UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

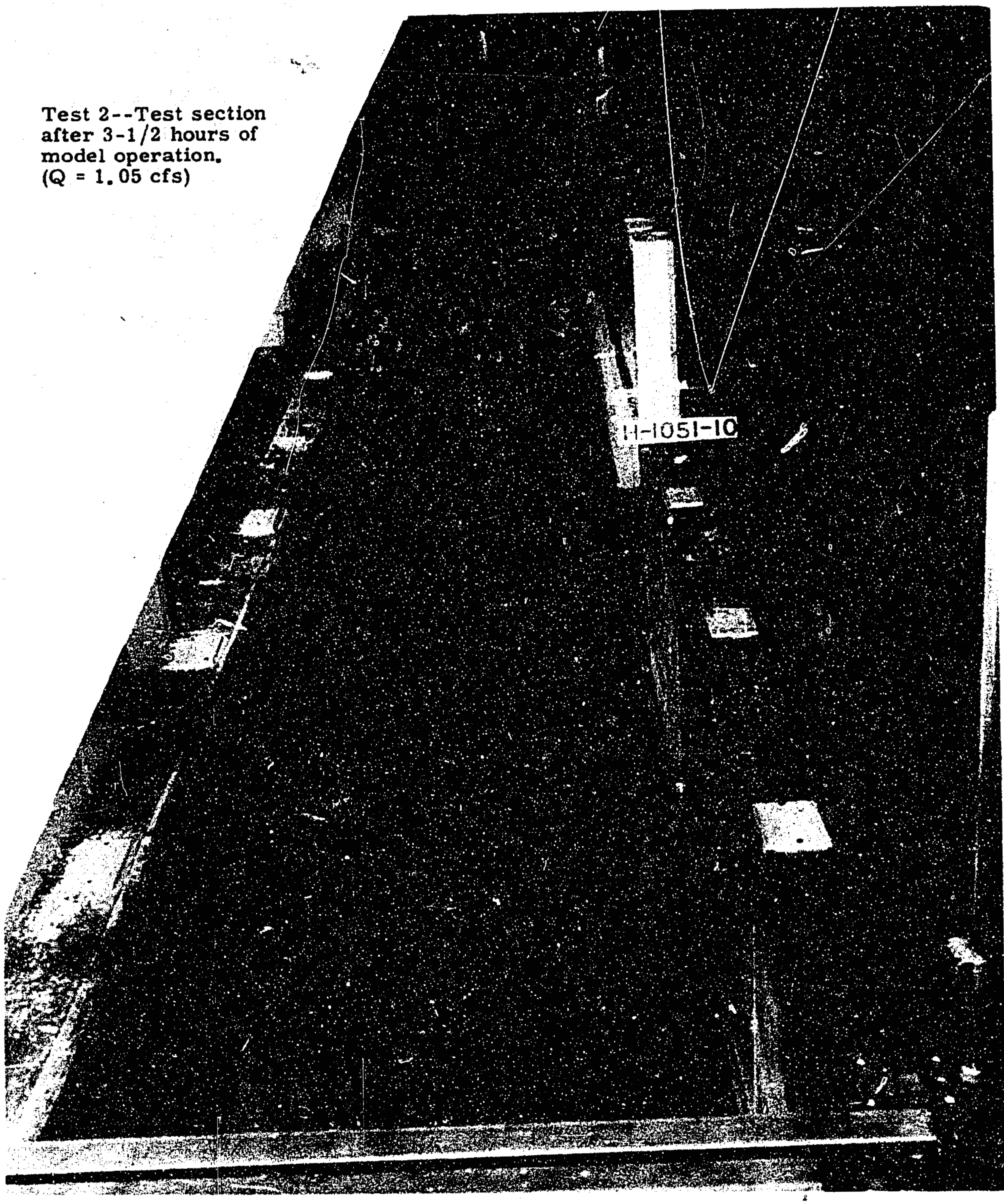
# RESULTS OF SOIL AND HYDRAULIC TESTS ON PROPOSED CANAL-LINING MATERIAL FROM BORROW AREA 13 FOR MADERA IRRIGATION DISTRICT MADERA DISTRIBUTION SYSTEMS MADERA CONSTRUCTION DIVISION CENTRAL VALLEY PROJECT

Progress Report No. 2
General Report No. 16
Same As HYD-358

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

November 23, 1953




Test 2--Test section after 3-1/2 hours of model operation. (Q = 1.05 cfs)

Central Valley Project
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

FRONTISPIECE

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## APPENDIX

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Design and Construction Division
Engineering Laboratories Branch
Denver, Colorado
November 23, 1953

*General Report No. 16
Earth Laboratory and Hydraulic Laboratory Sections
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Subject: Results of soil and hydraulic tests on proposed canal-lining material from Borrow Area 13 for Madera Irrigation District--Madera Distribution System--Madera Construction Division--Central Valley Project

## INTRODUCTION

The tests reported herein were made on soil samples representative of Borrow Area 13 which was proposed for use as canal-lining material for laterals and sublaterals in Unit No. 1 of the Madera Irrigation District.

Borrow Area 13 is located 7 miles south and 5 miles west of Madera, California, on County Road 7-E. The location map is shown in Figure 1 and the plat location with the location of samples in the borrow area is shown in Figure 2.

Twenty-nine sack samples were transmitted to the Earth Laboratory by letter dated March 26, 1952, from the Construction Engineer, Friant, California, to the Chief Engineer under the subject "Earth samples, proposed Borrow Area No. 13--Madera Construction Division--Central Valley Project." The letter requested tests on the soil to determine suitability for earth canal lining and compacted embankments. Also, a request was made to determine the amount of alkali present and its effect on canal embankments caused by leaching action.

## SOIL TESTS

Visual classifications of the material from Borrow Area 13 indicated that it would probably be suitable for compacted embankment but that it lacked the cohesion necessary for a suitable canal lining.

*See Laboratory Reports No. Hyd-358 and EM-303

Representative samples of the average, finest, and coarsest materials were selected for gradation, specific gravity, compaction, permeability and Atterberg limits tests, and portions of the representative samples were submitted to the Chemical Engineering Laboratory for quantitative alkali tests.

A summary of the soil tests is shown in Table 1. The gradation curves are in Figures 3 through 5 and the compaction curves in Figures 6 through 9. Quantitative tests on the soil samples submitted to the Chemical Engineering Laboratory showed that the soluble sulfate content of all samples was below 0.04 percent. Also, electrical resistivity tests produced very low values. This indicates that the leaching of salts from the soil in an embankment would be negligible and would not affect the soil stability.

## HYDRAULIC MODEL STUDIES OF EARTH MATERIAL

The soil in question was nonplastic and ordinarily would be rejected for use as canal-lining material. Little information concerning the use of such soil for this purpose is available. In an effort to obtain such information, a model canal section using the material as a lining was constructed in the Hydraulic Laboratory and subjected to flowing water of various boundary shears. The model study was the first of its type conducted in the Hydraulic Laboratory. Due to the limited time available for the study and the lack of sufficient personnel, the tests were undertaken with a view of taking only limited data. These data are plotted and discussed in the succeeding pages. Quantities of soil sufficient for the lining in the model were obtained by forming a composite sample of field samples not used for the soil tests mentioned above. A representative sample of the material used for the hydraulic tests was also subjected to the soil tests enumerated in the preceding paragraph.

### Construction and Operation of the Model

The model, in which the tests on the earth-lining material were made, had no geometric scale relations to the prototype structure. The action of the earth-lining material under the boundary shears actually occurring in the prototype was desired. As it is known that the boundary shear varies with the velocity, the model was designed so that the average velocity could be varied to values above and below the prototype design velocity. The model was built in an existing flume, which was constructed of timber lined with sheet metal, and which had cross-sectional dimensions 2 feet wide and 2 feet deep. As shown in Figure 10, the model consisted of a head box, a rock baffle, a 12-foot approach section to a compacted earth section 12 feet long, a 5-foot section downstream from the compacted earth section, a gravel transition to the flume, and a tailgate for controlling the depth of water in the model. On the left side of the channel was a glass window through which the compacted earth section could be viewed during model operation. The approach to the compacted earth-lined section and the section downstream from it were built of cement grout supported by wire mesh on a wooden framework. In cross section they represented a partial section of the preliminary canal design cut off by a vertical wall of tin and glass. The portion of the canal represented consisted of a 6-inch bottom and a side slope of 1-1/2:1. The earth section was placed and compacted over steel plates that had been laid on the flume floor with coarse sand compacted around them. The steel plates were used to reduce the resilience of the floor so greater density could be obtained by hand compaction. The side slope and bottom width of the compacted earth section were varied for the different tests. General over-all photographs of the preliminary design are shown in Figure 11. Water for the tests was measured by a 6-inch venturi meter in the supply line, and the discharge was varied by the manual operation of a valve near the head box. The depth of water in the model was controlled by raising and lowering the tailgate in the channel. Water-surface elevations were read by means of hook gages in stilling-wells outside the channel. Cross sections were taken before and after each run at Stations 0+03.9, 0+05.9, 0+07.9, 0+09.9, and 0+11.9 when these stations were not in a transition area. The cross sections were taken with a point gage mounted on a level aluminum channel support. A network of velocity readings was taken at each appropriate cross-sectional station. Velocities were determined with a pygmy current meter mounted on the level channel support. For each test photographs were taken of the water-surface conditions and the scour pattern. Photographs showing the gradation of surface material were taken when a gravel cover was used over the compacted earth.

## Placement of Soil

The composite soil sample used for lining was brought up to optimum moisture content (13.6 percent of the dry weight of soil) by mixing water with the soil in a hand-shoveling operation. The soil was compacted in thin layers to a depth of 5 inches in the test section representative of a portion of the canal bottom and one side slope (see Figure 10). Density tests on the soil were made by forcing a small steel ring of known volume into the soil and obtaining the weight of soil in the ring. The average of the density test results showed that the dry density of the lining as placed in the model was 95.3 percent of the standard laboratory maximum dry density. The maximum dry density was 114.8 lb per cu ft.

## Statement of Hydraulic Problem

It is generally known that water flowing in an open channel has a velocity distribution that varies throughout the depth--the variation depending on the type of flow. For most open channels, turbulent flow occurs throughout most of the depth. As explained by H. A. Einstein in Technical Bulletin No. 1026, United States Department of Agriculture, the velocity distribution for open channels is best described by the logarithmic formulas based on Von Karman's similarity theorem, with the constants proposed by Keulegan. The formulas are given for two cases: the first case, as shown in Figure 12a, represents a condition where the boundary is smooth and a laminar sublayer exists near the boundary; the second case, as shown in Figure 12b, represents a condition of turbulent velocities from zero velocity to the water surface. A formula derived from Von Karman's universal logarithmic velocity distribution law by V. A. Vanoni (Civil Engineering, June 1941) agrees with the above formula in the turbulent range of flow.

As pointed out by E. W. Lane in his "Progress Report on Results of Studies on Design of Stable Channels," Report No. Hyd-352, when a particle is resting on a level bottom of a canal the force acting to cause motion is that due to the motion of the water past the particle. If scour is to be prevented, this motion must not be rapid enough to produce forces on the particle sufficiently large to cause it to move. From the general velocity distribution curves of Figure 12 it may be seen that the velocity distribution near the bed plays an important part in moving the particle. The higher the velocity gradient past a given particle the larger the force acting on the particle. Therefore, the slope of the velocity distribution curve near the boundary plays an important part in moving the sediment load. It is doubtful that the velocities which cause the bed load to move can be compared by comparing mean velocities in the model and prototype, but could be compared on the basis of the velocity distribution near the boundary. Due to the limited time of the study and the equipment available at the time, it was deemed impractical to measure velocities nearer to the boundary than about 0.1 of the depth or 0.06 foot. In an attempt to compare velocity distributions in the model and prototype, the actual velocity distributions in the model, for values above 0.1 of the depth, are plotted with the Vanoni theoretical velocity distribution in the model and prototype, using the dimensionless ratio y/d.

As the present knowledge of velocities near the bed is limited, the bed-load movement is usually related to the average boundary shear at the bed ($T_o$ = wds), where $T_o$ is the average boundary shear, w is the specific weight of water, d is the depth of flowing water and s is the slope of the energy gradient. The result from this method is valid for a bed near the center of a wide channel. For the bed of a narrow channel the tractive force is usually given as ($T_o$ = wrs) where r is the hydraulic radius and the other symbols have the same meaning as in the preceding formula. For side slopes of trapezoidal or other channels, a correction factor must be applied. Figure 13 shows the average boundary shear of the model and prototype plotted against the velocity. It is recommended that, in additional studies of this type, equipment for measuring velocities nearer the bed be developed.

Further information regarding the movement of material by velocities in the boundary layer and the relation of the tractive force to velocities near the bed may be obtained from G. H. Keulegan's

"Laws of Turbulent Flow in Open Channels," National Bureau of Standards Research paper RP1151, and from A. A. Kalinske's "Movement of Sediment as Bed Load in Rivers," Transactions American Geophysical Union, Volume 23, August 1947, pp. 615-620.

Hydraulic Model Tests

Each model test consisted of recording the changes in the compacted earth lining under the action of flowing water and determining the boundary shear acting on the compacted earth lining. The design velocity in the preliminary design for the prototype lateral was 1.14 fps. In the model tests the average velocity was varied between the approximate velocities of 0.8 and 2 fps. In order to create the higher velocities in the channel, the slope of the channel bottom was designed for normal flow at a velocity of 2.5 fps and a depth of 0.8 foot. To keep the model flowing at a desired depth and velocity, below 2.5 fps, at a given station it was necessary to raise the tailgate slightly. This created a back-water curve with flow greater than normal depth, and as a result, the depth of water varied slightly from station to station, the depth decreasing with the distance upstream from the tailgate. The decrease was slight, although measurable, and it seemed to have very little effect on the velocity distribution. As is shown in the following pages, a reasonable prediction of a portion of the theoretical vertical velocity distribution in the prototype and the general action of the lining material under the velocities occurring may be obtained by use of the model data.

The section first tested in the model proved unsuitable, therefore, two additional side slopes, 1-3/4:1 and 2:1, and sand-gravel blankets, to cover the earth and stabilize the slopes, were tested. The sand-gravel blankets were of two different gradations, one with a 3/8-inch maximum size and the other with a 3/4-inch maximum size (see gradations in Figure 5). The grading was similar to that from an aggregate deposit (Los Banos) which could be used for the laterals of the Madera Irrigation District.

A description of the various earth sections tested in the hydraulic model and the results of the tests are presented in the following pages.

Test 1 (preliminary design). The preliminary compacted earth test section was of the same dimensions as the constructed sections upstream and downstream. It consisted of one vertical wall of tin and glass, a 6-inch-wide bottom of compacted earth, and one 1-1/2:1 side slope of compacted earth, as shown in Figures 10 and 11. The model was filled slowly, from the downstream end, with a garden hose and a discharge of 0.655 cfs was set in the supply line. As the discharge was set, the tailgate was manipulated so that the depth of water at the end of the test section remained constant at 0.80 foot. The average velocity occurring in the test section for this depth and discharge was 0.78 fps. The model remained in continuous operation at the preceding conditions for a period of 23 hours. After all data necessary were taken, the model was turned off and the tailgate manipulated so as to maintain the 0.80-foot depth. The water was then gradually lowered from the compacted earth test section over a period of 4 hours. In all tests the same procedure was used in filling and draining the model.

Immediately after flow started over the test section, it was noticed that the water became cloudy with suspended sediment. In a few minutes the water began to clear and remained clear for the remainder of the operational period. When the water became clear, loose particles on the surface of the compacted earth were observed moving diagonally down the side slope. The particles appeared to stop about halfway down the side slope; but after running the model overnight, they appeared to have continued to the bottom of the channel. A few very small sand riffles formed after approximately 8 minutes of operation, but smoothed out after a few hours. The lining appeared to stand exposure to the flowing water very well, but it became very soft to the touch during the later stages of operation. Detrimental sloughing, as shown in Figure 14, was noticed when the water was lowered in the test channel. The sloughing began when the water surface had been lowered about 0.1 foot below the test level and continued until the water had been completely withdrawn.

The cross-sectional data taken before and after the test run are shown plotted in Figure 15. From these data a slope of the energy grade line of $3.75 \times 10^{-4}$ and a Manning's "n" value, for the compacted earth, of 0.019 was calculated (Table II and Appendix I). Velocity measurements, taken in the model at 0.70 foot from the vertical wall, are shown plotted on Figure 16. These plotted points are shown in the form of a dimensionless ratio (y/d) plotted against the velocity. A curve, representing the average velocity distribution occurring in the plane (0.70 foot from the vertical wall), has been drawn through the plotted points. The average velocity occurring in the plane is taken as the velocity which occurs at 0.63 of the depth below the surface. The depth is computed from the Von Karmen formula as presented by V. A. Vanoni,

$$V = \bar{V} + \frac{1}{k} \sqrt{grs}\,(1 + 2.3 \log \frac{y}{d}).$$

in which a logarithmic velocity distribution is assumed and the terms are defined as :

$V$ = the velocity at any distance y from the bottom of the channel

$\bar{V}$ = the average velocity in the plane

$k$ = Von Karmen's universal constant having a value of 0.4

$g$ = the acceleration of gravity

$r$ = the hydraulic radius

$s$ = the slope of the energy gradient

$y$ = the distance above the bottom of the channel to any point

$d$ = the depth of flowing water

The hydraulic radius r instead of the depth d was used in the term $\sqrt{grs}$ in an attempt to compensate for the difference in shape between model and prototype. The hydraulic radius with reference to the compacted earth, according to a method presented by Dr. H. A. Einstein in Paper No. 2140 of the ASCE Transactions (see Appendix 1) was used in the formula for calculating the velocity distribution in the model. The average velocity occurring in the plane was read from the plotted curve of velocities measured in the model. Using this average velocity, the theoretical vertical velocity distribution, at the center line of the prototype, was computed and plotted in dimensionless form in Figure 16. For all calculations of the prototype normal flow is assumed to exist. On the same figure the theoretical velocity distribution occurring in the model is also plotted. As may be seen from a study of Figure 16 the curves are in good agreement between the values of $y = 0.2d$ and $y = 0.8d$--the maximum deviation being approximately 3 percent. Due to the small depth in the model and the limitation of the instruments available, very few data were taken above or below these depth ratios.

The hydraulic radius with reference to the compacted earth is used in computing the average boundary shear for the model. The various boundary shears for each model test are presented in Table 2. The boundary shear acting in the vertical plane 0.7 foot from the vertical wall is computed from the average velocity distribution curve. As may be seen from a study of Table II, the boundary shear occurring in the plane 0.7 foot from the vertical wall is, in general, higher than the average boundary shear occurring on the compacted earth. Due to the short test section the difficulty of measuring the energy gradient accurately, the inability to take velocities close to the bed and the necessity of using various questionable formulae in the computations, it is felt that the boundary shear values shown in Table II are approximate only. The average boundary shear that is expected in the prototype at normal depths may be seen plotted in Figure 13. As an aid in comparing the boundary shears that occurred in the model and the boundary shears expected in the prototype, the average values for various model tests have also been plotted on the graph of Figure 13.

Test 2. As the preliminary section proved unsatisfactory, a sand-gravel protection blanket was placed over the compacted earth for comparison. As shown in Figure 17a, half of the test section (the upstream 6 feet) was of compacted earth as in Test 1. The downstream 6 feet was built to the same cross section and consisted of the compacted earth lining protected by a 2-inch layer of sand-gravel of 3/8-inch maximum size (Figure 5). A discharge of 1.05 cfs was set and a depth of 0.80 foot was held at Station 0+12.00. This created an average velocity in the test section of 1.21 fps. The model was in continuous operation for a period of 3-1/2 hours. Cross sections throughout the earth-lined section were taken before and after the test.

Erosion of the unprotected earth section was considerably more than that of the same section in Test 1 with the lower velocity. A study of the photograph of the model in operation (Figure 17b) reveals the erosion due to the higher velocity. The photograph in Figure 18a, and the frontispiece, shows the section after it was drained. Figure 19 shows that the sand-gravel blanket maintained the original canal shape quite well. The small sand particles on the surface of the sand-gravel blanket were washed out, leaving a rough gravelly surface exposed. No sloughing occurred in the downstream test section when the water was drained from the model.

From the data taken during the run, a slope of the energy grade line of $8.71 \times 10^{-4}$ and a Manning's "n" value, for the earth test section, of 0.019 was calculated, as shown in Table 2. As in Test 1, velocity measurements were taken and those at 0.7 foot from the vertical wall are shown plotted in the dimensionless form on Figure 20. The three curves, representing the actual velocity distribution in the model, the theoretical velocity distribution in the model, and the theoretical velocity distribution in the prototype, are shown. The two theoretical velocity distributions were calculated as explained under Test 1. As in the preceding test, there is fair agreement in the velocity distributions between the values $y = 0.2d$ and $y = 0.8d$. It will be noticed that near the surface the actual velocity appears to become smaller. The theoretical velocity distribution does not have this tendency.

The boundary shears for Test 2 (see Table 2) are higher than for Test 1. This was due principally to the higher velocities which created a steeper energy gradient. It may be seen from a comparison of Figures 20 and 16, that while the velocity difference between $y = 0.1d$ and $y = 0.2d$ was approximately 0.23 fps for Test 2; it was only 0.14 fps for Test 1.

Test 3. In Test 3 the compacted earth of the preliminary test was protected by a 3-inch layer of 3/4-inch maximum sand-gravel (gradation shown in Figure 5). The 12-foot test section was divided into two 5-foot lengths each at different side slopes with 1-foot transitions between. As shown in Figure 21, the upstream 5 feet of the test section was the same dimensions as Test 1, with a 1-1/2:1 side slope and a 6-inch bottom width. A 1-foot transition connected the upstream section to a 5-foot test section with a 1-3/4:1 side slope and a 5-inch bottom width. At the end of the downstream 5-foot section another 1-foot transition connected the test section to the formed concrete shape on a 1-1/2:1 side slope. A discharge of 0.824 cfs was maintained throughout Test 3. In order to maintain approximately the same freeboard as in the previous tests, a smaller depth was maintained than for the first two tests. A depth of 0.66 foot was held at Station 0+12.00. The average velocity resulting in the test section was 1.17 fps. The model remained in continuous operation for a period of 22-1/2 hours.

This test indicated that the sand-gravel blanket on the 1-3/4:1 side slope withstood erosion considerably better than that on the 1-1/2:1 side slope. The difference is noticeable on the cross sections plotted in Figure 22. More sand fines were washed from the surface of the 1-1/2:1 side slope than from the 1-3/4:1 side slope. From a study of the photographs in Figure 23 it may be seen that although there is a distinct demarcation where the water surface existed on the 1-1/2:1 side slope, the water line is hardly distinguishable on the 1-3/4:1 side slope. No sloughing was observed when the water was drained from the model.

The slope of the energy gradient of Test 3 was $6.66 \times 10^{-4}$ and the Manning "n" value for the compacted earth was 0.016. The velocity distribution at 0.7 foot from the vertical wall is shown in Figure 24. As in previous tests, the theoretical velocity distributions are also plotted on this figure.

Test 4. As in Test 3, the earth was protected by a 3-inch layer of 3/4-inch maximum size sand-gravel blanket (Figure 5). At the upstream and downstream end of the test section a 1-foot transition connected the concrete-formed sections having a 1-1/2:1 side slope to 10 feet of test section having a 2:1 side slope as shown in Figure 25. The model was filled slowly and a discharge of 0.830 cfs was maintained in the supply line. The resulting average depth and velocity in the test section was 0.649 foot and 1.09 fps. The model was operated continuously for 20 hours.

With the exception of some sand sizes being washed from the surface of the sand-gravel blanket, there was little erosion observed. The stability of the cross section can be seen from a study of the plotted data on Figure 26 and the photographs on Figure 27. If the photograph of the sand-gravel surface on Figure 18b is compared with the photograph of the sand-gravel surface of Test 3, Figure 23, the existence of smaller particles on the 2:1 side slope will be noticed.

An energy gradient of $6.70 \times 10^{-4}$ and a Manning's "n" value for the compacted earth of 0.017 was calculated. As with previous tests, the vertical velocity distribution curves, both actual and theoretical, are shown on Figure 28. The curves are in good agreement over the largest percentage of the depth.

Tests at higher Boundary Shears. Although no boundary shears higher than 0.03 lb per sq ft were expected in the prototype canal it was decided to determine the action of the lining under boundary shears of approximately 0.06 lb per sq ft. Consequently velocities as high as 1.9 fps were set in Test Sections 3 and 4. The model was operated continuously at these higher velocities for periods ranging from 24 to 48 hours. Observations and data from these tests indicated that somewhat more erosion of the sand-gravel blankets occurred at the higher velocities than occurred at the lower velocities; more fines were washed from the surface of the sand-gravel blanket and it became noticeably rougher. The vertical velocity distribution at 0.7 foot from the vertical wall and the theoretical velocity distributions revealed poor agreement at the higher velocities. The velocity distribution was not as uniform as theory indicated and a much greater boundary shear resulted. As no boundary shears of the magnitude found in the high velocity tests are expected in the prototype, no further report on the results of the high velocity tests will be made.

## DISCUSSION OF RESULTS

The soil used for the earth-lining material in the first test was a fine sand with excess silt. It was nonplastic with very little cohesion. At average boundary shears of approximately 0.009 lb per sq ft the lining eroded very little but sloughed badly when the water level was lowered. At higher boundary shears of approximately 0.017 lb per sq ft a considerable amount of erosion and sloughing occurred. The hydraulic tests showed that this material is not suitable for a canal-lining material. A material with more cohesion is necessary to remain stable in the canal bottom and on the side slopes.

The earth-lined section in the model was considerably more stable with a sand-gravel protection cover. The 3/8-inch maximum size sand-gravel cover which was used in Test 2 on a 1-1/2:1 side slope eroded slightly more than did the 3/4-inch maximum size in Test 3 on the same slope. The erosion of the sand-gravel blankets was progressively less in sucessive tests as the side slope was flattened. At the flattest side slope used (2:1) the sand-gravel blanket was relatively stable at an average boundary shear of approximately 0.017 lb per sq ft. In all tests, sand was washed from the surface of the protection cover until larger, more stable particles were exposed.

The plots of vertical velocity distribution indicate that velocities can be computed with reasonable accuracy over a major area of the depth of flowing water. Near the surface the vertical velocity distribution, deviates from the accepted logarithmic velocity distribution formula, as indicated from this and other model and prototype tests. Velocities were taken as close to the bed and surface as possible with the equipment available.

## CONCLUSIONS AND RECOMMENDATIONS

Although the soil is suitable for canal embankment, it is unsuitable for canal lining. At average boundary shears of approximately 0.017 lb per sq ft the material, when used as lining, was subject to considerable scour. When water was drained from the section there was considerable sloughing of the earth material.

The quantity of soluble salts present in the soil is too small to allow any appreciable leaching action and consequent reduction of soil stability in an embankment.

The use of a sand-gravel blanket over the soil in the hydraulic model increased the stability of the earth side slope. The blanket with 3/4-inch maximum size gravel was superior in this respect to that with 3/8-inch maximum size.

The sand-gravel blanket on a 2:1 side slope resisted erosion considerably better than that on a 1-1/2:1 or 1-3/4:1 side slope. A sand-gravel protection blanket with side slopes of 2:1 is considered to result in a side slope of sufficient stability for the prototype lateral in question.

The vertical velocity distribution was in fair agreement with the theoretical logarithmic velocity distribution in all areas measured except near the water surface for average velocities below 1.2 fps. With equipment available, data nearer to the bed than 0.1 of the depth could not be taken. It is recommended that in future studies where deeper channels are available, additional studies of vertical velocity distribution and boundary shears be undertaken.

## TABLE 1

## STANDARD PROPERTIES TEST RESULTS



| Sample Identification | | | Grain-size Fractions In Percent | | | | | | Atterberg Limits | | Classification Symbol Modified Casagrande Method | Specific Gravity | Compaction | | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Laboratory Sample No. 18D- | Field Designation | Depth of Strata (ft) | Clay to Silt: Smaller than 0.005 mm | Clay to Silt: 0.005 mm to 0.074 mm | Sand 0.074 mm to No.4 size | Gravel No. 4 size to 3 inches | Cobbles 3 inches to 5 inches | Oversize Larger than 5 inches | Liquid Limit | Plasticity Index | | | Maximum Dry Density (pcf) | Optimum Moisture Content (%) | Penetration Resistance (psi) | Soluble Constituents | Coefficient of Permeability (ft/yr) |
| X30 | AH-38 | 0.0-6.0 | 6.9 | 40.3 | 52.8 | - | - | - | 19.3 | NP | SF--Silty | 2.66 | 114.5 | 13.0 | 1350 | | 0.47 |
| X31 | AH-43 | 0.0-6.0 | 2.9 | 17.0 | 80.1 | - | - | - | 13.7 | NP | SF--Silty | 2.66 | 123.9 | 9.2 | 850 | | 1.94 |
| X32 | AH-47 | 0.0-6.0 | 6.0 | 32.0 | 62.0 | - | - | - | 17.7 | NP | SF--Silty | 2.68 | 118.3 | 12.0 | 1050 | | 0.41 |
| X33 | * | | 14.0 | 37.0 | 49.0 | - | - | - | 18.6 | NP | SF--Silty | 2.70 | 114.8 | 13.6 | 960 | | - |

*Composite of samples from AH-39, 40, 41, 42, 44, 45, 46, 48, 49.

EM 95-49A (Map Bond)

## HYDRAULIC PROPERTIES OF MODEL

| Run | Q cfs | A | V | S = x $10^{-4}$ | d | $P_b$ | $R_w$ | $(R_w)d$ | $A_b$ | $R_b$ | $N_b$ | $T_o$ | $\tau_s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.655 | 0.841 | 0.779 | 3.75 | 0.788 | 1.92 | 0.140 | 0.110 | 0.731 | 0.381 | 0.0195 | 0.0089 | 0.0097 |
| 2 | 1.051 | 0.869 | 1.21 | 8.71 | 0.780 | 1.97 | 0.144 | 0.112 | 0.757 | 0.384 | 0.0192 | 0.0209 | 0.0372 |
| 3 | 0.824 | 0.702 | 1.17 | 6.66 | 0.688 | 1.73 | 0.168 | 0.116 | 0.586 | 0.339 | 0.0160 | 0.0141 | 0.0306 |
| 4 | 0.830 | 0.758 | 1.09 | 6.70 | 0.649 | 2.02 | 0.151 | 0.098 | 0.660 | 0.327 | 0.0169 | 0.0137 | 0.0265 |

Q = Discharge cfs

A = Area of cross section $ft^2$

V = Average velocity $= \frac{Q}{A} = \frac{ft}{sec}$

S = Slope of energy gradient ft per ft

d = Average depth of test section--ft

$P_b$ = Wetted perimeter of earth material--ft

$R_w = \left(\frac{n_w V}{1.49 S^{\frac{1}{2}}}\right)^{1.5}$ Hydraulic radius with reference to vertical wall

$(R_w)d = A_w$-$ft^2$ area with reference to vertical wall

$A_b = (A-A_w)$-$ft^2$ area with reference to earth material

$R_b = \frac{A_b}{P_b}$ Hydraulic radius with reference to earth material

$n_b = \frac{1.49}{V} S^{\frac{1}{2}} R_b^{\frac{2}{3}}$ Manning's n of earth material

$T_o = WR_bS$ lb/$ft^2$

$\tau_s$ = Boundary shear at 0.7 foot from the vertical wall as computed from the vertical velocity distribution curves

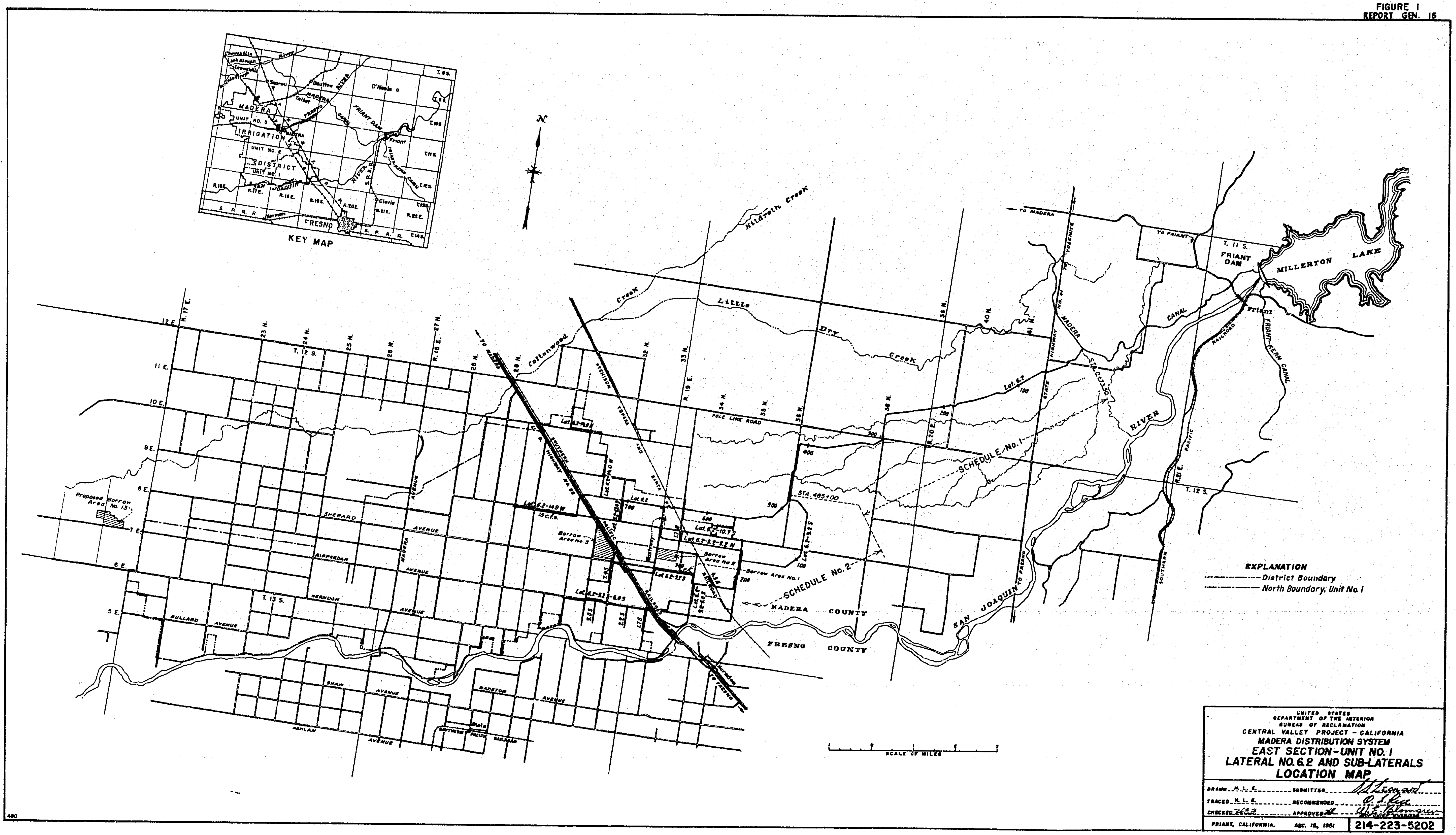

Test Section Shape

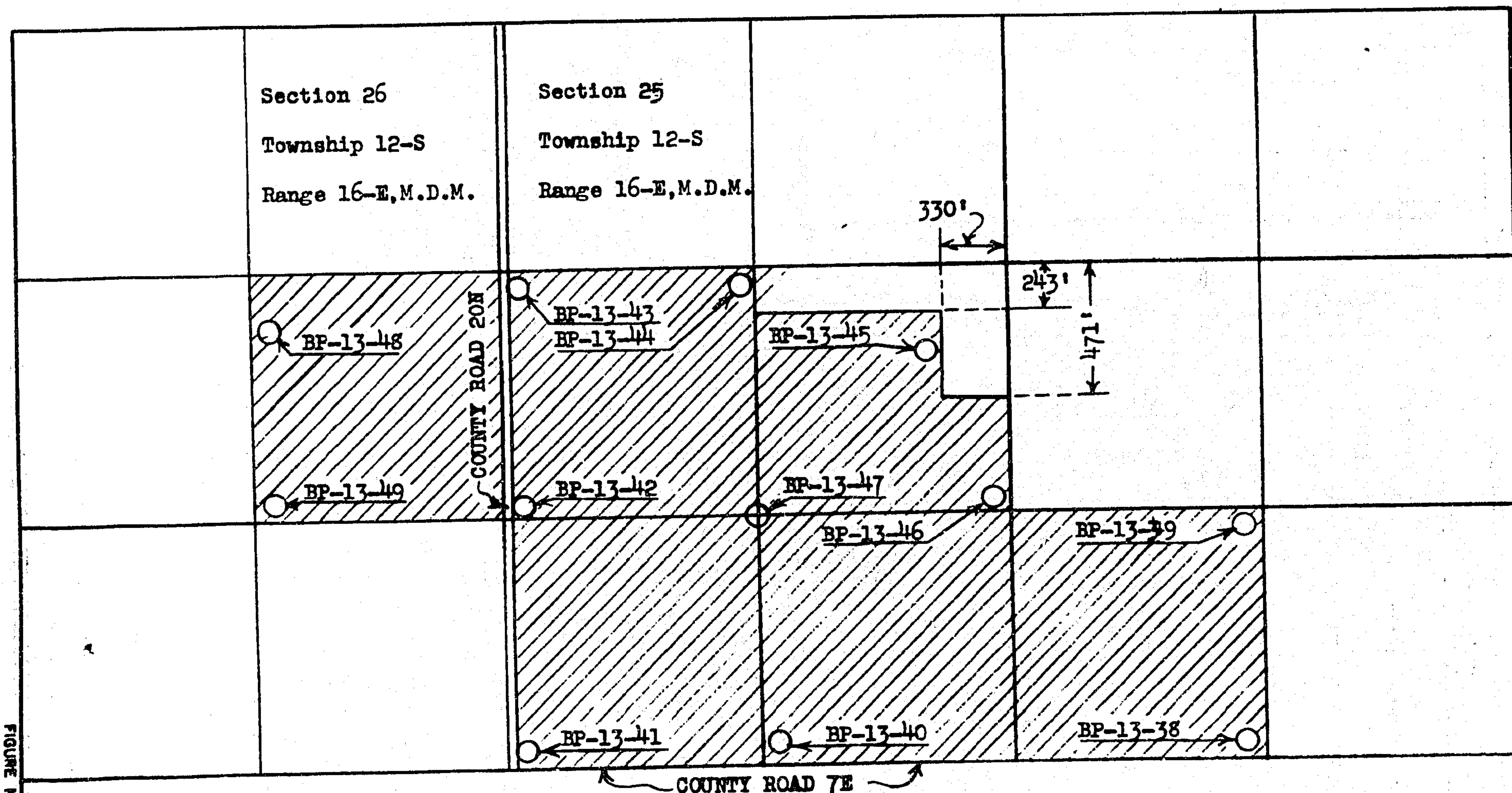
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

Central Valley Project

Table II

FIGURE 1
REPORT GEN. 16






UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

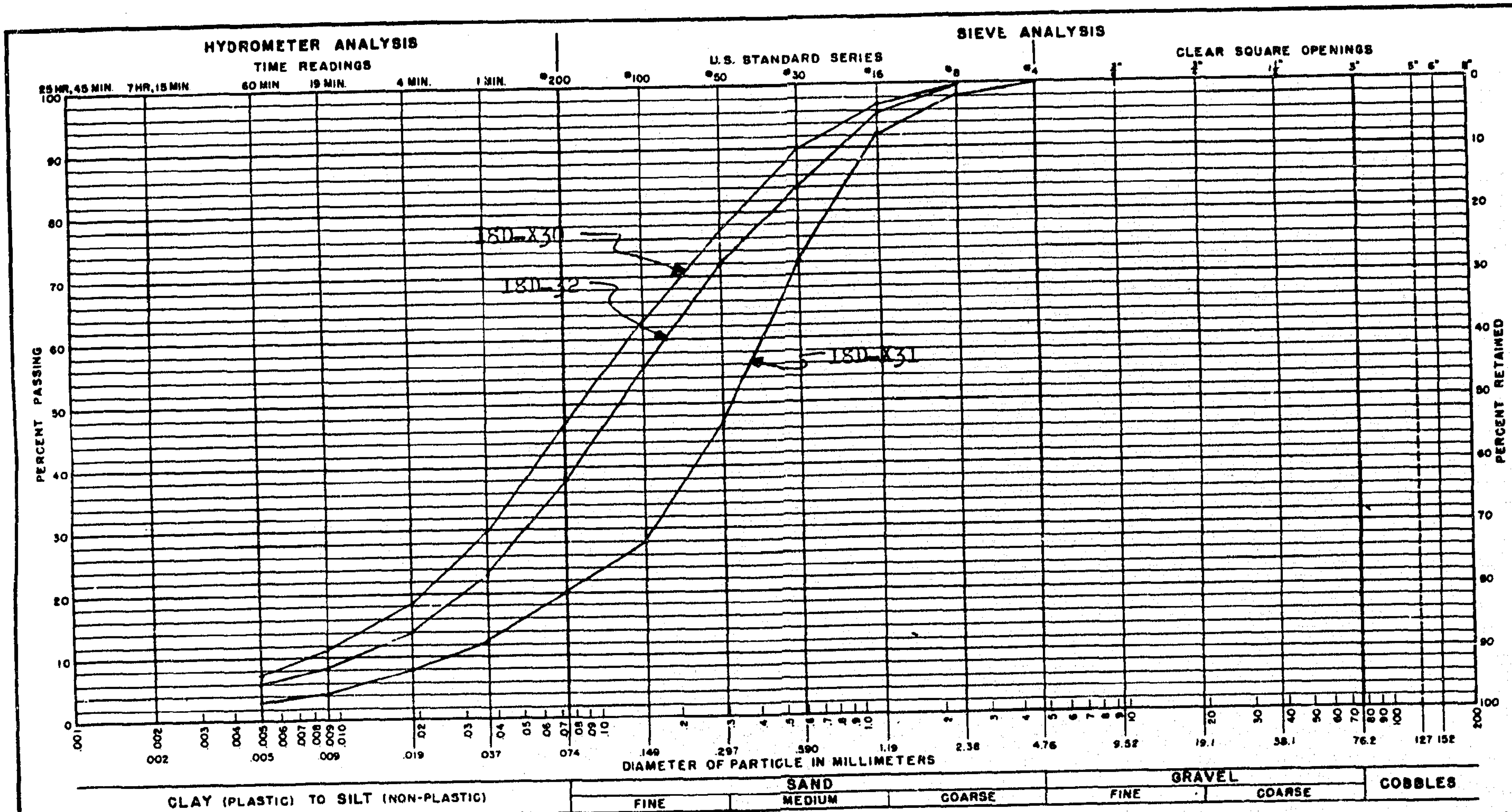
Madera Construction Division

PROPOSED BORROW AREA NO. 13

DRAWN J.P.B. CHECKED DATE 5-6-52

FIGURE NO. 2

X-D-355




NOTES:

| Lab. Sample No. | Excavation No. | Depth (ft) |
|---|---|---|
| 18D-X30 | AH-38 | 0.0-6.0 |
| X31 | -43 | 0.0-6.0 |
| X32 | -47 | 0.0-6.0 |

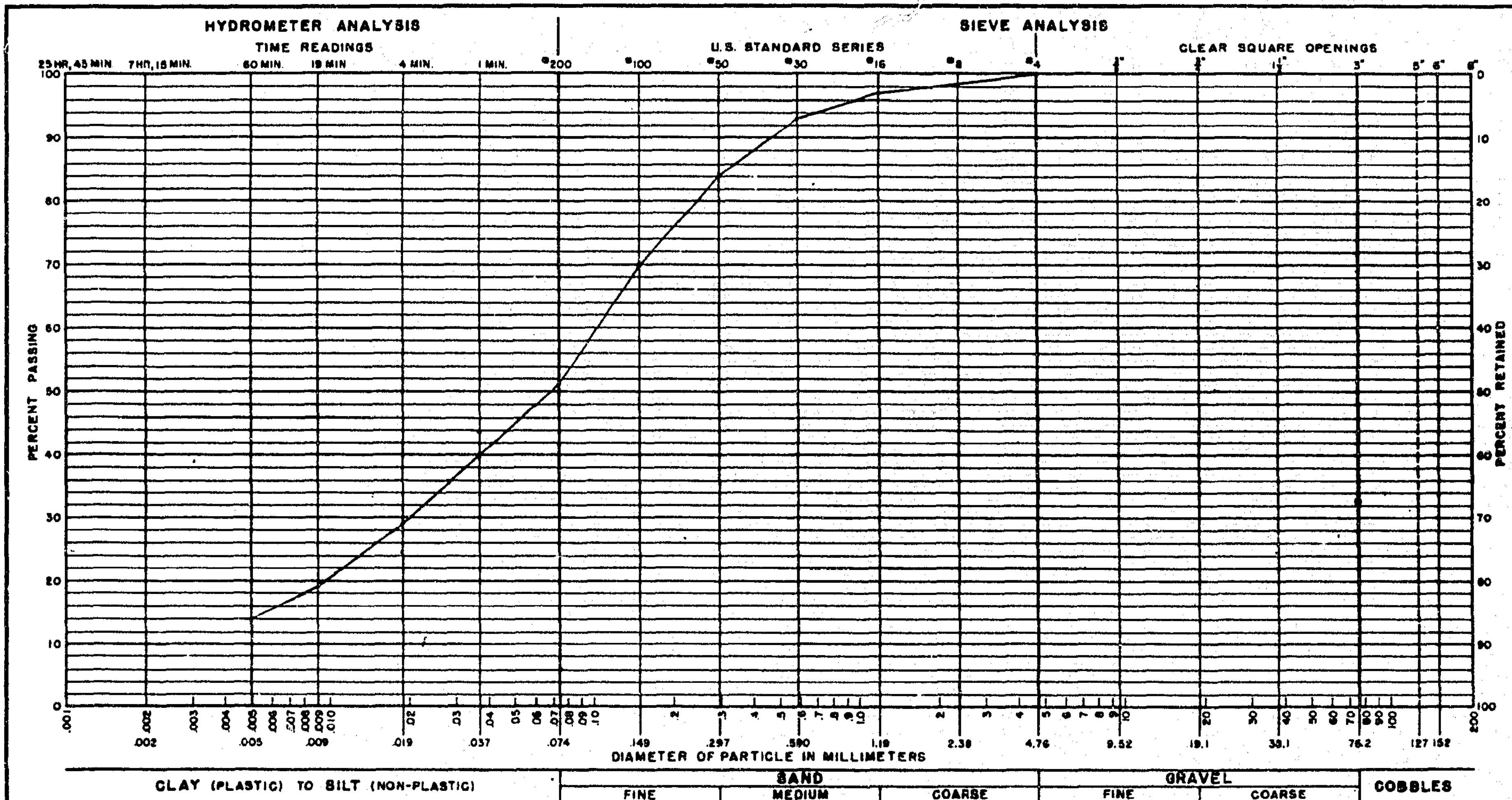
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

**GRADATION TEST**

Central Valley Project
Madera Construction Division
PROPOSED BORROW AREA NO. 13

DRAWN JB CHECKED CWJ DATE 4-17-52

FIGURE NO. 3




NOTES:

Laboratory Sample 18D-X33. Composite of AH-39,40,41,42,44,45,
46,48,49.

UNITED STATES
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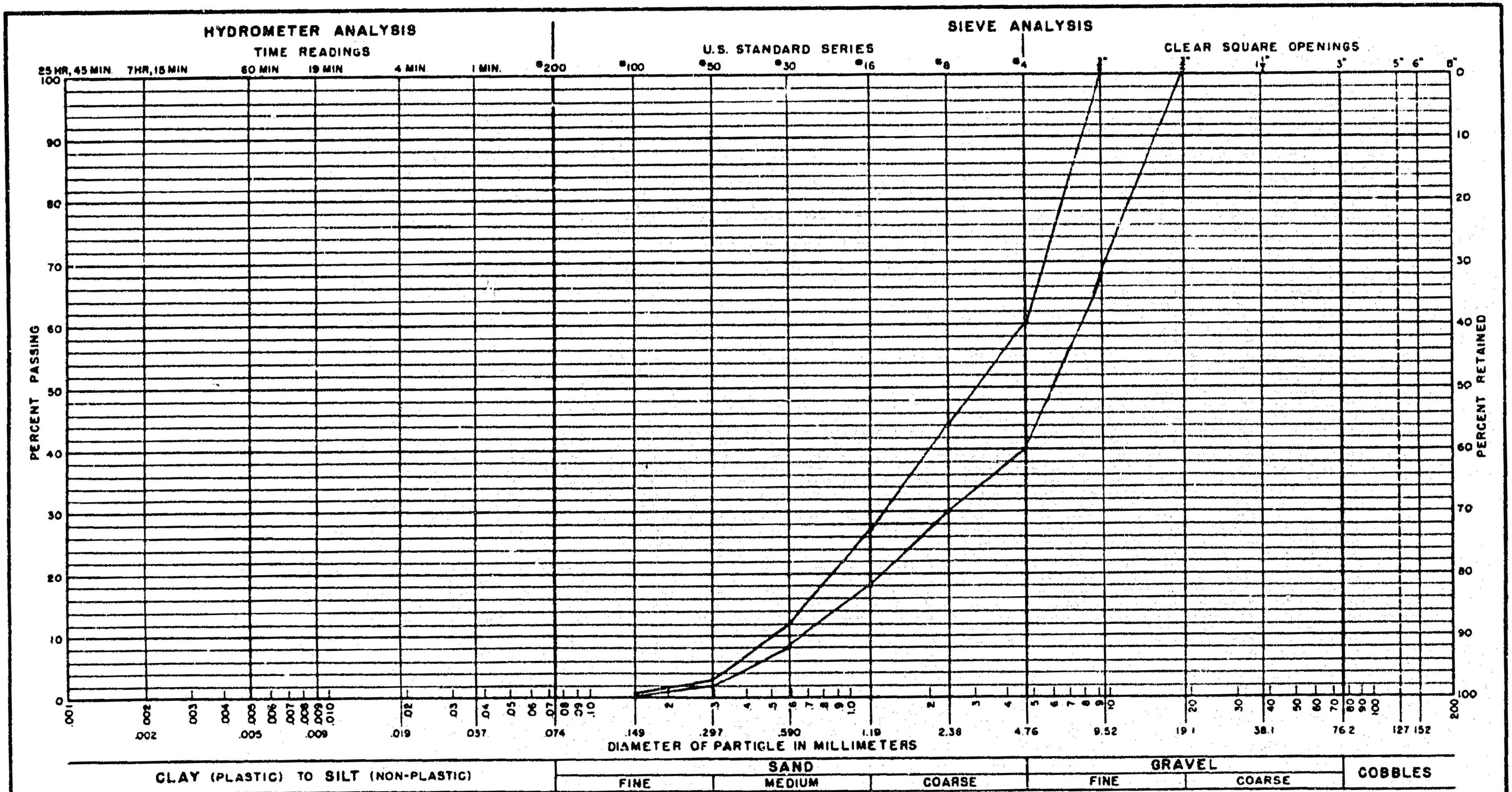
BUREAU OF RECLAMATION

GRADATION TEST

Central Valley Project
Madera Irrigation District
PROPOSED CANAL LINING MATERIAL

DRAWN CWJ CHECKED CWJ DATE 5-21-52

FIGURE NO. 4




NOTES:

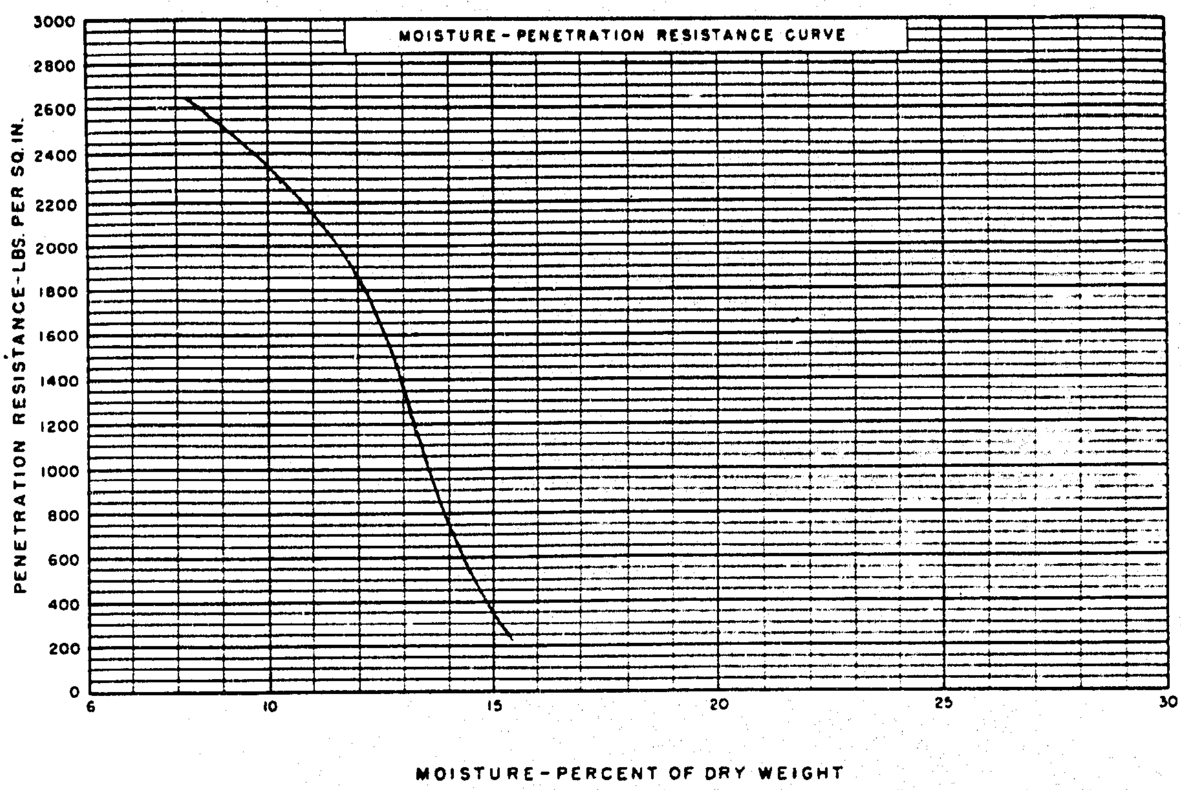
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

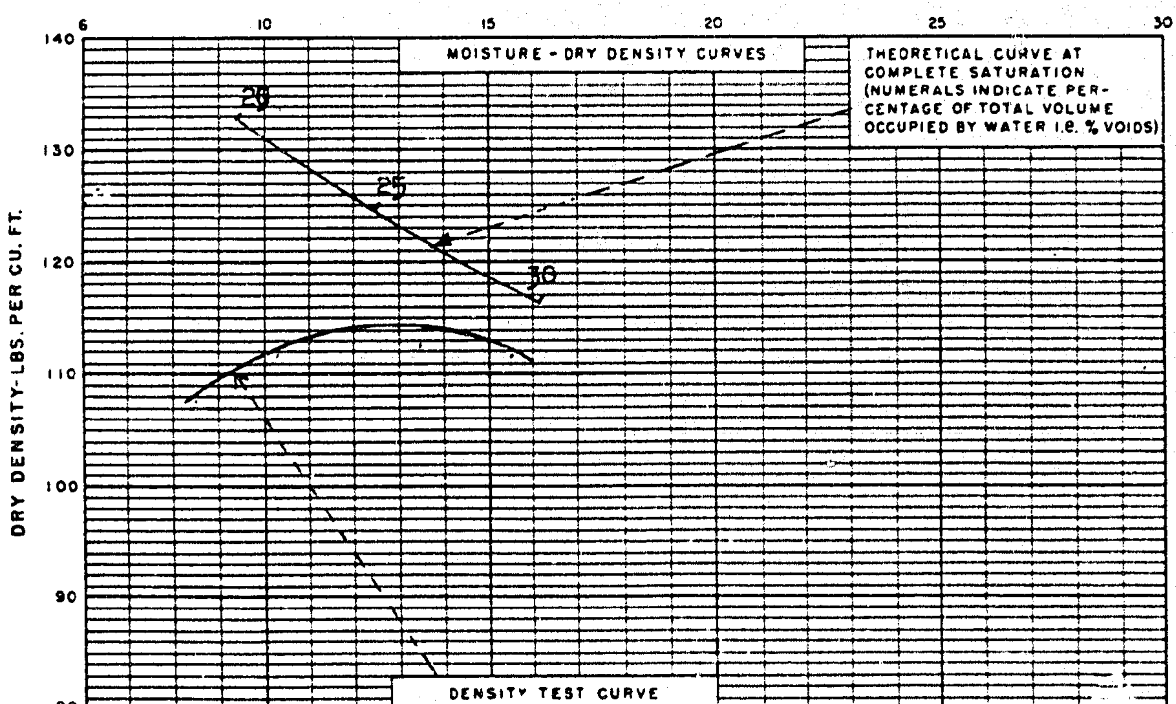
**GRADATION TEST**

Central Valley Project
Madera Irrigation District
Gravel Used as a Blanket to
Protect Earth Lining

DRAWN CWJ CHECKED CWJ DATE 5-21-52

FIGURE NO. 5




**COMPACTION**

25 BLOWS PER LAYER
3 LAYERS
5.5 LB. HAMMER
18 IN. DROP

Lab. Sample 18D-X30

**SOIL PROPERTIES**

2.66 SPECIFIC GRAVITY
ML SOIL CLASSIFICATION
0 % LARGER THEN TESTED
114.5 MAX. DRY DENSITY (P.C.F.)
13.0 OPT MOISTURE (%)
1350 PEN RES. AT OPT. MOIST. (PSI)

REV 9-17-46

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

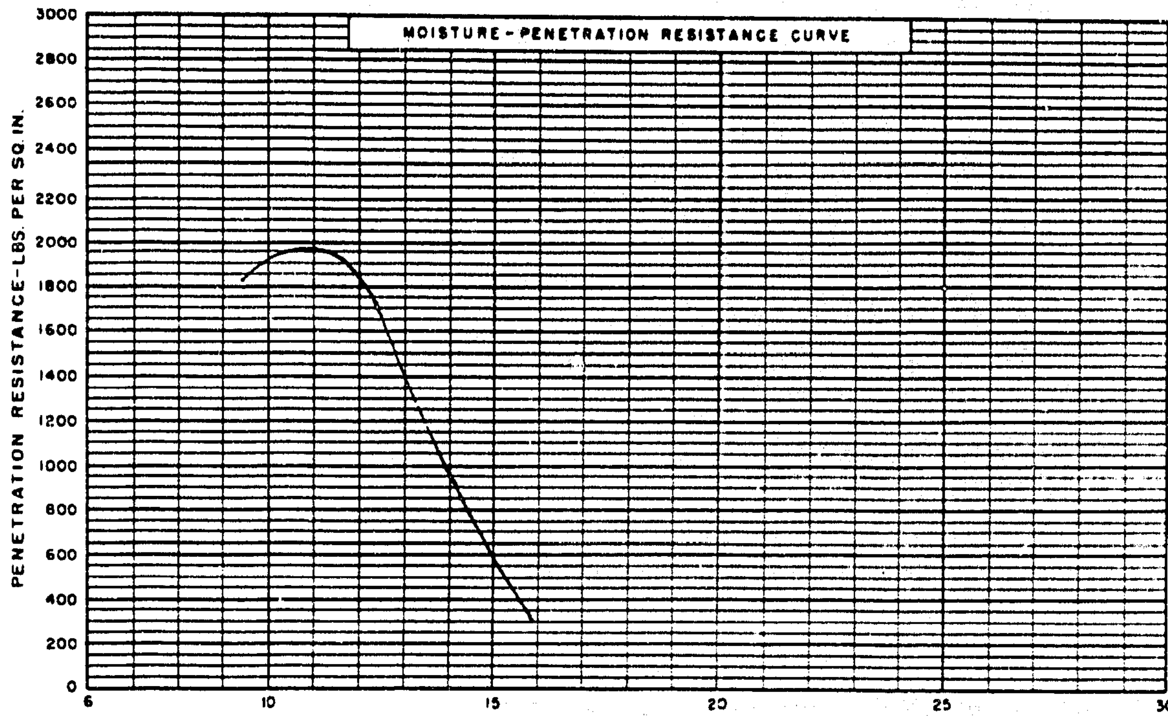
**COMPACTION TEST CURVES**

Central Valley Project
Madera Construction Division
PROPOSED BORROW AREA NO. 13

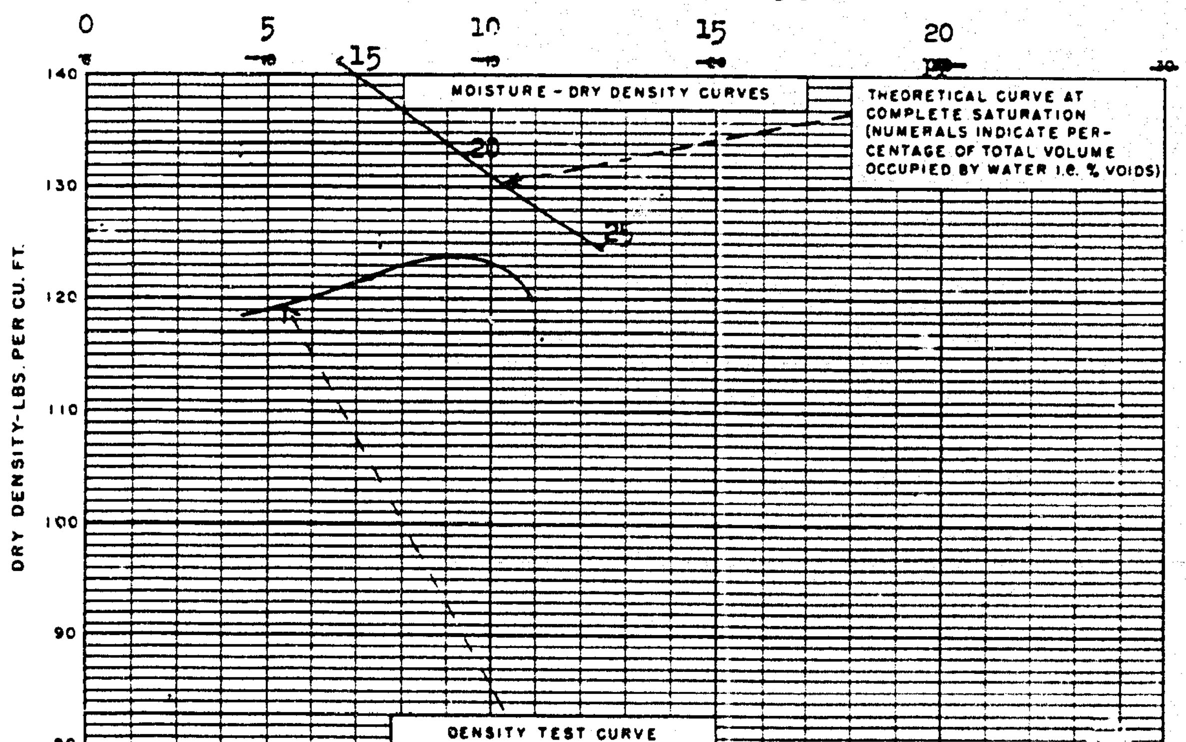
DRAWN JB CHECKED CWJ DATE 5-21-52

X-D-930

FIGURE No 6




MOISTURE - PERCENT OF DRY WEIGHT




| COMPACTION | | SOIL PROPERTIES | |
|---|---|---|---|
| 25 | BLOWS PER LAYER | 2.66 | SPECIFIC GRAVITY |
| 3 | LAYERS | SP | SOIL CLASSIFICATION |
| 5.5 | LB. HAMMER | 0 | % LARGER THEN TESTED |
| 18 | IN. DROP | 123.9 | MAX. DRY DENSITY (PCF) |
| | | 9.2 | OPT MOISTURE (%) |
| | | 850 | PEN RES. AT OPT. MOIST. (PSI) |

Lab. Sample No. 13D-X31

REV 9-17-46

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

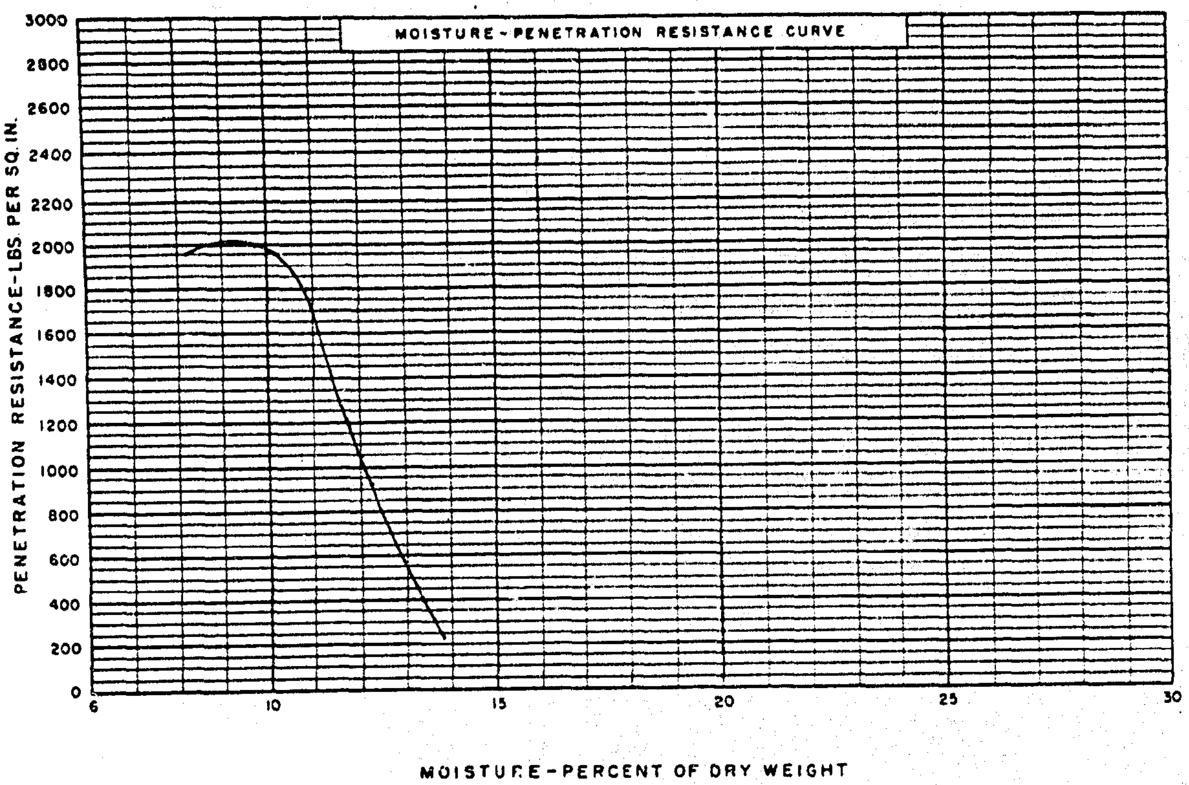
**COMPACTION TEST CURVES**

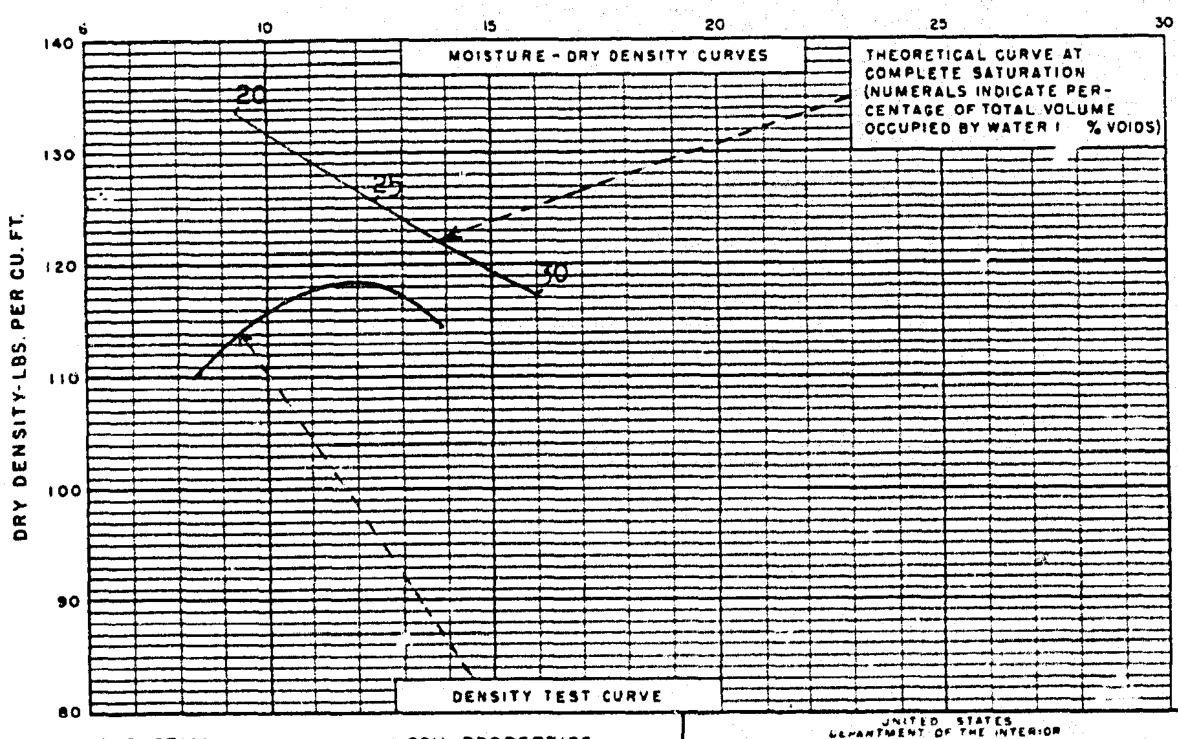
Central Valley Project
Madera Construction Division
PROPOSED BORROW AREA NO. 13

DRAWN JB CHECKED CWJ DATE 4-14-52

X-D-930

FIGURE No 7




| COMPACTION | | SOIL PROPERTIES | |
|---|---|---|---|
| 25 | BLOWS PER LAYER | 2.68 | SPECIFIC GRAVITY |
| 3 | LAYERS | ML | SOIL CLASSIFICATION |
| 5.5 | LB. HAMMER | 0 | % LARGER THEN TESTED |
| 18 | IN DROP | 118.3 | MAX. DRY DENSITY (PCF) |
| | | 12.0 | OPT MOISTURE (%) |
| | | 1050 | PEN RES. AT OPT. MOIST (PSI) |

Lab. Sample No. 18D-X32

REV 9-17-46

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

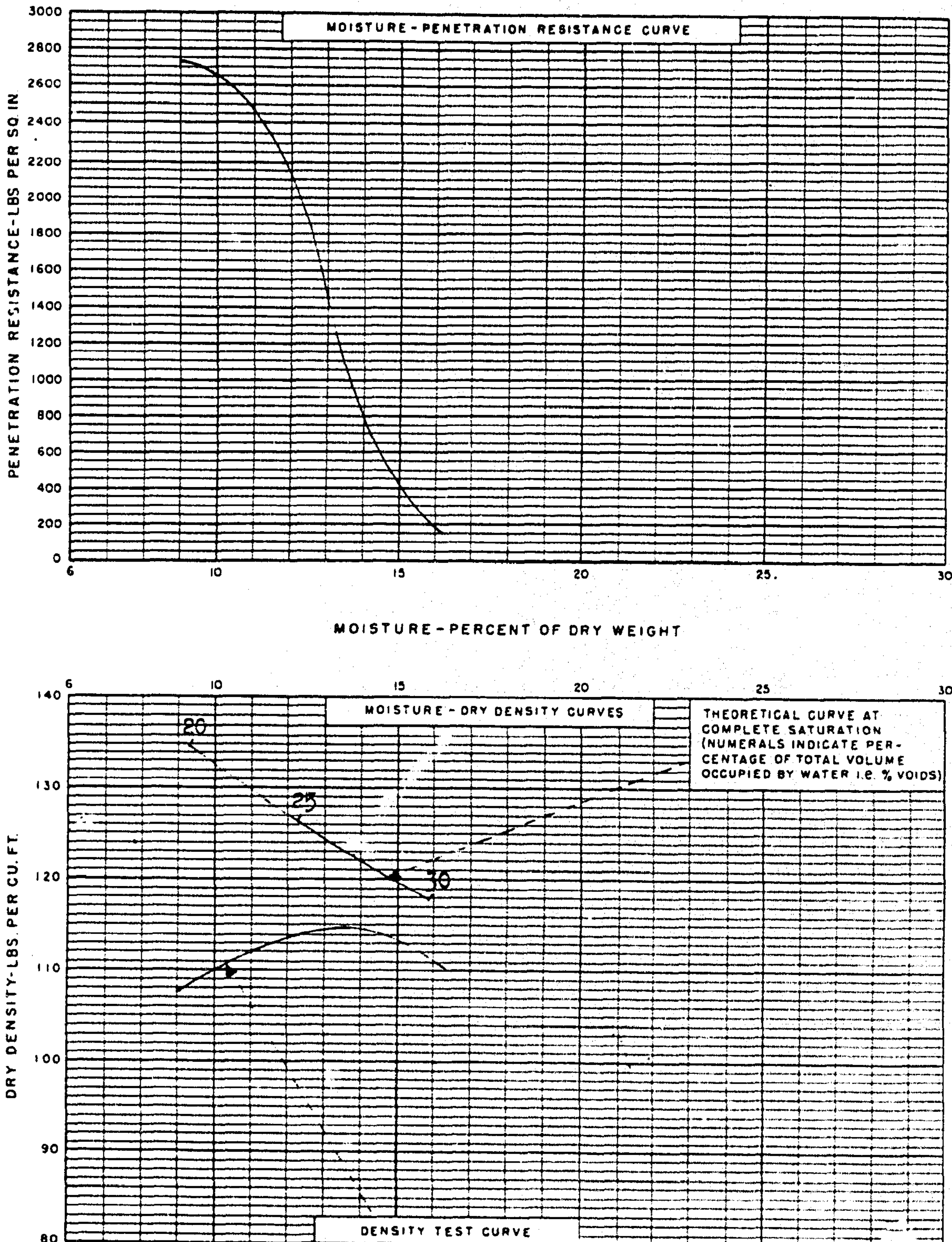
**COMPACTION TEST CURVES**

Central Valley Project
Madera Construction Division
PROPOSED BORROW AREA NO. 13

DRAWN JB CHECKED CWJ DATE 4-11-52

X-C-930

FIGURE No 8




**COMPACTION**

- 25 BLOWS PER LAYER
- 3 LAYERS
- 5.5 LB HAMMER
- 18 IN DROP

**SOIL PROPERTIES**

- 2.70 SPECIFIC GRAVITY
- ML SOIL CLASSIFICATION
- 0 % LARGER THEN TESTED
- 114.8 MAX DRY DENSITY (P.C.F.)
- 13.6 OPT MOISTURE (%)
- 960 PEN RES AT OPT MOIST (PSI)

Lab. NO. 1SD-X33

REV 9-17-45

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

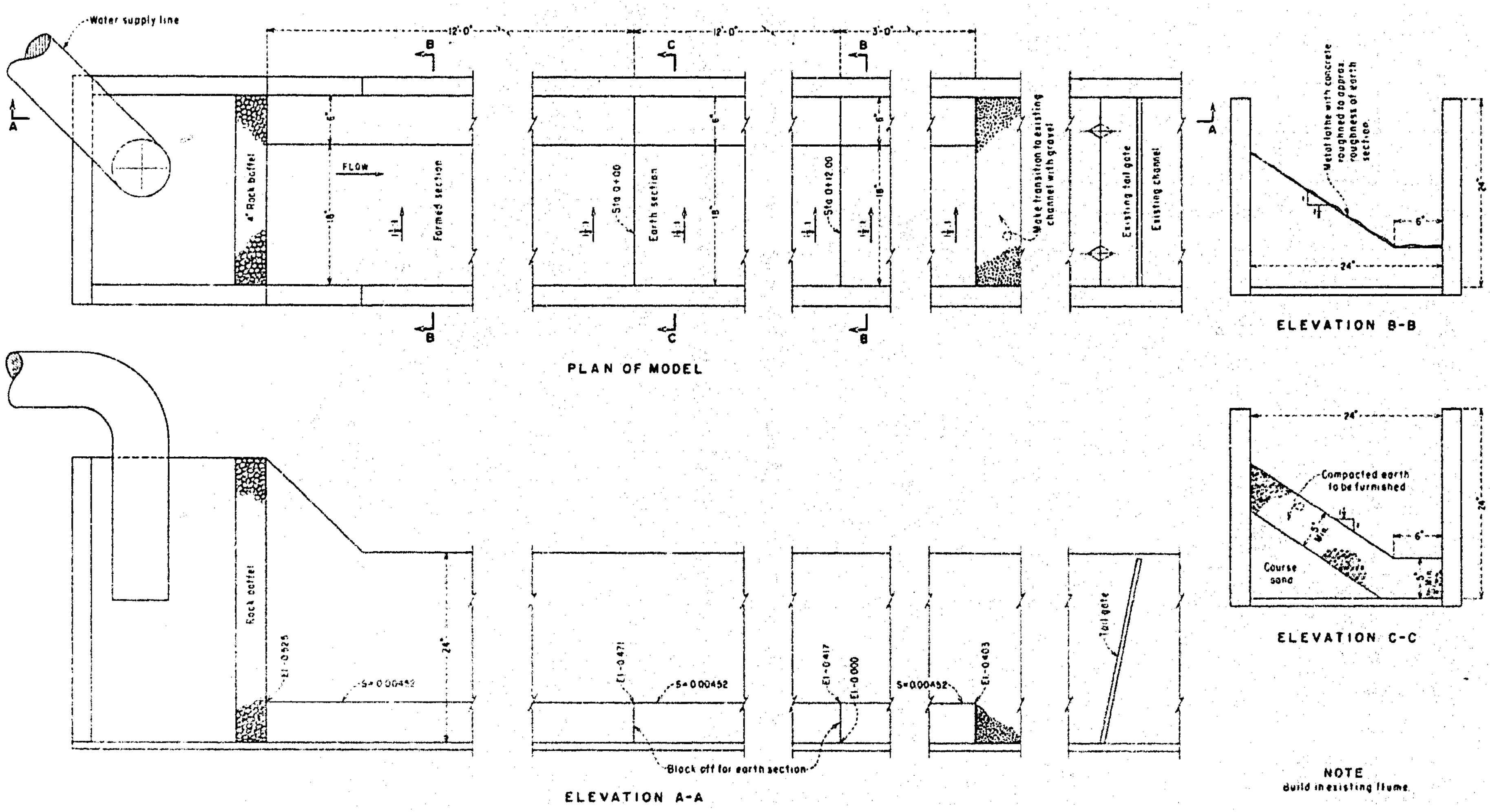
**COMPACTION TEST CURVES**

Central Valley Project
Madera Irrigation District
PROPOSED CANAL LINING MATERIALS

DRAWN CWJ CHECKED CWJ DATE 5-21-22

X-D-930

FIGURE No 9



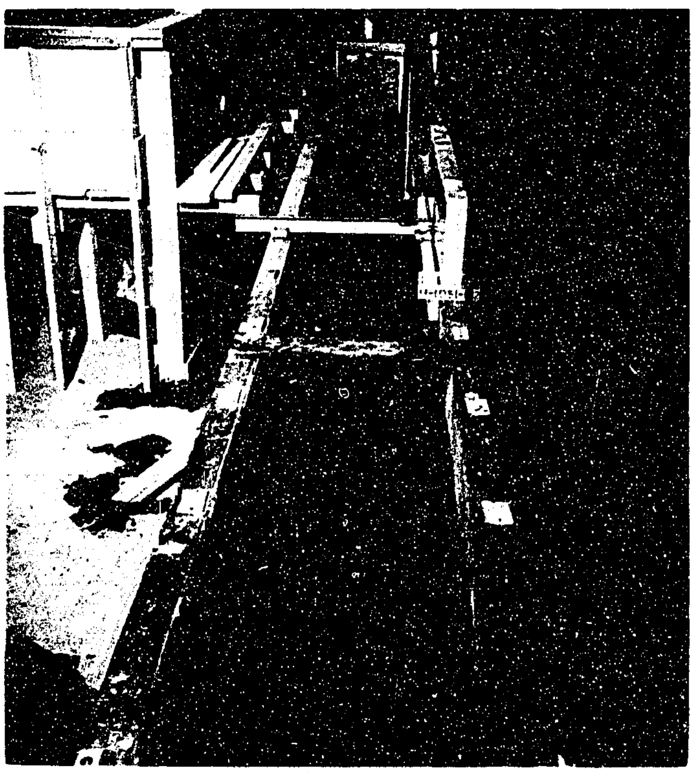

CENTRAL VALLEY PROJECT

EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING

HYDRAULIC MODEL

FIGURE 10
REPORT GEN. 34

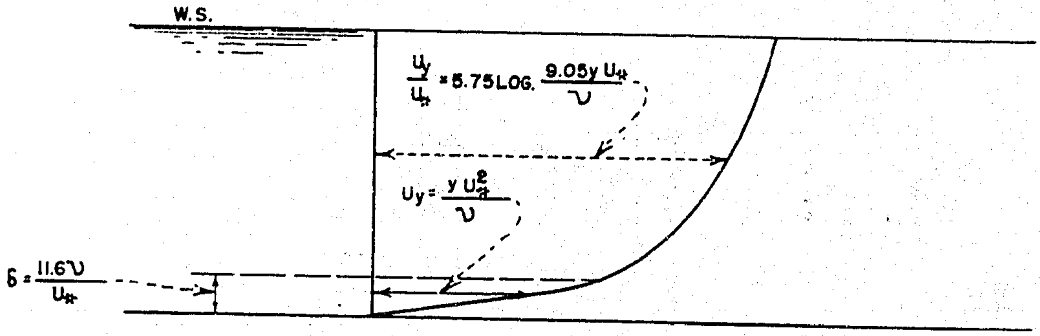
(a) View of compacted earth lining test section in hydraulic model prior to start of test. This shows the supply line at the upper end of the channel with the rock baffle. Also the glass window can be seen behind the photography number.



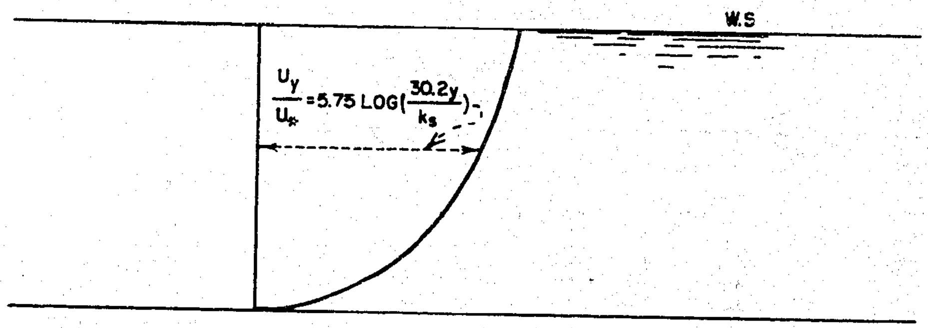
(b) Water flowing through the model during test. The point gage for measuring cross sections can be seen by the glass window. In the right foreground is the top of a hook-gage in a well for measuring water surface elevations.

Central Valley Project
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

PRELIMINARY DESIGN (TEST 1)




VERTICAL VELOCITY DISTRIBUTION FOR SMOOTH BOUNDARIES
(a)




VERTICAL VELOCITY DISTRIBUTION FOR ROUGH BOUNDARIES
(b)

FROM VON KARMAN'S SIMILARITY THEOREM WITH KEULEGAN'S CONSTANTS

$V_y$ = THE AVERAGE POINT VELOCITY AT DISTANCE "Y" FROM THE BED

$U_*$ = THE SHEAR VELOCITY = $\sqrt{gRs}$

$S_e$ = THE SLOPE OF THE ENERGY GRADE LINE

R = THE HYDRAULIC RADIUS

g = THE ACCELERATION DUE TO GRAVITY

y = THE DISTANCE FROM THE BED.

$\nu$ = THE KINEMATIC VISCOSITY OF THE WATER

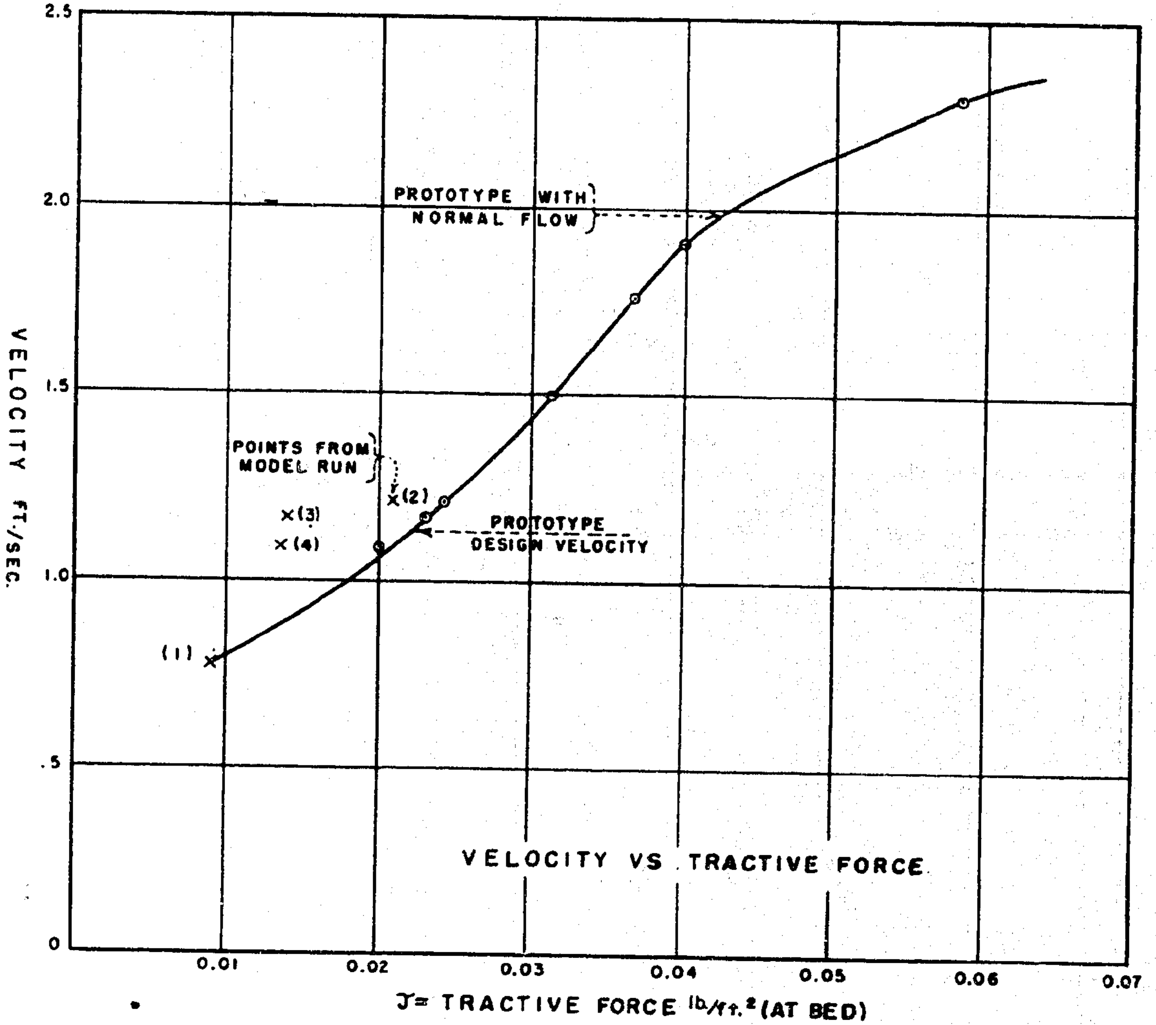
$k_s$ = THE ROUGHNESS OF THE BED

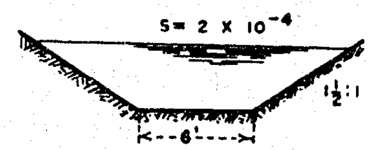
$\delta$ = THE THICKNESS OF THE LAMINAR SUBLAYER NEAR A SMOOTH BOUNDARY

CENTRAL VALLEY PROJECT

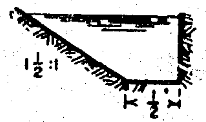
EARTH AND HYDRAULIC STUDIES
OF PROPOSED MADERA CANAL LINING MATERIAL

THEORETICAL VELOCITY DISTRIBUTION




PROTOTYPE




MODEL

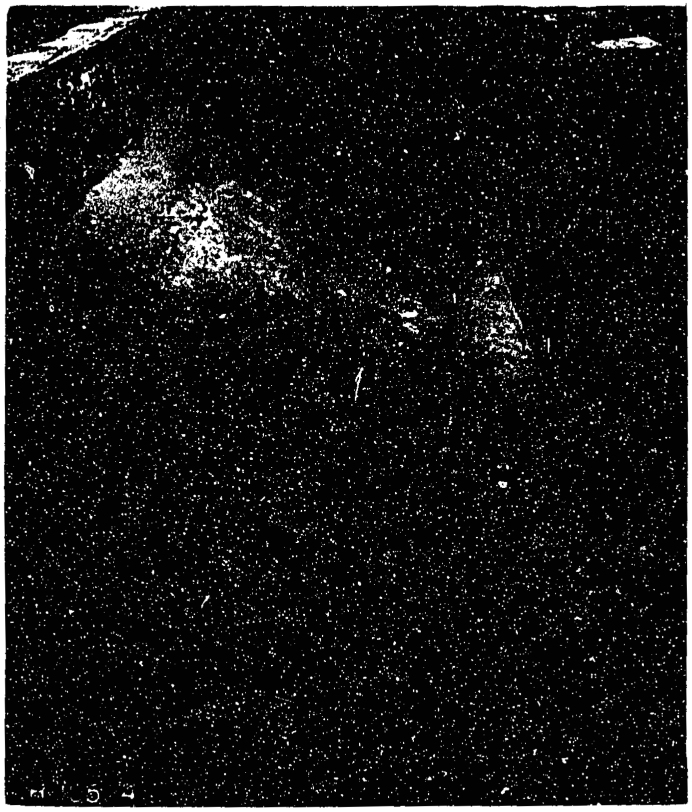
| RUN | $S \times 10^{-4}$ |
|---|---|
| 1 | 3.75 |
| 2 | 6.71 |
| 3 | 6.66 |
| 4 | 6.70 |

CENTRAL VALLEY PROJECT

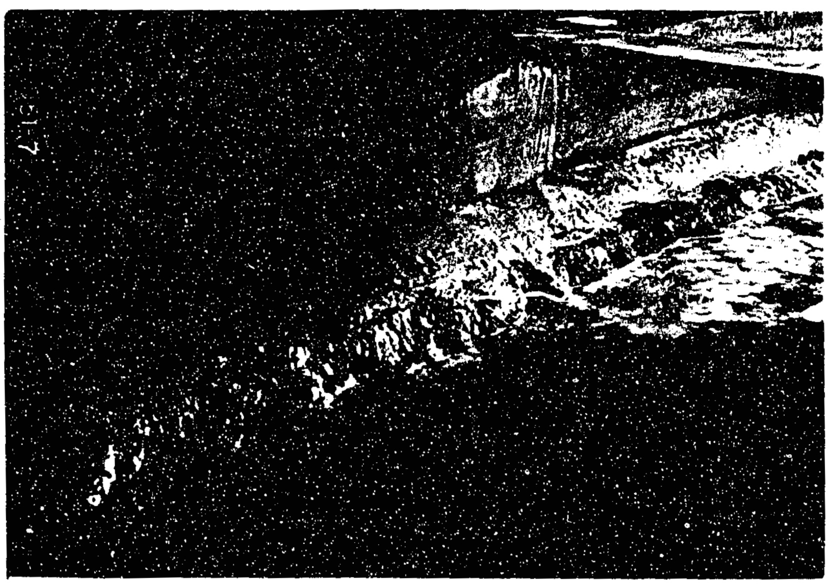
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

## AVERAGE BOUNDARY SHEARS OF PROTOTYPE AND MODEL

Figure 14



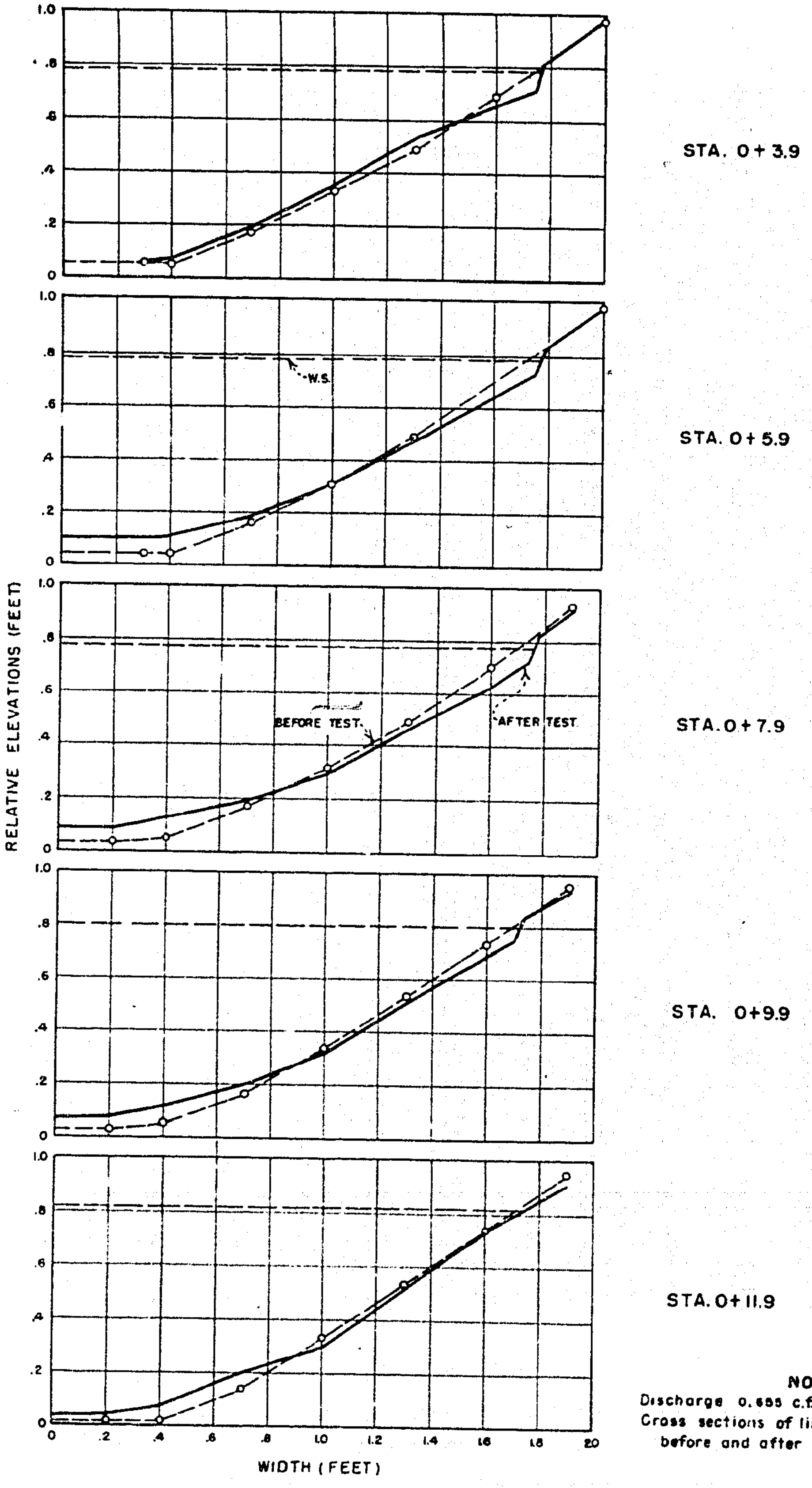
(a) General view of sloughed earth lining after water had been removed.



(b) Close-up of sloughing of earth lining as water level was being lowered.

Central Valley Project
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

SLOUGHING OF PRELIMINARY DESIGN (TEST 1)



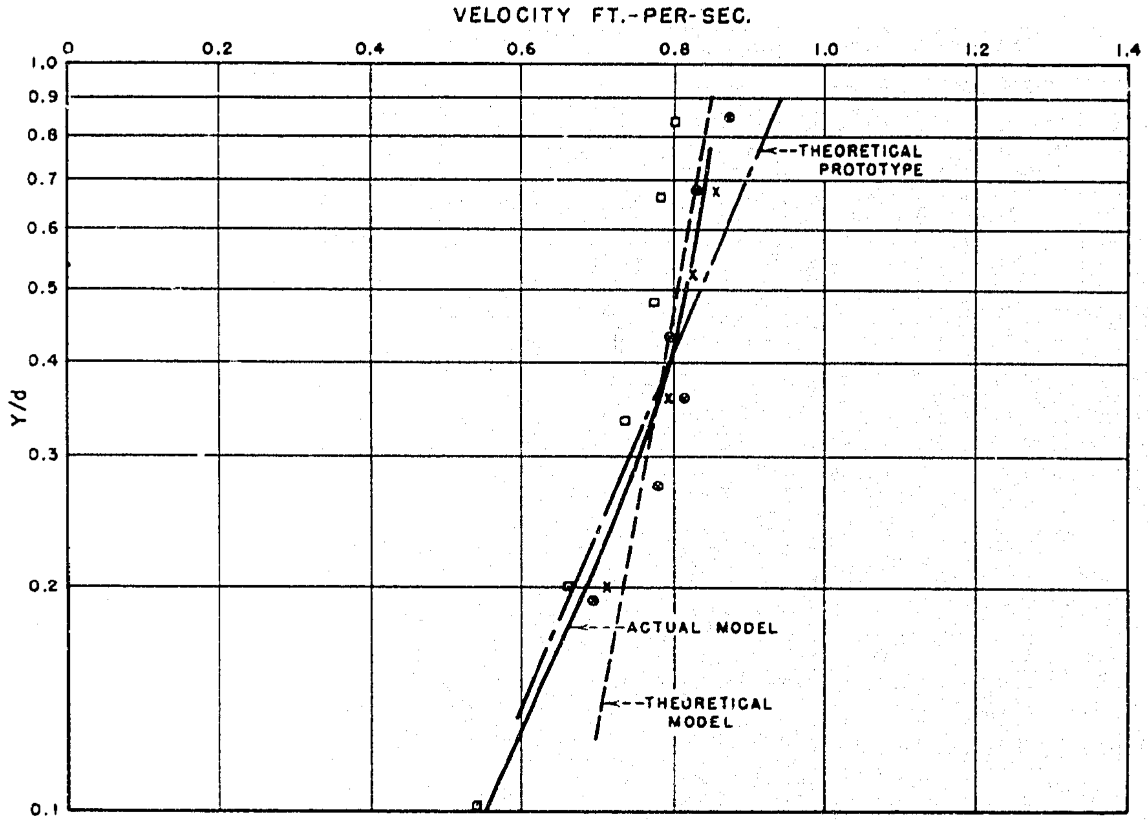

NOTES
Discharge 0.655 c.f.s.
Cross sections of lining in hydraulic model before and after 23 hours operation.

CENTRAL VALLEY PROJECT

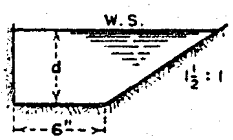
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

CROSS SECTIONS OF TEST I

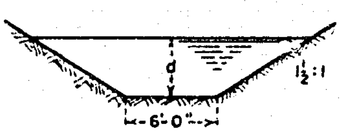
FIGURE 16
REPORT GEN. 16




TEST 1
VERTICAL VELOCITY DISTRIBUTIONS
0.7-FOOT FROM THE VERTICAL WALL IN THE MODEL AT THE ℄ IN THE PROTOTYPE




MODEL SHAPE

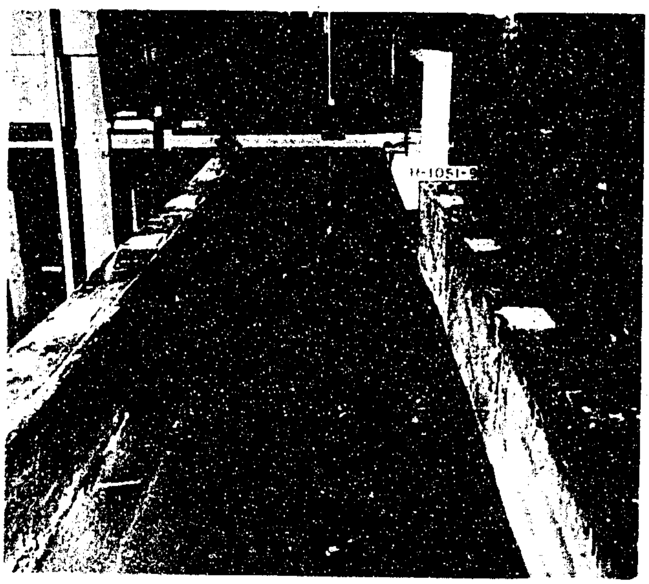



PROTOTYPE SHAPE
$S = 2 \times 10^{-4}$

KEY:
Y = ANY DISTANCE FROM THE BOTTOM OF THE CHANNEL.
□ = AT STATION 0 + 11.90
X = AT STATION 0 + 7.90
⊗ = AT STATION 0 + 3.90

CENTRAL VALLEY PROJECT
EARTH AND HYDRAULIC STUDIES
OF PROPOSED MADERA CANAL LINING MATERIAL
VERTICAL VELOCITY DISTRIBUTIONS FOR TEST 1


(a) Prior to start of test. Upstream 6 ft of compacted earth. Downstream 6 ft of compacted earth with 2 inch sand-gravel cover of 3/8 inch maximum size.

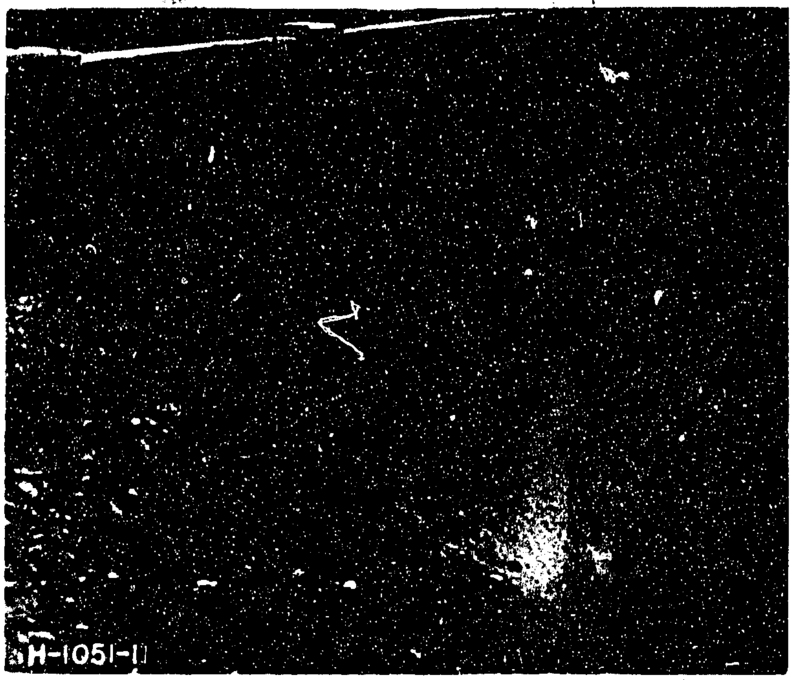


(b) Model in operation (Q - 1.05 cfs). Note pygmy current meter mounted on aluminum channel support.

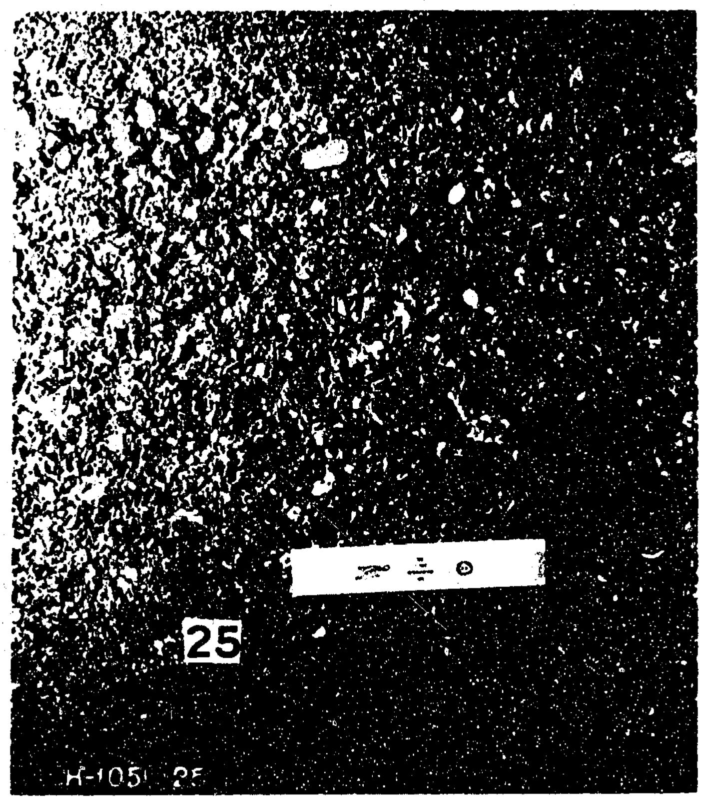
Central Valley Project
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

COMPACTED EARTH SECTION OF TEST 2

Figure 18



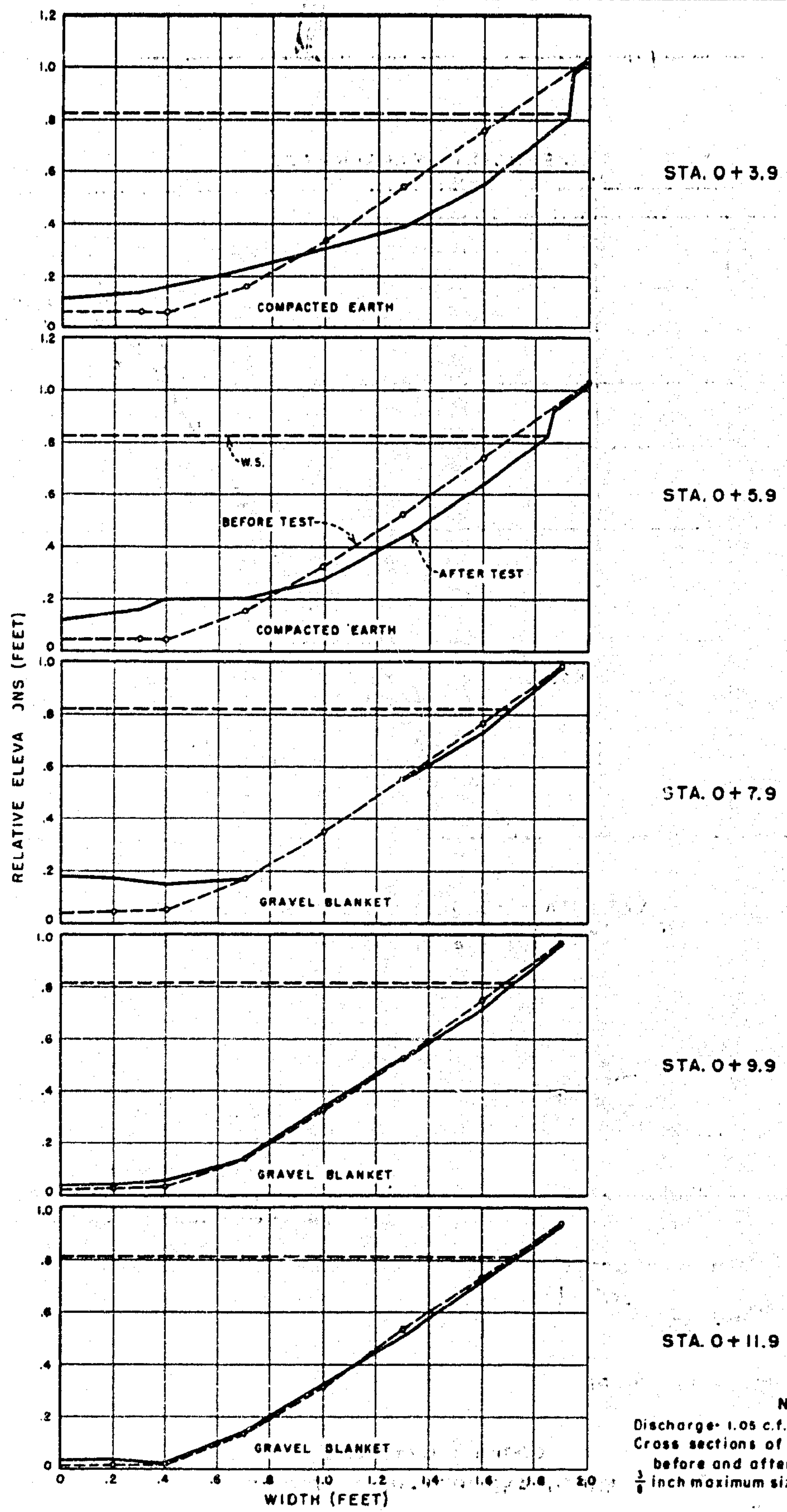

(a) Test 2--Close up of sloughing of earth section after 3-1/2 hours of operation (Q = 1.05 cfs) and removal of water.




(b) Test 4--Close up of sand-gravel surface after 20 hours of model operation. The difference in gradation at the water line can be seen near the top of the photograph. Note fines in channel bottom.

**Central Valley Project**
EARTH AND HYDRAULIC STUDIES OF
PROPOSED MADERA CANAL LINING
MATERIAL

EARTH LINING AND COVER MATERIAL
Tests 2 and 4



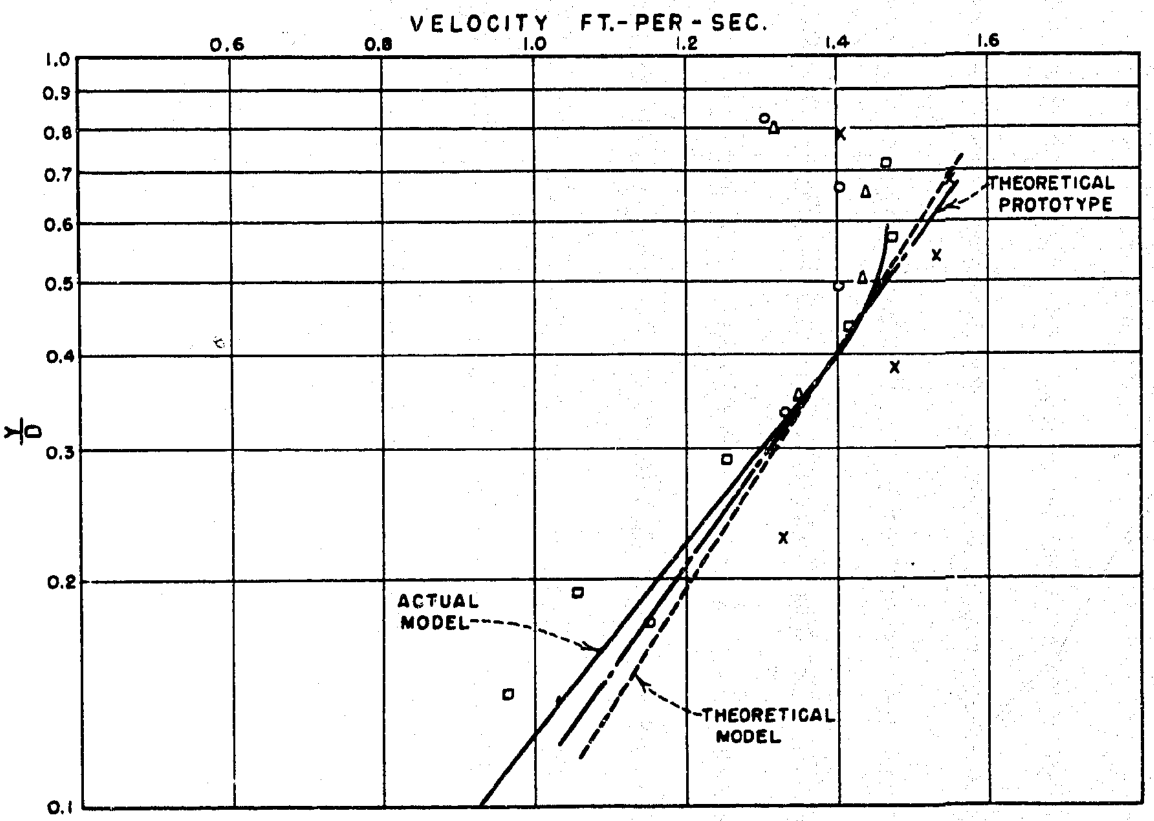

**NOTES**

Discharge- 1.05 c.f.s.
Cross sections of lining in hydraulic model before and after $3\frac{1}{2}$ hours of operation.
$\frac{3}{8}$ inch maximum size sand-gravel blanket.

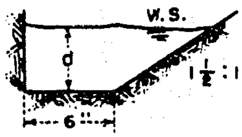
CENTRAL VALLEY PROJECT

EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

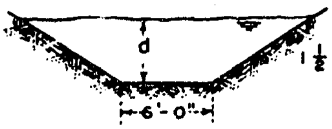
## CROSS SECTIONS OF TEST 2




TEST 2
VERTICAL VELOCITY DISTRIBUTION
0.7-FOOT FROM VERTICAL WALL IN THE MODEL
AT THE ℄ IN THE PROTOTYPE



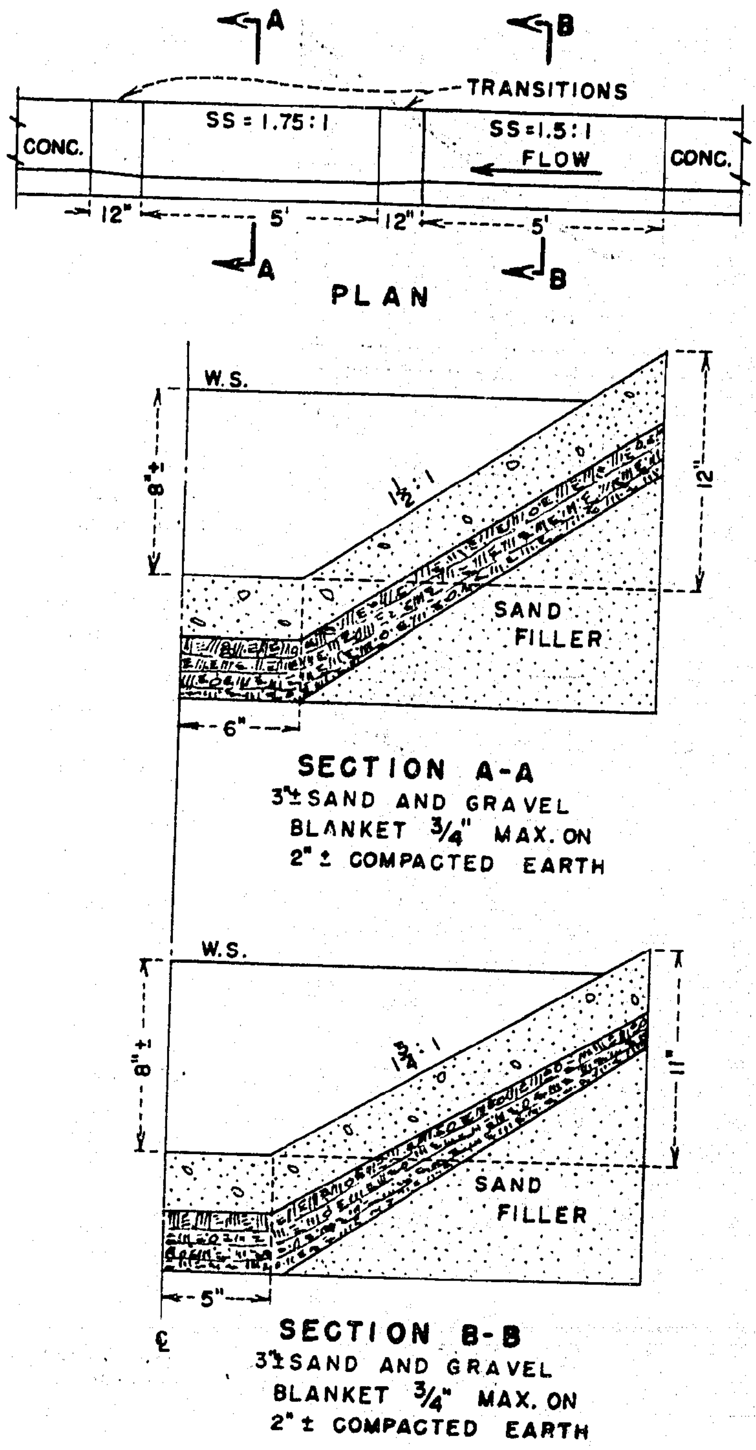

MODEL SHAPE




PROTOTYPE SHAPE

KEY
Y = ANY DISTANCE FROM THE BED OF THE CHANNEL
□ = AT STATION 0+11.90
X = AT STATION 0+7.90
○ = AT STATION 0+3.90
Δ = AT STATION 0+5.90

CENTRAL VALLEY PROJECT
EARTH AND HYDRAULIC STUDIES
OF PROPOSED MADERA CANAL LINING MATERIAL
VERTICAL VELOCITY DISTRIBUTIONS FOR TEST 2

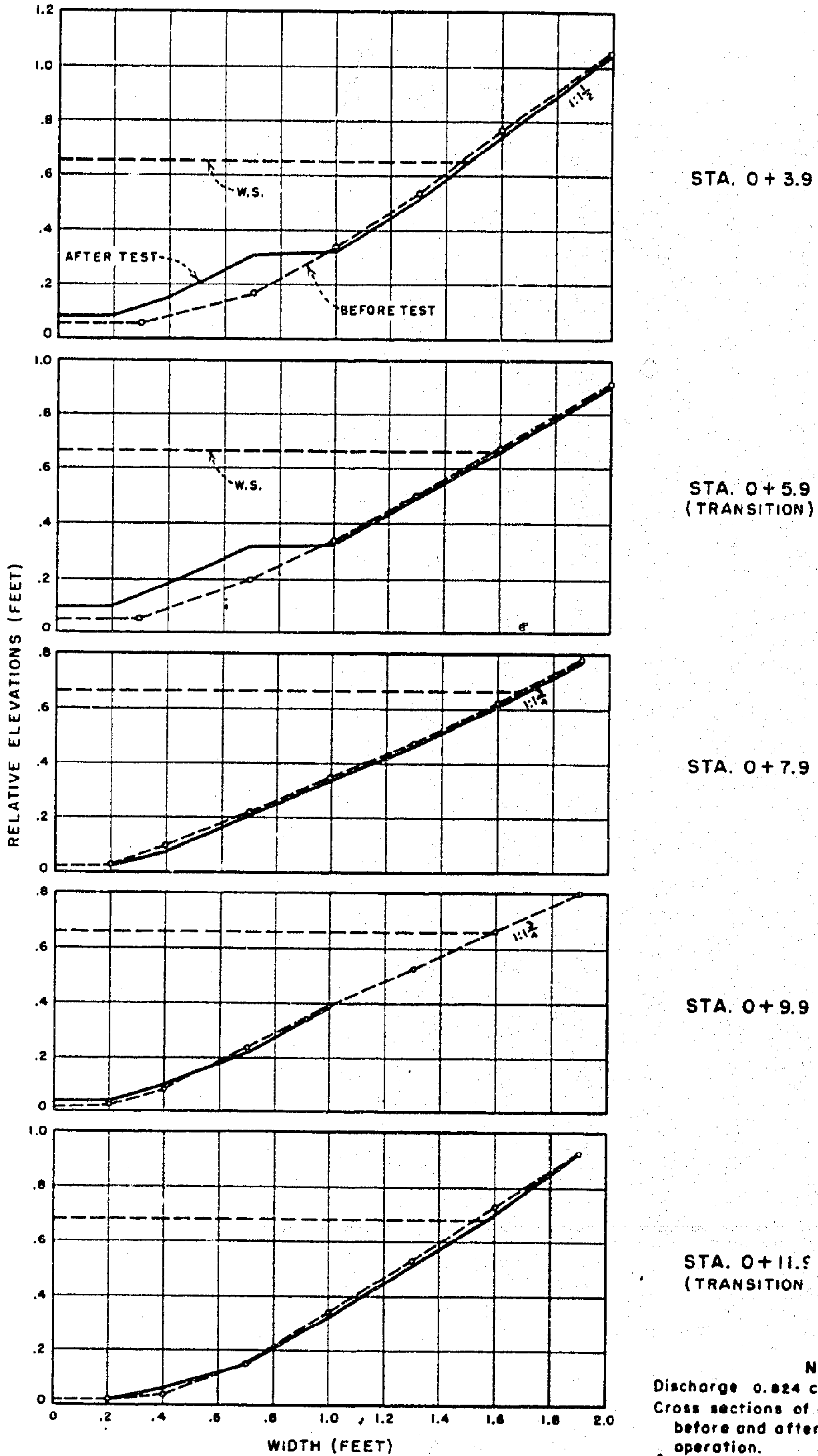



CENTRAL VALLEY PROJECT

EARTH AND HYDRAULIC STUDIES
OF PROPOSED MADERA CANAL LINING MATERIAL

DESIGN FOR TEST 3

FIGURE 22
REPORT GEN. 16




**NOTES**

Discharge 0.824 c.f.s.

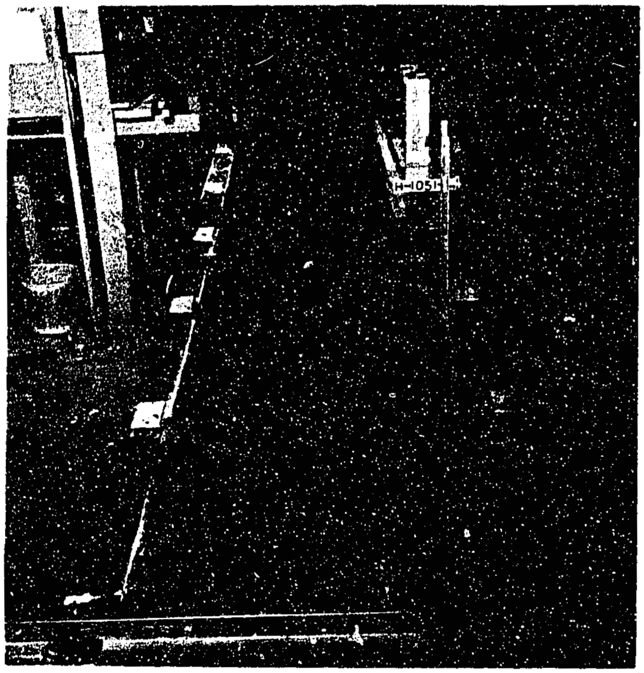
Cross sections of lining in hydraulic model before and after $22\frac{1}{2}$ hours of model operation.

$\frac{3}{4}$ inch maximum size sand-gravel blanket.

CENTRAL VALLEY PROJECT

EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

## CROSS SECTIONS OF TEST 3

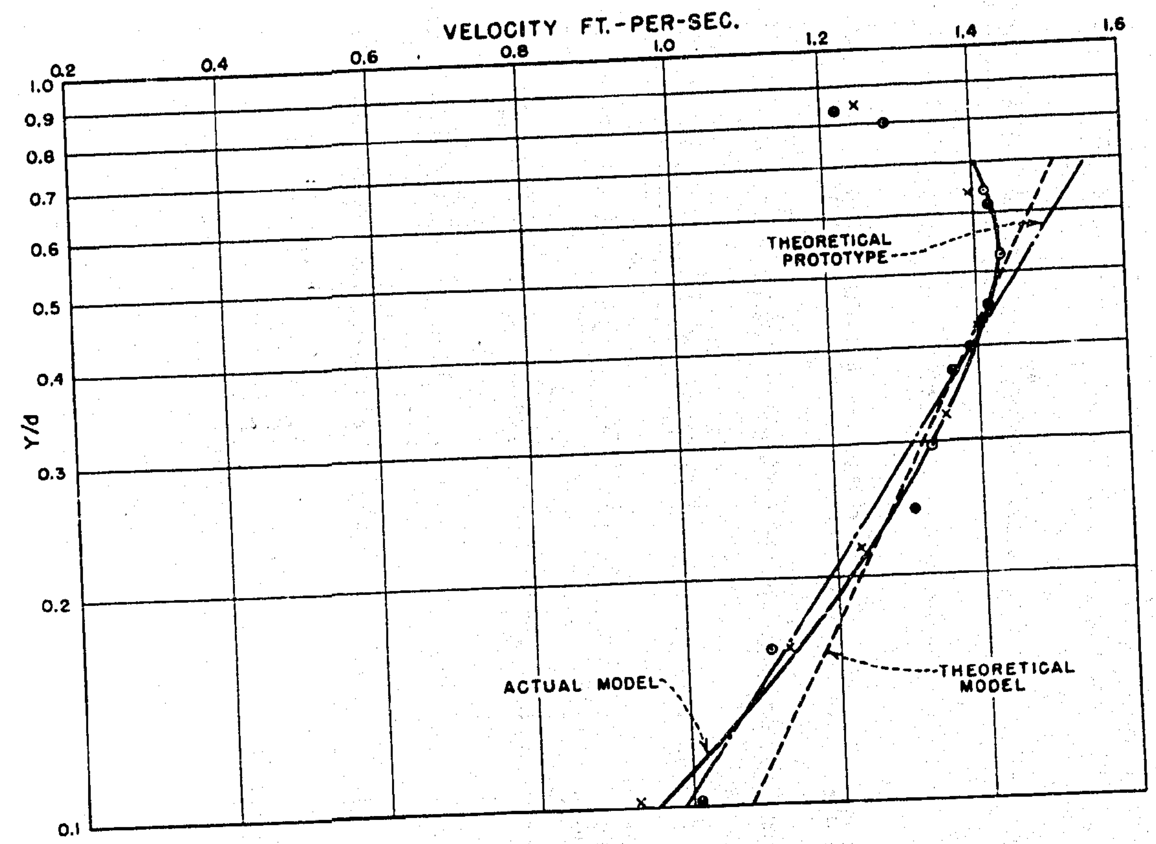


(a) View of test section after 22-1/2 hours of operation (Q=0.824 cfs). The 1-3/4 to 1 slope is in the foreground with the 1-1/2 to 1 slope in the background.


(b) Close-up of the surface of the sand-gravel blanket on the 1-1/2 to 1 slope after 22-1/2 hours of operation (Q=0.824 cfs). More sand fines were washed from the surface of this slope than on the 1-3/4 to 1 slope. Note the fines left in the area that was above the water surface.

Central Valley Project
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL.

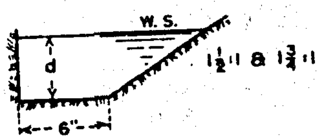
EARTH LINING OF TEST 3




TEST 3

VERTICAL VELOCITY DISTRIBUTIONS

0.7-FOOT FROM THE VERTICAL WALL IN THE MODEL AT THE ℄ IN THE PROTOTYPE




MODEL SHAPE

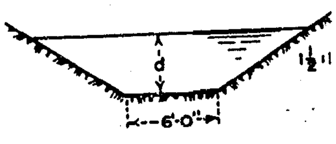
KEY:

Y = ANY DISTANCE ABOVE THE BED OF THE CHANNEL.

o = AT STATION 0 + 9.90

x = AT STATION 0 + 7.90

⊗ = AT STATION 0 + 3.90



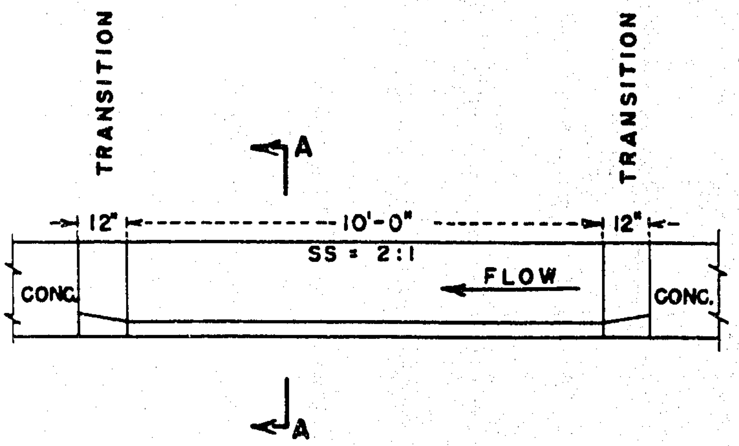

PROTOTYPE SHAPE

CENTRAL VALLEY PROJECT

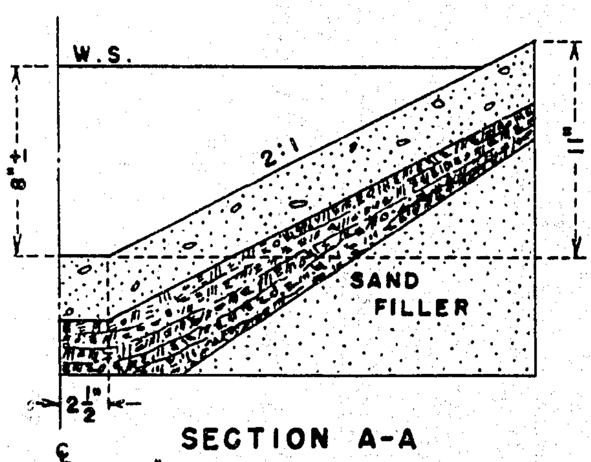
EARTH AND HYDRAULIC STUDIES

OF PROPOSED MADERA CANAL LINING MATERIAL

VERTICAL VELOCITY DISTRIBUTIONS FOR TEST 3




PLAN



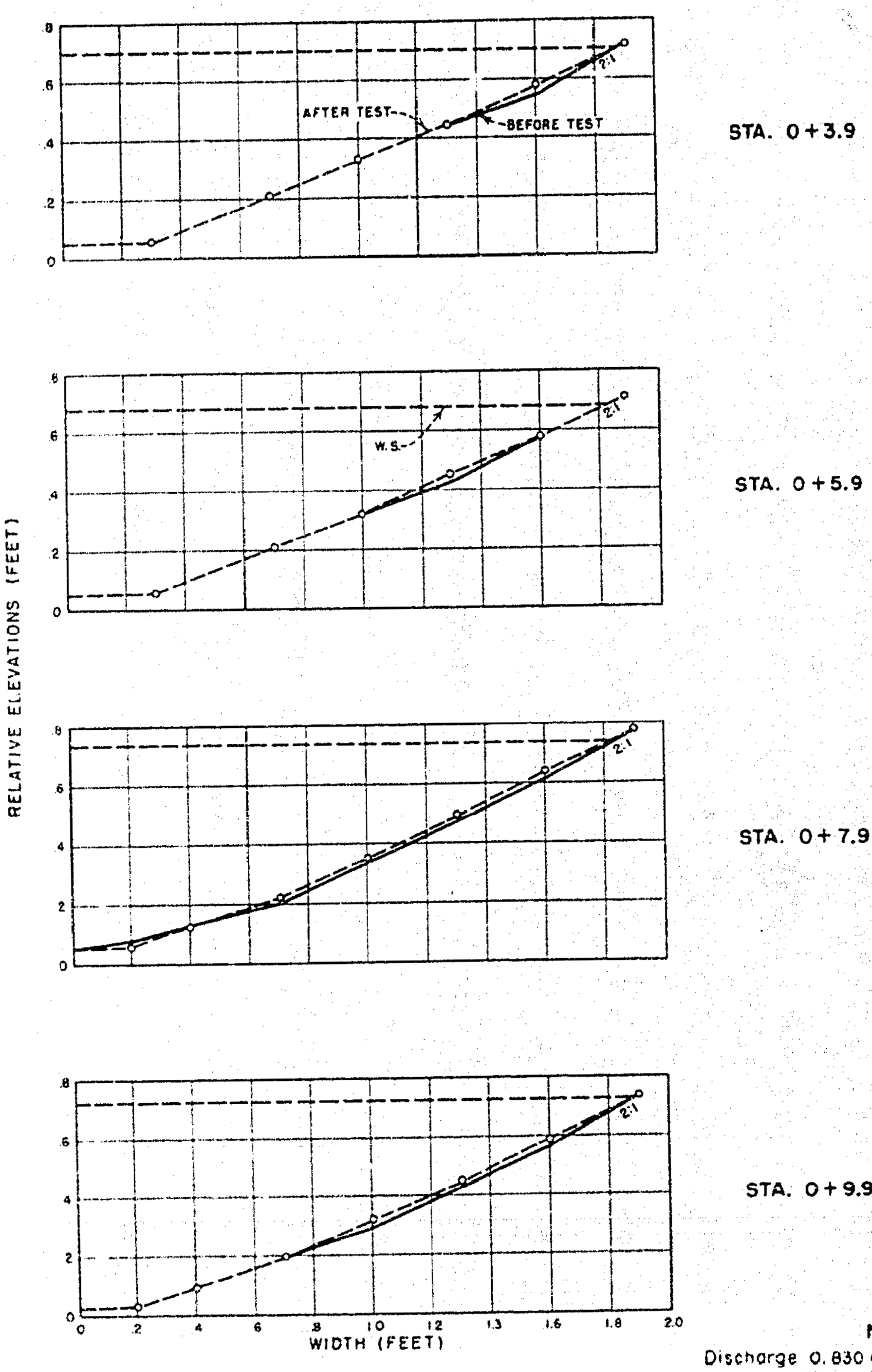

SECTION A-A

3"± SAND AND GRAVEL BLANKET 3/4" MAX. ON 2"± COMPACTED EARTH

CENTRAL VALLEY PROJECT

EARTH AND HYDRAULIC STUDIES
OF PROPOSED MADERA CANAL LINING MATERIAL

DESIGN FOR TEST 4




**NOTES**

Discharge 0.830 cfs.
Cross sections of lining in hydraulic model before and after 20 hours of model operation.
¾"-Maximum size sand-gravel blanket.

CENTRAL VALLEY PROJECT

EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

## CROSS SECTIONS OF TEST 4

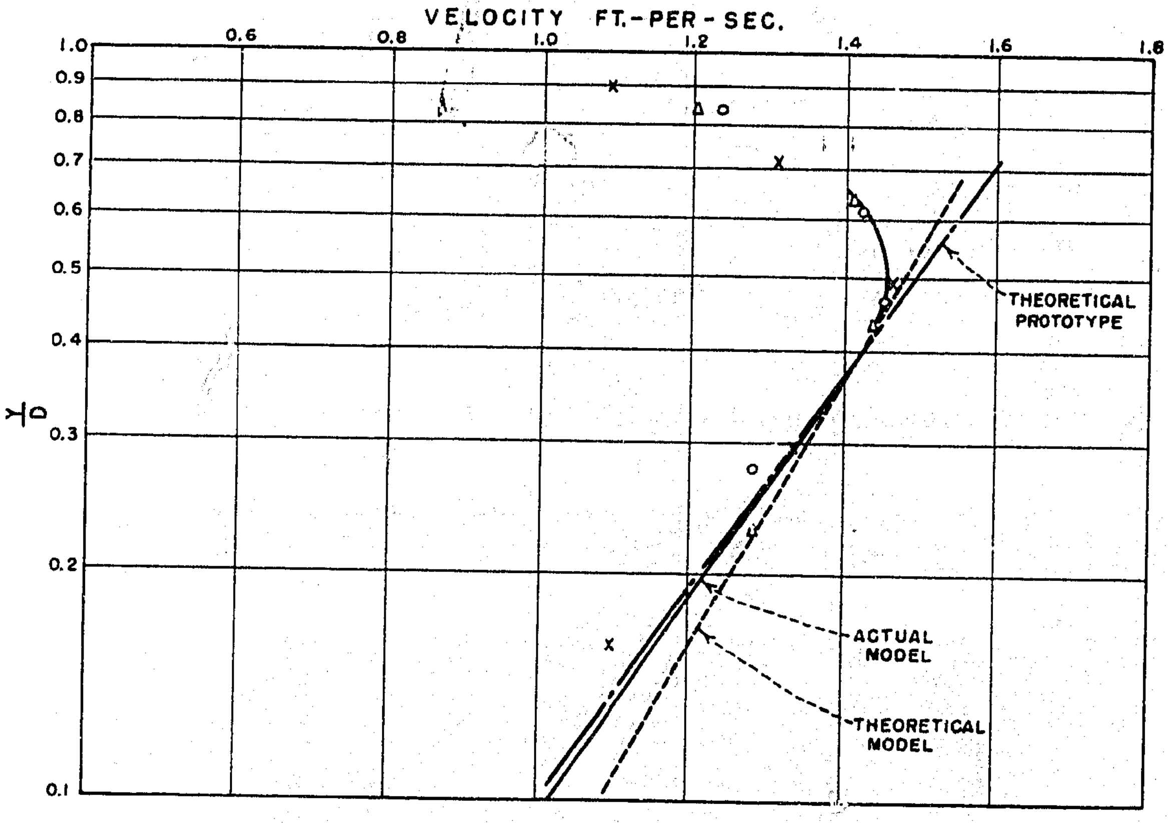
Figure 27

(a) View of test section before testing.

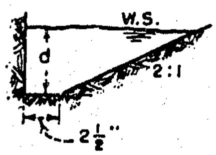
(b) View of test section after 20 hours of model operation. Some sand was washed out near the surface but the cross sections (Figure 26) show very little erosion.

Central Valley Project
EARTH AND HYDRAULIC STUDIES OF PROPOSED MADERA CANAL LINING MATERIAL

MODEL BEFORE AND AFTER TEST 4

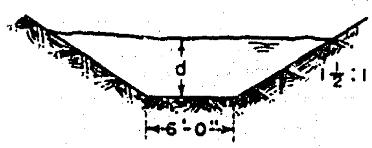



TEST 4
VERTICAL VELOCITY DISTRIBUTIONS
0.7-FOOT FROM VERTICAL WALL IN THE MODEL
AT THE ℄ IN THE PROTOTYPE




MODEL SHAPE

KEY
Y = ANY DISTANCE ABOVE THE BED OF THE CHANNEL
○ = AT STATION 0+ 9.90
X = AT STATION 0+ 7.90
Δ = AT STATION 0+ 5.90



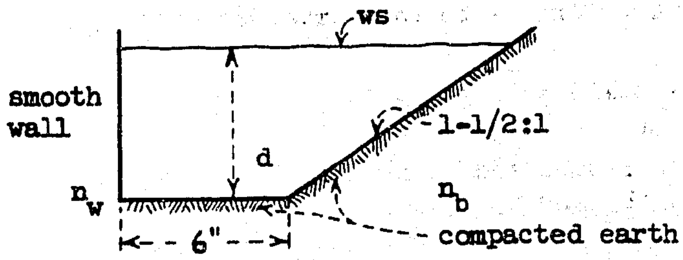

PROTOTYPE SHAPE

CENTRAL VALLEY PROJECT
EARTH AND HYDRAULIC STUDIES
OF PROPOSED MADERA CANAL LINING MATERIAL
VERTICAL VELOCITY DISTRIBUTIONS FOR TEST 4

APPENDIX

EXAMPLE CALCULATIONS OF HYDRAULIC PROPERTIES

For compacted earth*




$d = 0.788$ ft

$A = 0.841$ sq ft

$s = 3.75\ (10^{-4})$

$Q = 0.655$ cfs

$n_w = 0.010$

$$V = \frac{0.655}{0.841} = 0.779 \text{ fps}$$

For computing hydraulic radius with reference to the wall ($R_w$)

Assume: V and s are the same for both the compacted earth and the wall.

From:

$$V = \frac{1.49\, s^{\frac{1}{2}} R_w^{\frac{2}{3}}}{n_w}$$

$$R_w = \left(\frac{n_w\ V}{1.49\ s^{\frac{1}{2}}}\right)^{1.5} = 0.140$$

The area with reference to the wall ($A_w$)

From: $R_w = \dfrac{A_w}{P_w}$ and $P_w = d$ = wetted perimeter with reference to the wall

* A method presented by Dr. A. Einstein in Paper No. 2140 of the ASCE Transactions, 1942.

then: $A_w = R_w d = 0.110$ sq ft

The area with reference to the compacted earth ($A_b$)

$A_b = 0.841 - 0.110 = 0.731$ sq ft

The hydraulic radius and Manning's n value with reference to the compacted earth ($R_b$ and $n_b$)

$$R_b = \frac{A_b}{P_b} \quad \text{and} \quad P_b = 1.93 \text{ ft}$$

$$R_b = 0.381$$

$$n_b = \frac{1.49 \; s^{\frac{1}{2}} \; R_b^{\frac{2}{3}}}{V} = 0.0195$$



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