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THE USE OF SURCHARGES IN HIGHWAY CONSTRUCTION

By

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In Memoriam
Donald R. Whetsel
1935 - 1964

This manuscript is dedicated to Donald R. Whetsel, Highway Engineering Technician I, whose untimely death in an automobile accident while on duty with the California Division of Highways ended a promising career in the field of soil mechanics.

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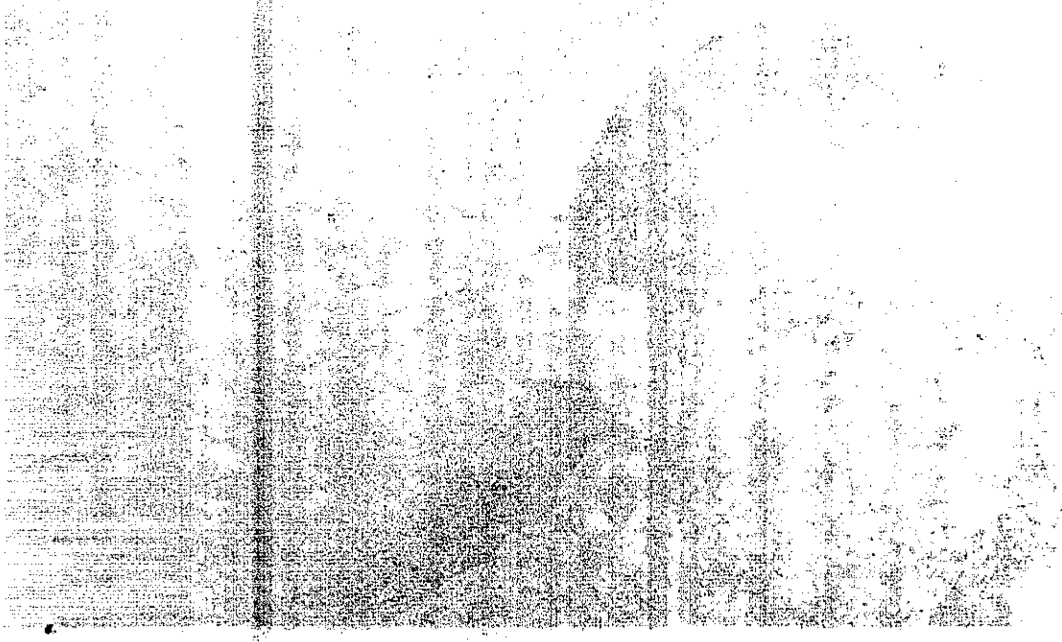

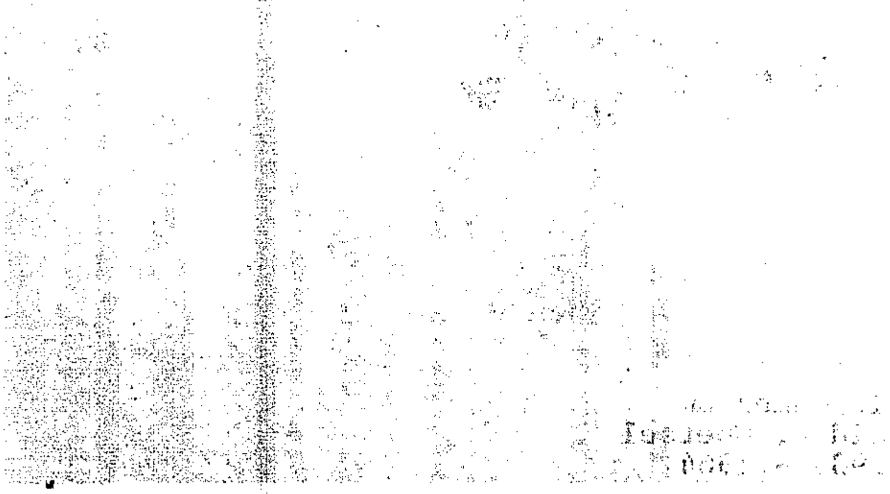

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This is an advance copy of a paper which is included on the program of the "Technical Conference on Design of Foundations for Control of Settlements" to be held at the Technological Institute, Northwestern University, Evanston, Illinois, on Tuesday through Friday, June 16 - 19, 1964, sponsored by the American Society of Civil Engineers. This advance copy is primarily to stimulate discussion and to enhance the effectiveness of the technical sessions. The paper is subject to modification and is not to be published as a whole or in part pending its release by the Society.

THE USE OF SURCHARGES IN HIGHWAY CONSTRUCTION

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THE USE OF SURCHARGES IN HIGHWAY CONSTRUCTION

By

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KEY WORDS: clay; consolidation; earthwork, embankment, rate of loading; settlement; silt; soil mechanics; strength; surcharge; time studies; waiting period.

ABSTRACT: The benefits of surcharges and waiting periods in highway construction are predicted by the application of the principles of soil mechanics. The use of these methods of construction minimize the amount of detrimental settlement subsequent to paving. Time-consolidation data are used to determine the length of waiting periods. Unconfined and quick-undrained triaxial compression test results are used to determine the safe height of embankments. Berms permit construction to greater heights. Time studies and consolidated quick-undrained triaxial compression test data can be used to determine the increase in strength compatible with controlled rate of loading, but interpretation of test data and engineering judgment are significant. Comparison of field measurements and calculations based on test data indicate that the predictions of amount of settlement are somewhat more reliable than the predictions of the rate of settlement.

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THE USE OF SURCHARGES IN HIGHWAY CONSTRUCTION

By

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SYNOPSIS

The construction of our modern highways, particularly those which are designated as part of the Interstate Highway System with the rigid design requirements of relatively flat grades and long radius horizontal curves, requires the construction of much higher embankments than were being built 10 or 15 years ago. In some instances it is impractical or almost impossible to avoid marsh lands or tidal flats where the foundation soils consist of weak, plastic, compressible silts and clays.

Special treatment of the foundation soils and unusual construction methods not covered in the California Standard Specifications, are usually necessary to construct stable embankments in these areas. The use of berms and controlled rates of construction to assure the construction of stable embankments, as well as the use of surcharges and waiting periods to minimize the amount of detrimental settlement subsequent to paving on 4 State of California highway contracts are described.

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Surcharges and waiting periods have been used in the construction of highway embankments by the California Division of Highways for a number of years. This paper is a discussion of the methods used in the design and construction of embankments across four lagoons in San Diego County.(1)(2) The projects, part of the Interstate Highway 5, are located from a point within the north end of the City of San Diego and extend northerly for a distance of approximately 12 miles. The construction across the lagoons where the poor foundation soils exist, covers a distance of approximately 2.7 miles. This new alignment is roughly parallel to and approximately 1 mile inland or east of the existing U.S. Highway 101 which closely follows the Pacific Coastline. (Fig. 1).

The soil conditions in the 4 sloughs or lagoons are quite variable. The thickness of the soft compressible silts and clays ranges from 2 ft. to as much as 40 ft. Interspersed with silt and clay layers are lenses or layers of fine sand ranging in thickness from less than 1 in. to 10 or 12 ft. The heights of the embankments range from 11 ft. to 90 ft. The surcharges which were used range from 1 ft. to 10 ft. above final profile grade. The size of berms range from 6 ft. high and 30 ft. wide to 30 ft. high and 80 ft. wide. The rates of construction used were 2 and 3 ft. per week. The waiting periods range from 60 days to as much as 2 or 3 yrs. The principles of soil mechanics are utilized in the design and construction of the embankments. The illustrations show comparisons of theoretical and observed settlements and the soil conditions at 2 locations in each of the 4 lagoons.

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The amounts and rates of settlement are computed from laboratory consolidation test data. The measured amounts are within approximately 25% or less of the calculated amounts, except in 1 lagoon where the measured settlements exceed the predictions by approximately 60% to 70%. The measured rates are in good agreement with the theoretical rates at 4 locations, while at the other 4 locations the settlement occurred at a rate much faster than had been predicted.

It was necessary to obtain some increase in strength during construction, as well as during a waiting period prior to a second stage of construction, in order to construct the embankments to the desired heights. The rate of construction and length of waiting period as determined from time-consolidation curves and the increase in strength as determined from consolidated-quick-undrained triaxial compression test data were sufficiently accurate to permit construction of the planned embankments.

INTRODUCTION

The California Division of Highways is currently using, and has used for a number of years, surcharges or overloads and waiting periods in the construction of highway embankments. The purpose of these applications is to minimize the amount of detrimental settlement subsequent to the construction of grade separation structures or bridges and paving. Also, an increase in strength of foundation soils occurs during the waiting period and this increase sometimes must be developed before a second stage of embankment construction can safely be undertaken. The

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amount of surcharge and the length of waiting period are dependent on the amount and rate of settlement that will occur in the foundation soils due to the added load of the embankment.

The application of soil mechanics gives reasonably accurate solutions to these problems. The reliability or safety of the final design in any foundation investigation depends, to a large degree, on the thoroughness of the soil sampling, the quality of undisturbed samples, the use of suitable test procedures(5), and most important, a thorough analysis and proper interpretation of test data by an experienced and competent soils engineer.

The foundation soils in the lagoons discussed herein are of such poor quality that they would not support the proposed embankments without some special treatment or the application of special methods of construction. Early in the planning and preliminary investigation stages of these projects, it was proposed to strip most of the weak compressible foundation soils, dewater the areas, and build the embankments in compliance with the Standard Specifications and the ordinary construction methods. After a study of the budget schedule it was evident that a period of 4 or 5 yrs. would be available from the time of commencing the embankments until the time of final paving over the approximate 12 miles of new alignment. A study of the mass diagrams indicated that there would be a large excess of excavation on these projects. In this case it would be necessary to make provisions for disposal sites. Also, it would probably be necessary to place the first foot or so of embankment under water, and it would be desirable to have a granular material for this purpose. Some areas in the

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excavation would contain suitable material for this operation and the working platform could be built with select material from designated areas. It was decided to construct the embankments on the soft foundation soils, provide berms for stability which would utilize most of the excess excavation, and make provisions for lengthy waiting periods to minimize settlement subsequent to paving. This meant a more thorough program of sampling and testing, particularly to obtain consolidation data, than was necessary if the special treatment consisted of stripping. Papers which describe stripping and other methods of special treatment for construction of highways and soil behavior during and after construction have been presented by Root(6), and Cedergren and Weber(7).

Progressing in a northerly direction from the City of San Diego the lagoons or tidal areas are named as follows: (1) Los Penasquitos Lagoon (North-East Quadrant), Station 1087± to Station 1097±; (2) San Dieguito River Basin, Station 1216± to Station 1280±; (3) San Elijo Lagoon, Station 1380± to Station 1408±; and (4) Batiquitos Lagoon, Station 1682± to Station 1725±. Due to the variable soil conditions, particularly the thickness of the soft compressible clays, and the different heights of embankment, an individual design and method of construction was used at each of the sloughs.

The embankments were designed with a safety factor just slightly above unity. Settlement platforms, piezometers, inclinometers(2) and heave stakes were installed to observe the behavior of the foundation soils during construction and the

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waiting periods. Data from the settlement platforms and piezometers may influence the Resident Engineer to determine when to commence a second stage of embankment construction or construction of the structures and removal of the surcharges. The heave stakes and inclinometers enable the Engineer to determine if any horizontal movement or shear failure has occurred in the foundation soils.

At one location it was necessary to provide berms which had not been planned, to assure the construction of stable embankments. At another location it was necessary to delay the start of a structure, on a second contract, approximately 2 months. Field settlement data indicated that settlement was not complete after the recommended 1-yr. waiting period following a grading contract. The soil conditions, design of embankment and subsequent construction in each of the lagoons are presented below.

EQUATIONS

Notation: The letter symbols used in this paper are defined where they first appear in the text, and are arranged alphabetically, for convenience of reference, in the Appendix.

METHODS OF ANALYSIS

Settlement: The one-dimensional theory of consolidation as set forth by Terzaghi and Peck(3) and also as presented by Taylor(4), is used to estimate the amount and rate of settlement. The formula for calculating the amount of settlement is:

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$$2H_s = 2H \frac{e_o - e_f}{1 + e_o} \quad \text{when}$$

$2H_s$ = amount of settlement,

$2H$ = thickness of compressible layer,

e_o = the in-place void ratio of the material when loaded with pressure equal to the existing overburden pressure, and

e_f = the void ratio of the material due to additional pressure (embankment).

Due to the depth and thickness of the compressible layer in relation to the width and height of the embankment, it is assumed that the total pressure of the embankment is effective throughout the total thickness of the compressible layer. Fig. 2 shows the pressure-void ratio curve representative of the very soft clay layer in the San Dieguito River Basin, Station 1278+50. The measured settlement at this location is shown on Fig. 7.

The time for a given degree of consolidation varies directly with the square of the length of the drainage path and inversely with permeability of the soil. The Logarithm of Time Fitting Method presented by Taylor(4) is used on routine investigations. A complete discussion of the validity of the assumptions used to make time-settlement predictions cannot be made here. The time for 50% consolidation of a laboratory specimen can be determined from the time-consolidation curves and the time for 50% settlement in the field is calculated by the following formula:

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$$T_{50} = \frac{H^2 \, t_{50}}{h^2} \quad \text{when}$$

T_{50} = time for 50% settlement in the field,

t_{50} = time for 50% consolidation of laboratory specimen,

H = length of drainage path in the field, and

h = length of drainage path in laboratory specimen.

The value of t_{50} is usually the average obtained from several time-consolidation curves. The presence of sand layers validates the assumption of double drainage in the field and the time for various percentages of settlement in the field is obtained by the use of the time factors presented by Taylor[4]. The time-consolidation curves for the very soft clay in the San Dieguito River Basin at Station 1278+50 are shown on Fig. 3.

Stability: The well-known graphical stability analysis, presented by Taylor[4] and based on the Swedish circular arc failure surface and the method of slices developed by Fellinius is used to determine the safe height of embankments. The stability of the embankment is proportional to the forces tending to resist sliding and the forces tending to produce sliding. These forces are summed up in the formula to calculate safety factor as follows:

$$S.F. = \frac{\Sigma N \tan \phi + cL}{\Sigma T} \quad \text{when}$$

S.F. = safety factor,

ΣN = summation of normal forces acting on potential slip plane,

Tan ϕ = tangent of angle of internal friction of the soil,

c = cohesion of the soil,

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L = arc length of potential slip plane, and

ΣT = summation of tangential forces acting on potential slip plane.

The in-place strength of the foundation soils, cohesion and angle of internal friction which are used in the stability analysis, is obtained from unconfined compression and quick-undrained triaxial compression tests. The increase in strength due to consolidation is determined from consolidated-quick-undrained triaxial compression tests. The rate at which this increase occurs can be determined from the time-consolidation curves and a study of the soil profile, the gradation of the compressible material and other factors. Because of the many indeterminate factors used in rate studies a great deal of sound engineering judgment is used to determine a rate of construction and length of waiting period to minimize settlement subsequent to paving. Quite often when the stability analysis indicates a safety factor of approximately unity a controlled rate of loading is recommended. This will tend to increase the safety factor and will give the Resident Engineer the opportunity to observe the behavior of the foundation soils during construction.

Field Conditions: Select material was used to construct a working platform across the unstable foundation areas. This material was obtained from designated areas in the roadway excavation. The working platform was constructed by dumping successive loads in a uniformly distributed layer of a thickness necessary to support the equipment while placing subsequent layers at the specified rate and compaction. The settlement

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platforms were installed as soon as practicable after placement of the working platform. They were installed on centerline of the embankment, where the maximum amount of settlement would occur.

In some instances the soil profiles shown on the figures may indicate rather shallow exploration for the height of embankments presented in this paper. Many other borings were made along the alignment and they showed considerably more depth of sand.

DISCUSSION OF SOIL CONDITIONS, ANALYSIS, DESIGN AND CONSTRUCTION

Example No. 1 - Los Penasquitos Lagoon

The new highway alignment crosses approximately 1000 ft. of this lagoon, Station 1087± to Station 1097±. The original ground is relatively flat at about Elevation 6. The area is slightly beyond tidal limits but most of the time the water table is only a few feet below the ground surface. Sometimes water, from rain and run-off from surrounding hills, tends to impound in this flat area. The planned height of the mainline embankment ranges from approximately 12 ft. to a maximum of approximately 23 ft. The embankments for frontage roads and ramps range in height up to 18 ft.

The preliminary investigation revealed the foundation soils to consist of layers, 4 to 12 ft. thick, of very soft to soft silt and clay with lenses or layers of sand or silty sand. The weak compressible clays are mainly in the upper 10 to 20 ft. of depth and these plastic materials are underlain by relatively dense sand. Some of the borings revealed clay at the surface and others revealed sandy surface material underlain by the soft clay.

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The results of unconfined compression tests on the clay indicated in-place shear strength in the order of 150 to 250 lbs. per sq. ft. The stability analyses indicated that not more than 5 or 6 ft. of stable embankment could be built without some special treatment or precautions during construction.

The consolidation test data indicated that settlements in the order of 1 to 2 ft. could be expected. Due to variations in the thickness of the clay layers, differential settlements within the lagoon might be as much 1 ft. The amount of settlement, after a waiting period of 2 or 3 yrs., might be not more than 1/2 ft. The use of a surcharge would shorten the waiting period and minimize the amount of settlement subsequent to construction. Time studies and stability analyses showed that the embankments could be built without serious failures with the use of berms and a controlled rate of loading.

The Special Provisions specified that the embankments should be built at a controlled rate not to exceed 2 ft. of embankment per wk. The embankments were built to a surcharge height of 4 ft. above profile grade. The size of the berms varied with the height of the embankment, but generally were in the order of 8 ft. high and 40 ft. wide. Construction of the embankments was begun in August, 1962, and completed in February, 1963; it is planned to start a paving contract early in 1965.

The amounts of settlement that have occurred at 2 locations are shown on Fig. 4 and Fig. 5. The theoretical time-settlement curves are corrected for construction and are considered to be in very good agreement with the actual measured settlement. The amount shown for the calculated utimate is

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based on the amount of embankment to profile grade, while the theoretical curve is based on the amount of embankment to surcharge height of 4 ft. above profile grade. The amount of measured settlement is already slightly more than the calculated ultimate, but the rate is decreasing, and it is anticipated that the settlement subsequent to paving will be negligible.

Example No. 2 - San Dieguito River Basin

The river basin is approximately 6400 ft. wide, Station 1216± to Station 1280±. The basin is filled with typical marsh land soils of soft silts and clays, with loose sand extending to depths of 30 ft. or more. The elevation of original ground is about 10 at the south and north sides of the river basin and about 2 near the center. Over these soft soils, the height of embankment will be about 90 ft. at the south side, sloping down to about 16 ft. near the center, and increasing to about 52 ft. at the north side of the basin. The San Dieguito River Bridge is located near Station 1248, and the Via De La Valle Overcrossing is located in the vicinity of Station 1277.

Unconfined compression and quick-undrained triaxial compression tests showed shear strength of approximately 300 lbs. per sq. ft. for the soft foundation soils. Time studies indicated that some increase in strength could be expected during construction. The stability analyses indicated that, with the increase in strength due to settlement during construction, approximately 30 ft. of embankment could be constructed.

Calculations indicated that settlement in the order of 3 ft. could be anticipated under embankments of 80 ft. or 90 ft. height; approximately 1/2 ft. of settlement would occur in the

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center of the river basin; and approximately 5 ft. would occur under 50 ft. of embankment on the north side of the basin, vicinity of Station 1278.

The conclusions of the complete analysis were: (a) with a controlled rate of loading and the use of berms the embankment could be built to a maximum height of 60 ft.; (b) The berms should be 1/2 the fill height with a maximum height of 30 ft. and they should be 80 ft. wide; (c) In order to assure some increase in strength during construction, the embankments should be built at a rate not in excess of 3 ft. per wk., and after a height of 60 ft. provisions should be made for a waiting period of 1 yr.; (d) The second stage of construction should also be controlled at a rate of 3 ft. per wk.; (e) A surcharge of 1 to 2 ft. should be placed between Station 1216 and Station 1276 and a surcharge of 10 ft. should be used in the vicinity of Station 1278; (f) A waiting period of 1 yr. in the vicinity of Station 1224 and a period of 3 yrs. in the vicinity of Station 1278 would reduce the amount of settlement subsequent to paving to a negligible quantity.

The first stage construction was begun in March 1962 and completed in February 1963. Construction of the second stage of embankment between Station 1205± and Station 1228± began on November 8, 1963. The estimated completion date for this work is September, 1964. Paving this embankment will probably begin in June 1965, with completion in early 1966.

The settlement at Station 1224, and at Station 1278+50 where the 60 ft. of embankment includes a surcharge of 10 ft. above profile grade, is shown on Figs. 6 and 7, respectively.

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In one case the actual amount of settlement will be about 20% greater than the calculated ultimate. In the other case the calculated ultimate is about 27% more than the actual measured settlement as of March 12, 1964. The measured settlement curves show a decreasing rate of settlement during the 1-yr. waiting period. At Station 1224 the actual rate is in fair agreement with the theoretical rate during construction to the height of 60 ft., but the difference between the two curves is increasing during the waiting period. The settlement curve also shows the expected increase in settlement during the second stage of construction. At Station 1278+50 the two curves converge and there is a slight increase in the rate of settlement near the end of the waiting period. Construction operations for the Via De La Valle Overcrossing at this location were delayed 2 months to allow more time for settlement, but this will not delay the overall completion of the contract. Some settlement will occur during the waiting period after construction of the structure. The abutments for this structure are set on spread footings in the embankment and provisions have been made for jacking or raising the bridge deck, as necessary, to maintain a smooth profile from structure to embankment. The settlement curves indicate that the scheduling of construction, with the use of surcharges and waiting periods will assure a tolerable amount of settlement after paving.

<u>Example No. 3 - San Elijo Lagoon</u>

The new embankment crosses approximately 1500 ft. of this lagoon, Station 1381± to Station 1400±, and a bridge for crossing the waterway and Manchester Avenue is located in the vicinity

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of Station 1396. The height of embankment to profile grade is 67 ft. at Station 1383 and slopes down to a height of 33 ft. at Station 1400. The elevation of the ground is about +2. An earth dike near the mouth of the channel prevents flooding during high tides, but the area does become flooded due to rain and surface runoff from surrounding hills.

The soils investigation showed a surface layer, 3 to 6 ft. thick, of soft to very soft, moderately compressible, highly plastic clay with a minor amount of organic material. The clay is underlain by loose to dense silty sand or sand. Only 1 boring, out of a total of 13, showed a surface layer of sand above the clay. Laboratory strength tests indicated in-place shear strength in the order of 100 to 150 lbs. per sq. ft. for the very soft clay. It was immediately apparent that this material would not support even the minimum height of embankment without some special treatment and precautions during construction. However, the material would consolidate quite rapidly, and some increase in strength during construction would permit placement of a stable embankment to a height of approximately 20 ft. These soil conditions are such that it would probably be ideal to use the stripping method as a means of special treatment, but the budgeting of this and connecting projects would allow a period of 4 or 5 yrs. from the start of construction to final paving.

Stability analyses and time studies indicated that if berms 20 ft. high by 50 ft. wide are used, and if the embankment were built at a controlled rate not to exceed 2 ft. per wk., a stable embankment could be built to a maximum height of 50 ft. The time studies indicated that it would be necessary to make

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provisions for a waiting period of 60 days in order to obtain the strength necessary for construction of the embankment to final grade. Calculations indicated that settlement in the order of 1 ft. or slightly more could be anticipated. A surcharge of 2 ft. above profile grade, mainly to compensate for settlement, and a waiting period of 90 days, would result in a negligible amount of settlement subsequent to paving.

The contract for construction of the embankment across San Elijo Lagoon included the embankment across Batiquitos Lagoon, which will be discussed later, and also included construction of the San Elijo Bridge. This contract was awarded in August, 1961, and completed in May, 1963. A contract which includes several structures, paving across San Elijo, and several miles of new freeway construction was advertised in December, 1963. The paving operations will probably start in December, 1964, and the contract is scheduled for completion in June, 1965.

The settlements, which have occurred under 69 and 62 ft. of embankment in San Elijo Lagoon are shown on Figures 8 and 9, respectively. These are examples of the least accurate estimates of settlement, as at both locations the amount of measured settlement is approximately 60% greater than the calculated ultimate and the settlement has occurred in about 1/2 the time as calculated from the laboratory consolidation test data. The satisfying feature of the measured settlement curves is that they show a decrease in the rate of settlement during the waiting period after construction to a height of 50 ft., an increase in the rate of settlement during the second stage of

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construction to surcharge height of 2 ft. above profile grade, and they are beginning to show a very slow rate of settlement during the second waiting period. These data definitely show that the settlement subsequent to paving should be negligible.

Example No. 4 - Batiquitos Lagoon

The marsh is approximately 4000 ft. wide at this location, Station 1685± to Station 1725±, and 2 structures will be constructed within these limits. The La Costa Avenue Over-crossing is located in the vicinity of Station 1689± and the Batiquitos Bridge is located in the vicinity of Station 1716±. The maximum height of the approach embankments to the over-crossing will be approximately 39 ft. The mainline embankment will be about 15 ft. high in the vicinity of the overcrossing, slope down to a height of about 12 ft. near the middle of the lagoon and increase to a height of 40 ft. on the north side. The elevation of original ground, similar to the other lagoons, is approximately +1 or +2. As at San Elijo Lagoon, poor drainage conditions cause flooding of the area during and after periods of rain.

The very weak compressible clay soils extend to a maximum depth of approximately 20 ft. and are interspersed with lenses of loose sand and peaty material. The preliminary investigation revealed dense sand in the bottom of all borings. The in-place strength of the soft mud, as indicated by unconfined compression and quick-undrained triaxial compression tests, was in the order of 100 to 150 lbs. per sq. ft. Time studies and stability analysis indicated that berms, a controlled rate of loading, and two-stage construction would be necessary to build stable

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embankments to the planned heights. Calculations indicated that settlement in the order of 2½ to 3½ ft. could be anticipated. Time studies and examination of the soil profiles showed that the rate of settlement within the lagoon would be highly variable due to the difference in thickness of the clay layers and the alternating layers or lenses of sand and silty sand. In some areas noticeable settlement would occur 2 or 3 yrs. after construction. Berms and loading at the rate of 2 ft. per wk. would permit construction to a height of 25 ft. in the first stage. The berms would have to be 12 ft. high and 50 ft. wide in order to build to the planned profile grade plus some surcharge.

The construction of the embankments was commenced during August, 1961, and was completed in May, 1963. The Special Provisions specified a rate not to exceed 2 ft. in height per wk. Provisions were made for a waiting period of 180 days after construction to a height of 25 ft. This period would be necessary to obtain the increase in strength of the foundation soils necessary for the second stage of construction, at the same controlled rate of loading. The embankments were built to a surcharge height of 10 ft. above profile grade in the vicinity of the overcrossing. The time-settlement studies indicated that if the surcharge remains in place for a period of 2 yrs., the settlement subsequent to construction will be negligible. The contract for construction of the structures and paving is scheduled to commence in September, 1964; actual paving will probably start in September, 1965, and the contract will be completed about June, 1966. Typical settlement curves and soil data for Batiquitos Lagoon are shown on Fig. 10 and Fig. 11.

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The curves indicate that the amount of actual settlement will be very close to the calculated ultimate figure. At Station "LC-2" 1687+50 the actual rate of settlement is faster than the theoretical rate while at Station "LC" 1693+50 there is very good agreement between the actual and theoretical rates, especially during the first stage of construction. The curves show the expected leveling-off during the waiting periods and give good evidence that the settlement after paving will cause very little distortion of the pavement profile.

This is the 1 lagoon where some minor mud waves or shear failures occurred during the placement of the working platform. Some berms, which were not planned, were placed to assure stability of the embankment. Quaking or sponginess was noticeable during construction in the area where the berms were added. Some cracking appeared in the embankment after the first stage of construction. A careful field review and study of the settlement data indicated that the cracks were probably due to differential settlement and the sandy embankment material cracking at relatively low strain. The embankment appeared stable at the end of the waiting period. The second stage was constructed as planned and there was no delay in completion of the contract.

SUMMARY

The construction of highways across marsh lands or tidal flats usually requires some special treatment of the foundation soils and unusual construction methods. Stripping of the soft compressible soils, sand drains and stage construction with surcharges and waiting periods are among the methods which

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are often considered and investigated by the California Division of Highways.

The choice of method of construction is determined only after a thorough foundation investigation, including economic comparisons of several alternates, estimates of costs of maintenance and reconstruction and the total period of time available for the construction. The principles of soil mechanics are used to predict the behavior of foundation soils during and after construction.

Laboratory consolidation test data are used to predict amounts and rates of settlement that will occur in foundation soils when loaded with highway embankments. The safe height to which embankments can be built without precautions during construction is determined from unconfined and quick-undrained triaxial compression test results. Berms are utilized to construct the embankments to greater heights. Time-consolidation curves, consolidated-quick-undrained triaxial compression test data and sound engineering judgment are the basis for determining a safe controlled rate of loading in order to construct the embankments to still greater heights. The use of surcharges and waiting periods to minimize detrimental settlement subsequent to paving has been described.

Experience in California has shown that reasonably accurate estimates of the amounts of ultimate settlement due to consolidation of fine-grained soils can be made. Predictions of the rates of settlement are less reliable because of the many indeterminate factors used in time studies and the actual observed rates do not always agree with the calculations.

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The use of surcharges and waiting periods on approach embankments to structures are becoming common practice in the construction of highways in California. They are also used in construction across marsh lands where after-paving settlement of the foundation soils would cause distortion of the finished profile and damage to or destruction of the pavement.

Comparison of measured settlement and predicted settlement at 2 locations in each of 4 lagoons in San Diego County, California, has been presented. There is "good" or "very good" agreement between the actual and theoretical rates in 4 instances especially during construction and early in the waiting period. In the other 4 instances the actual rate is much faster than the calculated rate. As of March 1964 the measured amount of settlement exceeds the calculated amount by 20% or less at 4 locations. At 2 locations the measured amount is approximately 27% less than the calculated amount; and at the other 2 locations, in San Elijo Lagoon, the measured amount of settlement is approximately 60% to 70% more than the theoretical amount.

The projects described herein are good examples of the benefits that can be obtained from the use of surcharges and planned waiting periods. The actual field measurements are as close to the theoretical predictions as can be expected in these areas where the thickness of the soft silts and clay, interspersed with layers or lenses of loose sand, is quite variable within any one lagoon. While it will be 2 or 3 yr. before completion of the pavments, the recorded settlements furnish good evidence that the settlement subsequent to paving will not be detrimental to the riding qualities of the finished roadway.

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ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Fig. 1 Location Map

Fig. 2 Typical Pressure-Void Ratio Curve, soft silty clay, San Diequito River Basin, Station "SD" 1278+50.

Fig. 3 Typical Time-Consolidation Curves, soft silty clay, San Diequito River Basin, Station "SD" 1278+50.

Fig. 4 Settlement at Los Penasquitos Lagoon, Station "SD" 1095.

Fig. 5 Settlement at Los Penasquitos Lagoon, Station "CV-3" 1096.

Fig. 6 Settlement at San Dieguito River Basin, Station "SD" 1224.

Fig. 7 Settlement at San Dieguito River Basin, Station "SD" 1278+50.

Fig. 8 Settlement at San Elijo Lagoon, Station "A" 1383+50.

Fig. 9 Settlement at San Elijo Lagoon, Station "A" 1386.

Fig. 10 Settlement at Batiquitos Lagoon, Station "LC-2" 1687+50.

Fig. 11 Settlement at Batiquitos Lagoon, Station "LC" 1693+50.

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APPENDIX - NOTATION

The following symbols, adopted for use in this paper, conform essentially with "Glossary of Terms and Definitions in Soil Mechanics, ASCE Proc. Paper 1826, October, 1958:

c	= cohesion per unit area;
e_o	= void ratio at pressure equal to existing over-burden pressure;
e_f	= void ratio due to additional pressure;
H	= length of drainage path in the field;
$2H$	= thickness of compressible layer in the field;
$2H_s$	= settlement or change in thickness in the field;
h	= length of drainage path in the laboratory specimen;
L	= arc length of potential slip plane;
S.F.	= safety factor;
T_{50}	= time for 50% settlement in the field;
t_{50}	= time for 50% consolidation in the laboratory specimen;
ϕ	= angle of internal friction;
$\tan \phi$	= tangent of angle of internal friction;
ΣN	= summation of normal forces acting on potential slip plane; and
ΣT	= summation of tangential forces acting on potential slip plane

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FIGURE I

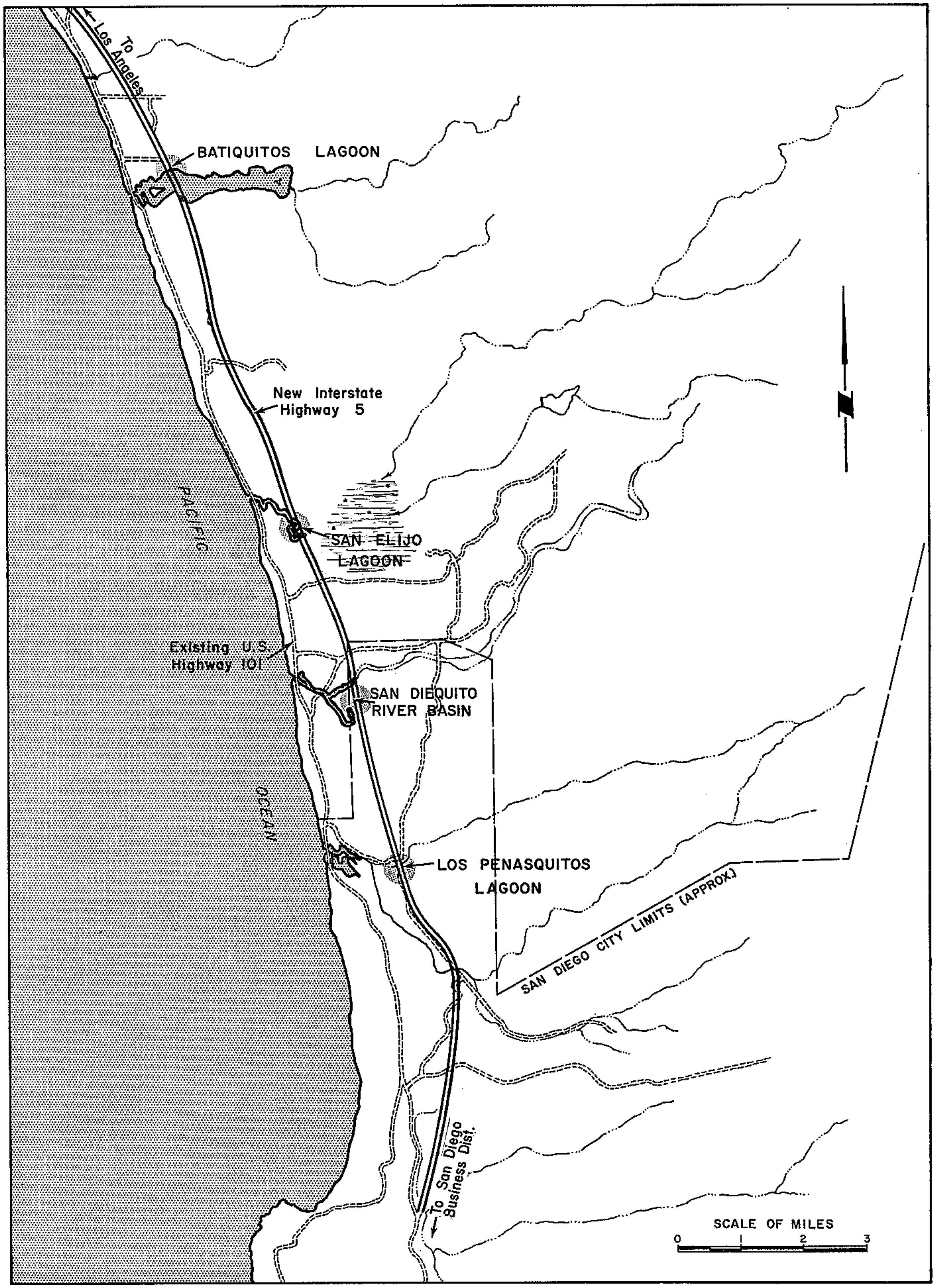

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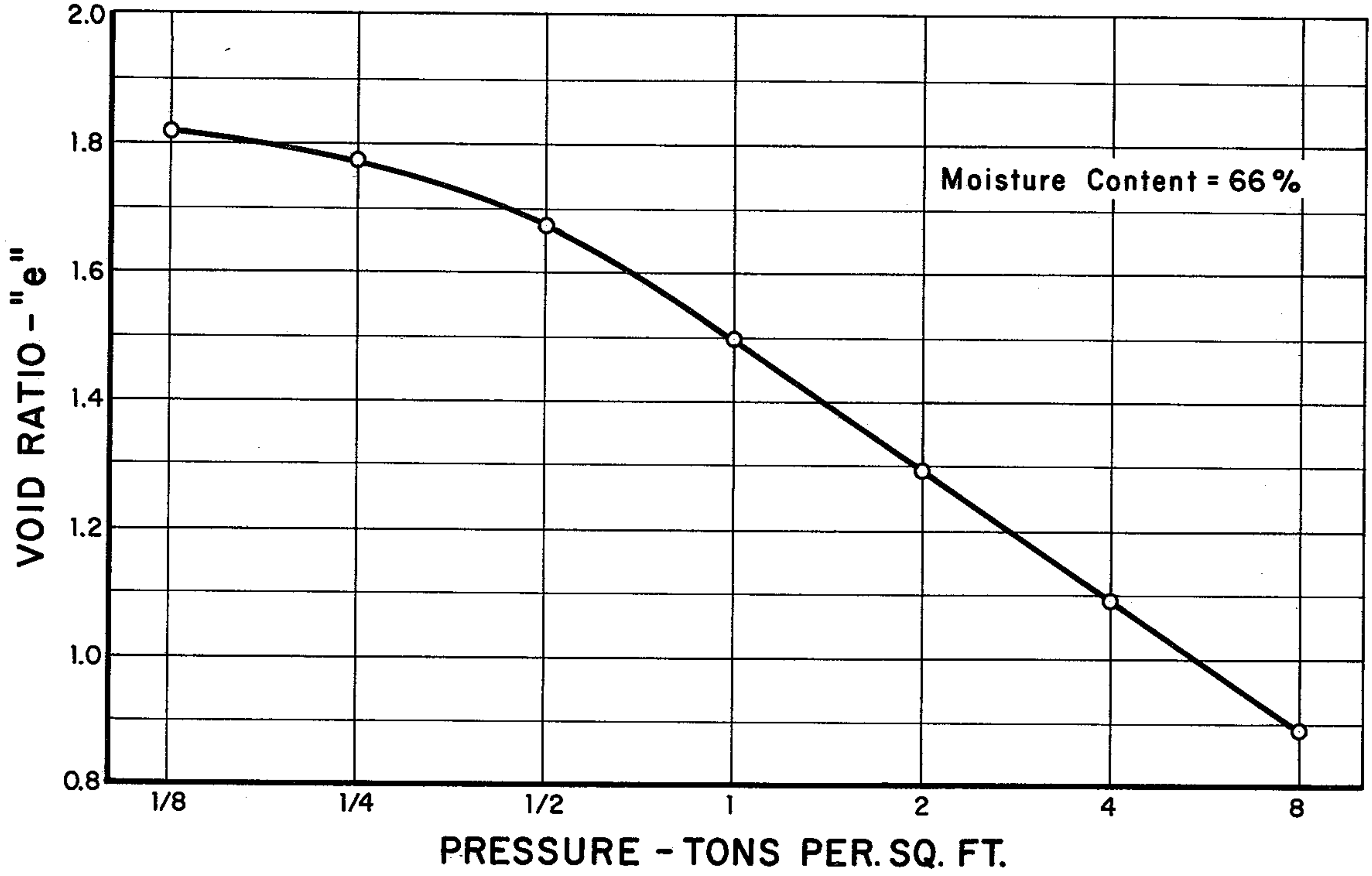
FIGURE 2



TYPICAL PRESSURE-VOID RATIO CURVE, SOFT SILTY CLAY
SAN DIEQUITO RIVER BASIN, STATION "SD" 1278+50

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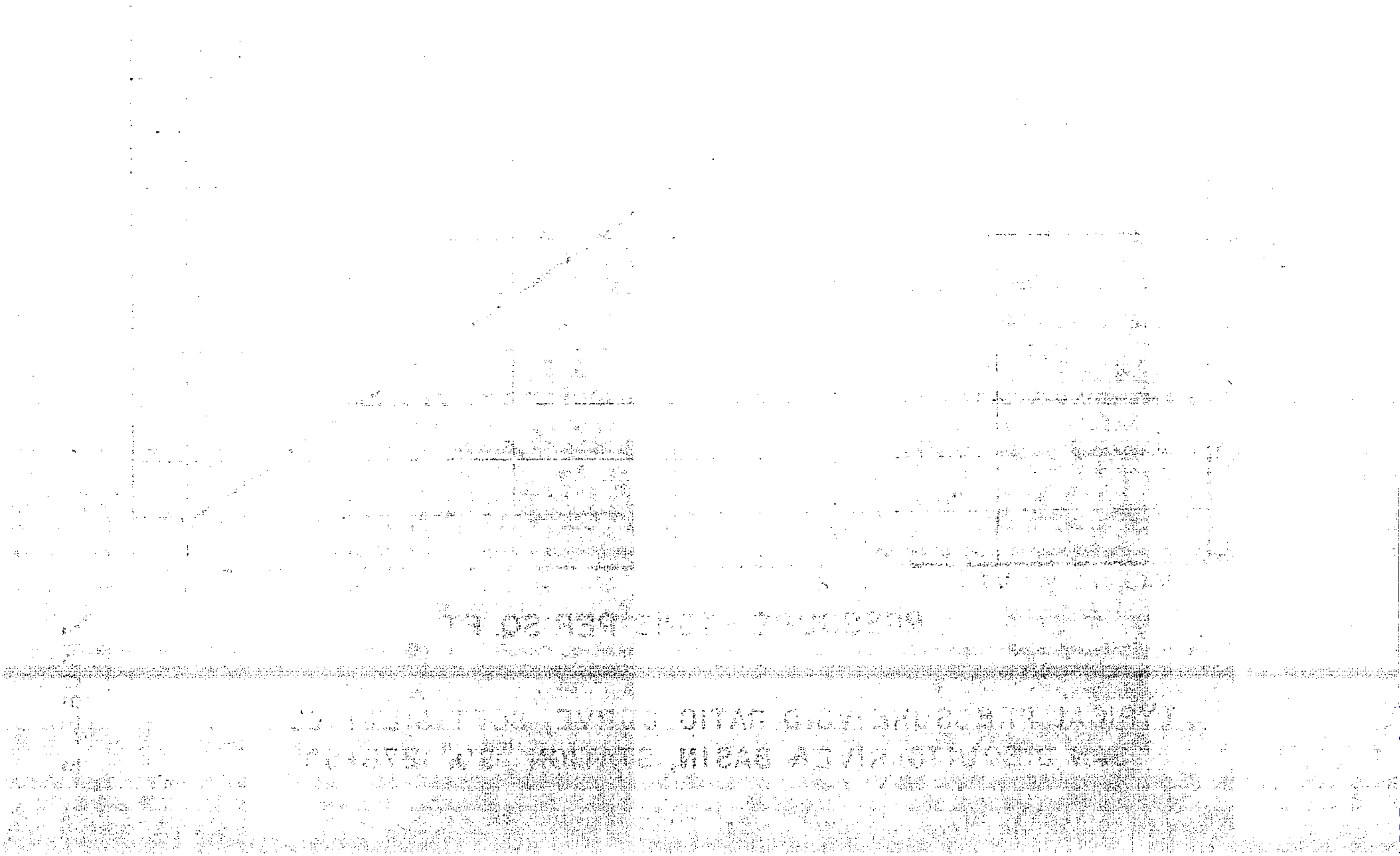

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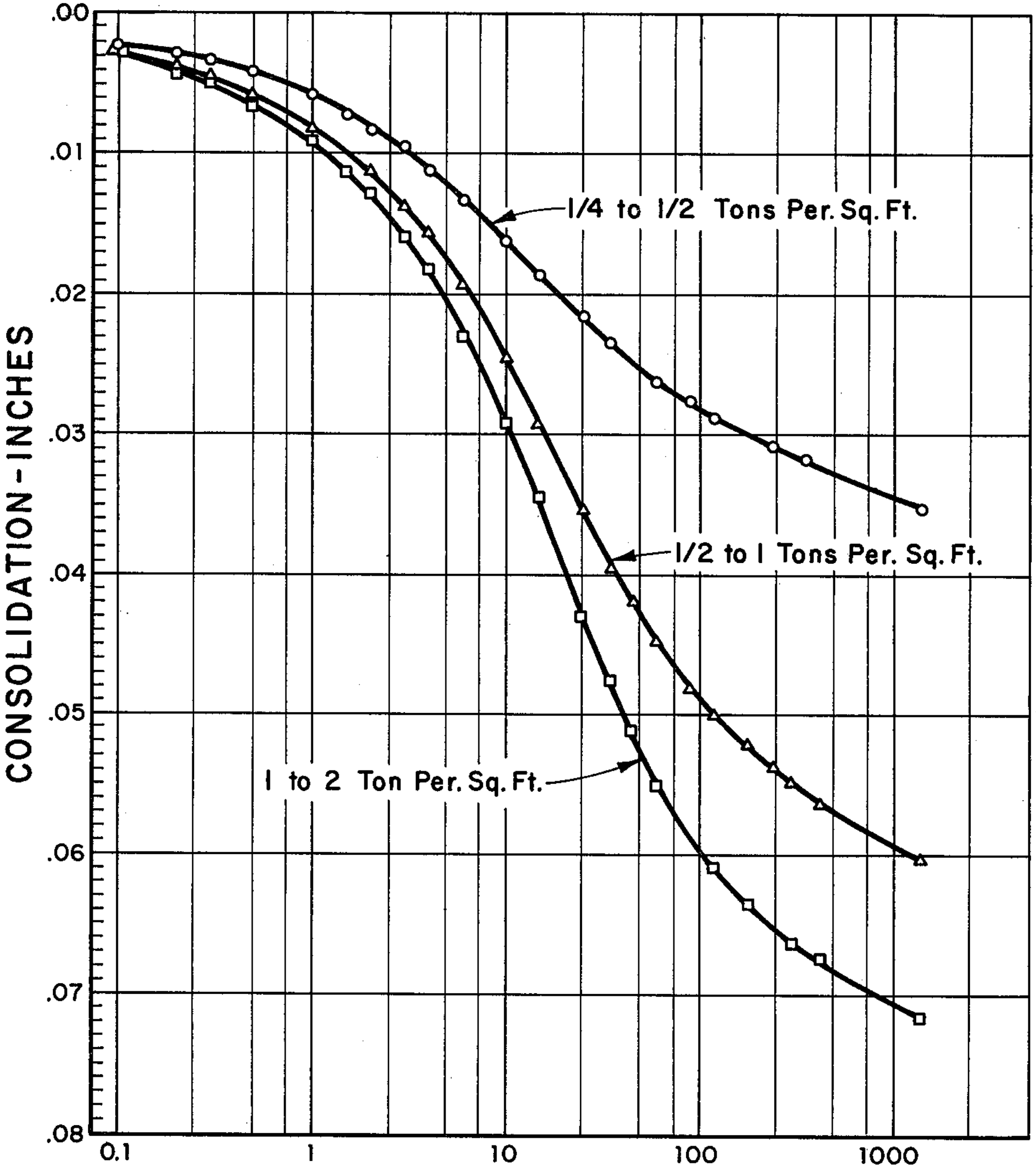

TIME - MINUTES

TYPICAL TIME-CONSOLIDATION CURVES
SOFT SILTY CLAY, SAN DIEQUITO RIVER BASIN
STATION "SD" 1278+50

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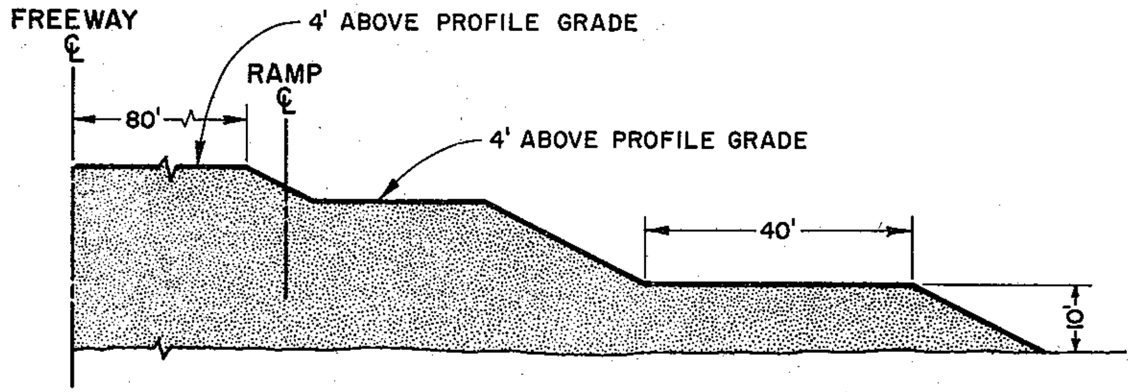
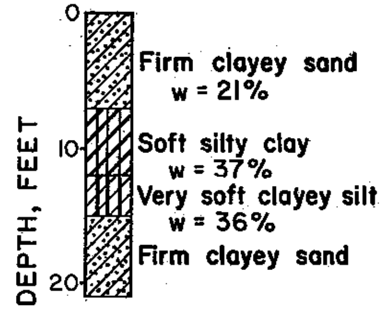
FIGURE 4

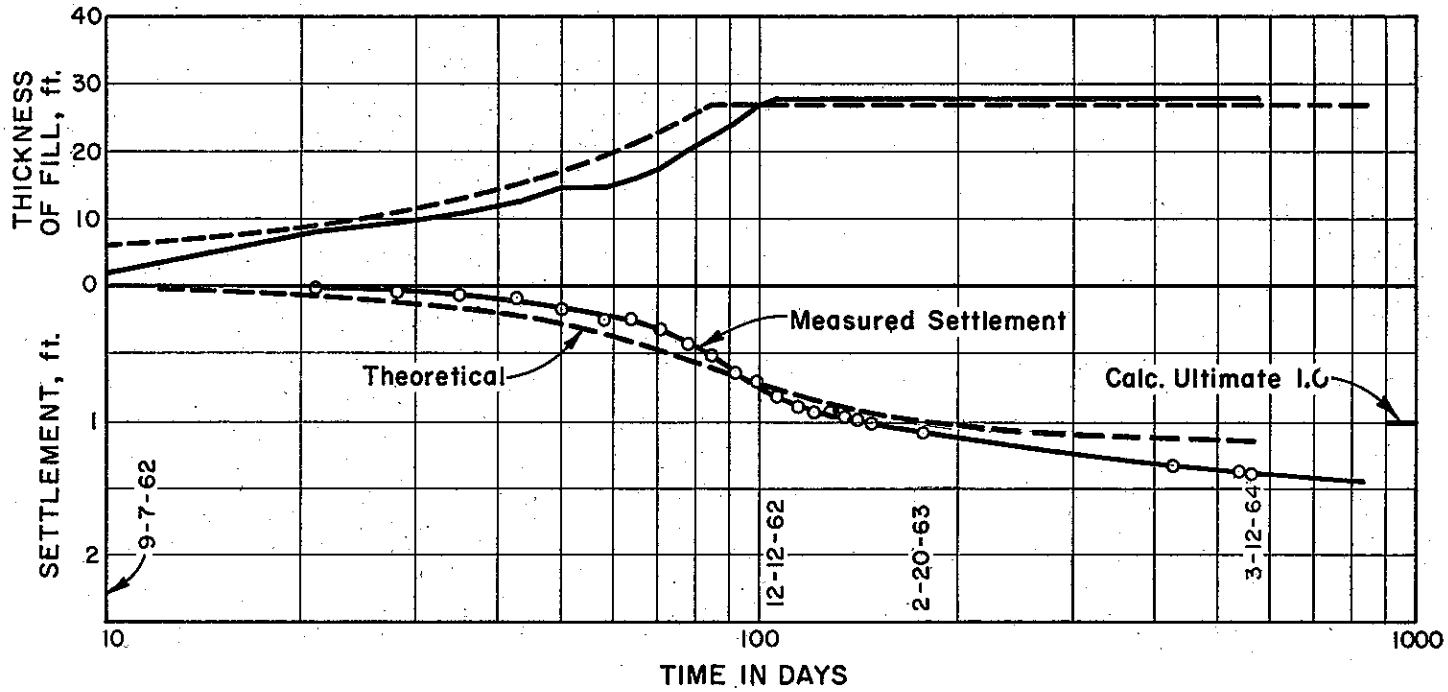


HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET 0 20 40

SOIL PROFILE





SETTLEMENT AT LOS PENASQUITOS LAGOON
STATION "SD" 1095

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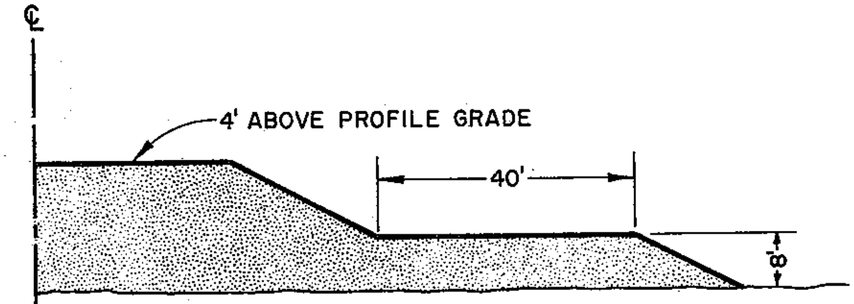
FIGURE 5

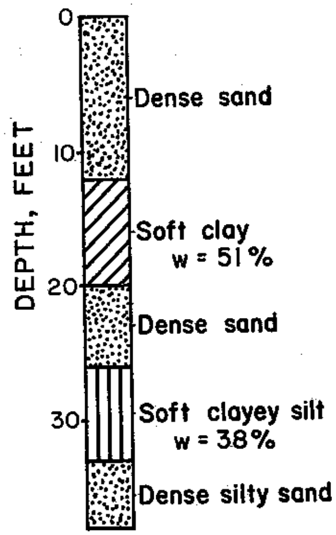


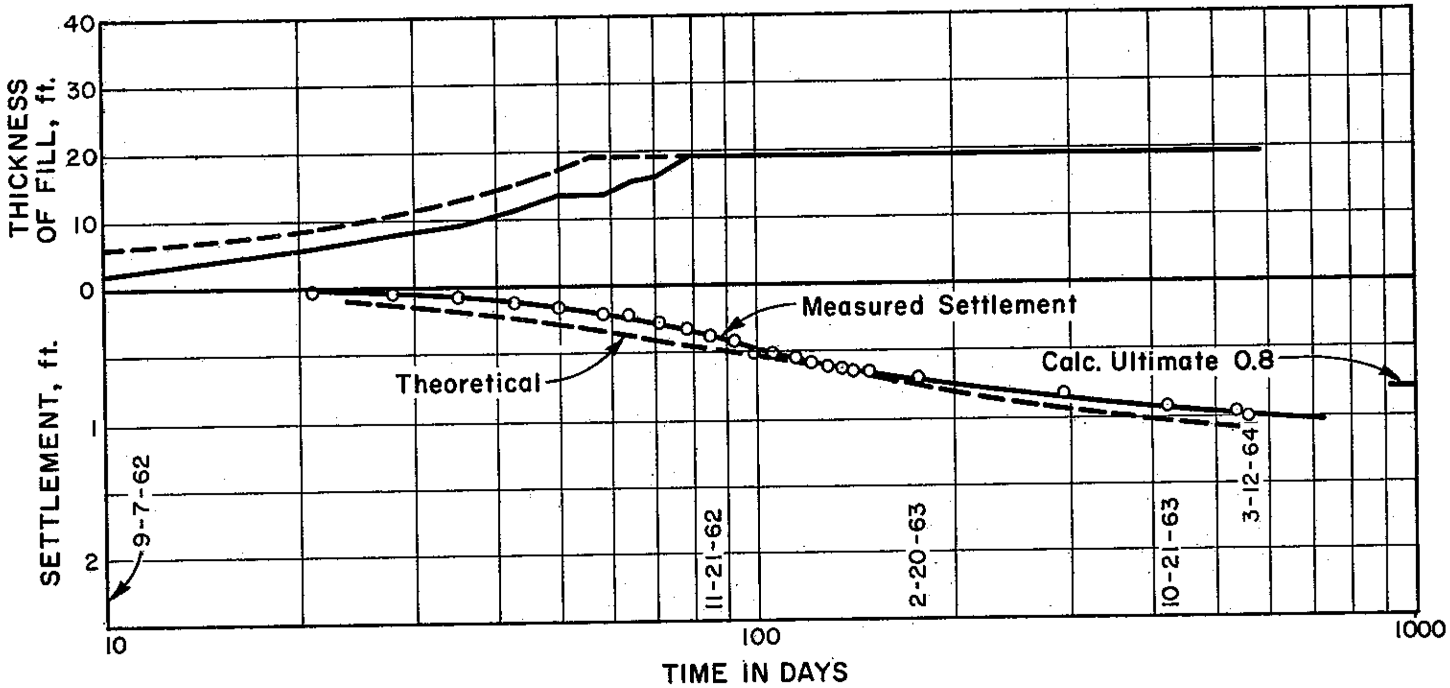
HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET

0 20 40

SOIL PROFILE





SETTLEMENT AT LOS PENASQUITOS LAGOON
STATION "CV-3" 1096

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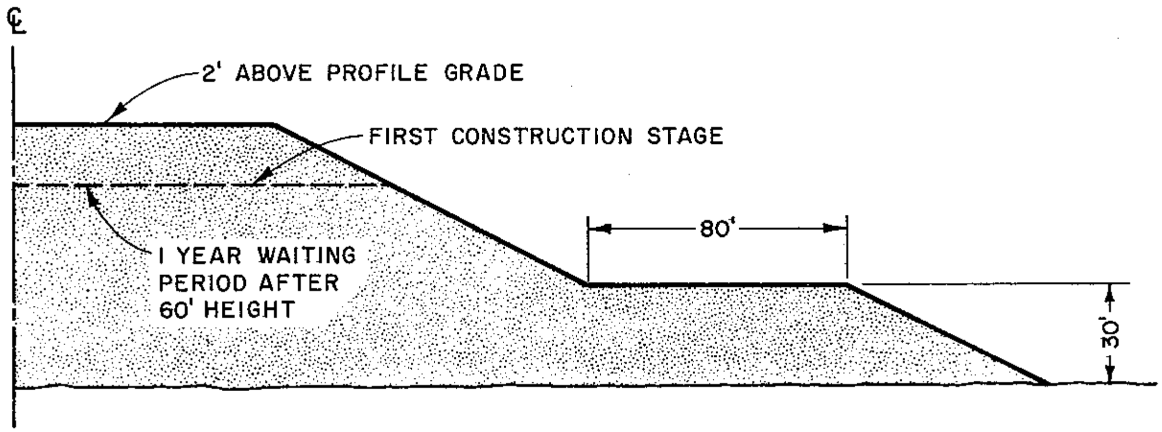

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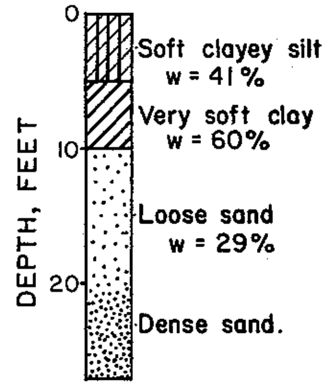

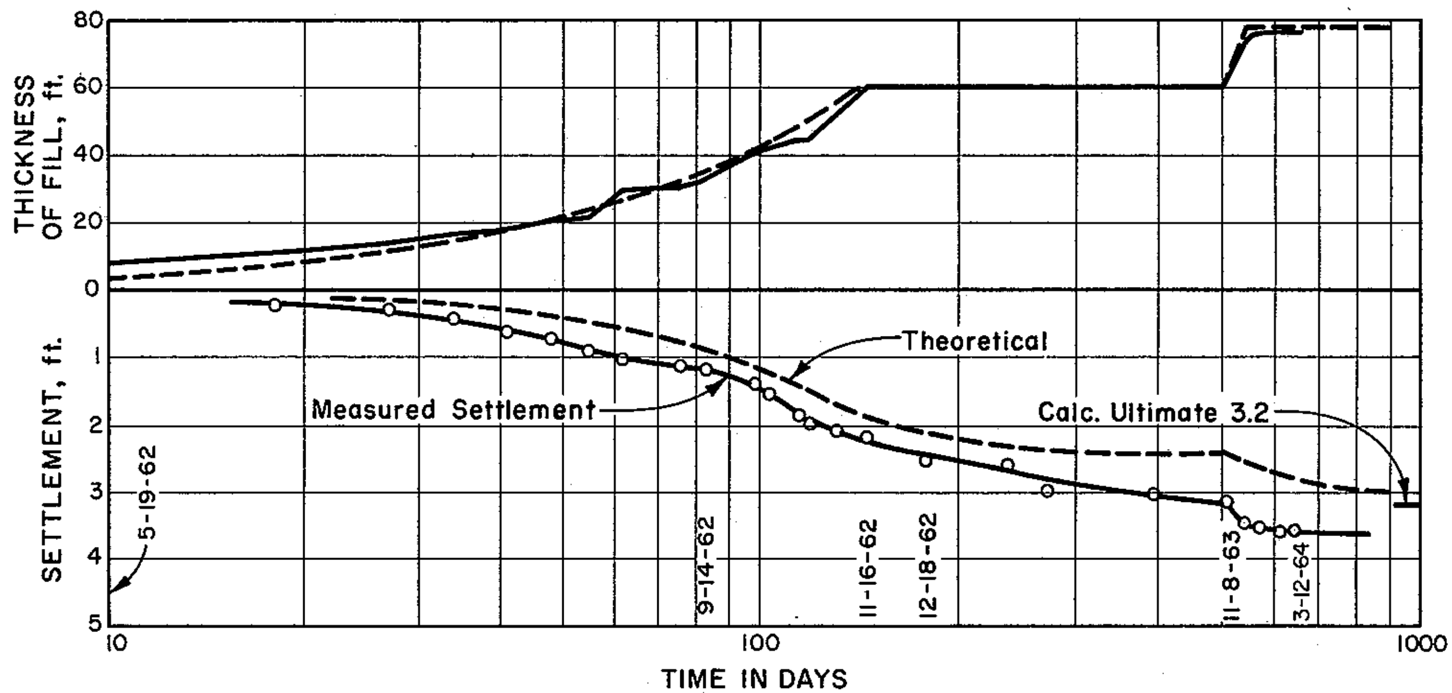

SETTLEMENT AT SAN DIEQUITO RIVER BASIN
STATION "SD" 1224

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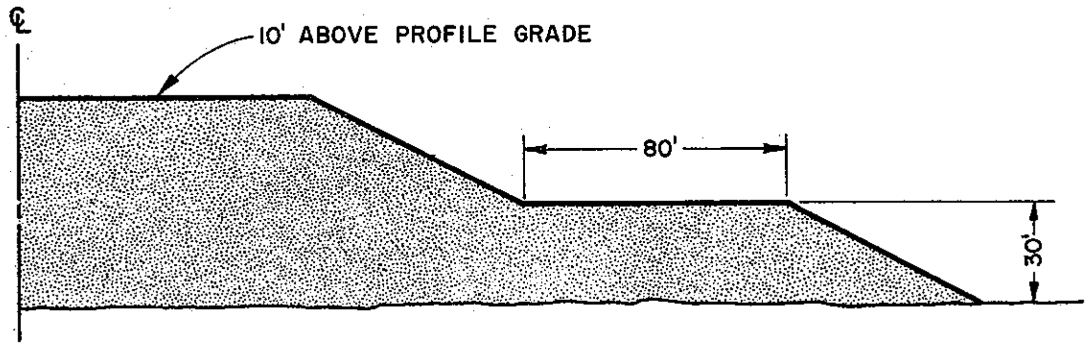
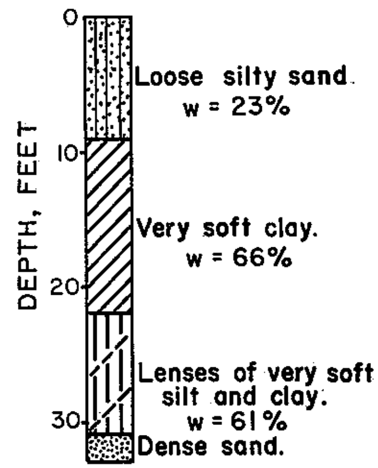
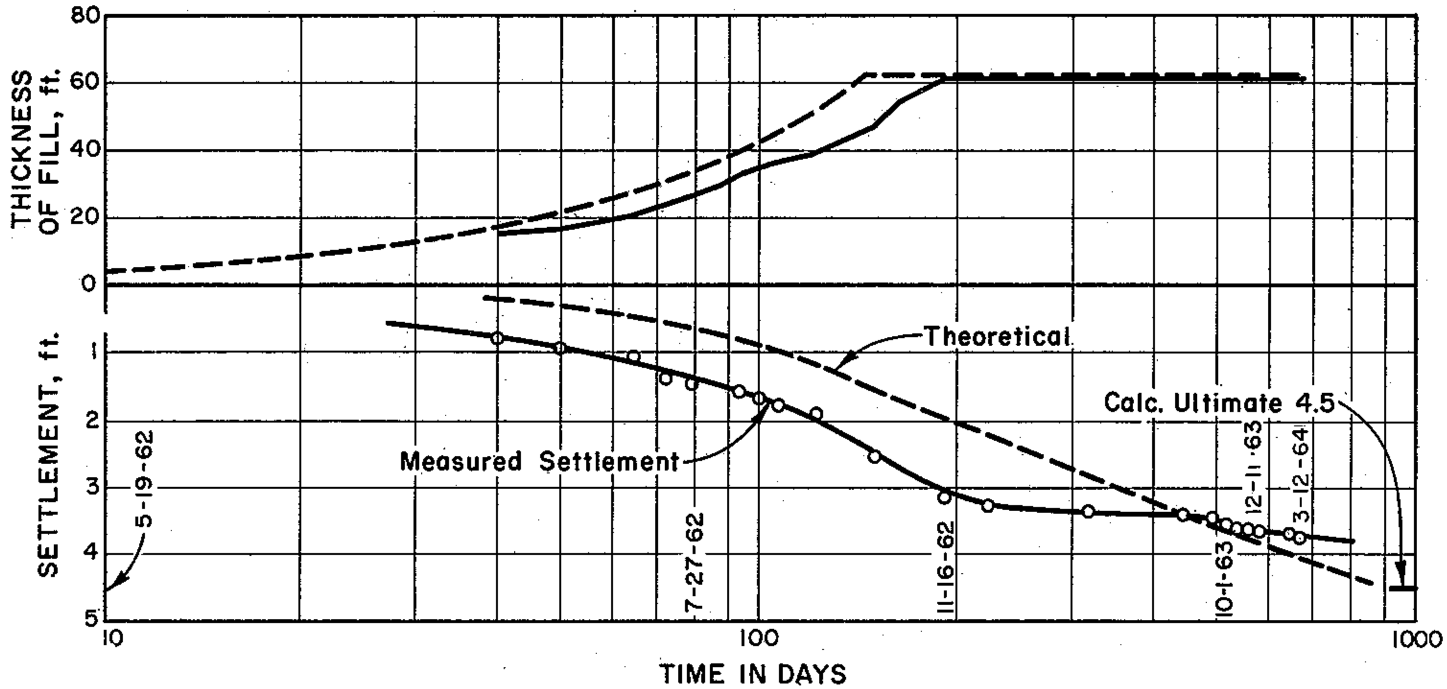


HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET 0 40 80

SOIL PROFILE





SETTLEMENT AT SAN DIEQUITO RIVER BASIN
STATION "SD" 1278+50

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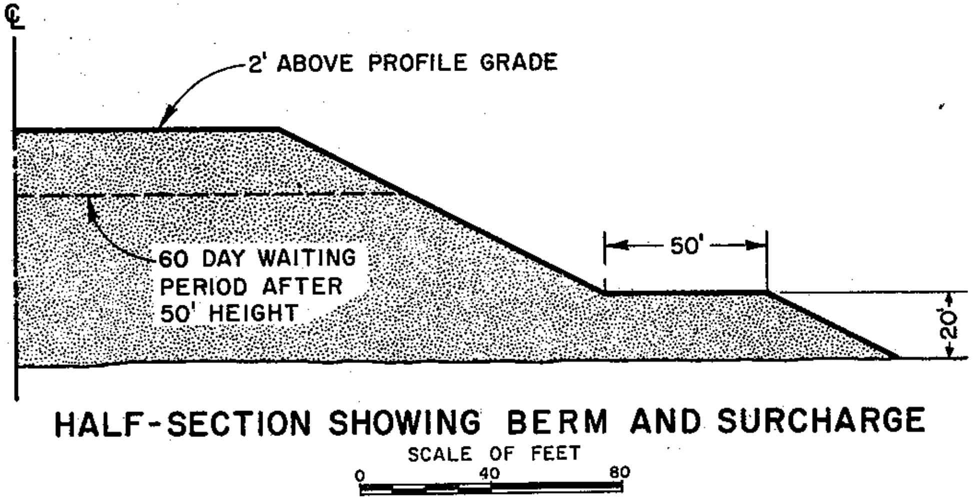

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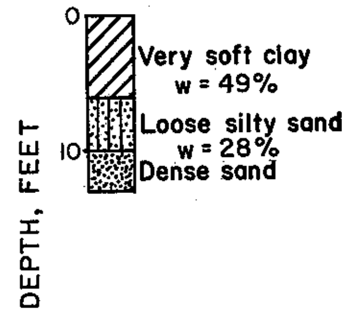
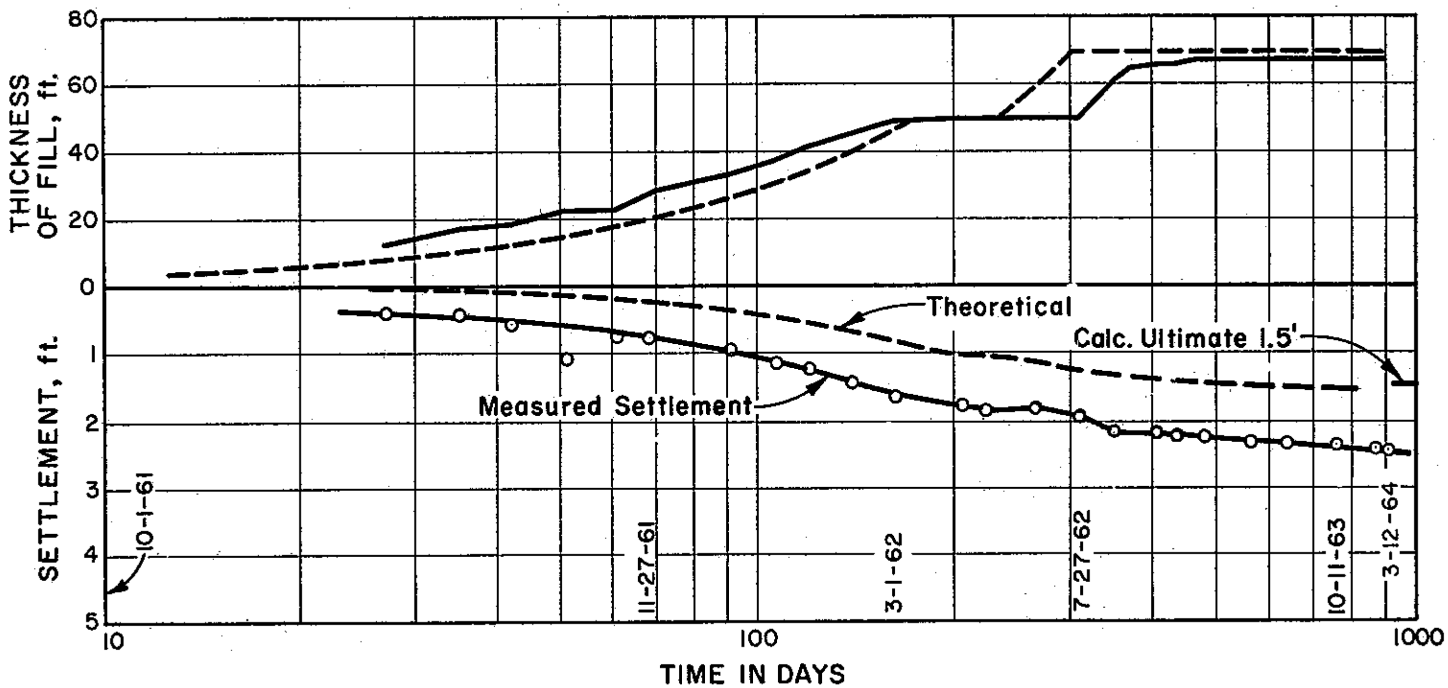
SOIL PROFILE





SETTLEMENT AT SAN ELIJO LAGOON
STATION "A" 1383+50

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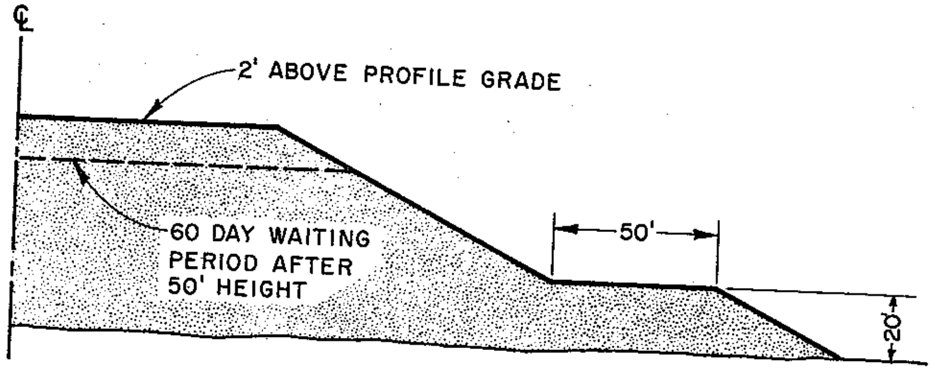
FIGURE 9



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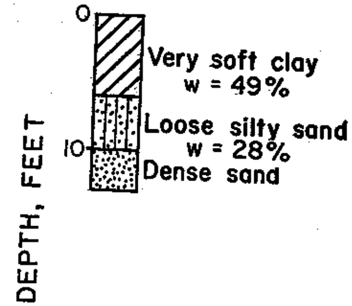
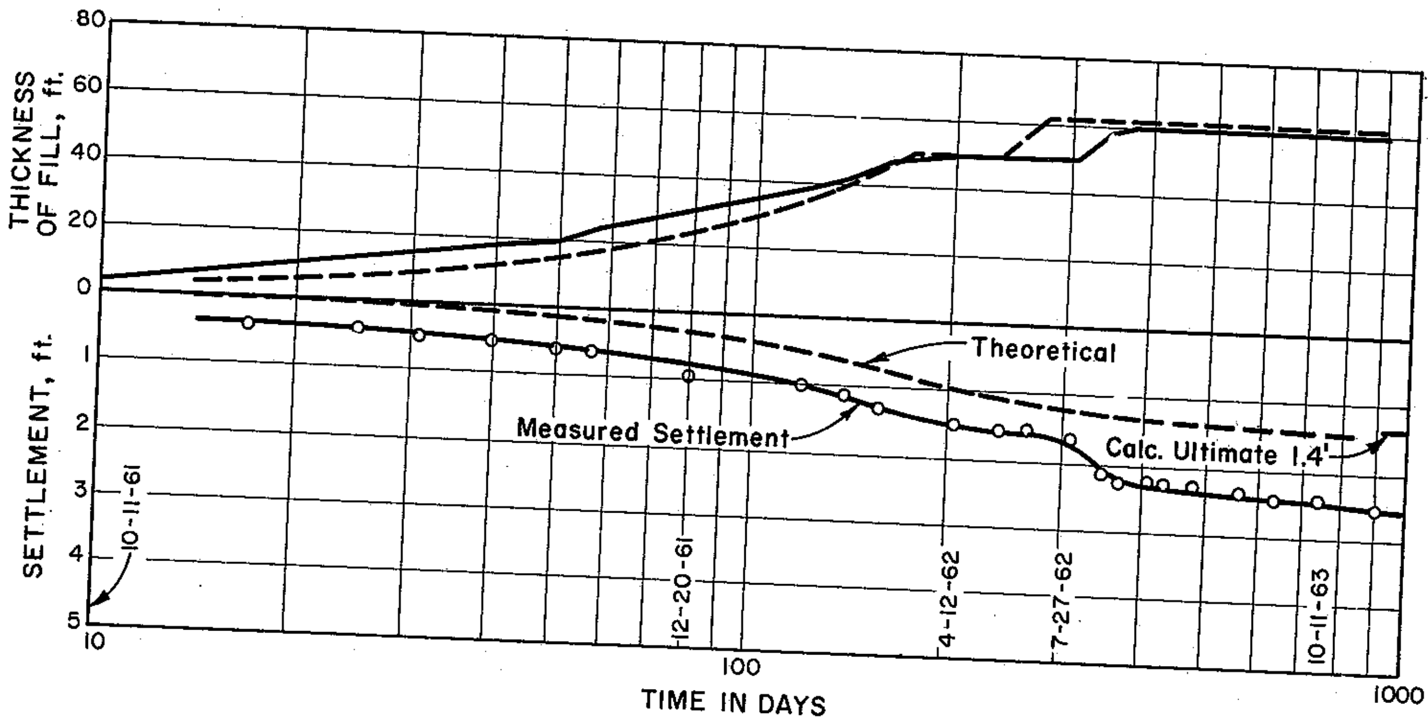
SOIL PROFILE





SETTLEMENT AT SAN ELIJO LAGOON
STATION "A" 1386

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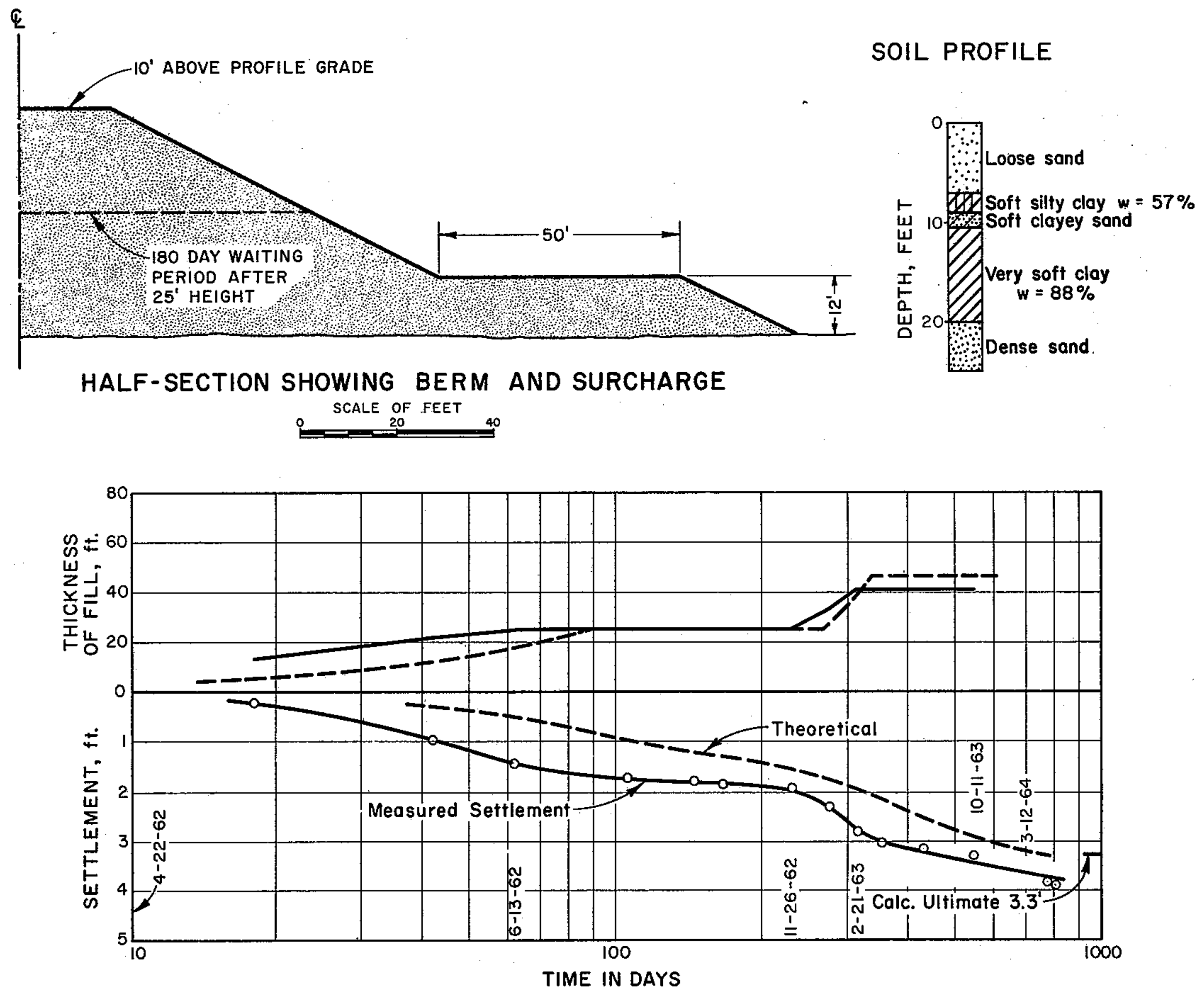
FIGURE 10



SETTLEMENT AT BATIQUITOS LAGOON
STATION "LC-2" 1687+50

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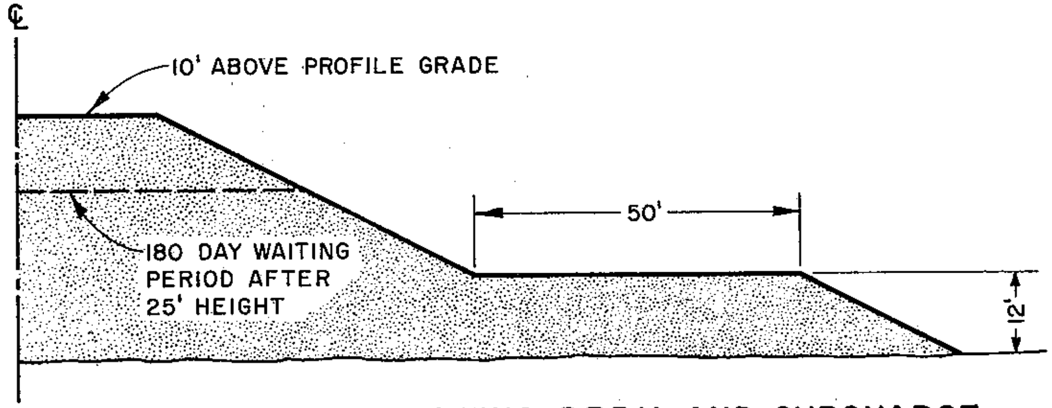
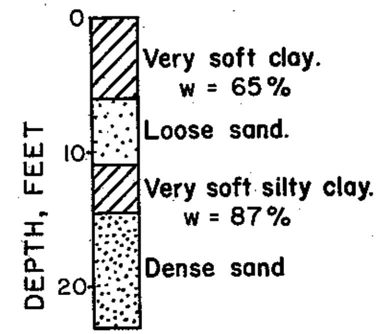
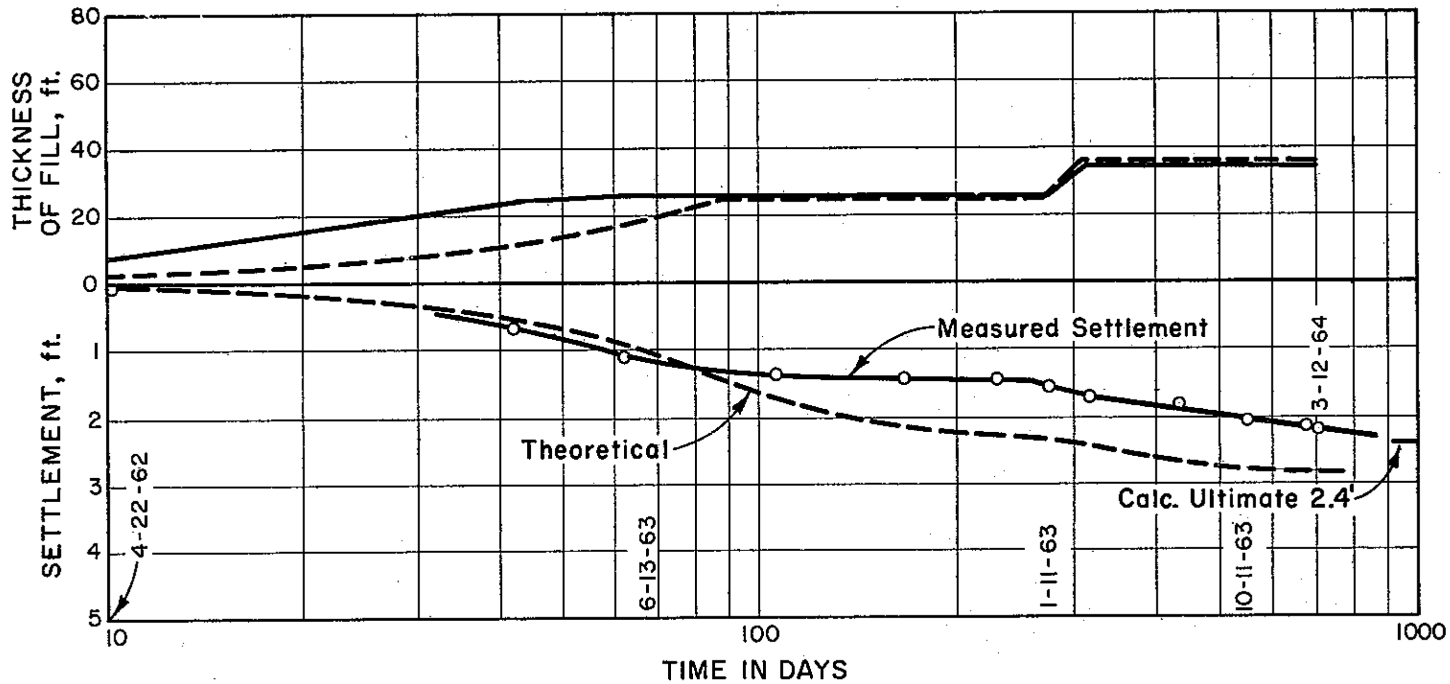


HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET
0 20 40

SOIL PROFILE





SETTLEMENT AT BATIQUITOS LAGOON
STATION "LC" 1693+50

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