DEPARTMENT OF THE INTERIOR
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BUREAU OF RECLAMATION
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HIGH-PRESSURE RESERVOIR OUTLETS

A REPORT ON BUREAU OF RECLAMATION INSTALLATIONS

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INTRODUCTION.

A large part of the water used for domestic, power, and irrigation purposes is taken from surface streams, most of which are subject to large fluctuations in flow. Originally these fluctuations were of little importance, the demand for water being relatively small and coming within the low-stage flow of the stream. However, an increase in the demand has rendered the low flow insufficient in many cases, necessitating the construction of reservoirs in which the flood waters can be stored for use at times of low normal flow.

The stored water may be led directly into pressure mains or power penstocks, or it may be discharged into low-level canals or into the original stream bed for diversion and use at some lower point. This report deals mainly with outlets of the latter type. Where the quantity of water to be discharged is small, or where the head is low, the outflow can be controlled with comparatively simple equipment. Where large flows must be released under high heads the undertaking becomes hazardous, owing to the tremendous amount of energy which must be dissipated.

When the Bureau of Reclamation entered the irrigation field in 1902 very little precedent existed for high-head outlet works of large capacities. Since that time the bureau has had wide experience in the design and operation of such works, and it is the purpose of this report to arrange and discuss the accumulated data in such a way as to make them available for guidance in the preparation of future designs. Record drawings of a number of important installations have been photolithographed and are listed on page VI of the report in order that they may be placed permanently on record.

The drawings and data presented have been compiled from correspondence, project histories, feature reports, technical papers, special reports prepared for this purpose by the project managers, and from personal inspection of the installations described.

It is not practicable to give a complete record of all the outlet works of the bureau, but it is believed that the works chosen are representative and that most of the essential features are covered. Owing to lack of time and funds, it is not possible to include the records of important installations outside of the Bureau of Reclamation, though such records would add greatly to the value of the report.

The writers are indebted to a number of engineers in the Bureau of Reclamation for valuable assistance in the preparation of this report. Special acknowledgment is due to C. M. Day, Julian Hinds, Walker R. Young, and N. B. Hunt, engineers, Bureau of Reclamation, and Ralph Lowry, assistant engineer, Bureau of Reclamation, who have been largely responsible for the preparation of drawings and assembling data.

HIGH-PRESSURE RESERVOIR OUTLETS.

CHAPTER I.

HISTORICAL SKETCH.

ANCIENT CONTROL WORKS.

The use of dams to divert and store water probably antedates the beginning of recorded history. Numerous references are made in the literature of all ages to works of this kind, but little definite information as to details can be found, even in regard to comparatively recent installations. In the earliest storage reservoirs the discharge was probably passed through open outlets controlled by large stones or other obstructions, and early development no doubt followed along

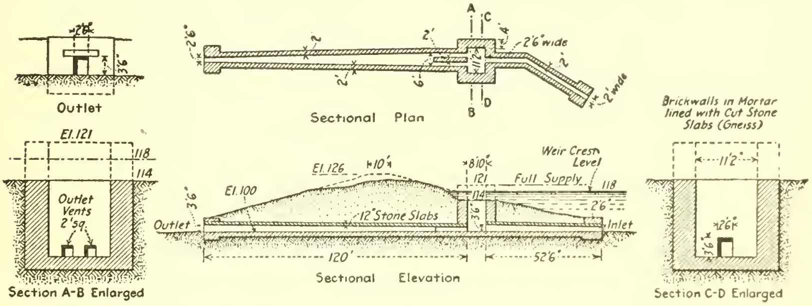


FIG. 1.—Outlet works Pavat Kulam Tank, Ceylon. Built about 250 B. C.

the line of surface control devices similar in principle to the simpler devices used for spillway control at the present time.

In the Engineering News of September 22, 1910, W. G. Bligh gives an interesting description of the ancient irrigation works on the island of Ceylon. The structure illustrated in Figure 1 is described in this paper and is stated to have been built about 250 B. C. Bligh believes that the outlets from the valve well shown were controlled by stone slab gates, probably opened with a lever arrangement and closed by driving.

Other works are described in which both the entrance and the outlet to the well were controlled by gates. Some of these structures are in a fair state of preservation at the present time. According to Bligh, "valve-well" outlet structures were not introduced into Europe until the nineteenth century.

Records indicate that bronze sliding gates, under appreciable heads, were used for reservoir-outlet purposes as early as the beginning of the sixteenth century. Rollers under the seats of sliding gates to reduce the force required for operation were introduced in Ireland in 1883 by F. M. Stoney. Since that time "Stoney" gates have been successfully used in large sizes under moderate heads for canal lock gates and checks. Neither roller gates nor plain sliding gates have, however, been found suitable for high-head outlets.

The use of valves in pipe lines appears to have had an ancient origin. The 6-inch bronze cock shown on Plate I, *A*, was constructed probably 2,000 years ago and used in the water-supply system of ancient Rome. (See Frontinus and the Water Supply of the City of Rome, Clemens Herschel, p. 198.) There is no indication that this valve was improved upon for many centuries.

AMERICAN GATE VALVES.

The crude gate shown on Plate I, *B*, was installed in New York City in 1776. (See Engineering News, July 23, 1914, p. 218.) The valve shown on Plate I, *C*, was installed in New York City in the early part of the nineteenth century. The body and leaf of this valve are of cast iron, the other parts being of wrought iron. (See Engineering News, September 3, 1914, p. 494.)

The gate valve developed rapidly after the general introduction of iron pipe, and a great variety of sizes and types are now carried in stock by numerous manufacturers. Plates I, *D*, and I, *E*, show two standard types of gate valves for installation in pipe lines. It is not necessary to mention the many valves of special design now manufactured for comparatively small pipes, since they have no bearing upon the type of outlet works under consideration.

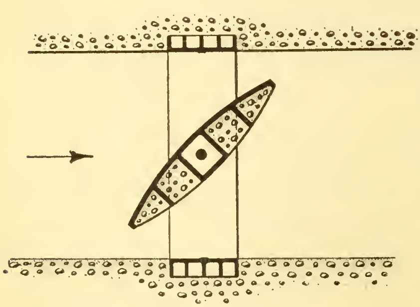
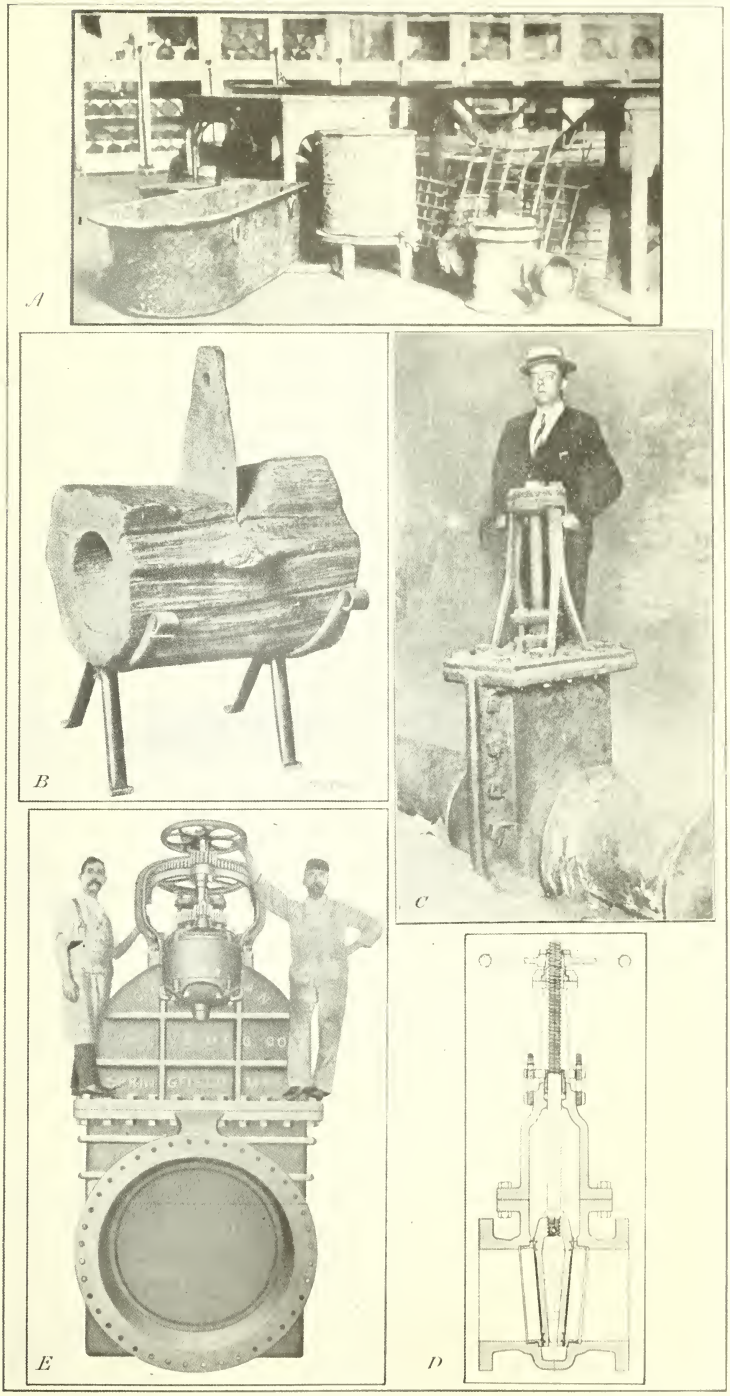


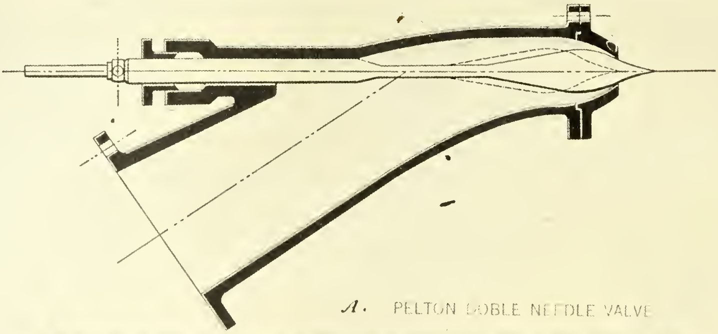
FIG. 2.—Butterfly gate.

BUTTERFLY GATES.

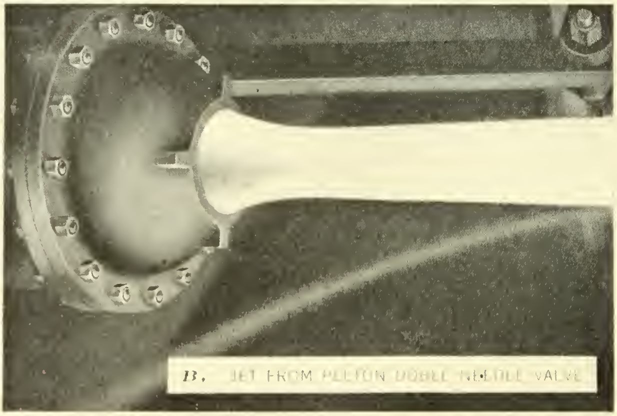
The type of valve shown in Figure 2, known as the butterfly gate, is used to a limited extent in pipes, but it is not believed to have been used continuously to produce an appreciable drop in pressure. The



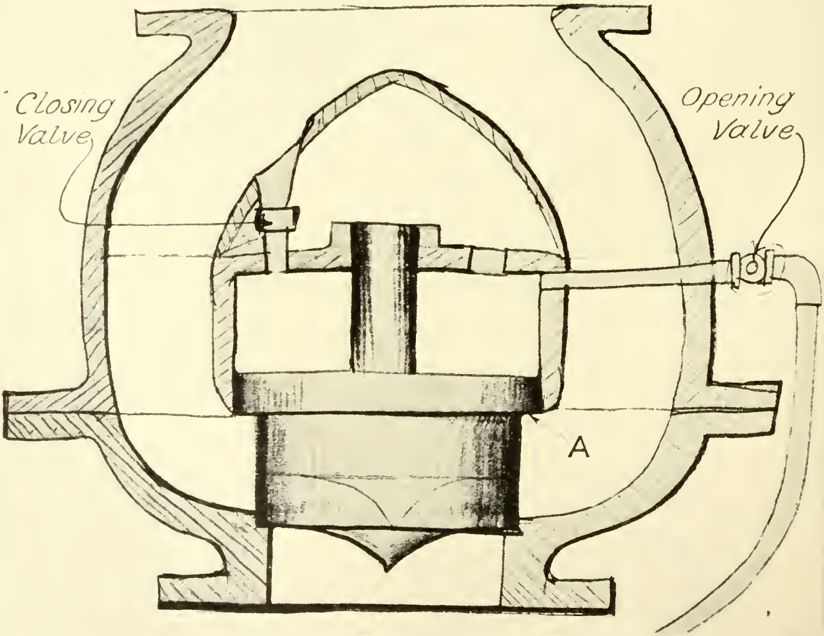
A, WATER SUPPLY EQUIPMENT OF ANCIENT ROME. *B*, GATE VALVE INSTALLED IN NEW YORK CITY IN 1776. *C*, AN OLD WATER-WORKS VALVE, NEW YORK CITY. *D*, A MODERN GATE VALVE. *E*, A LARGE MODERN WATERWORKS VALVE.



A. PELTON DOBLE NEEDLE VALVE



B. JET FROM PELTON DOBLE NEEDLE VALVE



C. EARLY SKETCH OF THE ENSIGN BALANCED VALVE use of such a valve as an emergency gate will be subsequently discussed.

CYLINDER GATES.

Slide gates of large size under high heads require a large operating force, a difficulty which may be avoided by the use of a balanced gate. An early type of cylindrical balanced gate is shown in Figure 3. This gate was installed about 1890 in connection with the locks in the Muskingum River in Ohio. (See Engineering News, April 9, 1908, p. 400.) This gate is rendered water-tight by a close fit into the lower conical seat and by the self-adjusting leather seal at upper seat. It was designed by Col. W. E. Merrill, Engineer Corps, U. S. Army, and is said to be very similar to a valve previously used in the Central Canal of France. The cylindrical gate is opened by being lifted up into the dome above it, the operating force being only that required to lift the weight of the gate and to overcome friction of the gate in the guides, the friction being independent of the head on the gate. The casing around the stem is carried up above the water surface to avoid a stuffing box. Although probably not originally intended for that purpose, this casing, if open at the top, forms an excellent air vent.

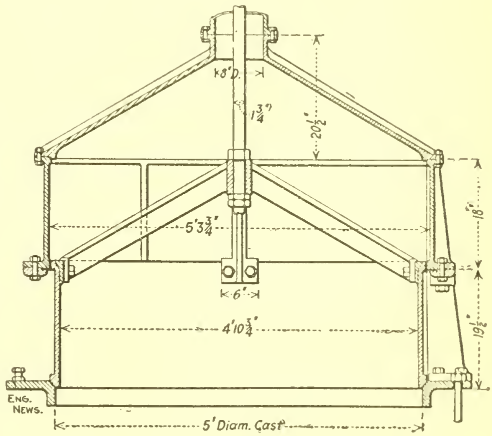


FIG. 3.—Balanced cylinder gate, 1890.

The cylinder gate shown in Figure 4 was installed in the new Croton Dam outlet works, New York City water-supply system, in 1905. The gate is set at the bottom of an outlet well and operates under a maximum head of about 95 feet. The discharge enters through eight ports and passes downward into a conduit connecting with the main aqueduct. (See Engineering News, October 4, 1906, p. 346.) An outlet gate of similar design was installed at the Lahontan Dam on the Newlands project, Nevada, in 1914, for operation under a maximum head of 100 feet. This installation is described in detail in Chapter XIV.

The cylinder gate shown in Figure 5 is a more recent type, the metal dome being replaced by a concrete tower extending to the water surface. This arrangement permits the installation of more than one gate in the same tower. Outlets controlled by gates of this type are discussed in Chapters XVII and XVIII. Similar gates, designed to operate on the outside of the concrete tower, have also been proposed.

NEEDLE VALVES.

The demand for power in the early mining days of California led to the development of the Pelton wheel, which is driven by the impact of a jet discharged at high velocity against buckets attached to the perimeter of the wheel. In order to secure the maximum efficiency from these machines, it is essential that the jet be discharged with a velocity approaching as nearly as possible the theoretical spouting velocity. In the first installations the flow to the nozzle was controlled by a gate valve in the supply pipe. The inefficiency of these valves at partial opening led to the adoption of deflectors and other devices for controlling the speed of the wheel without diminishing the volume of the jet. These devices were wasteful of water and subject to other objections, and the demand for a control capable of diminishing the volume of discharge without destroying the solidity of the jet or materially reducing the velocity led to the development of the needle valve. The term needle valve is now generally applied to any valve having a circular discharge orifice, closed by a pointed plunger. The Pelton needle is operated by external mechanical force applied to the stem, which is brought out through a stuffing box. Plate II shows the essential parts of such a valve. In power development, where efficiency is of great importance, refinements of

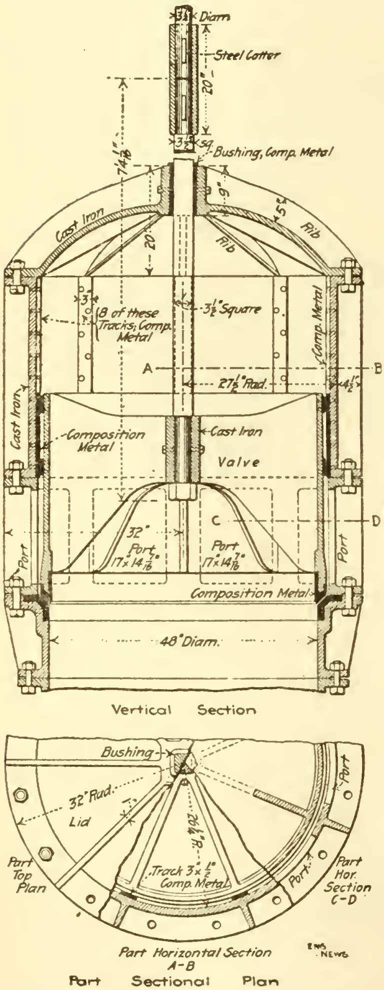


FIG. 4.—Cylinder gate, new Croton Reservoir.

design and manufacture were introduced to produce a smooth, solid jet. The form of jet secured is illustrated on Plate II.

The success of the needle valve in power development under high heads led to the adoption of this general type of valve for high-pressure reservoir outlets. In this development, however, refinements were omitted and efficiency sacrificed to some extent to secure simplicity and low cost. In the larger sizes required in irrigation work, mechanical operation becomes difficult because of the heavy loads imposed on the operating mechanism, and various means of partially or completely balancing the hydraulic forces on the plunger have been employed. In the 38-inch needle valve illustrated in Figure 6, no attempt is made to balance the water load on the plunger. In the motor-operated valves at the Roosevelt Dam, described in Chapter VI, and in the Minatare valves, Figure 7, the load is partially balanced. In the valves of the type illustrated in Plate II and in Figures 8 to 11, inclusive, the water load is completely balanced by inclosing the rear end of the plunger in a close-fitting cylinder in which the pressure can be controlled. The latter form has proved most success-

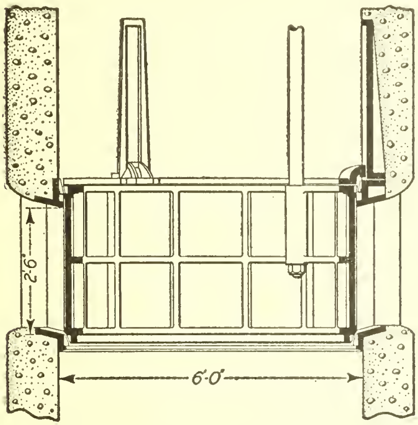


FIG. 5.—Inside cylinder gate.

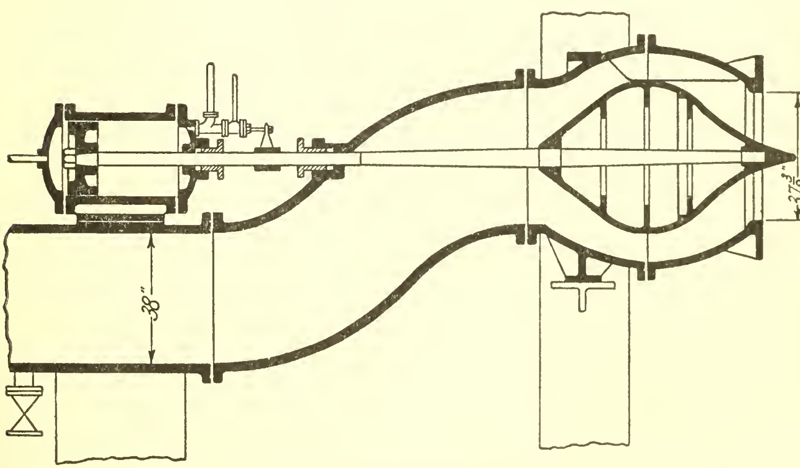


FIG. 6.—Needle valve, 38 inches in diameter, South Tunnel, Roosevelt Dam.

ful in irrigation work and is generally referred to as a "balanced needle valve" or simply as a "balanced valve."

BALANCED VALVES.

The free-hand sketch, Plate II, represents an early step in the development of the balanced valve and the most recent practice is

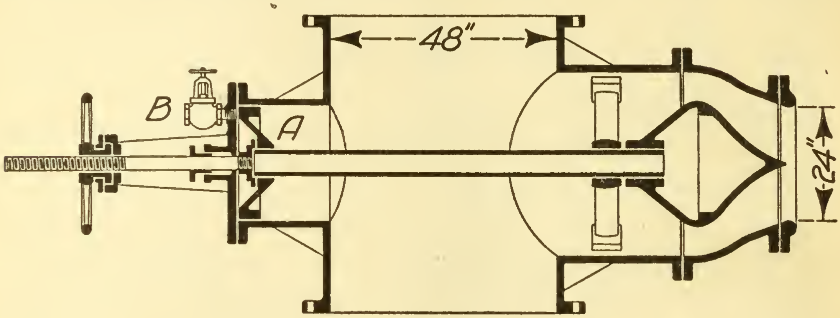


FIG. 7.—Needle valve, Minatare Dam.

reverting to this general arrangement of parts. This sketch was drawn in 1906 by O. H. Ensign, then chief electrical engineer of the Bureau of Reclamation, and was used as a basis for a design of an experimental valve tested at the Roosevelt Dam. Force for

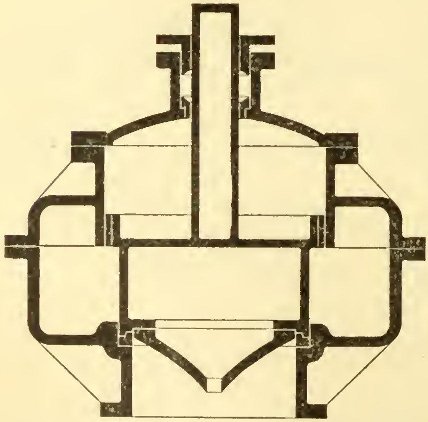


FIG. 8.—Experimental balanced valve, Roosevelt Dam, 1906.

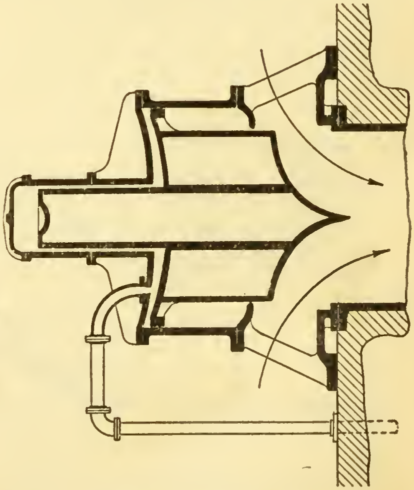


FIG. 9.—Balanced valve, Arrowrock type.

opening the valve is provided by the pressure on ring "A," and operation is effected by the two control valves shown. A section of the experimental valve as built in 1906 is shown in Figure 8, and a description of this valve will be found in Chapter V. Figures 9 and 10 show, respectively, the types of valves installed at Arrowrock and Elephant Butte Dams. These valves were designed for hydraulic control and are typical of the balanced valves installed in the dam or on the water face of a dam. The operating principles and results obtained from these valves will be discussed in subsequent chapters. This form of installation requires the dissipation of a considerable amount of energy within the outlet conduits, especially when working at partial openings, with the result that the conduits are often seriously damaged. On this account most of the later high-head installations provide for taking the flow

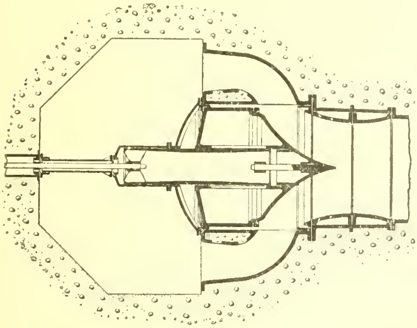


FIG. 10.—Balanced valve, Elephant Butte Dam type.

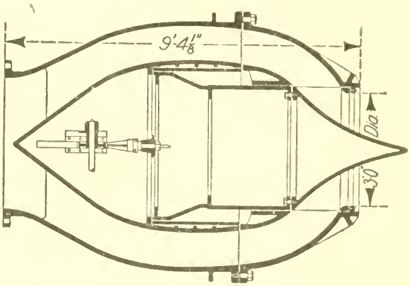


FIG. 11.—Needle valve, 36 inches in diameter, Shoshone Dam, 1922.

through the dam under full pressure and discharging it freely into the air, the dissipation of energy being effected entirely below the structure. The balanced valve illustrated in Figure 11 is one of the latest developments in the design of balanced needle valves, and a full description will be found in Chapter V.

There have been various commercial developments more or less independent of the work of the Bureau of Reclamation, notably by R. D. Johnson, who patented a valve of this type in 1912, and more recently by the Larner-Johnson Valve & Engineering Co., the Wellman-Seaver-Morgan Co., and the Coffin Valve Co. These valves are described in the chapter on needle valves.

Chapter II.

ARRANGEMENT AND DESIGN OF OUTLET WORKS.

SELECTION OF TYPES.

It is not possible to lay down definite rules from which the correct form of outlet for a given case may be determined. Careful consideration must be given to the head, volume of water to be discharged, kind of dam, foundation materials, ice conditions, trash conditions, operating plan of reservoir, and to certain general principles which have been established from experience with various arrangements of gates and valves. Most of the difficulties with the outlets built by the Bureau of Reclamation can be attributed to the effects of vacuum in the conduits below the regulating devices. Generally the damage to the conduits has been more serious than to the valves, although under extreme conditions the valves have also been seriously damaged.

In valves and conduits carrying water at high velocities an irregular pitting or cavitation of the lining is often observed. This appears first as a slight blemish on the surface, but if allowed to continue the material becomes honeycombed to a considerable depth and is ultimately destroyed. The surface is not worn away by attrition or sand-blast action, but is roughened as though attacked by chemical action. Cast iron is particularly subject to this action, steel is somewhat less affected, and some kinds of bronze will stand up fairly well. Concrete appears to withstand this action better than some metals, although experience with this material is not strictly comparable with the experience with metals. Similar action has been observed in water-wheel runners, particularly when operated at improper speed. Cavitation usually occurs downstream from some irregularity in the water passage and is undoubtedly caused by the formation of a local area of low pressure, due to the stream leaving the surface. The most generally accepted theory is that nascent oxygen is released from the air in solution as it enters the area of low pressure. This powerful oxidizing agent acts on the material present, producing a relatively soft oxide, which is carried away by the stream. A number of cases of damage to throat pieces and other parts of gates are cited later, all of which are probably due to this action.

The other important result of vacuum is the mechanical action of the surging water on the walls of the conduit, which has in many instances torn up massive concrete linings, heavy metal castings, and hard native granite. These results are no doubt partly due to direct impact of the flowing stream and partly to violent surges resulting from breaking and reforming the vacuum, which occurs when the outlet is running nearly full.

Although it is difficult to explain the results of the action of the water, it is easy to determine the source of the destructive energy. Assume, for example, that the area of the tunnel is twice the area of the gate opening and that the velocity of discharge through the gate into a perfect vacuum is 100 feet per second, the grade of the tunnel being level. Let the tunnel be arranged so that it will run full, let no air vent be provided, and let the gate opening be 4 feet square. The velocity head will be 156 feet at the gate and 39 feet at the end of the tunnel, the drop being 117 feet. The increase in pressure head is from zero to 1 atmosphere, or 34 feet, which leaves a net drop of 83 feet. The energy corresponding to this loss of head must be converted into heat within the tunnel. The conversion must be made by agitating the water, and, since the volume subject to agitation is small, the disturbances must be violent. The disturbances will be distributed over the length of tunnel necessary to secure an approximately uniform distribution of velocities.

The practical remedy applied is the introduction of air immediately below the regulating devices to relieve the vacuum. This plan has been carried out in many cases and greatly improves the operating conditions and increases the life of the installation. The improvement is probably due to a number of causes. The production of nascent oxygen is stopped and oxidation prevented, the surging action of the water is materially reduced, the velocity through the orifice is reduced by increasing the back pressure, and the air cushions the force of the water against the walls of the conduit.

In the design of outlets for high heads any conditions tending to produce vacuum should be avoided as far as practicable, and, if this is impossible, an ample air supply should be provided. If the water can safely be brought through the dam under pressure and the regulating valve, usually a needle valve, allowed to discharge freely into the air, all danger of vacuum is eliminated. This form of outlet is proving very satisfactory for high heads, although it is quite expensive. An entirely different theory is used in the design of the cylinder gates now in successful use under heads up to 100 feet. This is the complete dissipation of the energy of the jets within the outlet, ample air being supplied to prevent vacuum. Each form has its advantages and disadvantages. In general the cylinder gate is applicable to heads below 100 feet, while the needle valve is especially suitable for higher heads.

ELEMENTARY TYPES.

A few elementary types of outlets are illustrated in Figures 12 to 18, inclusive, a brief discussion of the merits of the various arrangements being given in the accompanying text. Before preparing a design, detailed studies and comparative estimates should be made for all types which appear to be applicable, and from these studies

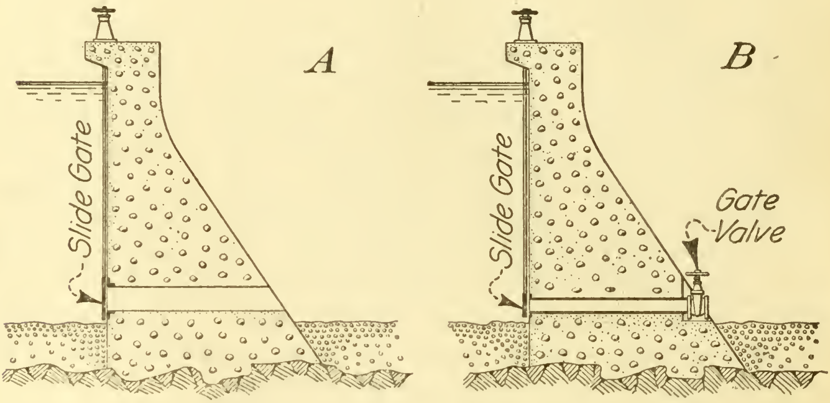


FIG. 12.—*A*, Single slide-gate outlet; *B*, Gate-valve outlet.

the most suitable type of outlet should be selected. Alterations and combinations of the types may be made as required.

The outlet shown in Figure 12, *A* is simple and is widely used for small reservoirs. It is suitable only for low heads. The unprotected location of the gate renders it especially subject to interference from trash and ice. An installation consisting of several small gates in parallel is preferable to one large gate, since in the former case the failure of a single unit will not completely destroy the usefulness of the outlet. If proper allowance is made for contingencies this type of outlet may be used for operating heads up to 75 feet, and by installing a series of outlets at different elevations it is possible to provide for any depth of reservoir. However, this outlet is recommended only for the most unimportant installations. If the head exceeds 10 or 15 feet an air vent should be provided immediately below the gate to relieve any vacuum which may tend to form there.

The type shown in Figure 12, *B*, is used to a limited extent, regulation being secured by operating the gate valve on the downstream end of the conduit pipe. The upstream gate is intended for use only in case of accident to the gate valve. The leaf of the gate valve should be rectangular rather than circular, to provide greater strength and better guiding and to avoid a moon-shaped orifice at partial opening. Both valve housing and leaf should have brass or bronze seats, and the design should be such as to eliminate chattering. The valve should preferably be at the end of the pipe; otherwise an air vent will be required. A gate valve is not well suited to free discharge control and this type of outlet is not recommended for heavy duty or high heads.

The arrangement shown in Figure 13, *A*, embodies the principles of the original outlets at Roosevelt Dam, the failure of which is fully described in Chapter VI. The Roosevelt outlets, which were not air vented, were designed to operate under a maximum head of 220 feet, but were soon destroyed under a much lower head. A very similar outlet for the Strawberry Reservoir, provided with air vents, has proved successful under heads as high as 50 feet.

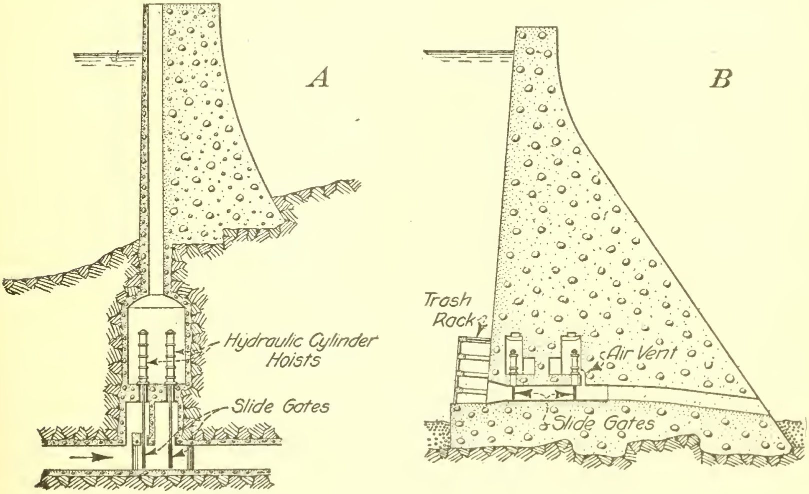


FIG. 13.—*A*, Slide-gate control in tunnel; *B*, Double slide-gate outlet.

The type of outlet illustrated in Figure 13, *B*, is superior to that just discussed and is similar to the sluice outlets at Elephant Butte Dam, the operation of which is discussed in Chapter XIII. The gates are of heavy cast iron, with bronze seats, and are operated by hydraulic cylinders set in cavities provided for them in the body of the dam. Entrance to the two operating chambers is made through separate passages so arranged that a break in one chamber will not flood the other. The upstream gate is intended for emergency use only, any necessary regulation being effected by the downstream gate.

The Elephant Butte sluice outlets were not designed to be used for regulating purposes, but were intended only for draining the reservoir or for removing silt from in front of the outlet works. However, these outlets were used for a time to discharge water for irrigation under heads varying from 89 to 113 feet. The resulting damage to the cast-iron conduits is discussed in the chapter on Elephant Butte Reservoir. The castings were pitted below irregularities, such as gate grooves and recesses for bolt heads. The gates were operated in the fully open position only, and the gate leaves were not injured. These outlets are not air vented and if operated at part opening, under the heads named, would probably be rapidly destroyed, as were the Roosevelt Stoney gates. This type of outlet is not recommended for heads of more than 75 feet, and the regulat-

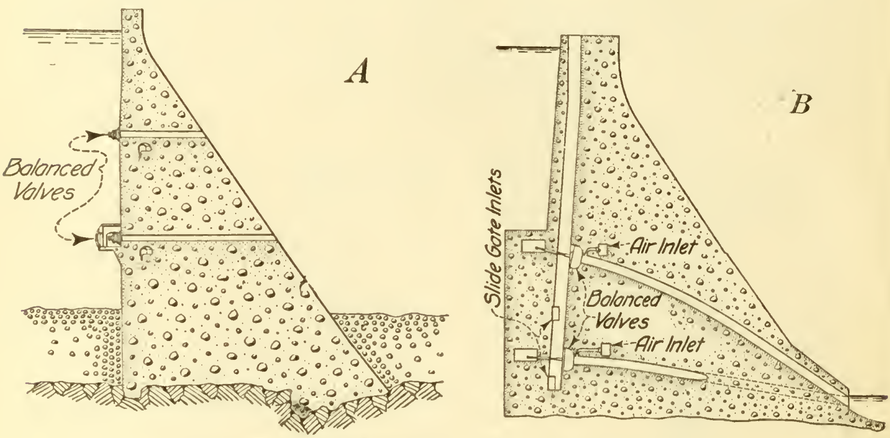


FIG. 14.—*A*, Balanced-valve outlet, Arrowrock type.
B, Balanced-valve outlet, Elephant Butte type.

ing gate should be amply air-vented. The necessity for trash racks will be determined by local conditions.

Figure 14, *A*, illustrates the simplest form of balanced valve outlet and is similar to the outlets used at Arrowrock Dam. The valve is of the type illustrated in Figure 9. This outlet has been found to be very satisfactory in service, except that the throat pieces of the valves show a tendency to "cavitation" unless properly supplied with air, and some erosion of the conduits has been observed. The valve is unprotected, and no emergency gate is provided. However, the balanced valve is considered less liable to damage in operation than the slide gate, and this outlet is recommended for operating heads as high as 200 feet where the reservoir can be drawn down at least once each year to allow the valves to be inspected and repaired. It has the advantage of being simple and cheap in comparison with other balanced-valve and needle-valve installations.

Figure 14, *B*, represents the balanced-valve outlets at Elephant Butte. (See Chap. XIII.) Balanced valves of the type illustrated in Figure 10 draw the discharge from an intake well which is supplied through slide gates set at two or more elevations. Flow is controlled by the valves, the slide gates being operated fully open. The valves may be installed in two or more tiers to avoid the necessity for operating the lower ones under extremely high heads. The conduit from the upper valve in the figure is shown dipping down, so as to discharge under water. Access may be had to the valves at any time by closing the guard gates.

The outlet illustrated in Figure 15, *A*, is similar to the one just discussed, except as to type of valve used and location of guard gates. Both of these types are good and are recommended where the un-

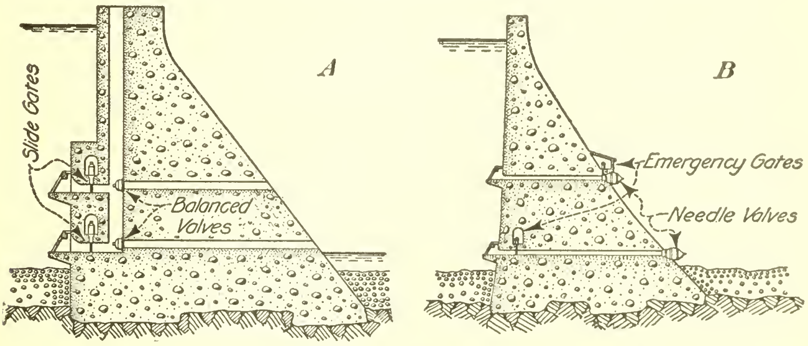


FIG. 15.—*A*, Guarded Arrowrock type outlet; *B*, Downstream needle-valve outlets.

guarded balanced valve is not considered safe. The valves should preferably not be operated under heads exceeding 200 feet.

The lower outlet in Figure 15 *B*, represents the most approved type for high heads. The flow is taken through the dam in a metal-lined conduit and discharged through a needle valve into free air. A pool is soon formed where the jet strikes the water, and the dissipation of energy is accomplished without damage to the structure. Guard gates are provided near the upstream end of the conduit. The outlets may be arranged in tiers if the depth of the reservoir is great. The guard gate may be located near the downstream face of the dam, if desired, as shown in the upper outlet, but this arrangement does not permit of repairs to the metal conduit. A clear space may be provided around the conduit to avoid the possibility of introducing water under pressure into the body of the dam. It is sometimes recommended that the metal lining be omitted, the conduit being formed simply by a hole through the concrete. This practice is somewhat dangerous for high-head outlets, especially for dams not designed for full uplift. The concrete immediately surrounding such unlined conduits should be carefully placed to avoid seepage of water under pressure into the body of the dam, and reinforcing should be provided to take the full hydrostatic pressure. The maximum head under which large needle valves may be safely operated has not been definitely determined, but certain limiting heads are suggested in the chapter on needle valves.

The outlet shown in Figure 16, *A*, embodies the principles of the south tunnel outlet at Pathfinder Dam, the operation of which is discussed in Chapter IX. Unless air is provided, the conduits and the tunnel are rapidly destroyed. This is not a desirable type.

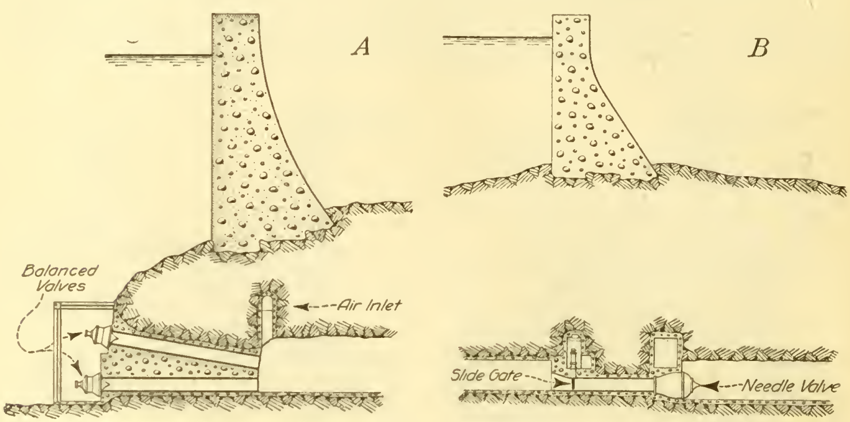


FIG. 16.—*A*, Balanced valves in tunnel; *B*, Needle valve in tunnel.

The outlet shown in Figure 16, *B*, has not been used or proposed by the Bureau of Reclamation, but it is understood that outlets of this type are being recommended for important installations elesewhere. On account of the short discharge pipe, this outlet is lower in first cost than an outlet of the type shown in Figure 18, *D*, but it is subject to the serious objection that the energy of the issuing jet must be largely dissipated within the tunnel. A needle valve brought out into the open air is very much to be preferred.

Figure 17, *A*, illustrates the simplest form of outlet for an earth dam. It is suitable only for the most unimportant work.

The type shown in Figure 17, *B*, is somewhat more elaborate. The gates and stems are in a protected location, and trash bars may be provided at the entrance. In this type, as in all other gate-tower types, the location of the gate shaft or tower should be carefully considered. With the setting shown a crack in the conduit upstream from the gate is liable to introduce water under pressure into the body of the dam, which might cause leakage. If the shaft is set out into the reservoir, there is danger of water creeping down the outside of the shaft, unless it is located at the extreme upstream end of the conduit, in which position it is subject to damage by ice and waves.

A somewhat better type of outlet is illustrated in Figure 17, *C*. The tower is divided into two parts by a partition, and an upstream gate is provided for emergency use, making it possible to unwater the downstream gate for repairs without emptying the reservoir. This

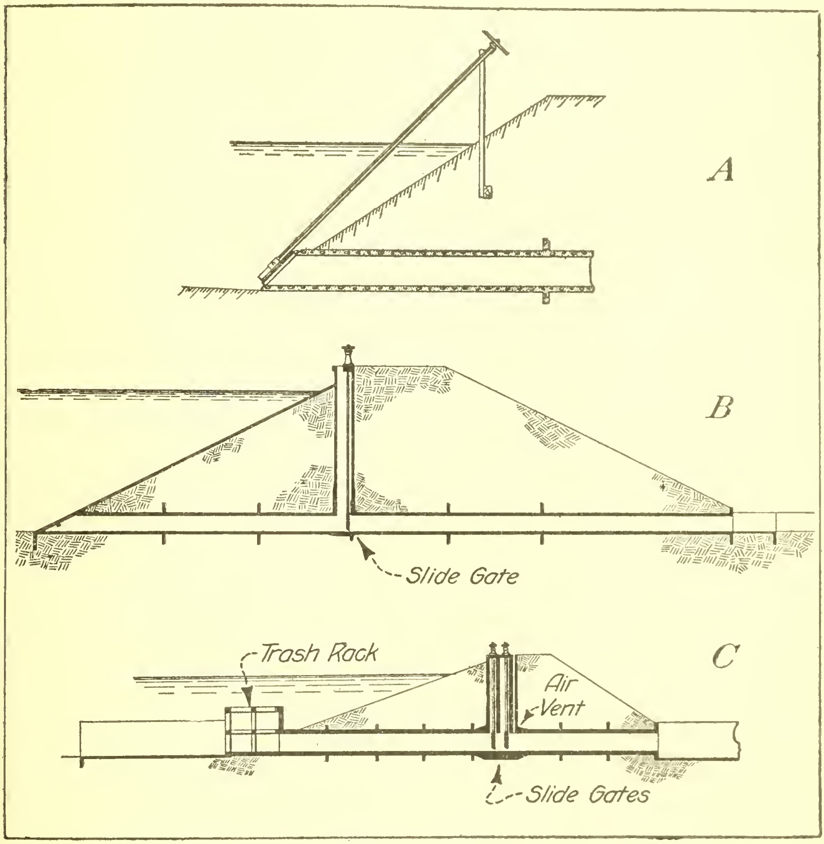


FIG. 17.—*A*, Simple outlet through earth dam.
B, Single slide-gate tower outlet.
C, Double slide-gate tower outlet.

type may be used for heads up to 75 feet. Unless conditions are such that the tunnel below the gate tower can not possibly run full, or nearly full, an air vent of ample capacity should be provided below the downstream gate.

The outlet shown in Figure 18, *A*, is similar to the outlet at Lahontan Dam, Newlands project, the operation of which is described in Chapter XIV. The valve is of the type shown in Figure 4. This outlet can be made to work satisfactorily if properly designed and supplied with air. An open pipe connecting the valve dome with the air, similar to the stem housing shown in Figure 3, greatly improves the operation of the valve. If the cross-sectional area of the conduit remains constant below the valve seat, no other vent is required, but if it is expanded the air inlets shown are necessary.

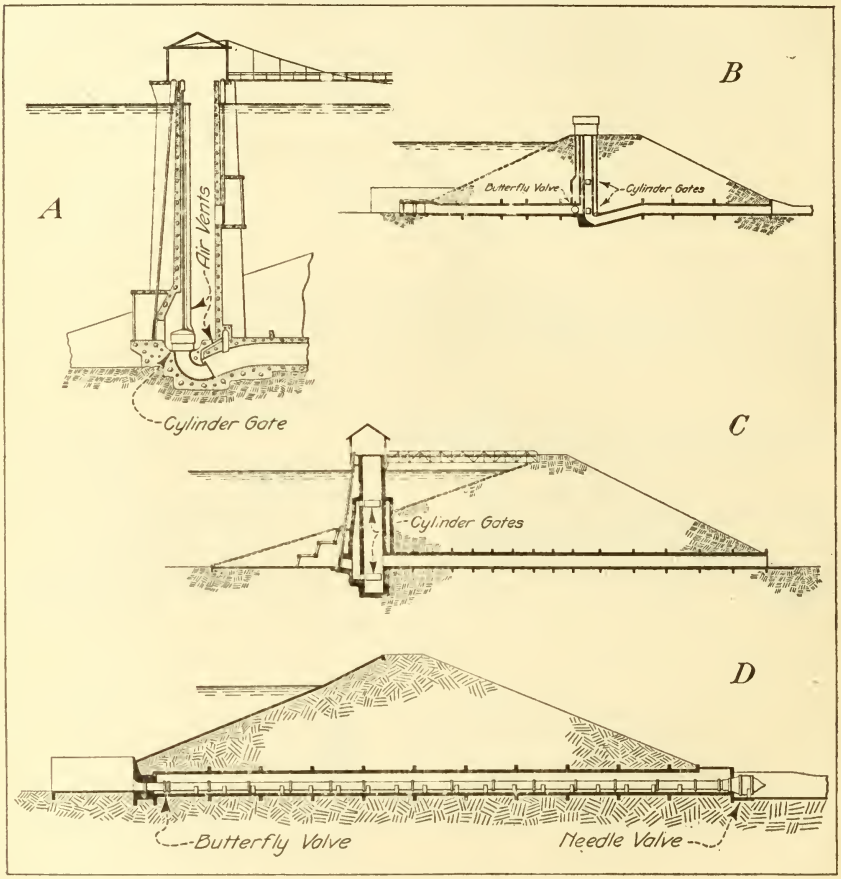


FIG. 18.—*A*, Cylinder-gate outlet, Lahontan type.
B, Cylinder-gate outlet, Sherburne Lakes type.
C, Cylinder-gate outlet, McDonald Lake type.
D, Needle-valve outlet through earth dam.

Figures 18, *B*, and 18, *C*, illustrate settings for the cylinder gate shown in Figure 5. These types may also be adapted to the outside cylinder gate. (See discussion of cylinder gates in Chap. III.)

Figure 18, *D*, illustrates the adaptation of the needle valve to an earth dam. The Minatare outlet on the North Platte project is of this type, except as to details of the needle valve. (See Chap. XV.) This type is also adapted to installation in tunnel through natural ground around the end of a masonry or earth dam. The use of the butterfly or sliding guard gate is optional. This outlet has the advantage of requiring no gate tower.

OUTLET LOSSES.

The number and size of the outlet units required to fulfill a given set of conditions depend, among other things, upon the relation of head to discharge for a single unit. This relation is influenced by all the details of the outlet, and it is impossible, in all but the simplest cases, to make a direct determination of the proper size or number of units. A definite unit must be assumed and cost and capacity curves constructed, from which an economical outlet may be chosen.

The losses through the outlet may be classified as follows:

(*a*) *Trash-rack losses*, which occur where the flow passes through a trash-rack structure. The designed velocity through the meshes of the rack is usually low and the corresponding loss is small. It is usual, however, to assume that the bars are likely to become choked with trash sufficiently to cause a measurable loss of head. In case of a high demand for water with a low reservoir, it may be assumed that any obstruction sufficient to cause a loss of head in excess of 0.50 foot will be removed, and it is recommended that ordinarily an allowance of 0.50 foot be made for loss of head through trash racks. If conditions are very favorable to cleaning, a smaller loss may be assumed.

(*b*) *Entrance losses*, where the flow enters the outlet conduit. The amount of entrance loss, which depends upon the velocity in the conduit and the form of the intake, may be expressed with sufficient accuracy as a percentage of the velocity head corresponding to the velocity in the conduit. Experimental data from which to determine the percentage of loss are meager. For a square entrance, as through the gate frame in Figure 12, *A*, and for balanced valves of the Arrowrock or Elephant Butte types, it is recommended that a loss equal to 0.50 of the velocity head be assumed. For a perfect bell-mouth entrance the loss will probably not exceed 0.05 of the velocity head. For an excellent tunnel entrance a factor of 0.10 may be used. The loss through a gate in a thin wall, as through the ports of the cylinder gates, Figure 18, *C*, or through any orifice where contractions are not suppressed may be as high as 1.50 times the velocity head in the orifice. If the corners are rounded, a factor of 1 may be sufficient. The last two factors correspond to "discharge coefficients" of 0.62 and 0.71, respectively. It should be borne in mind that these losses are due principally to contraction of the jet and that the actual velocities often approach the theoretical velocities.

(*c*) *Transition losses*, where the size of conduit is changed. If the change in conduit section is gradual, the loss will be small. In case of a sudden decrease in size of conduit the factors recommended for entrance losses may be applied, the change in velocity head being used in place of the velocity head. In case of an enlargement a loss twice as great as would be taken for a contraction of the same form is probably conservative. The total loss due to the expansion should not be taken greater than the change in velocity head.

(*d*) *Bend and curve losses*, which occur wherever the direction of flow is changed. The existing information from which to determine curve losses is very unsatisfactory, as is shown by Figure 19. The losses are given in percentage of velocity head for a 90° bend and are based upon data given in Merriman's Hydraulics. It is not possible to reconcile or average the various observations. The heavy curve marked "Recommended" has been adopted tentatively by the Bureau of Reclamation, but there is no assurance that it is any more nearly correct than any other curve. For bends other than 90° it seems to be agreed that the percentage of loss varies as the square root of the angle.

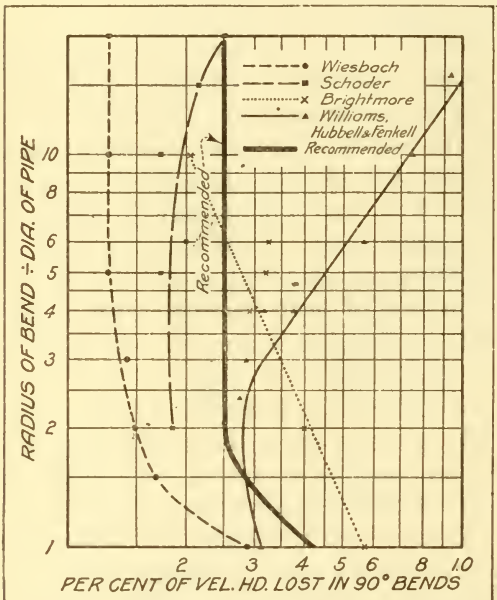


FIG. 19.—Curve losses in pipe.

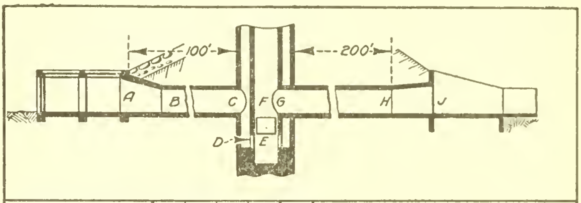
Where the direction of flow changes abruptly through a right angle, the entire velocity head before the change may be considered as lost. For example, in an outlet of the type shown in Figure 18, *B*, it may be assumed that all the velocity head in the intake tunnel will be lost at the base of the tower, the head due to vertical velocity in the well will be lost at the entrance to the gates, the velocity head through the gate orifice will be lost in changing to vertical flow in the inside well, and the velocity head in the well will be lost at the entrance to the outlet conduit.

(*e*) *Friction losses in the conduits.* Where conduits are circular and regular, the friction loss may be computed from any accepted pipe discharge formula. Where the shapes are irregular or special "Kutter" may be used to advantage. For concrete conduits a value of 0.014 for Kutter's "*n*" is recommended.

(*f*) *The velocity head* at point of emergence or at some other controlling point. If at any point the energy of flow is more than sufficient to overcome the resistance below that point, such point becomes a control. If air is available at such point, the discharge may be computed as if the conduit ended there; otherwise the effect of vacuum must be considered.

Typical computations and discharge curve for a cylinder gate outlet are illustrated in Figure 20.

This outlet involves more separate losses than any other commonly used type. A straight outlet through the dam, controlled by one or more gates with gates wide open, involves only entrance loss and friction. If the outlet is controlled by a single balanced valve at the upstream end, as at Arrowrock Dam, friction may be neglected unless the outlet tube is long. Unless the conduit is contracted, the velocity will be reduced below the valve, and the energy thus set free may be counted upon to overcome frictional resistance. No reliable observations have been made on cylinder-gate outlets for the purpose of determining actual losses of head. The computed losses shown in Figure 20 are based on very rough assumptions and are therefore only approximate.



Discharge, Sec. Ft	200	400	600	800	Area
+ Static Pressure at H	0.00	00.00	00.00	00.00	28.27
Velocity Head at H	0.78	3.11	7.00	12.42	.
Friction G to H	0.50	1.98	4.46	7.92	..
△ Entrance Loss at G	0.39	1.56	3.50	6.21	.
Velocity Head at F	0.78	3.11	7.00	12.42	..
Friction E to F	0.03	0.10	0.22	0.40	.
° Head thru Gate D to E	3.09	12.32	27.73	49.37	20.00
Vert Velocity Hd at D	0.16	0.63	1.42	2.52	62.83
Friction C to D	0.01	0.03	0.08	0.14	.
Hor. Velocity Hd. at C	0.78	3.11	7.00	12.42	28.27
Friction B to C	0.25	0.99	2.23	3.96	..
□ Transition A to B	0.06	0.25	0.56	1.00	
△ Entrance Loss at A	0.08	0.32	0.68	1.21	64.00
Trashrack Loss	0.50	0.50	0.50	0.50	
Total Ft.	7.41	28.01	62.38	110.49	

+ Neglecting recovery H to J.
° Discharge Coefficient = 0.71
□ 0.1 Change in Velocity Head.
△ 0.5 Velocity Head.

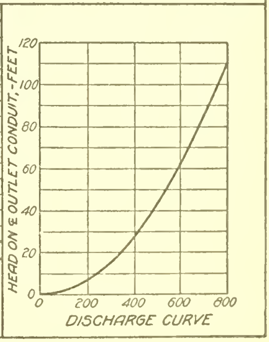


FIG. 20.—Typical computations for outlet losses.

ECONOMIC OUTLET CAPACITY.

A discharge curve similar to that shown in Figure 20 can be constructed for any outlet and may be used for determining whether the assumed structure is of sufficient size to meet the requirements. It is often assumed that a certain fixed discharge will be required at all times, the storage below the point at which the required flow can be maintained being considered valueless. If both the required discharge and the minimum head are known, the necessary size of outlet or the required number of outlet units of a given size may be determined from the discharge curve. If the discharge only is known, the proper minimum head must be determined by comparing the cost of the outlet works with the value of the lost storage or the storage below the required discharge head.

As an example let it be required to find the economic number of Arrowrock valves for discharging 4,000 second-feet from a given reservoir, the cost of one outlet being taken as $6,500 and the value of an acre-foot of storage capacity as $10. From the rating curve for one outlet unit (not shown) and the known or assumed elevation of the outlet find the water-surface elevation required to maintain the given flow with any number of units and list as in column 2, Table 1. From the storage capacity curve for the reservoir (not shown) fill in column 3, all storage below the required discharge level being considered lost. Then fill in columns 4 and 5 and combine to get column 6. Eight gates are found to be more economical than any other number.

TABLE 1.—*Economic number of 52-inch outlets to discharge 4,000 second-feet.*

Number of units.	Required head on outlets.	Storage loss acre-feet.	Cost of outlets, $6,500.	Value of lost storage at $10 acre-foot.	Cost of outlets plus value of lost storage.
1	2	3	4	5	6
4	111.7	36,000	$26,000	$360,000	$386,000
5	71.5	12,900	32,500	129,000	161,500
6	49.6	5,700	39,000	57,000	96,000
7	36.8	3,400	45,500	34,000	79,500
8	27.9	2,300	52,000	23,000	75,000
9	22.1	1,700	58,500	17,000	75,500
10	17.9	1,300	65,000	13,000	78,000
11	14.8	1,000	71,500	10,000	81,500
12	12.4	850	78,000	8,500	86,500

The case illustrated is very simple. The cost of the entire installation will not in all cases vary directly with the number of units, a factor which must be taken into account in computing column 4 of the table. It is not necessary that the outlet units be of the same size or type or that they be all located at the same elevation. Column 1 may denote size of outlet rather than number of units of a given size. For greatest economy the outlets should be located at as low an elevation as practicable. If the value of the lost storage is not known, it may be determined from the estimated cost of increasing the total capacity of the reservoir a corresponding amount.

The above determination applies to the lowest tier of valves only. If the reservoir is deep, additional valves may be needed at higher levels to avoid operating the lower valves under excessive heads. The possibility of securing greater economy in the entire installation by raising or lowering the lower set of gates from the position first assumed should be investigated. The cost of upper-tier gates required in combination with a given number of lower gates may be included in the cost of outlet column in Table 1.

STRUCTURAL FEATURES.

It is not possible, in the space available, to go into detail in regard to the structural features of outlet works, nor does the scope of this report make this necessary. While the particular forms taken by such structures introduce special problems in design, the underlying principles do not differ from those applicable to other building work. Special attention should be given to the smoothness of surfaces, easy transitions, absence of irregularities, and other points affecting the hydraulics. All connections to concrete structures should be secure against leakage, all chambers and passages should be drained, valves and pipe should be protected against frost, and other necessary precautions taken to insure safety and efficiency of operation. Stresses in concrete and other materials should follow standard practice. Reinforcing steel should be well embedded to prevent corrosion. The tension in reinforcing steel for conduits carrying water under pressure should not be greater than 12,000 pounds per square inch to avoid excessive deformation. Outlet conduits through earth dams should be set on solid foundation, and should be designed to support the entire weight of the saturated fill above them, or the submerged fill plus any probable unbalanced water pressure. The backfill around outlet conduits should be very thoroughly compacted by tamping or puddling.

TRASH RACKS.

Suggestive details and arrangements for trash-rack structures will be found in the drawings accompanying descriptions of actual installations. The clear area of waterway in such structures should be as large as possible, since high trash-rack velocities cause objectional losses and increase the tendency of the structure to become choked with trash. The velocity here should preferably not exceed 2 feet per second, and in power-plant work it is often held down to less than half that amount. The distance between the bars will depend upon the size of outlet and the kind and quantity of trash to be excluded. Generally a smaller spacing than 6 inches on centers will not be required for large-capacity outlet works. A much closer spacing is, however, required for small outlets and for penstocks.

The load which must be borne by a trash-rack structure is normally small, but if the rack becomes totally or partially choked the load materially increases. The correct load for which to design the structure can not be rationally determined. In order to be perfectly safe, the structure should be made of sufficient strength to support the entire water load above it, but the chance of complete stoppage is remote, and the expense of providing for such a contingency is not always warranted. It is recommended in general that the bars be designed to be stressed to their ultimate strength under a head equal to half the depth of water above them, but not less than 20 nor more than 50 feet, and that the supports be designed for a factor of safety of two under the same head. In case of failure, it is desirable that the bars break before the structure fails.

OUTLET-CONDUIT VELOCITIES.

Table 2 shows the conduit velocities in the different outlet works covered by this report. The discharge in second-feet is the normal or designed capacity under minimum reservoir heads. The estimated maximum velocity is based on full reservoir head or limiting heads considered safe for that particular type of outlet.

TABLE 2.—*Velocities in outlet conduits.*

Reservoir.	Outlet.	Number and type of conduits.	Purpose of discharge.	Normal designed capacity.		Estimated maximum velocity.
				Discharge (second-feet.)	Velocity feet per second.	
Roosevelt	South Tunnel	Two 48-inch steel pipes	Irrigation	325 each	26	35
Do	North Tunnel, conduit below 58-inch balanced valves.	Three 60-inch cast-iron pipes.	do	900 each	32	70
Do	North Tunnel, conduit above 54-inch needle valves.	Three 54-inch steel pipes.	do	800 each	50	60
Shoshone	Lower Outlet Tunnel through gate passages.	Three rectangular cast-iron lined.	do	1,000 each	42	45
Do	Power	One 84-foot horseshoe lined tunnel.	Power	500	8	10
Do	By-pass, above 36-inch needle valve.	One 42-inch steel pipe	Irrigation	400	42	50
Pathfinder	North Tunnel, above 58-inch needle valves.	Two 6 foot diameter concrete conduits.	do	1,000 each	35	45
Do	South Tunnel, below 58-inch balanced valves.	Six 60-inch cast-iron pipes.	do	1,050 each	53	70
Do	South Tunnel, below 58-inch balanced valves.	Six 52-inch steel pipes.	do	1,000 each	63	70
Belle Fourche	North conduit	One concrete	do	650	14	35
Strawberry	Outlet tunnel	One 98-inch diameter concrete.	do	636	12	25
Arrowrock	Balanced-valve outlets.	Seventeen 52-inch diameter concrete.	do	1,000 each	68	70
Do	Sluice gates	Five 60-inch cast-iron and concrete.	Sluicing			70
Elephant Butte	Service outlets	Four 60-inch cast-iron and concrete.	Irrigation	1,200 each	61	70
Do	Power outlets	Six 60-inch cast-iron pipes.	Power	250 each	9	11
Lahontan	Cylinder gates	Two 9-foot horseshoe concrete.	Irrigation	1,400 each	21	30
Minatare	Outlet tunnel	Two 48-inch steel pipes.	do	150 each	12	20
Jackson Lake		Twenty concrete	do		44	45
Sherburne Lake	Outlet tunnel	Two concrete	do	500 each	12	20
McDonald Lakes.	do	One 6 foot diameter concrete.	do	300	21	25

CHAPTER III.

GATES.

SLIDE GATES.

A list of the actual slide-gate installations described in this report will be found in Table 4. The present discussion will be confined to gates of moderate size under comparatively high heads. The gate leaf may consist of a cast-iron or cast-steel plate supported by ribs in two directions, or it may be built up of rolled-steel plates and shapes. An exact analysis of the stresses is impracticable. The strength of the face plate is usually determined by considering it supported on four sides, the stresses being determined as explained, for example, on page 363 of Machinery's handbook, 1914 edition. It is recommended that the horizontal ribs of cast gates be figured as T beams, the width of the T being taken equal to the depth of the rib, except that the assumed width should not exceed the distance center to center of ribs. No allowance need be made for the overlapping of plate and beam stresses. The unit working stresses shown in Table 3 are recommended. There is little, if any, economy in making the castings thinner than one-half inch. The ribs should not be of less thickness than the plate, the height and spacing being adjusted to give the required strength. The edges of the gate leaf are necessarily thicker than other parts, but sudden and large changes in thickness of the castings should be avoided, as they are likely to cause shrinkage cracks.

TABLE 3.—*Recommended working stresses in slide gates, pounds per square inch.*

Material.	Tension.	Compression.	Shear.
Cast iron	2,000	12,000	2,000
Cast steel, hard	15,000	15,000	12,000
Cast steel, medium	12,500	12,500	10,000
Cast steel, soft	10,000	10,000	8,000
Structural steel	12,000	12,000	8,000
Rolled Tobin bronze	16,000	15,000	10,000
Rolled manganese bronze	16,000	15,000	10,000
Cast manganese bronze	16,000	15,000	10,000
Phosphor bronze	7,500	10,000	7,000
Gun bronze	7,500	10,000	7,000

NOTE.—Smaller factors of safety may be used when the work is relatively unimportant.

The width of the gate seats should be such that the bearing pressures will be low. If the pressures are too high, the seats are soon scored and worn out under the motion of the leaf. The following bearing pressures are recommended for the design of gate seats: Cast iron on cast iron, 300 pounds per square inch; cast iron or cast steel on bronze, 400 pounds per square inch; bronze on bronze, 500 pounds per square inch. These bearing pressures are not well established, higher values having been used in some instances. It is believed, however, that these pressures should not be greatly exceeded until more definite data are available.

TABLE 4.—*Slide-gate and gate-valve installations described in report.*

Reservoir.	Gates.				Operating head on center of gate.		Depth below spillway to center of gate.	Method of operation.	Year installed.	Specification No.
	Purpose.	Number.	Width.	Height.	Designed for—	Maximum to date.				
			Ft. In.	*Ft. In.*	*Feet.*	*Feet.*	*Feet.*			
Roosevelt [1]	Irrigation	3	5 0	10 0	220	120	220	Hydraulic	1909	....
Do	Emergency	2	2 6	3 2	221	221	221.25	....do	1915	416-F
Shoshone	Power	4	[2] 2 6	....	....	227.5	226	Hand	1913	....
Do	....	3	3 8	7 1	150	127	218	Hydraulic	1908	122
Minidoka	Sluice	5	8 0	12 0	....	44	47	Electric	1906	12
Do	Penstock	5	[2] 10 0	....	14	14	9	do	1910	153
Pathfinder	Emergency	4	3 8	6 5¼	183	180	180	Hydraulic	1909	122
Do	Sluice	1	3 0	5 0	60	Not operated.	182	do	1922	386
Do	Emergency	2	5 0	5 0	160	....do....	154.33	....do	1922	386
Belle Fourche	Irrigation	3	4 0	6 0	52.5	....	52	Hand	1906–1908	56
Strawberry	Emergency	2	3 0	5 0	51	....	49	Turbine	1913	....
Do	Irrigation	2	3 0	5 0	51	Not operated.	49	....do	1913	....
Do	....do	1	3 0	5 0	30	30	27.5	....do	1913	....
Do	....do	1	3 0	5 0	22	22	19.5	....do	1913	....
Arrowrock	Sluice	5	5 0	5 0	75	55	244	Hydraulic	1913	221
Elephant Butte	....do	4	3 11	5 0	80	113	173	....do	1914	235
Do	Penstock	6	3 11	5 0	142–173	Not operated.	132–162	....do	1914	235
Do	Emergency	4	3 11	7 6	147–186	110	147–186	....do	1915	243
Lahontan	Sluice	2	3 0	3 0	....	....	100.5	....do	1914	223
Do	Emergency	6	3 0	8 0	94	42	88	....do	1914	223
Do	....do	6	3 0	8 0	48	40	42	....do	1914	223
Jackson Lake	Irrigation	20	8 0	6 6	38	36	38	Gasoline	1914	240
Sherburne Lakes	Emergency	6	3 0	7 0	70	40	70	Hydraulic	1915	F-9, F-10, 307, 3-D.

[1] Stoney gates changed to slide gates in 1909.
[2] Diameter.

Bronze seats are much more durable than iron seats and should be provided on all gates of importance. They lessen somewhat the force required to move the gate and are less likely to rust together after a period of disuse.

Tests conducted by O. H. Ensign in Los Angeles, Calif., in 1906, led to the adoption by the Bureau of Reclamation of two special bronzes, known as class C and class D, for use in gate seats. Various samples were tried, until two were found which could be rubbed together under a pressure of 3,000 pounds per square inch at a speed of 30 feet per minute without chattering or abrasion. The compositions of the bronzes selected are as follows:

	Per cent.
Class C bronze:	
Copper	82 to 83
Tin	7 to 8
Lead	4 to 5
Zinc	5 to 6
Class D bronze:	
Copper	82 to 83
Tin	4 to 5
Lead	7 to 8
Zinc	5 to 6

The leaf is lined with one grade and the frame with the other, the two metals in combination having been found to give the best results. The bronze seats should be set into grooves and fastened to the castings with countersunk screws.

Stem connections must be sufficient in strength to take the direct force of the hoist and secondary stresses due to torsion. The stem connection to the gate should be arranged to eliminate, as far as possible, any tendency of the gate to bind in its guides, and adequate provision should be made for holding the stem against turning. Experimental data relative to the force required to open a slide gate are given in Chapter IX. The force required to start a gate that has stood closed for a long time is likely to be considerably higher than that required to keep it in motion after starting. It is recommended that a starting force be provided sufficient to overcome a coefficient of friction of 0.7 between the gate leaf and the seat. After the gate is started a coefficient of friction of 0.35 will in most cases be sufficient.

The gate frame must be proportioned from precedent, since it is not subject to a stress analysis. It should be of ample strength for handling and shipping, and should be designed so that it may be securely attached to the concrete structure. Unless the gate is large the main frame is usually made in one casting, but frames made up of separate pieces are satisfactory if properly designed and carefully finished.

STONEY AND ROLLER GATES.

Leaf gates provided with rollers to reduce the force required for operation were invented by F. M. Stoney, and are called "Stoney" gates. The rollers of the Stoney gate are not rigidly attached to either the frame or the gate leaf, but are free to move like the rollers of a roller bearing. In another type of roller gate, occasionally used, the rollers are attached to the leaf and act as wheels. Some special mechanism must be provided to keep the free roller of the Stoney gate in place, a complication which is avoided by the use of the wheel-type roller. The wheel roller offers a greater resistance to motion than the Stoney roller. Neither the Stoney gates nor roller gates are used for high-head outlets. The tendency at the present time is to limit leaf gates to moderate sizes and to operating heads of 50 to 75 feet. These limits make it possble to use plain sliding gates, which are preferable on account of their simplicity. Stoney gates have been extensively used for checks and locks, where large gates under low heads are required. Such gates are often built up of heavy steel shapes and plates.

CYLINDER GATES.

The water pressure on a cylinder gate is theoretically carried by the barrel in simple compression. Additional metal and stiffening ribs should be provided to care for accidentally unbalanced pressure and for vibrations. These factors are usually provided for by adopting low-unit working stresses. The details of the gates listed in Table 5 and described in Chapters XIII, XIV, XVII, and XVIII may be used as a guide in preparing designs for similar sizes. The strength of the frames and guides must be determined from practical considerations. One, two, or three stem connections may be provided, and these should be sufficient in strength to support the weight of the gate and to provide a factor of safety in operation. Three stems are preferable and should be used on all but the smallest gates. Guides should be provided to hold the gate in position and to prevent rotation.

TABLE 5.—*Cylinder-gate installations described in report.*

Reservoir.	Gates.			Operating head on center of gate, in feet.		Depth below spillway to center of gate, in feet.	Method of operation.	Year installed.	Specification No.
	Purpose.	Number.	Diameter of cylinder.	Designed for—	Maximum to date.				
			Ft. in.						
Elephant Butte	Waste	4	10 4$\frac{5}{8}$	11	Not operated.	9	Hand[1]	1916	5-D
Lahontan	Irrigation	2	8 6	100	92	95	Hydraulic cylinders	1914	223
Sherburne Lakes	do	1	12 0	81	52	81	Hand[1]	1918	310, 1-D
Do	do	1	12 0	26	Not operated.	26	do	1918	2-D
McDonald Lake	do	1	5 9$\frac{7}{16}$	64	48	51.5	do	1917	355
Do	do	1	5 9$\frac{7}{16}$	40	Not operated.	27.5	do	1917	355

[1] Counterweights provided.

It is believed that it would be desirable in most cases to place the cylinder gate on the outside of the concrete tower. To date (1922) no outside gates have been installed, but there appears to be no reason why such a design will not prove successful. The greater diameter of outside gates calls for greater strength, but their location outside of the gate shaft renders them much safer against damage from water disturbance.

In gates of the hooded type, as installed at Lahontan Dam, an air vent of ample capacity should connect with the hood. The hood should be securely supported and braced against the walls of the tower and the cylinder should be firmly guided against rotation. (See Chap. XIV for an account of difficulties encountered due to rotation at Lahontan Dam.) These gates are usually provided with one stem only, though two or three stems can be used if desired.

BUTTERFLY GATES.

Five installations of butterfly gates, 4 feet in diameter and larger, have been made to date by the Bureau of Reclamation, as follows:

Minatare Dam, two 4 feet diameter; maximum head, 49 feet.

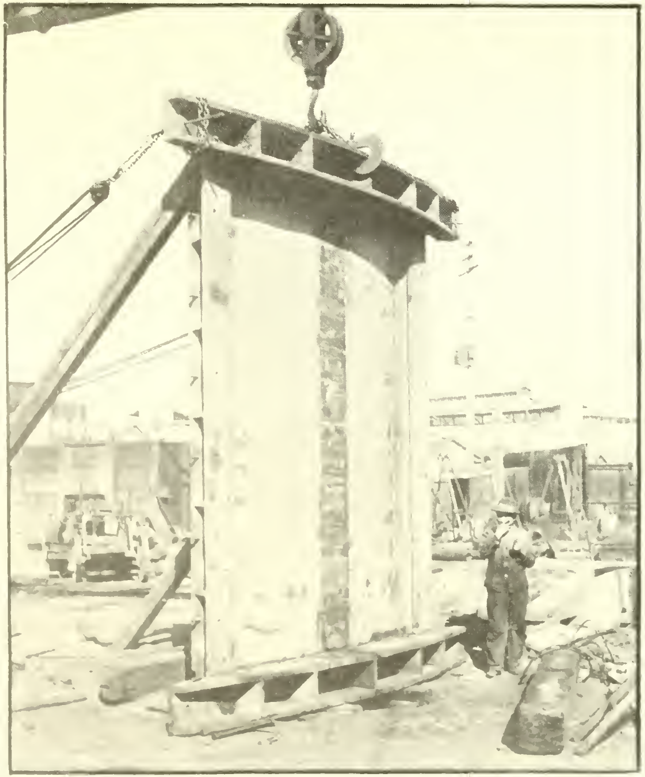
McDonald Reservoir, one 6 feet 3½ inches diameter; maximum head, 69 feet.

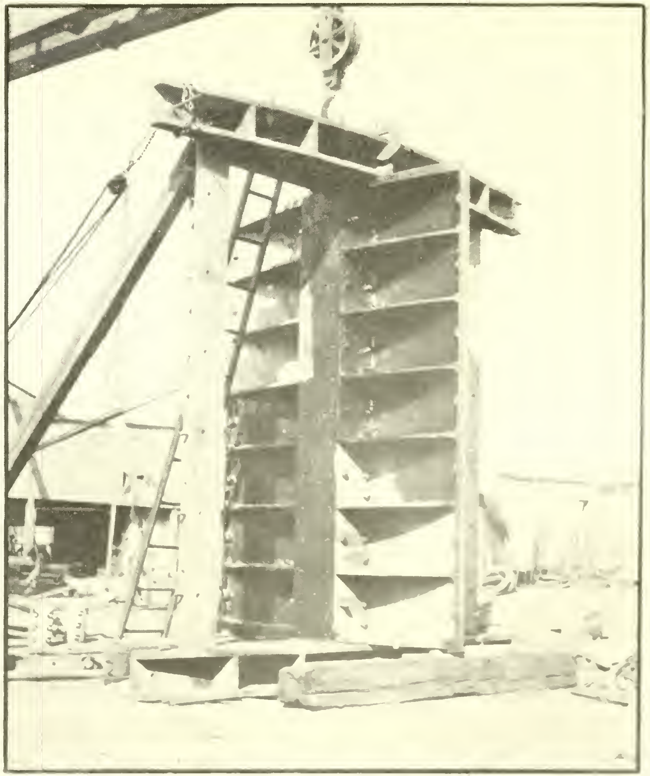
Tabor Reservoir, one 6 feet 3½ inches diameter; maximum head, 126 feet.

Crosscut Power Plant, two 8 feet diameter; maximum head, 7 feet.

Boise Power Plant, three 9 by 12 feet; maximum head, 27 feet.

The butterfly gates in the first three installations listed above are used as emergency gates, protecting reservoir control valves, and





[illegible] FOOT BY 12 FOOT BUTTERFLY GATES BOISE POWER PLANT

those in the last two serve as stop gates at the entrance to the penstocks.

Butterfly gates are balanced when closed or fully opened, but the balance is destroyed at any intermediate position. At partial opening water is discharging through orifices whose hydraulic functions are entirely different, due to the relation between the periphery of each half of the gate leaf and the adjacent side of the conduit. The unbalanced condition of the leaf in partially open positions precludes the use of this type of gate for regulating the flow of water, especially where head and velocity are high. This type is, however, well adapted for a simple stop gate.

Design.—The design of the operating mechanism must be based largely on experience and must be liberal, making allowance for the unbalanced gate leaf and the possibility of silt packing back of the leaf. A self-locking worm and gear is a necessity, and further gear reductions may be used, depending on the conditions of operation and size of the gate. Following is a brief description of the larger butterfly gates installed by the Bureau of Reclamation.

Minatare butterfly gates.—The 4 foot diameter butterfly gates for Minatare Dam are described in Chapter XV, and their design is shown on Plate 71 of the record drawings.

Tabor and McDonald butterfly gates.—The 6 foot 3½ inch diameter butterfly gates for Tabor and McDonald Reservoirs are described in Chapter XVIII. While this description covers McDonald Reservoir only, the butterfly gates in Tabor Reservoir are identical in design and installation with the exception of the difference in maximum head. Their design is shown on Plate 86 of the record drawings.

Boise butterfly gates.—There are three 9 by 12 foot butterfly gates installed in the Boise Power Plant, each gate supplying water to a turbine pit. The gate leaf is supported by a thrust bearing under the lower pivot or stem, this being composed of one steel and three bronze disks, resting on a large screw, by which the vertical position of the leaf may be adjusted. A grease gun is provided to supply grease under pressure to the bearing. The vertical gate seats are made adjustable, with taper surfaces allowing the gate leaf to wedge into place when closed. The operating mechanism was designed for one-man operation under 27 feet head. Considerable difficulty has been experienced, however, in opening these gates, and a more powerful device should have been provided. The design of these gates is shown on Plate 1 of the record drawings and Plate III of this volume shows two views of one of the gates taken in the shop. The three gates were furnished in February, 1912, by the Fulton Engine Works, Los Angeles, Calif. The contract price was $9,848. The weight of each gate is 40,000 pounds.

Crosscut butterfly gates.—There are two 8 foot diameter butterfly gates installed in the head works of the Crosscut Power Plant, Salt River project, each closing a 7-foot penstock. The operating mechanism is designed for opening and closing by hand and for emergency closing by compressed air from the power house located 3,000 feet away. The air pipe for each gate is embedded in the concrete of the opposite penstock, so that in case of a break in either penstock emergency closure of the gate is still possible.

Compressed air is stored at all times under sufficient pressure and in sufficient quantity to operate the gates by opening a valve in the power plant. The air pressure is applied to the surface of oil in a pressure tank, forcing oil into the operating cylinder, these cylinders always being full of oil on both sides of the piston. The oil displaced by the moving piston flows into an open tank. The design of the gate and operating mechanism is shown on Plate 2 [1] and the installation on Plate 3.[1]

The two gates and operating mechanism, including tanks, were furnished in August, 1913, by the Union Machine Co., of San Francisco, Calif., the contract price being $2,410 and the weight of each gate 5,900 pounds.

[1] Record drawing series.

Chapter IV

GATE HOISTS AND STEMS.

SCREW HOISTS.

General description.—Screw-lift gate hoists are generally used for small slide gates and cylinder gates. The simplest type of screw lift is shown in Figure 21, *A*, which is taken from a standard design for a small handwheel hoist. The hoist shown in Figure 21, *B*, is provided with ball thrust bearings both above and below the lifting-nut collar. Where the power supplied by a handwheel is not sufficient, reducing gears may be added as required. A standard 24 to 1 geared hoist is illustrated in Figure 21, *C*. This hoist embodies all the principles of the screw hoists used in the actual installations discussed later. Power may be used for operation where desired. Where an installation consists of a number of units, the hoists may be driven by a line shaft from a single source of power, or an individual motor may be used on each stand. The power is usually supplied by an electric motor, gasoline engine, or turbine, and auxiliary equipment is usually provided for hand operation in case of failure of the power. A list of the actual installations described in this report will be found in Table 6.

Capacity.—The determination of the strength and capacity of even the most simple type of hoist is complicated by the multiplicity of factors involved. Only a small percentage of the applied power is available for actually moving the gate. Allowance must be made for friction at the threads, on the base and side of the nut, in bearings, and between the teeth of gears. Formulas for the losses at these points may be found in standard books on machine design. Threads of large lead are most efficient, and ball thrust bearings add greatly to efficiency of the hoist. Coefficients of resistance to motion have been determined by experiment and are given in a number of handbooks. Where a hoist is to be used at infrequent intervals, or where it is to be exposed to the weather, the allowance for frictional losses should be much more liberal than for machines which receive more careful attention.

Formulas for use in preparing designs usually express the efficiency of the various parts of the hoist. The efficiency of the lifting nut is dependent upon the details and dimensions, as well as the size of stem and pitch of threads. General formulas for this efficiency are complicated, and where a number of designs are to be based upon the same assumed data diagrams or tables should be prepared, from which the screw efficiency may be readily determined. The combined efficiency of bearings and teeth of gears is often expressed as a single factor. The efficiency of bearings decreases as the ratio of gear to shaft diameter decreases, and tooth efficiency is greatest for gears of equal size.

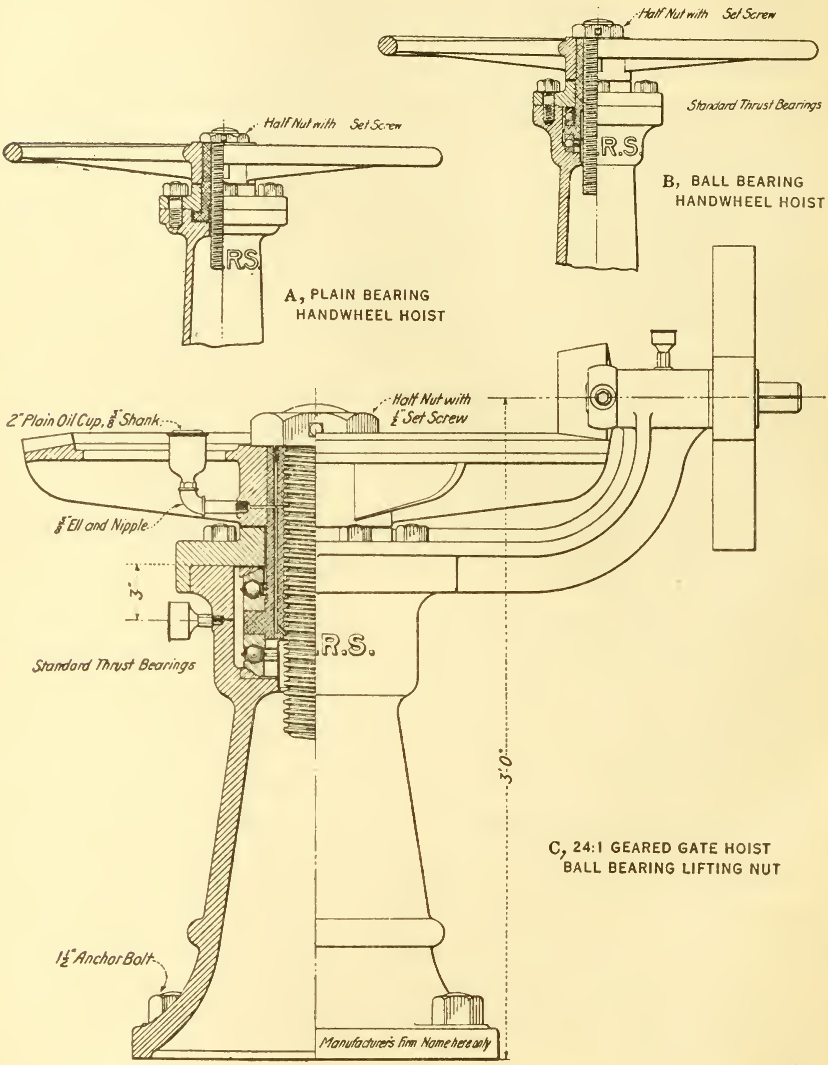


Fig. 21.—Typical gate hoists.

The cost of increasing the power of a hoist above the absolutely necessary amount is not, as a rule, of great importance, but an over-powered hoist is objectionable because of the high strains likely to be produced by overwinding. This objection can be partially overcome by a limit nut on the gate stem. In the case of hand-power hoists the additional time required for operation is objectionable. An underpowered hoist, if power driven, may result in an inoperative gate, and if hand driven the labor required for operation may be excessive.

The practicability of using a hand hoist is often determined by the time required for operation. There is little actual information as to the amount of work that a man can perform upon a hoist crank. Trautwine states that an average man can exert a crank effort of 16 pounds at the rate of 150 feet per minute, and that he can keep this up for 8 hours with a 25 per cent allowance for rest. The coefficients of friction and the crank efforts assumed in the design of screw hoists used in installations described later are not known, and the actual required pulls have not been determined. Standard hoists designed by the Bureau of Reclamation, based upon a crank effort of 40 pounds to start and 20 pounds after starting, have been found to give satisfactory service.

The actual speed of the gate leaf in operation should not be high, and where a number of gates must be opened or closed quickly sufficient power should be supplied for operating all units simultaneously. Limit switches or other safety devices should be provided for all power-driven hoists.

Strength of parts.—All parts of the stand for supporting the hoist machinery should be of ample strength to withstand any strain likely to occur in operation or in handling. Gears, shafting, bearing surfaces, and ball bearings should be properly proportioned for the loads to be transmitted. The depth of the lifting nut is determined by the allowable bearing on the threads. Special attention should be given to anchorage and to the tensile strength of the stand. A number of commercial hoists have been found to be weak in these two respects.

TABLE 6.—*Installation of screw hoists described in report.*

Reservoir.	Number of hoists.	Kind of power.	Gear reduction.	Gate.		Year installed.	Specification No.
				Type.	Size.		
Shoshone	4	Hand	....	Slide	2 feet 6 inches diameter.	1913	....
Minidoka	5	Hand or electricity.	[1] 6:1 or 24:1	...do	8 by 12 feet	1906	12
Do	5	.....do	4:1	...do	10 feet diameter	1910	153, 157
Belle Fourche	3	Hand	....	...do	4 by 6 feet	1906–1908	56
Strawberry	6	Hand or turbine	[2] 72:1	...do	3 by 5 feet	1913	....
Minatare	2	Hand	$84\frac{4}{7}$:1	Butterfly	4 feet diameter	....	....
Jackson Lake	20	Hand or Ford motor.	$20\frac{1}{4}$:1	Slide	8 by 6 feet 6 inches	1915	....
Sherburne Lakes.	2	Hand	[3] $18\frac{4}{7}$:1	Cylinder	12 feet diameter	1918	F-7
McDonald Lake.	1	.....do	264:1	Butterfly	6 feet 3 inches diameter.	1917	355
Do	1	.....do	[1] $5\frac{1}{3}$:1	Cylinder	5 feet $9\frac{7}{16}$ inches diameter.	1917	355

[1] Duplex with two cranks.
[2] Gear reduction 16:1 with turbine.
[3] Counterweights provided.
NOTE.—Screw-operated needle valves described elsewhere.

HYDRAULIC HOISTS.

Hydraulic hoists are widely used for the operation of reservoir outlet gates. A list of such hoists shown on the plates accompanying this report will be found in Table 7. The operating force is derived from water or oil under pressure acting against a piston moving in a cylinder. The cylinder should preferably be brass or bronze lined, and the piston should be provided with rings or packing. Stuffing boxes should be accessible for tightening and repacking. The hydraulic hoist is comparatively simple, can be installed in any location or position, and is not seriously affected by dirt or moisture. These hoists can often be installed immediately above the gates to be operated, thus avoiding the use of long stems, and the stems are not subjected to torsion.

TABLE 7.—*Hydraulic-operated hoists for Stoney, slide and cylinder gates described in report.*

Reservoir.	Number of hoists.	Diameter of cylinder.	Stroke.	Gate.		Year installed.	Specification No.
				Type.	Size.		
		Ft. In.	*Ft. In.*				
Roosevelt	6	2 2	14 8	Stoney [1]	5 by 10 feet	1908	......
Do	2	13	3 6½	Slide	2 feet 6 inches by 3 feet 2 inches.	1915	416-F
Shoshone	3	24	7 0	...do	3 feet 8 inches by 7 feet 1 inch.	1908	122
Pathfinder	4	24	7 0	...do	3 feet 8 inches by 6 feet 5½ inches.	1909	122
Do	1	18	5 0	...do	3 by 5 feet	1922	386
Do	2	24	5 0	...do	5 by 5 feet	1922	386
Arrowrock	5	24	5 0	...do	5 by 5 feet	1915	221
Elephant Butte	4	24	5 0	...do	3 feet 11 inches by 5 feet 0 inches.	1914	235
Do	6	24	5 0	...do	3 feet 11 inches by 5 feet 0 inches.	1914	235
Do	4	24	7 6	...do	3 feet 11 inches by 7 feet 6 inches.	1915	243
Lahontan	2	16½	3 2½	...do	3 by 3 feet	1914	223
Do	[2] 6	16½	8 2½	...do	3 by 8 feet	1914	223
Do	[2] 6	16½	8 2½	...do	3 by 8 feet	1914	223
Do	2	16½	3 0	Cylinder.	8 feet 6 inches diameter	1914	223
Sherburne Lakes	6	18	7 ⅛	Slide	3 by 7 feet.	1917	F-9

[1] Downstream set of three Stoney gates changed to slide gates in 1909. No change in operating mechanism.
[2] Upper and lower sets of emergency gates.

STRENGTH OF STEMS.

Screw hoists are usually set on top of the dam or outlet tower, and the operating force must be transmitted to the gates through long stems. In addition to the operating force the stem is subjected to torsion due to the action of the lifting nut. The effect of torsion is often considerable, and the torsional stresses should be combined with direct tension or compression in computing the size of the stem. Where the gate must be pushed down, as in the case of a slide gate. the column strength of the stem, combined with torsion, will usually govern. For cylinder gates and other gates which offer little or no resistance to closing, the size of the stem is determined from combined tension and torsion. Rankine's formula for columns is recommended for stems under compression, and Merriman's formulas for combined stresses may be used for combining torsion and axial stresses. Formulas from which the torsion may be found are given in books on machine design, or the torsion may be taken as the lifting-nut moment required to start the gate, all parts of the hoist except the threads being assumed to be 100 per cent efficient.

Data used by the Bureau of Reclamation in the preparation of standard designs for screw-lift hoists are given in Table 8. The coefficient of friction for line-bearing nuts is assumed to apply to lifting nuts having the bearing surfaces slightly curved, so that only a comparatively narrow ring is in contact with the support. A higher coefficient is recommended for nuts with flat bearing surfaces on account of the uncertainty as to the center of application of the frictional force and because flat surfaces are only used on cheap hoists where the workmanship is likely to be poor. A coefficient of 0.20 is allowed for threads on account of the difficulty of providing proper lubrication for the stem, with the resultant tendency of the thread surfaces to corrode.

TABLE 8.—*Screw hoist and stem data, Bureau of Reclamation standard design.*

Coefficient of sliding friction, bronze on cast iron or steel, line-bearing nuts	0.15
Coefficient of sliding friction, bronze on cast iron or steel, flat-bottom nuts and threads	.20
Coefficient of sliding friction, steel on babbitt	.125
Coefficient of rolling friction, ball bearings	.002
Coefficient of sliding friction, gate seat, starting	.7
Coefficient of sliding friction, gate seat, moving	.35
Efficiency of spur gear and bearing, cut teeth	.90
Efficiency of spur gear and bearing, cast teeth	.85
Efficiency of bevel gear and bearing, cut teeth	.85
Efficiency of bevel gear and bearing, cast teeth	.80
Practicable hand pull for starting ... pounds	40
Practicable hand pull after starting ... do	20
Allowable tension or compression in cold-rolled steel gate stems, combined axial stress and torsion, true stress ... lbs. per square inch	12,000
Allowable shear in cold-rolled gate stems, combined axial stress and torsion, true stress ... pounds per square inch	10,000
Allowable bearing load on threads ... do	750
Allowable shear on bronze nuts ... do	1,500
Allowable tension in cold-rolled shafts, combined flexure and torsion, true stress ... pounds per square inch	10,000
Allowable shear in cold-rolled shafts, combined flexure and torsion, true stress ... pounds per square inch	8,000
Direct tension in gate stand pedestals ... do	1,000

Strength of gear teeth, see Machinery's handbook.

Other stresses as per Table 3.

Determine compressive stresses in columns from Rankine's column formula, using Merriman's constants.

For combined torsion and tension or compression use Merriman's formulas for true stresses.

CHAPTER V.

NEEDLE VALVES.

GENERAL DESIGN.

The hydraulic forces acting on the plunger of a needle valve are approximately balanced laterally at all times, and the cylindrical jet tends to steady the plunger and hold it central. A circular section of jet is the natural shape for high efficiency, since it is symmetrical about all axes and gives the minimum opportunity for eddies and cross currents. This shape is also adapted to low manufacturing costs. Needle valves are operated by various external mechanical means or by suitable control of the hydraulic forces acting on the plunger. The usual method of hydraulic control is to inclose the rear end of the plunger in a close-fitting cylinder in which the pressure can be controlled to balance or overcome the forces acting on the pointed end of the piston. This type of valve is generally referred to as a balanced needle valve, or simply as a "balanced valve." Various forms of screw and nut mechanisms, racks and pinions, or hydraulic cylinders are used where the valve is operated by external mechanical force.

High efficiency desirable.—The amount of energy in large jets under high heads is enormous, and in designing regulating valves it is essential that reasonable precautions be taken to produce a device which will interfere as little as possible with the passage of water. The efficient valve not only gives greater discharge for the amount of money invested, but, what is more important, it withstands the severe service better, has longer life, and is more reliable.

Needle valves adapted to high-head service.—For heads up to 75 feet there is little difficulty in regulating water by means of sliding gates, and large discharges can be cheaply obtained by this method. For higher heads, however, the troubles with sliding gates become so serious that it is advisable to use a different type. The needle valve is the only device which has given reasonable satisfaction under high heads. Balanced needle valves for discharge and regulation of water have been used by the Bureau of Reclamation under heads up to 225 feet. Impulse water wheels with needle nozzles are in successful operation at heads of over 2,000 feet. There appears to be no reason why this type of valve can not be successfully used for any feasible height of dam.

Open installation recommended.—Needle valves connected to the ends of pipe lines and discharging into the air have been thoroughly tested in small sizes in impulse water-wheel work, and this arrangement has many advantages as applied to reservoir discharge. The valves and operating mechanism are accessible for inspection and repair. Free access of air to the jet is obtained and the effects of vacuum eliminated. In high-head water-wheel plants provision is made for dissipating the energy of the jet when deflected from the wheels by means of baffle plates designed to turn the stream back upon itself. The same general principle can be applied to the jet discharged from any nozzle, but it is simpler and generally more desirable in irrigation work to allow the jet to fall into the river bed, where it will soon scour out a pool sufficiently large and deep to absorb the energy without damage to adjacent structures. It is usually desirable to place above the regulating valve an emergency gate by means of which the water can be cut off when desired. Such gates should be designed for closure against full head in case of failure of the regulating valve, and due consideration should be given to the protection and accessibility of the operating mechanism in such an emergency. In the colder climates it is essential to protect the valves against freezing. The emergency valves should be warmly housed or so located that the cold air does not reach them and everything below these valves drained during the cold weather.

Design of needle.—In order that a valve shall give a smooth jet, it is necessary that the needle and nozzle tip be of proper shape and smooth surface. The water passages should have easy flow lines, avoiding abrupt changes in direction or velocity. The seats or section where regulation is effected should be at a point of inflection or concave curvature of the needle surface and the nozzle tip so shaped that the stream will be deflected against the needle. In small sizes the needle is of bronze, but in larger sizes it is usually a hollow iron casting with a bronze seat shrunk on or fastened in place by bolts with heads on the inside, properly locked. Another method is to make the tip a separate piece and clamp the seat ring between it and the body of the needle. The seat rings are usually of manganese bronze, since this metal withstands the action of the water and has high mechanical strength and toughness.

Guides.—In the smaller sizes, like the Minatare valves for example, where the weight of the needle is small, guides are provided on the stem only, the needle being held in open stream, but in larger sizes it becomes necessary to support the needle, and guides are introduced near the discharge orifice. In some forms, like the Roosevelt north tunnel valves, the upstream end of the needle is protected by a shield pointed on the upstream end into which the needle is withdrawn in opening and which also serves to support the guides. It is, of course, desirable to have the guides of bronze or some other noncorroding material. Phosphor bronze, or special gate-guide bronze, have been used with good results. Countersunk bronze screws of composition similar to the guides are used for fastenings, but it is essential that all screws, bolts, and nuts be located out of the water current and securely locked against turning.

Nozzle.—The nozzle tip should be shaped to accelerate the water toward the point of exit and should flare abruptly below the seat to permit free access of air to the jet, and smooth surface and easy contour upstream from the seat is desirable. The wedging action of the needle in closing, as well as the bursting pressure of the water, requires that special attention be given to reinforcing the discharge opening. Stationary seats, where they are separate parts, are of the same general character as those on the needle and are fastened by cap screws from the outside or by any other approved method.

Valve body.—In designing the valve body careful attention should be given to the contour of the water passages and the variation of velocity through the valve. The problem becomes more difficult when various partial gate openings, as well as wide open discharge, are considered, and a compromise is usually the best that can be accomplished. Sudden enlargements and offsets should be avoided, since the stream will not follow abrupt changes in direction, and local areas of partial vacuum are liable to be formed, which tend to produce cavitation of the metal. Ribs or parts extending across the water passage should be sharpened upstream and tapered gradually downstream from the thickest section. Plate 33 of the record drawings contain a study of the velocity through the Pathfinder needle valves. This shows that the velocity through the valve body is about 30 per cent less than pipe-line velocity. It is a question whether or not this drop in velocity is an advantage. Johnson valves apparently keep pipe-line velocity constant through the valve body to the nozzle.

Hydraulic balance.—The water load on the needle may be partially or completely balanced by inclosing the upstream end with a close-fitting housing provided with a drain pipe to carry away leakage. A separate balancing piston on the valve stem fitting into a cylindrical recess provided with a drain pipe accomplishes the same result and was used with success on the Minatare valves.

Mechanical operation.—Operation by means of a screw and nut has the advantage of being positive and self-locking, which is important in regulating discharge. In small sizes no special difficulties are encountered in this design, and even in large sizes the only serious difficulty is in taking care of the thrust, which necessitates heavy bearings and strong supports. Hand gearing is usually sufficient in small sizes, but in larger sizes motor operation is desirable. Limit switches to prevent overtravel of the stem are essential with motor-operated valves, and remote control can be provided if desired. All of these features are embodied in the North Tunnel outlets of the Roosevelt Dam. Operation can also be accomplished by means of hydraulic cylinders, as in the Roosevelt South Tunnel needle valves, shown on Plate 7 of the record drawings. This method eliminates the thrust bearing, but it is difficult to hold the needle in any desired intermediate position. To overcome this tendency, the Roosevelt South Tunnel valves are provided with small pilot valves, by means of which a slight closing motion of the piston admits pressure to the opening end of the cylinder and checks the motion.

Hydraulic operation.—All forms of needle valves described above require external power for their operation, entailing considerable added expense for an operating mechanism and source of power. This expensive feature is largely avoided in valves designed for automatic hydraulic operation in which the water to be discharged furnishes the power for operating the valve. Such valves are generally known as "balanced valves" and are described in the following pages.

BALANCED VALVES.

Principle of operation.—The balanced valve consists essentially of a cylindrical piston with one end pointed to guide and regulate the discharge, the other end being provided with a "bull ring" of larger diameter, fitting a stationary cylinder in which it moves. The valve seat is circular, and the movable seat is located at the periphery of the pointed end of the piston. The discharge crosses the seat and, striking the pointed end of the piston, is turned through an angle and discharged axially. In some instances the valve is mounted on the water face of the dam, the control pipe being carried to the downstream side. In other installations the valve is provided with an external casing receiving water from the closed conduit. The principle of operation is the same in the various types and is illustrated by Figure 22.

The bull ring fits the cylinder closely, but the clearance provided is sufficient to equalize the pressure inside and outside of the cylinder, provided the control pipe is closed. With equal pressures inside and outside of the cylinder the valve piston will be held against its seat like a check valve, since the pointed end is in this position subjected to atmospheric pressure only, while the back of the piston is subjected to reservoir pressure. The pressure in the cylinder can be reduced by opening the drain or control pipe of larger area than the clearance around the bull ring and can be reduced below atmosphere by applying a vacuum. With the pressure in the cylinder reduced to atmosphere, the pressure on the pointed end will be bal-

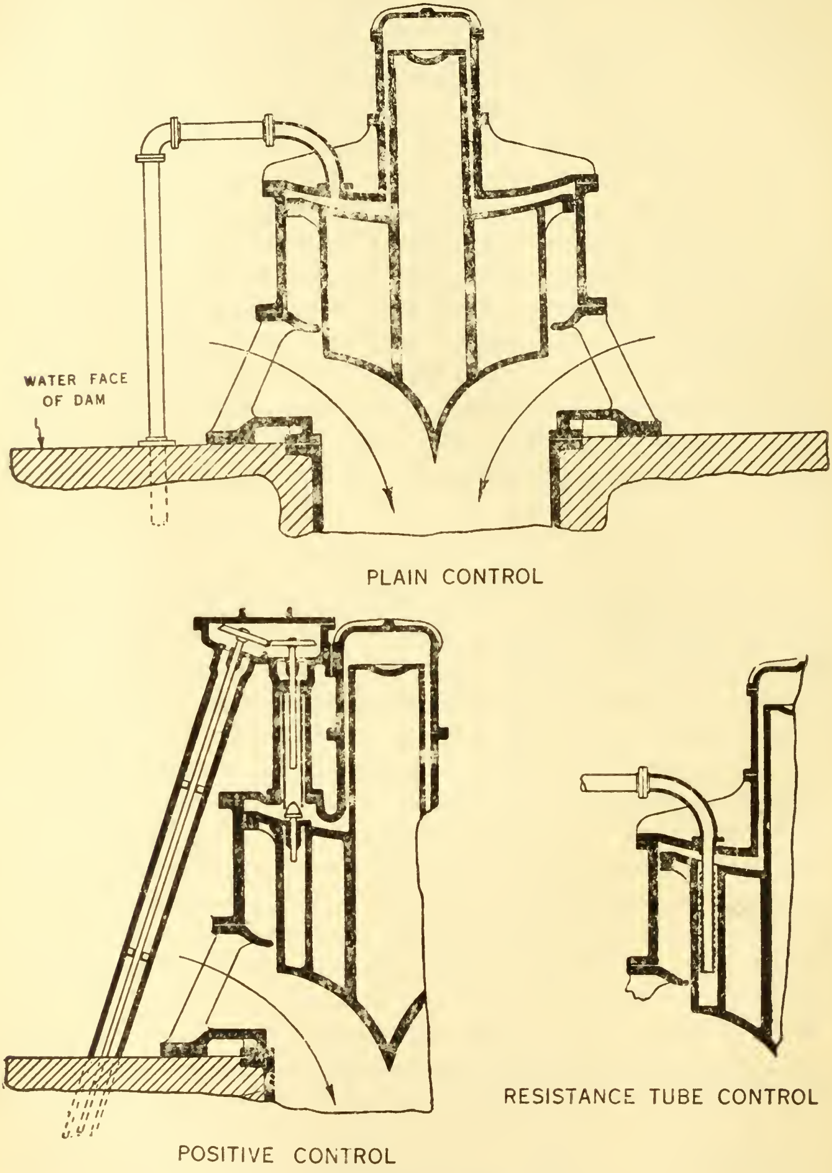


Fig. 22.—Principle of balanced valve.

anced by equal pressure on the corresponding area inside the cylinder. The annular space between the circumference of the plug and the bull ring will be subjected to reservoir pressure, tending to move the plug from its seat. A corresponding area in the cylinder is subject to atmospheric pressure only. The resultant is an opening force on the piston, and the valve will open as fast as the water can be forced out of the cylinder. If it is desired to close the valve, the control pipe is closed, and as the pressure accumulates in the cylinder through the clearance space the resultant becomes a closing force, since the pressure in the cylinder is the same as that on the annular ring and the pressure on the pointed end is less than the reservoir pressure on account of the velocity of the water.

Close regulation of discharge.—It will be evident that the balanced valve can be held either wide open or entirely closed by a simple valve in the control pipe, but, since the discharge of irrigation water requires very close regulation, it is necessary to devise some means of maintaining the valve in any desired intermediate position. To hold the valve in such position, the forces acting on the piston must be approximately balanced. The forces are reservoir pressure acting on the annular ring, pressure and reaction of the jet on the needle end, both tending to open the valve, pressure in the cylinder tending to close it, friction of the piston in its guides and cylinder resisting motion in either direction. The pressure in the cylinder can be controlled through the control pipe and control valve, and to check the opening motion the control valve is slowly closed until the desired balance is produced. The balance of forces attained in this way is extremely sensitive, and a slight accumulation of sediment or washing out of such material from the point of throttling at the control valve will cause the piston to creep open or shut. It is therefore necessary to provide some more positive means of bringing about a balance of forces to maintain the valve in partially open position.

Resistance tube.—The device employed for this purpose in the Roosevelt, Pathfinder, and Belle Fourche valves is known as the resistance tube. This consists of a stationary corrugated tube attached to the cylinder head and forming an extension of the control pipe into the cylinder of the balanced valve. This tube is grooved on its outer surface and fits into a corresponding recess in the movable piston. As the main valve opens, the resistance tube enters the recess, and a resistance proportional to the gate opening is introduced into the control pipe. Such resistance to the outflow of water increases the pressure in the cylinder and tends to prevent further movement of the piston. If through any cause the piston should start to close, the resistance tube is withdrawn from the piston, reducing the resistance to the outflow of control water, lowering the pressure in the cylinder, and checking the closing movement. This device, in the absence of actual experience with its operation, appeared to be very desirable on account of its simplicity. In practice, however, it proved to be unreliable, although by careful manipulation of the control valve and great patience in adjustment it was possible to effect an approximate regulation of the flow. The point of balance is not well defined, and accumulations of sediment in the clearance spaces around the bull ring, in the control tube itself, or at the control valve are sure to disturb the balance of forces and

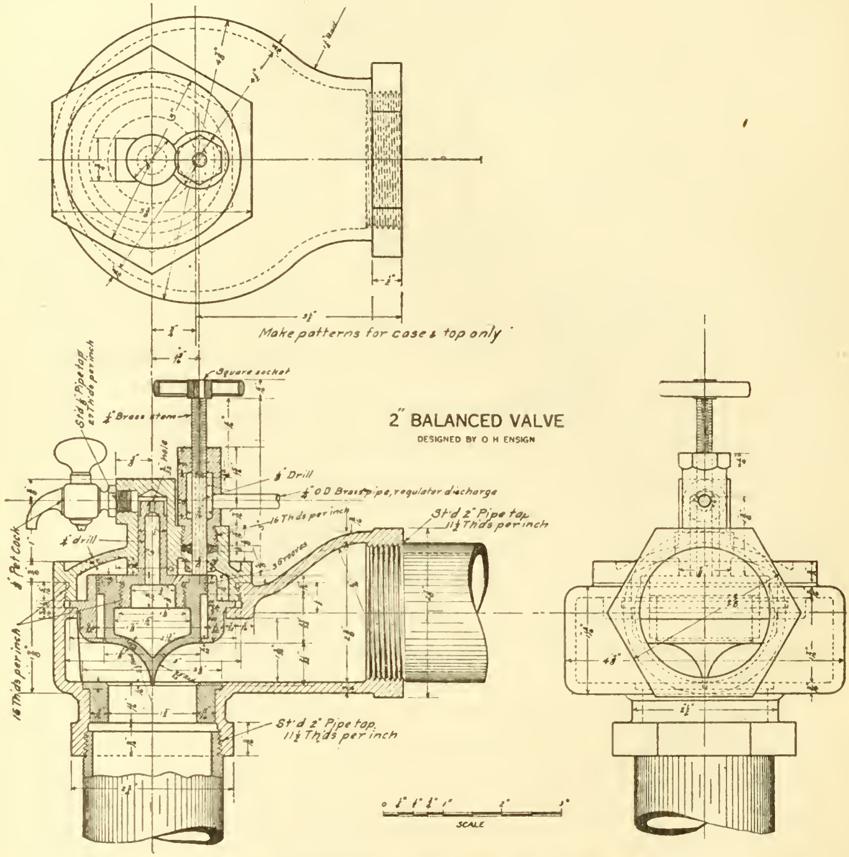


FIG. 23.—Balanced valve, 2 inches in diameter.

cause a movement of the main piston. The use of the resistance tube was abandoned in the later installations on account of these difficulties.

Sleeve control.—The designs of the 2-inch valve, Figure 23, Roosevelt valves, Plate 8,[1] and the Arrowrock positive control valves, Plate 48,[1] all show control by means of a movable tube at the entrance to the control pipe, forming an extension of same into the cylinder of the valve. This type of control was successfully ap-

[1] Record drawing series.

plied to the valves at Arrowrock and Shoshone Dams. The movable sleeve is controlled by a suitable gearing from an inspection gallery in the dam or other convenient location. The control sleeve registers with a seat on the back of the main valve piston, and if the sleeve is withdrawn from this seat the entrance to the control pipe is opened, and the resulting reduction in the pressure in the cylinder produces an opening movement. The piston will continue to move open until the seat comes in contact with the end of the control sleeve, thus closing the outlet through the control pipe, building up a pressure in the cylinder, and bringing about an equilibrium of forces.

Applications.—The balanced valve is adapted for high-head discharge and can be used under any condition to which a needle valve is applicable. The design can be made simple and compact where the valves are to be mounted on the water face and discharge into a passage through the dam. The installations at Roosevelt, Pathfinder, Arrowrock, Shoshone, and Belle Fourche are of this general type, and the objections to, as well as the advantages of, this plan have been well demonstrated. Where the reservoir is frequently emptied and the valves thus made accessible and where the discharge passages can be made short and straight, this plan is very successful. With large hold-over capacity, however, the valves may be submerged for many years and proper maintenance is impossible. The passages below the valves are particularly subject to damage by the discharge if not straight and smooth and must be very carefully constructed. The damage to the passages below the valves is one of the strongest arguments in favor of placing the valves at the end of a pipe and allowing free access of air to the discharging jet.

Early types.—The first balanced valve used by the Bureau of Reclamation was designed by O. H. Ensign and made by the Fulton Engine Works, of Los Angeles, under contract dated April 6, 1906, contract price $836. It had a discharge diameter of 20 inches and was equipped with needle points of various shapes for experimental purposes. In addition to the control valve for draining the cylinder to the atmosphere, the original design included a device for holding the piston in any desired position. This regulator is shown in Plate IV and consists of a perforated stationary sleeve fixed in the cylinder head and connecting with the interior of the plunger, which in turn is vented into the discharge pipe through the needle tip. Inside the perforated tube is a plug sufficiently long to cover all the perforations in the tube. The plug can be moved back and forth by means of a handwheel outside the cylinder head, and in withdrawing it the perforations are uncovered, venting the cylinder and causing the valve to open. The opening motion will continue until the perforations are again covered by the bushing in the piston body to such an extent as to build up the pressure in the cylinder and bring about a new balance of the forces acting on the piston. The valve was tested in May, 1906, and proved very successful, except that the automatic-control feature did not operate as anticipated. The cylinder apparently received back pressure from the discharge end of the valve through the control sleeve, and the valve would not open more than one-third stroke. The control was therefore modified to drain the cylinder into the air through a movable sleeve.

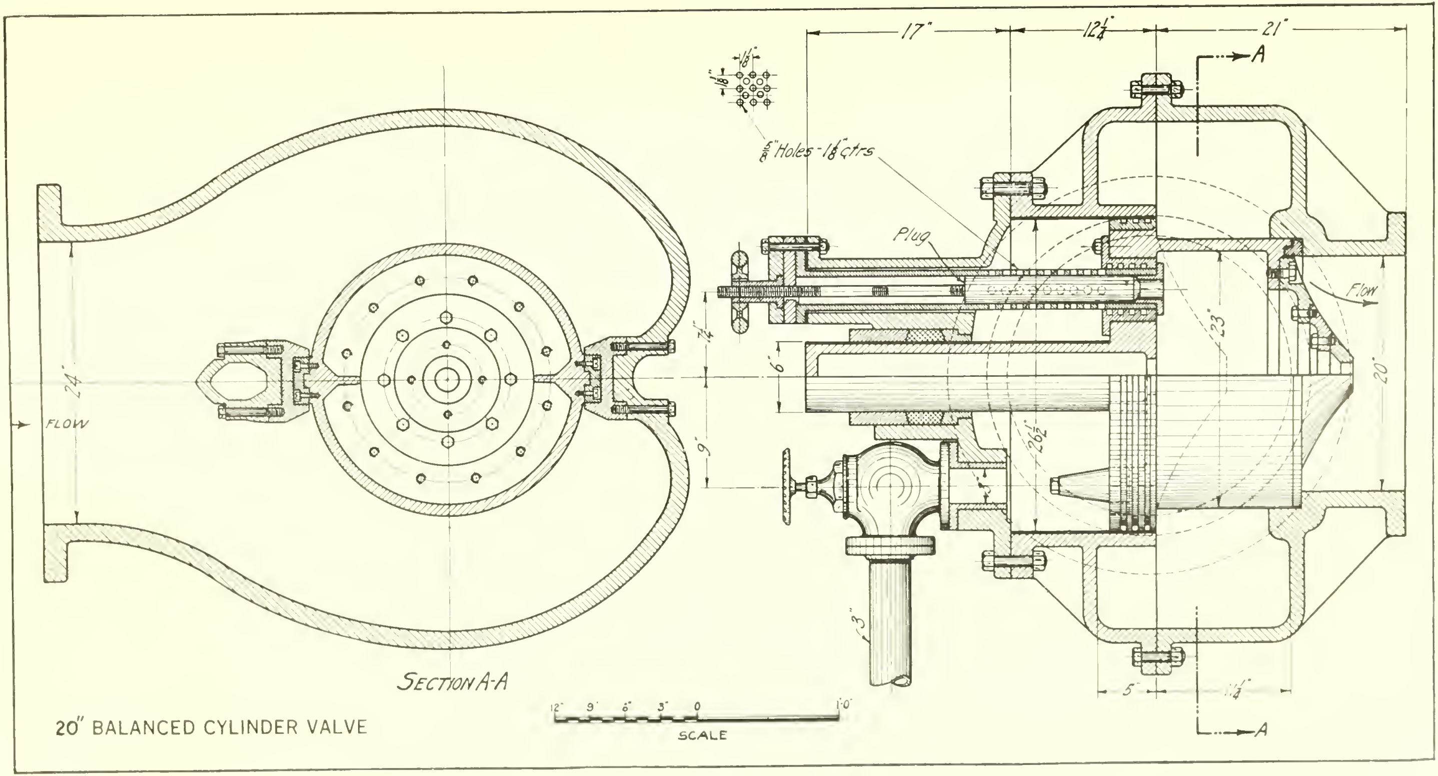
The valve shown on Figure 23 was designed in the fall of 1906 and embodies the results of the earlier experiments. It is for connection with a 2-inch standard pipe and is controlled by means of a movable sleeve.

Plans of the 43-inch balanced valves for the Roosevelt Dam were made public and bids invited under date of November 5, 1908. The 58-inch balanced valves for this dam were similarly advertised August 3, 1909. These installations are fully described in Chapter VI.

Recent developments.—The balanced needle valves designed for the north tunnel, Pathfinder Dam, are intended to embody the good features of the positive-control valves, at the same time avoiding risk of damage to the outlet passages and lack of accessibility. The general arrangement of these valves is shown on Plate 32 of the record drawings. The general principles of operation are identical with the Arrowrock valves, but an outside casing is provided to permit installation below the dam. The needle has been made longer and given easier flow lines. The control sleeve has been placed in the axis of the cylinder, making it unnecessary to prevent rotation of the plunger. The front end of the piston is supported by bronze shoes bearing against the inside of a cylindrical bronze-lined housing, and the ribs supporting the inner cylinder also serve as guides near the discharge orifice. These changes make it possible to omit the V-shaped guides, which are an objectionable feature of the earlier design. An emergency gate immediately above the valve permits inspection and will be used to cut off the water to prevent freezing during the winter months. Access to the interior is provided through a manhole. The 36-inch valve at Shoshone Dam follows the same general design, except that the control valve is outside the cylinder, connection being made to the main piston through suitable gearing and a shaft brought out through a stuffing box. A typical installation is shown by Figure 24.

COMMERCIAL TYPES.

Johnson valve.—In 1912 R. D. Johnson patented a valve for installation in pipe lines, which is very similar in principle to the



20" BALANCED CYLINDER VALVE

balanced valve developed by the Bureau of Reclamation. This valve has been extensively used as a stop valve in penstocks and pipe lines

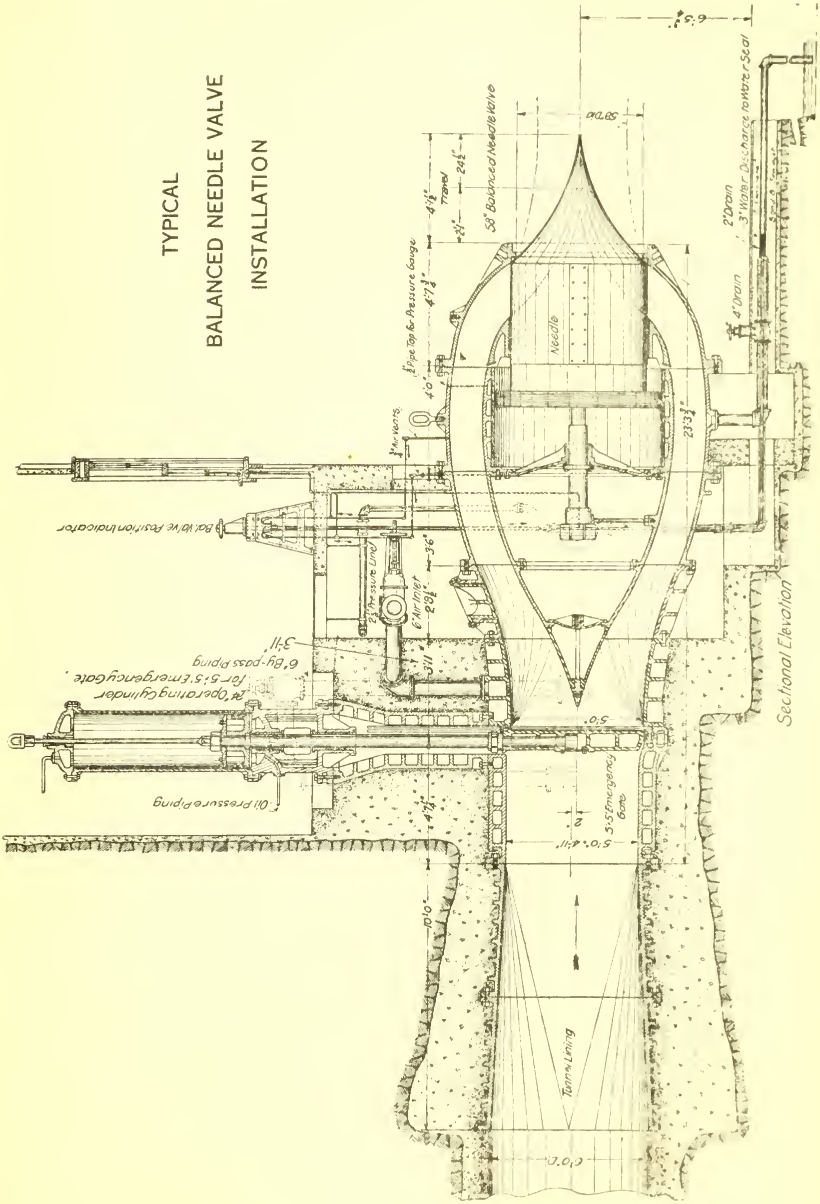


FIG. 24.

and is built in sizes as large as 20 feet diameter of orifice. Johnson's patent is No. 1,030,890, and his application was filed October 8, 1909. The Larner-Johnson Valve & Engineering Co. has recently developed the Johnson valve for free discharge service. This valve is shown in Figure 25. The control water is discharged through the tip of the needle, which eliminates external piping, and the control stem is made heavy in order that mechanical force can be applied to the piston, if necessary.

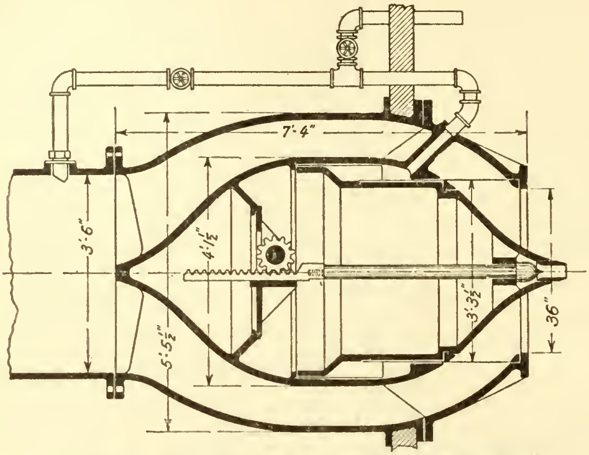


FIG. 25.—Johnson Type N discharge regulator.

Wellman-Seaver-Morgan hydraulic valve.—A valve recently brought out by the Wellman-Seaver - Morgan Co., of Cleveland, Ohio, is illustrated in Figure 26. The novel feature of this valve is the equalizing connection between the interior of the valve and the pipe lines below

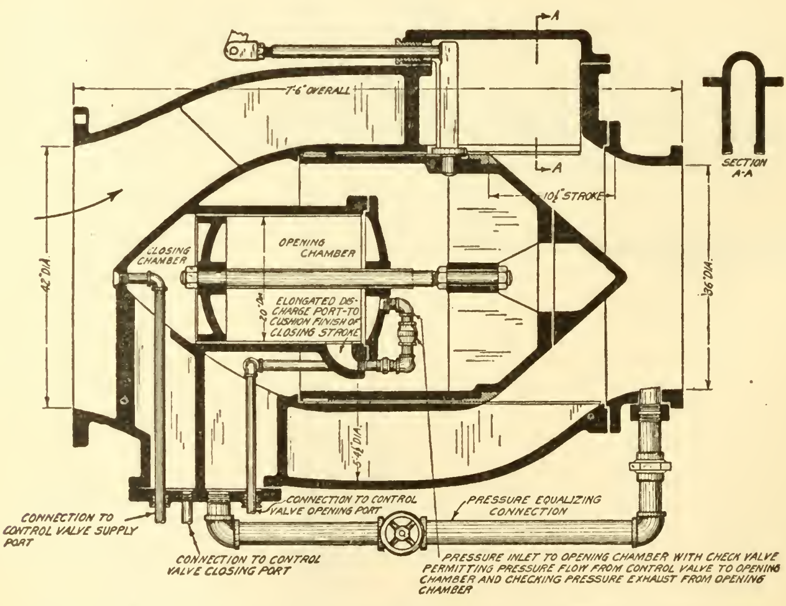


FIG. 26.—Wellman-Seaver-Morgan hydraulically operated free-discharge valve.

the seat. The illustration shows the hydraulically operated valve, but in another form mechanical operation by means of a rack and pinion is substituted for the hydraulic cylinder. Two valves of the latter type have been installed as emergency valves in the penstock connections at Shoshone Dam.

Coffin hydraulic valve.—A valve brought out in 1921 by the Coffin Valve Co. is shown in Figure 27. In this design the central control stem is threaded and screws into a nut which forms a part of the main piston. The stem is operated by bevel gears inside the cylinder and is arranged to apply mechanical force to the piston, as well as to control the outflow of water from the cylinder. This company also offers valves similar to the Elephant Butte balanced valves, as well as several modifications of the design shown in the figure.

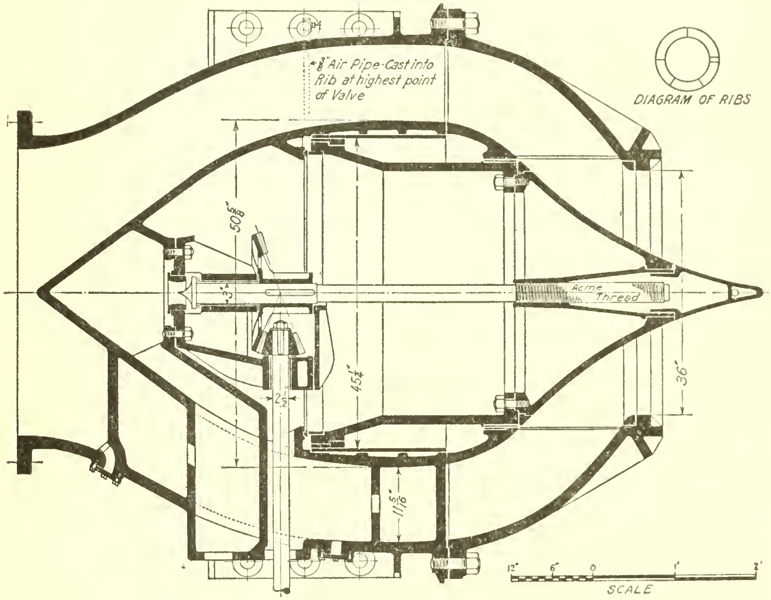


Fig. 27.—Coffin 36-inch needle valve.

Control valves.—Figure 28 shows two forms of control valves used in connection with balanced-valve installations. The plain needle valve needs no description. The combined ejector and needle valve was designed to simplify the piping and to facilitate the change from pressure to vacuum required by certain conditions of operation. This valve is in successful use at the Arrowrock and Shoshone Dams. A method of automatic control for the balanced valve by means of a float in the canal was worked out in connection with the Belle Fourche installation and is described in Chapter X. Plate 38 of the record drawings shows the design and operation of this device.

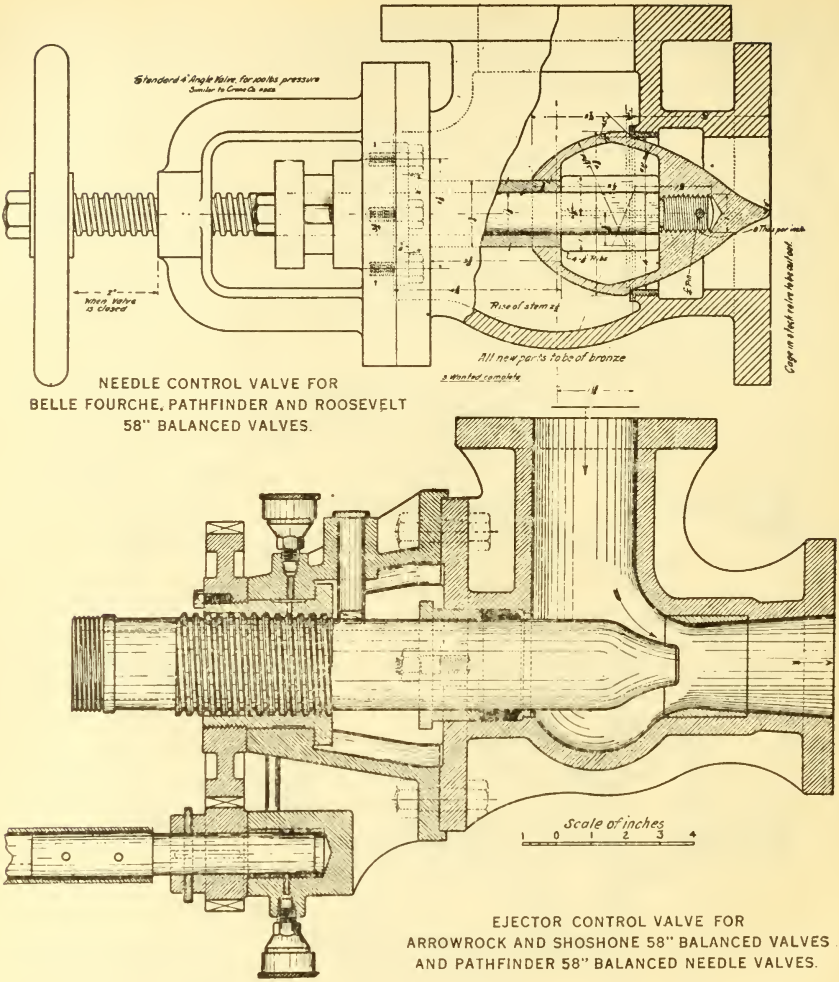


Fig. 28.—Control valves.

TABLE 9.—*Needle-valve installations of the Bureau of Reclamation.*

Reservoir.	Number of valves.	Nozzle diameter.	Maximum operating head.	Depth below spillway to center of valve.	Method of operation.	Specification No.
		Inches.	*Feet.*	*Feet.*		
Roosevelt	2	43	150	219	Balanced	Cont. 248
Do	3	58	110	107.9	.....do	Cont. 299
Do	3	54	155	140.3–146.3	Motor	354
Do	2	38	135	201.9	Hydraulic cylinder	302
Pathfinder	6	58	125	106–123.5	Balanced	165–A
Do	2	58	155	155.5	.....do	386
Shoshone	2	58	220	215.8	.....do	266
Do	2	48	226	226	Motor	243–D
Do	1	36	225	216.3	Balanced	401
Elephant Butte	4	60	120	117–173	Balanced and auxiliary cylinders.	242
Arrowrock	20	58	110	106–193	Balanced	266
Belle Fourche	3	58	52.5	51.5–52.5	.....do	165–A
Minatare	4	24	49	48	Hand	248

Chapter VI.

ROOSEVELT RESERVOIR.

General Description.

Reservoir.—The Roosevelt Dam is situated in the Salt River Canyon, just below the mouth of Tonto Creek, about 60 miles in a northeasterly direction from Mesa, Ariz. The reservoir supplies water to the Salt River project and has a capacity of 1,367,300 acre-feet. The capacity curve is shown on Figure 29.

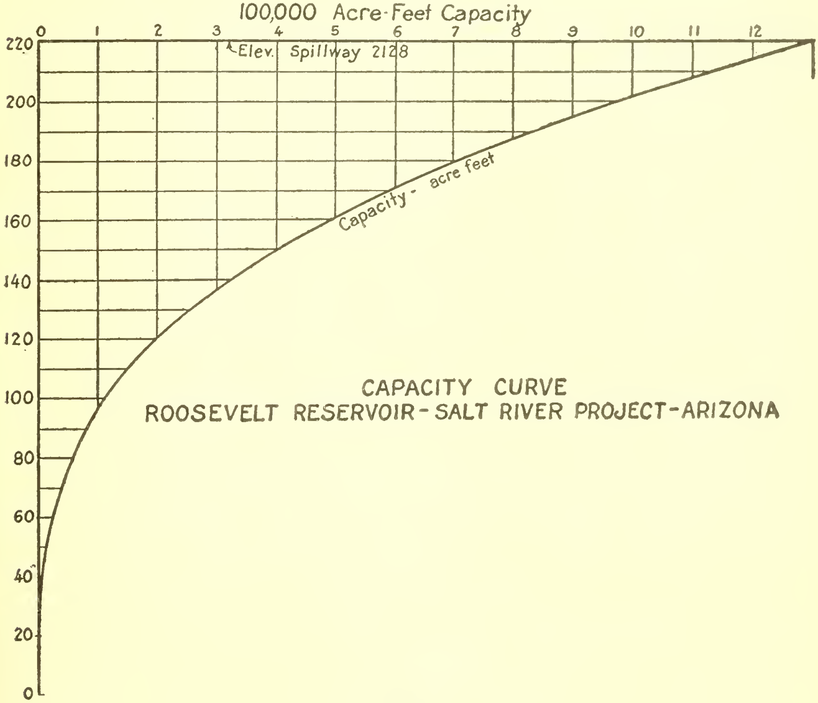


Fig. 29.

Dam.—The dam is a gravity structure, arched in plan, of rubble masonry, with coursed rubble faces laid in Portland-cement mortar and vertical joints filled with concrete. The principal dimensions are as follows: Height, 280 feet; base width, 158 feet; least width near top, 16 feet; top length, 1,125 feet; arch radius at center line of top, 410 feet.

The dam contains 342,325 cubic yards of masonry, with a 16-foot roadway along the top and a spillway at each end. Construction was begun in May, 1905, and completed February 5, 1911. The formal dedication took place March 18, 1911. The general plan of the dam and outlets is shown on Plate 4 of the record drawings.

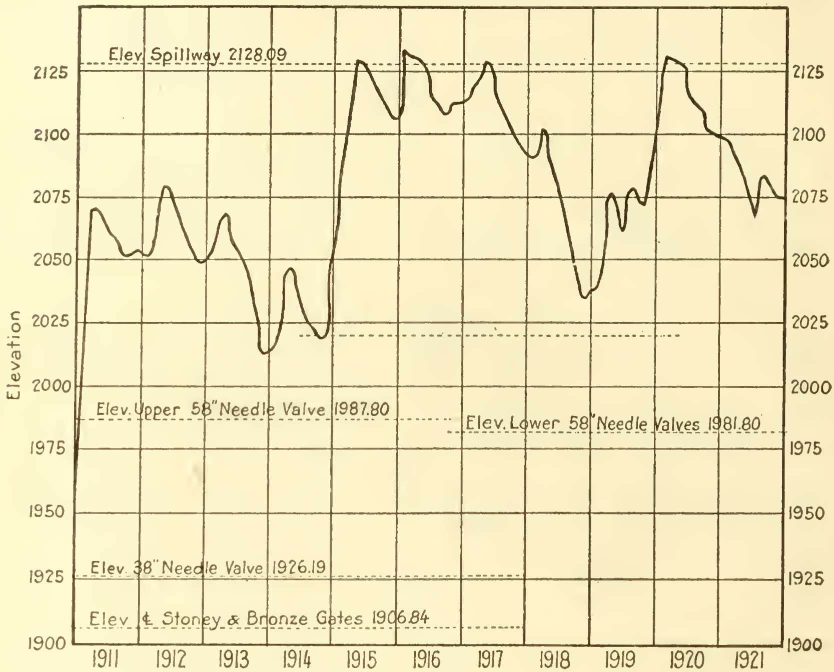


FIG. 30.—Water-surface elevations, Roosevelt Reservoir.

Figure 30 shows the variation in water surface in the reservoir and indicates the conditions under which the outlets have been operated.

Outlets.—The following table is a complete list of the devices installed for the regulation of the discharge through the dam:

Outlets, Roosevelt Dam.

Location.	Number.	Type.	Size.	Maximum head on center line.
				Feet.
South tunnel	6	Stoney gates	10 by 5 feet	220
Do	2	Slide gates	30 by 38 inches	221
Do	2	Needle valves	38 inches	202
North tunnel	3	Balanced valves	58 inches	108
Do	3	Needle valves	54 inches	146
Power house	2	Balanced valves	43 inches	219
Do	1	Cylinder valves	10 feet	182
Do	5	Hydraulic turbines	30½ inches [1]	225
Do	1	do	53 inches [1]	225

[1] Runner.

SOUTH TUNNEL.

Stoney gates installed in 1908.—During the construction of the Roosevelt Dam the stream was diverted through a sluicing tunnel 12 feet wide, 10 feet high, and 490 feet long, driven through the solid rock at about river-bed elevation. The entrance to the tunnel is protected by trash racks, and the tunnel was originally closed by two sets of three Stoney gates of special design, the downstream set for regulation and the upstream set for emergency closure, to permit inspection or repair of the service gates. The installation is fully described in an article by F. W. Hanna, which appeared in the Engineering News of May 30, 1907. Plate 5 of the record drawings shows the south tunnel outlet in its present condition (1922).

Each Stoney gate closes an opening 10 by 5 feet and is operated by a hydraulic cylinder located in a well extending down from the top of the dam and to a point 33 feet above the floor of the sluicing tunnel. Each gate was originally provided with a false face, consisting of a bronze seat extending entirely around the gate and a roller track on each side, all securely bound together with bronze plates. The roller track was paralled with the bed of the gate, but the seat sloped away from the track toward the top with a batter of 1 in 30. The gate frame carried a similar bronze face, except that the roller tracks had tongues running longitudinally up through centers to engage corresponding grooves in the rollers and the seat had a batter of 1 in 30 in the opposite direction to that of the seat of the false face. When the gate was closed, the battered faces came into contact and the total pressure on the gates was borne by the seats. As soon as the gate began to rise the pressure was transferred from the seats to the rollers, due to the arrangement of the battered faces. Each train contained 31 Tobin-bronze rollers, 4 inches in diameter, $5\frac{9}{16}$ inches in length, spaced on $4\frac{1}{8}$-inch centers, except at the separators, where the spacing was increased to $6\frac{3}{8}$ inches. The roller trains were supported from the top of the gallery by means of bronze-wire rope. An 8-inch by-pass pipe is provided.

Each gate is operated by a brass-lined hydraulic cylinder, designed for a maximum pressure of 700 pounds per square inch, having a piston connected to the gate by means of a bronze lifting rod about 6 inches diameter and about 32 feet long. The hydraulic cylinders are operated by means of an electrically actuated pump located in the power house. Each gate is provided with an automatic cut-off system designed to stop the inflow of water just as the piston reaches its highest point and the outflow just as the piston reaches its lowest point. Check valves are used to prevent shock at the moment of closure and safety valves are provided to protect the cylinders. Contract was made with Llewellyn Iron Works, of Los Angeles, Calif., on November 14, 1904, for furnishing and installing the six gates and operating mechanism, the contract price being $102,000. The side walls and roof of the tunnel below the gates were lined with concrete when the gates were installed, but the floor was left for a more convenient time.

Outlet damaged by flow in 1908–9.—After the water had been passing through the tunnel for several months it was found that the bottom was washing out. Concrete, placed at points where the floor was excavated below grade, was found to be damaged. The winter rains of 1908 made it necessary to allow the sluice gates to discharge at full capacity, and they were operated in this manner until the head gradually rose to about 90 feet. May 2, 1909, an examination disclosed much greater damage to the entire outlet than was anticipated. There were holes in the floor of the tunnel from the gates to the lower portal from 4 to 6 feet deep. The condition of the service gates is described in A. L. Harris's report, as follows:

All the roller trains were either entirely gone or broken in two and partly gone. Some of the deflector plates belonging to the walls and piers above each of the gates had been carried away or loosened. The bronze gate seats were all damaged by the blows of iron or other loose parts, the worst of these being where a strip patched onto the river side-gate seat had been knocked loose by a heavy blow. Various bolts in the other castings were loose, apparently by turning caused by vibration. The large nuts securing the piston rods to gate leaves were turned, the worst one being about 4 inches out of position. The cast-iron struts behind and above the gate had become loosened in several cases and slipped out of place. One or two of the guide strips in front of the gates had been torn off.

The concrete in the floor, roof, and piers was badly eroded by the water jets. A piece about 10 feet in diameter had fallen from the tunnel roof about 20 feet downstream from the gates, and the concrete floor, originally extending about 20 feet below the gates, had been undercut several feet back toward the piers.

Repairs made in 1909.—The work of lining the bottom of the tunnel with concrete was at once begun and approximately 250 cubic yards of concrete was placed. The entire surface of the tunnel was lined with $\frac{5}{8}$ and $\frac{3}{4}$ inch steel plates for a distance of 25 feet below the gates. The joints were made with countersunk rivets and $1\frac{1}{8}$-inch patch bolts. The plates were set in concrete and anchored by means of bolts of special design, which permitted the nuts to come approximately flush with the surface of the plate. The roller feature of the service gates was abandoned, and these gates were fitted with new plain seats of class C and D bronze, described in Chapter III. It was, of course, impossible to make any changes in the design of the emergency gates without emptying the reservoir, which was out of the question at that time.

Used as service outlet 1909 to 1914.—Aside from the south tunnel outlet, the only means of drawing water from the reservoir below elevation 117, at which point the three 58-inch balanced valves are located, was the 10-foot penstock, with its entrance at elevation 75, equipped with two 43-inch balanced valves. The limited capacity of the latter outlets made it necessary to use the sluice gates for the discharge of irrigation water under heads up to 120 feet, and subsequent to the repair of the sluicing tunnel they were operated as required, preference, however, being given to the use of the 43-inch balanced valves. This use resulted in considerable damage to the steel plate linings on the floor of the tunnel immediately below the gates, and in the spring of 1914 consideration was given to repairing this damage by means of bronze plates butting against the gate-valve seats at one end and fastened to the steel floor lining at the other, the space beneath to be grouted.

Careful inspection of the conditions, however, led to the conclusion that more extensive repairs were necessary. It was found that the steel lining in the tunnel immediately below the middle service gate had been torn up and twisted back into the tunnel and the concrete beneath it carried away for some 2 feet in depth. The steel lining plates in all the compartments below the service gates were very badly rusted and pitted, and in some places the material had entirely rusted away. Many of the rivet heads holding the plates to the tunnel walls were entirely gone, and the majority of them were so badly damaged that their strength was largely impaired. The condition of the emergency gates could not be definitely determined, but, judging from the condition of the service gates, there was serious doubt as to whether the rollers of the emergency gates were still in place. There was also doubt as to the strength of the unprotected concrete side lining being sufficient to resist the maximum pressure from leakage. The principal cause of the damage appeared to be the impact of spouting water, although serious damage to the metal work was also attributed to chemical action resulting from the salts in solution and the gases produced by decaying vegetable matter.

Reports of inspections in 1914.—W. S. Cone inspected the gates July 26, 1914, and reported the condition of the new bronze facing strips of the service gates, which were made of special bronze composition used by the Bureau of Reclamation, as follows:

> The operation of the gates had taken off all signs of corrosion and the bronze facings appeared to be in as good shape as they were when they were put in. They did not show any signs of wear. In some places the bronze showed its original color, but it was perfectly smooth and did not look as if it had been cut or worn any, simply polished bright by the action of the gate.

O. H. Ensign inspected the gates on November 9, 1914, and states that—

> The thing that interested me most was that the seats of the lower gates, which had not been in use, showed a very high state of corrosion, evenly dis-

tributed over the face of the bronze. It was in the form of a thin layer of copper and other oxides. The gate which they had been using, however, for this season's control, while somewhat mottled in appearance, showed a remarkable surface, considering the water and chemical action. There were no scratches or grooves of any kind, showing that our special bronzes for this purpose are as good as anything that can be found. This thick layer of oxide on this peculiar bronze is certainly a strong indication of what must be the condition of the cables carrying the roller train of the upper gates. * * * I was very much surprised to note the tightness of the upstream gates, there being just a fine stream of spray leaking out of the top of the outside gate, the head against them being about 110 feet.

Board decides to install supplemental bronze slide gates, 1915.—The maintenance of these control works is vital to the safety of the dam and water supply for the project, and the question of repairs and installation of additional gates was considered by a board of engineers[1] at five different meetings between June 9, 1914, and January 5, 1915. It was decided to abandon the use of the Stoney gates and install a concrete plug in the sluicing tunnel immediately below these gates. The plug was to be provided with two 54-inch bronze outlet pipes connecting with solid-bronze sliding gates, 30 by 38 inches free opening, operated by hydraulic cylinders. These valves connect with steel pipes, 48 inches inside diameter, extending outside the tunnel and connecting with 38-inch needle valves placed in a concrete chamber in the bank of the channel leading from the south spillway to the river. The center line of these outlets is at elevation 23.1. At a point approximately 135 feet from the bronze valves a cross connection is made between each of the two pipes and the 7-foot penstock, which supplies water to units 1, 2, and 3 in the power plant. It was considered probable that the required irrigation supply could be discharged through the 10-foot power penstock with the elevation of the reservoir water as low as 110. The new outlets were designed to have a combined capacity sufficient to discharge an average of 650 second-feet, or 1,300 acre-feet, per day when the reservoir was being emptied between elevations 70 and 50, requiring 17 days.

The general design of the sliding gates is shown on Plate 6.[2] The entire structure, with the exception of the piston rod, bolts, and nuts, is of gun bronze, 88 per cent copper, 10 per cent tin, and 2 per cent zinc, having an ultimate tensile strength of about 30,000 pounds per square inch. The gate leaf is a box casting and makes a lap contact at the bottom. There is a slight vertical offset at the valve designed to protect the lower stationary seat from damage by gravel or other extraneous material in the water. The operating cylinder is 13 inches diameter, designed for a working pressure of

[1] L. C. Hill, F. W. Hanna, O. H. Ensign, and F. Teichman.
[2] Record drawing series.

about 300 pounds per square inch, and tested at a pressure of 500 pounds per square inch. The water for the operation of the cylinders is obtained from a concrete tank on the hill above the power plant. The gates were designed under the direction of O. H. Ensign and are covered by specifications No. 416F. A contract, dated March 2, 1915, was awarded to the Pelton Water Wheel Co. for the lump sum of $6,600, shipping weight 16,000 pounds. The contract for the bronze linings, under specifications No. 396F, was awarded to the Llewellyn Iron Works for a lump sum of $4,731, shipping weight 19,000 pounds.

38-inch needle valves in South Tunnel.—The general assembly of the needle valves is shown on Plate 7.[2] The needle is an iron casting and is supported by three radial ribs 1½ inches wide, which bear on the cylindrical outer surface of the middle zone of the needle. The movable seat is of bronze shrunk on to the needle casing, while the stationary seat is held in the nozzle tip by means of cap screws. The stem is of bronze and is carried through the shell of the pipe in a stuffing box. It connects with a piston operating in a bronze-lined cylinder, 21 inches in diameter, designed for operation under a head of 700 feet. A small pilot valve operated by an adjustable clamp on the piston rod is so arranged that after being clamped in position a closing movement of the main needle will admit pressure to the operating cylinder to prevent further closure. The needle valves were covered by specifications No. 302, and contract was made with the Rosedale Foundry & Machine Co. for the lump sum of $6,240, shipping weight of two valves 86,000 pounds, f. o. b. Pittsburgh, Pa., contract No. 637, dated June 7, 1915. Shortly after the contract for these valves were let the Pelton Water Wheel Co. claimed infringement of Patent No. 660789, and its claim was finally compromised for a nominal royalty of $10 per valve.

South Tunnel plugged in 1915.—The concrete plug in the sluicing tunnel was completed and excavation for the gate chamber begun in the spring of 1915. The filling of the reservoir and overflow of the spillway in April of that year, however, delayed the completion of the excavation work and installation of the bronze gate valves until September, 1915. The floods of the following winter completely blocked the outlet of the sluicing tunnel, and the work of installing the steel pipe with connection to the 7-foot penstock and the needle valves was not completed until October, 1917.

Needle valves operated in 1917.—The valves were operated for the first time in the winter of 1917–18, with the elevation of the reservoir at 180 feet, representing a head of 157 feet above the center lines of the nozzles. This head is in excess of that for which the valves

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[2] Record drawing series.

were designed, and operation at that time was due to urgent demand for water in excess of the capacity of the other outlets. It was found that they operated satisfactorily. No vibration was detected at any point in the valves or pipe line. The valves were once operated with the reservoir at elevation 200, giving a head of 177 feet above the nozzles. Under these conditions they vibrated rather seriously in opening, but the vibration ceased when the valves were open. Although no damage was caused by this operation in excess of their designed head, future operation is to be limited to heads of 135 feet above the valves, or elevation 158 in the reservoir.

FORTY-THREE INCH BALANCED VALVES IN ROOSEVELT POWER PLANT.

The two 43-inch balanced valves shown on Plate 8 [3] were designed in 1908 and are installed in the power plant as shown on Plates 9 and 10.[3] Each connects with a 55-inch branch from the 10-foot steel penstock, which supplies water to power units 4, 5, and 6. The branches are located upstream from the turbine connections, and the valves discharge through steel pipes 25 feet long, increasing from 45 inches diameter near the gate to 64 inches diameter at the discharge end. The purpose of these valves was to provide easy means of compensating fluctuations in discharge due to variations of load on the turbines. The valves are located 219 feet below the spillway crest. The damage resulting from discharging water through the Roosevelt Stoney gates and on other projects indicated the advisability of using extreme caution under heads above 100 feet, and the 43-inch valves have, therefore, never been operated to any great extent with high water in the reservoir. The valves were designed under the direction of O. H. Ensign, and a contract, dated January 21, 1909, was made with the Fulton Engine Works to furnish the two valves for $7,500 f. o. b. Los Angeles, Calif. The installation was completed and the valves tested in March, 1911.

Minor difficulties experienced in operation.—Some difficulty was experienced in opening the valves at first, apparently due to excess of leakage past the bull ring. The resistance tube of No. 1 valve was turned down three-sixteenths inch on the diameter and an additional control pipe connected to the 1½-inch vent in the cylinder head. After these changes were made the valves could be opened and closed without external pressure. They could be held in a partially opened position by careful adjustment of the waste valves, but the control for partial discharge by means of the resistance tubes was never entirely satisfactory. The valves were operated as required under heads up to 148 feet. Operation at the higher heads was accompanied by heavy concussions, which at times seemed to shake the dam itself. This difficulty appeared to be due to the formation of a vacuum in

[3] Record drawing series.

the discharge pipe just below the valve, followed by a sudden inrush of air, and was no doubt aggravated by the flaring section of the discharge tubes.

In August, 1913, it was found that the two end courses of the discharge pipe had become loosened, and further operation was considered hazardous. To relieve the vacuum, a 12-inch hole was cut through the concrete immediately below the valve, and a large number of small holes drilled through the steel lining to admit air. This experiment eliminated to a large extent the difficulty due to the formation of the vacuum, and no further trouble was experienced from this source. The 43-inch valves were further modified in 1914 by installing new bronze seats, using square hydraulic packing, the original rubber packing rings having been washed out, and also by the substitution of sleeve control for the resistance tube originally installed. The operation of these valves interferes somewhat with the operation of the turbines connected to the 10-foot penstock. They have been used very little since 1913, and since February, 1916, have been submerged by backwater, due to the choking of the river channel by material brought down by the flood of 1915. They are still in good operating condition.

NORTH OUTLET 58-INCH BALANCED VALVES.

In May, 1909, shortly after the damage to the South Tunnel had been discovered, O. H. Ensign and L. C. Hill discussed the question of an additional outlet at the north end of the dam, and on account of the difficulties in handling large quantities of water at the full head it was decided to install the new valves at an elevation of 117 feet above the river bed, or 108 feet below the spillway crest. It was proposed that three valves of a new type mounted on the water face of the dam be arranged to discharge into individual conduits lined with cast-iron bell and spigot pipe, converging into an outlet tunnel driven through the rock to a point well below the dam. The three valves, which weigh approximately 45,000 pounds each, were purchased from Chas. F. Elms Engineering Works, Chicago, under contract No. 299, dated October 20, 1909, at a total price of $13,890. Plate 11 [4] shows the assembly of the valve and method of control. Plate 12 [4] shows the general arrangement of the outlet.

Valves installed in 1909–10.—On November 15, 1909, the first parts arrived at Roosevelt and erection of the valves was completed by January 1, 1910. On account of difficulty with marking of the various parts the base of valve 2 was erected wrong side up, which brought the control pipe at the top instead of at the bottom. After erection the pistons were moved back and forth by means of jacks, and there

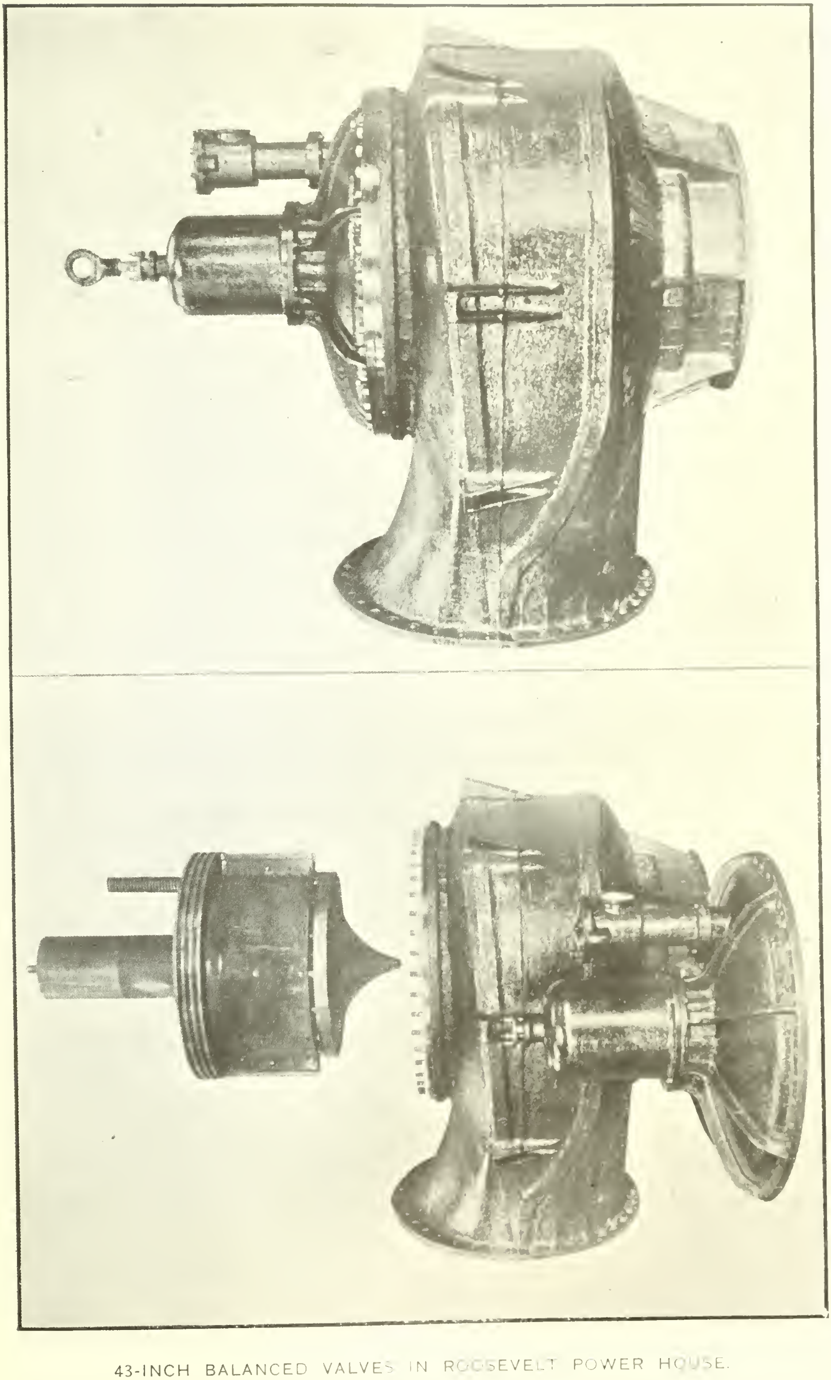
[4] Record drawing series.

was some difficulty through sticking at certain parts of the stroke. The valves were put in as good condition as possible, however, and a test with water pressure made January 15, 1910. The outlet was operated under normal conditions for the first time April 8, 1910, with the water 8 feet 3 inches above the center of the valves, and they were controlled without difficulty under these conditions. No extensive tests were made at this time because they would have interfered with construction work. The water was gradually drawn down in the reservoir below the valves and they were not operated again during 1910. An examination made in December, 1910, disclosed a considerable quantity of black, slimy sediment inside the cylinders, believed to be due to the chemical action of the water, but this discovery did not cause any apprehension.

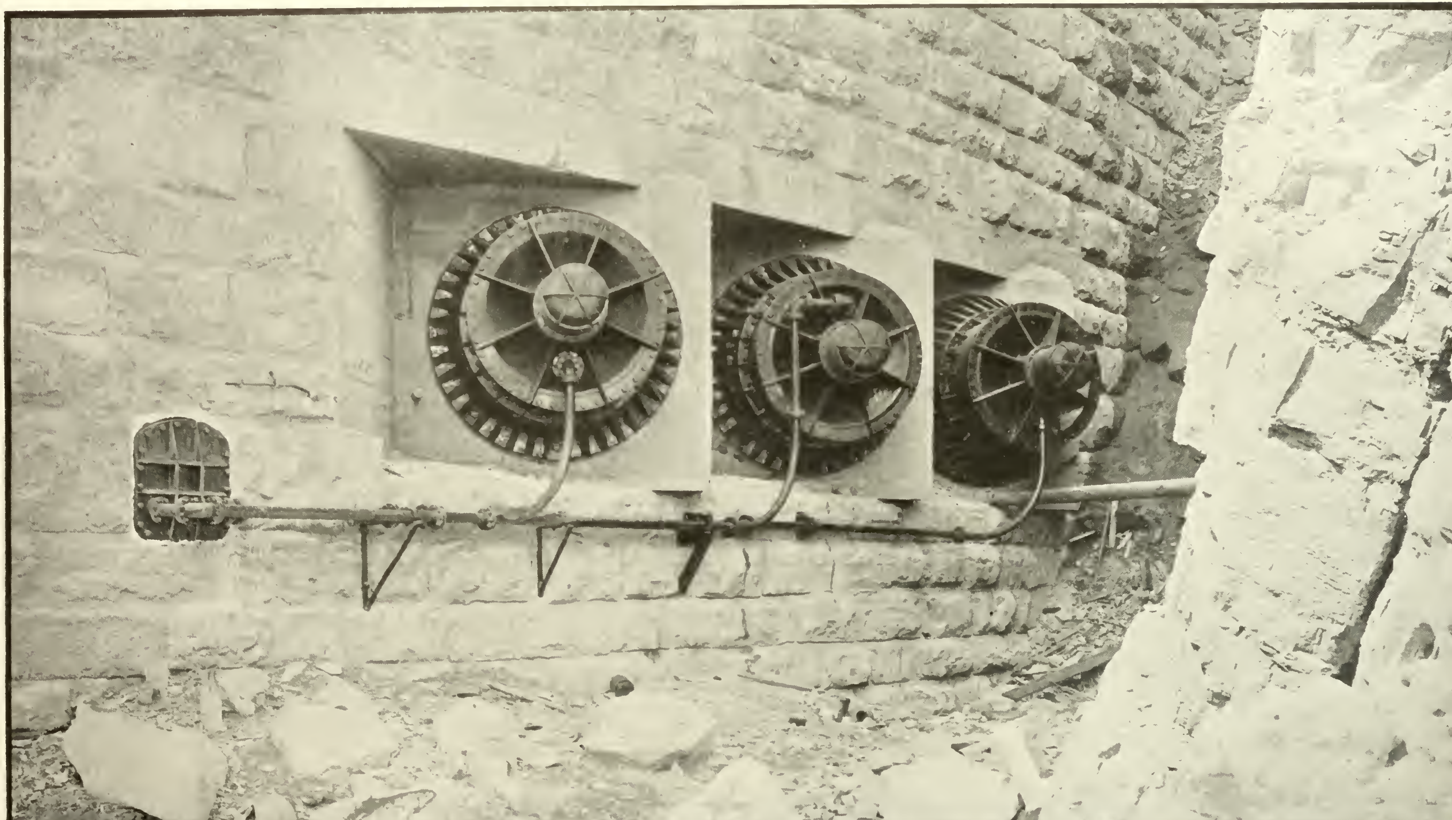
Regular service begun in 1911.—Water rose over the valves in February, 1911, and the valves were opened with water at elevation 135.35, and shortly after this were put in regular service. There was some difficulty in regulating the valves, which required vacuum for opening and external pressure at times for closing. They would not close tight, the leakage amounting to 3 or 4 second-feet. The water master soon began to complain of variation in the discharge from the reservoir, and it was found that the valves could not be depended upon to remain in any position after being set. Valve 1 caused considerable trouble by resisting closure, which required considerable external pressure to overcome. Those in charge of the valves were given instructions to use great care, but in spite of all that could be done the valves would occasionally slip and change the discharge when it was desired to hold it constant. The fact that it was impossible to tell the position of the valves was somewhat annoying and added to the time required in adjusting for the desired discharge.

The outlet was inspected December 26, 1911, and it was found that the cement grout in the joints of the bell and spigot pipes had been cut out in a few places, but the conduits and discharge tunnel were found to be otherwise in good condition. The valves leaked considerably, and it was believed that the rubber seats had been washed out as in the case of the 43-inch valves.

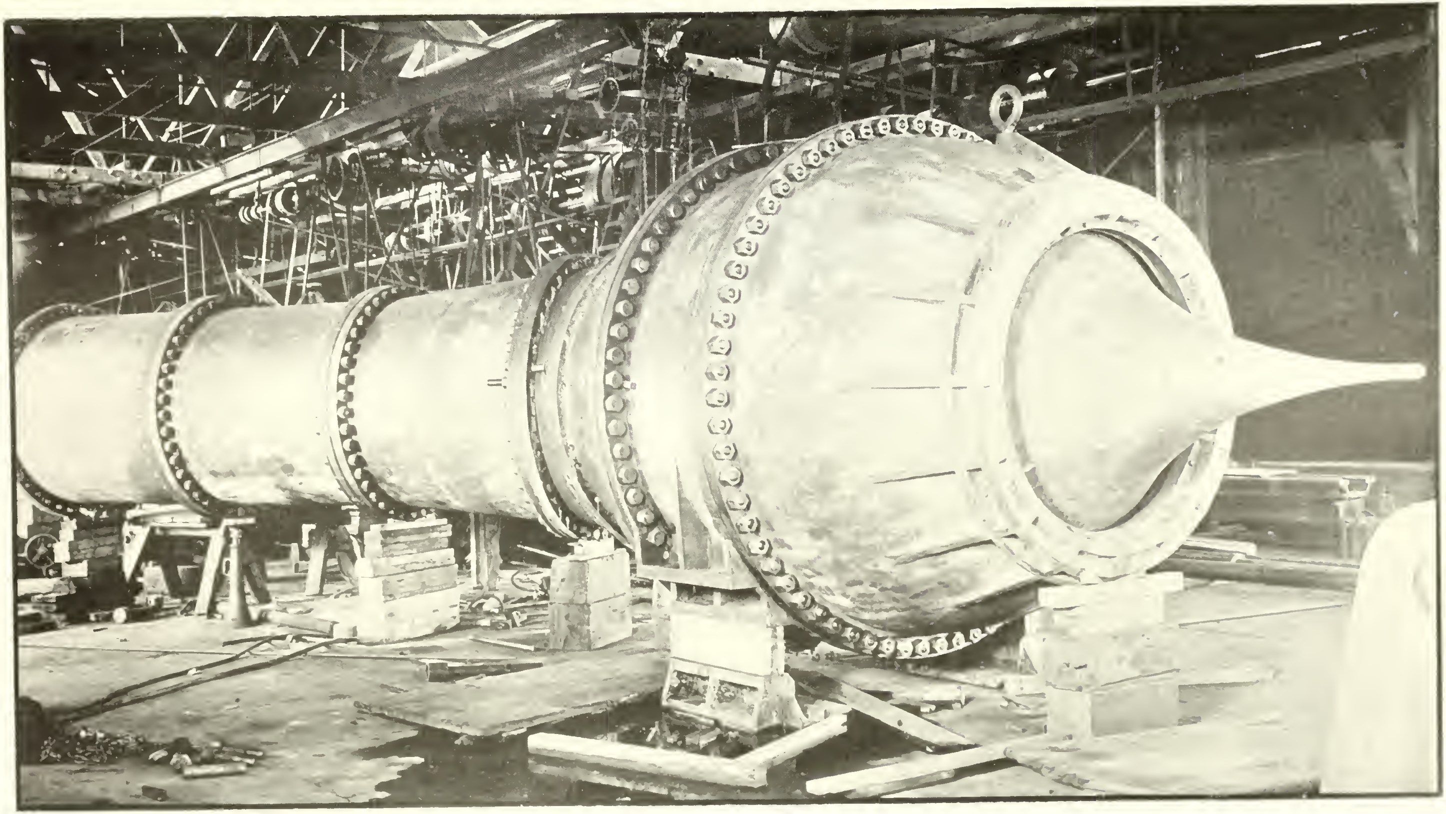
The outlet was operated for regular irrigation service throughout the season of 1912, and when tested in January, 1913, a considerable variation in discharge was noted, valve 3 discharging 358 second-feet and valve 1 discharging 594 second-feet under 31-foot head. None of the valves would maintain constant partial discharge. These irregularities were attributed to mechanical defects in manufacture and erection and to the disturbance of the delicate balance of hy-



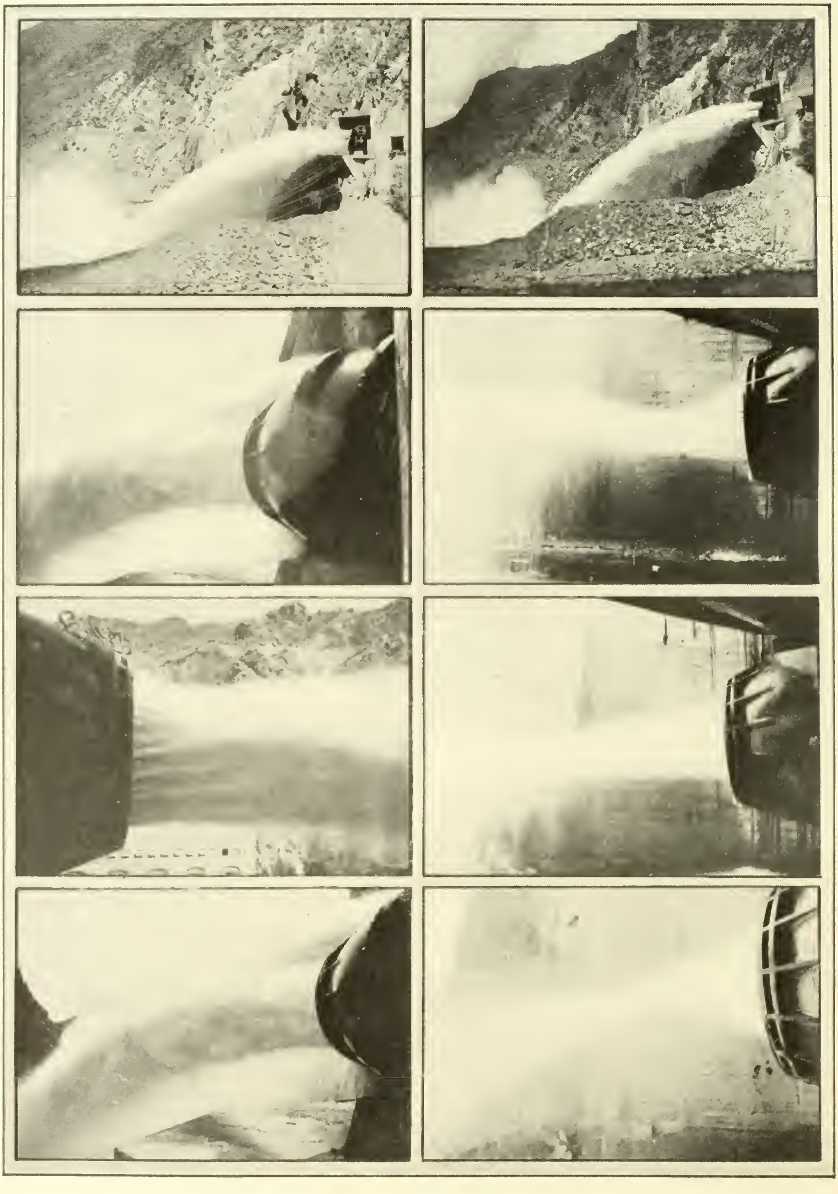
43-INCH BALANCED VALVES IN ROOSEVELT POWER HOUSE.



58-INCH BALANCED VALVES, NORTH TUNNEL, ROOSEVELT DAM.



54-INCH NEEDLE VALVE, NORTH TUNNEL, ROOSEVELT DAM.



MOTOR-OPERATED NEEDLE VALVES, 54 INCHES DIAMETER, NORTH TUNNEL, ROOSEVELT DAM.

draulic forces by accumulations of sediment in leakage spaces and control mechanism.

The valves were operated for regular irrigation service throughout of the season of 1913, and on account of the continued slipping of the valves it was planned to equip each with a float regulator similar to that successfully used at the Belle Fourche Dam. Designs were prepared, but the equipment was not installed. The reservoir was drawn down below the valves in the fall and careful examination made of the outlet.

The following extracts are from I. C. Harris's report to O. H. Ensign, October 19, 1913, covering inspection of valves on October 18, 1913.

We found the tire steel seats of the valves in bad shape, and the first section of the discharge pipe, which is bolted to the grillage frame, is also deteriorating very fast. * * * The seats and pipes are going the same way rapidly. The seats are in bad shape. In some places they are cut so that the retaining ring for the packing is half gone. * * * It does not act like ordinary wear, for the metal is "honeycombed" in peculiar shapes. This action is greatest near the V guides at top and bottom. These guides appear to have a very perceptible effect on the jet and it is noticeable in the pipes. The corrosion of the stationary seats is greatest, but the seats attached to the valves are affected, too.

Extracts from O. H. Ensign's letter of November 1, 1913, to L. C. Hill describe the conditions which were found at that time:

I examined the interior of the two outside valves * * * by taking off the elbow attaching the control pipe. The inner surface of the bronze work was in good shape; it was not scored or scratched. All exposed iron surfaces, whether bolts or cast iron, were covered with a thick, heavy scale of rust, and a quantity of this, which represented about 8 quarts loosely lying in a heap, but could perhaps be compressed into 1 quart if compressed in a case, was lying in the bottom of the cylinder; this was removed. The lining felt smooth to the hands. There was apparently no wear where the valves had stood for long periods in one position at a fixed discharge. The seats of the valves showed violent erosion and pitting. It will be remembered that at the very first, with the original design, the rubber seats blew out of these valves, and they have leaked ever since they were installed. * * * The pitting was so bad that we could not insert the new square hydraulic packing in the two valves. * * * The ring on the movable portion of the valve did not show any pitting; only a few rust blisters.

Now, as to the conduit immediately below the valve, there are pits varying from one-fourth inch in diameter to one-half inch in all the pipes, but the worst is on No. 2, which had the largest discharge and is pitted right up close to the valve, although under the present condition it is possible that four or five years of service at no greater head can still be obtained, but it plainly indicates that we must be prepared to put an inner lining of some sort inside these cast-iron pipes.

To repair this damage, new bronze stationary and movable seat rings, fitted with square hydraulic packing, were substituted for the damaged tire steel rings. The outlet pipes were patched with Smooth-on. Following these repairs the valves were operated as required for irrigation, and the reservoir was filled for the first time in 1915.

The control became more and more difficult and the project manager reported on July 29, 1915, in part as follows:

> The operation of the three 58-inch valves at the Roosevelt outlet tunnel has not been very satisfactory this year. * * *
>
> These cast-steel seats were removed and bronze seats put in their places. As far as we can tell by inspection, these seats are performing their work satisfactorily. At the time the new seats were put in * * * I removed several quarts of scale from each cylinder. This scale seems to come from around the inside surface of the cylinder, and as scaling continues I think the clearance between the cylinder and the piston is increasing, consequently giving an excess leakage around the piston. In operating the valves now they often stick, and the capacity of the pumps in the power house is scarcely sufficient to operate them at all.
>
> * * * The first length of pipe next the valve is very seriously pitted, and I do not think they will stand up another year without relining. * * * Two years ago these pipes showed the same pitting. At that time the abrazed part was filled with Smooth-on, leaving a satisfactory surface on the inside of the pipe. The inspection showed that this pipe was in very good condition the first of this season, but they have been discharging under such a high head that this filling seems to have been worn away, and the metal itself is beginning to disappear. Where the pipes discharge into the tunnel, the No. 3 valve (the farthest from the vent in the north side) has commenced cutting into the concrete lining of the tunnel very seriously.

Motor-operated needle valves recommended.—These conditions were considered October 6, 1915, by a board of engineers,[5] who recommended that temporary repairs be made and that the outlet be permanently remodeled by extending the three pipes separately from the balanced valves to the face of the cliff and installing positive-control needle valves at this point. Various alternative designs for the new outlets were prepared and submitted to a board of engineers,[6] who recommended in their report of June 23, 1916, that three motor-operated needle valves be installed in a cave at the face of the cliff under the north spillway and connected with the balanced valves by a reinforced concrete and steel pipe. New steel linings were to be placed inside the cast-iron outlet pipes, the space between being filled with grout. The steel linings for this installation were purchased and installed in the old pipes in the spring of 1918. The construction of the new valves, however, was very much delayed by the war, and they were not installed until the summer of 1919.

The inspection of the outlets in April, 1918, showed that the floor of the tunnel near the point where the three pipes converge was being damaged by the action of the water and the linings were becoming

[5] D. C. Henny, E. H. Baldwin, and W. S. Cone.

[6] O. H. Ensign, D. C. Henny, L. C. Hill, E. H. Baldwin, and W. S. Cone.

slightly loose. Operation of the balanced valves was continued with difficulty until the motor-operated valves were placed in service.

The manager for the water users' association, then operating the project, reported on the operation of the valves during the season of 1918, as follows:

Valve 1 during the 1918 irrigation season could be opened only very slightly, or enough to discharge about 250 second-feet. Every available means was tried to open this valve without success.

Valve 2 operated satisfactorily and was depended upon, as always in the past, for regulation of water discharge.

Valve 3 operated satisfactorily, as far as opening and closing was concerned, but the setting could not be changed for small changes for regulating purposes. This valve gave occasional trouble, as was the case formerly, from slipping and causing variations in the water discharged.

FIFTY-FOUR INCH MOTOR-OPERATED NEEDLE VALVES.

Pursuant to the recommendations of the board of engineers under date of June 23, 1916, designs and specification No. 354, covering three 54-inch motor-operated needle valves, were prepared. In the new design the needle is mechanically operated by means of a screw, nut, and worm gear. The valve stem makes an angle of 30° with the run of the pipe and is brought out through a stuffing box. Cast-iron diaphragms are cast inside the valve to divide the water and guide it around the needle stem. The needle proper is provided with bronze seats and telescopes inside of a stationary central casing, pointed at its upstream end and connecting with the diaphragms above mentioned. The needle is designed to produce a comparatively smooth jet of water, and the area of the water passages through the valve are proportioned to avoid sudden changes in velocity.

In the design of these valves an attempt was made to avoid the difficulties experienced with the original outlets at Roosevelt as well as those at the Pathfinder and Elephant Butte Dams. The valves were made accessible by connecting them to pipes and placing them below the dam. The effects of vacuum below the point of regulation were eliminated by giving a free discharge into the air below the nozzle tip. The difficulty of accurate regulation was overcome by a positive self-locking mechanical operating gear. The corrosion of the submerged parts of the original valves was detrimental principally by reason of its mechanical effect in increasing the clearance around the bull ring, but in the new design such corrosion can not cause serious trouble, since the operation of the valve is not dependent on leakage clearance or close fits under water. The moving parts are guided only by narrow bronze strips, with the idea of eliminating the probability of accumulation of scale or sediment, offering serious resistance to the motion of the needle. This valve, shown on Plates 13 and 14,[7] is designed for remote electrical control from the power plant. The design also provides for relieving a portion of the hydraulic load on the nut by venting the space behind the needle through 6-inch motor-operated valves also controlled from the power plant. Mechanical position indicators and suitable limit switches are provided.

After readvertisement, contract, dated January 26, 1917, was made with the El Paso Foundry & Machine Co. for a lump sum of $39,570, shipping weight 246,000 pounds. Work on the contract was delayed by the war and delivery was not completed until the summer of 1919.

The valves were installed during the winter of 1919–20, and the Nos. 2 and 3 valves were placed in operation in March, 1920. Owing to difficulty in opening the No. 1 Ensign balanced valve, the No. 1 needle valve was not operated until the middle of July, 1920. The submerged part of the control piping of the No. 1 Ensign balanced valve had become damaged, and in order to open this valve it was necessary to use a hydraulic jack, which was supported in the conduit just below the valve and operated against the needle tip. After filling the conduit with water the valve was jacked open and left in this position. It will be impossible to remove the jack or close the Ensign valve until the reservoir drops below the elevation of the valve.

The original motor on No. 3 valve was found to be inadequate, and it was replaced with a 5-horsepower motor. The original motors on the other two valves had sufficient torque, and they were not changed. Leakage of water from the needle case into the thrust-bearing housing has caused some inconvenience on all three valves, making it necessary to periodically drain these bearings. The leakage occurs along the valve stem between the stem and the bronze sleeve. The only real trouble that has been experienced in the operation of these valves has been the failure of the rollers in the thrust bearings. The rollers have been removed from these bearings and the bronze cages filled up with Babbitt metal. The result is a bearing of the Kingsbury type, which has been operating satisfactorily.

The valves operate smoothly and without vibration. Close regulation of the released water is maintained by means of a float gauge located several hundred yards below the dam and indicating in the power house.

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[7] Record drawing series.

Chapter VII.

SHOSHONE RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Shoshone Dam is located about 8 miles west of Cody, Wyo., on the Shoshone River, a short distance below the confluence of the south and north forks. The reservoir has a storage capacity of 456,600 acre-feet and is the principal storage reservoir of the Shoshone project.

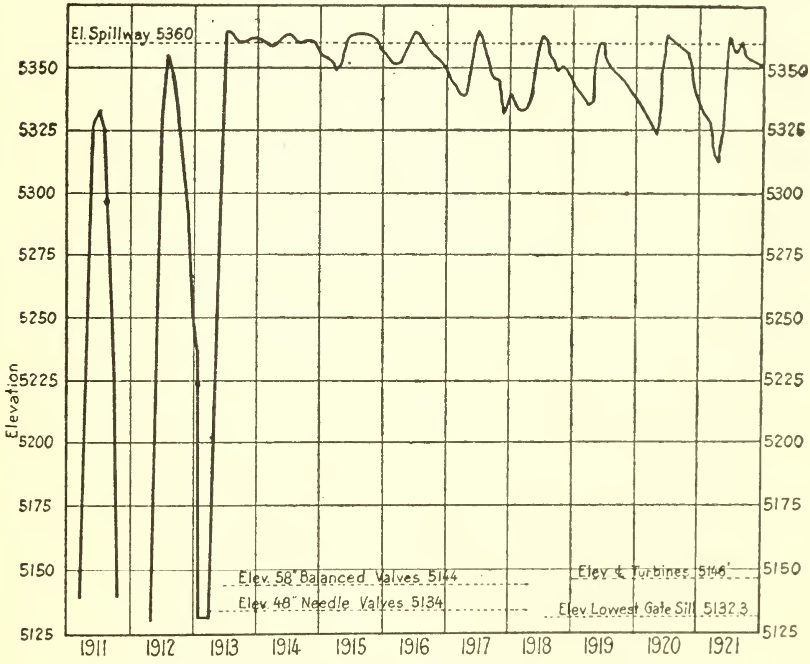


FIG. 31.—Water-surface elevations, Shoshone Reservoir.

Dam.—The dam is a monolithic, rubble concrete structure of the arch type, having the following dimensions: Height, 328 feet; base width, 108 feet; least width at top, 10 feet; crest length, 200 feet; arch radius, 150 feet; spillway length, 300 feet; spillway elevation, 5,360 feet. The dam contains 78,576 cubic yards of masonry. Construction was begun in November, 1905, and completed in January, 1910. Plate 16 of the record drawings shows the general plan of the dam, and Figure 32 gives the water-surface elevations up to and including the year 1921.

Outlets.—The various outlets for the discharge and regulation of water are listed in the following table:

Outlets, Shoshone Dam.

Location.	Number.	Type.	Size.	Maximum head on center line.
				Feet.
South tunnel	3	Slide gates	44 by 77¼ inches	218.25
Do	2	Balanced valves	58 inches	215.75
Penstock	2	Needle valves	48 inches	226
Do	1	do	36 inches	214
Do	1	Gate valve	42 inches	214
Do	2	Turbines	29½ inches [1]	230
Upper tunnel [2]				
Through dam	1	Pipe	16 inches	

[1] Runner.
[2] No valves; tunnel plugged with concrete.

SLIDING GATES.

A board of engineers[1] met at Denver February 19–22, 1906, and after consideration of the various alternative designs for the outlet works at the Shoshone Dam recommended the installation in the outlet tunnel of a set of three slide gates as a means of regulating the discharge of irrigation water. The board expressed some doubt as to the possibility of securing satisfactory regulation in this manner and suggested that in case it was demonstrated to be impracticable to properly regulate, under full reservoir head by means of the proposed sliding gates, that two alternative plans for additional regulating devices might be considered—first, an additional outlet tunnel at the higher level, and, second, valves of a different type in the lower tunnel, using the first set as emergency gates. Commenting on the measures which might be required to improve conditions in the outlets, the board suggested that it would be desirable to consider departing from former practice under lower heads and smaller volumes and to make experimental tests upon some form of gate which promised to eliminate the doubtful features of slide gates when used at partial openings under high heads.

Design of high-pressure gates.—The conditions at the Shoshone Dam, as far as they could be foretold at that time, required a discharge of 4,200 second-feet under a head of 175 feet, 2,500 second-feet under a head of 85 feet, and from 1,000 to 2,000 second-feet under 13-foot head. The gates were designed to fulfill these conditions as

[1] H. N. Savage, Charles E. Wells, A. J. Wiley, and O. H. Ensign.

closely as possible. Designs were prepared under the direction of O. H. Ensign during the spring of 1906 and are embodied in specifications No. 122. A general assembly of the gates is given on Plate 17[2] and plan and sections of the lower outlet tunnel on Plate 18.[2]

These specifications and drawings were approved by a board of engineers,[3] which met at Los Angeles, Calif., July 17, 1906. This board also considered the results obtained at Roosevelt, Ariz., of the test of a 20-inch balanced valve designed pursuant to the recommendations of the board of February, 1906, and recommended that detail designs be developed for the regulation of the discharge from the Shoshone and Pathfinder Reservoirs.

Contract No. 150, dated February 14, 1907, was made with the New Jersey Foundry & Machine Co. for the construction and installation of three sliding gates at the Shoshone Dam and four sliding gates at the Pathfinder Dam in accordance with specifications No. 122. The contract price for gates for the Shoshone Dam was $55,500. The construction and erection of the gates was completed in a satisfactory manner by the contractors.

The lower outlet tunnel, driven through the solid granite around the south end of the dam, is approximately 488 feet in length and is 10 by 12 feet in section. Its entrance is protected by a course grillage, and at a point approximately 231 feet from the entrance the three sluice gates are located. The gates are identical with those installed at Pathfinder Dam, and a description will be found in Chapter IX.

Access to the operating chamber is obtained through an adit driven horizontally from the face of the cliff near the south abutment at the elevation of the floor of the operating chamber. Pressure for the operation of the hydraulic cylinders is obtained from a triplex pump driven originally by a 15-horsepower gasoline engine, but subsequently belted to a hydraulic turbine.

The installation of the gates was completed in the summer of 1908, and all gates were left wide open until the spring of 1909, when one of the gates was closed. On June 2, 1909, with the water surface approximately 50 feet above the gate sill, the operation was tested for the first time by D. W. Cole, construction engineer, with the following results: With 50-foot head of water against the gate it was started from its seat with 125 pounds gauge pressure in the operating system, opened to about halfway with 100 pounds and the balance of the way with from 75 to 50 pounds per square inch. One man easily operated the hand-pressure pump, it requiring about an hour to open the gate to its full height. The motion of the gate in opening was smooth and steady, and there was no perceptible chattering or vibration. There was no leakage of oil from fittings or stuffing boxes, no

[2] Record drawing series.

[3] H. N. Savage, A. J. Wiley, L. C. Hill, O. H. Ensign, and W. H. Sanders.

slip on the pump, and a few turns of the crank against closed valves forced the pressure up to 500 pounds without apparent effort on the part of the man operating the pump.

The following is quoted from Mr. Cole's report of December 17, 1909, which summarizes the operation of the gates up to that date:

These three gates were wide open throughout the flood season, discharging under a maximum head of 65 feet and an average head of about 50 feet for three months. For the balance of the year they have discharged muddy water, sand, gravel, stones, boards, logs, and other débris with a head of 1 to 20 feet. Upon examination of the gates and tunnel a month or so ago the following were noted: The concrete lining of the tunnel was sensibly worn, more particularly on the bottom, which showed material increase of scour since the previous season's flood. The total depth of erosion of floor now amounts to about half an inch, the greater part of which occurred during the recent flood, the balance during three preceding floods.

The concrete in the side walls was only superficially affected, except in a few places where quality of work was below par and the water found a chance to get hold to the extent of sucking out the finer particles and leaving a honeycombed spot, probably corresponding to the few places where the voids had not filled in placing the concrete and they had been afterwards pointed up.

At the gates the wood sill in the floor at upstream edge of gate frames had been sucked out by the water, an unimportant loss.

Three or four of the bronze bolt fastenings of the steel lining plates had partly unscrewed and were projecting half an inch or less from their countersunk seats.

Perhaps a dozen nuts of anchor bolts for steel plate lining of sluiceways had rattled off and disappeared, these probably being the ones where the bolt ends were too short for riveting, as I had required to be done with all these anchor bolts. The sluiceway plates were noticeably scoured, all of the paint and the skin of the metal being gone, and in places around the bolts there was distinct pitting of the steel, as from the jetting action of the water in passing the obstruction.

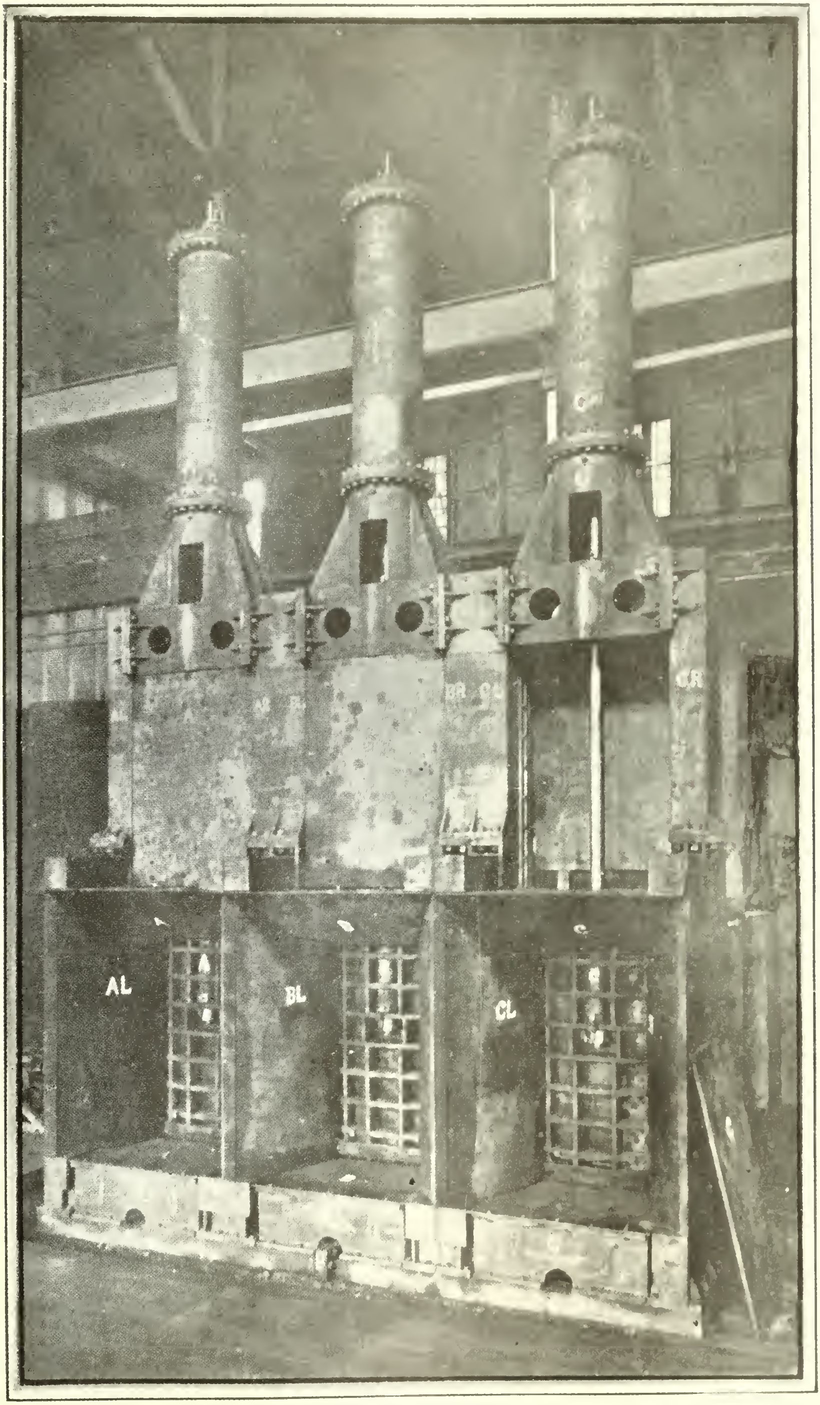
The most marked scour of the gateway parts was in the Babbitt metal gate seat in the floor. This seat, like the tunnel floor, was of course exposed to the grindstone action of the sand-laden water, and naturally was more severely attacked than the sides of the sluices. The scour of this seat was in the form of rounded pits.

The bronze gate seats and other vital parts were not affected in the least, and it may be said that on the whole this set of gates was but slightly affected by the first season of use.

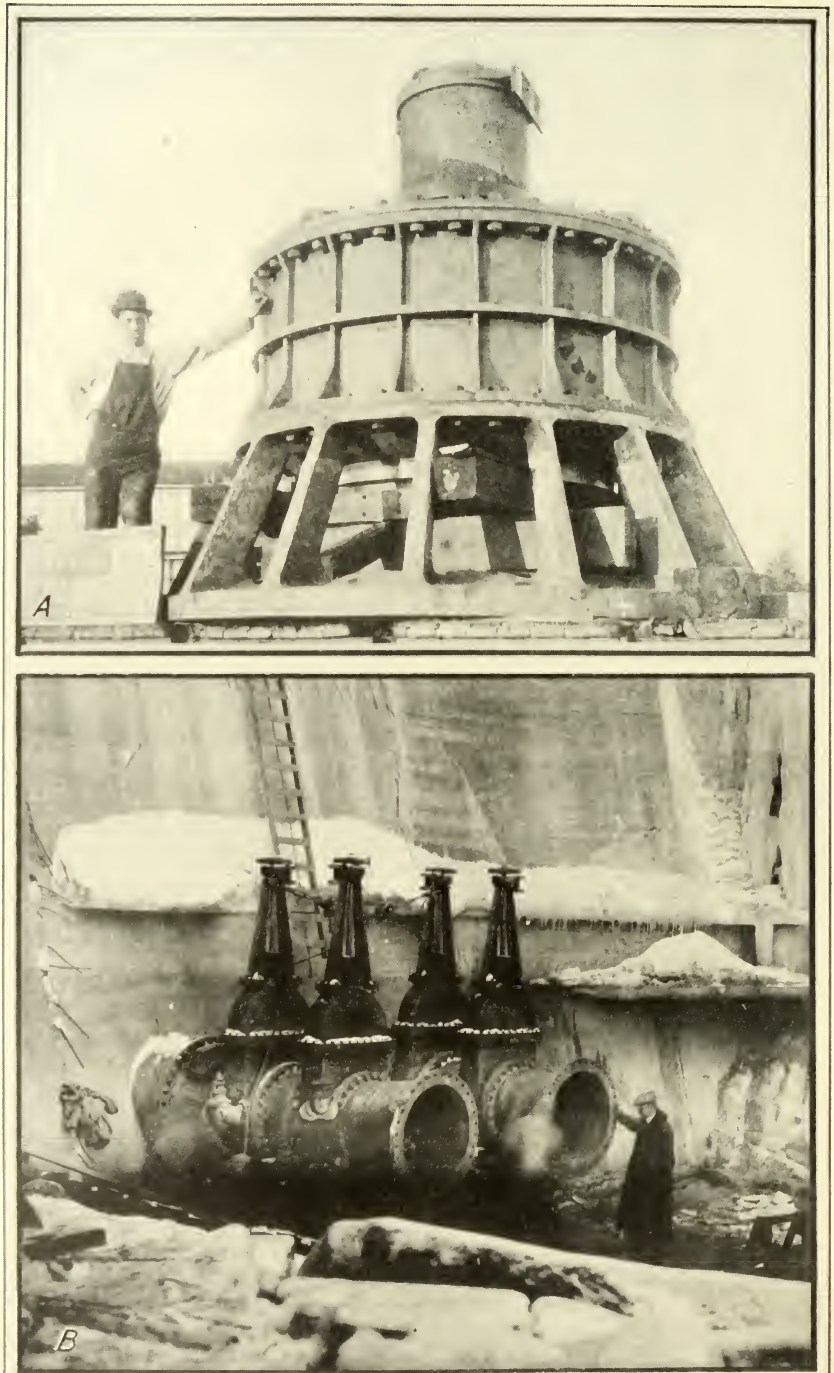
The worn Babbitt seats may result in jetting of water under the closed gates with full reservoir, which may require looking after, but just now the condition of these gates and the tunnel is very satisfactory.

During the season of 1910 the gates were operated wide open during the greater part of the season, the head reaching a maximum of 158 feet and continued to show the same difficulties, although the effects did not become at any time serious. An inspection in the spring of 1911 is reported by C. P. Williams as follows:

Silt has been flushed out of the lower outlet tunnel and the gates and gate frames inspected. There has been but little change in the condition of the



HIGH-PRESSURE GATES, LOWER OUTLET TUNNEL, SHOSHONE DAM



A, BALANCED VALVE, 58 INCHES DIAMETER, SHOSHONE DAM; *B*, BLOW-OFF VALVES, 30 INCHES DIAMETER, SHOSHONE DAM.

gates and frames since examination was made in 1910 by D. W. Cole, constructing engineer, and V. W. Russel, assistant engineer. The floor of the tunnel shows slight erosion. The sides of the tunnel show practically no erosion and no deterioration or new cracks. The gates show no signs of wear. The bolts that hold the faceplates of the piers show signs of considerable vibration. Some of the nuts were off and have been replaced. All nuts about the gate seats have been tightened. Two or three of the special brass bolts were jarred loose and lost. New bolts have been ordered to replace these. In putting in new bolts it is expected to use bolts one-half inch longer and after bolts have been placed and nuts tightened, to drill through the bolts and put in a cotter pin.

In 1911 the gates were operated for considerable periods, wide open for the greater part of the time, and in the fall and winter it became necessary to make minor repairs, replacing bolts and nuts, although no extensive damage occurred and no serious difficulty was encountered in opening or closing the gates. In the spring of 1912 they were successfully opened and closed under a head of 50 feet. They were left open during the latter part of May, and when the reservoir had reached a depth of 127 feet over the gate sill an attempt was made to close them. The two outside gates were successfully closed, but the middle gate stuck when open about 3 feet. It was found that the cup leather packing of the piston had failed and oil was leaking around the piston. This was repacked, and by installing a 15-horsepower gasoline engine and speeding up the oil pump the gate was lowered to within 2 inches of its seat. Several attempts were made to close it at higher heads in the reservoir, but without success until the head had been reduced to 127 feet.

No further attempt has been made to regulate the discharge by means of these gates, and during the seasons of 1913–1914 a control was secured by means of stop planks on the spillway. This course was adopted more on account of the difficulties which had occurred at the Pathfinder and Roosevelt Dams than on account of the operation of the Shoshone gates, which had given remarkably good service considering the conditions under which they were operated.

BALANCED VALVES.

On February 15, 1913, a board of engineers[4] considered the question of providing additional outlets from Shoshone Reservoir and recommended that the south tunnel be closed at its lower end and positive-control Ensign gates be installed near the closed end for regulating the discharge.

Pursuant to this report, studies were made on the project of methods of carrying out these recommendations, and on April 26, 1914, a board of engineers[5] recommended the installation of a bulk-

[4] A. P. Davis, D. C. Henny, H. N. Savage, and O. H. Ensign.
[5] O. H. Ensign, D. C. Henny, A. J. Wiley, and H. N. Savage.

head on the lower end of the tunnel and, between this bulkhead and the sliding gates, two sleeve-control Ensign balanced valves discharging into the canyon.

Plans for carrying out this work were prepared by Mr. Ensign, and the valves were purchased, in connection with 20 similar valves for the Arrowrock Dam, from the Joshua Hendy Iron Works, under contract 548. (See Plate 48.)[6]

In order to provide for renewing large parts of the valves, it was necessary to make the bulkhead removable, as the tunnel portal is the only means of access to the point where the valves were to be installed. The bulkhead (shown on Plate 18[1]) consists of a series of vertical steel beams supported by heavy iron castings set in a concrete plug approximately 95 feet from the lower tunnel portal.

Drainage provided back of tunnel lining.—The rock of the canyon wall contains a large number of small fissures, and in order to prevent leakage and accumulation of dangerous pressures in the rock the question of drainage was given careful consideration.

A portion of the original tunnel lining was removed and one 4-inch and two 3-inch drain pipes were installed in the upper right, upper left, and lower left corners, respectively, of the main tunnel, with branches from each of the balanced valve chambers, all drains discharging below the bulkhead. The main and branch drains were laid adjacent to the rock surrounded by gravel. Holes were drilled into the rock to intercept and provide exit for all water percolating in the vicinity, and hemp ropes coated with soft soap were laid against the rock to assist the drains in gathering seepage and provide water connection between the drain lines. The surface of the rock was cleaned and coated with cement mortar placed with a cement gun, and the drains and surface were covered with an outer lining of lean concrete with a minimum thickness of 9 inches. The surface of this lining was covered with gunnite, followed by a coat of bitumastic, applied at a temperature of 300° Fahrenheit. An inner lining, also 9 inches thick, of dense concrete was constructed.

Valves discharge through adits.—The balanced valves are placed in small chambers excavated at the side of the main tunnel and discharge into separate tunnels leading through the canyon wall. The roofs of the tunnels are cut away at their outer ends to provide access of air to the jets below the valves. The positive-control mechanism is carried vertically to an operating chamber excavated in the rock as a branch to the adit, leading to the hydraulic cylinders of the sliding gates, as shown on Plates 19 and 20.[6] Construction work was started in August, 1914. The installation of the

[6] Record drawing series.

valves was begun in February, 1915, and completed in May of that year.

Bulkhead fails under test.—The bulkhead and valves were operated under pressure for the first time May, 1915, by opening the 18-inch by-pass on the sliding gates. The vertical cast-iron beam at the right-hand side of the bulkhead frame failed under this test, apparently due to accumulation of pressure behind the casting caused by seepage. Repairs were made by replacing the broken beam with concrete, bracing the horizontal frame beams and the remaining vertical frame post, and preventing as far as possible the accumulation of seepage pressure. The work was completed September 16, 1915.

Valves tested in November, 1915.—The balanced valves were tested November 10 and 11, 1915, for the first time with the 18-inch by-pass wide open. Both valves were successfully opened and closed several times, the maximum opening being about three-tenths of the travel of the piston. It was at times necessary to apply external pressure to move the piston, but no difficulty was experienced during the test. In view of the possibility of trouble in closing the sliding gates if they had been opened for a complete test of the balanced valves and some accident had occurred, further test was postponed until the beginning of the irrigation season of 1916.

On May 12, 1916, the tests of the previous November were repeated, and the three sliding gates were then opened wide and water discharged through each of the balanced valves up to approximately half opening, with the reservoir full, giving a head of 216 feet above the center lines of the balanced valves.

High-head tests in 1918.—Further test was made June, 1918, with a full reservoir, and the project manager reports a test made July 27, 1918, as follows:

The indicator was set at full opening and the valve opened. It took about 1 minute from the time of opening the needle valve in the operating chamber until the valve began to discharge some water, and it required 1 minute more for the valve to reach its maximum discharge. In former tests of this valve with the indicator set at five-tenths or six-tenths opening, it has always been possible to close the valve by shutting the needle valve, but with the valve at full opening it would not close, and each time it was necessary to apply additional pressure by means of the centrifugal pump. It required an average of about 2 minutes from the time additional pressure was applied until the valve fully closed, and it was also noticed that from the time the discharge began to diminish until it ceased the interval was very close to 1 minute. It was also found that it was not possible to hasten the movement of the valve by opening wide the operating valves and allowing the additional pressure of 15 pounds to act on the rear of the piston.

The upstream valve was tested in similar manner, with the indicator set at full opening. This valve opened in an average of about 1 minute. It required about 45 seconds from the time the needle valve was opened until water began to discharge, and the full discharge of the valve was reached in an additional period of about 15 seconds. In closing this upper valve it required an average of about 3 minutes from the time the pressure was applied on the piston until the discharge ceased, and it was not possible to appreciably hasten the movement of the valve.

Each valve was opened and closed several times, and at no time was any shock or jar noticed. The valves seem to open and close under ideal conditions, and it does not seem possible for a careless operator to do any serious damage to these valves, although it has been our practice, and always will be, to operate these valves in a very careful manner.

While the valves are discharging, there is a noticeable rapid vibration, which seems to be more noticable in the outer canyon than in the operating chamber. The manhole leading from the operating adit to the pressure tunnel is filled with water, and there is hardly any perceptible movement in the water surface when the valve directly underneath is operated at full opening.

Concrete damage below valves.—The project manager reports the operation of the valves for the year 1917 as follows:

The lower tunnel at Shoshone Dam has been unwatered and the balanced valves opened and the discharge tunnels inspected. In 1917 the downstream valve was opened 30 per cent, May 13 to June 23; 100 per cent, August 1 to September 6; 50 per cent, September 7 to 24. It was found that a portion of the concrete lining had been carried away by the high velocity of the water, which travels at about 100 feet per second. The concrete was intact all around the end of the steel discharge pipe. On the floor of the tunnel it had been entirely torn out and also the left side wall. The right wall and the roof were intact. At the time this concrete lining was placed in the two discharge tunnels it was expected that it would not be able to stand the high velocity of the water. The slight damage that has occurred is not serious, and no benefit could be derived by replacing this concrete. The upper valve was not operated except to open and close it several times during the season, so as to be certain it was in good condition.

The lining in the upper discharge tunnel is still intact with the exception of a slight erosion just below the steel discharge tube. This starts on the concrete side walls at the elevation of the horizontal axis of the steel discharge tube and about 6 inches beyond the end of the tube. It continues thence downward at an angle of about 30°, diverging slightly and reaching its greatest depth at a point about 4 feet beyond the end of the tube, where a hole has been started in the concrete floor. It is certain that the entire concrete floor will be carried out after this valve has been operated a short time. It was also noted that at one small area in the top of the discharge tube of the lower valve, about 10 inches beyond the valve seat, there appeared to be some erosive action on the metal. The marks left by the finishing tool had been slightly deepened and the surface felt rougher than on other portions of the pipe. The discharge tube on the upper valve was carefully examined and was found in excellent condition. At the close of the operating season the upper tube will be carefully examined to see if the water has caused any excessive wear on this steel tube.

POWER OUTLET.

Thirty-inch gate valves installed 1913.—There are two 42-inch pipes laid straight through the dam with center lines at elevation 5,134, 226 feet below the crest of the spillway. It was intended to use these pipes for future power development as well as for such regulation of discharge as could be accomplished by free discharge or full closure of the valves to be attached to the lower ends. The pipes were allowed to discharge freely until the fall of 1913, when on each pipe were installed two 30-inch, double-disk, rising-stem, bronze-fitted, outside-screw-and-yoke gate valves suitable for a test pressure of 300 pounds per square inch. The valves were purchased from James B. Clow in 1908 at a price of $1,573 f. o. b. Waterford, N. Y. The upper valve on each pipe was provided with a by-pass, and the proposed method of operation was to equalize the pressure on the upper valve and raise it before attempting to open the lower one. In this way it was thought the upper valve could be kept in good repair even though the lower one might be damaged.

The valves were installed in the winter of 1912–13, and in order to complete the installation it was necessary to empty the reservoir, which resulted in some large damage claims, due to drifting dust and silt on Irma Flat.

Valves wrecked by discharge.—The north valves were opened under low head in the spring of 1913 and remained open until August 27, when an attempt was made to close them under a head of 227.5 feet. The lower valve was closed about 1 foot, when it was found impossible to close it further. The upper valve was then lowered about 1 foot, and by working the valves alternately about half an inch at a time both were practically closed. Just before the upper valve seated the casting holding the stem nut was broken and teeth were stripped from the pinion of the downstream valve. In October, 1913, the assistant engineer at the dam reported that the upper valve was opened approximately 1½ inches and there was some flow through the valve, as was evidenced by a small amount of vibration, and that four men working on the operating gear were unable to close it. The lower valve was opened approximately 10 inches at that time, but was subsequently practically closed. In October, 1914, it was found that the lower valve was missing, having apparently been torn off by the discharge water from the south pipe.

The south valves were opened under low head in the spring of 1913 and remained open until the fall, when an attempt was made to close them. The upper valve was closed to within 5 inches of its seat, but on account of water backing up into the gate house an attempt was made to reopen it. The stem was broken loose from the disk in this attempt, and the valve remained about half open with the lower valve wide open until the spring of 1914. About the middle of March, 1914, the lower valve was damaged and in May it was found to be tilted to an angle from the vertical. It was torn away from the pipe in May. The upper valve was torn away in June, the break extending up through the cast-iron bonnet, thus leaving the south 42-inch pipe discharging freely without control.

UPPER OUTLET OR MIDWAY TUNNEL.

The upper or midway tunnel was driven to serve three purposes—for a reservoir vent at middle levels; to avoid the use of the lower tunnel gates under high heads; for power development; and for the possible means of supplying water to the head of the canal to Oregon Basin. The work was undertaken in the winter of 1909–10 and completed by June, 1910. June 2, 1912, the tunnel was plugged with concrete and on December 22, 1912, a portion of the plug was removed. The plug was replaced April 26, 1913, and remains in this condition at the present time. No control works have ever been installed.

POWER DEVELOPMENT 1921–22.

The development of power was undertaken in 1921, and in order to supply water to the turbines the 42-inch pipes were equipped with needle-type emergency valves and connected with a tunnel driven in the north canyon wall. The tunnel connects at its lower end with a steel manifold, with branches for the three turbines and an extension of smaller diameter connecting with a 36-inch needle bypass valve.

Emergency valves.—The emergency valves are located immediately below the dam and serve as a means of shutting the water out of the penstock tunnel for inspection or in case of a break. These valves (see fig. 31) were designed and manufactured by the Wellman-Seaver-Morgan Co., contract 851, dated February 1, 1921. The contract price of the two valves was $12,610 and the total weight 42,000 pounds. One thousand five hundred and fifty dollars additional was paid for extending the shaft and placing the operating mechanism on a separate bedplate. The valves are provided with flange connections for 48-inch pipe and are operated by motors controlled either from the power plant or at the valve. The plunger of the valve is a simple piston with pointed tip telescoping into a stationary cylindrical housing with pointed upstream end. Approximate balance of the hydraulic forces is obtained by an equalizing pipe connecting the interior of the cylinder with the throat of the valve below the stationary seat. Operating force is applied to the plunger through a rack and pinion centrally located in the cylinder, the operating shaft being brought out and through a stuffing box and extended to a motor-operated worm gear and Dean motor control located on an operating platform 17 feet above the valve. The installation is shown on Plate 21 of the record drawings.

Penstock tunnel.—The penstock tunnel is 518 feet long and has a horseshoe section 8 feet 6 inches by 8 feet 6 inches inside the concrete lining, which has a minimum thickness of 9 inches. An elaborate system of drainage between the lining and the rock has been provided, the seepage being collected into four tile pipes laid in gravel, two above and two below the bore. The steel pipes are connected to anchor castings set in concrete keys in the tunnel section.

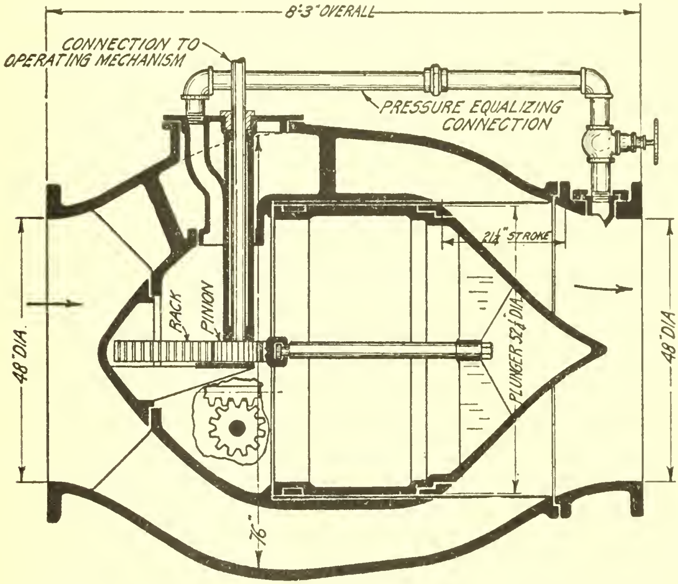


FIG. 32.—Emergency needle valve, 48 inches in diameter, power outlet, Shoshone Dam.

The distance between the end of the concrete lining and the face of the cliff is at no point less than 50 feet.

36-inch needle valve.—The by-pass valve is located at the end of a 48-inch extension of the penstock manifold and is protected by a 42-inch motor-operated gate valve. The gate valve was furnished by the Pittsburg Valve, Foundry & Construction Co., under contract 850, dated February 16, 1921, at a price of $2,580, weight 14,000 pounds. The needle valve was purchased from the same company under specifications No. 401, at a price of $5,431, weight 28,000 pounds. The needle valve is similar to those installed on the North Tunnel outlet at Pathfinder Dam. The design has been modified by placing the control valve outside the valve body and making connection with the main piston by means of a rack and pinion and shaft brought out through a stuffing box. This arrangement simplifies the machine work and makes the control accessible for inspection and repairs. The gate valve is a 42-inch double-seated, rising-stem, iron-body, bronze-mounted, motor-operated gate valve with bronze stem. Both valves are installed in a concrete gate house, and the needle valve discharges into an inclined tunnel, the lower portal of which is submerged. This arrangement was adopted to limit the formation of spray, which might prove objectionable around the power plant. Plates 22 and 23 [7] show the assembly of the valve and operating mechanism. The installation is shown on Plate 21.[7]

Table 10.—Cost of lower tunnel outlet, Shoshone Dam.

	Quantity.	Cost.	Subtotal cost.
	Cubic yards.		
Tunnel (contract work 1905–1906), excavation	2,370		$20,245
Tunnel (appurtenant work 1907–8):			
Plant and preliminary work		$2,376	
Excavation	571	11,008	
Supplies and miscellaneous material		3,205	
General expense, superintendence, and engineering		4,386	
			20,975
High-pressure gates (1908):			
Plant and preliminary work		1,216	
Gates, contract price installed		55,500	
Labor		1,990	
Concrete		4,157	
Freight		2,865	
General expense, superintendence, and engineering		4,707	
			70,435
Channel excavation, east of dam	2,800		4,128
Balanced valves (1915–16):			
Plant and preliminary work		7,391	
Tunnel excavation		12,069	
Tunnel drainage		2,734	
Two 58 inch balanced valves		13,829	
Removable bulkhead		3,537	
Gate operating machinery		2,349	
Concrete		10,524	
Labor, teams		1,950	
General expense, superintendence, and engineering		16,413	
			70,796
Repairs on removable bulkhead:			
Plant		48	
Excavation		1,170	
Concrete		297	
Structural steel		1,583	
General expense, superintendence, and engineering		509	3,607
Total cost, lower tunnel outlet			190,186

[7] Record drawing series.

Chapter VIII.

MINIDOKA DAM AND OUTLETS.

GENERAL DESCRIPTION.

The Minidoka Dam is located in Idaho on the Snake River, about 6 miles south of the town of Minidoka. As will be seen from Plate 24 of the record drawings, the dam consists of an earth and rock fill section, an overflow section, a power-house section, and two sections containing the head gates for the north side and south side canals of the Minidoka project. The dam was built for diversion and power purposes only, but it was later found to be advisable to provide a limited amount of storage by placing flashboards on the crest of the overflow portion of the dam. Piers for supporting these flashboards were installed in 1909 and the crest raised 5 feet, providing a storage capacity of 53,500 acre-feet. The reservoir is called Lake Walcott.

The flow of water through the dam is controlled by nine 5 by 7 foot slide gates at the North Side Canal headworks, with sills, at elevation 4,230.5; nine 5 by 6 foot slide gates at the South Side Canal headworks, with sills at elevation 4,234; four 10 by 12 foot radial sluiceway gates, with sills at elevation 4,228; five 10-foot diameter penstock gates, with inverts at elevation 4,226; and five 8 by 12 foot slide gates, with sills at elevation 4,192. The radial sluiceway gates were installed in the winter of 1912–13 to reduce the necessary amount of flashboard manipulation. Designs for the dam and outlets were prepared in 1903–4 by J. L. Savage, at that time assistant engineer, under the direction of D. W. Ross, supervising engineer, and A. J. Wiley, consulting engineer.

BOARD MEETING.

A board of engineers[1] met at Boise, Idaho, on March 21, 1904, to discuss the plans for Minidoka Dam and appurtenant features. Preliminary plans submitted by J. L. Savage were approved. This board met again on December 5, 1904, at which time slight changes were made in the original plans, particularly in the location of the power house.

[1] A. P. Davis, George Y. Wisner, and H. N. Savage.

PENSTOCK GATES.

The cast-iron penstock gates, details of which are shown on Plate 25 of the record drawings, close circular openings 10 feet in diameter and are used as guard gates for the power units. These gates operate under a maximum head of 14 feet on their centers. A trash rack covers the entrance to the penstocks. The gate seats are of bronze, and two bronze stems are provided for each gate. The hoists for the two stems are geared together and driven by a single motor, controlled by switches located in the power house. Provision is made for hand operation in case of emergency. Under contract dated July 18, 1918, specifications No. 153, S. Morgan Smith Co. furnished the five penstock gates, without electrical equipment, f. o. b. York, Pa., for $4,975, and electrical equipment to operate one gate for $2,400. The electrical equipment for operating the other four gates was purchased under contract No. 290, specifications No. 157, from the Fulton Engine Works, f. o. b. Los Angeles, Calif., for $6,605.

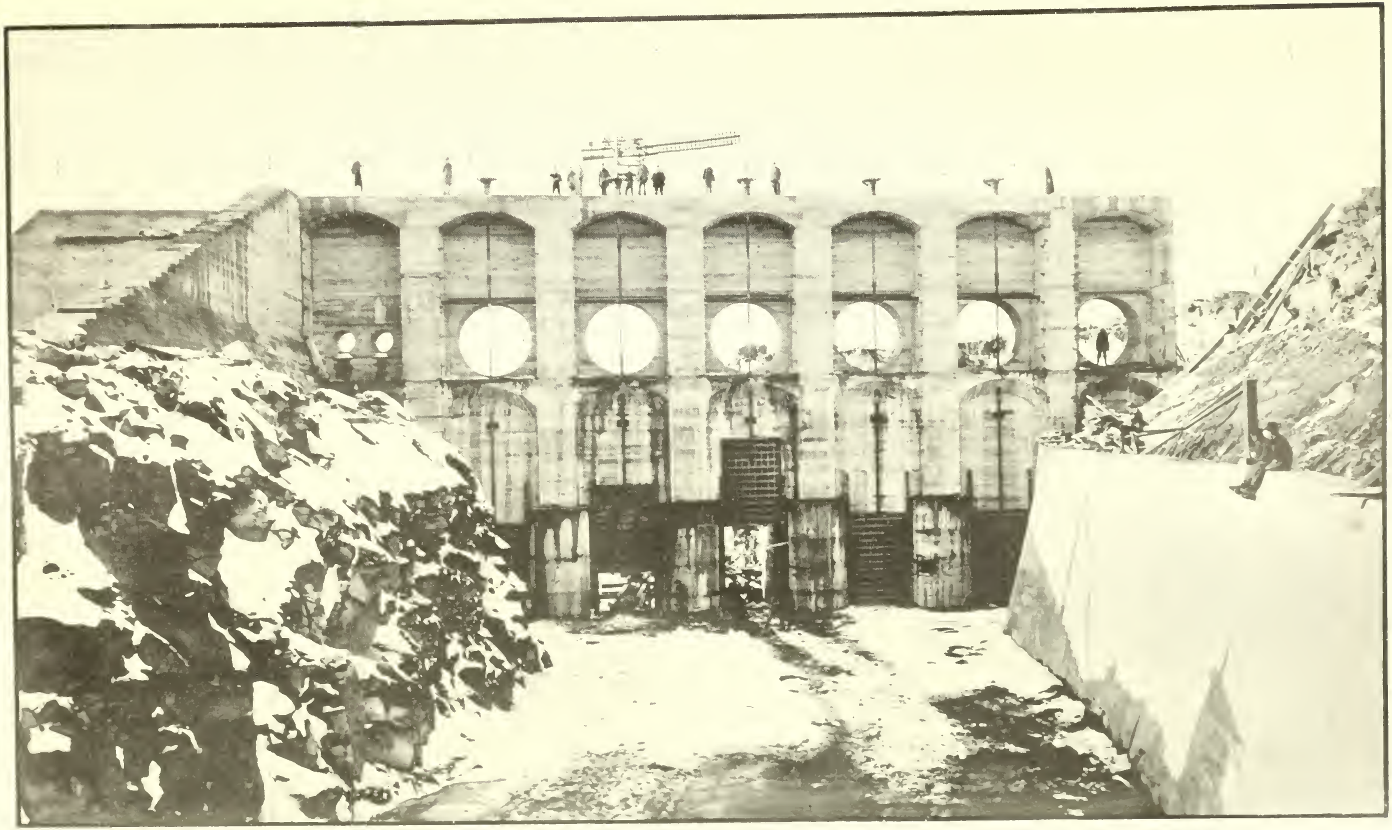
The installation of these gates was completed in 1906, and they have operated satisfactorily since that time.

EIGHT BY TWELVE FOOT SLIDE GATES.

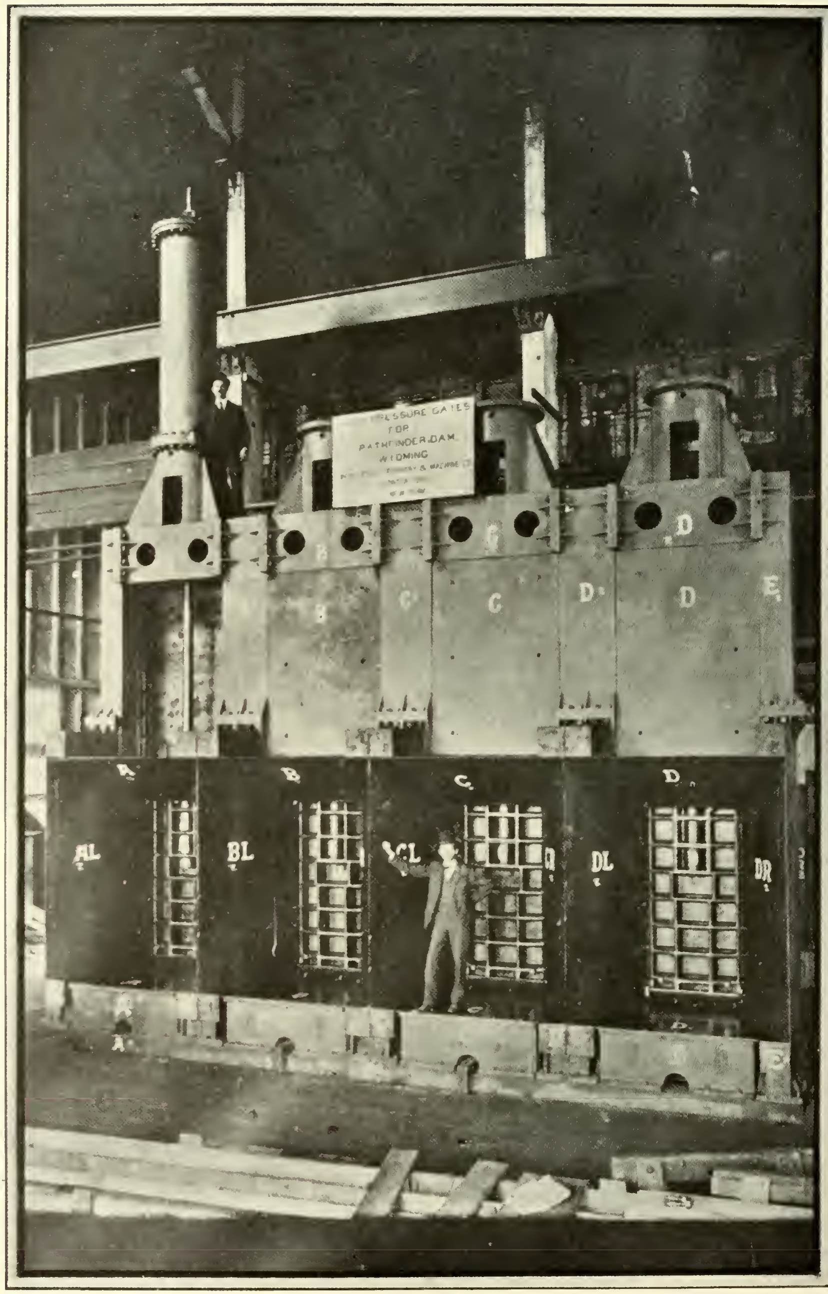
The five 8 by 12 foot cast-iron slide gates, with sills at elevation 4,192, were installed in 1905 and 1906. They are operated by Coffin standard ball-bearing stands, with variable speed gears. Details of the gates and hoists are shown on Plate 26 of the record drawings. These gates were installed primarily to control the flow of the river during the construction of the dam. They were first operated in 1906 and were again opened in 1908–9 to facilitate the construction of the power house. At this time one of the gates could not be raised, and it has not been operated since 1906. No information is available as to why this gate could not be opened.

The hoists were originally intended for hand operation, but a portable electric motor, belt connected to the crank shaft, was later provided. The gates have not been operated since the installation of the radial sluice gates in 1913, and it is not expected that they will be operated again. The draft tubes from the turbines are located immediately below these gates and must be removed before the gates are opened.

The gates and hoists were included as an item in the contract for the construction of the dam and were furnished and installed by the Coffin Valve Co. for the contract price of $18,500. With the exception of the failure of one of the gates to open, as noted above, these gates have operated satisfactorily. The reservoir is usually maintained near the full supply level.

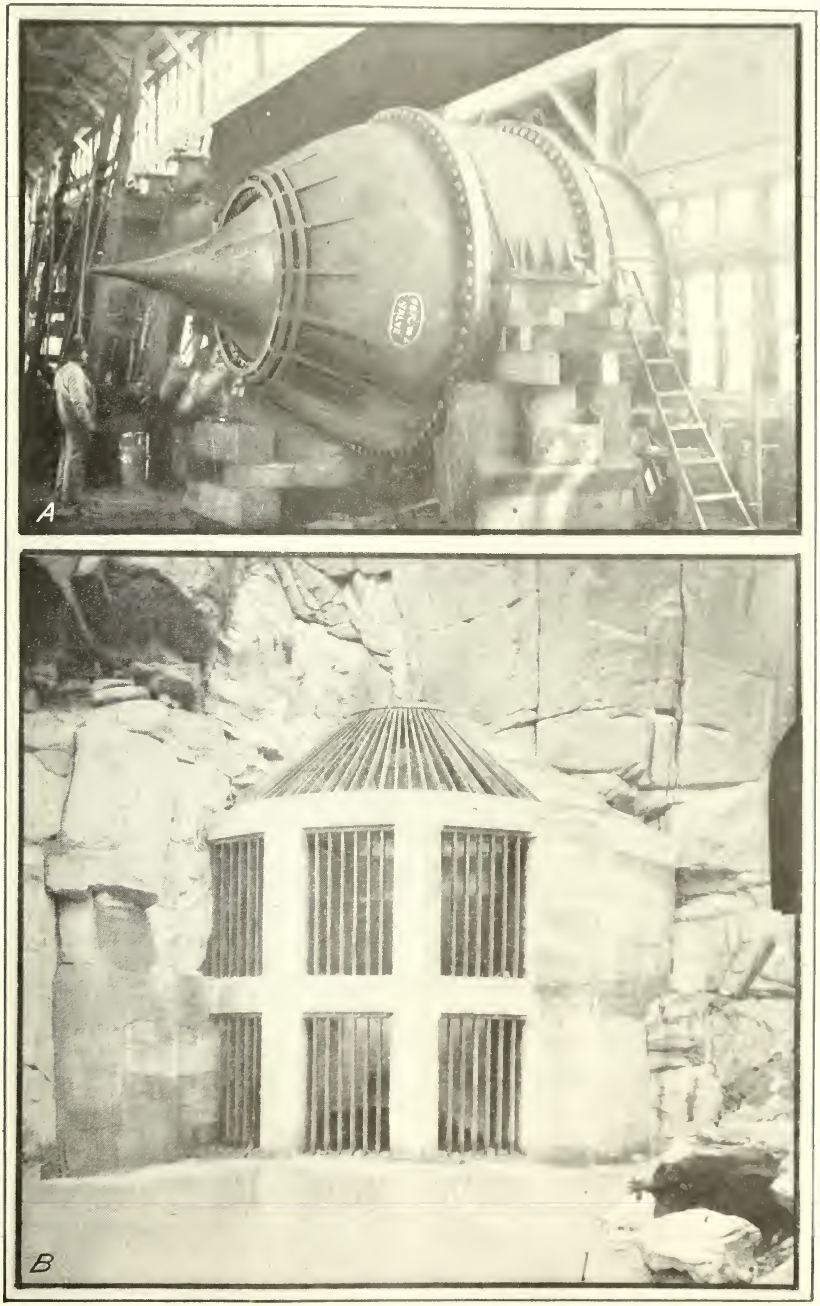


SLUICE GATES AND OPENINGS FOR PENSTOCK GATES, MINIDOKA DAM.



HIGH-PRESSURE GATES, NORTH TUNNEL, PATHFINDER DAM.

PLATE XIII.



A, 58-INCH BALANCED NEEDLE VALVE, NORTH TUNNEL, OUTLET. *B*, NORTH TUNNEL GRILLAGE, PATHFINDER DAM.

OPERATION OF 58-INCH BALANCED NEEDLE VALVE IN NORTH TUNNEL OUTLET, PATHFINDER DAM.

Chapter IX.

PATHFINDER RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Pathfinder Dam is located below the junction of the North Platte and Sweetwater Rivers, approximately 47 miles in a southwesterly direction from Casper, Wyo. The reservoir supplies water to the North Platte project and has an available storage capacity of 1,070,000 acre-feet. At maximum storage the reservoir is about 27 miles long and covers 22,700 acres.

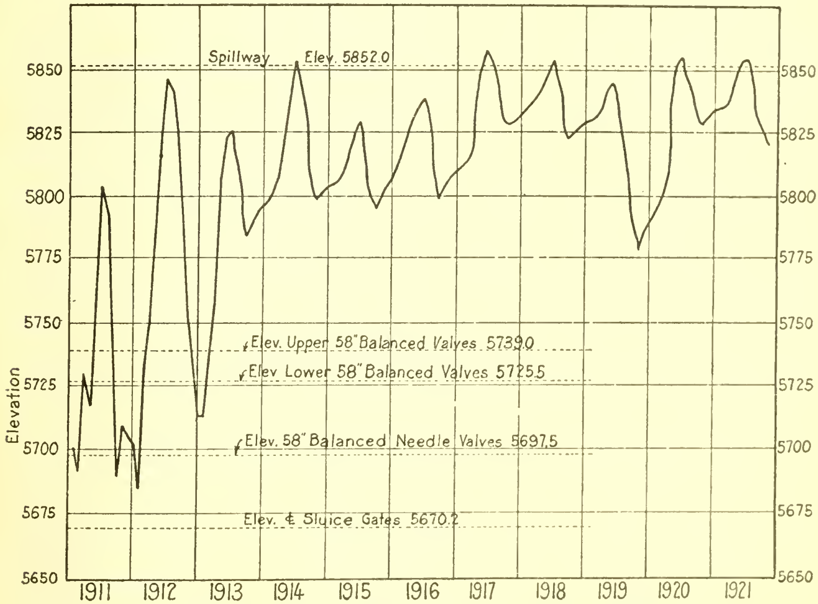


Fig. 33.—Water-surface elevations, Pathfinder Reservoir.

Dam.—The dam is an arched, monolithic, uncoursed, cyclopean, granite masonry structure, except for the two faces, which are laid in 2 and 3 foot courses. The principal dimensions are as follows: Height, 218 feet; base width, 94 feet; least width at top, 10.9 feet; crest length, 432 feet; arch radius, 150 feet; spillway length, 605 feet; spillway elevation, 5,852 feet. The dam contains 60,210 cubic yards of masonry. Plate 27 of the record drawings shows the general plan and maximum section of the dam, and Figure 35 gives the water-surface elevations to date. Construction was started September 25, 1905, and completed June 14, 1909.

Outlets.—The following table is a complete list of the outlets installed for the discharge and regulation of water through the dam:

Outlets, Pathfinder Dam.

Location.	Number.	Type.	Size.	Maximum head on center line.
			Inches.	*Feet.*
North tunnel	4	Slide gates	44 by 77¼	183
Do	1	....do	36 by 60	183.74
Do	2	Emergency gates	60 by 60	152
Do	2	Balanced needle valves	58	154.5
South tunnel	6	Ensign balanced valves	58	133.5
Dam	1	Culvert	48 by 72	150.8
Do	2	Pipes	38	174.7

NORTH TUNNEL.

The north tunnel is 13 feet wide, 10 feet high in the center, 9 feet high on the sides, and 480 feet long. It is cut through solid granite, the floor at the intake being at elevation 5,670 and the grade 1 per cent. There are two shafts 8 by 16 feet in section extending from the tunnel to the ground surface, approximately 180 feet above. The upper, or emergency, shaft is located 127 feet below the face of the grillage structure, and the lower, or service, shaft 59 feet below the upper shaft. It was the original intention to provide the tunnel with two sets of gates, but only the upper set was installed. This tunnel served as a diversion tunnel during the construction of the dam. Construction of the tunnel was started February 7, 1905, and completed July 26, 1905. In 1921 a concrete plug was placed in the tunnel immediately below the lower gate shaft and a 3 by 5 foot sluice gate installed. Two 6-foot reinforced concrete circular conduits were carried diagonally from the tunnel to the face of the cliff, terminating in 58-inch balanced needle valves protected by 5 by 5 foot hydraulically operated emergency gates. These outlets are to be used in regulating the discharge of water from the reservoir in connection with the six balanced valves installed in the south tunnel. A section and plan of the north tunnel is shown on Plate 28 of the record drawings.

Sliding gates installed in 1909.—The high-pressure sliding gates were designed for a static head of 240 feet, and each of the four gates closes a rectangular opening 44 inches wide by 77¼ inches high. The gate frames are box-shaped iron castings rigidly bolted together and mounted on a cast-iron bed plate extending across the tunnel. The partition columns between adjacent gates and the end columns extend upward, forming pockets into which the gate leaves are drawn when opened and supporting the base of the operating cylinders. The entire structure is rigidly bolted together and embedded in concrete. Each gate is operated by a 24-inch cylinder located in an operating chamber. The gate leaf is a heavily ribbed iron casting fitted with bronze sealing strips at the sides and top and designed for butt contact against a babbitted stationary seat at the bottom. The piston is of cast iron with cup-leather packing. The gate seats are of the special C and D bronzes, described in Chapter III. The 5-inch gate stem is of Parsons manganese bronze, having an ultimate tensile strength of 65,000 pounds per square inch, an elastic limit of 30,000 pounds per square inch, and an elongation in 8 inches of 20 per cent. The general design of the gates is shown on Plate 29 of the record drawings.

Coefficients of friction.—The coefficient of friction under actual operating conditions was determined in 1915 and 1916 with results as stated in Table 11.

The friction in stuffing boxes and cylinder varies considerably as shown by tests on other gates, and, when using the coefficients of friction given in this table, a liberal factor of safety should be used, a coefficient of 0.70 to 0.75 having been adopted by the Bureau of Reclamation for starting friction and 0.35 to 0.40 for moving friction.

TABLE 11.—*Friction of bronze on bronze, high-pressure gates, Pathfinder Dam. Tests made September 2, 1915, and October 12, 1916.*

Head on center of gate ... feet..	127
Size of gate leaf ... inches..	53 by 90
Area of gate leaf under pressure ... square inches..	4,400
Weight of moving parts (about) ... pounds..	10,000
Friction in stuffing boxes and cylinder (assumed) ... do....	25,000
Cylinder, 24 inches diameter:	
Area upstroke ... square inches..	432.8
Area downstroke ... do....	452.4

RESULTS OF FIVE TESTS: THREE ON GATE A AND TWO ON GATE C TO RAISE GATE.

	Maximum.	Minimum.	Average.
Starting pressure in cylinder ... pounds per square inch..	360	330	344
Load on gate due to pressure ... pounds..	242,000	242,000	242,000
Total force applied by cylinder ... do....	155,000	143,000	149,000
Net force required to overcome gate friction ... do....	120,000	108,000	114,000
Coefficient of friction ...	0.496	0.446	0.472

Average time of opening, 15 minutes.
Gate A had been closed 34 days prior to test.

	On gate leaf.	On seats.
Composition of bronze liners:		
Copper ...	82.8	82.7
Lead ...	8.0	4.9
Tin ...	4.8	7.1
Zinc ...	4.4	5.3

Maximum bearing pressure on bronze seats, 313 pounds per square inch.

The concrete plug in which the gates are installed is an arched structure 20 feet long, with four water passages each 46 inches wide by 87 inches high and 19 feet long. The passages are separated by concrete piers 33 inches thick. These passages were originally lined with ½-inch sheet steel extending from the gate frames to pointed castings on the downstream end of the piers and were secured to the concrete by ¾-inch anchor bolts. These linings were destroyed by the action of the water after the gates had been in operation a short time and were replaced with rectangular cast-iron linings, well ribbed and terminating in round-nosed castings at the downstream end of the piers. An 18-inch cast-iron by-pass pipe was installed to equalize the pressure on the emergency gates when the service gates were in place. However, since the installation of service gates was abandoned, this by-pass was permanently closed.

A gate chamber lined with concrete is located with its floor 16 feet 3 inches above the floor of the tunnel. Access to this chamber is obtained through the shaft, which is lined with concrete and has a stone house at the top in which the operating machinery is installed. Pressure for operating the gates is obtained by a motor-driven triplex pump, power for the motor being furnished by an 18-horsepower, 4-cylinder, Sheffield gas engine, direct connected to a 10-kilowatt, 250-volt, direct-current generator. The gates were furnished and installed by the New Jersey Foundry & Machine Co., under contract dated February 14, 1907, the contract price being $68,000. Installation was started on April 3, 1908 and completed in April, 1909.

Tunnel damaged by discharge in 1909.—On April 17, 1909, the gates were closed and water stored in the reservoir until May 10. The gates were open from that date until August 19, when the discharge was reduced. As the area of cross section of the tunnel below the gates is about 70 per cent greater than the total area of the gate openings, it was thought that this portion of the tunnel would never be under pressure. During the summer, however, when the reservoir was at its highest, water backed up through the drainpipe into the gate chamber to a depth of 12 feet, showing that the tunnel below the gates was actually under pressure.

The reservoir was emptied at the close of the season, and inspection showed that the concrete floor was torn up for a distance of 130 feet below the gates; about one-third of the ½-inch steel lining was gone. The anchor bolts were sheared off in some cases, the nuts stripped from the bolts in others, and the concrete was gone from the north side of "A" conduit. The gates were uninjured. The closure of three of the leaves was tight and of the fourth nearly so.

Repairs made in 1910–11.—On December 8, 1909, a board of engineers[1] met at the dam to investigate work necessary for the com-

[1] D. C. Henny, W. H. Sanders, O. H. Ensign, R. F. Walter, E. H. Baldwin.

pletion of the Pathfinder Dam. This board recommended that the steel linings below the gates be replaced with rectangular ribbed cast-iron linings terminating in round-nosed castings at the downstream end of the piers, that the floor of the tunnel be replaced with reinforced concrete, and that a drain tunnel be excavated from the gate chamber to the canyon wall. This board also recommended the construction of an entirely new outlet tunnel at the south end of the dam, which is described later in this chapter. The drainage tunnel, 5 feet wide, 6 feet high, and 154 feet long, was completed July 27, 1910, and the repairs and installation of the cast-iron linings were completed March 21, 1911. On April 1, 1911, the operation of the gates was resumed, and they were in constant use throughout the ensuing season. In May, 1911, the lower gate shaft was covered with concrete slabs heavily reinforced and underlaid with 20-pound rails.

Vacuum produced by large discharge.—When the discharge through the gates exceeded 2,500 second-feet, it was noted that reverberating sounds issued from the tunnel below the gates. A deflection of about 3½ inches was observed in the floor slab in the lower shaft, and it was estimated that a vacuum of 5 inches of mercury was required to produce this deflection. An inspection of the tunnel on June 21, 1911, showed that one of the cast-iron tunnel linings and two of the round-nosed castings had been torn out by the water. Another inspection on June 26 showed that another section of tunnel lining and the entire concrete floor for 42 feet below the gates had been washed out. Conduit " A " was the only one not damaged. This indicated the danger of continuing to discharge a large volume of water, and accordingly three of the gates were closed and water discharged through the " A " gate only: The deficiency was made up by blasting away the timber bulkhead in the culvert through the dam. Little difficulty was experienced with the mechanical operation of the gates during this year.

Linings replaced in 1911–12,—At the close of the season the cast-iron linings were replaced by new castings, the concrete floor was replaced, and the sides of the tunnel were lined with concrete doweled to the walls by reinforcing steel set in drill holes. The concrete cover on the top of the lower gate shaft was replaced by heavy reinforced slabs resting on 20-pound rails, supported by two 20-inch, 100-pound I beams and twenty 2½-inch holes were left in the slabs to serve as vents to relieve the vacuum when the gates were operating. The slabs suffered no further damage, but the whistling of the air passing through the vent holes could be heard a quarter of a mile away.

Vacuum effects studied in 1912.—In November, 1912, during the process of testing the gates and lifting devices, it was discovered that the hammering noises previously described were produced by the discharge through the gates when it exceeded 2,500 second-feet and that the intensity of this disturbance increased with the discharge after it reached this quantity. It was noted that during the opening of the gates the steady draft of air through the drainpipe in the bottom of the emergency gate shaft increased in velocity with the increasing discharge until the pounding began. At this stage the velocity of the air fluctuated, the fluctuations becoming more violent as the volume of the discharge and the pounding noises increased in the tunnel below. The pounding resembled the noises of an approaching thunderstorm, varying from low and indistinct rumblings during the incipient stages to sharp peals and explosions during the period of maximum discharge. It was noted by an observer lowered into the lower gate shaft that these disturbances were most violent when the water began to seal the tunnel below the gates, thus preventing free admission of air to the outlet passages. From these observations it was concluded that the damage which the gate passages had suffered was the result of the vacuum in and immediately below these conduits, and the discharge from the tunnel was never allowed to exceed a maximum of 2,500 second-feet and was maintained at the smallest possible amount. The roof of the tunnel immediately below the gates was cut out, starting at the lower end of the conduits and inclining upward, to a height of 20 feet at the lower gate shaft. This permitted free entrance of air to the end of the conduits and prevented the formation of a vacuum.

Two gates become inoperative in 1913.—April 15, 1913, " D " gate refused to open with a pressure of 800 pounds per square inch in the cylinder. On October 2, 1913, it was found that the upper horizontal bronze seat on " B " gate had been bent downward from the center of the gate opening, a portion of the casting in which it was fastened having been broken off, allowing a leakage of about 4 second-feet. Operation of these gates was discontinued was as soon as the damage was discovered. During the seasons of 1913, 1914, 1915, 1916, and 1917 conditions remained practically unchanged in the tunnel. Gates "A " and " C " could be operated without difficulty and were used at partial opening to supplement the discharge from the south tunnel. This practice was, however, discontinued at the end of the 1917 season. On April 5, 1918, gate " C " stuck when nearly closed. An inspection showed that a piece of metal had become wedged between the gate leaf and the seat, allowing a leakage of about 20 second-feet.

Balanced needle-valve installation.—In December, 1918, Andrew Weiss and J. M. Gaylord visited Pathfinder Dam to report on the condition of the outlets and make recommendations for additional discharge capacity. At that time only one of the gates in the north tunnel was in operating condition and the leakage of about 20 second-feet through the gate "C" was eroding the floor of the water passage below the gate frame. Both the north and south tunnel outlets are inaccessible for repairs without practically emptying the reservoir, and the various difficulties with the south tunnel valves, described later, as well as with the high-pressure gates, made it advisable to make plans for the protection of the present outlets and for supplemental works of a more reliable character. Additional discharge capacity was also required to supply the increasing irrigation demands.

Pursuant to recommendations made at that time plans were prepared for plugging the north tunnel just below the lower gate shaft and driving an adit from the face of the cliff to connect with the tunnel above the plug. Two balanced needle valves protected by emergency gates were to be installed at the face of the cliff and connected to the tunnel by reinforced concrete pipe laid in the adit. The plug in the tunnel was to be provided with a sluice gate for draining the reservoir when necessary, and a 24-inch pipe with a nozzle, for supplying a small amount of water for the city of Casper, was later included. General plan of the works is shown in Plate 28.[2]

Needle valve.—The balanced needle valve shown on Plate 32[2] is an adaptation of the Ensign valve and is designed for installation at the lower end of a pipe.

The operating cylinder is supported centrally in the valve body by means of radial ribs, the space between the cylinder and the outer shell forming the water passage. The ratio of bull-ring area to seat-ring area is the same as in the Ensign valve, but the piston has been lengthened to give easier flow lines and better guiding. The rear stem guide was omitted to make room for the central control sleeve and an additional circular guide provided in the nozzle. The V guides, which caused cavitation of the throat pieces in earlier installations, were omitted, and the nozzle ribs were bored to proper diameter to assist in guiding the piston as it approaches the closed position. Positive control is provided by means of a sleeve similar to that used in the Arrowrock valves, but the sleeve is located centrally in the cylinder, which makes keying the piston against rotation unnecessary, though possibly desirable. The inner shell is pointed upstream, and the tip is made removable to permit access to the interior of the cylinder without dismantling the valve. The valve is operated from a control house above the valve, where a stand is provided for the control hand wheels and indicator.

[2] Record drawing sereis.

Emergency gate.—A 5 by 5 foot emergency gate is located immediately above each needle valve to permit inspection and repairs and to prevent freezing during the winter months. The gate leaf, cylinder, and transition casting between this gate and the needle valve are cast steel. The frame, bonnet, and tunnel linings are semisteel and the gate stem of open hearth forged steel. The general design is very similar to that of the five sluice gates in Arrowrock Dam.

The tunnel lining extends about 15 feet upstream from the valve, the upper 10 feet of which forms a transition from 6 feet diameter to 5 feet square. The hydraulic cylinder is cast steel with brass lining and is designed for a pressure of 1,000 pounds per square inch. Oil pressure will be furnished by a motor-driven triplex pump. The control house is a reinforced concrete building constructed inside the cave, access being from a walkway across the river. The assembly of the gate is shown on Plate 31 of the record drawings. The emergency gates are embedded in concrete. A storage battery for operating the pressure pump is provided in the upper gatehouse.

The 3 by 5 foot sluice gate and the two 58-inch balanced needle valves were manufactured by Joshua Hendy Iron Works, of San Francisco, Calif., under contract No. 817, dated October 29, 1919. The purchase price of the sluice gate was $7,600, and the approximate weight 27,400 pounds. The contract price for the two needle valves was $44,720 and the approximate weight 196,000 pounds. The two 5 by 5 foot emergency gates were manufactured on a cost basis by the Rock Island Arsenal, the cost being $39,312, and the approximate weight of the two gates 191,000 pounds.

Construction of the needle-valve outlet was started in October, 1919, but owing to lack of funds the installation was not completed until April, 1922.

Valves tested in May, 1922.—The outlet was placed in operation and tested in May, 1922. The needle valves respond to control perfectly under all conditions, and there is no perceptible vibration. The motion of the plunger is not uniform, but consists of a succession of short jumps, and the plunger seats with a slight shock. The rear seat on the plunger cuts off all leakage when the valve is wide open, and pressure from an external source must be introduced into the cylinder to start closure. When full reservoir pressure is applied continuously, the valve will close in about one and one-half minutes. If external pressure is applied only long enough to start the plunger from the rear seat, about three and one-half minutes is required to close the valve. The plunger can be held in any position by means of the control sleeve.

It was found, however, that between one-half and full gate the plunger exerted sufficient force against the sleeve to make the operation of the handwheel exceedingly difficult. This was remedied by drilling a ⅝-inch hole through the cylinder wall to increase the leakage. The jet from the needle valve is not smooth. There are ridges opposite each radial rib in the water passage and smaller rough places between. With a discharge of 1,058 second-feet under 145 feet gross head, the minimum diameter of the jet was 3.93 feet and occurred 3 feet from the end of the valve. This gives a coefficient of contraction of 0.78, based on the net area of the nozzle. The hydraulic efficiency of the valve, or ratio of power in the jet to power received by the valve, is 0.86. The coefficient of discharge, based on the head at the inlet to the valve, is 0.72. The loss of head in the outlet below the lower gate shaft when discharging 1,058 second-feet was 26 feet. This loss is the difference between the head (118.27 feet) due to a jet velocity of 87 feet per second and the static head on the center line of the valve, as determined by the water surface in the lower gate shaft.

The emergency gates and the sluice gate operated smoothly and without vibration. One of the emergency gates was closed without difficulty with its needle valve wide open. The maximum pressure in the cylinder during this operation was 150 pounds per square inch.

SOUTH TUNNEL.

Ensign balanced valves installed in 1911.—The developments in the operation of the north tunnel up to 1909 indicated the need for more effective control, as well as greater discharge capacity. In December, 1909, a board of engineers[3] met at Pathfinder Dam to consider the proper control of discharge from the reservoir. As it was thought desirable to discharge under as low a head as possible and as about 90 per cent of the capacity of the reservoir is above elevation 5,765, it was recommended that an additional outlet tunnel be driven around the south end of the dam, with grade at entrance at elevation 5,725, and that six 58-inch balanced valves be placed at the upper portal.

The outlet, as recommended by the board of engineers and originally constructed, is as follows: The tunnel is 15 feet wide, 14 feet high, and 360 feet long. It tapers at the upper end to about 40 feet wide by 30 feet high, and in this portion is located a concrete plug containing the six balanced-valve conduits. The balanced valves are arranged in two tiers on the upstream face of this plug. These valves are identical with the Belle Fourche valves and practically the same as those at the Roosevelt Dam. A detailed description of the design and operation of the valves is given in Chapter V. The six valves were purchased from the Pittsburg Valve, Foundry &

[3] D. C. Henny, W. H. Sanders, O. H. Ensign, R. F. Walter, and E. H. Baldwin.

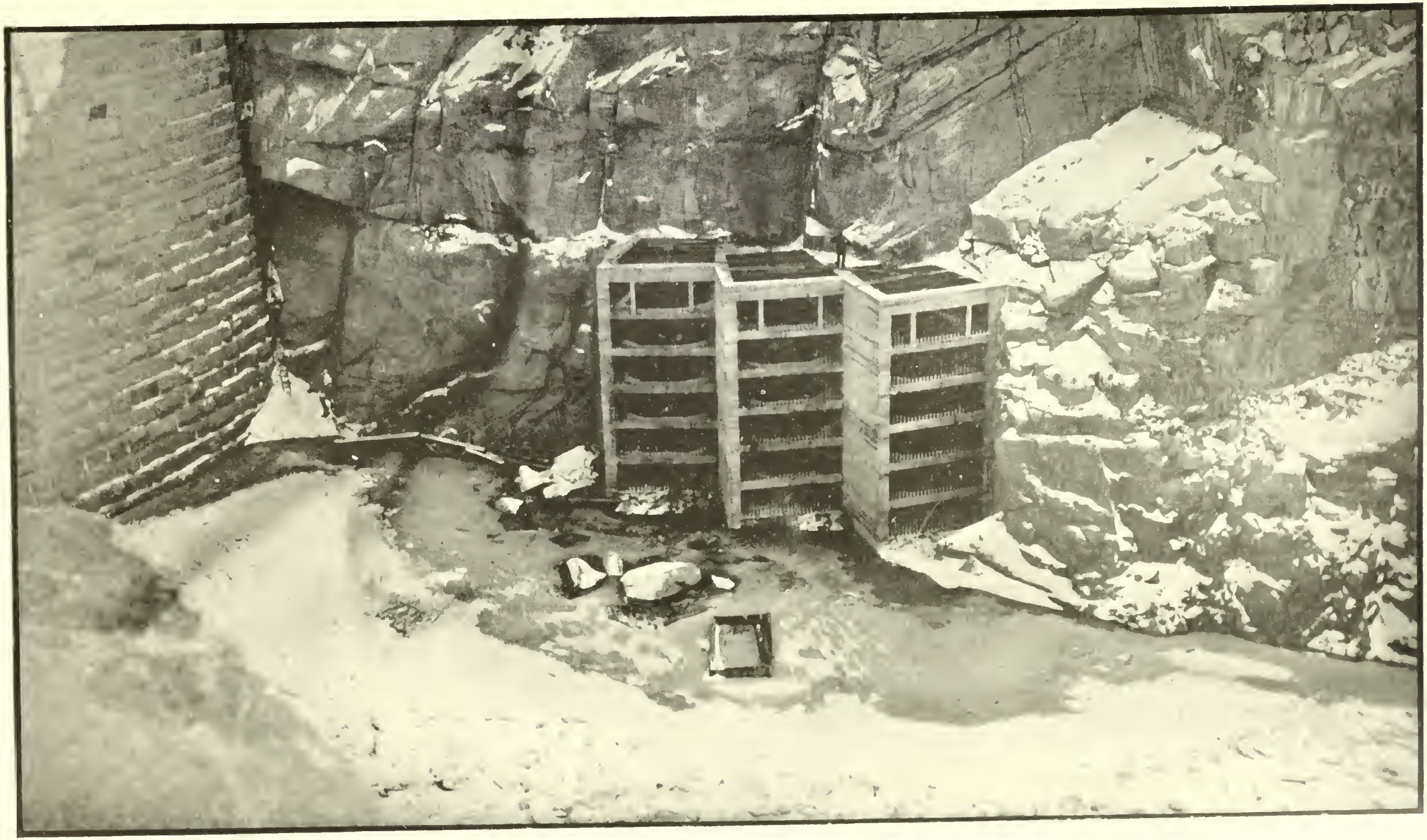
Construction Co., of Pittsburgh, Pa., on contract dated August 6, 1910, the contract price being $3,890 each. A general assembly of the valve is shown on Plate 37 of the record drawings.

The valves are protected by a grillage, which consists of three concrete chambers, each protecting two valves, one above the other, the grillage bars being located in the front face and top of each structure. Each valve discharges into a circular conduit 5 feet in diameter lined with cast-iron bell and spigot pipe. The cast-iron lining and end castings were purchased from Charles F. Elmes Engineering Co., of Chicago, Ill., on contract dated October 12, 1910, the purchase price being $6,500.

The control-pipe lines were originally carried through the concrete in which the conduits are located, the pipes for the three upper valves being spiraled around the conduits and carried thence through the concrete floor to the drain tunnel and into a control chamber, where the needle-control valves were located. Below the control valves, the control pipes extend down the face of the canyon about 24 feet into a sealing tank. This gave a draft-tube action when required to open the valves. A set of gate valves was located above the control valves to take the pressure from the latter when not in use and another set placed in the floor of the drain tunnel to drain the control pipes in winter. A 2-inch pipe line was connected to the reservoir and also to a hand pump located in the control house to permit the application of pressure to the back of the balanced-valve piston. A 30-inch butterfly valve was set in a concrete plug at the junction between the main tunnel and the drain tunnel, an operating shaft being carried into the control chamber. A lip, or rock barrier, was left in the floor of the tunnel at the outlet end to hold the water up in connection with possible future power development, and to create a water cushion in the tunnel to absorb the energy of the jets from the balanced valves. The general arrangement of the installation of the valves is shown on Plate 27 [4] and the general plan of the south tunnel on Plate 34.[4]

Construction work was started in January, 1910, and the concrete plug, containing the conduits and the concrete floor of the tunnels, were completed March 18, 1911. As it was desirable to start storing water, the 5-foot openings were closed by timber bulkheads. On June 7, 1911, the bulkhead on No. 5 opening broke, letting about 800 second-feet of water through the tunnel. This opening was closed by means of a hollow wooden ball, filled with scrap iron and concrete. On account of the trouble that developed in the north tunnel on June 28 it became necessary to close the sliding gates. An attempt to remove the wooden ball in No. 5 conduit with a seven-

[4] Record drawing seriees.



GRILLAGE PROTECTING 58-INCH BALANCED VALVES, SOUTH TUNNEL, PATHFINDER DAM.

eighths-inch chain failed, so the bulkhead over No. 4 was opened with dynamite.

The construction of the grillage structure and the installation of the valves was completed January 25, 1912, and of the control piping and control house April 13, 1912.

Balanced valve operation started in 1923.—The valves were closed on February 7, 1912, to begin storage of water in the reservoir. On May 4 valve No. 5 was opened and discharged 900 second-feet until May 16, developing a characteristic, since shown to be permanent, of sticking at about 85 per cent discharge opening and requiring an excess pressure of 15 pounds per square inch to close it. On June 17 all of the valves were opened until the discharge was 4,200 second-feet. The valves opened readily, except under low heads, but usually required pressure in excess of reservoir pressure for closing. On June 24, for the purpose of inspection, it was desired to close them. All of the valves were successfully closed except No. 4, and the oscillations of the pressure gauge on the control pipe for this valve indicated that the control pipe was broken. The successive automatic opening of the other valves from June 24 to July 10 indicated that the concrete floor in the tunnel, in which the control pipes were embedded, had been gradually torn up, breaking all of the control pipes. From this time until the end of the season it was impossible to control the discharge. The valves discharged under heads up to 110 feet, delivering a maximum of 6,800 second-feet.

On account of the lip left at the mouth of the tunnel a discharge of over 2,000 second-feet sealed the tunnel. When the tunnel was sealed, rumbling noises, pulsations, and explosions occurred similar to those described in connection with the north tunnel, increasing in intensity as the discharge increased. The disturbances were of sufficient intensity to cause a continual tremor in the canyon wall. An observer at the mouth of the tunnel noted that the discharge was greatly agitated, resembling a mass of foam intermingled with masses of air, which poured out in gulps varying in magnitude and coming at intervals at from 5 to 30 seconds. This indicated the formation of a partial vacuum at the mouth of the 5-foot conduits.

Control pipes relocated.—These conditions demonstrated that it was impossible to maintain the original arrangement of control piping and it was decided to install these pipes in a separate tunnel. This tunnel, known as the auxiliary tunnel, heads just east of the grillage structure and ends about 45 feet below the dam. The 4-inch control pipes were carried from the valves downward to the floor of the grillage, this portion being of extra heavy galvanized pipe, thence along the floor and through holes cut in the grillage walls into the tunnel and through the plug, this section being 4-inch cast-iron bell and spigot pipe, covered with 12 inches of concrete, and from the end of the plug to the control chamber on the concrete floor of the tunnel, this section being standard galvanized-iron pipe. Drain valves in each pipe line were placed just below the concrete plug. An additional 3-inch control pipe was connected to the casing head of valve No. 6 with connections in the control chamber similar to the other valves. This pipe provides greater capacity for disposing of the leakage from this valve. The general arrangement of the valves, piping, and control chamber is shown on Plate 34 of the record drawings. A control chamber was excavated in the canyon wall at the lower end of the auxiliary tunnel and closed by a concrete wall and roof. The arrangement of control valves was similar to that in the original control chamber, except that the sealing tank was omitted and the discharge ends of control pipes for valves 4 and 5 were bent upward in the form of U tubes for water seal, these two having connections for breaking the vacuum, as in the old control house.

Changes made in south tunnel, 1912–13.—On November 18, 1912, a board of engineers[5] met at Pathfinder Dam to consider conditions in the south tunnel. This board recommended that the concrete plug containing the 5-foot valve conduits be extended downstream approximately 25 feet, the 5-foot circular conduits connecting with the cast-iron-lined conduits to be unlined and located so as to give a parallel discharge into the tunnel. This board also recommended that the lip at the mouth of the tunnel be removed, that the tunnel wall on the outer curve of alignment be lined with concrete in order to reduce the height of water in the tunnel, thus admitting air to the lower face of the plug, and that the pistons of the balanced valves be filed in spots to allow greater leakage past them, thus facilitating the regulation of the discharge. This work was started December 31, 1912, and was completed April 15, 1913. The pistons on all valves, except No. 6, were filed in spots to increase the leakage. The concrete plug and conduits were extended about 32 feet, the conduits terminating with parallel axes located on 7-foot centers vertically and horizontally, the bottoms of the lower conduits being at tunnel-floor grade. The lip at the mouth of the main tunnel was removed, about two-thirds of the guide wall on the left side of the tunnel was removed, being of no further value after the removal of the lip, and beginning about 90 feet below the concrete-plug extension the tunnel was widened to 20 feet in width as an additional precaution against the possibility of the tunnel filling completely when discharging the maximum amount of water.

[5] O. H. Ensign, D. C. Henny, R. F. Walter, and Andrew Weiss.

Air supplied to relieve vacuum.—As it was believed that the previous damage to the tunnel was caused by the making and breaking of a vacuum just below the end of the 5-foot conduits, it was thought that an air inlet at this point would prevent further damage. Accordingly, a crosscut tunnel 4 by 5 feet in section was driven from a point 10 feet below the plug in the auxiliary tunnel to the roof of the south tunnel about 10 feet below the end of the concrete conduits, a distance of 55 feet. The cast-iron linings showed considerable deterioration, the metal being pitted and honeycombed over considerable areas. The worst of the holes were filled with Smooth-on, and the upper 8 feet of conduit No. 5 was lined with ½-inch boiler plate fastened to the cast-iron lining with 1-inch patch bolts. The alterations and repairs were completed April 15, 1913.

Operation in 1913.—Storage for 1913 began on February 8 and the valves remained closed until April 29, except for occasional testing. All valves were opened and closed without serious difficulty, except No. 3, which could not be opened at any time during that year. It is thought that when the valve pistons were filed in 1913 so much clearance was given No. 3 piston that the control pipe was inadequate to relieve the pressure in the main cylinder. Valve No. 6 closed readily under reservoir pressure, but the other valves required pressures up to 32 pounds per square inch.

On May 3, after valve No. 5 had been open only four days, an inspection of the tunnel showed a hole in the concrete extension of this conduit on the outside of the curved portion about 6 feet below the end of the cast-iron lining. At the end of the season several yards of concrete were gone from the concrete conduits of Nos. 1, 4, 5, and 6. Conduit No. 2 was still intact, though used more than any other. The greatest damage in Nos. 1, 4, and 5 was on the outside of the curve from 5 to 15 feet below the end of the cast-iron lining. There was little curvature in conduit No. 6, and the damage was mostly on the bottom. The damage to the concrete conduits indicated a shattering of the mass rather than an abrasion, as the concrete surfaces were jagged and rough.

The crosscut air tunnel acted as was anticipated, there being a tremendous suction through it into the south tunnel, tests of air velocities at the mouth of the auxiliary tunnel showing that with a discharge of 1,100 second-feet into the south tunnel the air velocity was 27 feet per second, and with a water discharge of 4,400 second-feet the air velocity was 97 feet per second. With three or more valves discharging, great care had to be exercised in passing through the 2½ by 6 foot door in the control chamber to prevent being drawn against the piping. There occurred none of the violent explosions and other disturbances at the mouth of the conduits previously described, indicating that the crosscut tunnel supplied the remedy. At the close of the season of 1913 it was not considered necessary to make any extensive repairs, the only work done being to plug up the holes in the concrete conduits with a rich concrete and fill the pitted places in the cast-iron linings with Smooth-on.

Operation in 1914.—During the 1914 season five valves were operated, the discharge reaching a maximum of 5,000 second-feet. On June 25 the reservoir reached its maximum elevation, 5,853.03, or 1.03 feet over the spillway, making a head of 125.53 feet on the lower tier of valves. At no time was there any trouble in opening any of the valves, except No. 3, which still refused to open. Valves Nos. 1 and 5 gave trouble in closing, No. 1 requiring 58 pounds per square inch and No. 5 requiring 30 pounds per square inch in excess of reservoir pressure.

It was evident from past experience that excess pressure would always be required to close the valves, and as the hand pump was inadequate a turbine-driven centrifugal pump was installed on the ledge under the original control chamber. This unit consists of a 12-inch Trump turbine, developing 14 horsepower under 25 feet head, requiring 6 second-feet of water and running at 575 revolutions per minute. The turbine is direct-connected to a 2½-inch, two-stage centrifugal pump, capacity 150 gallons per minute against 140 feet head. The pump suction is connected to the reservoir by a pipe passing through the culvert in the dam. The turbine has a 14-inch penstock connecting with a small forebay in the south tunnel, controlled by the butterfly valve at the junction of the two tunnels.

After a few days' operation of the balanced valves the patches in the concrete conduits began to go out, and by the end of the season there were large holes in the conduits, the damage being much greater than in the previous season, probably due to the increased use of the outlet. The damage to the cast-iron conduit linings had also increased. There were holes entirely through the 1½-inch shell in many places, and the surface presented a spongy appearance. This damage was believed to be caused by the formation of a vacuum around the jet issuing from the valves. The sheet-steel lining placed in the conduit of No. 5. valve in 1913 was undamaged.

Conduits lined with steel plates, 1915.—Two board meetings were held to discuss repairs to the south tunnel, the first [6] at Mitchell on December 9, 1914, and the second [7] at Salt Lake City on December 14, 1914. The conclusions of both these boards were substantially the same, and recommendations were made to remove the new portion of the concrete extension to the valve conduits, grout 52-inch sheet-

[6] D. C. Henny, R. F. Walter, Andrew Weiss, and H. D. Comstock.
[7] R. F. Walter, D. C. Henny, and O. H. Ensign.

steel pipes inside of the present cast-iron conduit linings, and to extend the air inlet from the crosscut tunnel to the downstream end of the original concrete plug.

Accordingly, the concrete extension was removed, a trench was cut across the top of the south tunnel from the crosscut tunnel, and a floor put in across this trench, leaving an air opening above the end of the conduits. The outer curve of the tunnel was trimmed and lined 8 feet high with concrete, this lining extending 148 feet below the conduits.

A cast-steel throat piece $14\frac{1}{2}$ inches long was connected to each valve, reducing the opening from 58 to 52 inches diameter. The sheet-steel lining of $\frac{1}{2}$-inch boiler plate was riveted to the throat piece, expanding in diameter from 52 to 54 inches in about 12 feet and continuing 54 inches diameter to the end of the conduit. The lining was constructed with butt joints, one side being riveted to a circular cover plate on the outside, the other side being fastened with $\frac{7}{8}$-inch patch bolts. All rivets had countersunk heads on the inside. A detail of this lining and throat piece is shown on Plate 34 of the record drawings. After the steel linings were in place the end of the concrete plug was squared up with concrete and a grout of 1:2 mix was forced into the space between the steel and cast-iron linings to refusal under 80 pounds per square inch. Great difficulty was experienced in this grouting on account of the seepage of water from the reservoir collecting in pockets, thus keeping the grout from filling them. This work was completed April 22, 1915.

Operation in 1915.—All of the work done the previous winter stood up well during the 1915 season, except the steel conduit linings. The lining in No. 4 loosened after 12 hours' use and in No. 1 after four days' use. These two valves were not used further that season, and valve No. 3 still refused to open. An inspection made in July showed that the loosening of these linings was not caused by vacuum at the end of the conduits, as careful measurements had been taken between the issuing jets and near the floor of the tunnel, resulting in a maximum reduction of air pressure equal to 8 inches of water. The loosening of the steel linings was evidently caused by defective grouting between them and the old cast-iron linings, and as it was evident that a vacuum was produced around the jet issuing from the valves a vibration may have been induced in the steel linings, causing the bond between them and the grout to be broken. The linings were all regrouted under 150 pounds pressure, taking special care to fill all voids, and all broken rivets were replaced.

Experiments with concrete nozzles.—Early in the season of 1916 it was decided to experiment with different-shaped tubes. Accordingly each conduit, except No. 3, was lined with concrete, giving the entrance a nozzle effect, those in Nos. 4 and 5 being merely a contraction of the conduit, with a very slight taper from the throat to the mouth, and in Nos. 1, 2, and 6 being enlarged from the throat to some point midway between throat and mouth. The details of these linings are shown on Figure 34.

Observations of jets issuing from the conduits and measurements of the discharge from the valves with a head of 106.8 feet on the lower tier of valves were made as follows:

Valve No. 6.—The jet sprayed out below the end of the pipe, this spray increasing in volume and violence as the valve opened. This spray had about the same appearance as before the concrete lining was put in, indicating that the latter had little or no effect on this feature. There was a rumbling sound noticeable, varying in intensity about every four seconds. The discharge under 106.8-foot head was 1,103 second-feet, and the measured discharge was the same after the concrete lining had been washed out. In the comparisons which follow this is assumed as the normal discharge of all valves, allowance being made for the difference in head on the upper tier.

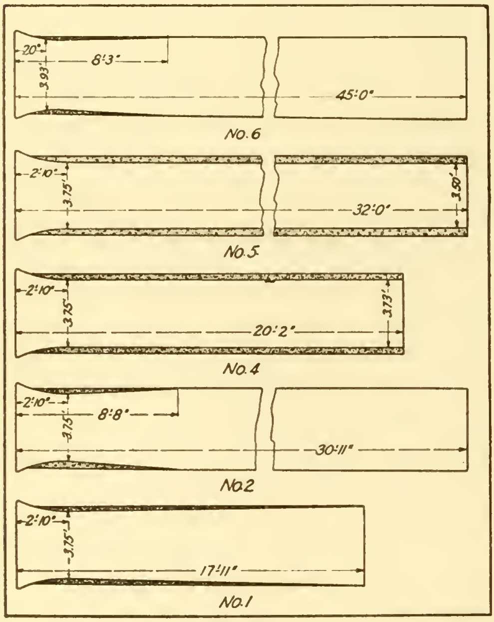


FIG. 34.—Experimental conduits, South Tunnel, Pathfinder Dam.

Valve No. 5.—The jet came out straight from the pipe with very little spray. There were small ridges on the jet about 1 inch deep and slight pulsations were noticeable, the rumbling sound being less than in No. 6 and quite steady. The discharge under 106.8 feet was 765 second-feet, or 69.4 per cent of its normal discharge.

Valve No. 4.—The jet had practically the same appearance as that from No. 5. The discharge under 106.8-foot head was 826 second-feet, or 74.9 per cent of its normal discharge.

Valve No. 2.—It was impossible to observe the jet, as clouds of spray filled the air conduit. It was evident that this conduit was spraying worse than No. 6. The discharge under a head of 92.3 feet was 880 second-feet, or 85 per cent of its normal discharge.

Valve No. 1.—The jet was straight and smooth, with no ridges and very little spray. The conduit was not quite full, a segment occurring about 45° from the top. The rumbling noise was not as pronounced as in the other valves and was quite steady. The discharge under 95.4-foot head was 826 second-feet, or 79.1 per cent of its normal discharge.

Each valve was operated from one to two hours in making the tests, and at the finish the concrete linings were more or less washed out with the exception of that in conduit No. 5, which was practically intact at the end of the 1916 season. Valve No. 3 was opened partially early in the season and was used with the other valves.

Operation in 1917–18.—All of the valves were operated during the seasons of 1917 and 1918 for the normal discharge of irrigation water. The outlets were inspected periodically, and the only damage discovered was a progressive loosening and pitting of the steel linings. In December, 1918, it was found that the pitting covered almost the entire area of some of the conduits and varied from minute cavities to deep scratches parallel with the direction of flow. It was noted that the deep scratches were in almost every case immediately downstream from a rivet head or other slight projection above the surface. Many rivets were loose, some had disappeared, and in conduit No. 2 one cover plate was loose and the adjacent steel plate was cracked. Slight erosion of the No. 3 needle tip was noted, due probably to the operation of this valve at partial discharge.

Air ducts installed in outlet tubes.—In order to prevent the formation of a vacuum in the tube immediately below the valve, steel air ducts perforated at the upper ends and terminating at the face of the concrete plug in the tunnel were installed inside the steel linings (see Fig. 35). This experiment in tube No. 2 resulted in a much smoother discharge from the tube into the tunnel. The pitting of the lining was practically stopped and the damage to the throat piece materially retarded. Cavitation continued to some extent at the top and bottom of the throat casting just below the V guides of the valves where flow conditions are apparently worst. Similar air ducts have been installed in all tubes except No. 3.

THIRTY-SIX INCH PIPES.

Two 36-inch cast-iron pipes were built into the dam, their inverts being at elevation 5,675, or 5 feet above the floor of the north tunnel. These pipes were intended to carry the flow of the river during construction of the dam and discharged water from 1907 to 1911 under heads up to 158 feet without damage other than some erosion and pitting for about 4 inches in from the bell mouth. In 1911 it was decided to close both these pipes, and accordingly two hollow wooden balls were made, weighted with scrap iron and concrete, and lowered in front of the pipes then discharging under a head of 120 feet. The motion of the water drew the balls into the mouth of the pipes, closing them effectively. The location of these pipes is shown on Plate 27 of the record drawings.

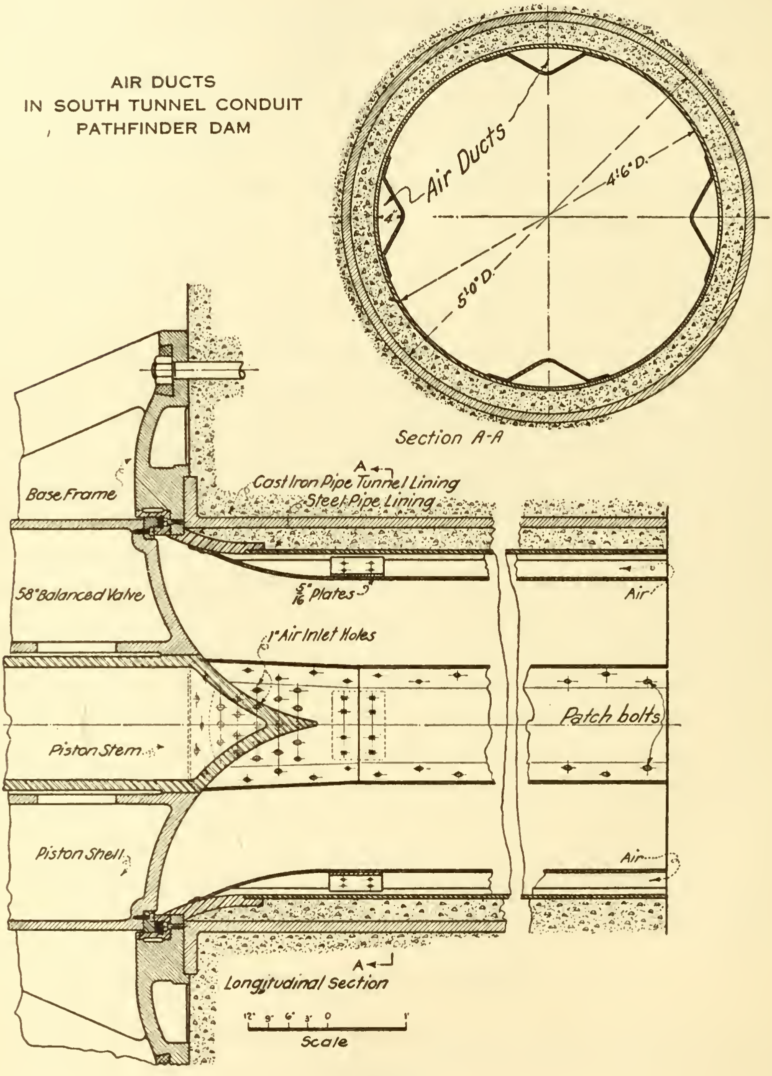


FIG. 35.

4 BY 6 FOOT CULVERT.

When it became necessary in 1907 to close the diversion tunnel to install the emergency gates it was found that the two 36-inch pipes were not large enough to carry the flow of the river, and a 4 by 4 foot opening surmounted with a semicircular arch was left through the dam, the elevation of the invert being 5,691.2. The upper end is enlarged to 6 feet in width by 7 feet high in order to reduce the loss of head at the entrance and to provide a wedge-shaped portal that could be effectively closed if necessary.

The culvert remained open during 1908 and 1909, discharging under heads up to 140 feet without damage. In 1910 the culvert was closed by a timber bulkhead on the upstream face of the dam. In 1911, on account of the trouble in the north tunnel, it was necessary to open the culvert, and this was done by blowing out the bulkhead with dynamite. It was closed again in 1912 with a bulkhead of 8 by 16 inch timbers, and has not been opened since that date.

TABLE 12.—*Cost of outlet works, Pathfinder Dam.*

NORTH TUNNEL.

	Quantity.	Detail costs.	Total costs.
Excavation:	*Cubic yards.*		
Tunnel, Class III (1905–6)		$22,926	
Approaches		2,017	
Approaches, Class I		401	
Shaft, Class III		15,708	
Grillage:			
Removing rock above		1,556	
Unwatering site		1,436	
Excavation		257	
Concrete	95	2,745	
Bars and castings		1,547	
			$48,593
High-pressure gates (1909):			
Gates installed, contract price		88,618	
Excavation, Class III	325	8,453	
Concrete	950	17,182	
Tunnel bulkhead		1,407	
Ladder in shaft		255	
Gas engine and generator installed		2,000	
Emergency gatehouse		5,005	
			122,920
Total cost, north tunnel			171,513

	Detail costs. 1911	Detail costs. 1912	Total costs.
Repairs:			
Cast-iron linings replacing steel linings destroyed	$8,961	$3,454	$12,415
Concrete	4,822	4,750	9,572
Bulkhead repair, chipping concrete, pumping, etc	6,612	945	7,557
Total repairs 1911 and 1912			29,544

TABLE 12.—*Cost of outlet works, Pathfinder Dam*—Continued.

SOUTH TUNNEL.

[Original installation in 1911.]

	Quantity.	Detail cost.	Total cost.
	Cubic yds.		
Excavation, Class III	6,545	$66,479	
Concrete	1,964	46,747	
Grillage beams and bars		5,326	
Ladder		800	
Six 58-inch balanced valves in place		43,510	
Cast-iron conduit linings in place		14,646	
Control piping in place		5,422	
Protecting valves from ice with steam		4,856	
Total cost, south tunnel (original)			$187,786
In 1913 conduit, concrete linings and control piping were destroyed by the action of water, and the following repairs and additional work were required:			
Repairs—			
Excavation, enlarging tunnel, plug, etc	553	7,864	
Concrete		11,774	
Valves and concrete tunnel linings		3,072	
Additional work, auxiliary tunnel—			
Excavation		13,662	
Concrete		1,886	
Control piping		4,496	
Crosscut tunnel		4,556	
Total repairs and additional work (1909)			47,310
Repairs in 1915:			
Rock excavation		1,590	
Concrete		10,964	
Grouting	30	2,411	
Steel pipe, conduit linings, 70,000 pounds		8,893	
Concrete excavation	165	3,467	
Mercury gauge		263	
Centrifugal pumping unit		1,287	
Total repairs in 1915			28,875
Further repairs in 1916			6,409

The above costs include general expense and engineering.

Chapter X.

BELLE FOURCHE RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Belle Fourche Dam is located about 12 miles in a northeasterly direction from Belle Fourche, S. Dak. The reservoir supplies water to the Belle Fourche project and has an available capacity of 203,000 acre-feet.

Dam.—The reservoir is formed by an earthen dam having the following dimensions: Height above cutoff trench, 115 feet; top

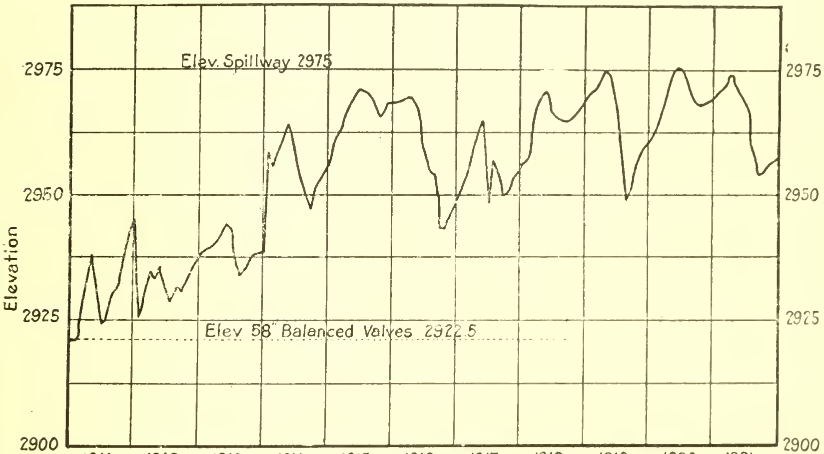


Fig. 36.—Water-surface elevations, Belle Fourche Reservoir.

width, 18 feet 7 inches; side slopes, 2 to 1; crest length, 6,493 feet; spillway length, 314 feet; spillway elevation, 2,975 feet. The dam contains 1,546,000 cubic yards of earth and 26,160 cubic yards of masonry. Construction work was begun in March, 1906, and completed in June, 1911. The general design of the dam is shown on Plate 35 of the record drawings. Figure 36 shows the variation of water elevations in the reservoir since construction of the dam and indicates the condition under which the outlets have been operated.

Outlets.—Outlets consist of two concrete conduits through the dam, one for the north canal and one for the south canal. Regulating devices in these outlets are as follows:

Outlets, Belle Fourche Dam.

Location.	Number.	Type.	Size.	Maximum head on center line.
			Inches.	*Feet.*
North conduit	2	Slide gates	48 by 72	52
Do	2	Balanced valve	58	52.5
South conduit	1	Slide gate	48 by 72	52.5
Do	1	Balanced valve	58	52.5

SLIDING GATES.

There are two 4 by 6 foot sliding gates in the north conduit and one in the south conduit, installed as shown on Plate 36 of the record drawings. The gate stems are approximately 69 feet long and are equipped with hand-operated ball-bearing stands. Stop-log guides are provided immediately above each gate. The gates are covered by item 17 of specifications No. 56 and were furnished and installed by Orman & Crook, general contractor for the dam. The south outlet was built in 1906 and the north outlet in 1908. The sliding gates were never satisfactory as a means of controlling the discharge. The operating stands proved inadequate, and it was found impossible to move the gates under high head. They were operated for the regulation of water under low head, but since this put the conduit under pressure and involved danger of saturating the dam even this use was permitted only during the difficulty with the control of the balanced valves described later in this chapter.

BALANCED VALVES.

The subject of the control of the outflow from the Belle Fourche Dam was considered at Denver January 25, 1910, by a board of engineers,[1] who found the original arrangement of outlets objectionable. Its report contains the paragraphs:

The supervising engineer advises that the conduits are founded on clay in place with sufficient thickness of shell and with sufficient steel reinforcement in the portion upstream from the present gates to resist all strains due to water pressure and superincumbent load, and that the shaft linings are also of sufficient strength and contain sufficient reinforcement to resist water and earth pressures.

There is no certainty, however, of the concrete being perfectly water-tight and of the conduits preserving their alignment perfectly, excluding all possibilities of cracks due to settlement.

[1] D. C. Henny, W. H. Sanders, and R. F. Walter.

In view of the gate shafts having been placed downstream from the center line of the dam, the conduits upstream from the gates and also the shafts will be under full water pressure, due to the elevation of the water in the reservoir, and in case of leakage along concrete or leakage through cracks it is deemed possible that water may follow along the outer face of conduit to the downstream toe of the dam in spite of cut-off collars. Such contingencies we regard as constituting a serious danger to the dam in view of it having been built entirely of clay, and we deem it necessary to absolutely guard against this possibility.

We know of no method which will produce results as safe as that of installing gates at the intake end of the conduit, and we know of no gates which are liable to give as satisfactory results and are as easily operated as the balanced Ensign gate.

Recommendations.—We recommend that definite designs and estimates be made for the installation of the Ensign gate and that the supervising engineer proceed with his present program of testing conduits and shafts and cement washing their interior surfaces.

It was estimated that the maximum discharge requirements, including a certain amount of flood flow, might reach 1,600 second-feet in the north canal and 450 second-feet in the south canal. The discharge capacity of one 58-inch Ensign valve under the maximum head of 47 feet was estimated at 712 second-feet. It was therefore decided to install two of these valves in the north conduit and one in the south conduit.

Balanced valves installed in 1910–11.—Specifications No. 165–A covers six valves for Pathfinder Dam and three for Belle Fourche Dam. Under these specifications contract No. 334, dated August 6, 1910, was made with Pittsburg Valve Foundry & Construction Co. at a total price of $35,010, weight 400,000 pounds. Under specifications No. 168, contract No. 340, dated October 31, 1910, 293,976 pounds of cast-iron pipe and miscellaneous steelwork was purchased from the Marshall Foundry Co. at a cost of $7,697.25.

Work preparatory to the installation of the valves was begun in the fall of 1910, and the installation was completed March 18, 1911. No particular difficulties were encountered in the work except that of transporting the heavy pieces of cast-iron pipe from the railroad station to the dam. On account of delay in receiving the valves and piping and necessity for beginning the storage of water in the reservoir early in the spring, it was necessary to rush the work of installation. The year 1910 was one of very low run-off, and an extreme shortage of water followed the emptying of the reservoir for the installation of the valves, making this year a landmark in the local history.

Immediately after erection each valve was tested by opening it with a jack and closing with water pressure. Valve "A" was opened easily, requiring about 1½ tons to move the piston. It closed with water standing in the cylinder 3 feet above the center line. Leakage around the bull ring was estimated at 6 gallons per minute. Valve "B" required at least 3 tons to move the piston and a head of about 12 feet above the center line to close. The leakage amounted to only a fast dripping and practically ceased when the valve was closed. Valve "C" required about 1½ tons to move the piston and closed with the water in the cylinder about 3 feet above the center line. The leakage was estimated at 12 gallons per minute.

Valves fail to regulate discharge properly.—Following installation of the valves the reservoir filled very slowly, and the valves were first operated May 2, 1911, under a head of 14½ feet above the center of the valve. The valves responded readily to the operation of the control valve, but trouble was immediately experienced in holding the valves at the desired partially open position. This difficulty was apparently due to the accumulation of silt in the clearance around the bull-ring resistance tube and at the control valve, which disturbed the balance of forces acting on the piston and changed the setting.

This action was especially annoying in the case of the south outlet, where the valve capacity is in excess of the canal capacity, and throughout the years 1911 and 1912 it was necessary to keep a very close watch on the valves to prevent dangerous fluctuations of the discharge. At times the valves were opened wide and the control of the discharge accomplished by the sluice gates near the center of the dam. The north tunnel valves did not operate as easily as the south tunnel valve and seemed to have a greater tendency to slip and change the discharge, the "B" valve being especially annoying in this respect, probably on account of the closer clearance around the bull ring, which was noted at the time the valves were erected. On this account external pressure obtained from an artesian well, giving pressure above reservoir, has been introduced into the north tunnel valves to assist in their operation. The south tunnel valve, however, was operated satisfactorily without the use of external pressure.

Automatic regulator installed.—In the spring of 1913 a regulating device operated by a float in the canal was installed on the south conduit. This device is shown on Plate 38 of the record drawings and consists of a balanced piston valve connected into the control pipe and operated by means of a float in a well connected to the canal. As the float rises, the relay valve closes, cutting off the flow in the control pipe and closing the balanced valve. As the water in the canal falls, reverse action takes place. When in normal operation, the relay valve operates approximately once a minute and the water surface in the canal is subject to a fluctuation of less than $\frac{1}{10}$ feet. Very little difficulty has been experienced in controlling the discharge since the installation of this device. Occasionally flakes of rust or accumulations of silt have choked the relay valve or prevented its operation to such an extent that the balanced valve opened wide or closed. For this reason, it has been considered necessary to keep a gate tender near the valves at all times and alarm bells have been installed to give warning when a change in flow takes place. In 1914 the rubber packing ring was washed out of one of the north tunnel valves, but the resulting leakage has been very slight and no serious results have occurred. The operation of the valve since the regulating device was installed has been very satisfactory. No repairs have been necessary except minor repairs to the regulating device.

Conditions at the Belle Fourche Dam are not ideal for the installation of the Ensign valves. The reservoir has considerable holdover capacity and the valves are inaccessible for several years at a time. The valve chambers are located in the bottom of the reservoir and are subject to accumulation of silt. The head does not exceed 53 feet above the center line of the valves, and it is doubtful if this head requires this type of valve. However, the results obtained from this installation have been very satisfactory.

TABLE 13.—*Cost of outlet works, Belle Fourche Dam.*

Slide gates (contractor's earnings, 1909):	
Gates, 24,400 pounds	$2, 074
Stop planks	990
Two gatehouses	1, 423
Total, slide gates	4, 487
Balanced valves (1910–1911):	
Three 58-inch balanced valves, including freight	24, 112
Excavation	3, 065
Concrete—	
Material	5, 468
Labor	4, 458
Labor—	
Hauling and placing	3, 055
Placing control piping	432
Miscellaneous supplies	2, 708
General expense and engineering	8, 734
Total, balanced valves	52, 032

Chapter XI.

STRAWBERRY RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Strawberry Storage Reservoir is located on the Strawberry River, in central Utah, about 25 miles east of Springville. The storage capacity is 278,000 acre-feet with the water surface at the spillway crest; elevation, 7,558. The reservoir is unusual in that the outlet works are not located at or near the dam. The water is drawn out through a tunnel which pierces the divide between the Colorado River watershed, in which the reservoir is located, and the drainage basin of the Great Salt Lake.

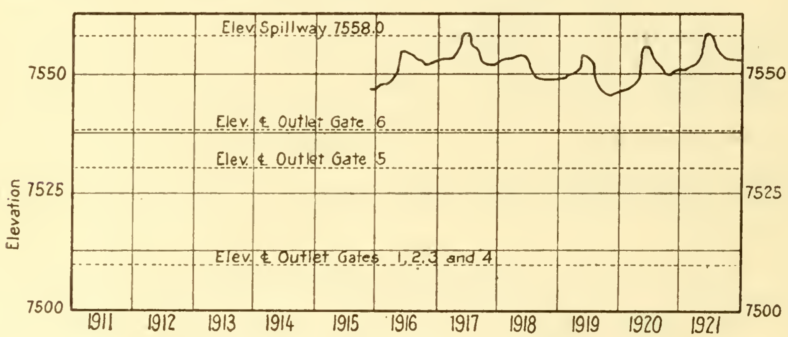


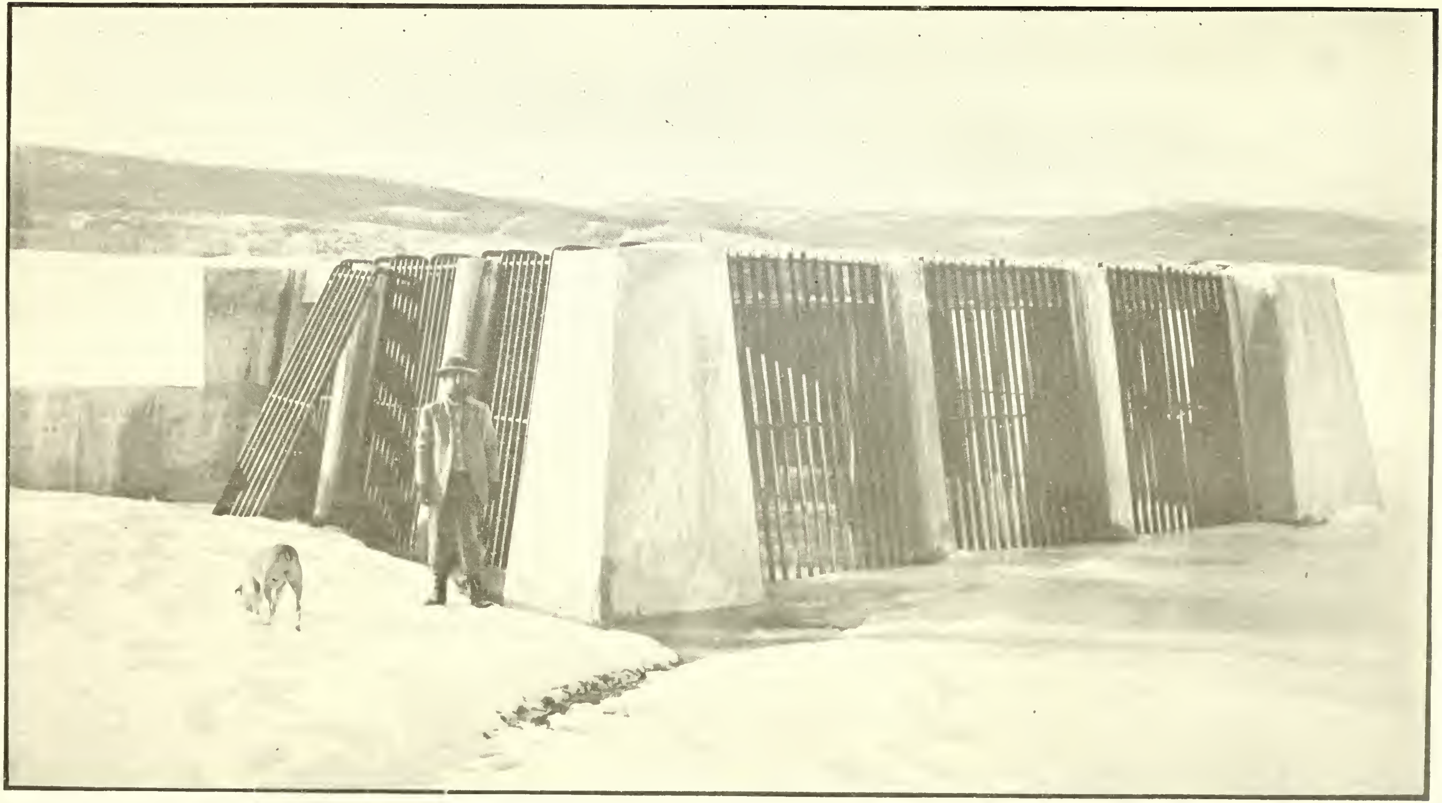
Fig. 37.—Water-surface elevations, Strawberry Reservoir.

The dam and Indian Creek Dike.—The reservoir is formed by an earth dam across the river and an embankment called the Indian Creek Dike, which closes a depression about 2 miles southwest from the dam. The maximum height of the dam is 71 feet, and the crest length is 485 feet. The dike is 1,311 feet long, with a maximum height of 37 feet. Both the dam and the dike have paved upstream slopes and concrete core walls. The dam contains 110,000 cubic yards of material and the dike 102,000 cubic yards.

TUNNEL.

The tunnel intake is located near the western extremity of the reservoir. The tunnel runs almost due west a distance of 19,897

PLATE XVI.



TRASH RACK STRUCTURE, STRAWBERRY RESERVOIR CONTROL WORKS

feet to the west portal, where it emerges into a natural drainage channel which conducts the discharge to the Spanish Fork River, from which the flow is later diverted for irrigation. Details and arrangement of the tunnel and appurtenant structures are shown on Plate 39 of the record drawings. The tunnel is concrete lined throughout and has a rectangular cross section and an arched top. It is 7 feet wide by 8 feet 6 inches high. The slope is 0.003. A value of Kutter's $n=0.012$ was assumed at the time the design was prepared, and the maximum discharge capacity was expected to be 636 second-feet. The actual maximum capacity has not yet been determined (1922), but indications are that it will be considerably less than originally estimated. The maximum flow recorded to date is 455 second-feet.

CONTROLLING WORKS.

The entrance to the tunnel is protected by a trash-rack structure, and the flow is controlled by a set of slide gates installed in a well about 1,650 feet distant from the entrance. The trash-rack structure is so designed that stop planks can be inserted on all sides, and by covering the top with canvas it is expected that the flow into the tunnel can be reduced to such a small amount that the guard gates can be repaired at times of low reservoir levels without completely draining the reservoir. The arrangement and details of the outlet are shown on Plates 39 to 43,[1] inclusive. Control is effected by heavy cast-iron slide gates designed to operate under a maximum head of about 50 feet. The two upstream gates are used for guard gates only, the flow being regulated by the downstream gates. There are four control gates, two at the level of the guard gates and two at higher levels to be used when the reservoir is full. All of the gates are 3 feet wide by 5 feet high and are identical in detail except as to stems. The gates are opened and closed by screw-lift geared hoists, which may be operated by hand or by a small turbine installed in the gate well.

All designs for these controlling works were prepared in 1911 at the Provo office of the Strawberry Valley project by R. F. Ewald, under the supervision of L. C. Hill, supervising engineer, and J. L. Lytel, project manager. The gates and operating machinery were purchased from the Vulcan Iron Works, of Chicago, Ill., under specifications prepared on the project. The costs of the principal features are given in Table 14.

[1] Record drawing series.

OPERATION.

The installation of the operating machinery was completed and the gates tested out on December 12, 1913. The gates have given no trouble since that time. The reservoir heads to which the gates have been subjected are shown in Figure 37. Shortly after the gates were installed some of the stem guides on gate No. 3 were sheared off by overwinding the hand-operating mechanism. The hoists were designed for an assumed coefficient of friction on the gate seats of unity and were so powerful that the guides were damaged before any noticeable resistance was offered. One set of the reducing gears was removed to prevent a recurrence of this trouble. The replacement of the broken stem guides and the putting in of new oak sealing strips at the bottom of gates 3 and 4 constitute all the repair work that has been necessary on the outlets to date. A considerable portion of the tunnel, however, has required relining.

TABLE 14.—*Cost of Strawberry outlet works.*

Feature.	Quantity.	Unit.	Unit cost.	Total cost.
Shaft excavation	1,009	Cubic yard	$5.26	$5,306.35
Shaft lining	725.3	do	24.13	17,499.24
Gates and machinery	6	Set	1,932.41	11,594.43
Gatehouse	4,880	Cubic foot	.66	3,161.11
Intake	389	Cubic yard	18.79	7,309.70
Total				44,870.83

Chapter XII.

ARROWROCK RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Arrowrock Reservoir is located on the Boise River, about 22 miles in a northeasterly direction from Boise, Idaho. It supplies water to the Boise project and has an available capacity of 280,000 acre-feet. The reservoir is 17 miles long and covers a maximum area of 2,860 acres.

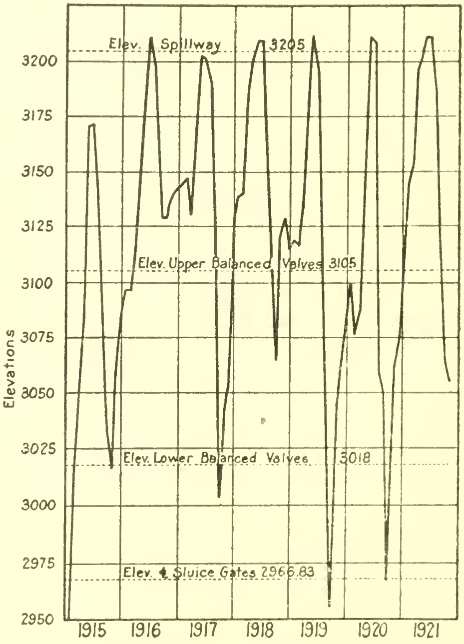


Fig. 38.—Water-surface elevations, Arrowrock Reservoir.

Dam.—The dam is a concrete, gravity section, arched structure, with the following dimensions: Height, 348.5 feet; base width, 223 feet; least width near top, 15.5 feet; crest length, 1,100 feet; arch radius, top, 672.5 feet; spillway length, 402 feet; spillway elevations—concrete weir, 3,205; automatic spillway gates, 3,211. It contains 585,165 cubic yards of concrete and carries a 16-foot roadway across its top. Construction was begun in the spring of 1911 and completed in November, 1915. General plan, maximum section, and upstream face of the dam are shown on Plates 44 and 45.[1] Figure 38 gives the water-surface elevation up to and including the year 1921 and indicates actual heads under which the outlets were operated.

[1] Record drawing series.

Outlets.—The question of outlets was considered at Boise, Idaho, April 10, 1912, by a board of engineers,[2] who recommended that five high-pressure sluice gates be designed and purchased, and that studies be prepared for two sets of 10 balanced-valve outlets for regulating the discharge. A board of engineers[3] met at Boise, Idaho, February 13, 1913, and after hearing the report by Mr. Henny on the results of the operation of the balanced valves at the Roosevelt, Pathfinder, and Belle Fourche Dams, recommended the purchase and installation of 20 Ensign balanced valves in two tiers, three valves in each tier to be provided with positive sleeve-control mechanism. Outlets were installed in substantial conformity with the recommendations of these two boards. The outlets are listed in the following table:

Outlets, Arrowrock Dam.

Outlet.	Number.	Size.	Maximum head on center line.
		Inches.	*Feet.*
Sluice gates	5	60 by 60	238.17
Lower balanced valves	10	58	187
Upper balanced valves	10	58	100

SLUICE GATES.

Smooth, straight conduits provided.—The sluicing outlets (shown on Plates 44 and 46[4] are 165 feet long, located just above the water surface below the dam. At the upstream face of the dam the outlet is 6½ feet high by 7 feet wide, with the bottom flush with the floor of the trash-rack structure. It tapers by easy curves in a distance of 4 feet to a section 5 feet high by 6 feet wide, and this section continues 29.09 feet to the gate seat, the last 12.71 feet of this distance being lined with cast iron. Below the gate seat a transition casting 8 feet long changes the section from 5 feet by 4 feet 11 inches to 5 feet diameter, and this circular section is maintained in the unlined conduit to the face of the dam. The unlined portions of the outlets are built of a special mix of concrete, proportions 1:1.85:4.5, the cement being composed of 75 per cent sand cement (45 per cent blend) and 25 per cent straight Portland cement. Great care was taken to produce a smooth dense concrete around the passages, and metal-covered forms were used to secure a smooth surface. All irregularities were ground off with a portable emery wheel and the entire inner surface coated with one coat of water-gas and one coat of coal-gas tar.

[2] A. P. Davis, A. J. Wiley, F. E. Weymouth, and C. H. Paul.
[3] A. P. Davis, A. J. Wiley, D. C. Henny, O. H. Ensign, F. E. Weymouth, and C. H. Paul.
[4] Record drawing series.

Design of gates.—The five sluice gates (shown on Plate 47 of the record drawings) were purchased from the Wheeling Mould & Foundry Co., Wheeling, W. Va., under contract 466, dated December 10, 1912, specifications No. 221, for the lump sum of $26,100; total weight, 360,000 pounds. The gate is designed for hydraulic operation, the cylinders of the five gates being located in an inspection gallery running at right angles to and immediately above the sluicing outlets. The valve body is bolted to the cast-iron outlet linings, and the bonnet or housing extends up through the concrete to the inspection gallery, where the removable cover supports the operating cylinder. The gate leaf is a steel casting making a butt contact at the bottom and so arranged that it can be withdrawn into the inspection gallery after the cylinder and housing cover has been removed. The guides are of the special bronze compositions used by the Bureau of Reclamation for this purpose, and the contact at the bottom is made against a babbitt seat. A slight vertical offset just upstream from the seat is designed to protect it from damage due to rolling stones and other heavy material. The cylinder is a bronze-lined steel casting, designed for a pressure of 1,000 pounds per square inch. It is the intention that these gates shall be operated only at heads below 75 feet. All parts are designed so that the gates can be opened in case of emergency under heads as high as 125 feet, but such operation is considered hazardous and only to be undertaken in cases of extreme necessity. A rod attached to the piston extends through the upper cylinder head, acting as an indicator and a means of suspending the gate in open position if desired.

Installation of gates.—The gates were received at Arrowrock on August 3, 1913, and installation was completed September 15. Concreting around the gates and outlet forms was started on September 17 and finished on September 20, 1913. Water was turned through the outlets for the first time on October 21, 1914. In the latter part of November of that year the entire flow of the river was turned through them prior to the plugging of the diversion tunnel. Storing of the water was begun February 21, 1915, and the sluice gates were used very successfully for regulating the discharge until February 28, when the water reached the lower set of regulating outlets. The greatest head under which the sluice gates have been operated is 55 feet, and no trouble has been experienced with either the gates or the conduits.

REGULATING OUTLETS.

Arrangement of conduits.—The 20 regulating outlets (see Plates 44 and 46 [5]) are arranged in two sets of 10 each, at elevations 100 and 187 feet, respectively, below the spillway crest. The lower outlets are each 129 feet long, while each upper outlet is 70 feet in

[5] Record drawing series.

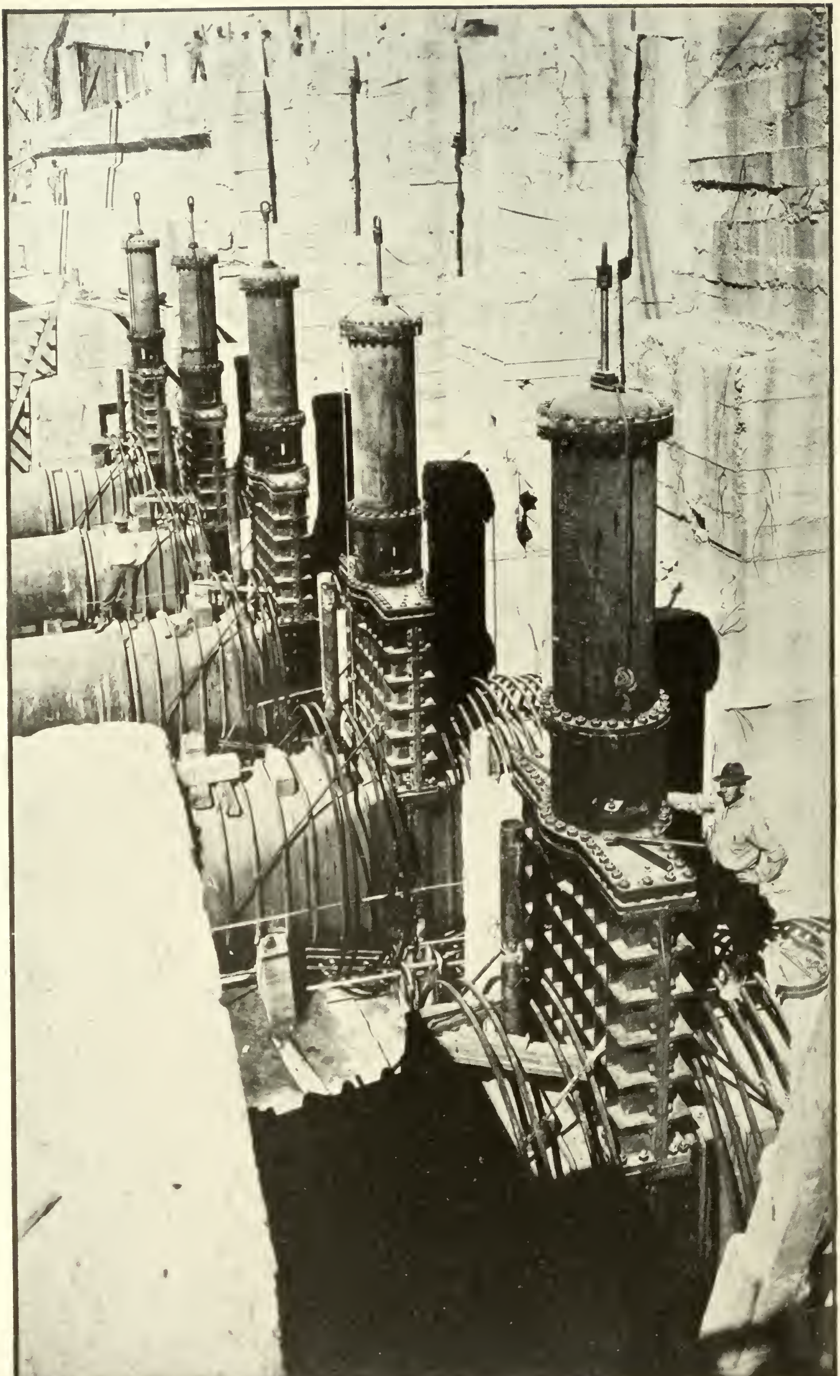
length. Three valves in each set are provided with positive-control mechanism and are adapted for operation at partial opening for regulating the discharge. The remainder of the valves are plain control, intended for wide-open discharge only. The three valves of the lower set, next the cliff, are provided for future power development and are referred to as power outlets. The discharge outlet of each valve is 58 inches internal diameter, and all of the regulating outlets are provided with throat pieces immediately below the valve, reducing the diameter of the outlet to 52 inches inside diameter. In the positive-control outlets the throat pieces are provided with holes to admit air. Each conduit is lined with semisteel pipe for a distance of 28 feet. The unlined portion of the passage is surrounded by special mortar mixed in proportion of 1 part Portland cement to 1.85 parts sand. Great care was taken in placing this mortar to insure a smooth, dense surface. After the forms had been removed the surface was carefully gone over to eliminate all surface defects and the entire inner surface of the passage painted with a coat each of water-gas and coal-gas tar.

The valves for the power outlets are plain-control type, and the discharge pipes taper from 58 inches to 6 feet diameter in the 28 feet of lined section. No reducing rings are provided at the entrances. These outlets are reinforced throughout their entire length with 1½-inch square bars welded into hoops 7 feet 2 inches in diameter and spaced 7 inches on centers.

Design of valves.—Te balanced valves (see Plate 48 [6]) are similar to those installed at the Roosevelt and Pathfinder Dams, except that the resistance tubes have been omitted, and in the case of positive-control valves a special form of moving sleeve is provided in the cylinder, as shown on Plate 49.[6] The water controlling the operation of the balanced valve must pass out from the cylinder through this movable sleeve and there is an acorn-shaped seat on the main piston of the balanced valve, which engages the end of the sleeve and cuts off the outflow of water when the piston has opened to the desired position. The sleeve is operated through bevel gears by means of a shaft inside the control pipe. The operating shaft passes through a stuffing box and terminates in the operating gallery, where a crank is attached for hand operation. Water discharged from the control pipe is wasted through the combined needle and ejector valve (see Fig. 28) into an open drain. A motor-driven centrifugal pump, located in the lower control chamber, provides pressure in excess of reservoir for closing and for the operation of the ejector to produce vacuum when required. The plain control valves are operated by the proper manipulation of valves (shown on Plate 46 [6]).

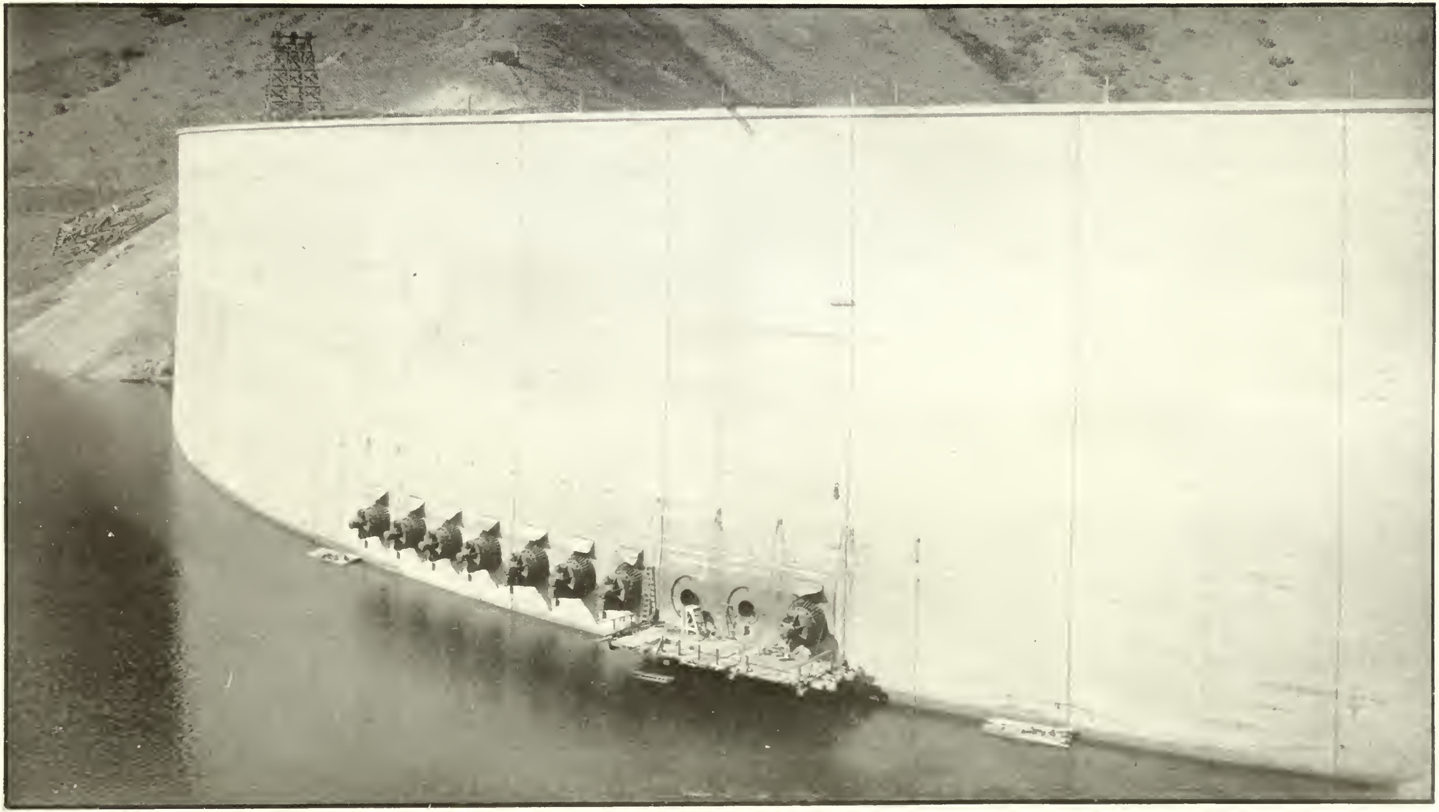
[6] Record drawing series.

ARROWROCK DAM, UPPER OUTLETS DISCHARGING.

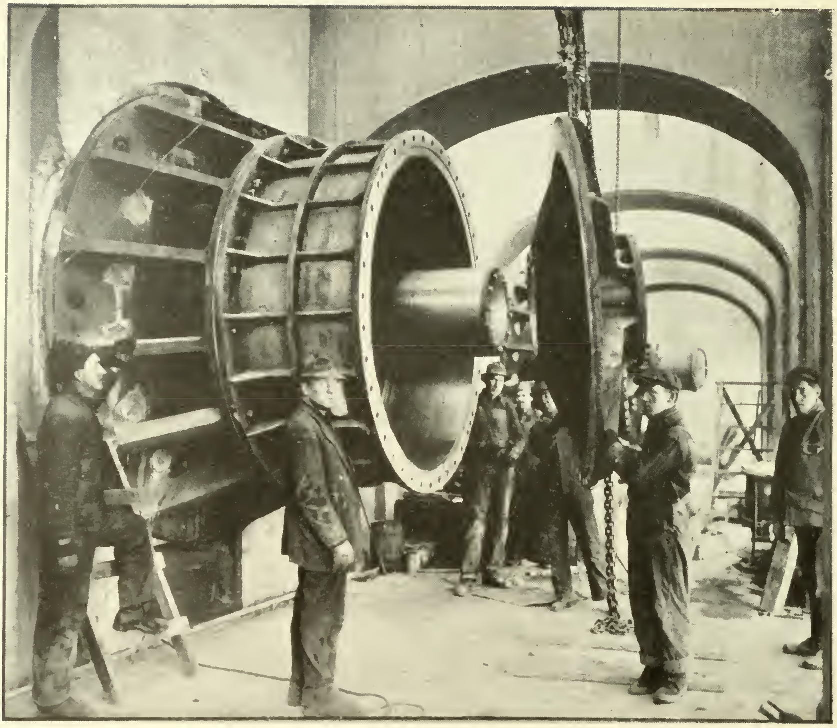


PLACING 5-FOOT BY 5-FOOT SLUICE GATES, ARROWROCK DAM.

Plate XIX.



PLACING UPPER 58-INCH BALANCED VALVES, ARROWROCK DAM



A, PLACING 58-INCH BALANCED NEEDLE VALVE, ARROWROCK DAM.

B, BALANCED VALVE CONTROL CHAMBER, ARROWROCK DAM.

Protection from ice.—In winter ice forms on the reservoir to a thickness of about 2 feet, and to prevent the valves from freezing in such weather provision has been made for pumping warm water through the control pipe and wasting it into the reservoir through the clearance around the bull ring and through safety pop valves located in the cylinder heads. A boiler is installed in the inspection gallery for the purpose of heating water, which is pumped through the valves by the motor-driven centrifugal pump.

Manufacture of valves.—The 20 valves were furnished under specifications No. 266, contract 548, dated June 5, 1914, by the Joshua Hendy Iron Works, of San Francisco, Calif., for the lump sum of $64,317; total net weight, 903,250 pounds. The semisteel linings under specifications No. 244 were furnished by the Minneapolis Steel & Machinery Co. for a total price of $19,420.42; weight, 680,096 pounds. Before accepting these valves from the manufacturer tests were made to determine the amount of leakage past the bull ring under a head of approximately 48 feet and the head required to move the piston. Representative results were as follows:

	Valve No. 5-1.	Valve No. 5-2.
Test pressure	22 pounds square inch	21 pounds square inch.
Clearance around bull ring	0.012-inch diameter	0.016-inch diameter.
Leakage, gallons per minute	31.1	28.1.
Head required to move piston	4 feet 10 inches	2 feet 4 inches.
Time to close valve	5 minutes	3 minutes.

The first valve arrived at Arrowrock November 28, 1914, and installation of the 10 valves for the lower set was completed about February 15, 1915. The installation of the upper set was completed in September, 1915.

Operation 1915–1921.—A number of the valves were operated during the season of 1915, and since that time all except the power outlets have been in regular operation. The following table gives the number of days each of the 11 plain-control valves have been operated during the period from January 1, 1916, to September 30, 1921:

TABLE 15.—*Balanced-valve operating record, Arrowrock Dam.*

Valve No.	Number of days operated.						Total for period.
	1916	1917	1918	1919	1920	1921	
7	35	66	73	90	27	34	325
8	42	36	27	43	105	38	291
9	46	24	9	58	56	3	196
10	70	2					72
11	118	131	71	82	49	95	546
12	60	167	79	83	40	104	533
13	71	104	65	79	103	89	511
14	76	82	77	21	96	127	479
18	140	60	95	102	121	150	668
19	116	54	95	62	8	116	451
20	159	53	84	57		106	459

Close regulation of flow.—The control has been perfect under heads from 3½ to 118 feet maximum. In a test with 3½ feet of water above the center line of the lower valves, an external pressure of about 5 pounds per square inch started the valves to close, and one valve was opened without the use of the ejector. With a head of 15

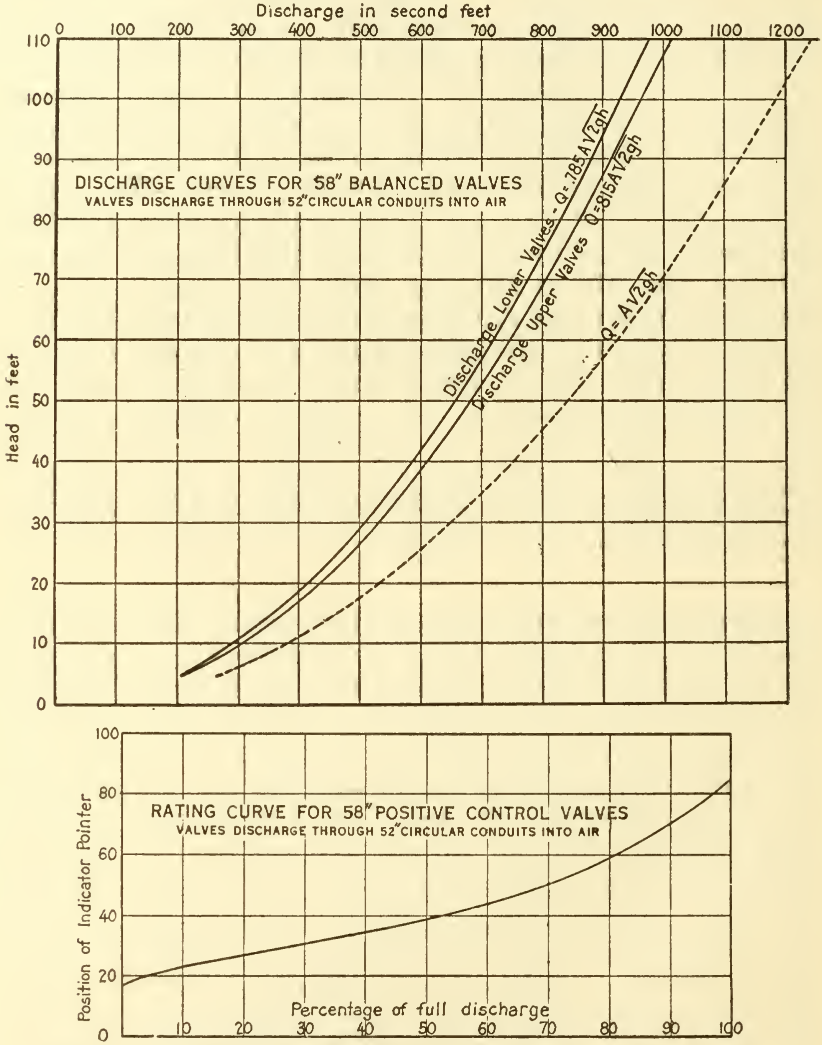


FIG. 39.—Discharge curves for 58-inch balanced valves, Arrowrock Dam.

feet above the center line of the valves the positive control worked perfectly, the piston following and backing away from the movable sleeve smoothly and easily.

An idea of the accuracy with which the discharge can be controlled may be obtained from the results during the flood season of 1916.

Heads of water up to 6 feet were passing over the spillway weir, which is 402 feet long. As the water surface dropped, it was very difficult to hold the river below the dam steady, as the discharge over the spillway weir varied as the three halves power of the head. A very small drop in the water surface had a very decided effect upon the discharge, as the weir is long. A sudden rise or drop in the river has a very serious effect upon the distribution system on the project, and an attempt was made to hold the river at a constant state by manipulation of the balanced valves. The nearest gauge was about 4 miles below the dam, and it took the water a little over an hour at that stage to reach the gauge. The operator at the dam was in telephone connection with the gauge reader, who reported the reading every hour. Under these severe conditions the river at the gauge was held to a variation of 0.05 foot by adding water in 50 second-feet increments. The automatic gauge sheets presented a curve made up of " saw teeth " with the points on a horizontal line. Later, when the water stopped flowing over the spillway, the gauge was held to a fluctuation of 0.02 foot by the addition of water in increments of 25 second-feet, which, with the outlets discharging under a 100-foot head, is considered by those operating the valves as an extreme refinement.

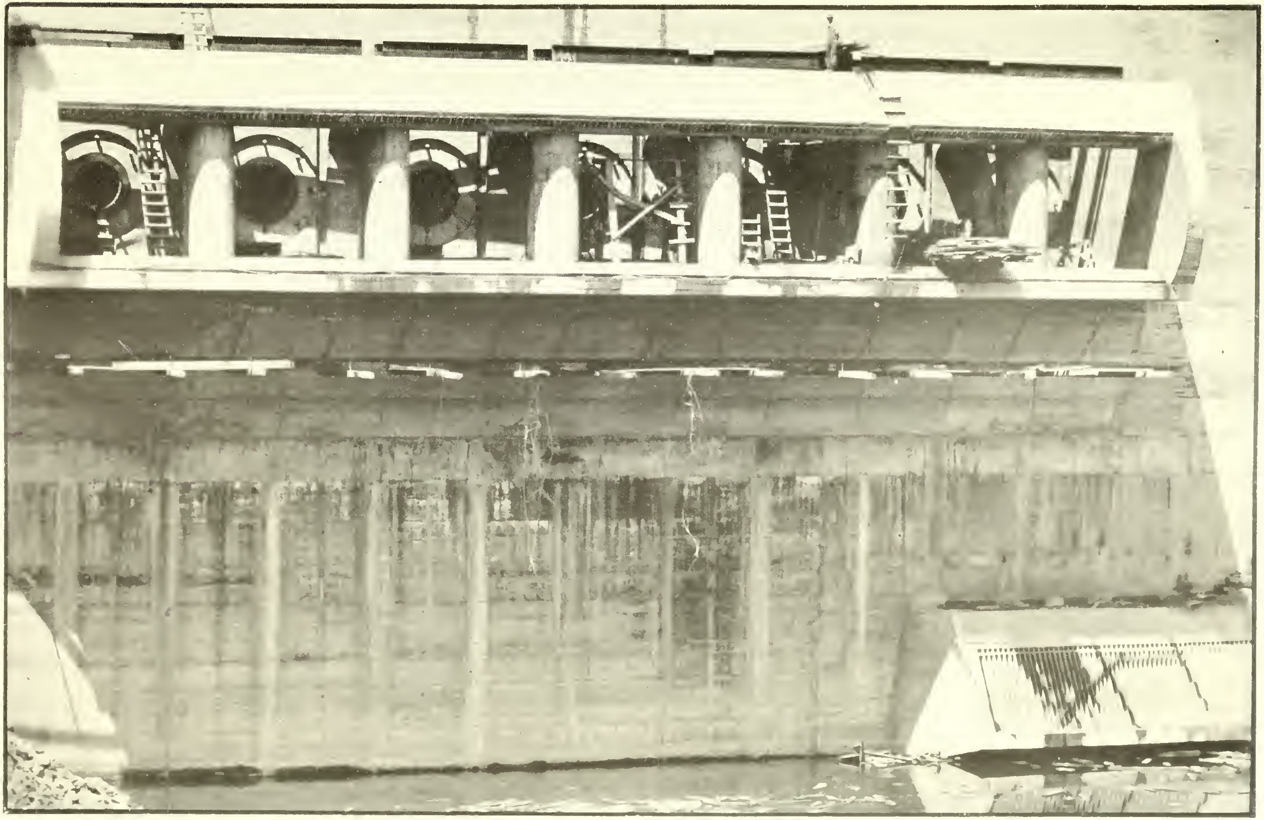
Operation under high head.—During the spring of 1916 the upper regulating outlets were used to pass flood waters. Over a considerable length of time all 10 were running wide open under heads as great as 103 feet. Under this condition the vibration was very slight, and knocks or jars were barely perceptible. Each outlet was discharging approximately 1,000 second-feet, the water falling 145 feet to the river. The jets present a very beautiful and spectacular sight. They are green and perfectly clear when the exit from the dam is made, but become opalescent, pearly, and pure white as they gradually ravel off in their descent. The bulk of the jet remains fairly solid and strikes the pool with a roar, sending the spray over the top of the dam, 250 feet above, when the wind is upstream. As the jets descend they converge into a solid sheet of water at the pool, due to the outlets being built on radial lines. Under a 28-foot head the discharge from the upper outlets clears the toe of the dam, and under a head of 100 feet falls into the pool about 100 feet below the dam.

In 1915, after a part of the upper outlets had discharged under heads up to 78.3 feet, soundings were taken in the pool, and it was found to be 23 feet deep.

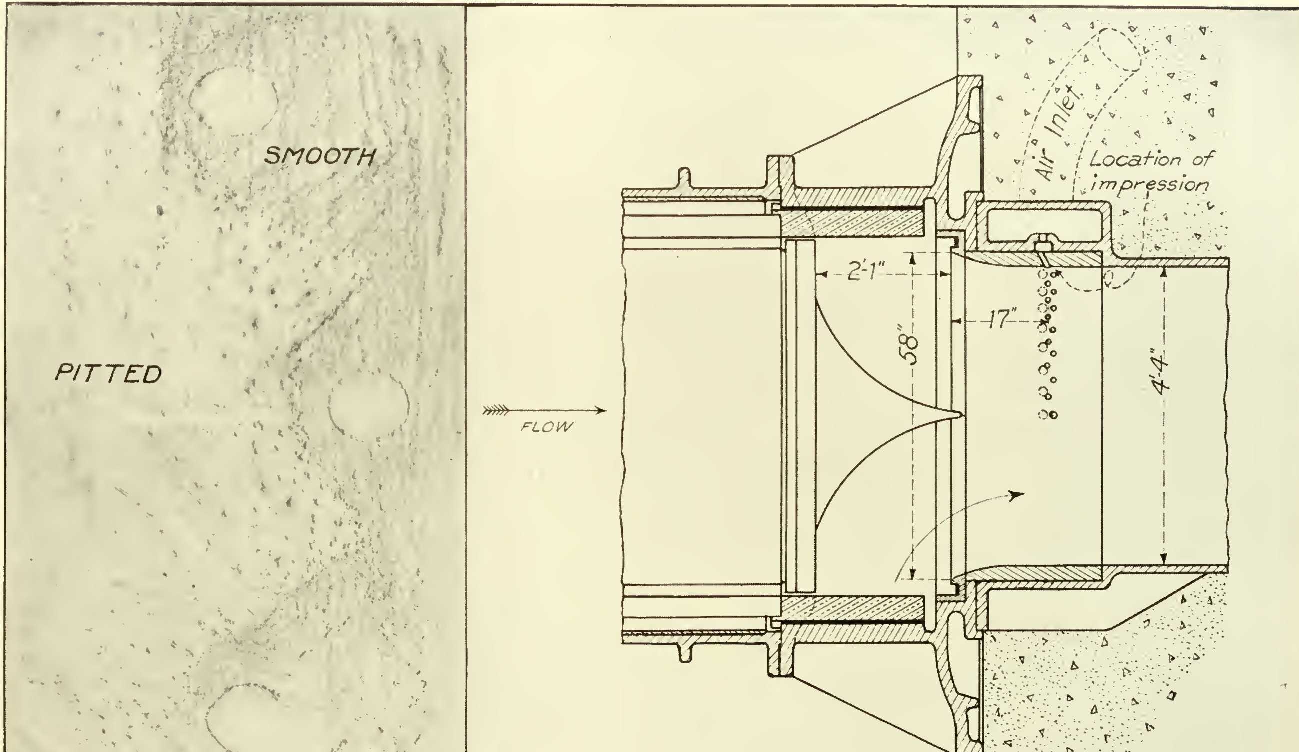
Slight erosion of conduits found in 1916.—An inspection of the lower three positive-control outlets on May 6, 1916, after they had discharged intermittently under usual working conditions for eight months, one of them working continuously over six months under heads up to 118 feet, with a corresponding velocity of about 70 feet per second, showed them to be in almost perfect condition. During the previous season these same outlets were operated under heads up to 106 feet. Altogether one outlet (No. 6) worked for 8½ months before the inspection was made. The valve was tight. The tar coating on the semisteel lining was in perfect condition; that on the concrete was about half gone, the heaviest wear being at the lower quarter points. Where the tar was gone the cement was in perfect condition. The whole surface was slick and to the touch was slimy, indicating that there is very little or no silt carried in the water and that the coefficient of friction must be very small. The patches in places were exposed. In no case was there any erosion at the edges of the patch, nor was any patch dug out. At one place at the quarter point there was a small hole 6 inches long, 1½ inches wide, and ½ inch deep eroded parallel to the axis of the outlet, probably along a horizontal joint between the layers of mortar.

Inspection at the close of the irrigation season of 1916 disclosed no wear in the plain-control outlets, except slight loss of paint and a few flakes of cement wash. Positive-control outlet No. 6 showed a honeycombed area in the concrete conduit about ½ inch deep and 3 feet wide by 3 feet 5 inches long on the north side of the outlet, 1 foot from the bottom and 4 feet from the end of the lining. Positive-control outlet No. 17 showed a hole in the concrete about 10 inches in diameter and about 1½ inches maximum depth on the north side of the conduit.

Patching of conduits required in 1921.—Annual inspections of the outlets have been made since the valves were first installed. The wear in the conduits was very slow at first, and the condition of the valves and conduits in the fall of 1920 was reported to be practically as good as when first installed. In the fall of 1921, however, the throat liners and the concrete conduits below the semisteel linings were found to be considerably worn. In the positive-control outlets the wear was most extensive in the concrete of the conduits, while in the plain-control outlets the throat liners showed the greatest wear. The pitting of the throat pieces had the peculiar, rough, honeycomb appearance noted in many of the other outlets of the service and was most severe immediately below the V guides of the balanced valves. In the positive-control valves air is supplied through holes in the upper half of the throat piece for the purpose of relieving the vacuum at this point and thus preventing cavitation. The effectiveness of this remedy is indicated by the impression shown on Plate XXII of the pitted surface of valve No. 16. The metal for a distance of about one-half inch upstream from each air hole is smooth, but above this



TRASH RACK STRUCTURES FOR LOWER BALANCED VALVES AND SLUICE OUTLET, ARROWROCK DAM



PENCIL IMPRESSION OF PITTING AROUND AIR HOLES IN THROAT PIECE OF POSITIVE CONTROL VALVE NO. 16 IN UPPER TIER. ARROWROCK DAM. OCT. 8, 1921.

point pitting begins. There was practically no pitting below the air holes. The fact that the positive-control liners are pitted less than those of the plain-control valves also indicates that considerable benefit has been obtained from the admission of air.

No. 16 positive-control valve in the upper tier was in the worst condition. The stationary bronze seat of this valve was slightly pitted at top and bottom, opposite the V guides. The throat liner was pitted about $\frac{1}{8}$ inch deep, opposite the V guides, but the pitting stopped around the air holes and below. There was slight pitting of the semisteel lining at one point on the bottom, but the paint is still on this metal over almost the entire area. The concrete at the bottom of the conduit below the metal lining eroded in waves about 1 to 5 inches deep, 1 foot wide, and for a distance of 12 feet along the pipe. On the right-hand side of the pipe, facing downstream, there were two pits about $2\frac{1}{2}$ inches deep, 1 foot wide, and 3 feet long. On the left-hand side there were pits 3 inches deep and 1 foot wide, extending 6 feet along the pipe. The tar paint was about half gone from the rest of the outlet.

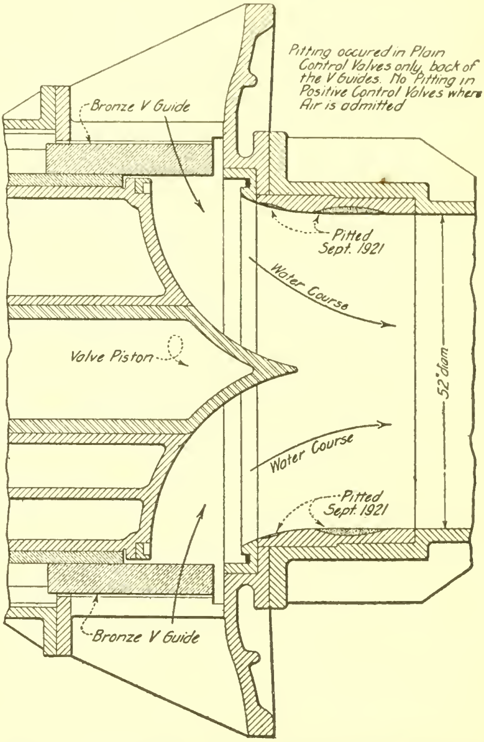


FIG. 40.—Pittings of upper outlet castings, Arrowrock Dam.

No. 18 plain-control valve in the upper tier was in the worst condition of any plain-control outlet. The stationary bronze seat was pitted at top and bottom about $\frac{1}{16}$ inch deep. The throat piece was pitted at the bottom about 1 inch deep and over an area of about 18 inches in diameter. Almost the entire top half of the liner and the conduit for a few inches below the liner was pitted to a maximum depth of about $1\frac{1}{2}$ inches. The semisteel linings were not damaged and the concrete was intact. The paint was about half gone from the concrete, but that on the metal linings was nearly intact. The damaged concrete was patched and the cavities in the throat liners were filled with Smooth-on.

Minor mechanical difficulties.—A few minor mechanical difficulties have developed with continued operation of the valves, but these have been successfully overcome. The most serious of these difficulties was the breakage of a thrust spider for the sleeve-operating screw and the bending of a sleeve-operating screw. This would indicate that the piston has at some time moved back against the sleeve with considerable force. The acorn-shaped seat is mounted on a spring to provide a certain amount of flexibility of contact, but apparently the allowance is barely sufficient for the purpose. The total cost of repairs for the seven years of service has been $1,262.

TABLE 16.—*Approximate cost of outlet work, Arrowrock Dam (1913)*,

	Quantity.	Cost.
Five sluice outlets (installed in 1914–15).		
Five 60 by 60 inch high-pressure gates, tunnel linings, control piping, and accessories ....pounds..	360,000	$27,807
Labor, installing gates, etc....	....	1,925
Freight....	....	3,629
Trash-rack structure:		
Reinforced concrete....cubic yards..	238	5,177
Grillage bars, structural steel, castings....pounds..	67,000	2,610
Outlet conduits, reinforced concrete....	....	7,833
Main cableway service....	....	652
Total sluice outlets....	....	49,663
Cost per outlet, $9,932.60.		
20 regulating and power outlets (installed in 1914–15).		
Twenty 58-inch balanced valves....pounds..	930,250	64,317
Semisteel tunnel linings....do....	680,100	19,420
Control piping....	....	8,665
Miscellaneous material and supplies....	....	3,707
Labor installing....	....	12,553
Painting metal work, labor and material....	....	440
Freight....	....	11,665
Trash-rack structure:		
Reinforced concrete....cubic yards..	1,284	17,782
Grillage bars, structural steel....pounds..	573,000	18,982
Seventeen 52-inch irrigation outlet conduits, reinforced concrete, (1,703 linear feet) ....cubic yards..	1,292	19,120
Three 72-inch power outlet conduits (387 linear feet)....	....	8,466
Main cableway service....	....	645
Total regulating and power outlets....	....	185,862
Cost per outlet, $9,293.10.		

The above costs include all items of expense, except general expense and engineering, which amounted to about 8 per cent.

Chapter XIII.

ELEPHANT BUTTE RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Elephant Butte Reservoir is located on the Rio Grande, 120 miles northwest of El Paso, Tex. It supplies water to the Rio Grande project and lands in Mexico and has an available capacity of 2,637,000 acre-feet.

Dam.—The dam is a straight structure of the gravity type, built of rubble concrete, with the following dimensions: Height, 306 feet; base width, 154 feet; least width, 18 feet; top length, 1,674 feet.

The dam contains 605,200 cubic yards of masonry. Plate 51 [1] shows the general plan, elevation, and maximum sections of the dam. The reservoir location and capacity curve are given on Plate 50.[1] Figure 41 shows the variation of water elevations in the reservoir since construction of the dam and indicates the conditions under which the outlets have been operated.

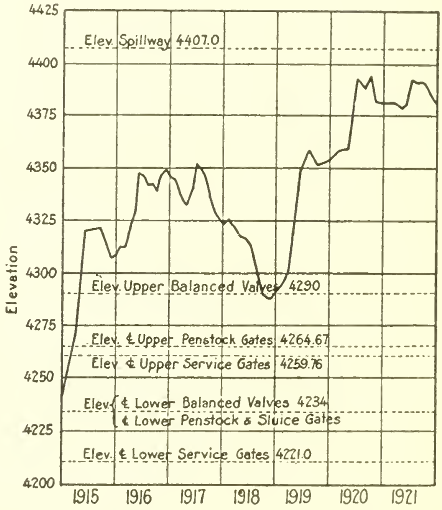


Fig. 41.—Water-surface elevations, Elephant Butte Reservoir.

Outlets.—The following table is a complete list of the devices installed for the regulation of the discharge through the dam.

Outlets, Elephant Butte Dam.

Purpose.	Number.	Type.	Size.	Maximum head on center line.
			Inches.	*Feet.*
Sluicing	4	Slide gates	47 by 60	173
Power	6	.....do	47 by 60	142.33–173
Emergency	4	.....do	47 by 90	147.24–186
Irrigation	4	Balanced valves	60	117–173
Spillway	4	Cylinder gates	120	....

[1] Record drawing series.

A board of engineers [2] met at Los Angeles, Calif., February 5, 1913, and outlined the general principles to be followed in the design of the Elephant Butte outlets. Another board [3] meeting was held at Portland, Oreg., March 5, 1913, at which the designs prepared by Mr. Teichman for penstock and sluicing gates were considered and their adoption recommended. Further discussion was had by this board [4] at El Paso, Tex., March 27, 1913. The design of all the outlets was carried out under the immediate direction of Mr. Teichman.

SLUICING GATES.

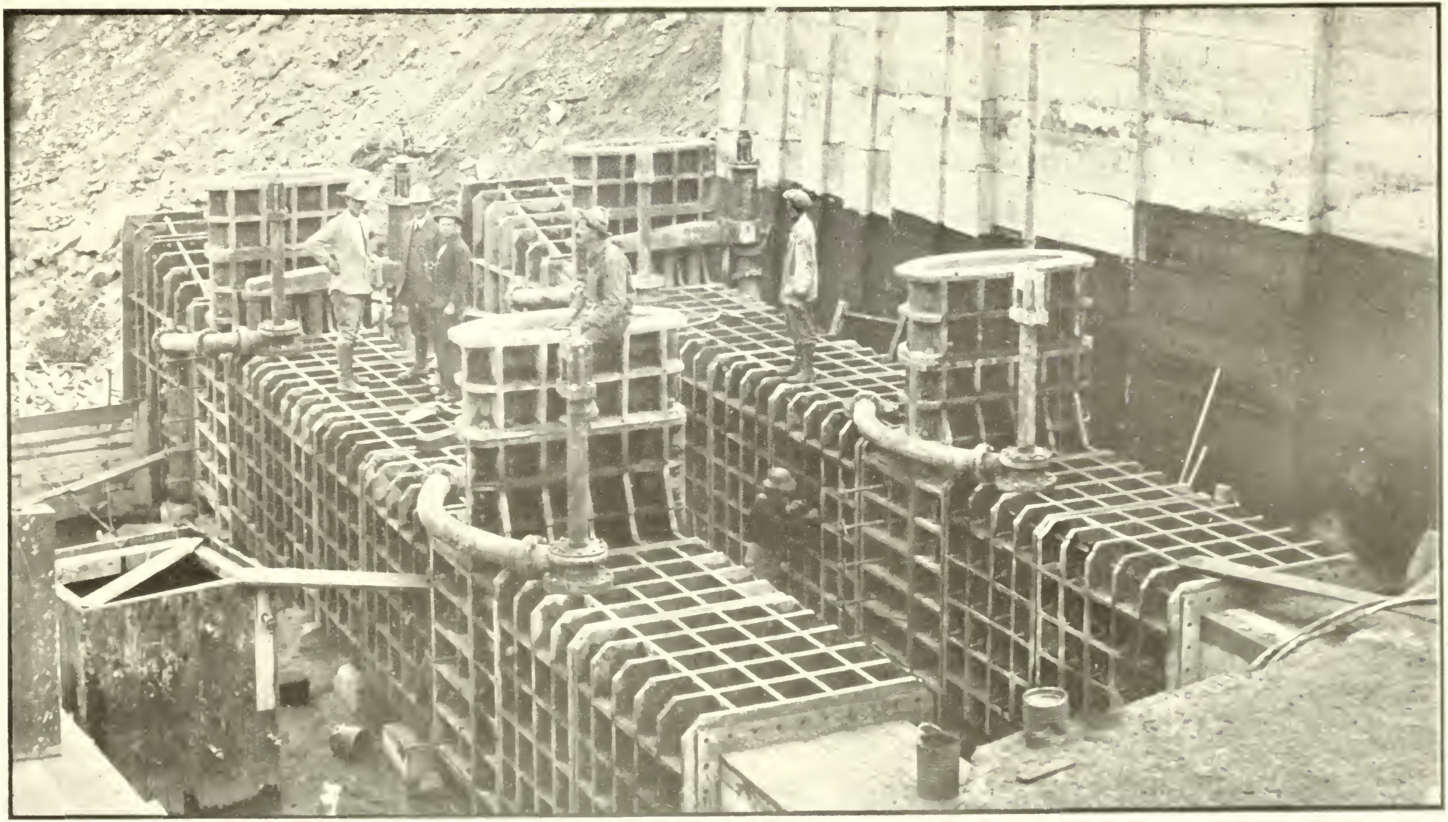
There are two sluicing conduits through the dam, with the center line of the entrances at elevation 4,234 and the outlet at elevation 4,221.5. Each conduit is provided with two sluice gates in series and is lined with iron castings for a distance of 47 feet from the entrance. The total length of the east conduit is 162.33 feet and the west conduit 161.83 feet. The entrance is a rectangular opening 65.03 by 103¼ inches. The passage tapers to a minimum cross section at the first gate of 47 by 60 inches, and this section is maintained throughout the remainder of its length. The first gate is located 10 feet from the entrance and the second 25 feet below the first gate. The general arrangement of the installation is shown on Plate 52 of the record drawings.

Details of design.—The two gates, an assembly of which is shown on Plate 53 of the record drawings, are practically identical and are made of very heavy iron castings. They are operated by hydraulic cylinders and are so arranged that the bonnet cover can be removed and the gate leaf drawn up into the operating chamber, the floor of which is 10 feet above the gate sill. The seats are fitted with bronze strips of the special Class C and D bronzes, and the leaf makes a butt contact at the bottom against the babbitt seat. The stem is of rolled manganese bronze, having an ultimate tensile strength of 80,000 pounds per square inch and is connected to the gate by means of a crosshead and two short stems. The cylinder has an internal diameter of 24 inches and is a steel casting with rolled-bronze lining. The piston is provided with square hydraulic packing, and a bronze rod extends through the cylinder head to serve as an indicator. An unusual feature is the single stuffing box between the water space above the leaf and the hydraulic cylinder, which necessitates removing the cylinder for inspection or adjustment of the packing. The upper gate is provided with a 5-inch by-pass for equalizing the pressure preparatory to opening the gate. The gates and operating

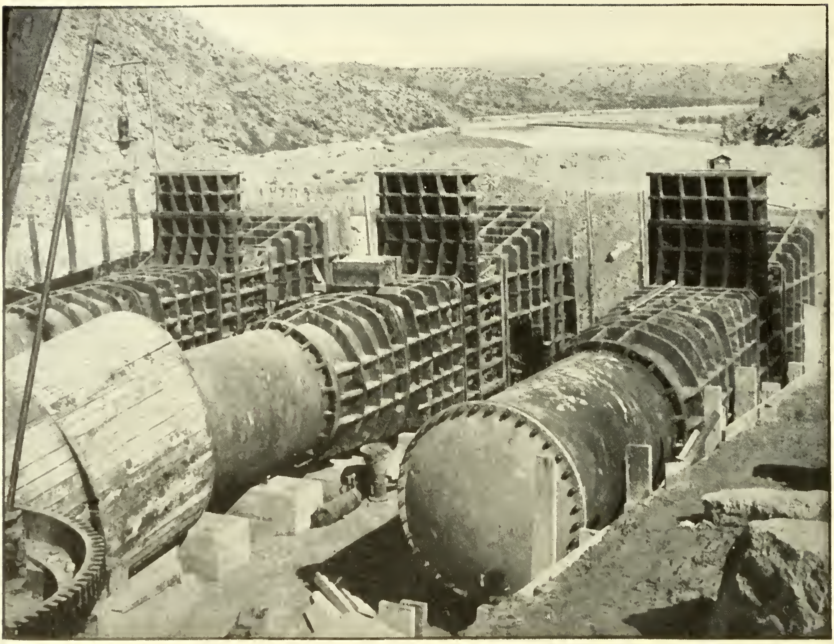
[2] L. C. Hill, O. H. Ensign, F. Teichman, and D. C. Henny.

[3] D. C. Henny, L. C. Hill, and F. Teichman.

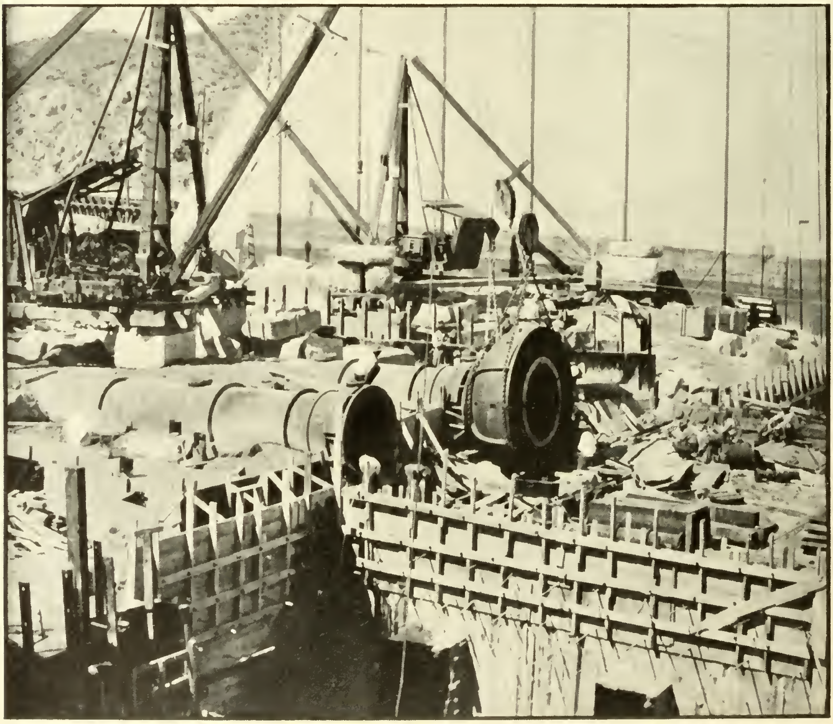
[4] Board of March 5, 1913, with O. H. Ensign.



PLAÇING SLUICE GATES, ELEPHANT BUTTE DAM.



A, PLACING PENSTOCK GATES, ELEPHANT BUTTE DAM.



B, PLACING 60-INCH BALANCED NEEDLE VALVES, ELEPHANT BUTTE DAM.

mechanism are covered by specifications No. 235. Water for operating the hydraulic cylinders is supplied by a motor-driven, triplex pump, located in the power plant, having 35 gallons per minute capacity against 1,200 pounds pressure per square inch.

Purchase and installation 1913–1915.—Contract 506, dated August 1, 1913, was made with the Hinman Hydraulic Manufacturing Co., Denver, Colo., for 10 gates, 4 for the sluicing conduits and 6 for the penstocks. The total weight of the material delivered on this contract was 790,000 pounds and the total payments $55,917.31. Material was delivered at the dam between January 27 and April 9, 1914, and the work of erection completed in February, 1915.

Tunnel linings damaged by discharge, 1915–1917.—It was the intention that these sluice gates should be operated only for removing silt from in front of the penstock openings and at heads not exceeding 80 feet, under which conditions it was estimated that the balanced valves might not have sufficient capacity to deliver the required irrigation flow. After water had been discharged through the balanced valves for a few months it was discovered that the throat pieces were eroding to a considerable extent. On account of the difficulty of renewing these parts the practice was begun of operating the sluice gates for the delivery of irrigation water. During the year 1917 the east sluice gates were operated in this manner for a period of 116 days and the west gates for a period of 152 days under heads varying from 89 to 113 feet. In January, 1918, it was found that the castings below the gates were eroding to quite an extent, some of the castings being cut through to the concrete. The extent of this action is shown on Plate 54 of the record drawings. Erosion was confined to the cast-iron linings, the concrete passages being in excellent condition. The damage in every case started from an irregularity in the casting, being most noticeable immediately downstream from the pockets for the cap screws which hold the bronze seats. The damage was patched as far as possible with a rich concrete mortar, and subsequent operation proved these repairs to be fairly effective, the concrete remaining intact, although the erosion of the metal continued to some extent.

A board of engineers [5] on June 12, 1918, considered the operation of the various outlets and recommended that the balanced valves be used exclusively for discharge and regulation of water and that the use of the sluice gates for this duty be discontinued. Repairs and improvements in the operating mechanism for the balanced valves were also recommended to permit their easy manipulation.

[5] O. H. Ensign, J. M. Gaylord, R. F. Walter, and L. M. Lawson.

PENSTOCK GATES.

Provision for future power development.—Six penstock entrances, the general arrangement of which is shown on Plate 52,[6] have been provided for future hydroelectric development. Each penstock is closed by a sliding gate at its entrance, immediately below which is a transition casting from a rectangular section 47 inches by 60 inches to a 60-inch circular opening. To the lower end of each of these transition castings a cast-iron bumped head is attached for the purpose of closing the pipes until they are needed for the development of power. The total length of cast-iron lining at each entrance is 34 feet 4¾ inches. The gates are identical with the sluicing gates and were purchased under the same contract. The assembly of these gates is shown on Plate 55.[6]

60-INCH BALANCED VALVES.

The four 60-inch balanced valves at the Elephant Butte Dam are installed in two separate wells extending vertically from the bottom to the top of the dam, two valves being placed in each well at different- elevations, as shown on Plate 56.[6] Water is admitted at the bottom through sliding service gates, shown on Plates 56 and 57,[6] which can be closed for inspection of the balanced valves.

Details of design.—Each 60-inch balanced valve consists of a cast iron piston provided at one end with a pointed tip and at the other with a bronze bull ring of slightly greater diameter than the seat ring. The piston moves in a bronze-lined cylinder with a small clearance around the bull ring, and when closed the circular seat ring engages a corresponding stationary seat at the entrance of the cast-iron discharge tubes. Plate 58 [6] shows an assembly of the valve equipped with the new auxiliary control and throat pieces.

The bowl-shaped casting supporting the cylinder is cast in the concrete of the dam and makes a flange connection with the discharge pipe. Water enters the bowl-shaped casting parallel with the axis of the cylinder, is turned through an angle, and discharged around the pointed end of the piston into the circular outlet passage. The entrance of the discharge tube is provided with a contracted throat piece, with a large number of holes through which air is admitted around the jet. The main cylinder head is provided with a cylindrical extension, which acts as a guide for the extended piston stem and also connects with a pipe running across the well through the concrete and into the control chamber. The bronze tail rod passes through this pipe and extends through a stuffing box into the control chamber, serving as an indicator and

[6] Record drawing series.

a means of applying additional force for opening the valve in case of necessity. The valve is designed to operate by means of hydraulic pressure, the entire area of the piston being available for applying either pressure or vacuum for moving the piston. The operation is controlled by means of valves in the control chamber, which connect with the cylinder through the pipe and cylindrical extension of the piston head surrounding the tail rod. A movable locking tube, concentric with the tail rod, serves to hold the valve in any desired position through control of the pressure on the piston.

Operation described.—Assume that the valve is closed and the locking tube is pressed against its seat by means of the spring on the tail rod. If the operating valves are closed, leakage past the bull ring will establish full reservoir pressure in the cylinder and press the piston firmly to its seat. To open the valve, a vacuum is established in the cylinder by means of a draft tube. This, aided by reservoir pressure on the annular space (about 191 square inches) between the circumference of the seat and the circumference of the bull ring, is usually sufficient to start the piston from its seat. Reaction of the issuing jet aids in opening the valve after it is once started. To hold the valve in any desired position, the locking tube is clamped and an outlet opened by which water escaping from this tube may be carried off. Then pressure building up back of the plug causes it to move toward its seat, taking the tail rod with it and opening the passage into the locking tube. This relieves the pressure in the cylinder, causing the piston to move outward and again closing the outlet passage through the locking tube.

Purchase and installation.—The balanced valves are covered by specifications No. 242 and were purchased from Best & Co. under contract No. 527, dated January 7, 1914. The total weight of material involved was approximately 364,000 pounds for the four valves, and the total cost f. o. b. factory was $25,848.59. Difficulty was experienced by the contractor in manufacturing the locking tubes, owing to their length and thin section. Inspection was handled by the Pittsburgh Testing Laboratory, and the material accepted was of high quality both as to material and workmanship. Valves were erected under the supervision of an erecting engineer representing the manufacturers.

Cylinders deformed by compression of concrete.—The valves were first operated on January 7, 1915. During the first six months of operation it became constantly more difficult to open the valves, and after six months it was practically impossible to open them. The service gates were closed and the valves were inspected. The two lower valves were found to be full of mud and it was found that the piston was binding in the cylinders. In the first valve the plug was filed and replaced. In the other three caliper measurements were made showing that the cylinders had been compressed in a vertical diameter and elongated in the horizontal. Since the valves worked perfectly when first installed, the distortion must have been gradual, and it is probable that the concrete over the casting continued to compress for a long time after being placed. Since the plugs do not revolve, the portion of the bull ring showing binding was hand-dressed with files until a good fit was secured. The maximum distortion was noted in the lower west valve, 0.027 inch in a diameter of 6 feet 2 inches. The upper valves, located 60 feet higher with a consequent lower head of concrete, showed a maximum distortion of 0.015 inch.

Operating forces inadequate.—It was the original intention to close the valve by reservoir pressure, but it was found that after the plug had remained in one position for some time, this pressure was not always sufficient to start it. Water at a pressure of 140 pounds per square inch is available in the operating gallery, and a connection was made with the control pipe for introducing additional pressure into the cylinder, a relief valve being provided to limit the pressure in the cylinder to 80 pounds per square inch. The vacuum used in opening the valve is assisted by the pressure on the annular space between the circumference of the seat and the circumference of the bull ring, but it was found impossible at times to obtain sufficient opening force in this way, and a more reliable means of opening was found to be desirable. No difficulty was experienced in holding the valve in any desired position by means of the locking tube assisted by the friction of the piston in its guides. The operating mechanism has been criticized as being unduly complicated, yet the valves have the advantage of being accessible, and as a tail rod extends into the operating gallery, it is always possible to tell the exact position of the piston and to apply additional force to assist in the operation of the valve.

Throat pieces damaged by discharge.—After the valves had been operated for six or eight months inspection showed that the semisteel throat pieces of the lower valves were being eroded from the seat ring downstream for a distance of 18 inches, pits ranging from one-sixteenth to one-fourth inch in depth giving the metal a honeycombed appearance.

The condition of the lower valves in June, 1916, was reported as follows:

Lower west valve.—Erosion of the throat liner immediately downstream from the seat ring continues around circumference to a depth of three-eighths inch. Erosion tapered off and disappeared about 12 inches downstream. The plug was badly eroded between the points of contact of the six guides.

Lower east valve.—The same erosion of throat liner to a depth of one-half inch, tapering off as above and extending downstream 24 inches. The plug shows practically no erosion. These conditions are to be expected, as the east valve operated full open while the west one was used to regulate the quantity discharged and consequently worked partially open. In both valves the deepest erosion of the throat liner is about 2 inches downstream from the bronze seat ring. The seat rings themselves show no wear; neither do the bronze plug rings.

Metal-spraying process unsuccessful.—On account of the difficulty of renewing the throat pieces, an attempt was made to repair them by means of a metal-spraying process. The work was done by a representative of the metal-spraying company. The parts were carefully sand-blasted and then coated with various metals for purpose of comparison. Copper, lead, and zinc were used, also a combination of zinc overlaid with copper. The east valve was then operated 90 hours and the west valve 50 hours under a head of 110 feet. At the end of this trial a portion of the zinc coating of the west valve remained in fairly good condition, while all the other coatings had disappeared. The metal-spraying process appears to be without value for such repairs as these.

On account of the progressive damage to the throat pieces caused by the discharge of water, the use of the balanced valves was discontinued and water regulated by means of the sluice gates. This in turn resulted in damage to the sluicing outlets, and the entire question of outlets for the Elephant Butte Dam was considered by a board of engineers[7] June 12, 1918.

Auxiliary control installed.—It was recommended that new bronze throat pieces and seat rings be provided and that a means of auxiliary control of the balanced valves be installed. The repair parts are covered by specifications No. 178–D, bids opened February 10, 1918. The four sets of throat pieces were purchased from the Rosedale Foundry & Machine Co. at a contract price of $10,850, shipping weight, 22,000 pounds. The four sets of auxiliary control parts were purchased from the Stearns-Roger Manufacturing Co. at a contract price of $6,250, shipping weight 13,400 pounds.

The auxiliary control provided for the balanced valves consists of two single-acting cylinders mounted in the control chamber and arranged to apply an opening force to the tail rod of the valve. Pressure for operating the cylinders can be obtained from a pump located in the hydroelectric plant below the dam or from a hand pump to be placed in the operating gallery. The valve seats were made renewable by making them in two concentric parts, the outer ring being made thin to give it flexibility to facilitate erection. The throat

[7] O. H. Ensign, R. F. Walter, J. M. Gaylord, L. M. Lawson.

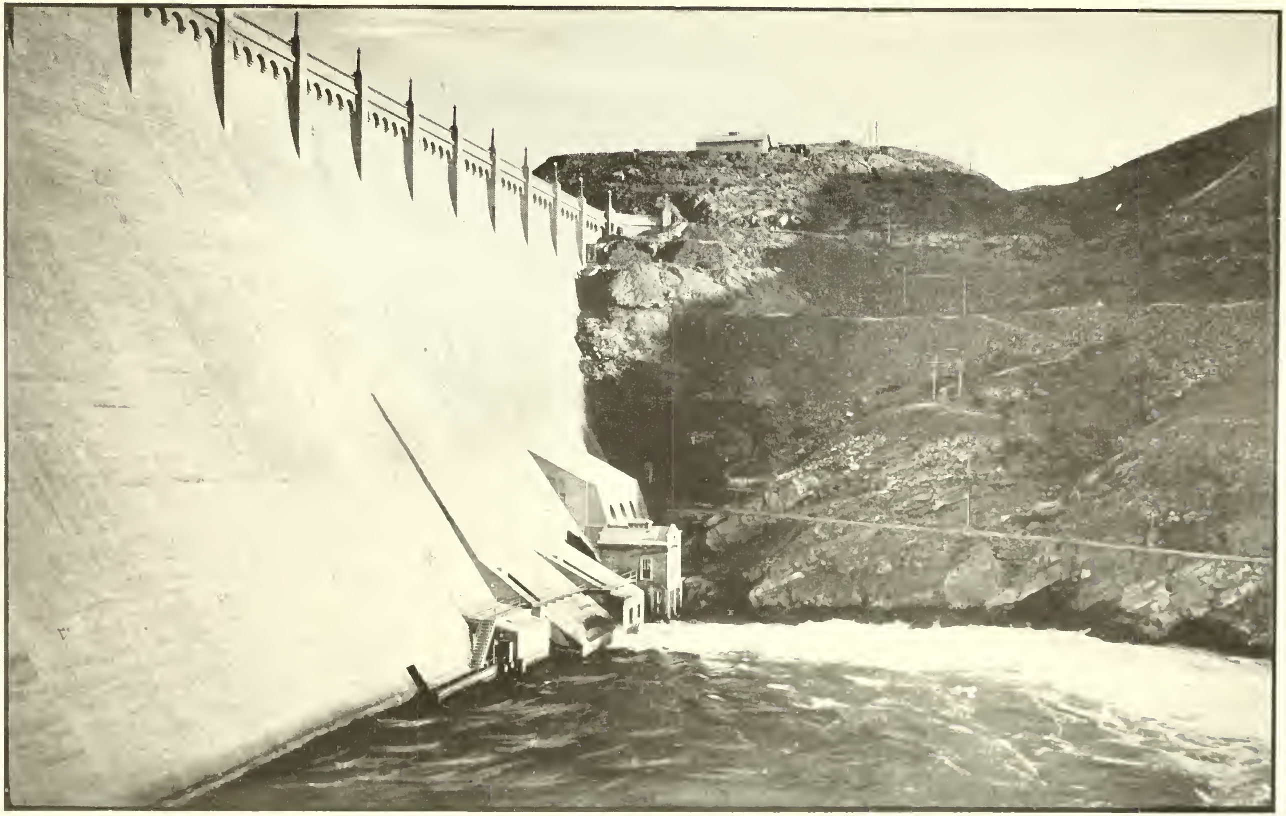
pieces were made in two sections, each 2 feet long, the lower one of semisteel and the upper one of manganese bronze, provided with a large number of holes to admit air. Details of these parts are shown on Plate 59.[8] The installation of the new throat pieces and auxiliary cylinders was completed in August, 1920.

Pistons eroded by discharge.—The board's report of June 12, 1918, mentions slight pitting of the main needles of the balanced valves, but no immediate repairs were recommended. The west valves were inspected in August, 1920, just after completion of the installations of the auxiliary control on the east valves. The needle of the lower west valve was found to be badly pitted, the casting being perforated in numerous places. As perforations at this point would interfere with the control of the valve, repairs were immediately undertaken. New pistons were designed, having renewable bronze tips, and two such pistons purchased from the National Marine Engine Works, of Scranton, Pa., under specifications No. 392, contract dated April 21, 1921. The contract price was $4,100 and the shipping weight 24,000 pounds. These pistons will be installed in the two lower valves. The upper valve pistons will probably not require renewal for a considerable time. The design of the new piston is shown on Plate 58.[8]

CYLINDER GATES IN SPILLWAY.

The spillway contains four 10-foot cylinder gates to assist in regulating flood discharge. The general plan of these gates is shown on Plate 60 of the record drawings. The gate cylinders were purchased under specifications No. 5–D, advertisement No. 853, dated November 10, 1915, from the Western Pipe & Steel Co., for the lump sum of $960, shipping weight 19,000 pounds. The seats and operating gear were purchased separately. Each gate consists of a boiler-plate cylinder, 10 feet 4 inches internal diameter and 8 feet high, mounted within a cylindrical concrete tower. The cylinder is provided with two counterweights and is raised by means of a hand-operated gate stand supported on structural-steel beams at the elevation of the roadway. A single seat at the bottom is provided and the clearance between the cylinder and the concrete is kept at a minimum to prevent leakage over the top of the cylinder in case of very high water. The lower seat ring is an iron casting set in the concrete and carries three cast-iron posts which help to support the concrete tower. Each gate discharges through a curved concrete draft tube leading under the spillway weir. The gates were installed in 1916, but to date (1922) have not been operated, as water has never reached the spillway.

[8] Record drawing series.



OUTLETS AND POWER PLANT, ELEPHANT BUTTE DAM.

TABLE 17.—*Cost of outlet works, Elephant Butte Dam (1913–1915).*

	Six penstock gates.	Four sluice gates.	Four service gates	Four 60-inch balanced valves.
Plant charge	$29	$60	$69	$136
Wells, forms:				
Labor				546
Material				155
Conduits, forms:				
Labor	1,260	161	102	1,532
Material	627	7	524	763
Operating gallery, forms:				
Labor		113		
Material		54		
Gates, or valves:				
Delivered cost	45,237	24,979	27,039	35,278
Installation—				
Labor	2,123	1,168	1,228	1,487
Materials	2,172	1,365	1,511	4,486
Painting	279	150	177	603
Hauling	202	43	148	109
General expense, superintendence, and engineering	3,089	1,227	1,468	3,745
Total cost	55,018	29,327	32,266	48,840

CHAPTER XIV.

LAHONTAN RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Lahontan Reservoir is located on the Carson River, about 18 miles west of Fallon, Nev., and is one of the main storage units of the Newlands project. It is fed by the Carson River and by a feeder canal from the Truckee River. The feeder canal enters the reservoir from the downstream side, and a by-pass makes it possible to deliver the flow directly into the river below the dam if desired. This by-passed water is used for generating power. The reservoir has a storage capacity of 290,000 acre-feet. The stored water is discharged into the river channel through a tower and outlet near the center of the dam.

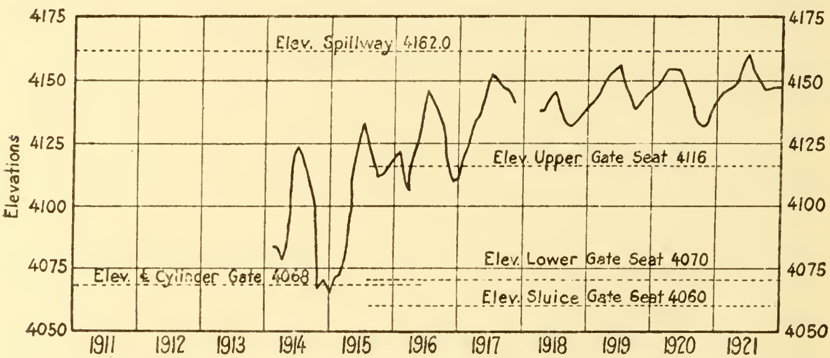
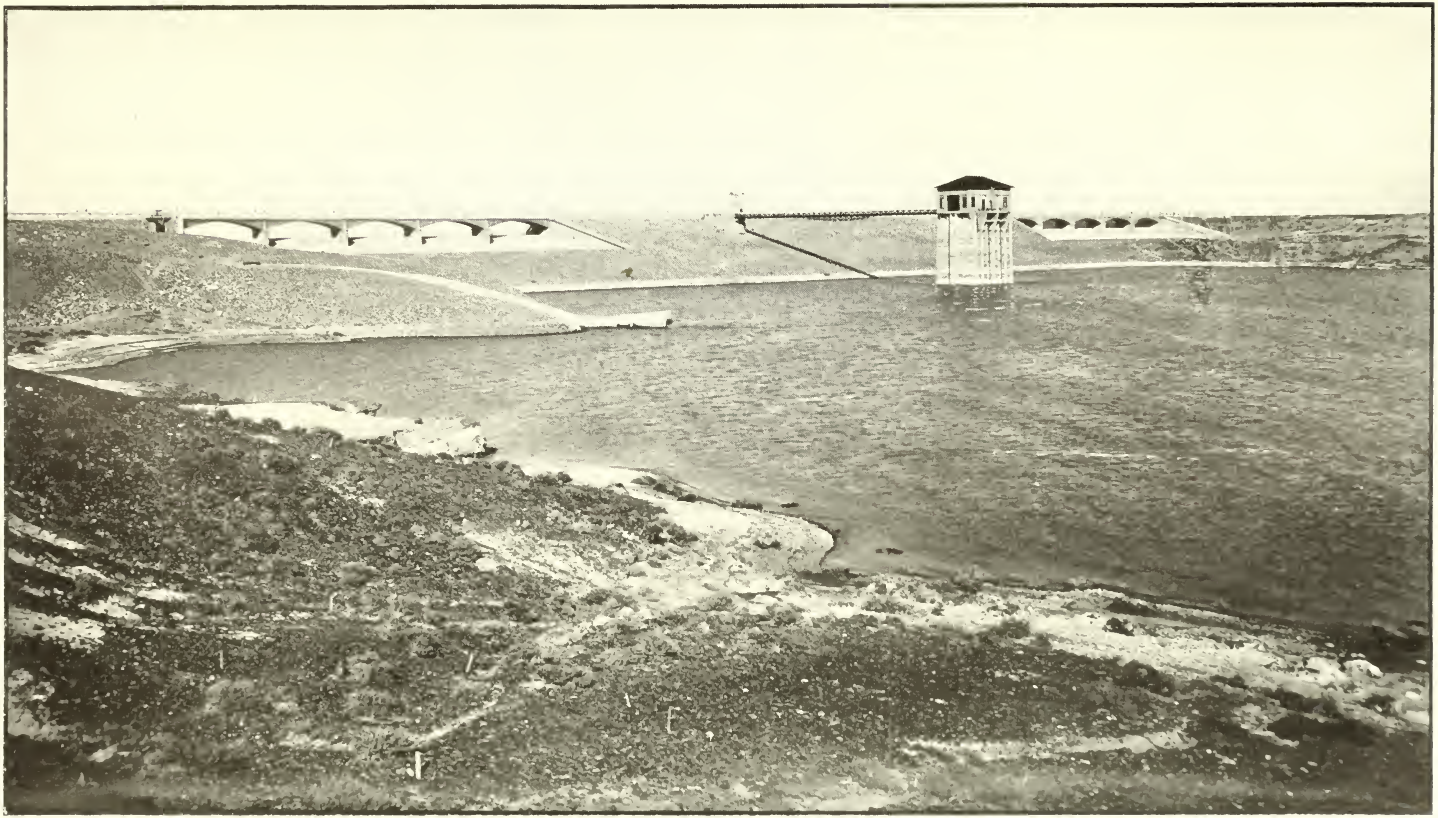


FIG. 42.—Water-surface elevations, Lahontan Reservoir.

Dam.—The dam consists of a gravel and earth fill section, flanked on the south end by a low dike. A concrete spillway is provided at each end of the dam. The maximum height of the dam is 129 feet, and the crest length, including the spillways, is 1,400 feet. The dike has a crest length of 4,000 feet and an average height of about 5 feet. The spillway is of a somewhat unusual type. Details of the dam and other features are shown on Plates 61 to 69,[1] inclusive.

[1] Record drawing series.



SPILLWAY AND OUTLET WORKS, LAHONTAN DAM.

Construction work on the dam was started in 1911, and the outlet gates were put into service in 1914.

OUTLET STRUCTURE.

The outflow of stored water is controlled by two cylinder gates located in a tower near the upstream toe of the dam. The tower is a rectangular concrete structure containing two cylindrical shafts each 14 feet in diameter. The cylinder gates are of the hooded type and operate in a vertical position in the bottom of the shafts. The flow from each gate is deflected to a horizontal direction by a gooseneck connecting the gate to a 9-foot horseshoe outlet tunnel. Flow into the gate shafts is controlled by two sets of slide gates. The two outlet units are entirely separate throughout. The tower is founded on mudstone and tough clay. Access to the tower is afforded by a suspension footbridge of 220-foot span connecting with the crest of the dam.

SLIDE GATES AND HOISTS.

Each gate shaft is fed by two sets of cast-iron slide gates located at different elevations. Each upper set consists of three 3 by 8 foot cast-iron gates to each shaft, with sills at elevation 4,126 located on the downstream side of the gate tower and operating under a maximum head of 52 feet on the sills. Each lower set consists of three 3 by 8 foot gates, with sills at elevation 4,070 located on the upstream side of the gate tower. The lower gates are intended to be put into operation when the head on the upper gates becomes too small to maintain the required discharge. This requires a maximum operating head of about 65 feet. In addition to the gates already described each outlet unit is provided with one 3 by 3 foot sluice gate, which discharges directly into the gooseneck below the cylinder gate. These sluice gates are for use only in case the reservoir is to be completely drained and have been operated only twice since 1914. All gates are protected by trash racks and operated by hydraulic hoists located at the top of the tower. Oil under pressure is supplied to the hoists by a direct-connected motor-driven triplex pump located on the floor of the gate house. Details of slide gates and hoists are shown on Plate 67 of the record drawings.

These gates have given no trouble in operation. They were not originally intended for operation at partial openings, the cylinder gates being expected to afford complete control of the flow. Certain difficulties with the cylinder gates, to be described later, made it desirable, however, to use the slide gates at partial openings to reduce the head on the cylinder gates. No difficulty resulted from such operation.

CYLINDER GATES AND HOISTS.

The two 8-foot 6-inch diameter cylinder gates located in the bottom of the circular shafts in the gate tower are the controlling units of the outlet. The gates are of the hooded type, the stems passing through stuffing boxes in the tops of the hoods. Each gate is provided with one stem operated by a hydraulic hoist at the top of the tower. Oil for operating the hoists is supplied from the same pumping equipment used for the slide-gate hoists. The gate cylinders and the hood are of cast iron, the details being as shown on Plate 67 of the record drawings.

OPERATION AND REPAIRS.

The cylinder gates have been operated since their installation in 1914 under heads up to 92 feet. Three sources of trouble developed during the first year's operation, as follows:

(*a*) Vacuum in the valve domes caused surges in the outlet tubes and violent upheaval of the valves. The valve domes were not originally air vented.

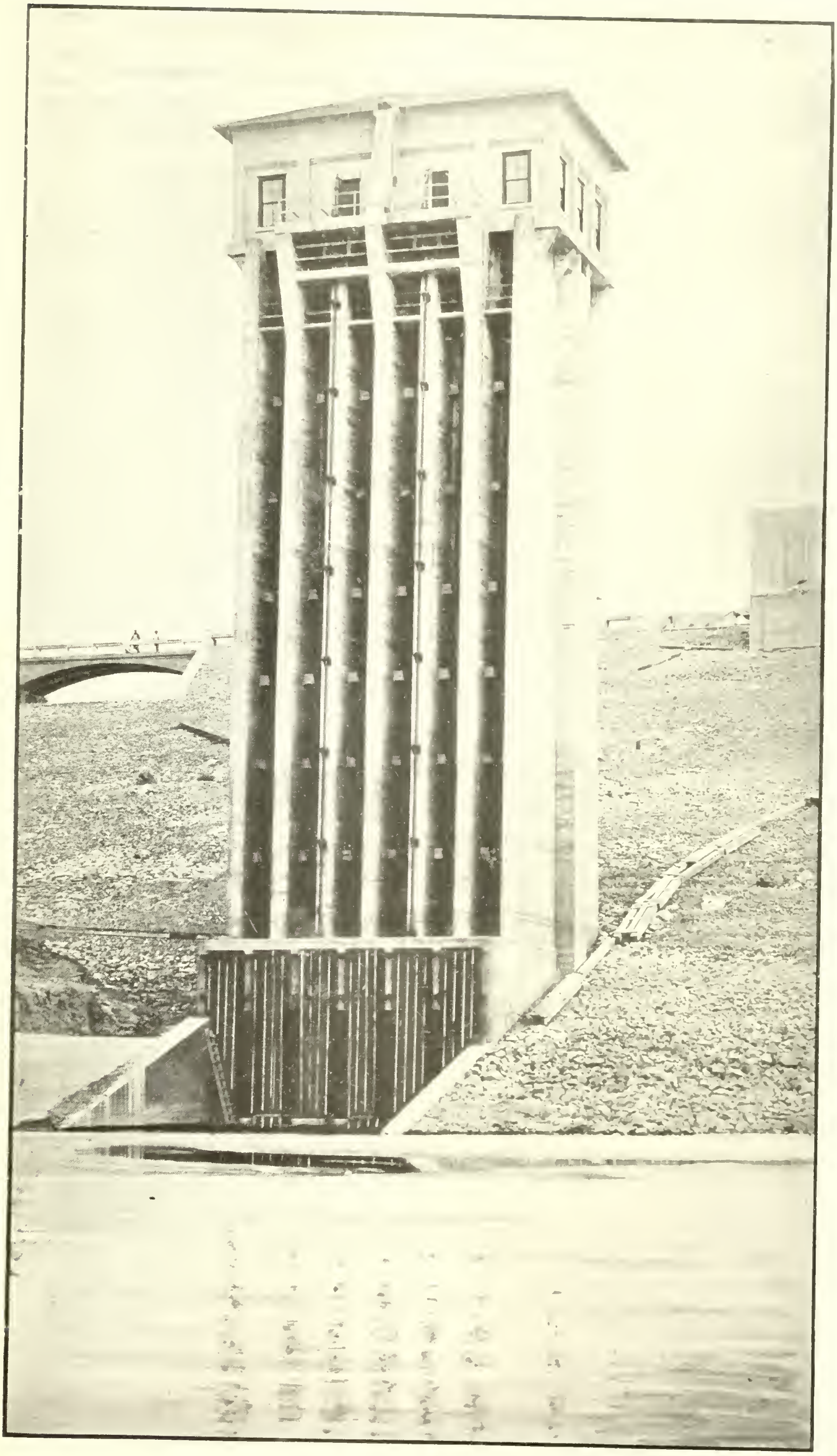
(*b*) The valves tended to rotate, which resulted in the destruction of the guides on the valve and the valve casing.

(*c*) The gates pounded directly against the valve case legs, causing the guide strips to wear out and break at points of impact and breaking the lower webs of the gate in numerous places.

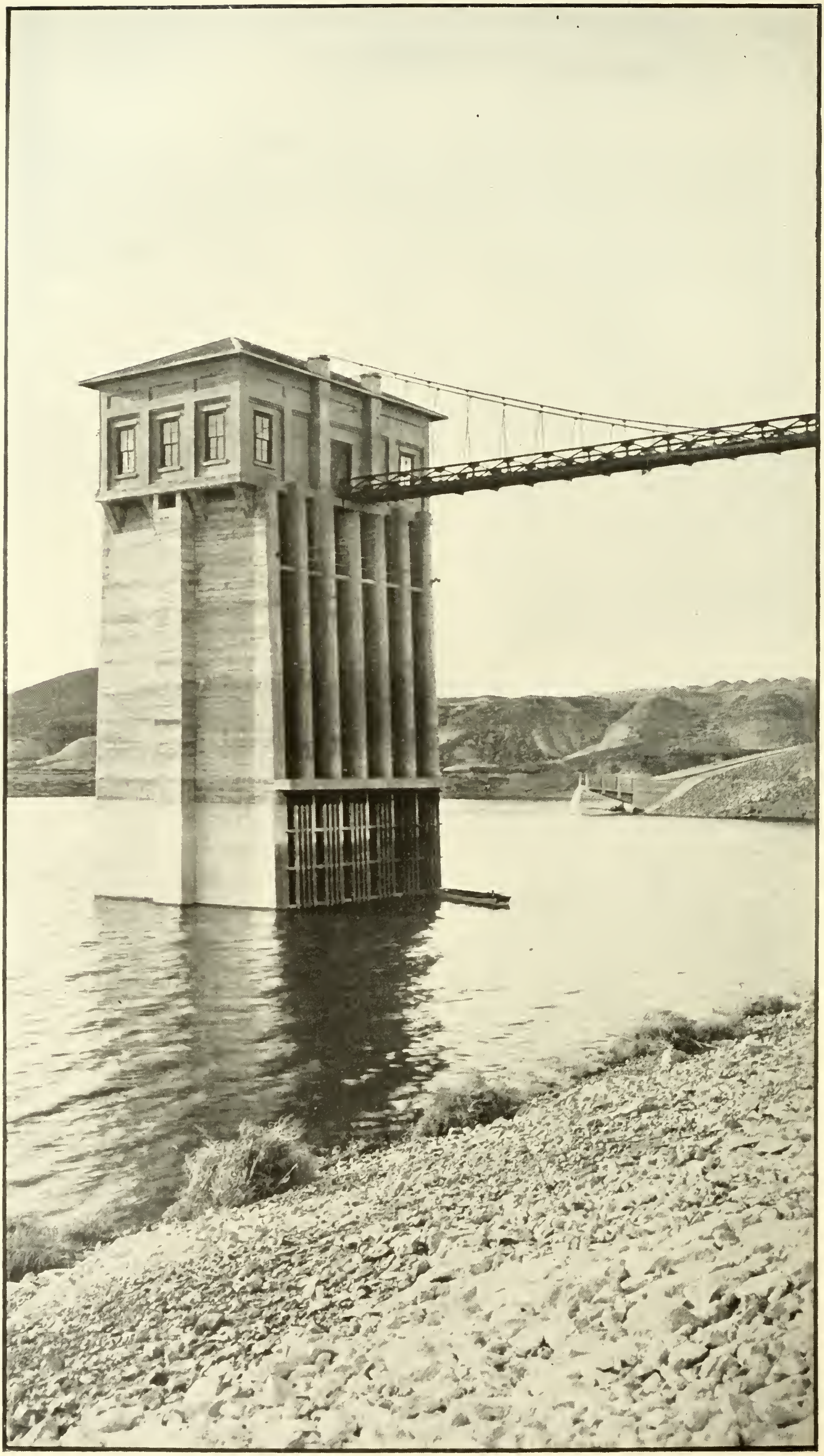
The vacuum in the dome was relieved by a 12-inch steel pipe carried up above the high-water level, and attempts were made to resist the pounding and rotating action by the installation of stronger guides. After several trials it became evident, however, that strengthening of the guides alone would not overcome troubles (*b*) and (*c*). The original bronze guides had a life of about two months, and heavy steel guides tried later lasted about six months.

On October 10, 1917, a board of engineers[2] met at Hazen, Nev., to consider possible improvements to the Lahontan cylinder gates. They recommended repairs and alterations to the outlet works as shown on Plates 68 and 69.[3] Six radial concrete guide walls were provided in the tower outside of the valve to guide the water straight into the ports and stop the tendency of the gate to rotate. Semisteel guides filled with babbitt and bolted to the legs of the dome were provided to fit into grooves formed by heavy semisteel guide strips bolted to the gate cylinders near the bottom. Semisteel guides were also provided to fit over the six radial ribs of the gate casing. The proposed repairs were installed in the latter part of 1918, and

[2] D. C. Henny, J. T. Whistler, D. W. Cole, J. M. Gaylord, and J. L. Savage.
[3] Record drawing series.



GATE TOWER, LAHONTAN DAM.



GATE TOWER AND SUSPENSION BRIDGE, LAHONTAN DAM.

the valves have been operated with entire satisfaction since that date. In order to test the gates under as severe working conditions as possible, all the irrigation water used in 1919 was carried through the north gate and for 1920 through the south gate. During the 1921 season all the water was again carried through the north gate. Both gates are entirely intact and in the same condition as when the repairs were completed in 1918. The heads to which the outlet has been subjected since its installation are shown in Figure 42.

MANUFACTURE AND COST OF GATES.

All designs for the original outlet works were prepared by L. W. Hall under the direction of D. W. Cole, project manager, and D. C. Henny and E. G. Hopson, supervising engineers. The slide gates, cylinder gates, and all operating mechanisms were furnished under specifications No. 223 by the Rosedale Foundry & Machine Co., of Pittsburgh, Pa., for the contract price of $31,832. The total cost of the original installations in place, including overhead, was $50,829.28, and the cost of subsequent repairs has amounted to $18,830.

Chapter XV.

MINATARE RESERVOIR.

GENERAL DESCRIPTION.

Reservoir—Lake Minatare, or Reservoir No. 3, is one of the supplemental reservoirs of the North Platte project. It is located about 8 miles north of Minatare, Nebr., and its function is to store water for the project lands east of that point. It has available storage capacity of 60,766 acre-feet.

Dam.—The dam is of the earth and gravel type, the upstream portion being of earth and the downstream portion of gravel. Principal dimensions are as follows: Height, 63 feet; top width, 20 feet; side slopes, 2½ to 1 and 2 to 1; crest length, 3,700 feet; spillway length, 100 feet; spillway elevation, 4,125. Construction of the dam was begun in June, 1912, and completed in June, 1915. Water was first stored in the lake in the fall of 1914. The general plan of the dam and reservoir is shown on Plate 70 of the record drawings. Figure 43 shows the variation of water elevations in the reservoir and indicates the conditions under which the outlets have been operated.

FIG. 43.—Water-surface elevations, Minatare Reservoir.

Outlets.—The design of the outlet works for this dam was considered May 2, 1912, by a board of engineers.[1] The Ensign balanced valve was considered, but owing to difficulties experienced in the regulation of the valves at the Belle Fourche Dam the board recommended a different installation, including pipes through the dam with needle valves at the lower end. The valves installed for regulating the flow are listed in the following table:

[1] A. P. Davis, D. C. Henny, R. F. Walter, and Andrew Weiss.

Outlets, Minatare Dam.

Type.	Number.	Size.	Maximum head above center line.
		Inches.	*Feet.*
Butterfly valves	2	48	48
Needle valves	4	24	48

Design of outlets.—The designs of the outlet works were prepared under the direction of O. H. Ensign. The outlet conduit is located just east of the low point of the valley and is built wholly on brule clay. It consists of a reinforced concrete conduit 12 feet 10 inches in horizontal diameter and 11 feet in vertical diameter, and carries two lines of 48-inch steel lock-bar pipe. Each line of pipe is closed at the upper end by a 48-inch butterfly valve and at the lower end by needle valves, which control the discharge. Near the lower end each 48-inch pipe turns through a right angle, and immediately below the elbow on each pipe two 24-inch needle valves are installed, discharging in a direction parallel to the main discharge pipes.

A reinforced concrete deflector is installed 16 feet in front of each needle valve. This deflector is designed to receive the discharge from the nozzle and turn it through an angle of 180° directly back upon itself, thus breaking up the jet and destroying the velocity of the water.

BUTTERFLY GATES.

The butterfly gates were contracted to the S. Morgan Smith Co., of York, Pa., on April 21, 1913, which company designed and manufactured the valves under general specifications prepared by the Bureau of Reclamation. Each valve has a nominal diameter of 48 inches, a length of 15 inches, and is hand-operated by means of a worm gear. (See Plate 71 of the record drawings.) The weight of each valve is approximately 6,000 pounds and the contract price $555 f. o. b. York, Pa.

LOCK-BAR PIPE.

Under contract 528, dated January 24, 1914, the East Jersey Pipe Co. furnished 536 feet of lock-bar pipe and two expansion joints; net weight, 127,675 pounds; price, $4,288 f. o. b. Paterson, N. J. The pipe is 48 inches in internal diameter, and the shell thickness is $\frac{5}{16}$ inch. Nickel-steel bolts, having an ultimate strength of 80,000 pounds per square inch, are used in all flanges.

NEEDLE VALVES.

The needle valves were manufactured by the Pittsburgh Valve, Foundry & Construction Co. under specifications No. 248, contract

522, dated December 17, 1913, from designs furnished by the Bureau of Reclamation. The contract price of four 24-inch valves, two 48-inch elbows, and two 48-inch bumped heads was $4,528 f. o. b. Pittsburgh, Pa.; weight, 61,000 pounds.

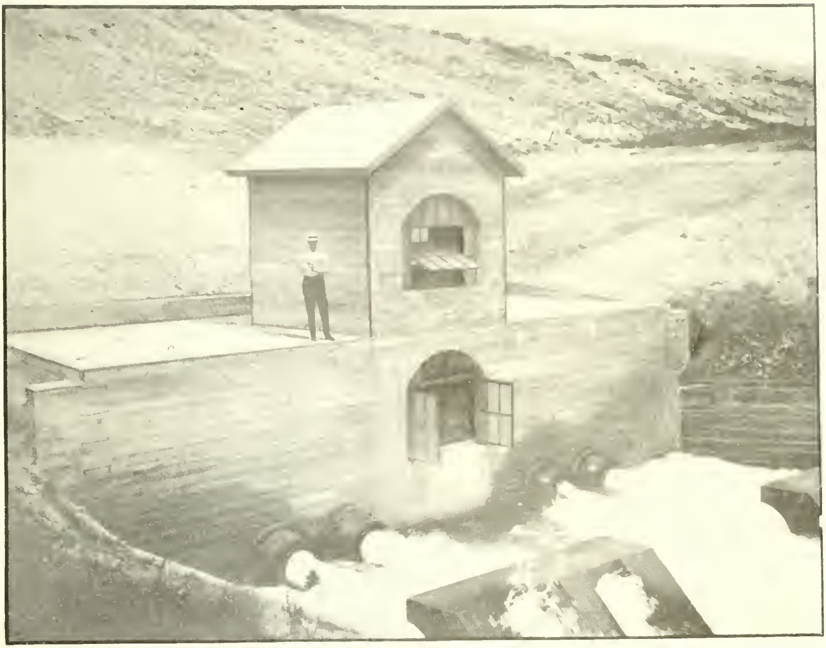
Each of these valves (shown in assembly on Plate 72 of the record drawings) is in the form of a T, the nozzle being at right angles to the run of the pipe. The operating stem extends across the pipe and passes through a stuffing box to a hand-wheel operating stand. At the side of the T nearest the operating stand is a bronze-lined chamber in which a balancing piston is placed. A 1-inch valve provides a means of relieving the pressure behind the balancing piston and thus removes a portion of the load from the nut and operating gear. The valve proper is of cast iron and is provided with renewable manganese-bronze seats. A three-arm spider supports a bronze-bushed guide just behind the needle, and the steel stem is bronze-covered where it passes through this guide. The operating mechanism consists of a 30-inch hand wheel with a bronze nut and plain bearings.

In the design of this valve efficiency of discharge was sacrificed to a considerable extent in securing simplicity and ease of operation. The shape of the needle and tip is such that the jet is not smooth, and the velocity through the valve is irregular, especially at partial opening. The arrangement of the outlet involves several abrupt changes in direction of flow, and the stem and guide spider no doubt causes eddies and loss of head.

The pipe and valves were installed in the fall of 1914 by Bartlett & Kling, general contractors for the dam, on a basis of cost plus 15 per cent. No especial difficulty was encountered, and the work was accomplished at a reasonable price.

Operation satisfactory.—The valves were operated for the first time October 24, 1914, under a head of about 22 feet and have been operated as required by irrigation demands under heads up to 34 feet since that time. The outflow can be adjusted accurately to any desired amount, and hand operation has proven entirely satisfactory. The valves have shown no wear, but the concrete jet deflectors have been worn to such an extent that the steel is exposed in places. The butterfly valves are located in a somewhat inaccessible position and designs were prepared for a distant mechanical operation. This device, however, has not been installed.

In July, 1916, a capacity test was made, all valves being opened wide. The lake elevation at that time was 4,095.5 and the head at the center of the valves 19.5 feet. The total discharge under those conditions was 300 second-feet. This gives an over-all discharge efficiency of 68 per cent based on the nozzle area of 3.14 square feet. No measurements of actual head at the valves were made during



A, GATEHOUSE AND NEEDLE VALVES, MINATARE DAM.

B, TESTING 24-INCH NEEDLE VALVES, MINATARE DAM.

the test. The jet contracts slightly after leaving the tip, the coefficient of contraction being estimated at 86 per cent. Various estimates of the losses through the outlets have been made, but the data available are insufficient to support definite conclusions as to the efficiency of the valve alone. The efficiency could undoubtedly be improved by modifying the shape of the needle and tip to produce smoother flow lines and avoid the changes in velocity along the path of the water through the valve. The fact that the point of closure comes at a point of convex curvature of the needle tends to produce a rough jet and reduce the efficiency of the valve. As an operating device the valves have proved highly satisfactory. Figure 43, giving the history of the reservoir, shows the head under which the valves have been operated.

Minor mechanical troubles.—In 1920 the worm sector of one of the butterfly gates failed and was replaced. The new part also failed soon after installation, and this part was then redesigned to give greater strength. In 1920 one of the needles broke away from the stem by shearing the threads of the fastening, and examination showed that the needle was cracked, probably by freezing of water which leaked into the hollow casting. To remedy these defects, new solid stems with stronger fastenings for the needle and new needles with small drain holes for entrapped water were purchased.

TABLE 18.—*Cost of outlet works, Minatare Dam.*

Cast-iron pipe	$559.13	
Freight	173.24	
Hauling and installing	196.90	
		$909.27
Two 48-inch butterfly gates:		
Initial cost	1,110.00	
Freight	83.42	
Hauling	27.94	
Installing	58.72	
		1,280.08
48-inch lock-bar steel pipe:		
Initial cost	4,288.00	
Freight	1,099.94	
Hauling, 8 miles	355.90	
Installing	578.55	
		6,322.39
Four 24-inch needle valves:		
Initial cost	4,528.00	
Freight	444.00	
Hauling	185.53	
Installing	204.67	
		5,362.20
Total		13,873.94

These costs do not include inspection, engineering, general expense, nor concrete or excavation.

The last two items included in contract for construction of dam.

Chapter XVI.

JACKSON LAKE RESERVOIR.

GENERAL DESCRIPTON.

The Jackson Lake Dam is located at Moran, in the northwestern corner of Wyoming, on the south fork of the Snake River. It is about 69 miles from Ashton, Idaho, and 48 miles from Victor, Idaho, both on the Oregon Short Line Railway. During 1905, 1906, and 1907 a temporary timber-framed dam was constructed at this site, providing about 200,000 acre-feet storage for use on the Minidoka project. During 1910–11 a new dam was constructed to provide a storage of 380,000 acre-feet. To satisfy demands for water from the Carey Act projects located in southern Idaho, in addition to the requirements of the Minidoka project, the dam was enlarged during the years 1913 to 1916, inclusive, to provide a storage capacity of 789,000 acre-feet. The present dam (1922) is shown on Plate 73 of the record drawings. It consists of a concrete overflow section across the river channel with dikes of earth and of earth and rock fill on the two sides. Flood discharge is controlled by 19 radial gates on the crest of the overflow section, and storage below the permanent crest level is discharged through twenty 8 feet by 6 feet 6 inches cast-iron slide gates.

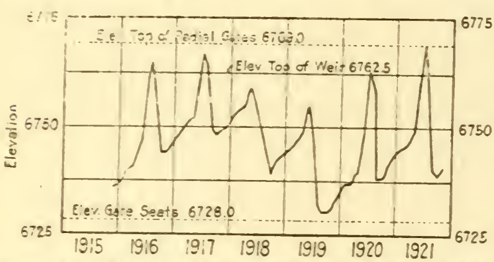
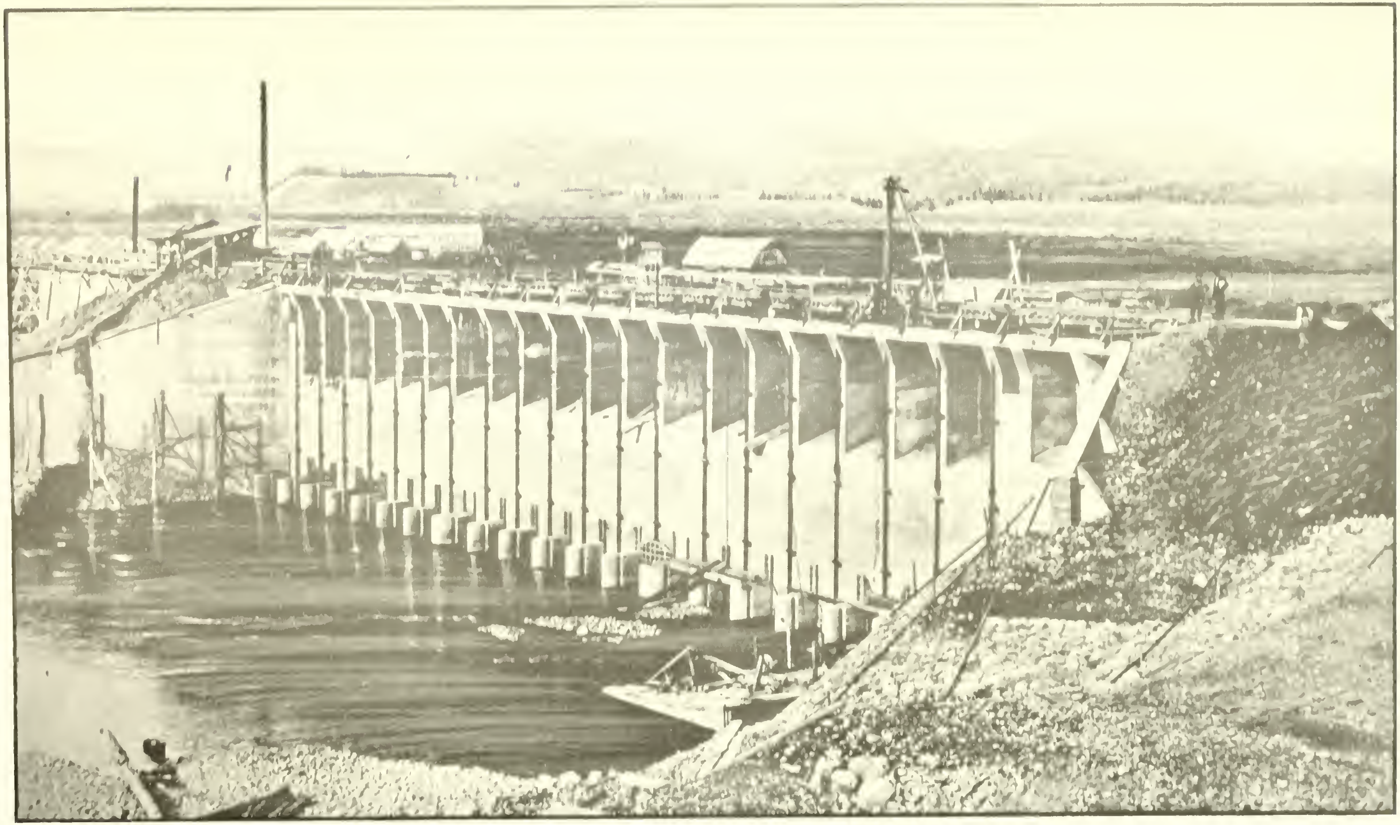


FIG. 44.—Water-surface elevations, Jackson Lake Reservoir.

SLIDE GATES.

The slide gates are mounted upon the upstream face of the concrete section of the dam and discharge through straight tunnels through the dam. A 6-inch air pipe is provided just below the gate. Each gate is provided with a geared hoist equipped for either hand or power operation. Power may be applied to any hoists by

PLATE XXX.



UPSTREAM VIEW OF SLIDE GATES JACKSON LAKE DAM

means of a roller chain driven from a portable Ford engine mounted on a car.

Designs for the sluice gates were prepared in the office of Supervising Engineer F. E. Weymouth, and the lifting devices were designed in the office of Consulting Engineer A. J. Wiley. Details of gates and the lifting devices are shown on Plate 74 of the record drawings. The heads to which the gates have been subjected are shown on Figure 44. Vibration is noticeable when the gates on being opened or closed reach a height of 4 feet above the gate sills. No other operating trouble has been experienced, except that on two occasions bolts or stones have gotten behind the leaf of a gate when in raised position and have caused the upper bronze seat to be broken upon lowering the gate. The gates complete, except lifting devices, were purchased from the Steacy-Schmidt Manufacturing Co. under contract No. 497. The American Hoist & Derrick Co. furnished the lifting devices. The total cost of the 20 gates complete in place was $33,650.

CHAPTER XVII.

SHERBURNE LAKES RESERVOIR.

GENERAL DESCRIPTION.

Reservoir.—The Sherburne Lakes Reservoir is located on Swift Current Creek in the Blackfeet Indian Reservation, Mont., about 13 miles south of the Canadian boundary and 45 miles northwest of Browning, the nearest railway station. Lower Sherburne Lake, a natural body of water, is utilized for the reservoir. The impounded water is released into the old creek channel and diverted farther down for use on the Milk River project. The total storage capacity with the water at the top of the proposed movable spillway gates is 75,000 acre-feet. A maximum discharge of 1,000 second-feet is required for irrigation.

Dam and spillway.—The dam, as shown on Plate 75 of the record drawings, consists of an earth embankment having a core wall of screened gravel for its full height. The dam is 1,070 feet long, 87 feet high, and contains approximately 250,000 cubic yards of material. The spillway, which is located at the north abutment, is to be provided with movable gates to hold the water surface up to elevation 4,793. These gates have not yet been installed (1922). The original design called for a concrete chute connecting the spillway with the creek channel below the dam, but earth movements, induced by the excavation of the spillway channel, have prevented the construction of the permanent chute. A temporary wooden flume carries the spillway flow at the present time. The spillway is designed for a maximum discharge of 8,000 second-feet with water surface at elevation 4,793, which provides a freeboard of 10 feet, the outlet works being counted upon for an additional flood discharge of 2,000 second-feet. Construction work was started in July, 1915, and completed in March, 1918.

BOARD REPORTS.

On April 28, 1915, a board of engineers[1] met at Portland, Oreg., to consider the type of outlet to be installed at Sherburne Lakes. On account of the similarity of conditions at Sherburne Lakes to those at Keechelus Dam on the Yakima project, it was recommended that the design be prepared in accordance with recommendations of a previous board for the Keechelus outlet. This board met at Yakima,

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[1] A. J. Wiley, D. C. Henny, C. H. Swigart, E. G. Hopson, and F. Teichman.

Washington, on April 24, 1915, the personnel being the same as above except for the absence of Mr. Hopson. The recommendations were essentially as follows:

(*a*) The outlet should discharge 700 second-feet for irrigation under a head not exceeding 7 feet and 2,000 second-feet at full reservoir depth to supplement the spillway.

(*b*) Rock foundations are not available, and the material on which the outlet works must be founded is easily eroded; therefore velocities in the conduit exceeding 10 or 12 feet per second should be avoided.

(*c*) A gate tower should be provided for the installation of trash bars.

(*d*) With low velocities in the outlet conduit, energy dissipation must be had in the gate tower itself, either by permitting the water to drop in the gate tower or by providing for submerged discharge, in both cases causing a large part of the energy to be dissipated by radial inward impact of the water in the center of the tower.

(*e*) A heavy cast-iron cylindrical gate affords the most practicable and economic means of controlling the outflow.

(*f*) Two such gates are desirable, one about halfway up the tower and one depressed below the outlet tunnel.

(*g*) The tendency of water inside the inner tower to rotate should be prevented by radial diaphragms.

(*h*) A cylinder gate was considered for use as an emergency gate, but the large size, difficulty in securing tight closure, and complexity of forces acting upon such a gate caused the recommendation of a large number of small gates of the ordinary type for emergency control.

OUTLET.

Designs for the outlet were prepared in the months of June and July, 1915, under the direction of F. Teichman. The outlet as designed and constructed consists of a double-wall circular concrete gate tower, connected on the upstream side with a forebay containing a trash-rack structure and on the downstream side with a double-barreled outlet conduit. The general arrangement is shown on Plates 75, 76, and 77.[2] Flow from the forebay into the outer chamber of the tower is controlled by six 3 by 7 foot hydraulically operated slide gates. These gates are designed for use as guard gates only and are normally operated fully open. Regulation is effected by two cylinder gates set at different elevations, which control the flow through passages between the outer and inner chambers. The maximum head on the sill of the slide gates is 73 feet.

[2] Record drawing series.

If the lower cylinder gate should fail with the reservoir full, it might be necessary to operate these gates under full head, but ordinarily the operating head can be reduced by admitting water to the tower through a small by-pass gate located at the top of the outside tower. The upper cylinder gate operates under a maximum head of 28 feet on the sill, and the maximum operating head for the lower gate need not exceed 54 feet. The metal work for the outlet was purchased under contract as listed in Table 19. Costs of the principal items of the outlets are shown in Table 20.

SLIDE GATES AND OPERATING MECHANISM.

The slide gates are of cast iron, as shown on Plate 78.[3] The gates are operated through long stems by hydraulic cylinders located at the top of the gate tower. The cylinders are designed for a working pressure of 900 pounds per square inch. A 3 by 10 inch vertical triplex plunger pump, with 2½-inch suction and 2-inch discharge, driven by a 20-horsepower, 2-cylinder, 4-cycle gasoline engine, is provided to supply oil under pressure to the hydraulic cylinders. A small hand-operated pump is also provided for emergency use.

CYLINDER GATES AND OPERATING MECHANISM.

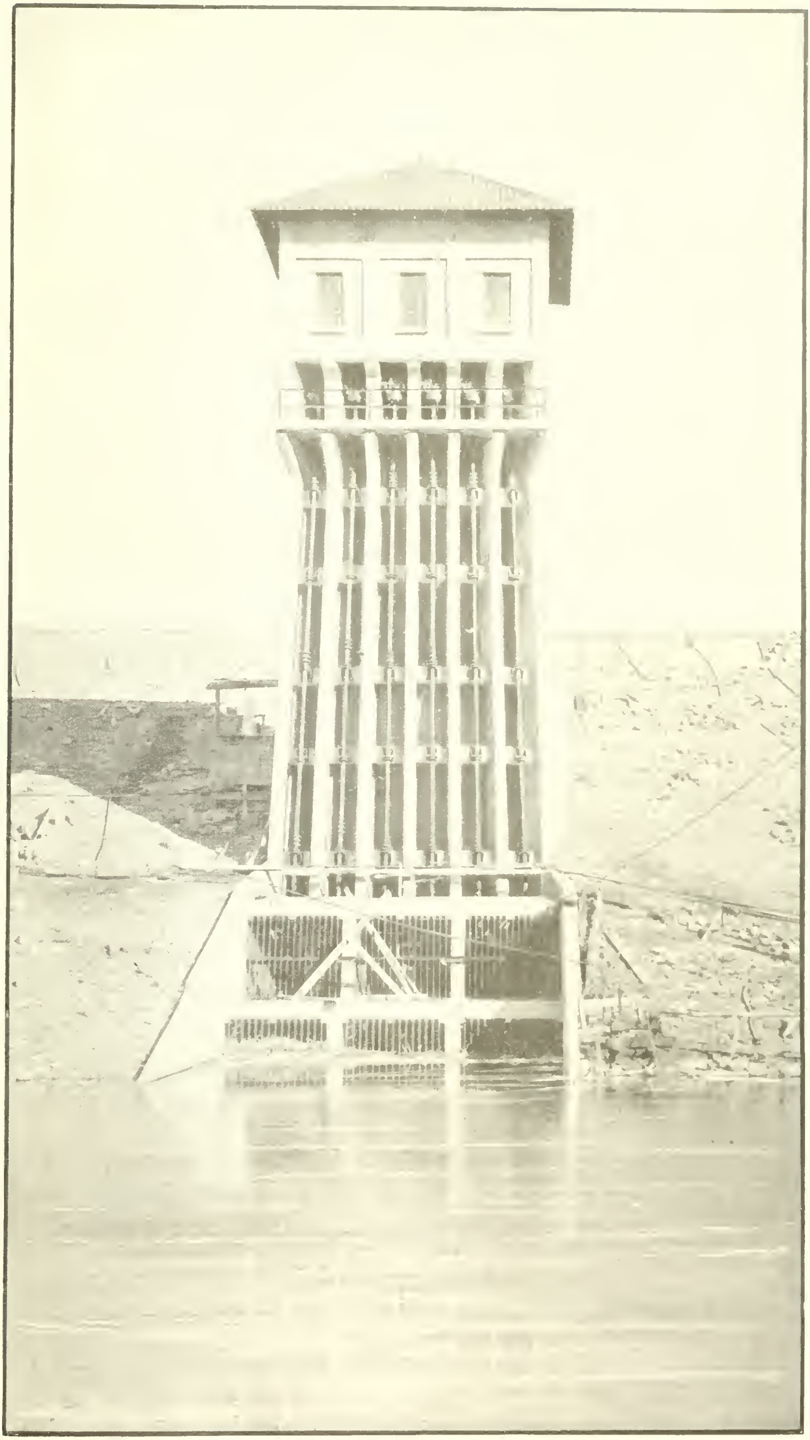
Each cylinder gate consists of a heavy cast-iron cylinder moving in a cast-iron guide frame, the details of which are shown on Plates 79 and 80.[3] Each gate is operated by means of three long stems and three interlocked screw hoists located on the operating floor at the top of the tower. Plate 79[3] shows the gates as originally designed and installed. After the gates were placed in operation it was found that gravel and other débris collected in the space back of the gate to such an extent as to interfere with its operation. The gates were altered as shown in Plate 81[3] to overcime this difficulty.

RESULTS OF OPERATION.

No attempt was made to store water in 1918. An effort was made to maintain by means of the lower cylinder gate a lake level of 4,735, causing a head of about 15 feet above the floor of the outlet tunnel, to provide water transportation for sand and gravel. It was found at this time that the gate could not be lowered within 6 inches of the closed position on account of gravel which had collected in the pocket back of the cylinder. The gate tower was unwatered during the winter of 1918–19 and the obstructing gravel removed. The sump below the gate was found to be half full of gravel.

During June, July, and August, 1919, 33,000 acre-feet of water was stored, producing a maximum head on the cylinder gate of

[3] Record drawing series.



GATE TOWER, SHERBURNE LAKES DAM.

approximately 52 feet. Trouble was again experienced in the operation of the cylinder gate, due to the collection of gravel and other débris in space back of the gate. During this season it was necessary to use the slide gates for regulation when the required discharge was 400 second-feet or less. The accumulation of gravel behind the cylinder of the lower gate increased during the operating season of 1920 and 1921 to such an extent that the gate could not be brought to within 2 feet of the closed position. The tower was unwatered in the fall of 1921 and the obstructing material removed. A large percentage of the material was found to be water-soaked twigs and chips mixed with fine gravel. Very little coarse gravel was found. To eliminate this trouble the recess in the frame has been filled with concrete and an oak sealing strip has been bolted to the top of the gate to keep out the débris. A true surface on the concrete was secured by the use of a cast-iron form made especially for the job. It is expected that these repairs will be effective.

The slide gates have at all times worked satisfactorily under heads up to 40 feet, requiring from 75 to 100 pounds per square inch maximum pressure in the hoisting cylinders. Operation has in general been accomplished by the hand pump. After each operating season the trash-rack structure was found matted with roots, brush, etc., to such extent as to materially reduce the waterway area.

TABLE 19.—*Sherburne Lakes outlet, purchase of materials.*

Description.	Contractor.	Address.	Specification No.
Slide gates:			
Gate structure, metal work	Hardie Tynes Manufacturing Co	Birmingham, Ala.	307
Stems, stem guides, and couplings.	Walker Manufacturing Co	Denver, Colo	3-D
Operating mechanism	Lakeside Bridge & Steel Co	Milwaukee, Wis	F-9
Pressure pumps	Rumsey Pump Co	Seneca Falls, N. Y.	F-10
Cylinder gates:			
Cylinder gates	Power & Mining Machinery Co	Cudahy, Wis	310
Bases and brackets for stem supports.	Walker Manufacturing Co	Denver, Colo	1-D
Gate stems	do	do	2-D
Operating mechanism	Vulcan Iron Works Co	do	F-7

TABLE 20.—*Cost of Sherburne Lakes outlet.*

Items.	Slide-gate structure.		Cylinder-gate structure.		Grillage structure.	
	Total.	Unit.	Total.	Unit.	Total.	Unit.
Weight (pounds) of metal including all operating mechanism	212,130		175,474		56,449	
Cost of metal	$10,992.32	$0.0518	$9,204.32	$0.0524	$1,298.33	$0.0230
Railroad freight to Browning, Mont	1,441.98	.0068	1,152.46	.0066	385.09	.0068
Hauling, Browning to Sherburne, 45 miles	1,540.98	.0073	1,516.05	.0086	405.14	.0072
Erection:						
Labor	4,968.00	.0234	4,636.80	.0264	603.13	.0107
Supplies	1,094.40	.0052	1,309.44	.0075	86.00	.0015
Minor miscellaneous expense including painting, plant, and equipment	838.08	.0039	852.48	.0049	124.32	.0022
Total	20,875.76	.0984	18,671.55	.1064	2,902.01	.0514

Chapter XVIII.

McDONALD LAKE RESERVOIR.

GENERAL DESCRIPTION.

The McDonald Lake Reservoir is located on Post Creek about 12 miles northeast of St. Ignatius, Mont. McDonald Lake, a natural body of water, is included within the area of the reservoir. The storage capacity at the present time is 8,200 acre-feet, which may be increased at some future time to 10,800 acre-feet by a 12-foot addition to the dam. The present maximum height of the dam is 60 feet. A concrete spillway located near the center of the dam is controlled by flashboards. The flashboards are to be replaced at some future time by five 20 by 5 foot radial gates. A cylinder gate outlet tower is located near the left bank of the original creek channel. In order to make the storage of the natural lake available, the outlet tunnel was set in a cut considerably below the level of the creek bed. The general arrangement and details of the dam and other features are shown on Plates 82 to 87,[1] inclusive.

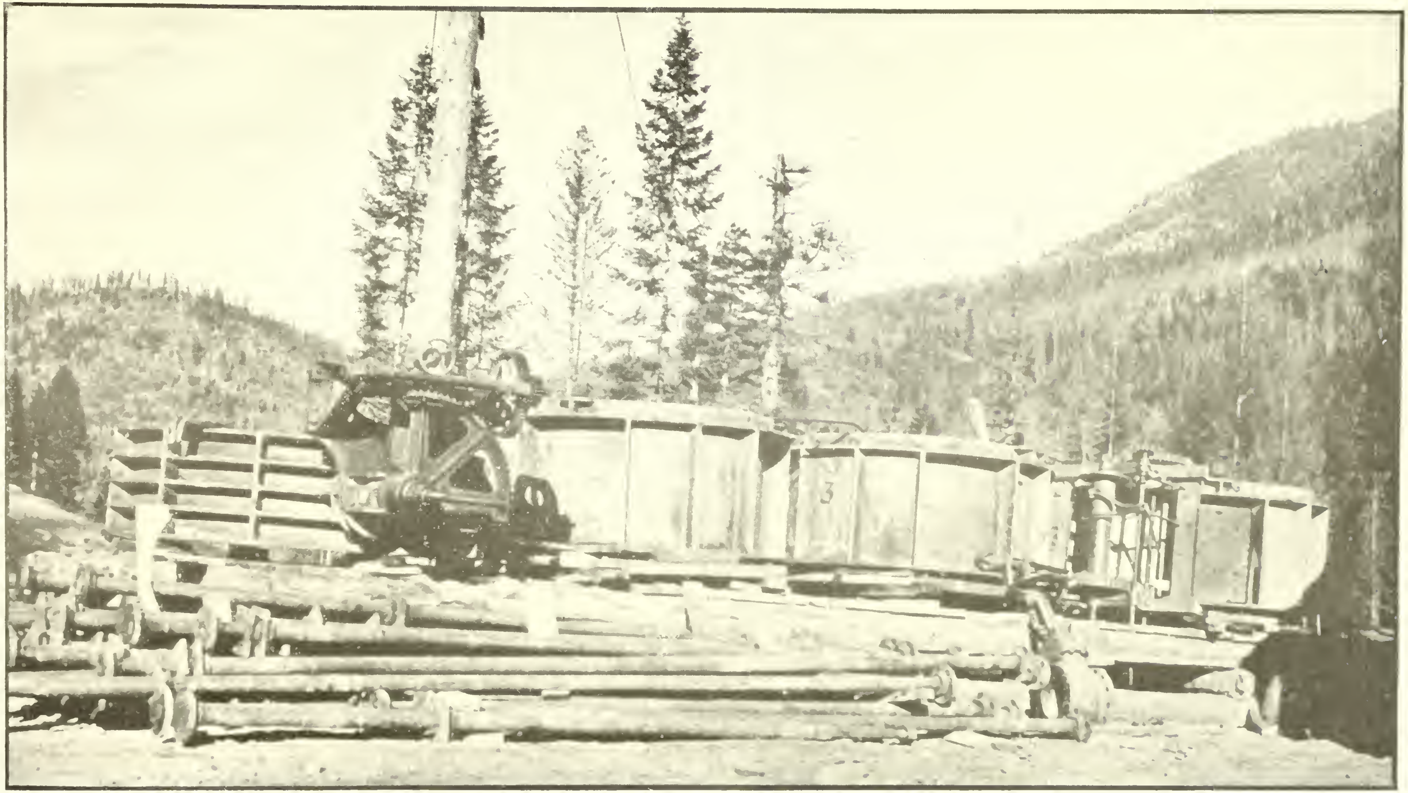
OUTLET.

The outlet tower, containing two cylinder gates, is located in the body of the dam. The tower consists of two concentric concrete cylinders, both of which extend to the crest of the dam. The two cylinder gates which control the flow are inside the smaller cylinder, with sills at elevations 3,544.4 and 3,568.4. Water enters the outside cylinder through a 5 by 6 foot egg-shaped concrete lined tunnel controlled by a 6-foot 3-inch diameter butterfly gate. The two cylinder gates control the passages between the inner and outer chambers, and the inner tower is connected by a gooseneck with the outlet tunnel.

BUTTERFLY GATE AND OPERATING MECHANISM.

The 6-foot 3-inch diameter cast-iron butterfly gate is installed just upstream from the entrance to the outside chamber of the gate tower. This gate is intended for emergency use only. The hand-power worm and sector operating mechanism is located in a chamber

[1] Record drawing series.



BUTTERFLY AND CYLINDER GATES, McDONALD LAKE DAM.

above the intake tunnel and is reached through a well on the side of the outlet tower. The maximum head on this gate with the present height of dam is 51 feet, and when the dam is enlarged the maximum head will reach 63 feet. The details of the gate and the operating machinery are shown on Plate 86 of the record drawings. A by-pass valve is provided by which the operating pressure on the gate can be reduced. This gate has operated satisfactorily, except that small twigs and trash catching under the leaf prevent absolutely tight closure.

CYLINDER GATES AND HOISTS.

Details and arrangement of the cylinder gates and hoisting mechanism are shown on Plates 82, 83, 84, and 87.[2] Each of the two cylinder gates closes four 2 feet by 2 feet 6 inch openings in the walls of the inner concrete cylinder. The gate cylinders are of cast iron provided with bronze seats top and bottom, which close against similar seats on the gate frame. The gate is guided by three cast-iron lugs bolted onto the top of the cylinder and fitting into cast-iron channel guides attached to the top of the frame and supported against the wall of the tower. Each gate is provided with two stems extending to the top of the tower where the hand-operated geared gate hoists are located. The hoists for the two stems are connected by a cross shaft to insure simultaneous operation. The cylinder gates were installed in 1917, and in 1918, 1919, and 1920 the lower gate was operated under heads not exceeding 18 feet. In 1921, after the completion of the dam and spillway, the storage was increased and the lower gate was operated for a short time under a head of 48 feet. No trouble was experienced in operation, and subsequent inspection showed no wearing of the concrete except a slight scouring where joints in the forms occurred and the surface was not well made. The entrance to the cylinder-gate openings, the gooseneck, and the chambers of the tower all appear to be in excellent condition. The upper gate has not been operated.

MANUFACTURE AND COSTS OF MATERIALS.

The butterfly gate, cylinder gates, and all operating machinery were furnished by the Vulcan Iron Works Co., of Denver, Colo., under specifications No. 355. The total cost of all equipment in place, exclusive of overhead, was $9,374.

[2] Record drawing series.

APPENDIX.

PARTIAL LIST OF ARTICLES IN TECHNICAL AND OTHER PERIODICALS ON THE BUREAU OF RECLAMATION

AND

LIST OF BOOKS ON IRRIGATION.

PARTIAL LIST OF ARTICLES IN TECHNICAL AND OTHER PERIODICALS ON THE BUREAU OF RECLAMATION.

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