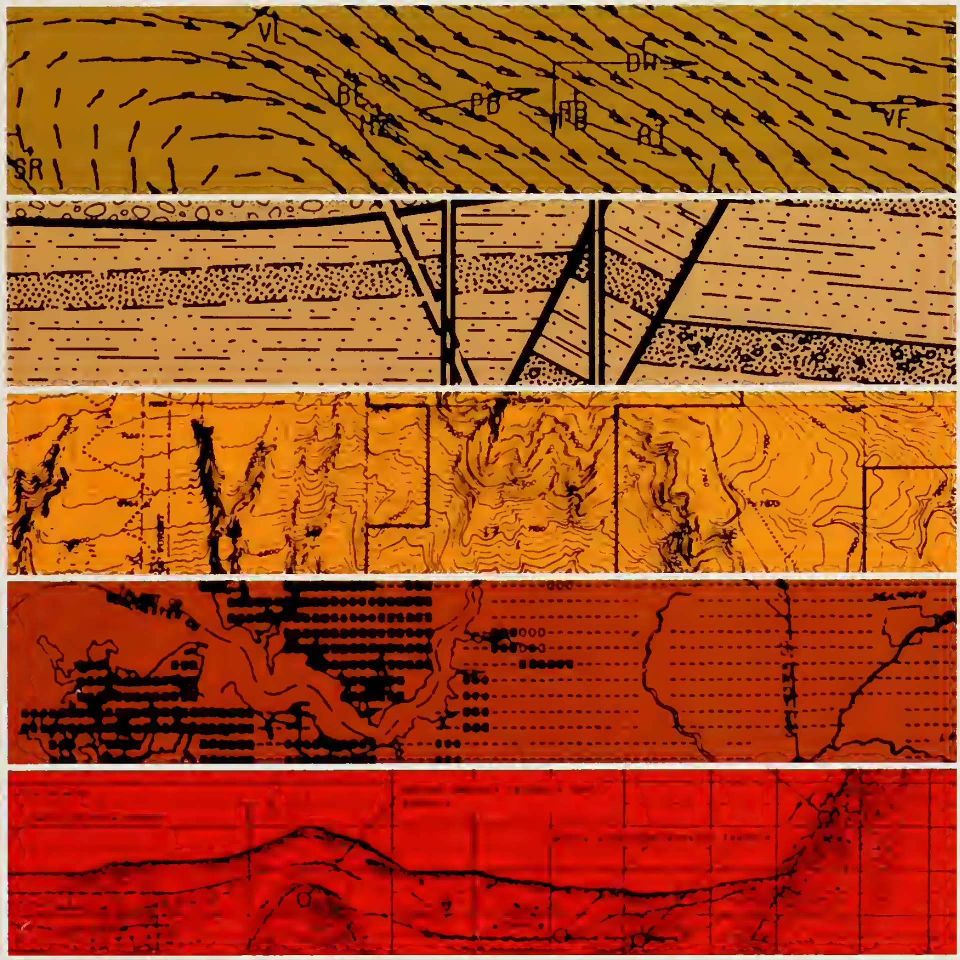

REPORT
GEOLOGIC HAZARD EVALUATION
ALCATRAZ ISLAND
GOLDEN GATE NATIONAL RECREATION AREA
FOR THE NATIONAL PARK SERVICE

Dames & Moore

REPORT
GEOLOGIC HAZARD EVALUATION
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OCTOBER 29, 1982

JOB NO. 2050-064-03

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Mr. Howard H. Chapman
Regional Director, Western Region
U.S. Department of the Interior
National Park Service
450 Golden Gate Ave., P.O. Box 36063
San Francisco, CA 94102

Attention: Division of Safety

Gentlemen:

Report
Geologic Hazard Evaluation
Alcatraz Island
Golden Gate National Recreation Area
For the National Park Service

INTRODUCTION

This report presents the results of our geologic hazard evaluation of recently unstable portions of Alcatraz Island. Two areas in particular were investigated:

1. The steep rock slope and retaining wall system adjacent to the Warden's Residence and Lighthouse, above the Parade Ground.

2. A portion of the West Road where undermining of the roadway has occurred.

These areas had been identified as hazardous in a study conducted in 1979*. Their locations are illustrated on Plate 1, Plot Plan.

---

*"Structural-Safety Hazard Study, Alcatraz Island, Golden Gate National Recreation Area"; Denver Service Center - National Park Service, United States Department of the Interior, and Royston Hanamoto Beck & Abey/GFDS Engineers, July 1, 1979

APPENDIX A

STEREOGRAPHIC ANALYSIS OF GEOLOGICAL DATA

DATA COLLECTION

The diversity of instruments used for measuring the orientations of joints and of techniques used in plotting these orientations, together with the differing backgrounds of geologists and engineers who are involved in joint mapping surveys, has resulted in a number of different methods of measuring, recording and plotting joint orientations.

Traditionally, geologists have specified joint orientations in terms of strike and dip. This method has the following advantages:

1. It is convenient for the presentation of a limited amount of data on a map.

2. It is the most widely used system of specifying orientations.

3. It is the most convenient way of specifying orientation data measured using the geologists traditional field tool, the Brunton compass.

However, this method also has certain disadvantages in that orientation measurements are made in two stages, one for the strike and one for the dip. Also, unless some arbitrary convention is adopted relating the direction of dip to the measured strike

direction, the general direction as well as the magnitude of the dip must be specified.

More recently, the growing use of data on geological discontinuities in an engineering context has led to an increasing trend in recording discontinuity data in terms of dip vector, defined by the dip and dip direction of the joint. This trend has been facilitated by the introduction of a new style of compass, in particular, the Clar (or Breithaupt) compass. Advantages of using this system for measuring and recording data are:

1. Both dip and dip direction are measured and read directly in a single operation. This greatly increases the speed of taking measurements and minimizes the risk of errors in measurements since no interpretation of direction by the geologist is required.

2. The joint orientation is specified uniquely by purely numerical data. This enables direct plotting of the data and is the most convenient form for considering the data analytically.

All the data on the orientation of joints and other dividing planes (rock structure) have been collected using this method.

PRESENTATION AND ANALYSIS OF DATA

Data on the orientation of joints and bedding planes have been

presented by using spherical projection (see Plate A-1).

They have been analyzed using the Dames & Moore computer program EP 68 (KRPLOT); the program plots on an equal area projection a scatter diagram (individual points) of the poles of specified geological discontinuities. It then performs a statistical analysis by contouring the poles using the Schmidt method (Plate A-2).

SPHERICAL PROJECTION

SPHERICAL PROJECTION IS A SIMPLE AND USEFUL TOOL FOR THE PRESENTATION AND ANALYSIS OF STRUCTURAL GEOLOGICAL DATA, AS WELL AS FOR ANALYSIS OF THE STABILITY OF TWO AND THREE DIMENSIONAL ROCK STRUCTURES. THE TECHNIQUE USES A REFERENCE HEMISPHERE TO REPRESENT THE ORIENTATION OF PLANES (SUCH AS JOINTS OR SHEARS) OR LINES (PARTICULARLY THE NORMALS OR DIP VECTORS OF MEASURED PLANES). THE INTERCEPT OF THE LINE OR PLANE WITH THE REFERENCE HEMISPHERE IS PROJECTED ONTO A HORIZONTAL PLANE, WHERE LINES PROJECT AS POINTS AND PLANES PROJECT AS LINES, AS SHOWN IN FIGURE 1. THIS PROJECTION COMPLETELY AND UNIQUELY DEFINES THE ORIENTATION OF THE STRUCTURE. GRADUATED NETS ALLOW FEATURES TO BE PLOTTED DIRECTLY ON THE PROJECTION PLANE.

THE DISTRIBUTION OF DEFECT ORIENTATIONS CAN BE ANALYZED STATISTICALLY ON AN EQUAL AREA PROJECTION, FOR WHICH A UNIT OF AREA ANYWHERE ON THE PROJECTION REPRESENTS THE SAME FRACTION OF THE TOTAL AREA OF THE REFERENCE HEMISPHERE. THE NUMBER OF JOINT POLES FALLING WITHIN A COUNTING CIRCLE OF AREA 1% THAT OF THE NET IS DETERMINED AT POINTS OVER THE NET, AND THESE VALUES ARE CONTOURED.

PLOTS OF BOTH INDIVIDUAL POINTS AND CONTOUR DIAGRAM ARE PRODUCED AUTOMATICALLY BY THE DAMES & MOORE COMPUTER PROGRAM KRPLOT. FURTHER ANALYSIS CAN GIVE THE PROBABILITY DISTRIBUTION OF EACH CONTOUR CLUSTER APPEARING ON THE NET, AS WELL AS THE DISPERSION OR RANDOMNESS OF THE ENTIRE JOINT SYSTEMS.

FIGURE 1A LOWER HEMISPHERE EQUAL AREA PROJECTION TO A HORIZONTAL PLANE

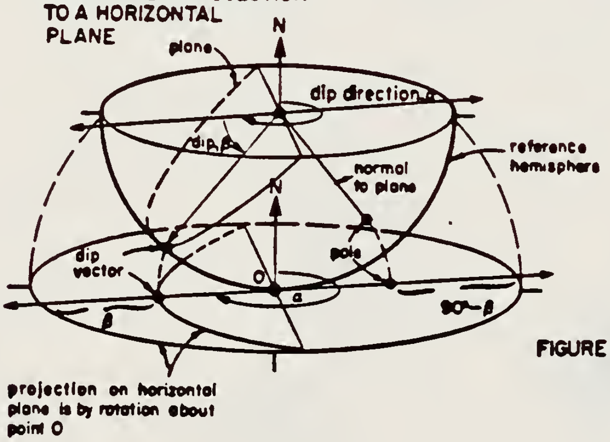
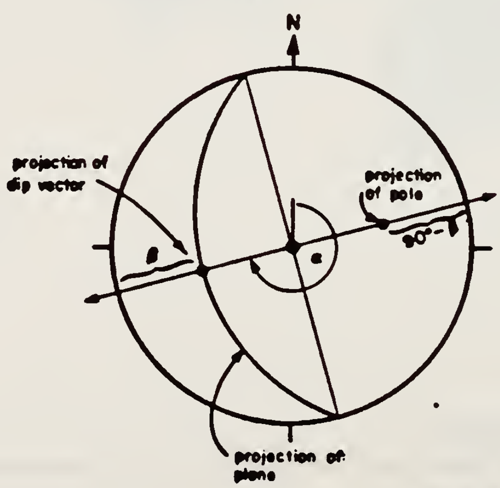


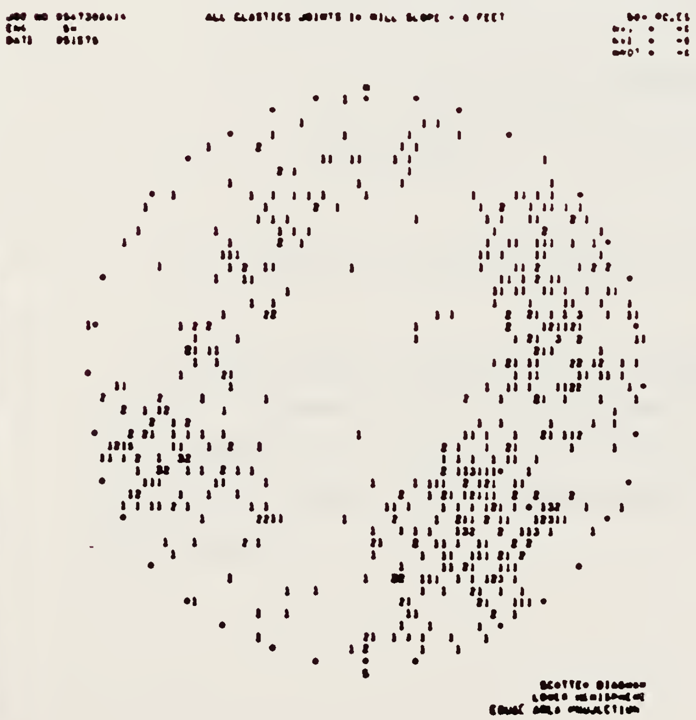
FIGURE 1B REPRESENTATION OF A PLANE ON A NET



ANALYSIS OF GEOLOGICAL DATA

THE DAMES & MOORE COMPUTER PROGRAM KRPLOT REDUCES GEOLOGICAL DATA BY PLOTTING A SCATTER DIAGRAM OF THE POLES OF MEASURED STRUCTURAL GEOLOGIC DISCONTINUITIES ON AN EQUAL AREA PROJECTION. IT THEN PERFORMS A STATISTICAL ANALYSIS BY CONTOURING THE DENSITY OF THESE POLES.

ON AN EQUAL AREA PROJECTION, EQUAL AREAS ON THE REFERENCE SPHERE CORRESPOND TO EQUAL AREAS ON THE NET INDEPENDENTLY OF THEIR POSITION ON THE SURFACE OF THE SPHERE. CONTOURING OF THE POLES IS THEREFORE PERFORMED BY MOVING A COUNTING CIRCLE OF FIXED RADIUS OVER THE SURFACE OF THE NET AND COUNTING THE NUMBER OF PLOTTED POINTS WHICH FALL WITHIN THE CIRCLE AT EACH LOCATION. THE AREA OF THE COUNTING CIRCLE IS 1% THAT OF THE NET. CONTOUR INTERVALS ARE SELECTED ACCORDING TO THE MAXIMUM DENSITY OF POINTS AND ARE PRINTED AT THE TOP OF THE CONTOUR DIAGRAM. THE CONTOURED DIAGRAMS PROVIDE THE QUANTITATIVE BASIS NECESSARY FOR THE ANALYSIS OF THE STABILITY OF ROCK MASSES.



STUDY OBJECTIVES

The original intent of the present study as described in our proposal of March 9, 1982 was to:

1. Define the problems:

   a. evaluate the stability of the steep rock slope and retaining wall adjacent to the Warden's Residence and Lighthouse;

   b. evaluate the stability of the undermined portion of West Road;

   c. evaluate the impact and likelihood of future slope instability on the Warden's Residence, Lighthouse, and West Road; including an assessment of the urgency of the problems.

2. Develop a series of alternate conceptual remedial schemes:

   a. to increase the stability of the affected areas;

   b. to mitigate the consequences of additional instability on the structural integrity of the affected areas and safety to visitors.

3. Provide relative costs for the alternative conceptual schemes.

As the study progressed, it became apparent that very few conceptual remedial schemes could be considered feasible for certain problem areas. Accordingly, our report addresses only those types of solutions judged reasonable, rather than undertaking a comprehensive discussion of numerous alternatives.

This report provides professional analysis for management decision and should be followed by a second phase to provide the specifications and drawings for correction of safety hazards if remedial work is to be undertaken.

METHOD OF STUDY

To accomplish the objectives stated above, a program consisting of the following components was followed:

1. A review of available data, such as records, reports, drawings and photographs of the affected areas in order to reconstruct the history of instability.

2. A field reconnaissance by a geologist and an engineer from our office to observe existing geologic conditions and obtain structural data for an evaluation of future stability.

3. Detailed investigation including measurement of orientations of planes of mechanical instability (joints, bedding, shears etc.) on the steep rock slope immediately southeast of the Warden's Residence.

4. Computer analysis of structural data describing planes of mechanical instability to assess the severity of the slope stability problem on the steep rock slope.

5. A limited field exploration program consisting of six hand auger holes to depths ranging from 1.9 to 4.3 feet in the garden area between the east wall of the Warden's Residence and the retaining wall for the garden.

6. Review of all data to evaluate the severity of the problems, alternative courses of action and development of relative costs.

SITE CONDITIONS

Alcatraz Island is located in San Francisco Bay, approximately 1.5 miles north of the city of San Francisco. The island is composed of graywacke (dirty sandstone) with some interbedded shale of the Franciscan Formation. Prior to 1853 Alcatraz Island was a barren rock; in 1853 the U.S. government began construction of military fortifications on the island. During the next 110 years the island passed from being a Fort to a Military Prison to a Federal Penitentiary. Throughout this time construction activity occurred and gradually the island took on its present configuration. The island now consists of two levels: 1) the upper level where the Lighthouse, Warden's Residence, and Cell Block building are located; and 2) the lower level which includes the Parade Ground and numerous other structures. These features are shown on Plate 1. The upper level probably reflects the original upper surface of the island; the lower level primarily represents a quarried surface.

Warden's Residence

The Warden's Residence is located on the southeast corner of the upper surface adjacent to the Lighthouse, at an elevation of 125 feet above sea level. The structure was built in 1929 on the site of the post headquarters. Immediately southeast of the Warden's Residence is a steep rock slope; to the northeast of the building is a garden and retaining wall. A section of old masonry wall and several hundred cubic yards of rock and soil fell from the steep rock slope during this January's severe storm. This area is illustrated in photographs on Plate 2. In addition, the masonry retaining wall for the Warden's Residence garden has about a three-inch-wide vertical crack in the southeastern corner of the garden area. This is shown in photograph A, Plate 3. The crack has been monitored by the NPS and has shown about four millimeters of movement since September 1981. Observation of the exposed base of the wall indicates that the wall was probably founded on the original ground surface, not bedrock, and is locally undermined by erosion of supporting soil. Two intersecting cracks were also observed in the north-eastern corner of the retaining wall.

Steep Rock Slope

Investigations of the steep rock slope involved the application of modified climbing techniques using ropes and auxiliary climbing equipment. Three vertical traverses of the cliff face and one foot traverse of the base of the cliff were made to collect data on the orientation and spacing of rock structural features such as joints, bedding, and shears. These data were evaluated in the form of polar diagrams where each plane of discontinuity is represented by the perpendicular (pole) to that plane. Dames & Moore's computer program KRPLOT was used to reduce the structural data and to plot a scatter diagram of the poles of measured structural discontinuities on an equal area projection; this plot is presented as Plate 4. The program also performed a statistical analysis by contouring the density of the poles, as shown on Plate 5. The methodology involved in the stereographic projection technique is explained in Appendix A.

Based on these analyses and the results of field observations, the critical unstable surfaces were identified. There are two dominant joint sets whose intersections appear to be the primary location of wedge-type failure; these sets have the following orientations: 1) striking N16°E and dipping 80° E; and 2) striking N82°E and dipping 72°S; the data are synthesized on Plate 6.

Garden Retaining Wall

Six hand auger holes were drilled in the garden area adjacent to the Warden's Residence at the locations shown on Plate 7. Holes 1,2,3 and 5 encountered concrete at depths of 1.9, 4.1, 4.1, and 2.5 feet, respectively. These data suggest the presence of a previous platform or slab in this area. Hole 4 encountered sandstone at a depth of 4.1 feet which suggests that the older platform or slab is founded on bedrock. Hole 6 encountered brick, sandstone and concrete at a depth of 2.3 feet which may represent a wall associated with the older structure, or newer fill. A cross section through the garden and the retaining wall showing this older feature and the estimated bedrock surface is presented on Plate 8.

West Road

The West Road is located on the lower surface of Alcatraz Island and forms part of a road system which traverses the island's perimeter. This road system was developed during the initial fortification of Alcatraz in the 1850's and the foundations for the present road system are undoubtedly composed of portions of these and later construction phases. The West Road is currently being undermined where the road is located on fill. The undermining has occurred along approximately 160 feet of roadway. The most severe undermining is located along the southern 80-foot-long stretch where the road crosses a filled ravine. This ravine was filled with rubble faced by brick; the fill reaches a maximum thickness of approximately 30 feet. This portion of road may be entirely built on fill. The remaining 80 feet of the affected area has as yet only been undermined locally along its outer edge. Fill in this zone, although obscured by bird droppings, appears to be composed of rubble and to range in depth from a few to 10-15 feet. The inner portion of this section of roadway is cut into the hill slope and is considered likely to be founded on bedrock.

EVALUATION OF EXISTING CONDITIONS

This section presents an evaluation of the existing conditions, modes of failure and urgency of remedial action for each area of concern.

Warden's Residence

The unbraced walls of the Warden's Residence have been declared extremely hazardous to tour groups. Particular concern has been expressed about the building's western wall and northwestern corner, which are the closest to visitor access. Since the publication of the Structural-Safety Hazard Study in 1979 additional rockfalls have occurred adjacent to the structure's southeast wall. Thus the wall foundations have almost been undermined, and continued rockfalls in this area could jeopardize a significant part of the building shell.

Steep Rock Slope

The steep dips of the joint surfaces and their intersection (which are the surfaces of failure) suggest that ravelling and small rock slides are likely to be the most common modes of failure in the future. Failures up to several feet in depth (similar to that which occurred in January 1982 and slightly larger) can occur, however, and must be protected against if the Warden's Residence is to be maintained.

Failure of this steep cut is presently threatening a portion of the roadway adjacent to the lighthouse and continued movements in this area would undermine the road, ultimately jeopardizing the lighthouse structure. However, the cut is sufficiently far from the cell block structure that it is very unlikely that slope movements could affect it.

Garden Retaining Wall

Based on the results of the hand auger holes, we anticipate that the wedge of fill behind the retaining wall has a maximum thickness of about 15 feet. Pictures taken in 1946 indicate that the crack in the southeastern corner of the retaining wall was present at that time, which suggests that failure of the wall may not be imminent. A similar crack on the extreme northerly corner of the wall suggests that the entire mass may be moving slowly as a unit.

West Road

The West Road is being currently undermined along sections which are built across fill. Continued undermining could completely destroy the southern 80 feet of the road. Undermining of the northern 80 feet is not considered likely to affect the entire width of the road because the inner portion is believed to be founded on stable bedrock.

POSSIBLE REMEDIAL ACTIONS

This section addresses the possible remedial actions which could be taken in each area and presents a discussion of the advantages and disadvantages of the various measures.

Warden's Residence

In response to NPS concerns, an internal bracing system has been designed by William S. Kaplan, Structural Engineer. This system consists of a series of timber struts and braces and additional concrete footings to provide sufficient reaction for the inclined struts. The draft plans and specifications for this project have been transmitted under separate cover.

Steep Rock Slope

The classical approaches toward stabilization of an unstable slope are:

1. flattening back to a more stable configuration;

2. buttressing by placing a fill against the slope;

3. draining the slope;

4. structurally strengthening the slope, for instance by using rock bolts.

The rock underlying the Warden's Residence is relatively strong, so the stability of the cliff is controlled by the fracture systems within the rock mass rather than by the strength of the rock itself. The dominant joint systems in the slope are quite steep, averaging about 70° to 80° from the horizontal. Thus, flattening the slope to a more stable configuration would involve laying the slope back to something on the order of 60° or so to minimize the likelihood of continued wedge-type failures. This grading

would require demolition of the Warden's Residence, so if preservation of this structure is desired, flattening the slope is not considered a viable alternative. Slope flattening could also probably include the access roadway adjacent to the lighthouse, which we understand must be maintained.

The slope is about 60 feet high and in order for a buttress-type of solution to be effective, the buttress would have to be almost that high. Accordingly, buttressing is also not considered feasible because of the volume of fill required and the overall expense.

Although drainage of slopes is usually a desirable stabilization measure, in this case, due to the limited recharge area and the fractured conditions of the rock mass, drainage would not necessarily accomplish a significant increase in stability. Rock bolting is therefore judged to be the only viable stabilization measure.

Rock bolts would be installed, probably in a regular pattern to a prescribed depth and tensioned to a prescribed load. The face could be sheathed with wire mesh and/or gunite to retard the effects of weathering. Details of the actual remedial solution should be developed during a design study. The bolting should extend across the portion of the cliff closest to the lighthouse in order to protect the roadway from continued slope degradation which could ultimately cut access to the lighthouse and endanger the structure.

In addition to the rock bolting program, we suggest the removal of eucalyptus trees from the top of the cliff near the Warden's Residence. Trees, eucalyptus in particular, have been known to weaken slopes by their root action, especially during windstorms. The removal of these trees would be a small but positive step toward increased stability.

<u>Garden Retaining Wall</u>

Three options are considered for alleviating problems associated with failure of the retaining wall:

1. Drilled anchors - This method, shown on Plate 8A, involves the installation of rock bolts which extend into bedrock in a gridwork pattern across the wall. This approach requires that the wall have some structural integrity.

2. Tied back to deadmen - This method, shown on Plate 8B, involves the installation in the garden area of several concrete pillars founded in bedrock. Metal plates with attached cables would be installed on the front of the wall and the cables tied back to the pillars, Installation of the cables involves trenching so the lowest placement of the plates on the retaining wall is controlled by the depth to bedrock which in this locality is approximately 4 feet. For this retaining wall the anchors would therefore be placed at 4 feet below the top wall and approximately 5 to 25 feet above the base. This method, therefore, requires substantial structural integrity of the wall in order to transfer the tieback loads across the wall.

3. Tear the wall down. This measure involves tearing the wall down and removing the wedge of fill behind it. It is an expensive version of the "no action" alternative of allowing the wall to eventually fail. Unless this area or the area below is desired for public use, this measure is unnecessary.

The wall has not been investigated in detail, but in all likelihood it consists of unreinforced rubble masonry with very little structural integrity. Therefore, options 1 and 2 would also necessarily involve some overall structural support such as wire mesh and gunite to allow the transfer of stresses from the anchors or cables across the wall as a unit.

West Road

Appropriate remedial measures for the re-establishment of the West Road are different for the northern and southern sections:

1. Northern Half If the inner portion of the road in this location is founded on bedrock as expected, then the most cost effective means of stabilizing the road is to support the outer portion on drilled piers. Relocation of the road inland is possible but would involve extensive excavation.

2. Southern Half The most cost effective means of stabilizing this section of the road would be to relocate the road inland. This approach assumes that slightly inland from the road's present location, the new road could be founded on bedrock. This assumption seems reasonable based on older topographic maps and the fact that this area is a quarried plateau. Other possibilities include structurally bridging across the old filled zone, but costs would be significantly higher for this approach.

If no action were taken, a pathway could probably be established inland of the southern section and along the inside of the northern section.

ESTIMATED COSTS

Table 1 presents estimates of the costs associated with the options for remedial measures discussed above. These are only rough estimates because no remedial measures have been designed; however, the estimates do reflect the relative costs of one option versus another option.

The following Plates, Table and Appendix are attached and complete this report:

Plate 1	Plot Plan
Plate 2	Photographs
Plate 3	Photographs
Plate 4	Raw Rock Structural Data
Plate 5	Interpreted Rock Structural Data
Plate 6	Stereographic Presentation of Cut Slope and Critical Planes
Plate 7	Location of Hand Auger Holes
Plate 8	Interpretive Cross Section Through Warden's Residence Garden
Plate 9	Possible Schematic Approaches Toward Support of Garden Retaining Wall
Table 1	Estimated Costs of Remedial Measures
Appendix A:	Stereographic Analysis of Geological Data

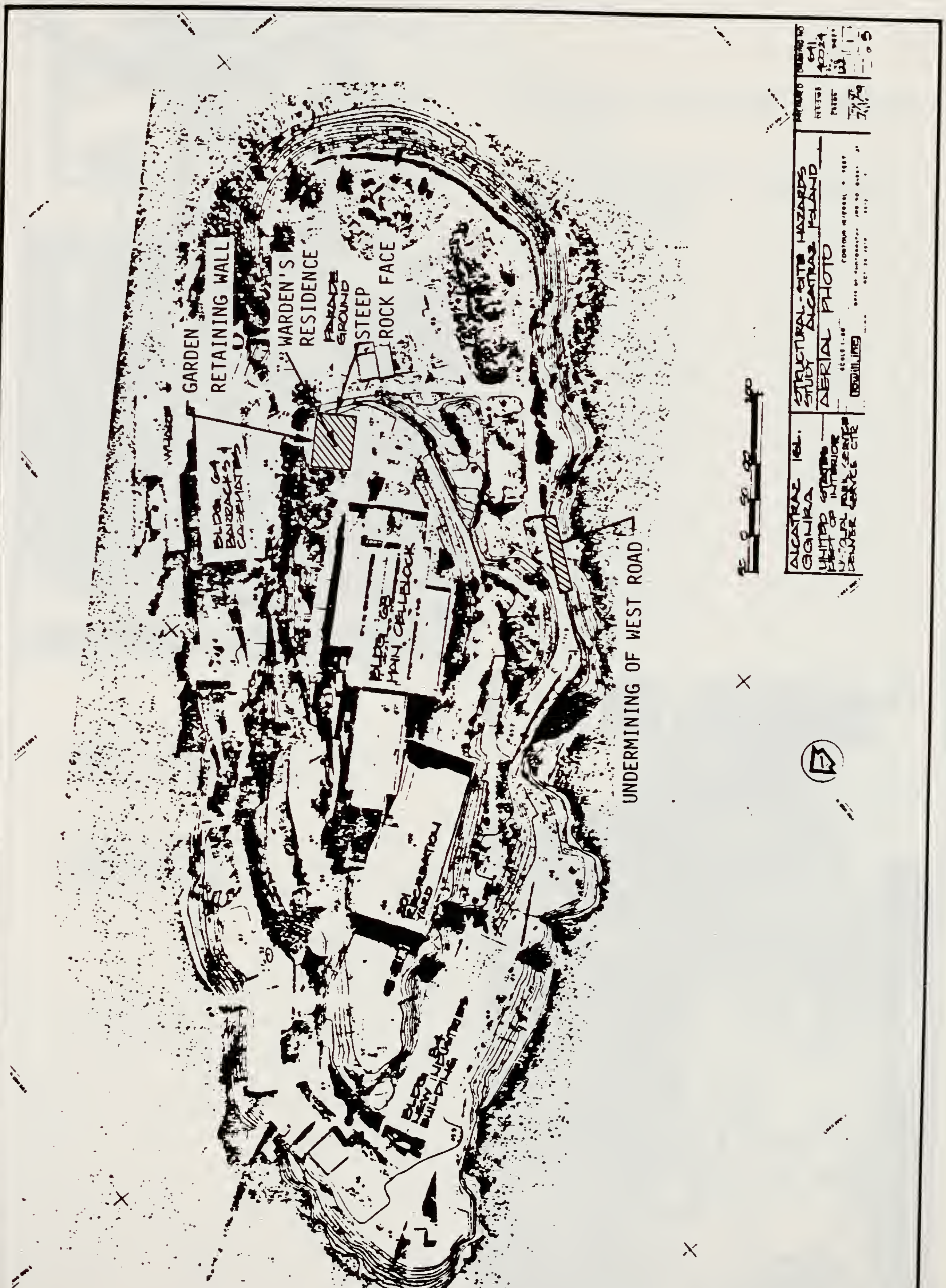
Respectfully submitted,

DAMES & MOORE

Raymond H. Rice

Raymond H. Rice
Partner

RHR:SEG:fz



PLOT PLAN

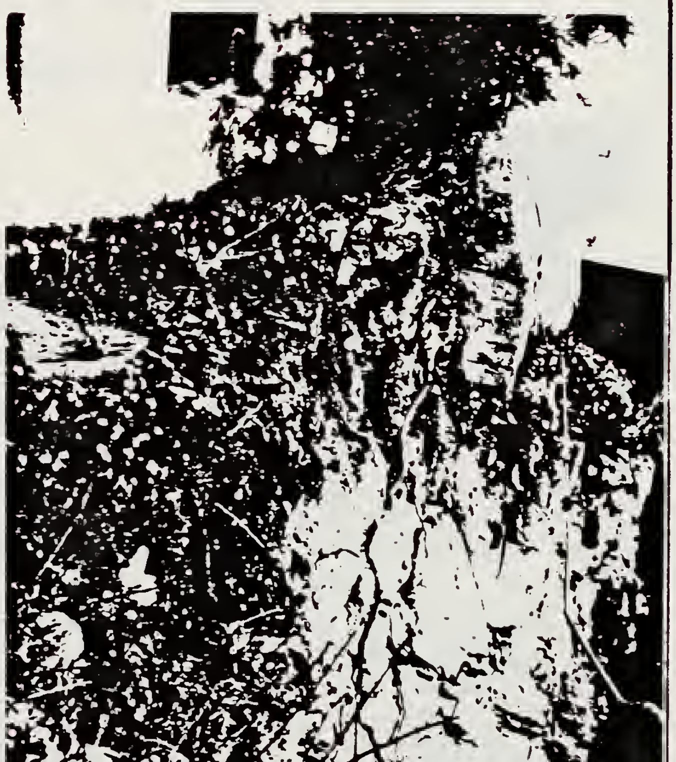
Dames & Moore

CHECKED BY ______ FILE ______ BY ______ DATE ______

A.

STEEP ROCK FACE ADJACENT TO WARDEN'S RESIDENCE

NOTE RECENT ROCKFALL AND MISSING SECTION OF WALL



B.

DETAIL OF TOP OF STEEP ROCK FACE AT LOCATION OF RECENT ROCK FALL

NOTE MISSING SECTION OF WALL AND PROXIMITY OF FAILURE TO WALL OF WARDEN'S RESIDENCE

Dames & Moore

CHECKED BY ______ FILE ______ BY ______ DATE ______

A. CRACK IN GARDEN RETAINING WALL NEAR WARDEN'S RESIDENCE

B. DAMAGE DUE TO UNDERMINING OF WEST ROAD

DAMES & MOORE

JOB NO 0205006403 ALCATRAZ--WARDENS HOUSE
ENG SEG
DATE 052782

247 POLES
NV1 = 0
NV2 = 0
NROT = 0

SCATTER DIAGRAM
LOWER HEMISPHERE
EQUAL AREA PROJECTION

RAW ROCK STRUCTURAL DATA

DAMES & MOORE

JOB NO 0205006403 ALCATRAZ--WARDENS HOUSE
ENG SEC
DATE 052782

247 POLES
NV1 = 0
NV2 = 0
NROT = 0

CONTOUR INTERVALS 1 2 3 4 5 MAX 6.5

SCHMIDT METHOD
LOWER HEMISPHERE
EQUAL AREA PROJECTION

INTERPRETED ROCK STRUCTURAL DATA

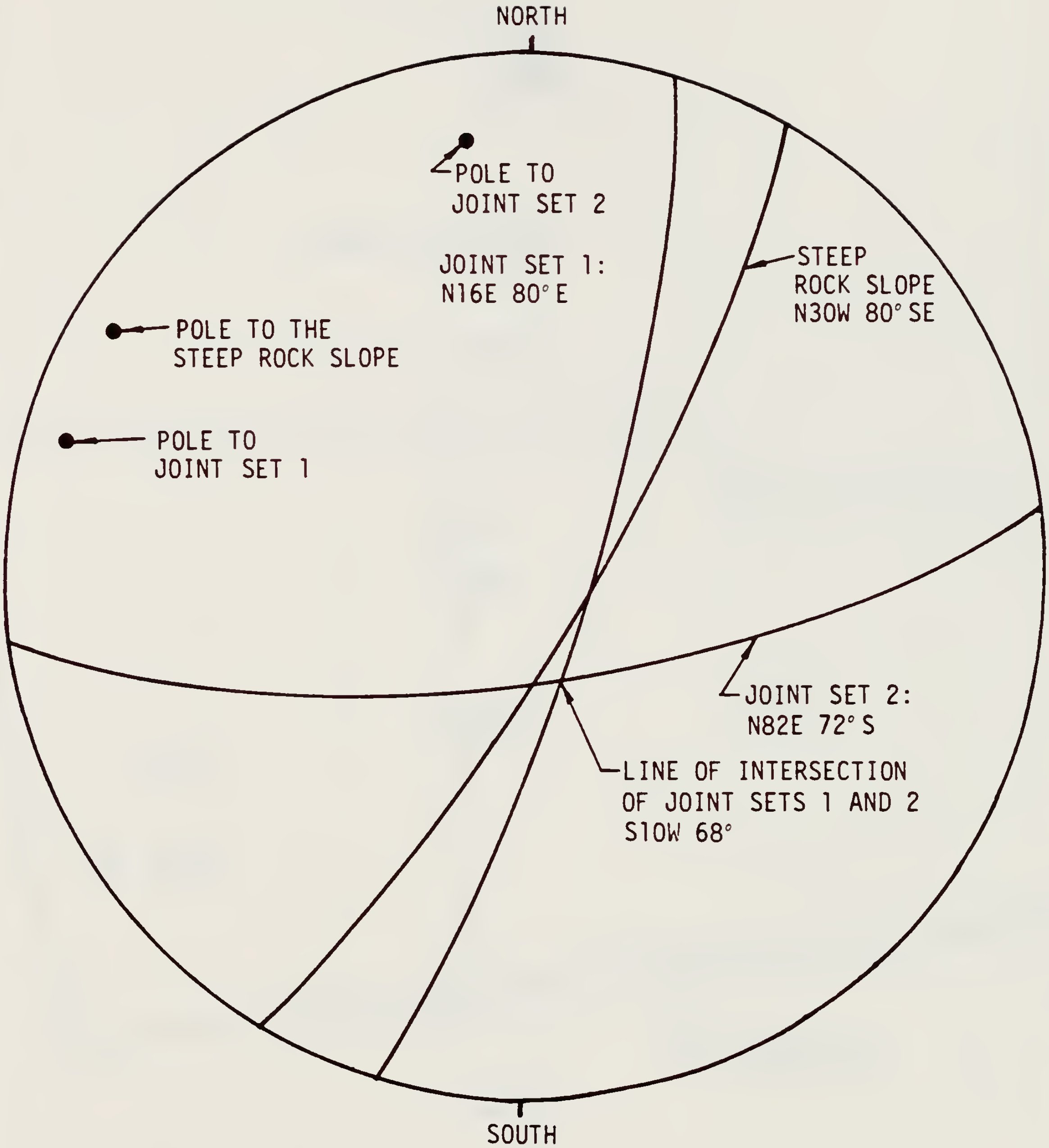
DAMES & MOORE

PLATE 5

BY ______ DATE ______

FILE 2030-06A

CHECKED BY ______

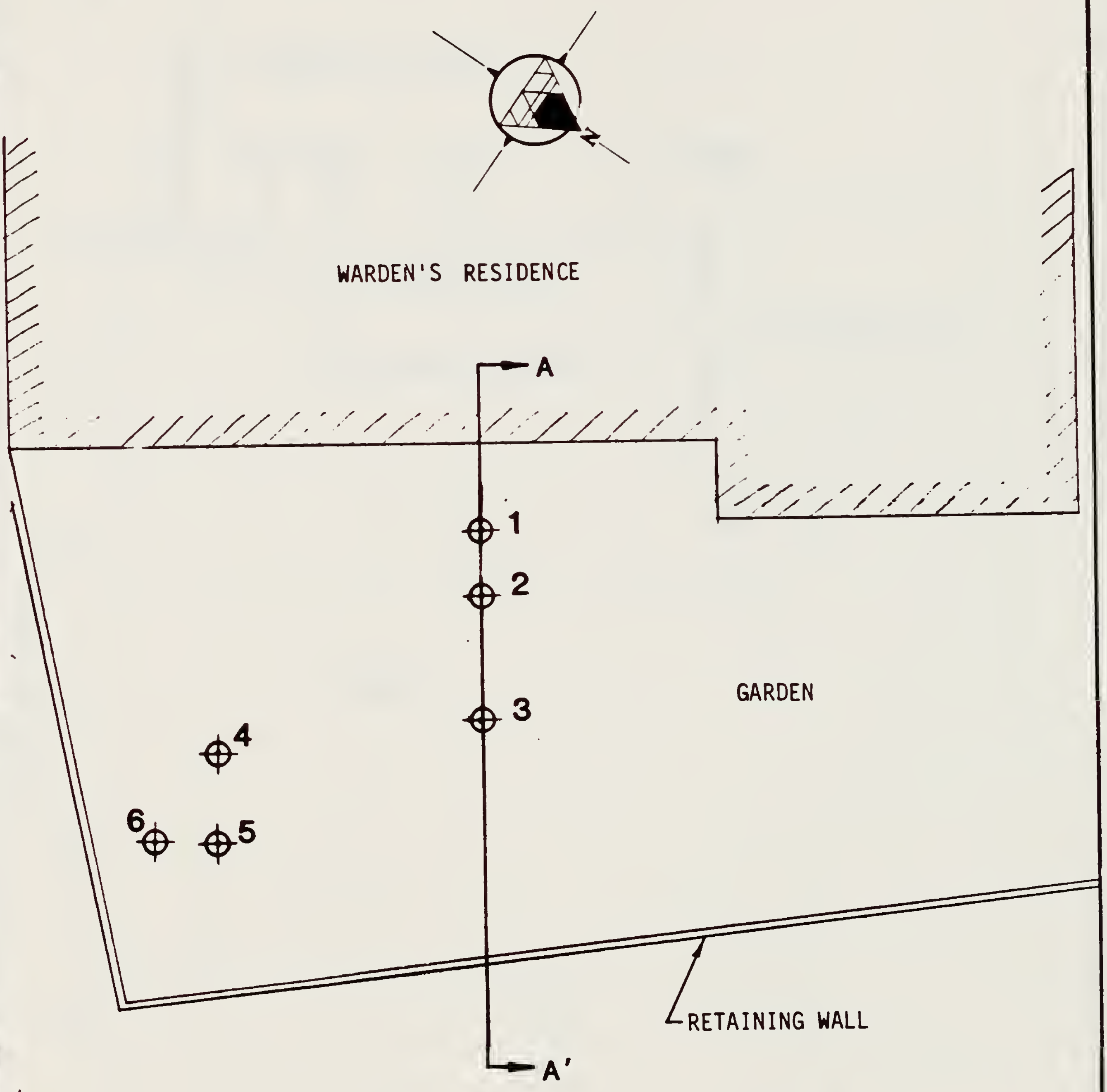


STEREOGRAPHIC PRESENTATION OF CUT SLOPE AND CRITICAL PLANES

DAMES & MOORE

PLATE 6

BY ____ CHECKED BY ____ FILE ____ BY ____ DATE ____



LOCATION OF HAND AUGER HOLES

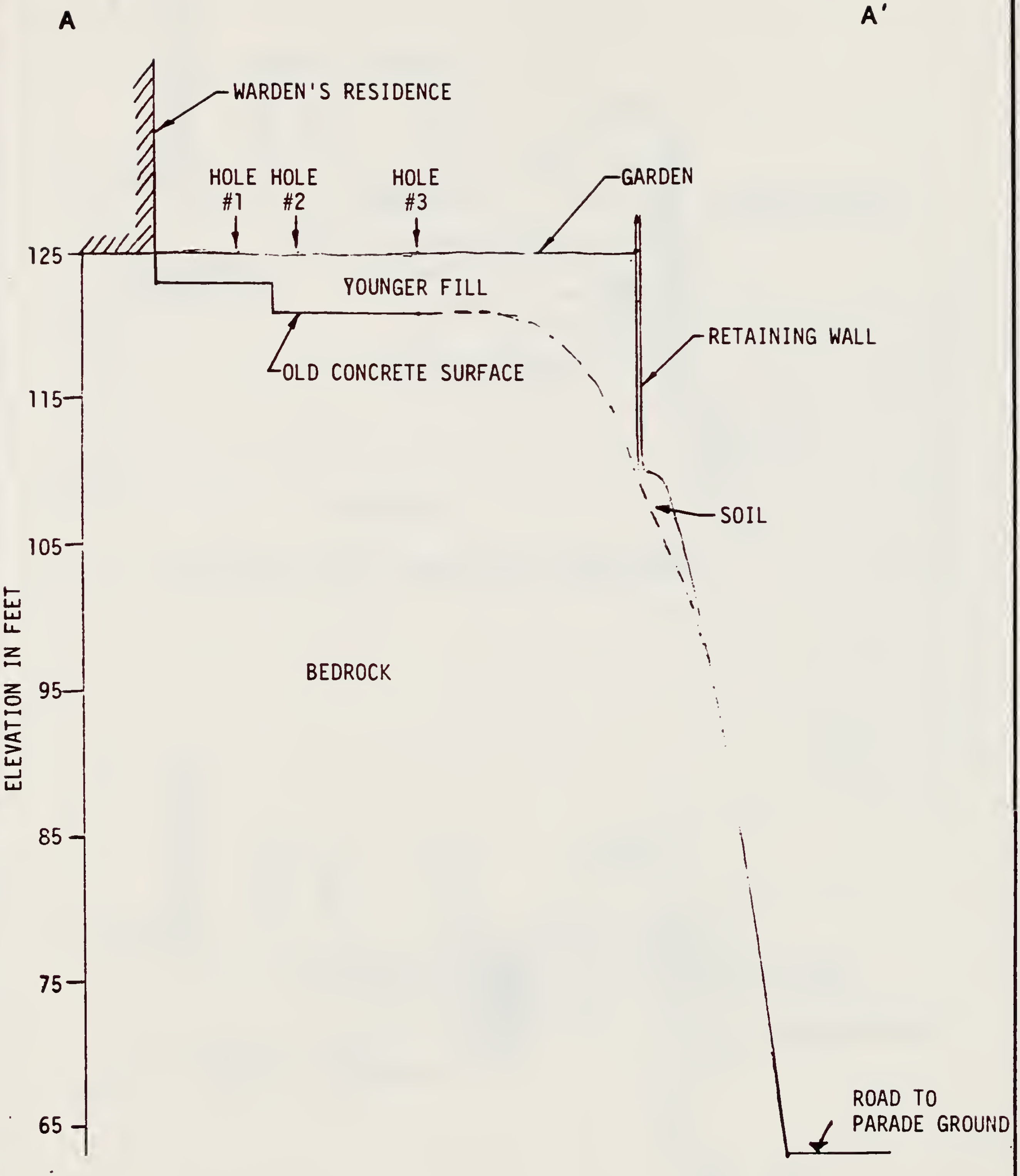
FEET

5 0 5 10 15 20 25

Dames & Moore

PLATE 3

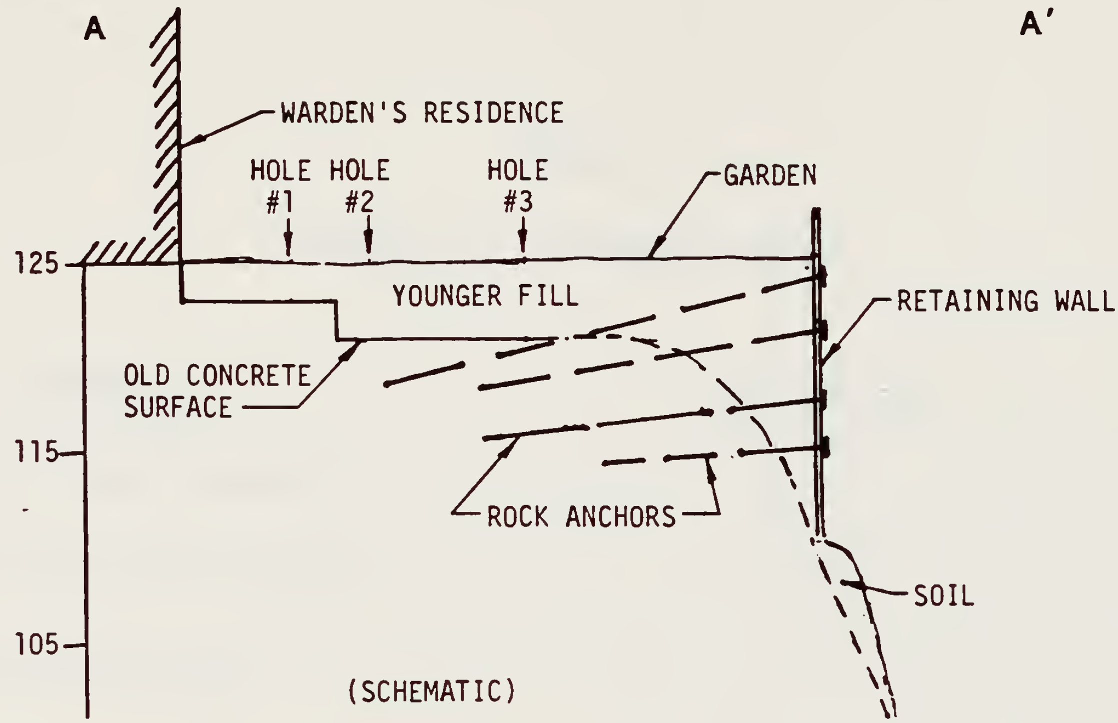
FILE 2050-064 BY DATE CHECKED BY



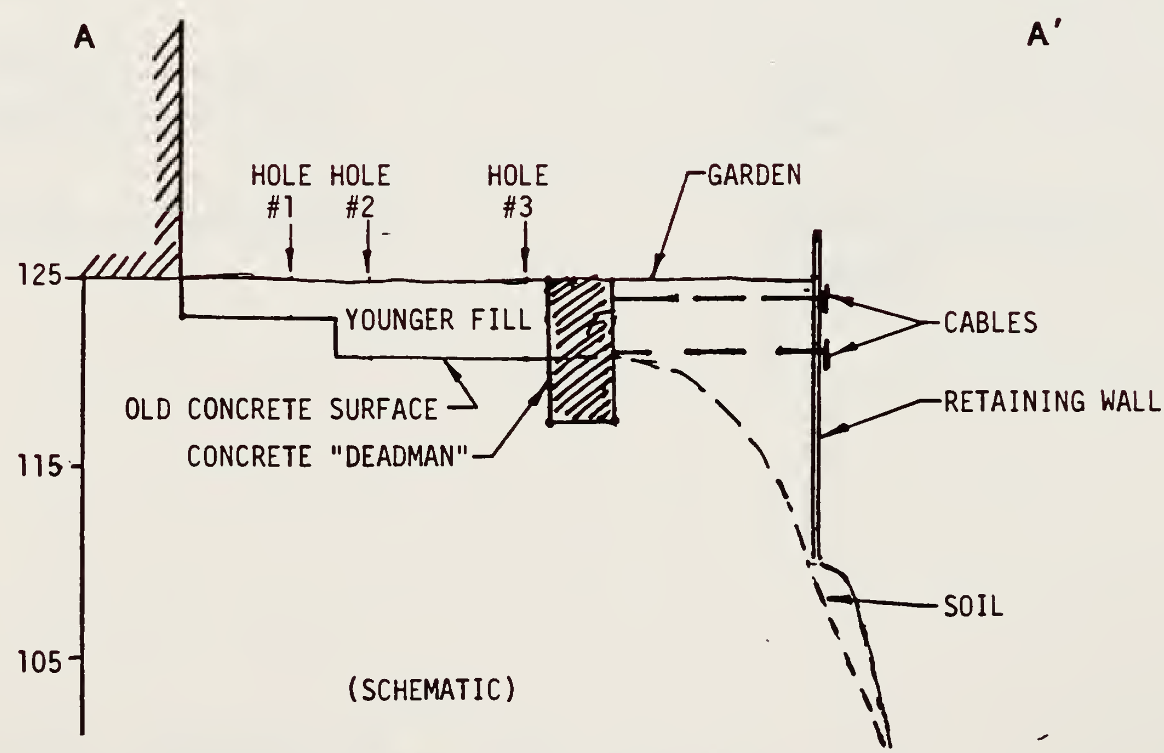
INTERPRETIVE CROSS SECTION A–A'

Dames & Moore

BY ____ DATE ____ REVISIONS BY ____ DATE ____ FILE 2050-004 CHECKED BY ____



A. ROCK ANCHOR OPTION: GARDEN WALL STABILIZATION



B. TIED-BACK TO DEADMAN OPTION: GARDEN WALL STABILIZATION

TABLE 1

ESTIMATED COSTS OF REMEDIAL MEASURES

IMPROVEMENT	ESTIMATED COST
Bracing Warden's Residence	$60,000
Rock Bolting Steep Rock Face	70,000
Garden Retaining Wall	
Option 1: Rock Anchors	50,000
Option 2: Cables & Deadmen	35,000
Option 3: Demolition	
West Road	
Southern Portion (80 LF)	12,000
Northern Portion (80 LF)	22,000
Mobilization & Demobilization	25,000 per construction episode

APPENDIX A

STEREOGRAPHIC ANALYSIS OF GEOLOGICAL DATA

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More recently, the growing use of data on geological discontinuities in an engineering context has led to an increasing trend in recording discontinuity data in terms of dip vector, defined by the dip and dip direction of the joint. This trend has been facilitated by the introduction of a new style of compass, in particular, the Clar (or Breithaupt) compass. Advantages of using this system for measuring and recording data are:

1. Both dip and dip direction are measured and read directly in a single operation. This greatly increases the speed of taking measurements and minimizes the risk of errors in measurements since no interpretation of direction by the geologist is required.

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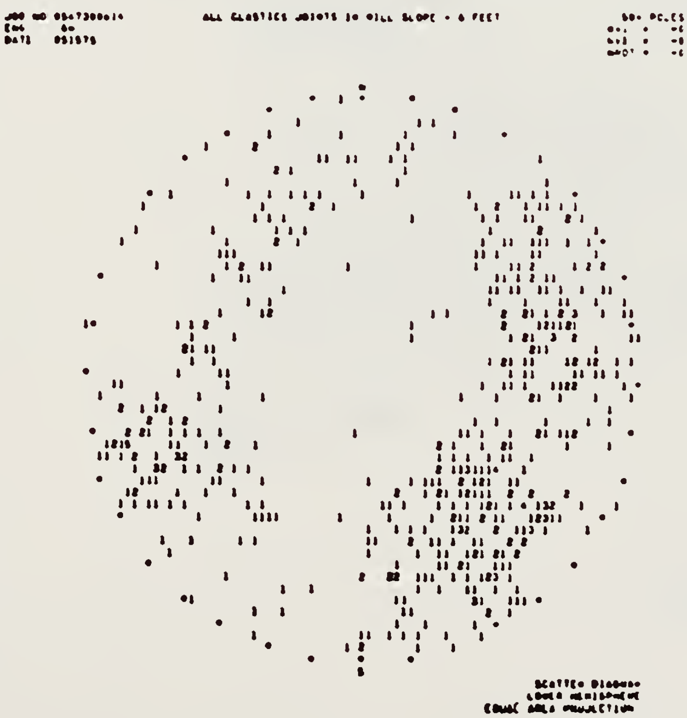
THE DAMES & MOORE COMPUTER PROGRAM KRPLOT REDUCES GEOLOGICAL DATA BY PLOTTING A SCATTER DIAGRAM OF THE POLES OF MEASURED STRUCTURAL GEOLOGIC DISCONTINUITIES ON AN EQUAL AREA PROJECTION. IT THEN PERFORMS A STATISTICAL ANALYSIS BY CONTOURING THE DENSITY OF THESE POLES.

ON AN EQUAL AREA PROJECTION, EQUAL AREAS ON THE REFERENCE SPHERE CORRESPOND TO EQUAL AREAS ON THE NET INDEPENDENTLY OF THEIR POSITION ON THE SURFACE OF THE SPHERE. CONTOURING OF THE POLES IS THEREFORE PERFORMED BY MOVING A COUNTING CIRCLE OF FIXED RADIUS OVER THE SURFACE OF THE NET AND COUNTING THE NUMBER OF PLOTTED POINTS WHICH FALL WITHIN THE CIRCLE AT EACH LOCATION. THE AREA OF THE COUNTING CIRCLE IS 1% THAT OF THE NET. CONTOUR INTERVALS ARE SELECTED ACCORDING TO THE MAXIMUM DENSITY OF POINTS AND ARE PRINTED AT THE TOP OF THE CONTOUR DIAGRAM. THE CONTOURED DIAGRAMS PROVIDE THE QUANTITATIVE BASIS NECESSARY FOR THE ANALYSIS OF THE STABILITY OF ROCK MASSES.



DAMES & MOORE

SPHERICAL PROJECTION

SPHERICAL PROJECTION IS A SIMPLE AND USEFUL TOOL FOR THE PRESENTATION AND ANALYSIS OF STRUCTURAL GEOLOGICAL DATA, AS WELL AS FOR ANALYSIS OF THE STABILITY OF TWO AND THREE DIMENSIONAL ROCK STRUCTURES. THE TECHNIQUE USES A REFERENCE HEMISPHERE TO REPRESENT THE ORIENTATION OF PLANES (SUCH AS JOINTS OR SHEARS) OR LINES (PARTICULARLY THE NORMALS OR DIP VECTORS OF MEASURED PLANES). THE INTERCEPT OF THE LINE OR PLANE WITH THE REFERENCE HEMISPHERE IS PROJECTED ONTO A HORIZONTAL PLANE, WHERE LINES PROJECT AS POINTS AND PLANES PROJECT AS LINES, AS SHOWN IN FIGURE 1. THIS PROJECTION COMPLETELY AND UNIQUELY DEFINES THE ORIENTATION OF THE STRUCTURE. GRADUATED NETS ALLOW FEATURES TO BE PLOTTED DIRECTLY ON THE PROJECTION PLANE.

THE DISTRIBUTION OF DEFECT ORIENTATIONS CAN BE ANALYZED STATISTICALLY ON AN EQUAL AREA PROJECTION, FOR WHICH A UNIT OF AREA ANYWHERE ON THE PROJECTION REPRESENTS THE SAME FRACTION OF THE TOTAL AREA OF THE REFERENCE HEMISPHERE. THE NUMBER OF JOINT POLES FALLING WITHIN A COUNTING CIRCLE OF AREA 1% THAT OF THE NET IS DETERMINED AT POINTS OVER THE NET, AND THESE VALUES ARE CONTOURED.

PLOTS OF BOTH INDIVIDUAL POINTS AND CONTOUR DIAGRAM ARE PRODUCED AUTOMATICALLY BY THE DAMES & MOORE COMPUTER PROGRAM KRPLOT. FURTHER ANALYSIS CAN GIVE THE PROBABILITY DISTRIBUTION OF EACH CONTOUR CLUSTER APPEARING ON THE NET, AS WELL AS THE DISPERSION OR RANDOMNESS OF THE ENTIRE JOINT SYSTEMS.

FIGURE 1A
LOWER HEMISPHERE EQUAL AREA PROJECTION TO A HORIZONTAL PLANE

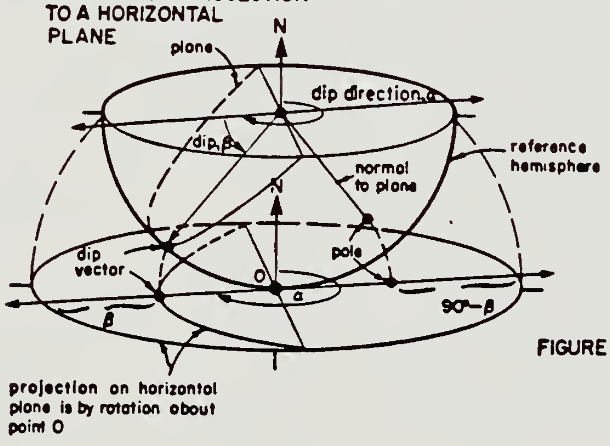


FIGURE 1B REPRESENTATION OF A PLANE ON A NET