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Smith, Travis W.; McCauley, Marvin L.; Mearns, Ronald W.; Lister, Bobby L.; Johns, Bennett

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16. ABSTRACT
This research project is intended to determine if seismic velocities can be used to improve the accuracy of design earthwork factors. The procedures used by the contractor for earthwork construction were investigated. Densities were taken in the cut areas at finished grade by District personnel. These values were compared to the average compacted in-place densities of the fills and the difference in volume was calculated. The total volume of boulders protruding from the cut faces was estimated. The total volume of boulders that rolled down slopes and out of the embankment areas was estimated. A total of forty-two seismic refraction lines were obtained from the entire length of the project. Field earthwork factors, determined after construction, were compared to design earthwork factors and to the seismic velocities obtained in the cut areas. A table was developed comparing seismic velocities to earthwork factors.

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Earthwork factors, shrinkage and swell, earthwork construction, seismic velocities, mass diagram, research

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HIGHWAY RESEARCH REPORT

CORRELATION OF SEISMIC VELOCITIES WITH EARTHWORK FACTORS

EPORT

71-16

STATE TERIALS AND RESEARCH DEPARTMENT

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

RESEARCH REPORT

NO. M & R 632103

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration June, 1971

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

June, 1971

Research Project
P.W.O. 632103

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research report titled:

CORRELATION OF SEISMIC VELOCITIES

WITH EARTHWORK FACTORS

Principal Investigator
Travis Smith

Co-Investigators
Marvin McCauley
Ronald Mearns

Field Work and Report by
Bobby Lister and Bennett John

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Smith, Travis W.; McCauley, Marvin L.; Mearns, Ronald W.; Lister, Bobby L.; Johns, Bennett. "Correlation of Seismic Velocities with Earthwork Factors": State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 632103, June 1971.

ABSTRACT: This research project is intended to determine if seismic velocities can be used to improve the accuracy of design earthwork factors. The procedures used by the contractor for earthwork construction were investigated. Densities were taken in the cut areas at finished grade by District personnel. These values were compared to the average compacted in-place densities of the fills and the difference in volume was calculated. Final cut and fill slope angles were measured and compared to the designed slope angles and the difference in volume was calculated. The total volume of boulders protruding from the cut faces was estimated. The total volume of boulders that rolled down slopes and out of the embankment areas was estimated. A total of forty-two seismic refraction lines were obtained from the entire length of the project. Field earthwork factors, determined after construction, were compared to design earthwork factors and to the seismic velocities obtained in the cut areas. A table was developed comparing seismic velocities to earthwork factors.

KEY WORDS: Earthwork factors, shrinkage and swell, earthwork construction, seismic velocities, mass diagram, research.

Acknowledgments

The authors wish to express their appreciation to the construction personnel of District 11 of the California Division of Highways.

Special thanks are extended to Mr. Robert Winterborne, the Resident Engineer on this project, for his time, comments, and for supplying the construction information used in this report.

This investigation was made in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Agreement Number F-07-92.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

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Introduction

An important objective of the mass diagram of a large earthwork project is obtaining the most economical balance of quantities. The ultimate goal is to place into the embankments the same amount of material that is excavated. This would be possible if such factors as different types of materials, subsidence of original ground, different construction methods, compacting the fills to exact specifications, constructing the exact designed slopes, and the shrinkage and swell of the excavated material did not exist.

The shrinkage and swell of the excavated material can be corrected by applying an earthwork factor. The earthwork factor is a ratio expressing the number of cubic yards of embankment resulting from one cubic yard of excavation. An earthwork factor less than 1.0 indicates a shrinkage; an earthwork factor greater than 1.0 indicates a swell.

There is no standard method for determining the design earthwork factor for the excavated material. Common practice is to determine a shrinkage factor for the surface material and then estimate the shrinkage or swell of the rock in the area from previous construction projects or previous information on the rock type involved. The overall earthwork factor is then obtained by determining the amounts of the various materials involved and their estimated shrinkage and swell.

The amounts of the various materials involved are often estimated by visual inspection or from a limited number of borings. These methods may be adequate where relatively small cuts are involved but not for large earthwork projects.

The California Highway Districts in recent years have made increasing use of shallow seismic studies for design purposes. By the use of this method, under favorable conditions, it is possible to obtain a relatively clear picture of the subsurface conditions. In 1966 and 1967 two of the California Highway Districts, working independently, attempted to correlate seismic velocities with earthwork factors. Both studies were mostly in granitic rock. This department evaluated the data obtained and determined that there was a reasonable correlation. Since this evaluation, we have been providing information for earthwork factors from seismic velocities on granitic rock to all districts that request it.

The demand for this type of information has increased rapidly, and we are now receiving requests for earthwork factor estimates in a variety of rock types. This study will provide information needed to evaluate the validity of earthwork factors obtained from seismic velocities on igneous, sedimentary and metamorphic rock.

A Bison Model 1570 signal enhancement seismograph instrument was used for determining the seismic velocities in this study. The impact of a 10-pound sledgehammer striking an aluminum plate was used to generate shock waves. The maximum length seismic line was 150 feet.

District personnel involved in determining the design earthwork factor, in all eleven California highway districts, were contacted. This was to obtain any pertinent information or ideas that the districts might have about the design earthwork factor and also to determine if all districts use a common method to obtain the earthwork factor.

The majority of the districts indicated that the principal methods used by each to derive design earthwork factors are materials investigations, records of past construction projects with similar soil conditions, and experience. One district determines the design earthwork factors by using a ratio of the percent relative compaction of proposed excavations to an estimated percent relative compaction of the same material compacted into the embankments.

The principal objectives of this research study are to:

1. Determine if earthwork factors can be correlated to seismic velocities.

2. Determine the relationship between field earthwork factors and design earthwork factors.

3. Determine which construction procedures influenced the final earthwork quantities.

Conclusions

There was a reasonable correlation between seismic velocities and field earthwork factors for the igneous material on this project. A table was developed from the information correlating field earthwork factors to seismic velocities.

The construction procedures that influenced the final earthwork quantities on this project were:

1. Protruding boulders were not removed from the cut faces for aesthetic reasons. This resulted in less material from the cuts than designed.

2. Some boulders rolled down and out of the fill areas. This resulted in more material for the fills than designed.

3. An average of 95 percent relative compaction was attained instead of the required 90 percent. This resulted in more material in the fills than designed.

4. The material used for concrete aggregate, aggregate base, C.T.B., aggregate subbase and structure backfill came from two of the cuts on the job. This resulted in less material for the fills.

The above construction procedures should have resulted in a shortage of fill material. Since there was an excess of material, the design earthwork factors used for this project were much too low.

This is the first of three interim reports to be published for this research study. Projects constructed in sedimentary and metamorphic materials will be investigated before final conclusions can be attained.

Geological Description

The material on this project is a dark gray to brown silty sandy soil that overlies biotite quartz diorite bedrock. The soil composition clearly reflects the mineral composition of the underlying parent rock. Quartz, plagioclase, degraded biotite and hornblende are the predominant mineral constituents; halloysite is commonly a minor constituent and locally montmorillonite is present in significant amounts.

The degree of weathering of the rock on this project varied with the mineral composition of the rock.

Construction

This project is on Interstate Highway 8 located 6.0 miles east of Alpine to Japatul Valley Road in San Diego County. The project consists of about 6.4 miles of freeway constructed by grading and surfacing with portland cement concrete and asphalt concrete on cement treated base and aggregate base. Two bridges were constructed, one over the Sweetwater River and the other over Japatul Valley Road. This research study includes only the portion of the project between Stations 895+00 and 60+00 on the mainline. The location of this project is shown in Figures 1 and 2.

The project was in the final stages of construction when the field portion of this study began (see Photo 1). Construction methods and details were obtained from the resident engineer and the project inspectors.

A large cut on the west end of the job consisted of hard granitic material (see Photo 2). Approximately 90 percent, 1.6 million cubic yards, had to be blasted. Close pattern drilling and shooting was required to get the rock small enough to transport by a special conveyor belt. Three-inch holes were bored on a 7 x 7 foot pattern and five-inch holes were bored on an 8 x 8 foot and larger pattern to depths between 27 and 40 feet.

The explosive material, a commercial product called Pellite, was hose fed into the drilled holes and detonated. The powder ratio for the job averaged 1.5 pounds per cubic yard of material. The average shot broke up 10,000 cubic yards.

The "shot" rock was moved across the existing highway by the conveyor belt capable of handling rock as large as four feet in diameter. Rock larger than four feet was placed into a special disposal area on the west end of the cut.

The rock spilled from the end of the belt into a large fill area across from the cut. It was then loaded onto trucks and spread to build the largest fill on the project, approximately 4000 feet long with a maximum height of 365 feet, containing 3 million cubic yards of material.

This fill was constructed by spreading decomposed granite, from a cut on the east end of the fill, onto layers of the shot rock. The finer material flowed into the rock voids more readily when it was on the dry side. Two segmented type compactors were utilized, but most of the compaction was obtained by the hauling equipment. Compaction tests could not be taken on this fill because of the high percentage of large rock.

The rest of the project was a routine scraper-ripper operation with some "boulder popping" work.

Summary

Design earthwork factors were provided on the mass diagram for three separate areas of the portion of the project investigated. Station 886 to Station 931 is designated as Area 1, Station 931 to Station 973 as Area 2 and Station 973 to Station 60 as Area 3. These three areas were investigated separately for earthwork quantities. A field earthwork factor was calculated from the earthwork quantity sheets for each area and compared to the design earthwork factors. Table 1 shows that the design earthwork factors are lower than the field earthwork factors.

Table 1

Area	Surplus Cubic Yards	Earthwork Factors Design	Earthwork Factors Field
1	362,250	1.15	1.25
2	48,615	1.10	1.14
3	142,230	1.00	1.07

There was a surplus of 800,000 cubic yards of material above the design quantity which included a massive slide at Station 961 of 180,000 cubic yards. Material from the big rock cut was of such quality that it was used for concrete aggregate and aggregate base. The decomposed granite was used for CTB aggregate, aggregate subbase and structure backfill. The surplus in the three areas shown in Table 1 was 553,100 cubic yards and the total surplus for the project amounted to 675,000 cubic yards.

Compaction was not a problem on this project. Only 12 relative compaction tests failed out of the 340 tests taken in Areas 2 and 3. Area 1 could not be tested because of the high percentage of rock. The average relative compaction in Areas 2 and 3 was 95 percent of the California maximum impact test.

If the average relative compaction on the fills tested had been 90 percent instead of 95 percent there would have been another 200,000 cubic yards of surplus material.

The final earthwork quantities would be affected if there is a difference in the designed slope angles and the constructed slope angles of cuts and fills. If the fill from Station 921+00 to Station 958+00 had been constructed one degree steeper than designed, there would have been another 90,000 cubic yards of surplus material.

All the slope angles were measured at approximately 100-foot intervals after the project was completed. The angles of the finished slopes were so close to the designed slope angles that the volume of material involved did not affect the final earthwork quantities.

The special provisions for this project specified a 5-foot tolerance for any point measured at right angles to the finished slope in lieu of the 2-foot tolerance in the standard specifications for excavation in rock. Most of the finished cut slopes had protruding boulders that were not removed in order to provide a more natural looking slope (see photos 3 and 4). The protruding boulders amounted to approximately 2700 cubic yards.

During the construction of the rock fills, some of the material rolled down the slopes and out of the project area. The large fill at Station 920 to Station 959, constructed from "shot" rock and decomposed granite 365 feet high, accounted for almost all of the lost material. The volume of rock that rolled out of the fills was estimated at approximately 3300 cubic yards (see Photos 5 and 6).

The resident engineer said they had taken several in-place densities in the cut areas at finished grade and the average of these tests was 160 pounds per cubic foot. This is approximately 20 pounds per cubic foot higher than the overall average of the compacted densities in the fills.

An earthwork factor based on the ratio of the densities in the cut areas to the compacted densities would be 1.14 for all of the job except the material that went into the big rock fill where compaction tests were not taken. The average of the field earthwork factors for Area 2 and Area 3 is 1.11 or .03 less than the one calculated by the density ratio.

Forty-two seismic lines were required to investigate the entire length of project. Layer thickness of the material in the cuts having the same velocities was determined and plotted on the project cross-sections. There were at least two layers of material in each cross-section with some having three and four. The volume of material having the same velocities was determined from the cross-sections using a planimeter and the average end area formula.

The three areas to which the district assigned earthwork factors were separated and a single weighted average velocity was determined for each area. The weighted average was obtained by the summation of the percentages of material having the same velocity in each area.

Field earthwork factors were calculated from the project quantity sheets for each of the three areas and compared to the average seismic velocity for that area. Table 2 summarizes this data.

Table 2

Area	Average Seismic Velocity	Field Earthwork Factor
1	5900 fps	1.25
2	3400 fps	1.14
3	3600 fps	1.07

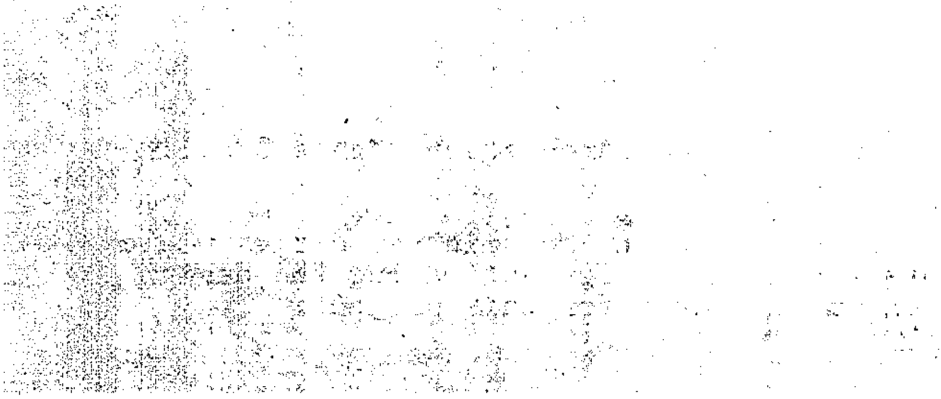
Table 3 was developed using the field earthwork factors calculated from the earthwork quantity sheets after the project was completed and the average weighted seismic velocities. Velocities in the 4000 feet per second to 5500 feet per second range were not encountered on this project. The earthwork factors between 1.15 and 1.24 were extrapolated from the data attained.

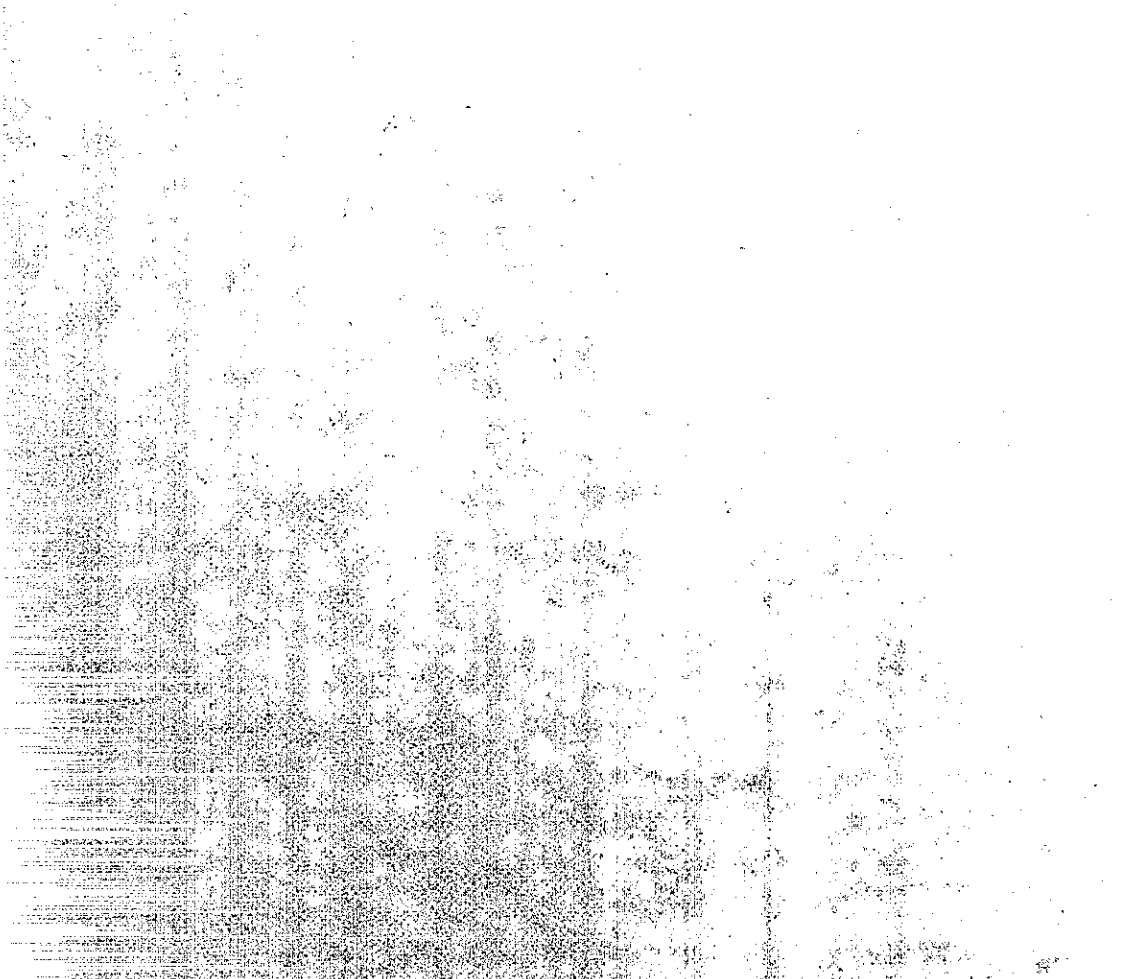
Table 3

Earthwork Factor	Seismic Velocity
1.05 - 1.14	3000 - 4000 fps
1.15 - 1.24	4000 - 5500 fps
1.25 - 1.34	5500 - 6500 fps

As more data is obtained from this research study, Table 3 will be expanded and revised.

Although the correlation is not perfect, seismic velocities would have provided more accurate guidelines for estimating the design earthwork factors than the method used for this project.





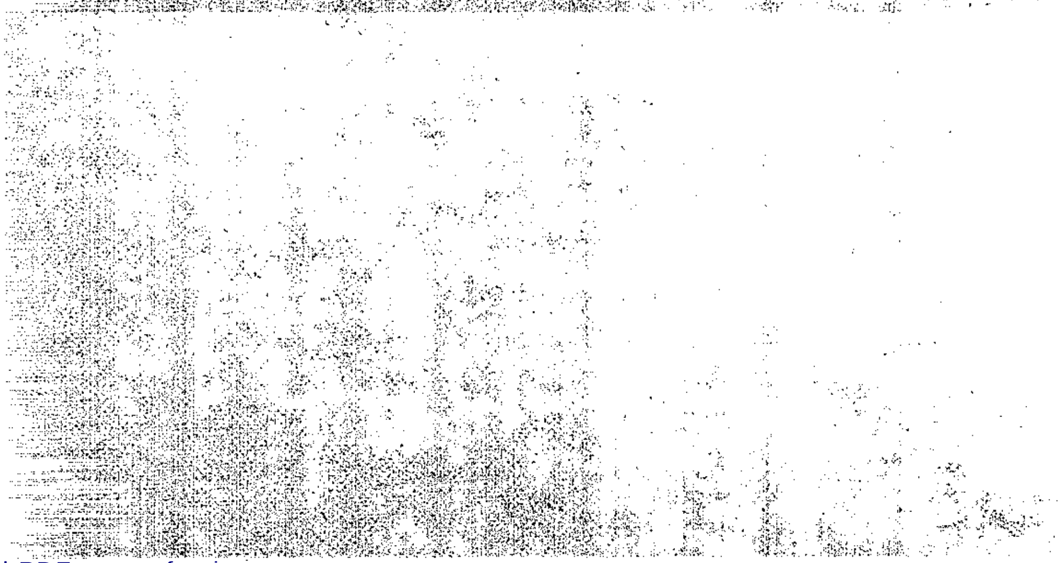


Figure 1

LOCATION MAP

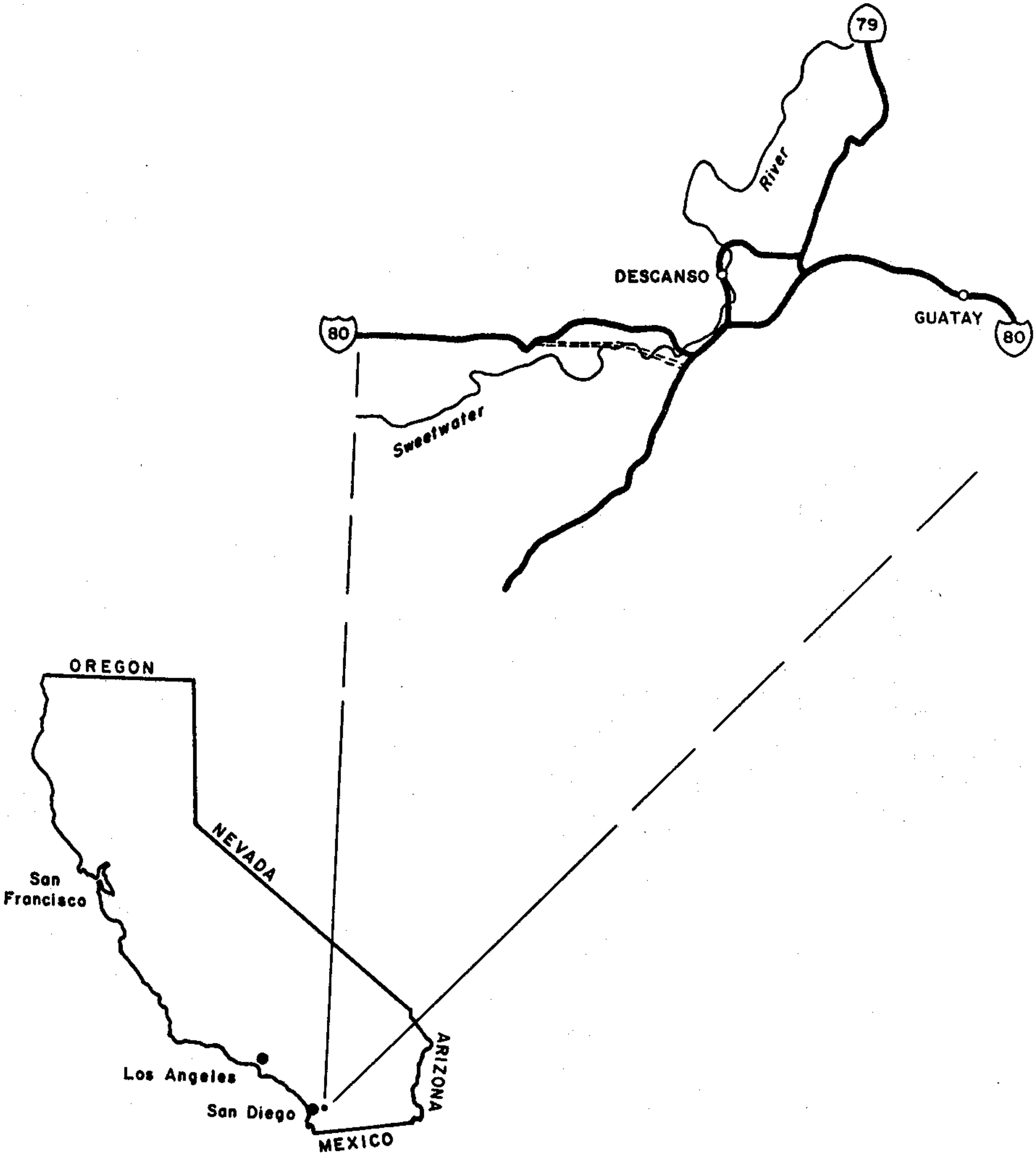
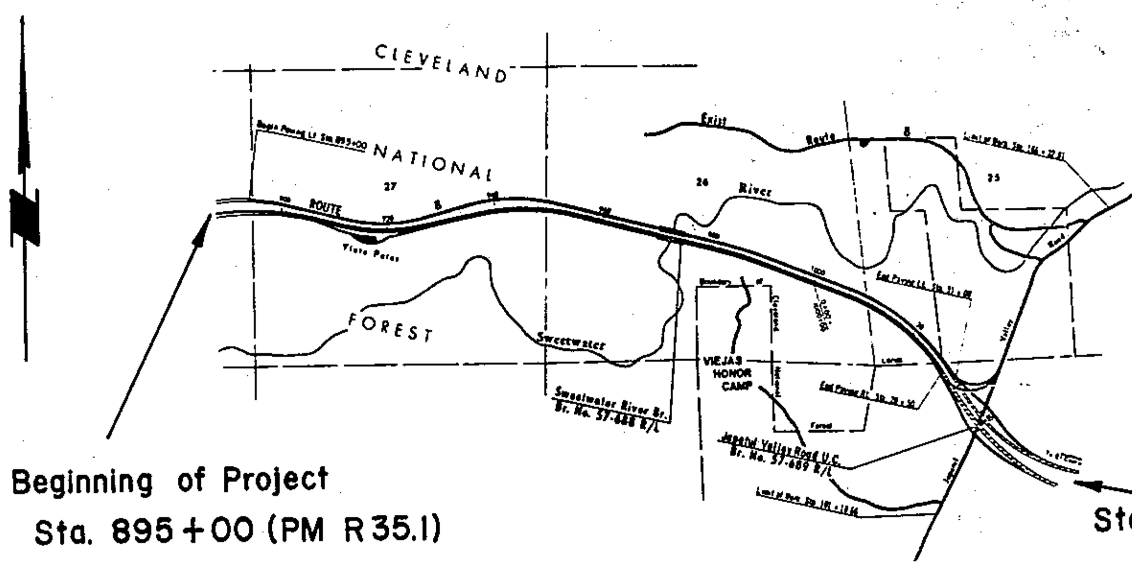


Figure 2

IN SAN DIEGO COUNTY BETWEEN 5.8 MILES EAST OF
WEST VICTORIA DRIVE AT ALPINE AND
0.4 MILE EAST OF JAPATUL VALLEY ROAD



Beginning of Project
Sta. 895+00 (PM R35.1)

End of Project
Sta. 60+00 (PM R38.2)

Scale in feet

0 2000 4000

Length of Project = 3.1 miles

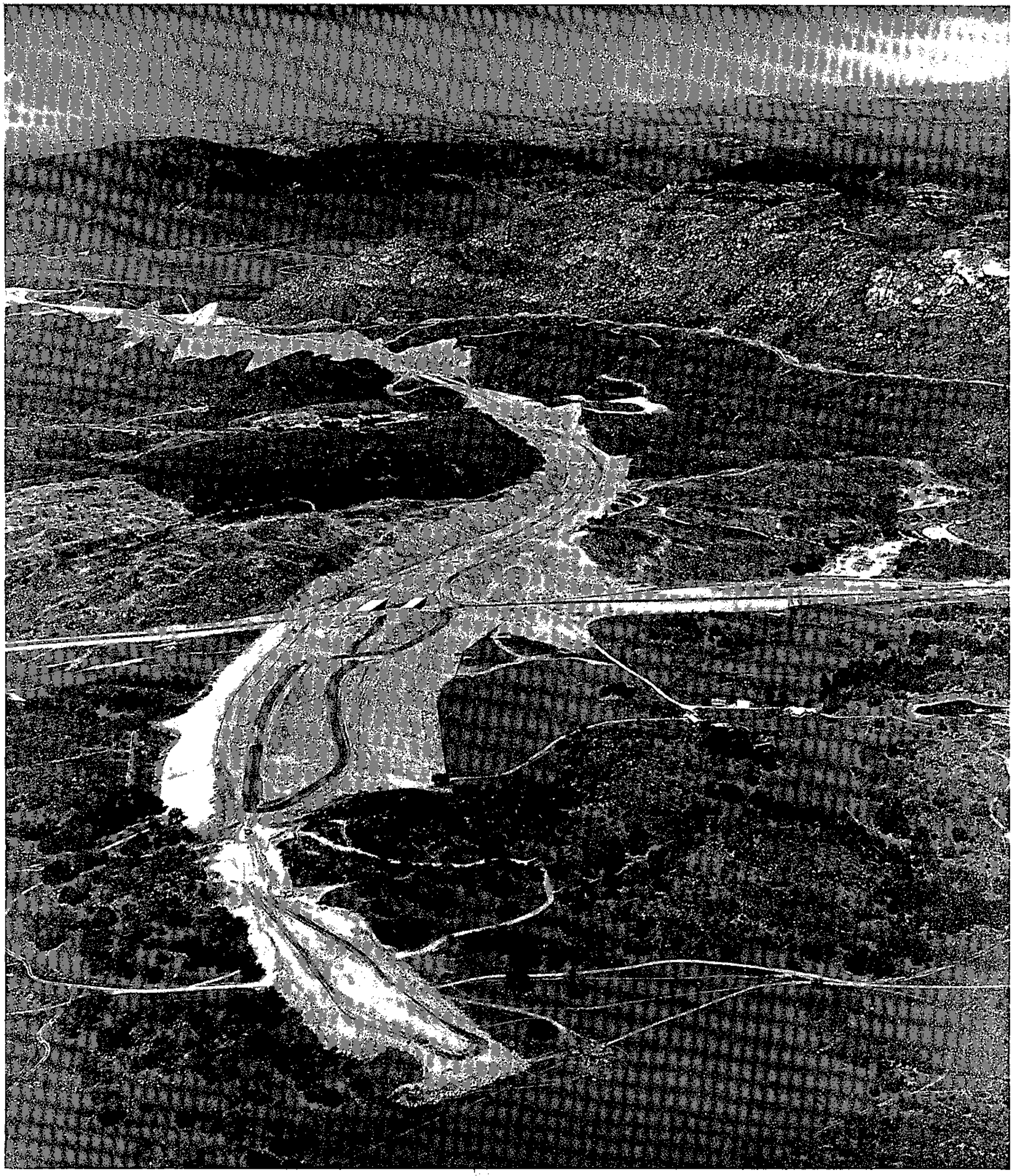


Photo 1   Length of Project

Photo 2   Rock Cut and Fill

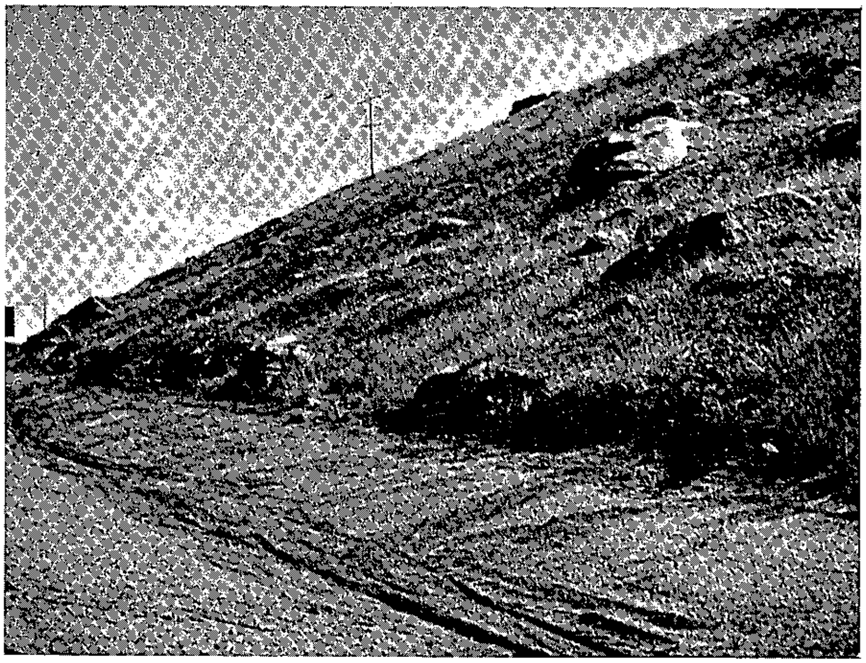


Photo 3 Protruding Boulders

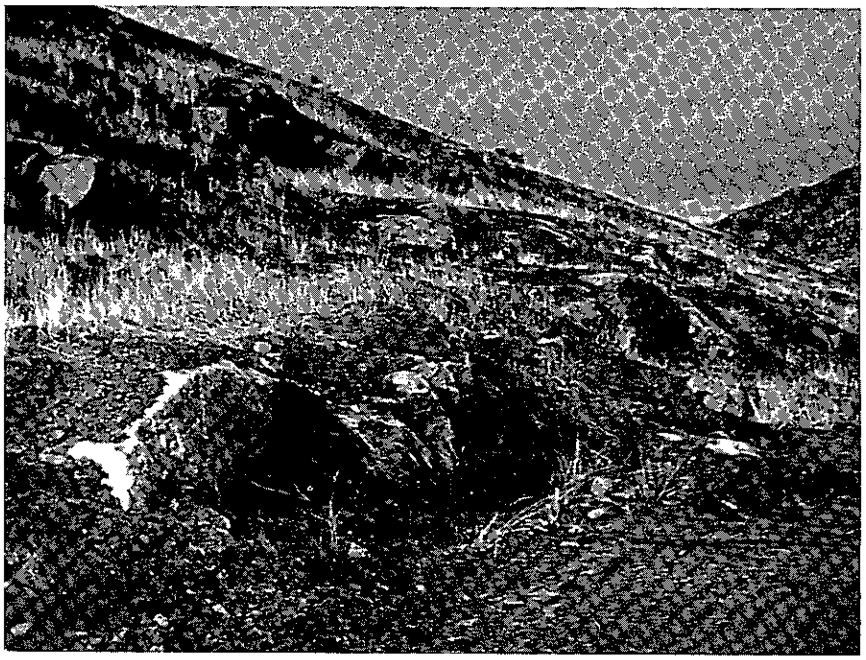


Photo 4 Protruding Boulders

Photo 5   Boulders Rolled Out of Fills

Photo 6   Boulders Rolled Out of Fills