page 55.

stability and might have been beneficial in providing better sealing.

Comparison of the aggregate densities in the pavements with the densities obtained by vibrating the dry aggregates indicated that, in several cases, additional compaction probably could have been obtained in the pavement if the limits of compactibility of the mixtures had been available as a basis for judging when sufficient rolling had been done. In other cases, the high densities of the pavement samples (see table 9, column 2) corresponding, in the case of sample 15–B, to 149 pounds per cubic foot or slightly more than 4,000 pounds per cubic yard, indicated that about the maximum practical density had been attained.[5]

An outstanding characteristic of the aggregates in most of these bituminous concrete surfacing mixtures was their low dust content and the fact that, with these low dust contents, most of the dry aggregates were capable of being compacted to aggregate densities of 85 to 90 percent, corresponding to aggregate void contents of 10 to 15 percent.

These highly compactible aggregates were produced by combining in carefully regulated proportions various sizes of crushed stone or slag with artificial or local natural sand without the addition of any filler material. The combined effect of low dust content and high density obtained by interlocking of the stone fragments accounts for the uniformly satisfactory stability of the mixtures in service. Such relatively harsh mixtures have the great advantage of high resistance to shoving even when not fully compacted and, because of the absence of filler material, are easily mixed. For this reason, attention could well be given to the advisability of permitting reduction of both the mixing temperature and mixing time when this type of surfacing aggregate is available.

Mixtures prepared with these harsh aggregates require special care in laying and finishing to prevent segregation, but experience has proven conclusively that uniform appearing, smooth-riding pavements can be built with them. In addition to having generally high stability, these pavements usually show either a typical sandpaper or a mosaic, nonskid surface texture depending upon their age and the amount and type of traffic carried.

SUMMARY

As indicated by the data obtained in this investigation, the performance of the pavements was influenced by so many variable factors that it is impossible to draw positive conclusions or to set up definite recommendations based on the data. However, the data do show certain trends that merit attention and suggest further investigation.

1. The design of the surfacing mixtures, as regards grading of the aggregate and quantity of asphalt used, appears to have been excellent as does the technique employed in constructing and finishing the wearing courses. The data indicate that only in rare instances was insufficient asphalt used or compaction short of a practical maximum obtained. In all cases, sufficient stability for the service required was obtained and the riding quality of the surfaces was generally excellent.

2. The type and condition of the bases had a very important bearing on the behavior of the surfaces. Obviously, no amount of care in the design, construction, and maintenance of the surfacing could be expected to compensate for failure of the base to furnish ample support. This investigation was not undertaken to determine what was wrong with the bases, but the effect of base conditions had to be considered in order to arrive at a fair evaluation of the effects of other factors.

3. The character of the recovered asphalt, as judged by the Oliensis spot test, appears to have some bearing on the pavement condition. As a group, the average and poorer pavements on average or better bases contained 5 negative-spot and 4 positive-spot asphalts, while among the good and excellent pavements there were 15 negative-spot as compared to only 6 positive-spot materials. Thus the negative-spot asphalts were fairly definitely associated with satisfactory pavement behavior. As shown in figure 5, the positive-spot asphalts appeared to be somewhat more susceptible to the changes evidenced by hardening than those that showed a negative reaction to the spot test.

The data appear to show some superiority for the negative-spot asphalts extracted from the pavement samples. However, it is not known whether or not any of the asphalts were positive at the time the paving mixtures were prepared.

4. The data indicate that the drastic changes in the asphalt that were found to result from normal mixing operations probably resulted in the loss of many months of satisfactory pavement service.

It has been shown that both hardening and loss of ductility appear to continue throughout the life of the pavement. It has also been shown that, for the 50–60 penetration asphalt involved in this investigation, satisfactory service is quite likely not to continue after the penetration has fallen appreciably below 57 percent of the original or to an actual penetration of something less than 30 while the corresponding critical ductility appears to be about 10 or perhaps 13 centimeters. It seems logical to conclude, therefore, that any hardening or reduction in ductility that occurs during mixing must shorten the life of the pavement by about the number of months that would be required to produce the same changes under service conditions. Thus, the mixing losses assume considerable importance because they add materially to the annual pavement costs.

Since oven loss tests on penetration grade asphalts generally produce little or no weight loss at 325° F., a temperature comparable to the mixing temperatures of 275° to 375° F. employed in Ohio, it appears that the changes that occur in the asphalt during mixing must be largely chemical in nature. Therefore, it is impossible to judge, from the data presented, whether the percentage penetration loss or the actual residual penetration is the better index of deterioration of the asphalt. Certainly the critical values suggested for either, as appropriate for 50–60 penetration asphalt, should not be applied indiscriminately to other grades without previous investigation.

5. Alterations in the asphalt caused by mixing appear to depend upon two factors, namely, the susceptibility of the asphalt to alteration and the conditions and time involved in the mixing operation.

It would be unreasonable to expect that asphalts of such low susceptibility to hardening could be produced that they could not be damaged by oxidation, overheating, or excessive mixing. Furthermore, it is

[5] Subsequent investigations made by the Ohio Department of Highways, comparing the densities of newly laid pavements with the respective densities after several months' service, indicate that ultimate density is seldom obtained during construction even under the most stringent rolling requirements. The tendency for the aggregate particles to rearrange under traffic and to approach the vibrated aggregate densities increases with the use of softer asphalts.

unlikely that improvements in plant design and management can entirely eliminate hardening, particularly for the asphalts that are highly susceptible to alteration. It does seem reasonable to expect that both the character of the asphalt and the design and management of mixing plants can be improved so that alteration of the asphalt will be very materially reduced and pavement life correspondingly increased.

It has been pointed out previously [6] that specification requirements seeking to control both the asphalt furnished and the manipulation to which it is subjected, by establishing minimum requirements that must be met by the asphalt extracted from the finished pavement, result in dividing the responsibility between the producer who furnishes the asphalt and the contractor who uses it. The specifications should accomplish two distinct objectives: (1) They should assure that the asphalt, as delivered, is resistant to alteration, and (2) they should assure that the asphalt shall not be unduly altered by the contractor.

To control the quality of the asphalt delivered, insofar as its resistance to alteration is concerned, a clause should be inserted in the material section of the specifications providing that the asphalt shall meet certain minimum requirements in a suitable laboratory test. This will necessitate the development of a laboratory test that, when properly correlated with mixing plant data, will furnish a dependable index of the resistance of the asphalt to the alterations evidenced by changes in penetration and ductility. Because of the large number of samples handled daily by many laboratories during the construction season, the test should be as simple as possible. A number of laboratories are now working on this problem.

To assure protection of the asphalt through high-type mixing plant equipment and management, a clause in the construction section of the specifications might be justified to provide that the asphalt extracted from the freshly laid pavement shall meet suitable minimum requirements for penetration and ductility. Assuming that the asphalt, as delivered, had shown satisfactory qualities in the test for resistance to alteration, the construction or protection clause would then make the contractor definitely responsible for any excessive alteration of the asphalt during manipulation.

Improvement of mixing plant management involves the modification of present practices to take full advantage of relatively recent developments in the design of the mixtures and of improvements in equipment and methods of construction.

As noted in the first part of this report, the early design of the fine aggregate type of bituminous concrete required the addition to the aggregate of a considerable portion of mineral dust or filler. Under the present practice in Ohio, the mixtures contain only such dust as occurs naturally in the crushed aggregate and the natural or artificial sand. Field mixing tests have indicated that some of these aggregates can be satisfactorily coated with asphalt in less than 30 seconds of wet mixing as compared to the 45 or more seconds quite generally specified for mixtures to which dust is added.

The mixing temperatures required in early specifications were necessarily high enough to provide sufficient heat for rolling after such time-consuming operations as hauling the mixture to the job in slow conveyances and laying it by hand. With modern hauling and spreading equipment, heat losses between the plant and the pavement are considerably reduced. It is also significant that a somewhat cooler mixture can be handled satisfactorily by a mechanical spreader that can be finished by hand raking.

In general, the tendency has been to retain in present day specifications both the mixing times and the mixing temperatures dictated by the less favorable considerations of early design and construction methods. The use of lower mixing temperatures or shorter periods of mixing or both, when possible, should result in reduced hardening and loss of ductility.

Attention has been directed to what are believed to be reasonable and feasible measures for improving specifications and mixing-plant management. There remains the possibility of improving the design of mixing equipment further to protect the asphalt from the damaging effects of exposing it to the air at high temperatures and in thin films as is now the normal practice.

6. Protection of the asphalt against weathering changes after it is in the pavement is a third means of prolonging satisfactory service. Just how far weathering in the pavement can be reduced is not predicted but consistent attainment of all the conditions tending to retard weathering should be of material benefit. These include the provision of both surface and sub-base drainage to prevent the entrance of moisture into the mixture, the use of densely graded aggregates with sufficient asphalt to fill essentially all the pore spaces in the aggregate at optimum field compaction and, finally, the definite attainment of optimum compaction during construction.

[6] Needed Research on Asphalts, by E. F Kelley. Proceedings Highway Research Board, 1935, p. 264.

(Continued from p. 128)

watchmen in protecting grade crossings. The computed hazard index of practically every crossing at which gates had been installed or a watchman employed was lower than the index of other crossings in the same assigned priority group. It is possible, however, that a majority of the committee desired to eliminate as many as possible of the crossings protected by gates or watchmen and therefore, consciously or unconsciously, assigned a higher priority to these locations than if rating had been by means of the mathematical formula. A few of the crossings, such as the first and third in the first priority group, were actually considered as one project, which increased the hazard of the combination above that of the projects with a single site and was a factor in their joint selection.

ADDITIONAL FACTORS CONSIDERED IN OTHER FORMULAS

The plan of rating all crossings which has been used by the Utah and Idaho Highway Planning Surveys includes a good example of an approximate formula which, although its coefficients and weights are based on judgment, apparently produces a reasonably satisfactory rating. More detailed information than is generally available in other States was collected and used in the development of the priority ratings. The formula, though based on earlier studies made in

Table 2.—*Hazard rating of 25 rural crossings in Maryland which were grouped by the State in 5 priority divisions*

Priority group No.	Route No.	Highway traffic	Train traffic	Protection	Highway factor (H^a)	Train factor (T^b)	Protection factor (P^c)	I_u	K	I	Total I for group
1	Co. 870	654	109	Gates (24-bour)	3.01	2.03	2.56	3.06	−0.37	2.69	20.54
	Md. 434	2,908	73	Lights and bells	3.88	1.91	2.25	4.21	+3.15	7.36	
	Co. 874	780	109	Gates (24-hour)	3.11	2.03	2.56	3.16	−.23	2.93	
	Md. 202	1,224	107	Gates (24-hour)	3.34	2.02	2.56	3.37	+.12	3.49	
	Co. 872	1,090	76	Lights and bells	3.25	1.92	2.25	3.55	+.52	4.07	
2	Md. 30	2,537	12	Bells	3.78	1.45	1.78	3.94	+1.96	5.90	17.08
	Md. 175	733	73	Ligbts and bells	3.07	1.91	2.25	3.34	+.06	3.40	
	Md. 131	1,314	34	Gates (24-hour)	3.38	1.70	2.56	2.87	−.57	2.30	
	US 220	2,279	16	Flashing lights	3.71	1.52	2.18	3.32	+.02	3.34	
	Co. 102	467	34	Lights and bells	2.84	1.70	2.25	2.75	−.66	2.09	
3	Md. 64	1,476	17	Bells	3.46	1.53	1.78	3.80	+1.35	5.15	15.13
	Co. 406	758	45	Watchman (24-hour)	3.09	1.78	2.52	2.79	−.64	2.15	
	Co. 216	346	107	Watchman (16-hour)	2.70	2.02	2.43	2.87	−.57	2.30	
	US 11	2,592	18	Lights and bells	3.79	1.54	2.25	3.31	0	3.31	
	US 15	1,258	28	Watchman (24-hour)	3.35	1.66	2.52	2.83	−.61	2.22	
4	Md. 201	2,933	17	Flashing lights	3.88	1.53	2.18	3.48	+.36	3.84	13.80
	Md. 30	2,322	10	Lights and bells	3.72	1.42	2.25	3.01	−.43	2.58	
	Co. 323	251	73	Lights and bells	2.55	1.91	2.25	2.76	−.65	2.11	
	Co. 142A	179	107	Gates (16-hour)	2.39	2.02	2.47	2.50	−.78	1.72	
	US 13	1,302	6	Signs	3.37	1.30	1.65	3.39	+.16	3.55	
5	Md. 149	139	112	Gates (24-hour)	2.29	2.03	2.56	2.33	−.83	1.50	11.42
	Md. 36	2,078	11	Flashing lights	3.66	1.44	2.18	3.10	−.31	2.79	
	Md. 351	874	29	Lights and bells	3.16	1.66	2.25	2.98	−.45	2.53	
	US 219	802	35	Lights and bells	3.12	1.71	2.25	3.03	−.40	2.63	
	Co. 100	399	34	Lights and bells	2.77	1.70	2.25	2.67	−.70	1.97	

Illinois and Connecticut, includes some valuable additions.

The index of hazard used in Utah and Idaho is calculated from a formula that assumes that hazard to the public is a function of the volume of vehicular and railroad traffic and of the nature of these movements over the crossing and the physical conditions existing there. Factors for the various elements entering into the hazard of the crossings have been selected with which to weight the items in relation to their relative importance. These factors are substituted in the following formula:

Hazard index $(HI) = VT\ (T_1 + S + A + N + C + M)$

where V = factor representing volume of vehicular traffic,

T = factor representing volume of train traffic,

T_1 = train type and speed,

S = view factor,

A = intersection angle,

N = number of tracks,

C = highway alinement, and

M = special conditions.

It is probable that the outstanding addition made by the Utah and Idaho formula to previous grade crossing formulas is the item covering type and speed of train movement. It is contended in these States that the likelihood of inaccurate judgment on the part of a vehicle operator increases roughly in proportion to the train speed and the time that the train blocks the crossing. Certain types of trains can be better controlled than others and the probability of an accident varies in proportion to this control. Electric trains, for instance, are generally shorter and more controllable than steam trains. The new streamlined models, due to their high speed, reach a crossing from a distant point within the clear view of a crossing in a surprisingly short time and, since they require a considerable distance in which to come to a stop, they are generally more dangerous to highway traffic than other types of train movement. Information concerning the type and speed of trains should add considerably to the value of a priority rating based upon a hazard formula.

A study of grade crossing accidents in Oregon developed some interesting suggestions that appear to be well worth considering. It was concluded in this State that the general formula used by most States was unnecessarily complex. For example, the Oregon study indicated that road surface conditions, sight distance, angle of intersection, number of tracks, and alinement had little or no effect on the number of accidents. It was not contended that these factors did not affect accident hazard, but it was assumed that adverse conditions in these factors caused enough motorists to exercise special caution to balance the undesirable conditions to such a degree that no more accidents occurred at crossings with poor conditions than if these conditions were normal.

The following simple formula was used in Oregon to rate all crossings:

$$HI = VT_1\ (S_v + S_t)\ (1 + A)$$

where HI = index of hazard,

V = average daily vehicular movements,

T_1 = average daily train movements (weighted to take care of the greater probability of night accidents),

S_v = vehicular speed factor,

S_t = train speed factor, and

A = accident record.

The most interesting item introduced by the Oregon Highway Planning Survey is the inclusion of a factor concerning the traffic, both vehicular and train, during the hours of darkness. Their studies indicated that while traffic volume generally decreases after dark, the accident rate increases. This tendency was pronounced, and it was determined that motor vehicle and train movements at night in urban areas were potentially 3.0 times as dangerous as daylight movements, and in rural areas 1.8 times as dangerous as daylight movements. Records of traffic movement were carefully divided into day and night traffic and the night traffic given greater weight in accordance with their findings. This increase in accidents during the hours of darkness probably accounts for a large portion of the great increase in the rate of accident occurrence in the months of October, November, and December, when traffic volume is generally decreasing. The inclusion of some factor that gives greater weight to traffic that moves during the hours of darkness seems logical.

ADDITIONAL DATA MIGHT ENABLE DEVELOPMENT OF AN IMPROVED FORMULA

It appears from the study that has been made that some additional information should be obtained concerning the accidents and the conditions that existed at the crossings at the time of their occurrence. Better estimates of the highway and railroad traffic for the day and hour of the accident would be helpful. More complete descriptions of the accidents and the possible causes contributing to them should be given instead of using such stock phrases as "failed to observe signal" or "carelessness of driver." Reports concerning the causes of accidents, prepared by a public official trained to observe the necessary conditions and details, would be preferable to reports required of railroad officials. It is probable that a comparatively small amount of more reliable and more representative data would make possible the development of a formula that would be considerably more reliable than the ones given in this article.

Regardless of the dependability of the computed hazard rating for any crossing or group of crossings, this index should be used only as one type of measure of the need of crossing elimination. In some locations where motor-vehicle traffic volume is very low, protection may be desirable to protect railroad property, especially fast-moving trains, from slow-moving trucks or other large vehicles that are a hazard to the train passengers, crew, and equipment. As many factors as can be obtained should be considered along with the hazard rating.

The plan developed by the Maryland Highway Planning Survey has been adopted by the planning surveys in several other States to aid in the selection of crossings for elimination and in the assignment of priority numbers to these crossings or to groups of crossings. In this plan data concerning the more important crossings, as measured by highway and railroad traffic, are tabulated. These tabulations are submitted to several engineers concerned, including railroad officials, and a rating for each crossing is requested. The several ratings assigned are then combined by scoring points for first choice, second choice, etc., and priority ratings thus obtained. When a sufficient number of crossings have been assigned priority numbers for elimination, the balance may be studied concerning their protection needs.

It is believed that the hazard rating computed from the formula described herein and the protection coefficients suggested will be of value when combined with other independent ratings. Any rating made by individuals, as suggested above, could be combined with one made by using the hazard formula outlined in this report. A priority listing made on the basis of exposure (railroad times highway traffic) as related to cost of elimination might also be included. The combination of these data in each State should point to certain crossings or groups of crossings that should be eliminated and to others that should have some type of protection or at which better protection should be provided.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF JULY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 359,177	$ 178,600	14.9	$ 7,066,399	$ 3,507,095	243.5	$ 1,662,300	$ 826,300	39.1	$ 1,564,288
Arizona	152,929	109,520	6.0	1,451,225	1,009,728	65.3	802,198	540,370	21.0	1,192,106
Arkansas	1,930,539	872,713	20.0	1,350,981	673,944	48.6	536,750	268,137	30.2	537,294
California	15,000	15,000		9,318,812	4,992,774	129.7	2,558,467	1,352,096	58.6	2,551,115
Colorado	404,854	232,450	17.3	2,172,689	1,258,368	102.5	1,769,277	998,748	140.5	2,100,788
Connecticut	13,227	6,614		2,018,841	984,064	23.9	832,797	405,834	9.3	842,532
Delaware				959,800	471,598	22.8	333,462	166,701	11.7	962,473
Florida				1,171,020	613,349	58.5	1,901,171	918,996	15.9	2,799,519
Georgia	538,133	269,066	13.2	6,711,024	3,365,762	265.3	5,105,264	2,552,632	217.8	4,888,345
Idaho	357,080	220,045	26.9	1,586,648	979,124	74.7	420,248	244,352	25.0	1,421,879
Illinois	507,476	254,488	10.0	8,332,012	4,166,006	172.2	3,309,556	1,654,222	30.5	3,252,148
Indiana	997,764	498,882	12.3	7,388,703	3,450,336	122.5	1,570,056	751,828	21.2	1,479,575
Iowa	40,777	19,450	8.3	4,649,076	2,222,358	156.2	2,903,447	1,339,790	111.7	174,810
Kansas	205,217	102,556	6.8	6,156,751	3,120,495	325.8	3,072,508	1,356,142	153.3	3,678,301
Kentucky	479,860	244,280	16.4	4,973,065	2,364,847	125.7	4,846,796	2,383,140	109.3	1,036,210
Louisiana	655,635	327,796	15.8	2,175,129	1,079,147	46.2	2,568,556	1,259,086	56.3	3,032,294
Maine	386,500	193,250	13.6	1,831,746	937,197	22.0	468,930	234,465	7.9	458,266
Maryland	862,000	431,000	11.7	3,458,362	1,677,678	20.9	753,000	317,000	6.1	1,187,839
Massachusetts	168,361	83,769	3.8	4,080,919	2,060,960	25.5	985,544	488,569	7.9	2,813,321
Michigan	1,943,200	971,600	37.5	6,549,320	3,262,060	142.0	2,049,600	1,024,800	24.1	1,584,592
Minnesota	506,687	253,343	63.7	8,996,185	4,457,622	453.6	3,178,990	1,586,630	176.3	1,571,909
Mississippi	426,800	213,400	26.5	7,764,712	3,817,506	435.5	407,700	202,100	17.5	912,583
Missouri	879,972	439,986	36.5	10,522,093	5,093,754	225.4	4,724,130	1,644,523	104.1	3,116,709
Montana	671,893	379,185	40.0	2,699,251	1,530,117	115.0	935,390	531,862	64.9	3,675,154
Nebraska	82,603	41,301	9.3	5,887,428	2,964,095	582.8	2,033,270	1,016,635	194.5	2,429,227
Nevada	21,720	18,935	4.4	2,451,864	2,132,544	109.2	336,339	291,898	13.0	489,986
New Hampshire	93,165	46,120	1.9	784,811	391,593	9.7	481,115	228,877	7.0	820,247
New Jersey	1,046,050	523,025	10.0	4,842,632	2,421,236	32.7	44,810	22,405		1,738,880
New Mexico	208,323	125,577	7.7	1,342,345	838,645	72.3	178,498	115,416	25.8	1,856,148
New York	1,744,145	871,173	30.1	11,195,737	5,570,467	136.5	1,983,300	830,900	19.6	3,534,891
North Carolina	97,560	32,885	1.1	4,665,614	2,344,150	208.0	1,561,566	773,320	51.9	2,045,336
North Dakota	737,590	388,233	73.2	3,436,730	1,831,459	275.2	3,284,780	1,651,067	276.8	3,014,116
Ohio	380,195	190,197	2.9	17,865,818	8,780,051	146.1	1,823,190	719,270	14.2	3,508,304
Oklahoma	281,800	148,847	7.3	3,470,474	1,794,581	122.4	2,516,120	1,301,744	71.3	4,246,442
Oregon	274,571	167,510	19.4	4,296,805	2,307,856	89.6	886,315	405,110	16.1	609,763
Pennsylvania	846,738	423,369	15.4	13,435,596	6,612,059	107.4	3,254,985	1,578,355	33.8	2,408,649
Rhode Island	145,865	72,925	1.6	1,234,850	615,462	10.4	116,277	58,139		946,713
South Carolina	239,350	116,500	26.6	4,097,797	1,876,344	132.1	1,516,753	279,827	33.1	1,858,391
South Dakota	603,550	343,440	44.6	4,389,413	2,744,793	510.5	1,083,840	674,160	160.6	2,388,045
Tennessee	222,098	111,049	4.2	5,633,244	2,816,622	135.7	1,177,794	588,897	24.5	3,133,974
Texas	929,165	460,375	43.9	14,459,325	7,139,584	625.9	3,183,498	1,481,460	131.8	5,853,985
Utah	68,825	52,475	16.2	2,322,620	1,685,546	53.4	308,652	182,190	13.1	531,138
Vermont	136,537	67,759	2.9	1,308,575	649,480	31.2	534,806	267,403	15.5	76,512
Virginia	411,254	205,132	10.6	5,177,955	2,427,827	89.3	435,864	217,932	11.3	1,715,316
Washington	197,670	105,700	4.7	2,996,486	1,597,694	42.0	929,618	467,085	10.5	747,645
West Virginia	430,900	214,260	9.5	3,828,901	1,903,706	59.1	502,390	251,195	6.2	1,458,817
Wisconsin	420,997	208,730	12.8	3,152,374	1,566,878	117.4	4,311,734	1,796,563	128.0	2,964,300
Wyoming	37,683	24,086	10.6	1,561,022	990,771	151.8	452,932	246,929	46.4	1,089,062
District of Columbia	172,023	86,000	1.4	754,001	376,190	1.3				427,984
Hawaii	140,808	70,395	1.1	431,890	248,149	6.6	296,658	277,186	3.2	1,705,325
Puerto Rico				1,562,404	771,610	16.9	683,965	334,890	5.5	551,005
TOTALS	22,474,266	11,432,991	774.6	239,971,474	122,495,281	7,298.8	81,615,146	39,107,176	2,773.9	98,984,251

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF JULY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 227,842	$ 113,918	6.9	$ 1,218,214	$ 611,541	55.7	$ 317,800	$ 153,230	26.2	$ 413,108
Arizona	67,371	48,972	4.5	135,027	100,270	.8	53,969	39,230	8.7	357,900
Arkansas	82,198	40,837	7.8	330,456	164,637	24.8	288,925	144,423	14.8	164,875
California	17,000	17,000		1,487,878	998,288	22.3	129,976	74,930	3.6	448,063
Colorado	63,585	35,343	3.7	88,061	39,905	17.0	117,948	42,994	2.1	281,543
Connecticut	105,456	49,907	1.8	192,579	86,423	4.3	249,242	109,263	4.8	80,871
Delaware				262,653	128,712	7.3	148,223	59,293	8.8	158,438
Florida	112,906	56,453	4.4	1,026,052	512,576	7.4				251,187
Georgia	31,541	15,771	4.9	957,205	555,952	54.4	1,095,750	547,875	102.8	711,128
Idaho	106,084	62,208	8.7	189,796	116,707	10.4	40,937	7,402	1.2	235,432
Illinois	42,000	21,000	3.7	1,692,710	846,355	75.7	261,500	118,050	10.2	361,191
Indiana				1,333,305	633,496	71.7	406,400	203,200	14.8	598,434
Iowa	110,705	52,640	34.3	557,527	245,818	124.3	67,726	31,705	6.8	428,933
Kansas				1,558,781	786,561	84.5	1,117,004	556,006	132.1	694,943
Kentucky	188,419	49,500	7.0	1,103,256	275,888	49.5	878,089	232,224	61.6	204,713
Louisiana				564,708	230,289	20.6	289,362	138,761	21.5	446,100
Maine				14,200	7,100	.8				159,720
Maryland				689,000	344,325	19.6	113,000	56,500	2.9	199,221
Massachusetts	30,398	15,199	.4	764,718	398,912	13.7				362,739
Michigan	87,200	43,600	6.8	1,265,960	632,980	66.2	309,800	152,900	22.6	419,754
Minnesota	88,594	44,297	12.7	1,367,275	691,445	149.5	866,816	433,008	102.6	386,982
Mississippi				1,134,994	557,312	61.3	343,561	166,231	9.1	485,642
Missouri	55,672	27,836	4.5	491,716	233,275	36.7	488,802	203,003	75.9	787,133
Montana	29,368	16,572	1.1	394,715	224,332	49.6	41,962	23,859	10.3	659,491
Nebraska	30,772	15,386	5.0	671,127	340,841	67.8	77,778	38,889	17.6	384,779
Nevada				122,442	106,515	12.8	187,489	162,927	15.8	65,098
New Hampshire				155,106	76,532	4.7	187,417	92,808	3.5	88,885
New Jersey				499,182	261,105	11.0	472,020	231,875	17.4	354,146
New Mexico	51,831	32,472	11.5	374,625	236,375	31.1	64,258	41,550	3.6	178,277
New York	222,320	111,160	3.8	1,161,914	583,655	28.0	203,000	101,500	3.2	594,650
North Carolina	39,770	19,885	5.0	600,259	304,708	50.0	125,218	45,000	8.8	364,461
North Dakota				52,986	29,992	2.4	808,050	793,860	42.7	483,046
Ohio	262,720	131,360	7.1	1,860,560	977,855	55.5	452,870	210,500	4.8	846,492
Oklahoma	78,400	41,411	1.3	284,426	150,150	20.4	856,486	452,224	64.6	741,010
Oregon	16,615	10,140	3.2	567,153	289,503	41.3	211,366	96,830	21.3	190,785
Pennsylvania	385,828	192,914	7.4	1,961,267	969,567	37.7	160,564	80,282	2.9	41,831
Rhode Island	84,274	42,080	.9	126,824	66,911	1.7	3,920	1,960		63,989
South Carolina	18,217	7,500	5.6	626,450	241,666	38.0	353,000	135,124	11.5	164,848
South Dakota				25,302	15,768	9.0	1,153,880	1,053,460	120.8	489,674
Tennessee	27,640	13,820	.2	1,381,928	690,964	34.2	474,516	237,258	30.2	437,708
Texas	203,860	101,380	26.7	1,093,456	533,711	99.6	307,835	149,875	28.7	1,356,521
Utah	17,470	7,796	5.7	231,725	148,387	13.8				208,507
Vermont	34,027	17,013	1.2	2,192	1,096					91,346
Virginia	31,750	10,000	.6	474,190	231,352	17.0	202,000	82,152	2.5	383,586
Washington				420,865	244,139	20.3	145,651	39,700	6.4	222,924
West Virginia				704,324	351,549	26.2				320,571
Wisconsin	343,263	171,610	11.1	1,143,332	569,698	45.4	1,082,977	394,180	36.4	181,678
Wyoming	147,903	92,283	9.1	261,048	84,945	18.8	289,451	101,400	18.7	99,412
District of Columbia	56,011	28,000	.6	2,192	1,096		28,024	13,550	.3	74,394
Hawaii				1,096	1,096					250,559
Puerto Rico				231,364	112,855	10.6				134,597
TOTALS	3,499,010	1,757,263	219.2	33,858,121	17,045,130	1,725.4	15,472,562	8,050,991	1,105.1	18,111,315

U. S. GOVERNMENT PRINTING OFFICE: 1941

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

Work of the Public Roads Administration, 1940.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP . . Roadside Improvement. 10 cents.

No. 272MP . . Construction of Private Driveways. 10 cents.

No. 279MP . . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

Specifications for Construction of Roads and Bridges in National Forests and National Parks. 1 dollar.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP . . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF JULY 31, 1941

STATE	Completed During Current Fiscal Year: Estimated Total Cost	Federal Aid	Number: Grade Crossings Eliminated by Separation or Relocation	Number: Grade Crossing Structures Reconstructed	Number: Grade Crossings Protected by Signals or Otherwise	Under Construction: Estimated Total Cost	Federal Aid	Number: Grade Crossings Eliminated by Separation or Relocation	Number: Grade Crossing Structures Reconstructed	Number: Grade Crossings Protected by Signals or Otherwise	Approved for Construction: Estimated Total Cost	Federal Aid	Number: Grade Crossings Eliminated by Separation or Relocation	Number: Grade Crossing Structures Reconstructed	Number: Grade Crossings Protected by Signals or Otherwise	Balance of Funds Available for Programmed Projects
Alabama						$ 218,339	$ 216,539	3	3	3	$ 275,373	$ 275,151	5	2	5	$ 800,893
Arizona						168,266	168,266	1			29,350	29,350		1	2	208,296
Arkansas						452,612	452,283	5			173,273	171,563	1		4	336,347
California	$ 373,845	$ 188,129	1			1,315,838	1,309,865	9	1		23,290	23,290			8	1,473,769
Colorado	5,685	5,646				582,845	575,612	5			12,758	12,758	1			568,938
Connecticut	166,223	165,415	2								293,086	283,416		2		351,963
Delaware						94,135	94,135	1			697,074	508,721	3	1	1	51,500
Florida						341,563	340,574	4		5	564,570	560,314	4		34	709,591
Georgia	160,128	160,128	2	1		1,089,304	1,089,304	8	6	2	1,024,001	1,024,001	4	5	22	1,162,515
Idaho	11,301	11,301				216,402	207,730	2	1		120,444	120,444	2		4	252,590
Illinois	28,907	26,730			11	1,897,887	1,692,465	7	1	51	403,670	386,664	3		26	1,911,232
Indiana	2,033	2,033			2	787,687	775,200	6	1	6	195,859	190,150			47	832,885
Iowa						1,110,006	872,718	8	2	3	684,985	663,361	4	1	65	288,491
Kansas						383,757	383,757	8		2	424,799	424,484	3		10	955,756
Kentucky	87,515	87,515	2			996,297	995,297	6	1		147,955	141,842	2		1	352,675
Louisiana						454,657	454,657	6			449,979	448,812	5		1	766,047
Maine						113,072	113,072	1			278,011	278,011	1		1	115,569
Maryland	100,000	100,000	1			702,459	670,666	3	2	6	429,953	429,475	1		16	231,439
Massachusetts						435,901	425,263	2			1,408,925	1,407,670	6	3		908,141
Michigan	132,000	132,000				1,212,055	1,212,055	3	4	4	515,674	485,513	2		18	613,837
Minnesota	75,799	75,799		2		1,095,448	1,095,448	7	3		380,249	380,249	2	3	1	732,570
Mississippi	175,200	175,200	1			568,175	568,175	8			145,199	145,199	1	1	11	545,338
Missouri						2,034,922	1,579,502	6	4		59,161	59,161		1		1,289,828
Montana						174,019	174,019	2			65,416	65,416	1		2	464,383
Nebraska	112,950	112,950		1	2	1,006,679	1,006,679	17		6	201,067	201,067	6		17	139,173
Nevada						120,830	120,830	3			71,448	71,448	1		5	107,895
New Hampshire	63,682	62,862	2			144,098	144,098	1	1		162,246	161,946	3	1	2	203,156
New Jersey	214,360	214,360	2			978,013	852,463	4	1	1	356,760	316,805	1	2		802,451
New Mexico						2,560	2,560				259,103	252,068	3		1	403,805
New York	331,658	324,885		2		3,512,506	3,458,185	5	15		617,945	579,285		2		2,748,455
North Carolina	4,330	4,330			1	539,933	539,933	2	7	4	244,818	244,818	1		33	884,344
North Dakota	49,670	49,670	1			547,300	534,363	8			395,520	395,520	3			333,598
Ohio						2,410,587	2,379,544	11	1		1,896,627	1,591,430	7		7	1,059,082
Oklahoma	89,005	85,589	1		4	87,602	86,112	1		5	1,203,212	1,143,255	8		27	1,113,503
Oregon						420,835	357,222	5			10,523	10,523			5	390,976
Pennsylvania						3,724,763	3,690,554	22			1,273,167	1,266,570	8			1,587,188
Rhode Island						206,703	206,703		1							178,256
South Carolina	23,546	23,546			4	260,032	249,932	6	1	6	481,658	349,084	2	3	21	726,341
South Dakota	296,340	296,340	8			382,792	382,792	9			377,183	361,233	7		9	587,095
Tennessee	64,350	64,350	1	1		852,105	843,105	5	2		515,023	515,023	3	1		916,442
Texas	68,400	68,400	2			1,999,561	1,983,081	19			496,663	474,709	7		2	1,393,651
Utah	11,608	11,608			4	74,921	74,179	3		10	94,602	94,602			33	232,380
Vermont						257,986	257,986	2		3	3,297	3,297			1	50,478
Virginia						807,874	807,415	5	5		77,869	58,369	1		5	582,794
Washington						379,654	379,654	3	2		11,977	11,977			4	458,898
West Virginia						612,732	607,112	8		2	297,750	297,750	1	1	6	509,681
Wisconsin	10,624	10,624			2	870,371	840,387	5	2	7	177,335	177,335			39	1,156,114
Wyoming	163,685	163,685	1			316,421	316,420	4			5,322	5,322			5	290,375
District of Columbia						3,655	3,655				298,213	273,744		1		
Hawaii	192,574	192,567	2			212,708	212,193	2								181,412
Puerto Rico						742,969	735,496	10								337,988
TOTALS	3,015,418	2,815,662	29	7	30	37,921,836	36,539,255	271	67	126	18,332,382	17,372,195	113	31	501	33,300,124

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D. M. BEACH, *Editor*

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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SALES TAXES AFFECTING MOTOR-VEHICLE OPERATION

AN ANALYSIS OF GENERAL SALES TAX REVENUES RESULTING FROM MOTOR-VEHICLE OPERATION

BY THE DIVISION OF CONTROL, PUBLIC ROADS ADMINISTRATION

Reported by WILLIAM L. HAAS, Assistant Transportation Economist

Motor vehicle owners and operators contributed approximately $357,443,000 from 1932 to 1939 in the form of sales taxes affecting motor-vehicle operation. All but a very small part of this was directed to the general support of State governments and was not used for highway purposes. This amount was in addition to the regular highway-user tax contributions by motor-vehicle owners.

Collections from the various types of sales or excise taxes levied by the several States were very small in 1932, but increased rapidly in succeeding years. Although only 2 States levied sales taxes in 1932, 22 States were levying such taxes in 1939. In addition Kentucky and Maryland levied excise taxes specifically on motor vehicles.

Sales or excise taxes on new or used vehicles accounted for 64.5 percent of the total sales taxes levied on motor vehicles and allied automotive sales from 1932 to 1939. The next largest item was accounted for by the operations of filling service stations, parking lots, and auto hotels, whose contribution was 17.7 percent of the total. Garages and repair shops contributed 6.2 percent of the total while the sales of accessories, tires, batteries, and parts accounted for 5.7 percent.

Contributions of sales and excise taxes in 1938 averaged $4.40 per vehicle in the 24 States in which such taxes were levied. In the same 24 States the average highway-user taxes per vehicle were $35.22.

Sales taxes have not been initiated in recent years by any additional States but the increase in receipts from these taxes on motor-vehicle owners has been occasioned by the increase in motor-vehicle ownership, the increase in general price levels, and improved economic conditions.

Several kinds of taxes are imposed on the ownership and operation of motor vehicles, the most productive being taxes on motor fuel and the fees and licenses levied annually on motor vehicles. These taxes, commonly known as highway-user taxes, have been imposed directly upon motor-vehicle owners for many years.

A special study of the extent of such taxes in 1932, made by the Public Roads Administration,[1] indicated that more than one billion dollars was collected in that year from State, county, and local highway-user fees and taxes, personal property taxes, Federal excise taxes, and public bridge and ferry tolls.

Data collected annually by the Public Roads Administration indicate that the receipts from such taxes have increased so that the State motor-vehicle and motor-fuel taxes alone yielded approximately $1,250,000,000 in 1939. At the time of the special study in 1932 the general sales tax was but little used in the United States and yielded only a small amount of revenue. The effect of such taxation on motor-vehicle operation in 1932 was too small to warrant its inclusion in the special study. The study reported herein was, therefore, undertaken to supplement the special 1932 study of other taxes affecting motor-vehicle operation and the subsequent statistical summaries of such other taxes that have been made and reported each year since 1932.

The general sales tax, evidently a product of the depression, has grown rapidly in importance since 1932 so that its relation to motor-vehicle operation can no longer be ignored in any analysis of the total extent of taxes affecting motor-vehicle ownership and operation.

From 1932 through 1939, approximately $357,443,000 was contributed by motor-vehicle owners through sales taxes affecting motor-vehicle operation. This amount constituted 17.2 percent of the total of approximately $2,077,836,000 which was collected in general sales taxes, use or compensating taxes, and motor-vehicle excises in the States that levied such taxes during that period. The contribution by motor-vehicle owners, essentially all of which was directed to the general support of State governments and was not assigned for highway purposes, was accounted for by:

1. Taxes on sales of motor vehicles, amounting to $230,418,000 or 64.5 percent.
2. Taxes on filling and service station sales, amounting to $63,309,000 or 17.7 percent.
3. Taxes on garage and repair shop sales, amounting to $22,311,000 or 6.2 percent.
4. Taxes on sales of accessories, tires, and batteries, amounting to $20,360,000 or 5.7 percent.
5. Taxes on the sale operations of the automotive and petroleum industries, amounting to $17,276,000 or 4.8 percent.
6. Taxes on the sale of other allied motor-vehicle goods and services, amounting to $3,769,000 or 1.1 percent.

Only two States had imposed general sales taxes in 1932 and the revenue was relatively insignificant. In that year revenues from sales taxes on automotive goods were less than $200,000. By 1937, when 30 States had adopted and 22 States still retained a sales tax, the automotive portion of collections exceeded $75,000,000. Although the automotive portion in 1939 dropped slightly below $74,000,000, it is expected that with improved economic conditions and the probable adoption of sales taxes by additional States, the motor-vehicle portion will increase.

STUDY MADE TO DETERMINE EXTENT OF TOTAL HIGHWAY-USER TAXATION

While the concept of special taxes on the highway user to finance road improvements has generally been limited to such levies as registration fees and gasoline

[1] Then the Bureau of Public Roads. Report was published as "The Taxation of Motor Vehicles in 1932," G. P. St. Clair, October 1934.

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taxes, the amount of sales taxes paid on account of highway use is an important related problem. Some consideration has been given to the amount of highway-user taxes used for other than highway purposes but little thought has been given to the amount of these other taxes specifically resulting from motor-vehicle operation, of which only a small portion finds its way to the support of highways. Since all levies to which the motor-vehicle operator is subject because of his use of the highways directly affect the amount he is willing or able to pay for such highway services, the extent of all taxes affecting his use of the highways must be given adequate consideration in any taxing program.

Since the beginning of motor-vehicle transportation, almost every year has witnessed the imposition of a higher aggregate of specific taxes on the highway user. While the extent of direct taxation in the form of gasoline taxes and registration fees is largely a matter of general information, the public is not generally aware of the contributions, particularly in recent years, by the highway user in the form of other indirect but inescapable charges.[2] Legislators—Federal, State, and local—seeking new sources of revenue for various purposes, and undoubtedly impressed by the apparently inexhaustible source of funds which the highway user appeared to provide, soon cast covetous eyes in that direction for additional funds. The multiplicity of taxes now levied on the highway user is such as to make it almost impossible to determine the full extent of his contribution toward the support of government in the form of taxes resulting from his ownership and use of a motor vehicle.

The following summary of the principal taxes on motor-vehicle owners by the various governmental agencies outlines the types of taxes levied at the various levels of government.

1. Federal.
   Excise taxes on gasoline, lubricating oil, automobiles and motorcycles, trucks, tires and tubes, and parts and accessories.
2. State.
   a. *Special.*—Taxes on gasoline and lubricating oil; registration, title and operators' and chauffeurs' permit fees; gross receipts and ton-mile taxes; occupational and privilege taxes; road and bridge tolls.
   b. *General.*—Personal property and sales taxes.
3. County.
   a. *Special.*—Taxes on gasoline; registration fees and wheel taxes; operators' license fees; road and bridge tolls.
   b. *General.*—Personal property taxes.
4. Municipal.
   a. *Special.*—Taxes on gasoline; registration fees and wheel taxes, operators' license fees, operating and franchise taxes; road and bridge tolls and parking meter charges.
   b. *General.*—Personal property and sales taxes.
5. Other units.
   a. *Township, special road districts, etc.*—Personal property and special franchise taxes.
   b. *Special road and bridge authorities.*—Tolls.

These are by no means all of the taxes eventually paid by the motor user, but they illustrate the complexity of the problem. Partial figures on the various kinds and amounts of motor-vehicle taxation prepared by various governmental agencies, industrial organizations, and other interested parties are available, but these have been confined largely to State and Federal taxes.[3]

The report by the Public Roads Administration entitled "The Taxation of Motor Vehicles in 1932," published in 1934, is still the most comprehensive survey ever made of motor-vehicle taxation in the United States. However, that report purposely excluded indirect charges such as real property taxes on automotive properties (factories, garages, truck and bus terminals, etc.), State chain store and retail sales taxes, and income and similar taxes which are not levied directly on the ownership and operation of the motor vehicle.

SALES TAXATION AN IMPORTANT ELEMENT IN MANY STATE TAX SYSTEMS

Renewed attention has been directed recently to the problem of determining the extent of taxation, other than the specific highway-user taxes, imposed on motor-vehicle owners. Inquiry into State and local taxation has been made by field representatives of the Public Roads Administration in connection with the highway planning surveys. Efforts were directed toward making a general survey of conditions in each State relative to real and personal property taxes, special assessments, sales, and other special taxes on motor-vehicle ownership or operation, as well as on allied properties and businesses directly associated with the motor vehicle or its operation.

One of the primary facts disclosed by this investigation in several States is that general sales taxation has become an important element in many State tax systems. In 7 of the 22 sales tax States the tax has increased in importance until in 1937 it was the largest single source of revenue, displacing the gasoline tax which held this distinction for many years.[4] Moreover, examination of the reported collections from this type of tax indicated that motor-vehicle owners as a class contributed more than was ordinarily supposed. The magnitude of these contributions and the disclosure that these data were readily available prompted a Nation-wide survey to determine the approximate amount of sales taxes paid by the motor-vehicle owner.

The data were obtained by field representatives of the Public Roads Administration from the various State departments or sales tax department records, with the assistance of the highway planning survey personnel in many States.

Generally, sales tax data were available showing the amounts paid by the principal tax-paying groups. Though variations existed between the States in the business classifications followed, major groups were generally common to all States. In some instances it was necessary to use estimates provided by State officials or based on the previous or the following year's data. In the majority of cases, however, the desired information was available directly from the State records.

The data reported here vary in some instances from published figures, but these variations are the result of

[2] For recent trends in highway taxation, see Trends in Highway Financial Practices, a report of the Department of Highway Finance, Highway Research Board, Thomas H. MacDonald, chairman. Proceedings of the Nineteenth Annual Meeting, 1939, page 15.

[3] A special report, Local Imposts on Motor Vehicles in Missouri, by John H. Long and Bailey H. Mayes appeared in PUBLIC ROADS, May 1940, page 49.

[4] Ohio, Illinois, Michigan, Iowa, Missouri, North Dakota, and California; see Tax Systems, Eighth Ed., Tax Research Foundation, pp. 325–348.

necessary adjustments to allow for refunds, errors, and similar items. The amounts include penalties and interest, registration and permit fees, and merchants' or retailers' commissions. In some cases it has been necessary to present gross figures, but generally net figures are presented and all data are reconcilable to official published releases.

Although an attempt was made to obtain the sales tax data for the same fiscal period in each State, it was impossible to do so. Consequently, the data are presented for the fiscal period used in each State. The fiscal period applying to the data in the respective States is indicated in table 1. The period of this study extends from the year 1932, when the first retail sales tax was enacted, through the fiscal years ending during the calendar year 1939. For convenience of analysis and comparison, the States have been grouped according to the geographic divisions followed by the United States Bureau of the Census.

The sales tax employed by most States is a flat or ad valorem levy made upon the sale or gross proceeds derived from the sale of commodities, properties, or services. It may be imposed upon retailers, wholesalers, manufacturers, producers, public utilities, trades, occupations, or professions. It may be imposed upon the sales of a particular commodity or it may be restricted to sales of tangible personal property at retail for use or consumption. In any event the sales tax is usually paid by the ultimate consumer to the retailer or vendor, who pays the money to the State.

TABLE 1.—*Total collections from State general sales taxes, use taxes and motor-vehicle excise taxes, 1932–39*

Geographic division and State	Collections for fiscal year ending in—									Data for fiscal year ending—	Sales tax effective—
	1932	1933	1934	1935	1936	1937	1938	1939	Total		
Middle Atlantic:	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*		
New York [1]			23,156	7,623	[2] 15	[2] 26	[2] 15		30,835	June 30	May 1, 1933.
New Jersey [1]					6,937	[3] 157	[3] 81		7,175	June 30	July 1, 1935.
Pennsylvania [1]		9,122	[4] 442	[4] 240	[4] 65	[4] 61	[4] 20	[4] 4	9,954	May 31	September 28, 1932.
Subtotal		9,122	23,598	7,863	7,017	244	116	4	47,964		
East North Central:											
Ohio				48,105	57,979	52,015	40,969	47,911	246,979	December 31	January 27, 1935.
Illinois		36,633	39,034	53,912	71,823	83,281	79,193	87,137	451,013	December 31	July 1, 1933.
Michigan			34,872	38,798	46,596	55,309	51,706	51,503	278,784	June 30	July 1, 1933.
Subtotal		36,633	73,906	140,815	176,398	190,605	171,868	186,551	976,776		
West North Central:											
Iowa			[5] 44	11,288	13,442	15,041	15,693	15,810	71,318	June 30	April 1, 1934.
Missouri			4,257	6,602	11,608	17,202	20,924	22,868	83,461	December 31	January 15, 1934
North Dakota				1,966	2,742	2,886	2,806	2,905	[6] 13,305	December 31	May 1, 1935.
South Dakota					2,458	3,076	1,033	4,211	[7] 13,778	June 30	July 1, 1935.
Kansas							[8] 11,204	9,804	21,008	June 30	June 1, 1937.
Subtotal			4,301	19,856	30,250	38,205	54,660	55,598	202,870		
South Atlantic:											
Maryland [1]				1,955	3,135	710	438	516	[9] 6,754	September 30	April 1, 1935.
West Virginia			1,769	7,012	8,341	9,447	9,020	8,590	[10] 14,179	June 30	April 1, 1934.
North Carolina			6,012	7,658	10,184	11,328	11,013	10,998	[11] 57,193	June 30	July 1, 1933.
Subtotal			7,781	16,625	21,660	21,485	20,471	20,104	108,126		
East South Central:											
Kentucky [1]				9,317	7,220	1,380	1,121	955	[12] 20,023	June 30	July 1, 1934.
Alabama						2,903	5,544	5,882	14,329	September 30	March 1, 1937.
Mississippi	1,371	2,506	3,649	3,955	5,305	6,123	5,874	6,515	35,298	December 31	May 1, 1932.
Subtotal	1,371	2,506	3,649	13,302	12,525	10,406	12,539	13,352	69,650		
West South Central:											
Arkansas					3,269	4,309	4,655	5,032	17,265	June 30	July 1, 1935.
Louisiana [1]					597	3,539	4,428	6,219	14,783	December 31	October 1, 1936.
Oklahoma			3,825	4,768	5,835	11,501	12,650	11,784	[9] 50,363	June 30	July 10, 1933.
Subtotal			3,825	4,768	9,701	19,349	21,733	23,035	82,411		
Mountain:											
Idaho [1]				1,525	[13] 1,852				3,377	December 31	July 1, 1935.
Wyoming					1,484	1,776	1,944	1,809	7,013	April 30	April 1, 1935.
Colorado				4,411	6,603	8,119	8,414	9,231	36,778	December 31	February 2, 1935.
New Mexico			1,112	2,131	2,617	3,649	3,404	3,813	16,726	December 31	June 1, 1934.
Arizona			1,130	1,687	2,929	3,703	3,898	3,569	16,916	June 30	July 1, 1933.
Utah		14	1,731	2,496	2,967	3,412	3,465	3,636	17,721	June 30	May 1, 1933.
Subtotal		14	3,973	12,250	18,452	20,659	21,125	22,058	98,531		
Pacific:											
Washington					9,654	12,278	12,703	11,772	46,407	April 30	May 1, 1935.
California			46,586	60,615	73,286	88,411	86,732	89,471	445,101	June 30	August 1, 1933.
Subtotal			46,586	60,615	82,940	100,689	99,435	101,243	491,508		
Total	1,371	48,275	167,619	276,094	358,943	401,642	401,947	421,945	2,077,836		

[1] States that have repealed sales tax or permitted law to expire. Louisiana subsequently repealed sales tax effective December 31, 1940.
[2] Delinquent assessments; law expired June 30, 1934.
[3] Delinquent assessments; law repealed October 25, 1935.
[4] Delinquent assessments, penalties and interest; law expired February 28, 1933.
[5] Amount estimated; largely permit fees.
[6] Includes highway privilege taxes.
[7] Includes original license fees for calendar year.
[8] Data for 13 months; law effective June 1, 1937.
[9] Includes excise tax on motor vehicles.
[10] Includes tax on certification of title for motor vehicles.
[11] Includes highway privilege tax on motor vehicles.
[12] Includes motor-vehicle usage tax effective May 15, 1936.
[13] Includes approximately $89,000 delinquent collections made subsequent to repeal of law in 1936.

STUDY INCLUDED BOTH GENERAL SALES TAXES AND SPECIAL USE TAXES

This study is confined to the States levying general sales or use taxes on the sale of commodities and services variously designated as "gross receipts," "retail sales," "occupation," "use," "compensating," or "retailers." A general analysis of the operation of the various sales taxes in the several States was necessary to a determination of the relation of automotive goods taxation to the total sales taxation structure. Therefore, discussion of the basic principles of the operation of general sales taxation has been included in this report because the taxation of automotive goods under the general sales taxes is not an independent part of the tax structure.

Twenty-two States levied general sales or use taxes on the sale of commodities during 1939. It should be noted that neither the business or occupation taxes of West Virginia and Washington, nor the retail sales taxes levied by several larger cities, notably New York City, are included.

Connecticut, Delaware, Pennsylvania, and Virginia at present levy a restricted sales or merchants' license tax, but, because of their limited nature, the data for these States have been omitted from this study. Data for the general sales taxes imposed by Pennsylvania for a 6-month period in 1932–33, however, have been included. The gross income tax of Indiana is in the same category as general sales taxes, but because of the fundamental difference from the predominating type of "sales" taxes studied, data for that State were also omitted from the study.

Vermont passed a gross retail sales tax law effective in 1934, but it was declared unconstitutional in 1935 and was repealed by the legislature. The tax was in effect for approximately a year and yielded only a small amount of revenue. Consequently, Vermont's sales tax data have not been included in this study.

Similarly, Rhode Island imposed a restricted sales tax in 1932 to help finance unemployment relief. The law provided for levy and collection by local township authorities but was loosely interpreted and failed to produce the desired amount of revenue. Data for the Rhode Island sales tax were therefore also omitted from this study.

To make the data for the various States comparable, it was necessary to include certain special sales or excise taxes. For example, the motor-vehicle excise tax levied by Oklahoma is in effect a tax on motor-vehicle sales and therefore has been included. Likewise, it was believed desirable to include in this study the automobile usage tax levied by Kentucky, which is 3 percent on the retail price of the vehicle with standard equipment the first time it is registered in the State, and the excise tax levied by Maryland for every original motor-vehicle certificate of title issued at the rate of 2 percent of the fair market value.

The highway privilege tax in North Dakota, the original license fee in South Dakota, and the privilege taxes in West Virginia and North Carolina, all of which are in effect special sales taxes, have been included in this study. Maine, Massachusetts, New Hampshire, and Washington impose special excises or permit fees on motor vehicles. However, these imposts are in the nature of property tax levies, or in lieu of property taxes; they are not special sales excises and, therefore, have not been included in this study.

The extensive use of general sales taxation in the United States is evidently a product of the depression. Of the States included in this study, the earliest general sales tax law was enacted by Mississippi in 1932 and the latest States to impose sales taxes were Alabama and Kansas in 1937. In almost all cases, the primary reason for the original enactment of the sales tax laws was a desire to bolster declining revenues as well as to provide for property tax relief. In most cases, too, the sales tax was adopted as a duration-of-the-emergency measure, usually for a 2-year period, under the belief that conditions might later become such that the impost could be dropped from the State's tax system.

STATE SALES TAX REVENUES 1932–39 EXCEEDED 2 BILLION DOLLARS

However, the startling success of the sales tax as a revenue producer has made an impression on legislators and even the severest critics of the tax have had to admit its success in that particular. In addition, the period during which sales tax laws were most widely adopted witnessed an increasing demand by the people that the States assume new functions and provide new services. The social security programs inaugurated by the Federal Government and several States in recent years, probably more than anything else, have led many States to seek other sources of revenues than those on which they had previously relied. The ease with which the sales tax could be collected, the large sums that could be derived therefrom, and the quickness with which the tax could be applied for emergency purposes were factors leading to the adoption of this particular form of taxation by many States.

The total revenue derived by the States from general sales taxation since 1932 is well in excess of 2 billion dollars. The annual income to the States from this source during the last few years has been approximately 400 million dollars, the proceeds during 1939 being $421,945,000. In that year the sales tax income constituted 22.5 percent of the State tax revenues in sales tax States, evidence of the importance of sales taxes in the taxation systems of those States.

The relative magnitude of sales tax revenues in so many States suggests that reliance has been put on this form of taxation. The continued failure of property and other taxes to meet governmental requirements, the inertia of long established tax systems and consequent inability to meet rapidly changing social and economic conditions, the growing disapproval of the property tax as a major source of revenue, and the changing attitude on the part of the public toward the sales tax may result in the sales tax becoming more than a temporary or emergency tax.

A summary of the sales tax collections by years and the per capita collections are shown in figure 1 and table 2.

Table 3 presents data by States showing the relative importance of the sales tax in each State's fiscal structure in 1937 and 1939. Sales tax collections in 1937 represented 25.2 percent of the total State tax revenues, and although this percentage was only 22.5 in 1939, receipts, as shown in table 2, were actually greater than in 1937. This change was caused by the increasing importance in more recent years of such imposts as the unemployment insurance taxes. Of all the States, Illinois derived the greatest percentage of its revenue from the sales tax—47.4 percent in 1937 and 34.2 percent in 1939—while Louisiana obtained the least—5.1 percent in 1937 and 7.7 percent in 1939. Table 3 indicates that Maryland and Kentucky derive the lowest percentages of income from sales taxes; however, these States do not impose a general sales tax but only special excises on motor vehicles. The large proportion of total State revenues represented by sales taxes in many States indicates that there is probably no immediate prospect of

TABLE 2.—*Amount of annual sales tax collections, 1932–39* [1]

Year	Amount	Per capita [2]	Number of States imposing sales taxes [3]
	$1,000		
1932	1,371	$0.63	2
1933	48,275	2.35	9
1934	167,619	3.26	15
1935	276,094	4.23	24
1936	358,943	5.70	24
1937	401,642	6.58	22
1938	401,947	6.39	22
1939	421,945	6.71	22
Total	2,077,836		

[1] Includes motor-vehicle excises as well as general sales taxes.
[2] Based on United States Bureau of the Census 1940 population for sales tax States.
[3] In effect at end of calendar year.

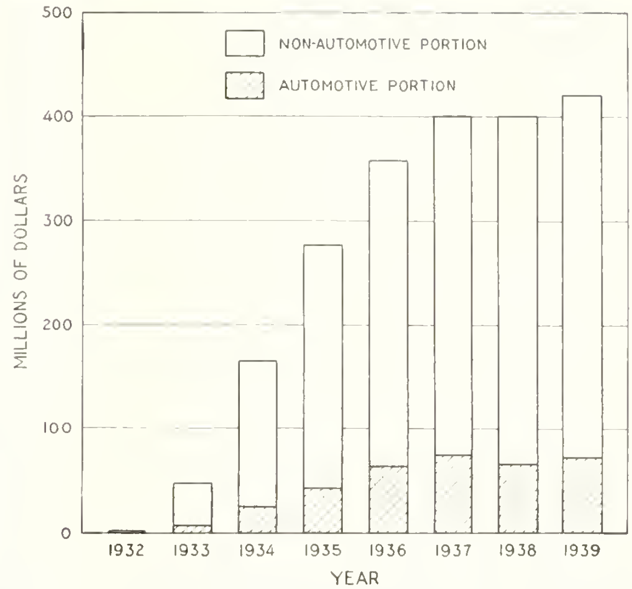

FIGURE 1.—ANNUAL REVENUE FROM SALES TAXATION SHOWING THE AUTOMOTIVE PORTION, 1932–39.

TABLE 3.—*Comparison of total State taxes and total sales taxes collected in 1937 and 1939*

Geographic division and State	Taxes collected in 1937			Taxes collected in 1939		
	Total State taxes [1]	Sales taxes		Total State taxes [1]	Sales taxes	
		Amount	Percentage of total		Amount	Percentage of total
East North Central:	*$1,000*	*$1,000*		*$1,000*	*$1,000*	
Ohio	235,632	52,015	22.1	255,588	47,911	18.7
Illinois	175,520	83,281	47.4	254,663	87,137	34.2
Michigan	148,027	55,309	37.4	169,944	51,503	30.3
Subtotal	559,179	190,605	34.1	680,195	186,551	27.4
West North Central:						
Iowa	65,149	15,041	23.1	69,002	15,810	22.9
Missouri	88,296	17,202	19.5	88,943	22,868	25.7
North Dakota	10,404	2,886	27.7	12,191	2,905	23.8
South Dakota	12,931	3,076	23.8	16,044	4,211	26.2
Kansas	25,515	(2)		41,501	9,804	23.6
Subtotal	202,295	38,205	18.9	227,681	55,598	24.4
South Atlantic:						
Maryland	33,942	[3] 710	2.1	44,721	[3] 516	1.2
West Virginia	46,603	9,447	20.3	52,626	8,590	16.3
North Carolina	73,300	11,328	15.5	77,453	10,998	14.2
Subtotal	153,845	21,485	14.0	174,800	20,104	11.5
East South Central:						
Kentucky	48,088	[4] 1,380	2.9	52,825	955	1.8
Alabama	41,992	2,903	6.9	48,978	5,882	12.0
Mississippi	27,020	6,123	22.7	29,580	6,515	22.0
Subtotal	117,100	10,406	8.9	131,383	13,352	10.2
West South Central:						
Arkansas	22,405	4,309	19.2	31,280	5,032	16.1
Louisiana	69,373	3,539	5.1	80,640	6,219	7.7
Oklahoma	59,712	11,501	19.3	61,210	11,784	19.3
Subtotal	151,490	19,349	12.8	173,130	23,035	13.3
Mountain:						
Wyoming	8,930	1,776	19.9	10,716	1,809	16.9
Colorado	29,964	8,119	27.1	35,589	9,231	25.9
New Mexico	13,120	3,649	27.8	15,492	3,813	24.6
Arizona	17,856	3,703	20.7	18,717	3,569	19.1
Utah	15,385	3,412	22.2	17,740	3,636	20.5
Subtotal	85,255	20,659	24.2	98,254	22,058	22.4
Pacific:						
Washington	67,750	12,278	18.1	65,767	11,772	17.9
California	253,828	88,411	34.8	319,953	89,471	28.0
Subtotal	321,578	100,689	31.3	385,720	101,243	26.2
Total	1,590,742	401,398	25.2	1,871,163	421,941	22.5

[1] From Tax Systems, eighth ed., The Tax Research Foundation.
[2] Sales tax effective June 1, 1937.
[3] Motor-vehicle excise tax only.
[4] Automobile usage tax only.

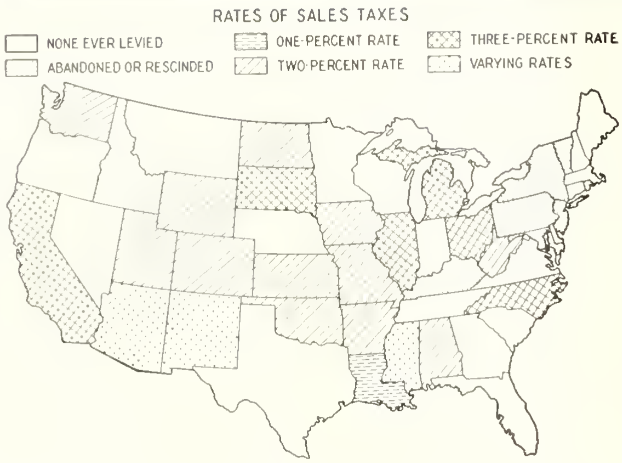

FIGURE 2.—STATUS OF THE STATE GENERAL SALES TAXES IN 1939.

eliminating such taxes from the revenue systems of those States.

The fact that 22 of the 30 States that have had sales taxes still retain them emphasizes the continued reliance by legislators on this tax to augment other sources of State revenue or to replace the decreasing revenues of certain out-moded taxes. Figure 2 shows that no region of the United States has escaped sales taxation entirely. Although eight States have discontinued their sales taxes, several others that do not now impose such levies have been seriously considering the adoption of this form of taxation. In Oregon sales tax proposals have been defeated twice by referendums and the Texas legislature has voted down a similar proposal. In several other States active sales tax blocs are continuing their campaigns for the adoption of such taxes.

It is significant, however, that none of the highly industralized States in the East now has a sales tax; the only area on the Atlantic seaboard north of North Carolina that has such a tax is New York City. It will be seen in figure 2 that six States in this area which at one time had sales taxes repealed them or allowed them to become ineffective. Only two other States in the rest of the country, Kentucky and Idaho,[5] discarded their sales taxes. The fact that none of the industrialized States on the eastern seaboard now has a sales tax may indicate the ability of those States to satisfy their revenue requirements from other tax sources, in contrast to southern and western States. However, the absence of such taxes may be caused by disapproval on the part of a public largely made up of wage earners, as compared with the larger portion of the population in southern and western States deriving relatively less of its total income from wages. Sales taxes normally would affect the wage earner more than the agricultural worker, since practically everything by which the former carries on the normal functions of living is subject to tax.

General acceptance of the sales tax appears to be based on the following principles:

1. Success and reliability as a revenue producer and ease of administration.

2. The fact that "everyone contributes a little." Although generally referred to as a "poor man's" tax, it is often defended on the grounds that the proceeds are usually earmarked for aid to the needy, aged, blind, dependent children, education, and such purposes.

[5] Louisiana subsequently repealed its sales tax, effective December 31, 1940.

USE AND COMPENSATING TAXES DESIGNED TO SUPPLEMENT SALES TAXES

Many sales tax States impose complementary taxes generally known as use or compensating taxes which are intended primarily to plug the loopholes of the sales tax acts. They are designed as companions to the sales tax to compensate the State for taxes that might be lost as a result of purchases made outside the State. A further purpose of the use tax is to enable local merchants to meet the competition of merchants in adjacent States which do not impose a sales tax.

In 1939, 18 of the 22 general sales tax States imposed special use or compensating taxes. In Arkansas, Colorado, and Louisiana, the use-tax features are incorporated into the sales tax laws. It can be expected that additional use taxes will be enacted in those States retaining or adopting a general sales tax inasmuch as merchants or retailers are likely to insist on the imposition of use taxes to meet competition in adjacent non-sales-tax States.

A more recent development in sales tax administration has been fostered by a United States Supreme Court decision which upheld the right of a State to tax sales made within the State on merchandise which is shipped to the buyer from a point outside the State. The Missouri Sales Tax Department subsequently issued a regulation requiring the payment of the sales tax on out-of-State purchases contracted for in Missouri. Other States are reported to have adopted similar regulations.

Another recent United States Supreme Court decision[6] held taxable under the use tax all sales made in Iowa including mail order sales filled from out-of-State mail order divisions. The Court ruled that companies may be compelled to collect use taxes provided they are registered to do business and maintain retail stores in the State. As a result of this decision, it is believed that sales tax States generally will attempt to collect taxes on sales made by mail order houses. Since a large percentage of these sales involve tires, batteries, parts and accessories, and other automotive equipment, it can be expected that the portion of the sales taxes attributable to the motor vehicle and its operation will show a substantial increase in the future.

Since the imposition of the first use tax by the State of Washington in 1935, the revenue produced by these taxes through 1939 amounted to $23,053,800. In 1939 the proceeds totaled $9,666,600 or 2.29 percent of the total sales and use-tax revenue. The use-tax receipts for the years 1936 through 1939 are shown in table 4.

TABLE 4.—*Collections from State use or compensating taxes, 1936–39* [1]

Tax year ending in—	Collections from use taxes: Amount	Collections from use taxes: Percentage of total sales tax collections
1936	$2,169,300	0.06
1937	4,153,300	1.03
1938	7,064,600	1.76
1939	9,666,600	2.29
Total	23,053,800	1.45

[1] Includes merchant's commissions and deductions.

[6] *Nelson et al.* v. *Sears Roebuck and Company*, and *Nelson et al.* v. *Montgomery Ward and Company*, February 17, 1941.

A large portion of the use taxes is attributable to automotive sales. Of the total of $23,053,800 in use-tax proceeds in the period from 1936 through 1939, approximately $8,276,300 or 35.9 percent was assessed against motor-vehicle and allied sales.

Of the 22 States that levied general sales taxes in 1939, 6 had rates of 3 percent, 12 had a 2-percent rate,[7] and 1 State imposed a 1-percent tax. The remaining 3 States imposed taxes at rates varying from one-eighth of 1 percent to 2½ percent (table 5).

Although the various sales tax laws in general provide for taxation of approximately the same sales, many differences exist with regard to taxable sales which come within the scope of the sales tax law either specifically or through administrative interpretation.

For example, the Illinois tax law provides that sales for resale are generally not taxable. Under the law, sales of milk, cream, sugar, etc., to a company to be used in manufacturing ice cream are not taxable, since the sales tax department rules that "sales of goods which, as ingredients or constituents, physically enter into and form part of tangible personal property sold by the buyer" are not sales at retail. "The test of a sale at retail is whether the sale is to a purchaser for use or consumption and not for resale in any form as tangible personal property * * * In general, the tax is intended to be measured by receipts from a sale which constitutes the last actual transaction prior to ultimate use or consumption." It is evident that many difficulties could arise in the interpretation of this provision.

In Mississippi, sales include "barter or exchange of properties as well as the sale thereof for money, every closed transaction constituting a sale."

[7] Alabama's rate on automobiles is ½ of 1 percent on new motor vehicles. All other sales are taxed at 2 percent.

In North Dakota, sales mean "any transfer, exchange, or barter, conditioned or otherwise in any manner or by any means whatsoever, for any consideration."

South Dakota defines sales as "sale of tangible personal property to the consumer or user thereof, or to any person for any purpose other than for resale."

The above examples of what is considered a sale subject to sales taxes are sufficient to indicate that the intent of the law is widely different in the several States. That the administration of the law varies considerably in the States is readily acknowledged by State tax administrators. At the eighth annual conference of the National Association of Tax Administrators held in St. Louis, Missouri, in May 1940, this lack of uniformity was admitted and a committee was appointed to draw up a uniform sales tax law for adoption by all States and a uniform set of regulations governing such a law.

EXEMPTIONS FROM SALES TAXATION DIFFER AMONG STATES

The sales tax laws usually state specifically the businesses or transactions which do not come under the provisions of the law. In all States, sales to the Federal Government and transactions in interstate commerce are not taxable. In some States exemptions are limited to the sales of gasoline and other items already taxed under another law. Other States extend the exemptions to include sales of real property, gas, electricity, and water, sales of food products for human consumption, etc.

Action has been taken by the Federal Government to prevent the imposition of State sales taxes on certain activities connected with the national defense program. The statement of the Government's position was given in a memorandum early in June 1941 from Acting

TABLE 5.—*States which have imposed general sales and use taxes, and status as of 1939*

State	General sales tax				Use or compensating tax	
	Year first effective	Status in 1939	Tax base	Rate	Tax in effect	Effective date
				Percent		
Alabama	1937	In effect	Gross receipts of sales	[1] 2	Yes	1937
Arizona	1933	do	Gross proceeds of sales	[2] Varying	No	
Arkansas	1935	do	do	2	Yes	1937
California	1933	do	Gross receipts of sales	3	Yes	1935
Colorado	1935	do	Gross proceeds of sales	2	Yes	1936
Idaho	1935	Repealed 1936				
Illinois	1933	In effect	Gross receipts of sales	3	No	
Iowa	1934	do	do	2	Yes	1937
Kansas	1937	do	Gross proceeds of sales	2	Yes	1937
Kentucky	1934	Repealed 1936				
Louisiana	1936	In effect [3]	Gross proceeds of sales	1	Yes	
Maryland	1935	Expired 1936				
Michigan	1933	In effect	Gross proceeds of sales	3	Yes	1937
Mississippi	1932	do	do	[4] Varying	Yes	1938
Missouri	1934	do	Gross sales receipts	2	No	
New Mexico	1934	do	Gross proceeds of sales	[5] Varying	Yes	1939
New Jersey	1935	Repealed 1935				
New York	1933	Expired 1934				
North Carolina	1933	In effect	Gross proceeds of sales	[6] 3	Yes	1939
North Dakota	1935	do	Gross receipts of sales	2	Yes	1939
Ohio	1935	do	Amount of retail sales	3	Yes	1936
Oklahoma	1933	do	Gross proceeds of sales	2	Yes	1937
Pennsylvania	1932	Expired 1933				
Rhode Island	1932	Abandoned	Retail sales	Varying	No	
South Dakota	1935	In effect	Gross receipts of sales	3	Yes	1939
Utah	1933	do	do	2	Yes	1937
Vermont	1934	Repealed 1935				
Washington	1935	In effect	Retail sales (selling price)	2	Yes	1935
West Virginia	1934	do	Gross proceeds of sales	2	No	
Wyoming	1935	do	Retail sales	2	Yes	1937

[1] Rate on new automobiles ½ of 1 percent.
[2] Rates from ¼ of 1 percent to 2 percent.
[3] Subsequently repealed, effective Dec. 31, 1940.
[4] Rates from ⅛ of 1 percent to 2½ percent.
[5] Rates from ⅛ of 1 percent to 2 percent.
[6] Rates on wholesalers 1/20 of 1 percent.

Attorney General Francis Biddle to John H. Hendren, Jr., Chairman of the Committee on Uniform Sales Taxation, National Association of Tax Administrators.

The memorandum stated that the Department of Justice would resist in the courts the imposition of State sales taxes or use taxes on cost-plus-fixed-fee contractors on the national defense program with respect to purchases of supplies and materials made by them. These taxes, it was pointed out, were in effect taxes on the Federal Government since the contractors were "instrumentalities of the United States."

The validity of taxes levied solely on vendors and legally absorbed as part of the sales price, and of nondiscriminatory State taxes levied on fees paid to contractors by the Federal Government, would not be challenged for the present, the Department stated.

According to the Department the statement was occasioned by the delay that had already occurred as a result of the imposition of sales taxes in certain States. Since there was no authority for the Government's disbursing officers to pay such taxes, payments had been withheld, and stoppage in the flow of critical materials to the construction sites had been threatened.

A number of States, by administrative action or legislative enactment prior to the Department's ruling, had already exempted the Federal Government and cost-plus-fixed-fee contractors from State taxes. The Department suggested that other States follow a similar procedure wherever possible and that the assessment or collection of taxes levied on defense work be withheld until the United States Supreme Court had had an opportunity to consider their validity.

Agricultural States usually exempt farm produce and agricultural products. Southern cotton-raising States generally exempt sales of cotton and cotton products. Some western States exempt sales of water for irrigation, domestic, and industrial use. Although personal services, labor, repair work, etc., are exempt in most States, Colorado and West Virginia levy a service tax which subjects these items to taxation. While there are a number of exemptions common to all States, each State apparently has particular transactions which it exempts for one reason or another.

Special efforts are made in many States to tax motor-vehicle sales. Some States (Oklahoma, Maryland, and Kentucky) resort to special excises. Other States have adopted a use tax or use-tax features to insure tax collections from motor-vehicle sales. Inasmuch as the manufacture of motor vehicles is confined to a small number of States, use or compensating taxes which provide for a tax on "property used or brought into a State" are particularly adapted to the taxation of vehicles. Additional safeguards are utilized in a number of States by provisions of the law which require the payment of the sales tax before a certificate of title or license can be issued. The sales tax law in other States specifically covers the sale of motor vehicles, and in three States the law provides for a special rate to apply to the motor vehicle.

In addition to these special provisions to insure taxation of the vehicle, practices differ widely as to the extent of taxation. A few States tax the vehicle only once, in the form of a single excise on new vehicles. Other States collect the tax upon new vehicles when first licensed in the State, and upon used vehicles only at time of first transfer of title during a calendar year. Still others tax each and every sale regardless of the number of times a vehicle may be involved in sales during the year, resulting in multiple taxation.

Following is a brief discussion of methods employed by various States to tax the motor vehicle. These methods have been classified as privilege taxes and original license fees, motor-vehicle excises, special use taxes, special sales taxes, and general sales taxes.

South Dakota collects an "original license fee" under legislation which provides that "in addition to any and all other license fees, registration fees, and compensation for the use of the highways, there shall be paid to the county treasurer upon the application for the first or original registration of a motor vehicle, an additional and further license fee of 3 percent of the purchase price of such motor vehicle or the fair market value thereof, whichever is the greater; the payment of such 3-percent license fee shall be in full and in lieu of all occupational, sales, excise, privilege, and franchise taxes levied by this State upon the gross receipts from all sales of motor vehicles." The proceeds go into the State general fund.

North Dakota imposes a "highway privilege" tax enacted primarily to protect dealers against the competition of dealers in non-sales-tax States. The rate is "2 percent of the sales price of any vehicle purchased or acquired for use on the streets and highways of this State requiring registration thereof under the motor-vehicle laws of North Dakota." The tax is collected at time of first registration and no registration plates or certificate may be issued until the tax is paid. The proceeds are credited 50 percent to the State Highway Department and 50 percent to the counties for highway purposes.

In addition to the taxes levied by any other law, North Carolina imposes upon every person for the privilege of using the streets and highways of the State a tax of 3 percent of the sales or purchase price of any new or used motor vehicle purchased or acquired for use on the streets and highways of North Carolina and requiring registration under the motor-vehicle laws of the State. However, no tax payment may exceed $15 and it must be paid at the time application is made for certificate of title or registration of motor vehicle. No certificate of title or registration plates are to be issued unless and until the tax is paid. The tax is also imposed on trailers. The proceeds are used for school purposes.

West Virginia imposes a tax upon certification of title for a motor vehicle. The tax is imposed for the privilege of effecting the certification of title of each motor vehicle in an amount equal to 2 percent of the value of vehicle at the time of certification. The proceeds go into the State road fund to be expended for construction and maintenance of secondary roads.

Oklahoma imposes an excise of 2 percent upon the value of the vehicle, to be collected upon the first transfer of title of used vehicles during the calendar year, as well as upon every new vehicle when first licensed in the State. Proceeds go to State assistance and general funds.

Kentucky imposes an automobile usage tax which is a special levy on the privilege of using the automobile. This special excise levies a tax of 3 percent on the retail price of the vehicle with standard equipment at the time of its first registration in the State. The proceeds go into the State general fund.

Maryland levies an excise tax for every original motor-vehicle certificate of title at the rate of 2 percent of the fair market value. This tax was imposed at a rate of 1 percent prior to September 30, 1939; after that date the rate was increased to 2 percent. The tax affects new cars primarily, but also affects used vehicles brought into Maryland from out of the State and registered in Maryland for the first time. The proceeds go into the general fund.

The Arkansas sales tax on motor vehicles is specifically collected under the use-tax law providing for the taxation of property purchased outside the State for use in Arkansas. Motor vehicles are specifically mentioned in the use-tax law. The proceeds are used for free textbooks, schools, homestead exemption, charitable institutions, and public welfare.

Iowa's use-tax law provides for a 2-percent excise on the value of motor vehicles and trailers to be collected by the county treasurer at the time the owner applies for a certificate of registration. No certificate can be issued until the tax is paid. The proceeds of the use tax go to the general fund.

The motor vehicle is taxed specifically in Mississippi under the general sales tax law at a special rate of 1 percent of gross proceeds of sale. Rates under the sales tax law vary from one-eighth of 1 percent to 2½ percent on specified transactions. Proceeds go into the State general fund.

The New Mexico sales tax law taxes the motor vehicle and allied businesses at the following rates:

	Percent
Car dealers (new and used cars)	½
Trucks and tractors	¼
All other businesses	2

Proceeds of this tax go into the school fund.

Sales of new motor vehicles are taxed by Alabama at the rate of one-half of 1 percent. All other sales are taxed at the 2-percent rate. The proceeds go into the State general fund.

In the remaining States, no specific provision is made to tax the motor vehicle, although it is subject to taxation under the general provisions of the sales tax laws. The proceeds are used for purposes of State general funds, relief, old age pensions, schools, and for similar purposes.

COLLECTION OF TAXES INSURED BY SPECIAL ARRANGEMENTS

A few States have special arrangements in tax collection procedure to insure the taxation of motor-vehicle sales. In Michigan, for example, the Secretary of State is made responsible for the collection of the sales tax on motor vehicles. The dealer is required to register the vehicle and secure title in the purchaser's name when the sale is made, and the application for registration must be accompanied by the sales tax payment. The Secretary of State renders an account of such collections to the proper administrative officials.

Likewise, Arkansas requires the sales tax on new automobiles to be paid before a license is issued even though the car may have been purchased outside the State. The law requires the commission to collect the tax before licensing a vehicle. Iowa's use-tax law provides for the collection of the sales tax on motor vehicles by the county treasurers at the time of application for certificate of title. No certificate can be issued until the tax is paid. Similarly, Oklahoma's motor-vehicle excise is collected on new vehicles at the time of first registration, and on used vehicles at the time of first transfer of title.

Other States are reported to have under consideration the adoption of similar provisions to secure the payment of sales taxes on motor vehicles.

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Gasoline for highway use is generally exempt from general sales taxation, but in some States where refunds of fuel tax or exemptions of the gas tax are permitted, special effort is made to impose the sales tax on tax-exempt gasoline sales.

In California motor-fuel sales for nonhighway purposes, which are subject to refunds, are liable for taxation under the sales tax act. The sales tax is collected by the State controller, who deducts the tax from the refund and transfers the amounts so collected to the sales tax fund. Iowa employs a similar method to collect the sales tax on refund gas sales. South Dakota also assesses sales taxes against refund-gasoline sales. The tax is collected by the State auditor at the time refunds are paid.

In North Carolina, there exists an unusual provision of the sales tax with regard to a tax on gasoline, whereby under certain conditions a tax can be levied on all gasoline sales. Apparently, it was not the intent of the law to exempt gasoline from the sales tax, nor was it considered expedient to levy a tax on the wholesale distribution of gasoline payable at the source of distribution. Therefore, to satisfy the intent of the law, a portion of the gasoline tax of 6 cents per gallon is to be determined and deemed in satisfaction of the sales tax as follows: The director of the budget, the chairman of the highway commission, and commissioner of revenue in the first 15 days of each quarterly period determine the total amount of gasoline sold in the State in the preceding 3 months, and the average retail price, inclusive of gasoline tax, and on this basis compute the amount of tax liability at the rate of tax levied on retail sales. The sum so computed shall be deducted from the tax of 6 cents a gallon and credited by the State treasurer to the sales tax revenue account.

These sums are made available only after full provision has been made for the expense of collecting highway revenues, for the administration of the highway and public works commission, for the service of the debt, and for reasonable maintenance of State and county highways. Nor is the money available to the general fund unless the director of the budget finds such sums to be reasonably necessary to meet appropriations from the general fund. The amount so allocated to the general fund shall not be transferred from the highway fund nor become a definite charge against it until the surplus in the general fund at the end of the fiscal year, together with current revenues, has been exhausted or until the director of the budget finds that such a transfer is necessary to prevent a deficit in the general fund or until the appropriations from the highway funds have been provided for. However, no gasoline tax receipts have been diverted to the general fund by the director of the budget in recent years.

EVASION OF SALES TAXATION BELIEVED PREVALENT

In the other sales-tax States no special effort is made to collect the sales tax on refund or tax-exempt gasoline sales presumably used for nonhighway purposes. Another problem which is part of the question of sales taxes on gasoline is the condition that exists in a few States where the tax on sales of gasoline constitutes a tax on the price of the gasoline plus the State and Federal gasoline taxes. This condition of multiple taxation can be avoided only by careful drafting of the enabling legislation, as it appears that it is not the legislative desire to enact laws that cause such multiple taxation.

Opinion is rather prevalent among tax officials that there is considerable evasion of sales taxes. The adoption of use or compensating taxes in many States was designed to plug the loopholes in the sales tax acts and to prevent "legal evasion" through interstate sales. The failure of the use taxes to accomplish this purpose is evidenced by the fact that use taxes have not been successful as revenue producers. However, failure of the use tax to produce revenue is not in itself proof of the failure of that tax to function properly. It may perform its function by decreasing the purchase of goods in non-sales-tax States with a resultant increase of purchases in the State of residence and a corresponding increase in the sales-tax collections. The latter increase takes the place of any increase in the receipts from use taxes but results directly from the presence of the use tax on the statute books.

Evidence of failure of the compensating tax is found in the admission of tax administrators. A typical comment on the subject is that of the State Tax Commission of Kansas.[8]

Corporations and others that keep books or accounts have very little chance of avoiding this tax, but individuals purchasing motor vehicles, trailers, farm machinery, mechanical equipment, office furniture and fixtures, household goods and furnishings, radios, jewelry, etc., that do not keep records are not voluntarily declaring and paying the compensating tax. It is extremely difficult, takes a great deal of time, and is very expensive to locate purchases of this kind, assess and collect the compensating tax on them.

Because of the great number of retailers who are required to report the sales tax, there is undoubtedly a considerable number who fail either to collect or to remit the full amount of the tax as required by law. In some States this condition cannot be corrected because of the small administrative force available to enforce the sales tax. Unquestionably the lack of sufficient auditors to audit the records of such a large number of retailers tends to encourage the evasion of taxes.

It is the general opinion of tax officials that the motor vehicle often escapes general sales taxation entirely unless provisions are adopted to insure the payment of taxes such as requiring a sales tax receipt before a vehicle license can be issued. This condition, coupled with the belief that the ownership of a motor vehicle indicates a superior tax-paying ability, has caused the adoption of safeguards to insure the payment of the taxes on motor vehicles and has promoted zealous efforts in the collection of these taxes.

Sales tax officials also believe that the sales of tires, batteries, parts, and similar motor-vehicle accessory items through large mail-order houses largely escape taxation, notwithstanding the fact that the use taxes were designed to tax sales of this kind.

COLLECTION AND ADMINISTRATION COSTS UNUSUALLY LOW

Although no attempt was made in this study to determine the actual administrative and collection costs of the sales tax, it has been generally reported that these costs have been unusually low, in some cases less than 1 percent of the total collections. This unusually low cost has contributed much to the ready acceptance of sales taxation, and inasmuch as this item is an important reason for the remarkable showing of sales taxes, the subject warrants some consideration.

In most States, the retail merchants are made involuntary agents of the State in collecting the sales tax. The collection of this tax from the consumer population of each State is practicable only because the retailer or vendor acts as a tax collector. While the tax-paying group almost approximates the total population of the States, the tax is actually collected and paid over to the State by the relatively small number of retailers or vendors operating in each State. The administrative machinery of the State needs to function, therefore, only between the State and the retailers or vendors and not between the State and the hundreds of thousands or millions of tax-paying consumers. Thus, the expense of collection is borne by the merchants, who in the majority of cases are not reimbursed.

Another reason for the low cost of collection is due in part to the lack of effective enforcement. Legislators appear to be more than pleased with the revenue produced by the sales taxes, and as a result they have failed to appropriate sufficient funds for adequate enforcement. A typical official observation on the administrative side of the sales tax is given in the following excerpt from the Biennial Report of the Department of Revenues 1936–38 for the State of Arkansas, pages 56–57.

Due to the great number of retailers required under the law to collect and remit the tax, there is found a considerable number who either neglect or fail to remit the tax as required by law, and it appears beyond a doubt that in many cases they do not collect the tax * * * the law itself was inducive to evasions in the beginning, and is to some extent at the present time. Act 233 of 1935 allowed so many exemptions that it was hard to administer when everything worked together because of the loopholes wherein retailers could claim exemptions to which they were not entitled. In the passage of Act 154 of 1937, most of the exemptions were removed but still there were insufficient restrictions left around the exemptions allowed, especially exemptions of items sold for resale. Through this avenue the State has lost many thousands of dollars it should have collected. The principal other difficulty is a result of not having had previous experience in collecting a tax of such wide spread in that sufficient administrative force was not provided, especially there were not sufficient auditors allowed to audit a very large percent of the retailers who were collecting the tax.

It should be mentioned that many States compensate in an indirect manner the merchants who collect the sales tax. The retailer or merchant collects the tax on each individual sale but is permitted to pay the State on a gross sales basis. The reimbursement would be small in most cases, especially in those States that collect the tax through the use of mill tokens. In those States in which a bracket system is employed, however, it is conceivable that there would be considerable difference between the tax collected on individual sales and the tax collected on a gross basis.

For example, assume a State imposes a 2-percent tax, or 1 cent for all sales from 15 cents to 65 cents. A business selling low-priced articles collects the tax on 100 individual articles costing an average of 25 cents each. The total tax collected from the individuals is $1. The tax settlement to the State, however, would be on the basis of gross sales of $25 at the tax rate of 2 percent which would be 50 cents. The merchant in this particular case would have profited to the extent of 50 cents as the result of the transactions.

It is obviously impossible to estimate the amount of deductions permitted in the above manner but it is evident that the amounts involved conceivably could reach large proportions. These legitimate collection charges are, of course, never included with the costs of administering the tax.

Since the adoption of the first general sales tax and

[8] Sixteenth Biennial Report of the Tax Commission, 1936–38. Pp. 14A and 15A.

until 1939 only five of the 28 sales tax States permitted commissions to merchants and agents for the collection of taxes.[9] Three States, Kentucky, Missouri, and Ohio, allowed a 3-percent deduction, while Louisiana and Colorado [10] both permitted 5 percent commissions on sales and use taxes, although the latter State allowed only 3 percent deductions on service taxes. The States of Oklahoma and Alabama subsequently compensated the merchants at a 3-percent rate effective June 1, 1939, and October 1, 1939, respectively.

The approximate total of merchants' commissions allowed during the period of this study in the five States was $11,549,800 or 3.1 percent of the total sales tax collections. These deductions are never reported as legitimate costs of collection; consequently, this fact has undoubtedly contributed much toward the popular belief that the collection and administrative costs of sales taxes are unusually low.

Inasmuch as these commissions properly should be included as tax collections in order to show actual collections, they have been added to the proper State totals. The estimated amount of these deductions attributable to the motor vehicle was determined by the relationship of the automotive portion to the total sales taxes contributed in the States permitting commissions to merchants. The amounts for each of the five States are shown in table 6.

TABLE 6.—*Approximate amount of merchants' deductions and commissions permitted for period 1935–39* [1]

Year	Colorado	Missouri	Louisiana	Ohio	Kentucky [2]	Total
1935	$219,900			$1,443,200	$280,400	$1,943,500
1936	327,000			1,739,400	216,200	2,282,600
1937	386,200	[3] $331,100		1,560,400	28,400	2,306,100
1938	382,300	548,200	$97,800	1,229,100	22,700	2,280,100
1939	415,400	604,200	261,500	1,437,300	19,100	2,737,500
Total	1,730,800	1,483,500	359,300	7,409,400	566,800	11,549,800

[1] For fiscal years reported: Oklahoma and Alabama permitted commissions effective 1939 after close of fiscal period.
[2] Merchants retained 3 percent of gross receipts tax; clerks retain 2 percent of vehicle usage tax.
[3] Commission effective June 1937, estimated for 7 months.

COLLECTIONS SEGREGATED BY MAJOR BUSINESS CLASSIFICATIONS

Most of the sales tax laws require the administrative agency to keep records of the collections. As a result it was possible to obtain relatively satisfactory data for tax payments by major business classifications as follows:

- Apparel.
- Automotive.
- Contractors–consumers.[11]
- Farm and garden produce.
- Food.
- Furniture and fixtures.
- General merchandise.[12]
- Hotels, amusements, liquor stores.
- Lumber and building.
- Manufacturing, jobbing, trading.
- Professional and personal service.
- Public utilities.
- Unclassified.[13]
- All other.

[9] Kentucky permitted such commissions while its sales tax was in effect.
[10] 5 percent on sales and use taxes, 3 percent on service taxes.
[11] Includes construction, industrial, mercantile, governmental, public utility, private institutions, and miscellaneous individual consumers.
[12] Includes department and general stores, dry goods, hardware and paint, jewelry, sporting goods, five and ten, drug stores, etc.
[13] Includes amusements, hotels, newspapers, magazines, farm implements, liquor stores, recreation parlors, coal, fuel, ice, drug stores, hardware, theaters, barber shops, etc.

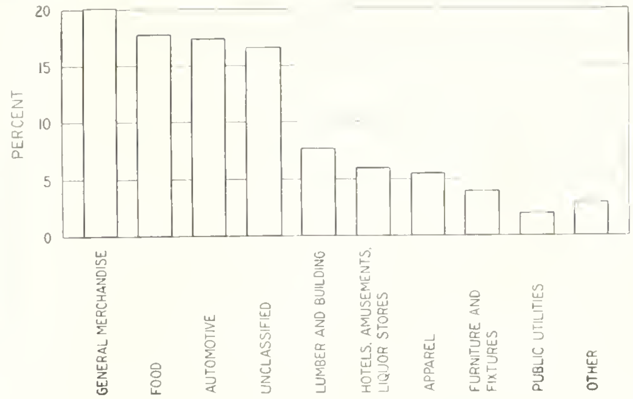

FIGURE 3.—PERCENTAGE DISTRIBUTION OF SALES TAX COLLECTIONS BY MAJOR BUSINESS CLASSIFICATIONS IN 1939.

These classifications were by no means uniform in the States, but they were sufficiently similar in their grouping to permit the arrangement of the data for general comparative purposes. While these classifications were generally maintained in most States, there were many differences in the States within a major business group. Obviously, it is practically impossible to obtain a standard classification of the thousands of businesses. Furthermore, a few States used more or less general classifications and it was impracticable to obtain the data in the desirable detailed form.

In order to establish the relative importance of the major business groups with regard to their contributions in sales taxes, the tax collections were compiled by the groups indicated above. Although data were obtained for a number of years for those States that have repealed as well as those that have retained a sales tax, it was believed little significance could be attached to data for States that no longer levy the tax. Consequently, the contributions by each major business group are presented for the fiscal years ending in 1939 for the present sales tax States. The detailed data by States for the various business classifications are given in table 7 and are summarized in table 8, which shows that in 1939 the largest sales tax contributions were made by the general merchandise group with 20.2 percent of the total. The second largest contribution was by the food group with 17.8 percent of the total. This group was closely followed by the automotive group with 17.4 percent of the total tax payments. The unclassified group represents 16.6 percent of the total. Payments by the remaining business groups range in importance from the lumber and building group with 7.7 percent down to the farm and garden produce group with an insignificant 0.1 percent. The relative importance of the several groups is also shown in figure 3.

The total collections by the 22 sales-tax States and the two States having motor-vehicle excises in 1939 amounted to $421,941,000 or $6.71 per capita.[14] The largest per capita payment was by the general merchandise group with $1.35. Second largest was the food group with $1.20 per capita, closely followed by the automotive and unclassified group representing $1.17 and $1.11, respectively. The remaining groups ranged from lumber and building with $0.52 to contractors–consumers and farm and garden produce with $0.01 per capita.

[14] Based on United States Bureau of the Census total for 1940 of 62,875,746.

TABLE 7.—*Sales, use, and motor-vehicle excise tax collections by major business classifications in 1939*

Geographic division and State	Apparel	Automotive	Contractors-consumers	Farm garden produce	Food	Furniture and fixtures	General merchandise	Hotels, amusements, liquor stores	Lumber and building	Manufacturing, trading, jobbing	Professional and personal service	Public utilities	Unclassified	All other	Total
	$1,000	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*
East North Central:															
Ohio	6,100	9,358			5,492	2,426	12,969		3,014				8,552		47,911
Illinois	6,094	13,755		188	18,200	2,676	14,302	8,817	5,088				18,017		87,137
Michigan	3,606	10,257			15,008	1,660	7,187		3,157				10,628		51,503
Subtotal	15,800	33,370		188	38,700	6,762	34,458	8,817	11,259				37,197		186,551
West North Central:															
Iowa	845	2,373	244	67	3,420		3,128		1,364	582	84	1,265	2,046	[1] 392	15,810
Missouri	1,285	3,264		204	5,782	824	3,078		1,340		17	2,182	4,173	[2] 719	22,868
North Dakota	267	591		5	609	39	608		193	37	11	179	344	[3] 22	2,905
South Dakota	176	817		8	891	72	1,202		272	23	15	314	421		4,211
Kansas	440	1,505		24	2,591	265	2,030		568	324	69	1,004	984		9,804
Subtotal	3,013	8,550	244	308	13,293	1,200	10,046		3,737	966	196	4,944	7,968	1,133	55,598
South Atlantic:															
Maryland		512												4	[4] 516
West Virginia	500	957			2,350	228	2,953		521		650		169	[5] 262	8,590
North Carolina	915	1,435			2,242	755	4,075		629				947		10,998
Subtotal	1,415	2,904			4,592	983	7,028		1,150		650		1,116	266	20,104
East South Central:															
Kentucky		951												4	[6] 955
Alabama	253	582			1,731	178	1,961		363				814		5,882
Mississippi	202	975			1,388	130	1,609		411	560		436	732	[7] 72	6,515
Subtotal	455	2,508			3,119	308	3,570		774	560		436	1,546	76	13,352
West South Central:															
Arkansas	157	673	17		1,021	127	1,288		264			482	1,003		5,032
Louisiana	305	1,522			1,440	268	500		654				1,530		6,219
Oklahoma	520	2,416	44		2,517	332	2,793		727		630	1,176	629		11,784
Subtotal	982	4,611	61		4,978	727	4,581		1,645		630	1,658	3,162		23,035
Mountain:															
Wyoming	67	273			415	39	410		120	76	9	194	202	[8] 4	1,809
Colorado	514	1,358	143	50	1,933	223	1,661	186	453	429	591	554	823	[9] 313	9,231
New Mexico	75	320	134		698	85	1,028	68	220	199	229	198	4	[10] 555	3,813
Arizona		354	93		191			75		64		175	2,562	[11] 55	3,569
Utah	213	542			817	173	671	84	229			285	622		3,636
Subtotal	869	2,847	370	50	4,054	520	3,770	413	1,022	768	829	1,406	4,213	927	22,058
Pacific:															
Washington	671	1,818			2,888	631	1,942		1,442				2,130	[12] 250	11,772
California		16,892			3,611	5,402	19,745	[13] 15,723	11,464				12,822	[14] 3,812	89,471
Subtotal	671	18,710			6,499	6,033	21,687	15,723	12,906				14,952	4,062	101,243
Total	23,205	73,500	675	546	75,235	16,533	85,140	24,953	32,493	2,294	2,305	8,444	70,154	6,464	[15] 421,941

[1] Includes taxed gasoline sales of $150,312; the balance is use tax.
[2] Includes admissions, news, advertising, and natural resources.
[3] Use tax $6,880 and penalties and interest $14,904
[4] Excise tax on motor vehicles; includes $4,124 collections of delinquent assessments 1935 sales tax.
[5] Tax on liquors.
[6] Motor-vehicle usage tax; includes $3,732 collections of delinquent assessments 1935 sales tax.
[7] Tax on natural resources.
[8] License fees.
[9] Service tax business, rental, and custom service.
[10] Includes tax on natural resources of $547,710.
[11] Printing and publishing $36,426; other $18,808.
[12] Penalties and interest.
[13] Includes drugs, tobacco, confectionery, meals, and beverages.
[14] Includes books, stationery, musical instruments, and permits.
[15] Does not include $4,000 in delinquent collections in New York, which are included in table 1.

TABLE 8.—*Sales, use, and motor-vehicle excise tax collections in 1939 by major business classifications*

Business class	Amount	Percent	Per capita [1]
	$1,000		
Apparel	23,205	5.5	$0.37
Automotive	73,500	17.4	1.17
Contractors-consumers	675	.2	.01
Farm and garden produce	546	.1	.01
Food	75,235	17.8	1.20
Furniture and fixtures	16,533	3.9	.26
General merchandise	85,140	20.2	1.35
Hotels, amusements, liquor stores	24,953	5.9	.40
Lumber and building	32,493	7.7	.52
Manufacturing, jobbing, trading	2,294	.6	.04
Professional and personal services	2,305	.6	.04
Public utilities	8,444	2.0	.13
Unclassified	70,154	16.6	1.11
All other	6,464	1.5	.10
Total	421,941	100.0	6.71

[1] Based on data of the United States Bureau of the Census for 1940 showing population in the 22 sales tax States and two motor-vehicle excise States of 62,875,746.

TABLE 9.—*Comparison of total collections from sales taxes and automotive sales taxes by geographic divisions in 1939* [1]

Geographic division	Total sales taxes	Automotive sales taxes	Percentage automotive of total	Amount per capita [2]	
				Total sales	Automotive sales
	$1,000	*$1,000*			
East North Central	186,551	33,370	17.9	$9.30	$1.66
West North Central	55,598	8,550	15.4	5.91	.91
South Atlantic	20,104	2,904	14.4	2.76	.40
East South Central	13,352	2,508	18.8	1.70	.32
West South Central	23,035	4,611	20.0	3.46	.69
Mountain	22,058	2,847	12.9	7.46	.96
Pacific	101,243	18,710	18.5	11.71	2.16
Total	421,941	73,500	17.4	6.71	1.17

[1] For only the 22 sales-tax States and the 2 States having motor-vehicle excises.
[2] Based on 1940 population, United States Bureau of the Census.

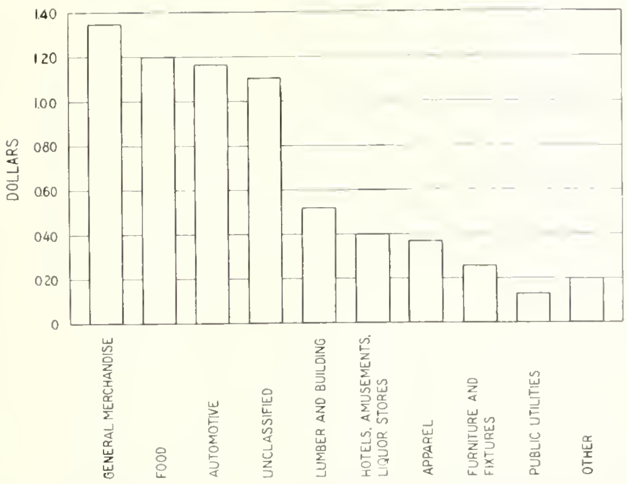

FIGURE 4.—PER CAPITA SALES TAX COLLECTIONS BY MAJOR BUSINESS CLASSIFICATIONS IN 1939.

The per capita total collections by geographic divisions varied from $1.70 in the East South Central to $11.71 in the Pacific region. A partial explanation of the low per capita figures for the South Atlantic and East South Central States is that the Maryland data in the former group and the Kentucky data in the latter group represent only motor-vehicle excise taxes and not general sales taxes (table 9).

The per capita payments of the automotive group totaled $1.17 (fig. 4). The per capita payments varied from $0.32 in the East South Central division to $2.16 in the Pacific group.

TAX COLLECTIONS FROM AUTOMOTIVE GROUP LARGE

In this study the automotive group was more thoroughly investigated than the other groups in order to determine the exact nature of the taxable transactions. Data were obtained and compiled by the following businesses within the automotive group:

New and used cars and dealers.
Garages and repair shops.
Accessories, tires, batteries, parts, etc.
Filling and service stations, parking lots, auto hotels.
Vehicles for hire, truck and bus lines.
Other automotive.
Motor-vehicle excise, original license fees, etc.
Petroleum and automotive industries, refund gas sales.

In order to determine the total contributions resulting from new and used car sales, that group and the motor-vehicle excises should be combined. The separation of these related items was maintained because in all cases the excises were special taxes levied on the motor vehicle, whereas the others were general taxes. "Other automotive" includes collections from automotive stores and miscellaneous sales not included in other classifications.

It should be noted that the taxes paid by the petroleum and automotive industries are not directly paid by the motor-vehicle owner or user; however, they are eventually paid by the owner, inasmuch as these taxes are passed on to the ultimate user.

Refund gas sales represent taxes collected on sales of gasoline on which refunds of the gasoline tax itself are permitted. Presumably the use of such gasoline is for nonhighway purposes in which case the sales taxes collected should not be credited to the motor user. However, because of the close relationship to the automotive and petroleum industries and because it presents a special problem in some States, these tax payments have been included.

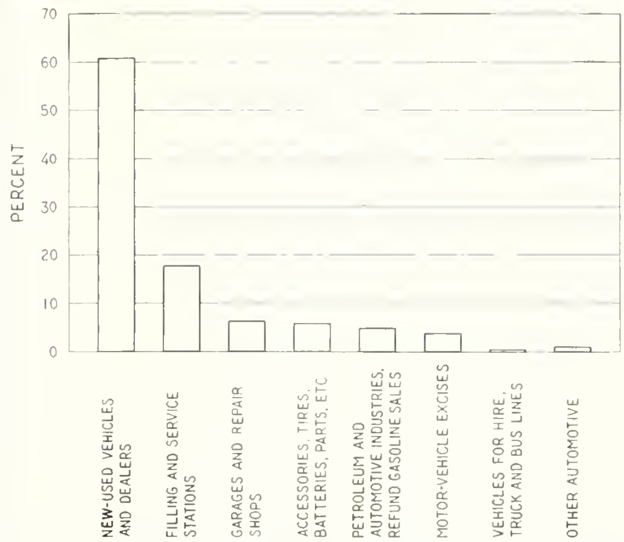

FIGURE 5.—PERCENTAGE DISTRIBUTION OF AUTOMOTIVE GROUP SALES TAXES BY MAJOR CLASSES, 1932–39.

Although the business separation of the motor-vehicle group was generally maintained, some States failed to maintain a satisfactory breakdown and as a result it was necessary to resort to estimates. In such cases these were usually prepared with the assistance of the sales tax officials. In other cases, when only a particular year's or several years' data were not properly separated an estimate was prepared based on the previous or following year's data. As can be expected, the separations were not always maintained in a comparable manner and in a few instances a detailed segregation was not attempted in this study.

From the time of the imposition of the first general sales tax in 1932 through 1939, the total contributions in State sales taxes by the automotive groups were $357,443,000, or 17.2 percent of the total sales tax collections. The taxes levied on the motor-vehicle and allied businesses have increased from less than $200,000 in 1932 to an annual total in 1939 of more than $73,000,000. The highest contribution in a single year was in 1937 when the motor-vehicle group paid $75,703,000 in sales taxes, or 18.8 percent of the total collections.

The annual collections from taxes levied on motor-vehicle and allied automotive sales in each State since the first tax was initiated in 1932 are shown in table 10. It is anticipated that the total taxes of this kind for 1940 may exceed the previous high figure of 1937, due principally to the large sales of automobiles in 1940, an item which, as can be seen in table 11 and figure 5, accounted for almost two-thirds of the taxes collected on automotive sales.

All sections of the country represented in this study show approximately similar percentages of contributions of the total sales taxes credited to the automotive group. In 1939 the South Atlantic area showed the lowest percentage, with 14.4 percent of the total, and the West South Central area showed the highest, with 20 percent of the total (table 9).

Table 10.—*Total sales taxes collected from motor vehicles and allied automotive sales, 1932–39*

Geographic division and State	Taxes for fiscal year ending in—								
	1932	1933	1934	1935	1936	1937	1938	1939	Total
Middle Atlantic:	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*
New York			4,330	1,707					6,037
New Jersey					[1] 650				650
Pennsylvania		[2] 1,368							1,368
Subtotal		1,368	4,330	1,707	650				8,055
East North Central:									
Ohio				6,638	10,225	11,331	6,659	9,358	44,211
Illinois		5,092	5,440	7,876	10,982	12,855	11,746	13,755	67,746
Michigan			5,771	7,258	10,136	12,753	9,856	10,257	56,031
Subtotal		5,092	11,211	21,772	31,343	36,939	28,261	33,370	167,988
West North Central:									
Iowa			6	1,439	2,008	2,414	2,477	2,373	10,717
Missouri			464	737	1,515	2,337	2,564	3,264	10,881
North Dakota					426	460	461	591	1,938
South Dakota					408	511	667	817	2,403
Kansas							1,850	1,505	3,355
Subtotal			470	2,176	4,357	5,722	8,019	8,550	29,294
South Atlantic:									
Maryland				485	901	594	397	[3] 512	2,889
West Virginia			85	506	1,097	1,258	1,077	957	4,980
North Carolina			782	995	1,324	1,473	1,432	1,435	7,441
Subtotal			867	1,986	3,322	3,325	2,906	2,904	15,310
East South Central:									
Kentucky				1,036	680	1,299	1,092	951	[4] 5,058
Alabama						267	472	582	1,321
Mississippi	191	336	497	549	753	883	828	975	5,012
Subtotal	191	336	497	1,585	1,433	2,449	2,392	2,508	11,391
West South Central:									
Arkansas					540	584	619	673	2,416
Louisiana					159	1,098	1,031	1,522	3,810
Oklahoma			956	1,394	1,443	2,825	3,053	2,416	12,087
Subtotal			956	1,394	2,142	4,507	4,703	4,611	18,313
Mountain:									
Idaho				280	429				709
Wyoming					242	335	321	273	1,171
Colorado				530	910	1,142	1,088	1,358	5,028
New Mexico			91	174	214	298	261	320	1,358
Arizona			130	194	331	431	418	354	1,858
Utah		2	303	432	475	512	518	542	2,784
Subtotal		2	524	1,610	2,601	2,718	2,606	2,847	12,908
Pacific:									
Washington					1,744	2,317	2,101	1,818	7,980
California			6,962	10,248	17,773	17,726	16,603	16,892	86,204
Subtotal			6,962	10,248	19,517	20,043	18,704	18,710	94,184
Total	191	6,798	25,817	42,478	65,365	75,703	67,591	73,500	357,443

[1] Data for three months only—July 1 to September 30, 1935.
[2] Estimated at 15 percent of total.
[3] Motor-vehicle excise 2 percent rate effective October 1, 1939; previously 1 percent.
[4] Includes motor-vehicle usage tax effective May 15, 1936.

Of the automotive sales taxes, the amount levied on the sales of motor vehicles constituted 64.5 percent of the total, or $230,418,000. This amount was composed of $216,619,000 in general taxes imposed on new and used car sales and $13,799,000 of special excises levied on the motor vehicle (table 11 and fig. 5).

UPWARD TREND IN AUTOMOTIVE SALES TAX COLLECTIONS INDICATED

Filling and service stations, parking lots, and auto hotels were assessed $63,309,000 or 17.7 percent of the total, while garages and repair shops paid $22,311,000 or 6.2 percent of the total. Accessories, tires, batteries, and parts produced 5.7 percent of the total or $20,360,000, and the amount attributable to the automotive and petroleum industries, including refund gasoline sales, was $17,276,000 or 4.8 percent. Vehicles for hire and other automotive contributed $968,000 or 0.3 percent and $2,801,000 or 0.8 percent, respectively (table 11).

In the period of study the automotive portion of the sales taxes averaged 17.2 percent of all sales taxes. The lowest percentage of the total, 13.9 percent, occurred in 1932 and the highest, 18.8 percent, in 1937. Table 12 and figure 6 indicate that there is apparently an upward trend in the motor-vehicle portions, but present conditions incident to national defense, including possible restrictions on the number of vehicles produced as well as increased taxes, make it difficult to forecast the future trend of the motor-vehicle portion of tax collections.

According to preliminary estimates by the Bureau of Foreign and Domestic Commerce, retail sales were 8 percent more in 1940 than in 1939. Certain commodity sales showed a considerable increase over the previous year, the most significant of which were sales in the automotive group, up 25 percent over 1939.

It has been noted earlier that 35.9 percent of the $23,053,800 collections from use or compensating taxes from 1936 through 1939 was derived from automotive sales. By far the larger portion of the automotive total of $8,276,300 was directly attributable to the

TABLE 11.—*Total collections from sales taxes levied on motor vehicles and allied automotive sales, 1932–39*

Geographic division and State	New-used vehicles, dealers	Garages, repair shops	Accessories, tires, batteries, parts	Filling-service stations, parking lots, auto hotels	Vehicles for hire, truck and bus lines	Other automotive	Motor-vehicle excise, original license fees, etc.	Petroleum and automotive industries, refund gas sales	Total
	$1,000	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*
Middle Atlantic:									
New York	4,335		1,493					[1] 209	6,037
New Jersey	411	44	81	111		3			[2] 650
Pennsylvania	1,026					342			1,368
Subtotal	5,772	44	1,574	111		345		209	8,055
East North Central:									
Ohio	31,220	3,291	2,203	6,862		635			44,211
Illinois	24,142	8,112	2,537	22,060		1,132		9,763	67,746
Michigan	32,368	3,238	3,151	17,274					56,031
Subtotal	87,730	14,641	7,891	46,196		1,767		9,763	167,988
West North Central:									
Iowa	5,394	1,400	921	2,314	22	79		[3] 587	10,717
Missouri	6,041		[4] 2,544	1,992	238	66			10,881
North Dakota	576	471	212	621	8	8	42		1,938
South Dakota	661	151	95	664		4	699	[3] 129	2,403
Kansas	1,991	286	307	691		80			3,355
Subtotal	14,663	2,308	4,079	6,282	268	237	741	716	29,294
South Atlantic:									
Maryland			233				2,228	[5] 428	2,889
West Virginia	453	399	144	725	264		2,995		4,980
North Carolina	4,461	167	720	1,975		118			7,441
Subtotal	4,914	566	1,097	2,700	264	118	5,223	428	15,310
East South Central:									
Kentucky	37	1,215	97	222	6	5	3,476		5,058
Alabama	412		788			121			1,321
Mississippi	1,335	788	200	2,468	67	15		139	5,012
Subtotal	1,784	2,003	1,085	2,690	73	141	3,476	139	11,391
West South Central:									
Arkansas	1,431	177	203	604	1				2,416
Louisiana	1,687		764					[6] 1,359	3,810
Oklahoma	1,952	282	840	1,835	209	89	4,359	2,521	12,087
Subtotal	5,070	459	1,807	2,439	210	89	4,359	3,880	18,313
Mountain:									
Idaho	583	35	28	33				30	709
Wyoming	358	570	39	177		27			1,171
Colorado	2,771	1,216	386	627	3	25			5,028
New Mexico	283	469	124	310	150	22			1,358
Arizona	1,135		723						1,858
Utah	2,338		149	267		30			2,784
Subtotal	7,468	2,290	1,449	1,414	153	104		30	12,908
Pacific:									
Washington	5,125		1,378	1,477					7,980
California	84,093							[3] 2,111	86,204
Subtotal	89,218		1,378	1,477				2,111	94,184
Total	216,619	22,311	20,360	63,309	968	2,801	13,799	17,276	357,443

[1] Tax on lubricating oil.
[2] Data for 3 months only; July 1 to September 30, 1935.
[3] Tax on refund gas sales.
[4] Includes garages and repair shops.
[5] Tax on gasoline, $402,000; on lubricating oil, $26,000.
[6] Includes tax on gasoline of $759,000; on oil, $40,500; oil-field equipment, $248,500; and miscellaneous, $180,000.

TABLE 12.—*Taxes collected on automotive group sales, 1932–39*

Year	Amount	Per vehicle [1]	Percentage of total taxes
1932	$191,000	$1.26	13.9
1933	6,798,000	2.00	14.1
1934	25,817,000	2.53	15.4
1935	42,478,000	3.09	15.4
1936	65,365,000	4.43	18.2
1937	75,703,000	5.15	18.8
1938	67,591,000	4.40	16.8
1939	73,500,000	4.59	17.4
Total	357,443,000		17.2

[1] Based on private and commercial vehicle registration for the sales tax States including cars, trucks, busses, motorcycles, and trailers. From Public Roads Administration tables MV-1.

sales of motor vehicles. Tax collections on such sales amounted to $7,026,600 or 84.9 percent of the automotive portion during that period. Table 13 shows the automotive portion of the use taxes by principal businesses. In the 4-year period during which such taxes have been in effect, the $8,276,300 automotive portion represents 2.9 percent of the total of $282,159,000 collected for all sales taxes on the automotive group during that same period.

TABLE 13.—*Automotive portion of collections from use or compensating taxes, 1936–39*

Type of business	Tax collections: Amount	Tax collections: Percent
Vehicles and dealers	$7,026,600	84.9
Petroleum and automotive industries	968,300	11.7
All other	281,400	3.4
Total	8,276,300	100.0

Although it was possible to segregate the motor-vehicle portions of the sales tax payments in many

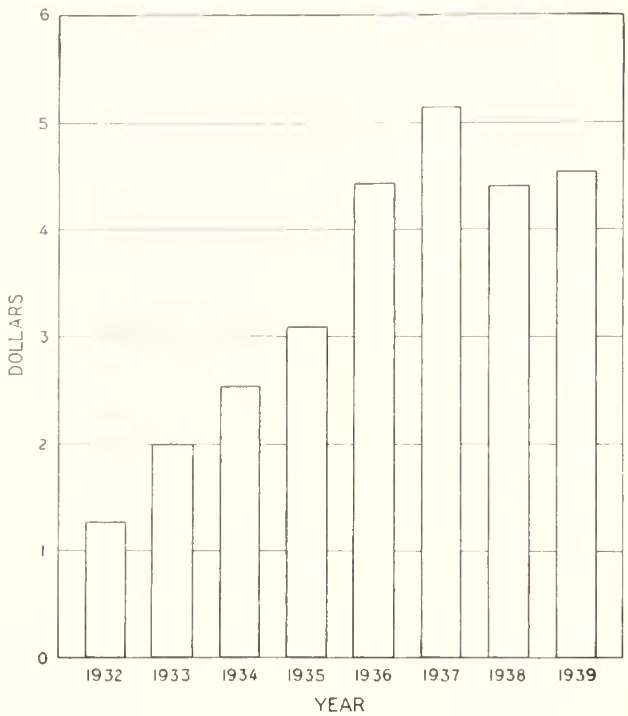

Figure 6.—Collections per Vehicle From the Automotive Group Sales Taxes, 1932–39.

States, the records in other States were such as to prevent a clear separation of the items desired. Consequently, the sales tax payments often do not include the contributions by certain related groups, or else include only a part of the payments by these groups.

The sales tax receipts generally excluded from the automotive classification are:

1. Payments for motor-carrier and general trucking operations, usually classed with the public utility or transportation groups and not readily separable.

2. The portion of department-store sales taxes attributable to the sales of tires and tubes, parts, batteries, accessories, etc. This is particularly true in the case of chain stores and mail order houses. This item undoubtedly is considerable and it has been variously estimated to approximate from 10 to 20 percent of the total sales of such concerns.

3. Sales taxes collected by tourist camps, auto hotels and courts, outdoor advertising concerns and others that cater primarily to the motor user. In many instances these items are included with other groups and no attempt was made to obtain their contributions.

4. Sales taxes collected by joint businesses such as combination units of store and filling station, lunch room and service station, etc. These are usually classed according to major business and are in other than the automotive groups. No estimate of the portion attributable to the motor vehicle was possible.

5. Other related payments such as those by road contractors for materials and supplies used in construction work, and oil well supply and equipment purchases by the oil industry upon which sales taxes were paid. These sales tax items were usually included in the contractor–consumer or in the unclassified group.

There are undoubtedly other items that might be attributed to the highway users or allied businesses or industries, but those mentioned above are sufficient to indicate that the amounts shown in this study as paid by the automotive group represent a conservative estimate of the total contributions of the highway-users' group to sales taxes on automotive goods and services.

It was not possible, of course, to select those business classifications that include only automotive goods and services. In some States, the motor-vehicle classification included bicycle and aircraft dealers, wagon manufacturers, and farm tractor sales. However, those States using such classifications estimated a relatively insignificant amount creditable to these businesses. Just as there are joint business enterprises such as filling station and grocery store which were not included, there are undoubtedly similar businesses whose tax payments rightly should be credited to other than the automotive group. Such payments are probably more than offset by those of similar character creditable to the automotive group.

AUTOMOTIVE SALES TAXES 12.7 PERCENT AS GREAT AS HIGHWAY-USER TAXES IN 1939

The yield from State highway-user taxes in 1938 for the United States was $1,174,887,000 or $38.30 per vehicle. For the same period the sales taxes paid by the automotive group were $67,591,000 or $2.20 per vehicle (table 14). In 1939 highway-user taxes increased to $1,249,356,000 or $39.13 per vehicle and automotive sales taxes rose to $73,500,000 or $2.30 per vehicle.

A more significant comparison is obtained when data are presented for sales tax States only. The collections for highway-user taxes and automotive sales taxes in 1938 were $541,528,000 or $35.22 per vehicle, and $67,591,000 or $4.40 per vehicle, respectively (table 15). Corresponding figures for 1939 (table 16) show motor-user taxes of $578,659,000 or $36.16 per vehicle and automotive sales taxes totaling $73,500,000 or $4.59 per vehicle. Thus, the yield from automotive sales taxes was 12.5 percent and 12.7 percent, respectively, as great as the highway-user taxes for 1938 and 1939.

The per-vehicle sales tax payments in 1938 ranged from a low of $2.30 in the South Atlantic group to $5.83 in the Pacific States. Illinois reported the highest per-vehicle collection with $6.49. In 1939 the per-vehicle automotive sales tax payments were again lowest in the South Atlantic division with $2.16 per vehicle, and the highest were in the East North Central States with $6.02. The highest per-vehicle collection was in Illinois with $7.31 (table 14). It should be noted that these per-vehicle figures are averages for all registered vehicles. Actually, a significant number of vehicle owners pay much higher amounts than these, in taxes incurred particularly in the purchase of vehicles. In such cases the tax on this item alone, exclusive of other automotive sales taxes paid, will amount to at least four or five times as much as the per-vehicle figures cited above.

Although this study was particularly designed to include the sales taxes levied by the various States, the Federal excises imposed on motor vehicles, parts and accessories, tires and tubes, oil, and gasoline, are also of interest for comparative purposes because such excises have far exceeded in amount those levied by the States. These excises are, in effect, identical to the sales taxes levied by the States. Even though the Federal excises are generally levied on manufacture or production, it is recognized that these taxes are eventually paid by the motor-vehicle owner.

The total amounts collected by these excises have

TABLE 14.—*Comparison of highway-user tax and sales tax revenue in States levying sales taxes in 1938 and 1939*

Geographic division and State	Taxes collected in 1938				Taxes collected in 1939			
	Highway-user taxes		Automotive sales taxes		Highway-user taxes		Automotive sales taxes	
	Amount	Per vehicle	Amount	Per vehicle	Amount	Per vehicle	Amount	Per vehicle
	$1,000		*$1,000*		*$1,000*		*$1,000*	
East North Central:								
Ohio	73,655	$37.11	6,659	$3.36	79,613	$39.22	9,358	$4.61
Illinois	58,479	32.31	11,746	6.49	63,752	33.89	13,755	7.31
Michigan	48,966	31.49	9,856	6.34	52,378	32.11	10,257	6.29
Subtotal	181,100	33.85	28,261	5.28	195,743	35.32	33,370	6.02
West North Central:								
Iowa	25,568	30.80	2,477	2.98	27,215	31.37	2,373	2.74
Missouri	21,567	24.72	2,564	2.94	23,254	25.45	3,264	3.57
North Dakota	[1] 3,834	21.86	461	2.63	[1] 4,372	24.59	591	3.32
South Dakota	[1] 6,243	31.19	667	3.33	[1] 6,191	29.24	817	3.86
Kansas	15,158	26.05	1,850	3.18	15,855	27.26	1,505	2.58
Subtotal	72,370	27.21	8,019	3.02	76,887	27.94	8,550	3.11
South Atlantic:								
Maryland	[1] 14,608	36.43	397	0.99	[1] 15,532	36.01	512	1.19
West Virginia	[1] 14,419	51.61	1,077	3.85	[1] 15,852	54.52	957	3.29
North Carolina	31,772	54.66	1,432	2.46	34,084	54.96	1,435	2.31
Subtotal	60,829	48.19	2,906	2.30	65,468	48.78	2,904	2.16
East South Central:								
Kentucky	[1] 16,595	39.96	1,092	2.63	[1] 17,990	41.04	951	2.17
Alabama	18,094	59.00	472	1.51	19,675	59.43	582	1.76
Mississippi	14,311	65.86	828	3.81	13,992	56.27	975	3.92
Subtotal	49,000	52.17	2,392	2.55	51,657	50.74	2,508	2.46
West South Central:								
Arkansas	13,001	56.26	619	2.68	13,885	54.95	673	2.66
Louisiana	21,530	62.99	1,031	3.02	22,865	64.40	1,522	4.29
Oklahoma	21,153	36.92	3,053	5.33	22,043	38.53	2,416	4.22
Subtotal	55,684	48.60	1,703	4.10	58,793	49.83	4,611	3.91
Mountain:								
Wyoming	3,299	36.16	321	3.52	3,150	36.71	273	2.91
Colorado	10,603	31.61	1,088	3.24	11,358	32.79	1,358	3.92
New Mexico	5,910	49.47	261	2.18	6,422	51.97	320	2.59
Arizona	5,485	40.99	418	3.12	5,767	42.27	354	2.59
Utah	4,584	35.81	518	4.05	4,864	36.32	542	4.05
Subtotal	29,881	36.98	2,606	3.23	31,861	38.19	2,847	3.41
Pacific:								
Washington	18,882	34.76	2,101	3.87	20,761	37.15	1,818	3.25
California	73,782	27.69	16,603	6.23	77,489	27.92	16,892	6.09
Subtotal	92,664	28.88	18,704	5.83	98,250	29.47	18,710	5.61
Total	541,528	35.22	67,591	4.40	578,659	36.16	73,500	4.59
United States total	1,174,887	38.30	67,591	2.20	1,249,356	39.13	73,500	2.30

[1] Does not include "Special titling taxes" reported in tables MV–2, 1938 and 1939, Public Roads Administration. These taxes are included here with automotive sales taxes.

TABLE 15.—*Comparison of total collections from highway-user taxes and automotive sales taxes by geographic divisions in 1938* [1]

Geographic division	Highway-user taxes	Automotive sales taxes		Amount per vehicle [2]	
		Amount	Percentage of highway-user taxes	Highway-user taxes	Sales taxes
	$1,000	*$1,000*			
East North Central	181,100	28,261	15.6	$33.85	$5.28
West North Central	72,370	8,019	11.1	27.21	3.02
South Atlantic	60,829	2,906	4.8	48.19	2.30
East South Central	49,000	2,392	4.9	52.17	2.55
West South Central	55,684	4,703	8.4	48.60	4.10
Mountain	29,881	2,606	8.7	36.98	3.23
Pacific	92,664	18,704	20.2	28.88	5.83
Total	541,528	67,591	12.5	35.22	4.40

[1] For the 22 sales tax States and the 2 motor-vehicle excise States.
[2] For private and commercial vehicles only

TABLE 16.—*Comparison of total collections from highway-user taxes and automotive sales taxes by geographic divisions in 1939* [1]

Geographic division	Highway-user taxes	Automotive sales taxes		Amount per vehicle [2]	
		Amount	Percentage of highway-user taxes	Highway-user taxes	Sales taxes
	$1,000	*$1,000*			
East North Central	195,743	33,370	17.0	$35.32	$6.02
West North Central	76,887	8,550	11.1	27.94	3.11
South Atlantic	65,468	2,904	4.4	48.78	2.16
East South Central	51,657	2,508	4.9	50.74	2.46
West South Central	58,793	4,611	7.8	49.83	3.91
Mountain	31,861	2,847	8.9	38.19	3.41
Pacific	98,250	18,710	19.0	29.47	5.61
Total	578,659	73,500	12.7	36.16	4.59

[1] For the 22 sales tax States and the 2 motor-vehicle excise States.
[2] For private and commercial vehicles only.

increased steadily from $84,294,000 in the calendar year 1932, when the portion paid by highway users is estimated to have been $75,320,000 to the 1937 total of $359,948,000, when the highway users' portion was estimated to have been $324,494,000. Business conditions were such that the highway portion of the 1938 revenue decreased to $266,130,000 but rose again in 1939 to $322,221,000. Total collections of $453,872,000 in 1940 exceeded those for any previous year, and were greater than those of the previous 1937 peak by more than 26 percent. It is estimated that the highway-users portion of these 1940 collections amounted to

TABLE 17.—*Total collections from Federal excise taxes relating to motor vehicles and estimated highway users' share, 1932–40* [1]

Calendar year	Collections from taxes on—								Total collections	
	Gasoline		Lubricating oil		Motor vehicles and parts					
	Total	Highway users' share [2]	Total	Highway users' share [3]	Tires and tubes	Automobiles and motorcycles	Trucks	Parts and accessories	Total	Highway users' share [4]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	$1,000	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*
1932 [5]	62,840	56,870	7,068	4,064	7,545	4,221	720	1,900	84,294	75,320
1933	181,126	163,919	22,290	12,817	23,836	22,476	3,047	4,443	257,218	230,538
1934	170,109	153,949	24,844	14,658	24,704	31,534	5,261	5,886	262,338	235,992
1935	172,263	155,898	28,819	17,003	28,102	42,263	6,674	7,019	285,140	256,959
1936	186,542	168,821	28,985	16,522	38,242	56,475	8,045	8,748	327,037	296,853
1937	203,025	183,738	33,681	17,514	40,088	64,722	8,812	9,620	359,948	324,494
1938	200,881	181,797	30,495	15,858	26,772	29,405	5,230	7,068	299,851	266,130
1939	215,217	198,410	29,837	15,515	41,131	51,063	7,145	8,957	353,350	322,221
1940	281,654	259,657	34,420	17,898	45,091	71,275	9,285	12,147	453,872	415,353
Total	1,673,657	1,523,059	240,439	131,849	275,511	373,434	54,219	65,788	2,683,048	2,423,860

[1] Data supplied by U. S. Bureau of Internal Revenue.
[2] Highway users' share estimated by Public Roads Administration.
[3] Based on material in Automobile Facts aud Figures, 1941, published by the Automobile Manufacturers Association.
[4] Sum of columns 3, 5, 6, 7, 8, and 9.
[5] Federal excises effective June 21, 1932.

approximately $415,353,000 or more than the total collections for any previous year. A summary of the annual collections since 1932 is shown in table 17.

With recent increases in the taxation of these motor-vehicle items to help finance the National Defense program, it is probable that, for the present fiscal year, the proceeds from Federal excises may exceed one-half billion dollars, resulting in part from the increased rates and in part from improved economic conditions. A comparison of the old schedule of rates and the new schedule applying to each commodity is shown in table 18.

TABLE 18.—*Comparison of Federal excise rates in effect before and after July 1, 1940*

Item	Rates in effect—	
	Before July 1, 1940	After July 1, 1940
Tires	2¼ cents per pound	2½ cents per pound.
Tubes	4 cents per pound	4½ cents per pound.
Trucks	2 percent	2½ percent.
Automobiles and motorcycles	3 percent	3½ percent.
Parts and accessories	2 percent	2½ percent.
Gasoline	1 cent per gallon	1½ cents per gallon.
Lubricating oil	4 cents per gallon	4½ cents per gallon.

The data obtained from this analysis indicate that the total tax contributions by highway users cannot be measured alone by the direct highway-user taxes such as the gasoline taxes and registration fees. In the 8-year period from 1932 through 1939 the collections from State taxes on automotive sales amounted to more than 357 million dollars or 3.4 percent of the total of all State and Federal highway, motor-vehicle excise, and general sales taxes on automotive goods and services (table 19). In all States levying sales taxes, the revenue obtained from the taxes are generally used for other than highway purposes. Only the proceeds of the West Virginia certificate of title excise and the North Dakota highway privilege tax are used for highway purposes. These revenues constitute considerably less than 1 percent of the total sales tax collections from the automotive group.

In none of the remaining States is any of the sales tax revenue used for highway purposes. Increasing attention has been directed in recent years to the problem of the use of highway-user taxes for other than highway purposes. Since there has also been an annually increasing levy on the highway user in connection with his purchase of automotive goods, it is evident that he is increasingly contributing to other governmental functions not only by that portion of his highway-user taxes which are not expended for highway purposes but also by those State sales taxes paid in connection with the purchase of automotive goods. A summation of these items is given in table 20 and illustrated in figure 7 which shows that from 1932 through 1939 the total of these taxes used for other than highway purposes amounted to $1,458,194,000, of which 24.3 percent resulted from sales taxes on automotive goods. In this figure the small amount of State automotive sales taxes used for highway purposes ($3,037,000) is included with the State highway-user taxes used for highway purposes.

TABLE 19.—*Tax contributions by motor-vehicle owners, 1932–39*

Year	Annual collections from—			
	Federal excises [1]	State highway-user taxes [2]	State automotive sales taxes	Total
	$1,000	*$1,000*	*$1,000*	*$1,000*
1932	[3] 75,320	838,412	191	913,923
1933	230,538	820,719	6,798	1,058,055
1934	235,992	883,799	25,817	1,145,608
1935	256,959	950,971	42,478	1,250,408
1936	296,853	1,066,341	65,365	1,428,559
1937	324,494	1,176,964	75,703	1,577,161
1938	266,130	1,174,887	67,591	1,508,608
1939	322,221	1,249,356	73,500	1,645,077
Total	2,008,507	8,161,449	357,443	10,527,399
Percent	19.1	77.5	3.4	100.0

[1] From table 17.
[2] Public Roads Administration tables MV-2, G-1, and MC-1.
[3] Federal excises effective June 21, 1932.

The highway user is evidently contributing annually to the support of governmental functions other than highways to a greater extent than is ordinarily realized. In the past the amount of such contributions has increased rather than decreased. From 1932 through 1939 the diversion of State highway-user taxes to other than highway purposes has increased from 9.2 percent to 14.5 percent of the total State highway-user taxes. Increased collections from State sales taxes in the period studied have also resulted in a larger amount of such

TABLE 20.—*Sales taxes collected on automotive goods and highway-user taxes that were used for other than highway purposes, 1932–39*

Year	State automotive sales taxes	State highway-user taxes not used for highways[1]	Total
	$1,000	*$1,000*	*$1,000*
1932	191	76,747	76,938
1933	6,798	91,577	98,375
1934	25,817	122,150	147,967
1935	42,301	147,143	189,444
1936	64,636	169,344	233,980
1937	74,859	161,413	236,272
1938	66,894	[2] 155,942	222,836
1939	72,910	[2] 179,472	252,382
Total	354,406	1,103,788	1,458,194

[1] The "highway privilege tax" of North Dakota totaling $42,000, and West Virginia certificate of title excise amounting to $2,995,000 are not included.
[2] Tables DF, Public Roads Administration, adjusted for motor-vehicle excises in South Dakota, Maryland, and Kentucky.

taxes on the highway user being diverted to governmental functions other than highways.

SUMMARY

In addition to the millions of dollars paid annually by motor-vehicle owners in the form of direct highway-user taxes, these same motor-vehicle owners paid more than 350 million dollars during the period 1932–39 in general sales and use taxes and motor-vehicle excises occasioned directly by their ownership and operation of motor vehicles.

Collections from sales taxes on automotive goods were exceeded in 1939 only by collections from taxes on food and general merchandise. Since many States have come to rely so greatly on sales tax collections, attention should be given to the extent to which these sales taxes constitute an additional tax burden on a specific group of the population.

The revenue obtained by the State governments from such sales taxes are almost entirely used for nonhighway purposes. The highway user, therefore, is contributing to the support of general government not only through the ordinary taxes which he pays such as property and income taxes, but also through taxes which result directly from his operation of a motor vehicle. Such contributions are derived from those portions of the direct highway-user taxes, such as motor-vehicle fees and motor-fuel taxes, which are used for other than highway purposes and from those portions of the sales taxes, substantially all of which go to

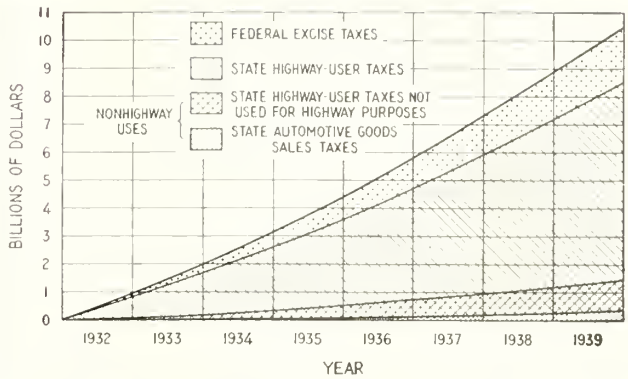

FIGURE 7.—TOTAL CUMULATIVE TAXES ON HIGHWAY USERS, 1932–39.

the support of general government, which result from motor-vehicle operation.

Any taxation program that affects the motor-vehicle operator primarily or solely because of his operation of a motor vehicle must be carefully analyzed with reference to the motor-vehicle operator's ability or willingness to pay. While there is no indication that the present tax schedules have reached a point where increased rates will reduce motor-vehicle use and possibly reduce the total revenues, this possibility must always be considered.

It is evident that an analysis of the effect of any tax schedule or governmental policy on the motor-vehicle owner must give full consideration to all taxes to which the motor-vehicle owner is already subject. Similarly, the effect of any changes in tax rates must be carefully watched in order to determine the motor-vehicle owner's willingness and ability to pay at increased rates and the effect which his reaction may be expected to have on total governmental revenues.

The data obtained in this study indicate the relative importance of sales taxes in the governmental economy of almost half of the States, and the portion of these sales taxes that constitute additional levies on the highway user as an immediate result of his ownership and use of a motor vehicle.

Present trends indicate the possibility of the increased use of and dependence on the sales tax as a source of revenue. Sales tax officials anticipate the possible decrease in the importance of the property tax as a revenue source and the substitution therefor of such taxes as the sales tax. This possibility further emphasizes the need for careful examination of the tax structure as it affects the highway user.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF AUGUST 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 1,266,060	$ 628,140	57.9	$ 6,290,477	$ 3,122,905	200.6	$ 1,923,600	$ 956,000	50.8	$ 1,369,238
Arizona	358,113	257,663	13.9	1,418,169	986,705	64.4	705,196	456,280	15.6	1,151,076
Arkansas	2,170,060	992,377	25.4	1,268,783	632,941	46.7	690,164	344,038	44.0	382,732
California	1,308,316	738,100	27.3	8,234,402	4,421,954	112.9	2,517,797	1,346,896	54.6	2,404,034
Colorado	1,015,358	576,577	39.6	1,975,083	1,147,229	164.2	1,458,815	823,594	81.9	2,018,578
Connecticut	216,382	106,530	2.8	2,023,642	986,420	22.1	880,736	409,063	10.5	737,030
Delaware	32,514	16,257	.2	927,286	455,341	22.6	333,402	166,701	11.7	964,421
Florida	213,440	106,720	24.9	1,034,599	543,629	34.8	2,239,046	1,088,783	27.5	2,592,732
Georgia	1,379,455	689,728	53.2	6,107,803	3,064,151	237.0	4,836,397	2,418,199	206.1	4,967,853
Idaho	638,947	393,670	40.2	1,326,743	819,178	61.4	555,484	338,368	42.7	1,314,471
Illinois	1,594,726	798,113	43.0	7,712,762	3,856,381	144.8	2,824,119	1,411,293	24.8	3,269,767
Indiana	1,340,874	670,437	21.4	7,389,293	3,450,631	118.4	1,251,656	625,828	16.3	1,447,985
Iowa	804,860	377,950	31.2	5,273,503	2,509,958	164.2	1,631,544	747,190	82.4	121,911
Kansas	1,137,025	587,680	47.4	5,662,672	2,854,062	335.2	3,434,920	1,517,110	143.1	3,354,895
Kentucky	1,148,584	578,105	46.3	6,106,432	2,907,760	157.8	3,065,532	1,524,678	47.4	1,017,934
Louisiana	655,635	327,796	15.8	2,175,129	1,079,147	46.2	2,568,556	1,259,086	56.3	3,048,042
Maine	388,000	194,750	13.6	1,834,538	938,169	22.0	606,285	303,142	10.9	387,117
Maryland	1,073,200	536,000	15.7	3,972,162	1,875,678	22.9	628,000	44,000	.5	1,157,839
Massachusetts	373,530	186,304	8.9	3,979,690	2,024,370	20.9	969,024	481,308	7.5	2,761,686
Michigan	2,560,310	1,280,155	50.9	5,932,210	2,953,505	128.6	3,183,900	1,591,950	36.1	1,021,100
Minnesota	1,580,427	790,011	137.2	9,766,253	4,842,095	468.3	2,091,168	1,042,309	129.0	1,200,863
Mississippi	783,600	391,800	45.6	7,417,112	3,643,706	416.4	733,900	365,200	37.3	686,561
Missouri	2,939,939	1,452,342	83.0	9,717,204	4,596,949	216.3	4,224,672	1,207,765	75.7	3,120,672
Montana	983,341	555,414	52.5	2,524,180	1,431,432	114.9	1,366,422	776,948	90.0	3,392,163
Nebraska	513,976	256,988	74.4	6,621,370	3,331,066	623.8	1,520,436	760,218	90.5	2,243,732
Nevada	356,406	310,712	28.8	2,122,754	1,845,612	85.0	330,763	287,053	12.7	489,986
New Hampshire	93,165	46,120	1.9	1,142,544	562,195	15.2	183,812	86,090	2.4	792,432
New Jersey	2,348,574	1,174,287	20.5	3,549,038	1,774,439	22.2	35,880	17,940	-	1,754,818
New Mexico	349,483	210,669	23.8	1,280,754	805,004	64.3	369,980	234,765	47.1	1,710,415
New York	2,991,994	1,495,097	50.6	11,461,860	5,653,279	133.4	1,926,105	771,627	17.1	2,888,274
North Carolina	858,300	413,255	38.0	4,056,244	2,039,465	173.1	1,503,637	744,045	49.3	2,004,954
North Dakota	1,551,027	890,547	130.8	3,764,623	1,979,375	301.1	2,485,020	1,249,655	216.7	2,979,223
Ohio	906,675	453,337	6.1	17,723,038	8,708,661	146.7	3,768,180	1,451,750	30.3	2,595,831
Oklahoma	589,200	311,215	23.3	3,271,074	1,689,236	113.8	2,408,120	1,244,720	63.9	4,247,682
Oregon	706,897	427,246	25.9	4,512,318	2,333,080	91.9	505,893	217,610	24.6	537,305
Pennsylvania	1,642,175	817,516	20.3	13,861,456	6,828,048	114.6	2,955,468	1,466,928	29.8	1,909,910
Rhode Island	146,505	73,245	1.6	1,238,490	617,282	10.4	443,912	221,949	2.6	780,826
South Carolina	300,440	144,915	36.0	4,037,067	1,847,929	122.6	1,516,753	279,826	33.1	1,858,391
South Dakota	1,128,020	660,940	125.4	4,085,993	2,551,043	464.7	1,633,960	1,014,080	211.7	1,927,736
Tennessee	682,698	341,349	21.5	5,650,496	2,825,248	116.2	1,110,846	555,423	34.6	2,883,564
Texas	2,524,145	1,253,865	115.6	13,534,195	6,663,584	567.5	3,582,248	1,592,895	149.6	5,440,676
Utah	68,825	52,475	16.2	2,438,573	1,745,722	56.6	271,296	171,075	12.9	482,077
Vermont	213,233	105,219	6.5	1,745,313	868,736	41.1	61,624	30,812	2.0	67,517
Virginia	898,145	450,222	21.3	4,839,414	2,259,586	84.8	1,289,782	641,841	19.5	1,225,310
Washington	197,670	105,700	4.7	3,133,925	1,673,994	42.9	785,589	392,185	9.5	769,044
West Virginia	892,070	444,433	27.8	3,509,751	1,744,544	44.5	414,970	207,485	3.7	1,432,888
Wisconsin	633,404	314,230	36.6	4,251,091	2,109,428	142.0	3,181,292	1,303,000	90.6	2,809,813
Wyoming	82,696	53,687	20.1	1,519,009	964,170	142.3	666,645	383,082	58.5	950,295
District of Columbia	308,832	154,231	1.9	533,602	266,209	.4	395,468	167,000	2.0	302,734
Hawaii	140,808	70,395	1.2	461,052	277,311	6.6	278,002	258,530	3.2	1,694,819
Puerto Rico	11,692	5,585	.3	1,584,677	782,650	17.7	650,000	318,265	4.4	551,005
TOTALS	47,099,751	24,270,129	1,779.0	235,999,848	119,891,192	7,089.0	79,016,016	37,315,578	2,525.0	91,251,957

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF AUGUST 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 558,374	$ 277,768	22.6	$ 1,042,082	$ 524,890	60.3	$ 366,700	$ 177,280	10.7	$ 311,858
Arizona	67,371	48,972	4.5	140,210	104,037	.8	53,969	39,230	8.7	354,133
Arkansas	192,696	95,624	16.4	228,758	114,250	16.2	279,694	139,847	12.3	165,051
California	204,080	119,500	5.6	1,340,298	935,288	16.7	129,976	74,930	3.6	410,088
Colorado	63,585	35,343	3.7	155,808	78,154	18.9	50,440	28,478	.2	260,002
Connecticut	105,456	49,907	1.8	458,827	202,361	9.1	-	-	-	74,196
Delaware	-	-	-	306,002	150,387	12.3	102,873	37,618	3.9	158,438
Florida	112,906	56,453	4.4	1,036,052	522,576	7.4	-	-	-	241,186
Georgia	112,946	56,473	11.2	904,252	529,476	53.4	1,067,298	533,649	97.4	711,971
Idaho	106,084	62,208	8.7	189,796	116,706	10.4	105,582	44,410	11.7	198,424
Illinois	332,400	166,200	7.3	1,554,910	777,455	83.6	254,600	114,600	20.5	292,329
Indiana	46,400	23,200	1.8	1,591,405	762,546	81.4	101,900	50,950	3.3	598,434
Iowa	299,158	142,290	81.0	375,454	159,238	80.5	164,983	77,375	27.9	380,453
Kansas	239,335	122,553	15.0	1,739,038	873,781	112.8	746,889	361,003	88.2	680,173
Kentucky	197,166	53,595	7.0	1,231,749	307,893	66.0	730,791	196,124	45.1	204,713
Louisiana	372,100	134,040	5.7	192,608	96,249	14.9	289,362	138,761	21.5	446,100
Maine	-	-	-	69,250	34,625	3.9	193,170	92,491	8.1	40,967
Maryland	54,000	27,000	2.0	635,000	317,325	17.6	113,000	56,500	2.9	200,051
Massachusetts	114,492	56,927	3.4	680,624	357,185	10.8	-	-	-	364,552
Michigan	122,600	61,300	8.9	1,278,960	639,480	70.7	336,800	166,400	18.5	382,054
Minnesota	221,768	110,884	37.7	1,642,698	829,907	175.7	788,320	393,760	87.6	222,942
Mississippi	76,200	38,100	10.5	1,240,934	610,282	54.2	772,021	335,261	32.8	225,542
Missouri	161,282	80,641	13.7	605,244	286,223	55.2	458,462	175,971	75.8	707,971
Montana	148,516	84,252	23.3	317,528	180,511	37.7	57,223	32,537	13.9	630,735
Nebraska	69,057	34,529	12.7	641,123	325,839	60.1	77,778	38,889	17.6	379,063
Nevada	83,816	72,853	10.7	38,626	33,662	2.1	196,813	171,030	15.8	56,995
New Hampshire	-	-	-	345,081	170,620	8.2	-	-	-	87,606
New Jersey	203,250	101,545	4.4	510,792	276,990	9.9	277,160	134,445	14.2	334,146
New Mexico	66,762	42,126	13.7	420,988	265,777	32.5	106,603	68,929	11.6	112,712
New York	301,720	150,860	4.8	1,196,714	601,055	29.2	325,000	131,140	4.9	516,500
North Carolina	68,690	34,345	7.0	622,889	341,798	47.9	261,738	107,020	21.2	252,852
North Dakota	27,520	14,750	2.4	25,466	15,242	-	808,050	793,860	42.7	483,046
Ohio	487,140	243,570	15.2	1,816,210	955,295	48.8	270,200	119,550	3.5	847,792
Oklahoma	246,780	130,349	9.7	116,046	61,212	11.9	856,486	452,224	64.6	741,010
Oregon	190,907	80,654	15.0	427,676	233,989	30.0	305,875	135,830	26.5	142,165
Pennsylvania	545,262	272,631	12.1	1,962,397	970,132	35.9	-	-	-	41,831
Rhode Island	84,274	42,080	.9	130,744	68,871	1.7	-	-	-	63,989
South Carolina	18,217	7,500	5.6	626,450	241,666	38.0	353,000	135,124	11.5	164,848
South Dakota	21,680	12,146	9.0	14,072	9,482	6.2	1,143,430	1,047,600	114.5	489,674
Tennessee	118,804	59,402	5.5	1,432,638	716,319	38.3	388,698	194,349	20.8	409,680
Texas	379,960	188,949	42.1	1,127,671	547,467	100.8	195,190	93,050	23.5	1,313,938
Utah	17,470	7,796	5.7	231,725	148,387	13.8	-	-	-	208,507
Vermont	34,027	17,013	1.2	2,192	1,096	-	-	-	-	85,313
Virginia	102,350	45,300	2.1	605,590	278,204	18.0	41,350	12,500	3.8	371,087
Washington	2,165	2,165	-	515,615	258,739	21.4	149,371	50,700	10.2	195,175
West Virginia	-	-	-	704,324	351,549	26.2	-	-	-	323,700
Wisconsin	501,608	250,750	22.3	1,411,380	675,998	52.6	659,608	257,560	16.9	132,858
Wyoming	253,617	112,283	15.7	235,493	100,945	17.5	209,292	65,400	13.4	99,412
District of Columbia	56,011	28,000	.6	2,192	1,096	-	28,024	13,550	.3	74,394
Hawaii	-	-	-	2,375	2,375	-	-			249,280
Puerto Rico	45,960	22,305	2.5	185,404	90,550	8.1	-			134,597
TOTALS	7,835,962	3,877,131	517.1	34,309,360	17,255,180	1,729.6	13,817,719	7,289,925	1,032.1	16,574,533

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF AUGUST 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama						$ 339,139	$ 337,339	6	3	3	$ 159,657	$ 159,435	2	2	6	$ 795,809
Arizona						170,211	170,211	1			137,517	117,313		2	2	118,388
Arkansas	$ 44,761	$ 44,761				573,664	571,625	6		1	25,827	25,827			8	318,709
California	373,845	188,129	1			1,315,838	1,309,865	9	1		23,290	23,290			8	1,474,004
Colorado	5,685	5,646				595,603	588,370	6								569,236
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		351,963
Delaware						94,135	94,135	1			697,074	508,721	3	1	1	67,869
Florida	13,313	13,313			2	386,875	385,886	4		12	505,946	501,690	4		25	709,591
Georgia	164,528	164,528	2	1	1	1,084,904	1,084,904	8	6	1	1,029,969	1,029,969	4	5	23	1,156,547
Idaho	11,301	11,301				302,225	293,553	3	1		34,621	34,621	1		4	252,818
Illinois	70,841	58,755			26	2,209,791	2,002,366	9	1	51	426,888	403,044	2	1	21	1,571,511
Indiana	2,033	2,033			2	793,948	781,461	6	1	7	320,944	315,235	1		50	707,932
Iowa	69,809	66,400	1			1,238,947	994,070	10	2	7	526,431	513,009	2	1	64	251,776
Kansas	10,974	10,914			1	593,707	593,707	9		1	219,236	218,921	2		13	942,952
Kentucky	96,070	95,525	2			1,136,242	1,129,128	8	1	1	306,574	306,574	3			46,196
Louisiana						454,657	454,657	6			605,296	604,128	6		1	610,731
Maine						113,072	113,072	1			278,010	278,010	1		1	117,217
Maryland	270,000	270,000	2			536,259	504,466	2	2	7	596,153	452,355	2		15	204,759
Massachusetts						696,691	685,053	3	1		1,148,135	1,147,880	5	2		909,853
Michigan	148,900	148,900			4	1,210,955	1,210,955	3	4	1	501,974	471,814	2		18	621,137
Minnesota	214,162	214,162	1	2	1	1,153,579	1,153,579	8	4		183,755	183,755		2		732,570
Mississippi	175,200	175,200	1			590,574	590,574	8	1	1	232,800	232,800	2		10	435,338
Missouri						2,034,922	1,579,502	6	4		73,526	73,526		1		1,291,724
Montana						232,790	232,790	3			6,645	6,645			2	464,382
Nebraska	122,502	122,502		1	5	1,121,534	1,121,534	22		6	105,601	105,601	1		14	109,716
Nevada	64,346	64,346	1			56,484	56,484	2			71,448	71,448	1		5	107,895
New Hampshire	63,682	62,862	2			303,989	303,689	4	2		3,817	3,817			2	201,694
New Jersey	214,360	214,360	2			1,057,883	932,333	4	2	1	496,150	436,725	2	1		608,512
New Mexico						2,560	2,560				318,427	311,393	4		1	344,481
New York	331,658	324,885		2		3,627,806	3,573,185	5	16		717,445	614,285		2		2,598,455
North Carolina	43,620	43,620		1	5	518,743	518,743	2	6	5	223,893	223,893	1		28	897,097
North Dakota	83,460	83,460	2			697,230	684,293	8			223,120	223,120	2			322,278
Ohio	116,214	116,214		1		3,651,853	3,570,810	16			545,437	286,380	2		8	1,056,652
Oklahoma	100,000	96,584	1		7	91,129	89,639	1		7	1,192,299	1,132,337	8		24	1,119,977
Oregon	14,610	14,192			2	412,433	348,820	5			4,733	4,733			3	390,976
Pennsylvania	334,565	334,565	3			3,623,559	3,583,800	21			1,293,806	1,288,759	8			1,337,188
Rhode Island						206,703	206,703		1							178,256
South Carolina	60,046	60,046	1		4	371,332	358,932	6	2	6	333,858	203,584	1	2	21	726,427
South Dakota	301,900	301,900	8			440,842	440,842	10			313,573	297,623	6		9	587,095
Tennessee	92,670	83,670	1	2		1,240,014	1,240,014	7	1		162,925	162,925	1	1		352,311
Texas	213,600	213,300	3			2,160,454	2,144,170	21			192,780	170,930	4		2	1,392,560
Utah	15,988	15,988			6	85,742	85,000	3		13	79,401	79,401			28	232,399
Vermont						322,164	310,299	2		4						1,462
Virginia						807,875	807,415	5	5		77,869	58,369	1		5	590,516
Washington	55,443	55,443		1	1	333,418	333,418	3	1		9,672	9,672			3	452,150
West Virginia						623,242	617,622	8		6	287,240	287,240	1	1	2	509,681
Wisconsin	34,568	34,568			8	874,811	844,828	5	2	6	148,951	148,951			34	1,156,114
Wyoming	451,586	451,586	5			28,520	28,519				5,322	5,322			5	290,911
District of Columbia						3,655	3,655				298,213	273,744		1		
Hawaii	192,574	192,567	2			214,170	213,655	2								179,950
Puerto Rico						742,969	735,496	10								337,988
TOTALS	4,745,036	4,521,640	43	11	75	41,541,554	40,078,402	298	71	147	15,377,622	14,231,554	85	26	466	31,305,753

PUBLIC ROADS

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PUBLIC ROADS ADMINISTRATION

VOL. 22, NO. 8 — OCTOBER 1941

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PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 8 — October 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

THE PUBLIC ROADS ADMINISTRATION - - - - - - - - Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS - - - - - - - - - - - - - - - Federal Building, Civic Center, San Francisco, Calif.

▼

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DISTRICT No. 2. California, Arizona, and Nevada.
Federal Building, Civic Center, San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
254 New Customhouse, Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
1109 Main Post Office Building, St. Paul, Minn.

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729 U. S. Courthouse, Kansas City, Mo.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Room 502, United States Court House, Fort Worth, Tex.

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STABILIZATION OF GRAVEL RUNWAYS ON WASHINGTON NATIONAL AIRPORT

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by HENRY AARON, Associate Highway Engineer and J. A. KELLEY, JR., Assistant Highway Engineer

The Washington National Airport was built under the joint supervision of several Federal agencies. This report covers the participation of the Public Roads Administration in the stabilization of the gravel runways.

The runways, varying in length from 4,200 to 6,875 feet and surfaced with 3½ inches of bituminous concrete on a stabilized gravel base 9 inches thick, are located almost entirely on what was originally shoal water and mud flats along the Virginia shore of the Potomac River. This low area was filled to an elevation of 12 to 16 feet above the normal water level with material consisting of sand, gravel cobbles, silt, and muck pumped by means of hydraulic dredges from borrow pits located in the river on the outskirts of the field. By placing the pipelines of the hydraulic dredges longitudinally along the runways, the granular material was collected in the runway areas and the silt and muck floated off to be deposited by ponding in the intermediate areas between and outside of the runways.

The gravel in the runways was combined with soil from adjacent upland areas to produce a dense, well-graded, stable base course for the bituminous concrete surfacing. The work of stabilization consisted of scarifying the graded gravel runways, removing oversize stone, adding the proper amount of soil, mixing the gravel and soil by means of cultivators, disk harrows, and plows, compacting with rollers, and shaping with motor graders and drags. The desired gradations, physical properties, and densities were obtained by coordinating the construction operations with laboratory tests performed on the materials and the mixtures.

THE LANDING FIELD of the Washington National Airport occupies over 500 of the 720 acres comprising the airport. About 325 acres of the landing area is located in what was originally shoal water and mud flats along the Virginia shore of the Potomac River. This low area was filled to an elevation of 12 to 16 feet above the normal water level with material pumped from the river by means of hydraulic dredges. The remainder of the landing field was brought to grade with dry fill obtained during the grading of the adjacent upland areas.

Preliminary borings disclosed that there was a layer of soft mud varying from 5 to 20 feet in thickness over most of the site. Underlying the mud was a stratified deposit of sand, gravel, cobbles, and silt.[1] In order to obtain as stable a foundation as possible for the runways and to reduce the differential and ultimate settlements likely to occur, the runway areas were trenched to a width of 200 feet and a depth of 12 feet below mean low water or to hard bottom if encountered at less depth.

The excavated trenches were then backfilled with material pumped from borrow pits located in the river on the outskirts of the field.

The material in the borrow pits contained 60 percent of sand and gravel and 40 percent of silt and muck. By placing the pipe lines of the hydraulic dredges longitudinally along the runways, the granular material was collected in the runway areas and the silt and muck floated off to be deposited by ponding in the intermediate areas between and outside of the runways.

The gravel fill was built up to a height of 6 to 8 feet above the final grade of the runways, the additional material serving as a surcharge to hasten consolidation of the newly placed fill material and any compressible material in the foundation below. It served also to furnish gravel for widening the runways and for use in other areas of the airport.

The hydraulic filling was started in December 1938 and completed in December 1939.

STABILIZATION REQUIRED TO PROVIDE UNIFORM SUPPORT FOR PAVEMENT

In October 1939, the Public Roads Administration was requested by the engineering authorities at the Washington National Airport to make a study of the character and quality of the gravel deposited in the runway areas, and to determine what measures should be taken to produce a satisfactory base course for an asphaltic concrete wearing surface. In addition to the four runways, the paving program included taxiways, aprons, access and service roads, parking areas, and the relocation of about 1.75 miles of the Mount Vernon Memorial Highway. The layout of these facilities is shown in figure 1.

The investigation disclosed that the material in the runways did not consist of uniform mixtures of sand and gravel. Instead, the fill contained stratifications and pockets of sand, gravel, and cobbles, and in certain locations layers and pockets of clay and muck were encountered.

The behaviour of the existing runway material under the action of construction traffic showed a large variation in stability Some portions became well compacted while other sections remained loose and became rutted. Sponginess and rutting were observed in the mucky areas. These conditions indicated the need for stabilization in order to provide satisfactory support over the entire area to be paved.

The design called for a stabilized base 9 inches thick after compaction for the runways and taxiways located in the hydraulic fill area and a 12-inch base constructed in two 6-inch courses for the dry fill areas of the landing field as well as for the relocated Mount Vernon Memorial Highway over Four Mile Run. Access roads, service roads, parking zones, and most of the taxiways were designed to have a 5-inch compacted gravel lower course and an 8-inch stabilized gravel upper course. The stabilized base extended 3 feet beyond the edges of the asphaltic concrete surface which was 200 feet wide on the North-South and the Northwest-Southeast runways, 150 feet on the Northeast-Southwest and East-West runways, and 75 feet on the taxiways. Typical cross sections are shown in figure 2.

[1] Washington National Airport, by Lt. R. C. Tripp, Corps of Engineers, U. S. Army. The Military Engineer, September-October 1939.

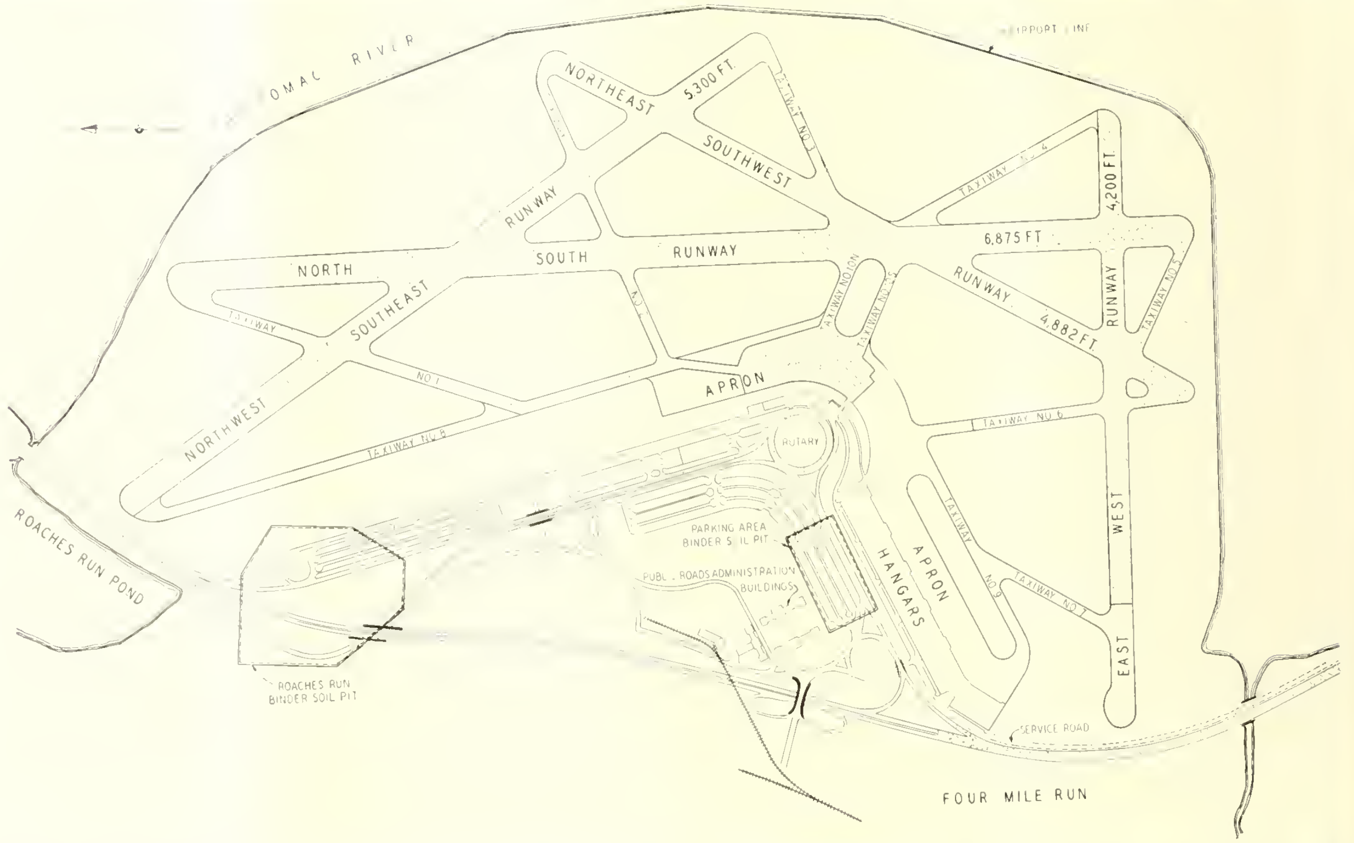

Figure 1.—Layout of Runways, Taxiways, Aprons, and Roads at the Washington National Airport. Shaded Areas Indicate Work Completed During 1940

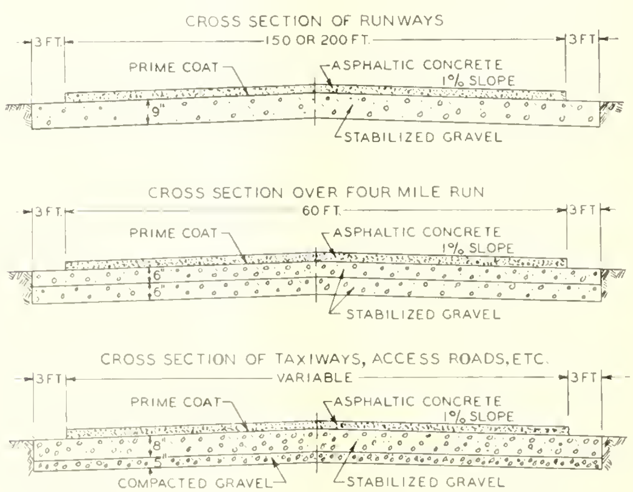

Figure 2.—Typical Paving Cross Sections, Washington National Airport.

Construction of the stabilized base was commenced on March 6, 1940, and continued until the end of the year when the stabilization operations were suspended for the winter. The work completed during this construction period, amounting to approximately 544,000 square yards of stabilized base and indicated by the shaded areas on figure 1, may be summarized as follows:

Facility:	*Area completed, square yards*
Runways	392, 600
Taxiways	87, 900
Apron	31, 000
Mount Vernon Memorial Highway	21, 000

Figure 3.—Typical Formation of Gravel Deposited by Pumping Operations.

Facility—Continued.	*Area completed, square yards*
Access roads	7, 900
Parking zones	3, 600

This report, covering the participation of the Public Roads Administration in the base course stabilization, describes the character of the materials, the methods of construction and control, the sampling, testing, and proportioning of materials, and presents a summary of the results obtained.

The character of the gravel formations as deposited by the pumping operations is illustrated in figure 3. Tests performed on samples taken from the upper 12 inches of the runways (see table 1) indicated that the material, in general, was a nonplastic mixture of sand and gravel with variable amounts of large rock and

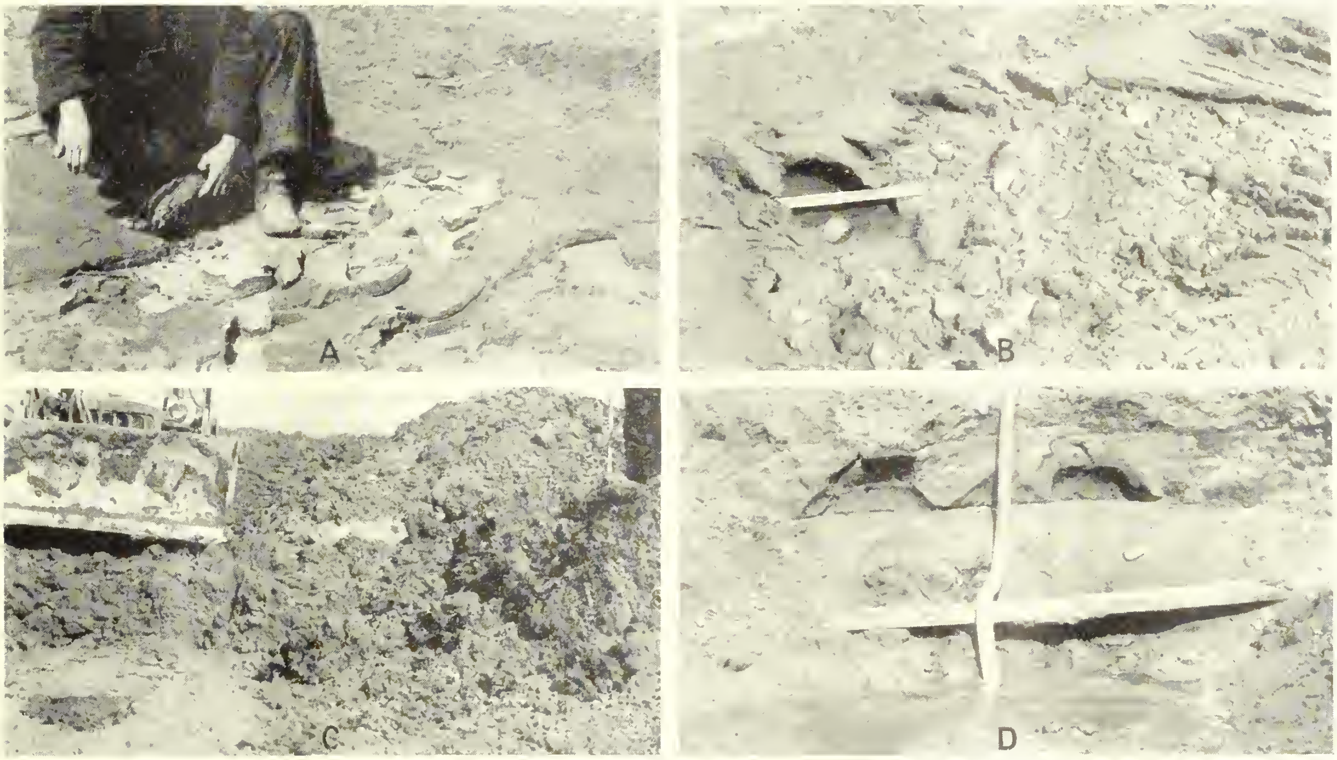

FIGURE 4.—TYPICAL EXAMPLES OF POCKETS AND LAYERS OF MUCK AND SAND. A, THIN LAYERS OF MUCK; B, POCKET OF MUCK, GRAVEL, AND ENTRAPPED WATER; C, DEEP POCKET OF SOFT MUCK; AND D, SANDY DEPOSIT WITH THIN LAYERS OF MUCK.

cobbles. The percentage of large rock varied considerably from place to place. After removing this material, however, the remaining sand and gravel was fairly well graded but was lacking in material passing the No. 200 sieve. As a result, it was decided to stabilize the gravel by the addition of a binder soil from the adjacent upland area.

In addition to variations in the amount of large rock in the gravel fill, layers and pockets of muck and fine sand were encountered in many locations. These conditions are illustrated in figure 4. Mechanical analyses and physical properties typical of these materials are given in table 2.

TABLE 1.—*Results of tests performed on samples typical of gravel pumped into runways of Washington National Airport*

SIEVE ANALYSIS

	Sample No.—							
	1	2	5	7	9	12	13	16
Percentage passing:								
2-inch sieve	86	100	100	92	96	63	75	100
1½-inch sieve	86	95	96	89	93	58	70	98
1-inch sieve	85	85	95	81	89	53	62	93
¾-inch sieve	80	71	92	71	82	46	56	86
⅜-inch sieve	65	53	79	51	62	36	45	71
No. 4 sieve	53	40	66	37	44	29	36	58
No. 10 sieve	42	34	55	25	32	24	29	48
No. 40 sieve	25	27	36	14	13	11	18	34
No. 200 sieve	3	2	5	7	2	2	5	5

PHYSICAL CONSTANTS OF MATERIAL PASSING NO. 40 SIEVE

Liquid limit	(1)	(1)	(1)	[2] 30	(1)	(1)	(1)	(1)
Plasticity index				9				

[1] Nonplastic.
[2] Sample No. 7 was taken in an area containing a thin layer of muck.

TABLE 2.—*Typical analyses of muck and sandy material*

	Sand	Muck
Mechanical analysis:		
Coarse sand (2.0 to 0.25 mm.) ... percent	16	4
Fine sand (0.25 to 0.05 mm.) ... do	61	5
Silt (0.05 to 0.005 mm.) ... do	16	24
Clay (smaller than 0.005 mm.) ... do	7	57
Physical properties:		
Liquid limit	19	71
Plasticity index	(1)	27
Shrinkage limit		31
Shrinkage ratio		1.4
Centrifuge moisture equivalent	7	51
Field moisture equivalent	31	53

[1] Nonplastic.

The formations consisting largely of fine sand were quite spongy when associated with a high water table resulting from blocked drainage. These areas were drained but the material itself was too fine to produce a stabilized base by means of an admixture of binder soil. It was necessary to add both gravel and binder soil.

The muck had physical characteristics typical of the group A-8 subgrades. It was extremely unstable and had to be removed and replaced with gravel during the construction of the stabilized base.

FOUR DIFFERENT GRADINGS PERMITTED IN STABILIZED MIXTURES

Two portions of the upland area, one at Roaches Run and the other at the proposed parking zone south of the Public Roads Administration laboratories (fig. 1), were designated as the locations most convenient for obtaining binder soil without interfering with the grading operations. Accordingly, a soil survey of these areas was made to determine the character and quantities of soils available for use as binder material for stabilization.

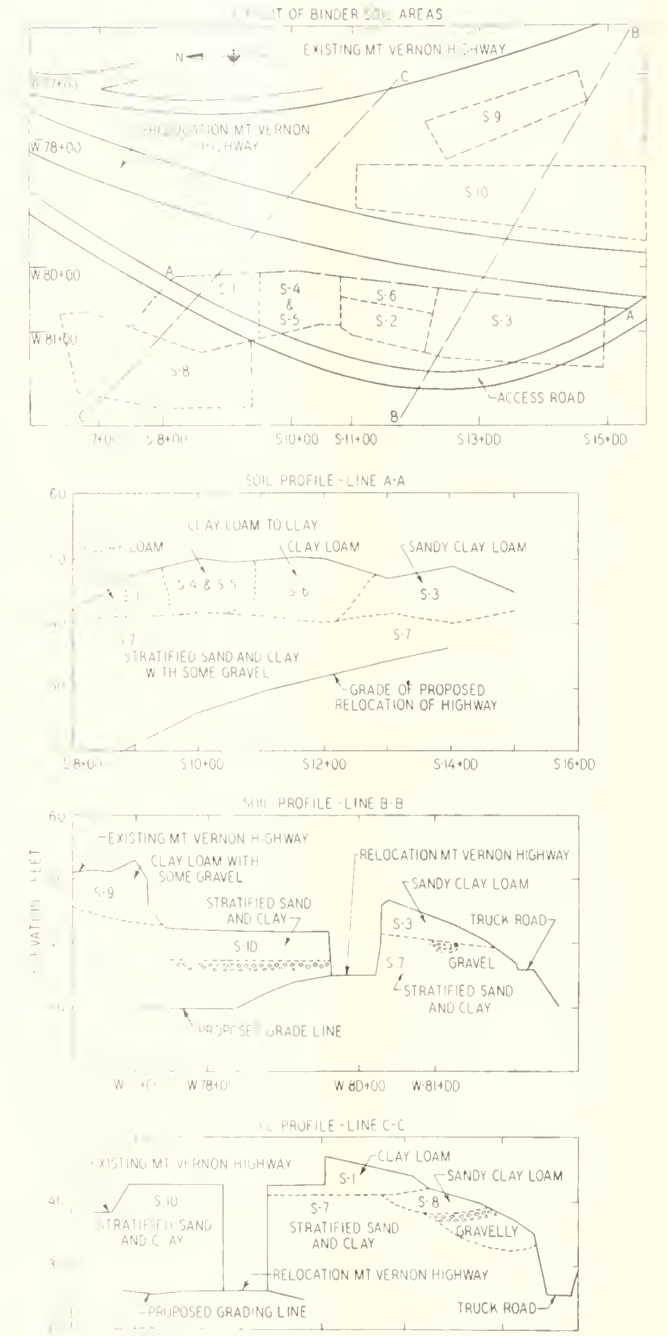

FIGURE 5.—LAYOUT AND SOIL PROFILES OF BINDER SOIL PIT AT ROACHES RUN.

Borings were made to determine the soil profiles and samples representative of the different layers of the profile were taken and tested in the Public Roads Administration soils laboratory. The soil profiles for the Roaches Run pit are shown on figure 5 and the results of tests performed on the samples of soil are given in table 3. The soil profiles and test results for the parking area pit are presented in figure 6 and table 4.

With the exception of the material designated S–7, all of the soils encountered in the two pits were found to be satisfactory for use as binder soil. The S–7 material was too sandy for this purpose. Approximately 24,000 cubic yards of binder soil of acceptable quality was available in the Roaches Run pit and about 27,000 cubic yards in the parking area pit, making a total of 51,000 cubic yards which was more than sufficient for the proposed stabilization.

TABLE 3.—*Results of tests performed on samples from Roaches Run binder soil pit, Washington National Airport*

SIEVE ANALYSIS

	Sample No.—									
	S–1	S–2	S–3	S–4	S–5	S–6	S–7	S–8	S–9	S–10
Percentage passing:										
No. 10 sieve	100	100	100	100	100	100	100	100	100	100
No. 40 sieve	98	96	98	99	99	99	95	96	99	97
No. 60 sieve	94	74	89	97	95	95	75	85	95	83
No. 200 sieve	66	32	48	82	70	65	25	49	66	40
HYDROMETER ANALYSIS OF MATERIAL PASSING NO. 10 SIEVE										
Sand, percent	41	72	57	24	37	42	79	57	43	65
Silt, percent	31	10	20	42	30	31	10	20	36	20
Clay, percent	28	18	23	34	33	27	11	23	21	15
PHYSICAL CONSTANTS OF MATERIAL PASSING NO. 40 SIEVE										
Liquid limit	26	23	27	33	31	29	19	23	25	19
Plasticity index	9	4	9	11	12	9	0	6	7	2

TABLE 4.—*Results of tests performed on samples from parking area binder soil pit, Washington National Airport*

SIEVE ANALYSIS

	Sample No.—					
	P–1	P–2	P–3	P–4	P–5	P–6
Percentage passing:						
No. 10 sieve	100	100	100	100	100	100
No. 40 sieve	99	99	99	99	99	99
No. 60 sieve	97	87	97	94	98	90
No. 200 sieve	76	40	78	63	83	57
HYDROMETER ANALYSIS OF MATERIAL PASSING NO. 10 SIEVE						
Sand, percent	31	65	28	43	22	48
Silt, percent	37	17	38	30	36	28
Clay, percent	32	18	34	27	42	24
PHYSICAL CONSTANTS OF MATERIAL PASSING NO. 40 SIEVE						
Liquid limit	30	22	31	28	38	25
Plasticity index	10	4	10	10	17	8

The acceptable soil materials in general were yellowish and yellowish-red sandy loams and clay loams. They were friable in consistency and could be readily pulverized. With respect to the gradations of the samples, the fraction passing the No. 200 sieve ranged from 32 to 83 percent. The liquid limits varied from 19 to 38 and the plasticity indexes from 2 to 17.

In order to provide for variations in the materials encountered in the runways, four different gradings were permitted in the stabilized mixtures. They were based on the maximum size of the gravel in the mixture after the large rock and cobbles had been removed. The permissible gradings limits are given in table 5.

It was required that the gravel be combined with binder soil in such proportions that the resulting mixture would fall within the limits of grading B, C, D, or E, whichever best fitted the material available. However, since it was desired to use any suitable material existing in the runways that would be satisfactorily stabilized, some tolerance from the limits given in table 5 was allowed at the discretion of the engineer.

In addition to the grading requirements, it was required that the fraction passing the No. 200 sieve

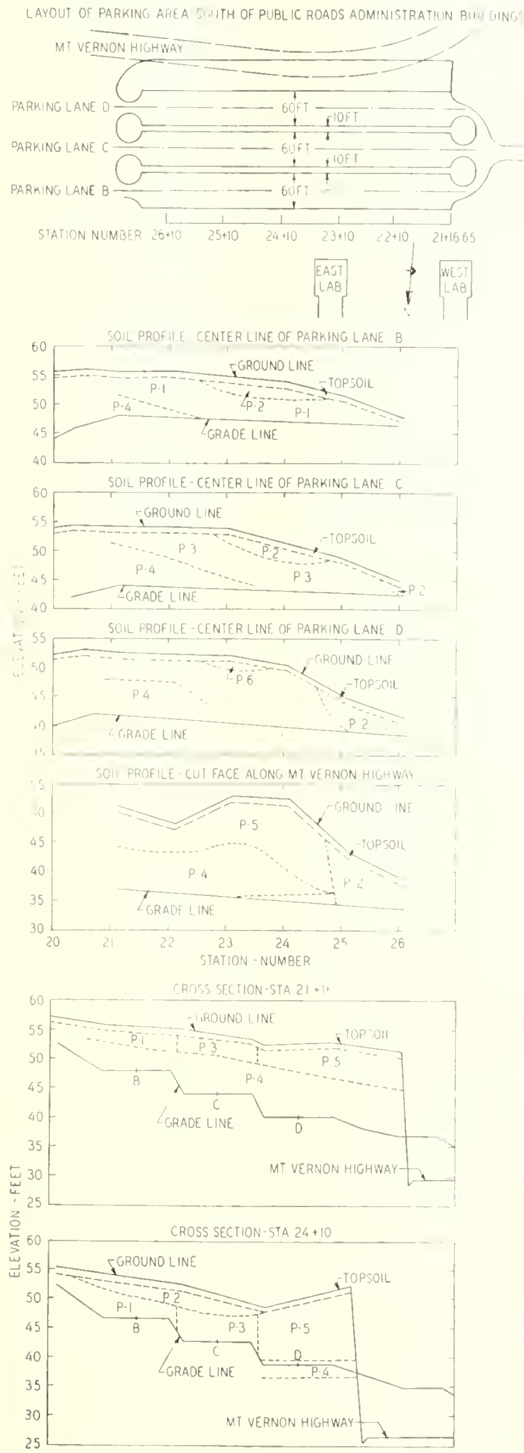

Figure 6.—Layout, Soil Profiles, and Cross Sections of Binder Soil Pit at Parking Area.

should be less than one-half the fraction passing the No. 40 sieve, and also that the fraction passing the No. 40 sieve should have a liquid limit not greater than 25 and a plasticity index not greater than 6.

Control over the base stabilization in accordance with these requirements was accomplished by coordinating the construction operations with the tests performed on the raw materials and the mixtures. This work was directed from a portable field laboratory (fig. 7) located on the runways.

Figure 7.—Portable Laboratory (center) and Offices on Runways.

Table 5.—*Gradation requirements for stabilized mixtures*

Sieve designation	Percentage by weight passing square mesh sieves			
	Grading B	Grading C	Grading D	Grading E
3-inch	100			
2-inch	65-100	100		
1½-inch		70-100		
1-inch	45-75	55-85	100	
¾-inch		50-80	70-100	90-100
⅜-inch	30-60	40-70	50-80	70-100
No. 4	25-50	30-60	35-65	50-90
No. 10	20-40	20-50	25-50	35-80
No. 40	10-25	10-30	15-30	20-50
No. 200	3-10	5-15	5-15	8-25

The rough grading was generally performed by bulldozers which pushed the surcharged fill materiall off to the sides of the area to be stabilized. When gravel was needed in other locations, it was pushed into large piles by the bulldozers and loaded into trucks by means of a dragline (fig. 8–A). Motor patrol graders were used to bring the runway to approximate grade and cross section.

Many areas containing unstable mucky materials were encountered during the grading operations. When the muck was in the form of seams or thin layers, it was excavated by means of large tractor-drawn scrapers (fig. 8–B). Deep pockets were removed with draglines (fig. 8–C). All muck deposits were removed to a minimum depth of 3 feet below subgrade elevation and replaced with gravel.

After the grading was completed, the runway material was scarified with a heavy-duty rooter (fig. 8–D) to an approximate depth of 12 inches. The scarified gravel was then further loosened with a field cultivator and all oversized stone brought to the surface (figs. 8–E and 8–F) were removed by hand. These operations were continued until the depth to be stabilized was, for all practical purposes, free of all stones larger than about 3 inches and other objectionable material such as clay balls.

When sections of the runway had been satisfactorily cleared of oversize stone and other undesirable material, samples were taken from the 12 inches of loosened material and their gradations were determined in the laboratory. At the same time, samples of binder soil were obtained from the pit and analyzed. The percentage of binder soil to be added to the gravel and the area to be covered by each load of binder soil was calculated from the results of these tests.

MATERIALS THOROUGHLY MIXED AND COMPACTED

As the removal of the stone from a section sufficiently large to permit satisfactory operation of the mixing equipment was nearing completion, a crew of

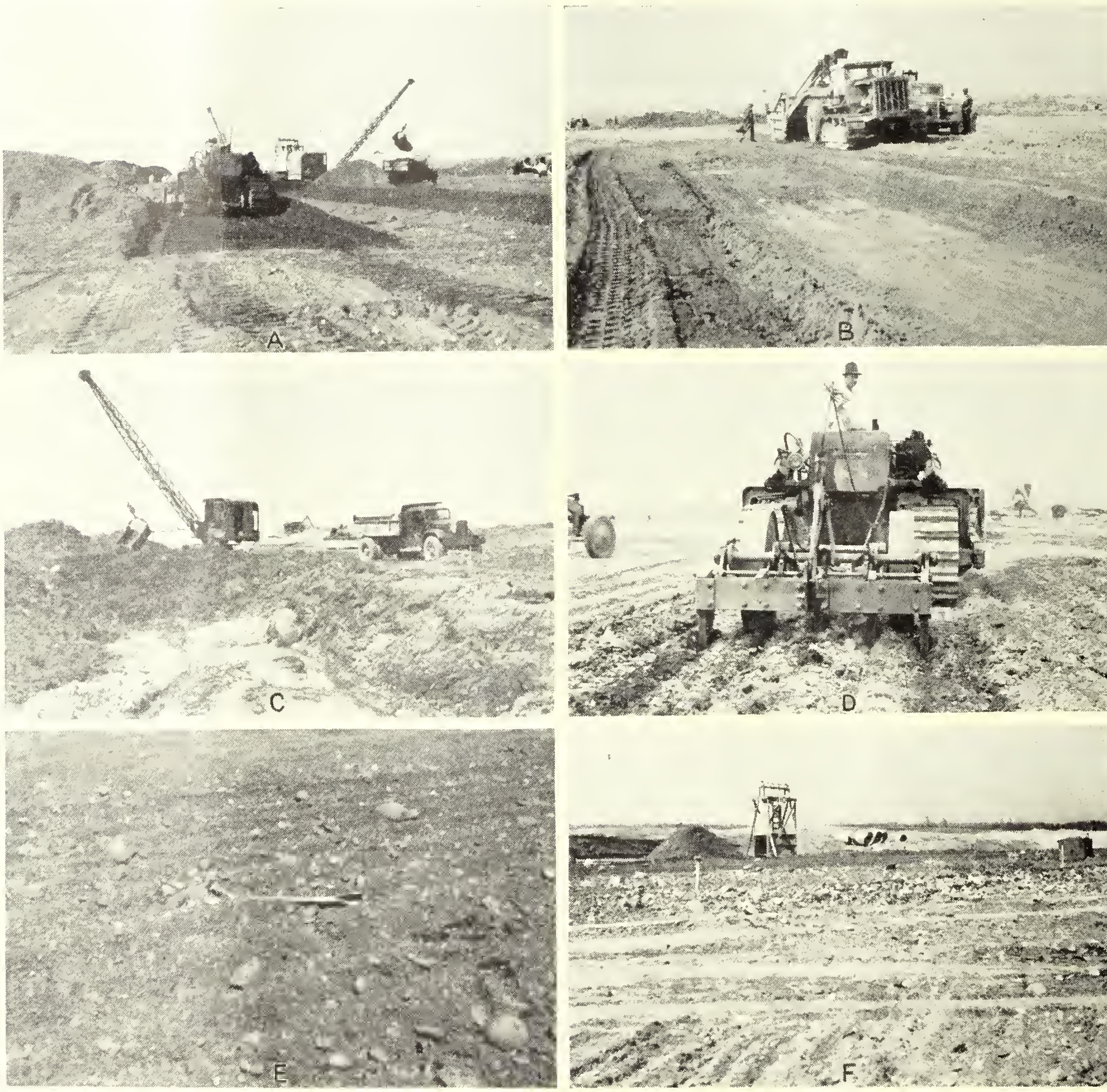

FIGURE 8.—CONSTRUCTION OF RUNWAYS: A, GRADING OPERATIONS; B, THIN LAYERS OF MUCK BEING EXCAVATED BY SCRAPER; C, DEEP MUCK BED BEING EXCAVATED BY DRAGLINE; D, SCARIFYING MATERIAL WITH HEAVY-DUTY ROOTER; E. OVERSIZE STONE BROUGHT TO SURFACE BY SCARIFYING; AND F, OVERSIZE STONE IN EXCESSIVE AMOUNTS GENERALLY ENCOUNTERED AT RUNWAY INTERSECTIONS.

laborers was sent to the binder soil pit where a bulldozer had stripped off the topsoil containing vegetable matter and had pushed up a large pile of approved binder soil. The binder soil was loaded by hand into transportable, bottom dump, 2-cubic yard boxes (fig. 9–A), hauled to the runways, dumped (fig. 9–B), and spread by hand over an area previously staked out in accordance with instructions issued by the testing laboratory.

The first step in the mixing was to cut in the binder soil by means of the field cultivator (fig. 9–C). This was followed by one trip with a two-way tandem disk harrow (fig. 9–D) equipped with disks 28 inches in diameter. In order to facilitate the distribution of the binder soil through the full depth to be stabilized, the disked material was turned with a four-bottom gang plow (fig. 9–E). Mixing with the disk harrow and cultivator was then continued until the binder soil and gravel were thoroughly and uniformly mixed to the specified depth.

Water was applied (fig. 9–F) whenever necessary during the mixing operations. The need for water was determined by the requirements for compaction. Tests made on the base course material in locations where satisfactory compaction was obtained showed that 5 to 7 percent of moisture was required to give the desired results. This checked very closely with the optimum moisture content of 10 percent (American

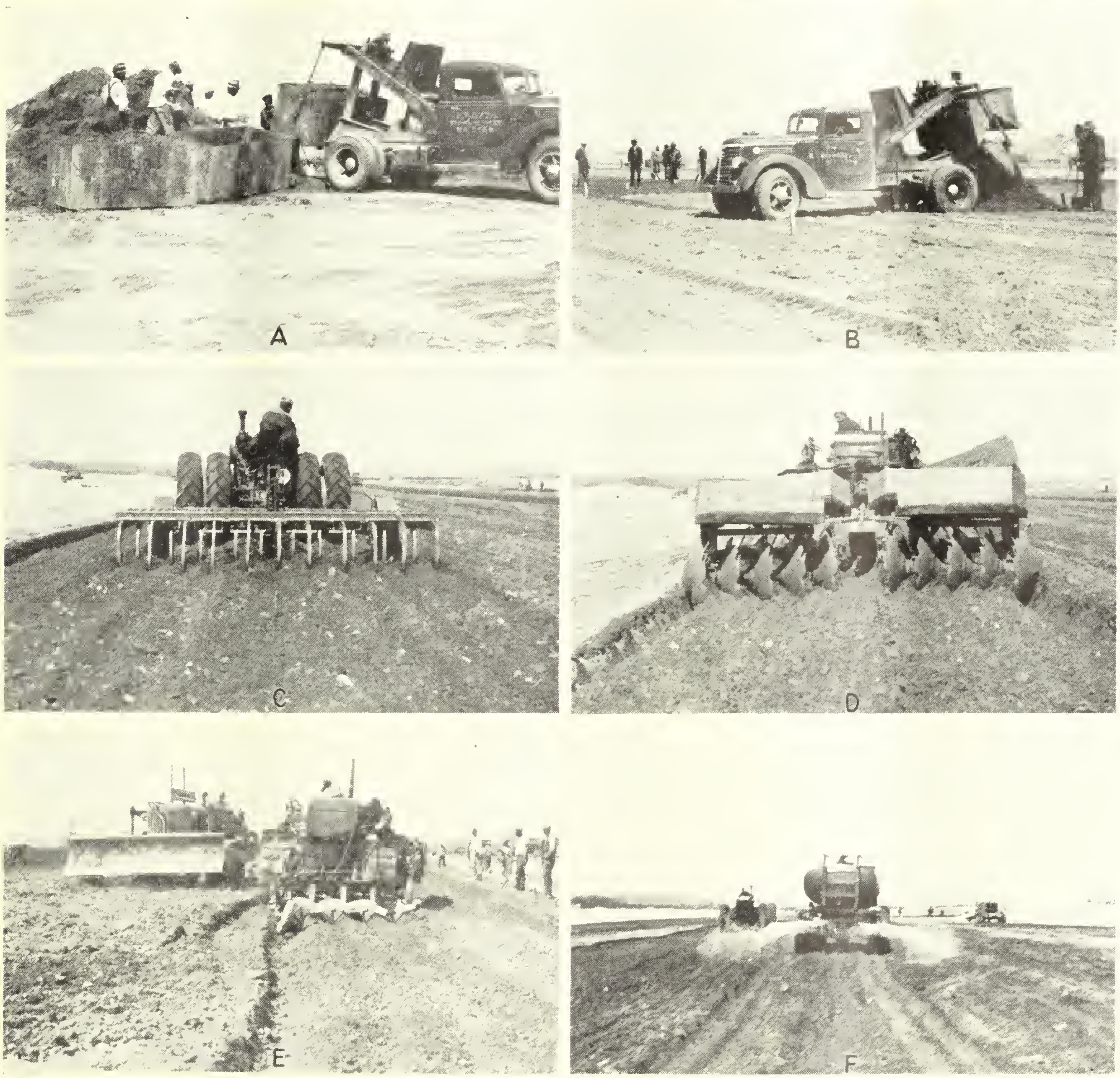

FIGURE 9.—STABILIZATION OF RUNWAYS: A, LOADING BINDER SOIL IN 2-CUBIC YARD BOXES; B, DEPOSITING AND SPREADING BINDER SOIL; C, CUTTING IN BINDER SOIL WITH FIELD CULTIVATOR; D, MIXING WITH TWO-WAY TANDEM DISK HARROW; E, TURNING DISKED MATERIAL WITH FOUR-BOTTOM GANG PLOW; AND F, SPRINKLING DURING MIXING OPERATIONS.

Association of State Highway Officials' Method T 99–38) on the material passing the No. 4 sieve, which averaged about 60 percent of the total mixture.

While the mixing was in progress, frequent checks were made on the moisture content, the uniformity of the mixture, and the depth of the mixed material.

The loose mixture of gravel and soil was bladed to approximate cross section with a motor patrol and then compacted with multi-wheel, pneumatic-tired rollers (fig. 10–A) weighing about 6 tons. This rolling was continued until an unyielding surface was produced under the weight of these rollers. At least two trips were required to obtain this condition. The appearance of the compacted mixture is illustrated in figure 10–B. Final compaction was obtained by means of a three-wheel, 10-ton roller (fig. 11–A). The motor patrol (fig. 11–B) and a multiple-blade drag (fig. 11–C) were used to keep the surface properly shaped during rolling.

The surface was maintained in a moist condition by sprinkling while these operations were in progress.

Weak spots which developed in the base or subgrade during the rolling were examined by means of test pits and corrected according to the needs of the particular case. A further check on the subgrade stability was obtained by operating a 12-ton, solid-tired truck (fig. 12–A) over the compacted surface. A failure due to weak subgrade is shown in figure 12–B.

After the base had been compacted to a minimum dry density of 130 pounds per cubic foot, the elevation and cross section was checked by an engineering party. Final shaping consisted of cutting the high spots and filling in low areas in accordance with stakes driven to

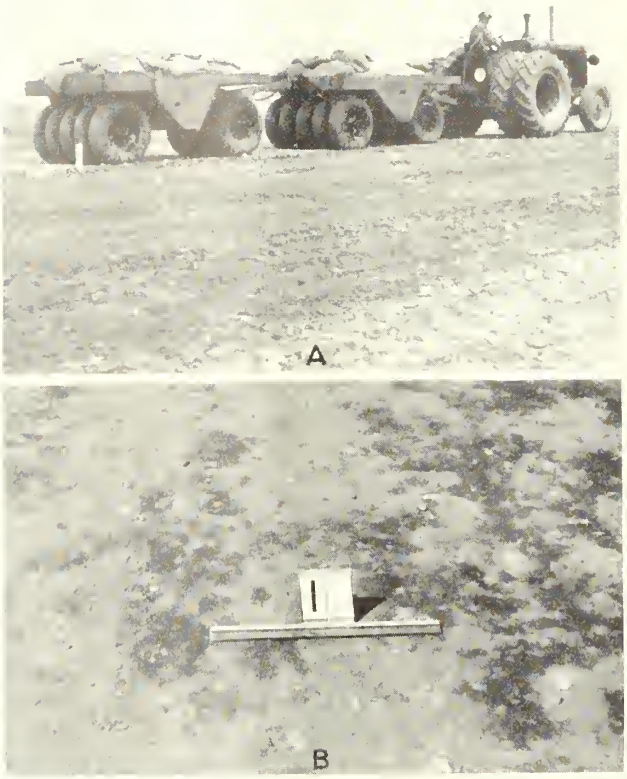

Figure 10.—A, Compacting Stabilized Base with Pneumatic-tired Rollers; and B, Appearance of Base after Compacting with Pneumatic-tired Rollers.

grade elevation at 25-foot intervals. This work was performed by hand or by motor patrol depending on the size of the area to be corrected. The surface was then finished by rolling with an 8-ton tandem roller (fig. 12–C). The appearance of the completed base course is shown in figure 12–D.

The quality of the stabilized mixture was checked by tests performed on samples taken at regular intervals after the mixing was completed. When the results of tests indicated an unsatisfactory mixture at a certain location, additional samples were obtained in sufficient number to determine the limits of the area in this condition. All such areas were reconstructed.

The final step in the stabilization procedure was an application of tar prime at a rate of about 0.25 gallon per square yard. Application of the tar was not permitted until the base course conformed with all the requirements relating to quality of mixture, density, and stability.

The same procedure was followed for each layer of the two-course construction on the Four Mile Run fill and for the upper 8 inches on the taxiways, access roads, etc. (see fig. 2).

STABILIZED MIXTURES TESTED TO DETERMINE CONFORMITY WITH REQUIREMENTS

The results of the sieve analyses performed on the samples of stabilized mixtures from the runways are summarized in table 6. These results are shown graphically in figure 13. The samples were grouped into gradation ranges corresponding as closely as possible to the grading requirements given in table 5.

None of the samples had a gradation typical of the B grading. This grading was included in the require-

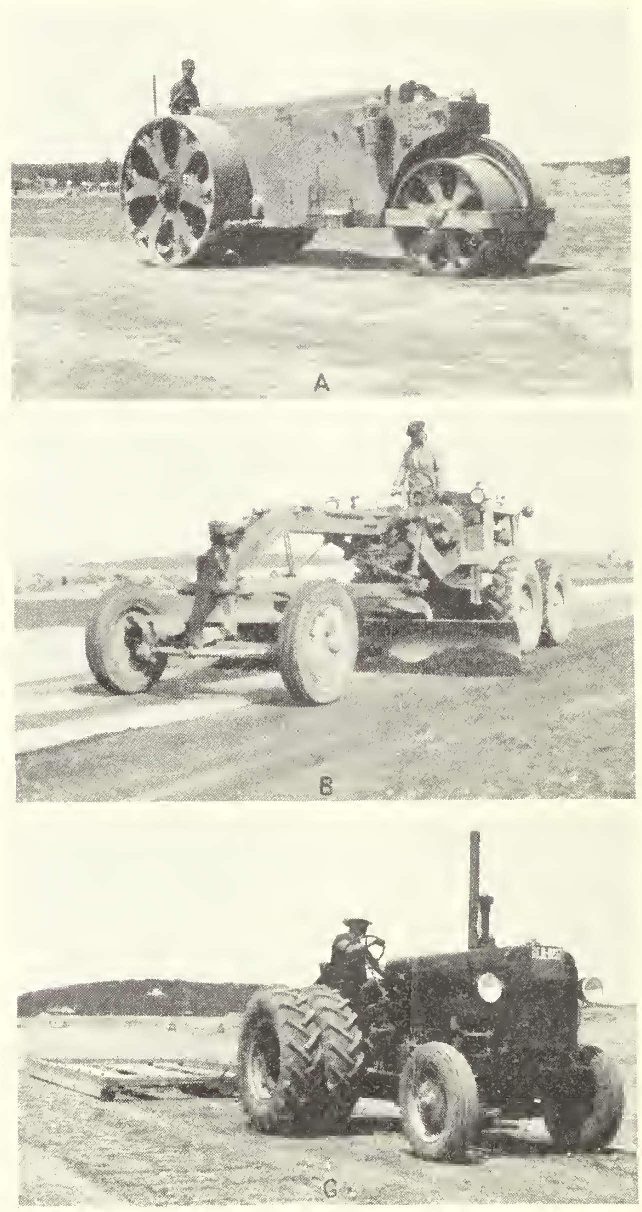

Figure 11.—A, Compaction with 3-wheel, 10-ton Roller; Shaping, during Rolling, with Motor Patrol (B), and with Multiple Blade Drag (C).

ments on the basis of materials represented by samples 12 and 13 in table 1. However, practically all of the material remaining after removal of the oversize stone during the construction operations was smaller than 2 inches. Only one sample had more than 10 percent retained on the 2-inch sieve and was included with the samples in grading C.

The range in gradations designated D–E was made necessary by the fact that almost all the gravel samples had some material retained on the 1-inch sieve but many of these could not be placed in the C or D grading because of the high percentages passing the smaller-sized sieves. Many of the samples with material coarser than 1 inch had more than 80 percent smaller than the ¾-inch sieve. These samples generally had more material passing the No. 10 and No. 40 sieves, even before the addition of binder soil, than was permitted in the specifications for the C and D gradings. Since binder soil was required in practically all instances,

TABLE 6.—*Summary of results of sieve analyses performed on stabilized mixtures from runways on Washington National Airport*

RANGE IN GRADATION [1]

Sieve designation	Percentage by weight passing square mesh sieves			
	Grading C	Grading D	Grading D-E	Grading E
2-inch	89-100	93-100	100	----------
1½-inch	80-100	86-100	91-100	100
1-inch	72-85	86-92	86-100	95-100
¾-inch	63-80	75-80	81-90	91-100
⅜-inch	49-65	51-70	63-79	78-91
No. 4	40-56	38-60	47-70	65-83
No. 10	34-47	29-53	37-64	54-76
No. 40	22-35	16-36	19-45	25-57
No. 200	4-13	3-13	4-14	3-19

AVERAGE GRADATION

Sieve designation	Grading C	Grading D	Grading D-E	Grading E
2-inch	99	100	100	----------
1½-inch	89	96	98	100
1-inch	81	88	92	98
¾-inch	75	78	86	95
⅜-inch	61	62	71	85
No. 4	51	51	60	74
No. 10	43	42	50	63
No. 40	27	26	30	41
No. 200	8	8	8	11

[1] Range in gradation shows the maximum and minimum percentages passing each sieve for the particular group of samples falling within the grading band indicated.

the gradations of the resulting mixtures could not possibly fall within the limits specified. For this reason, all samples having between 80 and 90 percent passing the ¾-inch sieve were included in the D-E grading while those having more than 90 percent finer than the ¾-inch sieve were placed in the E grading.

The samples having 80 percent or less passing the ¾-inch sieve were placed in the C grading if the amount smaller than the 1-inch sieve did not exceed 85 percent and in the D grading when the percentage finer than the 1-inch sieve was greater than 85 percent.

The ratios of the fractions passing the No. 200 sieve to the fractions passing the No. 40 sieve ranged from 0.14 to 0.50 with an average of 0.27 for all the samples from the runways.

With respect to the physical properties of the fractions passing the No. 40 sieve, the results of tests may be summarized as follows:

Maximum liquid limit	23
Average liquid limit	18
Maximum plasticity index	6
Average plasticity index	1

A liquid limit of 25 and a plasticity index of 6 were the maximum permitted. In the design of the mixture an attempt was made to hold the plasticity index to 3 or less in order to insure a stable base course under adverse moisture conditions. Only 4 percent of the samples tested had plasticity indexes higher than 3 while 36 percent had plasticity indexes of zero. Another 36 percent were so granular that the plasticity index could not be determined. Of interest in this connection is the fact that the nonplastic mixtures were compacted just as readily as those having a measurable plasticity index.

The base course densities obtained on the runways ranged from 126 to 143 pounds per cubic foot with an average dry density of 134 pounds per cubic foot as compared with the density of 135 pounds per cubic foot used in designing the mixture. The low density of 126 pounds per cubic foot was obtained on the northwest end of the Northwest-Southeast runway. This portion of the runway was constructed before arrangements had been made to control the density or to check the stability of the subgrade.

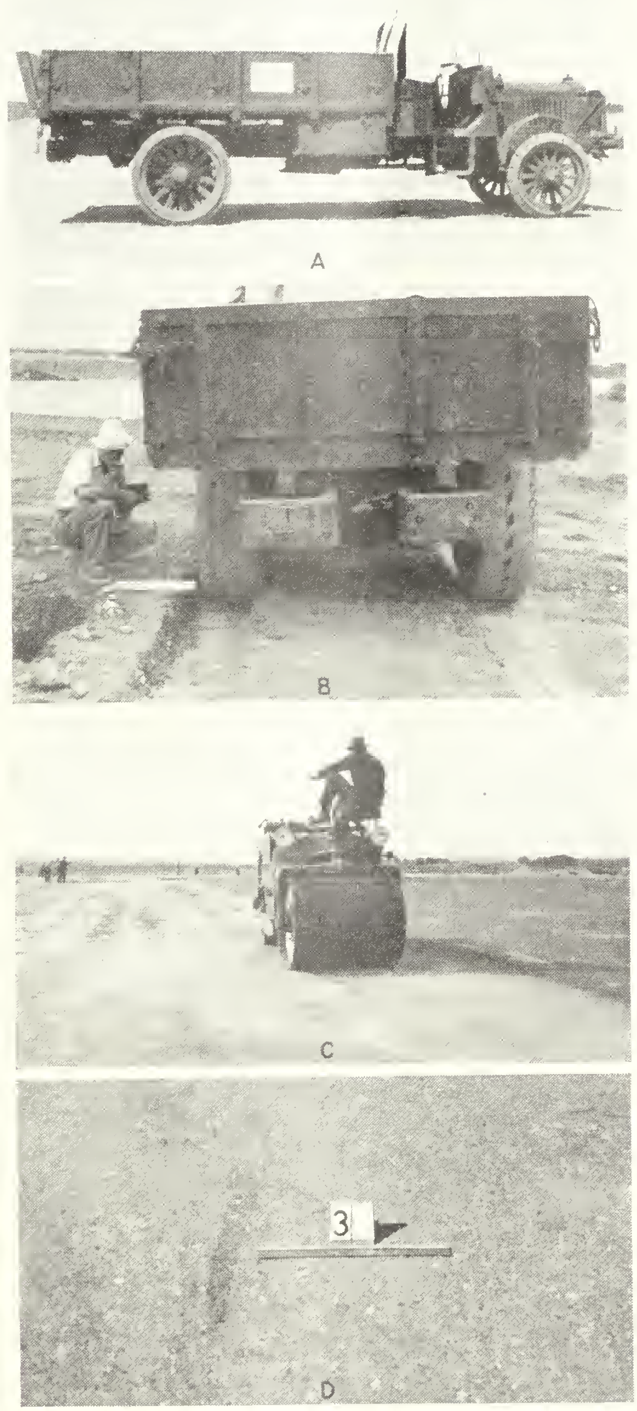

FIGURE 12.—A, CHECKING BASE STABILITY WITH A 12-TON, SOLID-TIRED TRUCK; B, FAILURE DUE TO WEAK SUBGRADE; C, FINAL ROLLING WITH AN 8-TON TANDEM ROLLER, AND D, APPEARANCE OF COMPLETED BASE COURSE.

After the minimum density requirement of 130 pounds per cubic foot was established, lower densities were permitted only when the amount of rolling indicated that no increase in density could be obtained. Such conditions were encountered in a few isolated cases where the mixtures were sandy rather than gravelly in character. These mixtures had densities ranging from 128 to 130 pounds per cubic foot.

In addition to the determination of the density of the 9-inch compacted base course, tests were made at three

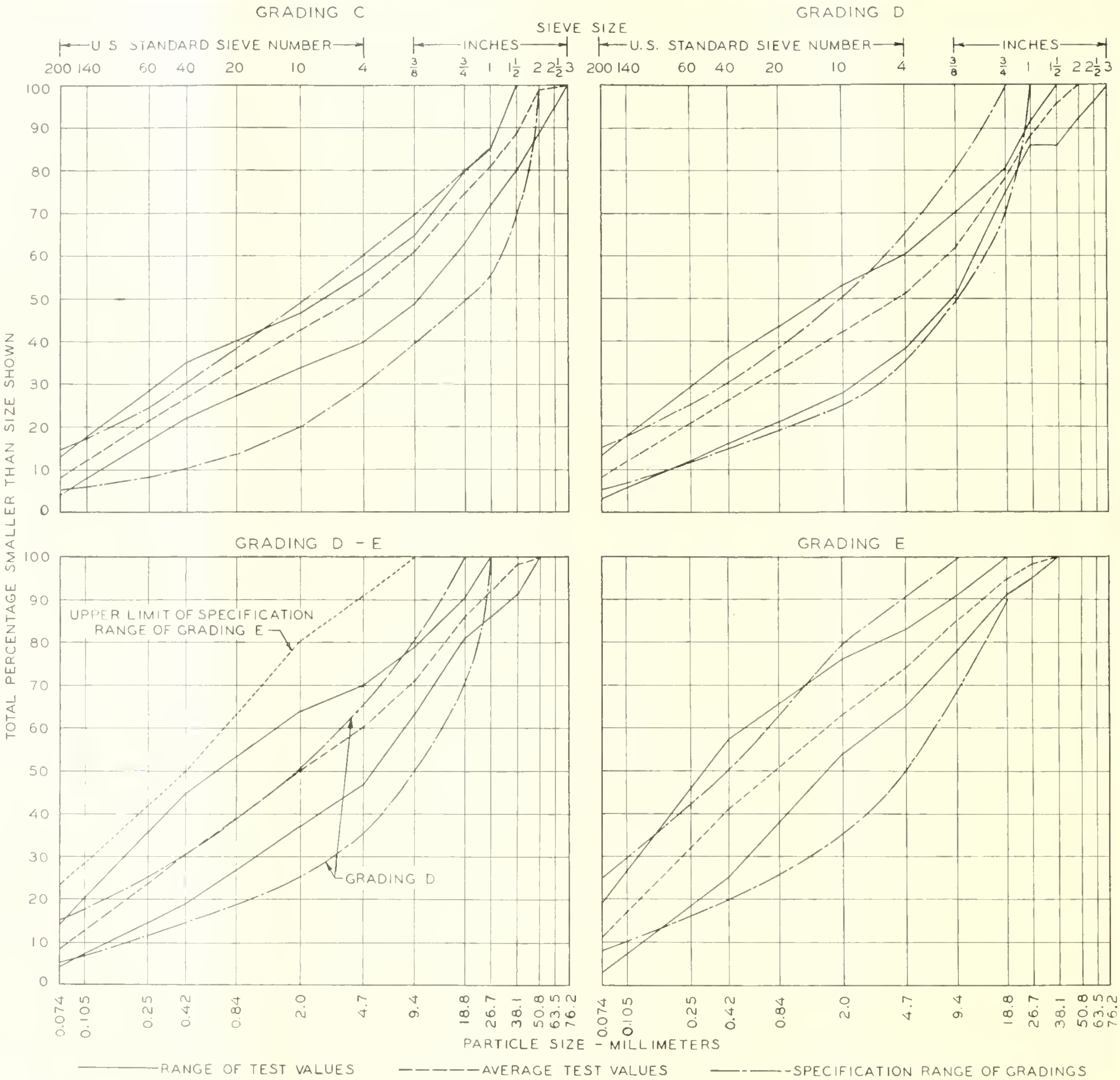

Figure 13. Results of Sieve Analyses of Stabilized Base Course Mixtures Compared with Specification Requirements.

locations on the Northwest-Southeast runway to determine the density of the upper 4½ inches. The two tests at each location were at places not more than 12 inches apart. The results are given in table 7.

Table 7.—*Densities of samples from Northwest-Southeast runway*

Station	Thickness tested	Dry density
	Inches	*Pounds per cubic foot*
36+50	4½	134.1
	9	129.4
40+50	4½	138.5
	9	134.2
44+50	4½	133.7
	9	130.6

These results show that the density of the upper half of the compacted stabilized base was about 103 percent of the density of the full 9 inches. On this basis the average density of 134 pounds per cubic foot for the 9-inch thickness indicates a density of 138 pounds per cubic foot in the upper 4½ inches. Assuming that the density for the 9-inch thickness is equal to the average of the densities of the upper and lower 4½ inches, the density of the lower 4½ inches may be calculated by multiplying the density of the 9-inch thickness by 2 and subtracting the density of the upper 4½ inches. The values obtained in this manner for stations 36+50, 40+50 and 44+50 are respectively 124.7, 129.9 and 127.5 pounds per cubic foot which correspond to densities averaging 94 percent of the densities of the upper 4½ inches and 97 percent of the densities of the full 9 inches.

The moisture contents of the base course, determined as a part of the density test, varied from 2.3 to 7.2 percent with an average of 4.4 percent.

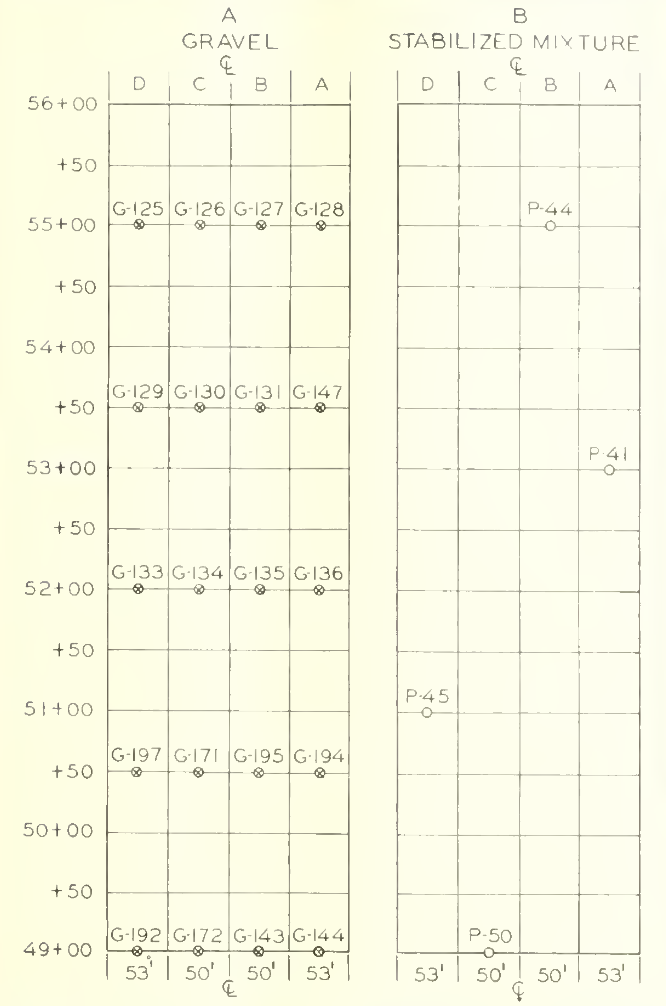

Figure 14.—Plan of Locations at Which Various Samples Were Taken.

Tests made at three different locations on the North-South runway disclosed an average density of 125 pounds per cubic foot after four trips with the pneumatic-tired roller. After two trips with the three-wheel roller, the average density was increased to 128.7 pounds per cubic foot, and two additional trips increased it to 133.3 pounds per cubic foot.

SAMPLING AND TESTING PROCEDURES DESCRIBED

Sampling of the gravel consisted of digging a hole 12 inches deep in the graded runway after the oversize stone had been removed and collecting approximately 15 pounds of material from the sides of the hole. The runways were divided into strips 50 or 53 feet wide and samples were taken from each strip at intervals of 150 feet as illustrated in figure 14. The samples were placed in dust-tight canvas bags and delivered to the portable field laboratory which was located as close as possible to the section of the runway under construction.

The sample was first dried in shallow pans over a gasoline camp stove (fig. 15–A); it was stirred continuously to prevent burning. After the dried sample had cooled off, it was quartered down to about 4 pounds, placed in a pan, and ground with a rubber-covered pestle to break up the aggregation of particles. Any fine material having a tendency to adhere to the coarse gravel was removed with a wire brush. All of the

Figure 15. Laboratory Tests on Samples. A, Drying Gravel Samples on Double-burner Gasoline Camp Stoves; and B, Determining Weights of Material Retained on Various Sieves.

material was then shaken through a nest of sieves ranging in size from the maximum to the minimum called for in the gradation requirements for the stabilized mixtures. The fraction retained on each sieve added to that retained on the sieves with larger openings was weighed (fig. 15–B) and the percentage of the total sample retained on each sieve was calculated. The form used for recording the data is shown in figure 16.

At the start of the work, samples of binder soil were obtained from the pit. After the hauling was commenced, samples were taken from the soil deposited on the runways. These samples were tested for moisture content as well as gradation, which was determined in the same manner as for the gravel.

One sample of the stabilized mixture was taken for each 200 lineal feet of runway as shown in figure 14–B. Some of these samples were tested in the portable field laboratory. The majority, however, were sent to the Public Roads Administration laboratory where their gradations, liquid limits, and plasticity indexes were determined in accordance with the standard methods of the American Association of State Highway Officials.

In practically all cases, the gravel required the addition of binder soil in order to provide a stable mixture. It was found that with the materials available best results were obtained with a mixture having approximately 7 or 8 percent passing the No. 200 sieve for the B, C, and D gradings and about 10 or 11 percent for the E grading. Tests performed on the mixtures showed that the liquid limit and plasticity index requirements could be satisfied with any acceptable gradation resulting from the combination of the existing gravel with the binder soils used on this project.

This simplified the proportioning to the considera-

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PUBLIC ROADS ADMINISTRATION
Washington, D. C.

Sieve Analyses Record - Washington National Airport

Sample No. G-127 Date 5-9-40
Station 55+00
Location B Lane
North - South Runway

Sieve	Retained: Weight grams	Retained: Percent	Passing Percent	Variation from grading limits Type......
3 in.				
2 in.			100	
1 in.	142	11	89	
3/4 in.	263	20	80	
3/8 in.	528	39	61	
No. 4	757	56	44	
No. 10	885	66	34	
No. 40	1097	82	18	
No. 200	1318	98	2	

Passing No. 200 sieve .....27...... grams
Wt. of total sample .....1345...... grams
Tested by....K.... Checked by....T.......

Sample No. ________ Date ________
Station ________
Location ________

Sieve	Retained: Weight grams	Retained: Percent	Passing Percent	Variation from grading limits Type......
3 in.				
2 in.				
1 in.				
3/4 in.				
3/8 in.				
No. 4				
No. 10				
No. 40				
No. 200				

Passing No. 200 sieve .... grams
Wt. of total sample .... grams
Tested by .... Checked by..........

Sample No. ________ Date ________
Station ________
Location ________

Sieve	Retained: Weight grams	Retained: Percent	Passing Percent	Variation from grading limits Type......
3 in.				
2 in.				
1 in.				
3/4 in.				
3/8 in.				
No. 4				
No. 10				
No. 40				
No. 200				

Passing No. 200 sieve ....grams
Wt. of total sample .... grams
Tested by......... Checked by ....

Sample No. ________ Date ________
Station ________
Location ________

Sieve	Retained: Weight grams	Retained: Percent	Passing Percent	Variation from grading limits Type......
3 in.				
2 in.				
1 in.				
3/4 in.				
3/8 in.				
No. 4				
No. 10				
No. 40				
No. 200				

Passing No. 200 sieve .... grams
Wt. of total sample .... grams
Tested by .... Checked by...........

FIGURE 16.—FORM USED FOR RECORDING SIEVE ANALYSES.

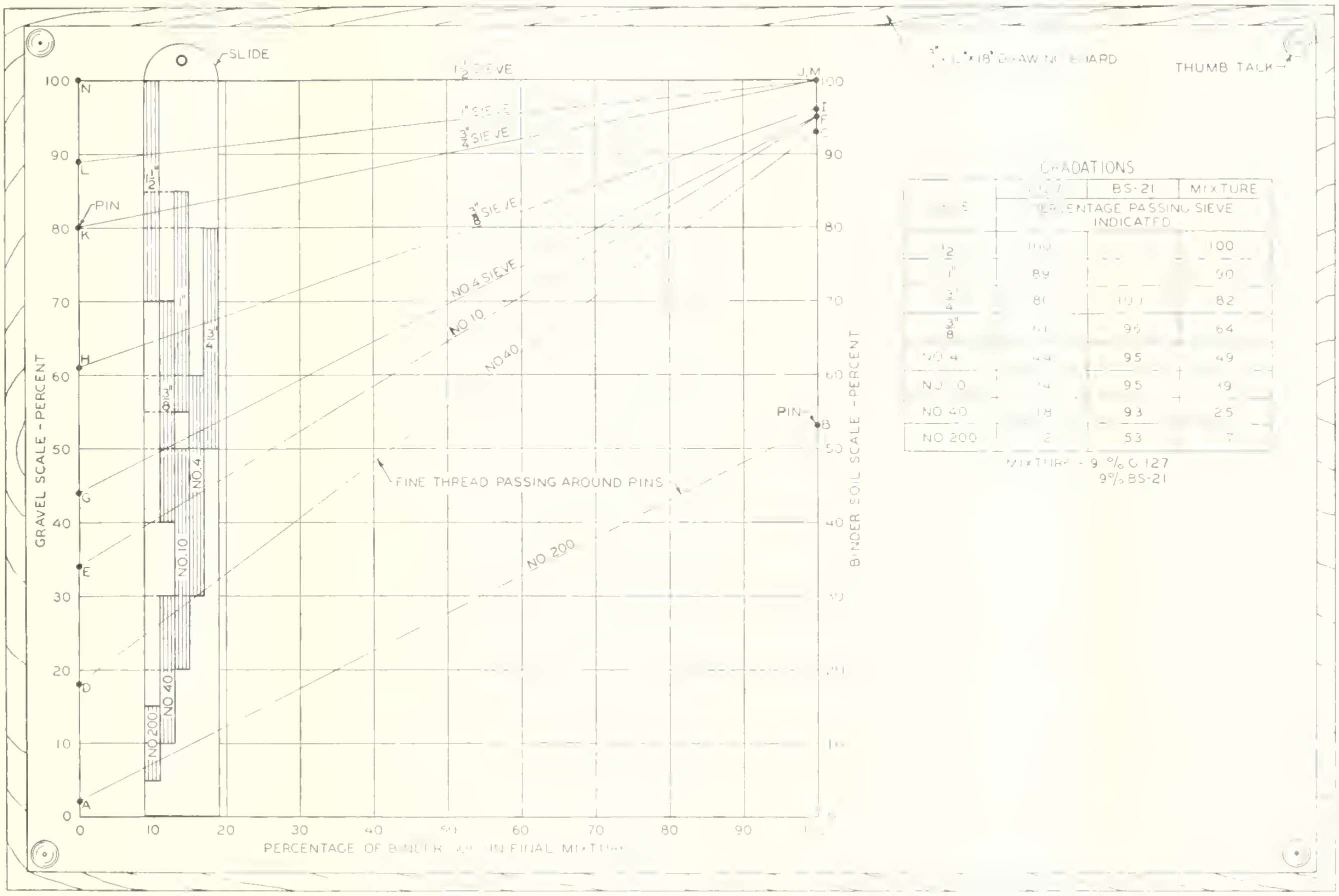

FIGURE 17.—GRAPHICAL METHOD FOR PROPORTIONING TWO SOIL MATERIALS TO PRODUCE SPECIFIED GRADING OF STABILIZED MIXTURE.

tion of grading alone. On the basis of their gradations, the proper proportions of the two materials, gravel and binder soil, were determined by either the trial-and-error method or the graphical method. The trial-and-error method consisted of assuming a certain percentage of binder soil to add to the gravel and calculating what the resulting mixture would be. If this assumed percentage did not prove satisfactory other percentages were tried until the calculations indicated a suitable mixture. After a little experience with the available materials, the desired combination could be obtained on the first trial.

The proportioning of the materials by the graphical method was performed using the mechanical device illustrated in figure 17. This consisted of a 12- by 18-inch drawing board on which was mounted a piece of cross section paper at least 10 inches long by 10 inches wide and having 10 divisions to the inch in each direction, a movable paper scale, several pins (represented by the small circles on the figure), and a fine thread looped around the pins. The fine thread is represented in figure 17 by the lines connecting the pins and having sieve designations.

GRAPHICAL METHOD USED IN PROPORTIONING MIXTURE

The movable scale is a strip of cross section paper having the same vertical scale as the fixed sheet. The limits of the specified grading are blocked off on this scale. A different movable scale had to be made for each grading band.

The operation of this device may best be illustrated by an example. For convenience in following the procedure, the sieve analyses of gravel sample 127 (G–127) and binder soil sample 21 (BS–21) which are to be combined are shown on figure 17. The first step is to place pins along the vertical scales of the fixed sheet at points corresponding to the percentages passing the various sieves, on the left for the gravel and on the right for the binder soil. Next, the end of the fine thread is tied to pin A marking the percentage of gravel passing the No. 200 sieve (2 percent) and stretched across to pin B designating the percentage of binder soil passing the same sieve (53 percent). The thread is then extended straight up along the binder soil scale to pin C, across to pin D, up along the gravel scale to pin E, across to pin F, and so on to pins G, H, I, J, K, L, M, and ending at pin N.

The movable scale is placed under the threads along the pins on the left side and then moved to the right until the line (indicated by the left edge of movable scale) is reached where the greatest number of threads are crossing within the limits specified for the corresponding sieve sizes marked on the scale. The intersection of this line with the horizontal scale at the bottom of the sheet indicates the percentage of binder soil to be added to the particular sample of gravel, while the gradation of the mixture produced by this combination is read on the vertical scale at the points where this line intersects the lines formed by the different segments of the thread running across the sheet between the pins.

The calculation of the binder soil distribution was based on (1) the compacted dry density of the stabilized base assumed for design purposes as 135 pounds per

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PUBLIC ROADS ADMINISTRATION
Washington, D.C.

Binder Soil Distribution Calculation - Washington National Airport

Design data:
Compacted weight of stabilized mixture (lbs. per cu. ft.)... 135 ..... Computed by.... K ....
Thickness stabilized (inches) .... 9 ..... Checked by .... T ....
Compacted weight of stabilized mixture (lbs. per sq. yd.)... 911 ..... Date ... 5-9-40 ....

Binder soil pit	R.R.	R.R.	R.R.	R.R.			
Binder soil type	BS-21	BS-21	BS-21	BS-21			
Moisture content (percent)	8	12	8	8			
Binder soil required (percent)	4	6	9	9			
Binder soil per load (lbs.)	4870	4870	4870	4870			
Dry binder soil required (lbs. per sq. yd.)	36	55	82	82			
Moist binder soil required (lbs. per sq. yd.)	39	59	89	89			
Distribution (sq. yds. per load)	125	83	55	55			
Width of spread (ft.)	26½	25	25	25			
Lineal distance per load (ft.)	42	29	20	20			
Gravel samples represented	125	126	127	131			

R.R. denotes Roaches Run

Figure 18.—Form Used for Calculation of Binder Soil Distribution.

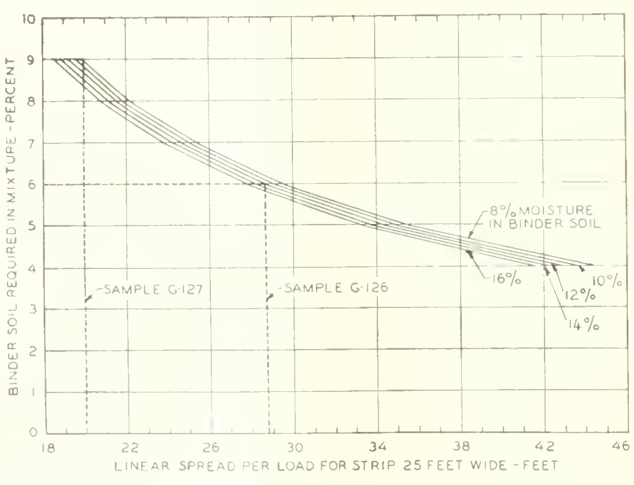


Figure 19.—Graphical Determination of Binder Soil Distribution

cubic foot, (2) the moisture content of the soil as determined in the laboratory, (3) the percentage of binder soil in the mixture determined as described above, and (4) the weight of soil contained in the 2-cubic yard transportable box which was found to average 4,870 pounds. The variation in weight of any individual load from the average was negligible in amount.

The form used for the calculation is illustrated in figure 18. On the basis of a dry density of 135 pounds per cubic foot, the weight of dry materials in 1 square yard of compacted stabilized base, 9 inches thick, equals 911 pounds. The amount of dry binder soil in pounds per square yard to be spread on the runway is equal to 911 multiplied by the percentage of binder soil in the mixture divided by 100. In the case of gravel sample 127 and binder soil sample 21, for example, this amounts to $\frac{911 \times 9}{100}$ or 82 pounds. Correcting for a moisture content of 8 percent, this value becomes 82×1.08 or 89 pounds of moist binder soil per square yard. Dividing the weight of a load of binder soil (4,870 pounds) by 89 gives 55 square yards as the area covered by one load of binder soil.

For convenience in spreading by hand, the width of spread for each load was fixed at a maximum of 25 feet for the inside 50-foot strips of the runways and 26½ feet for the outside strips 53 feet wide. The linear distance in feet per load was computed for the corresponding width.

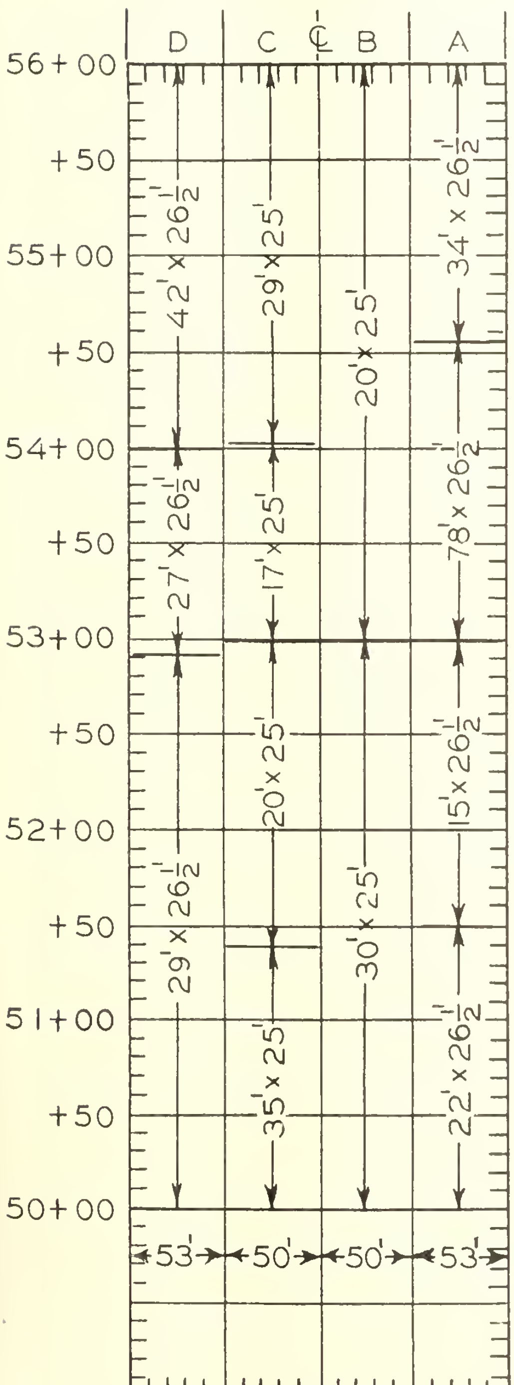
It will be seen from the above calculation that for a given width of spread the linear distance per load depends on the percentage of binder soil in the mixture and the moisture content of the binder soil. Accordingly charts were constructed from which the distribution of the binder soil was determined graphically. The chart used when the width of spread was 25 feet is shown in figure 19.

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION
Washington, D.C.

Stabilization Record - Washington National Airport

Location NORTH - SOUTH RUNWAY

Date MAY 9, 1940



To - Superintendent of Stabilization
From - Inspector (P.R.A.)

Subject - Binder soil distribution.

The area indicated on sketch by .... is in condition to receive binder soil type BS-2J from pit located in upland area ROACHES. RUN .... and shall be distributed as follows:

Sta. to Sta.		Strip	Quantity in lbs. per sq.yd.	Lineal feet per load for width of 25' & 26½'
50+00	56+00	ABCD	VARIABLE	SEE SKETCH

Figure 20.—Instruction Sheet for Distribution of Binder Soil.

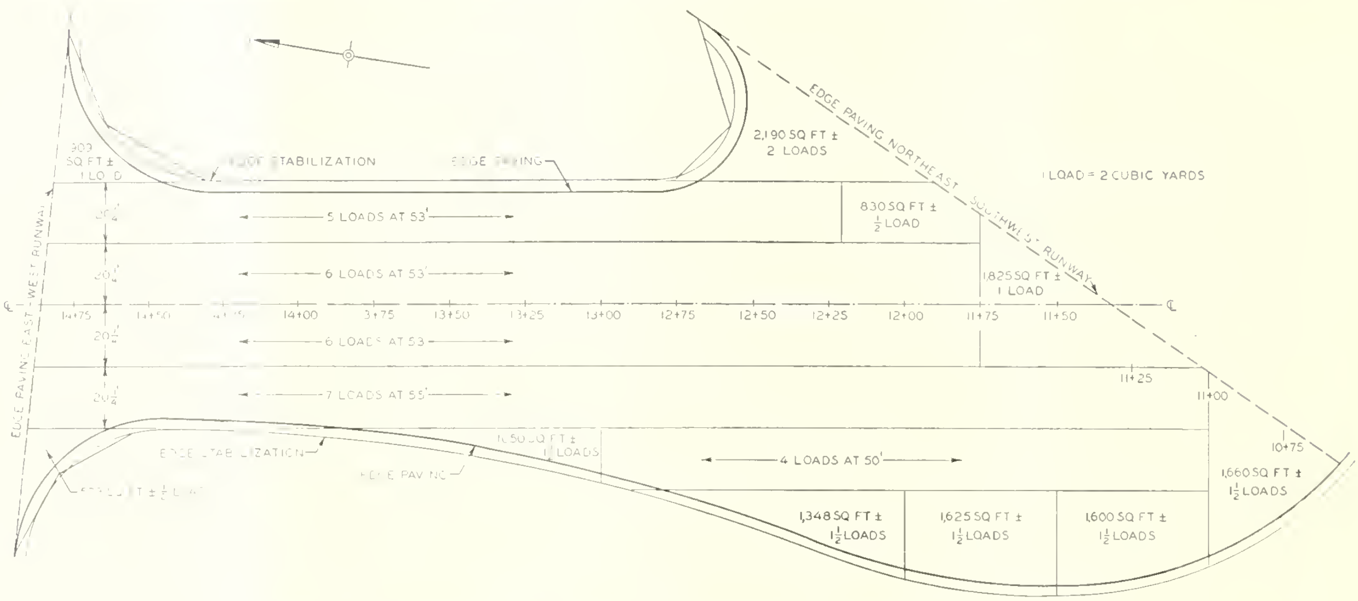


Figure 21.—Binder Soil Distribution Sheet for Taxistrip No. 6, Section 1.

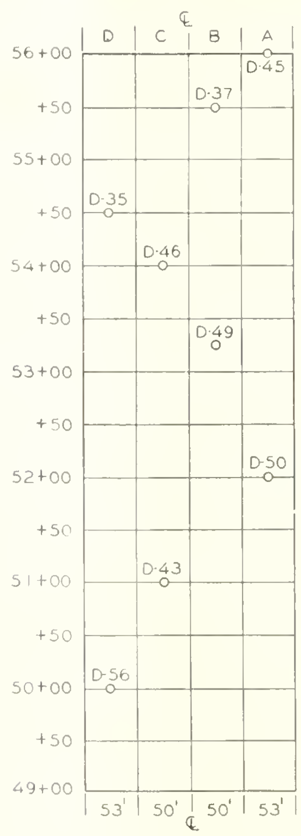


Figure 22.—Plan of Locations at which Density Samples were Taken.

Figure 20 is an example of the sheet furnished to the superintendent of stabilization showing the dimensions of the area for each load of binder soil to be placed on different parts of the runway. In runway or taxiway sections of irregular shape, a binder soil distribution sheet such as that shown in figure 21 was issued to the superintendent. Under these conditions, the application of binder soil was made to the nearest ½ load or 1 cubic yard.

MOTOR OIL USED IN DENSITY DETERMINATIONS

The locations where density tests were made depended on the order in which different areas were completed. A typical pattern is shown in figure 22. The test procedure used on this project was as follows:

A soil collecting tray, 15 inches square, having a 4½-inch circular opening in the center was set in place on the leveled surface (fig. 23–A) and a hole was dug through the compacted base by loosening the material with a trowel or pointed bar. The loosened material was scooped out with a large spoon, placed in a pail, and weighed on a spring scale of 30 pounds capacity (fig. 23–B). The indicator on the scale was adjusted for the weight of the pail so that the weight of the material removed from the hole was read directly. The moisture content of this material was then determined in the laboratory.

The circular opening in the tray served as a template for digging the hole while the tray itself collected the loosened material which tended to scatter during the digging, together with any that might have spilled from the spoon in transferring the material from the hole to the pail.

After all the loosened material had been removed, the hole was filled with motor oil (S. A. E. 40) from a 3-gallon can (fig. 23–C) and the can plus the oil remaining in it after filling the hole was weighed (fig. 24). The weight of the can plus the original volume of oil had been previously determined. The difference between the two weights gave the weight of oil in the hole. A hand suction pump was used to remove the oil from the hole.

The volume of the hole was then determined by dividing the weight of the oil in the hole by the known weight of 56 pounds per cubic foot of oil.

The density of the base course in pounds per cubic foot as compacted in the moist condition was calculated by the formula:

$$\text{Wet density} = \frac{\text{weight of moist material removed from hole}}{\text{volume of hole}}.$$

(*Continued on p. 191*)

LIGNIN BINDER USED IN TEST SECTIONS SUBJECTED TO ACCELERATED TRAFFIC

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by EDWARD A. WILLIS, Associate Highway Engineer, and RICHARD C. LINDBERG, Junior Highway Engineer

An investigation is reported in which crusher-run limestone, granite, slag, and gravel were mixed with a binder soil and tested in an outdoor circular track. The mixtures were first tested without any form of surface application. They were then treated with lignin binder and the tests continued. Finally, they were tested as base courses under a thin bituminous surface treatment.

Tests with distributed traffic prior to the application of lignin binder showed that an admixture of 10 percent of hydrated lime, which was present in two sections, improved the performance of both the granite-soil mixture and the gravel-soil mixture as surface courses. Under the same test conditions, the other four sections which had no chemical admixture showed signs of raveling under prolonged traffic.

The application of lignin binder at the rate of ½ gallon per square yard tended to cause softening and instability for a time. This condition gradually improved as traffic was continued. Thereafter the sections remained stable; and although the lignin did not prevent raveling, it did retard raveling as compared with tests on the untreated sections.

All sections gave good performance when tested under normal conditions of moisture as base courses for a thin bituminous surface treatment. Under extreme conditions the two sections containing granite became unstable. The lignin binder which was present while the materials were being tested as base courses did not alter the performance, either adversely or beneficially, from that which was anticipated from laboratory tests prior to the addition of the lignin binder.

LIGNIN BINDER, a by-product in the manufacture of paper from wood by the sulfite process, has been used, at least experimentally, in road construction for many years.[1] Since 1936, this sulfite liquor, marketed under a trade name, has been used by several of the State highway departments for the treatment of gravel surfaces and base courses.

This report is the fifth in a series describing investigations of materials for surface and base course construction. Former reports discussed laboratory tests and accelerated tests on a circular track of sand-clay, sand-clay-gravel, nonplastic granular materials with admixtures of water-retentive chemicals, and chert-gravel.

The present report describes similar investigations in which crusher-run materials—limestone, granite, slag, and gravel—were mixed with a binder-soil and tested in an outdoor circular track.

The circular track used in these investigations was the same as that used in the studies of water-retentive chemicals as admixtures with nonplastic roadbuilding materials, which have been reported previously.[2] The tire equipment was 30 inches by 5 inches of the high-pressure type inflated to a pressure of 80 pounds per square inch. The load on each wheel was 800 pounds during the entire test.

Distributed traffic was obtained by means of a mechanical device which gradually shifted the rotating beam with respect to its axis of rotation. Concentrated traffic was used in testing the materials after the surface treatment had been constructed. This was obtained by locking the sliding pivot of the beam in such a position that the wheels pursued two concentric circular courses having centerlines about 2½ inches on each side of the centerlines of the test sections.

SIX SECTIONS TESTED IN CIRCULAR TRACK

Six sections were tested in this investigation. Each section was 18 inches wide, 6 inches deep, and approximately 6.3 feet long. All the test sections were laid over a porous, crushed-stone subbase through which water introduced from below could pass.

Three different kinds of crusher-run aggregate (limestone, slag, granite) and crushed Potomac River gravel were used as coarse material in the test sections. The binder soil used was a local clay having a liquid limit of 41 and a plasticity index of 18. Two of the sections, Nos. 5 and 6, had 10 percent by weight of hydrated lime combined with the soil-aggregate mixtures.

The compositions of the six sections are shown in table 1. Thus, for example, section 1 contained 90 percent by weight of limestone screenings and 10 percent by weight of binder soil. Section 5 was identical with section 2 except for the admixture of 10 percent by weight of hydrated lime, and section 6 was like section 4 except for the addition of 10 percent of hydrated lime.

The gradings and soil constants of the mixtures used are given in table 2. The effect of the hydrated lime admixture in increasing

TABLE 1.—*Composition of sections*

Section No.	1	2	3	4	5	6
	Percent [1]	*Percent* [1]	*Percent* [1]	*Percent* [1]	*Percent* [1]	*Percent* [1]
Granite		92			92	
Slag			80			
Limestone	90					
Gravel				85		85
Binder soil	10	8	20	15	8	15
Total	100	100	100	100	100	100
Hydrated lime					10	10

[1] Percentage based on dry weight.

TABLE 2.—*Gradings and soil constants of mixtures used in the track*

Section No.	1	2	3	4	5	6
Grading:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Passing ¾-inch sieve	100	100	100	100	100	100
Passing ⅜-inch sieve	100	100	98	94	100	94
Passing No. 4 sieve	98	96	78	70	96	72
Passing No. 10 sieve	65	69	54	56	68	52
Passing No. 40 sieve	34	48	37	38	46	35
Passing No. 200 sieve	21	22	23	19	22	17
Dust Ratio [1]	62	46	62	50	48	49
Tests on material passing No. 40 sieve:						
Liquid limit	19	24	25	20	29	27
Plasticity index	5	2	7	5	2	5

[1] $\text{Dust ratio} = 100 \dfrac{\text{Percentage passing No. 200 sieve}}{\text{Percentage passing No. 40 sieve}}$.

[1] Dust Preventives and Road Binders, by Prevost Hubbard. John Wiley and Sons, New York, 1910.

[2] Studies of Water-Retentive Chemicals as Admixtures with Nonplastic Road-Building Materials, by E. A. Willis and C. A. Carpenter, PUBLIC ROADS, vol. 20, No. 9, Nov. 1939.

the liquid limit can be seen by comparing the analysis of section 5 with that of section 2 and section 6 with that of section 4.

The circular track tests were divided into three parts. The mixtures were first tested without any form of surface application. They were then treated with lignin binder and the tests continued. Finally, they were tested as base courses under a thin bituminous surface treatment.

The procedure for preparing the materials for the track tests, constructing the test sections, applying waste sulfite liquor, and surface treating, was as follows:

1. The aggregates were proportioned by weight from stock piles and were thoroughly mixed before any water was added.

2. Hydrated lime was added to the materials for sections 5 and 6 and thoroughly mixed before wetting.

3. Water was then added in amount sufficient to cause the mixture to make a firm ball when squeezed in the hand and mixing continued to distribute the moisture uniformly.

4. The moistened mixtures were placed in the trough of the track in two approximately equal layers, each layer being compacted with pneumatic-tired traffic uniformly distributed over the surface. Material was added to the top lift of each section as compaction took place until the surface of the base course was from ½ inch to 1 inch below the curbs.

5. Compaction with distributed traffic was continued on the top layer for 40,000 wheel-trips. At this time all of the sections showed some corrugation and raveling. Section 3 had only a slight amount of corrugation and section 6 had the least of all.

6. The sections were trimmed smooth to a level 1 inch below the top of the curbs. It was necessary to add more material to sections 1 and 4 to bring them up to the desired level. This was done by lightly scarifying the compacted surface, placing additional material and hand tamping. Two thousand six hundred wheel-trips of distributed traffic were used to compact this material.

7. The sections were then tested without any form of surface treatment but with different ground water elevations; 160,000 wheel-trips of distributed traffic were applied to the materials in this first phase of the testing.

8. An application of a commercial grade of waste sulfite liquor at the rate of ½ gallon per square yard was made on the reshaped sections at the conclusion of the previous part of the test. The liquor contained 46 percent solids as received and was diluted with an equal part of water before it was applied.

9. After application of the waste sulfite liquor and compaction by 6,200 wheel-trips of distributed traffic, 100,000 wheel-trips of distributed traffic were applied, with different ground water elevations. This comprised the second phase of the testing procedure.

10. High places in the sections were leveled off and all loose material was removed preparatory to the application of a surface treatment.

11. A light tar prime was applied at the rate of 0.2 gallon per square yard and allowed to cure.

12. A surface treatment of 0.4 gallon of hot application bituminous material and a cover of 50 pounds per square yard of ¾-inch maximum size stone was applied.

13. The treatment was consolidated by additional distributed traffic until the surface was well sealed and showed no movement.

14. Concentrated traffic in the amount of 160,000 wheel-trips was then applied while the water elevation in the trough was varied. This was the third and final phase of circular track tests.

BEHAVIOR OF TEST SECTIONS JUDGED BY APPEARANCE AND DISPLACEMENT

The behavior of the materials being investigated was judged on the basis of the appearance of the sections at various stages of the tests, supplemented by measurements of vertical displacements of the surface. The measurements were made with the transverse [3] and longitudinal [4] profilometers which have been described in previous reports.

The schedule of traffic applications and changes in water elevation with notations on the behavior of the six test sections are shown in table 3. The average vertical displacements measured by the transverse and longitudinal profilometers are shown in figures 1 and 2. Initial profile measurements were taken at the beginning of each of the three phases of testing after apparently complete compaction by distributed traffic had been obtained. Changes in the behavior of the various sections under altered test conditions are shown by changes in the slopes of the displacement curves.

All of the sections compacted well initially. At the conclusion of the first compaction period (42,600 wheel-trips) water was admitted until its level was 1 inch above the top of the subbase. Initial profiles were taken at this time and traffic resumed. Less than 3,000 wheel-trips of traffic caused section 2, composed of granite and soil, to become soft and unstable. The section was consequently reshaped, tamped, and sprinkled but little benefit was noted. From time to time it was necessary to add to section 2 to replace material pushed over the curbs.

At this time the other sections were in good condition. At 70,000 wheel-trips section 5, which was similar to section 2 except for the addition of hydrated lime, began to develop a soft spot which later (82,600 wheel-trips) had to be filled with additional material. At 80,000 wheel-trips section 3, composed of slag and binder soil, began to shove but this condition had ceased by the time profiles were taken at 82,600 wheel-trips. So much raveling and movement had taken place in section 2 that the profile trace would not fall upon the profile paper used in the measurements of displacement. Sections 3 and 5 had also worn so badly it was necessary to add material to them. The remaining sections were in good condition at this time.

Traffic was continued under the same conditions for an additional 20,000 wheel-trips. Section 2 required sprinkling to keep the surface knit together, and it was necessary to rake material from the curbs to the center of the section. This was also necessary in section 3 where it adjoined section 2. Profiles were taken at 102,600 wheel-trips, or at the end of 60,000 wheel-trips with water 1 inch above the top of the subbase. Profiles taken at this time of sections 2, 3, and 5 were not truly representative of actual wear and displacement because of the material added to prevent jarring of the beam.

Distributed traffic was continued with the water level 1 inch below the top of the subbase. Section 2 improved somewhat during this time as regards stability

[3] Circular Track Tests on Low-Cost Bituminous Mixtures, by C. A. Carpenter and J. F. Goode, PUBLIC ROADS, vol. 17, No. 4, June 1936.

[4] A study of Sand-Clay-Gravel Materials for Base Course Construction, by C. A. Carpenter and E. A. Willis, PUBLIC ROADS, vol. 20, No. 1, March 1939.

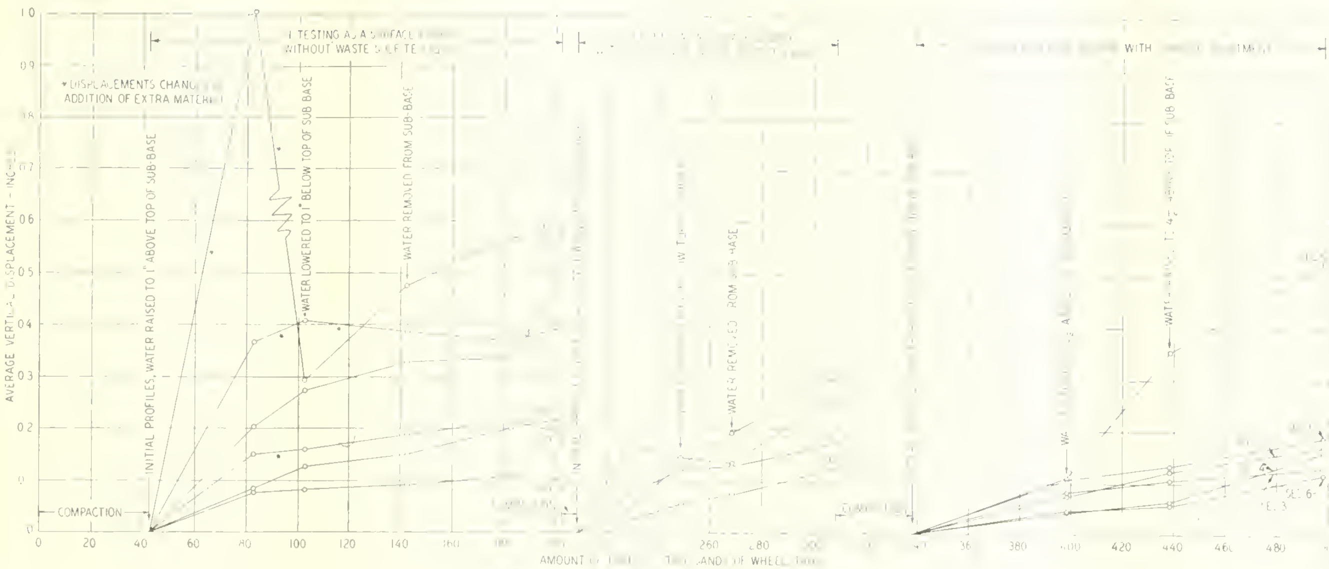


FIGURE 1.—RATE OF SURFACE DISPLACEMENT, TRANSVERSE MEASUREMENTS.

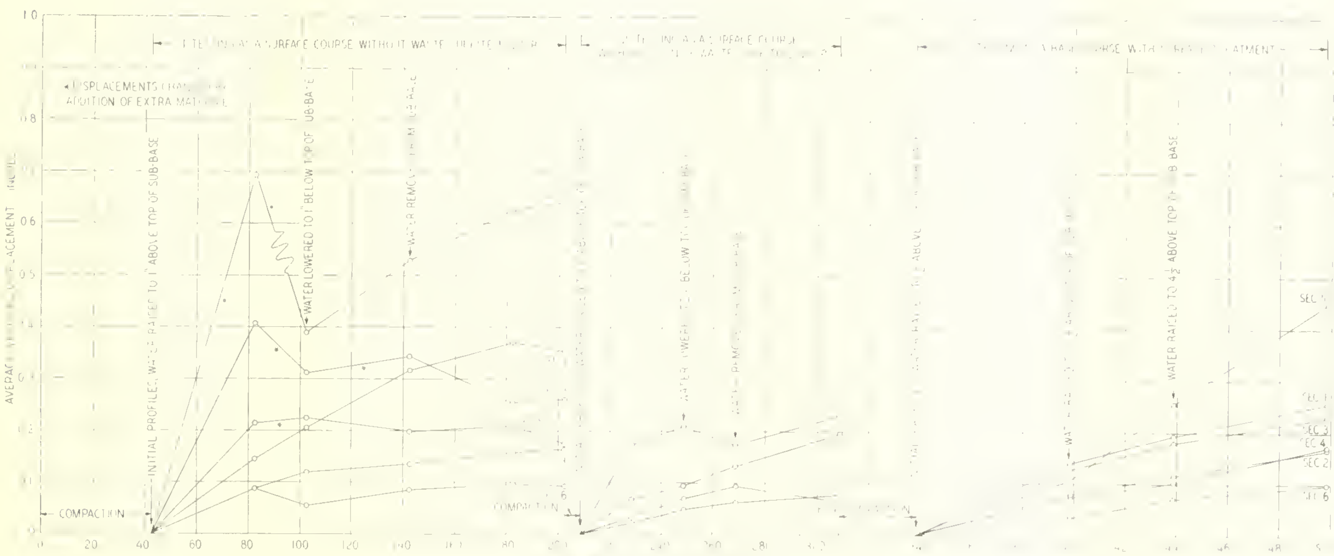


FIGURE 2.—RATE OF SURFACE DISPLACEMENT, LONGITUDINAL MEASUREMENTS.

but raveling of the surface was observed. When profiles were taken at 142,600 wheel-trips, sections 2 and 3 showed the most displacement and sections 4 and 6 the least.

Distributed traffic was continued with the water completely removed from the subbase. During the testing period, from 142,600 to 202,600 wheel-trips, there was a general improvement in the appearance of all the sections although the displacement as measured by the profilometers continued to increase with few exceptions.

Visual inspection and the profiles showed that section 2 had suffered the greatest displacement and wear, much loose material being present on the surface. Section 1, consisting of limestone and binder soil, showed some corrugation but underneath the loose surface the material was well knit together. Sections 3 and 4, composed of slag and binder soil and gravel and binder soil, respectively, were not unduly loose on the surface. Sections 5 and 6, both of which contained hydrated lime, were in the best condition.

The appearance of the sections after 202,600 wheel-trips is shown by the photographs in figure 3. Corrugations in section 1 are shown in figure 3–A; beneath the loose material the section was firm. The extremely loose condition of the surface of section 2 is shown in figure 3–B. The condition of sections 3 and 4 at the end of this phase of the testing is illustrated by figure 3–C. Figure 3–D shows section 6 and is representative of both sections 5 and 6. This photograph shows the hard, plaster-like appearance of the surface in many parts of these two sections which had been treated with hydrated lime. Loose material had been swept away from a part of the surface shown near the center of the photograph.

WASTE SULFITE LIQUOR APPLIED AS SURFACE TREATMENT

In the second phase of the tests (see table 3) waste sulfite liquor was applied to the surface of the sections at the rate of ½ gallon per square yard. Testing with distributed traffic was then continued.

Table 3.—*Schedule of operations and behavior of test sections*

Operation	Traffic	Water level above top of subbase	Behavior					
			Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
	Wheels trips	*Inches*						
Placing and compacting	0–[1] 42,600	[2] 0	Raveling	Some raveling	Some raveling	Raveling	Some raveling	Good.
1. Testing as surface course, without waste sulfite liquor	42,600– 82,600	1	Good	Unstable [4]	Slightly unstable	Good	Slightly unstable	Do.
Do	82,600– 102,600	1	do	Raveling [4]	Some raveling [4]	Some raveling	Some raveling [4]	Do.
Do	102,600– 142,600	[3] −1	Some raveling	Some raveling	do	Good	Good	Do.
Do	142,600– 182,600	[2] 0	do	Raveling	do	Some raveling	do	Do.
Do	182,600– 202,600	[2] 0	do	do	do	do	do	Do.
Compaction of surface after treatment with waste sulfite liquor	202,600– 208,800	[2] 0	Good	Good	Unstable	Good	Unstable	Unstable.
2. Testing as surface course with addition of waste sulfite liquor	208,800– 228,800	1	do	Slightly unstable [4]	Good [4]	Slightly unstable	do.[5]	Do.[5]
Do	228,800– 248,800	1	do	Good	do	do	Good	Good.
Do	248,800– 268,800	[3] −1	do	do	do	Good	do	Do.
Do	268,800– 308,800	[2] 0	Some raveling	Raveling	Raveling	do	do	Do.
Compacting surface treatment	308,800– 338,800	[2] 0	Good	Good	Good	do	do	Do.
3. Testing with concentrated traffic as a base course, waste sulfite liquor still present	338,800– 398,800	½	do	do	do	do	do	Do.
Do	398,800– 438,800	2½	do	do	do	do	Slightly unstable	Do.
Do	438,800– 498,800	4½	do	Slightly unstable	do	do	Failed	Do.

[1] 2,600 wheel-trips to compact additional material in sections 1 and 4.
[2] No water in subbase.
[3] Water level 1 inch below top of subbase.
[4] Necessary to add material to prevent jarring of the beam.
[5] Unstable at start but gradually improved after scarifying during second phase of testing.

In applying the lignin binder, the sections first were scarified to about 2 inches below the curbs and more material was added until the loose material was about ½ inch above the curbs. After the sections had been lightly sprinkled, waste sulfite liquor was applied at the rate of ½ gallon per square yard to the loose, uncompacted material. The attempt to apply traffic was unsuccessful as the rubber-tired wheels picked up the material and whipped it away.

Failure of this attempt at compaction resulted in trial of other means. All material was removed down to where the base was solid and firm, and new material was added. This material was tamped into place, lightly sprinkled with water, and allowed to dry overnight. Two hundred wheel-trips were used to compact the surface. Then waste sulfite liquor was applied at the rate of ½ gallon per square yard. After 48 hours, the treatment appeared to have penetrated thoroughly. Places where there seemingly was an excess of sulfite liquor had a shiny, slick surface much like a road on which excess bituminous material had been used. Figure 4 shows the appearance of the surface after the application of the waste sulfite liquor.

The water level was raised to 1 inch above the top of the subbase and distributed traffic was then continued. Two thousand wheel-trips were at slow speed and the 4,000 wheel-trips at regular speed. The lignin binder which had failed to penetrate in section 5 adhered to the tires when they passed over and was removed from the surface in this manner. At these places, the compacted material underneath was quite moist with capillary water. Section 6 started to break up at 205,150 wheel-trips and it was necessary to scarify and allow the loosened material to dry before resuming traffic.

In section 5 wherever there was a skin of surplus liquor on the surface, the base beneath was very moist and the same scarifying treatment was given this section as well. Water was withdrawn from the subbase during the drying period. After drying, the material in both sections was replaced and tamped firmly. Section 3 was showing signs of movement at this time but it was not deemed necessary to scarify this material.

At 208,800 wheel-trips, initial profiles for the second phase of the tests were taken of sections 1 to 4. Sections 5 and 6 were so unstable that no attempt was made to measure their displacements. Distributed traffic was continued. At 216,200 wheel-trips, section 4 developed a soft spot which increased in size. Sections 1, 2, and 3 were in good condition. Sections 5 and 6, which were unstable at the start of the second phase of testing, had improved and were very stable.

At 248,800 wheel-trips, the water level was dropped to 1 inch below the top of the subbase and traffic resumed. At this time all sections were in good condition. The waste sulfite liquor treatment had a tendency to scale off in sections 1 and 3. There appeared to be very little penetration of the material.

After withdrawal of water from the subbase at 268,800 wheel-trips distributed traffic was resumed. Sections 1, 2, and 3 showed signs of raveling, particularly section 3, at the completion of 40,000 wheel-trips without water in the subbase. The other three sections were in good condition.

At the conclusion of the second phase of the testing at 308,800 wheel-trips, all loose material was swept from the surface and all high places were leveled off. A light tar prime was applied at the rate of 0.2 gallon per square yard and a thin bituminous surface treatment consisting of 0.4 gallon of hot application bituminous material and 50 pounds of ¾-inch maximum size stone per square yard was constructed. Compaction of the surface treatment was accomplished with 30,000 wheel-trips of distributed traffic. Sections 5 and 6, which had been particularly unstable at the start of the previous phase of the investigation, were now tested as base courses without any changes in their composition.

The performance of the sections as bases is best shown by the displacement curves, figures 1 and 2. Section 5, composed of granite, soil, and hydrated lime, showed the greatest displacement of all the sections. It began to shove at about 418,800 wheel-trips with the water elevation at 2½ inches above the

FIGURE 3.—APPEARANCE OF TEST SECTIONS AFTER 202,600 WHEEL-TRIPS OF DISTRIBUTED TRAFFIC ON THE UNTREATED MATERIAL. A, SECTION 1; B, SECTION 2; C, SECTION 4, WHICH IS ALSO REPRESENTATIVE OF THE APPEARANCE OF SECTION 3; AND D, SECTION 6, WHICH IS ALSO REPRESENTATIVE OF THE APPEARANCE OF SECTION 5.

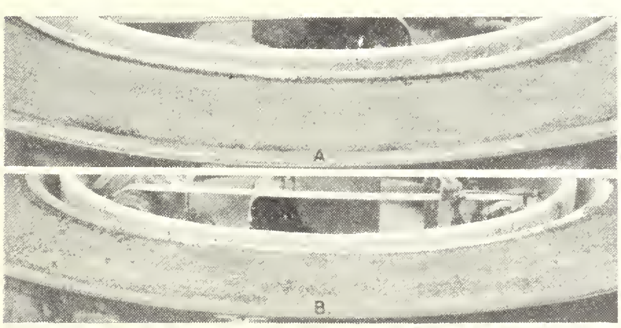


FIGURE 4.—APPEARANCE OF TEST SECTIONS AFTER APPLICATION OF WASTE SULFITE LIQUOR. A, SECTIONS 1, 2, AND 3 (FROM LEFT TO RIGHT); and B, SECTIONS 4, 5, AND 6.

top of the subbase. At 498,800 wheel-trips (the end of the test) section 5 had completely failed. At this same time section 2, composed of granite and soil, was shoving slightly under the wheels. Sections 1, 3, and 4 were in a satisfactory condition, and section 6, which

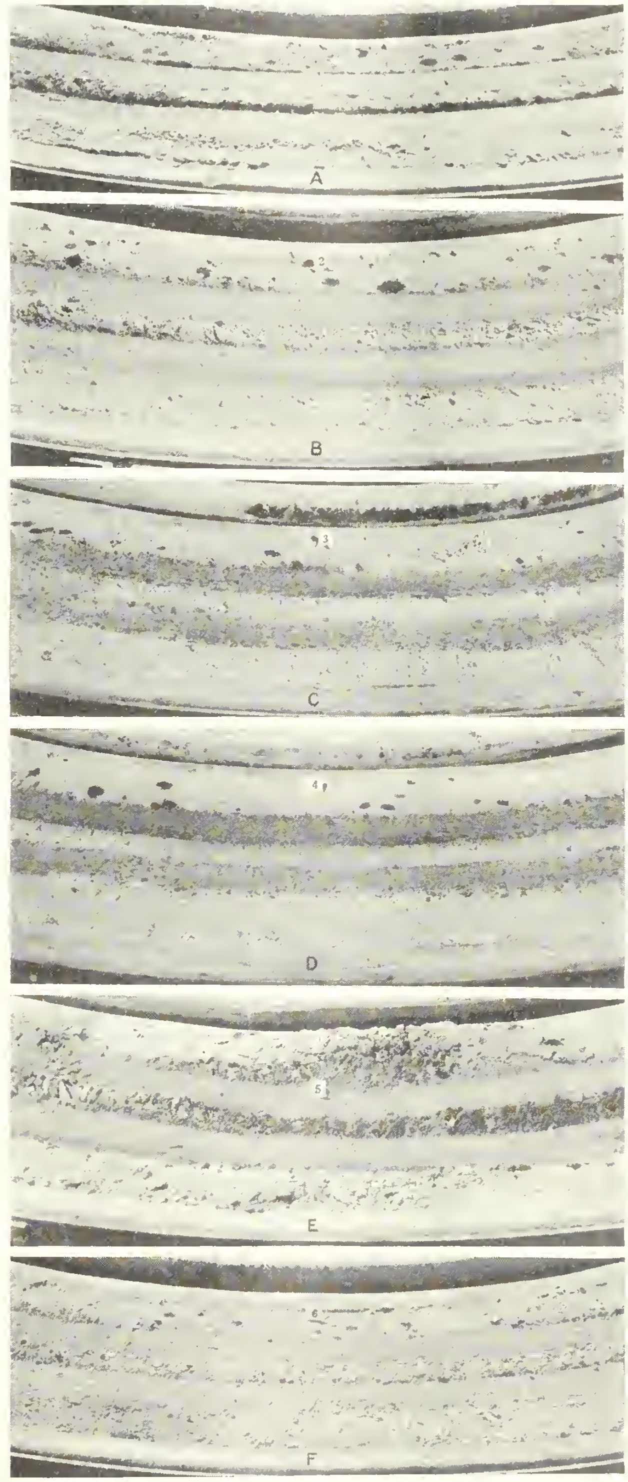


FIGURE 5.—APPEARANCE OF TEST SECTIONS AFTER 498,800 WHEEL-TRIPS. PICTURES A TO F CORRESPOND TO SECTIONS 1 TO 6, RESPECTIVELY.

had become unstable temporarily when tested with a treatment of waste sulfite liquor, was in the best condition of all the sections. Figure 5 shows the condition of the sections at the conclusion of the test.

At the conclusion of the track tests, samples were taken from each section for density and moisture content determinations. Table 4 shows the values obtained and also the volumetric composition of the samples.

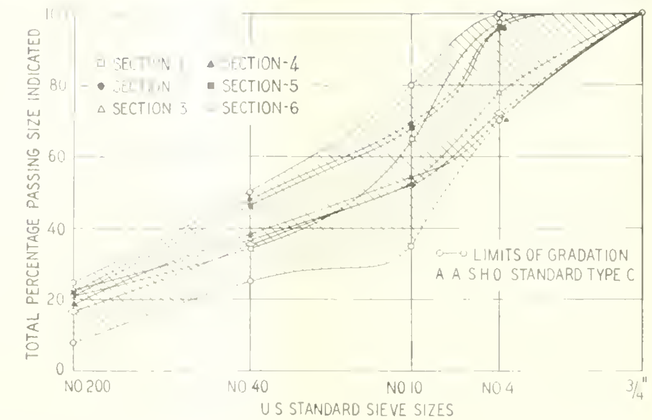


Figure 6.—Gradings of Materials Used in Track Tests.

The addition of hydrated lime reduced the density and also increased the moisture content of those mixtures in which it was present. Thus, the volumetric composition of section 2 was 81.9 percent solids, 10.9 percent water, and 7.2 percent air. The composition of section 5, which differed from section 2 only by the addition of 10 percent of hydrated lime, was 70.5 percent solids, 20.4 percent water, and 9.1 percent air. Similarly, section 4 had 83.3 percent solids while section 6, containing lime, had only 76.0 percent solids.

Section 1, consisting of limestone screenings and soil, had the highest density of any of the sections. The solids by volume of the sample from this section were 87.8 percent. Sections 2, 3, and 4 all had approximately the same density at the end of the test, as shown in table 4.

Table 4.—*Density of specimens taken from track at end of test*

Section No.	Density		Moisture	Composition by volume		
	Wet	Dry		Solids	Water	Air
	Lb. per cu. ft.	*Lb. per cu. ft.*	*Percent*	*Percent*	*Percent*	*Percent*
1	151.2	145.2	4.1	87.8	6.5	5.7
2	144.7	135.5	6.8	81.9	10.9	7.2
3	146.2	134.1	9.0	81.1	14.4	4.5
4	145.0	137.8	5.2	83.3	8.3	8.4
5	131.3	116.5	12.7	70.5	20.4	9.1
6	139.6	125.7	11.1	76.0	17.8	6.2

SUMMARY

The grading curves for the six combinations of materials tested are shown in figure 6. The shaded band in this figure is drawn to include the A. A. S. H. O. specification requirements for crusher-run (type C) surface-course materials. The grading requirements for the similar type of base-course materials are identical with those for surface courses.

The gradings of all the mixtures tested in the 6 sections of the track fall within the shaded band and, consequently, meet the grading requirements of the specifications.

The A. A. S. H. O. specifications for type C or crusher-run materials further stipulate that the fraction passing the No. 40 sieve shall have a liquid limit not greater than 35 and a plasticity index not less than 4 or more than 9 if the materials are to be used as surface courses, and that the same fraction shall have a liquid limit of not more than 25 and a plasticity index of not more than 3 if the materials are to be used as base courses. These specifictions also state the ratio of the fraction passing the No. 200 sieve to the fraction passing the No. 40 sieve shall be less than two-thirds for surface-course materials and less than one-half for base-course materials.

Consequently, sections 1, 3, 4, and 6 meet the requirements for surface-course materials only, the plasticity index being too high to conform to the specification limits for base course materials. Section 2 falls within the base but not the surface course requirements because it has a plasticity index of 2. Section 5 does not conform to the A. A. S. H. O. specifications for either base- or surface-course materials. The plasticity index of 2 is too low to meet the surface-course requirements and the liquid limit of 29 is too high to meet the base-course requirements.

Performance as surface courses.—The tests with distributed traffic prior to the application of lignin binder showed that the addition of 10 percent of hydrated lime improved the performance of both the granite-soil mixture (compare secs. 2 and 5) and the gravel-soil mixture (compare secs. 4 and 6) as surface courses.

Thus, the behavior of section 2, which was a mixture of 92 percent granite screenings and 8 percent binder-soil meeting the grading requirements but not the plasticity index requirements of the A. A. S. H. O., type C, surface-course material specifications, was definitely unsatisfactory throughout the first phase of the testing The behavior of section 5, which differed in composition from section 2 only in the addition of 10 percent of hydrated lime, while inferior to some of the sections, was considerably better than that of section 2.

The gradings of the mixtures used in the two sections were almost identical and both had a plasticity index of 2. The appearance of the two sections after 202,600 wheel-trips and just before the application of the lignin binder is illustrated by figures 3–B and 3–D.

Section 4, consisting of a mixture of 85 percent river gravel and 15 percent binder soil, met all requirements for the A. A. S. H. O., type C, surface-course material specifications. Its behavior in the first phase of the track tests can be classed as fair. Some difficulty was experienced in getting this material to set up initially but thereafter, it remained stable although there was a tendency for the surface to loosen under prolonged testing with low water elevation (see fig. 3–C). Section 6 had the same composition as section 4 except for the addition of 10 percent of hydrated lime. The behavior of section 6 was excellent throughout the first phase of the testing (see table 3 and fig. 3–D).

Section 1 consisted of 90 percent limestone screenings and 10 percent binder soil. This mixture conformed to all requirements of the A. A. S. H. O. specification for type C, crusher-run surfacing materials. Its behavior like that of section 4 can be rated as fair. It was loose during the compaction period but finally set up and was stable under the applied loads. It tended to wear and become loose on top under continued traffic with low water elevation as shown in figure 3–A.

Section 3 consisted of 80 percent slag screenings and 20 percent binder soil. This mixture had a plasticity index of 7, the highest of any tested in this investigation. During the compaction period and while testing with water 1 inch above the top of the subbase, this section was unstable and exhibited considerable movement under traffic. When the water level was lowered, the stability of the section improved but wear on the surface was considerable.

(*Continued on p. 190*)

POSSIBLE SUBSTITUTES FOR ALUMINUM PAINT

By E. F. HICKSON, Chemist, National Bureau of Standards, and H. A. GARDNER, Chemical Engineer, The Institute of Paint and Varnish Research

Editor's note: As a result of the present need to conserve aluminum, the Office of Production Management has been giving attention to the uses of aluminum paint, including those in which the substitution of some other paint is entirely feasible and those in which a satisfactory substitution is difficult.

The Office of Production Management is endeavoring to allot a limited amount of aluminum powder and paste for those few uses where aluminum paint is deemed essential and where substitution is difficult. Therefore, each order for aluminum powder and paste for paint that is placed with the producing companies is reviewed on the basis of technical considerations regarding its use, and the material is released only for the most urgent defense purposes. Other protective and decorative coatings must be substituted in the majority of instances where aluminum paint has been employed in the past.

The Office of Production Management has requested the Public Roads Administration to bring this information to the attention of the administrative officials of the State highway departments.

As is the case with many other materials which are critical during the present National Emergency, such as tung oil, shellac, etc., we know of no one paint that has all the desirable properties of aluminum paint for special uses. We have in mind such properties as durability, visibility, low emissivity, impermeability to moisture, reflectivity, opacity, etc. For example, for certain specialized purposes, such as for aircraft use, where light weight, good reflectivity and good durability in sea water are necessary, as a heat-resisting paint (above 600° F.), as a coating for low-temperature (cold storage) and refrigeration plants, as an anti-bleeding, weather-resisting and light-colored coating for bituminous roofing, etc., it is difficult at the moment to suggest a universally satisfactory alternate for aluminum paint. There are, however, a number of types of paint which are available, and which if used for the particular purpose indicated, should prove satisfactory. It is with this in mind that the following recommendations are made:

Painting structural steel (bridges, tanks, etc.).—After priming the clean surface with a rust-resisting primer, such as red lead paint (F. S. TT–P–86),[1] basic lead chromate paint (F. S. TT–P–59) etc., use a finish coat (instead of aluminum) of gray paint (or any other tint) conforming to Federal Specification TT–P–36a or TT–P–156. If chalk-resistant titanium oxide is specified, Federal Specification TT–P–101a or War Department Cantonment Paint, Standard Specification 8000E, page 88, June 30, 1941, may also be used, tinted gray or any other desired color. If color is of no moment, dark-colored paints such as iron oxide (F. S. TT–P–31a) or black (F. S. TT–P–61) will be more durable than white or light-tint paints. The black and iron oxide paints will be just about as durable as aluminum paint. Additional information on painting structural steel may be found in National Bureau of Standards Letter Circular 422.

If light or heat reflectivity is the important factor, such as in the case of gasoline-storage tanks, then a white paint on a titanium-lead-zinc base (F. S. TT–P–101a) may be used. This is a durable paint, but not as durable as aluminum paint, but is said to be more efficient in preventing gas losses. Special proprietary "Tank White" paints have also been developed for this purpose.

Painting interiors; plaster walls and woodwork.—Use one coat of a primer and sealer, such as is covered by Federal Specification TT–P–56, followed by a coat of either eggshell flat wall paint (F. S. TT–P–51a) or gloss enamel (F. S. TT–E–506a).

Priming exterior wood. For this purpose, for which aluminum paint has been used to some extent, use either Federal Specification TT–P–36a, TT–P–101a, TT–P–156, or one of the proprietary special undercoaters. One pint of linseed oil should be added to each gallon of the Federal Specification paints.

Sealing knots.—A thin coat of shellac varnish, a heavy coat of white lead paint, or one of the brands of special prepared paint undercoaters may be used.

Prevention of bleeding of bituminous coatings. A good resin emulsion paint (F. S. TT–P–88) is suggested for interior use and has, in fact, been used successfully outdoors on Robertson (bituminous) protected metal. It prevents bleeding and serves as a primer.

Painting metal roofs. On tin and other metal roofs where aluminum paint has been used increasingly of late, a good red metallic iron oxide roof paint (F. S. TT–P–31a) should be used. Red lead paint (F. S. TT–P–86) makes an excellent primer. Prepared metal paints made on a rust inhibitive pigment base well serve the purpose.

Painting smokestacks, boiler fronts, etc.—A good grade of black asphalt varnish (TT–V–51), a heat-resisting gray or black enamel, or certain of the proprietary heat-resisting compositions may be used.

Painting interior structural steel. In industrial plants where good light reflection from the structural steel is desired, the following procedure may be used. Apply a priming coat of quick-drying red lead paint (Procurement Division Specification No. 358), followed by either two coats of eggshell flat white paint (F. S. TT–P–51a) or gloss white enamel, sometimes called "mill gloss white" (F. S. TT–E–506a). The enamel will be more water-resistant and more durable. For special conditions where fumes are encountered, such as in chemical laboratories, bakeries, tobacco factories, cafeterias, etc., a special enamel known as fume- and heat-resisting enamel (National Bureau of Standards Letter Circular 489) may be used.

Machinery and metal equipment.—A good machinery gray enamel (F. S. TT–E–506a) may be substituted in many instances.

Radiators and hot water piping. The same paint used on the sidewalls may be used for this purpose. This may be eggshell flat wall paint (F. S. TT–P–51a) or white enamel (F. S. TT–E–506a). Where eggshell flat wall paint is used, we suggest the addition of one pint of interior varnish (F. S. TT–V–71a) to each gallon of the paint.

General considerations. As can be seen from the foregoing, it is possible to use Federal Specification materials or their equivalents as substitutes for aluminum

[1] A table giving the complete designation of the Federal Specifications referred to herein will be found at the end of this article (p. 190).

paint under a variety of conditions. We have purposely avoided specifically recommending synthetic resin paints and enamels, because of the shortage of certain ingredients used in these paints. Similarly, certain highly durable cellulosic finishes could be employed, but the plasticizers and solvents for these are also developing an acute shortage.

Talc and mica-aluminum finishes.—In cases where it is believed essential to use some aluminum powder in order to produce an aluminum appearing finish, a great saving could be effected by employing mica or talc with the aluminum powder. As high as three parts by weight of mica or talc and one part by weight of aluminum powder may be stirred into a mixing varnish to produce a finish that has the characteristic aluminum appearance. This is in the proportion of two pounds of the total pigment (including the talc and aluminum powder) to one gallon of the mixing varnish. If the fine lining grade of aluminum powder (F. S. TT–A–476, Type B) is used, as little as ½ pound of it and ½ pound of mica, suitable for paint, may be mixed with 1 gallon of varnish (F. S. TT–V–81a) to produce a paint which is reported to have good durability.

Wherever Federal Specifications are referred to in this memorandum, they cover products which will be satisfactory for the usage referred to, but for the general buying public similar products may be obtained under trade brands at any paint store throughout the country. The paint dealer will readily recognize the material referred to.

Complete titles of Federal Specifications referred to in the body of the article:

Federal Specification No.—	*Title*
TT–P–86	Paint, Red Lead Base; Linseed-oil, Ready-Mixed.
TT–P–36a	Paints, Lead-Zinc Base, Ready-Mixed, and Semipaste, White and Tinted.
TT–P–156	Paint, White Lead Base; Basic Carbonate, Ready-Mixed, Light Tints and White.
TT–P–101a	Paint; Titanium-Zinc and Titanium-Zinc-Lead, Outside, Ready-Mixed, White.
TT–P–31a	Paints; Iron Hydroxide and Iron Oxide, Ready-Mixed and Semipaste.
TT–P–61	Paint; Ready-Mixed, and Semipaste, Black.
TT–P–56	Paint; (For) Priming Plaster Surfaces (Plaster Primer and Sealer).
TT–P–51a	Paints; Oil, Interior, Eggshell-Flat-Finish, Ready-Mixed and Semipaste, Light Tints and White.
TT–E–506a	Enamel; Interior, Gloss, Light Tints and White.
TT–V–51	Varnish, Asphalt.
TT–P–88	Paint, Paste, Resin Emulsion, Interior, Light Tints and White.
TT–V–71a	Varnish; Interior.
TT–V–81a	Varnish; Aluminum Mixing.
TT–P–59	Paint, International Orange.
TT–A–476	Aluminum-Powder (For) Paints (Aluminum-Bronze-Powder).

(Continued from p. 188)

Performance with surface application of lignin binder.—Sections 5 and 6, which contained hydrated lime and had given good service when tested as surface courses in the first phase of the investigation, became unstable when subjected to traffic after the application of lignin binder on the surface. They were so soft and shoved so badly that it was necessary to scarify them at 205,150 wheel-trips. After the mixtures had dried out and were recompacted, they gradually set up under traffic and by the end of the second phase of testing they were in satisfactory condition to receive a bituminous surface treatment.

Section 3, slag and binder soil, was also unstable during the compaction period after the application of the lignin binder. However, it was not necessary to scarify this section and its behavior gradually improved under continued traffic. Some raveling of the surface was noted toward the end of the second phase of the testing.

Section 2, granite and binder soil, was stable during the compaction period but when water was raised to 1 inch above the top of the subbase it showed a tendency to shove under traffic for a time. The condition gradually improved under continued traffic as shown in table 3. The behavior of section 4, gravel and soil binder, was similar to that of section 2.

Section 1, limestone and binder soil, remained in good condition throughout the entire period of testing after the application of the lignin binder except for slight raveling near the end of the second phase of the testing.

In general, the application of the diluted lignin binder tended to cause softening and instability under traffic for a time. This condition gradually improved as traffic was continued. Thereafter, the sections remained stable and while the lignin binder did not prevent raveling, it appeared to retard it somewhat as compared with the tests on untreated sections.

Performance as base courses.—All six sections gave good performance when tested as base courses for a thin bituminous surface treatment with water ½ inch above the top of the subbase. Previous investigations had shown that concentrated traffic with this ground water condition provides a condition sufficiently severe to identify the definitely unsatisfactory materials.

With the water elevation raised to 2½ inches above the top of the sub-base, section 5 (granite, soil, and hydrated lime) began to move under traffic and had failed completely at the end of the tests with the water 4½ inches above the top of the subbase (see fig. 5–E). Section 2, granite and soil, was also exhibiting considerable movement under the wheels at the end of the test although the displacements as measured by the profilometers were not excessive. The remaining four sections were in good condition throughout the third phase of the track investigations.

CONCLUSIONS

The following conclusions appear to be justified for the sections considered as surface courses without lignin binder treatment:

1. Mixtures of limestone screenings and soil (section 1), slag screenings and soil (sec. 3) and gravel and soil (sec. 4) meeting the requirements of the A. A. S. H. O. specifications for type C surface-course materials gave fair to good service when tested with distributed traffic.

2. The combination of granite screenings and binder soil (sec. 2) which met the grading but not the plasticity index requirements of the same specifications gave poor service.

3. The addition of 10 percent of hydrated lime improved the performance of both the granite-soil and the gravel-soil mixtures (secs. 5 and 6).

For the sections considered as surface courses after treatment with lignin binder, the tests showed that:

4. The performance of section 2 was materially improved. Raveling was prevented for the duration of the tests in section 4 and was delayed to some extent in sections 1 and 3. Both sections 5 and 6, which contained hydrated lime, became soft and unstable but after scarifying and reworking the condition of these sections improved under traffic.

For the sections considered as base courses, it was found that:

5. All of the mixtures gave satisfactory service under normal conditions of moisture. Under extreme conditions, with the water elevation at 4½ inches above the top of the subbase, the two sections containing the granite screenings became unstable, section 5 which had the hydrated lime admixture failing completely. Previous investigations have indicated that this behavior could have been anticipated from the laboratory tests performed on the materials prior to the addition of lignin binder.

It is therefore concluded that the use of lignin binder in base courses under thin bituminous surface treatments does not affect the performance of base-course materials, either adversely or beneficially.

(*Continued from p. 182*)

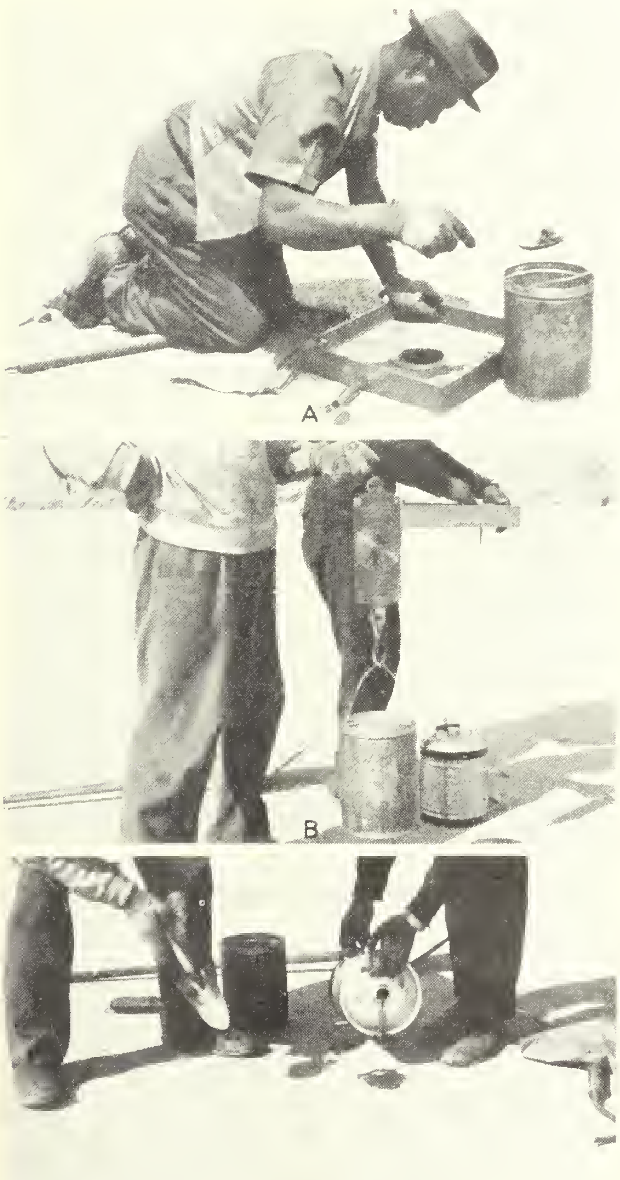


Figure 23.—Three Steps in Making a Density Test: A, Removing Loosened Base Course Material from Hole; B, Weighing the Base Course Material Removed; and C, Filling Hole with Oil.

Figure 24.—By Determining the Weight of Oil Remaining in the Can, the Weight and Volume of Oil Required to Fill the Hole are Determined.

After the moisture content of the material removed from the hole was determined, the dry density of the base in pounds per cubic foot was computed by the formula:

$$\text{Dry density} = \frac{\text{wet density} \times 100}{\text{percentage of moisture} + 100}.$$

For a rapid calculation of the density in the field, the chart shown on figure 25 was used. In one of the tests, the weight of oil in the hole was 5.2 pounds, and the weight of moist material removed from the hole was 12.65 pounds. The weight of the oil is spotted on the chart at point A. This corresponds to a volume of 0.0929 cubic foot at point B.

A vertical line from point B intersects the curve corresponding to 12.65 pounds of moist material at point C. The wet density of 136.2 pounds per cubic

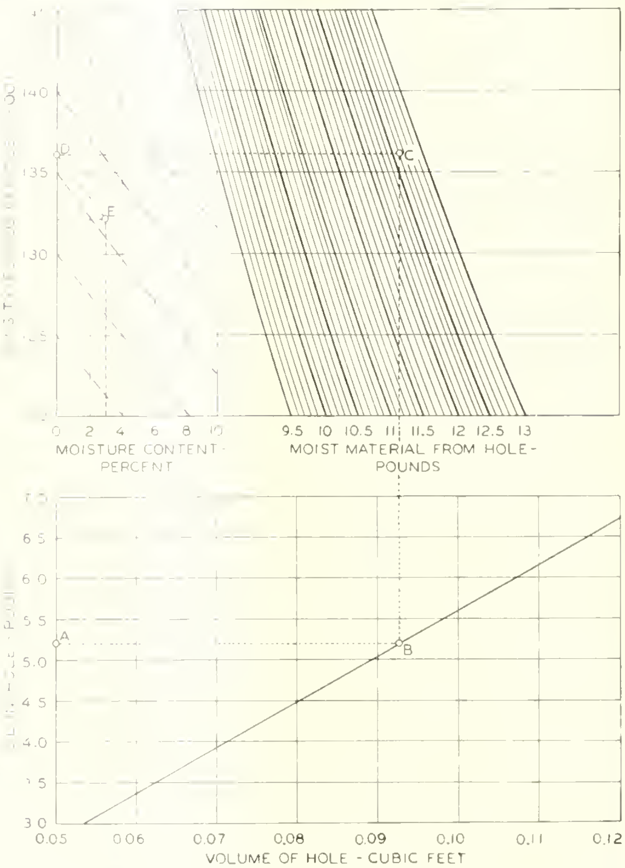


FIGURE 25.—GRAPHICAL CALCULATION OF DENSITY FROM TEST DATA

foot is indicated at point D on the density scale. With a moisture content of 3 percent the dry density of 132.2 pounds per cubic foot is found at point E. This chart was set up to cover the ranges in weights, volumes, and densities encountered on this particular project.

The sampling and testing in the portable field laboratory were performed by two trained operators with the aid of five laborers. The following is a list of the equipment used:

3 sets of sieves, each set consisting of pan and cover and sieves with square openings as follows: 3-inch, 2-inch, 1½-inch, 1-inch, ¾-inch, ⅜-inch, No. 4, No. 10, No. 40, No. 200.
4 No. 10 sieves.
4 No. 200 sieves.
3 No. 40 sieves.
1 metric solution balance, 5 kilograms capacity.
1 triple beam balance, 100 grams capacity.
4 double-burner gasoline camp stoves.
1 enameled pan, 10 inches diameter by 4 inches deep.
1 enameled pan, 14 inches diameter by 1½ inches deep.
6 enameled pans, 8 inches diameter by 1½ inches deep.
1 enameled pan, 6 inches diameter by 1½ inches deep.
24 tin pans, 11½ inches long, 8½ inches wide, 1½ inches deep.
1 pan brush, 2-inch diameter.
1 pan brush, 1-inch diameter.
2 brass wire brushes for sieves.
3 rubber-covered pestles.
2 iron pots, 10-inch diameter by 4 inches deep.
1 spoon, 12 inches long.
4 spoons, 14 inches long.
1 mason's trowel, 7 inches long.
1 Fahrenheit thermometer.
4 porcelain evaporating dishes, 3-inch diameter.
1 gasoline storage can, 5 gallons.
1 water storage tank, 30 gallons.
1 long handle shovel.
1 short handle shovel.
1 pick.
2 soil collecting trays for density tests.
1 spring scale, 30 pounds capacity.
1 oil can with spout, 3 gallons capacity.
1 tin pail, 2 gallons capacity.
1 grease suction pump.
1 garden trowel.
1 pointed bar, 1½-inch diameter, 30 inches long.
3 clip boards.
1 slide rule.
1 triangle.
1 water cooler and paper cups.
Supply of canvas sample bags, tags, twine, pencils, notebooks, cross section paper, waste rags, towels, and laboratory forms.

In addition to the above, the laboratory was supplied with work tables, shelves, chairs, fire extinguishers, an office desk, and miscellaneous office supplies.

INDEX TO PUBLIC ROADS, VOLUME 21, NOW AVAILABLE

The index to PUBLIC ROADS, volume 21, is now available. A chronological list of articles and a list of authors are included with the index. The index will be sent free to subscribers to PUBLIC ROADS requesting it. Requests should be addressed to the Public Administration, Roads Federal Works Agency, Washington, D. C.

Indexes to volumes 6 to 8 and 10 to 20, inclusive, are also available and will be sent to PUBLIC ROADS subscribers upon request. Indexes to volumes 1 to 5, inclusive, have never been prepared. The supply of the index to volume 9 is exhausted.

DISPOSITION OF STATE MOTOR-FUEL TAX RECEIPTS - 1940

COMPILED FOR CALENDAR YEAR FROM REPORTS OF STATE AUTHORITIES

STATE	NET TOTAL RECEIPTS OF CALENDAR YEAR	ADJUSTMENTS DUE TO UNDISTRIBUTED FUNDS, ETC. 1/	NET TOTAL FUNDS DISTRIBUTED 2/	EXPENSES OF COLLECTION AND ADMINISTRATION	FOR OTHER ADMINISTRATIVE PURPOSES 3/	FOR STATE HIGHWAY PURPOSES: CONSTRUCTION, MAINTENANCE, AND ADMINISTRATION: ON STATE HIGHWAYS 4/	ON STATE PARK AND FOREST ROADS, ETC. 5/	STATE HIGHWAY POLICE	SERVICE OF STATE HIGHWAY OBLIGATIONS: STATE HIGHWAY BONDS AND NOTES	REIMBURSEMENT OBLIGATIONS 6/	TOTAL
	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS
ALABAMA	15,535	-73	15,462	[illegible]	[illegible]	6,208	12	-	1,1[illegible]	-	[illegible]
ARIZONA	4,769	-10	4,759	-	-	[illegible],115	-	[illegible]	-	-	-
ARKANSAS	11,412	-	11,412	[illegible]	-	2,595	-	[illegible]	[illegible]	[illegible]	[illegible]
CALIFORNIA	[illegible],978	-[illegible]	[illegible]	[illegible]	-	9,909	-	-	-	-	-
COLORADO	8,291	[illegible]	[illegible]	[illegible]		[illegible]	-	[illegible]	-	-	1,[illegible]
CONNECTICUT	11,084	[illegible]	10,7[illegible]		-	[illegible]	-	-	-	[illegible]003	[illegible]
DELAWARE	[illegible],325	-	[illegible]	[illegible]	-	4/ 1,669	-	[illegible]	[illegible]	3[illegible]	[illegible]
FLORIDA	27,448	[illegible]	27,[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	4,[illegible]	4,357
GEORGIA	22,841	-7	[illegible],834	[illegible]	-	4,[illegible]	-	-	[illegible]	-	[illegible]
IDAHO	4,817	[illegible]	4,[illegible]			[illegible]	-		[illegible]	-	[illegible]
ILLINOIS	41,824	-	41,824	[illegible]	[illegible]	[illegible]	-	-	-	-	-
INDIANA	26,068	-	26,068	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-
IOWA	14,655	[illegible]	14,6[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]
KANSAS	10,562	-	10,562		[illegible]	[illegible],705	-			6[illegible]	[illegible]76
KENTUCKY	14,717	-536	14,181	4[illegible]	-	[illegible]	-	[illegible]	-	-	-
LOUISIANA	18,671	-1,66[illegible]	17,[illegible]	[illegible]	[illegible]	[illegible]	-	-	7,[illegible]44	-	7,[illegible]44
MAINE	5,929	-	5,[illegible]	[illegible]	-	[illegible]	-	[illegible]	[illegible]	-	1,655
MARYLAND	11,448	-	11,448	[illegible]	-	[illegible]	-	-	-	-	-
MASSACHUSETTS	21,454	-481	[illegible]	[illegible]	-	[illegible]	11/ [illegible]	[illegible]	11/ [illegible]	-	[illegible]
MICHIGAN	[illegible],298	[illegible]	[illegible]	[illegible]	-	[illegible],361	-	-	4,[illegible]	-	4,[illegible]
MINNESOTA	18,526	[illegible]	18,[illegible]	[illegible]	[illegible]	11,[illegible]	-	[illegible]	-	-	-
MISSISSIPPI	11,9[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible],875	13/ [illegible]	-	[illegible]	-	[illegible]
MISSOURI	13,455	-	[illegible]	52	[illegible]	7,832	-	[illegible]	[illegible]	[illegible]	[illegible]
MONTANA	5,074	15[illegible]	5,[illegible]	21	[illegible]	4,[illegible]	-	-	[illegible]	-	[illegible]
NEBRASKA	11,828	-25	11,8[illegible]	3[illegible]	[illegible]	[illegible],518	-	-	-	-	-
NEVADA	1,507	-	1,507	[illegible]		1,472	-	-	-		7
NEW HAMPSHIRE	3,617	-	[illegible],617	(14/)	-	[illegible],309	-	[illegible]	-	-	802
NEW JERSEY	24,[illegible]	[illegible]12	[illegible],549	2[illegible]5	-	9,125	[illegible]	304	[illegible]14	-	[illegible]14
NEW MEXICO	4,699	-	4,699	98	[illegible]	2,691	-	-	[illegible]	-	1,[illegible]97
NEW YORK 17/	73,116	-1,00[illegible]	72,115	[illegible]10	-	7,599	[illegible]	[illegible]	[illegible]	-	[illegible],331
NORTH CAROLINA	27,372	-	27,[illegible]	-	[illegible]	4/ 19,347	-	-	6,5[illegible]	[illegible]9	[illegible]
NORTH DAKOTA	3,452	[illegible]9	3,5[illegible]1	46	[illegible]	2,583	-	-	-	-	-
OHIO	18/ 50,789	[illegible],153	51,942	104	-	21,919	-	-	-	-	-
OKLAHOMA	15,067	31	15,098	445	65	1[illegible],349	-	-	-	-	-
OREGON	11,[illegible]45	-	11,[illegible]45	43	-	7,118	-	259	2,031	[illegible]	2,039
PENNSYLVANIA	62,495	-	62,495	197	-	[illegible]1,100	76	2,274	2,954	-	2,954
RHODE ISLAND 19/	[illegible]45	-	[illegible],345	14	-	1,372	[illegible]	132	140	-	140
SOUTH CAROLINA	1[illegible],847	-	[illegible],847	47	[illegible]4	[illegible],790	-	-	1,721	749	[illegible],470
SOUTH DAKOTA	4,[illegible]	-[illegible]06	[illegible]	[illegible]1	1[illegible]	3,6[illegible]7	[illegible]	43	2	-	2
TENNESSEE	[illegible]	-361	[illegible],817	[illegible]1	[illegible]	[illegible],541	[illegible]	-	2,348	600	[illegible]48
TEXAS	47,[illegible]	-390	47,14[illegible]	[illegible]	-	[illegible]67	-	[illegible]7	-	7,[illegible]	7,[illegible]87
UTAH	[illegible]8	3	3,[illegible]	1[illegible]	1	[illegible],74[illegible]	-	152	-	-	-
VERMONT	2,781	-	2,781	2	-	1,[illegible]	[illegible]	-	376	-	[illegible]76
VIRGINIA	[illegible]	[illegible]	19,454	-	[illegible]	4/ 18,[illegible]8	-	[illegible]	1[illegible]	-	1[illegible]
WASHINGTON	17,185	-	17,185	[illegible]	-	[illegible]	-	-	[illegible]27	[illegible]	[illegible]7
WEST VIRGINIA	[illegible],6[illegible]1	-	[illegible]	[illegible]	-	4/ [illegible]	-	-	[illegible]	-	[illegible]
WISCONSIN 20/	[illegible]	-	21,[illegible]11	76	[illegible]	[illegible]	-	-	-	[illegible]	[illegible]
WYOMING	[illegible]	-	[illegible]	[illegible]	-	[illegible]	-	[illegible]	[illegible]	-	[illegible]
DISTRICT OF COLUMBIA	[illegible]	[illegible]	[illegible]	([illegible])	-	-	-	-	-	-	-
TOTAL	[illegible]	-[illegible]	[illegible]66,259	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

STATE	TOTAL FOR STATE HIGHWAY PURPOSES 2/	FOR LOCAL ROADS AND STREETS: FOR WORK ON COUNTY AND LOCAL ROADS 4/ 7/	FOR WORK ON CITY STREETS 8/	SERVICE OF LOCAL HIGHWAY OBLIGATIONS	TOTAL	FOR NONHIGHWAY PURPOSES: TO GENERAL FUNDS 9/: INSPECTION FEES, DEALERS LICENSES, ETC.	MOTOR-FUEL TAX	FOR RELIEF OF UNEMPLOYMENT OR DESTITUTION	FOR EDUCATION	FOR OTHER PURPOSES 10/	TOTAL	STATE
	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	
ALABAMA	7,[illegible]1	7,725	145	-	7,91[illegible]	-	-	-	-	-	-	ALABAMA
ARIZONA	[illegible]57	*1,460	-	-	1,460	-	-	-	-	-	-	ARIZONA
ARKANSAS	[illegible]71	[illegible]	-	163	[illegible]	-	-	-	-	-	-	ARKANSAS
CALIFORNIA	[illegible]	*[illegible]	[illegible]	-	[illegible]	-	-	[illegible],625	-	-	2,825	CALIFORNIA
COLORADO	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	-	COLORADO
CONNECTICUT	10,677	-	-	-	-	-	1	-	-	-	1	CONNECTICUT
DELAWARE	[illegible]	(4/) [illegible]	[illegible]	-	[illegible]	-	-	-	-	18	18	DELAWARE
FLORIDA	[illegible]	-	-	-	-	[illegible]	1,[illegible]	-	1,[illegible]	17	4,239	FLORIDA
GEORGIA	14,066	[illegible],668	-	-	[illegible],668	[illegible]	-	-	[illegible],761	6	3,816	GEORGIA
IDAHO	3,5[illegible]	*1,[illegible]	-	-	1,[illegible]97	-	-	-	-	-	-	IDAHO
ILLINOIS	[illegible]	9,99[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	2,167	-	6,782	ILLINOIS
INDIANA	14,6[illegible]	[illegible],794	1,[illegible]	-	3,[illegible]	463	[illegible]	-	-	-	1,352	INDIANA
IOWA	7,[illegible]	*[illegible]		-	7,[illegible]	-	-	-	-	-	-	IOWA
KANSAS	[illegible]	[illegible]	-	-	2,[illegible]	-	-	-	-	-	-	KANSAS
KENTUCKY	1[illegible]	1,65[illegible]	-	-	1,65[illegible]	-	-	-	-	-	-	KENTUCKY
LOUISIANA	[illegible]	-	-	-	-	-	2,460	1,[illegible]	1,1[illegible]	1,1[illegible]	6,157	LOUISIANA
MAINE	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	-	MAINE
MARYLAND	5,[illegible]	[illegible]	[illegible]	[illegible]	4,865	-	-	-	-	-	-	MARYLAND
MASSACHUSETTS	[illegible]	[illegible]	-	11/ 1,[illegible]	[illegible]	[illegible]	-	12/ [illegible]	-	-	910	MASSACHUSETTS
MICHIGAN	25,642	*6,55[illegible]	-	-	6,[illegible]	-	-	-	-	-	-	MICHIGAN
MINNESOTA	12,[illegible]	*6,1[illegible]	-	-	6,100	[illegible]	-	-	-	-	102	MINNESOTA
MISSISSIPPI	6,[illegible]	*[illegible]	-	-	[illegible]	-	-	-	-	-	-	MISSISSIPPI
MISSOURI	13,2[illegible]	-	-	-	-	[illegible]	-	-	-	-	[illegible]8	MISSOURI
MONTANA	5,[illegible]	-	-	-	-	-	-	-	-	-	-	MONTANA
NEBRASKA	5,513	*[illegible],451	[illegible]	-	[illegible]	-	-	[illegible]	-	-	[illegible]	NEBRASKA
NEVADA	1,479	-	-	-	-	-	-	-	-	-	-	NEVADA
NEW HAMPSHIRE	3,1[illegible]	212	-	15/ 221	[illegible]	-	-	-	-	-	-	NEW HAMPSHIRE
NEW JERSEY	11,717	4,229	-	1,[illegible]	[illegible]49	-	16/ 4,284	1,81[illegible]	[illegible]	676	7,[illegible]28	NEW JERSEY
NEW MEXICO	4,[illegible]83	-	-	-	-	-	-	-	-	-	-	NEW MEXICO
NEW YORK 17/	13,2[illegible]0	9,249	1,787	-	11,[illegible]6	-	47,749	-	-	-	47,749	NEW YORK 17/
NORTH CAROLINA	26,104	(4/)	-	-	-	[illegible]64	-	-	-	149	1,133	NORTH CAROLINA
NORTH DAKOTA	2,583	822	-	-	8[illegible]	-	[illegible]	-	-	-	3	NORTH DAKOTA
OHIO	21,919	[illegible],660	7,[illegible]	-	15,568	-	12,991	-	-	-	12,991	OHIO
OKLAHOMA	13,349	*1,269	[illegible]38	-	4,007	[illegible]	-	-	-	-	232	OKLAHOMA
OREGON	9,416	*1,784	-	-	1,784	-	-	-	-	102	102	OREGON
PENNSYLVANIA	36,604	*9,949	-	-	9,949	-	15,662	-	-	83	15,745	PENNSYLVANIA
RHODE ISLAND 19/	1,551	32	-	-	32	-	[illegible],248	-	-	-	2,248	RHODE ISLAND 19/
SOUTH CAROLINA	11,260	*[illegible],267	[illegible]	-	[illegible],289	[illegible]	-	-	-	-	217	SOUTH CAROLINA
SOUTH DAKOTA	3,752	536	-	-	[illegible]	[illegible]	-	-	-	-	74	SOUTH DAKOTA
TENNESSEE	8,[illegible]92	5,930	-	-	[illegible]	[illegible]	-	-	-	6,223	7,431	TENNESSEE
TEXAS	2[illegible],6[illegible]1	*5,1[illegible]1	-	-	5,131	-	-	-	11,586	-	11,586	TEXAS
UTAH	3,[illegible]94	7	-	-	73	-	-	-	-	-	-	UTAH
VERMONT	1,44[illegible]	[illegible]	-	[illegible]	1,324	-	-	-	-	15	15	VERMONT
VIRGINIA	19,[illegible]1	4/ [illegible]	[illegible]4	-	394	-	-	-	-	9	9	VIRGINIA
WASHINGTON	[illegible],149	*[illegible]	[illegible]	12/ [illegible]	[illegible]	-	-	12/ 1,[illegible]	-	-	1,072	WASHINGTON
WEST VIRGINIA	1[illegible],6[illegible]6	(4/)	-	-	-	-	-	-	-	-	-	WEST VIRGINIA
WISCONSIN 20/	6,[illegible]	[illegible]	[illegible]	-	6,94[illegible]	-	7,150	-	-	-	7,180	WISCONSIN 20/
WYOMING	[illegible]	6[illegible]	-	-	6[illegible]	-	-	-	-	-	-	WYOMING
DISTRICT OF COLUMBIA	-	-	[illegible]	-	[illegible]	[illegible]	-	-	-	-	7	DISTRICT OF COLUMBIA
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14,679	-1,211	8,494	143,734	TOTAL

1/ AMOUNTS DISTRIBUTED DURING THE CALENDAR YEAR [illegible] BETWEEN ACCOUNTS OF COLLECTING AND EXPENDING AGENCIES.
2/ IN MANY STATES THE PROCEEDS OF HIGHWAY-USER TAXES ARE PLACED IN A COMMON FUND [illegible] MADE. THE AMOUNTS SO DISTRIBUTED HAVE BEEN PRORATED IN PROPORTION TO THE RECEIPTS NOT OTHERWISE DEDICATED. SEE TABLES MV-3 AND MF-2.
3/ WHERE REPORTED SEPARATELY FROM COLLECTION EXPENSES, FUNDS ALLOTTED [illegible] MOTOR [illegible] DEPARTMENT, AND REGULATION OF MOTOR VEHICLES ARE SHOWN IN THIS COLUMN.
4/ THE FOLLOWING AMOUNTS FOR CONSTRUCTION AND MAINTENANCE OF COUNTY ROADS UNDER STATE CONTROL ARE INCLUDED IN [illegible] FOR STATE HIGHWAY PURPOSES; DELAWARE, $4[illegible]6,000; NORTH CAROLINA, $[illegible]; VIRGINIA, $[illegible]; WEST VIRGINIA, $2,[illegible],000. THE THREE COUNTIES IN VIRGINIA WHICH HAVE COUNTY ROADS NOT UNDER STATE CONTROL RECEIVED $[illegible].
5/ AMOUNTS DISTRIBUTED FOR STATE PARK AND FOREST ROADS, ETC. WERE LISTED SEPARATELY, RATHER THAN UNDER "STATE HIGHWAY PURPOSES", ON TABLE [illegible] FOR 1939 AND PRIOR YEARS.
6/ REIMBURSEMENT TO COUNTIES AND LOCAL UNITS OF GOVERNMENT FOR AMOUNTS SPENT ON ROADS NOW ON STATE SYSTEM.
7/ IN STATES INDICATED BY STAR (*) LAW PROVIDES THAT THESE FUNDS MAY ALSO BE USED FOR SERVICE OF LOCAL HIGHWAY OBLIGATIONS, AMOUNTS SO USED NOT REPORTED SEPARATELY. IN COLORADO FUNDS MAY BE USED ON BOTH STATE AND LOCAL ROADS.
8/ THIS COLUMN SHOWS SPECIFIC ALLOTMENTS FOR CITY STREETS. WHERE REPORTED SEPARATELY, FUNDS ALLOTTED FOR URBAN EXTENSIONS OF STATE HIGHWAY SYSTEM ARE INCLUDED IN ALLOTMENTS FOR STATE HIGHWAY PURPOSES.
9/ TO STATE GENERAL FUNDS EXCEPT AS FOLLOWS: LOUISIANA, 1 CENT OF TAX TO PARISHES; WISCONSIN, $2,3[illegible] PAYMENT TO TOWNS, CITIES, AND VILLAGES IN LIEU OF PERSONAL PROPERTY TAX FORMERLY IMPOSED ON MOTOR VEHICLES. ALLOCATIONS TO COUNTY OR LOCAL GENERAL FUNDS MAY HAVE BEEN USED IN PART FOR HIGHWAYS, BUT SUCH AMOUNTS NOT REPORTED.
10/ FOR THE FOLLOWING PURPOSES: DELAWARE, STATE PARKS AND LANDS, MOSQUITO CONTROL, CCC DITCHING; FLORIDA, AVIATION; GEORGIA, INVESTIGATION OF WATER RESOURCES; LOUISIANA, HARBOR IMPROVEMENT; NEW JERSEY, DEBT SERVICE ON INSTITUTIONAL CONSTRUCTION BONDS, $[illegible], BOARD OF COMMERCE AND NAVIGATION, $[illegible]; NORTH CAROLINA, STATE PROBATION AND PAROLE COMMISSIONS; OREGON, STATE PARKS; PENNSYLVANIA, AVIATION, $[illegible], COOPERATIVE WORK OTHER DEPARTMENTS, $8,[illegible]; TENNESSEE, DEBT SERVICE ON NONHIGHWAY BONDS; VERMONT, DEBT SERVICE IN NONHIGHWAY PORTION OF [illegible] RELIEF BONDS; VIRGINIA, AVIATION.
11/ TO METROPOLITAN DISTRICT COMMISSION FOR PARKWAYS AND BOULEVARDS.
12/ INCLUDES DEBT SERVICE CHARGE [illegible] EMERGENCY RELIEF BOND ISSUES, PRORATED IN PROPORTION TO USE OF PROCEEDS FOR STATE HIGHWAYS, LOCAL ROADS AND STREETS, AND NONHIGHWAY PURPOSES.
13/ TO GULF COAST COUNTIES FOR MAINTENANCE OF SEA WALL PROTECTING STATE HIGHWAYS.
14/ PAID OUT OF MOTOR-VEHICLE REVENUE, $4,000. SEE TABLE MV-3.
15/ INCLUDES $117,000 PAID ON HIGHWAY RELIEF BONDS ISSUED BY STATE FOR LOCAL ROADS, AND $104,000 ON PRO-RATA SHARE OF HIGHWAY FLOOD BONDS.
16/ INCLUDES $3,000,000 ORIGINALLY APPROPRIATED FOR RELIEF BUT LATER TRANSFERRED BY LEGISLATIVE ACTION TO STATE GENERAL FUND.
17/ APPROPRIATIONS FOR HIGHWAY PURPOSES OUT OF STATE GENERAL FUND HAVE BEEN CREDITED AGAINST PAYMENTS OF MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES TO THE GENERAL FUND AND PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS NOT OTHERWISE DEDICATED.
18/ TAX OF $638,000 ON NON-MOTOR-VEHICLE FUELS NOT INCLUDED.
19/ EXPENDITURES FOR HIGHWAY PURPOSES HAVE BEEN CREDITED AGAINST PAYMENTS OF MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES TO THE STATE GENERAL FUND AND PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS NOT OTHERWISE DEDICATED.
20/ MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES ARE PAID INTO HIGHWAY ACCOUNT OF STATE GENERAL FUND, AND ARE USED FOR ANY PURPOSE, INCLUDING HIGHWAYS. EXPENDITURES FOR HIGHWAY PURPOSES HAVE BEEN CREDITED AGAINST RECEIPTS FROM MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES, PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS.
21/ PAID OUT OF GENERAL REVENUE, AMOUNT NOT REPORTED.

DISPOSITION OF STATE MOTOR-VEHICLE RECEIPTS - 1940

STATE	[illegible] AVAILABLE [illegible] YEAR	[illegible] FUNDS, ETC. 1/	[illegible] DISTRIBUTED 3/	[illegible] AND ADMINISTRATION 3/	FOR OTHER ADMINISTRATIVE PURPOSES 4/	STATE HIGHWAYS 5/	[illegible] FOREST ROADS, ETC. 6/	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 10/	[illegible] DISTRIBUTION	[illegible]	[illegible] 11/	[illegible]	STATE
	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	
ALABAMA	4,548	[illegible]	4,858	414	-	1,578		[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]		-	[illegible]	[illegible]	-	-	-	[illegible]	ALABAMA
ARIZONA	[illegible]	[illegible]	1,247	268	-	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]	-	-	1	-	-	-	-	-	ARIZONA
ARKANSAS	[illegible]	36	3,785	92	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	[illegible]	-	-	-	-	-	ARKANSAS
CALIFORNIA	27,914	-699	[illegible]	[illegible]	35	[illegible]	-	[illegible]	[illegible]	-	[illegible]	10,[illegible]	[illegible]	-	-	[illegible]	[illegible]	-	-	-	[illegible]	CALIFORNIA
COLORADO	2,797	2	2,799	565	-	[illegible]	-	[illegible]	[illegible]	-	[illegible]	1,1[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	COLORADO
CONNECTICUT	7,385	-171	7,214	898	-	[illegible]	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	CONNECTICUT
DELAWARE	1,252	-	1,252	148	-	[illegible] 796	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	-	1	-	-	-	8	8	DELAWARE
FLORIDA	8,002	-	[illegible]	[illegible]	-	-	-	[illegible]	-	-	-	-	-	-	-	-	-	-	[illegible]	-	[illegible]	FLORIDA
GEORGIA	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	[illegible]	-	-	-	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	GEORGIA
IDAHO	1,401	[illegible]	1,429	65	-	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	IDAHO
ILLINOIS	24,760	[illegible]	[illegible]	1,041	-	[illegible]	-	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	-	[illegible]		-	-	-	[illegible]	ILLINOIS
INDIANA	[illegible]	[illegible]	[illegible]	1,062	-	[illegible]	-	[illegible]	[illegible]	-	-	[illegible]	[illegible]	33	-	[illegible]	[illegible]	-	-	-	[illegible]	INDIANA
IOWA	[illegible]		[illegible]	605	-	[illegible]	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	-	-	IOWA
KANSAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	KANSAS
KENTUCKY	[illegible]	[illegible]	[illegible]	516	-	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]		-	[illegible]	[illegible]	-	-	-	[illegible]	KENTUCKY
LOUISIANA	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-		1	-	[illegible]	[illegible]	-		-	-	-	-	-	-	-	LOUISIANA
MAINE	4,162	[illegible]	4,397	270	-	[illegible]	-	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	-	[illegible]	[illegible]	-	-	-	[illegible]	MAINE
MARYLAND	6,698	-	6,698	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	-	[illegible]	[illegible]	-	[illegible]	-	[illegible]	[illegible]	-	-	-	[illegible]	MARYLAND
MASSACHUSETTS	7,319	[illegible]	7,481	1,568	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	-	[illegible]	-	-	47	MASSACHUSETTS
MICHIGAN	24,115	[illegible]	24,487	1,779	-	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	MICHIGAN
MINNESOTA	10,305	-94	[illegible]	590	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	[illegible]	-	-	-	[illegible]	MINNESOTA
MISSISSIPPI	[illegible]	[illegible]	[illegible]	188	-	104	-	[illegible]	-	-	-	40	[illegible]	-	-	[illegible]	-	-	-	-	-	MISSISSIPPI
MISSOURI	10,750	-6	[illegible]	555	-	6,022	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-	-	-	-	-	MISSOURI
MONTANA	[illegible]	[illegible]	1,797	64	-	-	-	[illegible]	-	-	-	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	-	-	MONTANA
NEBRASKA	[illegible]	[illegible]	2,819	[illegible]	13	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	NEBRASKA
NEVADA	[illegible]	-10	[illegible]	[illegible]	-	167	-	[illegible]	-1	-	[illegible]	[illegible]	-	-	-	-	-	-	-	-	-	NEVADA
NEW HAMPSHIRE	[illegible]	-	[illegible]	151	4	[illegible]	-	[illegible]		-		[illegible]	[illegible]	-	14/ [illegible]	340	-	-	-	-	-	NEW HAMPSHIRE
NEW JERSEY	[illegible]	[illegible]	[illegible]	2,207	-	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	1,741	[illegible]	649	4,162	NEW JERSEY
NEW MEXICO	1,994	1	1,995	181	126	664	-	141	-	-	-	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	-	-	-	616	NEW MEXICO
NEW YORK 15/	55,944	-946	[illegible]	2,965	194	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	*11,143	[illegible]	-	[illegible]	[illegible]	-	-	-	[illegible]	NEW YORK 15/
NORTH CAROLINA	8,174	[illegible]	8,556	546	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-	-	-	-	NORTH CAROLINA
NORTH DAKOTA	1,661	[illegible]	1,640	92	-	817	-	14	-	-	-	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	NORTH DAKOTA
OHIO	30,376	[illegible]	[illegible]	[illegible]	-	[illegible]	-	[illegible]	-	-	-	[illegible]	*12,61[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	298	OHIO
OKLAHOMA	6,435	-50	6,385	948	-	[illegible]	-	695	-	-	-	2,117	[illegible]	[illegible]	-	[illegible]	-	-	-	-	-	OKLAHOMA
OREGON	3,346	-5	3,341	410	-	[illegible]	-	68	[illegible]	2	[illegible]	2,442	*462	-	-	[illegible]	-	-	-	27	27	OREGON
PENNSYLVANIA	38,891	-66	38,825	1,944	-	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	-	[illegible]	-	-	-	79	79	PENNSYLVANIA
RHODE ISLAND 16/	3,218	-	3,218	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	-	105	1,244	24	-	-	[illegible]	[illegible]	-	-	-	1,694	RHODE ISLAND 16/
SOUTH CAROLINA	2,104	-	2,104	148	-	1,113	-	[illegible]	[illegible]	95	280	1,952	1	[illegible]	-	[illegible]	-	-	-	-	-	SOUTH CAROLINA
SOUTH DAKOTA	1,794	-24	1,770	[illegible]	-	[illegible]	[illegible]	[illegible]	-	-	-	[illegible]	1,331	-	-	[illegible]	[illegible]	-	-	-	15	SOUTH DAKOTA
*TENNESSEE	5,330	[illegible]	5,562	649	-	4,185	11	[illegible]	-	-	-	[illegible]	-	-	-	-	[illegible]	-	-	-	477	*TENNESSEE
TEXAS	[illegible]	-	[illegible]	1,852	-	[illegible]	-	[illegible]	-	-	-	[illegible]	[illegible]	-	-	[illegible]	-	-	-	-	-	TEXAS
UTAH	1,227	-106	1,121	157	[illegible]	-	-	-	118	-	118	118	[illegible]	[illegible]	-	[illegible]	37	-	-	-	[illegible]	UTAH
VERMONT	2,625	-14	2,611	[illegible]	-	[illegible]	4	112	329	-	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	-	-	-	[illegible]	[illegible]	VERMONT
VIRGINIA	7,159	-210	6,949	506	-	[illegible]	-	[illegible]	79	-	79	[illegible]	-	[illegible]	-	[illegible]	-	-	-	-	-	VIRGINIA
WASHINGTON	3,728	-16	3,712	476	15	[illegible]	[illegible]	[illegible]	-	-	-	[illegible]	9	-	-	9	-	-	-	-	-	WASHINGTON
WEST VIRGINIA	6,529	-	6,529	111	-	[illegible]	-	[illegible]	[illegible]	-	[illegible]	[illegible]	(5/)	-	-	-	-	-	-	-	-	WEST VIRGINIA
WISCONSIN 17/	13,075	-	13,075	858	-	[illegible]	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	559	-	[illegible]	[illegible]	-	-	-	[illegible]	WISCONSIN 17/
WYOMING	603	-12	591	16	-	[illegible]	-	[illegible]	52	-	52	575	-	-	-	-	-	-	-	-	-	WYOMING
DISTRICT OF COLUMBIA	1,751	-	1,751	197	-	-	-	-	-	-	-	-	-	1,554	-	1,554	-	-	-	-	-	DISTRICT OF COLUMBIA
TOTAL	439,178	-2,073	437,105	[illegible]	521	[illegible]	[illegible]	18,576	[illegible]	9,677	[illegible]	[illegible]	[illegible]	14,612	1,311	118,115	17,997	1,988	7,291	1,074	48,350	TOTAL

1/ AMOUNTS DISTRIBUTED DURING THE CALENDAR YEAR OFTEN DIFFER FROM ACTUAL COLLECTIONS BECAUSE OF UNDISTRIBUTED FUNDS AND LAG BETWEEN ACCOUNTS OF COLLECTING AND EXPENDING AGENCIES.

2/ IN MANY STATES THE PROCEEDS OF HIGHWAY-USER TAXES ARE PLACED IN A COMMON FUND FROM WHICH A DISTRIBUTION IS MADE. THE AMOUNTS SO DISTRIBUTED HAVE BEEN PRORATED IN PROPORTION TO THE RECEIPTS NOT OTHERWISE DEDICATED. [illegible] TABLES [illegible]-3 AND MC-2.

3/ COLLECTION EXPENSES IN MANY STATES INCLUDE SERVICE CHARGES DEDUCTED BY COUNTY AND LOCAL [illegible] COLLECTORS. SEE TABLE SF-4 FOR DETAILS OF AMOUNTS INCLUDED IN THIS COLUMN.

4/ WHERE REPORTED SEPARATELY FROM COLLECTION EXPENSES, MISCELLANEOUS EXPENSES OF MOTOR-VEHICLE, MOTOR-FUEL, AND MOTOR-CARRIER REGULATION ARE SHOWN IN THIS COLUMN.

5/ THE FOLLOWING AMOUNTS FOR CONSTRUCTION AND MAINTENANCE OF COUNTY ROADS UNDER STATE CONTROL ARE INCLUDED IN ALLOTMENTS FOR STATE HIGHWAY PURPOSES: DELAWARE, $203,000; NORTH CAROLINA, $2,312,[illegible]; WEST VIRGINIA, $[illegible].

6/ AMOUNTS DISTRIBUTED FOR STATE PARK AND FOREST ROADS, ETC. WERE REPORTED SEPARATELY, RATHER THAN UNDER "STATE HIGHWAY PURPOSES", ON TABLE MV-3 FOR 1939 AND PRIOR YEARS.

7/ REIMBURSEMENT TO COUNTIES AND LOCAL UNITS OF GOVERNMENT FOR AMOUNTS SPENT ON ROADS NOW ON STATE SYSTEM.

8/ IN STATES INDICATED BY STAR (*) LAW PROVIDES THAT THESE FUNDS MAY ALSO BE USED FOR SERVICE OF LOCAL HIGHWAY OBLIGATIONS. AMOUNTS SO USED NOT REPORTED SEPARATELY. IN COLORADO FUNDS MAY BE USED ON BOTH STATE AND LOCAL ROADS.

9/ THIS COLUMN SHOWS SPECIFIC ALLOTMENTS FOR CITY STREETS. WHERE REPORTED SEPARATELY, FUNDS ALLOTTED FOR URBAN EXTENSIONS OF STATE HIGHWAY SYSTEM ARE INCLUDED IN ALLOTMENTS FOR STATE HIGHWAY PURPOSES.

10/ TO STATE GENERAL FUNDS EXCEPT IN THE FOLLOWING STATES: ALABAMA, COUNTY AND MUNICIPAL GENERAL FUNDS; CALIFORNIA, GENERAL FUNDS OF COUNTIES AND CITIES, $6,784,[illegible]; NEW MEXICO, COUNTY GENERAL FUNDS, $385,000; WISCONSIN, $1,381,000 TO TOWNS, CITIES, AND VILLAGES IN LIEU OF PERSONAL PROPERTY TAX FORMERLY IMPOSED ON MOTOR VEHICLES. ALLOCATIONS TO COUNTY OR LOCAL GENERAL FUNDS MAY HAVE BEEN USED IN PART FOR HIGHWAYS, BUT SUCH AMOUNTS NOT REPORTED.

11/ FOR THE FOLLOWING PURPOSES: DELAWARE, STATE PARKS AND LANDS, MOSQUITO CONTROL, CCC DITCHING; NEW JERSEY, DEBT SERVICE ON INSTITUTIONAL CONSTRUCTION BONDS, $360,000, BOARD OF COMMERCE AND NAVIGATION, $189,000; OHIO, CARE OF INDIGENT PERSONS INJURED IN MOTOR-VEHICLE ACCIDENTS; OREGON, STATE PARKS; PENNSYLVANIA, AVIATION, $71,000, COOPERATIVE WORK OTHER DEPARTMENTS, $[illegible]; VERMONT, DEBT SERVICE ON NONHIGHWAY PORTION OF FLOOD RELIEF BONDS.

12/ TO METROPOLITAN DISTRICT COMMISSION FOR PARKWAYS AND BOULEVARDS.

13/ INCLUDES DEBT SERVICE CHARGES ON EMERGENCY RELIEF BOND ISSUES, PRORATED IN PROPORTION TO USE OF PROCEEDS FOR STATE HIGHWAYS, LOCAL ROADS AND STREETS, AND NONHIGHWAY PURPOSES.

14/ DEBT SERVICE ON HIGHWAY RELIEF BONDS, A STATE OBLIGATION INCURRED FOR IMPROVEMENT OF LOCAL ROADS.

15/ APPROPRIATIONS FOR HIGHWAY PURPOSES OUT OF STATE GENERAL FUND HAVE BEEN CREDITED AGAINST PAYMENTS OF MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES TO THE GENERAL FUND AND PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS NOT OTHERWISE DEDICATED.

16/ EXPENDITURES FOR HIGHWAY PURPOSES HAVE BEEN CREDITED AGAINST PAYMENTS OF MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES TO THE STATE GENERAL FUND AND PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS NOT OTHERWISE DEDICATED.

17/ MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES ARE PAID INTO HIGHWAY ACCOUNT OF STATE GENERAL FUND, AND ARE USED FOR ANY PURPOSE, INCLUDING HIGHWAYS. EXPENDITURES FOR HIGHWAY PURPOSES HAVE BEEN CREDITED AGAINST RECEIPTS FROM MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES, PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS.

DISPOSITION OF STATE MOTOR-CARRIER TAX RECEIPTS - 1940

COMPILED FOR CALENDAR YEAR FROM REPORTS OF STATE AUTHORITIES

STATE	NET TOTAL RECEIPTS OF CALENDAR YEAR	ADJUSTMENTS DUE TO UNDISTRIBUTED FUNDS, ETC. 1/	NET TOTAL FUNDS DISTRIBUTED 2/	EXPENSES OF COLLECTION AND ADMINISTRATION	FOR STATE HIGHWAY PURPOSES: CONSTRUCTION, MAINTENANCE, AND ADMINISTRATION: ON STATE HIGHWAYS 3/	CONSTRUCTION, MAINTENANCE, AND ADMINISTRATION: ON STATE PARK AND FOREST ROADS, ETC. 4/	STATE HIGHWAY POLICE	SERVICE OF STATE HIGHWAY OBLIGATIONS: STATE HIGHWAY BONDS AND NOTES	SERVICE OF STATE HIGHWAY OBLIGATIONS: REIMBURSEMENT OBLIGATIONS 5/	SERVICE OF STATE HIGHWAY OBLIGATIONS: TOTAL	TOTAL FOR STATE HIGHWAY PURPOSES 4/	FOR LOCAL ROADS AND STREETS: FOR WORK ON COUNTY AND LOCAL ROADS 3/ 6/	FOR WORK ON CITY STREETS 7/	SERVICE OF LOCAL HIGHWAY OBLIGATIONS	TOTAL	FOR NONHIGHWAY PURPOSES: TO STATE GENERAL FUNDS	FOR EDUCATION	FOR STATE PARKS	TOTAL	STATE
	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	
ALABAMA	328	19	347	56	281	1	-	-	-	-	282	9	-	-	9	-	-	-	-	ALABAMA
ARIZONA	185	16	201	39	155	-	6	-	-	-	161	1	-	-	1	-	-	-	-	ARIZONA
ARKANSAS	3	-	3	2	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	ARKANSAS
CALIFORNIA	3,155	-241	2,914	463	101	-	-	-	-	-	101	4	-	-	4	2,346	-	-	2,346	CALIFORNIA
COLORADO	784	-61	723	119	204	-	12	78	-	78	294	310	-	-	310	-	-	-	-	COLORADO
CONNECTICUT	320	8	328	71	119	-	-	-	21	21	140	-	117	-	117	-	-	-	-	CONNECTICUT
DELAWARE	(8/)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	DELAWARE
FLORIDA	361	-	361	75	-	-	-	-	-	-	-	-	11	270	281	-	5	-	5	FLORIDA
GEORGIA	96	-9	87	68	19	-	-	-	-	-	19	-	-	-	-	-	-	-	-	GEORGIA
IDAHO	64	7	71	20	20	-	31	-	-	-	51	-	-	-	-	-	-	-	-	IDAHO
ILLINOIS	(8/)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ILLINOIS
INDIANA	1,472	-78	1,394	107	706	-	35	-	-	-	741	425	76	-	501	45	-	-	45	INDIANA
IOWA	412	-32	380	90	48	-	-	-	37	37	85	•205	-	-	205	-	-	-	-	IOWA
KANSAS	1,417	-	1,417	348	709	-	14	23	70	93	816	253	-	-	253	-	-	-	-	KANSAS
KENTUCKY	357	11	368	54	272	-	5	-	-	-	277	37	-	-	37	-	-	-	-	KENTUCKY
LOUISIANA	113	-	113	22	-	-	-	-	-	-	-	-	-	-	-	91	-	-	91	LOUISIANA
MAINE	19	-	19	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	MAINE
MARYLAND	(9/)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	MARYLAND
MASSACHUSETTS	152	-	152	46	-	-	-	-	-	-	-	-	-	-	-	106	-	-	106	MASSACHUSETTS
MICHIGAN	501	700	1,201	335	866	-	-	-	-	-	866	-	-	-	-	-	-	-	-	MICHIGAN
MINNESOTA	43	-	43	42	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	MINNESOTA
MISSISSIPPI	165	-	165	46	-	-	-	-	-	-	-	•119	-	-	119	-	-	-	-	MISSISSIPPI
MISSOURI	866	-772	94	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	MISSOURI
MONTANA	60	4	64	64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	MONTANA
NEBRASKA	37	-	37	37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NEBRASKA
NEVADA	264	-4	260	11	216	-	33	-	-	-	249	-	-	-	-	-	-	-	-	NEVADA
NEW HAMPSHIRE	3	-	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NEW HAMPSHIRE
NEW JERSEY	100	1	101	-	101	-	-	-	-	-	101	-	-	-	-	-	-	-	-	NEW JERSEY
NEW MEXICO	224	65	289	55	234	-	-	-	-	-	234	-	-	-	-	-	-	-	-	NEW MEXICO
NEW YORK	36	-	36	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NEW YORK
NORTH CAROLINA	397	-	397	15	3/ 283	-	-	96	3	99	382	(3/)	-	-	-	-	-	-	-	NORTH CAROLINA
NORTH DAKOTA	42	-	42	42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NORTH DAKOTA
OHIO	598	24	622	102	387	-	-	-	-	-	387	133	-	-	133	-	-	-	-	OHIO
OKLAHOMA	204	47	251	25	139	-	-	-	-	-	139	87	-	-	87	-	-	-	-	OKLAHOMA
OREGON	1,357	3	1,360	213	708	-	49	202	1	203	960	•177	-	-	177	-	-	10	10	OREGON
PENNSYLVANIA	5	-	5	-	5	-	-	-	-	-	5	-	-	-	-	-	-	-	-	PENNSYLVANIA
RHODE ISLAND	9	-	9	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	RHODE ISLAND
SOUTH CAROLINA	268	-15	253	73	156	-	-	-	-	-	156	-	24	-	24	-	-	-	-	SOUTH CAROLINA
SOUTH DAKOTA	433	26	459	29	405	3	4	-	-	-	412	-	-	-	-	18	-	-	18	SOUTH DAKOTA
TENNESSEE	51	-	51	27	-	-	-	-	-	-	-	-	-	-	-	24	-	-	24	TENNESSEE
TEXAS	123	-	123	115	8	-	-	-	-	-	8	-	-	-	-	-	-	-	-	TEXAS
UTAH 10/	-	81	81	9	72	-	-	-	-	-	72	-	-	-	-	-	-	-	-	UTAH 10/
VERMONT	(8/)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	VERMONT
VIRGINIA	363	-1	362	54	293	-	9	4	-	4	306	-	2	-	2	-	-	-	-	VIRGINIA
WASHINGTON	174	-	174	174	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	WASHINGTON
WEST VIRGINIA	120	-	120	-	53	-	-	67	-	67	120	-	-	-	-	-	-	-	-	WEST VIRGINIA
WISCONSIN	1,692	-	1,692	90	-	-	-	-	-	-	-	-	-	-	-	1,602	-	-	1,602	WISCONSIN
WYOMING	292	6	298	27	265	-	6	-	-	-	271	-	-	-	-	-	-	-	-	WYOMING
DISTRICT OF COLUMBIA	248	-	248	-	-	-	-	-	-	-	-	-	-	-	-	248	-	-	248	DISTRICT OF COLUMBIA
TOTAL	17,913	-195	17,718	3,326	6,827	4	204	470	132	602	7,637	1,760	230	270	2,260	4,480	5	10	4,495	TOTAL

1/ AMOUNTS DISTRIBUTED DURING THE CALENDAR YEAR OFTEN DIFFER FROM ACTUAL COLLECTIONS BECAUSE OF UNDISTRIBUTED FUNDS AND LAG BETWEEN ACCOUNTS OF COLLECTING AND EXPENDING AGENCIES.

2/ IN MANY STATES THE PROCEEDS OF HIGHWAY-USER TAXES ARE PLACED IN A COMMON FUND FROM WHICH A DISTRIBUTION IS MADE. THE AMOUNTS SO DISTRIBUTED HAVE BEEN PRORATED IN PROPORTION TO THE RECEIPTS NOT OTHERWISE DEDICATED. SEE TABLES G-3 AND MV-3.

3/ APPROXIMATELY $118,000 FOR USE ON COUNTY ROADS UNDER STATE CONTROL IN NORTH CAROLINA INCLUDED IN ALLOTMENTS FOR STATE HIGHWAY PURPOSES.

4/ AMOUNTS DISTRIBUTED FOR STATE PARK AND FOREST ROADS, ETC. WERE REPORTED SEPARATELY, RATHER THAN UNDER "STATE HIGHWAY PURPOSES", ON TABLE MC-2 FOR 1939 AND PRIOR YEARS.

5/ REIMBURSEMENT TO COUNTIES AND LOCAL UNITS OF GOVERNMENT FOR AMOUNTS SPENT ON ROADS NOW ON STATE SYSTEM.

6/ IN STATES INDICATED BY STAR (•) LAW PROVIDES THAT THESE FUNDS MAY ALSO BE USED FOR SERVICE OF LOCAL HIGHWAY OBLIGATIONS. AMOUNTS SO USED NOT REPORTED SEPARATELY. IN COLORADO FUNDS MAY BE USED ON BOTH STATE AND LOCAL ROADS.

7/ THIS COLUMN SHOWS SPECIFIC ALLOTMENTS FOR CITY STREETS. WHERE REPORTED SEPARATELY, FUNDS ALLOTTED FOR URBAN EXTENSIONS OF STATE HIGHWAY SYSTEM ARE INCLUDED IN ALLOTMENTS FOR STATE HIGHWAY PURPOSES.

8/ NO SPECIAL TAXES ON MOTOR CARRIERS REPORTED.

9/ TON-MILE AND PASSENGER-MILE TAXES PAID BY MOTOR CARRIERS IN LIEU OF REGISTRATION FEES INCLUDED IN MOTOR-VEHICLE RECEIPTS, TABLE MV-3.

10/ MOTOR-CARRIER TAXES NO LONGER IMPOSED. AMOUNTS SHOWN REPRESENT DISTRIBUTION OF REVENUES COLLECTED IN PRIOR YEARS.

DISPOSITION OF RECEIPTS FROM STATE IMPOSTS ON HIGHWAY USERS-1940

STATE	TOTAL RECEIPTS OF CALENDAR YEAR 1/	AMOUNTS TO UNDISTRIBUTED FUNDS, ETC. 2/	NET TOTAL FUNDS DISTRIBUTED	EXPENSES OF COLLECTION AND ADMINISTRATION 3/	CONSTRUCTION, MAINTENANCE, AND ADMINISTRATION: ON STATE HIGHWAYS 4/	CONSTRUCTION, MAINTENANCE, AND ADMINISTRATION: ON STATE PARK AND FOREST ROADS, ETC. 5/	STATE HIGHWAY POLICE	STATE HIGHWAY OBLIGATIONS: STATE HIGHWAY BONDS AND NOTES	STATE HIGHWAY OBLIGATIONS: REIMBURSEMENT OBLIGATIONS 6/	STATE HIGHWAY OBLIGATIONS: TOTAL	TOTAL FOR STATE HIGHWAY PURPOSES 5/
	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS
ALABAMA	20,411	256	20,667	571	8,157	10	270	2,627	-	2,627	11,070
ARIZONA	6,179	28	6,207	369	4,203	-	154	-	-	-	4,367
ARKANSAS	14,814	386	15,200	444	3,493	-	191	7,174	2,471	9,645	13,320
CALIFORNIA	[illegible]	-1,656	[illegible]	4,137	34,215	-	2,050	[illegible]	-	[illegible]	40,860
COLORADO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	215	[illegible]	-	[illegible]	[illegible]
CONNECTICUT	[illegible]	-	[illegible]	[illegible]	[illegible]	-	[illegible]	-	[illegible]	[illegible]	14,017
DELAWARE	[illegible]	-	[illegible]	157	4/ 2,465	-	[illegible]	211	444	[illegible]	[illegible]
FLORIDA	[illegible]	87	[illegible]	1,141	13,800	-	[illegible]	-	[illegible]	[illegible]	23,478
GEORGIA	[illegible]	64	25,769	1,160	14,602	-	771	83	-	83	15,456
IDAHO	[illegible]	55	6,337	105	3,605	-	137	101	-	101	3,843
ILLINOIS	66,584	[illegible]	66,481	2,159	22,270	-	1,688	9,840	-	9,840	33,798
INDIANA	[illegible]	-487	47,649	1,367	19,643	-	980	-	-	-	20,623
IOWA	28,054	5	25,059	815	10,534	-	[illegible]	-	[illegible]	[illegible]	[illegible]
KANSAS	15,991	705	16,756	1,156	10,211	-	219	315	[illegible]	[illegible]	11,765
KENTUCKY	20,583	-555	20,028	632	14,687	-	266	-	-	-	14,953
LOUISIANA	24,176	-1,642	22,534	277	8,295	-	[illegible]	7,214	-	7,214	16,009
MAINE	10,110	[illegible]	10,345	[illegible]	5,658	-	[illegible]	[illegible]	-	[illegible]	8,745
MARYLAND	18,146	-	18,146	433	9,128	-	44	[illegible]	-	[illegible]	[illegible]
MASSACHUSETTS	29,925	[illegible]	28,606	1,760	5,762	11/ 1,093	[illegible]	12/ [illegible]	-	[illegible]	11,180
MICHIGAN	57,014	1,081	58,095	2,529	22,767	-	[illegible]	[illegible]	-	4,081	27,499
MINNESOTA	28,874	[illegible]	[illegible]	780	16,750	-	467	[illegible]	1,606	[illegible]	21,490
MISSISSIPPI	15,105	[illegible]	15,195	406	2,979	13/ 4[illegible]9	[illegible]	[illegible]	-	[illegible]	7,173
MISSOURI	25,071	-778	[illegible]	766	13,854	-	716	8,682	[illegible]	[illegible]	23,439
MONTANA	6,855	[illegible]	7,088	155	4,253	-	[illegible]	947	-	947	5,448
NEBRASKA	14,704	-45	14,659	[illegible]	6,255	-	157	-	-	-	6,412
NEVADA	2,084	-14	2,070	69	1,855	-	58	81	7	88	2,001
NEW HAMPSHIRE	6,672	-	6,672	158	4,738	-	193	804	-	804	5,735
NEW JERSEY	46,999	[illegible]	[illegible]	2,462	[illegible]	537	597	3,951	-	3,951	23,086
NEW MEXICO	6,917	66	6,983	473	3,389	-	141	1,897	-	1,897	5,627
NEW YORK 16/	129,076	-1,947	127,149	3,305	18,593	506	1,427	11,819	-	11,819	32,345
NORTH CAROLINA	35,943	[illegible]	36,325	696	4/ 25,161	-	547	8,490	298	[illegible]	34,496
NORTH DAKOTA	5,155	[illegible]	5,213	257	3,400	-	14	-	-	-	[illegible]
OHIO	[illegible]	[illegible]	80,737	[illegible]	29,624	-	821	-	-	-	[illegible]
OKLAHOMA	21,706	[illegible]	21,734	1,483	11,910	-	695	-	-	-	12,605
OREGON	16,048	-2	16,046	666	9,672	-	376	2,759	11	2,770	12,818
PENNSYLVANIA	101,391	-66	101,325	2,141	61,004	148	4,431	5,758	-	5,758	71,341
RHODE ISLAND 17/	7,172	-	7,172	279	2,406	13	231	245	-	245	2,895
SOUTH CAROLINA	16,209	-15	16,194	292	10,059	-	559	1,906	844	2,750	13,368
SOUTH DAKOTA	6,738	-104	6,634	148	4,434	25	51	2	-	2	4,512
TENNESSEE	27,559	-129	27,430	1,040	8,726	34	240	2,848	680	3,528	12,528
TEXAS	70,075	-390	69,685	2,709	29,835	-	719	-	7,287	7,287	37,841
UTAH	5,215	-17	5,198	204	3,814	-	152	118	-	118	4,084
VERMONT	5,406	-14	5,392	74	1,985	8	112	705	-	705	2,810
VIRGINIA	26,916	-151	26,765	590	4/ 24,988	-	519	221	-	221	25,728
WASHINGTON	21,087	-16	21,071	714	9,668	40	476	12/ 127	50	177	10,361
WEST VIRGINIA	17,340	-	17,340	126	4/ 9,231	-	44	7,939	-	7,939	17,214
WISCONSIN 18/	36,078	-	36,078	1,185	6,992	158	-	-	3,887	3,887	11,037
WYOMING	3,615	-6	3,609	56	2,680	-	67	117	-	117	2,864
DISTRICT OF COLUMBIA	5,228	3	5,231	197	-	-	-	-	-	-	-
TOTAL	1,327,227	-6,145	1,321,082	46,693	576,295	3,007	26,449	110,310	38,418	148,728	754,479

STATE	ON COUNTY AND LOCAL ROADS 4/ 7/	FOR WORK ON CITY STREETS 8/	SERVICE OF LOCAL HIGHWAY OBLIGATIONS	TOTAL	TO MOTOR-FUEL INSPECTION FEES, DEALERS LICENSES, ETC.	ALL OTHER HIGHWAY-USER IMPOSTS	RELIEF OF UNEMPLOYMENT OR DESTITUTION	FOR EDUCATION	FOR OTHER PURPOSES 10/	TOTAL
	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS	1,000 DOLLARS
ALABAMA	7,845	347	-	8,192	-	[illegible]	-	-	-	834
ARIZONA	•1,471	-	-	1,471	-	-	-	-	-	-
ARKANSAS	1,222	-	205	1,427	-	-	-	-	-	-
CALIFORNIA	•18,092	4,313	-	22,405	-	11,164	[illegible]	-	-	13,989
COLORADO	3,561	-	-	3,561	-	-	-	-	-	-
CONNECTICUT	[illegible]	117	-	3,226	-	1	-	-	-	1
DELAWARE	(4/)	2	-	2	-	-	-	-	26	26
FLORIDA	-	11	[illegible]	281	75	1,9[illegible]4	-	8,682	17	10,998
GEORGIA	[illegible]	-	-	[illegible]	29	-	-	3,781	6	3,816
IDAHO	•2,389	-	-	2,389	-	-	-	-	-	-
ILLINOIS	11,607	10,337	1,595	23,539	153	[illegible]	4,462	2,167	-	6,985
INDIANA	11,834	2,110	-	[illegible]	465	1,250	-	-	-	1,715
IOWA	•7,985	21	-	8,006	-	-	-	-	-	-
KANSAS	3,635	-	-	3,635	-	-	-	-	-	-
KENTUCKY	2,606	-	-	2,606	-	1,837	-	-	-	1,837
LOUISIANA	-	-	-	-	-	[illegible]	[illegible]	1,196	1,196	6,248
MAINE	1,158	-	-	1,158	-	142	-	-	-	142
MARYLAND	881	[illegible]	[illegible]	6,525	-	1,335	-	-	-	1,335
MASSACHUSETTS	[illegible]	-	12/ [illegible]	14,403	[illegible]	136	12/ 1,130	-	-	1,263
MICHIGAN	[illegible]	-	-	25,067	-	-	-	-	-	-
MINNESOTA	•6,106	-	-	6,106	[illegible]	145	-	-	-	247
MISSISSIPPI	•7,616	-	-	7,616	-	-	-	-	-	-
MISSOURI	-	[illegible]	-	-	[illegible]	-	-	-	-	88
MONTANA	1,441	44	-	1,485	-	-	-	-	-	-
NEBRASKA	•5,115	378	-	[illegible]	-	-	[illegible]	-	-	[illegible]
NEVADA	-	-	-	-	-	-	-	-	-	-
NEW HAMPSHIRE	435	-	14/ 344	[illegible]	-	-	-	-	-	-
NEW JERSEY	8,295	-	[illegible]	[illegible]	-	15/ 5,519	3,551	1,095	1,325	11,490
NEW MEXICO	231	36	-	[illegible]	-	616	-	-	-	616
NEW YORK 16/	•20,794	[illegible]	-	27,517	-	[illegible]	-	-	-	63,982
NORTH CAROLINA	(4/)	-	-	-	[illegible]	-	-	-	149	1,133
NORTH DAKOTA	1,539	-	-	[illegible]	-	-	-	-	-	[illegible]
OHIO	•22,412	[illegible]	-	33,785	-	[illegible]	-	-	[illegible]	[illegible]
OKLAHOMA	•5,965	1,449	-	7,414	[illegible]	-	-	-	-	[illegible]
OREGON	•2,423	-	-	2,423	-	-	-	-	139	139
PENNSYLVANIA	•12,019	-	-	12,019	-	15,662	-	-	162	15,824
RHODE ISLAND 17/	56	-	-	56	-	[illegible]	-	-	-	3,942
SOUTH CAROLINA	•2,268	49	-	[illegible]	217	-	-	-	-	217
SOUTH DAKOTA	1,867	-	-	1,867	74	33	-	-	-	107
TENNESSEE	5,930	-	-	5,930	1,208	501	-	-	6,223	7,932
TEXAS	•17,549	-	-	[illegible]	-	-	-	11,586	-	11,586
UTAH	565	[illegible]	-	873	-	[illegible]	-	-	-	37
VERMONT	1,848	-	632	[illegible]	-	-	-	-	28	28
VIRGINIA	4/ 320	118	-	438	-	-	-	-	9	9
WASHINGTON	•6,378	[illegible]	12/ [illegible]	[illegible]	-	-	12/ 1,072	-	-	1,072
WEST VIRGINIA	(4/)	-	-	-	-	-	-	-	-	-
WISCONSIN 18/	[illegible]	[illegible]	-	[illegible]	-	12,840	-	-	-	12,840
WYOMING	689	-	-	689	-	-	-	-	-	-
DISTRICT OF COLUMBIA	-	4,779	-	4,779	7	248	-	-	-	255
TOTAL	263,900	51,321	8,110	[illegible]	[illegible]	137,866	16,667	28,507	9,578	196,579

1/ INCLUDES RECEIPTS FROM MOTOR-FUEL TAXES, MOTOR-VEHICLE FEES AND FINES, AND SPECIAL IMPOSTS ON MOTOR VEHICLES OPERATED FOR HIRE (MOTOR-CARRIER TAXES). SEE TABLES G-3, MV-3, AND MC-2, WHICH GIVE DISTRIBUTION OF RECEIPTS SEPARATELY.

2/ AMOUNTS DISTRIBUTED DURING THE CALENDAR YEAR OFTEN DIFFER FROM ACTUAL COLLECTIONS BECAUSE OF UNDISTRIBUTED FUNDS AND LAG BETWEEN ACCOUNTS OF COLLECTING AND EXPENDING AGENCIES.

3/ INCLUDES EXPENSES OF COLLECTION AND ADMINISTRATION OF MOTOR-FUEL TAX, MOTOR-VEHICLE FEES, AND MOTOR-CARRIER TAXES, AND MISCELLANEOUS EXPENSES OF MOTOR-VEHICLE REGULATION.

4/ THE FOLLOWING AMOUNTS FOR CONSTRUCTION AND MAINTENANCE OF COUNTY ROADS UNDER STATE CONTROL ARE INCLUDED IN ALLOTMENTS FOR STATE HIGHWAY PURPOSES: DELAWARE, $629,000; NORTH CAROLINA, $10,519,000; VIRGINIA, $7,759,000; WEST VIRGINIA, $2,955,000. THE 3 COUNTIES IN VIRGINIA WHICH HAVE COUNTY ROADS NOT UNDER STATE CONTROL RECEIVED $320,000.

5/ AMOUNTS DISTRIBUTED FOR STATE PARK AND FOREST ROADS, ETC. WERE REPORTED SEPARATELY, RATHER THAN UNDER "STATE HIGHWAY PURPOSES", ON TABLE OF FOR 1939 AND PRIOR YEARS.

6/ REIMBURSEMENT TO COUNTIES AND LOCAL UNITS OF GOVERNMENT FOR AMOUNTS SPENT ON ROADS NOW ON STATE SYSTEM.

7/ IN STATES INDICATED BY STAR (•) LAW PROVIDES THAT THESE FUNDS MAY ALSO BE USED FOR SERVICE OF LOCAL HIGHWAY OBLIGATIONS. AMOUNTS SO USED NOT REPORTED SEPARATELY. IN COLORADO FUNDS MAY BE USED ON BOTH STATE AND LOCAL ROADS.

8/ THIS COLUMN SHOWS SPECIFIC ALLOTMENTS FOR CITY STREETS. WHERE REPORTED SEPARATELY, FUNDS ALLOTTED FOR URBAN EXTENSIONS OF STATE HIGHWAY SYSTEM ARE INCLUDED IN ALLOTMENTS FOR STATE HIGHWAY PURPOSES.

9/ TO STATE GENERAL FUNDS EXCEPT AS FOLLOWS: ALABAMA AND CALIFORNIA, COUNTY AND MUNICIPAL GENERAL FUNDS; LOUISIANA, PARISH GENERAL FUNDS; NEW MEXICO, COUNTY GENERAL FUNDS; WISCONSIN, $3,731,000 TO TOWNS, CITIES, AND VILLAGES IN LIEU OF PERSONAL PROPERTY TAX FORMERLY IMPOSED ON MOTOR VEHICLES. ALLOCATIONS TO COUNTY OR LOCAL GENERAL FUNDS MAY HAVE BEEN USED IN PART FOR HIGHWAYS, BUT SUCH AMOUNTS NOT REPORTED.

10/ FOR THE FOLLOWING PURPOSES: DELAWARE, STATE PARKS AND LANDS, $5,000, MOSQUITO CONTROL, $16,000, CCC DITCHING, $5,000; FLORIDA, AVIATION; GEORGIA, INVESTIGATION OF WATER RESOURCES; LOUISIANA, HARBOR IMPROVEMENT; NEW JERSEY, DEBT SERVICE ON INSTITUTIONAL CONSTRUCTION BONDS, $531,000, BOARD OF COMMERCE AND NAVIGATION, $794,000; NORTH CAROLINA, STATE PROBATION AND PAROLE COMMISSIONS; OHIO, CARE OF INDIGENT PERSONS INJURED IN MOTOR-VEHICLE ACCIDENTS; OREGON, STATE PARKS; PENNSYLVANIA, AVIATION, $146,000, COOPERATIVE WORK OTHER DEPARTMENTS, $16,000; TENNESSEE, DEBT SERVICE ON NONHIGHWAY BONDS; VERMONT, DEBT SERVICE ON NONHIGHWAY PORTION OF FLOOD RELIEF BONDS; VIRGINIA, AVIATION.

11/ TO METROPOLITAN DISTRICT COMMISSION FOR PARKWAYS AND BOULEVARDS.

12/ INCLUDES DEBT SERVICE CHARGES ON EMERGENCY RELIEF BOND ISSUES, PRORATED IN PROPORTION TO USE OF PROCEEDS FOR STATE HIGHWAYS, LOCAL ROADS AND STREETS, AND NONHIGHWAY PURPOSES.

13/ TO GULF COAST COUNTIES FOR MAINTENANCE OF SEA WALL PROTECTING STATE HIGHWAYS.

14/ INCLUDES $240,000 PAID ON HIGHWAY RELIEF BONDS ISSUED BY STATE FOR LOCAL ROADS, AND $104,000 ON PRO-RATA SHARE OF HIGHWAY FLOOD BONDS.

15/ INCLUDES $3,000,000 ORIGINALLY APPROPRIATED FOR RELIEF, BUT LATER TRANSFERRED BY LEGISLATIVE ACTION TO STATE GENERAL FUND.

16/ APPROPRIATIONS FOR HIGHWAY PURPOSES OUT OF STATE GENERAL FUND HAVE BEEN CREDITED AGAINST PAYMENTS OF MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES TO THE GENERAL FUND AND PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS NOT OTHERWISE DEDICATED.

17/ EXPENDITURES FOR HIGHWAY PURPOSES HAVE BEEN CREDITED AGAINST PAYMENTS OF MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES TO THE STATE GENERAL FUND AND PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS NOT OTHERWISE DEDICATED.

18/ MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES ARE PAID INTO HIGHWAY ACCOUNT OF STATE GENERAL FUND, AND ARE USED FOR ANY PURPOSE, INCLUDING HIGHWAYS. EXPENDITURES FOR HIGHWAY PURPOSES HAVE BEEN CREDITED AGAINST RECEIPTS FROM MOTOR-FUEL TAX AND MOTOR-VEHICLE REVENUES, PRORATED IN PROPORTION TO NET RECEIPTS FROM THESE IMPOSTS.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF SEPTEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 1,478,160	$ 734,140	58.2	$ 6,712,877	$ 3,332,605	219.4	$ 2,155,404	$ 1,072,000	57.7	$ 937,670
Arizona	528,890	380,976	33.1	1,520,054	1,039,490	54.7	692,577	437,998	17.6	993,258
Arkansas	2,306,936	1,057,900	33.0	1,189,406	593,887	45.0	643,482	320,692	38.4	379,609
California	2,985,331	1,602,150	67.8	6,831,858	3,695,654	76.7	2,442,327	1,319,196	47.0	2,293,984
Colorado	1,830,304	1,036,002	102.9	2,128,406	1,234,463	143.0	946,905	534,573	63.1	1,792,048
Connecticut	711,753	347,250	7.2	1,782,108	872,444	22.6	1,018,039	476,221	11.9	543,129
Delaware	161,292	78,259	2.7	832,264	410,217	22.4	299,647	149,824	9.5	964,421
Florida	726,447	363,224	52.4	790,609	422,194	12.9	1,992,059	971,708	22.0	2,574,738
Georgia	1,734,840	867,420	60.1	6,307,204	3,163,852	260.0	4,281,611	2,140,806	176.1	4,975,471
Idaho	769,197	474,099	46.5	1,452,670	896,825	79.5	744,770	352,533	25.1	1,145,568
Illinois	2,423,110	1,205,611	54.8	8,452,162	4,226,081	151.5	1,313,272	655,854	6.8	3,275,611
Indiana	2,286,484	1,143,037	33.4	7,179,179	3,345,574	113.3	1,048,828	524,414	16.3	1,187,880
Iowa	1,687,741	794,040	79.5	5,399,070	2,548,758	180.9	1,552,201	397,300	48.3	17,571
Kansas	2,722,963	1,380,649	125.9	4,517,261	2,271,489	283.4	3,740,394	1,629,695	142.7	3,034,643
Kentucky	1,649,115	828,370	60.2	7,268,067	3,472,718	182.1	3,334,853	1,665,199	26.6	63,131
Louisiana	780,863	390,410	21.5	2,049,901	1,016,533	40.5	2,568,556	1,259,086	56.3	3,048,042
Maine	586,610	295,745	17.4	1,932,733	992,327	23.9	316,350	158,175	5.1	376,932
Maryland	1,457,200	728,000	17.6	3,616,162	1,697,678	21.0	1,145,000	242,500	5.9	947,667
Massachusetts	1,841,207	925,139	15.6	2,728,357	1,393,614	16.6	1,175,721	584,274	8.4	2,587,729
Michigan	4,398,630	2,195,188	80.8	5,792,910	2,886,105	124.7	1,913,900	956,950	17.8	808,467
Minnesota	2,773,801	1,384,189	255.6	10,079,397	4,998,450	451.3	1,044,995	519,562	52.2	974,871
Mississippi	1,528,000	763,140	96.9	6,824,912	3,348,466	372.1	581,700	289,100	30.3	692,649
Missouri	3,546,023	1,752,996	122.5	9,943,674	4,581,855	199.3	3,137,820	722,764	43.1	3,322,492
Montana	1,002,360	566,147	55.7	2,797,717	1,587,047	117.6	1,817,409	1,033,378	129.0	3,047,638
Nebraska	711,460	350,995	97.8	7,050,962	3,545,518	638.7	1,000,298	500,149	59.0	2,195,446
Nevada	1,335,580	1,162,008	60.2	1,265,679	1,099,219	60.3	507,171	440,730	9.7	231,406
New Hampshire	158,132	78,009	3.4	1,149,390	553,787	13.8	186,503	87,573	2.4	772,510
New Jersey	2,348,574	1,174,287	20.5	3,562,648	1,781,244	22.2	22,270	11,135		1,754,818
New Mexico	511,382	315,352	42.1	1,401,016	882,765	80.8	405,333	226,824	35.2	1,535,912
New York	3,710,494	1,854,347	60.2	11,983,537	5,958,370	136.1	609,994	304,372	4.8	2,720,099
North Carolina	2,175,874	1,071,825	98.9	3,859,747	1,932,675	146.5	980,156	489,455	36.9	1,724,739
North Dakota	2,246,784	1,255,846	190.4	3,318,920	1,742,836	266.9	2,235,340	1,121,040	191.4	2,979,078
Ohio	3,366,050	1,680,631	23.4	15,883,577	7,697,616	134.2	3,825,680	1,572,500	25.6	2,262,748
Oklahoma	1,150,305	555,965	51.4	3,287,241	1,734,944	96.6	1,969,370	1,030,566	58.3	4,160,286
Oregon	1,113,005	673,096	37.2	4,112,297	2,204,640	80.7	576,548	275,190	29.9	379,224
Pennsylvania	2,901,181	1,445,098	39.6	14,121,292	6,959,761	114.4	1,427,965	705,232	10.8	1,960,988
Rhode Island	350,257	174,830	3.8	1,051,537	524,097	8.1	473,292	236,639	2.9	754,701
South Carolina	501,870	245,625	49.2	4,006,137	1,750,219	109.7	1,346,253	276,826	32.8	1,867,595
South Dakota	1,344,810	793,670	167.0	4,627,343	2,903,393	499.5	1,437,700	930,680	182.9	1,525,716
Tennessee	1,035,730	517,865	42.5	5,384,024	2,692,012	97.8	1,294,974	647,487	40.7	2,780,207
Texas	4,260,531	2,102,444	211.0	12,799,558	6,294,074	524.0	4,504,810	1,911,145	146.4	4,644,144
Utah	452,206	338,102	34.5	2,345,984	1,744,008	50.6	103,549	70,232	6.0	299,006
Vermont	316,447	156,509	10.7	1,645,765	819,232	37.6	56,299	28,150	1.3	81,521
Virginia	1,069,577	536,738	25.2	4,710,862	2,197,510	80.8	1,588,672	791,286	26.2	1,067,066
Washington	362,625	194,000	6.0	2,904,391	1,551,704	42.4	874,414	439,785	8.8	757,404
West Virginia	898,785	447,683	27.7	3,895,025	1,934,929	47.2	81,970	40,985	1.0	1,418,770
Wisconsin	704,085	349,450	43.5	6,357,268	3,000,608	191.7	1,522,491	621,400	59.0	2,579,700
Wyoming	592,467	380,262	76.3	1,949,404	1,220,635	150.9	211,772	136,167	17.3	614,172
District of Columbia	463,514	231,540	2.5	463,770	231,300	.2	310,618	124,600	1.7	302,734
Hawaii	40,808	70,395	1.1	701,887	518,147	9.5	41,366	21,894	.3	1,692,779
Puerto Rico	22,901	60,485	2.3	1,473,468	727,750	15.7	947,130	467,300	4.8	401,970
TOTALS	76,262,691	39,511,138	2,929.7	233,441,687	118,231,319	6,871.3	68,449,758	31,923,144	2,053.3	83,449,958

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF SEPTEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 832,405	$ 414,568	35.8	$ 782,052	$ 402,090	47.1	$ 366,700	$ 177,280	10.7	$ 297,858
Arizona	67,371	48,972	4.5	161,385	119,428	4.4	32,795	23,839	5.2	354,133
Arkansas	330,055	164,276	27.4	235,449	117,623	17.4	327,209	159,376	15.1	73,497
California	416,996	258,240	10.5	1,137,882	807,048	11.7	129,976	74,930	3.6	399,588
Colorado	63,585	35,343	3.7	212,975	110,431	21.0				261,938
Connecticut	105,456	49,907	1.8	458,827	202,361	9.1				74,196
Delaware	31,959	15,264		274,043	135,122	12.3	102,873	37,618	3.9	158,438
Florida	112,906	56,453	4.4	1,037,852	524,376	7.4				239,387
Georgia	190,596	95,298	22.6	903,019	528,859	48.9	1,003,221	501,610	90.6	705,801
Idaho	163,914	97,878	12.0	188,523	116,006	17.7	40,937	7,402	1.2	200,463
Illinois	519,080	257,546	15.9	1,409,710	704,855	82.6	226,800	97,450	13.7	291,402
Indiana	46,400	23,200	1.8	1,693,305	813,496	84.7				598,434
Iowa	430,113	204,792	109.9	317,941	130,918	59.4	183,539	86,080	38.7	338,342
Kansas	311,119	158,045	35.2	1,868,366	938,845	132.6	569,422	271,611	52.7	670,515
Kentucky	413,140	97,595	15.0	1,377,687	355,843	82.0	625,342	174,174	28.0	134,713
Louisiana	372,100	134,040	5.7	192,608	96,249	14.9	289,362	138,761	21.5	446,100
Maine	14,200	7,100	.8	206,670	103,335	9.7	96,540	42,559	4.1	15,089
Maryland	54,000	27,000	2.0	666,000	332,825	19.8	82,000	41,000	.8	201,634
Massachusetts	163,235	85,298	4.1	643,150	334,642	10.1				368,581
Michigan	147,500	73,750	9.0	1,485,760	740,880	79.3	100,326	50,163	9.9	384,441
Minnesota	657,590	334,545	88.2	1,688,908	847,262	186.5	332,608	165,904	35.2	210,624
Mississippi	210,600	105,300	11.2	1,108,534	545,082	53.5	772,021	335,260	32.8	223,542
Missouri	266,660	133,330	32.1	653,548	312,933	58.2	438,162	165,537	76.6	639,129
Montana	174,810	99,203	26.4	291,234	165,561	34.6	157,905	89,784	21.2	573,487
Nebraska	89,712	44,257	13.2	648,437	329,496	59.7	59,375	29,687	19.5	374,879
Nevada	118,591	103,169	12.8	45,276	39,865	5.0	248,349	191,981	15.4	2,243
New Hampshire				338,140	167,149	8.2	52,105	3,572	.1	89,007
New Jersey	246,870	123,355	5.1	603,782	319,350	16.5	140,550	70,275	6.8	334,293
New Mexico	413,533	259,915	42.6	189,504	122,533	15.1	167,514	101,129	5.1	5,968
New York	670,674	350,944	16.5	827,760	410,971	17.4	322,386	161,193	4.9	477,623
North Carolina	68,690	34,345	7.0	622,389	341,298	47.9	260,248	108,715	21.3	254,837
North Dakota	49,569	26,558	2.4	3,434	3,434		808,050	793,860	42.7	483,046
Ohio	712,072	355,780	25.2	1,782,070	938,225	41.8	175,170	87,485	5.0	793,655
Oklahoma	246,780	130,349	9.7	127,338	67,173	11.9	856,486	452,224	64.6	735,049
Oregon	222,717	100,124	21.0	444,242	244,029	31.8	257,499	106,320	18.7	142,165
Pennsylvania	545,262	272,631	12.0	1,962,397	970,132	35.9	72,000	36,000	1.8	28,089
Rhode Island	88,194	44,040	.9	139,310	73,157	1.7	4,080	2,040		55,703
South Carolina	212,727	57,376	20.2	431,940	191,790	23.4	353,000	135,124	11.5	164,848
South Dakota	32,130	18,006	15.2	3,622	3,622		1,143,430	1,047,600	114.5	489,674
Tennessee	219,950	109,975	8.1	1,488,772	744,386	47.9	234,030	117,015	8.7	408,374
Texas	468,379	231,648	46.3	1,145,441	547,318	108.1	97,520	48,550	12.0	1,315,888
Utah	92,095	52,881	13.3	157,099	103,302	6.2	23,217	12,000	.3	196,507
Vermont	36,231	18,109	1.2				170,240	85,120	7.8	193
Virginia	339,398	155,485	11.1	374,996	171,246	9.1	77,850	30,750	4.5	349,609
Washington	130,422	70,865	16.2	460,359	219,662	10.5	92,166	20,000	4.8	196,252
West Virginia	86,300	43,150	2.4	618,024	308,399	23.8	16,500	8,250		315,450
Wisconsin	586,425	293,120	29.6	1,920,667	862,483	61.5	60,662	29,420	.8	132,143
Wyoming	364,163	157,111	18.8	297,985	111,188	25.3	201,892	109,741	9.0	
District of Columbia	52,747	26,374	.6	28,024	13,550	.3				77,117
Hawaii				2,375	2,375					249,280
Puerto Rico	45,960	22,305	2.5	185,404	90,550	8.1				134,597
TOTALS	12,235,381	6,078,815	833.9	33,844,215	16,882,753	1,722.0	11,772,057	6,428,389	845.3	15,667,821

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

Work of the Public Roads Administration, 1940.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP. . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

Specifications for Construction of Roads and Bridges in National Forests and National Parks. 1 dollar.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF SEPTEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 2,839	$ 2,839			1	$ 424,722	$ 422,700	6	5	2	$ 71,235	$ 71,235	2		6	$ 810,911
Arizona						186,306	186,306	1	1		121,422	101,218		1	2	119,175
Arkansas	46,864	46,864			1	571,561	569,522	6			25,827	25,827			8	319,519
California	376,505	190,789	1		1	1,315,838	1,309,865	9	1		20,630	20,630			7	1,477,100
Colorado	5,685	5,646				590,186	590,186	6			10,955	10,955			5	556,466
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		351,963
Delaware						94,135	94,135	1			697,074	508,721	3	1	1	73,349
Florida	20,370	20,370			4	519,457	518,468	5		11	366,306	362,050	3		24	705,892
Georgia	368,009	368,009	5	1	1	963,435	963,435	6	6	1	971,048	971,048	3	5	27	1,133,402
Idaho	11,301	11,301				302,225	293,553	3	1		34,621	34,621	1		4	261,243
Illinois	70,841	58,755			26	2,209,791	2,002,366	9	1	51	447,513	423,669	2	1	32	1,560,359
Indiana	4,359	4,359			3	944,155	931,668	7	1	15	228,411	222,702	1		41	649,115
Iowa	77,032	73,590	1		2	1,388,262	1,134,614	11	3	9	499,481	488,245	1		71	129,155
Kansas	14,071	14,011			2	590,610	590,610	9			348,854	304,969	5		14	870,883
Kentucky	163,064	161,519	2		1	1,075,361	1,069,247	8	1		306,574	306,574	3			59,942
Louisiana						588,415	588,415	8			471,538	470,371	4		1	610,731
Maine						388,443	388,443	2			1,861	1,861			1	117,994
Maryland	464,400	432,607	2	2	2	344,709	344,709	2		6	593,303	449,505	2		14	204,759
Massachusetts						1,022,124	1,010,284	5	1		855,642	855,597	3	2		884,817
Michigan	359,700	359,700		1	4	1,000,155	1,000,155	3	3	1	525,632	495,471	2		28	599,154
Minnesota	238,051	238,051	1	3	1	1,127,961	1,127,961	8	3		252,095	252,095	1	3		693,398
Mississippi	177,900	177,900	1		1	587,874	587,874	8	1		235,900	235,900	2		11	432,668
Missouri						2,034,922	1,579,502	6	4		205,495	173,526		2		1,194,939
Montana						230,745	230,745	3			6,645	6,645			2	470,918
Nebraska	132,604	132,604		1	9	1,118,942	1,118,942	22		4	100,552	100,552	1		12	107,255
Nevada	119,580	119,580	2			56,484	56,484	2			21,703	21,703			7	103,558
New Hampshire	63,682	62,862	2			303,989	303,689	4	2		3,817	3,817			2	201,694
New Jersey	214,360	214,360	2			1,254,863	1,129,313	5	2	1	354,985	295,560	1	2		552,697
New Mexico						2,560	2,560				318,427	311,393	4		1	344,481
New York	984,228	958,002		7		2,975,236	2,926,252	5	11		701,610	662,685		2		2,563,872
North Carolina	324,980	324,980	2	1	13	313,183	313,183		6	3	169,871	166,993	1		24	889,961
North Dakota	83,460	83,460	2			697,230	684,293	8			223,120	223,120	2			331,653
Ohio	324,301	323,904	1	1	1	3,455,493	3,374,450	15		3	543,807	284,750	2		8	1,046,952
Oklahoma	121,346	117,930	1		14	766,212	762,802	5		3	502,456	444,414	4		21	1,113,391
Oregon	302,166	278,255	3		2	125,127	84,757	2			4,733	4,733			3	390,976
Pennsylvania	710,467	710,139	7			3,247,657	3,208,226	17			1,306,206	1,301,193	7			1,324,754
Rhode Island						208,896	208,896		1							176,063
South Carolina	124,756	124,756	2		6	372,732	360,332	5	3	6	314,748	178,074	1	2	19	688,745
South Dakota	341,870	341,870	10			656,402	640,452	12		5	58,043	58,043	2		4	587,095
Tennessee	92,670	83,670	1	2		1,309,479	1,309,479	8	1		93,460	93,460		1		852,311
Texas	648,990	639,990	7			1,734,475	1,726,891	17			210,900	202,450	4		5	1,351,629
Utah	41,268	40,526	2		12	72,149	72,149	1		11	67,714	67,714			24	232,778
Vermont	2,205	2,193				337,885	308,106	2		4						5,485
Virginia	32,555	32,555		1		777,750	777,290	5	4		106,935	87,435	2		5	566,936
Washington	55,443	55,443		1	1	333,418	333,418	3	1		12,151	12,151			4	451,910
West Virginia	6,320	6,320			2	811,462	805,842	9	1	4	97,130	97,130			3	505,251
Wisconsin	46,124	46,124			11	899,718	869,734	5	2	11	112,489	112,489			26	1,156,114
Wyoming	477,151	477,149	5			4,929	4,929				8,199	8,199			6	286,073
District of Columbia	2,193	2,193				1,462	1,462				298,213	273,744		1		5,493
Hawaii	192,574	192,566	2			214,170	213,655	2								179,950
Puerto Rico	103,629	102,980	1			639,340	632,516	9								337,988
TOTALS	8,116,135	7,806,136	67	21	121	41,254,347	39,825,541	295	67	151	13,157,705	12,027,977	69	24	473	30,642,917

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D. M. BEACH, *Editor*

Volume 22, No. 9 November 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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THE APPLICATION OF RANDOM SAMPLING TO FISCAL STUDIES

A DISCUSSION OF THE PROBLEMS INVOLVED IN DETERMINING HIGHWAY EXPENDITURES BY THE SEVERAL UNITS OF GOVERNMENT

BY THE DIVISION OF CONTROL, PUBLIC ROADS ADMINISTRATION

Reported by THOMAS M. C. MARTIN, Assistant Highway Engineer-Economist

Data on highway income and expenditures by all units of government are needed in planning future highway development. The multiplicity of local units —municipalities, townships, counties, school districts, etc.—makes collecting complete information from each a sizeable and expensive undertaking.

An investigation was made of the feasibility of applying sampling methods to the collection of local financial statistics. The procedures followed, formulas used, and results obtained, are reported herein. A graphical means is given of appraising various sample sizes in terms of their probable reliability.

ADEQUATE INFORMATION about highway finance in all units of government is a prerequisite to the orderly development of a comprehensive, forward-looking highway program. The amounts of money raised locally by the lesser governmental units, the amounts received by them as grants-in-aid from higher units of government, as well as the use made of these funds, are all essential planning data. These facts must be known if highway needs and revenues are to be intelligently proportioned to the other needs and corresponding revenue sources of the State.

The difficulty of obtaining adequate data on highway finances appears to vary inversely with the size of the governmental unit. Ordinarily little trouble is encountered in ascertaining information relative to State revenues and expenditures, and with some exceptions the fiscal operations of the counties in the United States are readily obtainable. These, however, are by no means all of the units of government that engage in highway activities. There are a large number of local units, both rural and urban, data for which are essential to a complete picture of highway operations. Moreover, in many States the gross amounts involved in financing these local roads and streets are as large as the amounts handled by the State highway departments. Frequently, accurate information regarding the receipts and expenditures of these smaller units of government is not readily available, and special studies are necessary to obtain proper information.

LOCAL ROAD FINANCE DATA VALUABLE

Knowledge of local road finances has been of particular value during the past decade in connection with a noticeable trend toward the assumption of greater responsibility for county and local roads by certain States. The taking over of the North Carolina county road system by the State on July 1, 1931, was preceded by a thorough study of the financial status of the county roads.[1]

Similarly, when the 5-year program of county and township road consolidation was initiated in Michigan in 1931, a comprehensive study was made of all Michigan roads.[2]

Accurate information upon which to base an estimate of the probable costs of such programs of consolidation is seldom available when legislative deliberations are in progress. Consequently, when the question suddenly arises, it can be determined only approximately whether or not the resources of the State, usually limited to highway-user revenues, will be adequate for the increased burden. The question of whether a State is financially able to assume the proposed additional responsibilities without seeking new sources of money is a very important matter. It usually happens that the governmental units previously responsible financed their work with a combination of State subventions and receipts from local property taxation.

It is likewise essential to know the mileage of roads owned by local units and the standards to which they were built and are maintained. These facts are necessary to gage properly the annual financial requirements arising from the added responsibilities. The need for such information becomes evident in still other ways, particularly when proposals are made to allocate large sums of highway-user or other State revenues to local units of government for highway or nonhighway purposes either as single lump-sum payments or as continuing annual subventions. The wisdom of enacting such proposals into law can receive a more thorough consideration and fuller debate when complete and accurate data concerning the needs and resources of all units are readily available. Dissipation of State funds into channels where the public does not receive a proportionate return on the funds it has contributed can best be prevented by making all of the facts available.

The several States and the Public Roads Administration have been engaged in studies of this problem for more than 20 years. Detailed reports of State highway mileage, receipts, and expenditures, have been prepared annually since 1921. The gathering of corresponding information for the local units of government was commenced as early as 1912, made more complete in 1917, and has been done annually since 1921. The relative incompleteness of the local statistics has long been recognized, and constant attempts have been made to improve the reporting system.

The difficulty in obtaining accurate data from units of government other than the State arises in a considerable measure from the large number of governmental units involved and the incomplete records kept by many of these spending agencies even for their own purposes.

[1] North Carolina County Road and Finance Survey, PUBLIC ROADS, vol. 11, No. 12, February 1931. (Report of a cooperative investigation by the North Carolina State Highway Commission, the North Carolina State Tax Commission, and the United States Bureau of Public Roads.)

[2] A Survey of Highway Transportation in Michigan, PUBLIC ROADS, vol. 13, No. 12, February 1933.
The Michigan Financial Survey, PUBLIC ROADS, vol. 14, No. 4, June 1933.

Table 1 shows the number of units in each of the States in 1939, as prepared by the Illinois Tax Commission. In the collection of State highway data the Public Roads Administration needs to concern itself only with the 48 States and the District of Columbia, but local rural road data must be obtained from approximately 20,000 units. Most of the counties and, in the States in which they exist, the towns and townships, carry on highway activities. In addition to these units, the sixth column of table 1 lists many road districts which at least until very recently carried on road functions similar to those of the townships.

Table 1.—*Taxing units in the United States, 1939*

State	Counties	Incorporated places	Towns and townships	School districts	All others	Total [1]
Alabama	67	296		112		476
Arizona	14	33		416	22	486
Arkansas	75	389		3,062	834	4,361
California	57	282		2,957	265	3,562
Colorado	62	237		2,051		2,351
Connecticut	8	40	173	26	114	362
Delaware	3	52		15		71
Florida	67	289		893		1,250
Georgia	159	593				753
Idaho	44	150		826		1,021
Illinois	102	1,134	[2] 1,625	12,115	123	15,100
Indiana	92	544	1,017	163	5	1,822
Iowa	99	917	1,602	4,873		7,492
Kansas	105	580	1,550	8,772	65	11,073
Kentucky	120	369		263	14	767
Louisiana	64	210		66	161	502
Maine	16	20	494	512		1,043
Maryland	23	137		24	20	205
Massachusetts	13	39	312		63	428
Michigan	83	477	1,267	6,550		8,378
Minnesota	87	726	1,902	7,692	1	10,409
Mississippi	82	305		5,796	756	6,940
Missouri	114	773	345	8,957		10,190
Montana	56	116		2,437		2,610
Nebraska	93	529	477	7,098		8,198
Nevada	17	16		293	19	346
New Hampshire	10	11	224	241		487
New Jersey	21	331	238	551	17	1,159
New Mexico	31	63		1,100		1,195
New York	57	615	927	7,913	96	9,609
North Carolina	100	386		169	139	795
North Dakota	53	333	1,470	2,271	37	4,165
Ohio	88	869	1,337	1,756		4,051
Oklahoma	77	463		4,697		5,238
Oregon	36	192		2,114	93	2,436
Pennsylvania	67	986	1,577	2,582	66	5,279
Rhode Island		7	32		54	94
South Carolina	46	265		39	10	361
South Dakota	64	311	1,136	3,437		4,919
Tennessee	95	233		95		424
Texas	254	580		6,000	271	7,106
Utah	29	197		40		267
Vermont	14	110	246	272		643
Virginia	100	215		100	2	418
Washington	39	221	73	1,491	371	2,196
West Virginia	55	202		55		313
Wisconsin	71	525	1,280	7,390	6	9,273
Wyoming	23	82		385		491
Total	3,052	16,450	19,304	118,667	3,624	161,145

[1] Includes one for State.
[2] Includes road districts in commission counties.

The total number of taxing counties in the United States, excluding those in States where the counties exercise no highway functions, is 2,666,[3] or an average of 72 counties per State in each of the 37 States involved. Although this figure is influenced slightly by the large number of counties in Georgia and Texas, the median number of counties is 67 or only slightly lower than the arithmetic mean. While the States must therefore deal with an average of approximately 50 percent more counties than the number of States with which the Public Roads Administration is concerned, the problem of the States is still more complicated. The 48 States have 16,450 incorporated places or a mean of 343, with the median State possessing a total of 286 such incorporated places. In addition 20 States have a mean of 851 towns and townships engaged in road work,[4] with a median of 710.

SAMPLING OBVIATES LARGE EXPENDITURES IN OBTAINING LOCAL DATA

Some information on the highway activities of the rural units (counties, towns, townships, and road districts) is available for the years since 1921, with the exception of 1922. More exhaustive surveys were conducted in 1921, 1926, and 1931 and the data for these years are believed to be more reliable than those for the intervening years when lack of funds and personnel made thorough studies impracticable.

The most exhaustive studies ever undertaken in this field were those conducted by the State-wide highway planning surveys which commenced in 1935. In these studies financial data were collected covering the receipts and expenditures for 1 fiscal year of all taxing agencies for all public purposes. This was done in order that a proper relationship could be established between highway and other governmental activities.

With the completion of these 1-year studies the problem again arises of collecting regularly adequate annual financial data relative to highways. The task has even increased recently, since it is becoming evident that the most urgent traffic problem requiring current solution is the provision of arterial approaches to urban centers both large and small. Authorities are generally agreed that the weakest links in the existing highway system are usually these roads in and near cities. It is on these roads that most traffic congestion occurs; consequently, it is there that the chief threat to the efficiency of highway transportation arises. It is also a fact that since these highways as a class are the most expensive of all to build, the financing of them is one of the most difficult and important tasks of the immediate future. Consequently, data from more than 16,000 incorporated places should also be collected annually if a complete representation of the street and highway problem is to be obtained.

The planning surveys have greatly stimulated the adoption of uniform reporting methods for all levels of government in many States and thus contributed to the solution of part of the problem, i. e., an improvement in the quality and availability of information. There is still the problem of the large number of units and the correspondingly large costs involved in analyzing their reports. And not to be overlooked is the fact that if uniform centralized reporting does not exist, field investigation will normally be required to obtain anything approaching the desired information. An investigation was made, therefore, of the feasibility of applying sampling methods to the collection of local financial statistics with the fiscal survey data of the Wisconsin State-wide Highway Planning Survey as the basis for the inquiry.[5] It is with the conduct and results of this investigation that the present article is chiefly concerned.

[3] The five counties of Rhode Island do not exist as taxing jurisdictions, while the counties in Connecticut, Delaware, Maine, Massachusetts, New Hampshire, North Carolina, Vermont, and West Virginia perform no highway functions. Only three of Virginia's counties engage in highway activities and in Pennsylvania the county road programs are of extremely minor character, with the possible exception of Allegheny County. None of these States has been included, therefore, in this figure.

[4] The townships of Indiana and Michigan for all practical purposes may be considered to have no road functions.

[5] The studies at Madison, Wisconsin, reported here were under the sponsorship of Dr. H. R. Trumbower, Senior Agricultural Transporation Economist, and were made in connection with the cooperative agreement between the University of Wisconsin and the Public Roads Administration.

The data employed in this investigation were gathered by the Wisconsin planning survey during its original operations and were for the calendar year 1935. The fiscal statistics for each Wisconsin town[6] had been recorded on forms which provided for a fairly extensive itemization of revenues and disbursements for all purposes. The separate classifications employed on these forms are not all of equal importance. Included to facilitate tabulation, many of them are not of particular significance in final analyses. The sampling of financial statistics should be restricted to include only items that are relatively stable in their occurrence in the reports of the individual units. Certain categories of both receipts and expenditures are entirely too variable to permit accurate estimation by sampling techniques. This would be true, for example, in the case of the borrowings of Wisconsin towns. In ordinary times these jurisdictions resort to such methods of financing very infrequently, and totals obtained by sample expansion would not be very reliable. Sampling accuracy depends upon a substantial degree of similarity in the individual members of the population or universe being sampled.

IN SAMPLING CERTAIN ELEMENTS REQUIRE SPECIAL TREATMENT

If the individual members of a population are radically different one from another, an accurate description of the characteristics of the group will be possible only through the inclusion of the entire population in the analyses. All that sampling procedures afford, where they are applicable, is a more expeditious and economical means of describing the properties of a large class of things or events by means of the observation of less than the whole number of individuals constituting the group. What is requisite is that there be some well-defined central tendency in the properties of the individual members of a given group. An arithmetic average may be computed for any set of numbers, but for purposes of sample expansion it is important that the individual numbers be fairly closely centered about their average value.

[6] A "town" in Wisconsin is an unincorporated rural unit of government and should not be confused with so-called towns which are in reality incorporated villages or cities.

In the present inquiry it was possible to include but a few of the more important classifications of receipts and disbursements which were provided for on the basic planning survey forms. On the revenue side these included (1) total local revenues, (2) total nonlocal revenues, and (3) total current receipts. On the disbursement side only total net expenditures were considered. All of the foregoing were further subdivided to show amounts collected and expended for highway purposes and for all public functions.

Table 2 presents data on the population distribution and expenditures of Wisconsin governmental units for 1935 from which the relative importance of the fiscal operations of the town units may be judged.

In applying random sampling to local units of government it is necessary to consider the possibility that certain extreme elements of the universe may require special treatment. In Wisconsin the seven towns of Milwaukee County provide such an example. The receipts and expenditures of towns necessarily bear some relation to the population which they include. The average population of the seven Milwaukee County towns is approximately 6,600. This is more than eight times the average population of the remaining 1,273 towns in the State, which is about 800. If there were a sufficient number of these large towns it would be possible to employ stratified sampling. These especially large towns would in effect be treated as a separate universe and independently sampled. A random sample, however, should ordinarily contain no fewer than 30 items. In this instance, consequently, as in most others which would be encountered in sampling data for local units of government, it was considered advisable to obtain data for all of the Milwaukee County towns. The sampling inquiry was extended therefore only to the remaining 1,273 towns.

There are a variety of ways in which a random selection could be effected. The method selected in this instance used the so-called "Tippett's Numbers."[7] This procedure involved the superposition of a new and independent characteristic, that of an ordinal number, upon the individual members of the universe.

[7] L. H. C. Tippett, Random Sampling Numbers, No. XV, Tracts for Computers, Edited by Karl Pearson, Cambridge University Press, London, 1927.

TABLE 2.—*Population distribution and net expenditure data for Wisconsin governmental units, 1935, classified by purpose* [1]

Unit of government	Number of places	Total population	Percentage of total population	Highways		Other public functions				Grand total	
						Education		Total			
				Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
Towns	1,280	1,086,944	37.1	$5,485,159	14.7	$13,071,972	23.8	$16,481,150	10.2	$21,966,309	11.1
Incorporated places having a population of 1-1,000	334	159,279	5.4	391,330	1.0	2,395,970	4.4	4,051,512	2.5	4,442,842	2.2
Rural areas	1,614	1,246,223	42.5	5,876,489	15.7	15,467,942	28.2	20,532,662	12.7	26,409,151	13.3
Incorporated places having a population of—											
1,001-2,500	88	137,613	4.7	429,117	1.2	2,269,350	4.1	4,702,805	2.9	5,131,922	2.6
2,501-5,000	36	128,990	4.4	453,731	1.2	2,139,826	3.9	4,155,669	2.6	4,609,400	2.3
5,001-10,000	20	141,905	4.8	412,970	1.1	2,388,745	4.4	4,816,365	3.0	5,229,335	2.6
10,001-25,000	14	223,821	7.6	392,249	1.1	3,997,845	7.3	8,745,482	5.4	9,137,731	4.6
25,001-50,000	9	305,175	10.4	678,083	1.8	5,129,930	9.4	12,332,469	7.6	13,010,552	6.6
50,001-100,000	3	175,703	6.0	246,954	.7	3,578,688	6.5	7,898,974	4.9	8,145,928	4.1
Milwaukee	1	577,083	19.6	1,462,027	3.9	10,826,334	19.8	26,624,041	16.5	28,086,068	14.1
Urban places	171	1,690,290	57.5	4,075,131	11.0	30,330,718	55.4	69,275,805	42.9	73,350,936	36.9
Counties				11,255,374	30.3	1,100,576	2.0	53,995,482	33.4	65,250,856	32.8
State				15,974,942	43.0	7,885,648	14.4	17,700,349	11.0	33,675,291	17.0
Grand total	1,785	2,936,513	100.0	37,181,936	100.0	54,784,884	100.0	161,504,298	100.0	198,686,234	100.0

[1] From Wisconsin State-wide Highway Planning Survey, basic analysis form, line 37.

Table 3.—*Expenditures in Wisconsin towns selected for preliminary sample*

Assigned serial No.	County	Town	Total net expenditures[1] Actual	Total net expenditures[1] Nearest $1,000
22	Ashland	Gordon	$11, 726	12
30	do	White River	16, 673	17
75	Bayfield	Pilsen	6, 257	6
106	Buffalo	Dover	13, 865	14
113	do	Mondovi	9, 759	10
124	Burnett	La Follette	7, 770	8
139	Calumet	Brillion	20, 382	20
151	Chippewa	Birch Creek	6. 555	7
182	Clark	Hixon	19, 659	20
199	do	Washburn	9, 978	10
205	Columbia	Caledonia	23, 655	24
217	do	Newport	6, 030	6
242	Dane	Burke	49, 523	50
304	Door	Nasewaupee	17, 966	18
322	Douglas	Summit	16, 270	16
334	Dunn	Otter Creek	8, 990	9
351	Eau Claire	Fairchild	12, 110	12
371	Forest	Blackwell	6, 833	7
381	do	Wabeno	36, 327	36
393	Fond du Lac	Lamartine	20, 399	20
396	do	Oakfield	16, 073	16
432	Grant	Watterstown	3, 451	3
486	Jackson	Albion	36, 375	36
506	Jefferson	Aztalan	14, 795	15
511	do	Ixonia	15, 717	16
524	Juneau	Cutler	12 850	13
532	do	Lisbon	10, 308	10
558	Kewaunee	West Kewaunee	20. 407	20
565	La Crosse	Hamilton	26, 022	26
608	Lincoln	Harding	6, 404	6
623	Manitowoc	Cooperstown	28, 173	28
638	do	Two Rivers	24, 202	24
693	Marinette	Porterfield	15. 893	16
708	do	Oxford	8, 903	9
712	do	Westfield	9, 094	9
724	Monroe	Glendale	12, 384	12
726	do	Greenfield	5, 355	5
730	do	Leon	12, 314	12
770	Oneida	Hazelhurst	5, 371	5
776	do	Pelican	22, 514	23
851	Polk	Johnstown	13, 089	13
852	do	Laketown	10, 541	11
863	Portage	Almond	15, 784	16
879	Price	Catawba	6, 300	6
893	do	Prentice	9, 655	10
899	Racine	Mount Pleasant	114, 049	114
918	Richland	Sylvan	20, 464	20
987	Sauk	Bear Creek	19. 289	19
995	do	Honey Creek	19, 936	20
1017	Sawyer	Meteor	5, 660	6
1018	do	Ojibwa	12, 307	12
1023	do	Weirgor	10, 128	10
1037	Shawano	Hutchins	11, 470	11
1071	Taylor	Ford	6, 675	7
1072	do	Goodrich	9, 161	9
1081	do	Medford	26, 479	26
1097	Trempealeau	Pigeon	23, 731	24
1164	Washburn	Gull Lake	4, 823	5
1169	do	Spooner	5. 564	6
1172	do	Stone Lake	5, 778	6
1179	do	Hartford	19, 242	19
1198	Waukesha	Ottawa	10, 924	11
1212	Waupaca	Larrabee	18, 656	19
1254	Winnebago	Utica	19, 692	20

[1] Data taken from basic analysis form.

A general discussion of random sampling methods is given in the appendix, page 207.

The numbering of the towns was the first task in commencing the actual selection of a sample. The 1,280 Wisconsin towns [8] were arranged alphabetically by and within counties, and then numbered consecutively. There was no important reason for an alphabetical arrangement of the towns. It rendered the location of data for the selected towns somewhat easier, but it was not prerequisite and the numbering could have followed any other scheme without affecting the remainder of the procedure.

Before the actual selection could be commenced it was necessary to make some decision relative to the size of the sample to be taken. The size of the ultimate sample, as will be emphasized later, must be predicated upon the probable accuracy which it is desired to attribute to the resultant expansions. This decision cannot very well be made without some knowledge of the characteristics of the universe being sampled. Specifically it is necessary to have some idea of the dispersion of the individual members about their mean. In these circumstances it is convenient to draw a small sample and compute certain statistics which facilitate the determination of final sample size. The initial sample in this instance consisted of 64 towns or approximately 5 percent of the total number of such units in Wisconsin. This preliminary sample was fixed at 5 percent instead of some other proportion because previous investigation had disclosed some facts relative to the range of town data. If the universe had been differently constituted, either quantitatively or qualitatively, or both, the choice of the initial sample would have been altered accordingly. In other words, familiarity with the general nature of the data being analyzed is a practical advantage for which there is no entirely satisfactory substitute.

[8] The seven Milwaukee County towns were numbered in regular order although they could have as easily been skipped inasmuch as they were not subjected to sampling for reasons outlined above.

IMPORTANT FORMULAS EXPLAINED

It was necessary to consider total net expenditures only in the preliminary computations since the stability of the other data was believed to be of approximately the same order. A given sample will not, of course, yield exactly the same reliability in all the different categories of receipts and expenditures. The individual reliability of these statistics varies with their respective dispersions. The size of the final sample, therefore, will depend upon the degree of reliability that is believed necessary in estimating the most widely dispersed of the items to be tabulated. It follows that the less widely dispersed items will be estimated with correspondingly greater reliability.

Table 3 includes the planning survey expenditure data for the initial sample just described. In this

Table 4.—*Computations required in the calculation of standard deviation and arithmetic mean from table 3*

Total net expenditures x	Frequency f	$(1)-M_a$ d	$(2)\times(3)$ fd	$(3)\times(4)$ fd^2
(1)	(2)	(3)	(4)	(5)
$1,000				
3	1	−12	−12	144
5	3	−10	−30	300
6	7	−9	−63	567
7	3	−8	−24	192
8	1	−7	−7	49
9	4	−6	−24	144
10	5	−5	−25	125
11	3	−4	−12	48
12	5	−3	−15	45
13	2	−2	−4	8
14	1	−1	−1	1
15	1	0		
16	5	1	+5	5
17	1	2	+2	4
18	1	3	+3	9
19	3	4	+12	48
20	7	5	+35	175
23	1	8	+8	64
24	3	9	+27	243
26	2	11	+22	242
28	1	13	+13	169
36	2	21	+42	882
50	1	35	+35	1, 225
114	1	99	+99	9, 801
	64		$\left\{ \begin{matrix} -217 \\ +303 \end{matrix} \right. = +86$	14. 490

table the total net expenditures are shown in the last column to the nearest thousand dollars. This forms a preliminary step in the transition to table 4 and in addition provides a convenient tabulation of the computed values necessary for substitution in the formulas for the standard deviation and arithmetic mean computed by the so-called "short-cut" method. The necessary notation follows:

X=variable.
M_x=mean value of X.
M_a=assumed mean class interval.
$f(x)$=frequency of occurrence of X.
$d=(x-M_a)$ deviation of each value of X from class interval of assumed mean.
$N=\Sigma f$=total frequency.
σ=standard deviation.
σ_M=standard error of the mean.

The important formulas are:

$$M_x=M_a+\frac{\Sigma fd}{N} \quad (1)$$

$$\sigma=\sqrt{\frac{\Sigma fd^2}{N}-\left(\frac{\Sigma fd}{N}\right)^2} \quad (2)$$

$$\sigma_M=\frac{\sigma}{\sqrt{N}} \quad (3)$$

In equation 2 the assumed mean should, for purposes of efficient calculation, be located as near the actual mean as possible while the correction term $\frac{\Sigma fd}{N}$ must be an algebraic summation with due care observed as to the sign of the individual terms, since the correction may be either positive or negative depending upon the location of the assumed mean.

Substituting the values from table 4 in these equations yields the following results:

$$M_x=M_a+\frac{\Sigma fd}{N} \quad (1)$$

$$=15+\frac{86}{64}=16.344.$$

$$\sigma=\sqrt{\frac{\Sigma fd^2}{N}-\left(\frac{\Sigma fd}{N}\right)^2} \quad (2)$$

$$=\sqrt{\frac{14490}{64}-\left(\frac{86}{64}\right)^2}=14.987.$$

$$\sigma_M=\frac{\sigma}{\sqrt{N}} \quad (3)$$

$$=14.987/8=1.873.$$

If the coefficient of variation be used as a measure of reliability and defined as follows, it will provide a convenient index for comparing various size samples.

Let V=coefficient of variation (percent).

$$V=\left(\frac{3\sigma_M}{M_x}\right)100 \quad (4)$$

In this case

$$V=\left(\frac{3\times 1.873}{16.344}\right)100=34.4 \text{ percent.}$$

The interpretation to be placed upon such a result is that in repeated trials, randomly drawn samples of the same size (5 percent) will seldom [9] yield means varying by more than 34.4 percent from 16.344. It is practically certain [10] that the true mean of the parent population lies between 16.344 ± 5.619 or between 10.725 and 21.963.

The practical problem which arises at this point is the determination of coefficients of variation for samples of different size. This first 5-percent sample produced a reliability as measured by this statistic of 34.4 percent. It is possible to effect a slight transformation in the basic equation for the coefficient of variation and derive an equation which will facilitate the calculation of acceptable estimates of the reliability which can be expected from larger samples randomly drawn from the same universe.

The original equation was:

$$V=\left(\frac{3\sigma_M}{M_x}\right)100 \quad (4)$$

Substituting for σ_M the value given in equation 3,

$$V=\left(\frac{3\sigma/\sqrt{N}}{M_x}\right)100$$

which can be written

$$V=\left(\frac{3\sigma}{M_x}\div\sqrt{N}\right)100$$

$$=\frac{300\sigma}{M_x}\div\sqrt{N} \quad (5)$$

This equation affords an expeditious means of calculation since the numerator can through reasonable assumptions be made a constant for a given problem, and the denominator is a direct function of the number contained in the sample. The assumptions necessary are (1) that the σ computed for the initial sample is a satisfactory estimate of the dispersion of the parent population from which the sample was drawn, and (2) that the value of the mean obtained from this sample

TABLE 5.—*Coefficient of variation of 5 to 75 percent samples of total net expenditures of Wisconsin towns, 1935, as calculated from initial sample of 64 towns*

Number in sample, N	Coefficient of variation [1] $300\frac{\sigma}{M_x}\div\sqrt{N}$
64	34.4
81	30.6
100	27.5
121	25.0
144	22.9
169	21.2
196	19.6
225	18.3
256	17.2
289	16.2
324	15.3
361	14.5
400	13.8
625	11.0
900	9.2

[1] $V=\frac{300\sigma}{M_x}\div\sqrt{N}=\frac{300\times 14.987}{16.344}\div\sqrt{N}=275.0917767\div\sqrt{N}$

[9] Presuming an infinite number of trials the variation would in the limit be greater only three times in a thousand.

[10] Observe a literal construction of "practically certain" as opposed, for example, to absolutely certain. Practically certain as here used does not imply the impossibility of an adverse result; it merely is indicative of the relatively infrequent occurrence of such events.

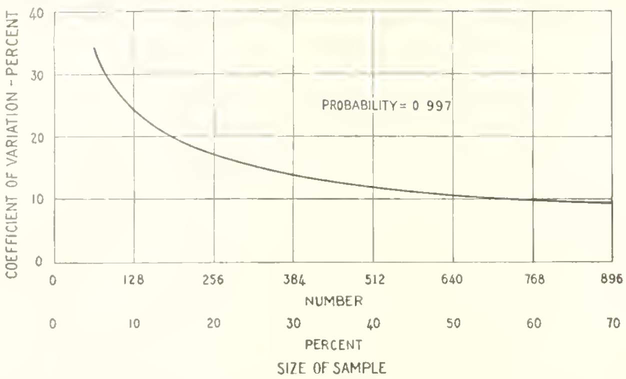

FIGURE 1.—RELATION BETWEEN COEFFICIENT OF VARIATION AND SIZE OF SAMPLE.

will suffice temporarily as an estimate of the population mean. Both of these assumptions are justified.

RELATIONSHIP BETWEEN RELIABILITY AND SAMPLE SIZE EXAMINED

The necessary calculations were arranged in this case as shown in table 5. The range of sample sizes was limited to 5 percent increments from 5 percent to 75 percent, since the only purpose of these computations was to provide sufficient points upon which to base a freehand curve of the probable relationship between reliability and sample size for this particular inquiry. This curve is reproduced as figure 1.

The responsibility for determining the size of an acceptable sample is not a proper function of the statistician. It is an administrative problem the proper solution of which will depend upon the use to be made of the resultant expansions. The construction of a curve such as that shown in figure 1 is helpful in making a decision as to proper size of sample. It provides a graphical means of appraising various sample sizes in terms of their probable reliability. For purposes of illustration it was assumed in this case that acceptable accuracy called for a coefficient of variation of less than 20 percent.[11] It appeared, therefore, that a sample of 200 towns or approximately 15 percent would be required.

The additional towns selected to raise the total sample to 200 are listed with their expenditure data in table 6. These towns were selected in the same manner as the first 64 towns, but, it should be noted, without duplication. The final sample, therefore, was precisely the same as though it had been randomly selected at one time instead of in two portions. The geographical distribution of the initial and final samples is shown in figure 2.

Table 7 combines the rounded-off expenditure figures from tables 3 and 6 while table 8 fulfills the same function as table 4 in providing data necessary to the calculations which follow:

Again substituting in the basic equations,

$$M_x = M_a + \frac{\Sigma fd}{N} \qquad (1)$$

$$= 15 + \frac{255}{200} = 16.275.$$

[11] This is a purely abstract assumption and could as well have been any other percentage.

$$\sigma = \sqrt{\frac{\Sigma fd^2}{N} - \left(\frac{\Sigma fd}{N}\right)^2} \qquad (2)$$

$$\sqrt{\frac{28059}{200} - \left(\frac{255}{200}\right)^2} = 11.772.$$

$$\sigma_M = \frac{\sigma}{\sqrt{N}} \qquad (3)$$

$$= 11.772 \div \sqrt{200} = 0.832$$

$$V = \left(\frac{3\sigma_M}{M_x}\right)100 \qquad (4)$$

$$= \frac{300 \times 0.832}{16.275} = 15.34 \text{ percent.}$$

TABLE 6.—*Expenditures of additional Wisconsin towns selected to complete final sample*

Assigned serial No.	County	Town	Total net expenditures [1]	
			Actual	Nearest $1,000
17	Adams	Strongs Prairie	$3,596	4
29	Ashland	Shanagolden	5,214	5
32	Barron	Arland	11,939	12
38	do	Crystal Lake	22,181	22
39	do	Cumberland	22,472	22
61	Bayfield	Cable	9,391	9
66	do	Hughes	11,694	12
67	do	Iron River	28,633	29
73	do	Orienta	7,350	7
91	Brown	Humboldt	16,311	16
99	do	Suamico	30,178	30
104	Buffalo	Canton	13,246	13
112	do	Modena	17,622	18
116	do	Nelson	28,927	29
121	Burnett	Dewey	9,910	10
126	do	Meenon	9,316	9
130	do	Sand Lake	7,461	7
144	Calumet	New Holstein	19,919	20
187	Clark	Lynn	10,818	11
188	do	Mayville	18,991	19
190	do	Mentor	14,984	15
221	Columbia	Scott	13,235	13
224	do	Wyocena	17,945	18
229	Crawford	Haney	16,330	16
230	do	Marietta	20,512	21
231	do	Prairie du Chien	6,505	7
237	Dane	Berry	13,878	14
239	do	Blooming Grove	67,560	68
257	do	Perry	13,374	13
261	do	Rutland	23,950	24
297	Door	Claybanks	8,095	8
310	Douglas	Bennett	9,267	9
323	do	Superior	29,646	30
327	Dunn	Eau Galle	16,028	16
329	do	Grant	12,133	12
330	do	Hay River	10,969	11
341	do	Tiffany	11,200	11
357	Eau Claire	Union	19,555	20
358	do	Washington	23,687	24
376	Forest	Laona	47,180	47
379	do	Popple River	8,715	9
389	Fond du Lac	Empire	18,559	19
391	do	Forest	15,500	16
401	do	Taycheedah	14,429	14
406	Grant	Cassville	15,559	16
411	do	Glen Haven	10,413	10
418	do	Little Grant	8,515	9
425	do	Paris	13,508	14
436	Green	Adams	16,538	17
449	do	Sylvester	17,090	17
458	Green Lake	Marquette	11,855	12
464	Iowa	Clyde	13,634	14
465	do	Dodgeville	36,443	36
466	do	Eden	8,583	9
468	do	Linden	17,380	17
473	do	Ridgeway	19,318	19
493	Jackson	Franklin	9,792	10
501	do	Melrose	14,301	14
510	Jefferson	Hebron	13,377	13
516	do	Oakland	18,332	18
522	Juneau	Armenia	13,027	13
523	do	Clearfield	10,751	11
525	do	Finley	7,749	8
530	do	Lemonweir	9,280	9
535	do	Necedah	32,979	33
544	Kenosha	Pleasant Prairie	71,446	71
552	Kewaunee	Franklin	19,326	19
569	La Crosse	Washington	5,080	5

[1] Data taken from basic analysis form, line 37, column J.

TABLE 6.—*Expenditures of additional Wisconsin towns selected to complete final sample*—Continued

Assigned serial No.	County	Town	Total net expenditures	
			Actual	Nearest $1,000
570	Lafayette	Argyle	13, 293	13
572	do	Benton	15, 991	16
581	do	New Diggings	19, 876	20
582	do	Seymour	13, 948	14
584	do	Wayne	28, 879	29
605	Lincoln	Birch	6, 811	7
609	do	Harrison	8, 464	8
615	do	Schley	15, 471	15
634	Manitowoc	Newton	20, 017	20
641	Marathon	Bern	7, 911	8
663	do	Knowlton	14, 178	14
725	Monroe	Grant	5, 688	6
746	Oconto	Bagley	5, 543	6
754	do	Little River	26, 911	27
756	do	Maple Valley	18, 592	19
784	Oneida	Woodboro	9, 005	9
798	Outagamie	Kaukauna	9, 102	9
799	do	Liberty	9, 315	9
809	Ozaukee	Grafton	14, 813	15
829	Pierce	Martell	13, 772	14
831	do	River Falls	24, 738	25
838	Polk	Aiden	20, 621	21
848	do	Farmington	12, 050	12
859	do	St. Croix Falls	18, 340	18
868	Portage	Dewey	10, 678	11
894	Price	Spirit	7, 209	7
895	Racine	Dover	19, 580	20
914	do	Orion	12, 737	13
916	do	Richwood	12, 428	12
917	do	Rockbridge	16, 460	16
929	Rock	Johnstown	14, 628	15
931	do	Lima	20, 453	20
932	do	Magnolia	16, 615	17
947	Rusk	Grant	17, 602	18
957	do	Strickland	10, 174	10
958	do	Stubbs	12, 911	13
959	do	Thornapple	17, 213	17
967	St. Croix	Cylon	10, 736	11
971	do	Forest	14, 773	15
984	do	Troy	16, 046	16
986	Sauk	Baraboo	23, 041	23
1004	do	Washington	25, 910	26
1010	Sawyer	Draper	20, 464	20
1014	do	Hunter	14, 100	14
1020	do	Round Lake	15, 576	16
1028	Shawano	Bartelme	6, 678	7
1040	do	Morris	11, 307	11
1052	Sheboygan	Holland	35, 947	36
1069	Taylor	Pershing	8, 979	9
1076	do	Holway	13, 654	14
1079	do	McKinley	10, 807	11
1091	Trempealeau	Chimney Rock	14, 645	15
1095	do	Hale	24, 295	24
1117	Vernon	Sterling	22, 397	22
1125	Vilas	Boulder Junction	11, 906	12
1128	do	St. Germain	8, 963	9
1152	Walworth	Whitewater	16, 907	17
1165	Washburn	Long Lake	9, 341	9
1166	do	Madge	7, 025	7
1175	Washington	Barton	11, 880	12
1184	do	Trenton	16, 893	17
1206	Waupaca	Dupont	17, 287	17
1218	do	Royalton	15, 651	16
1220	do	Scandinavia	12, 366	12
1225	Waushara	Aurora	14, 734	15
1241	do	Warren	11, 469	11
1250	Winnebago	Omro	20, 120	20
1277	Wood	Seneca	8, 965	9

It is now possible to say that in repeated trials, randomly drawn samples of 200 towns will seldom yield means varying by more than 15.34 percent from 16.275. It is practically certain, therefore, that the population mean lies between $16.275 \pm 3(0.832)$ or between 13.779 and 18.771.

The formulas which were applied in the calculation of the sampling error in total net expenditures are equally applicable to the determination of error in estimating any other statistics. Ordinarily the same sample should be used in estimating all data pertaining to the same class of governmental units for a given fiscal period. The dispersion of the various items may vary considerably, and consequently, as was previously emphasized, the choice of sample size should be governed by the minimum reliability required in the estimation of the most widely dispersed of the statistics tabulated. This procedure will necessarily result in a higher degree of reliability in certain items than might otherwise be required, but it is nevertheless the only practicable way sampling can be efficiently employed. If separate samples were to be used for different statistics the clerical work involved would increase and could easily dissipate the savings that would otherwise accrue through the use of sampling procedures. It was not feasible in the present instance to present complete calculations for statistics other than total net expenditures. Table 9 has been included, however, to provide some indication of the relative stability of other important receipt and disbursement classifications.

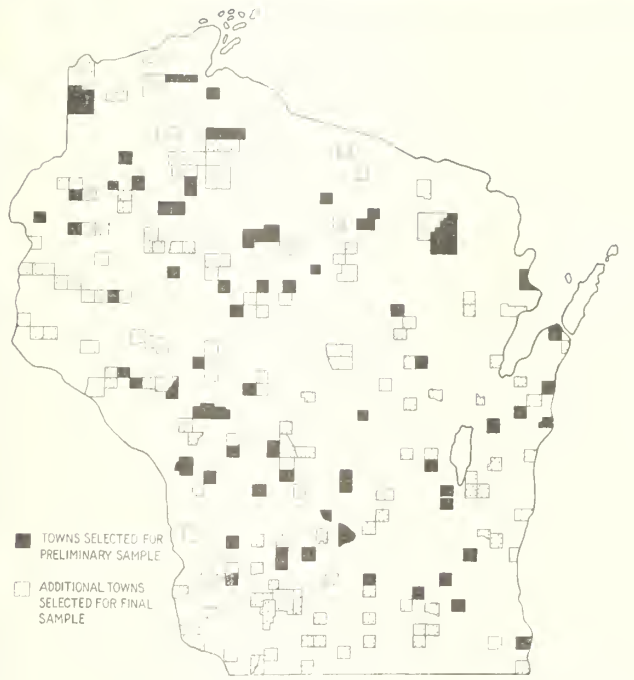

FIGURE 2.—GEOGRAPHICAL DISTRIBUTION OF INITIAL AND FINAL SAMPLES

The method of obtaining the results shown in table 9 are as follows:

The mean (M_x) of total net expenditures of the 200 Wisconsin towns selected for the final sample was found to be $16,275. There were 1,273 towns in the class to

TABLE 7.—*Frequency distribution of net expenditures of initial and final samples of Wisconsin towns taken from tables 3 and 6*

Total net expenditures	First 64 towns	Second 136 towns	Total 200 towns	Total net expenditures	First 64 towns	Second 136 towns	Total 200 towns
$1,000				*$1,000*			
3	1		1	21		2	2
5	3	2	5	22		3	3
6	7	2	9	23	1	1	2
7	3	7	10	24	3	3	6
8	1	4	5	25		1	1
9	4	14	18	26	2	1	3
10	5	4	9	27		1	1
11	3	9	12	28	1		1
12	5	9	14	29		3	3
13	2	8	10	30		2	2
14	1	11	12	33		1	1
15	1	7	8	36	2	2	4
16	5	10	15	47		1	1
17	1	8	9	50	1		1
18	1	5	6	68		1	1
19	3	5	8	71		1	1
20	7	8	15	114	1		1

which the 200 yielding this mean expenditure belonged. The expanded figure representing the over-all expenditures of the group is $20,718,075 and results from multiplying the mean, $16,275 by the number of towns, 1,273. The dissimilarity of the seven Milwaukee County towns was noted at the outset and it was remarked that it would be necessary to obtain actual data for all of them. The total net expenditures of these towns as shown in column 4 of table 9 was $1,423,660 which, added to the expanded figure for the 1,273 towns described above, provides a State total of $22,141,735 as shown in column 5. This latter amount was more than the known State total of $21,966,309 by $175,426 which facts are shown in columns 6 and 7 respectively. As shown in column 8 this is a relative error of +0.8 percent.

TABLE 8.—*Computations required in the calculation of standard deviation and arithmetic mean from table 7*—Continued

Total net expenditures x	Frequency f	$(1)-M_a$ d	$(2)\times(3)$ fd	$(3)\times(4)$ fd^2
(1)	(2)	(3)	(4)	(5)
$1,000				
3	1	−12	−12	144
5	5	−10	−50	500
6	9	−9	−81	729
7	10	−8	−80	640
8	5	−7	−35	245
9	18	−6	−108	648
10	9	−5	−45	225
11	12	−4	−48	192
12	14	−3	−42	126
13	10	−2	−20	40
14	12	−1	−12	12
15	8	0		
16	15	1	15	15
17	9	2	18	36
18	6	3	18	54
19	8	4	32	128
20	15	5	75	375
21	2	6	12	72
22	3	7	21	147
23	2	8	16	128
24	6	9	54	486
25	1	10	10	100
26	3	11	33	363
27	1	12	12	144
28	1	13	13	169
29	3	14	42	588
30	2	15	30	450
31		16		
32		17		
33	1	18	18	324
34		19		
35		20		
36	4	21	84	1,764
37		22		
38		23		
39		24		
40		25		
47	1	32	32	1,024
50	1	35	35	1,225
68	1	53	53	2,809
71	1	66	66	4,356
114	1	99	99	9,801
	200		{−533 {+788 = +255	28,059

SUMMARY

It is taken for granted that sampling would not ordinarily be undertaken where complete data are already available in the form desired. Consequently, in practical operations, it would be impossible to ascertain the actual error in expansions like those illustrated above. The only practical indices of error which can be derived are those predicated upon theories of probability. In the case of the present expansions complete data were available and it is, therefore, possible to compare the error which mathematical reasoning had indicated as a maximum which it was practically certain would not be exceeded, with the actual error which resulted.

In table 2 it was shown that the total net expenditures of Wisconsin towns for 1935 as developed from the reports of the entire 1,280 units amounted to $21,966,309. In table 9 it is shown that the corresponding figure resulting from this particular sampling experiment was $22,141,735. This difference of $175,426 or approximately 0.8 percent was much less than the coefficient of variation calculated from the sample of 200 units. The careful interpretation of this difference is of utmost importance. With such a result as a precedent there might be a tendency to assume that too great conservatism had been injected into the procedure, and that in reality much smaller samples could be relied upon to yield satisfactory expansions. This would be an unfortunate attitude to cultivate, for it overlooks certain fundamentals of probability theory.

In random sampling the most unbiased method will occasionally produce the most biased selection possible, while conversely, the most biased of sampling methods will now and then yield a sample that would satisfy every test for freedom from bias. It is a question of the frequency of particular results when an infinite, or at least a very large number, of trials are made. Even when a theoretically unbiased sampling method is employed it should be evident that the exact error can neither be foretold, nor indeed measured at all, save by tabulating all of the data, which procedure would, of course, completely vitiate the whole sampling attempt. The important consideration is, or should be, the relative frequency with which a biased selection can be

TABLE 9.—*Expansion of means obtained from sample of 200 Wisconsin towns together with a comparison of actual and relative errors resulting from the procedure*

Item	Average (from sample of 200 towns)	Expansion excluding Milwaukee County, 1,273×col. 2	Milwaukee County	Expanded to State total, col. 3+col. 4	Actual State total	Deviation of expanded from actual State total: Absolute, col. 5−col. 6	Deviation of expanded from actual State total: Relative, col. 7÷col. 6
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
							Percent
Local revenues:							
(13D) Highway	$845	$1,075,685	$24,167	$1,099,852	$1,140,305	−$40,453	−3.5
(13J) Total	8,180	10,413,140	688,645	11,101,785	10,672,104	+429,681	+4.0
Nonlocal revenues:							
(25D) Highway	1,600	2,036,800	23,618	2,060,418	2,152,891	−92,473	−4.3
(25J) Total	7,750	9,865,750	674,530	10,540,280	10,626,656	−86,376	−.8
All current receipts:							
(29D) Highway	2,430	3,093,390	47,785	3,141,175	3,333,196	−192,021	−5.8
(29J) Total	16,710	21,271,830	1,366,028	22,637,858	22,395,653	+242,205	+1.1
Net expenditures:							
(37D) Highway	3,875	4,932,875	326,096	5,258,971	5,485,159	−226,188	−4.1
(37J) Total	16,275	20,718,075	1,423,660	22,141,735	21,966,309	+175,426	+.8

expected through the use of a given sampling procedure on the particular data available. It should be obvious that the frequency theory is only important as it affects the chances of bias in the single selection which is ordinarily drawn. The actual error in a single selection may be any size whatever, and this fact must be recognized if erroneous conclusions are to be avoided. Theories of probability are helpful, however, even though but one sample is drawn instead of an infinite number.

The problem may be likened to one of the betting odds against the occurrence of a certain event such as the toss of a coin yielding a head, or the rolling of a die producing a four. Assuming freedom from bias in each case the odds against a head in the toss of a coin would be even or 1 : 1, and against a four in the roll of a die 5 : 1. Similarly, the odds against the occurrence of errors larger than certain specified departures from actuality can be calculated for the present sampling inquiry in exactly the same fashion in which it is done for coin tossing and die rolling experiments. The data in table 10 have been arranged to demonstrate these relationships.

TABLE 10.—*Probability of occurrence of theoretical errors in statistics abstracted from sample of 200 Wisconsin towns in comparison with actual errors*

Classification of item	Probable error				Actual error
	3σ (0.9974)	2σ (0.9546)	σ (0.6826)	P. E. (0.5000)	
(13)					
Local revenues:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Highway	34.4	23.0	11.5	7.7	−3.5
Total	22.8	15.2	7.6	5.1	+4.0
(25)					
Nonlocal revenues:					
Highway	18.0	12.0	6.0	4.0	−4.3
Total	12.4	8.3	4.1	2.8	−.8
(29)					
All current receipts:					
Highway	19.8	13.2	6.6	4.4	−5.8
Total	16.5	11.0	5.5	3.7	+1.1
(37)					
Net expenditures:					
Highway	15.5	10.3	5.2	3.5	−4.1
Total	15.3	10.2	5.1	3.4	+.8

The important conclusion to be obtained from this presentation is that the reliability of a sample cannot be improved by using less standard errors of the mean as a criterion for an acceptable sample. It is true that by being less conservative and permitting a choice of sample size to rest upon calculations using a single standard error of the mean, the resultant expansions will, apparently, be closer approximations of the actual totals. This improved accuracy is only apparent, however, since the odds against the error being of greater magnitude decrease with the number of standard errors used in determining the range. In the final analysis it is entirely a question of point of view; and a preference for one, two, or three standard errors of the mean is a matter of individual choice without substantial significance, providing it is understood that the probabilities are correspondingly altered and over-optimism is not engendered to the extent that too small a sample is selected.

APPENDIX

The method suggested in this article of selecting a sample by means of "Tippett's Numbers" opens up a field of inquiry that in itself is sufficiently extensive to require separate treatment. It is appropriate to discuss here a few of the reasons for the use of random sampling numbers.

By way of introduction it is pertinent to inquire exactly what is meant by a "random" sample. The statistical concept of randomness cannot be defined merely as the absence of design or purpose. It is not, as its name appears to suggest, the result of caprice. A definition sufficiently rigorous to satisfy the mathematician would fail in most respects to appease the lay reader. If, as is usually true, a random sample is taken to mean an unbiased sample, then the concept of randomness must be approached through a consideration of sampling methods rather than individual samples. It is the method that is biased or unbiased rather than particular samples drawn by that method.

An unbiased method is merely one which, repeated a very large number of times (theoretically an infinite number), rarely produces a biased sample. It is clear that defined in this manner the question of whether methods are biased or unbiased largely depends upon the frequency theory of probability. If it can be established either empirically or inductively that a given method of sampling produces a biased sample very infrequently, then by definition, such method may be termed a random method and samples produced through use of the method will be random samples. While all samples, as thus defined, will be random samples, they will by no means all be unbiased. The apparent inconsistency is not real since the definition for an unbiased method in nowise precludes the possibility of a biased drawing, but merely stipulates that such occurrences will be experienced relatively infrequently.

There is still another aspect of unbiased or random methods of selection that should be fully appreciated; and this is that a biased result may occur at any point in an infinite series of trials. There are no mathematical propositions upon which to base prognostications of the point at which a biased drawing will occur. It is important to remember this because in actual practice nothing approaching an infinite number of samples is drawn. In fact, usually but a single drawing is made and conclusions derived therefrom are attributed to the entire population from which the drawing was made.

A random sample, then, is one produced by a random method of selection. A random method is usually taken to mean an unbiased method, that is, a method which infrequently yields a biased result. A biased result, however, may as easily occur one time as another (including the first time) in an infinite number of trials, the exact incidence of occurrence being utterly unpredictable.

With meticulous regard for the foregoing distinctions, consideration may be given to the problem of drawing randomly. Stated in mathematical form, a random method is one in which every selection of M objects from an original N is equally probable. This is a task that is deceptive in its apparent simplicity. If rigorous mathematical treatment is adhered to, there are few statistical problems more difficult of practical accomplishment. It is clear that whatever other expedients are resorted to it will not suffice to leave the matter of selection to human discretion. This is true even when the individuals concerned are imbued with a conscious desire to avoid bias, are unaware of predispositions of any kind, and are above suspicion so far as intellectual honesty is concerned. The remarks of two leading English authorities, Kendall and Smith, are worth quoting in this particular connection.

> * * * House-to-house sampling, the sampling of crop yields, even ticket drawing have all been found to give results widely divergent from expectation. Apart from theoretical considerations, there is thus practical evidence to show that it is insufficient to define a random method as one free from purposive selection. The criterion of randomness in selection must be of a more objective kind.
>
> For the purpose of the discussion we require, at this point, a notion of independence. For the present we take this concept to be undefined, merely noting that it may be expressed in terms of probability. With its aid we may define a random method of selection, applied to the characteristic C of a Universe U, as a method which is independent of C in U.
>
> It is important to notice that this definition of random selection relates to a particular characteristic which is under consideration. There is no such thing as a random method of selection *per se*, considered apart from the universe whose members are being selected. A method which would be random for one universe is not necessarily random for another, and even within the same universe a method which is random in respect of one characteristic is not necessarily random in respect of another.
>
> This accords with general ideas on the subject. For example, a possible method of sampling inhabitants of a street is to take, say, every tenth house. This may give a random sample, but if every tenth house is a corner house, the sample may, or may not, lose its randomness. To decide this point, we shall have to consider the properties of the universe which are under investigation. If we were inquiring into the proportion of inhabitants with blue eyes, it might be sufficient to take the corner houses, on the assumption that the color of eyes was independent of geographical location. On the other hand, if we were sampling for income, the method might fail, since corner houses have, in general, higher rents and rates than others, and we should therefore expect to find them inhabitated by people with larger incomes.
>
> A practical question of great importance which arises in this connection is: How are we to determine whether a given method is independent of a given characteristic? The answer is that we cannot determine it without doubt, for to do so would require a full knowledge of the universe; and this is almost always in practice denied us, for otherwise there would be no point in a sampling inquiry. The assumption of independence must therefore be made with more or less confidence on *a priori* grounds. It is part of the hypothesis on which our ultimate expression of opinion is based.[1]

Ample evidence to substantiate Kendall and Smiths' recommendation against the use of so-called random methods of sampling involving the selection of every nth variate of an array has accumulated during the progress of the State-wide Highway Planning Surveys. To mention but one instance, the sampling of motor-vehicle registrations by taking each license number ending in naught was found quite unsatisfactory. It is useless to speculate upon the reasons for the bias which occurred, but important to note that it did occur in spite of a popular belief that the method was entirely adequate and practical.

Virtually the only situation in which the selection of every nth variate would fulfill the general requirements for an unbiased method would be where the variates were arrayed in random order at the outset. The sampling process would then consist merely in choosing the necessary number of variates, taking them in a block from any part of the array. This presupposes the existence of randomness in the arrayed order of the variates prior to selection, a condition seldom if ever satisfied. In fact the entire problem arises precisely because raw data as they are usually assembled are not randomly arrayed. Data tend to become what is termed "packaged" or grouped together in various and sundry ways. Sometimes packaging in data is readily discovered merely by inspection, while at other times its detection is extremely difficult.

Granted that the method of drawing every nth variate lacks virtue, consideration may be given the alternative chiefly resorted to prior to the advent of random sampling numbers, that is, lottery devices. These methods involve the same initial step necessary in the case of sampling by random numbers, the superimposing of an additional and independent characteristic upon the members of the universe. This is accomplished by numbering the members in any convenient way. Tickets, cards, marbles, beads, capsules, and an infinitude of similar media are numbered to correspond and placed in a variety of contrivances that supposedly effect thorough shuffling. Practical experiments, however, have demonstrated that it is impossible to mix balls or shuffle cards sufficiently to effect randomness in their arrangement. Speaking of this problem Karl Pearson of the University of London says,

> * * * The dice of commerce are always loaded, however imperceptibly. The records of whist, even those of long experienced players, show how the shuffling is far from perfect, and to get theoretically correct whist returns we must deal the cards without playing them. In short, tickets and cards, balls and beads fail in large scale random sampling tests; it is as difficult to get artificially true random samples as it is to sample effectively a cargo of coal or of barley.[2]

It is evident that what is needed is an unbiased method of sampling that will overcome the deficiencies of the alternative methods that have been discussed. A method is needed that will overcome the theoretical objections surrounding the taking of every nth variate of an array, and at the same time one that will avoid the practical difficulties involved in devising and operating an adequate shuffling mechanism for the randomizing of tickets, capsules, beads, etc. Fortunately, both objectives may be accomplished by the use of random sampling numbers.

Random sampling numbers are tables of numbers, the digits of which have been selected by unbiased methods. Presumably they represent a random set of possible ordinals. Until recently, relatively few tables have been offered, but a number of methods of producing satisfactory sets have been devised, including some very refined processes. There are a number of technical requirements to be satisfied in constructing a set of numbers, and there is still a measure of disagreement among students as to the necessary and sufficient tests that must be applied. The fact that no set of numbers has received the unqualified endorsement of all investigators is a circumstance of little consequence insofar as the present use of certain of these tables is concerned. The numbers of Tippett, Kendall and Smith, and possibly others, are entirely satisfactory.

One of the conditions to be satisfied by a set of random sampling numbers is "local randomness". The concept of local randomness arises from the necessity of distinguishing between a random table of numbers and a table of random numbers. Any set of numbers are random in the sense that they could have resulted from a random selection. A set of one million zeros might even have been produced by an unbiased method. Subsets of numbers drawn from such tables would not necessarily, in fact almost certainly would not, be

(Continued on page 212)

[1] M. G. Kendall and B. Babington Smith, Journal of the Royal Statistical Society, vol. 101, p. 151, 152.

[2] Karl Pearson, in foreword to Random Sampling Numbers, by L. H. C. Tippett, No. XV, Tracts for Computers. Cambridge University Press, London, 1927

EFFECT OF GLASSY SLAG ON THE STABILITY AND RESISTANCE TO FILM STRIPPING OF BITUMINOUS PAVING MIXTURES

REPORTED BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

In the various States that use blast-furnace slag as a road-building material, there appears to be considerable difference of opinion as to the amount of restriction that should be placed on the percentage of glassy particles in slag aggregates for bituminous paving mixtures. Glassy particles have been considered detrimental because it was feared that their smooth surface texture would impair the stability of bituminous mixtures and that the bituminous film would not adhere to them in the presence of water.

From an investigation to determine whether the stability and resistance to film stripping of bituminous paving mixtures prepared from slag aggregates were affected materially by the glassy-particle content of the slag, it was concluded:

1. The susceptibility to film stripping of the mixtures containing the six slags that were tested was not affected materially by variations in the content of glassy particles.

2. For bituminous mixtures containing 0, 15, and 30 percent of glassy particles in the fraction retained on the No. 4 sieve, the percentage of glassy material did not have a significant effect on stability.

3. The tests furnish no indication that specification requirements placing drastic limitations on the glassy-particle content of slag aggregates for bituminous concrete are necessary.

THERE appears to be a considerable difference of opinion in the various States that use blast-furnace slag as a road-building material as to the amount of restriction that should be placed on the percentage of glassy particles in slag aggregates for bituminous paving mixtures. This difference of opinion is reflected in the specification requirements of the States concerned. Several States that use slag place no restriction whatsoever on the amount of glassy material. Others allow various maximum percentages from 20 percent in some cases down to 10 percent in others. A third group of States words its specifications in such a way as virtually to prohibit the inclusion of any appreciable percentage of glassy particles.

As generally understood, glassy particles are those that by visual inspection appear to be composed of more than 50 percent of glassy material. They are characterized by a vitreous to waxy luster and are therefore easily distinguished from the rough-textured cellular material that usually comprises the major portion of blast-furnace slags. Glassy particles have been considered detrimental because it was feared that their smooth surface texture would impair the stability of bituminous mixtures and that the bituminous film would not adhere to them in the presence of water.

The investigation which is the subject of this report was undertaken to determine whether the stability and resistance to film stripping of bituminous paving mixtures prepared from slag aggregates were affected materially by the glassy-particle content of the slag.

The seven samples of slag used in the investigation were furnished by the National Slag Association and were obtained from representative plants in Ohio, Pennsylvania, and New York. They were normal materials for the plants that produced them and while not necessarily representative of slag aggregates for the entire country, they were typical of material produced in the areas from which they came. Samples 1 to 6 were composed of various proportions of glassy and nonglassy particles all retained on the No. 4 sieve. The percentage of glassy particles in each was determined by hand sorting the entire samples and weighing the glassy and nonglassy fractions. The fractions were then stored in separate containers and used either separately or recombined in definite proportions for the various tests to be described. Sample 7 was a slag sand sized to pass the No. 8 sieve. No attempt was made to determine its glassy-particle content. It was used as the fine aggregate in preparing all the mixtures for the stability tests but was not used in the mixtures for the film-stripping test since these mixtures contained only material passing the ⅜-inch sieve and retained on the No. 4 sieve.

The percentages of glassy particles contained in plant samples 1 to 6 inclusive, as determined in the Public Roads laboratory, were as follows:

Slag No.:	*Glassy particles, percent*
1	22
2	22
3	17
4	21
5	22
6	25

FILM-STRIPPING TESTS MADE ON INDIVIDUAL FRACTIONS AND ON BLENDS

From each of the six slags listed above, three classes of bituminous mixtures were prepared for the film-stripping test. The first contained only the nonglassy fraction; the second contained the same proportions of nonglassy and glassy particles as were found in the plant samples; and the third contained only glassy particles. A complete series of mixtures was made with each of four bituminous materials, namely, RC–3 cut-back asphalt, 85–100 penetration asphalt, and road tars RT–6 and RT–9. All the mixtures contained 5 percent by weight of bituminous material and 95 percent by weight of aggregate. The aggregates were sized to pass the ⅜-inch sieve and be retained on the No. 4 sieve. All the mixtures were oven-cured for 24 hours at a temperature of 140°F. before testing.

The stripping test was made in an apparatus similar to that described by Victor Nicholson in the Proceedings of the Association of Asphalt Paving Technologists, January 1932, page 43.[1] Certain modifications of the described machine were made such as the installation of an electric heater and thermostat in the bath and the provision of a variable-speed motor and odometer to permit variation of the number of turns obtained during the 60-minute normal test period. The rate of rotation used in these tests was 45 revolutions per minute.

The amount of stripping was recorded at 15-minute intervals during the 60-minute test period. The test temperatures were: For the first two 15-minute periods, 77° F.; for the third 15 minutes, 100° F. and for the

[1] See also Report of Committee on Characteristics of Asphalts, by E. F. Kelley, Chairman. Proceedings of The Highway Research Board, 1937, pp. 329 to 333.

fourth and final 15 minutes, 120° F. The degree of stripping at each time of observation was recorded as follows:

N = no stripping;
VS = very slight stripping (minute breaks showing in film);
S = slight stripping (dots of bare stone showing);
B = bad stripping (¼ of the aggregate surface exposed); and
VB = very bad stripping (more than ¼ of aggregate surface exposed).

In order to facilitate comparison of the behavior of the various test mixtures, two methods of assigning numerical ratings based on the test results were devised. In both methods the numerical values, 100, 90, 70, 40, and 0 were assigned to the five degrees of stripping—N, VS, S, B, and VB, respectively.

In the first method of rating (see table 1) the observed condition of the samples after 30 minutes of rotation at 77° F. was taken as the criterion of behavior and the numerical value previously assigned to the degree of stripping observed was used as the rating index.

In the second method (see table 2) the numerical values corresponding to the various degrees of stripping observed at the four stages of the test were averaged to give a rating index. By either method, the best possible rating would be 100 corresponding, in the first, to "no stripping" after 30 minutes rotation at 77° F. and, in the second, to "no stripping" after 15, 30, 45, and 60 minutes while the temperatures at the respective observation times were 77° F., 77° F., 100° F. and 120° F.

The results of the stripping tests on the entire series of mixtures using the first method of rating, as shown in table 1, indicate that the type and consistency of the bituminous material affected the amount of stripping to a much greater extent than did the variations in the glassy-particle content of the slag aggregate. In fact, no consistent and significant difference in the resistance to stripping appeared to result from the complete exclusion of glassy particles or the inclusion of 100 percent glassy particles in the mixtures with any of the bituminous materials. The most startling result of the tests was the fact that, in 22 out of 24 sets of samples where the only variable considered within the set was the glassy-particle content, the mixtures containing blends of glassy and nonglassy particles showed resistance to stripping equal to or greater than that shown by the mixtures containing all nonglassy particles; and that in 20 out of 24 cases, the mixtures containing all glassy particles resisted stripping as well as, or slightly better than those containing all nonglassy particles.

TABLE 1.—*Results of stripping tests for one test condition*[1] *(rating method 1)*

Slag No.	Glassy-particle content	Rating in the stripping test for slag aggregates mixed with— RC-3 Observed	RC-3 Index	85–100 penetration asphalt Observed	85–100 penetration asphalt Index	RT-6 Observed	RT-6 Index	RT-9 Observed	RT-9 Index	Average of all tests
1	0	Slight	70	Very slight	90	Bad	40	Slight	70	57
2	0	do	70	do	90	do	40	Bad	40	
3	0	do	70	Slight	70	Very bad	0	do	40	
4	0	do	70	do	70	do	0	do	40	
5	0	Very slight	90	do	70	Bad	40	Slight	70	
6	0	Slight	70	Very slight	90	do	40	Bad	40	
Average			73		80		27		50	
1	22	Slight	70	Very slight	90	Very slight	90	Bad	40	70
2	22	Very slight	90	do	90	Slight	70	do	40	
3	17	do	90	do	90	do	70	do	40	
4	21	do	90	do	90	Bad	40	do	40	
5	22	do	90	do	90	Slight	70	do	40	
6	25	Slight	70	do	90	do	70	do	40	
Average			83		90		68		40	
1	100	Slight	70	Very slight	90	Bad	40	Bad	40	55
2	100	do	70	do	90	do	40	do	40	
3	100	do	70	do	90	Very bad	0	do	40	
4	100	do	70	do	90	do	0	do	40	
5	100	Very slight	90	do	90	do	0	do	40	
6	100	do	90	do	90	do	0	do	40	
Average			77		90		13		40	

[1] Test condition: Temperature, 77° F.; time of rotation, 30 minutes.

TABLE 2.—*Results of stripping tests for four test conditions*[1] *(rating method 2)*

Slag No.	Glassy-particle content	Rating in the stripping test for slag aggregates mixed with— RC-3	85–100 penetration asphalt	RT-6	RT-9	Average of all tests
1	0	58	78	28	60	47
2	0	58	78	28	33	
3	0	50	50	0	33	
4	0	60	50	0	33	
5	0	73	68	28	50	
6	0	68	73	33	33	
Average		61	66	20	40	
1	22	58	85	63	28	55
2	22	78	85	50	28	
3	17	63	63	50	28	
4	21	63	73	20	28	
5	22	63	85	45	43	
6	25	58	85	45	43	
Average		64	79	46	33	
1	100	50	78	20	28	41
2	100	50	78	28	28	
3	100	40	63	10	28	
4	100	50	63	0	28	
5	100	63	73	0	43	
6	100	63	78	0	28	
Average		53	72	10	31	

[1] Condition observed at 15-minute intervals while test temperature is 77° F. for 30 minutes, 100° F. for 15 minutes, and 120° F. for 15 minutes.

The ratings obtained by method 2, as shown in table 2, are generally similar in the group relationships to those of table 1, although the numerical values are nearly all lower. It should be realized that the ratings in both tables are based on visual estimates of the extent of the stripping. Thus, they are, at best, only approximately quantitative and for that reason, slight differences in the ratings of individual samples should not be given too much consideration. However, the test results by groups of samples show a fair degree of consistency and, from these group relationships, it is concluded that the percentage of glassy particles in the slag aggregate has no important influence on stripping.

STABILITY TESTS MADE ON MIXTURES CONTAINING 0, 7.5, AND 15 PERCENT GLASSY PARTICLES

Both roller stability and Stanton-Hveem stability tests were made on a series of slag-asphalt concrete mixtures containing one 50–60 penetration asphalt and three different proportions of glassy and nonglassy particles. All six slags were brought to the following grading and 7.5 percent by weight of asphalt and 92.5 percent by weight of aggregate were used in all the mixtures.

Sieve size:	Total amount Passing percent
½-inch	100
⅜-inch	92
No. 4	50
No. 8	42

For all the mixtures, the material passing the No. 4 sieve and retained on the No. 8 sieve was obtained by crushing and sieving a part of the nonglassy material from the appropriate plant sample. In all cases, the fraction passing the No. 8 sieve consisted of a portion of slag sand, sample No. 7. As shown above, the sum of these two fractions, or the total amount passing the No. 4 sieve, comprised 50 percent of the aggregate in each test mixture.

Variations were made in the glassy-particle content of the 50 percent of the aggregate retained on the No. 4 sieve. In one set of six mixtures (one from each slag sample) no glassy particles were included in the fraction retained on the No. 4 sieve. In the next set, 15 percent of the material retained on the No. 4 sieve, or 7.5 percent of the total aggregate, consisted of glassy particles. In the third set, 30 percent of the coarse fraction or 15 percent of the total aggregate was glassy.

One 2½- by 4- by 8-inch specimen was prepared from each mixture and tested in the Public Roads roller stability machine.[2] Each specimen was compacted to develop the same aggregate density in the bituminous mixture as that obtained by vibrating the dry aggregate.[3] The compacted unit weights of the mixtures in grams per cubic centimeter and the roller stability values obtained on them are given in table 3.

The roller stability test is a simulated small-scale traffic test in which a series of small steel rollers are passed over the specimen, which is immersed in water maintained at the test temperature of 140° F. The measure of stability is taken as the number of roller passages required to produce an elongation in the specimen of 0.3 inch.

After the specimens had been tested in the roller stability machine, they were broken up and a portion of each was molded into a cylindrical specimen 4 inches in diameter by 2½ inches high for the Stanton-Hveem stability test. These specimens were molded under direct compression of 3,000 pounds per square inch by the double-plunger method. They were tested at a temperature of 77° F. The results of the Stanton-Hveem stability tests are given in table 4 and are shown graphically in figure 1.

TABLE 3.—*Results of roller stability tests on slag-asphaltic concrete*

Slag No.	Unit weight of test specimen			Roller stability at 140° F.		
	0 percent glassy	7.5 percent glassy	15 percent glassy	0 percent glassy	7.5 percent glassy	15 percent glassy
	Gm. per C. C.	*Gm. per C. C.*	*Gm. per C. C.*			
1	2.21	2.23	2.26	15	24	20
2	2.22	2.24	2.27	28	25	19
3	2.33	2.34	2.34	55	51	27
4	2.21	2.23	2.24	22	24	14
5	2.23	2.24	2.21	25	33	28
6	2.19	2.21	2.22	25	25	21
Average	2.23	2.25	2.26	28	30	22

[2] Apparatus and method of test described by E. L. Tarwater in PUBLIC ROADS, September 1935, p. 134.
[3] Apparatus and method of test described by J. T. Pauls and J. F. Goode in PUBLIC ROADS, May 1939, p. 55.

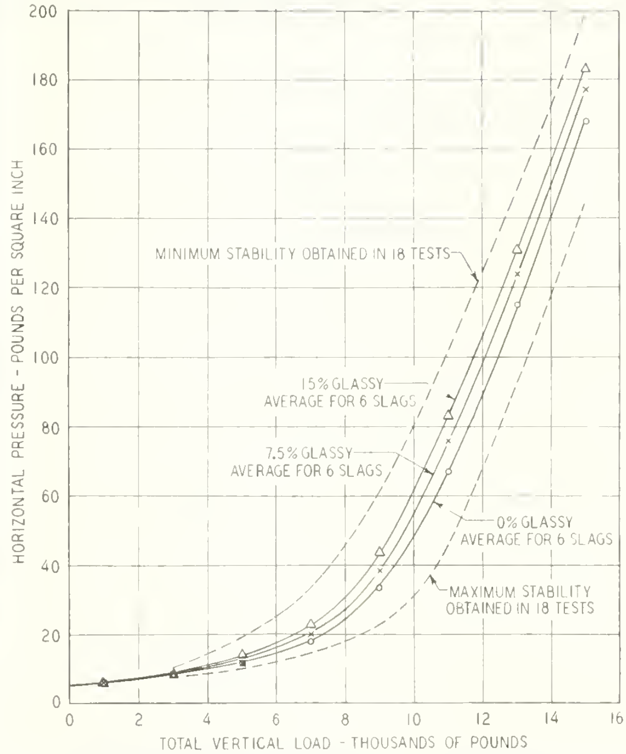

FIGURE 1.—MAXIMUM, MINIMUM, AND AVERAGE STANTON-HVEEM STABILITY CURVES FOR THE 18 TEST MIXTURES OF TABLE 4.

This stability test is a direct compression test in which a measurement is made of the lateral pressure generated in a cylindrical test specimen by the axial load. High lateral pressure for a given load indicates relatively low stability while low lateral pressure for the same axial load indicates relatively high stability.

Neither the roller nor the Stanton-Hveem test results indicated that the stability of this group of mixtures

TABLE 4.—*Results of Stanton-Hveem stability tests on slag-asphaltic concrete*

Slag No.	Glassy-particle content	Unit weight of test specimen	Horizontal pressure, when total vertical load was—								
			0	1,000 pounds	3,000 pounds	5,000 pounds	7,000 pounds	9,000 pounds	11,000 pounds	13,000 pounds	15,000 pounds
	Percent	*Gm. per c. c.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*
1	0	2.31	5	6	8	11	17	31	66	119	175
2	0	2.32	5	6	9	11	14	22	45	92	[1] 145
3	0	2.36	5	7	11	16	25	47	85	132	185
4	0	2.26	5	7	10	14	20	38	74	122	174
5	0	2.31	5	6	8	11	15	30	67	115	169
6	0	2.26	5	6	9	12	19	34	65	109	159
Average			5	6	9	13	18	34	67	115	168
1	7.5	2.30	5	6	9	13	21	38	74	122	176
2	7.5	2.33	5	6	9	12	17	30	63	112	165
3	7.5	2.38	5	7	11	16	27	51	90	139	190
4	7.5	2.27	5	6	9	13	20	41	81	129	182
5	7.5	2.31	5	6	9	12	19	35	74	121	174
6	7.5	2.28	5	6	9	11	17	34	72	122	174
Average			5	6	9	13	20	38	76	124	177
1	15	2.34	5	7	10	14	22	41	81	130	185
2	15	2.34	5	6	9	12	18	31	73	122	175
3	15	2.38	5	7	12	19	33	61	102	148	[2] 197
4	15	2.28	5	6	10	15	25	51	91	139	190
5	15	2.32	5	6	9	13	20	38	76	124	174
6	15	2.29	5	6	9	14	21	40	77	123	174
Average			5	6	10	15	23	44	83	131	183

[1] Most stable of the 18 mixtures.
[2] Least stable of the 18 mixtures.

was materially affected by the glassy-particle content of the slag aggregate. Considering individual slag samples, the roller stability test indicated that the mixtures containing 7.5 percent glassy particles might be slightly more stable than those containing 15 percent (see table 3). However, in two cases, the mixtures containing no glassy particles appeared to be slightly less stable than either of the mixtures containing glassy fractions and there were only two cases in which the nonglassy mixtures showed even slight superiority over both the corresponding glassy mixtures.

The Stanton-Hveem tests were quite consistent in showing a slight advantage for the all nonglassy mixtures over those containing 7.5 percent of glassy material and essentially the same advantage for the 7.5 percent mixtures over those containing 15 percent glassy material. These slight differences are not believed to be particularly significant since, without exception, the stability values for all 18 mixtures, whether obtained by the roller or Stanton-Hveem method, are well within the range considered necessary to assure satisfactory resistance to displacement under traffic.

CONCLUSIONS

1. The susceptibility to film stripping of the mixtures containing the six slags that were tested was not affected materially by variations in the content of glassy particles.

2. For bituminous mixtures containing 0, 15, and 30 percent of glassy particles in the fraction retained on the No. 4 sieve, the percentage of glassy material did not have a significant effect on stability.

3. The tests described furnish no indication that specification requirements placing drastic limitations on the glassy-particle content of slag aggregates for bituminous concrete are necessary.

(Continued from page 208)

random. Hence, a table of numbers from which randomly arrayed subsets may be drawn is designated "locally random".

The subject of local randomness cannot receive a full exposition here but some discussion of its fundamental importance in a set of random sampling numbers is believed to be desirable. The remarks of Kendall and Smith relative to tests for local randomness are worthy of quotation.

For practical purposes in deciding whether a given set is locally random, we have found that the following four tests are useful and searching. They are, however, not sufficient to establish the existence of local randomness, although they are necessary.

a. The first and most obvious test to be applied is that all the digits shall occur an approximately equal number of times. This test we call the frequency test;

b. Secondly, if the series is locally random, no digit shall tend to be followed by any other digit. If therefore we form a bivariate table showing the distribution of pairs of digits in the series, arranged in the rows according to the first digit, and in the columns according to the second digit, we should get frequencies which are approximately equal in all the cells. This test we refer to as the serial test;

c. Thirdly, if the digits are arranged in blocks of, say, five, there will be certain expectation of the numbers in which the five digits are all the same, the numbers in which there are four of one kind, and so on. This test we refer to as the poker test, from an analogy with the card game:

d. Finally, there are certain expectations in regard to the gaps occurring between the same digits in the series. For instance, if we take one digit, say, zero, in about one-tenth of the cases the first zero will be followed immediately by a second zero, and there will be no gap. In about nine-hundredths of the cases there will be one digit between two zeros. In about eighty-one thousandths of the cases there will be a gap of two digits between successive zeros, and so on. This we call the gap test.

These four tests taken together are very powerful. It is comparatively easy to form series that evade the first three. For example, the recurring series, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, evades the frequency test, the series 1–2–3–4–, etc., evades the frequency test, and the serial test if the dashes are filled with random digits. We have, however, not succeeded in constructing a series which would certainly evade the gap test. Such a series would, it appears, have to have a very peculiar bias indeed, such as would hardly ever rise in practice.

The gap test may be extended. Not only will there be an expectation of the frequency of the gaps, but there will also be an expectation of the gaps between gaps of the same kind; these in turn will have expected gaps between them, and so on. There is thus an infinite sequence of the gap tests no one of which includes the others. All these tests are necessary for local randomness, though we have not established their sufficiency. It appears, therefore, that there is no finite set of tests of this character which is sufficient to demonstrate the local randomness of all finite sets of numbers.[3]

There remains to be mentioned the manner of using a set of random numbers in drawing a sample. If the topics just discussed are kept in mind, the use of a table of random numbers is extremely simple and straightforward. As already indicated, the first step is to number the members of the universe being sampled in any convenient order. Then, recalling that the digits of a proper set of random numbers are locally random, it is seen that all that is required is the choice of some pattern for selecting subsets of the proper number of digits each of which will constitute the sample to be drawn from the universe in question.

Naturally, to maintain theoretical validity the pattern chosen to select subsets should be followed consistently until a sufficient number of ordinals are obtained or until the possibilities of this pattern are exhausted. Most sets are arranged in columns of four or five digit numbers. Assuming the set being used to be that of Tippett which contains columns of four digit numbers, the selection of a 10 percent sample, for example, from a universe of 1,000 variates becomes a matter merely of selecting, starting at any point and not retracing, the first 100 numbers less than 1,000 which appear. This will be taken as following an unbiased method of selection. Any other method of putting digits together vertically or horizontally, forwards or backwards to make numbers of the desired size will be equally satisfactory, providing only that the pattern of selecting subsets once chosen is followed consistently.

[3] M. G. Kendall and B. Babington Smith, Journal of the Royal Statistical Society vol. 101, pp. 154, 155.

HIGHWAY RESEARCH BOARD MEETS IN BALTIMORE DECEMBER 2–5, 1941

Changing a custom of twenty years' standing on account of the need for conserving Washington facilities for urgent defense needs, the Highway Research Board announces that its Twenty-fisrt Annual Meeting will be held at The Johns Hopkins University, Baltimore. Maryland, the first week of December 1941.

On Tuesday, December 2 several Departments of the Board will hold open meetings for the consideration of papers and reports.

Sessions of the Board for the discussion of topics relating to highway finance, economics, design, materials, construction, maintenance, traffic, and soils investigations will be held on Wednesday, Thursday, and Friday, December 3–5.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF OCTOBER 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 2,537,337	$ 1,261,780	92.8	$ 6,038,031	$ 2,996,115	193.3	$ 1,880,004	$ 934,850	49.2	$ 897,957
Arizona	531,710	383,026	33.1	1,825,980	1,226,780	67.8	558,314	372,325	12.2	875,129
Arkansas	2,710,335	1,258,509	49.6	845,756	422,558	29.0	575,078	286,701	37.8	393,967
California	4,980,409	2,639,950	88.0	5,149,495	2,808,374	61.1	3,496,621	1,752,090	61.4	1,725,978
Colorado	2,051,555	1,160,808	122.3	2,150,528	1,247,015	150.6	1,898,858	1,072,095	56.1	1,113,203
Connecticut	711,753	347,250	7.2	1,839,232	898,833	22.8	1,121,015	502,187	14.9	493,167
Delaware	214,010	104,617	4.9	811,153	399,662	21.2	268,040	134,020	8.4	979,278
Florida	772,915	386,458	52.4	1,537,392	794,925	30.5	1,892,110	922,393	16.1	2,236,146
Georgia	2,125,531	1,062,765	62.1	6,566,643	3,293,572	273.6	3,919,851	1,959,926	164.8	4,849,951
Idaho	1,361,855	839,942	72.8	1,168,465	720,832	63.7	604,926	373,507	20.4	942,750
Illinois	2,725,111	1,354,897	71.3	8,198,935	4,099,392	136.3	1,258,998	628,794	6.3	3,310,226
Indiana	2,600,929	1,296,650	39.4	6,951,227	3,233,098	108.3	1,567,842	783,921	20.7	909,495
Iowa	1,875,347	884,343	85.5	5,629,674	2,520,158	183.2	1,218,516	335,300	44.5	28,022
Kansas	3,205,430	1,621,883	161.5	4,777,500	2,392,926	277.2	3,360,461	1,389,534	128.5	2,936,917
Kentucky	2,398,662	1,203,144	93.6	6,920,394	3,296,653	155.1	2,932,980	1,466,490	20.3	70,280
Louisiana	800,645	400,301	22.3	2,030,120	1,006,642	39.7	2,568,556	1,259,086	56.3	3,053,749
Maine	708,657	356,578	20.2	1,893,742	972,831	22.3	270,170	135,085	3.9	364,973
Maryland	1,703,200	851,000	18.9	3,370,162	1,574,678	19.7	1,145,000	242,500	5.9	951,489
Massachusetts	2,253,419	1,129,370	17.3	2,316,145	1,189,333	14.9	1,175,721	584,274	8.4	2,593,405
Michigan	5,902,470	2,936,758	131.7	4,320,270	2,160,135	74.5	2,083,100	1,041,550	19.5	737,564
Minnesota	3,290,769	1,641,307	310.2	9,765,332	4,841,298	410.1	1,363,844	679,537	58.7	729,780
Mississippi	2,802,960	1,400,620	160.1	5,549,952	2,710,986	308.9	659,300	327,900	32.5	661,219
Missouri	3,923,098	1,936,666	141.6	10,254,546	4,659,107	190.1	3,162,480	757,629	44.5	3,045,965
Montana	2,002,944	1,132,347	98.9	2,847,172	1,617,899	136.6	753,264	428,306	66.9	3,080,650
Nebraska	756,448	373,489	109.9	7,319,146	3,694,565	647.0	710,611	355,306	38.5	2,176,430
Nevada	1,774,181	1,543,338	92.2	1,036,310	899,711	34.3	458,057	397,569	9.4	97,664
New Hampshire	292,328	144,253	5.3	1,223,881	585,889	14.3	18,224	7,312		770,981
New Jersey	2,348,574	1,174,287	20.5	3,562,648	1,781,244	22.2	22,270	11,135		1,759,929
New Mexico	943,125	580,478	71.0	1,404,425	868,207	87.2	16,182	10,463	5.0	1,507,962
New York	5,116,556	2,551,583	76.8	10,931,119	5,432,161	123.4	862,200	411,850	8.4	2,466,895
North Carolina	2,392,919	1,180,290	105.9	4,067,552	2,036,635	157.0	577,927	285,555	26.2	1,736,439
North Dakota	2,696,932	1,509,463	238.4	3,068,110	1,587,484	235.4	2,086,670	1,046,705	179.4	2,976,805
Ohio	5,211,504	2,599,677	43.2	14,054,902	6,786,461	114.4	4,064,080	1,691,485	27.3	2,164,705
Oklahoma	1,329,205	650,460	62.8	3,108,341	1,640,449	85.2	2,183,370	1,143,558	72.9	4,056,099
Oregon	1,142,629	689,896	37.6	4,344,409	2,283,840	97.6	449,649	221,190	14.7	371,582
Pennsylvania	3,082,916	1,535,850	41.8	13,941,192	6,869,809	112.1	2,234,606	1,070,884	18.0	1,669,073
Rhode Island	533,402	266,095	5.5	1,280,255	638,753	9.0	28,060	14,030	.3	773,816
South Carolina	891,504	415,437	64.7	3,876,970	1,793,057	96.7	1,594,553	687,327	37.8	1,250,646
South Dakota	1,732,723	1,008,810	224.0	4,565,593	2,892,779	484.1	1,435,890	898,660	171.6	1,369,857
Tennessee	1,583,516	789,774	60.1	5,322,162	2,661,081	96.4	1,821,164	910,582	52.0	2,312,934
Texas	5,393,989	2,645,034	286.0	12,971,773	6,328,224	495.8	5,484,880	2,244,670	182.1	3,776,213
Utah	648,455	484,518	42.1	2,214,987	1,670,431	43.7	75,033	55,188	5.4	251,387
Vermont	333,669	165,120	12.5	1,695,292	843,996	37.0	41,081	20,540	.3	57,640
Virginia	1,243,087	623,172	30.0	5,272,146	2,462,923	94.7	889,310	441,605	7.7	1,076,104
Washington	362,625	194,000	6.0	3,239,392	1,731,404	46.0	539,413	260,085	5.2	764,214
West Virginia	1,278,460	637,233	30.4	3,570,460	1,770,293	44.7	464,766	230,633	6.8	1,230,577
Wisconsin	908,049	446,770	46.8	6,329,197	2,988,288	194.3	1,939,320	731,759	62.8	2,393,602
Wyoming	1,414,675	903,980	148.3	1,148,529	754,151	78.9	737,311	474,086	44.6	239,335
District of Columbia	463,514	231,540	2.5	732,536	343,000	1.0	140,642	70,300	.9	247,214
Hawaii	140,808	70,395	1.1	701,887	518,147	9.5	41,366	21,894	.3	1,694,653
Puerto Rico	176,100	87,085	2.6	1,420,268	701,150	15.4	1,082,599	534,660	5.1	336,513
TOTALS	98,382,944	51,092,996	3,825.7	225,161,428	113,647,984	6,467.8	69,734,283	32,619,081	1,940.9	76,510,535

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF OCTOBER 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 832,405	$ 414,568	35.8	$ 991,152	$ 506,990	51.9	$ 165,900	$ 77,280	5.9	$ 294,164
Arizona	67,371	48,972	4.5	194,180	143,267	9.5	68,387	47,600	4.0	307,364
Arkansas	330,055	164,276	27.4	235,449	117,623	17.4	331,004	165,436	14.3	68,426
California	522,510	318,740	12.4	1,032,408	738,548	9.9	129,976	74,930	3.6	409,896
Colorado	142,204	70,526	20.7	129,755	72,649	2.1	4,602	2,598	1.9	262,976
Connecticut	105,456	49,907	1.8	458,826	202,361	9.1				76,648
Delaware	31,959	15,265		274,043	135,122	12.3	102,873	37,617	3.9	158,720
Florida	118,966	59,483	4.4	1,046,553	528,727	7.4				232,834
Georgia	293,032	131,516	26.7	993,558	589,129	61.8	833,048	416,524	73.5	697,801
Idaho	163,914	97,878	12.0	188,523	116,006	17.7	144,882	63,255	7.0	145,326
Illinois	680,650	337,436	28.6	1,434,510	717,255	76.4	31,700	12,600	7.1	286,246
Indiana	90,900	45,450	2.8	1,648,805	791,246	83.7				599,828
Iowa	508,912	240,491	124.3	363,952	153,398	71.6	245,880	115,426	43.0	252,470
Kansas	348,387	176,679	54.6	1,944,652	974,493	132.3	443,636	221,159	33.6	668,146
Kentucky	413,140	97,595	15.0	1,377,687	355,843	82.0	786,685	199,174	32.4	110,785
Louisiana	558,248	227,059	20.6	6,460	3,230		289,362	138,761	21.5	446,956
Maine	14,200	7,100	.8	251,758	125,879	11.7	63,650	26,114	2.2	9,491
Maryland	135,000	67,500	8.1	585,000	292,325	13.7	82,000	41,000	.8	202,116
Massachusetts	163,235	85,298	4.1	651,150	342,642	10.1				361,339
Michigan	323,068	161,491	27.2	1,307,660	653,830	61.0	727,370	363,685	23.0	71,980
Minnesota	829,633	420,567	113.5	1,562,365	783,990	171.8	539,972	255,078	48.8	103,952
Mississippi	477,700	238,850	20.6	1,012,161	491,346	49.7	1,008,600	367,376	45.2	112,643
Missouri	285,184	142,198	36.0	747,240	359,779	78.7	420,266	168,538	54.2	583,029
Montana	311,504	176,926	50.7	241,662	137,374	26.7	65,917	37,480	4.8	577,423
Nebraska	102,684	50,743	13.5	681,717	348,749	68.5	83,106	41,553	41.1	338,426
Nevada	118,591	103,169	12.8	129,863	93,360	9.7	159,363	138,486	10.8	2,981
New Hampshire				338,140	167,149	8.2	52,105	3,572	.1	89,289
New Jersey	246,870	123,355	5.1	624,812	329,865	16.5	82,910	41,455	1.8	353,335
New Mexico	413,533	259,915	42.6	189,504	122,533	15.1	167,514	101,129	5.1	6,907
New York	751,962	378,224	20.8	1,053,146	534,664	21.3	75,000	37,500	1.0	502,500
North Carolina	129,990	64,995	11.1	742,847	401,478	60.1	69,820	20,000	5.0	254,103
North Dakota	49,569	26,558	2.4	3,434	3,434		808,050	793,860	42.7	485,901
Ohio	845,072	422,280	30.2	1,709,240	901,810	37.1	115,000	57,500	4.7	795,592
Oklahoma	246,780	130,349	9.7	127,338	67,173	11.9	884,486	467,008	68.3	723,546
Oregon	324,677	162,124	26.6	487,315	260,529	30.8	134,541	51,670	14.1	120,289
Pennsylvania	620,078	310,039	14.1	1,887,581	932,724	33.9	72,000	36,000	1.8	43,101
Rhode Island	88,194	44,040	.9	139,310	73,157	1.7	3,610	1,805		56,220
South Carolina	310,932	100,066	33.9	690,000	284,224	21.2				165,627
South Dakota	32,130	18,006	15.2	3,622	3,622		1,143,430	1,047,600	114.5	490,587
Tennessee	230,843	114,430	8.1	1,479,414	739,707	47.9	234,030	117,015	8.7	409,820
Texas	561,809	272,011	59.3	1,047,627	504,517	95.1	429,420	201,550	40.8	1,168,978
Utah	186,949	123,241	17.0	62,245	32,943	2.5	79,538	36,884	1.0	172,273
Vermont	36,231	18,109	1.2	2,558	1,279		168,097	75,058	7.8	9,258
Virginia	339,398	155,485	11.1	374,996	171,246	9.1	59,050	29,525	4.5	351,901
Washington	151,705	92,113	16.2	565,560	265,814	15.4				149,770
West Virginia	86,300	43,150	2.4	623,774	311,274	23.8	15,700	7,850		313,609
Wisconsin	698,433	350,225	34.5	1,815,193	809,663	56.2	76,393	36,920	.8	124,441
Wyoming	364,162	157,111	18.8	464,237	204,529	31.7	43,601	16,400	2.6	721
District of Columbia	80,772	39,924	.9	2,558	1,279					76,120
Hawaii				2,375	2,375					249,562
Puerto Rico	45,960	22,305	2.5	185,404	90,550	8.1				134,883
TOTALS	14,811,257	7,377,738	1,063.5	34,113,319	16,992,699	1,694.3	11,442,474	6,191,971	807.9	14,630,299

U. S. GOVERNMENT PRINTING OFFICE: 1941

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

Work of the Public Roads Administration, 1940.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP . . Roadside Improvement. 10 cents.

No. 272MP . . Construction of Private Driveways. 10 cents.

No. 279MP . . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

Specifications for Construction of Roads and Bridges in National Forests and National Parks. 1 dollar.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T . . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP . . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–21, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF OCTOBER 31, 1941

STATE	Completed During Current Fiscal Year: Estimated Total Cost	Completed: Federal Aid	Completed Number: Grade Crossings Eliminated by Separation or Relocation	Completed Number: Grade Crossing Structures Reconstructed	Completed Number: Grade Crossings Protected by Signals or Otherwise	Under Construction: Estimated Total Cost	Under Construction: Federal Aid	Under Construction Number: Grade Crossings Eliminated by Separation or Relocation	Under Construction Number: Grade Crossing Structures Reconstructed	Under Construction Number: Grade Crossings Protected by Signals or Otherwise	Approved for Construction: Estimated Total Cost	Approved for Construction: Federal Aid	Approved Number: Grade Crossings Eliminated by Separation or Relocation	Approved Number: Grade Crossing Structures Reconstructed	Approved Number: Grade Crossings Protected by Signals or Otherwise	Balance of Funds Available for Programmed Projects
Alabama	$ 5,739	$ 5,739			2	$ 421,822	$ 419,800	6	5	1	$ 154,235	$ 154,235	3	1	6	$ 729,700
Arizona						309,635	300,944	1	2		13,255	13,255			2	92,976
Arkansas	107,311	107,256			1	511,114	509,130	6			33,786	33,786			11	313,381
California	376,504	190,789	1		1	1,315,838	1,309,365	9	1		20,630	20,630			7	1,501,452
Colorado	5,685	5,646				590,186	590,186	6			21,042	21,042			10	547,822
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		352,566
Delaware	4,380	4,380			1	94,135	94,135	1			692,694	504,341	3	1		73,707
Florida	33,447	33,447			6	767,560	762,376	8		14	203,082	203,021			19	610,361
Georgia	403,084	403,084	6	1	1	978,537	978,537	6	6	1	934,287	934,287	2	5	27	1,141,222
Idaho	11,301	11,301				302,225	293,553	3	1		34,621	34,621	1		4	262,324
Illinois	187,801	148,267			73	2,161,884	1,978,650	10	1	8	420,414	401,664	1	1	35	1,531,566
Indiana	173,001	173,001	1		8	775,513	763,026	6	1	10	234,376	228,667	1		44	644,992
Iowa	213,010	203,589	2	1	5	1,267,169	1,019,232	10	2	10	495,404	485,475	1		70	120,383
Kansas	34,334	34,229	1		2	569,456	569,456	8			348,854	304,969	5		14	874,766
Kentucky	163,064	161,519	2		1	1,075,361	1,069,248	8	1		319,265	319,265	3			48,565
Louisiana						588,415	588,415	8			473,319	472,152	4		2	610,118
Maine						390,447	390,447	2			8,680	8,680			3	109,934
Maryland	481,550	449,757	2	2	3	330,159	330,159	2		1	590,703	446,905	2		13	205,511
Massachusetts						1,120,671	1,109,293	6	2		763,830	763,830	2	1		878,999
Michigan	394,700	394,700		1	5	972,739	972,739	3	3	3	527,954	497,793	2		27	667,292
Minnesota	338,950	338,635	2	3	1	1,026,634	1,026,634	7	3		270,324	270,324	1	3	4	697,343
Mississippi	202,300	202,300	2		1	811,084	811,084	9	1		98,708	98,708	1		11	327,264
Missouri	55,240	55,240		1		1,979,682	1,524,262	6	3		330,551	223,526	1	2		1,147,479
Montana	56,726	56,726	1			174,019	174,019	2			6,645	6,645			2	474,600
Nebraska	142,718	142,714		1	12	1,187,289	1,187,289	23		6	26,502	26,502			7	116,137
Nevada	119,580	119,580	2			56,484	56,484	2			21,703	21,703			7	103,916
New Hampshire	63,682	62,862	2			306,045	305,745	4	2		9,464	9,464			4	194,348
New Jersey	214,360	214,360	2			1,254,863	1,129,314	5	2	1	354,985	295,560	1	2		554,080
New Mexico						68,342	68,342	1			259,103	252,068	3		1	338,650
New York	1,345,993	1,318,867		8		2,812,436	2,763,787	5	11		750,945	613,285		3		2,420,776
North Carolina	412,365	412,365	2	4	17	256,906	254,028		3	4	251,793	251,793	3		24	782,113
North Dakota	80,242	79,789	2			697,230	684,293	8			223,120	223,120	2			336,428
Ohio	324,301	323,904	1	1	1	3,457,893	3,376,850	15		4	541,407	282,350	2		7	1,049,956
Oklahoma	128,076	124,660	1		17	849,622	846,212	6		3	412,316	354,274	3		18	1,123,686
Oregon	302,166	278,255	3		2	125,127	84,757	2			4,733	4,733			3	391,816
Pennsylvania	873,683	873,355	7	1		3,243,392	3,203,414	17			1,147,255	1,142,789	6			1,330,260
Rhode Island	205,241	205,241		1		3,655	3,655									176,421
South Carolina	169,540	166,310	2		10	342,678	330,278	5	3	5	300,248	166,574	1	2	16	691,260
South Dakota	348,243	348,243	10		2	677,142	661,192	12		7	41,200	41,200	2			577,780
Tennessee	225,916	216,452	1	3		1,176,346	1,176,346	8			102,106	102,106		1	2	845,415
Texas	717,706	708,673	8			1,716,525	1,708,791	17			156,650	148,350	3		5	1,371,886
Utah	42,014	41,272	2		13	77,264	77,264	1		12	69,025	69,025			26	226,082
Vermont	9,723	9,711			2	331,830	302,051	2		2						4,381
Virginia	92,292	92,292		2		718,013	717,553	5	3		106,935	87,435	2		5	568,313
Washington	55,443	55,443		1	1	333,418	333,418	3	1		12,151	12,151			4	453,333
West Virginia	10,640	10,640			4	807,142	801,522	9	1	2	93,190	93,190			3	510,406
Wisconsin	156,539	128,261	1		14	840,100	838,394	4	2	21	61,692	61,692			13	1,159,125
Wyoming	477,151	477,150	5			4,929	4,929				8,199	8,199			6	286,556
District of Columbia	2,193	2,193				1,462	1,462				298,213	273,744		1		5,851
Hawaii	192,574	192,566	2			214,170	213,655	2								180,308
Puerto Rico	103,629	102,980	1			639,340	632,516	9			150,994	149,890	2			188,708
TOTALS	10,230,359	9,853,158	76	31	211	40,795,640	39,409,407	298	61	115	12,631,962	11,361,758	63	24	462	29,952,314

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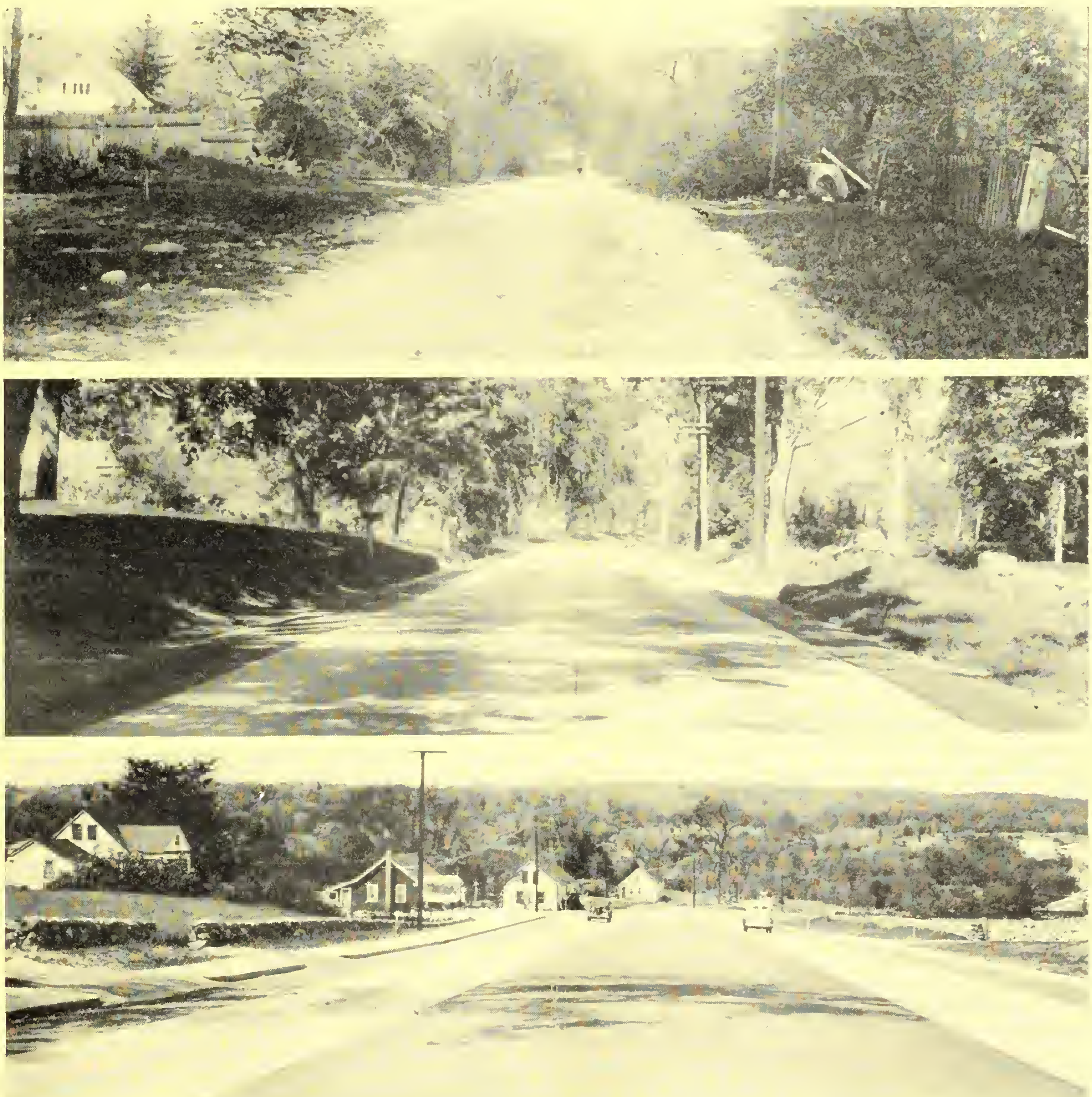

NOOSENECK HILL ROAD, RHODE ISLAND, IN 1912, 1923, AND 1941

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

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D. M. BEACH, *Editor*

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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BITUMINOUS TREATMENT OF SANDY SOIL ROADS IN NEBRASKA

Reported by PAUL F. CRITZ, Highway Engineer, Public Roads Administration and

C. M. DUFF, Testing Engineer, Nebraska Department of Roads and Irrigation

In 1928 the State of Nebraska began to study methods whereby the sandy soil roads in the sparsely settled areas of the State might be permanently improved and maintained at a cost reasonably commensurate with the traffic carried.

The bituminous mixed-in-place method of treatment offered possibilities. The first experiments showed promise but also indicated the necessity for obtaining definite information on the details of construction and on the performance of various combinations of bituminous materials and sand.

Slow-curing asphaltic materials of the type then being used with graded aggregate as well as medium-curing materials were tried out experimentally to determine their relative merits as binders for the poorly graded sand. Neither material alone was particularly satisfactory at first.

The slow-curing material did not provide the bond required for stability and it became necessary to increase the mechanical stability of the sand by the addition to fine inert soil which served as a filler. This modification of the original mixture produced adequate stability that was relatively independent of the bituminous material in that it was not greatly affected by changes in temperature.

The medium-curing asphaltic material was relatively slow in developing its ultimate binding property. During the early life of the experimental road, the sections containing this material had stability adequate for moving traffic but not for static loads. The upper portion of the mixture developed a crust as the volatile portion of the asphaltic material decreased but volatile material below the surface was dissipated very slowly. As a result this portion remained somewhat plastic and readily susceptible to deformation under load. This condition resulted in extensive surface cracking that gave the sections an unsightly appearance but did not seriously impair their serviceability. In time, the viscosity of the bituminous material increased as did the stability of the mixture so that surface cracking stopped.

The experiment provided information not only on possible methods of improving the sandy soil roads but also on the manner in which construction should be carried out. Most of this information developed by the experiment has already been incorporated in the State's specifications.

TO PROVIDE all-weather road surfaces in sparsely populated areas where the existing roads were very unsatisfactory and where natural road-building materials, other than sand, were not available, the Nebraska Department of Public Works, in 1928, began to experiment with bituminous mixed-in-place construction, using the sandy soil of the existing road and liquid asphaltic materials.

The area for which a suitable type of construction, was sought is known locally as the "sand-hill region." It lies in the north central portion of the State and occupies nearly one-fourth of the State's area. The mileage of the State highway system within this area and the population per square mile are much less than in other parts of the State. Agriculture is the only industry, with stock-raising and hay-growing the chief occupations. Few railroads traverse this territory and practically all products are carried over considerable distances by highway to reach markets or shipping points.

As may be inferred from the name commonly applied to this region, the sand-hill territory is rolling country. The soil is natural sand overlaid with a very light covering of humus which supports the growth of prairie hay. While most of the sand in this area is of considerable depth, some deposits of silty clay of low plasticity occur not only in the lower areas and along stream beds, but in considerable quantities elsewhere. However, this material, in comparison with the clays generally being used in 1928 as binders for sand and gravel surfaced roads, was not considered to be a satisfactory binder because of its low plasticity. Its successful use as a filler in bituminous mixtures came as a later development.

The sandy roads in this area were very difficult to travel over except in wet weather; and as the territory in which they lie receives very little rainfall, they were highly unsatisfactory most of the time. Prior to the start of bituminous construction in this area, the more heavily traveled roads were surfaced with clay upon which a fairly thin layer of gravel, which also had to be shipped in, was placed as a wearing course. Gravel deposits occur in areas bordering the sand-hill region but most of the surfacing gravel had to be imported.

The resulting surface, as would be expected, was very dusty in dry weather and the rather thin covering of gravel was not always effective in preventing slipperiness in continued wet weather. It was superior to the sandy road it replaced only because it was passable throughout the year. Not only was the cost of this type of construction relatively high, but it added little in the way of permanent improvement. Maintenance costs were likewise high in view of the fact that maintenance served merely to keep the road usable and in no sense could be considered betterment work such as often results from routine maintenance.

The average maintenance cost of a gravel road typical of roads in the sand-hill region and adjoining the experimental road to be described herein was $280 per mile annually for a period of 9 years.[1] In addition to surface maintenance, this sum included the cost of snow control and removal, maintenance of right-of-way, equipment repairs and depreciation, and administration. Of this total cost per mile, approximately 33 percent was required for the replacement of the sand-gravel surfacing material and 33 percent for blading and dragging the surface. In other words, an annual expenditure of $186 per mile was required to maintain the surface as constructed but without permanent improvement.

It was realized that the construction and maintenance of this type of surface was not economical; consequently, treatment of this character was limited to the most heavily traveled roads where a surface passable the year around was imperative. Less heavily traveled

[1] Annual Maintenance Expenditure Reports of the Nebraska Department of Roads and Irrigation, 1932–1940.

roads and those that were not so sandy were left unsurfaced.

Where the roads were composed only of sand and the traffic was light, prairie hay was sometimes spread on the surface. This rather novel method of maintenance made the road passable, but it introduced a fire hazard and at best was only a temporary expedient as the hay quickly ground up under traffic or was blown away by the wind.

It was apparent that a change in procedure was necessary in order to provide a more satisfactory all-weather surface at less cost and to obtain some degree of permanent gain.

EARLY STABILIZATION EXPERIMENTS SHOWED PROMISE

The first attempt to stabilize the sandy soil roads in the sand-hill region was made in September, 1928, and involved the construction of a bituminous mat composed of the sandy soil in the road and a liquid asphaltic material designated at that time as a fuel oil containing 78 percent of asphalt of 100 penetration. This experimental section was approximately ¼ mile in length and was constructed by the road-mix method. The mat was 4 inches thick, contained 3½ gallons of oil per square yard, and cost approximately 60 cents per square yard.

The results of the experiment were quite promising and although the cost appeared relatively high in relation to the volume of traffic, it was thought that the reduction in maintenance costs and the provision of an all-weather surface would make this type of construction adaptable to the sand-hill region.

The following summer, another experimental section was constructed near the first and was similar to it except that the 4-inch mat was constructed in two 2-inch layers instead of full depth in one operation as on the first section. The bituminous materials used on the second section were supplied by two refineries and, although both materials met the same specifications, the resulting bituminous mats were quite different in their characteristics.

One mat crusted on the surface and set up so that it could not be worked with a blade grader, while the other remained soft and could easily be manipulated with the blade. The bituminous material used in the former contained an appreciable amount of volatile material that was soon dissipated so that the mixture eventually contained a fairly viscous binder. The other oil did not have this volatile portion; consequently the mixture did not harden appreciably and remained poorly bonded. It was readily displaced by steel tires and by livestock and after a period of time began to dust under traffic.

Because of the difference in behavior shown by the bituminous materials used on this section, and on other sections being constructed at the same time, it was felt advisable to obtain more information on the advantages and limitations of different liquid asphaltic materials before initiating an extensive program of bituminous construction in the sand-hill region.

To obtain such information, a cooperative experimental road was constructed by the Nebraska Department of Roads and Irrigation and the United States Public Roads Administration (then the Bureau of Public Roads). This experimental road was constructed in Holt County, Nebraska, during 1929 and 1930, is located on U. S. Highway 281, and is 9½ miles in length. It begins at a point approximately 4½ miles south of O'Neill, and extends southward to the south fork of the Elkhorn River.

This experimental road is located near the eastern fringe of the sand-hill region and for the most part passes through territory that is characteristic of that region. The terrain adjacent to the north 4 miles is relatively flat and the soil is sufficiently fertile to produce crops of prairie hay in commercial quantities. The south 5½ miles of the road pass through typical sand-hill country where the terrain is rolling and the soil is very sandy and so light that only vegetation suited to cattle grazing is found. The nature of the country through which the road passes is shown in many of the photographs illustrating the construction of the road.

Prior to beginning the bituminous construction the road had been brought to grade using the soil adjacent to it. This material on the north 3½ miles and on the south 1,600 feet contained some clay and black silty loam, but on the remainder of the road it was practically all sand. Bituminous construction extended from September to November 1929, and from June to October 1930. The experimental road consists of 10 sections, nine of which are 1 mile in length and one is ½ mile in length. They are numbered consecutively from the north end where the stationing starts.

Three asphaltic materials were used in constructing the sections. One, designated as a 94+ road-oil cut-back, was a liquid asphalt containing approximately 95 percent of asphalt of 100 penetration, to which kerosene had been added to lower its viscosity. The second material, designated as 60–70 road oil, was a slow-curing asphaltic oil containing 60 to 70 percent of asphalt of 100 penetration. The third material, designated as a 100–120 cut-back, was an asphalt having a penetration of 100 to 120, cut back with kerosene.

Each section, excepting No. 10, was subdivided into two parts designated A and B. The aggregate in the bituminous mats on the A sections was the soil found in the road, but to all B sections limestone dust was added as a filler.

BITUMINOUS MATS CONSTRUCTED IN TWO 2-INCH LAYERS

The location, description, and cost of constructing the experimental sections are given in table 1. The analysis of the sandy soil in the top 4 inches taken from various locations on the road is given in table 2, and that of the subgrade on the north 3½ miles is given in table 3. The subgrade on the south 6 miles was sand excepting the south 1,600 feet of the road which was built on a fill and contained some silty loam. The analyses of the bituminous materials used in the sections are given in table 4 and the composition of, and results of physical tests on, the resulting mixtures are given in table 5.

The bituminous mats were constructed by the mixed-in-place method. They were built in two 2-inch layers, 21 feet wide and contained approximately 4 gallons of bituminous material per square yard (2 gallons per square yard in each 2-inch layer).

Scarifying was not required as the road soil could be manipulated easily with blades. Prior to applying the bituminous material sufficient soil to form the top 2-inch layer was windrowed to the shoulders. The bituminous material for the bottom 2-inch layer was then applied in ½-gallon increments by means of pressure distributors pulled by crawler-type tractors. Following each application of bitumen the mixture was turned with a disk. After the total amount of bitumen had been applied to a half-mile section, tractor-drawn blade graders mixed the aggregate and soil until a uniform mixture was obtained.

TABLE 1.—*Location, composition, and cost of the experimental sections*

Location			Composition			Cost per square yard			
			Bituminous material						
Section	Stations	Area	Type	Quantity per square yard	Dust per square yard	Bitumen	Dust	Manipulation	Total
		Sq. yd.		*Gallons*	*Pounds*	*Cents*	*Cents*	*Cents*	*Cents*
1A	211 to 237	6, 067	94+ road oil, cut back with kerosene	3. 98		38. 69		7. 90	46. 59
1B	237 to 264	6, 300	do	4. 12	9. 89	40. 05	6. 30	7. 90	54. 25
2A	264 to 290	6, 067	do	3. 82		37. 13		7. 90	45. 03
2B [1]	290 to 316+65	6, 116	do	3. 99	10. 07	38. 78	6. 30	7. 90	52. 98
3A [2]	316+90 to 344	6, 148	do	3. 86		37. 52		7. 90	45. 42
3B	344 to 370	6, 067	do	3. 94	9. 95	38. 30	6. 30	7. 90	52. 50
4A	370 to 397	6, 300	100–120 penetration asphalt, cut back with kerosene	3. 96		38. 49		7. 90	46. 39
4B	397 to 423	6, 067	do	4. 06	10. 00	38. 46	6. 30	7. 90	52. 66
5A	423 to 450	6, 300	do	4. 05		39. 37		7. 90	47. 27
5B	450 to 476	6, 067	do	3. 93	9. 99	38. 20	6. 30	7. 90	52. 40
6A	476 to 503	6, 300	do	3. 91		35. 01		7. 90	42. 91
6B	503 to 527	5, 600	do	4. 11	10. 36	39. 95	6. 30	7. 90	54. 15
7A	527 to 554	6, 300	60–70 road oil	3. 78		36. 74		7. 90	44. 64
7B	554 to 581	6, 300	do	3. 86	10. 03	37. 52	6. 30	7. 90	51. 72
8A	581 to 607	6, 067	do	4. 36		42. 38		7. 90	50. 28
8B	607 to 634	6, 300	100–120 penetration asphalt, cut back with kerosene	3. 83	9. 97	46. 04	6. 30	7. 90	60. 24
9A	634 to 660	6, 067	do	4. 11		49. 40		7. 90	57. 30
9B [3]	660 to 687+15	6, 335	do	4. 04	10. 01	48. 56	6. 30	7. 90	62. 76
10 [4]	700 to 726	6, 027	do	4. 04		48. 56		7. 90	56. 46

[1] Deduct 44 feet for bridge.
[2] Bridge from station 316+65 to 316+90. Deduct 75 feet for bridge.
[3] Station equation: 687+15=700+00.
[4] Deduct 17 feet for bridge.

TABLE 2.—*Mechanical analysis of sandy soil used in the bituminous mats*

Sieve size	Maximum	Minimum	Average
	Percent	*Percent*	*Percent*
Passing ¼-inch sieve, retained on No. 10	0. 4	0	0. 2
Passing No. 10 sieve, retained on No. 20	3. 6	. 7	1. 4
Passing No. 20 sieve, retained on No. 30	4. 5	1. 3	2. 5
Passing No. 30 sieve, retained on No. 40	21. 2	7. 3	10. 4
Passing No. 40 sieve, retained on No. 50	24. 5	11. 8	16. 3
Passing No. 50 sieve, retained on No. 80	45. 7	32. 6	38. 2
Passing No. 80 sieve, retained on No. 100	15. 7	8. 3	13. 8
Passing No. 100 sieve, retained on No. 200	19. 7	7. 0	12. 9
Passing No. 200 sieve	9. 6	1. 0	4. 3

TABLE 3.—*Analyses of subgrade soils on the north 3½ miles of the experimental road*

	Sample 5628; section 1A; top 8 inches	Sample 5662; section 1A; top 6 inches	Sample 5660; section 2B; top 4 inches	Sample 5661; section 2B; 4 to 14 inches	Sample 5663; section 3A; top 11 inches	Sample 5664; section 3B; top 2 inches	Sample 5665; section 3B; 2 to 5 inches	Sample 5676; section 4A; top 6 inches
Mechanical analysis:								
Coarse sand, 2.0 to 0.25 mm. percent	23	47	29	46	32	31	35	42
Fine sand, 0.25 to 0.05 mm. percent	53	43	48	44	58	38	44	40
Silt, 0.05 to 0.005 mm do	16	6	17	6	5	19	9	8
Clay, smaller than 0.005 mm. percent	8	4	6	4	5	12	12	10
Colloids, smaller than 0.001 mm percent	6	2	4	2	3	5	5	7
Tests of material passing No. 40 sieve:								
Liquid limit	13	17	19	17	16	36	22	23
Plasticity index	0	0	0	0	0	0	0	6
Shrinkage limit								20
Shrinkage ratio								1. 7
Centrifuge moisture equivalent	11	6	14	7	6	46	35	21
Field moisture equivalent	14	19	20	19	19	38	22	21
Soil group	A–3	A–3	A–3	A–3	A–3	A–2	A–2	A–2

The amount of manipulation required to produce a uniform, well-mixed mat varied considerably, depending upon the air temperature and the promptness and care

TABLE 4.—*Analyses of bituminous materials used in construction*

Analyses	94+ road oil cut back with kerosene; sections 1, 2, and 3		60–70 road oil; sections 7A, 7B, and 8A		100–120 penetration asphalt cut back with kerosene; sections 4, 5, 6, 8B, 9, and 10	
	Range	Aver.	Range	Aver.	Range	Aver.
Specific gravity at 25° C	0. 990–0. 995	0. 993	0. 966–0. 982	0. 973	0. 971–0. 985	0. 979
Flash point, open cup ° C	77–105	94	133–166	142	76–93	84
Specific viscosity, Engler, at 50° C	74. 0–90. 3	79. 1	45. 5–66. 2	52. 0	45. 7–91. 7	65. 8
Loss, 50 grams, 5 hours, 163° C percent	13. 1–14. 3	13. 7	4. 4–6. 0	5. 2	14. 5–17. 4	15. 9
Residue, float at 50° C. seconds	90–110	100	23–30	26	83–158	111
Loss, 20 grams, 5 hours, 163° C percent	17. 7–18. 8	18. 3	6. 2–8. 1	7. 1	20. 7–23. 9	22. 3
Residue, float at 50° C. seconds			27–37	32		
Residue, penetration at 25° C	136–197	167			76–185	111
Soluble in carbon disulphide percent	99. 6–100	99. 8	99. 8–100	99. 9	99. 7–99. 9	99. 8
Bitumen insoluble in 86° B. naphtha percent	16. 1–19. 5	18. 0	11. 4–14. 1	12. 5	13. 9–22. 2	19. 1
Residue of 100 penetration percent	77–79	78	62. 8–65. 5	64. 4	74–78	76

with which the mixing operation was performed. Upon completion of this operation, the mixture was spread and the sand that had been previously windrowed to the sides was bladed in and spread uniformly. Additional bituminous material was applied and mixing carried on in the same manner as in the construction of the bottom 2 inches. A considerable amount of manipulation was required in mixing the top portion to insure thorough coating of all sand particles and to eliminate pockets of uncoated material between the two layers.

All equipment, except the crawler-type tractors, cut deeply into the sand. It was found advisable to insert a drag between the rear wheels and the spray bars of the distributor to eliminate the ruts formed by the wheels and to provide a smooth surface for applying the bitumen. The wheels of the steel-tired blade graders cut into the sand and frequently, when the mixing operation was practically completed, uncoated

TABLE 5.—*Analyses and tests of bituminous mixtures sampled at intervals subsequent to construction*

Section	Identification: Date sampled	Identification: Location, station	Composition by weight: Bitumen [1]	Passing ¼ inch retained on 10	Passing 10 retained on 20	Passing 20 retained on 30	Passing 30 retained on 40	Passing 40 retained on 50	Passing 50 retained on 80	Passing 80 retained on 100	Passing 100 retained on 200	Passing 200	Approximate percentages of original volatile material remaining in mixtures [2]: Top inch	2nd inch	3rd inch	4th inch	5th inch	Hubbard-Field stability [3] at 77° F.: Top inch	2nd inch	3rd inch	4th inch	5th inch	Composite
			Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
1-A	Sept. 1930	214+25	6.9	0	2.7	2.7	8.8	13.1	31.2	12.7	14.7	7.2						(4)	(4)	(5)	(5)	(5)	
	Aug. 1933	214+25	6.9	.1	2.7	4.1	7.5	12.7	31.9	11.7	16.0	6.4	56	82	64	60		1,890	575	375			
	Oct. 1935	214+25	7.0	0	2.5	3.4	6.6	12.6	29.4	10.5	16.0	12.0	33	62	63	61		2,776	800	947	1,182		
1-B	Sept. 1930	251+75	6.5	0	3.5	3.9	9.7	14.0	29.3	11.1	12.5	9.5											670
	Aug. 1933	251+75	7.7	.2	4.0	5.1	8.0	13.1	29.8	10.5	13.5	8.1	70	64	82	85		1,917	825	767	667		
	Oct. 1935	251+75	7.3	.1	4.4	4.5	7.5	13.4	27.6	9.3	13.4	12.5	40	48	54			2,727	1,160	1,110			
2-A	Sept. 1930	271+60	5.5	0	2.2	2.8	9.3	14.7	32.8	12.3	12.7	7.7											1,280
	Aug. 1933	272	6.8	.4	2.7	4.3	7.9	14.1	32.4	10.7	14.0	6.7	45	65	68	82		2,492	1,150	715	446		
	Oct. 1935	272	6.7	0	2.7	3.6	7.3	14.2	32.1	8.9	13.8	10.7	34	44	25	20		3,757	1,938	1,798	2,398		
2-B	Sept. 1930	304+50	6.4	0	1.1	1.5	6.8	11.6	31.0	12.6	15.3	13.7											860-930
	Oct. 1935		6.7	0	1.5	2.0	5.1	11.9	31.1	10.1	15.9	15.7	43	46	60	70	62	3,046	2,330	1,512	1,092	827	
3-A	Sept. 1930	326	6.6	0	1.0	1.2	4.3	8.3	30.2	17.0	20.9	10.5											390
	Oct. 1935		7.3	0	.7	1.3	3.3	7.8	29.5	14.3	22.8	13.0	32	43	54			3,826	1,350	1,233			
3-B	Sept. 1930	352	7.1	0	2.1	2.0	5.8	9.7	27.6	12.9	17.0	15.8											1,640
	Aug. 1933	365	7.7	.2	.6	1.4	4.1	9.4	32.3	13.7	19.0	11.6	37	63	62			1,926	1,317	1,313	1,692		
	Oct. 1935		9.3	0	1.3	1.8	4.4	10.2	30.6	11.6	15.1	15.7	18	39	67	63		3,022	2,414	1,750	812	945	
4-A	Oct. 1930	380	7.2	0	1.1	2.1	7.5	12.2	30.0	12.9	15.1	11.9											1,120
	Oct. 1935	380	8.4	0	.9	2.0	5.1	11.1	30.4	11.0	15.6	15.5	32	30				3,336	3,008				
4-B	Oct. 1930	409	5.8	0	1.1	1.8	7.3	12.6	32.9	15.0	15.3	8.2											530
	Oct. 1935		7.2	0	1.9	3.1	6.4	12.9	30.2	11.4	17.2	9.7	34	48				3,308	1,562				
5-A	Oct. 1930	431	5.9	0	1.1	1.8	7.5	12.3	32.2	14.5	16.7	8.0											740
	Oct. 1935	436	6.9	0	1.4	3.5	7.2	13.6	32.2	10.8	16.4	8.0	26	38	39			4,254	1,918	1,084			
5-B	Oct. 1930	464	4.7	0	.5	1.2	7.3	14.2	36.4	15.0	16.1	4.6											320
	Oct. 1935		4.9	0	.9	2.0	5.0	10.9	32.2	13.2	21.1	9.8	20	31	48	43	37	3,462	1,940	1,288	1,248	1,343	
6-A	Oct. 1930	489	4.6	0	.8	1.9	8.3	14.0	37.4	15.3	14.6	3.1											320
	Oct. 1935	492	4.8	0	1.1	2.8	6.5	13.9	37.8	11.8	16.3	5.0	23	39	42	48		3,044	1,658	803	525		
6-B	Oct. 1930	513	4.5	0	1.3	1.9	8.0	13.4	36.5	15.4	15.3	3.7											310
	Aug. 1933	515	4.5	0	2.0	4.6	7.7	13.5	37.7	12.3	15.0	2.7	39	67	69	86	67	1,231	656	381	338	269	
	Oct. 1935	515	4.8	0	2.3	3.8	7.0	13.7	34.2	11.7	16.1	6.4	19	43	47			3,292	1,684	945			
7-A	Sept. 1930	Average of section	4.9	0	1.7	2.3	8.4	14.1	36.8	14.8	14.8	2.2						(6)	(6)	(6)	(6)	(6)	
	Oct. 1935	543	4.7	0	1.4	2.7	5.5	11.9	34.8	12.1	16.2	10.7						1,288	1,080	1,013	780		
7-B	Sept. 1930	Average of section	4.7	0	1.2	1.9	8.3	14.4	37.9	14.9	13.9	2.8						(6)	(6)	(6)	(6)	(6)	
	Aug. 1933	567	4.3	.1	1.1	3.0	6.4	12.9	37.4	11.6	14.7	8.5						375	494	381	367	292	
	Oct. 1935	573	4.8	0	1.1	2.7	6.3	13.6	35.7	10.9	14.2	10.7						1,224	1,220	1,228	1,016	855	
8-A	Sept. 1930	Average of section	5.4	0	1.1	1.6	7.5	14.3	39.2	15.1	13.7	2.1						(6)	(6)	(6)	(6)	(6)	
	Oct. 1935	594	5.7	0	1.0	2.0	5.3	12.9	37.6	10.9	14.3	10.3						1,108	850	882	787		
8-B	Oct. 1930	Average of section	3.9	0	1.2	1.9	7.9	14.1	39.4	15.4	13.9	2.3											140
	Oct. 1935	623	4.8	0	1.1	2.5	5.8	13.1	38.3	13.0	16.6	4.8	26	41	48	56		2,238	1,516	706	535		
9-A	Oct. 1930	Average of section	5.7	0	1.2	1.6	6.6	11.5	34.5	15.6	18.7	4.6											140
	Oct. 1935	617	6.3	0	.9	1.9	4.7	10.8	34.4	12.6	19.9	8.5	31	57				2,774	1,278				
9-B	Oct. 1930	Average of section	4.7	0	1.4	1.9	7.5	12.2	34.8	15.4	18.2	3.9											230
	Aug. 1933	673	4.9	0	1.7	3.8	7.0	12.5	37.5	12.2	17.7	2.7	49	75	81	80	71	1,800	769	456	394	331	
	Oct. 1935	673	4.8	0	2.1	3.7	7.2	13.9	33.8	11.4	16.9	6.2	29	46	53	53	51	2,768	1,618	772	658	633	
10	Oct. 1930	Average of section	6.0	0	1.3	1.1	4.2	8.5	29.4	15.1	22.3	12.1											860
	Oct. 1935	713	7.0	0	.7	1.3	3.5	8.5	30.3	11.5	21.4	15.8	45	59	52	58		3,288	2,062	1,654	1,283		

[1] Water-free.
[2] Calculated from the average losses at 163° C. of 20-gram samples of the original bituminous materials and the loss in weight of loose mixtures cured to approximately constant weight at 163° C. All calculations made on a water-free basis.
[3] Tests on mixtures sampled in 1930 were made on specimens molded in the laboratory from the loose mixtures. Tests on mixtures sampled in 1933 and 1935 were made on 2-inch specimens cored from the sections and cut into 1-inch layers for the Hubbard-Field test.
[4] Stability of sample of top 2 inches=1,000 pounds.
[5] Stability of sample of bottom 3 inches=400 pounds.
[6] Too soft to form specimens for testing.

sand was brought up by the wheels, necessitating additional manipulation. On one section 250 passes of the blade were required to complete the mixing operation.

Laboratory experiments had indicated the advisability of adding a filler to increase the stability of the poorly graded sand and it was decided to try commercial limestone filler for this purpose. Approximately 10 pounds per square yard of this filler were added to the south ½ mile of each section, designated as section B. Filler was applied with drill-type spreaders of the type commonly used in applying agricultural limestone. When the 5 pounds per square yard of filler to be used in a 2-inch layer had been spread, it was disked with the sand until the mixture appeared to be uniform. The bituminous material was then applied and construction carried out in the same manner as on the sections to which the filler had not been added. No additional mixing was required on account of the filler.

After the top layer had been mixed, it was spread and allowed to compact under traffic. Some light blading was done during the compacting period but the surface was not rolled.

Construction began at the north end nearest O'Neill where the filler and oil were received by rail. Equipment, trucks, distributors, and a small volume of other traffic passed over the sections as they were completed. Such traffic was encouraged to use the entire road width so that compaction, while relatively light, was fairly uniform except at the edges.

Figures 1, 2, and 3, illustrate various conditions and steps in the construction. Figure 1–A is a view of section 3A, near the north end and shows the condition of the soil and surface before bituminous construction began. Figure 1–B shows the sand that was to be used in the top 2 inches windrowed at the sides and the exposed surface of the bottom 2 inches ready to receive the bitumen. Figure 1–C shows the bitumen being applied to half the width of the road. Between the rear wheels and spray bars is a drag held by chains fastened to the front axle. The distributor wheels cut into the sand, especially on the lower 2 inches but the drag filled the ruts just ahead of the spray of bitumen. Immediately following an application of bitumen, a disk such as is shown in figure 1–D made a

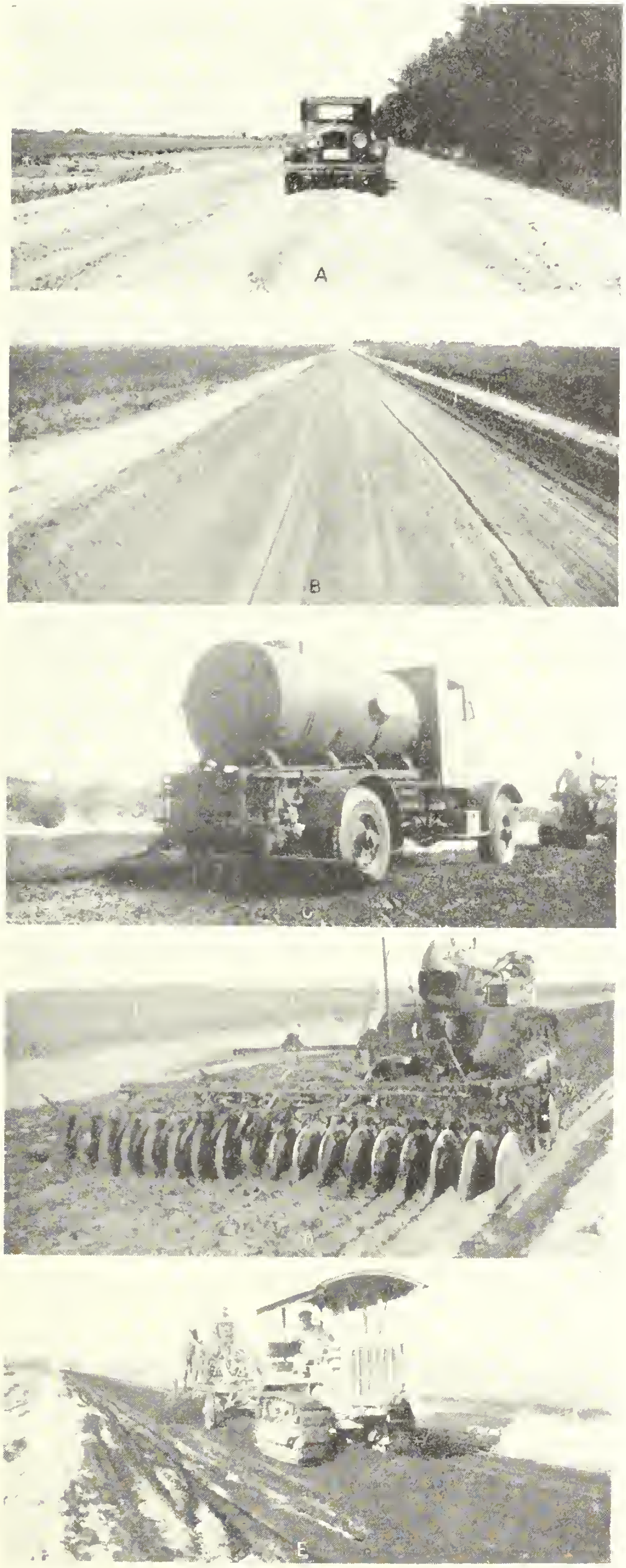

Figure 1.—Appearance of the Road before and during Construction of the Bituminous Surface. A, Portion of Section 3A before Bituminous Treatment. B, Sand for the Top 2 Inches Windrowed at the Sides. C, Bituminous Material Being Applied at the Rate of ½ Gallon per Square Yard. D, Pre-mixing of Sand and Bitumen with a Disk Harrow. E, Uniform Mixing Was Difficult with the Old Equipment Available.

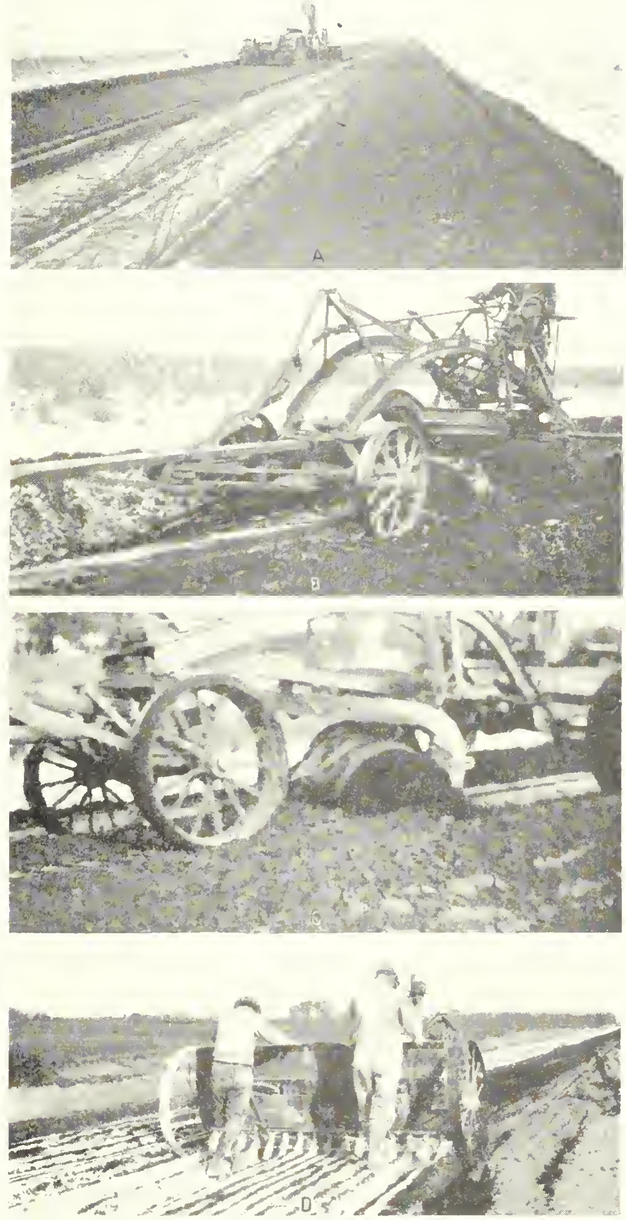

Figure 2.—Appearance of the Surface during Construction. A, Blade Grader Spreading the Top 2 Inches of the Surface; the Remaining Windrows Contain Material for the Shoulders. B, the Equipment Used Was Ill-suited to Perform the Work Required of it. C, in Cold or Cool Weather the Mixture Was too Ropy to Mix Well and Was Picked up by the Wheels. D, Spreading Limestone Dust with a Drill-type Spreader.

round trip over the area just covered. Figure 1–E shows the bottom 2 inches being mixed. The light areas within the side limits of the mixture are uncoated sand brought to the surface by the grader wheels. This might occur at any stage of the mixing process; and if it occurred when the mixing operation was nearly completed, a considerable amount of additional manipulation became necessary.

Figure 2–A shows the top 2 inches being spread for compaction by traffic. Figures 2–B and 2–C are other views of the mixing operation and show the type of

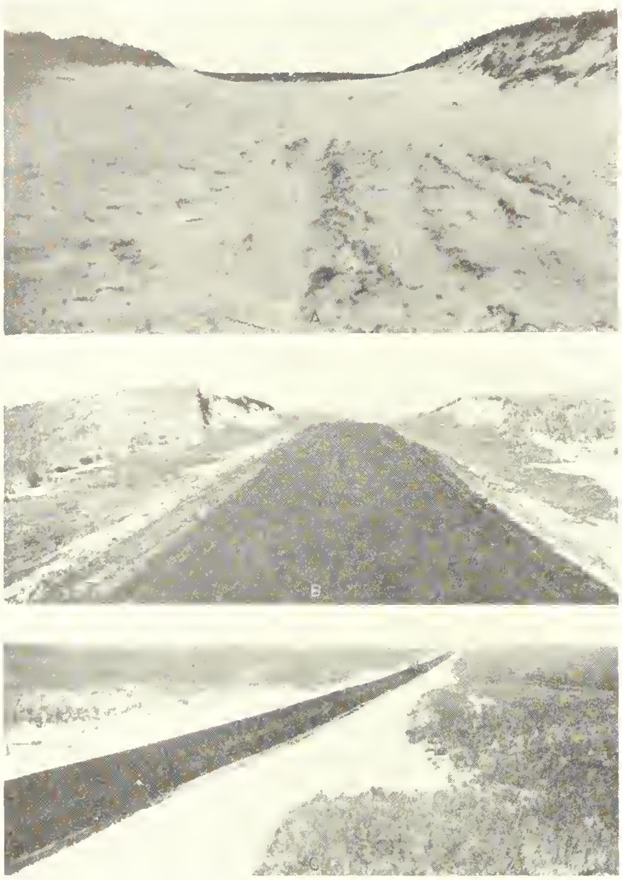

Figure 3.—A Portion of Section 6B before, after, and during Construction. A, this Portion of the Road Had to be Restored to Grade Twice before the Surface Was Mixed. B, Same Area Shown in A after the Mat Was Completed and the Shoulders and Slopes Had Been Seeded and Covered with Hay to Prevent Water and Wind Erosion. C, Constructing the Mat Through Typical Sand-hill Country.

equipment used. The cup-shaped rims of the steel wheels shown in figure 2–B were presumed to prevent side slip but were not effective in this respect. The difficulty in attempting to road-mix in cold weather is illustrated in figure 2–C. The mixture was very ropy and could not be mixed. The sticky mixture adhered to the wheels, making the blade difficult to handle and hard to pull.

WIND-SHIFTED SAND INTERFERED WITH CONSTRUCTION OPERATIONS

The limestone dust used on the B sections was spread with the spreader illustrated in figure 2–D. When applying dust to the bottom 2 inches, a tractor was needed to pull the spreader, but on the top 2 inches a truck was satisfactory most of the time. Figures 3–A, 3–B, and 3–C are photographs taken at stations 506 and 507. Figures 3–A and 3–B show the same area before and after bituminous construction. The cut shown in figure 3–A had to be brought back to grade twice before the bituminous mat was built. Wind-borne sand built up some portions and the wind removed sand from other portions so that no advantage was gained by bringing the surface to grade very far ahead of construction. Figure 3–B shows the same area after the bituminous surface was constructed. The shoulders and slopes have been covered with prairie hay to reduce wind and water erosion.

Figure 3–C is a view looking south from station 506 and shows typical sand-hill country. The trails paralleling the new road on both sides were used in preference to the old sand road. Figure 4, shows the most prevalent type of traffic, other than automobiles, that used the road. The gross load of this wagon was 8,430 pounds and was carried on wheels with 4-inch steel rims. The front wheels carried 410 pounds per inch width of tire and the rear wheels carried 644 pounds. Although the day on which the photograph was taken was warm and the cut-back section on which the vehicle traveled was not well compacted, the wheels while moving did not cut into the surface. They did mark the surface definitely but the marks were later ironed out by other traffic. Traffic such as that illustrated is fairly heavy during marketing season and, as the shipping point is O'Neill, all loaded vehicles traveled in the same direction and used the same side of the road. This concentration of relatively heavy traffic had no noticeable effect on the road surface.

Figure 4.—Loads of this Character Made up the Bulk of the Traffic, Other Than Motor Vehicles, that Used the Road.

Construction of bituminous mats by the mixed-in-place method is common practice at the present time and is not considered especially difficult where a reasonably substantial base is available and equipment adapted to the purpose is used. However, for the conditions existing on this road, as shown by the foregoing photographs, construction was not as simple as might be inferred. Two factors, especially, added considerably to construction difficulties. One that was present constantly was the problem of mixing the extremely loose sand to a given depth when the material that had to serve as a base was an indefinite depth of the same loose material.

The other factor was wind-drifted sand. So extensive was this movement at times that considerable work was required to restore the road grade immediately ahead of bituminous construction. During the mixing operation, especially when a section was only partially mixed, work had to be stopped when drifting became especially bad. Application of the limestone filler also was delayed at times because of the wind. When the bituminous mixture was being spread, drifting sand was sometimes deposited on it in sufficient amounts as to make some remixing necessary.

After a cut-back section had been laid down and had received even a small amount of compaction, drifting sand did not remain on the surface but was carried across it. Figure 5–A shows sand drifting across a cut-back section. It will be noted that where the surface has been made smooth by pneumatic tires, the sand is not intercepted but is filling the depressions made by the tractor cleats and also has covered the edges. On the road-oil sections the moving sand was more troublesome as it remained on the surface in considerable amounts and at one time, as illustrated in figure 5–B, nearly filled the side ditch and completely covered a 2-foot strip of the oiled-sand mat. It has become common practice more recently to use ordinary snow fence to control the drifting of sand in bad areas, not only as an aid during construction operations but also as a protective measure for the finished road.

FIGURE 5.—A, SAND DRIFTING ACROSS A CUT-BACK SECTION. THE WIND WAS BLOWING TOWARD THE CAMERA AND AT A SLIGHT ANGLE TO THE CENTERLINE OF THE ROAD. B, DRIFTED SAND ON A LOOSE, ROAD-OIL SECTION. THE SPADE MARKS THE RIGHT EDGE OF THE BITUMINOUS MAT.

The experimental road was constructed by contract except that the limestone dust was handled on a force-account basis. The unit costs of the various items contained in the contract were as follows:

	Cents per gallon
94+ road oil cut-back, applied	9. 72
60–70 road oil, applied	9. 72
100–120 penetration asphalt cut-back, applied [1]	9. 72
100–120 penetration asphalt cut-back, applied [2]	12. 02

	Cents per sq. yd.
Manipulating bitumen and aggregate	7. 90
Limestone dust in place (average cost) [3]	6. 30

[1] Used on sections 4, 5, and 6.
[2] Used on sections 8B, 9, and 10.
[3] Actual cost to contractor plus 15 percent profit.

SECTIONS VARIED IN APPEARANCE AND PROPERTIES

The costs of the different sections, based on the above unit costs, are given in table 1. These are merely the costs to the State and give no indication of the actual total cost of the experimental road.

As might be expected, the mats in which the cut-backs and slow-curing materials were used differed considerably in appearance and properties. The cut-back sections compacted under traffic and, except at the edges, very quickly acquired the color and appearance of a sheet asphalt pavement. The surface was dense and fairly smooth although the transverse profile of some of the sections was not especially uniform. The road-oil sections, on the other hand, remained in a loose condition and, while their surfaces compacted some under traffic, they did not attain any bond or acquire a smooth transverse profile. The mixture was readily displaced by traffic until the advent of cool weather when, because of the increased viscosity of the bitumen, temporary stability and bond were obtained.

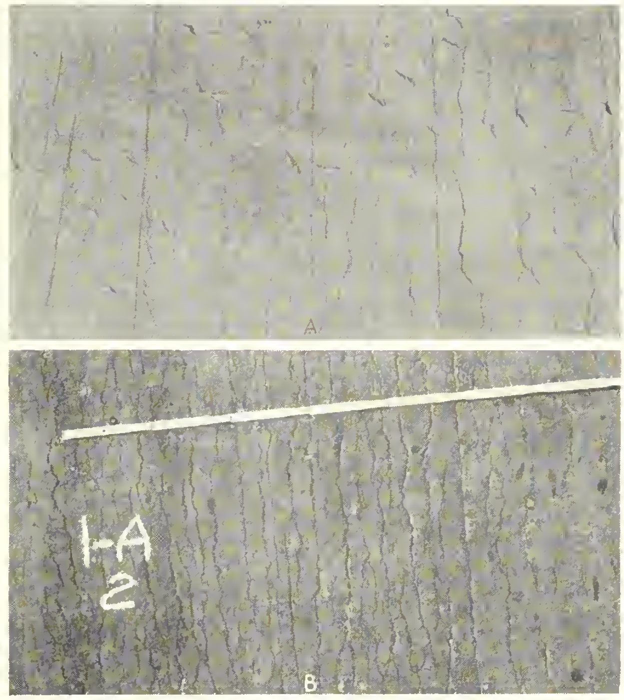

FIGURE 6.—THE SURFACES OF CUT-BACK SECTIONS CRACKED LONGITUDINALLY; A, DURING COMPACTION, AND B, AS THE SURFACE AGED.

Surface cracking was not observed on the road-oil sections but was very pronounced on the cut-back sections. Here fine longitudinal cracks appeared almost as soon as a section was subjected to traffic and became more extensive as the surface gradually developed a thin crust. Marks of steel-tired traffic, made while the surface was still soft, became cracks as the crust formed. Most of these cracks were extremely narrow and of no considerable depth. They did not affect the riding quality of the surface but did give it an unsightly appearance. For some time, as the sections increased in age, the cracks increased in number, but not greatly in size or depth, and they did not heal under traffic in spite of extended warm weather.

Loss of volatile material in the cut-back asphalt resulted in the formation of a surface crust that prevented the escape of the volatile material remaining in the mixture below it. Consequently, the mixture retained its original plasticity and moved under traffic, causing the thin surface crust to crack.

Figure 6–A illustrates the character of surface cracking that developed during the compacting period and immediately thereafter. Figure 6–B shows the extent to which cracking developed after a time in service. It should be noted, however, that while the cracking

Figure 7. The Road-oil Sections Remained in a Loose Condition Except in Cold Weather. After Fine Soil Filler Was Added the Mixture Compacted and Became Stable.

may be considered excessive, raveling was practically negligible. The pieces of surface crust, although detached from the adjoining surface, adhered to the more plastic mixture immediately below the surface and consequently were but rarely displaced by traffic.

Since the bituminous material in the road-oil sections 7A, 7B and 8A contained practically no volatile material that would be lost at normal temperatures, little permanent change in viscosity occurred except that caused by weathering. Consequently, with the return of warm weather in the spring following construction, the sections containing the road oil gradually softened and lost the bond they had during cooler weather. They were soon in the same loose, uncompacted state in which they had been immediately after construction. When in this condition, illustrated in figure 7, travel was difficult and traffic followed a single lane until the ruts that were formed extended below the bottom of the mat and travel became almost impossible. It was realized that some modification of the road-oil sections was necessary in order to increase their stability sufficiently to carry traffic in warm weather.

The first attempt to stabilize these sections was made in 1931 by adding sand to a 500-foot portion of section 8A. This did decrease the richness of the mixture but as the only sand available was similar to that already in the mixture, practically no increase in stability was obtained. Consequently, it was decided to experiment by changing the grading of the aggregate to obtain more frictional resistance by the addition of finely graded material. Commercial filler was deemed too expensive so it was decided to try soil as a filler.

Tests were made on clays from several pits whose soils had low plasticity indexes. The material selected was taken from a pit near the south end of the experimental road. It was not processed in the pit and considerable difficulty was experienced in breaking down the soil lumps during the mixing operation. Approximately 20 percent of filler by weight was added to the oiled sand of section 8A. This experiment gave quite satisfactory results in that sufficient stability was obtained to carry the traffic. The remainder of the road-oil sections rutted badly during the summer of 1931 and had to be bladed and dragged repeatedly.

With the return of warm weather in 1932, a repetition of this unsatisfactory condition was apparent so it was decided to add soil filler to all sections of the experimental road that contained road oil. From the experience gained in 1931, a different filler was selected. This material was a silty clay soil found in the bottom of an old clay surfacing pit about 8 miles south of the south end of the experimental road. This filler had the following characteristics:

	Percent
Mechanical analysis:	
Fine sand, 0.25 to 0.05 mm	20
Silt, 0.05 to 0.005 mm	66
Clay, smaller than 0.005 mm	14
Colloids, smaller than 0.001 mm	6
Tests of material passing No. 40 sieve:	
Liquid limit	25
Plasticity index	2
Shrinkage limit	20
Shrinkage ratio	1.7
Centrifuge moisture equivalent	20
Field moisture equivalent	30

This material was disked, pulverized, and windrowed in the pit. It was placed on the road in two applications. The first application was mixed with the lower half of the oiled sand which was exposed by windrowing the top half of the mat. The second application of filler was mixed with the top half of the oiled sand. A total of 42 pounds of filler per square yard was used.

FILLER MATERIAL CONSIDERABLY INCREASED STABILITY

The results obtained were quite satisfactory. The surface did not crust as much as that of the cut-back sections did, and traffic marked it somewhat. Sufficient stability was developed, however, to meet the demands of traffic. In table 5 are given the Hubbard-Field stability test results on cores taken in 1933 and 1935. It will be noted that considerable stability, as measured by this method, had resulted from the addition of the filler, since the mixtures sampled immediately after construction had practically no stability. Moreover the stability thus obtained not only was apparently adequate in warm weather but also, as shown by the curves in figure 8, was much less affected by temperature changes than was the stability of the original mixture.

After the soil filler was added, the road-oil sections remained in good condition for 5 years and required practically no surface maintenance. Figure 9–A, a view taken in October 1935, shows the typical condition of these three sections during this period, which is in marked contrast to their early appearance, as shown in figure 7.

Some dusting of the surface and pot-holing began to appear in 1937. Cracking also appeared in the outer wheel lanes, caused primarily by lack of shoulder support. This condition is shown in figure 9–B. The sections were surface-treated in May 1938 with 0.3 gallon of RC–2 cut-back [2] and 35 pounds of pit-run gravel per square yard. This treatment was beneficial in eliminating the previous defects. Maintenance through the spring of 1940 was practically negligible. The cost of maintaining, reconstructing, and surface-treating these sections is given in table 6.

In passing, it is interesting to note that the plan of adding mineral filler to increase the stability of road-oil sections was later used by the State on other road-oil-sand roads when it became necessary to increase their stability. Fillers were also used on all oiled sand roads

[2] Cut-back materials containing kerosene and naphthas had been used prior to the construction of this road but they varied considerably in composition and in their curing properties. About 1932, however, such materials were standardized on the basis of composition and rate of curing into medium-curing (MC) and rapid-curing (RC) materials having definite properties. Each class was further divided into several grades on the basis of viscosity. Thus, an RC–2 material is a rapid-curing, cut-back material having a Furol viscosity of 200 to 400 at 122° F. The MC–2, for example, is a medium-curing cut-back of the kerosene type having a Furol viscosity of 150 to 250 at 140° F.

The use of specific designations such as MC–2 or RC–2, therefore, is taken to refer to materials meeting the standard specifications for such definite materials, whereas the use of such general terms as cut-backs refers to the general type of materials such as were used in the construction of this road.

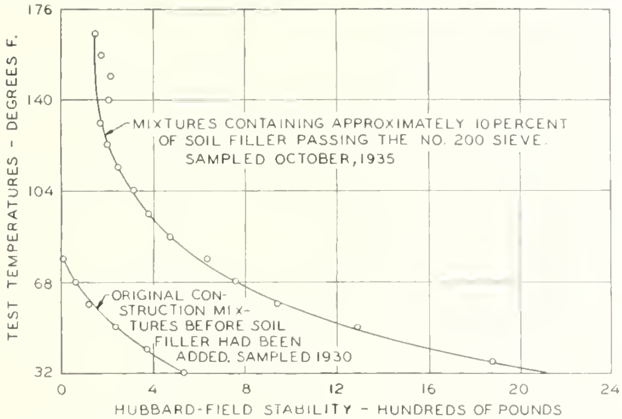

FIGURE 8.—EFFECT OF TEMPERATURE ON THE STABILITY OF LABORATORY MOLDED SPECIMENS OF ROAD-OIL SECTIONS 7A, 7B, AND 8A.

constructed in 1932 and later, when stability tests indicated that filler was necessary.

TABLE 6.—*Cost of maintaining the bituminous surfaces from Nov. 1, 1931, to Jan. 1, 1940, exclusive of equipment, depreciation and administration costs*

Section		Type of maintenance			Total cost		Average annual cost	
No.	Type	Routine	Reconstruction	Surface treatment	Per section	Per sq. yd.	Per sq. yd.	Per mile
		Dollars	*Dollars*	*Dollars*	*Dollars*	*Cents*	*Cents*	*Dollars*
1A	Cut-back	162		180	342	5.63	0.69	85
1B	do	60		180	240	3.81	.47	58
2A	do	94		180	274	4.52	.55	68
2B	do	230		199	429	7.01	.86	106
3A	do	92		219	311	5.06	.62	76
3B	do	153	213	248	614	10.12	1.24	153
4A	do	70	294	237	601	9.54	1.17	144
4B	do	35		180	215	3.54	.43	53
5A	do	37		180	217	3.44	.42	52
5B	do	33		180	213	3.52	.43	53
6A	do	45		180	225	3.57	.44	54
6B	do	49		180	229	4.09	.50	62
7A	Road oil	[1] 154	370	180	704	11.17	1.37	169
7B	do	[1] 133	370	180	683	10.84	1.33	164
8A	do	[1] 210	370	180	760	12.53	1.53	188
8B	Cut-back	40		220	260	4.13	.51	63
9A	do	27		210	237	3.91	.48	59
9B	do	58		220	278	4.39	.54	67
10	do	67		210	277	4.60	.56	69

[1] Includes cost of blading during the first 2 years before these sections were stabilized.

Cut-back sections 1A, 1B, and 2A were completed in 1929. Section 2B was partially constructed in 1929 and was completed in 1930, as were the remaining cut-back sections. There was no apparent difference in appearance or early service behavior between the sections with limestone dust and those without, or between those containing the cut-back made with 94+ road oil and the ones containing the 100–120 penetration asphalt cut-back.

Very shortly after construction, however, there appeared a condition on section 1A that was strictly local and that was not duplicated elsewhere on the experimental road. On approximately the south 100 feet of section 1A, the surface cracked extensively. The cracks opened to a considerable width and small areas bounded by such cracks displaced under traffic. What appeared to be pure viscous bitumen emerged through some of the cracks and spread over the surface in small pools. During the 1930 construction period, sections 1A,

FIGURE 9.—ROAD-OIL SECTION AFTER ADDITION OF FINE SOIL FILLER. A, NOTE VEGETATION COVERING THE SHOULDERS AND SLOPES; B, CRACKING APPEARED IN THE OUTER WHEEL LANE, AND ROUGHNESS, DUSTING, AND POT-HOLING DEVELOPED.

1B, 2A, and 2B were plowed, remixed, and relaid to obtain a more satisfactory cross-section. This work was done in September, and very shortly thereafter movement of bitumen to the surface again began on the south end of section 1A. As an experiment, a small portion of the area thus affected was torn up and remixed by hand. No materials were added and the mixture was relaid and hand tamped. This method of repair was successful, as the area reworked remained free from cracking and no bleeding or exuding of bitumen occurred. Figure 10–A, a view of this area 3 years after reworking, shows the stable area and also the adjacent areas through which bitumen continued to exude.

The subgrade under the south end of section 1A has high capillary and moisture retentive properties. Prior to construction of the bituminous mat traffic mired down in this area, which was a virtual swamp bog despite the fact that the soil contained considerable sand. A supply of moisture was continuously available and apparently was pumped to the surface of the base by a vibrating effect produced by traffic. Apparently, the hydrostatic pressure and the moisture vapor pressure during warm weather were sufficient to force the bitumen to flow out through the cracks in the mat.

CUT-BACK SECTIONS SUFFICIENTLY STABLE FOR MOVING VEHICLES

The cut-back sections remained in a satisfactory condition during the first winter but, with the advent of warm weather the following year, they softened some since the viscosity of the bituminous material naturally decreased as the air temperature increased. However, some permanent increase in viscosity had been obtained through the loss of some of the volatile material and consequently these sections increased in stability

Figure 10. Places Where Surface Failure Occurred. A, the Rectangular Portion in the Center Was Remixed and Tamped by Hand; Shiny Areas Are Pools of Bitumen. B, Break-up Caused by Untreated Sand Lying Between Upper and Lower Portions of the Mat.

independently of atmospheric conditions. At all temperatures they were sufficiently stable to carry moving traffic without detriment, but vehicles standing on the surface for any length of time in warm weather sank into the mat. The surface crust increased in thickness very slowly, due to the relatively slow rate at which the volatile material was dissipated.

By September 1932, section 3B had become unsatisfactory. The north end was very rough and the south end, apparently becoming rich and unstable, had shoved and cracked. The north end lies on a fill composed of mucky, silty loam which rests on soil of the same type. The south end of the section lies on a low sand fill. The entire section was scarified and remixed in September 1932. No bituminous material was added to either portion, but filler such as had been used in stabilizing sections 7A, 7B and 8A, was added to the south portion in the amount of 10 to 15 pounds per square yard. Remixing and aeration of the cut-back was beneficial but, on the north portion where the unsatisfactory condition was due primarily to the base material, this benefit was temporary.

The addition of filler to the south end of the section, together with the aeration of the cut-back, increased the stability of the mat considerably. The surface cracks present before remixing did not reappear and 1 year later this part of the section was in good condition, whereas the north portion, in the spring of 1933, had settled and was again rough and badly cracked.

At the time section 3B was reworked, the north two-thirds of section 4A was scarified and remixed to eliminate the badly cracked, checked, and rough condition of the surface. Four-tenths gallon of road oil per square yard was added in the remixing process. One year later this area was in good condition. The number of cracks in evidence was considerably less than before remixing and the mat showed no tendency to ravel. The south one-third of this section, which was not remixed, was badly surface cracked at this time.

In the spring of 1933, a part of section 3A near the north end again began to fail. On a 165-foot portion about 700 feet from the north end the mat began to break and settle into the mucky soil of the fill. As the cause of the failure lay in the base and subgrade rather than in the bituminous mat, an attempt was made to develop stability by constructing a drainage system in the fill. A French drain 2 feet wide by 2 feet deep was installed under the center of the road with two laterals to each side. Coarse material ranging in size from 1 to 5 inches was placed in the trenches. The fill was then restored to grade and cross section, after which the bituminous mat was remixed with 2.4 gallons of road oil per square yard and relaid. This drain was an effective remedy and after 7 years is still operating. Some displacement of the mat has occurred for about 200 feet from each end of the drained portion, indicating that an extension of the drains would have been beneficial.

With the exception of the work done on sections 3B and 4A in 1932 and 1933, the cut-back sections required little attention up to the fall of 1935. Little change in appearance occurred except that the number of cracks increased, adding to the unsightliness of the surface. The amount of raveling that occurred was practically negligible and there was a gradual increase in the stability of the mixture. As shown by the results of tests on cores taken in October 1935, the mixture below the surface had acquired considerable stability (table 5).

Maintenance of the surface prior to 1935, excepting the work described, consisted mainly of routine patching to fill depressions caused by standing vehicles, repair of raveled areas, and small replacements where the mat broke. In practically all of these small break-ups it was observed that the part of the mat that broke was very thin and that untreated sand lay between it and the mat below it. Figure 10–B shows several areas that failed from this cause, which was a construction defect.

Maintenance of other portions of the right-of-way consisted of seeding the slopes and shoulders and spreading hay on them to induce the growth of vegetation and prevent wind and water erosion. During the fall of 1934 the shoulders and slopes were rebuilt and surfaced with clay in the sandy sections, 5B to 9B inclusive, and a part of section 10. Work of this character ordinarily constitutes a greater part of the total maintenance required in the sand-hill area than does the actual maintenance of the road surface.

SEVERAL CUT-BACK SECTIONS GIVEN SURFACE TREATMENTS

In an attempt to seal the surface cracks, smooth the surface, and at the same time reduce the likelihood of raveling, several of the cut-back sections were given a seal treatment early in October 1935. The treatment was applied for a width of 18 feet and consisted of approximately 0.25 gallon of medium-curing cut-back asphalt (MC–2), and 30 pounds of unscreened sand-gravel cover per square yard. The bitumen and aggregate were not mixed but the completed surface was rolled with a pulled roller. The treatment was applied on the west half of the south 100 feet of section 3A (9-foot width) and to all of sections 3B, 4A, 8B, 9A, 9B and 10, all of which are cut-back sections. It was also applied to the south 100 feet of section 8A, which is a road-oil section.

When inspected later in October, the treatment was still relatively soft and it had not bonded with the surface crust of the old mat. Cool weather had apparently prevented the cut-back from softening the old mat and producing a bond and had also prevented sufficient loss of the volatile portion of the cut-back to develop stability. The treatment was easily marked by horses' hoofs and it had picked up somewhat under traffic.

The MC material was used in an unsuccessful attempt to obtain some surface penetration. The earlier behavior of the treatment would probably have been more satisfactory had a rapid-curing material been used, such as was used later on other sections. However, the seal containing the MC material gradually stiffened and eventually assumed the same appearance as that of the sections on which an RC material was used in constructing a seal treatment later.

The unscreened sand-gravel used as the cover material contained some relatively large pebbles that were embedded by rolling, as was some of the finer aggregate. Aggregate not held by the bitumen was whipped to the sides by traffic. Figures 11–A and 11–B are typical views of the surface treatment taken late in October.

In July 1937 a surface treatment was applied to the south 800 feet of section 2B and to all of section 3A. This treatment consisted of an application of 0.32 gallon of RC–2 asphalt and a cover of 35 pounds of pit-run gravel per square yard. A similar treatment was applied in May 1938 to all the sections of the experimental road that had not been previously treated.

As might be expected from the method of applying the treatments without manipulating the bitumen and cover, the resulting surfaces were not uniform in appearance generally. More bitumen and cover were held in the depressed areas, obviously, than on the higher areas. The cracks were sealed but they were covered only in the depressed areas where the surface treatment mat was of appreciable thickness. Figure 11–C is a view of the surface of section 9A 3 years after it was surface treated and is typical of the surface texture obtained by the treatments.

Aside from these treatments, surface maintenance requirements have been very light and have consisted almost entirely of patching to eliminate small depressions. The cost of constructing, maintaining, and re-treating the various cut-back sections is given in table 6.

As stated earlier, the main purpose of this experiment was to develop information on the use of various types of liquid asphaltic materials with poorly graded sand. It was expected that additional information on construction methods would be obtained that would be of value in formulating a program of bituminous construction suitable for the sand-hill region. The experimental road not only yielded direct information of considerable value but also indicated a number of phases of design and construction that required solution before a detailed plan of construction could be developed that would utilize local materials to the fullest extent and most economically.

Such information as was developed by the experiment was put to practical use in later construction work and in initiating research studies which the experiment indicated were necessary. Obviously most of the

Figure 11.—A, Cut-back Section after Re-Treatment. The Grass Line Marks the Edge of the Original Bituminous Mat and the Arrow Marks the Edge of the Re-treatment. Loose Material near the Edges Has Been Whipped to the Sides by Traffic. B, Appearance of the Surface Immediately after Re-Treatment. C, Appearance of Section 9A 3 Years after Surface Treatment. The Dark Strip is the Area Between Wheel Tracks and is Slightly Raised.

information developed by an experiment of this character can be used long before a report covering its history for any extended period can be published. However, since current specifications are based largely upon experience gained in previous construction and on closely observed experiments such as herein described, a discussion of the information obtained on this experiment and its part in the development of present-day methods of construction should prove of interest.

SEVERAL IMPORTANT FACTS REVEALED BY EXPERIMENT

In addition to emphasizing the necessity for using efficient equipment and for providing adequate supervision and control that are so essential in the low-cost types of construction, the experiment brought out a number of facts relative to design and construction, the more important of which were as follows:

1. The stability obtained with the cut-back asphalt was considerably greater than that obtained with the slow-curing road oil but neither material provided satisfactory stability with the natural blow-sand.

2. Lack of stability resulted in excessive surface cracking of the cut-back sections and caused the road-oil sections to remain in a loose, uncompacted state.

3. Loss of volatile material in the cut-back mixture

at the immediate surface caused the formation of a thin, hard surface crust but the mixture below the surface, retaining such volatile material, remained plastic and moved under traffic, thereby causing the surface crust to crack.

4. Extended manipulation did not remove sufficient volatile material from the cut-back sections to make them stable. The addition of filler material was much more effective than continued or extended manipulation.

5. The lack of mechanical stability of the blow-sand was not compensated for by the cut-back asphalt while it retained the volatile diluent or by the slow-curing oil which had little cementing value.

6. The presence of the relatively small percentage of commercial filler added to alternate sections could not be detected by visual inspection, on the basis of service behavior, or by analysis of the finished mixture. The filler naturally contained in the blow-sand varied considerably and, in many instances, was greater than the amount of commercial filler added.

7. The addition of a considerable amount of soil filler was effective in imparting satisfactory stability to the road-oil sections as well as to the cut-back asphalt section to which it was added.

8. The addition of soil filler to one of the cut-back sections was of apparently greater benefit than was remixing to increase stability and eliminate surface cracking.

9. Failure to eliminate the volatile portion of the cut-back asphalt prevented the formation of the expected cementitious residue. Had a more rapid-curing material been used, it would have lost a greater amount of volatile matter during the manipulation and would therefore have provided greater stability.

10. The desirability of mechanical compaction for greater immediate stability was indicated, although self-propelled rollers of the type then available did not appear suited to the conditions existing on the road.

11. Inefficient equipment added to the difficulty of construction. The narrow, steel-tired equipment, nonflexible in operation, prevented rapid and successful prosecution of the work. The need for equipment designed for the various operations required was very evident.

During construction as well as in the early life of the experimental road it was quite apparent that definite information was highly desirable on a number of factors, the most important of which were as follows:

1. The stability required for satisfactory service behavior.
2. The relation between the grading of the aggregate and the amount of bitumen required.
3. The relation between the character and grading of the aggregate and the type and character of the bitumen.
4. The character and amount of filler required.
5. Effect of compaction and amount required.
6. Essentials of construction procedure.

It will be observed that all of these factors, except possibly the last enumerated, directly affect that property of pavements referred to as stability which, for the purpose of this discussion, will be taken to mean the resistance of the bituminous mat to displacement under static and moving loads as measured by the Hubbard-Field stability test method.

That there was need to determine what stability is required for static and moving loads is very definitely indicated by the service behavior of the different experimental sections and by reference to the stability test results on mixtures (table 5).

It has been noted that, in their early life, the road-oil sections were unable to carry any load without displacement and that they had little or no stability as measured by the Hubbard-Field method of test. The cut-back sections, on the other hand, had considerable stability as measured by the laboratory test method and in service they carried moving traffic, although with some resulting deformation. Standing vehicles, as mentioned before, sank into the mat in warm weather. In 1932, however, soil filler was mixed with the road-oil sections and the resulting mats became entirely stable, so far as concerned their ability to carry traffic, and have so remained. The cut-back sections during this period did increase somewhat in stability as their plasticity decreased, but such increase was slow, whereas the road-oil sections attained a high resistance to displacement almost immediately after the soil filler was added.

The data in table 5 show that the stability, as measured by the Hubbard-Field test, is decidedly lower for the road-oil than for the cut-back sections. Apparently the mechanical stability afforded by the soil filler, although it failed to produce a mixture having a high Hubbard-Field stability, was of greater benefit than that developed by the cut-back asphalt binder. The former, having practically no plasticity, was not affected by temperature changes or by the amount or rate of application of load. The cut-back mixtures, however, could be expected to retain some degree of plasticity for an indefinite period and consequently would be more susceptible to deformation under load. The amount of such deformation would, moreover, be affected by the temperature and the amount and rate at which the load was applied. It is apparent, therefore, that a laboratory stability test alone cannot serve as a probable service indicator for the comparison of mixtures having such fundamentally different characteristics.

AMOUNT OF BITUMEN LESS IMPORTANT THAN AMOUNT OF VOLATILE MATERIAL RETAINED

In this experiment no attempt was made to determine the effect of the percentage of bitumen used. Approximately 4 gallons of bituminous material per square yard were applied on each section. The variations in bitumen content shown by extraction tests are due somewhat to unavoidable variations in applying the bitumen but primarily to variations in depth of the mixture. The resulting variation in bitumen content was not apparent in the behavior of the various sections nor does there seem to be any relation between the bitumen content and corresponding stability. This might be attributed to the fact that all of the sand mixtures, strictly speaking, were rather open and that small variations in bitumen content were therefore not important. Although the amount passing the No. 200 sieve varied from about 2 to 16 percent, the higher amount was only approximately half of that which would be contained in a densely graded material having the maximum size of this sand. Had the mineral aggregate been more densely graded, it is probable that the variation in bitumen content would have been reflected in the behavior of the section. So far as concerns this road, it is apparent that the amount of bituminous material the mixtures contained was of less importance than was the percentage of volatile material it retained.

The most important characteristic of the blow-sand comprising the aggregate portion of the bituminous mixture was its lack of inherent stability because of poor grading. It was known that had the grading of the aggregate been improved increased stability would have been obtained and less dependence upon the bituminous material would have been required. Materials deemed satisfactory at that time for blending to obtain an improvement in grading were not available; consequently, the bituminous materials were tried out experimentally to determine to what extent they would furnish the required stability.

As was shown by the service behavior of both the cut-back asphalt and the road-oil sections, neither material provided sufficient stability with the natural blow-sand for two reasons. One was the retention of a large percentage of volatile material, and the other was the unsatisfactory grading of the aggregate.

It will be recalled that sections 1A, 1B, and 2A, which are cut-back sections, were completed in the fall of 1929 and that they were torn up and remixed in September 1930 when the remaining sections were being built. Remixing of these three sections did not greatly increase their stability nor did it prevent surface cracking later. It might be assumed that a certain amount of the volatile portion of the bitumen was dissipated in the mixing operation, although reference to table 5 indicates that the percentage retained was relatively high. In contrast to this behavior was the behavior of section 3B, also a cut-back section, after it was remixed in September 1932 and filler was added to a portion of it. As before mentioned, the portion that contained the added soil filler developed considerable stability and the surface cracking that had previously been so pronounced did not reappear so extensively. The other portion of this section, which was remixed but to which soil filler was not added, was not permanently benefited by the remixing operation. Evidently sufficient volatile material was not eliminated in the latter case, whereas the addition of the filler in the first case compensated for the presence of the volatile material by providing a mechanical stability of the aggregate or by causing an increase in the apparent viscosity of the bitumen.

ADEQUACY OF FILLER DEPENDS UPON MANY FACTORS

Although the cut-back material was of the character now designated as medium-curing, it is apparent that the diluent, which was of the kerosene type, contained a certain percentage of heavy ends that were nonvolatile at ordinary atmospheric temperatures. This nonvolatile fraction was evidently present in sufficient quantities to prevent the formation of a binder of sufficient cementitiousness. Had the diluent been more highly and completely volatile, it would have been dissipated by the manipulation and a more viscous residue would have been obtained. The more volatile type of material was not used since it was believed that too rapid a loss of diluent would make such material unsuitable for the road-mix method of construction. Moreover, from lack of experience, it was expected that in the mixing operation most of the diluent in the kerosene cut-back would be eliminated and that the desired viscous residue would be obtained. Consequently the specifications did not provide for additional manipulation to eliminate the volatile material or designate what percentage of it should be eliminated before the mixture was spread for compaction.

The original plan of the experiment was to attempt to develop a stable mat by providing the stability required solely by means of bituminous materials irrespective of the grading of the blow-sand. It was recognized that the grading was poor and that it would be improved by the addition of coarser material or filler, both of which would be expensive. Coarse material was not to be found in the vicinity and filler material, at that time considered synonymous with commercial ground limestone, would be very expensive. However, as a result of preliminary laboratory experiments with mixtures of blow-sand, cut-back asphalt, and limestone filler, it was felt that the addition of some filler was justified. It has already been shown that the small amount of filler thus used was not effective but that the addition of considerable amounts of soil filler produced satisfactory results where it was used in 1932.

Because of these satisfactory results, the plan of adding soil filler was used not only on other sections where the oil-sand mat was lacking in stability but on new construction later. The material used as a filler in 1932 on the experimental road was a silty clay whose analysis has been given. It was selected primarily because it contained a high percentage of very fine material, could be pulverized fairly easily, and because it was the only such material near at hand. It was not selected because of its characteristics as determined by routine laboratory tests for soils, since the importance of such characteristics was not recognized at that time. On other road construction where the addition of filler seemed advisable, the material was selected on approximately the same basis, that is, upon its fineness and low cementing value. It was soon noted, however, that variable results were being obtained that were not indicated by a cursory examination of the apparently acceptable materials.

No great amount of any one material was available at any one location and it was realized that a method would have to be developed for evaluating the merits of a considerable variety of materials as fillers if uniformly satisfactory results were to be obtained without greatly increasing the cost of construction. This led to a laboratory study of a variety of finely divided materials that might serve as fillers and included soils of low plasticity, limestone dust, silica dust, volcanic ash, loess, and waste lime from sugar refineries.

Since the filler was probably the most important constituent of the mixture, effort was made not only to develop methods of comparing one material with another, but also for determining the amount of various fillers required to provide stability for given conditions and the corresponding percentages of bituminous materials to use with such fillers.

Formulas for proportioning in use in other States were tried out in Nebraska after modifying them to suit Nebraska conditions. In all of these formulas the percentage of material passing the No. 200 sieve has the greatest effect on the bitumen content required. Where a plentiful supply of crushed rock and stone dust is available at reasonable cost, as is the case in many States, a simple formula whose application is practically State-wide is adequate. In Nebraska, however, where no great supply of any one kind of material that might serve as a filler is available, the problem was more complicated in that it became necessary to develop by laboratory research certain tests by which suitable filler coefficients could be established for use in the formula.

In determining the suitability or the comparative value of a material as a filler, its void-filling capacity as well as its properties as measured by the tests ordinarily employed in soil analyses was determined. The amount of bitumen required for any given filler was termed the *S* factor and was determined by consideration of a number of properties of the material. It was found that the characteristics that most greatly affected the percentage of oil required were (a), the fineness of the portion of aggregate passing the No. 200 sieve, (b) the absorptive capacity and surface condition of the particles and (c), the specific gravity of the material.

The method of determining the suitability of materials as fillers and of determining the *S* factors of materials considered as suitable is given elsewhere [3] in detail.

Essentially the method is as follows: Routine soil tests are used to measure such properties as particle size, bulk specific gravity, volume change, plasticity, and cohesion or cementation. The latter test indicates the ease with which a material can be pulverized. The stabilizing action of the filler or fillers is then determined by observing the effect of the filler in changing the viscosity of the oil. By laboratory experimenting it was found that the consistency of the filler-bitumen mixture measured by the Furol viscosity and float test methods brought out very definitely the differences between fillers and indicated their relative stabilizing effect. The combination of filler and bitumen necessary to produce a mixture having a float of 1,000 seconds at 100° F., determined by the A. S. T. M. method (slightly modified) was arbitrarily termed the filler-bitumen ratio and from this ratio the *S* factor was then calculated.

RESULTS OF LABORATORY RESEARCH USED TO OBTAIN BETTER MIXTURES

Information obtained by laboratory research, and applied to field construction, resulted in the gradual accumulation of data and information that made it possible to establish definitely the proper proportioning for bituminous mixtures. Obviously the greatest consideration was given to the filler material and its effect upon the quantity of bitumen required and conversely the amount of filler required with a given type of bitumen for satisfactory service behavior.

In contrast to the sketchy preliminary work and outlined plan of the experimental road, the method of procedure now used in sand-oil construction includes a survey of the materials available, a laboratory study of those materials, and a detailed method of construction. A survey is made of the material on the road and of deposits of fine material that may prove satisfactory as a filler. In the laboratory such materials are tested in experimental mixtures. The *S* factor, previously mentioned, is then determined for the filler or fillers.

The amount of a given filler required with a given bituminous material is determined in the laboratory by a modified Hubbard-Field stability test. Trial mixtures containing different amounts of filler are prepared and aerated until 50 percent of the volatile portion of the bituminous material is removed. Briquets 2 inches by 4 inches are formed with this partially cured mixture and then tested for stability. A stability of 1,200 pounds at 77° F. formerly appeared adequate but it has more recently become necessary to raise this requirement to 1,800 pounds. Concentration of traffic in definite lanes after the center stripe was painted on the surface resulted in a gradual deformation of the bituminous mat and the sandy subgrade in many locations. In addition, the gradual loss of moisture in the sand subgrade during the drought years has lessened its supporting strength. For these reasons, it became necessary to increase the strength of the bituminous mat and consequently the stability requirement was raised from 1,200 to 1,800 pounds.

Since the designated stability can be obtained by a number of combinations of different fillers and a given bituminous material, the actual selection of the material can be made on the basis of economy.

In actual practice, the amounts of bituminous material and of filler are stated as master ranges in the specifications with the added requirement that the exact percentages for a given project shall be designated by the engineer. These exact percentages are determined in the laboratory, as previously discussed, and the information thus developed is supplied to the field engineer for his guidance during construction. To illustrate the application of this procedure, the specifications require that 3.3 to 3.9 gallons of bituminous material shall be used per square yard for a bituminous sand mix 5 inches thick. The percentages of filler required with different types of bituminous materials are as follows:

Type of bitumen:	Percent passing No. 200 sieve
Slow-curing liquid asphalt	10 to 30
Medium-curing liquid asphalt	5 to 25
Rapid-curing liquid asphalt	5 to 20
Emulsified asphalt	2 to 15

The actual amount of a given filler or fillers and the bitumen coefficients or *S* factors for each are determined on the basis of laboratory stability and float tests as previously described. Having determined this, the total bitumen requirement is based upon the following formula developed through laboratory study and field experience:

$$P=AG\ (0.02a)+0.04b+0.06c+Sd$$

when P=percent by weight of bitumen in the mix;
a=percent by weight of aggregate retained on the No. 50 sieve;
b=percent by weight of aggregate passing the No. 50 and retained on the No. 100 sieve;
c=percent by weight of aggregate passing the No. 100 and retained on the No. 200 sieve;
d=percent by weight of material passing the No. 200 sieve, which amount has been established in the laboratory;
A=an absorption factor for the aggregate as determined in the laboratory;
G=a specific gravity factor based on the relation of the gravity of the aggregate to 2.62; and
S=filler factor determined in the laboratory as previously described.

COMPACTION DURING CONSTRUCTION DEEMED ADVISABLE

On the experimental sections the bituminous mixtures were spread for compaction by traffic without mechanical rolling. It was felt that the types of rollers then available would not be satisfactory for the conditions existing and that satisfactory consolidation would eventually be obtained by traffic. Pulled rollers of the

[3] The Selection and Use of Mineral Fillers for Low-Cost Roads, by R. E. Bollen, Proceedings of the January 1937 meeting, Association of Asphalt Paving Technologists.

type now available, especially the multiple-wheeled, pneumatic-tired type, could probably have been used advantageously for obtaining greater initial density and correspondingly increased stability. However, the volatile material in the cut-back would have been trapped by the rolling and the actual viscosity of the bituminous material would have been unchanged. Consequently it cannot be definitely stated that rolling would have entirely prevented the movement and surface cracking that occurred.

For the purpose of obtaining information on the relation between density and stability, as well as other information, 2-inch cores were taken from each section in 1935. A sample consisted of 4 to 6 cores taken for the full depth of the pavement. The composition and the stability of the mixtures as taken from the road are given in table 5, while tests to determine density and stability obtained by other methods of compaction are given in table 7. The data given in table 7 were obtained in all cases from tests on mixtures obtained by coring the pavement.

The field cores were cut into specimens 1 inch high and the stability of each specimen was determined. Laboratory remolded specimens were afterwards made in standard Hubbard-Field molds in two ways, that is (a), by the routine method of applying a load of 3,000 pounds per square inch and (b), by applying a load sufficient to form a specimen having the same density that the material had in the road. All specimens were tested by the standard Hubbard-Field method of test.

The data obtained in this study of the mixtures show that, with few exceptions, the density and stability obtained by the standard Hubbard-Field method of test are considerably lower than those of the specimens compacted in service by traffic, and that the Hubbard-Field stability obtained on laboratory-prepared specimens molded by direct compression to the density of the field specimens is likewise considerably lower than that of the field specimens. The average stability obtained by the routine method of forming laboratory specimens was only 52 percent of that actually obtained in service while laboratory-made specimens having the same density as the field specimens had, on the average, only 65 percent of their stability. To obtain laboratory specimens having the same density as the field specimens, a series of specimens was molded to densities above and below the densities of the field specimens and, although these data are not included in table 7, it was observed that the stability increased as the density increased for a given mixture, that is, for any single 1-inch layer of material. It will be observed, however, by reference to table 7 that no relationship exists between density and stability of different 1-inch layers of the same core or of one sample as compared with another.

Apparently the stability depends less upon the actual density than upon the manner in which the density is obtained. The compaction obtained in service by traffic was therefore more beneficial than that which resulted from direct compression even though the density obtained by both methods was the same, which would indicate that the method of compaction was more important than the amount.

These test results seem to indicate that compaction with a device similar to the multiple-wheel, pneumatic-tired roller, which compacts with a kneading action similar to that of traffic, would probably have been beneficial in producing greater initial stability.

TABLE 7.—*Stabilities and densities of mixtures sampled in 1935*

Section No.	Field No.	1-inch layer	Cored field specimens		Standard laboratory molded specimens		Specimens molded to field density	
			Density	Stability	Density	Stability	Density	Stability
				Pounds		*Pounds*		*Pounds*
94+ CUT-BACK SECTIONS								
1A	7	Top inch	2.122	2,776	2.020	1,184	2.122	2,150
		2d inch	2.089	800	1.992	324	2.089	890
		3d inch	2.087	947	1.964	363	2.088	1,210
		4th inch	2.074	1,182	1.968	587	2.074	1,310
1B	4	Top inch	2.175	2,727	2.079	1,265	2.175	2,100
		2d inch	2.110	1,160	2.051	562	2.110	960
		3d inch	2.080	1,110	2.025	670	2.080	940
2A	8	Top inch	2.067	3,757	1.960	1,686	2.067	2,470
		2d inch	2.047	1,938	1.990	1,064	2.047	1,350
		3d inch	2.043	1,798	1.976	1,052	2.043	1,530
		4th inch	1.983	2,398	1.935	1,960	1.983	2,200
2B	9	Top inch	2.225	3,046	2.107	1,670	2.225	2,840
		2d inch	2.050	2,330	2.005	1,300	2.050	1,830
		3d inch	1.986	1,512	2.010	1,218	1.986	970
		4th inch	2.000	1,092	2.035	1,010	2.000	800
		5th inch	1.976	827	2.011	960	1.977	630
3A	10	Top inch	2.021	3,826	1.956	1,658	2.021	2,230
		2d inch	1.978	1,350	1.952	815	1.978	780
		3d inch	2.001	1,233	1.949	758	2.001	930
3B	11	Top inch	1.911	3,022	2.010	2,940	1.911	2,120
		2d inch	1.916	2,114	2.001	2,145	1.916	1,700
		3d inch	1.938	1,750	2.013	1,850	1.938	1,190
		4th inch	1.936	812	2.014	1,173	1.936	660
		5th inch	1.905	945				
100–120 CUT-BACK SECTIONS								
4A	18	Top inch	2.005	3,336	2.023	2,270	2.005	2,000
		2d inch	1.938	3,008	1.997	2,511	1.938	1,840
4B	12	Top inch	2.069	3,308	1.965	1,352	2.069	2,370
		2d inch	2.038	1,562	1.960	850	2.038	1,400
5A	19	Top inch	2.013	4,254	1.923	1,510	2.013	2,420
		2d inch	1.979	1,918	1.928	808	1.979	1,140
		3d inch	1.950	1,084	1.922	694	1.950	725
5B	13	Top inch	1.916	3,462	1.882	1,214	1.916	1,700
		2d inch	1.922	1,940	1.887	808	1.922	1,060
		3d inch	1.904	1,288	1.888	682	1.904	730
		4th inch	1.908	1,248	1.885	715	1.908	740
		5th inch	1.861	1,343	1.877	882	1.861	680
6A	20	Top inch	1.926	3,044	1.840	874	1.926	1,670
		2d inch	1.893	1,658	1.837	545	1.893	830
		3d inch	1.875	803	1.824	360	1.875	570
6B	14	Top inch	1.995	3,292	1.861	802	1.995	2,175
		2d inch	1.946	1,684	1.862	535	1.946	1,090
		3d inch	1.942	945	1.858	420	1.942	810
60–70 ROAD OIL SECTIONS								
7A	5	Top inch	2.001	1,288	1.926	421	2.001	970
		2d inch	1.976	1,080	1.927	405	1.976	650
		3d inch	1.967	1,013	1.921	368	1.967	570
		4th inch	1.939	780	1.931	447	1.939	460
7B	6	Top inch	1.992	1,224	1.929	422	1.992	710
		2d inch	1.996	1,220	1.922	356	1.996	640
		3d inch	1.977	1,228	1.931	398	1.977	580
		4th inch	1.947	1,016	1.928	366	1.947	410
		5th inch	1.951	855	1.920	259	1.951	320
8A	21	Top inch	1.915	1,108	1.895	426	1.915	500
		2d inch	1.902	850	1.884	362	1.902	370
		3d inch	1.896	882	1.884	362	1.896	380
		4th inch	1.870	787	1.910	470	1.870	310
100–120 CUT-BACK SECTIONS								
8B	15	Top inch	1.934	2,238	1.842	670	1.934	1,350
		2d inch	1.887	1,516	1.833	472	1.887	780
		3d inch	1.869	706	1.824	319	1.869	470
		4th inch	1.875	535	1.824	267	1.875	425
9A	22	Top inch	1.949	2,774	1.887	898	1.949	1,330
		2d inch	1.934	1,278	1.882	512	1.931	670
9B	16	Top inch	1.980	2,768	1.891	790	1.980	1,625
		2d inch	1.920	1,618	1.866	518	1.920	825
		3d incb	1.906	772	1.861	356	1.906	570
		4th inch	1.892	658	1.859	317	1.892	480
		5th inch	1.865	633	1.849	292	1.865	370
		6th inch	1.892	673	1.864	339	1.892	500
10	17	Top inch	1.987	3,288	1.977	1,578	1.987	1,740
		2d inch	1.997	2,062	1.983	1,131	1.997	1,170
		3d inch	1.959	1,654	1.948	978	1.959	1,000
		4th inch	1.862	1,283	1.915	977	1.862	660

The specifications governing the construction of the experimental sections, due to a lack of experience, were necessarily very indefinite. Practically no restrictions were placed upon the equipment to be used nor was the procedure to be followed definitely prescribed. The descriptions already given, as well as some of the photographs, best illustrate the procedure permitted under the specifications.

IMPROVED EQUIPMENT AND DESIGN MAKE DEFINITE CONSTRUCTION PROCEDURE POSSIBLE

Concurrently with the increase in knowledge of the properties of bituminous mixtures came the realization that old-fashioned, makeshift equipment not only was inefficient, but its use prevented the practical application of information gained by research in the laboratory. Obviously the ability to design satisfactory mixtures with a variety of materials served no useful purpose unless such design could be accurately produced by the construction operations.

Fortunately, with the increase in volume of low-cost road building, improvements have been made in the types of equipment in use and in the development of new equipment. Large-size pneumatic tires have replaced the narrow steel tires on blade machines; mechanical shifting has replaced hand shifting; and units having greatly increased power have made possible almost absolute control over the mixing operation. On the experimental sections it was practically impossible to control the depth of mixing, as the steel-tired wheels sank through the mix. With the blade machines available at the present time, mixing to a given depth is no longer such a difficult task even on loosely bonded bases such as existed on the experimental road. Mixing at the present time, moreover, is not confined to blade machines or to stationary mixing plants, but can be done on the road with traveling mixers. These machines pick up the untreated material from the roadway, pass it through the mixing chamber where it is accurately proportioned and mixed with the bitumen, and then deposit the mixture on the road for spreading by blade machines or it may be delivered directly to mechanical spreaders and finishers.

Self-propelled smooth rollers, formerly the only type available, were not considered suitable for use on work such as herein described, but the need for some initial compaction was felt. As a substitute for self-propelled rollers, pulled types of rollers were tried. Although such rollers had smooth continuous surfaces, they were a decided improvement over the old type. Perhaps, however, the greatest improvement was the development of the pneumatic-tired, multiple-wheel roller. Such rollers appear to simulate the action of traffic and provide the kneading movement that is so beneficial but which is not readily obtained with smooth rollers, except to a limited extent on hot mixtures.

With the foregoing equipment available for use, it becomes possible not only to construct a road having the properties designed for it but to permit the use of different methods of construction to accomplish a given purpose. On the experimental road a 4-inch mat was to be constructed. With the equipment then available this almost automatically implied the two-course construction that was specified. The difficulties encountered in construction with the equipment used and for the conditions existing on the road have already been indicated. With present-day equipment a similar procedure would have been no great problem. Blade mixing could be accomplished to the complete depth in one operation or, if desired, two-course mixing could readily be done. The use of traveling mixers now available would insure a uniform mixture both as to depth and composition.

During the course of construction it appeared that less difficulty in mixing would be encountered if the bitumen content in the lower 2 inches were held somewhat lower than that of the upper portion. This would have resulted in the formation of a leaner course that would have been less plastic, thereby affording somewhat greater support for the equipment while mixing the top 2 inches. The small amount of bitumen withheld from the lower 2 inches could have been placed in the top half to enrich it and delay weathering. In addition to improving the method of construction this procedure would have limited probable movement to the upper 2 inches and might have decreased the cracking caused by such movement. The specifications, however, did not provide for the alternate use of such procedure.

In contrast to the necessarily incomplete specifications that governed the construction of the experimental road, present-day construction of bituminous-sand surface courses is more definitely described by current specifications.

The equipment that is to be used must meet the approval of the engineer and be satisfactory for the purpose to be served. The composition of the mixture is specified definitely and the exact bitumen content to be used within those limits is set by the laboratory and based upon a study of the materials to be used.

Alternate methods of mixing are permitted, including blade mixing and travel-plant mixing.

The condition of the mixture immediately prior to spreading for compaction is also controlled by limiting the moisture content and by requiring that it shall have a specified stability.

The results being obtained by the procedure followed in Nebraska are very satisfactory and illustrate what can be accomplished by laboratory research and field application of the results of such research. Neither field studies nor laboratory research alone would have made possible the definite results being obtained at the present time. And in this respect the experimental road herein described was of considerable value not only because of the direct information it developed but also because it definitely exposed many of the problems that required a solution before a successful and economical plan could be developed for bituminous construction with sandy soils.

It is of additional interest to note that the information developed by this experiment was gained at a net saving in maintenance rather than at a somewhat increased cost which may frequently result and which is normally justified in experimental construction. The data given in table 6 show that the surface maintenance of the experimental road cost $92 per mile annually, which is in marked contrast to the $186 per mile annual cost of the sand-gravel surfaced road adjacent to it. This is a definite saving in addition to such intangible benefits as conserving material and providing a superior day-to-day riding surface.

EFFECT OF CARBON BLACK ON THE STRENGTH OF MORTAR

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by D. O. WOOLF, Materials Engineer

A small amount of black colloidal pigment may be added to portland cement concrete to improve its appearance and to reduce glare. Carbon black is the pigment generally used.

To determine the effect of carbon black on the strength of concrete at ages up to 1 year, a series of tests including both tension briquets and 2-inch cubes for compressive strength tests was made.

The results of these tests indicated that to an age of 1 year, none of the samples of emulsified carbon black tested caused any important reduction in the strength of the mortar. The tensile strength test appears to be preferable for use in determining the quality of samples of carbon black, and a strength ratio of 90 percent appears to be a suitable minimum value in such tests.

TO IMPROVE the appearance of concrete pavement and to reduce the glare from the road due to bright sunshine, a small amount of black colloidal pigment may be added to the concrete. In suitable amounts this pigment gives a deep black color to the concrete.

On different paving projects, amounts of pigment varying from 1 to 3 pounds per sack of cement have been used, with the larger amount the more common. In a recent specification for concrete pavement the following requirements for carbon black appear:

> Emulsified carbon black shall be a uniform colloidal dispersion of standard carbon gas black in a liquid medium. At least 25 percent by weight of the commercial product shall be carbon black. The product shall be free from lampblack, mineral black, silicas, asbestine, talc, bone black, or other fillers. Emulsified carbon black shall contain no substance which can adversely affect the strength, durability, or appearance of concretes or mortars when used in the concentration specified.
>
> Emulsified carbon black shall be so finely processed and dispersed that when one part of the product is stirred into 10 parts of tap water, the resulting liquid shall, upon standing without agitation for 72 hours, remain uniformly colored from top to bottom.

Carbon black is described [1] as a fluffy, black pigment produced by burning natural gas in a supply of air insufficient for complete combustion and collecting the liberated carbon on a metal surface by actual contact of the flame on the surface. Carbon black, also called channel black or gas black, is entirely different in physical characteristics from lampblack. The latter is gray in contrast to the deep black of carbon black. Lampblack usually is prepared by burning byproducts from the distillation of coal, petroleum, tar, and vegetable oils and, as it is somewhat soluble in ether, its presence in pigment can be determined. Mineral black is prepared by grinding and heating slate, shale, coal, or similar materials. Bone black is produced by calcining animal bones. Both mineral black and bone black contain mineral impurities that may be detected by the ash left after ignition.

Acceptance tests of carbon black usually include a mortar strength test to determine if the material has any deleterious effect on the strength. In this test the strength of mortar containing carbon black in the amount specified for the project is compared with the strength of an uncolored mortar made with the same cement and sand, and mixed with the same amount of water. Carbon black is added to the mixture in the form of an emulsion. The water in the carbon black emulsion is usually considered to be 75 percent by weight of the emulsion and the mixing water used is corrected accordingly. Tests are usually made at ages of 7 and 28 days.

To determine the effect of carbon black on the strength at greater ages, a series of tests including both tension briquets and 2-inch cubes for compressive strength tests was made. Four samples of carbon black representing the product of three manufacturers were obtained for these tests. The colored mortars contained 3 pounds of carbon black per sack of cement, and correction was made in the amount of mixing water for the water contained in the emulsion. The tensile strength specimens were made using a 1 : 3 mix with standard Ottawa sand and the usual stiff consistency employed in cement testing.[2] The compressive strength specimens were made using a 1 : 3.2 mix with Ottawa sand having a fineness modulus of 2.40; and a water-cement ratio of 0.6 by weight was used. This produced a mortar with a plastic to slightly wet consistency. Both types of test specimens were prepared on each of 3 days for testing at ages of 28, 60, 90, and 365 days. After removal from the molds at an age of 24 hours, all specimens were cured in running water until tested.

The results of these tests are given in table 1. Each value for the three rounds is the average for at least three specimens. Average values for the three rounds are plotted in figure 1.

In the compression tests the strength showed a marked increase from 28 to 60 days, followed by a steady decrease. The strengths at an age of 1 year were greater, however, than those at the initial test of 28 days. Some of the tension specimens showed a slight increase in strength from an age of 28 days to ages of 60 or 90 days but, in general, there was little change in strength during that period. At an age of 1 year the tensile strength was slightly less than that at 28 days. Some of the reduction in strength noted for all specimens at an age of 1 year was probably due to solution of a portion of the cement by the running storage water.

TENSION TEST GAVE BEST INDICATION OF EFFECT OF CARBON BLACK ON STRENGTH

At ages to and including 90 days the mortar containing carbon black sample No. 1 had higher strengths, both tensile and compressive, than any of the other samples. At an age of 1 year the mortars containing samples 2 and 3 had tensile and compressive strengths equal to or higher than that for sample No. 1. Samples 2 and 3, which were produced by the same manufacturer, showed about the same strength with the exception of the compressive strength at 28 days. Sample

[1] The Condensed Chemical Dictionary, Second Edition, 1930. The Chemical Catalog Co. Inc., New York, N. Y.

[2] A. S. T. M. Standard Method C 77-39, section 13.

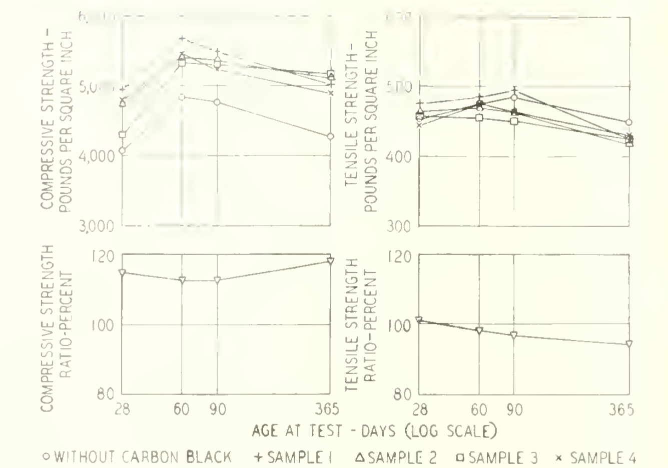

FIGURE 1.—STRENGTH OF MORTAR CONTAINING 3 PERCENT CARBON BLACK AND RATIO OF AVERAGE STRENGTH OF COLORED MORTARS TO STRENGTH OF PLAIN MORTAR.

No. 4 gave the lowest strengths at some ages, and strengths about the average for the remainder of the testing periods. In general there is little choice with respect to tensile or compressive strengths between mortars containing the four samples of carbon black.

The ratio between the average compressive strength of the mortars containing carbon black and that of the plain mortar showed little change with increase in age. That for tensile strength showed a slight decrease with increase in age. The values of the ratio for compression and tension are given in table 2. Of the two methods of test it is believed that the tension test is the more critical, and that it may furnish a more nearly correct indication of the effect of carbon black on strength.

No method has yet been established to use in interpreting the requirement quoted above (that the emulsified carbon black shall contain no substance which can adversely affect the strength of the mortar or concrete). The word "adversely" might be taken to mean that there must be no reduction in strength. However, it is customary to recognize some tolerance due to unavoidable errors in laboratory technique as a result of which presumably identical sets of specimens may show somewhat different test results. Reference to the literature shows that sand tested under A. A. S. H. O. Standard Method T71–38 is usually required to have a strength ratio of at least 90 percent. A strength ratio of 90 percent is also required for water proposed for use in concrete when tested under A. A. S. H. O. Standard Method T35–35. With these two specifications as examples, the use of the same strength ratio with the tensile strength test might be considered suitable for the acceptance of samples of carbon black proposed for use in concrete. All of the samples tested in this investigation meet this suggested requirement at all ages.

The results of these tests indicate that to an age of 1 year, none of the samples of emulsified carbon black included in this investigation caused any important reduction in the strength of mortar. The tensile strength test appears to be preferable for use in determining the quality of samples of carbon black, and a strength ratio of 90 percent appears to be a suitable minimum value in such tests.

TABLE 2.—*Compressive and tensile strength of mortars containing carbon black expressed as a percentage of the strength of plain mortars, at various ages*

Age, days	Strength ratio	
	Compression	Tension
	Percent	*Percent*
28	115	101
60	113	99
90	113	97
365	118	94

TABLE 1.—*Effect of carbon black on strength of mortar*

Carbon black sample number	Round	Compressive strength				Tensile strength			
		28 days	60 days	90 days	1 year	28 days	60 days	90 days	1 year
		Lb. per sq. in.	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*
None	1	4,050	4,675	4,650	(1)	460	485	480	435
	2	3,960	4,760	4,395	3,830	435	500	480	455
	3	4,245	5,090	5,135	4,740	470	440	490	460
	Average	4,085	4,840	4,730	4,285	455	475	485	450
1	1	4,900	5,390	5,280	(1)	465	455	510	420
	2	5,060	5,925	5,475	4,845	490	500	500	415
	3	4,910	5,720	5,730	5,190	465	495	470	445
	Average	4,955	5,680	5,495	5,020	475	485	495	425
2	1	4,520	5,380	5,470	(1)	485	470	460	435
	2	4,680	5,250	5,270	4,805	455	470	475	430
	3	5,060	5,635	5,290	5,435	460	465	465	400
	Average	4,755	5,420	5,345	5,120	465	470	465	420
3	1	4,105	5,155	5,440	(1)	455	465	450	430
	2	4,660	5,460	5,210	5,175	470	465	475	430
	3	4,140	5,360	5,260	5,270	455	435	420	410
	Average	4,300	5,325	5,305	5,220	460	455	450	425
4	1	4,525	5,220	5,255	(1)	425	445	455	435
	2	4,980	5,395	5,165	4,855	460	475	480	435
	3	4,835	5,720	5,450	4,945	445	505	465	415
	Average	4,780	5,445	5,290	4,900	445	475	465	430
All blacks	Average	4,700	5,470	5,360	5,065	460	470	470	425

[1] Specimens broken at 90 days.

TWENTIETH ANNIVERSARY OF FEDERAL HIGHWAY ACT

November 9, 1941, marked the twentieth anniversary of passage of the Federal Highway Act. During these 20 years the Federal-aid highway system created by the act has been steadily improved to serve a rapidly increasing volume of motor-vehicle traffic.

Pictures on the cover page vividly illustrate the evolution of a Federal-aid highway in Rhode Island. The top picture shows Nooseneck Hill Road in 1912, 4 years before Federal highway aid was initiated. (In 1912 there were 9 thousand registered motor vehicles in Rhode Island, 1 million in the entire country.)

The middle picture shows the same section of road in 1923, after it had been improved as a Federal-aid project by the construction of two 9-foot lanes of concrete. (In 1923 there were 76 thousand registered motor vehicles in Rhode Island, 15 million in the entire country.)

The bottom picture shows Nooseneck Hill Road in 1941, after it had been widened to four lanes and resurfaced as a Federal-aid project. The new surface consists of 25 feet of bituminous macadam flanked by 11-foot lanes of concrete and 10-foot bituminous shoulders. (In 1940 there were 190 thousand registered motor-vehicles in Rhode Island, 32 million in the entire country.)

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF NOVEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$3,222,587	$1,602,075	109.7	$6,327,985	$3,141,570	203.1	$1,258,992	$625,800	30.9	$721,276
Arizona	787,431	564,020	36.7	1,578,310	1,057,479	64.3	546,962	373,330	12.2	864,109
Arkansas	2,835,847	1,321,265	50.2	1,199,527	599,183	53.5	95,795	47,320	12.7	395,211
California	5,477,284	2,919,410	101.9	5,878,244	3,111,414	61.6	3,214,879	1,636,208	56.4	1,259,897
Colorado	2,291,427	1,296,089	154.6	2,557,455	1,476,916	139.9	1,621,622	909,448	50.2	910,687
Connecticut	1,216,857	595,915	12.7	1,917,853	922,053	22.7	491,595	216,825	9.4	512,588
Delaware	275,257	132,307	4.9	749,827	371,718	21.2	268,040	134,020	8.4	987,558
Florida	1,167,179	582,930	65.3	1,832,154	919,305	17.7	1,869,084	910,542	28.7	1,927,146
Georgia	2,543,841	1,270,628	84.5	6,343,846	3,181,673	258.0	4,017,506	2,008,753	170.4	4,716,832
Idaho	1,730,436	1,067,443	93.7	995,217	613,588	44.3	398,906	246,643	18.8	949,357
Illinois	3,066,506	1,524,662	77.6	7,916,907	3,957,832	133.6	1,447,517	723,599	6.4	3,193,146
Indiana	3,276,115	1,490,493	49.1	6,378,985	3,090,727	98.7	2,357,298	1,178,649	34.9	463,295
Iowa	2,223,834	1,047,843	94.3	5,788,544	2,594,458	196.0	711,159	97,500	22.9	31,494
Kansas	3,245,863	1,642,099	169.5	5,413,878	2,710,874	286.8	2,791,704	1,076,423	117.9	2,922,958
Kentucky	2,744,644	1,376,135	97.6	6,747,827	3,210,370	151.8	2,510,102	1,255,051	21.1	198,063
Louisiana	800,645	400,301	22.3	2,074,120	1,028,642	39.7	2,568,556	1,259,086	56.3	3,031,749
Maine	843,077	419,641	23.4	1,950,882	1,001,401	23.0	78,610	39,305	.1	369,120
Maryland	2,000,209	999,000	20.7	4,173,153	1,836,178	23.9				784,489
Massachusetts	2,346,521	1,175,891	17.3	2,223,103	1,142,862	14.9	1,175,721	584,274	8.4	2,601,239
Michigan	6,552,505	3,252,827	152.0	3,789,270	1,894,635	55.4	1,928,000	955,700	18.3	774,473
Minnesota	3,663,717	1,827,410	338.2	9,958,631	4,936,205	414.9	813,196	405,823	33.4	723,651
Mississippi	3,524,088	1,759,644	201.9	4,853,024	2,372,112	267.1	718,200	357,350	32.5	527,839
Missouri	4,003,565	1,973,458	142.6	10,272,484	4,668,076	192.7	3,828,486	742,646	51.4	3,021,266
Montana	2,181,671	1,233,971	117.1	3,026,292	1,719,746	142.4	1,335,989	759,643	86.7	2,552,867
Nebraska	1,371,553	682,292	182.3	6,713,713	3,393,274	575.2	706,289	353,144	37.8	2,171,080
Nevada	2,020,298	1,756,854	101.5	974,271	844,579	31.0	274,686	238,701	3.4	98,148
New Hampshire	339,179	167,678	5.9	1,177,545	565,221	13.6	531,352	262,450	6.6	559,566
New Jersey	2,348,574	1,174,287	20.5	3,562,648	1,781,244	22.2	23,910	11,955		1,759,109
New Mexico	943,125	580,478	71.0	1,404,542	899,084	87.2	364,655	235,786	17.9	1,266,286
New York	6,233,056	3,109,833	92.2	10,049,219	5,001,211	128.6	2,507,480	984,185	19.4	1,767,263
North Carolina	2,447,101	1,207,381	109.6	4,148,399	2,077,020	163.5	1,228,430	580,300	37.0	1,377,754
North Dakota	3,147,023	1,735,191	274.1	2,783,460	1,442,888	217.3	2,421,360	1,214,050	205.5	2,728,327
Ohio	6,311,454	3,149,377	58.1	12,998,932	6,258,751	99.5	6,704,900	2,700,918	40.5	1,138,998
Oklahoma	1,736,116	863,894	83.7	2,906,222	1,533,671	64.8	2,123,270	1,111,825	77.1	3,981,176
Oregon	1,770,398	1,070,826	64.6	3,958,496	2,135,468	77.8	394,852	191,270	7.8	170,881
Pennsylvania	4,501,005	2,243,123	54.9	12,924,315	6,344,572	101.9	3,864,226	1,891,708	32.1	747,355
Rhode Island	1,195,971	596,025	10.0	645,746	322,853	4.8	567,583	215,956	2.0	568,324
South Carolina	894,247	415,437	64.7	4,426,770	2,067,957	97.5	1,658,353	646,081	46.0	1,023,248
South Dakota	2,022,523	1,166,709	239.0	4,751,583	3,062,109	515.1	1,081,820	643,090	137.3	1,304,393
Tennessee	2,488,256	1,242,144	71.6	4,480,856	2,240,428	84.9	2,327,086	1,163,543	56.5	2,031,294
Texas	6,946,521	3,405,362	357.3	12,525,815	6,045,545	452.5	5,336,861	2,283,985	184.7	3,268,566
Utah	856,700	643,407	45.6	2,009,427	1,512,730	40.2	181,116	131,610	14.8	173,777
Vermont	565,928	278,466	22.7	1,467,207	729,953	26.9	36,906	18,453	.3	60,424
Virginia	1,725,659	864,287	39.8	4,834,174	2,244,108	86.2	859,610	426,755	6.4	1,083,463
Washington	745,789	390,247	13.1	2,923,116	1,561,904	39.6	551,037	268,500	5.4	731,048
West Virginia	1,789,960	892,433	35.5	3,253,125	1,610,358	41.5	555,662	277,831	6.3	1,088,276
Wisconsin	1,311,232	647,054	60.3	6,306,458	2,968,068	195.2	1,539,216	553,400	48.4	2,394,761
Wyoming	1,411,471	903,980	148.3	1,762,635	1,149,016	123.5	47,665	30,648		287,908
District of Columbia	448,744	224,166	2.5	873,178	413,300	1.9				254,588
Hawaii	140,808	70,395	1.1	744,378	540,561	9.5	471,159	294,217	5.2	1,399,922
Puerto Rico	176,101	87,085	2.6	2,116,647	1,044,620	17.7	251,149	124,950	.6	402,753
TOTALS	117,909,898	61,043,868	4,470.3	220,650,895	111,349,510	6,226.8	72,658,552	33,399,249	1,887.4	68,268,998

U. S. GOVERNMENT PRINTING OFFICE: 1941

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF NOVEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$848,005	$422,368	35.8	$987,352	$506,340	51.9	$255,259	$121,280	6.1	$243,014
Arizona	121,340	88,202	13.2	141,552	105,006	.8	126,721	59,418	6.8	294,577
Arkansas	408,089	202,544	32.6	301,968	150,918	21.3	189,486	94,743	5.1	67,556
California	582,990	350,340	14.0	1,110,504	790,478	11.9				401,296
Colorado	150,002	84,134	20.7	129,755	72,649	2.1	4,602	2,598	1.9	249,368
Connecticut	298,035	136,331	6.1	266,247	115,937	4.8				76,648
Delaware	31,959	15,264		274,043	135,122	12.3	102,873	37,617	3.9	160,439
Florida	450,722	225,361	4.7	714,798	362,849	7.1				232,834
Georgia	342,419	156,209	31.7	1,150,671	667,685	72.6	662,173	331,086	57.7	682,604
Idaho	224,756	135,497	15.6	127,680	78,387	14.1	189,612	90,911	10.1	117,670
Illinois	853,012	422,594	38.2	1,287,660	643,830	68.0	155,700	74,600	17.7	212,513
Indiana	197,450	98,725	9.1	1,542,255	737,971	77.4				593,828
Iowa	508,279	239,292	124.3	384,252	163,258	71.6	436,258	204,936	73.6	154,646
Kansas	348,387	176,679	54.6	2,021,192	1,012,763	141.6	516,394	258,197	37.7	592,838
Kentucky	593,804	155,245	25.0	1,404,741	352,567	35.0	582,618	144,800	19.4	110,785
Louisiana	558,248	227,059	20.6	14,160	7,080		289,362	138,761	21.5	443,106
Maine	35,700	17,850	2.1	277,058	138,529	12.1	16,850	2,714	.4	9,491
Maryland	337,000	168,500	16.9	465,000	232,325	5.6				202,116
Massachusetts	179,789	93,569	4.1	634,608	334,371	10.1				361,339
Michigan	643,168	321,541	50.4	997,860	498,930	37.8	630,770	315,385	23.0	115,130
Minnesota	1,120,968	566,234	159.4	1,353,885	679,750	134.9	418,730	194,457	39.8	123,146
Mississippi	601,094	300,547	28.2	896,867	439,249	42.0	1,020,900	381,800	45.1	88,619
Missouri	310,844	154,337	37.6	821,842	393,037	92.1	377,928	150,075	42.5	556,095
Montana	377,420	214,407	58.5	241,662	137,374	23.7	53,031	30,154	11.8	547,270
Nebraska	237,314	118,222	23.7	552,216	282,999	62.6	95,157	47,578	37.0	330,671
Nevada	156,815	135,496	17.8	160,533	120,012	10.9	98,898	79,290	4.5	3,198
New Hampshire	152,914	75,436	4.7	237,331	95,284	3.6				91,572
New Jersey	303,260	151,550	5.5	568,422	301,670	16.1	82,910	41,455	1.8	353,335
New Mexico	413,309	259,776	42.6	357,018	223,662	20.2				9,247
New York	831,023	419,785	21.9	1,040,396	521,914	21.3	499,660	211,330	1.5	299,900
North Carolina	224,260	112,130	23.2	648,577	354,343	48.0	69,820	20,000	5.0	256,228
North Dakota	49,569	26,558	2.4	3,434	3,434		808,050	793,860	42.7	485,901
Ohio	1,141,972	570,730	46.7	1,412,340	753,260	20.7	106,160	53,080	4.7	805,284
Oklahoma	336,340	177,384	19.2	74,842	39,515	8.4	847,786	447,631	62.4	723,546
Oregon	463,457	243,324	41.8	459,611	217,324	28.5	30,482	18,000	1.3	115,964
Pennsylvania	801,174	400,587	17.7	1,706,486	842,176	30.3	73,588	36,794	1.8	47,688
Rhode Island	220,936	111,505	2.6	11,494	7,497					56,220
South Carolina	461,032	170,066	44.9	539,900	214,224	10.2				165,627
South Dakota	32,130	18,006	15.2	3,622	3,622	.	1,143,430	1,047,600	114.5	490,587
Tennessee	333,741	165,879	10.9	1,430,720	715,360	48.5	190,926	95,463	5.3	404,270
Texas	694,216	337,241	74.1	1,009,341	486,118	92.2	369,000	179,000	33.6	1,146,237
Utah	186,949	123,240	17.0	84,238	49,485	2.9	52,253	25,664	.7	166,950
Vermont	36,231	18,109	1.2	180,204	59,279	7.8	46,514	23,257	1.1	3,059
Virginia	339,398	155,485	11.1	374,996	171,246	9.1	59,050	29,525	4.5	352,850
Washington	201,068	105,105	16.7	518,573	254,814	14.8				147,778
West Virginia	211,250	105,625	9.6	518,883	261,008	16.6				309,250
Wisconsin	793,627	397,321	38.0	1,708,472	756,743	52.7	76,438	37,300	.8	129,885
Wyoming	360,882	155,250	18.8	511,240	220,929	34.3				2,582
District of Columbia	80,772	39,924	.9	2,558	1,279					76,120
Hawaii				2,375	2,375					249,562
Puerto Rico	45,960	22,305	2.5	185,404	90,550	8.1				134,883
TOTALS	19,239,079	9,588,868	1,334.1	31,850,838	15,806,527	1,568.6	10,679,389	5,820,259	747.3	14,001,322

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF NOVEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR		NUMBER			UNDER CONSTRUCTION		NUMBER			APPROVED FOR CONSTRUCTION		NUMBER			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$80,836	$80,836		2	2	$346,725	$344,703	6	3	1	$154,235	$154,235	3	1	6	$729,700
Arizona						309,635	300,944	1	2		13,255	13,255			2	104,698
Arkansas	107,311	107,256			1	517,043	515,059	6		1	31,907	31,907			11	309,331
California	601,570	415,854	2		2	1,095,774	1,089,801	8	1		18,098	18,098			6	1,521,783
Colorado	5,685	5,646				590,186	590,186	6			94,118	94,118	1		10	474,949
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		352,566
Delaware	4,380	4,380			1	94,135	94,135	1			692,694	504,341	3	1		74,168
Florida	92,071	92,071			15	731,773	729,593	8		5	203,082	203,021			19	590,695
Georgia	403,084	403,084	6	1	1	1,061,641	1,061,641	6	7	9	851,183	851,183	2	4	19	1,141,222
Idaho	17,938	17,938			2	325,915	317,244	4	1		6,212	6,212			3	260,406
Illinois	183,389	150,471			74	2,162,122	1,978,887	10	1	13	423,644	404,694	1	1	36	1,543,758
Indiana	173,001	173,001	1		8	763,405	750,918	6	1	12	231,995	226,286	1		44	659,898
Iowa	219,964	210,540	2	1	7	1,510,353	1,254,581	11	2	15	247,894	245,800			64	119,305
Kansas	56,455	56,351	2		3	672,683	672,368	8		1	227,293	183,723	4		13	871,214
Kentucky	690,409	688,863	6		1	541,903	541,903	4	1		328,927	328,927	3			38,902
Louisiana						593,185	593,185	8			477,919	476,752	4		3	600,748
Maine						363,086	363,086	2			8,680	8,680			3	153,576
Maryland	481,550	449,757	2	2	8	686,237	685,759	3		3	234,625	91,305	1		11	205,511
Massachusetts	342,732	332,292	1			774,431	773,559	5	2		767,367	767,367	2	1	1	878,903
Michigan	398,512	398,512		1	7	1,137,505	1,137,505	4	3	7	358,145	327,984	1		21	668,725
Minnesota	382,370	382,055	4	3	1	1,103,537	1,103,537	6	4		162,704	162,704		2	4	684,640
Mississippi	209,275	209,275	2		1	815,109	815,109	9	1	4	92,208	92,208	1		7	322,764
Missouri	120,702	120,702		2		1,922,921	1,467,501	6	2		432,185	298,526	2	2		1,075,899
Montana	138,064	138,064	2		1	95,841	95,841	1			3,485	3,485			1	474,600
Nebraska	157,936	157,932		1	16	1,180,009	1,180,009	23		4	26,458	26,458			7	109,209
Nevada	119,580	119,580	2			56,484	56,484	2			26,644	26,644			9	98,975
New Hampshire	141,603	133,725	3			219,456	219,131	3	2	1	8,463	8,463			4	215,964
New Jersey	473,480	473,480	3			995,743	870,194	4	2	1	361,960	302,535	1	2	1	547,371
New Mexico						68,342	68,342	1			259,103	252,068	3		1	342,146
New York	1,739,083	1,711,427	2	10		2,667,646	2,520,227	3	11		502,645	464,285		1		2,427,803
North Carolina	436,625	436,625	2	4	22	242,986	240,108		3	2	326,223	326,223	3	1	21	712,407
North Dakota	177,392	176,939	4			600,080	587,143	6			223,120	223,120	2			336,428
Ohio	891,022	890,194	3	1	2	2,891,172	2,810,560	13		3	927,977	466,350	3		7	865,956
Oklahoma	148,883	145,088	1		20	843,319	839,909	6		5	402,791	344,749	3		14	1,122,238
Oregon	419,536	355,255	4		3	13,187	13,187	1			192,766	177,018	1		2	214,101
Pennsylvania	890,612	890,284	7	1		3,884,363	3,843,919	20			468,591	464,125	3			1,351,490
Rhode Island	205,241	205,241		1		3,655	3,655									176,421
South Carolina	181,848	178,618	2		12	342,678	330,278	5	3	5	287,940	154,266	1	2	14	693,472
South Dakota	365,743	365,743	10		6	659,642	643,692	12		3	41,200	41,200	2			577,780
Tennessee	228,346	216,452	1	3		1,182,063	1,182,063	8			163,851	163,851	1	1	2	777,953
Texas	717,706	708,673	8			1,853,625	1,837,591	20			105,446	105,348	1		5	1,286,088
Utah	44,855	44,113	2		14	74,424	74,424	1		11	69,025	69,025			26	226,161
Vermont	18,683	18,671			4	322,869	293,090	2								6,266
Virginia	92,292	92,292		2		778,475	758,515	6	3	1	42,541	42,541	1		4	572,245
Washington	55,443	55,443		1	1	337,650	337,650	3	1	1	7,919	7,919			3	472,371
West Virginia	247,260	241,640	3		6	654,982	654,982	6	1		8,730	8,730			3	510,865
Wisconsin	182,330	154,052	1		19	826,361	825,155	4	2	19	49,140	49,140			10	1,180,235
Wyoming	477,151	477,150	5			7,994	7,994			1	5,236	5,236			5	284,675
District of Columbia	2,193	2,193				1,462	1,462				298,213	273,744		1		5,851
Hawaii	192,574	192,566	2			214,170	213,655	2								180,308
Puerto Rico	103,629	102,980	1			639,340	632,516	9			150,994	149,890	2			188,708
TOTALS	13,586,566	13,148,719	98	36	260	39,839,534	38,383,656	289	60	128	11,250,205	9,870,479	56	21	422	29,341,448

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 22, NO. 11 ▽ JANUARY 1942

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FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 11 January 1942

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Commissioner of Public Roads, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DISTRIBUTION OF MOTOR-VEHICLE REGISTRATIONS AND TAX PAYMENTS BY REGIONS AND POPULATION GROUPS

BY THE DIVISION OF CONTROL, PUBLIC ROADS ADMINISTRATION

Reported by RALPH S. LEWIS, Associate Highway Engineer-Economist and HOMER L. BAKER, Associate Transportation Economist

SINCE 1921 the Public Roads Administration has been collecting from the States and publishing in the form of annual statistical tables data on motor-vehicle registrations, motor-vehicle registration fees, and motor-fuel taxes for the individual States.[1] Until very recently these data were available for areas smaller than the State in only a few instances; but with a growing interest in highway problems there came a realization of the usefulness of such data in connection with highway administrative and legislative programs, and with the initiation in 1935 of the State-wide highway planning surveys there came a means of obtaining these more detailed data.[2]

Fundamentally, the highway planning surveys are a series of related fact-finding studies with the common purpose of taking stock of the physical aspects of our present highway plant, finding out how it is being used, examining its financing, and seeing how it fits economically into the national transportation picture. It is the purpose of this report to present for the various rural and urban areas of the several States data on motor-vehicle registrations, motor-vehicle registration fees, and motor-fuel taxes, data that are now available for the first time as a result of the planning surveys.

One of the financial studies of the highway planning surveys, the motor-vehicle allocation study, was devised to obtain such information relative to motor-vehicle registrations and fees and motor-fuel tax payments beyond or in addition to the data that may be obtained from records regularly kept by the State. As its name implies, the motor-vehicle allocation study has as its primary purpose the collection and analysis of information concerning the geographical distribution or location of all classes of motor vehicles in a particular State, together with the corresponding motor-vehicle registration fees and motor-fuel taxes paid by their owners. In practically all States records of total motor-vehicle registrations, motor-vehicle registration fees, and motor-fuel taxes for each of the several classes of motor vehicles are readily available, but in no State are similar records for the various rural and urban areas within the State available.

It was intended that these data as determined by the motor-vehicle allocation study would be available for use, together with other data obtained in the surveys, in connection with setting up equitable bases for obtaining the necessary highway funds in a particular State and for apportioning those funds among the several classes of roads in the State. Since it is difficult to foresee exactly what types of information will be required for such an undertaking, a considerable amount of supplemental information was obtained. This supplemental information was in addition to the primary information relative to the location of motor vehicles and corresponding motor-vehicle registration fees and motor-fuel tax payments, and included data on year model or age, weight, capacity, and, in some cases, owner's occupation. The information obtained was in general the same for each of the States in which the motor-vehicle allocation studies were conducted.

DATA OBTAINED BY MEANS OF QUESTIONNAIRES

The data for the motor-vehicle allocation study were collected by means of questionnaires which were mailed or otherwise distributed to vehicle owners in each of the States in which the surveys were conducted. Approximately 3,300,000 of these questionnaires were completed and returned by motor-vehicle owners to the several planning survey organizations. The motor-vehicle owner was requested in every case to designate the county and also the name of the city, town, or rural district in which he resided. The vehicle description that was requested included the year of manufacture or year model, the passenger capacity of passenger cars and busses, and the carrying capacity of trucks. In some States the body type of all vehicles was requested, and if licensing practices were dependent upon such characteristics as empty weight or gross load, these data were also requested. In those States which did not have a flat rate registration fee the amount of the registration fee paid was also requested on the questionnaire. Finally, the vehicle owner was asked to make a statement of the number of miles driven during the year within the State of residence and in other States and of the average miles traveled per gallon of gasoline used, and to indicate whether these mileage and gasoline consumption data were based upon actual records or estimates.

The motor-vehicle allocation study data at this point represent only those vehicles whose owners completed and returned questionnaires. In order to prepare tabulations representing total motor-vehicle registrations, total motor-vehicle registration fees, and total motor-fuel tax receipts, these data were expanded statistically to give the required distributions of these known totals which were available from State records. Because annual mileage is related generally to the age of the vehicle, one of the most important control factors in connection with the expansion of annual mileages and gasoline consumptions and the subsequent determination of average annual mileages and average gasoline consumptions was that of year model. The motor-vehicle departments and related agencies supplied the basic data on total motor-vehicle registrations, total motor-vehicle registration fees, and total motor-fuel taxes in each State and the year-model control data were obtained in most cases from an analysis of the State registration records made for that particular

[1] The tables here referred to are MV-1, State motor-vehicle registrations; MV-2, State motor-vehicle receipts; and G-1, State motor-fuel tax receipts.
[2] The first highway planning survey was undertaken in Pennsylvania, in November 1935, and since that time the surveys have been undertaken in all States, the District of Columbia, and Hawaii.

FIGURE 1.—GROUPING OF STATES BY REGIONS.

purpose. The data obtained from the questionnaires were correlated with these data and expanded by individual year models for each of the several rural and urban areas within the State.

Approximately one questionnaire in every five indicated that the mileage and gasoline consumption data were based on records rather than estimates. The questionnaires based on records reported on the average considerably higher annual mileages than those based on estimates, as would be expected in view of the fact that those owners who keep records are in a majority of cases salesmen and other high mileage drivers who are required to keep records. The indicated miles traveled per gallon of gasoline used, on the other hand, were approximately the same for both records and estimates. The questionnaires further indicated that owners of newer cars returned a considerably larger proportion of questionnaires, on the basis of relative registrations, than did the owners of older cars, and thus demonstrated a further reason for the year-model control.

The results of the motor-vehicle allocation studies are now available for all States except Connecticut, Massachusetts, New Jersey, Rhode Island, Mississippi, New York, and Delaware. In order to complete the present study and to present national averages, the data for these States were estimated on the basis of corresponding data from similar adjacent States. Complete or partial year-model data as of the year of the motor-vehicle allocation studies and based on analyses of registration records are available for all of the States except Delaware, Georgia, Iowa, Mississippi, New Jersey, New York, Ohio, Pennsylvania, Texas, and the District of Columbia.

All data collected for the motor-vehicle allocation studies have been summarized on a population-group basis, with a primary division between rural and urban areas and with urban areas further classified on a population basis, as follows:

Unincorporated areas
Incorporated places having a population of
- 1,000 or less
- 1,001–2,500
- 2,501–5,000
- 5,001–10,000
- 10,001–25,000
- 25,001–50,000
- 50,001–100,000
- 100,001–250,000
- 250,001–500,000
- 500,001–1,000,000
- Over 1,000,000

This same grouping is used in the present study, and is applicable to all States except Maine, New Hampshire, Massachusetts, and Rhode Island, where, because of the nature of local governmental units, no unincorporated areas exist, and all units are classified on the basis of total population. Vermont and Connecticut would ordinarily be included in this list of excepted States, all of which are in New England, but because of the existence of incorporated villages and cities in Vermont, and boroughs in Connecticut, it was possible for planning survey purposes and in this study to handle these two States on a basis similar to that existing in the majority of States.

Of particular use in connection with the present study are those tabulations of the motor-vehicle allocation data that indicate by population groups for each State the distribution of ownership of motor vehicles of each type, the amounts of motor-vehicle registration fees and motor-fuel taxes paid by the owners of these vehicles, the average annual mileages traveled by motor vehicles of each type, and finally the year-model distribution of these vehicles. The tabulations that indicate the distribution of ownership of motor vehicles and corresponding payments of motor-vehicle registration fees and motor-fuel taxes present data on private vehicles owned by residents, on private vehicles registered in the State but owned by nonresidents, on public vehicles and, in the case of motor-fuel taxes, on "foreign" vehicles (private vehicles not registered in the State). Data in this report, however, are limited to private vehicles of residents and nonresidents; data on foreign vehicles and on public vehicles are excluded.

DATA PRESENTED BY GEOGRAPHIC REGIONS

Since the primary emphasis is placed upon the differences existing between population groups rather than upon those existing between States, the study does not in general present data for individual States. There are, however, important regional differences that cannot be overlooked in the study, and for that reason the data are presented by geographic regions. The regional classification that has been selected is based upon economic and geographic characteristics of the States. This classification, which is shown in figure 1, was used in an earlier study of trends in motor-vehicle registrations and receipts.[3] The regions, although few in number, are sufficient to show those important sectional differences that do not exist between individual States in the same section. In the case of the year model studies, complete data are available for only a relatively few States and it is not possible to present such data on a regional basis at this time.

The motor-vehicle allocation studies were carried on in most States for the registration year 1936, and the general method of the present study is to use the population group distributions of those studies for determining the population group distributions of motor-vehicle registrations and fees and motor-fuel taxes for the year 1939. The basic control data used in the study were provided by the Public Roads Administration's annual statistical tables for 1939. Data from these tables were allocated to population groups on the basis of the individual motor-vehicle allocation studies, so that the final results represent the best possible distributions of the latest available control data.

[3] Significant Trends in Motor-Vehicle Registrations and Receipts, by Robert H. Paddock. PUBLIC ROADS, Vol. 20, No. 8, October 1939.

Although shifts in population and other factors may, over a period of years, change to an appreciable extent the relative distribution of motor vehicles in a particular area, it is believed that a shift of population or other change over a period of approximately 3 years and within a region as large as those selected for this study would not significantly alter the basic distribution.

Only the 31,925,791 private and commercial vehicles registered in 1939 have been considered in this study. Publicly owned vehicles, which totaled 416,996 in 1939, have been excluded from consideration because they are not comparable with privately owned vehicles insofar as the payment of highway-user taxes is concerned.

A variety of practices exists in the registration of vehicles owned by the Federal and State Governments and by the counties and local units of government. Vehicles owned by the Federal Government are, in general, exempt from the payment of registration fees and from State motor-fuel taxes. However, some States require vehicles owned by the Federal Government to be registered although no fee is charged. In other States these vehicles are required to carry license plates for which nominal fees are charged. Some Federal agencies request regular license plates to be used on their vehicles instead of the official license plates of the Federal Government. In most States these plates are furnished without charge but in others nominal fees are charged. The variety of practices followed results in some confusion in the registration records maintained by the States. A majority of the States have no records of the number of Federal vehicles in the State. A few States have a record of the number of vehicles and exclude them from the regular registration records.

Motor vehicles owned by the State, counties, and local governmental units are excluded from this study in all but six States. In most States special classifications are maintained for these publicly owned vehicles and they are usually subject to special rates or are registered free of charge. However, it is not possible to segregate these vehicles from the privately owned vehicles in Colorado, Kansas, Massachusetts, Michigan, New Hampshire, and Vermont. Consequently, these publicly owned vehicles are included with the privately owned vehicles in the registration records and in the study.

Public Roads Administration table MV-1 for 1939 and the results of the motor-vehicle allocation studies for all available States were used as the basis for the preparation of table 1 showing the distribution of the four types of vehicles by regions and population groups. The registration records, as compiled by the State authorities and submitted to the Public Roads Administration, do not in all cases have the same classification as those used in the motor-vehicle studies. For example, busses and trucks are combined in one classification as commercial vehicles in Ohio and are not segregated in the official State registration records. When the motor-vehicle allocation study was conducted in Ohio for the year 1935 a special analysis of the registration records was made to determine the number of trucks and busses. Since the registration data for the year 1939 do not include a separation of these vehicle types the 1935 motor-vehicle allocation study data were used as the basis for estimating the number of busses included with trucks and other commercial vehicles in Ohio.

Revisions of this type were necessary in only a few instances. In other States, either because motor-vehicle allocation data are not available or a separation of trucks and busses is not made in the registration records, a complete segregation of vehicle types is not possible nor is it possible to make an estimate of the number of each type. Consequently, busses have been included with trucks in Delaware, Illinois, and Iowa and are so presented in table 1. The classification "other vehicles" includes all trailers and motorcycles in all cases.

BUS AND TRAILER INFORMATION INCOMPLETE

Because of wide variations in registration practices which affect in particular the registration of busses and trailers, it is difficult to present adequate and significant data concerning these vehicles. Accurate records of the registration of busses are not available for a large number of States. In general, only commercial busses are included in the official registration records supplied by the State authorities but in some instances school busses are included. In some States school busses are classed as publicly owned vehicles despite the fact that they may be privately owned and operated upon a contract basis. In other instances they are considered to be privately owned and subject to the same schedule of fees that the owners of other privately-owned vehicles pay. For these reasons the number of busses registered and the amounts of registration fees paid cannot be considered to be complete or entirely accurate.

Trailer registration regulations vary even more than those for busses. Some States require the registration of all trailers regardless of type, weight, or carrying capacity while others require only the registration of certain types of commercial or freight-carrying trailers. Because of the variations in practice it will be readily seen that the number of trailers reported as registered will not represent the number of trailers actually in existence. For this reason this study, while including all data reported, has placed major emphasis upon passenger cars and trucks for which it is believed adequate and accurate data are available. The operations of such vehicles also represent by far the major portion of traffic movement.

While the official State motor-vehicle registration records provide the data necessary for the preparation of State and regional figures, they do not provide the data relative to the number of vehicles registered in each of the population groups. In a few States records are maintained which would permit the direct tabulation of the number of vehicles owned in a particular city, town, or rural area. This is usually the case where motor-vehicle imposts are returned to the local governmental units on a basis that requires the number of vehicles registered in each local governmental unit to be determined. Since only a few States maintain these records, it was necessary to devise other procedures in order to determine the situs of ownership.

The motor-vehicle questionnaires, previously described, which were mailed to motor-vehicle owners throughout each of the States, were used as a basis for determining the distribution of vehicles by population group. It was necessary to devise a method of correcting the distortion in the returned sample caused by lack of uniform response by residents of the various population groups and the fact that owners of newer vehicles returned a larger proportion of questionnaires than did the owners of older vehicles.

TABLE 1.—*Distribution of vehicles by population groups in 1939* [1]

Region	Unincorporated areas	Incorporated places having a population of— 1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Non-resident	Total
PASSENGER CARS															
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Northeast	1,336,053	173,821	316,019	386,719	430,333	808,322	608,230	475,547	562,681	392,525	438,597	1,278,634	7,207,481	3,128	7,210,609
Southeast	1,726,678	188,491	222,140	204,758	210,046	260,504	193,134	246,279	219,544	274,487	....	....	3,746,061	8,337	3,754,398
Middle States	2,186,483	564,874	473,575	400,190	460,084	596,766	550,416	510,899	388,159	696,266	490,127	982,384	8,300,223	8,228	8,308,451
Northwest	750,110	197,058	151,741	98,535	114,260	177,368	65,476	53,395	143,240	86,737	....	....	1,837,920	1,520	1,839,440
Southwest	712,384	73,485	127,064	114,608	142,020	148,507	110,854	74,814	225,924	192,329	....	....	1,921,989	12,624	1,934,613
Far West	784,533	66,630	102,575	129,689	172,459	266,508	163,803	225,977	184,314	283,014	164,619	536,026	3,080,147	6,385	3,086,532
United States	7,496,241	1,264,359	1,393,114	1,334,499	1,529,202	2,257,975	1,691,913	1,586,911	1,723,862	1,925,358	1,093,343	2,797,044	26,093,821	40,222	26,134,043
TRUCKS															
Northeast	226,945	35,863	56,134	52,224	57,330	107,571	72,536	74,299	80,518	55,466	70,339	194,454	1,083,679	3,990	1,087,669
Southeast	385,567	44,063	49,734	45,520	42,765	53,206	34,590	46,086	36,824	45,005	....	....	783,360	10,316	793,676
Middle States	348,330	111,610	82,844	61,651	65,184	77,712	67,123	55,671	46,714	85,420	70,119	109,092	1,181,470	4,377	1,185,847
Northwest	197,224	43,300	31,514	19,600	20,806	29,497	10,874	8,033	21,642	11,353	....	....	393,843	3,082	396,925
Southwest	203,024	18,715	36,009	33,240	35,343	36,522	24,523	15,039	38,912	34,190	....	....	475,517	10,867	486,384
Far West	136,381	19,491	26,220	26,119	33,366	35,353	21,800	22,703	17,773	29,961	22,808	57,875	449,850	1,944	451,794
United States	1,497,471	273,042	282,455	238,354	254,794	339,861	231,446	221,831	242,383	261,395	163,266	361,421	4,367,719	34,576	4,402,295
BUSSES															
Northeast	580	425	977	955	1,403	3,348	4,385	1,994	4,297	2,426	1,160	4,078	26,028	2,446	28,474
Southeast	7,263	1,243	928	614	643	1,755	849	2,170	1,106	1,853	....	....	18,424	1,225	19,649
Middle States	924	326	195	195	233	324	664	542	465	1,483	1,455	323	7,129	547	7,676
Northwest	1,068	348	207	158	149	403	189	68	575	236	....	....	3,401	384	3,785
Southwest	317	18	36	181	240	455	511	179	2,125	524	....	....	4,586	415	5,001
Far West	932	144	255	307	501	629	454	599	715	884	2,457	1,650	9,527	63	9,590
United States	11,084	2,504	2,598	2,410	3,169	6,914	7,052	5,552	9,283	7,406	5,072	6,051	69,095	5,080	74,175
OTHER VEHICLES															
Northeast	34,018	6,357	10,384	9,581	9,637	18,142	10,772	10,365	9,821	5,768	9,259	34,642	168,746	590	169,336
Southeast	59,472	14,510	11,957	10,221	7,758	10,068	7,046	8,036	7,585	4,341	....	....	140,994	3,548	144,542
Middle States	185,329	60,732	47,319	35,512	36,460	43,249	35,865	34,776	34,087	31,978	15,161	37,083	597,551	4,068	601,619
Northwest	71,004	10,833	8,024	4,960	5,890	7,976	1,411	1,712	4,151	865	....	....	116,826	364	117,190
Southwest	29,072	3,145	6,127	5,625	5,898	7,246	4,419	3,201	9,926	6,758	....	....	81,417	1,767	83,184
Far West	52,582	7,224	13,029	14,095	20,278	18,037	12,035	14,353	8,935	10,032	6,514	22,083	199,197	210	199,407
United States	431,477	102,801	96,840	79,994	85,921	104,718	71,548	72,443	74,505	59,742	30,934	93,808	1,304,731	10,547	1,315,278
ALL VEHICLES															
Northeast	1,597,596	216,466	383,514	449,479	498,703	937,383	695,923	562,205	657,317	456,185	519,355	1,511,808	8,485,934	10,154	8,496,088
Southeast	2,178,980	248,307	284,759	261,113	261,212	325,533	235,619	302,571	265,059	325,686	....	....	4,688,839	23,426	4,712,265
Middle States	2,721,066	737,542	603,933	497,548	561,961	718,051	654,068	601,888	469,425	815,147	576,862	1,128,882	10,086,373	17,220	10,103,593
Northwest	1,019,406	251,539	191,486	123,253	141,105	215,244	77,950	63,208	169,608	99,191	....	....	2,351,990	5,350	2,357,340
Southwest	944,797	95,363	169,236	153,654	183,501	192,730	140,307	93,233	276,887	233,801	....	....	2,483,509	25,673	2,509,182
Far West	974,428	93,489	142,079	170,210	226,504	320,527	198,092	263,632	211,737	323,891	196,398	617,634	3,738,721	8,602	3,747,323
United States	9,436,273	1,642,706	1,775,007	1,655,257	1,873,086	2,709,468	2,001,959	1,886,737	2,050,033	2,253,901	1,292,615	3,258,324	31,835,366	90,425	31,925,791

[1] Source: Public Roads Administration table MV 1, 1939. Planning survey data were used for population group distribution and adjustments in vehicle types.

The proper determination of the distribution of passenger cars by population groups, when the determination is to be made through the use of questionnaires, involves a study of the distribution of year models. The year model distribution, which was obtained for each State by either a complete or partial analysis of the registration records, was used in adjusting the returned sample to correct for the distortion caused by the lack of uniform response.

The basis for determining the number of vehicles of each type registered in each population group in 1939 was provided by the results of the motor-vehicle allocation studies, which were available for all but seven States. The distribution of vehicles by population groups as determined by the motor-vehicle allocation studies was applied directly to the total number of vehicles registered in each State in 1939.

In those States for which results of motor-vehicle allocation studies were not available the distribution of vehicles by population groups was estimated. The distribution of vehicles in adjoining and nearby States having the same geographic and economic characteristics was used as the basis for making the estimates. Estimates of the vehicle distribution by population groups were made for Connecticut, Delaware, Massachusetts, Mississippi, New Jersey, New York, and Rhode Island.

In addition to the population group distribution a small number of vehicles in each region are designated as "nonresident" vehicles. These are vehicles registered in a State other than that of the residence of the owner. Some States require vehicles entering the State to register while others consider a bona fide registration in another State as meeting the local requirements. It is the practice of some corporations to pay all registration fees for vehicles from the home office of the corporation, which may be located in a State other than the one in which the vehicles are operated. In some States such registrations are considered as nonresident registrations and they are so considered in this study.

MIDDLE STATES HAVE NEARLY ONE-THIRD OF ALL PASSENGER CARS

The distribution of the four types of vehicles by regions and population groups is shown in table 1. The data given in this table for passenger cars and trucks are expressed in percentages in table 2. Passenger cars constitute the major part of the motor-vehicle registration with a total of 26,134,043, which is 81.8 percent of all vehicles registered. The 4,402,295 trucks constitute 13.8 percent of the total registration. Motor busses, trailers, and motorcycles make up a relatively small proportion of the total registration.

Approximately one-third of all the passenger cars in the United States were registered in the eight States comprising the Middle States region. The fact that the automobile industry is centered in this region is probably an important factor in the relatively high concentration of ownership in this area. The Northeast region ranked second in number of passenger cars with a total of 7,210,609 registrations. The Northwest region comprising nine States had the lowest total of the six regions with 1,839,440 passenger cars. Although the Middle States also had the largest registration of trucks, the ratio of passenger cars to trucks was higher than that of any other region. The 1,185,847 truck registrations accounted for 26.9 percent of the total truck registrations in the country while the passenger car registrations were 31.8 percent of the total. The Northeast region had the second largest truck registration with 1,087,669 vehicles while the Northwest had the lowest total with 396,925 registrations.

The distribution of motor vehicles, population, and land area of the six regions are compared in table 3. These data are presented graphically in figure 2. The densely populated Northeast region had 26.6 percent of the motor-vehicle registrations and only 5.8 percent of the land area of the country. The Northwest region with a total land area of 818,508 square miles, or 27.5 percent of the total area of the country, had only 7.4 percent of the total number of motor vehicles registered. The three Western regions as a group accounted for 27.0 percent of the motor vehicles registered in 1939 with only 20.1 percent of the population while the Middle States and the two Eastern regions had 73 percent of the vehicles and 79.9 percent of the population. The three Western regions, while having a relatively high number of vehicles when compared with the Middle States and Eastern regions on a population basis have relatively few vehicles when compared with these regions on an area basis. The three Western regions had 61 percent of the land area but only 27 percent of the vehicle registrations.

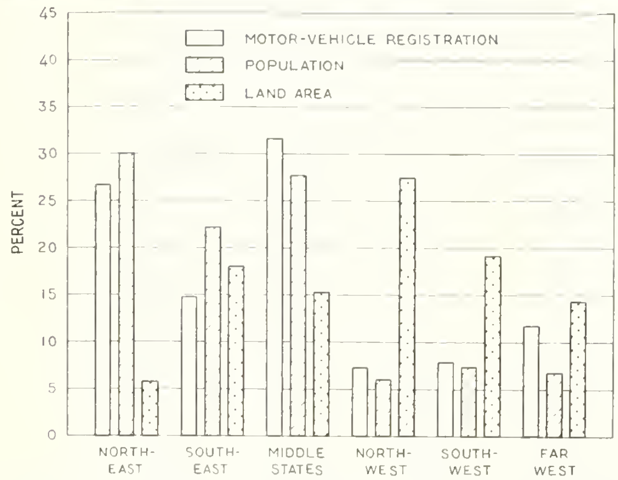

FIGURE 2.—PERCENTAGE DISTRIBUTION OF MOTOR VEHICLES REGISTERED IN 1939 AND POPULATION AND LAND AREA AS REPORTED BY THE 1930 CENSUS.

The relatively high concentration of vehicles in the Northeast is evident in table 4 which shows the number of passenger cars, trucks, and all vehicles per square mile in each of the six regions. The average number of passenger cars per square mile in the Northeast was 41.4 and for the United States was 8.8. The Northwest had only 2.2 passenger cars per square mile of area.

Table 5 shows the ratio of passenger cars to trucks for each region and population group in 1939. The ratio of passenger cars to trucks for the United States was 6.0. There is considerable variation in the ratio throughout the various population groups and regions, ranging from 3.4 in places having a population of less than 1,000 in the Far West and in places having a population of

TABLE 2.—*Percentage distribution of passenger cars and trucks by population groups in 1939*

PASSENGER CARS

Region	Unincorporated areas	Incorporated places having a population of— 1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Nonresident	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Northeast	18.5	2.4	4.4	5.4	6.0	11.2	8.4	6.6	7.8	5.4	6.1	17.7	99.9	0.1	100.0
Southeast	46.0	5.0	5.9	5.5	5.6	6.9	5.1	6.6	5.9	7.3			99.8	.2	100.0
Middle States	26.3	6.8	5.7	4.8	5.5	7.2	6.6	6.2	4.7	8.4	5.9	11.8	99.9	.1	100.0
Northwest	40.8	10.7	8.2	5.4	6.2	9.6	3.6	2.9	7.8	4.7			99.9	.1	100.0
Southwest	36.8	3.8	6.6	5.9	7.3	7.7	5.7	3.9	11.7	9.9			99.3	.7	100.0
Far West	25.4	2.2	3.3	4.2	5.6	8.6	5.3	7.3	6.0	9.2	5.3	17.4	99.8	.2	100.0
United States	28.7	4.8	5.3	5.1	5.8	8.6	6.5	6.1	6.6	7.4	4.2	10.7	99.8	.2	100.0

TRUCKS

Region	Unincorporated areas	1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Nonresident	Total
Northeast	20.8	3.3	5.1	4.8	5.3	9.9	6.7	6.8	7.4	5.1	6.5	17.9	99.6	0.4	100.0
Southeast	48.6	5.5	6.3	5.7	5.4	6.7	4.4	5.8	4.6	5.7			98.7	1.3	100.0
Middle States	29.4	9.4	7.0	5.2	5.5	6.5	5.7	4.7	3.9	7.2	5.9	9.2	99.6	.4	100.0
Northwest	49.7	10.9	7.9	4.9	5.3	7.4	2.7	2.0	5.5	2.9			99.2	.8	100.0
Southwest	41.7	3.9	7.4	6.8	7.3	7.5	5.1	3.1	8.0	7.0			97.8	2.2	100.0
Far West	30.2	4.3	5.8	5.8	7.4	7.8	4.8	5.0	4.0	6.6	5.1	12.8	99.6	.4	100.0
United States	34.0	6.2	6.4	5.4	5.8	7.7	5.3	5.1	5.5	5.9	3.7	8.2	99.2	.8	100.0

2,501 to 5,000 in the Southwest region to 10.4 in places having a population of 100,001 to 250,000 in the Far West region. In the Southwest region there was one truck registered for every four passenger cars while in the Middle States there was only one truck for every seven passenger cars. The low ratio of passenger cars to trucks in the unincoporated areas and small incorporated places is probably due to the use of trucks for carrying passengers as well as for general hauling on farms.

TABLE 3. *Distribution of motor-vehicle registration, population, and land area in the United States*

Region	1939 vehicle registration [1]		Population [2]		Land area [2]	
	Number	Percent	Number	Percent	Square miles	Percent
Northeast	8,496,088	26.6	36,783,866	30.0	173,944	5.8
Southeast	4,712,265	14.8	27,280,103	22.2	534,548	18.0
Middle States	10,103,593	31.6	33,961,444	27.7	450,735	15.2
Northwest	2,357,340	7.4	7,384,497	6.0	818,508	27.5
Southwest	2,509,182	7.9	9,079,645	7.4	568,125	19.1
Far West	3,747,323	11.7	8,285,491	6.7	427,916	14.4
United States	31,925,791	100.0	122,775,046	100.0	2,973,776	100.0

[1] Includes all registered motor vehicles, trailers, and motorcycles.
[2] Source: 1930 Census

TABLE 4.—*Motor vehicles registered per square mile in the United States in 1939*

Region	Passenger cars	Trucks	All vehicles [1]
Northeast	41.4	6.2	48.8
Southeast	7.0	1.5	8.8
Middle States	18.4	2.6	22.1
Northwest	2.2	.5	2.9
Southwest	3.4	.8	4.1
Far West	7.2	1.1	8.8
United States	8.8	1.5	10.7

[1] Includes busses, trailers, and motorcycles.

TABLE 5.—*Ratio of passenger cars to trucks in 1939, by regions and populatian groups*

Population group	Region						
	Northeast	Southeast	Middle States	Northwest	Southwest	Far West	All regions
Unincorporated areas	5.9	4.5	6.3	3.8	3.5	5.8	5.0
Incorporated places having a population of—							
Less than 1,000	4.8	4.3	5.1	4.6	3.9	3.4	4.6
1,001 to 2,500	5.6	4.5	5.7	4.8	3.5	3.9	4.9
2,501 to 5,000	7.4	4.5	6.5	5.0	3.4	5.0	5.6
5,001 to 10,000	7.5	4.9	7.0	5.5	4.0	5.2	6.0
10,001 to 25,000	7.5	4.9	7.7	6.0	4.1	7.5	6.6
25,001 to 50,000	8.4	5.6	8.2	6.0	4.5	7.5	7.3
50,001 to 100,000	6.4	5.3	9.2	6.6	5.0	10.0	7.2
100,001 to 250,000	7.0	6.0	8.3	6.6	5.8	10.4	7.1
250,001 to 500,000	7.1	6.1	8.2	7.6	5.6	9.4	7.4
500,001 to 1,000,000	6.2		7.0			7.2	6.7
More than 1,000,000	6.6		9.0			9.3	7.7
Total	6.6	4.8	7.0	4.7	4.0	6.8	6.0

THREE-TENTHS OF ALL VEHICLES OWNED BY RESIDENTS OF UNINCORPORATED PLACES

Of the 31,925,791 vehicles registered in 1939, persons residing in unincorporated areas owned 9,436,273 or 29.6 percent. Residents of incorporated places having a population of less than 1,000 owned 1,642,706 vehicles while 1,775,007 were owned in places having a population of 1,001 to 2,500. The residents of these three population groups, which include 43.6 percent of the total population of the country, owned 40.2 percent of the registered vehicles. However, the percentage of vehicles owned in the two smallest classes of incorporated places which include all those places having a population of less than 2,500 persons, exceeds the percentage of population residing in these two groups. Of the total population of the country, 8.1 percent resided in these groups while 10.6 percent of the vehicles were owned by these residents. Table 6 gives a comparison of population and motor-vehicle distribution expressed in percentages for each of the several population groups. The residents of unincorporated areas and cities having a population of more than 500,000 persons own fewer vehicles in proportion to the population in these groups than do residents of incorporated places that have a population of less than 500,000. A total of 17,848,154 vehicles were registered by owners residing in incorporated places having a population of less than 500,000. These latter population groups accounted for 47.5 percent of the population of the United States and 55.9 percent of the vehicles registered.

TABLE 6.—*Comparison of papulatian and motor-vehicle distributian expressed in percentages for the several population groups*

Population group	Percentage of population	Percentage of motor vehicles registered				
		Passenger cars	Trucks	Busses	Other vehicles	Total
Unincorporated areas	35.5	28.7	34.0	14.9	32.8	29.6
Incorporated places having a population of—						
Less than 1,000	3.8	4.8	6.2	3.4	7.8	5.1
1,001 to 2,500	4.3	5.3	6.4	3.5	7.4	5.5
2,501 to 5,000	4.1	5.1	5.4	3.3	6.1	5.2
5,001 to 10,000	4.9	5.8	5.8	4.3	6.5	5.9
10,001 to 25,000	7.4	8.6	7.7	9.3	8.0	8.5
25,001 to 50,000	5.2	6.5	5.3	9.5	5.4	6.3
50,001 to 100,000	5.3	6.1	5.1	7.5	5.5	5.9
100,001 to 250,000	6.1	6.6	5.5	12.5	5.7	6.4
250,001 to 500,000	6.4	7.4	5.9	10.0	4.5	7.1
500,001 to 1,000,000	4.7	4.2	3.7	6.8	2.4	4.0
More than 1,000,000	12.3	10.7	8.2	8.2	7.1	10.2
Nonresident	...	.2	.8	6.8	.8	.3
Total	100.0	100.0	100.0	100.0	100.0	100.0

The number of passenger cars registered per 100 persons living in each of the population groups is shown in table 7. There is considerable range in passenger car ownership per 100 persons in the several regions and population groups. In the Far West in incorporated places having a population of 50,001 to 100,000 there were 53.2 passenger cars per 100 persons while in the unincorporated areas of the Southeast there were only 10.2 cars per 100 persons. The unincorporated areas in the Northeast were above the average of 19.6 for the entire region with 21.7 passenger cars per 100 persons.

The comparatively small number of passenger cars owned per 100 persons in the larger cities is undoubtedly due in part to the extensive and efficient public transportation systems which make it unnecessary for many persons residing in those places to depend upon the automobile for local transportation. Lack of highly developed public transportation facilities in the smaller cities makes the ownership of an automobile almost a necessity under ordinary circumstances. Furthermore, the ownership of vehicles in the larger cities is considerably more expensive than it is in the smaller places due to higher operating costs and costs of storage and parking facilities.[4] These factors are reflected in the

[4] Family Expenditures in Selected Cities, 1935-36, Vol. VI, U. S. Department of Labor, Bureau of Labor Statistics.

lower ratio of passenger cars to population in cities over 500,000.

While the necessity for some means of local transportation is probably greater in the unincorporated areas than in the smaller cities, the low cash income of residents of these areas in many cases precludes the ownership of any kind of a motor vehicle. This is particularly true in the Southeast where in the unincorporated areas there were only 10.2 passenger cars registered per 100 persons and in the Southwest where the number registered per 100 persons was 14.8. The lack of passenger cars in the unincorporated areas is offset to some extent by a relatively large truck registration in all but the Southeast and Southwest regions.

TABLE 7.—*Number of passenger cars registered per 100 persons* [1]

Population group	Region						United States
	North-east	South-east	Middle States	North-west	South west	Far West	
Unincorporated areas	21.7	10.2	22.2	21.5	14.8	33.5	17.2
Incorporated places having a population of—							
Less than 1,000	24.1	18.1	33.6	27.2	24.5	45.0	27.4
1,001 to 2,500	25.0	19.0	30.9	27.9	25.7	42.6	26.6
2,501 to 5,000	25.5	19.4	29.8	28.2	26.2	40.9	26.6
5,001 to 10,000	21.6	21.0	27.9	29.7	26.0	39.5	25.4
10,001 to 25,000	21.6	19.6	26.2	29.7	30.7	43.6	25.0
25,001 to 50,000	25.3	21.8	26.2	28.4	31.2	38.3	26.4
50,001 to 100,000	19.4	19.7	26.7	28.1	28.0	53.2	24.4
100,001 to 250,000	18.7	21.2	24.7	24.4	27.4	36.0	22.8
250,001 to 500,000	21.5	17.7	25.0	30.2	34.8	29.7	24.2
500,001 to 1,000,000	15.5	------	21.3	------	------	25.9	19.0
More than 1,000,000	14.4	------	19.9	------	------	43.3	18.6
Total	19.6	13.7	24.4	24.9	21.2	37.2	21.3

[1] Based upon 1939 passenger car registrations and 1930 population.

Table 8 shows the number of trucks registered per 100 persons in each of the regions and population groups. The use of trucks as passenger vehicles as well as for hauling agricultural products and supplies probably accounts for the relatively high number of trucks owned by residents of rural areas. The incorporated places having a population of less than 10,000 had a relatively high truck registration compared to the larger cities. As in the case of passenger cars, the truck registration in the largest cities was comparatively low. Figure 3 is a graphic representation of the number of passenger cars and trucks registered per 100 persons in each of the population groups in the United States.

From a consideration of these data it is apparent that motor-vehicle ownership is more concentrated in the small and medium size cities than in the rural or unincorporated areas and the largest cities. It appears that increased ownership of vehicles will result in the largest cities only after adequate parking and storage facilities are provided and the convenience of using private vehicles is increased by relieving traffic congestion through improvement of street facilities. The economic status of large numbers of farmers and other residents of rural areas will also have to be changed considerably before any large increase in the number of rurally owned motor vehicles will result.

PASSENGER CARS GROUPED ACCORDING TO YEAR MODEL AND AVERAGE AGE

Since data regarding the distribution of passenger cars by year models in most States were obtained only for the year during which the motor-vehicle study was

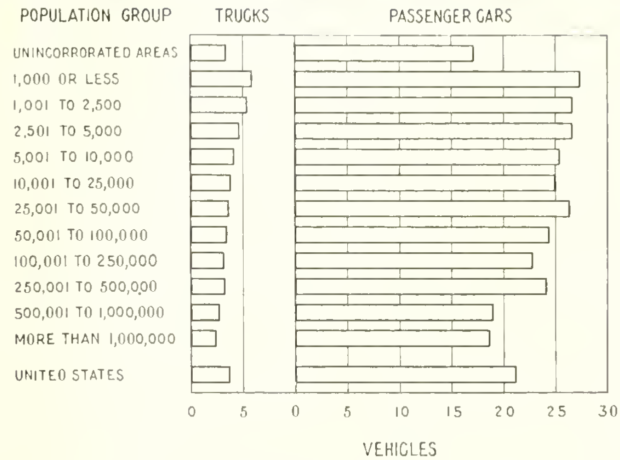

FIGURE 3.—TRUCK AND PASSENGER-CAR REGISTRATIONS PER 100 PERSONS IN 1939.

conducted, and since these data cannot be combined satisfactorily for average age computations for regions or on a country-wide basis, they are shown for individual States and for the period of the study only. Because the registration years vary considerably in the several States and because the motor-vehicle allocation studies were made for various periods, it is not considered practicable to present combined data for a particular period. Tabulations have been prepared which indicate the variation in the average age of passenger cars between rural areas and incorporated places in a number of States. In the case of two States, available data make possible the presentation of average age data for each of 3 years and for each of the population groups.

TABLE 8.—*Number of trucks registered per 100 persons* [1]

Population group	Region						United States
	Northeast	Southeast	Middle States	Northwest	Southwest	Far West	
Unincorporated areas	3.7	2.3	3.5	5.6	4.2	5.8	3.4
Incorporated places having a population of—							
Less than 1,000	5.0	4.2	6.6	6.0	6.2	13.2	5.9
1,001 to 2,500	4.4	4.3	5.4	5.8	7.3	10.9	5.4
2,501 to 5,000	3.4	4.3	4.6	5.6	7.6	8.2	4.7
5,001 to 10,000	2.9	4.3	3.9	5.4	6.5	7.6	4.2
10,001 to 25,000	2.9	4.0	3.4	4.9	7.6	5.6	3.8
25,001 to 50,000	3.0	3.9	3.2	4.7	6.9	5.1	3.6
50,001 to 100,000	3.0	3.7	2.9	4.2	5.6	5.3	3.4
100,000 to 250,000	2.7	3.6	3.0	3.7	4.7	3.5	3.2
250,001 to 500,000	3.0	2.9	3.1	3.9	6.2	3.1	3.3
500,001 to 1,000,000	2.5	------	3.0	------	------	3.6	2.8
More than 1,000,000	2.2	------	2.2	------	------	4.7	2.4
Total	2.9	2.9	3.5	5.3	5.2	5.4	3.6

[1] Based upon 1939 truck registrations and 1930 population.

The average age of passenger cars registered during the year on which the motor-vehicle allocation studies were based in each of the States has been computed from the available year-model data. The following paragraphs describe the procedure used in these computations.

The first step in the computation of the average age of passenger cars involved the determination of the age of vehicles that had been in service for a period of less than 1 year. During the period in which the motor-vehicle allocation studies were being conducted most of the manufacturers placed their new models on sale early in November. In more recent years the new models have in general been released during September and October. The count of the number of passenger cars of each year model in a State was made in most instances after the close of the registration year. Since the new car models were placed on sale during the fall season a few new models were usually registered in the calendar year preceding the year of the model. For example, a few 1939 model cars are included in the 1938 registrations of all States registering on a calendar-year basis or some period approximately coincident with the calendar year. In most cases new car registrations reported in November and December of each year represented sales of the new models for the next year. In order to include these cars in the average age calculations, vehicles registered in November were considered as having been in service an average of 2 months and vehicles registered in December as having been in service an average of 1 month on December 31.

In calculating the average age of vehicles of the same year model as the registration year in which the counts were made, the number of new car registrations effected during the year November 1 to October 31 was determined. Practically all of the new car sales for a particular year take place during the period from November of the year preceding the year of the model to the following October. For example, the major part of the 1938 models was sold during the last 2 months in 1937 and the first 10 months of 1938. Therefore, to compute the average age of the most recent year model the new car registrations in each month were tabulated. New vehicles registered in November and December were considered to have been in operation 12 months and 11 months, respectively, on the following October 31. Cars sold in each successive month were in service 1 month less. Vehicles sold in October were considered to have been in service for 1 month. The number of service months was obtained by multiplying the number of registrations in the month by the number of months in operation. The average age was determined by dividing the service months by the total number of new car registrations during the period. Adjustments to the beginning of the registration period were made by adding the difference in months between October 31 and the beginning of the registration period to the average age of the latest year models.

After determining the average age of vehicles in operation less than 1 year the average age of all passenger cars registered in each State was obtained by dividing the number of service years by the total registration. Automobiles of the year model preceding the latest year reported were considered to be 1 year older than the average age of the latest year model. Similarly, cars of earlier years were considered to be 2, 3, and 4 years older according to the year model of the vehicle.

Since many of the States did not determine the number of passenger cars of each year model older than 1925 a method was devised for apportioning these older vehicles to the several year model groups prior to the oldest year available. The number of 1924 and earlier year models registered in 1936 and subsequent years was so small that the omission of these vehicles from the calculations would have had but slight effect upon the results. Since a practical means of making the apportionment was available, they were included in the calculations.

AVERAGE AGE OF PASSENGER CARS IN 39 STATES VARIED FROM 4.49 TO 7.29 YEARS

A complete enumeration of all passenger cars registered in Connecticut by year models was made for the year 1939.[5] The number of vehicles of each model from 1904 to 1939 was determined in this study. Similar information obtained from Virginia, Missouri, Nebraska, and Alabama provided the basis for construction of a table of the number of cars remaining in service after attaining the age of 12 years. This table was used in determining the number of cars of each year model older than 12 years for each of the States. Of the total number of vehicles registered which were 12 years or older, approximately 1 percent were 19 years or older. These vehicles were grouped and were found to average 22.10 years of age. In distributing vehicles to the various year model groups older than 19 years this small fraction of 1 percent of the total registration was considered to have an average age of 22.10 years.

The average age of passenger cars in each of 39 States is shown in table 9 as of the date indicated. The dates selected in the tabulation were controlled by the time covered by the motor vehicle allocation study and the registration year. Of the States represented in the tabulation, Massachusetts with 4.49 years had the lowest average age for passenger cars. The highest average age was found in South Dakota where the automobiles had an average age of 7.29 years at the end of March 1938. In 26 of the 39 States the average age of passenger cars was greater than 5 years and less than 6 years. In only 5 States was the average age less than 5 years and in 8 States the average exceeded 6 years. With the exception of Louisiana all of the States whose passenger cars averaged less than 5 years were situated in the East and Northeastern part of the United States.

The average age of passenger cars owned by residents of unincorporated areas is considerably higher than that of automobiles owned in the incorporated places. The average age of passenger cars owned in unincorporated areas in the 15 States shown in table 10 is without exception higher than the average age of vehicles owned by residents of incorporated places. In 4 of the 15 States the difference in average age is less than 1 year; in 8 States the difference is between 1 and 2 years; and in Arkansas, Minnesota, and North Dakota the difference between average ages of vehicles owned in the cities and unincorporated areas is in excess of 2 years. Registration records indicate that the purchase of used cars by rural residents, rather than the long life of automobiles purchased new by that group, is the chief factor in the differences in average age of vehicles in the rural areas and incorporated places.

AVERAGE AGE OF ALABAMA AND ARKANSAS PASSENGER CARS GIVEN BY POPULATION GROUP

The motor-vehicle registration records for the registration years 1936, 1937, and 1938, for Alabama and Arkansas, have been tabulated on the basis of the number of year models of each type of vehicle registered in each of the several population groups in these States. These data have been used to compute the average age of passenger cars owned by residents of each population group for each of the three years.

[5] Cars of Yesteryears, Connecticut State Department of Vehicles. (Mimeographed report.)

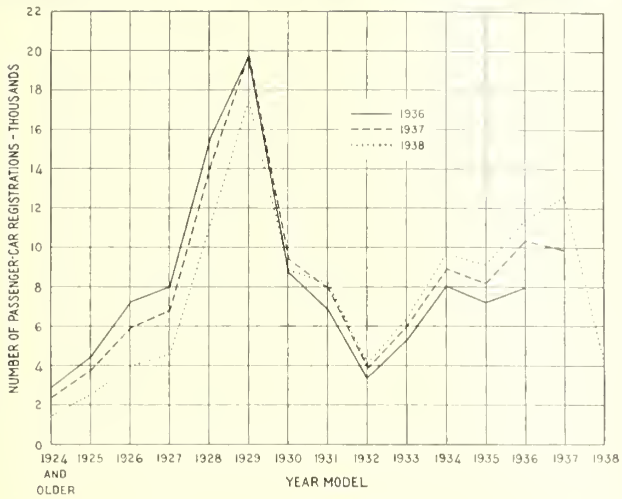

FIGURE 4.—REGISTRATION OF PASSENGER CARS BY YEAR MODELS IN THE UNINCORPORATED AREAS IN ALABAMA IN THE REGISTRATION YEARS 1936, 1937, AND 1938.

TABLE 9.—*Average age of passenger cars registered on dates indicated*

State	Date	Average age
		Years
Alabama	Sept. 30, 1936	5.53
Arizona	Oct. 31, 1936	5.91
Arkansas	Dec. 31, 1936	5.86
California	do	5.82
Colorado	do	6.61
Connecticut	Feb. 28, 1939	5.12
Florida	Dec. 31, 1936	5.36
Idaho	Oct. 31, 1936	5.78
Illinois	Oct. 31, 1935	5.20
Indiana	Dec. 31, 1936	5.80
Kansas	do	5.76
Kentucky	Feb. 28, 1937	5.94
Louisiana	Dec. 31, 1936	4.84
Maine	Dec. 31, 1937	5.36
Maryland	Mar. 31, 1937	4.70
Massachusetts	Dec. 31, 1937	4.49
Michigan	Oct. 31, 1935	5.51
Minnesota	Dec. 31, 1936	6.22
Missouri	Dec. 31, 1935	6.30
Montana	Dec. 31, 1936	5.48
Nebraska	Dec. 31, 1937	6.52
Nevada	Oct. 31, 1936	5.07
New Hampshire	do	5.13
New Mexico	Dec. 31, 1936	5.64
North Carolina	do	5.10
North Dakota	Dec. 31, 1935	6.83
Oklahoma	do	5.72
Oregon	Oct. 31, 1936	6.30
Rhode Island	do	4.89
South Carolina	do	5.70
South Dakota	Mar. 31, 1938	7.29
Tennessee	do	5.37
Utah	Oct. 31, 1936	5.55
Vermont	Mar. 31, 1937	5.60
Virginia	do	4.85
Washington	Oct. 31, 1936	6.52
West Virginia	June 30, 1936	5.42
Wisconsin	Oct. 31, 1936	5.96
Wyoming	do	5.06

Table 11 gives the average age of passenger cars for each population group in Alabama. The average age of automobiles owned by persons living in the unincorporated areas was approximately 1 year higher than the average of all vehicles in the State and slightly more than 2 years higher than automobiles owned in the incorporated places. The average age of the passenger cars in unincorporated areas remained practically unchanged during 1936 and 1937 and then increased from 6.56 in 1937 to 6.64 in 1938. The effect of the large sale of 1937 cars is noticeable in the reduction in average age in 1937.

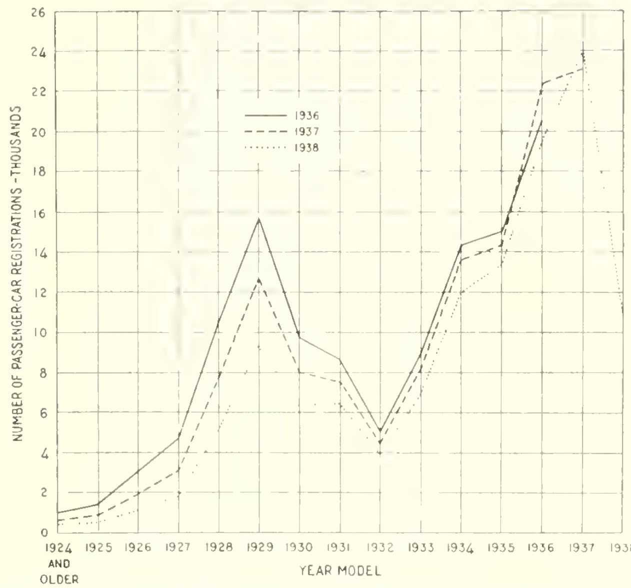

FIGURE 5.—REGISTRATION OF PASSENGER CARS BY YEAR MODELS IN THE INCORPORATED PLACES IN ALABAMA IN THE REGISTRATION YEARS 1936, 1937, AND 1938.

TABLE 10.—*Average age of passenger cars registered in unincorporated areas and in incorporated places on dates indicated*

State	Date	Unincorporated areas	Incorporated places	All areas
		Years	*Years*	*Years*
Alabama	Sept. 30, 1936	6.54	4.63	5.53
Arkansas	Dec. 31, 1936	7.10	4.56	5.86
Florida	do	6.10	5.09	5.36
Louisiana	do	5.48	4.50	4.84
Maryland	Mar. 31, 1937	5.11	4.41	4.70
Minnesota	Dec. 31, 1936	7.29	5.23	6.22
Missouri	do	7.46	5.56	6.30
North Dakota	do	7.71	5.54	6.83
Oklahoma	do	6.63	5.21	5.72
Oregon	Oct. 31, 1936	7.32	5.69	6.30
Utah	do	6.04	5.39	5.55
Vermont	Mar. 31, 1937	6.25	4.92	5.60
Virginia	do	5.21	4.15	4.85
Washington	Oct. 31, 1937	7.37	6.05	6.52
Wyoming	Oct. 31, 1936	5.64	4.66	5.06

TABLE 11.—*Average age of passenger cars in each population group in Alabama on September 30 of the registration years 1936, 1937, and 1938*

Population group	Registration year—		
	1936	1937	1938
	Years	*Years*	*Years*
Unincorporated areas	6.54	6.56	6.64
Incorporated places having a population of—			
Less than 1,000	4.91	4.62	4.69
1,001–2,500	4.34	4.10	4.40
2,501–5,000	4.53	4.24	4.52
5,001–10,000	4.50	4.34	4.51
10,001–25,000	4.58	4.35	4.51
Gadsen (32,586)	4.61	4.46	4.69
Montgomery (66,079)	4.55	4.23	4.50
Mobile (68,202)	5.20	5.07	5.17
Birmingham (259,678)	4.64	4.30	4.43
All incorporated places	4.63	4.37	4.55
All population groups	5.53	5.41	5.56

The shift of the older used cars from the cities to the rural areas is readily apparent when the data shown in figures 4 and 5 are compared. Figure 4 shows the number of passenger cars of each year model registered by residents of the unincorporated areas of Alabama for each of the three registration years 1936, 1937, and 1938.

Figure 5 shows comparable data for the incorporated places in Alabama. The predominance of 1929-year models in the rural areas and the slow rate at which they were being retired is apparent in figure 4.

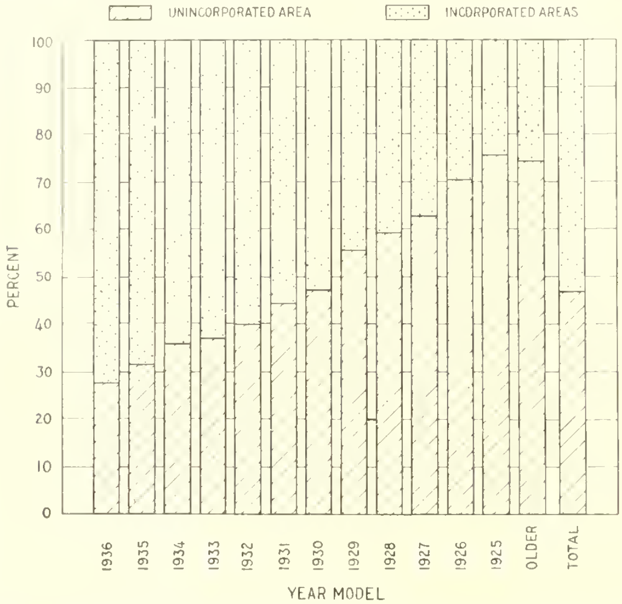

FIGURE 6.—PERCENTAGE OF EACH YEAR MODEL OF PASSENGER CARS REGISTERED IN THE UNINCORPORATED AND INCORPORATED AREAS OF ALABAMA IN 1936.

Starting with the 1931 models there was an increase in the number of older model cars registered in each of the three registration years. For example, there were 6,855 automobiles of the 1931 model registered in 1936. In 1937 this number had increased to 7,954 and in 1938 there were 8,171 of the 1931 models registered. There were similar increases for each subsequent year model for each of the three registration years. These increases in older car registrations were due to the shift of used cars from the cities to rural areas and the importation of used cars from other States.

In figure 5, which shows the number of vehicles registered in incorporated places, it is apparent that some of the older year models disappeared with each successive registration year with the exception of the latest model available during the registration year. The increase in the number of registrations of the latest model available is accounted for by sales of new vehicles after the close of the registration year on September 30.

In 1938, 10 years after the 1929-model automobile first became available, there were more cars of this model registered by residents of unincorporated areas than of any other year model. In the cities the registration of 1929-model cars was still large but they were disappearing at a rapid rate and in 1938 there were more cars of the 1934 and subsequent models registered than there were 1929 models. The percentage of each year model registered in the unincorporated and incorporated areas of Alabama in 1936 is presented graphically in figure 6. The predominance of newer cars in the cities is evidenced by the data shown in this graph.

Characteristics practically identical with the Alabama data are found in a similar presentation of Arkansas registration data for the registration years 1936, 1937, and 1938. There was, however, a general in-

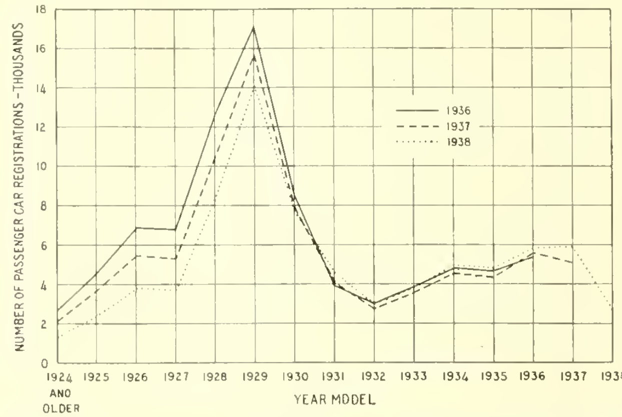

FIGURE 7.—REGISTRATION OF PASSENGER CARS BY YEAR MODELS IN THE UNINCORPORATED AREAS IN ARKANSAS IN THE REGISTRATION YEARS 1936, 1937, AND 1938.

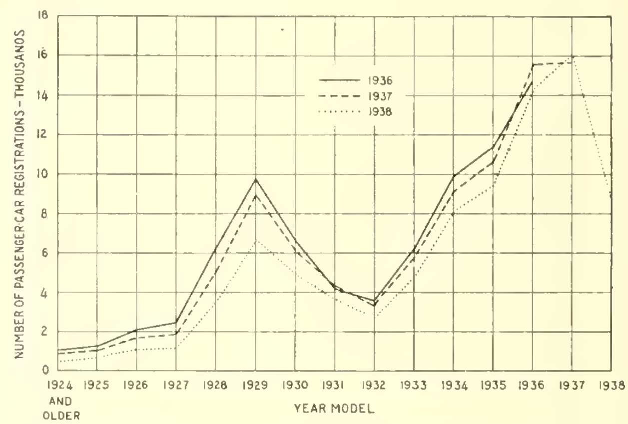

FIGURE 8.—REGISTRATION OF PASSENGER CARS BY YEAR MODELS IN THE INCORPORATED PLACES IN ARKANSAS IN THE REGISTRATION YEARS 1936, 1937, AND 1938.

crease in the average age of cars in Arkansas during the 3-year period. As in Alabama the average age of cars owned in the unincorporated areas was more than 2 years higher than the average age of cars owned in incorporated places. Table 12 gives the average age of Arkansas passenger cars for each of the registration years 1936, 1937, and 1938 and for each of the population groups in the State. Figures 7 and 8 show the number of vehicles of each year model registered in each of the three registration years. Here, as in Alabama, the preponderance of 1929 models is particularly outstanding in both the cities and rural areas. In 1938 there were still two and one-half times as many 1929 models registered as there were 1937 models. At the rate that used cars are being shifted from the cities to the rural areas it appears that the average age of cars owned in the rural areas in Arkansas will not be reduced an appreciable amount during the next several years.

MOTOR-VEHICLE REGISTRATION FEES CLASSIFIED BY POPULATION GROUPS

Collections of motor-vehicle registration fees totaled $353,533,000 in 1939, $237,612,000 of which was for passenger cars and $98,666,000 for trucks. Bus registration fees totaled $6,032,000 and owners of trailers and motorcycles paid $11,223,000 in registration fees. Table 13 shows the amounts of registration fees paid by owners of each of the four types of vehicles in each of

TABLE 12.—*Average age of passenger cars in each population group in Arkansas on December 31 of the registration years 1936, 1937, and 1938*

Population group	Registration year		
	1936	1937	1938
	Years	*Years*	*Years*
Unincorporated areas	7.10	7.41	7.57
Incorporated places having a population of—			
Less than 1,000	5.36	5.29	5.36
1,001–2,500	4.89	4.78	5.01
2,501–5,000	4.45	4.38	4.54
5,001–10,000	4.33	4.31	4.59
10,001–25,000	4.37	4.43	4.45
Fort Smith (31,429)	4.51	4.53	4.65
Little Rock (81,679)	4.20	4.28	4.24
All incorporated places	4.56	4.55	4.65
All population groups	5.86	5.90	6.02

the regions and population groups. These data are expressed in percentages in table 14 for passenger cars and trucks.

A comparison of the data shown in tables 2 and 14 indicates that the proportion of passenger cars registered in the unincorporated areas exceeds the proportion of registration fees paid by residents of these areas in all of the regions with the exception of the Northeast. The unincorporated areas of all regions combined accounted for 28.7 percent of the passenger-car registrations but residents of these areas paid only 26.4 percent of the total registration fees. Residents of incorporated places with populations of less than 1,000,000 paid registration fees which were proportional, with only slight variations, to the number of vehicles registered in each population group. The residents of cities having a population of more than 1,000,000 owned 10.7 percent of the passenger cars in the country and paid 12.9 percent of the total registration fees.

The net weight and horsepower of vehicles are the two bases which are predominant in the computation of license fees for passenger cars. Since a great many older cars, a large portion of which were light in weight, and a large portion of the lighter weight cars of the later models are registered in the unincorporated areas, it is to be expected that these factors would result in a low average registration fee in these areas and a low

TABLE 13.—*Total motor-vehicle registration fees paid in 1939, by population groups* [1]

Region	Unincorporated areas	Incorporated places having a population of—											All places	Non-resident	Total
		1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000			
PASSENGER CARS															
	$1,000	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$,1000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*
Northeast	14,528	1,961	3,558	4,165	4,408	8,308	5,800	4,939	5,130	3,611	3,851	16,981	77,240	46	77,286
Southeast	14,183	1,583	1,946	1,843	1,890	2,381	1,847	2,368	2,333	2,171	-----	-----	32,545	97	32,642
Middle States	20,016	5,623	4,703	4,107	4,516	6,025	5,533	5,301	3,745	6,665	5.272	9,814	81,320	89	81,409
Northwest	3,907	1,160	877	573	703	1,161	469	262	717	458	-----	-----	10,287	10	10,297
Southwest	5,510	578	1,069	1,022	1,133	1,380	913	750	2,009	1,983	-----	-----	16,347	75	16,422
Far West	4,690	320	607	814	1,166	1,687	1,092	1,624	1,072	1,426	1,181	3,845	19,524	32	19,556
United States	62,834	11,225	12,760	12,524	13,816	20,942	15,654	15,244	15,006	16,314	10,304	30,640	237,263	349	237,612
TRUCKS															
Northeast	5,901	871	1,468	1,376	1,588	2,931	1,883	2,416	2,256	1,621	1,596	8,054	31,961	250	32,211
Southeast	5,954	860	1,001	930	952	1,144	874	1,120	1,018	889	-----	-----	14,742	366	15,108
Middle States	6,487	2,524	1,943	1,445	1,617	2,096	1,921	1,592	1,435	2,509	2,146	4,356	30,071	202	30,273
Northwest	1,766	548	402	310	257	379	126	87	272	120	-----	-----	4,267	131	4,398
Southwest	2,732	357	798	796	850	897	577	329	909	1,139	-----	-----	9,384	358	9,742
Far West	1,722	270	378	369	494	530	334	345	271	575	498	1,101	6,887	47	6,934
United States	24,562	5,430	5,990	5,226	5,758	7,977	5,715	5,889	6,161	6,853	4,240	13,511	97,312	1,354	98,666
BUSSES															
Northeast	33	29	61	66	90	253	432	149	350	117	104	903	2,587	335	2,922
Southeast	93	27	18	21	34	85	83	147	193	188	-----	-----	889	101	990
Middle States	51	16	15	21	29	37	102	77	81	324	218	68	1,039	136	1,175
Northwest	21	7	6	4	4	21	5	1	39	5	-----	-----	113	35	148
Southwest	6	1	1	15	15	23	34	10	146	57	-----	-----	308	54	362
Far West	30	5	8	12	15	22	18	16	37	65	99	107	434	1	435
United States	234	85	109	139	187	441	674	400	846	756	421	1,078	5,370	662	6,032
OTHER VEHICLES															
Northeast	407	57	100	95	95	176	106	136	110	120	137	397	1,936	36	1,972
Southeast	554	180	193	202	165	202	135	175	195	130	-----	-----	2,131	208	2,339
Middle States	746	204	194	163	217	292	262	221	253	495	372	604	4,023	53	4,076
Northwest	158	35	28	18	18	33	6	7	20	12	-----	-----	335	13	348
Southwest	274	36	70	59	78	91	56	23	127	88	-----	-----	902	54	956
Far West	303	44	88	88	117	130	77	98	84	126	78	298	1,531	1	1,532
United States	2,442	556	673	625	690	924	642	660	789	971	587	1,299	10,858	365	11,223
ALL VEHICLES															
Northeast	20,869	2,918	5,187	5,702	6,181	11,668	8,221	7,640	7,846	5,469	5,688	26,335	113,724	667	114,391
Southeast	20,784	2,650	3,158	2,996	3,041	3,812	2,939	3,810	3.739	3,378	-----	-----	50,307	772	51,079
Middle States	27,300	8,367	6,855	5,736	6,379	8,450	7,818	7,191	5,514	9,993	8,008	14,842	116,453	480	116,933
Northwest	5,852	1,750	1,313	905	982	1,594	606	357	1,048	595	-----	-----	15,002	189	15,191
Southwest	8,522	972	1,938	1,892	2,076	2,391	1,580	1,112	3,191	3,267	-----	-----	26,941	541	27,482
Far West	6,745	639	1,081	1,283	1,792	2,369	1,521	2,083	1,464	2,192	1,856	5,351	28,376	81	28,457
United States	90,072	17,296	19,532	18,514	20,451	30,284	22,685	22,193	22,802	24,894	15,552	46,528	350,803	2,730	353,533

[1] Source: Public Roads Administration table MV-2, 1939. Planning survey data were used for population group distribution and adjustments in vehicle types.

TABLE 14.—*Percentage distribution of passenger-car and truck registration fees paid in 1939, by population groups*

Region	Unincorporated areas	Incorporated places having a population of—											All places	Nonresident	Total
		1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000			
PASSENGER CARS															
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Northeast	18.8	2.5	4.6	5.4	5.7	10.7	7.5	6.4	6.6	4.7	5.0	22.0	99.9	0.1	100.0
Southeast	43.4	4.8	6.0	5.6	5.8	7.3	5.7	7.3	7.1	6.7			99.7	.3	100.0
Middle States	24.6	6.9	5.8	5.0	5.5	7.4	6.8	6.5	4.6	8.2	6.5	12.1	99.9	.1	100.0
Northwest	37.9	11.3	8.5	5.6	6.8	11.3	4.6	2.5	7.0	4.4			99.9	.1	100.0
Southwest	33.5	3.5	6.5	6.2	6.9	8.4	5.6	4.6	12.2	12.1			99.5	.5	100.0
Far West	24.0	1.6	3.1	4.2	6.0	8.6	5.6	8.3	5.5	7.3	6.0	19.6	99.8	.2	100.0
United States	26.4	4.7	5.4	5.3	5.8	8.8	6.6	6.4	6.3	6.9	4.4	12.9	99.9	.1	100.0
TRUCKS															
Northeast	18.3	2.7	4.6	4.3	4.9	9.1	5.8	7.5	7.0	5.0	5.0	25.0	99.2	0.8	100.0
Southeast	39.4	5.7	6.6	6.2	6.3	7.6	5.8	7.4	6.7	5.9			97.6	2.4	100.0
Middle States	21.4	8.3	6.4	4.8	5.3	6.9	6.4	5.3	4.7	8.3	7.1	14.4	99.3	.7	100.0
Northwest	40.2	12.5	9.1	7.0	5.8	8.6	2.9	2.0	6.2	2.7			97.0	3.0	100.0
Southwest	28.0	3.7	8.2	8.2	8.7	9.2	5.9	3.4	9.3	11.7			96.3	3.7	100.0
Far West	24.8	3.9	5.5	5.3	7.1	7.6	4.8	5.0	3.9	8.3	7.2	15.9	99.3	.7	100.0
United States	24.9	5.5	6.1	5.3	5.8	8.1	5.8	6.0	6.2	6.9	4.3	13.7	98.6	1.4	100.0

proportion of the total registration fees compared to the number of vehicles registered. The relatively high average registration fees paid by owners of cars in the largest cities and the high proportion of registration fees compared to the proportion of vehicles registered are caused by the fact that a large portion of the newer and heavier vehicles are owned in these cities.

Characteristics similar to those for passenger cars are noted in the distribution of trucks and the corresponding payments of truck registration fees. However, there is a more marked difference between the proportion of trucks registered in the unincorporated areas and the proportion of registration fees paid by truck owners resident in these areas. The unincorporated areas account for 34.0 percent of the registrations and only 24.9 percent of the fees paid. The use of light pick-up trucks serving the dual purpose of passenger car and truck on farms is undoubtedly the major factor in the low average fee paid and the low proportion of fees compared to the number of truck registrations. While only 8.2 percent of all trucks are registered by owners residing in cities over 1,000,000 population, registration fees for these trucks are 13.7 percent of the total. The relatively high average truck registration fees and the consequently greater proportion of fees paid for trucks in the larger cities is due to the number of heavy, freight-carrying vehicles registered by the trucking companies in these cities.

Residents of unincorporated areas paid a total of $62,834,000 in registration fees on passenger cars and $24,562,000 on trucks. Since few busses are registered in unincorporated areas the fees paid on these vehicles by residents of unincorporated areas are a very small percentage of the total collected. Fees paid on motorcycles and trailers owned in unincorporated areas totaled $2,442,000. These amounts with the exception of the bus registration fees exceeded the payments made by residents of any other population group. The motor-vehicle owners resident in cities having a population of more than 1,000,000 were the second largest contributors of registration fees for all types of vehicles. Total collections from this population group were $46,528,000.

The average registration fees paid by owners of the four types of vehicles in each of the regions and population groups are shown in table 15. The averages shown in this table for passenger cars and trucks are based upon complete data and they are considered to be the most accurate obtainable. Since the bus and "other" vehicle data are not as complete as may be desired, the averages for these vehicles are not as accurate as those shown for passenger cars and trucks. Lack of data and the fact that the data for the various States are not entirely comparable make it difficult to present significant average figures for busses and "other" vehicles. The averages shown are based upon the best available data.

NORTHEAST REGION HAD HIGHEST AVERAGE REGISTRATION FEES FOR PASSENGER CARS AND TRUCKS

The average passenger-car registration fee in the United States in 1939 was $9.09 and the average truck registration fee was $22.41. The owners of busses paid an average registration fee of $81.31 per vehicle. Passenger-car and truck owners residing in the Northeast region paid a higher average registration fee on their passenger cars and trucks than residents of the other five regions. The range of average registration fees for passenger cars was from $5.60 in the Northwest region to $10.72 in the Northeast. Average truck registration fees ranged from $11.08 in the Northwest to $29.61 in the Northeast.

The average registration fees paid by nonresident owners of passenger cars were slightly higher than the average paid by residents in all regions except in the Southwest and Far West. Nonresident owners of trucks and busses paid average registration fees which ranged from one and four-tenths to four times as much as the average fees paid by resident owners, except in the Far West region where average fees paid by nonresident owners of busses were only one-third those paid by residents.

Passenger-car owners living in cities having a population of more than 1,000,000 paid the highest average registration fees of any population group while the residents of unincorporated areas paid the lowest average registration fees. The highest average fee for passenger cars, which was $13.28, was paid by residents of cities having a population of more than 1,000,000 in the Northeast region while the lowest average fee of $4.80

TABLE 15.—*Average vehicle registration fee paid in 1939, by population groups*

Region	Unincorporated areas	Incorporated places having a population of: 1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Nonresident	Total
PASSENGER CARS															
Northeast	$10.87	$11.28	$11.26	$10.77	$10.24	$10.28	$9.54	$10.39	$9.12	$9.20	$8.78	$13.28	$10.72	$14.73	$10.72
Southeast	8.24	8.40	8.76	9.00	9.00	9.14	9.56	9.61	10.63	7.91			8.69	11.55	8.69
Middle States	9.15	9.95	9.93	10.26	9.82	10.10	10.05	10.37	9.65	9.57	10.76	9.99	9.80	10.77	9.80
Northwest	5.21	5.89	5.78	5.82	6.16	6.55	7.16	4.91	5.00	5.28			5.60	6.29	5.60
Southwest	7.73	7.87	8.42	8.91	7.98	9.29	8.24	10.02	8.89	10.34			8.51	5.91	8.49
Far West	5.98	4.80	5.92	6.28	6.76	6.33	6.67	7.48	5.82	5.04	7.17	7.17	6.34	4.94	6.34
United States	8.38	8.88	9.16	9.38	9.03	9.27	9.25	9.61	8.70	8.47	9.42	10.95	9.09	8.62	9.09
TRUCKS															
Northeast	26.00	24.29	26.15	26.35	27.69	27.25	25.96	32.52	28.02	29.22	22.69	41.42	29.19	62.52	29.61
Southeast	15.44	19.54	20.13	20.13	22.26	21.50	25.27	24.30	27.66	19.76			18.82	35.47	19.04
Middle States	18.62	22.61	23.45	23.44	24.81	26.97	28.62	28.59	30.72	29.38	30.61	39.93	25.45	46.06	25.53
Northwest	8.95	12.67	12.74	15.80	12.35	12.86	11.56	10.78	12.55	10.61			10.83	12.62	11.08
Southwest	13.46	19.08	22.15	23.93	24.05	24.56	23.53	21.88	23.36	33.31			19.73	32.95	20.03
Far West	12.63	13.85	14.42	14.13	14.81	14.98	15.32	15.49	15.22	19.18	21.84	19.03	15.31	24.38	15.35
United States	16.40	19.89	21.24	21.93	22.60	23.47	24.69	26.54	25.42	26.22	25.97	37.38	22.28	39.15	22.41
BUSSES															
Northeast	57.93	67.97	62.41	69.42	64.02	75.46	98.52	74.55	81.50	48.24	89.54	221.39	99.39	136.81	102.60
Southeast	12.86	24.45	19.70	34.86	53.27	48.66	97.92	67.71	174.01	101.19			48.28	82.36	50.40
Middle States	55.31	49.86	77.62	106.30	123.25	114.73	153.07	141.71	174.25	218.09	149.78	211.80	145.65	249.24	153.04
Northwest	19.14	20.04	29.25	27.94	26.59	53.01	26.16	17.51	67.08	20.45			33.14	91.23	39.04
Southwest	20.27	33.44	36.83	85.56	62.60	49.78	65.75	57.63	68.80	108.17			67.23	129.53	72.10
Far West	32.19	34.72	34.37	39.09	29.94	34.61	40.50	25.97	51.32	73.47	40.13	65.05	45.57	14.05	45.36
United States	21.11	33.95	41.96	57.68	59.01	63.78	95.54	71.95	91.04	101.83	82.89	178.25	77.72	130.22	81.31
OTHER VEHICLES															
Northeast	11.96	8.89	9.65	9.95	9.79	9.74	9.87	13.06	14.23	20.85	14.79	11.46	11.47	61.12	11.64
Southeast	9.31	12.37	16.17	19.75	21.23	20.07	19.22	21.76	25.78	29.87			15.11	58.52	16.18
Middle States	1.02	3.36	1.09	1.59	5.96	6.75	7.30	6.34	7.42	15.48	21.53	16.30	6.73	13.42	6.78
Northwest	2.22	3.28	3.48	3.55	3.12	1.13	1.29	3.86	1.70	14.48			2.87	35.74	2.97
Southwest	9.43	11.40	14.34	10.54	13.24	12.51	12.60	7.18	12.83	13.06			11.08	30.70	11.49
Far West	5.76	6.09	6.75	6.24	5.77	7.21	6.42	6.85	9.41	12.60	12.02	13.48	7.68	6.18	7.68
United States	5.66	5.41	6.95	7.81	8.03	8.82	8.98	9.09	10.60	16.27	18.98	13.85	8.32	34.67	8.53
ALL VEHICLES															
Northeast	13.06	13.48	13.53	12.69	12.39	12.45	11.81	13.59	11.94	11.99	10.95	17.42	13.40	65.61	13.46
Southeast	9.54	10.67	11.10	11.47	11.64	11.74	12.47	12.59	14.11	10.37			10.73	32.90	10.84
Middle States	10.03	11.34	11.35	11.53	11.35	11.77	11.95	11.94	11.75	12.26	13.88	13.15	11.55	27.87	11.57
Northwest	5.74	6.95	6.86	7.35	6.97	7.41	7.77	5.64	6.17	6.00			6.38	35.32	6.44
Southwest	9.02	10.19	11.45	12.31	11.32	12.40	11.26	11.93	11.53	13.97			10.85	21.06	10.95
Far West	6.92	6.84	7.61	7.54	7.91	7.39	7.68	7.90	6.91	6.77	9.45	8.66	7.59	9.43	7.59
United States	9.55	10.53	11.00	11.18	10.92	11.18	11.33	11.76	11.12	11.04	12.03	14.28	11.02	30.16	11.07

was paid by residents of incorporated places having a population of less than 1,000 in the Far West region. Residents of unincorporated areas generally paid lower average registration fees for passenger cars in all regions than did the residents of the incorporated cities and towns.

Weight and horsepower of vehicles are the dominant factors in determining the amount of annual registration fees paid by automobile owners. A large proportion of the older vehicles registered in rural areas are comparatively light in weight and low in horsepower. These factors probably account for the difference in the average fees paid in the rural and urban areas. Another important factor is that the age of the vehicle has a direct effect upon the amount of license fee charged in nine States. The difference in age of cars owned in cities and those owned in the rural areas is sufficient to produce a significant difference in the average fee paid.

The comparatively low registration fee for passenger cars in Massachusetts and in the District of Columbia exerts considerable influence on the averages for the Northeast region. The several large cities in Massachusetts with populations in excess of 50,000 is the dominating influence which accounts for the low average fees in these places compared to the smaller cities and unincorporated areas in this region.

AVERAGE MOTOR-FUEL TAX ABOUT TWICE AVERAGE REGISTRATION FEE

Truck owners residing in unincorporated areas paid the lowest registration fee for this type of vehicle, the average being $16.40. The fact that special registration fee schedules are in effect for farm trucks in 17 States probably accounts for this low average fee in comparison with the higher fees paid by owners resident in the cities. The prevalence of light pick-up trucks which are used by farmers for both passenger and hauling service and which usually require a lower registration fee than the heavier trucks found in cities is another reason for the low average truck fee paid by residents of unincorporated areas.

Perhaps the most outstanding fact about motor-fuel tax collections is their relatively large amount as compared with registration fee receipts. A comparison of table 16 with table 13 indicates that in general the amount of motor-fuel tax collections is about twice the amount of registration fee receipts, both in total and for individual population groups. A similar comparison of table 17 with table 15 indicates that in general the amount of the average motor-fuel tax payment is about twice the amount of the average registration fee payment, in any or all population groups. For either the total or average amounts the relative differences are more pronounced in the case of passenger cars and less noticeable in the case of trucks. In the case of passenger cars, for example, total or average motor-fuel tax receipts for all population groups are more than double the corresponding total or average motor-vehicle registration fee receipts, and the same condition obtains in each of the individual population groups except one—incorporated places of more than 1,000,000 persons. In the case of trucks, however, total or average motor-fuel tax receipts for all population groups are consistently somewhat less than double the amount of corresponding total or average motor-vehicle registration fee receipts.

The relations existing between motor-fuel tax receipts and motor-vehicle registration fee receipts in the individual regions, although showing the same general tendencies, vary considerably from the relations which exist for the United States as a whole. For passenger cars in the Northeast, for example, total or average motor-fuel tax receipts are less than double the amount of corresponding total or average motor-vehicle registration fee receipts, in all except two of the population groups; while in the Southeast, total or average motor-fuel tax receipts are more than three times the amount of corresponding total or average motor-vehicle registration fee receipts in all population groups. For trucks in the Northeast, total or average motor-fuel tax receipts exceed corresponding total or average motor-vehicle registration fee receipts only slightly in a majority of the population groups, and in incorporated places of more than 1,000,000 persons are less than the corresponding total or average registration fee receipts. In the Southeast, however, total or average motor-fuel tax receipts for trucks are in all population groups about three times the amount of corresponding total or average motor-vehicle registration fee receipts.

Table 18 shows for the year 1939 net motor-fuel tax collections in the United States according to the several types of use on account of which the tax accrues. The primary distinction is between highway and nonhighway use, and of the $816,433,000 total net taxes collected, $804,059,000 or 98.5 percent was collected on

TABLE 16.—*Total State motor-fuel taxes paid for motor vehicle use in 1939, by population groups* [1]

Region	Unincorporated areas	Incorporated places having a population of— 1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Non-resident	Total
PASSENGER CARS															
	$1,000	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*	*$1,000*
Northeast	23,403	3,219	5,914	7,561	8,346	16,447	11,466	9,290	10,401	5,814	9,689	27,442	138,992	54	139,046
Southeast	44,347	6,265	7,379	7,104	7,030	9,059	6,535	8,389	8,912	9,304			114,324	249	114,573
Middle States	31,752	9,057	8,138	7,147	8,560	11,413	10,384	9,603	8,094	16,060	10,170	18,734	149,112	150	149,262
Northwest	11,001	3,230	2,718	1,759	2,084	3,293	1,319	1,101	2,880	1,713			31,098	33	31,131
Southwest	13,528	1,597	2,995	2,784	3,305	3,898	2,888	1,771	5,573	5,308			43,647	257	43,904
Far West	13,296	1,218	1,807	2,232	2,906	1,798	2,882	3,755	3,464	6,369	2,520	9,561	54,808	129	54,937
United States	137,327	21,586	28,951	28,587	32,231	48,908	35,474	33,909	39,324	41,568	22,379	55,737	531,981	872	532,853
TRUCKS															
Northeast	6,187	1,104	1,733	1,687	1,907	3,676	2,437	2,899	2,800	1,645	3,599	7,893	37,567	118	37,685
Southeast	17,702	2,893	3,305	3,138	2,764	3,899	2,492	3,003	3,335	2,497			45,028	621	45,649
Middle States	7,303	3,279	2,511	1,989	2,270	2,851	2,723	2,387	2,348	3,851	2,596	5,987	40,095	162	40,257
Northwest	4,045	1,493	1,238	774	806	1,333	401	312	798	419			11,619	103	11,722
Southwest	4,789	643	1,282	1,327	1,342	1,490	1,146	630	1,310	1,917			15,876	319	16,195
Far West	3,451	625	847	841	1,041	1,208	727	726	725	1,391	832	2,106	14,520	59	14,579
United States	43,177	10,037	10,916	9,756	10,130	14,457	9,926	9,957	11,316	11,720	7,027	15,986	164,705	1,382	166,087
BUSSES															
Northeast	66	63	145	131	187	650	912	461	1,055	451	299	1,202	5,622	471	6,093
Southeast	675	120	88	90	158	651	362	743	593	383			3,863	350	4,213
Middle States	50	26	26	33	50	62	165	153	97	392	333	74	1,461	161	1,622
Northwest	170	26	24	14	30	117	44	22	194	65			706	94	800
Southwest	85	2	5	44	67	123	163	46	814	204			1,553	87	1,640
Far West	69	22	37	52	57	114	76	64	190	257	210	229	1,377	12	1,389
United States	1,115	259	325	364	549	1,717	1,722	1,489	2,943	1,752	842	1,505	14,582	1,175	15,757
ALL VEHICLES															
Northeast	29,656	1,386	7,792	9,379	10,440	20,773	14,815	12,650	14,256	7,910	13,587	36,537	182,181	643	182,821
Southeast	62,724	9,278	10,772	10,332	9,952	13,609	9,389	12,135	12,840	12,184			163,215	1,220	164,435
Middle States	39,105	12,362	10,675	9,169	10,880	14,326	13,272	12,143	10,539	20,303	13,099	24,795	190,668	473	191,141
Northwest	15,216	4,719	3,980	2,547	2,920	1,743	1,764	1,435	3,872	2,197			43,423	230	43,653
Southwest	18,402	2,242	4,282	4,155	4,714	5,511	4,197	2,447	7,697	7,429			61,076	663	61,739
Far West	16,816	1,865	2,691	3,125	4,004	6,120	3,685	4,545	4,379	8,017	3,562	11,896	70,705	200	70,905
United States	181,919	34,882	40,192	38,707	42,910	65,082	47,122	45,355	53,583	58,040	30,248	73,228	711,268	3,429	714,697

[1] This table includes only motor fuel taxes paid by motor-vehicle owners for travel within the State of registration. It does not include motor-fuel taxes paid by vehicles traveling in States other than that of registration or taxes paid on gasoline used in publicly owned vehicles.

TABLE 17.—*Average State motor-fuel taxes paid in 1939, by population groups*

Region	Unincorporated areas	Incorporated places having a population of— 1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Non-resident	Total
PASSENGER CARS															
Northeast	$17.52	$18.52	$18.71	$19.55	$19.40	$20.35	$18.85	$19.54	$18.48	$14.81	$22.09	$21.46	$19.28	$17.17	$19.28
Southeast	25.68	33.24	33.22	34.69	33.47	34.78	33.84	34.06	40.60	33.89		...	30.52	29.85	30.52
Middle States	14.52	16.03	17.18	17.86	18.60	19.12	18.86	18.80	20.85	23.07	20.75	19.07	17.96	18.30	17.97
Northwest	14.66	16.39	17.91	17.85	18.24	18.57	20.15	20.62	20.11	19.75	...	...	16.92	21.87	16.92
Southwest	18.99	21.74	23.57	24.29	23.27	26.25	26.06	23.67	24.67	27.60			22.71	20.33	22.69
Far West	16.95	18.28	17.62	17.21	16.85	18.00	17.60	16.61	18.79	22.50	15.30	17.84	17.79	20.16	17.80
United States	18.32	19.45	20.78	21.42	21.08	21.66	20.97	21.37	22.81	23.15	20.47	19.93	20.39	21.67	20.39
TRUCKS															
Northeast	$27.26	$30.79	$30.88	$32.30	$33.27	$34.17	$33.59	$39.01	$34.77	$29.66	$51.16	$40.59	$34.67	$29.52	$34.65
Southeast	45.91	65.65	66.45	68.93	64.64	73.30	72.04	65.16	90.56	55.48		...	57.48	60.23	57.52
Middle States	20.97	29.37	30.31	32.26	34.83	36.68	40.57	42.88	50.26	45.08	37.02	54.88	33.94	37.09	33.95
Northwest	20.51	34.48	39.29	39.49	38.72	45.18	36.89	38.89	36.86	36.87	...	...	29.50	33.27	29.53
Southwest	23.59	34.34	35.60	39.91	37.98	40.81	46.72	41.87	33.67	56.08		...	33.39	29.35	33.30
Far West	25.30	32.07	32.30	32.20	31.20	34.16	33.34	31.98	40.78	46.43	36.47	36.38	32.28	30.62	32.27
United States	29.03	36.76	38.65	40.93	39.76	42.54	42.88	44.89	46.68	44.83	43.03	44.23	37.71	39.98	37.73
BUSSES															
Northeast	$114.92	$147.47	$148.18	$137.18	$133.33	$194.21	$207.92	$231.40	$245.51	$185.78	$257.76	$294.78	$216.01	$192.37	$213.98
Southeast	92.96	96.46	94.46	146.94	246.06	370.86	426.33	342.34	536.14	206.86			209.68	285.32	214.39
Middle States	53.52	81.05	136.78	170.18	214.63	189.06	248.88	282.26	209.37	264.18	228.59	229.54	204.95	294.14	211.31
Northwest	159.62	74.44	114.48	86.12	203.94	291.72	232.12	321.74	337.35	274.56	...	...	207.63	245.40	211.46
Southwest	268.78	96.67	132.80	244.39	278.34	270.76	318.57	257.94	383.14	389.59			338.58	209.67	327.89
Far West	74.03	152.78	145.10	169.38	113.77	181.05	168.40	106.15	265.12	291.28	85.30	138.64	144.52	194.78	144.85
United States	100.60	103.43	125.10	151.04	173.24	248.33	244.20	268.18	317.03	236.60	165.85	248.72	211.05	231.20	212.43

account of highway use. Of this total highway use, resident private vehicles accounted for $711,268,000 and nonresident private vehicles accounted for $3,429,000, so that the two types of private highway use account for $714,697,000 or 87.5 percent of total net collections. Publicly owned and "foreign" vehicles together account for $89,362,000 or 11 percent of total net collections.

TABLE 18.—*Motor-fuel tax collections in the United States in 1939*

Classification	Amount	Percentage of total
Highway use:		
Resident	$711,268,000	87.1
Nonresident	3,429,000	.4
Publicly owned	10,728,000	1.3
Foreign	78,634,000	9.7
Total highway use	804,059,000	98.5
Nonhighway use	12,374,000	1.5
Total net taxes collected	816,433,000	100.0

All distributions of motor-fuel taxes presented in this study are based on the $714,697,000 collected on account of resident and nonresident private vehicle use, data on publicly owned and "foreign" vehicles being excluded. To obtain the included distributions total net motor-fuel tax receipts as presented by the Public Roads Administration's annual statistical table G–1 for the year 1939 were separated by means of data supplied by the States into those resulting from highway use and those resulting from nonhighway use. The highway portion was then apportioned to vehicle types and to population groups on the basis of the motor-vehicle allocation studies. To make this apportionment it was assumed that the ratio of motor-vehicle fuel used by "foreign" and publicly owned vehicles to total motor-vehicle fuel used was the same in 1939 as in the year of the motor-vehicle allocation study, and on that basis it was possible to allocate a part of the highway portion of total net motor-fuel tax collections to travel by foreign and publicly owned vehicles.

The remainder of the highway portion of the net motor-fuel tax collections was attributable to travel by resident and nonresident privately owned vehicles and was apportioned to vehicle types by multiplying the number of vehicles of each type registered in 1939 by the average annual fuel consumption for that type as determined by the motor-vehicle allocation study, and converting the resulting gallonage to dollars on the basis of the applicable fuel tax rate in the particular State, and then adjusting to that amount of the highway portion of total net motor-fuel tax collections previously determined as being attributable to travel by resident and nonresident privately owned motor vehicles. This procedure corrects for relative increases or decreases in the different types of vehicles, but assumes that their distribution among population groups and their relative gasoline consumptions remain the same as during the year of the motor-vehicle allocation study.

NEWER CARS DRIVEN GREATER MILEAGE

An individual allocation of this kind was made for each State that had completed a motor-vehicle allocation study. In the case of those few States that had not made such studies, the total net motor-fuel tax receipts from highway use were allocated and apportioned on the basis of other States in the same region for which the studies were available. The final results, then, are a series of distributions by vehicle types and population groups of that portion of the total net motor-fuel tax collections for each State that is attributable to resident and nonresident privately owned motor vehicles. Motor-fuel tax collections resulting

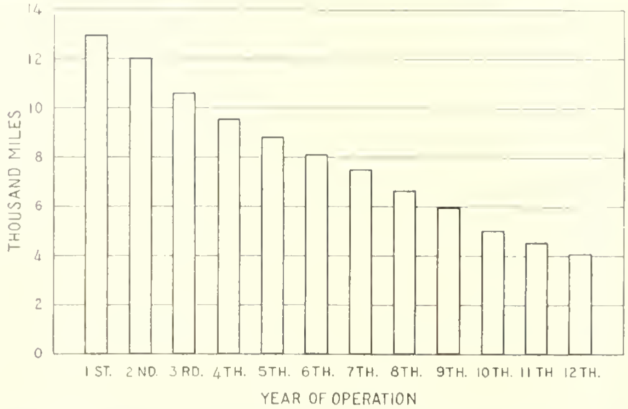

Figure 9.—Average Annual Mileage Traveled by Passenger Cars Classified by Year of Operation Based on Data From 35 States.

from highway use by publicly owned and "foreign" vehicles and from nonhighway use are not included, because they could not logically be apportioned to population groups.

The amount of motor-fuel taxes collected in any particular case depends on annual mileage, the gasoline consumption rate, the amount of the tax per gallon, and the number of vehicles involved. The computation of average motor-fuel tax payments, of course, eliminates the influence of the number of vehicles. Since the amounts of the tax per gallon are fixed, the determination of the amounts of motor-fuel taxes paid by owners of vehicles residing in each of the population groups requires a study of annual mileage traveled and rate of motor-fuel consumption only. There is considerable variation in the annual mileages that vehicles are driven during each year of their service lives, but the variation in motor-fuel consumption rates, as expressed in miles per gallon, is comparatively small during the lives of motor vehicles.

Table 19 shows the average number of miles passenger cars in various years of operation were driven and the average number of miles obtained per gallon of motor fuel consumed. The vehicles in all States represented were placed on a comparable basis by classifying them by year of operation at the time the motor-vehicle allocation study was made rather than by year model. Passenger cars in their first year of operation averaged 12,980 miles while those in the second year of operation averaged 12,060 miles. During the third year the average annual mileage dropped to 10,620. From the first year throughout the 12th year the average annual mileage traveled shows a steady decrease. While data are available for vehicles which had been operated for more than 12 years they are not included in this tabulation. Vehicles which were operating for their 13th and a greater number of years reported annual mileage figures ranging from 50 to 5,000 miles. The number of questionnaires returned from owners in this group were too few to be considered of value for purposes of computing average annual mileage. Figure 9 presents the average annual mileage traveled by passenger cars, classified by year of operation.

There are several apparent reasons for this variation in annual mileage by vehicles of various ages. One of the most significant of these is the need for new cars in commercial operations. Passenger cars used for business purposes are usually driven a very high number of miles during the first and second years of operation and

Table 19.—*Average annual mileage traveled and average number of miles traveled per gallon of gasoline consumed by passenger cars, by year of operation*

Year of operation	Average mileage traveled during year [1]	Average number of miles traveled per gallon of gasoline consumed [2]
First	12,980	16.1
Second	12,060	15.7
Third	10,620	15.6
Fourth	9,580	15.4
Fifth	8,820	15.0
Sixth	8,120	15.3
Seventh	7,500	15.5
Eighth	6,630	15.7
Ninth	5,950	15.6
Tenth	5,070	15.3
Eleventh	4,550	15.3
Twelfth	4,120	15.3

[1] Based on data from 35 States.
[2] Based on data from 30 States.

are then replaced with a new vehicle. Among private operators there is more interest shown in the operation of a relatively new vehicle and it is probable that owners of the newer vehicles make longer trips during the first few years of the life of the car. Frequently, new vehicles are purchased in anticipation of making a long vacation or business trip. During the first few years of the service life of a car, it is usually owned by a person whose income is adequate to operate it an annual mileage considerably higher than the average or it is used in a commercial operation which requires extensive usage. These vehicles are resold in the used-car market to purchasers in lower income groups with a consequent decrease in the annual mileage driven. As the vehicles become older and the resale price becomes less, persons in still lower income groups acquire them. The limited income of these groups permits only a limited use of vehicles resulting in low annual mileage.

Studies of the cost of automobile ownership [6] indicate that the purchase of used cars by persons in the low-income group is much more common than the purchase of new cars. Only in the higher income groups were new car purchases more common than purchases of used cars. This study also points out the relatively small amount of money available for operation of automobiles by persons in the low-income group which results in relatively low average annual mileages.

RATE OF FUEL CONSUMPTION LITTLE AFFECTED BY VEHICLE AGE

Trucks and busses do not show the decrease in annual mileage during each successive year of their operation that is characteristic of passenger cars. These commercial vehicles are not subject to changes in model to the same extent as passenger cars. In commercial operations trucks and busses are usually maintained on a basis which will permit daily operation and adherence to regular schedules resulting in a fairly uniform amount of annual travel during the greater part of their lives. Frequently, new motor assemblies are installed in trucks and busses which enable them to be operated to the same extent as a new vehicle. For this reason, the year model of these vehicles was not considered to be of as much importance in determining gasoline consumption as it was in the case of passenger cars, and so was not obtained in all motor-vehicle allocation studies. Consequently, year-model data for

[6] Family Expenditures in Selected Cities, 1935-36, vol. VI, United States Department of Labor, Bureau of Labor Statistics.

these vehicles are not available for a sufficient number of States to be presented in this study.

The average distance traveled per gallon of gasoline consumed, as shown in table 19, does not vary with the age of vehicles to the extent which might be expected. A greater number of miles per gallon of gasoline consumed was reported for vehicles in the first year of operation than in any other year. A steady decline in the number of miles per gallon of gasoline is noted for vehicles operated during the second, third, fourth, and fifth years. Older vehicles which were being operated for their sixth, seventh, eighth, or ninth year showed increases in the number of miles obtained per gallon of gasoline. Those vehicles which were being operated for the tenth and a greater number of years averaged 15.3 miles per gallon of gasoline consumed. Changes in motor design and the increase in efficiency of motors are factors which account for the variations in gasoline consumption rate. The discontinuance of the smaller size motors is probably an important factor also in the difference in the miles-per-gallon figure between the cars operating for their eighth year and those which had been in service only 5 years.

Table 20 shows the average annual mileages and the average motor-fuel consumption rates for passenger cars in each of the regions of the United States. The indicated variations are largely the result of average age, but are also influenced by such factors as climate, topography, industrial development, economic status, and density and distribution of population. Cars of a given age in one region may be driven more or less than cars of that same age in some other region, and in a particular region annual mileages for all cars may be high or low as compared with those in some other region. Table 20, for example, indicates higher annual mileages in the Southeast, Southwest, and Far West than in the Northeast, while table 21 indicates a lower average age in the Northeast than in any of the other regions. Nevertheless, average age is the major influence in determining annual mileage, perhaps because the other factors which influence annual mileage also directly influence average age. The influence of these other factors on motor-fuel consumption rates may be more pronounced, but in any event, variations in these rates are relatively small.

TABLE 20.—*Average mileage traveled and average number of miles traveled per gallon of gasoline consumed by passenger cars in each of the regions of the United States during year of motor-vehicle study* [1]

Region	Average mileage traveled during year [2]	Average number of miles traveled per gallon of gasoline consumed [3]
Northeast	8,740	15.1
Southeast	9,070	15.7
Middle States	8,120	15.1
Northwest	7,200	16.1
Southwest	8,960	16.0
Far West	9,020	16.3
United States	8,530	15.5

[1] The majority of these studies were conducted during 1936.
[2] Based on data from 35 States.
[3] Based on data from 30 States.

In only two States are data on average age of passenger cars available for all population groups but table 10 shows a marked difference in the average ages of cars in rural areas as compared with those in all incorporated places in 15 States. It may be assumed that similar differences exist among the different groups of incorporated places, and tables 11 and 12 support this assumption, particularly as regards the larger and very small incorporated places. Undoubtedly, the high average age of passenger cars in rural areas largely explains the low average motor-fuel tax payments in those areas, although these low averages are influenced also by favorable motor-fuel consumption rates which exist in these areas.

TABLE 21.—*Cumulative percentage distribution of passenger cars of different ages by regions*

Region	Percentage of all passenger cars with an average age of—											
	1 year and less	2 years and less	3 years and less	4 years and less	5 years and less	6 years and less	7 years and less	8 years and less	9 years and less	10 years and less	11 years and less	All years
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Northeast	18.4	29.8	38.7	45.5	52.3	62.1	73.2	85.4	92.4	95.9	98.0	100.0
Southeast	14.1	25.6	35.6	42.8	47.8	55.3	64.6	77.6	87.5	92.2	95.7	100.0
Middle States	11.7	21.0	27.7	32.6	39.3	48.8	63.8	77.1	85.5	91.5	95.4	100.0
Northwest	11.6	21.3	28.7	33.8	37.6	43.6	53.2	67.2	79.4	87.5	93.0	100.0
Southwest	12.3	21.5	28.7	33.0	38.3	47.6	63.7	78.0	86.0	92.0	95.9	100.0
Far West	14.6	25.2	31.7	36.9	40.4	47.3	56.7	70.4	79.6	86.1	91.8	100.0
United States	13.1	23.2	30.7	36.2	41.4	49.5	61.3	74.7	84.0	90.0	94.4	100.0

RELATIVE AVERAGE FUEL-TAX PAYMENTS LEAST FOR RESIDENTS OF UNINCORPORATED PLACES

The relative average motor-fuel tax rates per gallon in the different regions of the United States are shown in table 22 while table 23 shows the relative average motor-fuel taxes which would be paid by passenger-car owners in these regions if the tax rate were the same in all regions.

TABLE 22.—*Relative motor-fuel tax rates in effect in 1939*

Region	Relative motor-fuel tax rate
Northeast	0.931
Southeast	1.542
Middle States	.862
Northwest	1.018
Southwest	1.043
Far West	.875
United States	1.000

The tax rates per gallon indicated by table 22 are simple weighted averages computed by considering the several prevailing tax rates in each region and the number of gallons taxed at each prevailing rate in that region, and the indicated variations are actual existing variations. The effect of these varying tax rates has been eliminated in table 23 by assuming that the same tax rate per gallon exists in all regions so that the variations in this table are caused entirely by differences in annual mileages and in gasoline consumption rates. Both tables were prepared by assuming the value of the average of all population groups and all regions to be 1.000, and all other figures on the tables are ratios of that average.

Relative fuel tax rates per gallon according to table 22 vary from 0.862 in the Middle States to 1.542 in the Southeast with a range 0.680, but relative average fuel tax payments by residents of all places, according to table 23, vary from 0.816 in the Northwest to 1.070 in

TABLE 23.—*Relative average motor-fuel taxes (1939) for passenger cars if same tax rate were in effect in all States (all places, all regions = 1.000)*

Region	Unincorporated areas	Incorporated places having a population of—											Total
		1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	
Northeast	0.878	0.918	0.963	1.010	1.034	1.096	1.077	1.065	1.060	1.017	1.118	1.031	1.016
Southeast	.837	1.055	1.062	1.085	1.053	1.105	1.078	1.111	1.188	1.051			.972
Middle States	.809	.918	.990	1.018	1.065	1.076	1.048	1.115	1.117	1.186	1.214	1.221	1.024
Northwest	.697	.800	.863	.875	.867	.923	.960	.968	.994	.948			.816
Southwest	.888	1.028	1.113	1.147	1.080	1.250	1.157	1.137	1.184	1.325			1.070
Far West	.910	.790	.923	.957	.996	1.016	1.041	1.064	1.004	.994	.980	1.142	.999
United States	.835	.919	.988	1.021	1.033	1.079	1.065	1.088	1.094	1.107	1.141	1.119	1.000

the Southwest, and the range, 0.254, is considerably less than in table 22, indicating that the differences in average motor-fuel tax payments among the several regions are caused largely by the different tax rates in those regions.

Table 23 also indicates that the relative average motor-fuel tax payments by residents of the several population groups in a particular region vary considerably, even after the effects of the different motor-fuel tax rates have been eliminated. These average fuel tax payments for residents of all regions vary from 0.835 in unincorporated areas to 1.141 in incorporated places with a population of from 500,001 to 1,000,000 persons, with a range of 0.306. This range is larger than the corresponding range among regions, and it is evident that the influence of annual mileages and gasoline consumption rates on average motor-fuel tax payments is greater in the case of population group variations than in the case of regional variations. If the Northwest region with its very low relative average motor-fuel tax payments were disregarded, these variations among population groups would be even more decided as compared with those among regions. The differences in motor-fuel tax rates among the population groups of a particular region are very small, being occasioned only by the fact that all States in the region are not proportionally represented in all population groups, and these differences are minimized by the fact that the States in any one region do not have widely varying motor-fuel tax rates.

On the basis of tables 22 and 23, it may be concluded that, in general, there are significant differences in average motor-fuel tax payments between population groups in the same region and that these differences are largely the result of differences in annual mileages and gasoline consumption rates. Differences between regions, on the other hand, are primarily the result of different tax rates, although these differences, too, are influenced by mileage and consumption rates. For example, the relatively low motor-fuel tax payments for unincorporated areas as compared with other population groups shown in table 17, which presents actual rather than theoretical average motor-fuel tax payments and where variations are due not only to different annual mileages and consumption rates but also to varying tax rates, are the result of relatively low annual mileages driven by rural residents and, in the case of trucks, of relatively high mileage per gallon of gasoline due to the high percentage of light trucks in rural areas. The high average payments throughout all population groups of the Southeast region, however, are undoubtedly the result of high motor-fuel tax rates in that region.

SOUTHEAST REGION HAD HIGHEST AVERAGE FUEL TAXES

Table 17 further indicates that the highest average annual motor-fuel tax payment for passenger cars was the $40.60 paid by residents of places having a population of 100,001 to 250,000 persons in the Southeast region, and that the lowest average motor-fuel tax payment for passenger cars was the $14.52 paid by residents of unincorporated areas in the Middle States. The $40.60 figure is largely the result of the high motor-fuel tax rates in the Southeast region, although it is also influenced by mileage and consumption rates, but the $14.52 figure is apparently very largely influenced by mileage because residents of the Far West, and the Northeast, with only slightly higher motor-fuel tax rates, both pay much higher average motor-fuel taxes, the corresponding amounts being $16.95 and $17.52, respectively. The highest average annual motor-fuel tax paid for trucks was the $90.56 paid by residents of places having a population of 100,001 to 250,000 in the Southeast region, the same population group which paid the highest average motor-fuel tax payment for passenger cars. The lowest average motor-fuel tax payment for trucks was the $20.51 paid by residents of unincorporated areas in the Northwest region.

The $25.68 average motor-fuel tax paid for passenger cars by residents of unincorporated areas in the Southeast is lower than that paid for passenger cars by residents of any other population group in that region but, nevertheless, is higher than the highest average motor-fuel tax paid for passenger cars by the residents of any population group in the Northeast, Middle States, Northwest, or Far West, the highest average motor-fuel taxes paid for passenger cars in these regions being $22.09, $23.07, $20.62, and $22.50, respectively. The difference between this low average tax of $25.68 in unincorporated areas in the Southeast and the next higher average tax for passenger cars in that region, $33.22, is relatively large as compared with similar differences in other regions. The same situation exists in the case of trucks and the $45.91 average motor-fuel tax paid for trucks by residents of unincorporated areas in the Southeast, although lower than that paid for trucks by residents of any other population group in that region is, except in a very few instances, higher than the highest average motor-fuel tax paid for trucks by residents of any population group in any of the other regions.

In the case of busses, however, the average motor-fuel taxes paid by residents of the different population groups in the Southeast region are not consistently high as compared with corresponding taxes in the other regions, and in fact the $209.68 average motor-fuel tax paid for busses by residents of all places in the Southeast region is lower than the $211.05 average motor-fuel tax paid for busses by residents of all places in the United States. This condition is caused by the very large number of school busses that are included in the smaller places in the Southeast, which because of their relatively large number (table 1) and low annual mileage as compared with other busses, affect to a considerable degree the average motor-fuel taxes paid for busses by residents of those places. No doubt equally large numbers of school busses exist in the smaller places of the other regions, but because of different registration practices they are registered as passenger cars or trucks or as publicly owned vehicles, and so are not included as busses. In the larger places, however, except in those having a population of from 250,001 to 500,000 persons, the average motor-fuel taxes paid in the Southeast are larger than the corresponding taxes paid in the other regions.

In contrast with the high average motor-fuel taxes paid by residents of the Southeast region are those paid by residents of the Northwest region (table 17) where the average motor-fuel taxes paid for either passenger cars or trucks by residents of all places are lower than the corresponding taxes paid in any other region. Apparently these relatively low average motor-fuel taxes paid by residents of the Northwest region are almost entirely the result of low annual mileages in that region, since the Far West, the Northeast and the Middle States all have lower average motor-fuel tax rates and since the variation in consumption rates between regions, particularly for passenger cars, is slight. It might be noted as regards the individual population groups, however, that in the case of passenger cars in no single group are the average motor-fuel taxes paid in the Northwest lower than those paid in any of the other regions, and in the case of trucks only in unincorporated areas are the Northwest taxes low, so that in the Northwest region there must be less variation in annual mileages among the different population groups than exists in the other regions.

Just as average motor-fuel taxes paid depend on annual mileages, motor-fuel consumption rates, and the tax rate per gallon, so in turn total motor-fuel taxes paid depend on these same things and also on the total number of vehicles involved. Table 16 indicates, for example, that for all regions as a unit, and for both passenger cars and trucks, the second largest total motor-vehicle fuel taxes paid by residents of any population group are those paid by residents of incorporated places having a population of over 1,000,000 persons, although places of this size exist in only three of the six regions on which the tabulations are based; table 1 in turn indicates that more vehicles are registered in incorporated places having a population of over 1,000,000 persons than in any other place except unincorporated areas. The largest total motor-fuel taxes paid are those paid by residents of unincorporated areas, which taxes amount to about 2½ times as much as do those paid by residents of incorporated places having a population of over 1,000,000 persons; about 2½ times as many vehicles are registered in unincorporated areas as are registered in incorporated places having a population of over 1,000,000 persons. The smallest total motor-fuel taxes paid by residents of any population group are those paid by residents of incorporated places having a population of from 500,001 to 1,000,000 persons and fewer vehicles are registered in this population group than in any other.

ONE-FOURTH OF MOTOR-FUEL TAXES PAID BY RESIDENTS OF UNINCORPORATED AREAS

The relations between total motor-fuel taxes paid by residents of different population groups are further developed by table 24 which presents by population groups and regions a percentage distribution of total motor-fuel taxes paid in the United States in 1939. The motor-fuel taxes paid for passenger cars by residents of unincorporated areas in all regions amount to 25.8 percent of the taxes paid for passenger cars by all residents in all regions, which compares with the 28.7 percent of total passenger cars registered in unincorporated areas (see table 2) and the 26.4 percent of total motor-vehicle registration fees paid for passenger cars by residents of those areas in all regions (see table 14). For the individual regions the percentage of total motor-fuel taxes paid for passenger cars by residents of unincorporated areas varies from 16.8 in the Northeast to 38.7 in the Southeast, while the percentage of total passenger cars registered owned by residents of unincorporated areas varies from 18.5 in the Northeast to

TABLE 24.—*Percentage distribution of State motor-fuel taxes paid on fuel used in passenger cars and trucks in 1939, by population groups*

PASSENGER CARS

Region	Unincorporated areas	Incorporated places having a population of—											All places	Nonresident	Total
		1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000			
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Northeast	16.8	2.3	4.3	5.4	6.0	11.8	8.2	6.7	7.5	4.2	7.0	19.7	99.9	0.1	100.0
Southeast	38.7	5.5	6.5	6.2	6.1	7.9	5.7	7.3	7.8	8.1			99.8	.2	100.0
Middle States	21.3	6.1	5.5	4.8	5.7	7.6	7.0	6.4	5.4	10.8	6.8	12.5	99.9	.1	100.0
Northwest	35.3	10.4	8.7	5.7	6.7	10.6	4.2	3.5	9.3	5.5			99.9	.1	100.0
Southwest	30.8	3.6	6.8	6.4	7.5	8.9	6.6	4.0	12.7	12.1			99.4	.6	100.0
Far West	24.2	2.2	3.3	4.1	5.3	8.7	5.3	6.8	6.3	11.6	4.6	17.4	99.8	.2	100.0
United States	25.8	4.6	5.4	5.4	6.0	9.2	6.6	6.4	7.4	8.4	4.2	10.4	99.8	.2	100.0

TRUCKS

Region	Unincorporated areas	1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Nonresident	Total
Northeast	16.4	2.9	4.6	4.5	5.1	9.8	6.5	7.7	7.4	4.4	9.5	20.9	99.7	0.3	100.0
Southeast	38.8	6.3	7.2	6.9	6.0	8.5	5.5	6.6	7.3	5.5			98.6	1.4	100.0
Middle States	18.1	8.2	6.2	4.9	5.6	7.1	6.8	5.9	5.8	9.6	6.5	14.9	99.6	.4	100.0
Northwest	34.5	12.7	10.5	6.6	6.9	11.4	3.4	2.7	6.8	3.6			99.1	.9	100.0
Southwest	29.6	3.9	7.9	8.2	8.3	9.2	7.1	3.9	8.1	11.8			98.0	2.0	100.0
Far West	23.7	4.3	5.8	5.8	7.1	8.3	5.0	5.0	5.0	9.5	5.7	14.4	99.6	.4	100.0
United States	26.2	6.0	6.6	5.9	6.1	8.7	6.0	6.0	6.8	7.1	4.2	9.6	99.2	.8	100.0

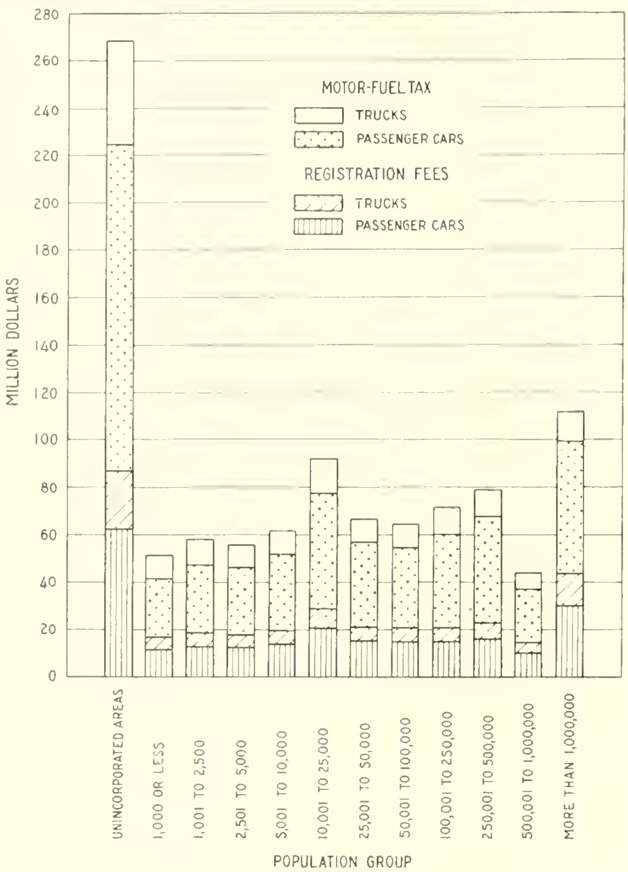

Figure 10.—Registration Fees and Motor-fuel Taxes Paid by Owners of Passenger Cars and Trucks in 1939.

46.0 in the Southeast and the percentage of total motor-vehicle registration fees paid for passenger cars paid by residents of unincorporated areas varies from 18.8 in the Northeast to 43.4 in the Southeast.

The influence of vehicle age on total motor-fuel tax collections is indicated by table 25 which compares on a percentage basis total gasoline consumption and total registration of passenger cars of different ages. For passenger cars 5 years of age and less, the percentage of total gasoline consumption is higher for each age group than the corresponding percentage of total registration, while for passenger cars 6 years of age and older, the percentage of total gasoline consumption is lower for each age group than the corresponding percentage of total registration. Cars 5 years of age and less use 55.5 percent of the total gasoline consumed by all cars but constitute only 41.4 percent of the total registration. These percentages, of course, vary in the different regions at any particular time, and because of shifts in ownership of vehicles and movements of large numbers of used cars from one section of the country to another, they vary from time to time in a particular region. Nevertheless, in any region and at any time, the effect of the age of vehicles in operation upon gasoline consumption appears to be relatively important, since the motor-fuel tax is the most important single tax source for highway purposes.

Table 26 presents data on average combined fees, which are simply a combination of average registration fees and average motor-fuel taxes. The relative importance of average combined fees cannot be over-

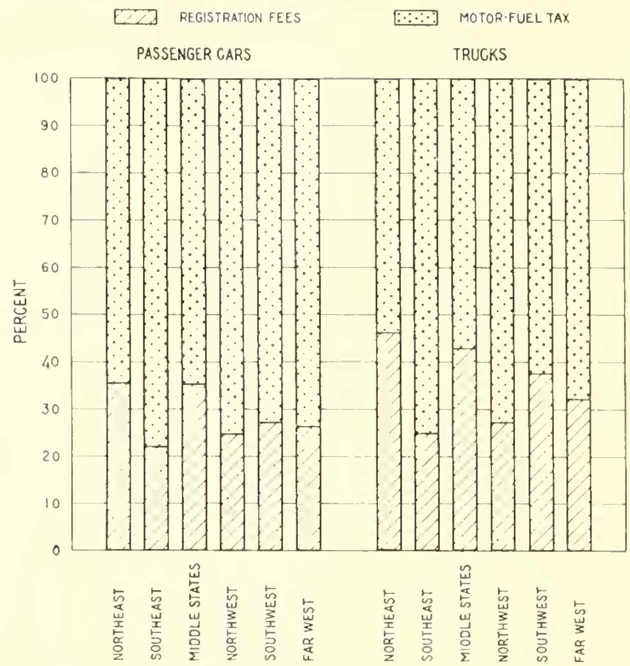

Figure 11.—Relative Registration Fees and Motor-fuel Taxes Paid by Owners of Motor Vehicles in the Several Regions in the United States.

emphasized because they represent what the average motorist pays for the privilege of operating his vehicle. Registration fees or motor-fuel taxes alone are not particularly significant because both must be paid, and it is the sum of the two which represents the motorists' outlay. Consequently, it may be stated that the tabulation of average combined fees indicates what are undoubtedly the most significant results of the present study.

Table 25.—*Percentage distribution of total gasoline consumption by passenger cars of each age classification and percentage distribution of passenger car registration*

Age, years	Gasoline consumption		Registration	
	Percentage of total	Cumulative percent	Percentage of total	Cumulative percent
1	19.6	19.6	13.1	13.1
2	14.4	34.0	10.1	23.2
3	9.5	43.5	7.5	30.7
4	6.3	49.8	5.5	36.2
5	5.7	55.5	5.2	41.4
6	7.9	63.4	8.1	49.5
7	10.6	74.0	11.8	61.3
8	10.5	84.5	13.5	74.8
9	6.6	91.1	9.3	84.1
10	3.7	94.8	6.0	90.1
11	2.4	97.2	4.4	94.5
12 and older	2.8	100.0	5.5	100.0
All	100.0		100.0	

It is apparent from table 26 that average combined fees are influenced much more by average motor-fuel taxes than they are by average registration fees. The average combined fees, for example, are highest in the Southeast, just as the average motor-fuel taxes are highest in that region, whereas the average registration fees are highest in the Northeast and are relatively low in the Southeast. Figures 10 and 11 show for each region the actual and relative amounts, respectively, of registration fees and motor-fuel taxes paid by residents

TABLE 26.—*Combined average vehicle registration fees and average State motor-fuel taxes paid in 1939*

PASSENGER CARS

Region	Unincorporated areas	Incorporated places having a population of— 1,000 or less	1,001 to 2,500	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	500,001 to 1,000,000	More than 1,000,000	All places	Non-resident	Total
Northeast	$28.39	$29.80	$29.97	$30.32	$29.64	$30.63	$28.39	$29.93	$27.60	$24.01	$30.87	$34.74	$30.00	$31.90	$30.00
Southeast	33.89	41.64	41.98	43.69	42.47	43.92	43.40	43.67	51.23	41.80			39.21	41.40	39.21
Middle States	23.67	25.98	27.11	28.12	28.42	29.22	28.91	29.17	30.50	32.64	31.51	29.06	27.76	29.07	27.77
Northwest	19.87	22.28	23.69	23.67	24.40	25.12	27.31	25.53	25.11	25.03			22.52	28.16	22.52
Southwest	26.72	29.61	31.99	33.20	31.25	35.54	34.30	33.69	33.56	37.91			31.22	26.24	31.18
Far West	22.93	23.08	23.54	23.49	23.61	24.33	24.27	23.79	24.61	27.54	22.47	25.01	24.13	25.10	24.14
United States	26.70	28.33	29.94	30.80	30.11	30.93	30.22	30.98	31.51	31.62	29.89	30.88	29.48	30.29	29.48
TRUCKS															
Northeast	53.26	55.08	57.03	58.65	60.96	61.42	59.55	71.53	62.79	58.88	73.85	82.01	64.16	92.04	64.26
Southeast	61.35	85.16	86.58	89.36	86.90	94.80	97.31	89.46	118.22	75.24			76.30	95.70	76.56
Middle States	39.59	51.98	53.76	55.70	59.64	63.65	69.19	71.47	80.98	74.46	67.63	94.81	59.39	83.15	59.48
Northwest	29.46	47.15	52.03	55.29	51.07	58.04	48.45	49.67	49.41	47.48			40.33	75.89	40.61
Southwest	37.05	53.42	57.75	63.84	62.03	65.37	70.25	63.75	57.03	89.39			53.12	62.30	53.33
Far West	37.93	45.92	46.72	46.33	46.01	49.14	48.66	47.17	56.00	65.61	58.31	55.41	47.59	55.00	47.62
United States	45.43	56.65	59.86	62.86	62.36	66.01	67.57	71.43	72.10	71.05	69.00	81.61	59.99	79.13	60.14
BUSSES															
Northeast	172.85	215.44	210.59	206.60	197.35	269.67	306.44	305.95	327.01	234.02	347.30	516.17	315.40	329.18	316.58
Southeast	105.82	117.91	114.16	181.80	299.33	419.52	524.25	410.05	710.15	308.05			257.96	367.68	264.79
Middle States	108.83	130.91	214.40	276.48	337.88	303.79	401.95	423.97	383.62	482.27	378.37	441.34	350.60	543.38	364.35
Northwest	178.76	94.45	143.73	114.06	230.53	344.73	258.28	339.25	404.43	295.01			240.77	336.63	250.50
Southwest	289.05	130.11	169.63	329.95	338.94	320.54	384.32	315.57	451.94	497.76			405.81	339.20	400.29
Far West	106.22	187.50	176.47	208.47	143.71	215.66	208.90	132.12	316.44	364.45	125.43	203.69	190.09	208.83	190.21
United States	121.71	137.38	167.06	208.72	232.25	312.11	339.74	340.13	408.07	338.43	248.74	426.97	288.77	361.42	293.74

of the different regions. In view of the relatively large amounts of fuel taxes as compared with registration fees, it is to be expected that the combined fees would show the same tendencies as do the fuel taxes.

The influence of average fuel taxes on average combined fees may be further illustrated by ranking numerically for the several regions average registration fees, average fuel taxes, and average combined fees for all population groups. The result of such ranking for passenger cars is indicated in table 27 which clearly shows that the influence of average motor-fuel taxes is more pronounced than that of average registration fees on average combined fees. Wherever there is a difference in the ranking of a particular region in the case of average registration fees as compared with average fuel taxes, its ranking in the case of combined fees is the same as in the case of fuel taxes.

TABLE 27.—*Numerical rank of average registration fees, average fuel taxes, and average combined fees for passenger cars, by regions*

[All population groups]

Region	Average registration fees	Average fuel taxes	Average combined fees
Northeast	1	3	3
Southeast	3	1	1
Middle States	2	4	4
Northwest	6	6	6
Southwest	4	2	2
Far West	5	5	5

In the case of individual population groups, however, it is not always true that combined average fees tend to follow average fuel taxes rather than average registration fees. Table 28 presents for unincorporated areas only the same rankings as are presented in table 27 for all population groups, but whereas in table 27 all regions rank the same as regards average fuel taxes and average combined fees, in table 28 only the Southeast ranks the same as regards average fuel taxes and average combined fees. In the Northwest and Far West, average registration fees and average combined fees rank the same, and in the other regions average combined fees rank midway between average registration fees and average fuel taxes.

TABLE 28.—*Numerical rank of average registration fees, average fuel taxes, and average combined fees for passenger cars, by regions*

[Unincorporated areas]

Region	Average registration fees	Average fuel taxes	Average combined fees
Northeast	1	3	2
Southeast	3	1	1
Middle States	2	6	4
Northwest	6	5	6
Southwest	4	2	3
Far West	5	4	5

RANGES IN MOTOR-FUEL TAXES AND REGISTRATION FEES COMPARED

Table 27 shows further that average registration fees and average fuel taxes as they exist in the different regions tend to equalize the average combined fees in those regions. Residents of the Northeast and Middle States, for example, pay the highest average registration fees, whereas residents of the Southeast and Southwest pay the highest fuel taxes. Residents of the Northwest and Far West, on the other hand, pay both the lowest average registration fees and also the lowest average fuel taxes. In other words, the highest average combined fees are somewhat less than they would be if the highest average registration fees and also the highest average fuel taxes were paid by residents of the same region or regions, but are not as low as they might be if the lower fees and taxes were more widely distributed throughout the different regions.

This particular situation may also be demonstrated by comparing the ranges or the differences between the high and low of average motor-vehicle registration fees, average motor-fuel taxes, and average combined fees. On a regional basis and for all population groups as a unit average motor-vehicle registration fees for passenger cars vary from $5.60 in the Northwest to $10.72 in the Northeast with a range of $5.12, while average motor-fuel taxes vary from $16.92 in the Northwest to $30.52 in the Southeast with a range of $13.60, and average combined fees vary from $22.52 in the Northwest to $39.21 in the Southeast with a range of $16.69. In the case of trucks average motor-vehicle registration fees vary from $10.83 to $29.49 with a range of $18.66, while average motor-fuel taxes vary from $29.50 to $57.48 with a range of $27.98 and average combined fees vary from $40.33 to $76.30 with a range of $35.97. If residents of the same region paid the highest existing average registration fee for passenger cars of $10.72 and the highest average existing motor-fuel tax for passenger cars of $30.52 they would pay an average combined fee of $41.24, whereas the highest average combined fee paid by residents of any region for passenger cars was actually $39.21, or somewhat less than the theoretical maximum. Similarly, the theoretical maximum range of average combined fees for passenger cars is $5.12 plus $13.60 or $18.72, whereas the actual existing range of average combined fees for passenger cars is $16.69.

That the combination of average motor-vehicle registration fees and average motor-fuel taxes tends to decrease the range and the actual amounts of the average combined fees paid by residents of a particular locality can be demonstrated on a population-group basis as well as on a regional basis. In the case of passenger cars, for example, average registration fees paid by residents of all regions vary from $8.38 in unincorporated areas to $10.95 in incorporated places having a population of more than 1,000,000 persons, or a range of $2.57, while average motor-fuel taxes vary from $18.32 to $23.15, or a range of $4.83, and average combined fees vary from $26.70 to $31.62, or a range of $4.92. Although these ranges are considerably smaller than those existing between regions, the maximum theoretical range of $2.57 plus $4.83 or $7.40 is considerably more than the actual range of $4.92. Likewise, the maximum theoretical combined average fee for all groups is $10.95 plus $23.15 or $34.10, whereas the highest existing combined fee is $31.62. Apparently the tendencies between individual population groups toward more stable average combined fees than the maximums theoretically possible are the same as those existing between regions.

A final fact which may be noted in connection with average combined tax contributions is that where the average contribution for all population groups existing in a particular region is high or low as compared with that existing in other regions, the average contributions in each individual population group of that region are not necessarily high or low as compared with similar contributions in corresponding population groups of the other regions. The lowest average combined fee for passenger cars for all population groups, for example, is the $22.52 paid by residents of the Northwest, but in the individual population groups the average combined contribution of residents of the Northwest is lower than that of residents of other regions in only three instances, the contributions of residents of the Far West being lower in the other seven instances. Similar variations exist in other regions and for the other vehicle types. Although such variations are neither unusual nor unexpected, they are worthy of notice in an analysis of data where the primary interest is in population-group relationships.

SUMMARY

In connection with this primary interest in population-group relationships, it will be recalled that the particular purpose of the present study is to present by population groups data on motor-vehicle registrations, motor-vehicle registration fees, and motor-fuel taxes. Such data have not previously been available on such a basis. In developing these data, numerous significant relationships as regards the ownership and operation of vehicles in the different population groups have been indicated. A few of the general conclusions which may be drawn from the data presented and analyzed are listed in the following paragraphs:

1. Although 40.2 percent of all vehicles in the United States are owned by persons residing in unincorporated areas and in incorporated cities and towns having a population of less than 2,500 persons, these persons constitute 43.6 percent of the total population of the country.

2. In unincorporated areas alone, however, 35.5 percent of the population of the country owned only 29.6 percent of the motor vehicles registered in 1939.

3. Of the total population of the United States, 47.5 percent resided in incorporated places having a population of less than 500,000 persons. The residents of these places owned 55.9 percent of the total number of vehicles registered in 1939.

4. The number of passenger cars registered per 100 persons varies from a maximum of 53.2 in incorporated places having a population of from 50,001 to 100,000 persons in the Far West to a minimum of 10.2 in unincorporated areas in the Southeast. In general, the number of cars per 100 persons in unincorporated areas and in cities having a population of more than 500,000 persons is low as compared with those in incorporated places having a population of less than 500,000 persons.

5. The average age of passenger cars owned by residents of unincorporated areas generally exceeds the average age of passenger cars owned in incorporated places by 1 to 2 years.

6. Average registration fees for all types of vehicles owned in unincorporated areas are lower than the average registration fees of vehicles owned in the incorporated cities and towns; vehicle owners living in cities having a population of more than 1,000,000 persons paid the highest average registration fees of any population group.

7. The average motor-fuel tax payments by residents of the different population groups in a particular region vary considerably, even after the effects of the different motor-fuel tax rates have been eliminated, such variations being due to differences in annual mileages and gasoline consumption rates.

8. The average motor-fuel tax payments by residents of the different regions vary considerably, but these variations, although influenced to a certain extent by differences in annual mileages and gasoline consumption rates, are largely the result of different motor-fuel tax rates.

9. The Southeast region which had the highest relative gasoline tax rate also had the highest average annual mileage reported for passenger cars.

10. Passenger cars 5 years of age and less use 55.5 percent of the total gasoline consumed by all cars but constitute only 41.4 percent of the total passenger-car registration.

11. Average combined fees are influenced much more by average motor-fuel taxes than by average registration fees, which is to be expected in view of the relatively large amounts of fuel taxes as compared with registration fees.

12. Although average combined fees are widely variable, just as are average registration fees and average motor-fuel taxes, the variation in the case of combined fees is not quite so extreme as would be theoretically possible, the fees being somewhat stabilized by the particular way in which the different average registration fees and average motor-fuel taxes are distributed among the different regions and population groups.

APPENDIX

Population and motor-vehicle registration data were not available for the year 1940 during the period in which this study was made. Since its completion the motor-vehicle registration data for that year have become available. Also, the population enumeration for the 1940 Census has been completed. Availability of these materials has made it possible to present tabulations which show the distribution of motor vehicles by States and population groups for the year 1940. Three tabulations have been prepared. They are:

A.—Distribution of privately owned automobiles by population groups in the United States in 1940.

B.—Distribution of privately owned trucks by population groups in the United States in 1940.

C.—Distribution of, all privately owned vehicles by population groups in the United States in 1940.

TABLE A.—*Distribution of privately owned automobiles by population groups in the United States in 1940*

State	Automobiles owned by residents of—										
	Unincorporated areas	Incorporated places having a population of—									All places
		2,500 or less	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	More than 500,000	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Alabama	123,098	23,192	14,995	15,149	19,658	13,441	24,609		38,972		273,114
Arizona	51,299	5,886	5,409	12,854		13,504	23,993				112,945
Arkansas	95,096	23,709	15,198	13,193	21,023	5,480	16,890				190,589
California	588,331	68,051	86,144	147,631	202,900	168,956	216,117	186,991	85,955	702,882	2,453,958
Colorado	73,857	43,341	17,216	18,372	23,916	12,971	12,503		90,450		292,626
Connecticut	111,591	3,551	3,170	5,833	49,061	100,084	28,288	115,078			416,656
Delaware	23,544	8,084	5,656	1,446				21,479			60,209
Florida	105,333	29,267	25,720	24,713	47,359	39,728	18,537	123,066			413,723
Georgia	165,421	41,971	22,920	23,263	36,790	5,064	47,760		69,250		412,439
Idaho	62,990	18,977	13,483	4,696	21,721	7,587					129,454
Illinois	314,429	171,349	76,680	114,138	130,569	145,156	143,643	29,967		580,708	1,706,639
Indiana	315,470	90,438	30,700	56,071	58,241	76,560	61,389	74,511	93,148		856,528
Iowa	218,853	171,143	52,976	44,637	41,864	48,593	69,201	43,990			691,257
Kansas	166,428	93,468	35,929	28,631	64,240	10,342	19,660	61,304			480,002
Kentucky	208,160	30,291	15,136	21,090	13,963	33,135	9,922		55,371		387,068
Louisiana	94,299	21,926	14,545	19,645	13,965	19,433	25,433		71,417		280,663
Maine		59,468	24,863	23,619	27,531	11,611	14,700				161,792
Maryland	165,973	25,263	14,599	7,842	20,693	14,264				135,340	383,974
Massachusetts		40,134	48,022	73,525	145,789	143,443	102,230	140,586		96,583	790,312
Michigan	287,267	137,376	69,204	84,520	105,793	107,286	109,276	82,163		417,953	1,400,838
Minnesota	244,563	132,123	34,968	52,763	47,299	7,339		20,442	206,792		746,289
Mississippi	110,272	21,226	11,791	10,549	24,315	6,662	11,663				196,478
Missouri	225,570	103,189	38,866	43,666	65,103	19,309	26,412		81,774	164,456	768,345
Montana	65,795	19,411	8,399	10,357	22,275	16,831					143,068
Nebraska	134,128	75,672	17,634	15,250	25,944		25,851	52,838			347,317
Nevada	14,983	3,190	2,765	5,976	8,350						35,264
New Hampshire		40,379	12,701	7,732	20,077	11,989	12,156				105,034
New Jersey	156,648	54,017	47,561	85,661	127,850	142,645	93,544	97,938	138,766		944,630
New Mexico	32,885	8,400	6,412	17,139	16,444	13,254					94,534
New York	467,747	99,886	79,824	70,556	167,898	89,883	90,179	109,557	58,840	1,165,126	2,399,496
North Carolina	216,301	82,641	29,393	30,746	48,790	28,233	48,048	19,342			503,494
North Dakota	76,161	34,734	1,841	10,267	13,487	9,256					145,746
Ohio	478,097	137,778	68,671	107,108	134,813	123,185	67,460	173,281	251,851	186,031	1,728,275
Oklahoma	154,828	62,848	25,158	37,700	66,104	16,270		104,191			467,099
Oregon	129,630	42,341	18,674	16,548	19,548	8,885			89,504		325,130
Pennsylvania	523,592	148,258	131,343	173,654	235,129	92,042	147,858	65,096		360,523	1,877,495
Rhode Island		3,597	10,466	13,605	20,129	59,481	17,199		41,864		166,341
South Carolina	148,810	31,144	19,777	19,139	22,448	17,667	30,103				289,088
South Dakota	68,248	41,369	9,383	12,542	18,984	12,726					163,252
Tennessee	158,019	25,373	23,373	22,639	23,047	4,809		68,050	52,006		377,316
Texas	445,395	109,143	82,587	91,086	99,418	66,718	120,968	43,928	283,618		1,342,861
Utah	23,347	21,729	10,619	5,696	6,144	10,370		39,121			117,026
Vermont	41,692	13,327	3,804	11,642	6,765	6,692					83,922
Virginia	266,425	20,981	12,483	16,307	12,248	23,880	24,088	46,179			422,591
Washington	186,226	46,481	21,919	11,206	33,064	22,468		59,805	91,879		473,048
West Virginia	110,296	30,930	13,452	17,708	22,354	14,247	41,307				250,294
Wisconsin	215,927	114,990	45,884	36,305	61,030	112,809	34,455			129,553	750,953
Wyoming	23,752	13,398	4,329	4,302	20,832						66,613
District of Columbia										146,612	146,612
Total	7,890,776	2,645,440	1,386,642	1,698,717	2,434,965	1,914,288	1,735,442	1,778,903	1,801,457	4,085,767	27,372,397

TABLE B.—*Distribution of privately owned trucks by population groups in the United States in 1940*

State	Trucks owned by residents of—										
	Unincorporated areas	Incorporated places having a population of—									All places
		2,500 or less	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	More than 500,000	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Alabama	30,919	6,108	3,624	3 217	4. 206	2,877	4,607		7,289		62,847
Arizona	12,582	1,358	1,312	3,099		1,283	5,474				25,108
Arkansas	34,977	10,003	5,592	4,462	6,415	1,332	3,377				66,158
California	74,540	19,714	19,064	29,044	28,459	21,441	22,716	15,689	8,669	80,365	319,701
Colorado	21 288	9,533	3,928	3,492	4,096	1,972	1,963		12,046		58,318
Connecticut	34,427	759	630	998	7,457	11,756	4. 003	15,809			75,839
Delaware	4. 852	1,492	908	219				4,083			11,554
Florida	23;992	5,932	5. 750	4,752	7,599	6,685	3,089	21,991			79,790
Georgia	38,634	10,799	4 760	4,652	7,514	1,036	8,115		11,672		87,182
Idaho	19,478	5,373	3,349	1,109	3,464	985					33,758
Illinois	50,679	31,165	11,040	13,799	15,415	15,670	13,521	3. 408		64,478	219,175
Indiana	53,210	18. 272	5,390	9,356	9,002	9,948	8. 271	9. 116	13,592		136,157
Iowa	22,355	30,540	9,591	7,861	7,136	7,936	10,436	6,857			102,712
Kansas	43,744	20. 161	6,635	5,257	9,931	2,070	3,619	11,016			102,433
Kentucky	42,806	6,623	3,390	3,815	2,811	6,596	1,331		8,519		75,891
Louisiana	41,212	6,792	4,336	5,810	3,566	3,503	3,734		12,840		81,793
Maine		19,038	6,360	6,216	6,047	2,867	3,386				43,914
Maryland	26,893	4,585	1,834	879	2,423	2,166				20,642	59,422
Massachusetts		9,079	8,325	12,189	21,409	15,187	13. 141	17,718		11,594	108,642
Michigan	29. 614	20,875	7,829	9,679	12,282	11,514	10,033	9. 048		40,001	150,875
Minnesota	50,365	24,741	5,647	8,674	7,388	1,140		2,774	23,734		124,463
Mississippi	37,544	6,887	3,415	2,895	6,665	1. 280	2,241				60,927
Missouri	42,905	23,000	8,841	8,461	11,389	3,319	5,517		13,928	32,666	150,026
Montana	32,247	4,200	1,637	2,236	4,271	3,373					47,964
Nebraska	27,148	15,198	3,668	2,974	4,449		3,403	7,649			64,489
Nevada	3,692	1,415	589	1,250	1,789						8,735
New Hampshire		14,339	3,681	2,005	5,019	2,438	2,580				30,062
New Jersey	25,537	7,807	5,859	9,892	15,656	17,519	15,572	14. 724	24. 560		137,126
New Mexico	12,035	2,872	1,982	4,412	4,749	3,211					29,261
New York	68,183	13,038	8,673	7,325	18,400	9,868	13,423	14,798	9,311	172,742	335,761
North Carolina	31,211	15,789	5,555	6,086	10,134	5,860	9,142	3,680			87,457
North Dakota	20,017	8,437	416	2,481	3,320	1,713					36,384
Ohio	53,457	17,715	7,745	12,102	13,735	11,920	4,307	19,378	28,587	21.708	190,654
Oklahoma	43,906	14,497	5,599	7,693	13,028	3,171		16,934			104,828
Oregon	34,401	10,854	4,103	3,238	3,730	1,459			9,971		67,756
Pennsylvania	79,126	19,194	14,874	19,164	27,374	10,265	22,903	9,363		60. 492	262,755
Rhode Island		584	1,606	1,884	2,602	6,189	1,737		6,115		20,717
South Carolina	19,925	5,839	3,989	3,973	4,194	3,265	5,221				46,406
South Dakota	13,534	8,827	1,921	2,261	3,791	1,964					32,298
Tennessee	30,897	5,994	5,099	4,552	3,819	672		12,039	7,595		70,667
Texas	132,457	33,543	26,665	28,085	28,222	16,649	25,261	8,353	51,205		350,440
Utah	5,138	5,337	2,485	1,105	1,385	1,533		5,251			22,234
Vermont	5,390	1,477	334	1,092	671	664					9,628
Virginia	54,230	2,677	1,600	2,511	2,033	3,797	3,371	6,028			76,247
Washington	46,426	10,532	4,332	1,921	4,542	3,123		7.552	9,806		88,234
West Virginia	22,417	5,497	2,344	3,555	4,411	2,725	10,571				51,520
Wisconsin	58,924	30,706	10,162	6,631	8,269	15,004	4,049			15,506	149,251
Wyoming	9,363	3,769	1,042	782	3,943						18,899
District of Columbia										13,928	13,928
Total	1,566,677	552,966	257,510	289,145	378,210	258,945	250,114	243,258	259,439	534,122	4,590,386

The basic materials used in the preparation of the population group distribution of vehicles for the year 1939 were used in preparing the 1940 tabulations. In the computation of the 1940 data the population of each group for 1940 was divided by the number of persons per vehicle in 1939 for that group except that for those individual places which had sufficient increase or decrease in population to cause a shift to a new classification the original ratio of persons per vehicle, based on the previous census, was used. The computed number of vehicles in each population group when totaled was of course at variance with the known registration totals for each State. This difference was eliminated by applying an adjustment factor uniformly to each population group in each State.

(*Continued on p. 261*)

SUBSTITUTION OF PAINT COATINGS FOR METALLIC ZINC COATINGS

By E. F. HICKSON, Chemist, National Bureau of Standards

This bulletin is issued at the request of the Protective and Technical Coatings Section of the Office of Production Management in the interest of conservation. The object is to suggest substitutes that at the time of writing are avilable to replace critical materials.

IN numerous ways zinc is vital to the nation's defense program. Thus for nondefense purposes, an increasing number of inquiries are being received with regard to suitable substitutes for the zinc coating formerly used on various iron and steel surfaces. This article will be confined to the use of organic protective coatings as possible substitutes for metallic zinc coatings.

As is the case with many other materials which are critical during the present National Emergency, no paint has all the desirable properties of the ordinary hot-dip galvanized or zinc-coated surfaces on steel, including such properties as resistance to abrasion, resistance to corrosion, weathering, relative freedom from cracking, chipping, peeling and scaling of the types encountered with paint coatings, etc. On the other hand, in a highly polluted industrial atmosphere, certain acid-resisting and water-resisting paints are advantageous.

Thus since the environment and other external factors have such a pronounced effect on the durability of both paint and metallic zinc coatings, only general statements can be made in this memorandum. Frequently painting systems have to be devised so as to cover each individual case. Thus any general procedure or recommendation may not cover a specific situation. It is with this thought in mind that the following suggestions are made.

Factory-primed exterior sheet steel formerly zinc-coated (roofing, flashings, etc.).—Since much of the work referred to herein will be done at the shop where the metal is rolled and fabricated, the priming paints to be employed for this purpose should be industrial finishes purchased by the steel manufacturer directly from the industrial finish manufacturer. Special industrial primers for preventing corrosion of black iron have been developed and are readily available. They generally consist of rust-inhibitive pigments such as red lead, white lead, blue lead, metallic lead, zinc oxide, with or without various percentages of chromate pigments, often combined with iron oxide pigments. They are usually ground in quick-drying varnish liquids. The articles are either sprayed or dipped with these primers. While they may air-dry rapidly, they are usually baked in suitable ovens. Baking for a relatively short period produces a hard, dry surface which may be handled, thus expediting production in the factory. On the other hand, where the objects are to be coated in the field by the user, the slower-drying types of primers, such as red lead in oil and similar rust-inhibitive primers, may be used.

The industrial finish manufacturer has also worked out special priming liquids and finishes for the interiors and exteriors of drums which are to hold certain industrial liquids such as oils, etc. These primers are usually baked on by the drum manufacturer, thus making them very much more resistant to various liquids. For those having problems of this character, it is suggested that they immediately get in touch with a reliable manufacturer of industrial finishes.

If the sheet steel is painted at the factory, it may be given a chemical treatment followed by a baked-on, high-grade priming paint. Sheet steel coated with vitreous or glass coating is also available. In connection with the chemical surface treatment, reference should be made to BMS Report 44, "Surface Treatment of Steel Prior to Painting," of the National Bureau of Standards. A copy of this report can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents. In this report, it was found that among surface treatments for plain steel subjected to accelerated weathering, salt spray, and condensation corrosion tests, the hot-dip phosphate treatments showed outstanding merit in improving the protective value of paints. Particularly effective protection was obtained when such treatments were used under severely corrosive conditions in combination with a primer of the inhibitive type. Two phosphate-chromate cold-wash treatments for plain steel also appeared to improve paint protection.

It is essential that the primer be baked on at proper temperatures and under proper operating conditions. It is also essential that the primer be of high-grade quality and that it be not thinned excessively on the job. As has been mentioned, the primer should contain rust-inhibitive pigments and the vehicle should be of a suitable baking type. Finish coat paints of the desired color may be applied on the job. For example, finish coats of white or light tint paints may be obtained under Federal Specifications TT–P–36a,[1] TT–P–156, and TT–P–101a; red and brown iron oxide paints under Federal Specification TT–P–31a, black paint under Federal Specification TT–P–61; and green paint under Federal Specification TT–P–71a.

Painting exterior sheet metal on the job formerly zinc-coated (roofing, flashings, window and louver heads, etc.).—The problem here is to have a sheet that must stand exposure to ordinary storage, handling, and fabrication, and then be able to be welded or soldered and subsequently painted. One Government agency specifies that for exterior sheet metal work for roof flashings and flashing at door, window, and louver heads the materials shall be either phosphate-treated steel or terne plate. It also specifies that the surfaces that are to be painted shall be thoroughly cleaned and all traces of flux removed. The steel shall be 26 gage, phosphate-treated, and given immediately a dip-coat of mineral oxide paint baked on at a temperature of 250° to 300° F. Both sides of phosphate-treated steel and all exposed surfaces of other sheet metal work, flashings, etc. (except copper), shall be painted with one coat of red lead and oil paint before placing. The red lead paint shall comply with Federal Specification TT–P–86.

Painting interior sheet steel formerly zinc-coated (air ducts, etc.).—The same recommendations of pretreating the steel prior to applying a baked-on, high-grade, rust-

[1] A table giving the complete designation of the Federal Specifications referred to herein will be found at the end of this article (p. 261).

inhibitive primer may be followed. However, for certain places where the surface is not to be exposed to the weather, the application of a bituminous base coating (F. S. SS–R–451) may serve the purpose. However, it should be required that this coating dry hard and free of tackiness. In the case of air ducts that become hot, it is suggested that instead of the above-described bituminous base coating, the ducts be dipped in asphalt varnish (F. S. TT–V–51). This will produce a coating that will bake on the surface at a temperature of 300° to 400° F. Special heat-resisting enamels in black and gray colors are also available. These enamels will withstand temperatures considerably above 400° F.

Painting exterior structural steel (girders, towers, etc.), formerly zinc-coated.—After priming the clean surface with a rust-resisting primer such a red lead paint (F. S. TT–P–86), basic lead chromate paint (F. S. TT–P–59), blue lead paint (F. S. TT–P–20), etc., use a finish coat of gray paint or any other tint conforming to Federal Specification TT–P–36a or TT–P–156. If chalk-resistant titanium oxide is specified, Federal Specification TT–P–101a, or War Department Cantonment Paint, Standard Specification 8000 E, page 88, June 30, 1941, may also be used, tinted gray or any other desired color. If color is of no moment, dark-colored paints such as iron oxide (F. S. TT–P–31a) or black (F. S. TT–P–61) will be more durable than white or light tint paints. Additional information on painting structural steel may be found in the National Bureau of Standards Letter Circular 422, "The Painting of Structural Metal."

Painting interior structural steel formerly zinc-coated.—In industrial plants where good light reflection from the structural steel is desired, the following procedure may be used. Apply a priming coat of quick-drying red lead paint (Procurement Division Specification No. 358), or a similar rust-inhibitive primer, followed by either two coats of eggshell flat white paint (F. S. TT–P–51a) or gloss white enamel, sometimes called "gloss mill white," (F. S. TT–E–506a). The enamel will be more water-resistant and more durable. For special conditions where fumes are encountered, such as in chemical laboratories, bakeries, tobacco factories, cafeterias, etc., a special enamel known as fume-and-heat-resisting enamel (National Bureau of Standards Letter Circular 489) may be used.

Painting steel surfaces formerly zinc-coated for subsoil or under-water exposure.—Bituminous base coatings are suggested for this purpose. The following paragraphs give some of the properties of these coatings:

(A) *Cold or brush application type.*

(1) *Solutions of either asphalt or coal tar in a volatile distillate.*—These coatings are of brushing consistency and are primarily intended for use as primers on surfaces which are subsequently to be coated with a hot application of asphalt. (See F. S. SS–A–701.) This type of material is also commonly used on surfaces where a black coating is desired, which will not be subjected to the action of heat or sunlight. These materials are known commercially as black or liquid asphaltum, bituminous paint, primers, etc.

(2) *Asphalt varnish or enamels.*—These materials are composed of a high-grade asphalt fluxed and blended with properly treated drying oils and thinned to a brushing consistency with a volatile solvent. (See F. S. TT–V–51.) Special types of this material will withstand dry temperatures up to 600° F. (see U. S. Navy Specification 52–E–2a, Enamel, Black, Heat-Resisting). These coatings in general are more durable than those listed under (1). They are primarily intended for use indoors as coatings for surfaces where a hard, black glossy surface is desired. They will, for a limited time, give adequate protection against moisture and corrosive vapors. They should not be used where they are alternately exposed to sunlight and moisture. These materials are known commercially as asphalt varnish, asphalt enamel, and heat-and-acid-resisting enamel.

(3) *Cold mastic type.*—These coatings consist of asphaltic materials (with or without fatty oils) and mineral filler, thinned to a heavy brushing consistency with a volatile solvent. (See F. S. SS–R–451.) This material is intended for use in the repair and coating of asphalt and metal roofing and for application to concrete, masonry, and steel structures as a dampproofing and protective coating.

(B) *Hot application type.*

(1) Asphalt, F. S. SS–A–666.

(2) Coal tar, F. S. R–P–381.

(3) Bituminous enamels.

A description of the characteristics and methods of application of these materials can be found beginning on page 3 of the National Bureau of Standards Letter Circular 42, "Acid-Proof Coatings for Concrete Surfaces." Reference should also be made to National Bureau of Standards Research Paper 1058, issued December 1937, "Soil-Corrosion Studies, 1934, Bituminous Coatings for Underground Service." This publication can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents.

Painted wire formerly zinc-coated.—The problem here is to suggest a paint that will be an acceptable substitute for galvanized wire screen (1-inch mesh) used in reinforcing stucco in home construction. Probably the best method would be to have the work done at the finishing plant, where the black iron screen could be passed through a tank of black, flexible enamel or japan, and then baked in suitable drying ovens prior to shipping the screen in rolls. This coating would be tough and flexible and would not chip off. The necessity of having some kind of a coating on the black iron is to prevent rust stains from "bleeding" through the stucco and paint after the building is erected. A cheaper but not as durable a method is to dip the roll of black iron screen being used on the job in a tank of a bituminous solution as described on page 259. This material would dry quickly, and since the amount of bituminous coating on any one wire would be relatively small, it is doubtful whether there would be any trouble from the bitumen "bleeding" through the stucco. Another possibility is to dip the roll in a quick-drying, thin spar varnish.

General considerations.—As can be seen from the foregoing remarks, it is possible to use Federal Specification materials or their equivalents as substitutes for zinc-coated surfaces under a variety of conditions. Recommending the use of synthetic resin paints and enamels has been avoided, because of the shortage of certain ingredients used in these paints. The same statement holds true for aluminum paint. Similarly, certain highly durable cellulosic finishes could be employed, but an acute shortage of the plasticizers and solvents for these is also developing.

As has been noted previously, the condition to which the surface is exposed has a direct influence on the durability of the paint coating. Thus a coating that may show excellent resistance under water (for example a bituminous coating) may fail rather quickly when exposed to the weather.

In using paint to replace galvanized or zinc coatings, it should be kept in mind that the condition of the surface is of utmost importance. It should be clean, dry, and free of all rust and scale prior to painting. Within practical limits, the protective value of a paint film is roughly proportional to its thickness. Thus for exterior exposure the safest procedure is to apply three coats of good paint, each coat being spread at a practical spreading rate (500 to 700 square feet per gallon). Where exposure conditions are particularly severe (for example an outside roof), it is suggested that two coats of primer and two coats of the finish paint be applied.

Equally important as the character of the surface and the thickness of paint film on the ultimate durability is the method of application. There is no substitute for skill in application. This is at least as important as the quality of the paint. It is for these reasons that the only proper method of evaluating a paint job is on the basis of cost of paint per square foot area applied per year of service.

Wherever Federal Specifications are referred to in this memorandum, they cover products which will be satisfactory for the use referred to, but for the general buying public similar products may be obtained under trade brands at any paint store throughout the country. The paint dealer will readily recognize the material referred to.

Complete titles of Federal specifications referred to in body of the article are given below. Copies of these specifications are available from the Superintendent of Documents, Government Printing Office, Washington D. C. at 5 cents each.

Federal Specification No.	Title
TT-P-20	Paint, blue-lead-base; basic sulfate, linseed oil, ready-mixed.
TT-P-31a	Paint; iron-oxide, ready-mixed and semipaste, red and brown.
TT-P-36a	Paints; lead-zinc-base, ready-mixed, and semipaste, white and tinted.
TT-P-51a	Paints; oil, interior, eggshell-flat-finish, ready mixed and semipaste, light tints and white.
TT-P-59	Paint, ready-mixed, international-orange.
TT-P-61	Paint; ready-mixed and semipaste, black.
TT-P-71a	Paint; ready-mixed and semi-paste, exterior, chrome-green.
TT-P-86	Paint, red-lead-base; linseed-oil, ready-mixed.
TT-P-101a	Paint; titanium-zinc and titanium zinc-lead, outside, ready-mixed, white.
TT-P-156	Paint, white-lead-base; basic carbonate, ready-mixed, light-tints and white.
TT-E-506a	Enamel; interior, gloss, light-tints and white.
TT-V-51	Varnish; asphalt.
SS-A-666	Asphalt; (for) built-up roofing, waterproofing, and dampproofing.
SS-A-701	Asphalt-primer; (for) roofing and waterproofing.
SS-R-451	Roof-coating; asphalt, brushing-consistency.
R-P-381	Pitch; coal-tar (for) mineral-surfaced built-up roofing, waterproofing, and dampproofing.

(Continued from p. 258)

TABLE C.—*Distribution of all privately owned vehicles by population groups in the United States in 1940* [1]

State	Vehicles owned by residents of—										
	Unincorporated areas	Incorporated places having a population of—									All places
		2,500 or less	2,501 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	100,001 to 250,000	250,001 to 500,000	More than 500,000	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Alabama	158, 260	30, 212	19, 051	18, 826	24, 824	16, 974	30, 428		47, 553		346, 128
Arizona	65, 693	7, 643	7, 040	16, 415		16, 972	30, 153				143, 916
Arkansas	135, 337	35, 686	21, 904	18, 527	28, 806	7, 264	21, 797				269, 321
California	711, 039	101, 424	117, 872	196, 265	249, 323	203, 479	253, 116	212, 321	98, 648	814, 002	2, 957, 489
Colorado	96, 254	53, 577	21, 400	22, 126	28, 252	15, 133	14, 648		103, 802		355, 192
Connecticut	149, 555	4, 471	3, 948	7, 021	58, 008	113, 687	33, 023	132, 708			502, 421
Delaware	29, 789	10, 005	7, 135	1, 835				26, 674			75, 438
Florida	133, 638	38, 644	34, 247	31, 371	57, 792	48, 449	22, 523	150, 642			517, 306
Georgia	211, 885	55, 397	28, 744	28, 800	45, 970	6, 345	58, 208		83, 848		519, 197
Idaho	93, 703	27, 917	19, 162	6, 592	28, 858	9, 891					186, 123
Illinois	372, 725	207, 011	89, 458	130, 277	148, 621	163, 616	159, 738	33, 967		656, 479	1, 961, 892
Indiana	396, 505	118, 101	39, 120	70, 870	72, 896	93, 986	75, 653	90, 665	116, 553		1, 074, 349
Iowa	245, 669	240, 222	74, 808	62, 309	57, 177	64, 683	90, 398	57, 679			892, 945
Kansas	212, 677	114, 971	43, 060	34, 285	75, 095	12, 565	23, 557	73, 309			589, 519
Kentucky	251, 807	37, 085	18, 610	25, 027	16, 845	39, 966	11, 360		64, 285		464, 985
Louisiana	141, 667	32, 583	20, 741	27, 188	18, 456	23, 940	30, 212		85, 923		380, 710
Maine		82, 498	33, 980	31, 785	35, 380	15, 288	18, 762				217, 693
Maryland	195, 994	30, 561	16, 758	8, 882	23, 519	16, 886				159, 193	451, 793
Massachusetts		51, 057	58, 203	88, 107	171, 813	162, 411	117, 831	161, 450		110, 033	920, 905
Michigan	359, 866	181, 519	86, 658	107, 737	131, 845	132, 530	131, 962	102, 424		483, 555	1, 718, 096
Minnesota	337, 503	173, 101	44, 407	67, 175	59, 862	9, 281		24, 887	247, 740		963, 956
Mississippi	151, 520	29, 289	15, 717	13, 825	31, 922	8, 160	14, 283				264, 716
Missouri	277, 405	136, 276	50, 855	54, 947	80, 201	23, 540	33, 241		99, 883	206, 505	962, 853
Montana	100, 861	24, 359	10, 369	13, 936	27, 465	20, 747					197, 737
Nebraska	191, 304	96, 977	22, 750	19, 432	32, 298		31, 055	64, 572			458, 388
Nevada	19, 173	4, 908	3, 462	7, 706	10, 510						45, 759
New Hampshire		56, 690	18, 957	10, 062	26, 043	15, 240	15, 248				142, 240
New Jersey	184, 912	62, 843	54, 145	96, 900	145, 759	163, 223	111, 088	114, 910	166, 377		1, 100, 157
New Mexico	45, 981	11, 729	8, 721	22, 486	22, 202	17, 199					128, 318
New York	548, 602	115, 713	90, 282	79, 516	190, 555	102, 311	106, 295	128, 362	70, 006	1, 373, 469	2, 805, 111
North Carolina	272, 731	107, 990	37, 411	38, 692	62, 079	36, 060	59, 342	23, 889			638, 194
North Dakota	96, 492	43, 533	2, 292	12, 886	17, 237	11, 278					183, 718
Ohio	610, 340	169, 238	81, 843	126, 800	157, 112	141, 755	73, 526	201, 109	292, 656	214, 046	2, 068, 425
Oklahoma	198, 869	78, 580	31, 247	46, 185	81, 767	20, 039		126, 871			583, 558
Oregon	164, 825	53, 774	23, 073	20, 009	23, 395	10, 332			100, 003		395, 411
Pennsylvania	618, 186	171, 266	148, 993	196, 630	268, 022	104, 439	174, 675	76, 247		431, 499	2, 189, 957
Rhode Island		4, 254	12, 241	15, 689	23, 002	66, 361	19, 107		48, 791		189, 445
South Carolina	172, 329	38, 183	24, 447	23, 641	27, 194	21, 551	36, 174				343, 519
South Dakota	95, 850	55, 574	12, 145	15, 900	24, 467	15, 595					219, 531
Tennessee	189, 006	31, 485	28, 567	27, 325	27, 021	5, 512		80, 663	60, 045		449, 624
Texas	598, 736	147, 971	113, 567	124, 364	132, 384	86, 492	151, 551	54, 135	345, 353		1, 754, 553
Utah	28, 689	27, 488	13, 338	6, 876	7, 608	12, 025		45, 047			141, 071
Vermont	48, 904	15, 229	4, 175	12, 996	7, 586	7, 503					96, 393
Virginia	326, 246	24, 426	14, 873	19, 874	15, 040	29, 060	28, 731	55, 464			513, 714
Washington	243, 254	59, 910	27, 682	13, 874	39, 708	26, 964		70, 854	106, 515		588, 761
West Virginia	134, 588	37, 371	16, 247	21, 680	27, 396	17, 375	52, 967				307, 624
Wisconsin	278, 303	147, 758	56, 808	43, 550	70, 118	129, 426	38, 979			146, 523	911, 465
Wyoming	38, 351	19, 303	5, 965	5, 536	27, 112						96, 267
District of Columbia										163, 501	163, 501
Total	9, 935, 023	3, 405, 802	1, 736, 478	2, 092, 737	2, 938, 545	2, 265, 533	2, 069, 631	2, 108, 849	2, 137, 981	4, 758, 805	33, 449, 384

[1] Includes automobiles, trucks, tractor-trucks, busses, trailers, semitrailers, and motorcycles.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF DECEMBER 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 3,222,587	$ 1,602,075	109.7	$ 7,152,099	$ 3,550,720	231.1	$ 509,310	$ 252,900	2.9	$ 680,197
Arizona	966,381	693,221	44.7	1,857,239	1,194,046	64.0	384,302	254,599	8.4	717,071
Arkansas	3,447,372	1,585,912	56.6	1,168,870	583,318	59.8	70,984	35,492	.3	158,258
California	6,616,026	3,508,870	110.5	5,426,924	2,939,466	67.1	2,488,150	1,254,696	42.2	1,223,897
Colorado	2,310,848	1,303,814	154.6	3,188,693	1,833,313	150.4	1,132,135	633,083	40.6	822,930
Connecticut	1,419,554	696,181	17.1	1,715,156	821,787	18.4	481,485	239,471	9.4	527,175
Delaware	275,257	132,307	4.9	749,827	371,718	21.2	268,040	134,020	8.4	987,558
Florida	1,167,179	582,930	65.3	2,281,618	1,144,037	28.5	1,332,477	642,238	17.9	1,970,717
Georgia	2,543,841	1,270,628	84.5	6,707,932	3,363,716	264.5	3,921,308	1,960,654	166.5	4,582,888
Idaho	1,751,600	1,067,364	93.7	1,222,674	754,224	45.4	171,449	106,007	17.8	949,436
Illinois	3,447,506	1,715,162	80.2	7,538,007	3,768,382	131.0	1,445,417	722,548	6.4	3,193,851
Indiana	4,482,275	2,073,573	73.8	5,349,003	2,595,736	76.2	2,191,200	1,095,600	32.7	458,255
Iowa	2,685,185	1,265,745	107.5	5,321,802	2,375,708	182.8	800,741	97,650	23.6	37,394
Kansas	3,805,380	1,921,856	217.1	5,421,029	2,717,936	258.1	2,628,261	986,446	105.1	2,726,461
Kentucky	3,496,959	1,732,580	118.6	6,555,435	3,133,886	143.8	2,216,538	1,041,355	19.0	131,797
Louisiana	850,231	425,091	22.3	1,997,922	990,543	39.7	2,553,917	1,251,767	56.3	3,052,377
Maine	958,357	474,582	26.8	1,835,602	944,301	19.6	313,400	156,700	8.2	253,884
Maryland	2,737,267	1,367,529	29.6	3,436,096	1,467,649	15.0	35,000	17,500		767,505
Massachusetts	2,348,774	1,177,018	17.3	2,223,103	1,142,862	14.9	1,173,468	583,147	8.4	2,601,239
Michigan	7,319,708	3,605,311	164.5	3,426,700	1,713,350	50.1	1,898,700	931,200	18.8	627,998
Minnesota	4,417,901	2,195,411	377.6	9,543,372	4,728,575	387.8	483,087	240,768	21.1	730,332
Mississippi	3,600,044	1,797,394	208.8	5,304,224	2,597,712	286.5	191,500	94,000	6.1	525,491
Missouri	5,079,259	2,515,015	160.1	10,026,526	4,385,652	190.0	2,982,972	493,509	36.5	3,018,258
Montana	2,181,671	1,233,971	117.1	3,428,246	1,948,298	150.8	905,844	519,282	78.3	2,564,676
Nebraska	1,606,558	798,385	204.9	6,499,968	3,268,939	552.6	709,046	354,523	37.8	2,178,588
Nevada	2,251,656	1,956,941	110.6	742,339	643,031	22.0	274,686	238,701	3.4	99,609
New Hampshire	339,179	166,213	6.0	1,238,815	595,091	14.8	470,083	232,580	5.4	564,113
New Jersey	2,854,311	1,424,881	26.5	3,065,908	1,532,874	16.2	23,910	11,955		1,756,886
New Mexico	1,234,207	759,224	94.9	1,125,166	718,439	68.3	352,949	228,216	12.9	1,294,397
New York	8,779,082	4,333,586	117.1	8,380,493	4,655,345	88.2	1,517,372	837,804	14.9	1,039,199
North Carolina	2,847,634	1,407,647	124.6	3,818,419	1,912,030	157.7	1,179,540	555,855	27.8	1,386,828
North Dakota	3,259,082	1,774,691	287.6	2,600,840	1,351,578	203.7	2,421,360	1,214,050	205.5	2,781,622
Ohio	8,565,694	4,276,497	84.6	11,394,492	5,456,531	73.1	6,058,000	2,377,468	40.4	1,148,045
Oklahoma	1,986,316	996,008	99.3	2,656,022	1,401,557	49.1	2,116,780	1,108,399	77.1	3,989,082
Oregon	2,139,084	1,288,406	69.2	3,720,608	1,992,888	73.4	264,054	116,270	7.5	170,881
Pennsylvania	8,243,356	4,091,634	82.4	9,793,781	4,811,703	75.6	3,618,747	1,768,991	30.9	818,401
Rhode Island	1,196,941	596,510	10.0	644,776	322,368	4.8	567,583	215,956	2.0	559,217
South Carolina	1,313,734	599,897	77.5	4,570,470	2,125,557	102.3	1,108,853	406,381	28.5	1,022,859
South Dakota	2,017,802	1,167,128	239.0	5,035,343	3,237,569	567.6	791,600	464,010	84.8	1,308,213
Tennessee	3,148,138	1,572,084	92.2	3,796,626	1,898,313	64.4	2,327,086	1,163,543	56.5	2,043,469
Texas	8,260,673	4,047,246	437.4	12,541,069	6,022,306	431.3	4,096,096	1,743,350	131.6	3,190,557
Utah	1,094,161	822,026	51.4	1,821,437	1,372,192	38.8	239,644	138,710	11.0	128,597
Vermont	819,505	400,394	28.8	1,211,974	602,337	20.8	36,906	18,453	.3	66,210
Virginia	2,319,701	1,162,308	52.3	4,281,492	1,966,767	74.2	818,250	406,075	5.9	1,085,245
Washington	1,328,015	692,995	18.9	2,956,655	1,581,304	38.3	43,686	23,400	1.0	654,000
West Virginia	2,183,960	1,089,365	41.7	2,950,912	1,459,318	37.7	463,776	229,588	3.1	1,091,344
Wisconsin	2,142,882	1,052,779	89.4	5,604,911	2,626,343	167.1	1,410,013	489,400	47.4	2,394,795
Wyoming	1,411,312	899,684	148.3	1,814,626	1,182,446	123.5	31,546	20,284	.1	269,156
District of Columbia	594,036	293,515	3.3	721,662	396,682	1.1				201,857
Hawaii	133,296	66,648	2.8	766,069	550,561	9.2	479,995	310,778	5.2	1,377,246
Puerto Rico	259,327	128,060	3.2	2,033,421	1,003,645	17.0	230,634	114,700	.6	413,003
TOTALS	143,460,804	73,808,292	5066.8	208,665,493	105,754,649	5,989.5	62,231,880	28,534,072	1,576.5	66,343,064

U S GOVERNMENT PRINTING OFFICE: 1942

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF DECEMBER 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 1,115,122	$ 555,768	38.0	$ 752,602	$ 399,640	49.7	$ 255,259	$ 121,280	6.1	$ 216,314
Arizona	121,340	88,202	13.2	141,552	105,006	.8	126,598	61,439	6.8	292,556
Arkansas	599,245	230,013	33.1	294,368	147,118	21.3	139,486	94,743	5.1	43,888
California	628,196	376,840	15.2	1,089,359	784,093	10.7				381,181
Colorado	150,002	84,134	20.7	129,755	72,649	2.1	152,387	35,323	5.0	216,644
Connecticut	298,035	136,331	6.1	266,247	115,937	4.8				85,891
Delaware	63,272	39,496		222,731	110,890	12.3	102,873	37,617	3.9	160,439
Florida	498,886	249,443	4.7	666,633	338,767	7.1	191,500	95,662	5.9	137,172
Georgia	349,325	159,662	31.7	1,302,120	743,410	79.5	496,996	243,493	50.8	686,014
Idaho	281,313	170,467	26.2	190,271	111,744	7.7	78,125	48,303	5.9	91,951
Illinois	932,510	462,147	51.4	1,210,660	605,330	55.3	151,700	72,600	17.7	213,460
Indiana	354,450	177,225	22.4	1,385,255	659,471	64.1	189,600	94,800	6.4	505,028
Iowa	525,803	247,570	125.8	473,357	205,568	37.3	324,069	152,325	60.5	159,071
Kansas	452,187	228,579	75.3	1,935,172	969,753	120.9	499,225	249,613	37.7	592,532
Kentucky	970,212	264,219	64.4	1,265,879	293,993	50.9	344,462	94,400	14.1	110,785
Louisiana	564,708	230,289	20.6	7,700	3,850		289,362	138,761	21.5	443,106
Maine	77,540	38,770	3.6	235,218	117,609	10.5	16,850	2,714	.4	9,491
Maryland	368,000	184,000	19.1	434,000	216,825	3.5				202,116
Massachusetts	179,789	93,569	4.1	634,608	334,371	10.1				361,339
Michigan	960,380	474,650	64.7	911,300	455,650	33.4	437,170	218,585	14.2	108,569
Minnesota	1,411,025	710,872	189.7	1,062,233	533,924	104.6	414,504	192,344	39.8	128,837
Mississippi	712,594	356,297	33.2	1,181,867	547,275	52.8	377,200	130,024	19.6	176,619
Missouri	364,178	180,434	42.9	912,206	438,515	95.4	260,942	100,486	41.0	534,181
Montana	377,420	214,407	58.5	241,662	137,374	23.7	45,312	25,764	11.8	551,659
Nebraska	326,809	164,896	40.7	497,029	253,128	60.1	53,654	26,827	22.5	334,621
Nevada	224,935	194,692	24.1	92,413	60,816	4.6	99,973	79,290	4.5	3,198
New Hampshire	152,914	75,436	4.7	237,331	95,284	3.6				91,572
New Jersey	330,780	165,310	5.6	540,902	287,910	16.0	82,910	41,455	1.8	353,335
New Mexico	408,981	255,920	42.6	346,212	223,860	20.2				12,907
New York	967,602	480,644	28.8	894,946	465,214	14.3	490,066	206,533	1.5	300,660
North Carolina	224,260	112,130	23.2	643,577	354,343	48.0	69,820	20,000	5.0	259,761
North Dakota	29,802	15,664	2.4	3,434	3,434		808,050	793,360	42.7	496,795
Ohio	1,669,162	833,445	56.1	835,150	490,545	11.2	177,160	88,580	6.7	771,575
Oklahoma	336,340	177,384	19.2	91,422	48,270	12.4	903,706	477,157	64.2	685,266
Oregon	463,457	243,324	41.8	459,611	217,324	28.5	30,482	18,000	1.3	115,964
Pennsylvania	1,110,416	554,650	21.3	1,397,243	688,113	26.7	73,588	36,794	1.8	54,611
Rhode Island	220,879	111,427	2.6	14,694	10,697					53,098
South Carolina	461,656	170,066	44.9	539,900	214,224	10.2				165,627
South Dakota	32,130	13,006	15.2	3,622	3,622		1,143,430	1,047,600	114.5	490,587
Tennessee	333,033	164,824	10.8	1,430,720	715,360	48.5	190,926	95,463	5.3	405,325
Texas	908,673	439,508	101.5	890,849	430,390	73.5	295,100	144,000	25.0	1,134,698
Utah	186,949	123,240	17.0	136,491	75,150	3.5	23,035	15,255	3.3	151,695
Vermont	36,231	18,109	1.2	180,204	59,279	7.8	46,514	23,257	1.1	3,059
Virginia	373,448	174,585	15.8	346,346	154,866	4.4	157,496	74,348	6.6	308,679
Washington	246,653	129,505	17.8	484,988	242,414	13.7				135,778
West Virginia	310,300	155,150	15.5	419,833	211,483	10.7				309,250
Wisconsin	775,206	387,779	38.0	1,700,988	756,743	52.7	76,438	37,300	.8	139,427
Wyoming	360,882	155,250	18.8	511,240	220,929	34.3				2,582
District of Columbia	80,772	39,924	.9	2,558	1,279					76,120
Hawaii				2,375	2,375					249,562
Puerto Rico	105,633	51,430	6.4	125,732	61,425	4.2				134,883
TOTALS	23,053,435	11,365,682	1,531.5	29,831,565	14,797,239	1,417.6	9,665,968	5,441,000	682.8	13,649,478

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF DECEMBER 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR		NUMBER			UNDER CONSTRUCTION		NUMBER			APPROVED FOR CONSTRUCTION		NUMBER			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 109,856	$ 109,336	1	3	2	$ 385,225	$ 383,203	6	2	1	$ 92,335	$ 92,335	2	1	6	$ 724,600
Arizona						309,635	300,914	1	2		13,255	13,255			2	104,698
Arkansas	454,715	454,386	5		1	169,639	167,929	1		1	31,907	31,907			11	317,203
California	603,990	418,274	2		3	1,095,774	1,089,801	8	1		15,678	15,678			5	1,521,783
Colorado	5,685	5,646				664,333	664,333	7			21,042	21,042			10	474,875
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		352,566
Delaware	4,380	4,380			1	278,423	276,691	2	1		508.406	321,785	2			76,604
Florida	92,071	92,071			15	736,439	734,259	8		6	206,346	206,285			19	582,765
Georgia	542,535	542,535	7	1	2	932,235	932,235	5	7	9	971,699	971,699	3	4	18	1,015,930
Idaho	20,101	17,938			2	325,915	317,214	4	1		6,212	6,212			3	261,709
Illinois	184,459	151,541			75	2,159,432	1,976,197	10	1	12	428,734	409,784	1	1	39	1,543,628
Indiana	432,063	419,575	5		17	583,089	583,089	3	1	8	153,096	147,387			39	661,911
Iowa	267,775	256,314	2	1	19	1,499,690	1,245,433	11	2	12	210,352	208,780			55	121,406
Kansas	56,455	56,351	2		3	679,037	678,722	8		3	220,939	177,369	4		11	871,550
Kentucky	1,049,147	1,047,601	8		1	512,092	512,092	5	1							38,903
Louisiana	6,965	6,965				586,220	586,220	8			481,835	480,667	4		4	596,832
Maine						363,086	363,086	2			8,680	8,680			3	154,353
Maryland	488,250	456,457	2	2	10	865,387	721,589	4		4	48,775	48,775			8	205,511
Massachusetts	346,270	335,829	1		1	774,431	773,559	5	2		763,830	763,830	2	1		878,903
Michigan	424,192	417,632		1	9	1,126,450	1,126,450	4	3	11	343,780	313,619	1		15	675,026
Minnesota	532,379	532,063	5	3	1	1,057,043	1,057,043	5	5		76,445	76,445		1	8	667,384
Mississippi	209,275	209,275	2		1	879,809	879,809	10	1	6	33,708	33,708			5	324,141
Missouri	120,702	120,702		2		1,922,921	1,467,501	6	2		430,255	328,565	2	2		1,045,891
Montana	141,549	141,549	2		2	99,778	99,778	1								470,663
Nebraska	169,663	169,298		1	17	1,172,608	1,172,608	23		4	18,863	18,863			5	112,840
Nevada	119,580	119,580	2			56,484	56,484	2			30,725	30,725			10	95,099
New Hampshire	207,015	199,138	4		2	162,506	162,181	2	2	3						216,308
New Jersey	814,982	814,982	4	1	1	659,433	533,883	3	1	1	354,985	295,560	1	2		549,223
New Mexico						68,342	68,342	1			259,103	252,068	3		1	344,507
New York	2,200,333	2,1[illegible]9,097	2	12		2,206,396	2,062,557	3	9		502,645	464,285		1		2,446,276
North Carolina	439,955	439,955	2	4	23	239,656	236,778		3	1	326,223	326,223	3	1	21	718,717
North Dakota	174,472	173,937	4			600,080	587,143	6			223,120	223,120	2			339,679
Ohio	1,209,529	1,204,314	6	1	5	2,586,052	2,505,440	10		2	917,290	460,050	3		6	882,428
Oklahoma	167,513	163,718	1		26	840,346	83[illegible],936	6		3	386,134	348,092	3		10	1,103,238
Oregon	419,536	355,255	4		3	13,187	13,187	1			192,766	177,018	1		2	214,101
Pennsylvania	1,275,304	1,274,976	11	1		3,632,907	3,587,997	17			359,074	359,074	2			1,346,963
Rhode Island	205,241	205,241		1		3,655	3,655									176,421
South Carolina	236,402	223,069	3		17	288,478	286,178	4	3	1	307,525	173,851	2	2	13	679,032
South Dakota	377,963	377,963	10		8	647,422	631,472	12		1	41,200	41,200	2			577,780
Tennessee	301,580	289,686	3	3		1,107,220	1,107,220	6			339,126	339,126	1	2	2	604,287
Texas	935,706	923,173	12			1,660,677	1,648,143	16		2	180,375	168,650	2		3	1,197,994
Utah	44,855	44,113	2		14	80,738	80,738	1		13	62,710	62,710			24	229,677
Vermont	18,683	18,671			4	322,869	293,090	2								6,320
Virginia	92,292	92,292		2		778,475	758,515	6	3	1	42,541	42,541	1		4	576,948
Washington	170,788	170,788	1	2	1	222,305	222,305	2		1	967,919	347,919	6		3	132,372
West Virginia	247,260	241,640	3		6	654,982	654,982	6	1		8,730	8,730			3	512,287
Wisconsin	446,056	417,061	2		31	585,405	584,417	3	2	12	26,870	26,870			5	1,180,235
Wyoming	477,151	477,150	5			7,994	7,994			1	8,416	8,416			6	281,495
District of Columbia	2,193	2,193				1,462	1,462				298,213	273,744		1		5,851
Hawaii	187,618	187,618	2			214,170	213,655	2								185,256
Puerto Rico	103,629	102,980	1			639,339	632,516	9			141,279	140,190	2			198,408
TOTALS	17,304,335	16,819,723	130	41	323	37,520,983	35,947,761	267	57	119	11,294,515	9,489,572	55	20	379	28,602,577

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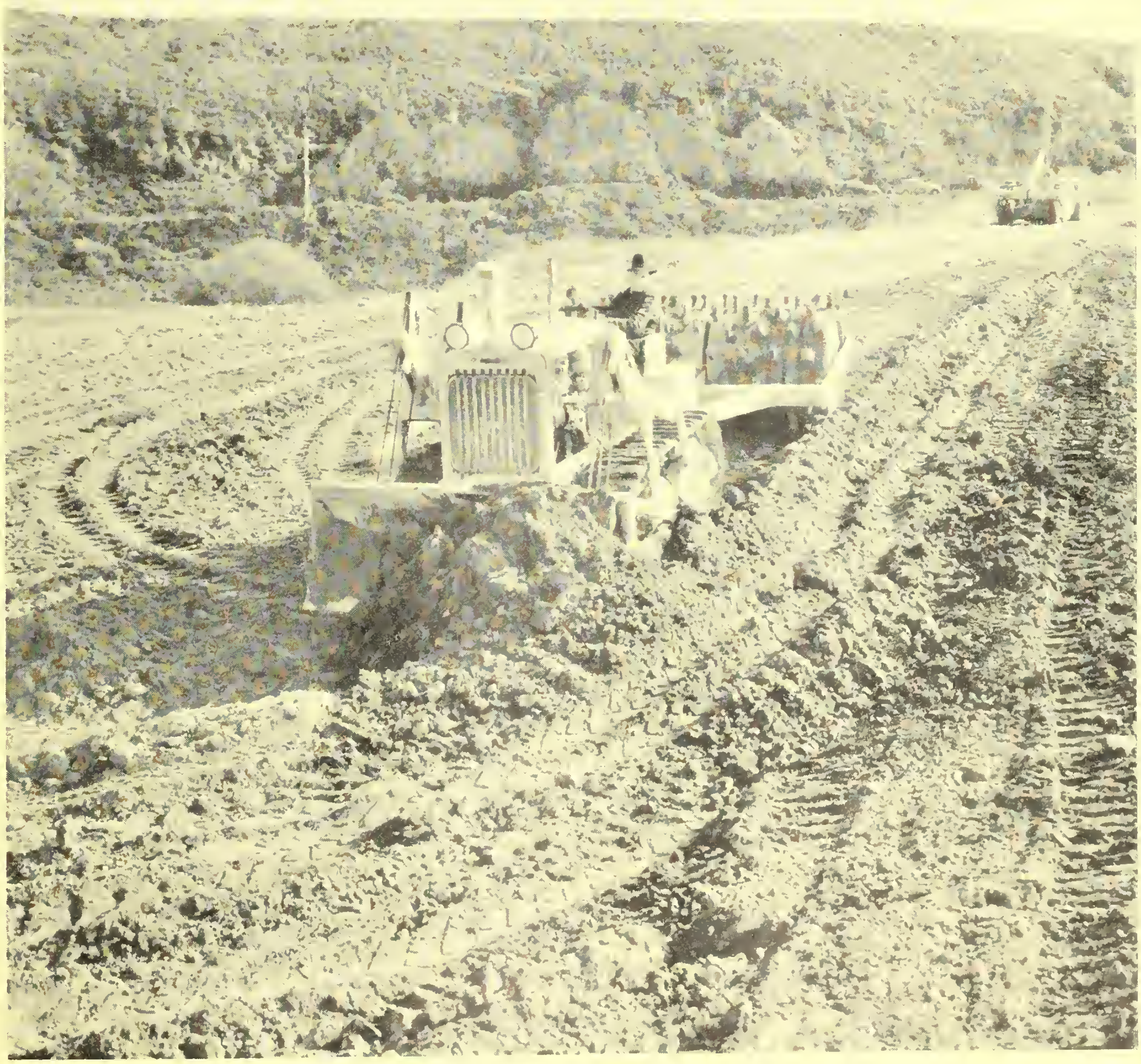

SPREADING AND COMPACTING SOIL IN A HIGHWAY FILL

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

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PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 12 February 1942

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CLASSIFICATION OF SOILS AND CONTROL PROCEDURES USED IN CONSTRUCTION OF EMBANKMENTS

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by HAROLD ALLEN, Materials Engineer

Methods of testing soils and the use of the test results in a classification system were presented in the June and July 1931 issues of PUBLIC ROADS. Desirable changes in the system have been developed through wide usage by highway engineers. The revised methods of testing and the simplified classification system reported are based on these developments.

The standard method of test for the determination of the relationship of soil moisture and density is described. The use of the results obtained by this testing procedure in soil classification and in the construction of embankments is discussed.

Construction methods used in the control of water content and compaction of soil are described. Testing procedures designed for field use in checking soil moisture and density are reported.

THE PURPOSE of this report is to present a revised and simplified version of soil identification and classification and to describe the field testing procedures which have been used successfully for the control of the work in the building of embankments. The method of soil grouping and classification, originally devised by the Public Roads Administration, has been widely used throughout the United States. A complete analysis of the original soil grouping and its application was published in the June and July 1931 issues of PUBLIC ROADS.[1]

The test procedures used for the determination of soil characteristics are A. A. S. H. O.[2] and A. S. T. M.[3] standards and complete details may be obtained from the publications of these organizations.

The physical properties of soil and the tests upon which they are based are outlined briefly as follows:

Mechanical analysis (*MA*)	Grain size.
Liquid limit (*LL*)	Plasticity.
Plastic limit (*PL*)	
Plasticity index (*PI*)	
Shrinkage limit (*SL*)	Volume change.
Shrinkage ratio (*SR*)	
Lineal shrinkage (*LS*)	
Field moisture equivalent (*FME*).	Moisture capacity of soils.
Centrifuge moisture equivalent (*CME*).	Resistance to flow of water.

Mechanical analysis.—The mechanical analysis of soils determines the size and grading of the particles. The grain sizes of the particles retained on a No. 200 sieve are determined by sieve analyses. The sizes of the soil particles passing a No. 200 sieve are determined by hydrometer analyses.

The hydrometer method of grain-size analysis is based upon the fact that particles of equal specific gravity settle in water at a rate which is proportional to the size of the particle (Stokes' law).

The hydrometer analysis is made by dispersing an air-dry sample, passing the No. 10 sieve, in water by means of a mechanical disperser such as a milkshake mixer. The soil-water mixture is placed in a liter graduate and water added to increase the volume of the suspension to 1,000 cubic centimeters. The weight of soil in suspension, expressed in grams, is determined by reading a hydrometer (Bouyoucos type) suspended in the soil-water mixture. The readings are taken at intervals of 1, 2, 5, 15, 30, 60, 250, and 1,440 minutes, and are used to calculate the grain size and percentage of each grain size in the sample. The sediment in the test cylinder is washed over a No. 200 sieve after the last hydrometer reading has been taken, dried and sieved with No. 20, 40, 60, and 140 sieves and the accumulative percentages passing each sieve are recorded.

A grain diameter accumulation curve is shown in figure 1.

The results, read from the accumulation curve, are usually reported as follows:

	Percent
Particles larger than 2 millimeters (No. 10 sieve)	
Coarse sand, 2.0 millimeters to 0.25 millimeter (No. 60 sieve)	
Fine sand, 0.25 to 0.05 millimeter (No. 270 sieve)	
Silt, 0.05 to 0.005 millimeter	
Clay, smaller than 0.005 millimeter	
Colloids, smaller than 0.001 millimeter	

All of the soil tests used for identification, except mechanical analysis, are made upon the portion of air-dried soil passing the No. 40 sieve.

SOIL TEST PROCEDURES DESCRIBED

Liquid limit.—The liquid limit is defined as that moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil will just begin to flow when jarred slightly. According to this definition, soils at the liquid limit have a very small but definite shear resistance which may be overcome by the application of little force. At the liquid limit the cohesion in the soil is practically zero.

The nature of the liquid-limit test is indicated in figure 2. The soil sample is placed in a porcelain evaporating dish about 4½ inches in diameter, shaped into a smooth layer about ⅜ inch thick at the center and divided into two portions by means of a grooving tool of standard dimensions (fig. 3). The dish is held firmly in one hand and tapped lightly 10 times against the heel of the other hand. If the lower edges of the 2 soil portions do not flow together, as shown in the lower part of figure 2, the moisture content is below the liquid limit. If they flow together before 10 blows have been struck, the moisture content is above the liquid limit.

[1] These issues are out of print but can be obtained at many public or college libraries.

[2] Standard Specifications for Highway Materials and Methods of Sampling and Testing, published by the American Association of State Highway Officials, 1220 National Press Building, Washington, D. C.

[3] A. S. T. M. Standards, Part II, published by the American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa.

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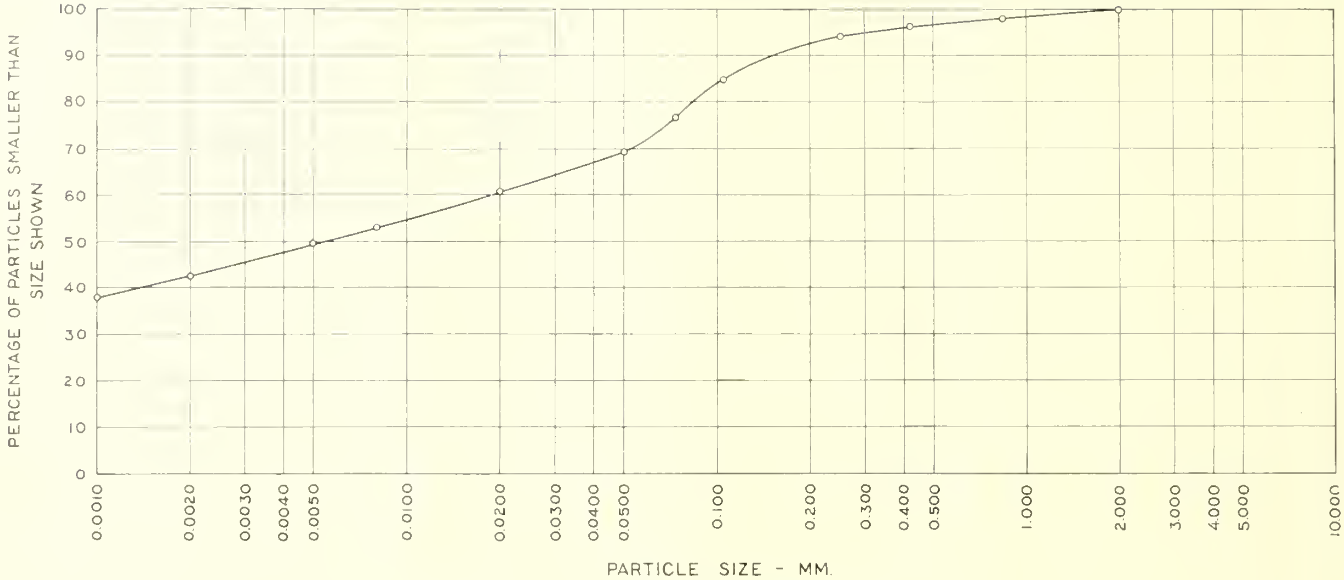


FIGURE 1.—GRAIN-SIZE ACCUMULATION CURVE.

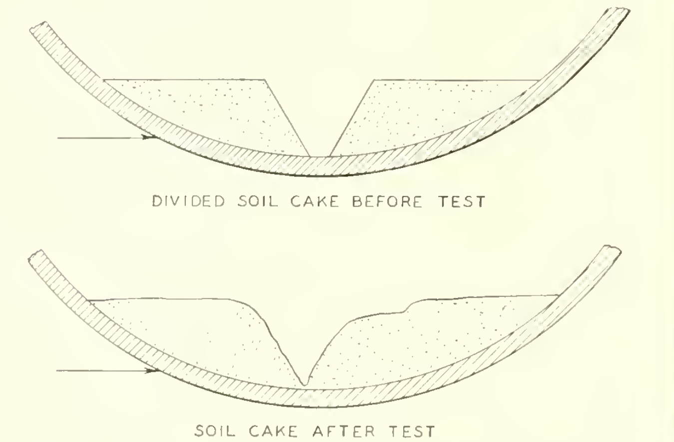


FIGURE 2.—PHENOMENON OCCURRING DURING LIQUID LIMIT TEST.

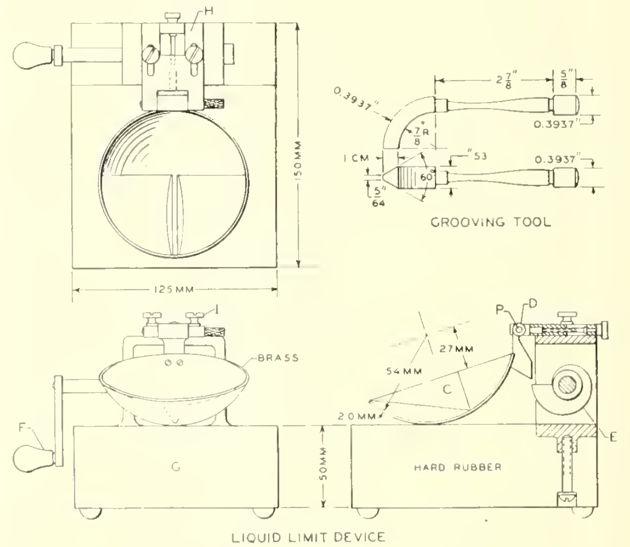


FIGURE 3.—LIQUID LIMIT DEVICE.

The test is repeated with more or less moisture, as the case may be, until the 2 edges meet exactly after 10 blows have been struck. The arrows indicate the direction of the blow on the dish.

A mechanical device which is calibrated against the hand method described above is used in most laboratories. The details of the device are shown in figure 3. In using the device, the soil mixed with water is placed in the brass cup, shaped into a smooth layer, and grooved in a manner similar to that described for the hand method. The cup is then attached to the carriage of the machine and dropped through a distance of 1 centimeter a sufficient number of times to close the groove. This process is repeated for several moisture contents. The object of the procedure is to obtain samples of such consistency that the number of drops or shocks of the cup required to close the groove will be both below and above 25. A "flow curve" is plotted on semilog graph paper using the moisture contents as abscissae on the arithmetic scale and the number of shocks as ordinates on the logarithmic scale. The moisture content corresponding to the intersection of the flow curve with the 25 shock ordinate is the liquid limit of the soil.

The liquid limits obtained by an operator of average experience and skill, using both methods, should check closely for identical soil samples.

Plastic limit.—The plastic limit is defined as the lowest moisture content, expressed as a percentage by weight of the oven dry soil, at which the soil can be rolled into threads ⅛ inch in diameter without breaking into pieces. Soil which cannot be rolled into threads at any moisture content is considered nonplastic.

Figure 4 shows the nature of the test for the determination of the plastic limit. The sample shown at the top of the figure, having a moisture content above the plastic limit, can be rolled into threads ⅛ inch in diameter without crumbling under the pressure exerted by the hand. The lower part of the drawing shows a soil thread which has crumbled because the moisture content of the soil has been reduced by evaporation to the plastic limit or below.

The plastic limit is the moisture content at which cohesive soils pass from the semisolid to the plastic state. It is also the moisture content at which the

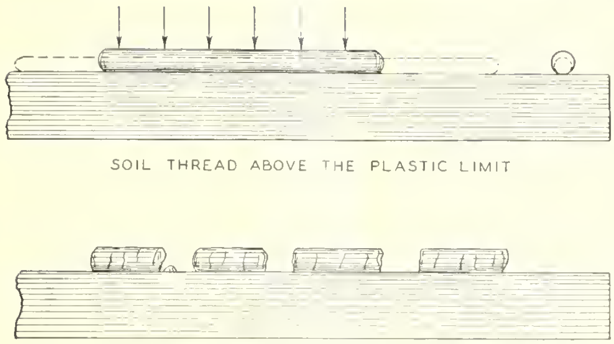


FIGURE 4.—PHENOMENON OCCURRING DURING PLASTIC LIMIT TEST.

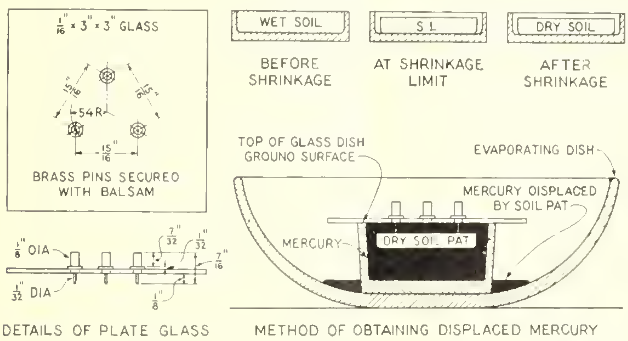


FIGURE 5.—APPARATUS FOR DETERMINING THE VOLUMETRIC CHANGE OF SUBGRADE SOILS.

coefficient of permeability of homogeneous clays becomes practically equal to zero.

Plasticity index.—The plasticity index is defined as the difference between the liquid limit and the plastic limit. It is the range of moisture content through which the soil is plastic. When the plastic limit is equal to or greater than the liquid limit, the plasticity index is reported as zero. When the plastic limit cannot be determined, the plasticity index may be designated by the letters NP (nonplastic) to indicate that the soil is entirely lacking in plasticity.

Shrinkage limit.—The shrinkage limit is defined as the moisture content, expressed as a percentage by weight of oven-dried soil, at which a reduction in moisture content will not cause a decrease in volume of the soil mass, but at which an increase in moisture content will cause an increase in volume of the soil mass. The relations of soil volumes to moisture contents at various stages in the test are illustrated in figure 5.

The shrinkage limit is a means of describing the pore space present in a soil after it has been allowed to compact itself to the maximum density obtainable (from a given moisture content) by shrinkage. It is a well defined point on the moisture content scale, marking the change from the solid to the semisolid state.

Shrinkage ratio.—The shrinkage ratio is equal to the bulk specific gravity of the dried soil pat used in obtaining the shrinkage limit. It is used in the calculation of volume change.

The volume change of soil from a given moisture content can be calculated, when the shrinkage limit and the shrinkage ratio are known, by means of the following formula:

$$VC=(w-S)R$$

in which VC=volume change;

w=moisture content;

S=shrinkage limit; and

R=shrinkage ratio.

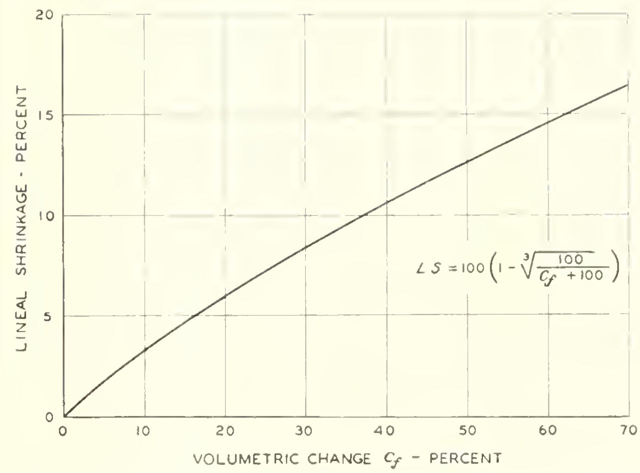


FIGURE 6.—RELATION BETWEEN VOLUME CHANGE AND LINEAL SHRINKAGE.

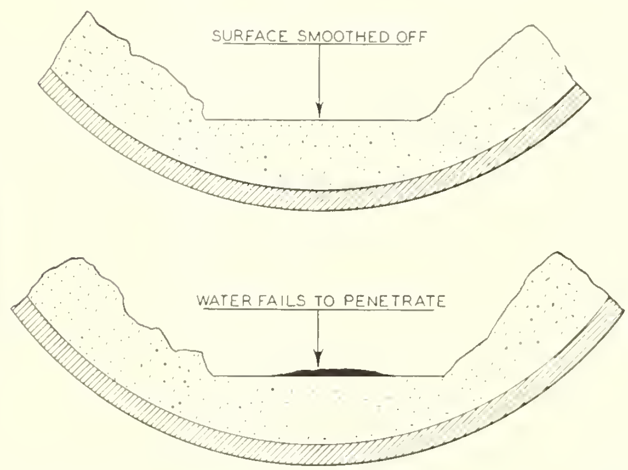


FIGURE 7.—PHENOMENON OCCURRING DURING THE FIELD MOISTURE EQUIVALENT TEST.

The most common value for w is the moisture content represented by the field moisture equivalent (FME) and, using this value, the formula is usually expressed as

$$C_f=(FME-S)R$$

in which C_f is the volume change from the field moisture equivalent.

Lineal shrinkage.—The lineal shrinkage of a soil is the decrease in a dimension of the soil mass, expressed as a percentage of the original dimension, when the moisture content is reduced from an amount equal to the field moisture equivalent to the shrinkage limit. It is usually obtained by calculation by means of the following formula:

$$LS=100\left(1-\sqrt[3]{\frac{100}{C_f+100}}\right)$$

or from the curve of figure 6.

Field moisture equivalent.—The field moisture equivalent is defined as the minimum moisture content, expressed as a percentage by weight of oven-dry soil, at which a drop of water placed on the smooth surface of the soil will not immediately be absorbed but will

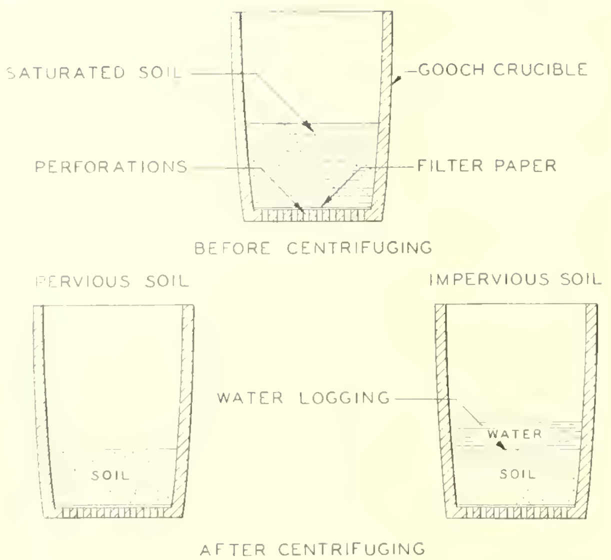


Figure 8.—Phenomenon Occurring During the Centrifuge Moisture Equivalent Test.

spread out over the surface and give it a shiny appearance. In making the test, water is mixed with the soil fraction passing the No. 40 sieve until the soil forms into balls when stirred and then in small increments until the moisture content is such that a drop of water will not penetrate the smoothed surface. This is illustrated in figure 7.

The drop of water fails to penetrate the wet and smoothed soil sample (1) when the pores of nonexpansive soils are completely filled, (2) when the capillarity of cohesionless expansive soils is completely satisfied, and (3) when cohesive soils possess moisture in amount sufficient to cause the smoothed surface of the sample to become impervious. This impervious skin may occur at moisture contents far below those required to satisfy the capillarity of cohesive soils.

Centrifuge moisture equivalent.—The centrifuge moisture equivalent is defined as the moisture content, expressed as a percentage by weight of oven-dried soil, retained by a soil which has first been saturated with water and then subjected to a force equal to 1,000 times the force of gravity for 1 hour. The test consists of first soaking a small sample of air-dried soil with water in a Gooch crucible, then draining it in a humidifier for at least 12 hours and, finally, centrifuging it for 1 hour. The effect of the centrifugal force on the soil moisture is illustrated in figure 8.

SOILS CLASSIFIED IN EIGHT GROUPS

Based upon their field performance, soils have been classified in eight groups designated as A–1 to A–8, inclusive. The results of tests made in accordance with the procedures described indicate the physical properties of soils and serve to identify them with respect to grouping. This method of classification does not eliminate possible overlapping or provide a rigid measure of soil behavior. Thus, some soils may have some of the characteristics of two groups. The engineer should learn to judge the value that different soils may have in construction, and the difficulties which may arise in their use, more upon the basis of the physical constants and their relationship than upon the fact that the soils fall in certain groups. This is illustrated by the fact that clay soils from different locations classed in the A–6 or A–7 group may have a wide range of plasticity constants and, therefore, may have different values for fill and subgrade construction. The soil classification should be used to designate general characteristics such as plasticity, permeability, bearing power, resistance to frost heave, etc.

It would be difficult to show all the soil constants in general reports or on soil maps, but the use of the eight groups gives the engineer who is not concerned with details a general picture of the soils on a project. The design and construction engineers, however, should have at their disposal the laboratory test results and should depend more upon those results in preparing specifications and plans and in placing the soils in the finished structure than upon the group classification.

Present knowledge of soil testing indicates a need for slight modification of the classification procedure as originally presented in the June and July 1931 issues of PUBLIC ROADS. The significant changes listed below are included in the simplified charts, figures 9, 10, and 11 which show the range of soil characteristics for each soil group.

1. The relations of the plasticity index to the liquid limit (see fig. 9) have been modified as follows:

a. A band instead of a single curve has been provided to define the limits of the A–6 group.

b. Keeping the origin at a value of the liquid limit equals 14 and a plasticity index equals 0, the curve separating the A–7 group from the A–5 and A–8 groups was rotated to the left slightly. At a value of the liquid limit equals 40, the relation now shows a plasticity index of 15 instead of the value of 16 shown in the original charts.

2. The minimum value of the liquid limit of the A–8 group is given as 35 instead of 45 as originally shown.

3. The maximum value of the liquid limit of the A–1 group was raised from 25 to 35 so as to include stabilized road surface materials covered by the standard A. A. S. H. O. and A. S. T. M. Specifications.

4. The symbol NP has been used for those materials for which the plastic and liquid limits cannot be obtained due to a lack of plasticity in the soil.

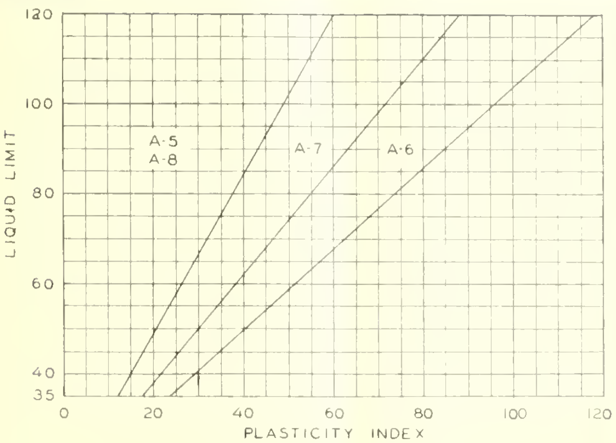
5. The liquid limit values for the A–3 group have been eliminated because the standard test procedure cannot be used on purely granular materials. As a substitute for the effective size of not less than 0.10 millimeter, 0 to 10 percent passing the No. 200 sieve has been inserted.

6. The limiting values for the centrifuge moisture equivalent for all groups except A–1, A–2, and A–3 have been omitted because experience indicates that the test values obtained are not essential for the identification of the remaining groups.

The gradings of the various soil groups, the limits within which the test values fall, and their general characteristics are outlined in the following paragraphs:

GENERAL CHARACTERISTICS OF FIRST THREE SOIL GROUPS GIVEN

Group A–1.—Soils of this group are composed of material well graded from coarse to fine, mixed with excellent binder; they are highly stable under wheel loads irrespective of moisture conditions; can be rolled to very high densities with either smooth-faced or tamping type rollers; and have practically no volume change. These materials have very high bearing capacity at high densities and function satisfactorily when used as bases for relatively thin wearing courses.



GROUP	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
COARSE MATERIAL	0-65	-o-	-o-	-o-	-o-		-o-	
SOIL MORTAR TOTAL SAND	70-85	55MIN.	-o-	55 MAXIMUM				
COARSE SAND	45-60	-o-	-o-	-o-	-o-		-o-	
SILT	10-20	-o-	-o-	-o-	-o-		-o-	
CLAY	5-10	-o-	-o-	-o-	-o-		-o-	
PERCENTAGE PASSING NO. 200 SIEVE	-o-	-o-	0-10	-o-	-o-		-o-	
LIQUID LIMIT	14-35	35MAX.	NP	20-40	35 MINIMUM			
PLASTICITY INDEX	4-9	NP-15	NP	0-15	SEE CHART ABOVE			

NOTE:- ONLY THE A-1 MATERIALS WITH VALUES OF LIQUID LIMIT NOT GREATER THAN 25 AND VALUES OF PLASTICITY INDEX NOT GREATER THAN 6 ARE SUITABLE FOR USE IN BASE COURSES FOR THIN FLEXIBLE SURFACES.

-o- NOT ESSENTIAL NP NONPLASTIC

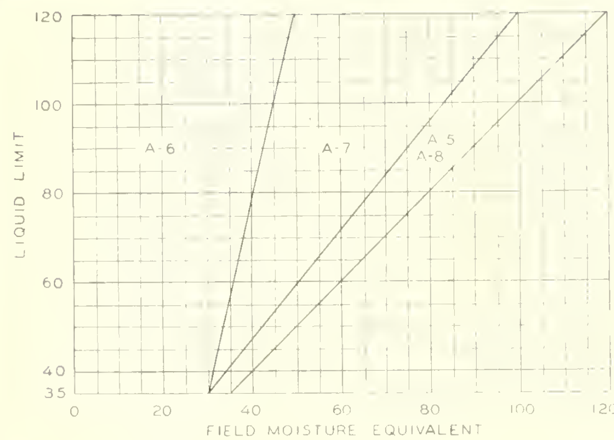
Figure 9.—Range of Soil Characteristics for Each Soil Group.

Grading: The soil mortar, that fraction passing the No. 10 sieve, should be graded as follows: Clay, 5 to 10 percent; silt, 10 to 20 percent; total sand, 70 to 85 percent; coarse sand, 45 to 60 percent.

Constants: The liquid limit is usually greater than 14 and less than 35; the plasticity index ranges from 4 to 9; the shrinkage limit from 14 to 20; the centrifuge moisture equivalent is less than 15. The field moisture equivalent is not a significant test for this type of soil.

The characteristics of this group of soils are such that the test constants fall into a rather narrow band inasmuch as small variations in grading and binder characteristics result in a soil of the A–2 group. Soils in the A–1 group do not exist over widespread areas and are usually found in relatively small deposits. When available in adequate amounts for proper thicknesses, these soils can be used as a base course for bituminous surfaces when the plasticity index does not exceed 6. They are excellent for use as blanketing materials over dry or silt soils.

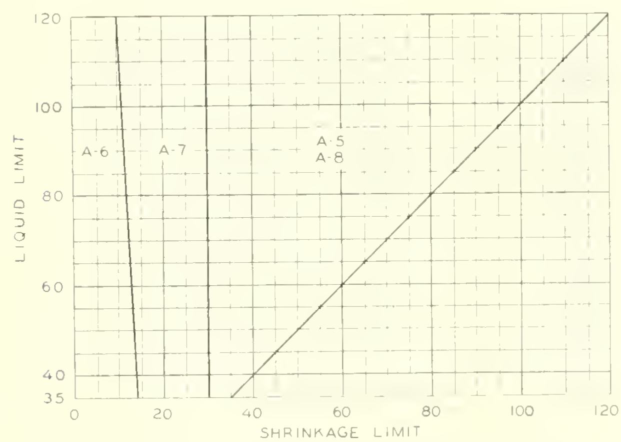
Group A–2.—The soils of this group are composed of coarse and fine materials mixed with binder but are inferior to the A–1 soils due to poor grading, inferior binder, or both. A–2 materials can be compacted with either tamping or smooth-faced rollers, the density obtainable depending upon the amount, grading, and character of the binder. In road surfaces, A–2 materials may be highly stable when fairly dry or, depending upon the amount and character of the binder, may soften during wet weather or become loose and dusty in dry periods. If used as base courses, plastic soils of this group may lose stability due to capillary saturation or lack of drainage. Some may be damaged by frost.



GROUP	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
LIQUID LIMIT	14-35	35MAX	NP	20-40	35 MINIMUM			
FIELD MOISTURE EQUIVALENT	-o-	-o-	-o-	30MAX	SEE CHART ABOVE			
CENTRIFUGE MOISTURE EQUIVALENT	15 MAX.	25 MAX	12 MAX	-o-	-o-			

-o- NOT ESSENTIAL NP NONPLASTIC

Figure 10.—Range of Soil Characteristics for Each Soil Group.



GROUP	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
LIQUID LIMIT	14-35	35MAX	NP	20-40	35 MINIMUM			
SHRINKAGE LIMIT	14-20	-o-	-o-	20-30	SEE CHART ABOVE			

-o- NOT ESSENTIAL NP NONPLASTIC

Figure 11.—Range of Soil Characteristics for Each Soil Group.

Grading: The sand content is not less than 55 percent.

Constants: The liquid limit is usually less than 35. Plasticity index may vary from NP to 15 depending upon grading and character of binder. The shrinkage limit usually does not exceed 25 and is significant only when the grading and character of the binder are considered. The centrifuge moisture equivalent does not exceed 25.

Soils falling in this group are of quite common occurrence. The group is usually divided into two parts, namely, the plastic and friable types. The friable type usually has a plasticity index ranging from NP to less than 3 and can be used as base course material for bituminous surfaces where a moisture content sufficient to insure stability can be maintained or where the material is completely confined. This type is also suitable for use as a blanketing material for very plastic subgrades over which concrete pavement is to be placed. The plasticity index of the plastic type ranges from 3 to 15. When the plasticity index of this type of soil exceeds 6, it is not suitable for use as a base for light bituminous surfacing and may cause warping of concrete pavements if large fluctuations of moisture content are likely to occur.

Soils of this group (plastic or friable) may be considered as stable if well compacted and they are satisfactory for the construction of embankments or the blanketing of the plastic or silty soils. They can be drained and may have sufficient plasticity to cause detrimental volume changes. Bituminous materials, portland cement, and other admixtures can be mixed with soils of this group with comparative ease.

Group A–3.—The soils of this group are composed entirely of coarse materials such as sand and gravel; they lack stability under wheel loads except when damp; are only slightly affected by moisture conditions; have no volume change. They cannot be compacted by rolling, but in most instances may be settled by disking and ponding. They drain rapidly and, when adequately confined, make suitable subgrades for all types of pavement.

Grading: The fraction passing the No. 200 sieve is less than 10 percent.

Constants: Soils of this group have no plasticity. The shrinkage limit and field moisture equivalent are not significant. The centrifuge moisture equivalent does not exceed 12.

A–3 soils are of common occurrence. Many of them can be stabilized successfully with bituminous materials.

SOILS OF FOURTH GROUP SUBJECT TO FROST HEAVE

Group A–4.—This group consists predominantly of silt soils containing only moderate to small amounts of coarse material and only small amounts of sticky colloidal clay. When fairly dry or damp, A–4 soils present a firm riding surface which rebounds but little upon removal of load. When water is absorbed rapidly, they may expand detrimentally or lose stability even in the absence of manipulation. They are subject to frost heave.

The soils of this group vary widely in textural composition and range from the sandy loams to silt and clay loams. A comparison of the grain-size analysis curves indicates wide variation in grading within the group.

The sandy loams can be rolled to comparatively high densities with either tamping or smooth-faced rollers and have good stability through a wider range of densities than do the silts and silt loams. They have only small volume change and do not produce severe pavement warping even though compacted in the dry state.

The silt loams and silts cannot be rolled to high densities because of the excess of voids which results from inferior grading and because of a lack of binder material. They are relatively unstable at all moisture contents but especially at the higher moisture contents when they have very low stability (low bearing capacity). Silts and some silt loams are difficult to roll because best rolling results may be obtained only through a very narrow range of moisture. Uniform compaction can be obtained on these soils by the use of smooth-faced rollers, provided the soil is neither too wet nor too dry. If the moisture content is too high or too low, "bridging" will occur with heavy smooth-faced rollers (soils will bulge up ahead and behind the roller) resulting in nonuniform compaction.

The clay loams of this group are somewhat better graded than are the silts and can be rolled to higher densities. On heavy clay loams tamping rollers have proved more effective than rollers of the smooth-faced type. The clay loams are quite stable at the lower moisture contents and higher densities but under these conditions are likely to show detrimental volume change if the moisture content is increased.

Grading: The sand content is less than 55 percent.

Constants: The liquid limit of soils in this group varies from 20 for sandy loams to 40 for clay loams. The plasticity index varies from 0 for coarse silts with no binder to 15 for clay loams. The shrinkage limit varies from 20 for the better graded sandy clay loams with good binder to 30 for silts. The centrifuge moisture equivalent (not essential for classification) varies from 12 to 50, depending upon the porosity and permeability of the soil. The field moisture equivalent does not exceed 30. When the centrifuge moisture equivalent is greater than the liquid limit, soils in this group are likely to be especially unstable in the presence of water. Group A–4 soils are likely to be highly expansive and approach the A–5 group when the field moisture equivalent exceeds the centrifuge moisture equivalent and when the shrinkage limit is greater than 25. The wide range of soils in this group extends from those which border the A–2 group to those which approach the lower limits of the A–5, A–6, and A–7 groups. The borderline soils are often designated as A–4–2, A–4–5, A–4–6, and A–4–7, indicating that they approach the latter group in characteristics, grading, and values of test constants.

Since the soils in this group are subject to frost heave, they should be covered with granular materials in areas where extremely low temperatures prevail and conditions conducive to frost heave exist. The thickness of cover required to prevent heaving varies from 18 to 48 inches.

When wet, these soils may become elastic and show considerable rebound upon removal of load.

The more plastic types in the group will expand with increases in moisture in sufficient degree to cause warping at the joints in concrete slabs if the soils are placed at moisture contents lower than the optimum.[4] Bituminous surfaces require substantial base courses when placed on subgrades consisting of any of the varieties of this group.

SOILS OF FIFTH AND SIXTH GROUPS NOT SUITABLE AS SUBGRADES FOR THIN, FLEXIBLE-TYPE BASE COURSES

Group A–5.—This group is similar to the A–4 group except that it includes very poorly graded soils which contain materials such as mica and diatoms which are productive of elastic properties and very low stability. Soils of this group are likely to be elastic and to rebound upon removal of load even when dry. Elastic properties of these soils interfere with the proper compaction of flexible-type base courses during construction and with the retention of good bond afterward.

Grading: The sand content is less than 55 percent (exceptions occur).

Constants: The liquid limit is usually greater than 35. The plasticity index usually ranges from 0 to 20 but in some cases may be as high as 60. The shrinkage limit is greater than 30 and less than 120 and usually exceeds 50 for the undesirable soils of the group. Field moisture equivalent varies from 30 to 120.

[4] See p. 270 for definition of optimum moisture content.

The soils in this group are not suitable for use as subgrades for thin stabilized base courses or bituminous surfaces. They are subject to frost heave and should be covered with granular materials when they are encountered in subgrades in areas where extreme freezing conditions prevail. They are usually difficult to compact due to their tendency to rebound upon removal of load. It has also been observed that pavements laid over subgrade soils of this group crack excessively.

Group A–6.—This group is composed of predominately clay soils with moderate to negligible amounts of coarse material. In the stiff or soft plastic state they absorb water only when manipulated. They can be compacted to relatively high densities by the use of heavy rollers and can best be compacted with tamping rollers; have good bearing capacity when compacted to maximum practical density; are compressible and rebound very little upon removal of load; are very expansive and productive of severe warping in concrete slabs if placed sufficiently dry to allow water to be absorbed in large quantities.

Grading: The sand content is less than 55 percent.

Constants: The liquid limit exceeds 35, the plasticity index is greater than 18, the shrinkage limit is less than 14, and the field moisture equivalent is less than 50.

The high plasticity indexes of the soils of this group indicate the very cohesive nature of the binder material (clay and colloids) at the lower moisture contents. The cohesion decreases as the moisture content increases. Therefore, since group A–6 soils do not possess much internal friction, they have low stabilities at the higher moisture contents. Consequently, they are suitable for use in fills and as subgrades only when they can be placed and maintained at a relatively low moisture content.

The very low shrinkage limits are indicative of high volume change. This is because any change in moisture content above the shrinkage limit is productive of a corresponding change in volume, and the range from a given moisture content to the shrinkage limit is greatest in soils of the A–6 group. The high shrinkage ratios, which are equal to the bulk specific gravities of the dried soil pats, show that the capillary pressure exerted as evaporation proceeds is of such intensity as to compress the soil particles in a very compact, dense mass. In the field, group A–6 soils are characterized by the presence of shrinkage cracks on all surfaces exposed to drying.

The value obtained in the centrifuge moisture equivalent test, which is not essential to classification, usually exceeds 25. The high values obtained and the fact that waterlogging often occurs in the test indicate that water moves very slowly through soils of the A–6 group even when under a very considerable head. Thus, these soils will take up water very slowly unless manipulated, and, conversely, once they become wet, they will dry out very slowly. The flow of gravitational water through them is negligible and, consequently, ordinary drainage installations are of little value. It should be emphasized that while the rate of flow of water through group A–6 soils is very slow, the capillary pressure which causes moisture to move from the wetter to the drier portions is very great and large forces can be developed for that reason.

Low field moisture equivalents are characteristic of compressible soils which rebound but little upon the removal of load. In the test a load is applied by means of the spatula which tends to compress and reduce the pore space on the smoothed surface. Particles of an elastic soil tend to separate and so absorb more water and have higher field moisture equivalents than the compressible soils.

Soils of the A–6 group are confined within closer limits in their general characteristics than are those of either the A–4 or A–7 group. Borderline soils are often designated as A–6–4 or A–6–7 soils.

Soils in this group are not suitable for use as subgrades under thin flexible base courses or bituminous surfaces because of the large volume changes that are caused by moisture fluctuations and the loss of bearing power upon the entrance of moisture. When concrete slabs are placed over these soils, the subgrades should be blanketed with nonexpansive materials or should be compacted to high densities at carefully controlled moisture contents. Areas immediately adjacent to the slab which are exposed to drying should be protected by covering with nonexpansive material, such as A–1 or friable A–2 soil, or other insulating material to prevent loss of moisture by evaporation from the subgrade and subsequent warping of the pavement due to reentrance of moisture.

Soils of this group occurring in subgrades for macadam or similar porous base courses should be covered with an impervious, nonexpansive material similar to soil of the A–1 or A–2 groups.

GROUP 7 SOILS TO BE USED WITH CARE; GROUP 8 SOILS TO BE AVOIDED

Group A–7.—Soils of this group are similar to those of the A–6 group except that at certain moisture contents they are elastic and deform quickly under load and rebound appreciably upon removal of load. This characteristic results from an inferior grading (steep grain-size curve through the silt fraction); from extraneous material such as organic matter, mica flakes, lime carbonate; from a variation in grain shapes or from a combination of any two or more of these causes. Alternate wetting and drying of the A–7 soils under field conditions leads to rapid and detrimental volume changes.

The soils of this group are more difficult to compact by rolling than are those of the A–6 group. Heavy tamping rollers have been found most effective for rolling A–7 soils. Soils in this group have good bearing capacities when compacted to high densities but are subject to excessive volume change unless properly compacted at a moisture content sufficiently high to insure minimum air voids. These soils have produced more severe warping of concrete slabs than have soils of other groups.

Grading: The sand content is less than 55 percent.

Constants: The liquid limit for soils of this group exceeds 35 and the plasticity index is greater than 12. The shrinkage limit may vary from 10 to 30; the field moisture equivalent may vary from 30 to 100.

The major difference between soils of the A–7 and A–6 groups is in their elasticity. This property is indicated by the higher shrinkage limit and the higher field moisture equivalent associated with soils of the A–7 group. The higher shrinkage limit may be due to poor grading or poor binder (binder which includes chalk, mica flakes, or an excess of organic matter). Similarly, the field moisture equivalent may be higher due to the higher absorption characteristics of a soil which has poor grading (considerable pore space) or which is made up of the constituents mentioned above.

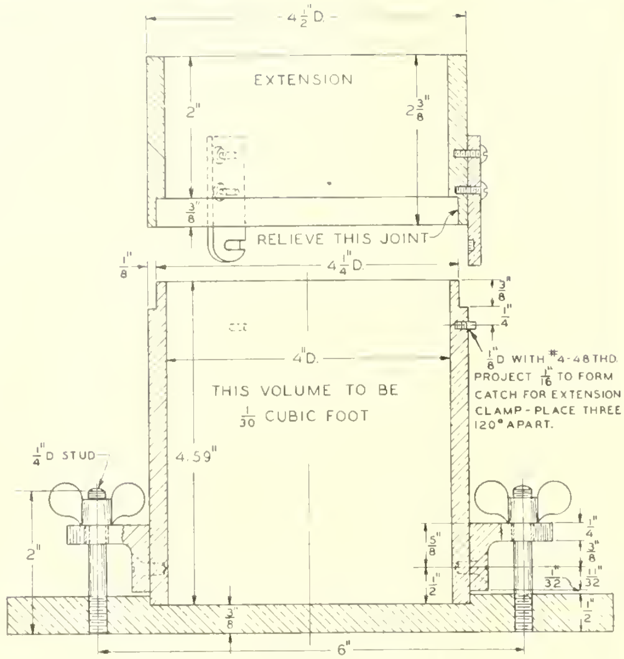


Figure 12.—Compaction Mold.

Like the A–4 group, the A–7 group constitutes a wide range of soils varying in characteristics from those bordering on the A–4 and A–5 groups of silts and loams and the A–6 group of clays to those approaching the lower limits of the A–8 group, which contain excessive organic material. Such borderline soils are often designated as A–7–4, A–7–5, A–7–6, and A–7–8 indicating similarities to the latter groups.

Since the soils in this group are even more expansive than those of the A–6 group, the same precautions in their use should be observed. Due to their elasticity and tendency to rebound, they should be compacted with great care when used as subgrades for concrete slabs, and should not be subjected to excessive loading immediately ahead of paving, if early cracking of the slab due to the force exerted by the rebounding soils is to be avoided.

In areas where low temperatures prevail, the soils in this group should be regarded with suspicion because some of them are subject to frost heave.

Group A–8.—The soils in this group are composed of very soft peat and muck. They contain excessive quantities of organic matter and moisture. They are obviously unsuitable for use in subgrades or embankments.

Grading: The grading is not significant.

Constants: The liquid limit ranges from 35 to 400, the plasticity index from 0 to 60 and is usually less than 25, the shrinkage limit varies from 30 to 120, and the field moisture equivalent from 30 to 400.

The high shrinkage limits and high field moisture equivalents are indicative of the presence of partly decomposed organic matter. The tendency to contain capillary moisture in large amounts far above the water table makes these soils unsatisfactory for use as foundation soils for embankments. Their use in any type of construction should be avoided whenever possible.

In addition to the results of the indicator tests already described, the density-moisture relations of soils in the compacted state are indicative of their value for embankment construction and as foundation materials. Under a fixed set of test conditions each soil has a maximum weight per unit of volume at one moisture content which is known as the optimum moisture content. The maximum dry weight varies with the soil type, being highest for granular well-graded soils in the A–1 group

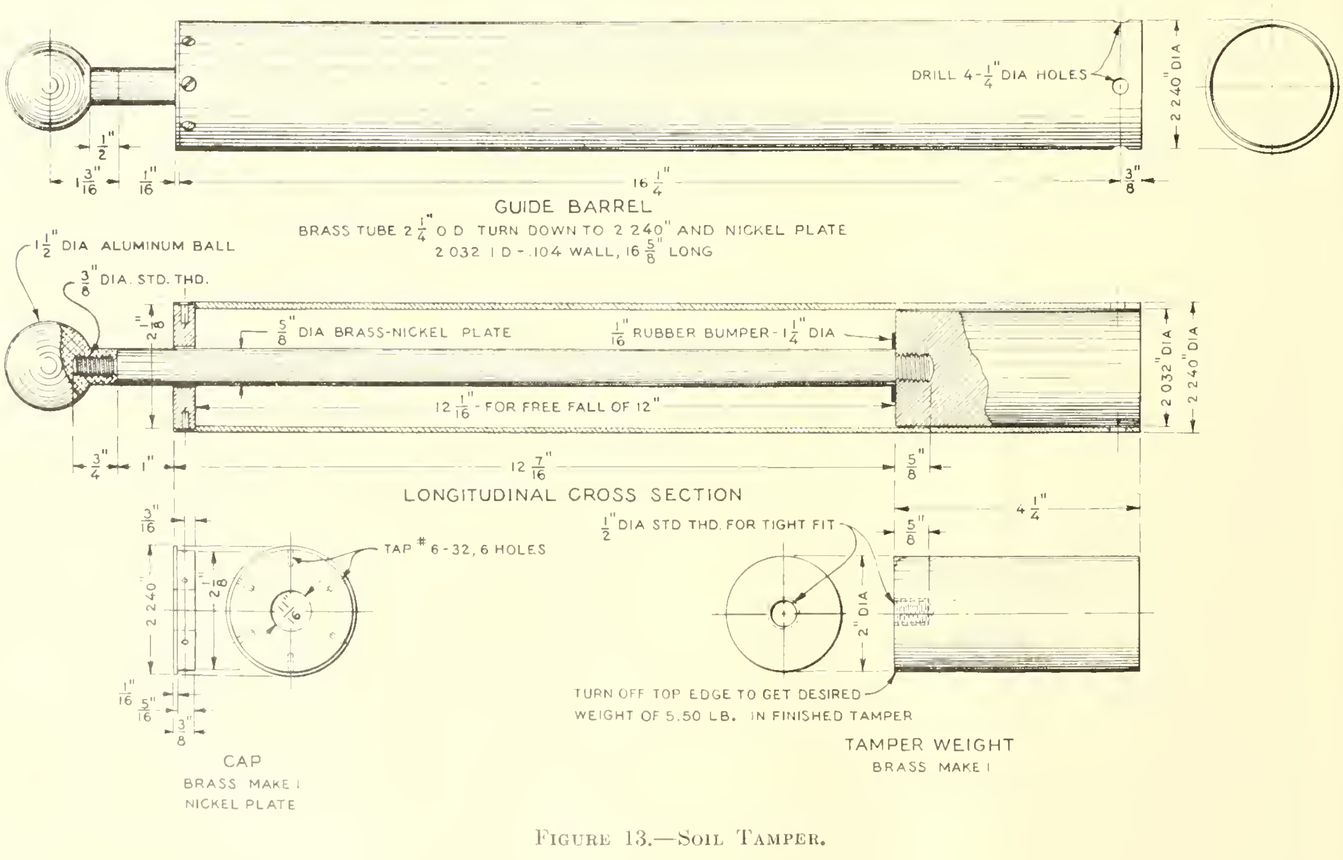


Figure 13.—Soil Tamper.

and decreasing to a minimum for soils in the A–5, A–6, A–7, or A–8 groups. In addition to the relation between density and moisture, a procedure has been developed for obtaining the relation of the moisture content and the resistance to penetration of a needle forced into the compacted soil under fixed conditions.

STANDARD COMPACTION TEST APPARATUS AND PROCEDURE DESCRIBED

The method of test for determination of the moisture-density and moisture-penetration relations is designated as the "standard compaction test" and is conducted in accordance with the following procedure.

The apparatus used shall consist of the following:

1. A cylindrical metal mold approximately 4 inches in diameter and 4½ inches high and having a cubical content of 1/30 cubic foot. This mold is fitted with a detachable base plate and a removable extension approximately 2½ inches high. (See fig. 12.)
2. A metal tamper having a striking face 2 inches in diameter and weighing 5½ pounds. (See fig. 13.)
3. A steel straightedge about 10 inches long.
4. A penetrometer to register the force required to cause the penetration of needles of known end area. (See fig. 14.)
5. A scale of 30 pounds capacity sensitive to ½ ounce.
6. A balance of 100 grams capacity sensitive to 0.1 gram.
7. Porcelain evaporating dishes.
8. Oven for drying soil samples.

The procedure is as follows:

A 6-pound sample, air dried to slightly damp, is taken from a portion of the material passing the No. 4 sieve.

The sample is thoroughly mixed and then compacted in the cylinder (with the extension attached) in three equal layers, each layer receiving 25 blows from the tamper dropped from a height of 1 foot above the soil. The extension is then removed. The compacted soil is carefully leveled off to the top of the cylinder with the straightedge and weighed. The weight of the compacted sample and cylinder, minus the weight of the cylinder, is multiplied by 30 and the result recorded as the wet weight per cubic foot of the compacted soil.

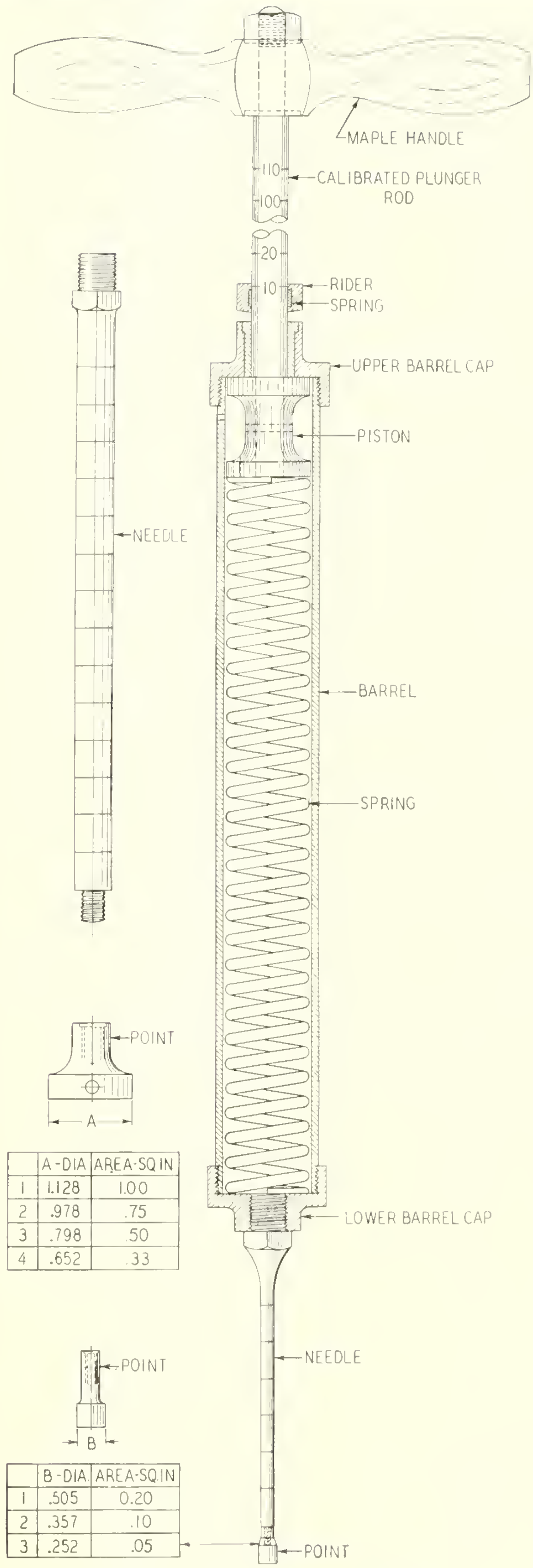
The compacted sample is tested with the penetrometer (fig. 14) and the resistance to forcing the needle into the soil at the rate of ½ inch per second to a depth of 3 inches is recorded. When the material is granular enough to interfere with the uniform penetration of the needle, the penetrometer test cannot be made.

A small sample of the compacted soil is oven dried to determine the moisture content.

The soil is removed from the cylinder and broken up until it will pass a No. 4 sieve. Water in sufficient amounts to increase the moisture content of the soil sample by increments of approximately 1 percent is added and the above procedure repeated for each increment of water added. This series of determinations is continued until the soil becomes very wet and there is a substantial decrease in the wet weight of the compacted soil.

The moisture content (percent by weight of dried soil) of the oven-dried sample is computed from the formula

$$100\times\frac{\text{weight of dish and wet soil}-\text{weight of dish and dried soil}}{\text{weight of dish and dried soil}-\text{weight of dish}}$$



	A-DIA	AREA-SQ IN
1	1.128	1.00
2	.978	.75
3	.798	.50
4	.652	.33

	B-DIA	AREA-SQ IN
1	.505	0.20
2	.357	.10
3	.252	.05

FIGURE 14.—SOIL PENETROMETER.

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The dry weight per cubic foot of compacted soil is computed from the formula

$$\frac{\text{wet weight per cubic foot}}{1+\frac{\text{percent moisture}}{100}}$$

MOISTURE-DENSITY CURVES USEFUL

Curves showing the relations of the moisture contents to the wet and dry densities of the compacted soil, expressed in pounds per cubic foot, and the penetrometer readings, expressed in pounds per square inch, may then be drawn on rectangular coordinate paper to such a scale as to permit reading the moisture contents to 0.2 percent. The peak of the moisture-density curve represents the maximum density for the soil tested and the percentage of water at this point represents the moisture content necessary for maximum compaction. The curves are used in classification and for control during construction.

The above procedure is designed to be used in laboratories where the facilities and time are adequate to permit the breaking down of the soil cylinder for the addition of each increment of moisture. In field laboratories the use of a separate sample for each increment of moisture has proved satisfactory. The samples should be prepared by breaking down approximately 40 pounds of soil from the borrow pit or fill to pass a No. 4 sieve, and drying or adding moisture to make the soil slightly damp. About 5 pounds of the soil thus prepared should be tested in accordance with the procedure described above. The procedure should be repeated by adding enough water so that the moisture content of each successive sample will be about 1 percent greater than the previous one.

The test data for a typical compaction test are shown in table 1. The wet and dry density and penetration curves are shown in figure 15.

The dry weight per cubic foot of soil as determined by the method described above is indicative of the suitability of the material for use in embankments and subgrades. With few exceptions the weight per cubic foot of soil determined by this method varies from 80 to 130 pounds. The granular materials, such as the well graded A–1 or A–2 soils, have the higher weights, and the highly plastic clays or muck soils (A–6, A–7 or A–8) will be at the lower end of the scale.

The Public Roads group classification, the rating for use in embankment construction on the basis of dry weight per cubic foot, the required compaction during construction, and the required thickness of sub-base, base, and surfacing, are included in the general summary of soil characteristics and classification shown in table 2.

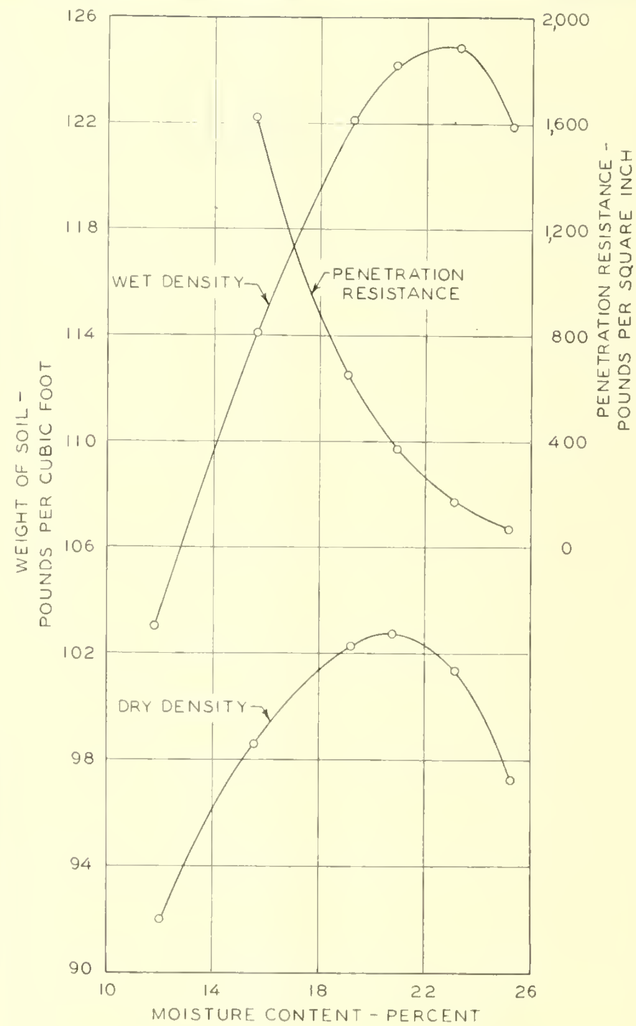


FIGURE 15.—DENSITY AND PENETRATION CURVES.

The approximate grading limits shown in this table will serve as a guide in the visualizing of the textural characteristics of the various soils and, except for those falling in the A–1 group, are not essential to classification.

The required compaction during construction, the procedures for obtaining it, and the methods of testing soil in place will be discussed later.

The rating of soils in table 2 is intended as a guide

TABLE 1.—*Compaction test data*

Weight of compacted sample [1] (pounds)	Wet weight of sample	Penetration test			Moisture determination							Dry weight of soil
		Needle		Pressure	Dish No.	Wet weight	Dry weight	Water weight	Dish weight	Soil weight	Water	
		Size	Reading									
	Pounds per cubic foot	*Square inch*	*Pounds*	*Pounds per square inch*		*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*	*Pounds per cubic foot*
3.433	103.0	1/20	[2] 100	[2] 2,000	1	85.08	79.34	5.74	30.72	48.62	11.8	92.1
3.803	114.1	1/20	81	1,620	2	87.47	80.45	7.02	35.55	44.90	15.6	98.7
4.070	122.1	1/20	33	660	3	90.77	81.71	9.06	34.60	47.11	19.2	102.4
4.140	124.2	1/20	19	380	4	89.99	81.46	8.53	40.51	40.95	20.8	102.8
4.161	124.8	1/20	9	180	5	88.53	79.00	9.53	37.96	41.04	23.2	101.3
4.063	121.9	1/20	4	80	6	84.83	75.58	9.25	38.80	36.78	25.2	97.3

[1] Maximum density 102.8 pounds per cubic foot; optimum moisture 20.8 percent.
[2] Greater than capacity of apparatus.

and not as a specification requirement. For example, if a soil weighing 100 to 110 pounds per cubic foot, which is classified as poor or very poor, is the only one available for the construction of an embankment, this classification should be interpreted to mean that the design of the embankment should be given special consideration, and that the soil should be compacted above the minimum requirements during construction.

The curves and data of figures 16 and 17 show the moisture-density and grain-size accumulation curves for typical soils from each of the groups except A–1 and A–8. Curves for samples of two soils classified in the A–2, A–3, A–4, and A–6 groups are shown in order to demonstrate the variation which may exist in soils having the same classification.

THICKNESSES OF SUB-BASE, BASE COURSE, AND SURFACE DEPEND ON SEVERAL FACTORS

Since the results of indicator tests have been correlated with the service behavior of soils in highway construction, it is possible to estimate the required combined thickness of sub-base, base course, and surfacing required for any type of soil. This information is shown in the last line of table 2 and represents the maximum and minimum thickness of sub-base and pavement (base course and surfacing) required for each soil type. These thicknesses were arrived at by observation and not by laboratory or field test or other purely scientific approach. The values, however, are the result of the experience of many engineers concerned with the successful use of soil materials and may be used with confidence.

The combined thickness of the sub-base composed of selected material, base course, and surfacing for each soil type, as shown in table 2, will vary with variations in the soil constants, in degree of compaction obtained, in the climatic conditions, and in the natural soil moisture. For example, a soil of the A–6 group with a plasticity index of 20 and a natural moisture content of 18 percent will require less cover than an A–6 soil with a plasticity index of 50 and a natural moisture content of 30 percent. When used in a dry climate and where the distance to ground water is great, the first soil (plasticity index of 20) will require less cover than where the ground

TABLE 2.—*Summary of soil characteristics and classification*

Group	A–1	A–2 Friable	A–2 Plastic	A–3	A–4	A–5	A–6	A–7	A–8
General stability properties.	Highly stable at all times.	Stable when dry; may ravel.	Good stable material.	Ideal support when confined.	Satisfactory when dry; loss of stability when wet or by frost action.	Difficult to compact; stability doubtful.	Good stability when properly compacted.	Good stability when properly compacted.	Incapable of support.
Physical constants:									
Internal friction	High	High	High	High	Variable	Variable	Low	Low	Low.
Cohesion	do	Low	do	None	do	Low	High	High	Do.
Shrinkage	Not detrimental.	Not significant.	Detrimental when poorly graded.	Not significant.	do	Variable	Detrimental	Detrimental	Detrimental.
Expansion	None	None	Some	Slight	do	High	High	do	Do.
Capillarity	do	do	do	do	Detrimental	do	do	High	Do.
Elasticity	do	do	do	None	Variable	Detrimental	None	do	Do.
Textural classification:									
General grading	Uniformly graded; coarse-fine excellent binder.	Poor grading; poor binder.	Poor grading; inferior biuder.	Coarse material only; no binder.	Fine sand cohesionless silt and friable clay.	Micaceous and diatomaceous.	Deflocculated cohesive clays.	Drainable flocculated clays.	Peat and muck.
Approximate limits:									
Sand ...percent	70–85	55–80	55–80	75–100	55 (maximum)	55 (maximum)	55 (maximum)	55 (maximum)	55 (maximum).
Silt ...do	10–20	0–45	0–45	(1)	High	Medium	Medium	Medium	Not significant
Clay ...do	5–10	0–45	0–45	(1)	Low	Low	30 (minimum)	30 (minimum)	Do.
Physical characteristics:									
Liquid limit	14–35 [2]	35 (maximum).	35 (maximum).	NP [3]	20–40	35 (minimum)	35 (minimum)	35 (minimum)	35–400.
Plasticity index	4–9 [2]	NP–3 [3]	3–15	NP [3]	0–15	C–60	18 (minimum)	12 (minimum)	0–60.
Field moisture equivalent.	Not essential	Not essential	Not essential	Not essential	30 (maximum)	30–120	50 (maximum)	30–100	30–400.
Centrifuge moisture equivalent.	15 (maximum).	12–25	25 (maximum)	12 (maximum).	Not essential	Not essential	Not essential	Not essential	Not essential.
Shrinkage limit	14–20	15–25	25 (maximum)	Not essential	20–30	30–120	6–14	10–30	30 120.
Shrinkage ratio	1.7–1.9	1.7–1.9	1.7–1.9	do	1.5–1.7	0.7–1.5	1.7–2.0	1.7–2.0	0.3–1.4.
Volume change	0–10	0–6	0–16	Noue	0–16	0–16	17 (minimum)	17 (minimum)	4–200.
Lineal shrinkage	0–3	0–2	0–4	do	0–4	0–4	5 (minimum)	5 (minimum)	1–30.
Compaction characteristics:									
Maximum dry weight, pounds per cubic foot.	130 (minimum).	120–130	120–130	120–130	110–120	80–100	80–110	80–110	90 (maximum).
Optimum moisture, percentage of dry weight (approximate).	9	9–12	9–12	9–12	12–17	22–30	17–28	17–28	
Maximum field compaction required, percentage of maximum dry weight, pounds per cubic foot.	90	90	90	90	95	100	100	100	Waste.
Rating for fills 50 feet or less in height.	Excellent	Good	Good	Good	Good to poor	Poor to very poor.	Fair to poor	Fair to poor	Unsatisfactory.
Rating for fills more than 50 feet in height.	Good	Good to fair	Good to fair	Good to fair	Fair to poor	Very poor	Very poor	Very poor	Do.
Required total thickness for subbase, base and surfacing, inches.	0–6	0–6	2–8	0–6	9–18	9–24	12–24	12–24	

[1] Percentage passing No. 200 sieve, 0 to 10.
[2] When used as a base course for tbin flexible surfaces the plasticity index and liquid limit should not exceed 6 and 25, respectively.
[3] NP—nonplastic.

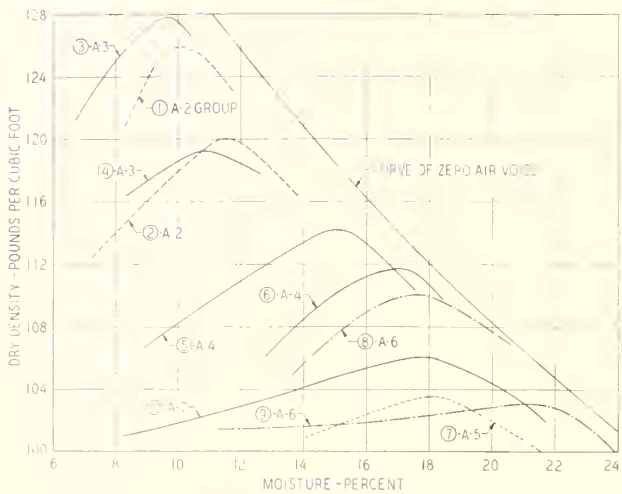
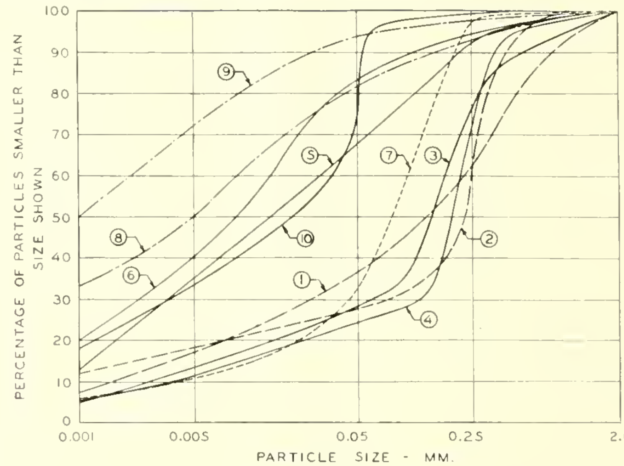


Figure 16.—Moisture-Density Curves.



PHYSICAL CONSTANTS

	GRADE	SOIL NUMBER	L.L	PL.	S.L	S.R	C.M.E	F.M.E.
1	A-2	S 14111	19	2	14	1.9	13	15
2	A-2	S 13908	22	4	—	—	—	—
3	A-3	S 13705	16	0	12	1.9	9	15
4	A-3	S 13703	NP	NP	—	—	5	17
5	A-4	S 13643	28	9	15	1.9	24	20
6	A-4	S 14089	34	13	15	1.8	23	23
7	A-5	S 9043	35	0	29	1.4	17	50
8	A-6	S 9673	54	29	19	1.8	29	25
9	A-6	S 13399	67	40	14	1.9	37	27
10	A-7	S 14135	48	24	16	1.8	30	30

Figure 17.—Grain-Size Accumulation Curves.

water is high and the moisture content will be greater throughout the year due to high continuous rainfall. The thickness selected will depend upon the judgment of the engineer.

The selected material for the sub-bases may be composed of soils similar to those of the A-1, A-2, or A-3 groups, natural gravels, which are stable but contain clay of such characteristics or quantity that they are not completely suitable for use in base courses, quarry wastes which are not suitable for base construction, or other materials having low volume change and relatively high density when compacted under a roller.

SOIL STABILIZATION EFFECTED BY CAREFUL SELECTION, PLACING, AND ROLLING OF MATERIALS

Properly constructed embankments may be divided on the basis of the method of compaction of the soil material used in their construction into the following types:

1. Uncompacted.
2. Jetted or ponded.
3. Rolled.

The embankments included under the uncompacted classification are those in which the materials consist either of pure sand or of earth mixed with large stones. The latter material usually occurs in mountainous regions or in highly glaciated areas. Since no special compaction methods are necessary to obtain a stable fill with such material, the thickness of lift used in placing the embankment can be much greater than in other types. When sand is used, the method of procedure is governed by the equipment used and is usually worked out to produce the greatest yardage per unit of time. When a mixture of soil and large stones is used, most specifications provide that the material shall be placed in lifts not to exceed 3 feet in thickness and that the fine material be so distributed that no pockets or voids will be left in the finished fill. The equipment used and the methods of procedure in the construction of embankments of this type have been described many times in engineering literature and need not be repeated.

Other embankments in which no special compaction methods are used are those placed with dragline and hydraulic equipment. The soil in this type of work is in a semiliquid state at the time of placing and the resultant fill is uniformly compacted by gravity and drainage to a relatively low density.

Jetting and ponding have been used extensively for the compaction of embankments. Explorations of old fills indicate that this method is successful when soils are sandy and slake down easily when inundated. Heavy clay soils do not compact when jetted and pockets of free water have been found in them several years after completion.

The jetting procedure is somewhat cumbersome and is a separate operation requiring special equipment and attention. The limitations of the method tend to restrict its use to those embankments which cannot be compacted by other means.

The stability of any embankment composed of fine-grained soil is dependent upon the moisture content and the density. There is no single moisture content and density at which soil will remain permanently. There is, however, a moisture content and density at which a soil will offer the greatest resistance to change. An increase or decrease in the moisture content will result in a loss of stability or a change in shape due to shrinkage or expansion. Settlement, softening, shrinkage, swell, and frost heave result from changes in moisture content and changes in temperature. The soil in a structure, therefore, is most stable when it has been placed at a moisture content which offers the greatest resistance to changes in that moisture content. Soil having a moisture content during compaction sufficient to result in a condition of maximum density with the pore spaces as nearly as possible filled with water offers greater resistance to the gain of moisture by absorption or the loss of moisture by evaporation than do soils compacted at any other condition. The process of soil stabilization in embankments consists, therefore, in the introduction of the proper moisture content to obtain a maximum density and the subsequent compaction of the soil mass to that density by means of proper equipment. This condition can best be accomplished by the careful selection, placing, and rolling of soil materials.

The recommended procedure in the construction of rolled embankments is as follows: The soil survey report should be studied by the engineer in charge and soils which are most suitable should be selected for use unless construction limitations make such selection uneconomical. An effort should be made in soil selection to arrange construction procedures so that the most desirable soils will be in the top of the finished grade. It will require close cooperation of the construction and inspection forces to accomplish the distribution of soil materials that will result in the best and most economical soil structure.

Before a plan of construction is adopted, the moisture content of the soil in the various borrow pits should be checked. A study should be made of the moisture-density relations of the soil in the various strata and of the specifications for the project. After these data have been studied, the construction equipment available should be checked over so that the rate at which the work will progress may be determined and any additional equipment necessary for a proper balancing of construction operations may be obtained before work starts. This procedure will also provide the engineer with information from which it will be possible to estimate the number of tests that it will be necessary to make each day and the number of inspectors that will be required to carry on the work most efficiently. The tests made in the field consist chiefly of moisture and density determinations of soils in place either in the borrow pit or in the embankment. A field laboratory should be provided on each project. Such a laboratory usually consists of a portable 10- by 12-foot frame structure properly lighted and equipped with a bench and table for use in making tests and preparing reports. This building is usually placed so that it is convenient to the work and may be moved from time to time as the work progresses.

NECESSARY FIELD LABORATORY EQUIPMENT LISTED

The field laboratory should be equipped with the following:

- 1 compaction mold (fig. 12).
- 1 soil tamper (fig. 13).
- 1 steel straightedge about 10 inches long.
- 1 gasoline camp stove.
- 3 alcohol burning soil moisture apparatuses (figs. 18 and 19).
- 1 small oven with thermometer.
- 1 penetrometer to register the force required to cause the penetration of needles of known end area (fig. 14).
- 1 scale of 30 pounds capacity sensitive to ½ ounce.
- 1 balance of 100 grams capacity sensitive to 0.1 gram.
- 2 4-inch post-hole augers and extensions.
- 1 railroad pick.
- 1 drain spade.
- 12 drying pans.
- 2 6-inch trowels.
- 1 2-gallon can for gasoline.
- 1 8-inch adjustable wrench.
- 1 100 cubic centimeter graduate.
- 1 No. 4 sieve.
- Notebooks, form sheets.
- Miscellaneous articles such as cloth bags, string, etc.

Soil as taken from borrow pits or cuts is usually either too dry or too wet for compaction to maximum density. Therefore, the first operation is preparation of the soil by adjustment of the moisture content.

Soil that is too dry is usually brought to the proper moisture content by irrigation of borrow pits or by sprinkling with water and mixing on the grade with blades, disks, harrows, or other available equipment.

Irrigation may be used either on sidehill locations or on flat areas. When sidehill locations are irrigated, contour ditches are cut with blade graders and water is pumped into the ditches until the desired average moisture content is obtained. On flat areas dikes are constructed and the ponds so formed are kept filled with water until the desired average moisture content is obtained. This method of treatment is suitable on sandy and silty loams which are sufficiently pervious to allow the diffusion of the moisture into the soils in a reasonably short time, but it has not been successful for the treatment of dense, impervious clays. The irrigation method is best adapted for use where heavy embankments are to be constructed from centrally located borrow pits. When rapid penetration is obtained, very little mixing has been found necessary after the material has been deposited on the grade.

Sprinkling may be accomplished by means of hose attached to pipe lines or by the use of gravity sprinkling wagons or pressure distributors. The latter method is the more common. The loose soil is placed on the grade in layers of the thickness necessary to result in the required compacted thickness, the water is added and the mixing done with several types of equipment. Heavy spring-tooth harrows have been used successfully in silty and sandy loams and disk plows have been used in clay loams. Tractor-drawn blades have been found to be most efficient in clay soils of the A–6 and A–7 groups.

The wetting of clay soils to a uniform moisture content is difficult and to be effective must be done very carefully. The following procedure has been found to produce reasonably satisfactory results. The soil is spread in a layer of uniform thickness and sprinkled with water. A shallow cut is made with the blade, placing the wetted soil in a windrow. The operation is repeated until the entire thickness of loose soil has been wetted and placed in the windrow. The wetted windrow is then bladed back into place in thin layers.

When the soil in the borrow pit or cut excavation contains moisture in excess of the optimum, it should be dried until it can be compacted to the density required by the specifications. This may be accomplished to a limited extent with the same equipment and processes which are used in the mixing of moisture into a dry soil. Obviously, such processing cannot begin until the soil has dried sufficiently to permit the working of construction equipment and in many instances further drying may not be necessary. The removal of excess moisture from soil is a much more difficult problem and will require more rigid inspection than the addition of moisture to dry soil. The process usually results in a delay of the work, but the increase in density and stability of embankments justifies such delay.

ALLOWANCE SHOULD BE MADE FOR EVAPORATION LOSSES

The results obtained in compaction operations will be affected by the placing and spreading of the soil layers. The loads should be so spaced that, when spread, the thickness of the resulting uniform layer will not exceed that necessary to obtain the required density. Soils of the correct moisture content should not be placed and spread so far in advance of rolling operations that they dry appreciably before rolling, since this procedure necessitates the addition of more water, additional mixing, and testing. The loss of some moisture by evaporation cannot be avoided in any case and in making calculations of water quantities allowance should be made for such losses. Experience with the soils available soon provides data that can be used to avoid duplication of operations and to estimate the excess water that must be applied to take care of evaporation losses.

The maximum thickness of soil layer that may be compacted in one operation is usually set by the specification, and on most work is 6 inches compacted depth. Some soils will not compact uniformly with certain types of rolling equipment when a loose thickness sufficient to produce 6 inches compacted depth is rolled; in such cases thinner layers must be used. The thickness for each soil type must be determined by trial and error since no test has been devised to give this information. Several small areas of soil of different thicknesses should be brought to optimum moisture content and rolled to determine the greatest thickness that may be used to compact to maximum density and the minimum number of roller trips required to produce that density.

The particular type of roller equipment used to compact embankments is of no importance if the required density is obtained and satisfactory construction progress is maintained. Sheepsfoot or tamping, smooth-faced, and rubber-tired rollers have been used with success.

Sheepsfoot or tamping rollers are used most extensively. These rollers vary in design from small single-drum rollers to the large double-drum type used on large dams and the compaction pressures range from 90 to 675 pounds per square inch. One of the chief advantages of this type of roller is that the unit load on the feet may be increased or decreased by variations in the ballast in the drum.

Tamping rollers should be of the twin-cylinder type with a frame and tongue that can be attached to a tractor in such a manner that the entire device may be either pulled or pushed in operation. The frames for the two rollers should be pivoted in a manner that will permit the rollers to adapt themselves to uneven ground surfaces and to rotate independently of one another. Cleaning teeth should be attached to the frame at the rear to prevent accumulation of soil between the tamping feet. The tamping feet should be placed in staggered rows.

Table 3 gives dimensions and weights typical of rollers in current use. This description is not intended to cover all rollers of this type in use and any roller must be judged by performance rather than by any dimensional requirements.

TABLE 3.—*Dimensions and weights typical of rollers in current use*

Item	Minimum	Maximum
Number of drums	2	2
Length of each drum (approximate) ... feet	4	4
Outside diameter of drum without teeth ... inches	38	42
Space between drums ... do	------	12
Length of tamper feet ... do	6	8
Bearing area of each foot ... square inches	4	13
Tamping feet per square foot of tamped area	1	2
Ground pressure under each foot ... pounds per square inch	100	------
Total weight ... pounds per inch of roller width	90	------

The tamping roller compacts the soil from the bottom of the layer toward the top and thus produces a uniform density through the entire thickness. The density of the soil layer increases up to about 10 to 12 passes of the roller for average soil conditions. If the number of passes to produce the required density exceeds 15, it indicates that the roller is too light or the layer of soil too thick and that an adjustment is necessary to produce the desired result. The compaction of clay soils usually requires the maximum weight to which the roller can be loaded. In some silty soils containing a very small amount of binder, the minimum weight of roller gives the greatest density in the least number of passes since this condition avoids the tearing of the soil by the roller feet. Tamping rollers do not operate satisfactorily in soils containing large quantities of gravel or stone particles.

In the operation of the tamping-type roller, it is important that the feet be kept free from mud and dirt. If they become clogged the efficiency of the roller is destroyed.

The smooth-faced roller compacts from the top down and usually requires from four to six passes of a 10-ton, three-wheel roller to compact a soil layer to required density in a 6-inch compacted thickness. Sandy loams having relatively low plasticity indexes can usually be compacted more economically with this type of roller than with the tamping type.

Rubber-tired rollers have not been used to any great extent on fill compaction. The information available indicates that satisfactory compaction may be obtained in sandy soils when thin layers are rolled with this type of equipment.

The compaction of embankments may be accomplished by the passage of hauling equipment, such as tractor wagons and trucks, over the soil layers during the process of construction. The distribution of equipment over the area to be compacted is difficult to control and the use of the method may result in a lack of uniformity in the density and moisture content of the soil in the finished embankment. The practice is not recommended as a substitute for rolling.

The essential factors to be given special attention in soil compaction may be summarized as follows:

1. Required moisture uniformly distributed.
2. Maximum thickness of soil layer.
3. Uniform thickness of soil layer.
4. Number of roller passes.
5. Weight of tamping rollers.
6. Cleanness of feet of tamping roller.

CONTROL TESTS SHOULD BE MADE IN THE FIELD DURING CONSTRUCTION

During processing and rolling operations, control tests should be made, the results of which will indicate the extent to which compaction has been completed. The following tests should be made in the field by the inspector during construction:

1. Compaction tests to determine moisture-density relations.
2. Moisture determinations of soil from borrow pits or cut sections.
3. Density tests of compacted soil in place.
4. Density tests of soil in place in borrow pit or cut sections.

The compaction test procedure for the determination of the moisture-density relation of soils has already been described. The data obtained by this test should be included in the soil survey report for each of the major types of soil on the project. It would be impossible, however, to anticipate at the time of the soil survey all conditions which may develop after work begins and therefore frequent compaction tests in the field laboratory are necessary in order to insure accurate control of the work. Compaction tests should be made when the soil type changes or when it may be necessary

Figure 18.—Apparatus for Drying Soil by Burning Alcohol.

to use a mixture of soils to facilitate construction operations. Frequent test borings should be made with a 4-inch post auger in advance of grading operations in order to anticipate conditions and obtain samples for making compaction tests.

The moisture content of soil may be determined in the field by evaporating to dryness on a gasoline stove, by mixing the soil with alcohol and burning off the alcohol-water mixture, or by the use of the penetration needle and the moisture-penetration curve.

Evaporating to dryness may be done in accordance with the following procedure:

1. Obtain a representative sample of soil to be tested. If a metric scale is available, the sample should not be smaller than 100 grams. If an avoirdupois scale graduated by ½ ounces is used, the sample should contain at least 50 ounces.
2. Weigh sample and record weight.
3. Place sample in pan and spread to permit uniform drying. Set pan in the oven (or in a second pan) to prevent burning of soil and place on stove.
4. Dry to constant weight. The temperature of the oven should not exceed 105° C. (221° F.). Stir constantly to prevent burning.
5. After the sample has been dried to constant weight, remove from oven and allow to cool sufficiently to permit the absorption of hygroscopic moisture. Weigh dried sample and record weight.
6. Compute moisture content as follows:

$$\text{Percent moisture} = \frac{\text{weight wet soil} - \text{weight dry soil}}{\text{weight dry soil}} \times 100.$$

The alcohol burning method consists of mixing the damp soil with sufficient denatured or grain alcohol to form a slurry in a perforated metal cup, igniting the alcohol and allowing it to burn off. Three burnings of alcohol are usually required to remove all moisture from the soil. Excessive soil temperatures are not produced by this method as is evidenced by the fact that a filter paper in the perforated cup does not char. The results obtained by this method check closely with these obtained by careful laboratory drying. The apparatus is shown in figures 18 and 19.

The procedure for this method is as follows:

1. Weigh the perforated cup with the filter paper in place in the bottom. Record weight.
2. Obtain a sample which is representative of the soil to be tested. Since this method requires a sample weighing between 25 and 35 grams, a metric scale is necessary.
3. Place the sample in the perforated cup and weigh cup and sample and record weight. Weight of moist sample equals this weight minus weight of cup and filter paper.

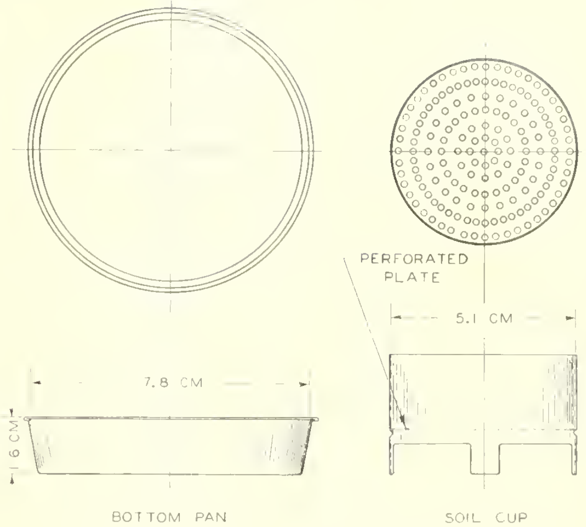


Figure 19.—Alcohol Soil Moisture Apparatus.

4. Place perforated cup in outside metal saucer and stir alcohol into the soil sample with a glass rod until a sufficient quantity has been added to produce a thin mud or slurry. Allow the stirring rod to dry and wipe soil particles clinging to it into the cup.
5. Ignite the alcohol in saucer and sample and burn off all the alcohol.
6. Repeat the process of adding alcohol and burning three times. The alcohol should be thoroughly mixed with the soil each time.
7. Weigh perforated cup and dry soil after last burning. The weight of dry sample equals this weight minus the weight of the cup and filter paper.
8. Calculate the moisture content as follows:

$$\text{Percent moisture} = \frac{\text{weight wet soil} - \text{weight dry soil}}{\text{weight of dry soil}} \times 100.$$

The apparatus shown in figures 18 and 19 may be increased in size if it seems desirable to use a larger sample. In a larger device the perforated dish should be shallow and the volume increased by increasing the diameter because a shallow sample dries faster and more uniformly and requires less alcohol.

MOISTURE DETERMINATION WITH PENETROMETER DESCRIBED

An approximation of the moisture content of soil for which moisture-penetration curves are available may be made with the standard soil penetrometer by the following procedure:

1. Place compaction mold on firm foundation.
2. Compact two layers of soil in the mold in accordance with the standard procedure used in the compaction test.
3. Record the pressure required to force the penetrometer needle into the compacted soil. The readings for three trials should be recorded and averaged. Convert the readings to pounds per square inch.
4. Read moisture content corresponding to unit pressure from the moisture-penetration curve for the sample being tested.

The evaporation to dryness method and the alcohol burning method of obtaining the moisture content of soil in the field have given satisfactory results. The first method is somewhat cumbersome and requires constant attention to prevent burning of the sample. Since large samples can be dried by this method, inaccuracies due to sampling may be reduced to a minimum. It is also adapted for use with materials containing large aggregates such as sand-gravel mixtures.

The alcohol method cannot be used for coarse granular mixtures unless the size of the containers is increased accordingly. The use of a large container will require the use of a large quantity of alcohol which would make the cost of the test prohibitive. The quantity of alcohol required for each burning is approximately twice the volume of the moisture in the sample. For example, a 100-gram sample containing 20 percent moisture would require 40 cubic centimeters of alcohol for each burning or a total of 120 cubic centimeters for complete drying.

The alcohol method has the advantages of being easy to use and utilizing equipment that does not easily get out of repair and which is compact, and low in cost. Several of the devices can be operated simultaneously without danger of burning the soil.

The penetrometer method of moisture determination can be used only in fine-grain soils and gives approximate values. The method is useful as a control test because the approximate moisture contents can be checked rapidly. The method is not used to replace the drying tests but may be considered as supplemental to them.

The determination of the density of compacted soil and of the undisturbed soil in excavation areas as the construction of an embankment proceeds is important as a control measure, as a means of checking the work against specification requirements, and for the calculation of the shrinkage factors used in estimating the volume of excavation necessary to produce embankments of given dimensions.

Density tests of soil in place may be made by measuring the weight, volume, and moisture content of undisturbed samples or by measuring the volume occupied by a disturbed sample and recording the weight and moisture content of the soil removed from that volume.

Undisturbed samples may be cut with hand tools and tested by the following procedure:

1. A sample is obtained by marking an area of the same size as the sample desired and digging the soil from around it with some sharp tool such as a knife, spatula or small trowel. A spade may be used if care is exercised not to disturb the core. The sample should be 4 to 5 inches in diameter and the full depth of the lift.

2. Immediately upon removal of the core a representative sample should be removed for moisture determination. The size of the moisture sample will depend upon the method to be used in the field laboratory for drying the moisture samples.

3. Trim loose material from soil core, weigh, and record weight to nearest ½ ounce.

4. Determine moisture content by drying moisture sample.

5. Immerse sample in hot paraffin until coated, remove, cool, and weigh. The gain in weight represents the weight of paraffin and the volume of the coating is calculated using 55 pounds per cubic foot as the weight of paraffin.

6. Weigh coated sample in water, record weight and calculate volume or measure volume of water displaced by means of a suitable overflow device. Deduct the volume of the paraffin coating.

7. Compute wet and dry density by the following formulas:

$$\text{Wet weight per cubic foot} = \frac{\text{weight of wet sample}}{\text{volume of sample}}.$$

$$\text{Dry weight per cubic foot} = \frac{\text{wet weight per cubic foot}}{1+\frac{\text{percent moisture}}{100}}.$$

For example assume wet weight of soil sample=8 pounds; volume of sample=0.06 cubic foot; and moisture content=15 percent; wet weight per cubic foot$=\frac{8}{0.06}=133$ pounds; and dry weight per cubic foot$=\frac{133}{1+0.15}=115.7$ pounds.

Undisturbed samples may also be obtained by driving a tube sampler into the soil layer. If the volume of the sampler is known, the determination of the volume of the sample becomes unnecessary. Care must be exercised in the use of the method to avoid disturbance of the soil.

METHODS OF DETERMINING DENSITY OF SOIL LAYER GIVEN

The density of a soil layer may be determined by finding the weight of a disturbed sample and measuring the volume occupied by the sample prior to removal. This volume may be measured by filling the space with a weighed quantity of a medium of predetermined weight per unit volume. Sand, heavy lubricating oil or water in a thin rubber sack may be used as a medium for measuring the volume formerly occupied by the sample. Except for the determination of the weight per cubic foot of the medium, the three procedures are the same and therefore the one using sand will be described in detail. It is as follows:

1. Determine weight per cubic foot of the dry sand to be used by filling a measure of known volume. The height and diameter of the measure used should be approximately equal and its volume should be not less than ⅒ cubic foot. The sand should be deposited in the measure by pouring through a funnel or from a measure with a funnel spout from a fixed height. The measure is filled until the sand overflows and the excess is struck off with a straightedge. The weight of the sand in the measure is determined and the weight per cubic foot computed and recorded.

2. Remove all loose soil from an area large enough to place a box similar to the one shown in figure 20 and cut a plane surface for bedding the box firmly.

3. With a soil auger or other cutting tools bore a hole the full depth of the compacted lift.

4. Place in pans all soil removed, including any spillage caught in the box. Remove all loose particles from the hole with a small can. Extreme care should be taken not to lose any soil.

5. Weigh all soil taken from the hole and record weight.

6. Mix sample thoroughly and take sample for moisture determination.

7. Weigh a volume of sand in excess of that required to fill the test hole and record weight.

8. Deposit sand in test hole by means of a funnel or from a measure by exactly the same procedure as was used in determination of unit weight of sand until the hole is filled almost flush with original ground surface. Bring the sand to the ground level by adding the last increments with a small can or trowel and testing with a straightedge.

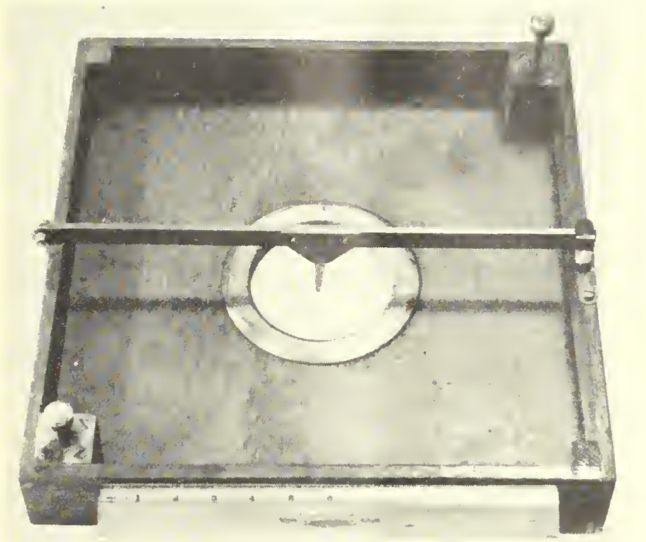


FIGURE 20.—SOIL TRAY FOR USE WITH POST AUGER IN SOIL DENSITY DETERMINATIONS.

9. Weigh remaining sand and record weight.
10. Determine moisture content of soil samples.
11. Compute dry density from the following formulas:

$$\text{Volume of soil} = \frac{\text{weight of sand required to replace soil}}{\text{weight per cubic foot of sand}}.$$

$$\text{Wet weight per cubic foot} = \frac{\text{weight of soil}}{\text{volume of soil}}.$$

$$\text{Dry weight per cubic foot} = \frac{\text{wet weight per cubic foot}}{1+\frac{\text{percent moisture}}{100}}.$$

For example assume weight per cubic foot of sand=100 pounds; weight of wet soil from auger hole=5.7 pounds; moisture content of soil=15 percent; and weight of sand to fill auger hole=4.5 pounds. Then volume of soil from hole$=\frac{4.5}{100}=0.045$ cubic foot; weight per cubic foot of wet soil$=\frac{5.7}{0.045}=126.7$ pounds; and weight per cubic foot of dry soil$=\frac{126.7}{1+\frac{15}{100}}=110$ pounds.

Assume that optimum moisture for this soil equals 15 percent and maximum density equals 115 pounds per cubic foot, then the compaction in the layer tested is $\frac{110}{115}=95.7$ percent.

If the specifications require not less than 95 percent of maximum density at optimum moisture, the compaction is satisfactory but very close to minimum requirements.

When the sand funnel device shown in figure 21 is used to determine the volume of the soil removed from the test hole, the volume of the jar above the valve may be determined by filling the apparatus with water, closing the valve, pouring off water retained in the large funnel, and weighing. The volume may be computed by dividing the weight of water in the jar by weight per cubic foot of water (62.4 pounds). After the volume of the apparatus is known, the weight of sand required to fill it may be determined and the unit weight computed. The device is used by placing the funnel over the hole, opening the valve and allowing the sand to flow until it stops. The valve is closed and the weight of sand left in the jar is determined. This value subtracted from the total weight of sand in the device gives the weight required to fill the hole and the cone. The weight of sand in the cone can be found by weighing the apparatus, placing it on a flat surface, opening the valve, allowing the sand to flow until it stops and closing the valve. The weight of sand in the cone equals the difference in weight of the apparatus before and after the filling operation.

FIGURE 21.—SAND JAR WITH FUNNEL FOR USE IN SOIL DENSITY DETERMINATIONS.

The jar may be calibrated to show cubic feet of sand removed as shown in figure 21 so that weighing is not necessary in the determination of soil volume. Such calibration should be made very carefully and requires more equipment than is usually available in a field

Figure 22.—Oil Jar and Pump for Use in Soil Density Determinations.

Figure 23.—Rubber Sack with Measuring Jar for Use in Soil Density Determinations.

laboratory. When volumetric measurements are used, the readings must be made carefully and care must be exercised not to compact the sand during the operation.

Any clean sand having rounded particles all of one size (usually passing the No. 20 and retained on the No. 30 sieve) may be used in this test. Standard Ottawa sand is used to a large extent but is not required. The sand may be salvaged after each test but should be rescreened before being used again. The use of slightly damp sand should be avoided because of the error introduced by bulking.

Heavy lubricating oil (S. A. E. 30 or 40) may be used instead of sand in the above test. The procedure and method of computing the results are the same. The weight per cubic foot of the oil may be found by weighing a measured quantity or by computing it from the specific gravity if that constant is known. The oil is removed from the hole with a suction pump and may be used until it becomes contaminated with soil particles to the extent that the weight may be changed. A calibrated container may be used if means are available for accurate calibration and etching of the quantities on the glass. The use of a device calibrated as shown in figure 22 is convenient due to elimination of weighing procedures and is accurate when the readings are carefully made. The suction pump shown in figure 22 is the type ordinarily used in the recovery of the oil.

The apparatus shown in figure 23 consists of a rubber pouch attached to a calibrated glass container and may be used to measure the volume of the space from which a disturbed sample is taken. The device comprises a closed system and is very convenient due to the fact that the necessity for the handling of oil or sand is eliminated. The volume of the rubber pouch must be determined accurately and correction for its volume made in the readings taken. To insure the filling of the entire volume from which the soil sample was taken, air pressure is introduced into the jar by means of the small bicycle pump shown in figure 23. The pressure is easily determined by trial since the water level will not be lowered by slight increases in pressure after the rubber has expanded into the irregularities of the hole.

The use of the sand funnel device of figure 21 or the calibrated container for measuring the volume of oil, figure 22, are limited to fine-grained soils where irregularities in volume due to large aggregate particles do not occur. The sand funnel cannot be placed over a hole irregular in shape and the quantity of the oil in the calibrated container is usually too small to fill the excess volume caused by the removal of stones, etc. It is obvious that the rubber pouch device can be used only in fine-grained soils since the rubber cannot be expanded into a test hole of irregular shape.

SOIL MASS IN EMBANKMENTS CONSISTS OF SOIL PARTICLES AND AIR AND WATER VOIDS

The form shown in figure 24 is suggested for use in recording field data obtained in the inspection of the compaction of embankments.

For the correct interpretation of soil data, the relationship of the soil particles, water, and air voids in the soil mass must be understood. The following fundamental facts may be used to interpret the test data correctly.

A soil mass as it exists in an embankment is made up of soil particles and voids. Part of the void space contains air and part of it contains water.

Let V_s=volume of soil particles in a unit volume of soil;

V_v=total volume of air and water;

V_w=volume of the voids filled with water;

V_a=volume of the voids filled with air;

then $V_s+V_v=V_s+V_w+V_a=\text{unity}$;

and let G=specific gravity of soil particles;

w=percent moisture by dry weight of soil;

W=wet weight per cubic foot of soil;

W_0=dry weight per cubic foot of soil;

a=percent moisture by dry weight of soil to fill all the voids (V_v);

and assume that $W=124$ pounds per cubic foot;

$w=17$ percent;

$G=2.70$;

Project ______________________ Data ____________

Location ______________________ Operators ____________

Field test No.						
Location of tests: Station						
Location of tests: Reference to C L						
Location of tests: Elevation						
Elevation: Original ground						
Elevation: Finished grade						
Type of roller						
No. of passes with roller						
Density determination						
A. Weight per cu. ft. of sand (or oil) =	100					
B. Weight sand (or oil) + weight of container =	18					
C. Weight sand (or oil) left in container + container =	13.5					
D. Weight sand (or oil) in auger hole (B - C) =	4.5					
E. Volume of auger hole (D ÷ A) =	.045					
Weight of wet soil from auger hole + weight of container =						
Weight of container =						
F. Weight of wet soil from auger hole =	5.7					
G. Weight per cubic foot of wet soil in fill (F ÷ E) =	126.7					
H. Weight of dry soil in 1 cubic foot of fill =	110					
K. Maximum dry weight per cu. ft. from Lab. No. =	115					
L. Compaction = (H ÷ K) x 100 =	96					
Moisture determination						
Dish and damp soil						
Dish and dried soil						
Weight moisture						
Weight dish (No.)						
Weight dry soil						
M. Percentage moisture	15					

FIGURE 24.—FORM OF REPORT ON EMBANKMENT COMPACTION.

then $W_0=\frac{W}{1+\frac{w}{100}}=\frac{124}{1+\frac{17}{100}}=106$ pounds per cubic foot.

$V_s=\frac{W_0}{G\times 62.4}=\frac{106}{2.70\times 62.4}=0.629$ cubic foot of solid particles in each cubic foot of soil.

$V_v=1-V_s=1-0.629=0.371$ cubic foot of combined air and water voids in each cubic foot of soil.

Since the percentage of moisture is known, the volume of the water in the voids may be calculated thus:

$$V_w=\frac{\frac{w}{100}\times W_0}{62.4}=\frac{\frac{17}{100}\times 106}{62.4}=0.288$$ cubic foot of water in each cubic foot of soil.

$V_a=V_v-V_w=0.371-0.288=0.083$ cubic foot of air in each cubic foot of soil.

Percentage of air voids by volume $=V_a\times 100=8.3$.

The volume of air voids may also be calculated from the following:

$$V_a=1-V_s-V_w$$

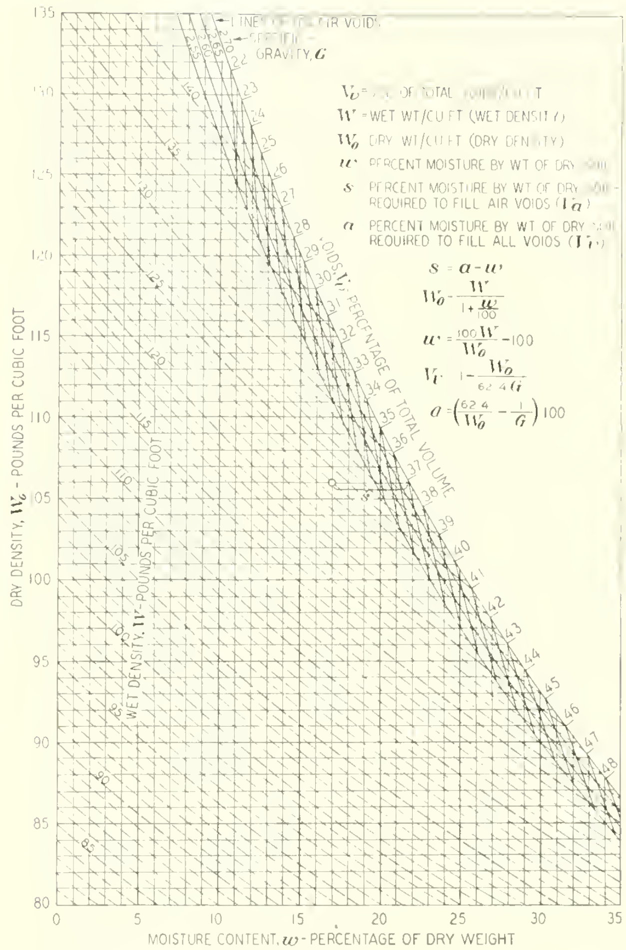
$$=1-\frac{W_0}{62.4G}-\frac{wW_0}{100\times 62.4}=1-\frac{W_0}{62.4}\left(\frac{1}{G}+\frac{w}{100}\right)$$

When the air voids are zero ($V_a=0$), the soil is saturated and $V_w=V_v=0.371$ cubic foot of water in each cubic foot of soil.

Percent moisture by volume for zero air voids $=V_v\times 100=37.1$.

The moisture content by volume for zero air voids may be converted to a weight basis by means of the following equation:

$$a=\left(\frac{62.4}{W_0}-\frac{1}{G}\right)100$$



EXAMPLE - GIVEN w=17, W=124, G=2.70 (POINT o). THEN, W_0 = 106; V_v=0.371, a = 21.9, s = 4.9

FIGURE 25.—CHART OF SOLIDS-WATER-VOIDS RELATIONS OF SOIL MASSES.

For the example above

$$a=\left(\frac{62.4}{106}-\frac{1}{2.70}\right)100=21.9$$

The relationship between the dry weight per cubic foot of soil and the percentage of moisture by weight necessary to fill the voids is useful in checking the values obtained by testing the density of the soil in place. Since the soil in place always contains some air voids, the percentage of moisture by weight of the soil cannot exceed the moisture content required to reduce the air voids to zero. Also, if the computed weight per cubic foot of soil in the embankment is higher than the weight when the air voids are zero, it is obvious that an error has been made in the determination of the weight or the moisture content. The test results can be checked conveniently by the use of curves constructed by plotting the moisture contents by weight for the zero air voids conditions against the dry weights per cubic foot for several specific gravities and drawing a smooth curve through the points. The dry weight per cubic foot and moisture content of soil can be plotted on such a chart with a minimum of effort and errors in testing procedure located and corrected without loss of time.

A series of curves for the more common specific gravities is shown in figure 25. These curves are also suitable for use in calculating the dry weight per cubic foot of soil from results of tests to determine the wet weight per cubic foot and the moisture contents of the soil in an embankment. As a check on test results, when the moisture content of the soil is plotted against the dry weight per cubic foot, the point should fall to the left of the zero air voids curve. If it does not, the test data are obviously in error.

RELATION OF EXCAVATION AND EMBANKMENT DENSITIES OFTEN USEFUL

The balance factor in earthwork is the ratio of the density of the embankment to the density of the cut or excavation. It involves a study of densities in the cut section as well as in the fill section. Accurate knowledge of cut densities is sometimes quite useful to the engineer in determination of the quantity of excavation in instances where borrow pits have been flooded and silted in after excavation and in instances where pits have been badly eroded or washed out. They are often useful in calculation of hydraulic excavation. The accuracy of earth quantities as measured by the method of average end areas obtained by cross sections is sometimes questioned. When the volumes calculated from cross sections are in doubt, data on both cut and fill densities are of considerable value in checking the final quantities.

Earthwork quantities are directly related to densities. That is, the cubic yards of embankment which are obtained from a given number of cubic yards of excavation are directly related to the density of the embankment and that of the excavation.

The formula for determining the balance factor may be derived as follows:

Let A=volume of excavation;
B=volume of embankment;
W=weight of material necessary to produce a given volume of excavation or embankment;
D_f=dry density in pounds per cubic foot of embankment;
D_c=dry density in pounds per cubic foot of excavation; and
$\frac{D_f}{D_c}$=balance factor;

then, since density$=\frac{\text{weight}}{\text{volume}}$,

$$\frac{W}{B}=D_f \quad (1)$$

$$\frac{W}{A}=D_c \quad (2)$$

$$W=BD_f \quad (3)$$

$$W=AD_c \quad (4)$$

$$AD_c=BD_f \quad (5)$$

then, balance factor:

$$\frac{D_f}{D_c}=\frac{A}{B} \quad (6)$$

Assume that the cubic yards of excavation necessary to produce an embankment of 5,000 cubic yards is to be calculated.

Then A=unknown.
B=5,000 cubic yards.

Assume D_f=106
D_c=97

Then substituting in equation 6,

$$A=5000\times\frac{106}{97}$$

$$A=5{,}464$$

$$\frac{D_f}{D_c}=\frac{106}{97}=1.093 \text{ (balance factor).}$$

The earth shrinkage from excavation to embankment is equal to the amount, in percent, that the volume of excavation exceeds the volume of embankment. It is calculated from the equation,

$$S=\frac{(D_f-D_c)}{D_c}100$$

where S=shrinkage, in percent
and

$$S=\frac{106-97}{97}100=9.3 \text{ percent.}$$

In the course of ordinary construction, when ordinary soils are taken from shallow excavation (borrow pits and shallow cuts) the balance factor will, if good compaction is being obtained, be greater than one (1.000). In some instances shales have been encountered where it has been either impossible or impractical to consolidate the material in the embankment to the very dense state in which the shale occurs in its natural bed or layer. Under such conditions a balance factor of less than 1 does not necessarily signify poor compaction.

Similarly, when soils are taken from very deep cut sections where they exist in a very compact condition, it has been found that even under good rolling procedure the resulting embankment density is lower than the density of the soil in the excavation.

Nevertheless, when either of the above conditions exists it should be thoroughly investigated to determine whether or not the best compaction is being obtained.

In using the balance factor to determine quantities of excavation, it should be kept in mind that factors such as wastage in hauling, loss of material by blading off grass and weeds, loss due to erosion by floods and any other losses or gains should be taken into consideration. With these factors in mind, it is easier to account for the discrepancies which might exist between the final results.

The conditions on earth work projects vary so widely that it is difficult to set forth the number of tests that will be necessary for adequate control of the compaction of embankments. Common practice requires that when the soil and moisture conditions are uniform, a minimum of four density and moisture tests should be made in each 8-hour day but not less than one test should be made for each 500 cubic yards of excavation. When soil and moisture conditions vary, the number of tests will have to be increased sufficiently to insure accurate control. Actually, the number of tests required will have to be determined by experience. In starting a project frequent tests should be made to establish in the mind of the inspector the appearance and consistency of the various soils when they are in most suitable condition for compaction. The inspector on important earth work must take his job seriously and learn by frequent testing the best methods to use to produce a good embankment from the available material.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF JANUARY 31, 1942

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$6,437,162	$3,199,140	227.6	$3,958,624	$1,964,205	113.2	$488,210	$242,350	2.9	$2,760,201
Arizona	1,393,527	979,140	58.6	1,444,743	900,035	50.0	384,302	254,599	8.4	2,160,619
Arkansas	3,460,021	1,590,151	56.6	1,173,174	585,470	60.1	66,680	33,340	.1	1,863,552
California	7,568,885	4,040,283	126.0	6,165,635	3,536,378	73.0	687,431	394,653	20.8	4,945,511
Colorado	2,310,848	1,303,814	154.6	3,200,996	1,840,260	150.4	1,120,230	626,362	40.6	2,616,120
Connecticut	1,419,554	696,181	17.1	1,715,156	821,787	18.4	481,485	239,471	9.4	1,228,870
Delaware	365,525	177,441	9.5	659,559	326,584	16.6	268,040	134,020	8.4	1,509,078
Florida	1,167,179	582,930	65.3	2,281,618	1,144,037	28.4	1,353,864	843,856	17.9	3,200,526
Georgia	2,772,525	1,384,970	100.7	6,789,779	3,404,640	265.9	3,649,716	1,824,858	148.9	7,080,615
Idaho	1,782,936	1,086,595	93.7	1,301,603	803,077	63.1	58,224	36,000	.1	2,189,363
Illinois	3,876,581	1,917,141	87.2	7,152,266	3,575,561	124.1	1,404,200	702,100	6.2	7,152,928
Indiana	4,525,625	2,095,222	74.4	5,305,469	2,573,969	75.6	2,191,200	1,095,600	32.7	2,868,489
Iowa	3,627,220	1,735,171	151.9	4,366,352	1,906,282	138.4	800,741	97,650	23.6	2,531,791
Kansas	4,526,360	2,289,183	250.2	4,966,257	2,491,064	237.6	2,158,829	783,867	76.7	5,281,813
Kentucky	3,771,487	1,861,214	139.1	6,386,223	3,051,471	125.1	2,083,762	974,967	17.2	2,005,284
Louisiana	1,013,101	506,526	23.9	1,835,052	909,108	38.1	2,553,917	1,251,767	56.3	4,551,560
Maine	954,535	472,598	26.8	2,070,392	1,061,696	27.8	78,610	39,305	.1	1,122,228
Maryland	2,737,267	1,367,529	29.6	3,474,909	1,480,154	15.0	35,000	17,500		1,587,207
Massachusetts	2,348,774	1,177,018	17.3	2,223,103	1,142,862	14.9	1,173,468	583,147	8.4	3,911,401
Michigan	8,312,252	4,065,652	173.7	2,855,748	1,427,874	44.9	1,831,600	907,500	18.5	3,517,357
Minnesota	4,480,915	2,219,233	378.0	9,536,083	4,724,469	388.4	368,018	184,009	20.1	3,470,206
Mississippi	3,584,667	1,784,718	208.8	5,310,224	2,603,712	286.5	197,500	100,000	6.1	2,306,675
Missouri	5,045,503	2,492,307	160.1	10,036,428	5,134,979	190.0	2,989,937	1,105,698	36.5	4,643,464
Montana	2,181,671	1,233,971	117.1	3,728,153	2,181,315	160.3	699,027	401,686	68.8	4,470,051
Nebraska	2,210,975	1,085,636	237.7	5,909,661	2,971,285	519.7	709,046	354,523	37.8	4,184,920
Nevada	2,244,854	1,946,128	110.6	742,339	643,031	22.0	274,686	238,701	3.4	1,385,808
New Hampshire	339,179	177,926	6.0	1,245,854	596,796	14.8	447,973	335,980	5.4	934,962
New Jersey	3,009,259	1,475,339	26.6	2,964,992	1,482,416	16.2	23,910	11,955		3,030,650
New Mexico	1,560,262	960,958	102.0	1,152,059	744,921	74.1				2,916,946
New York	9,597,967	4,717,100	126.7	7,910,755	4,906,145	80.6	1,083,700	633,400	12.8	5,430,481
North Carolina	3,292,024	1,629,777	136.6	3,454,449	1,730,110	145.6	1,138,663	573,423	27.0	3,716,426
North Dakota	3,287,136	1,802,745	287.6	2,572,786	1,323,524	203.7	2,421,360	1,214,050	205.5	4,280,623
Ohio	9,533,041	4,760,070	91.6	10,664,162	5,090,986	69.3	5,797,060	2,247,378	37.2	4,690,951
Oklahoma	2,097,080	1,054,494	107.1	2,545,022	1,342,949	41.4	2,106,280	1,102,854	77.1	6,267,587
Oregon	2,674,796	1,585,246	72.9	3,192,624	1,692,738	69.7	259,274	113,350	7.5	1,826,243
Pennsylvania	9,915,126	4,916,577	98.5	8,804,300	4,281,780	65.5	2,957,859	1,475,491	24.9	4,918,975
Rhode Island	1,196,941	596,510	10.0	644,776	322,368	4.8	644,448	322,224	2.0	940,591
South Carolina	1,946,604	891,797	87.2	3,971,331	1,823,981	90.0	994,153	379,881	26.8	2,352,037
South Dakota	1,985,584	1,149,084	232.2	5,054,628	3,248,383	578.7	644,800	381,560	69.6	2,941,136
Tennessee	3,242,183	1,617,780	94.7	4,851,864	2,572,126	84.0	1,199,978	647,546	34.4	3,954,218
Texas	8,467,428	4,145,126	447.9	13,733,944	6,559,286	464.1	2,669,301	1,120,520	88.4	9,492,388
Utah	1,206,046	907,446	53.8	1,761,015	1,325,602	41.3	72,348	54,000	5.4	1,298,207
Vermont	823,135	408,394	28.8	1,205,174	595,537	20.7	36,906	18,453	.3	552,510
Virginia	2,999,775	1,470,809	70.6	4,387,238	2,048,126	61.4	35,490	17,745	.4	2,937,659
Washington	1,474,775	765,618	20.2	2,809,895	1,503,654	36.9	43,686	23,400	1.0	2,244,808
West Virginia	2,778,324	1,380,071	51.4	2,344,962	1,162,723	28.1	463,776	229,588	3.1	2,205,205
Wisconsin	2,201,240	1,080,730	92.7	5,546,496	2,597,643	163.9	1,262,339	454,400	44.7	4,831,516
Wyoming	1,426,636	921,287	148.3	1,793,023	1,198,146	123.5	34,714	22,321	.1	1,475,803
District of Columbia	594,036	293,515	3.3	721,662	396,682	1.1	600,000	382,500	.2	306,857
Hawaii	133,296	66,648	2.8	1,065,560	700,306	10.9	180,505	161,032	3.5	1,864,746
Puerto Rico	417,697	206,815	3.6	1,875,051	924,890	16.6	342,531	170,280	1.7	850,861
TOTALS	160,319,519	82,271,754	5,499.2	200,863,168	103,377,123	5,754.4	53,568,777	25,560,860	1,348.9	160,808,023

Note: Includes apportionments for fiscal year 1943.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF JANUARY 31, 1942

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$151,956	$151,436	2	4	2	$383,125	$381,103	5	2	2	$52,335	$52,335	2		5	$1,129,771
Arizona	168,283	168,266	1			141,369	132,678		2		13,255	13,255			2	234,281
Arkansas	452,984	451,679	5		1	172,925	171,215	1		2	28,621	28,621			10	660,187
California	830,690	641,118	2	1	3	870,516	868,399	8			15,678	15,678			5	2,319,005
Colorado	5,685	5,646				664,333	664,333	7			21,042	21,042			10	730,378
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		525,593
Delaware	91,204	91,204	1		1	191,599	189,867	1	1		508,406	321,785	2			175,142
Florida	108,679	108,679			18	727,448	725,268	8		4	205,901	205,840			18	875,288
Georgia	547,990	547,990	7	1	3	939,400	939,400	5	7	10	959,078	959,078	3	4	16	1,515,472
Idaho	25,827	21,580			2	322,273	313,602	4	1		6,212	6,212			3	427,671
Illinois	685,009	563,091	2		80	1,661,232	1,566,997	8	1	9	426,384	407,434	1	1	37	2,557,257
Indiana	600,254	587,767	6		18	466,062	460,353	2	1	20	100,783	100,783			26	1,166,559
Iowa	338,129	324,372	3	1	24	1,459,107	1,206,930	10	2	17	180,636	179,225			45	661,098
Kansas	63,041	62,622	2		5	677,142	677,142	8		2	216,248	172,678	4		10	1,358,519
Kentucky	1,040,740	1,038,377	8		1	512,092	512,092	5	1							407,268
Louisiana	6,965	6,965				586,220	586,220	8			481,835	480,667	4		4	923,735
Maine						363,086	363,086	2			8,680	8,680			3	288,623
Maryland	488,250	456,457	2	2	10	868,458	724,660	4		4	48,775	48,775			8	399,876
Massachusetts	346,270	335,829	1		1	774,431	773,559	5	2		763,830	763,830	2	1		1,267,765
Michigan	1,300,420	1,293,532	3	4	13	262,616	262,616	1		9	338,780	308,619	1		13	1,324,681
Minnesota	532,379	532,063	5	3	1	1,057,043	1,057,043	5	5		76,944	76,944		1	8	1,134,810
Mississippi	209,275	209,275	2		1	887,709	887,709	10	1	9	25,808	25,808			2	644,407
Missouri	120,702	120,702		2		1,922,921	1,467,501	6	2		464,353	464,353	2	2		1,489,049
Montana	141,549	141,549	2		2	99,778	99,778	1								733,051
Nebraska	181,040	180,663	1	1	20	1,164,361	1,164,361	22		3	13,020	13,020			3	449,496
Nevada	119,580	119,580	2			56,484	56,484	2			30,725	30,725			10	192,599
New Hamnshire	207,015	199,138	4		2	162,506	162,181	2	2	3						313,808
New Jersey	845,837	844,536	4	1	1	629,879	504,329	3	1	1	354,985	295,560	1	2		925,870
New Mexico						68,342	68,342	1			259,103	252,069	3		1	521,753
New York	2,200,333	2,169,097	2	12		2,184,596	2,139,457	3	9		502,645	464,285		1		3,700,290
North Carolina	495,485	495,485	2	4	23	203,171	200,293		3	1	237,433	237,433	1	1	21	1,307,949
North Dakota	174,472	173,937	4			600,080	587,143	6			223,120	223,120	2			640,117
Ohio	1,541,619	1,526,404	8	1	5	2,770,192	2,446,470	10		3	401,060	196,930	1		5	1,701,412
Oklahoma	174,980	171,185	1		28	854,619	851,209	6		6	364,715	326,673	3		5	1,559,790
Oregon	419,536	355,255	4		3	203,552	187,715	2			2,733	2,733			2	442,391
Pennsylvania	1,275,304	1,274,976	11	1		3,632,907	3,587,997	17			359,074	359,074	2			2,514,389
Rhode Island	205,241	205,241		1		3,655	3,655									273,921
South Carolina	342,530	329,197	6		20	193,969	191,669	1	3		300,375	166,701	2	2	11	972,879
South Dakota	507,443	507,443	13		9	517,942	501,992	9			41,200	41,200	2			831,331
Tennessee	301,580	289,686	3	3		1,107,220	1,107,220	6			168,376	168,376	1	1	2	1,157,544
Texas	1,121,706	1,107,973	14			1,481,277	1,469,943	14		4	87,310	87,050	1		1	2,371,290
Utah	52,721	51,979	2		17	72,872	72,872	1		10	62,710	62,710			24	359,438
Vermont	18,683	18,671			4	322,869	293,090	2								103,978
Virginia	96,542	96,542		2	1	778,475	758,515	6	3	1	38,291	38,291	1		3	952,660
Washington	170,788	170,788	1	2	1	1,258,979	562,305	7		1	7,919	7,919			3	436,261
West Virginia	253,143	247,512	3		6	654,510	654,510	6	1	2	3,330	3,330			1	776,753
Wisconsin	467,875	438,879	2		36	574,972	573,984	3	2	9	15,484	15,484			3	1,679,851
Wyoming	483,177	468,524	5		1	1,974	1,974				8,416	8,416			6	428,019
District of Columbia	2,193	2,193				299,675	275,206		1							103,351
Hawaii	187,619	187,618	2			214,170	213,655	2								282,757
Puerto Rico	103,629	102,980	1			639,340	632,516	9			141,279	140,190	2			363,914
TOTALS	20,372,574	19,761,096	151	46	363	36,725,185	34,361,314	254	54	132	8,798,261	8,025,671	43	17	326	48,373,297

Note: Includes apportionments for fiscal year 1943.

PUBLICATIONS *of the* PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

Work of the Public Roads Administration, 1940.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP . . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

Specifications for Construction of Roads and Bridges in National Forests and National Parks. 1 dollar.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–21, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF JANUARY 31, 1942

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
abama	$1,390,472	$692,608	62.5	$520,331	$284,000	25.2	$212,180	$100,080	6.0	$580,971
rizona	125,776	91,405	13.2	137,116	101,803	.8	126,598	61,439	6.8	543,761
rkansas	610,518	233,221	33.1	348,210	174,039	26.3	135,644	67,822	.2	339,836
alifornia	760,788	438,134	17.8	975,209	724,693	8.1				1,077,518
olorado	150,002	84,134	20.7	129,755	72,649	2.1	152,387	35,323	5.0	530,458
onnecticut	298,035	136,331	6.1	266,247	115,938	4.8				199,604
laware	81,076	38,116		222,731	110,890	12.3	102,873	37,617	3.9	247,133
rida	498,886	249,443	4.7	666,633	338,767	7.1	191,500	95,662	5.9	387,671
orgia	455,428	212,714	36.9	1,196,017	690,358	74.4	496,996	248,498	50.8	1,126,523
ho	285,649	173,225	26.2	177,185	108,985	7.7	78,125	48,303	5.9	308,602
nois	1,073,033	518,949	59.4	1,084,660	542,330	47.5	152,500	76,250	17.7	906,871
iana	611,250	305,625	39.8	1,128,455	531,071	46.7	189,600	94,800	6.4	926,752
wa	586,080	276,641	144.8	409,422	175,208	68.3	346,551	161,825	60.5	587,786
ansas	550,267	276,484	84.6	1,834,382	919,358	111.6	499,225	249,613	37.7	1,042,437
entucky	1,161,015	321,329	83.2	1,063,884	274,908	32.1	344,462	94,400	14.1	397,091
L isiana	564,708	230,289	20.6	7,700	3,850		289,362	138,761	21.5	702,038
M ne	77,540	38,770	3.6	235,218	117,609	10.6	16,850	2,714	.4	161,104
Maryland	473,000	236,500	19.5	333,376	166,513	3.1				345,564
Massachusetts	179,789	93,569	4.1	663,233	352,683	10.1				572,304
Michigan	1,129,971	556,411	71.4	748,998	374,499	26.7	435,870	217,935	14.2	641,630
Minnesota	1,595,353	800,819	217.1	973,916	484,197	86.9	300,776	149,988	30.1	603,968
Mississippi	712,594	356,297	33.2	1,316,867	592,299	60.9	242,200	85,000	11.5	488,205
Missouri	394,608	195,649	49.7	889,132	426,978	89.7	253,830	96,986	39.9	1,052,689
Montana	377,420	214,407	58.5	292,724	170,722	31.0	13,569	7,715	4.5	889,999
Nebraska	352,367	176,722	42.4	493,205	251,216	71.7	31,940	15,970	9.2	684,035
Nevada	225,871	191,918	24.1	92,413	60,816	4.6	99,973	79,290	4.5	229,165
New Hampshire	152,914	75,436	4.7	241,629	119,915	3.6				152,254
New Jersey	446,840	219,205	7.2	466,582	257,385	14.5	51,500	25,750	1.8	568,852
New Mexico	408,981	255,920	42.6	346,212	223,860	20.2				296,853
New York	957,018	470,060	28.8	894,946	488,111	14.3	485,666	242,833	1.5	1,095,866
North Carolina	333,240	168,620	34.9	536,151	294,407	36.3	69,820	20,000	5.0	680,994
North Dakota	29,802	15,664	2.4	3,434	3,434		808,050	793,860	42.7	759,120
Ohio	1,698,902	848,314	56.4	355,410	475,675	11.0	177,160	88,580	6.6	1,387,630
Oklahoma	363,069	191,497	21.6	64,572	34,093	9.9	903,706	477,157	64.1	1,083,038
Oregon	463,659	243,290	41.8	459,611	217,324	28.5	30,482	18,000	1.3	405,495
Pennsylvania	1,673,012	835,832	31.7	834,647	406,931	16.3	73,588	36,794	1.8	777,528
Rhode Island	220,879	111,427	2.6	14,694	10,697					138,411
South Carolina	787,356	307,866	54.6	221,700	79,945	.5				397,720
South Dakota	32,130	18,006	15.2	3,622	3,622		1,143,430	1,047,600	114.5	766,698
Tennessee	333,033	164,824	10.8	1,430,720	715,360	48.5	200,802	100,401	5.3	770,082
Texas	1,054,286	512,692	109.2	978,649	472,397	85.9	43,500	21,700	4.8	2,250,366
Utah	186,949	123,241	17.0	136,491	88,790	3.5	23,035	15,255	3.3	334,707
Vermont	40,708	18,109	1.2	180,204	59,279	7.8	46,514	23,257	1.1	88,372
Virginia	370,460	174,585	15.8	346,346	154,866	4.4	158,096	74,648	6.6	631,425
Washington	274,693	157,545	17.8	456,948	214,374	13.7				413,290
West Virginia	395,983	197,988	19.8	332,673	167,903	6.4				501,897
Wisconsin	935,930	468,059	42.7	1,382,342	634,463	46.0	76,438	37,300	.8	601,597
Wyoming	357,528	158,064	18.8	508,423	218,112	34.3				220,633
District of Columbia	80,772	39,924	0.9	2,558	1,279					161,433
Hawaii				2,375	2,375					334,875
Puerto Rico	105,633	51,430	6.4	125,732	61,425	4.2				221,235
TOTALS	26,425,273	12,967,308	1,782.1	27,033,690	13,572,401	1,280.1	9,004,798	5,189,126	617.9	30,614,086

Note: Includes apportionments for fiscal year 1943.

U. S. GOVERNMENT PRINTING OFFICE. 1942

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