# SETTLEMENT STUDY

## Interim Report No. 1

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# A LIST OF VARIABLES USED IN THE REPORT

$\gamma$ = Unit weight of soil, T/ft$^3$
$\sigma o$ = Overburden pressure at midpoint of strata, T/ft$^2$
$\Delta\sigma$ = Imposed stress from the embankment, T/ft$^2$
$e$ = Voids ratio
$e_o$ = Voids ratio at the beginning of the test
$\Delta e$ = Change in voids ratio due to $\Delta\sigma$
$h_F$ = Thickness of stratum in the field, ft
$h_L$ = Thickness of soil in the lab, in
$H_F$ = Length of drainage path in the field, ft
$H_L$ = Length of drainage path in the lab, in
$t\upsilon$ = Time to reach $\upsilon$% consolidation in the lab, min
$\frac{t\upsilon\ H_F}{H_F \text{ for Unit}}$ = Weighted average of all $t\upsilon$'s within a unit, in
$\frac{H_L\ H_F}{H_F \text{ for Unit}}$ = Weighted average of all $H_L$'s within a unit, in
$T$ = Time factor (Terzaghi)
$Cv$ = Coefficient of consolidation, in$^2$/min
$t_F$ = Time in the field to reach $\upsilon$ amount of consolidation
$Tc$ = Thickness of the soil cake, in
$Ds$ = Depth of solids, in
$Ws$ = Weight of the dry soil cake, g
$G$ = Absolute specific gravity of the core
$A$ = Area of the consolidometer ring, cm$^2$
$U_{100}$ = Amount of consolidation at 100% primary consolidation
T/ft$^3$ = 32036 Kq/m$^3$ in = 2.54 cm
T/ft$^2$ = 95.76 kP
ft$^2$ = 0.092 m$^2$
in$^2$/min = 0.108 cm$^2$/sec

# ABSTRACT

This report covers methods of procedure used in the field and in the laboratory in computing the amounts and rates of settlement of several high embankments along I-20 and I-12 in Louisiana. It includes examples of a rather new calculation procedure developed by Ray, Covington and Arman, plus examples of standard calculation methods for comparison. These methods are to be compared to settlements in the field at a later date.

# INTRODUCTION

Although the Louisiana Department of Transportation and Development (DOTD) Office of Highways (OH) had conducted innumerable consolidation investigations, it had little experience in making field measurements of settlement of high embankments and correlating them to laboratory estimates. As a matter of policy, the Department limited its fill heights to that which caused less than 12 inches (0.304 m) of consolidation within a 30-year period based on the laboratory predictions. However, if the designed embankment would settle less than 12 inches (0.304 m) after one year of emplacement, i.e., between one and 30 years, that fill would be approved and left to settle the year before bridge construction was started. When settlement plates were installed, they usually were used in conjunction with surcharges to verify that a major portion of the settlement had occurred. Testing was discontinued when the surcharge was removed. Even without "hard data" there was suspicion among soils engineers and others of a discrepancy in the estimates of settlement time.

In 1964 B. J. Covington, Ara Arman and J. R. Ray completed a research project for what was then the Louisiana Department of Highways, now DOTD, entitled "Consolidation Study" (1)*. The Introduction of that report states:

> The Corps of Engineers, U. S. Army (2), has noted that most of the settlement has occurred within five years after the beginning of construction of the embankments on the Morganza and Atchafalaya Floodways.

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*Underlined numbers in parentheses refer to the references at the back of the text.

It is further stated that Shockley and Mansur (3) indicated that the estimated time of consolidation from laboratory tests was much longer than the time to reach a similar point in the field.

Ray et al set about formulating a method of estimating a rate of consolidation which more closely approximates the rate in the field. In the Conclusions it is stated that:

> A series of consolidation tests should be made on soils from various parts of Louisiana and the proposed method used to estimate field settlements. Field measurements should be carefully made to check the accuracy of the proposed method (1).

This study was undertaken to satisfy a portion of that requirement. In 1964 most of the interstate to be located in "various parts of Louisiana" was in the planning stage, so that the study came at a most auspicious time. Many fills were to be located over I-20 and I-12 or the interstates themselves were to span railroads and major highways. This afforded the opportunity to instrument some of these embankments and monitor them.

This report then is an attempt to familiarize the reader with both field and laboratory procedures including methods of predicting rate and amount of settlement. The actual settlement will be included in a final report.

## PURPOSE AND SCOPE

This project was initiated to check several methods of computing amounts and rates of settlement against actual field settlement records in the soils of Louisiana. It was hoped that all three types of foundation conditions, i.e., underconsolidated, normally consolidated and preconsolidated conditions, could be investigated, but there was no embankment designed over underconsolidated foundations. Therefore, only the last two were investigated, i.e., the normally loaded and preconsolidated cases.

### Normally Loaded Condition

In this case four locations were chosen along the route of I-20 as it crosses the Mississippi River floodplain, some 35 miles wide at this latitude. The sites are described as follows:

| FAP No. | Sta. Loc. | Structure Description | Fill Height | Crown Width |
|---|---|---|---|---|
| I-20-4(4)154 | 238+32 | Parish Road Overpass over I-20 | 23' | 34' |
| I-20-4(4)154 | 906+00 | I-20 over M.P.R.R. and Walnut Bayou | 32' | 132' |
| I-20-3(25)118 | 596+50 | Parish Road Overpass over I-20 | 22' | 34' |
| I-20-3(25)118 | 232+40 | La. 577 over I-20 | 25' | 34' |

All embankments were constructed with 4:1 side slopes.

## Preconsolidated Condition

Preconsolidated soils are located, among other places, along I-12 east of the Mississippi in the toe of the "boot" that forms Louisiana's outline. Two locations were chosen; both fills are quite formidable in that their structures pass over a road and a railroad. They are described as follows:

| FAP No. | Sta. Loc. | Structure Description | Fill Height | Crown Width |
|---|---|---|---|---|
| I-12-1(9)39 | 248+40 | I-12 over U.S. 51 and I.C.R.R. | 30' | 120' |
| I-12-1(9)39 | 1580+00 | I-12 over La. 59 and G.M.O.R.R. | 35' | 120' |

Both of these were built with 3:1 slopes.

Sketches of I-20 over the M.P.R.R. and Walnut Bayou, I-12 over U.S. 51 and I.C.R.R., and I-12 over La. 59 and G.M.O.R.R. appear in the Appendix. A general sketch is shown for the other three since they are single-structured overpasses described above.

# METHOD OF PROCEDURE

## Field Procedure Prior to Construction

In the fall of 1963 eight holes, two at each structure, were bored along the I-20 route between Waverly, Louisiana, and a point where the interstate crosses a local or parish road east of Tallulah. The geology of the area is well understood and was published by Fisk in 1944 (4). Suffice it to say that the soils are divided into three main strata--a top layer of fine sands, silts and clays about 54 to 71 feet (5.02 to 6.60 m) thick, an intermediate section of coarse sands with some gravel continuing down to 138 feet (42.09 m), and a layer of very hard, green, waxy clay with some shells below. The two upper layers are recent alluvium, and the lower strata is probably of the Eocene epoch. An attempt was made to drill through the coarse sand at each of the four locations but was successful twice. The other hole was stopped at the top sand.

On the I-12 route, four holes were drilled--three at the La. 59-G.M.& O.R.R. site and one at the U.S. 51-I.C.R.R. crossing. Here the geology is somewhat different. Recent alluvium is absent. From the surface to a depth varying from 54-65 feet (16.47-19.83 m), in the borings drilled for this project, are Pleistocene silty clays, clays and occasionally sands. These sediments overlie sands and interbedded clays of Miocene (?) age. Theory states that Pleistocene material was deposited in the form of deltas or at least in a deltaic environment by the rivers and streams of that time. Since then the deltaic deposits have been uplifted and dried to their present overconsolidated condition. Not much is known about the underlying sediments. Since not as much was known about the geology of this area as about the I-20 locale, the sediments were drilled to the limit of capability. In all cases the holes were continuously cored.

## Laboratory Procedure

All undisturbed cores were tested in accordance with the following:

1. LDH TR 407 - Mechanical Analysis of Soils
2. AASHTO T 216 - One dimensional consolidation properties of soils
3. LDH TR 423 - Classification of soils
4. LDH TR 428 - Atterberg limits of soils

Numbers 1, 3 and 4 above were done in order to classify the soil. Number 2 was modified slightly to comply with Department test procedures. The fixed ring type of consolidometer was used and the loading schedule varied in accordance with loading frame capabilities. At the time of testing, the Department had 20 load platforms--10 of 8 tons/ft$^2$ (765.6 kPa) capacity and 10 of 10 tons/ft$^2$ (956.6 kPa). The loading schedules were varied accordingly--1/4, 1/2, 1, 2, 4 and 8 tons/ft$^2$ and 5/16, 5/8, 1-1/4, 2-1/2, 5 and 10 tons/ft$^2$, respectively. (1T/ft$^2$ = 95.76 kPa.)

## Comments on the Methods of Computation

This project intends to check several methods of predicting <u>amount</u> and <u>rates</u> of settlements against one another and against field settlement records. Theoretically, if one was to measure the consolidation properties of all samples taken from a continuously cored hole, he should get the best possible prediction for that area. Unfortunately, this procedure is not often used because of cost. However, this study does just that for a comparison with the normal test program. Also, as mentioned before, a new procedure for predicting rate of settlement was to be compared to field data. All methods are listed as follows:

- Method A1 - Normal DOTD procedure for computing amount of settlement.
- Method A2 - Modified normal DOTD procedure for predicting rate of settlement.
- Method B1 - Computation of amount of settlement using all samples taken and DOTD procedure as above.
- Method B2 - Rate prediction using DOTD system and all samples taken.
- Method C2 - Rate computation using the method suggested by the research done by Ray, et al (1) and Method A1 for the amount.

A discussion of each method follows:

### Method A1

Normal DOTD procedure requires that one representative sample be tested for each layer encountered. For this procedure continuous cores are taken and brought into the laboratory where they are opened and inspected. Cores which are adjacent to one another vertically and are similar in texture and stiffness are grouped into one layer, and a representative sample is selected, tested and used for computing the settlement characteristics of all samples within that group. Even though all samples were tested for this study, the process described above was adhered to so that the representative sample for the layer could be used for computation.

### Method A2

The normal DOTD procedure for predicting rate of settlement is modified somewhat to fit into this project. Normally the rate of settlement computations are made so as to determine whether 12 inches (30.48 cm) of consolidation will occur between one and thirty years. (If the total amount of consolidation is less than 12 inches (30.48

cm) using Method A1, no rate is computed at all.) Terzaghi's time factor is utilized in the "one- to thirty-year" approach, determining the amount that takes place in one year and the amount that takes place in 30 years. The two are subtracted for the amount to take place after one year and before 30.

This procedure has been modified so that settlement curves can be drawn and compared to the curves required by Method C2--LSU's. In other words, the normal DOTD method does not require settlement curves. Here the same computations are altered so as to obtain the curve.

### Method B1

Instead of using just one test specimen per layer, all samples taken are used to determine the amount of settlement. Computation procedures are exactly the same as Method A1.

### Method B2

Again all samples are used to determine the rate of settlement and a curve drawn using the same computation as Method A1.

### Method C2

This is the method suggested by Ray, et al in the "Consolidation Study." It deals strictly with rate of settlement and considers secondary consolidation as well as primary. Assuming that the amount of consolidation is being computed correctly, the proposed method is quoted below (1).

> Proposed Method for Estimating Settlement
>
> 1. Run laboratory consolidation tests.
> 2. Plot dial reading versus time curves for each load increment using both square root of time and logarithm of time to find 100% primary consolidation.

3. If the values obtained for 100% primary vary appreciably, fit theoretical curves to the laboratory curves and determine which method (square root of time or logarithm of time) fits the data best. Use the method which best fits the data for finding the coefficient of consolidation.

4. Using the void ratio for 100% primary consolidation under each loading increment, plot a void ratio versus logarithm of pressure curve.

5. Find the maximum past pressure and determine the change in void ratio under the new load.

6. Using the relationships:

$$t_F = \frac{T(H_F)^2}{c_v} \qquad \text{and}$$

$$\Delta H = \frac{H_F \Delta e}{1 + e_o}$$

   Find the total settlement due to primary consolidation and draw the field settlement curve.

7. From the laboratory curve nearest the new overburden pressure, find $C_s$, the change in height per log cycle of the initial secondary slope.

$$\Delta H_L = C_s \log \frac{t_2}{t_1}$$

8. For secondary compression, estimate the time in the field and the change in height in the field on the basis of a linear relationship for change in height and the square of the ratio of the height for time.

$$\Delta H_F = \frac{\Delta H_L}{H_L} (H_F)$$

$$t_F = \left( \frac{H_F}{H_L} \right)^2 (t_L)$$

9. Draw a secondary settlement curve. This means add more points to settlement curve using eq above instead of

$$t_F = \frac{T(H_F)^2}{C_v}$$

10. Beginning at 90% primary consolidation, add the ordinate of the secondary curve to the primary curve.

## Sample Calculations

Rather than including all calculations necessary to this study, an example of one boring, Boring 4, will be shown and results from the others given. A list of variables is given at the beginning of this report.

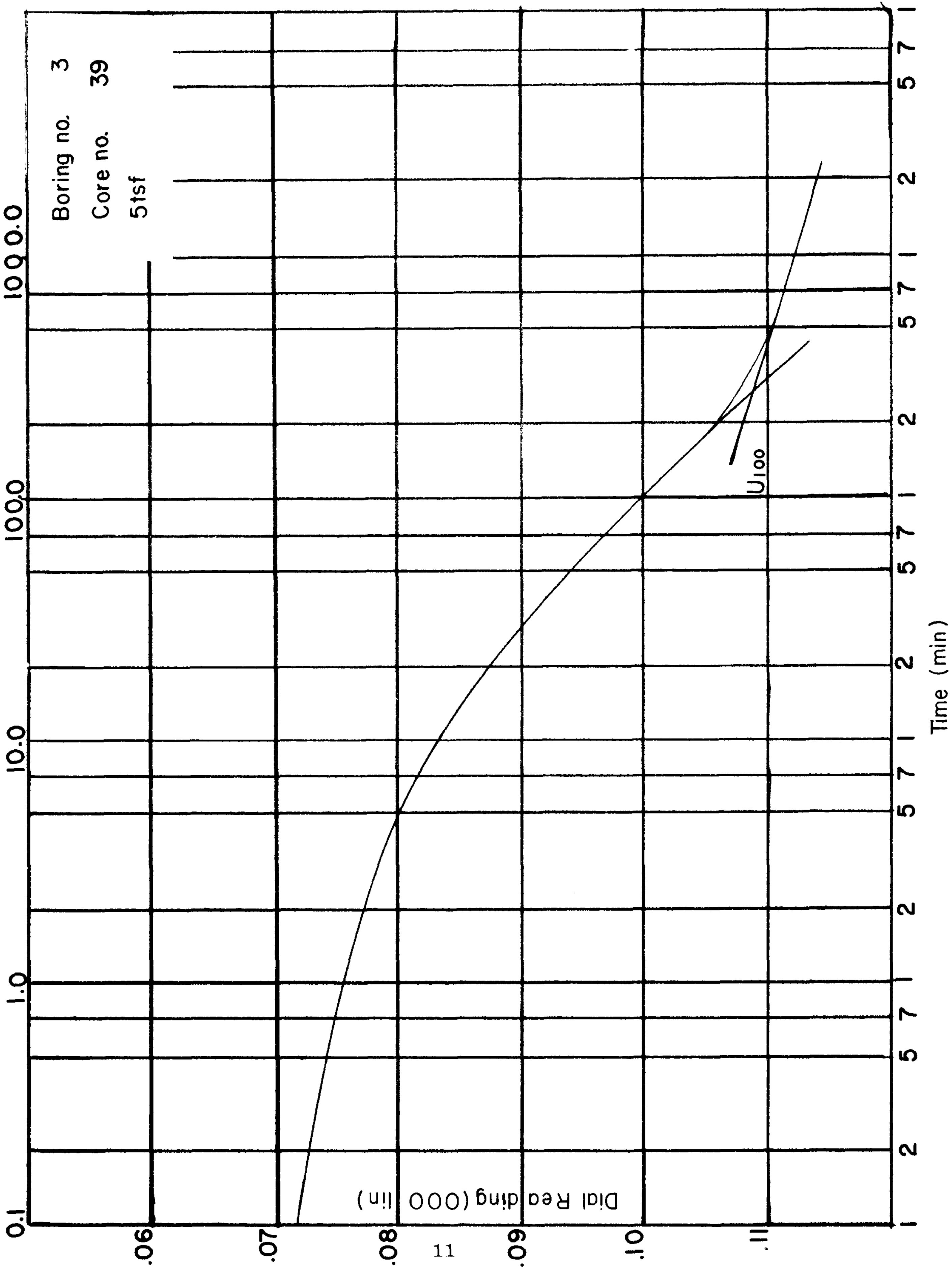
In working out the change in voids ratio with increasing pressure curve (e log P curve), there were several steps involved. First, a sample was run in a consolidometer under one of two loading schedules as mentioned. A dial (graduated to read in .0001 in (0.0025 mm)) was used to monitor the change in height during the time that particular load was held on the sample. At scheduled "elapsed time" (min) the dial was read and recorded. This was then plotted on five-cycle semilog graph paper, dial reading versus log of time (log time curve). When 100% primary consolidation ($U_{100}$) was established, the next load was placed on the sample. Figure 1 is an example.

When the full loading schedule was complete, including rebound--unloading along the same schedule--then the sample was removed from the consolidometer and an e log P curve was computed from the formula

$$e = \frac{Tc}{Ds} - 1$$

Since the height of the consolidometer ring was one inch and the soil cake is sliced to exactly fit the ring, the thickness of the soil cake was one minus the dial reading before each load is put on the core. On the other hand

Log Time Curve - FIGURE 1



$$Ds = \frac{Ws}{2.54\ AG}$$

The 2.54 converts the depth of the solids from centimeters to inches. The voids ratio was plotted against the log of the pressure. This was done for each core tested (Figure 2).

The next step was to compute a pressure distribution curve under the embankment. An example of this computation is given in the Appendix. With the pressure distribution curve, one has all the data needed in order to predict the amount of settlement that an embankment will undergo because of its weight.

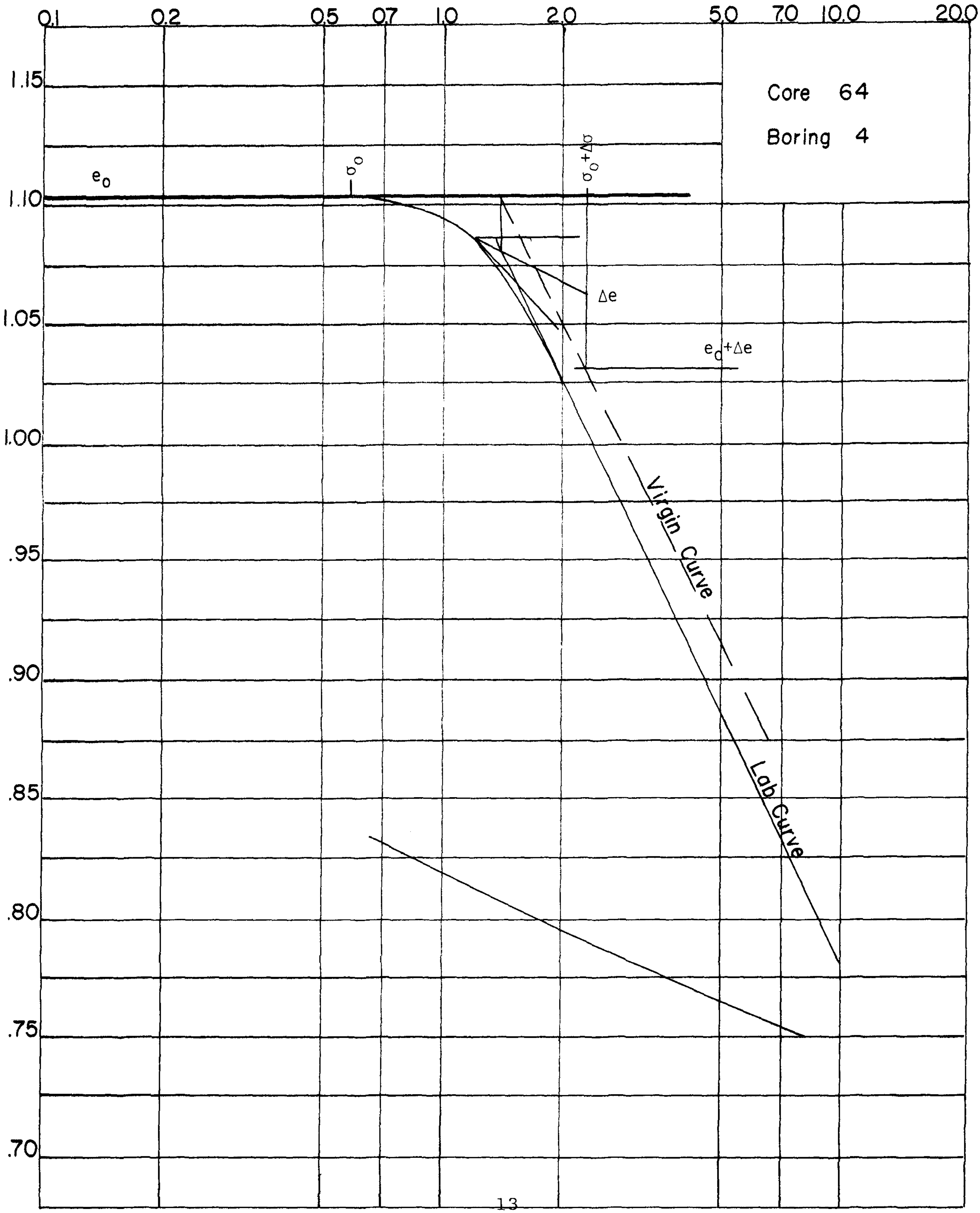
## Amount of Settlement

Before the actual calculation of settlement of a strata, certain manipulations must be made to each e log P curve under consideration. The e log P curve (see Figure 2) that was obtained in the laboratory was not considered similar enough to field or virgin e log P curve that is rendered by the load subjected by the embankment. With a method developed by Casagrande (5), the most probable preconsolidation pressure (M.P.P.P.) is obtained. For an explanation see Taylor, page 278 (6). Using the maxim that capillary forces keep the core from swelling when it is removed from the hole, then $e_o$ is the in situ e, and $e_o$ and the M.P.P.P. defines one point on the field e log P curve. A line drawn through this point and parallel to the lower portion of the laboratory curve is the field curve.

The computations on core #64 are shown below.

| C | $\gamma$ | Depth to Mid. Pt. | Depth of Layer | $\sigma o$ | $\Delta\sigma$ | $\sigma o+\Delta\sigma$ | 1+eo | $\Delta e$ | $\frac{\Delta e}{1+eo} h_F$ |
|---|---|---|---|---|---|---|---|---|---|
| 64 | 0.0239 | 15.0 | 12 | 0.576 | 1.762 | 1.690 | 2.104<br>~~2.266~~ | 0.069 | 0.393 |

*e Log P Curve - FIGURE 2*



$\gamma$ in T/ft$^3$ was obtained from Figure 3 which considers the weight of the undisturbed soil in the consolidometer ring and the volume of the ring. $\sigma o$ in T/ft is the summation of the overlying $\gamma$'s times their heights in the field plus the $\gamma$ of the layer under consideration times 1/2 the height under consideration (midpoint)--in this case:

$$\begin{aligned} 0.0239 \times \frac{12}{2} &\approx 0.143 \\ &+ \underline{0.433} \text{ from the strata above} \\ &\phantom{+ } 0.576 \end{aligned}$$

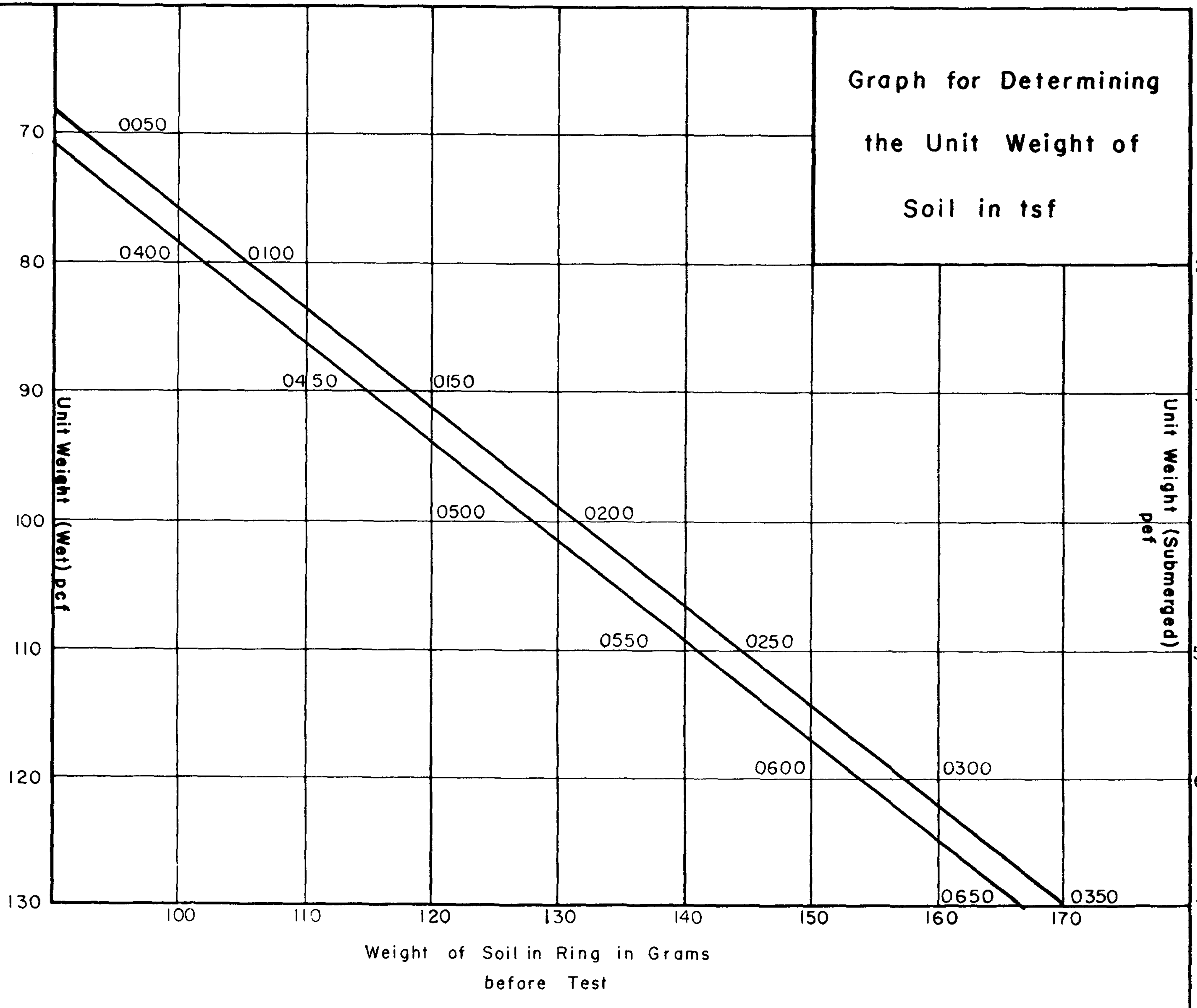
$\Delta\sigma o$ is from the pressure distribution curve, an example of which is shown in the Appendix. $\Delta e$ is obtained from the e Log P curve in Figure 2. It is equal to $e_o$ minus the e corresponding to $\sigma o + \Delta\sigma$ on the field curve. The settlement(s) is $\frac{\Delta e}{1+e_o} h_F$ for that stratum. Total is the summation of all $\frac{\Delta e}{1+e_o} h_F$ for the entire hole. In the Appendix is an example of the computation of S for one entire hole using both A-1 and B-1 methods.

## Rate of Settlement

This procedure is composed of three methods, A-2, B-2 and C-2. A-2 and B-2 can be explained together since, as with A-1 and B-1, Method A-2 uses representative cores, while B-2 uses all cores. Method C-2 incorporates A-1 into it, but it takes into consideration secondary consolidation as well as the primary.

### Methods A-2 and B-2

The first step in computing the rate of settlement is to decide which is to act as a drainage layer. Probably this can be done by examining the log time curves. The way this research approached the problem was to arbitrarily assume that any of the cores that require less than ten minutes to reach 100% consolidation would act as a drainage stratum for those that required longer.



Unit Weight of Cores from Consolidation Specimen

FIGURE 3

Using the load in the laboratory which most closely approximates the added load on that layer in the field, $\Delta\sigma$, the log time curve was fitted to Terzaghi's theoretical time curve as is done by Taylor (6) pages 241 and 242 (Figure 4). With this done, the coefficient of consolidation, Cv, was computed from the formula

$$Cv = \frac{TH_L^{\ 2}}{t_{L(50)}}$$

$H_L = \frac{Tc}{2}$ since two-way drainage was possible and $t_L$ was the time required to reach 50% compression.

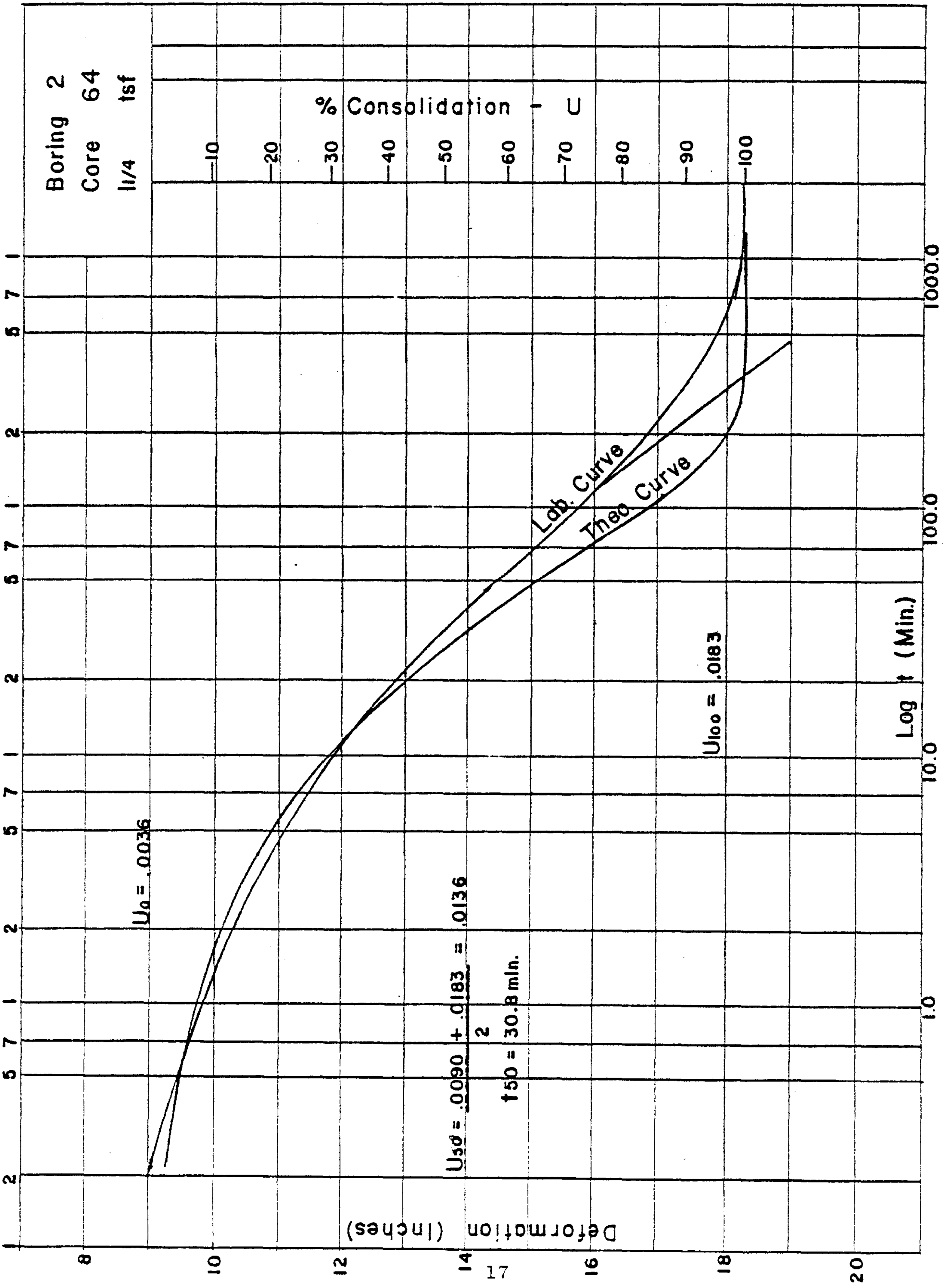
Here, the "unit" concept was instituted, i.e. all strata between drainage layers was considered a unit. A unit may have consisted of several strata with different Cv's. For instance, in Unit IV of the example hole shown in the Appendix (Method B-2) Cv is $1.87 \times 10^{-3}$ in.$^2$/min. ($2.02 \times 10^{-4}$ cm$^2$/sec) at the top of the unit (core 70) and $7.63 \times 10^{-3}$ in.$^2$/min. ($8.24 \times 10^{-3}$ cm$^2$/sec) at the bottom (core 77). Some sort of average had to be computed. A weighted average was chosen which gives more weight to the thicker strata for both $t_{L(50)}$ and $H_L$ at the $t_{50}$. Therefore, Cv was the coefficient of consolidation for the unit which was a weighted average of each strata within that unit.

With the Cv's computed for each unit, the amount of time required for each unit to settle 25%, 50% and 75% of their total in the field was computed from the equation:

$$t_F = \frac{TH_F^{\ 2}}{Cv}$$

T. Terzaghi's time factor, for 25, 50 and 75% consolidation are 0.05, 0.197, and 0.490 respectively. $H_F$ is the length of the drainage path in the field (in the example there is assumed to be two-way drainage so that $H_L$ is 1/2 the depth of the unit).

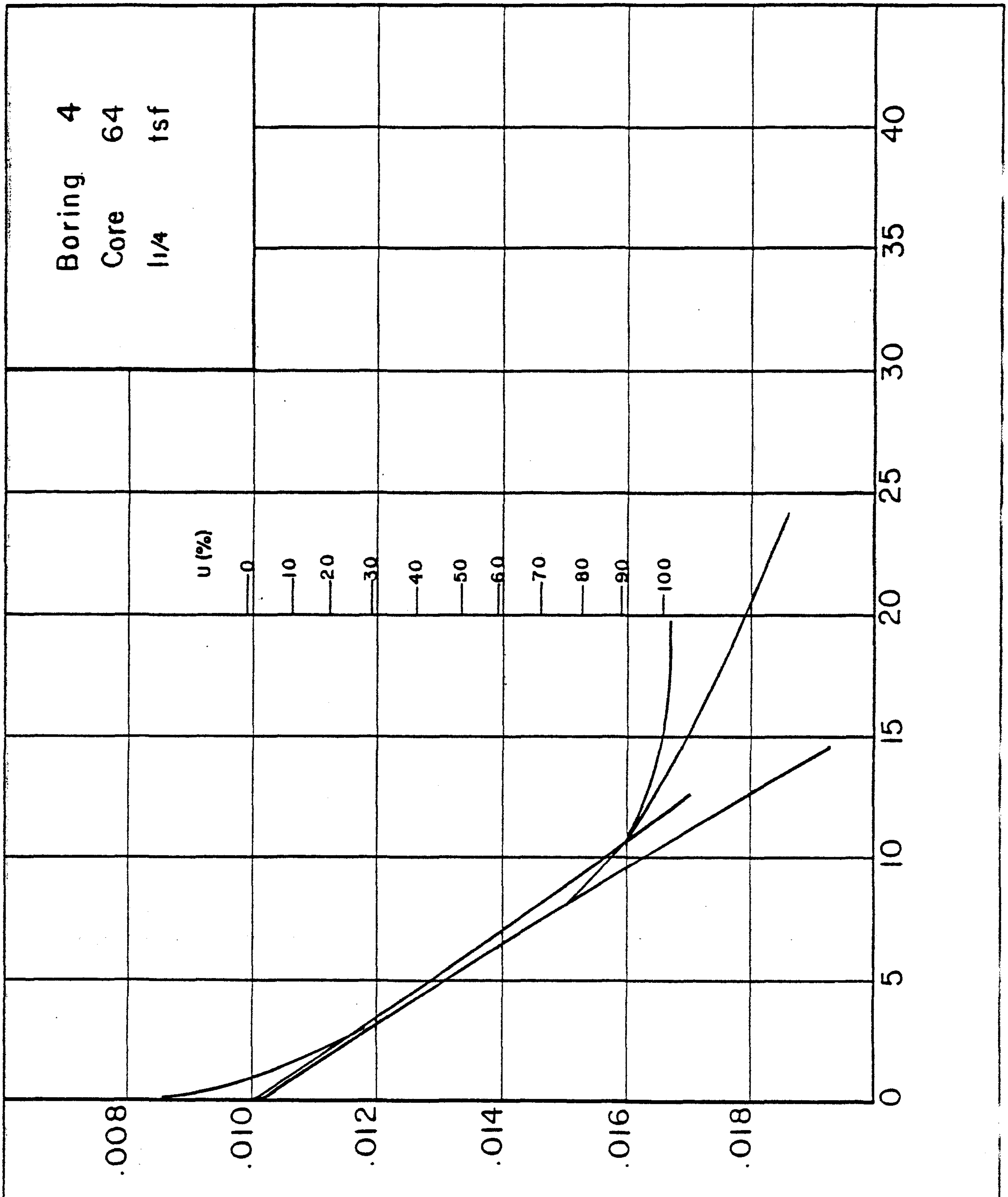
*Log Time Curve (Core 64) - FIGURE 4*



A curve plotting the time versus the amount of settlement was drawn for each unit. These unit rates of settlement curves were then summed for the total rate of settlement curve.

### Method C-2

The reader is referred back to pp. 12 and 13 for how the calculations are done. It should be recalled that Method A-1 was used for the amount of settlement and that Method C-2 uses the square root of time for its technique for computing the rate of primary consolidation rather than the log of time. The $\sqrt{t}$ curve is also fitted to Terzaghi's theoretical time curve in accordance with Taylor, page 239 (6). Figure 5 is an example. Another major difference between the two besides the $\sqrt{t}$ is the fact that secondary consolidation is added to the results of primary consolidation hoping that these two differences would make the predicted settlement rate closer to the settlement rate in the field. Example calculations are shown in the Appendix.



Square Root Time Curve (Core 64)

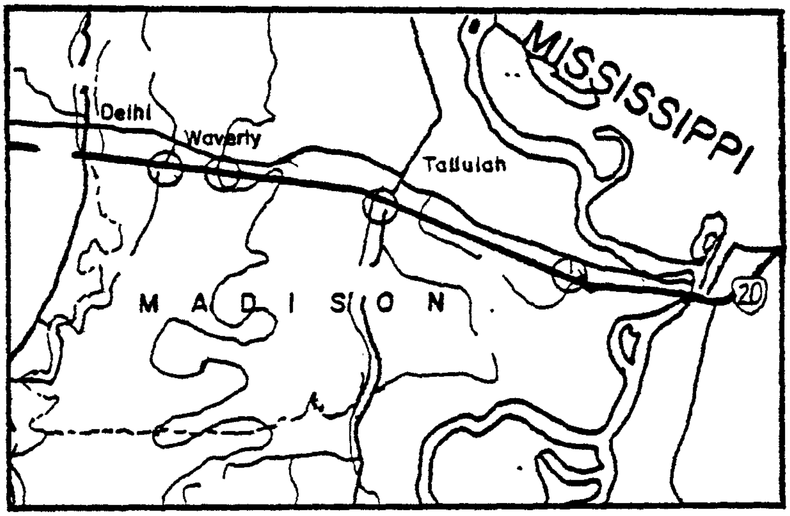
FIGURE 5

# DISCUSSION OF RESULTS

## I-20 Results

### General Location

In order to familiarize the reader with the general setting of the borings along I-20, Figure 6 is a vicinity map with the four locations shown.



*Vicinity Map of I-20 Locations*

*FIGURE 6*

### Location 1

The first structure from the east was a parish road overpass at Interstate Station No. 238+15 represented by Figure 7. From this figure it can be seen that the amount of settlement was negligible, from 0.39 to 0.48 feet (0.12 to 0.15 m), and the rate was relatively fast, within six months. In fact, the total settlement would have been completed by the time construction was finished.

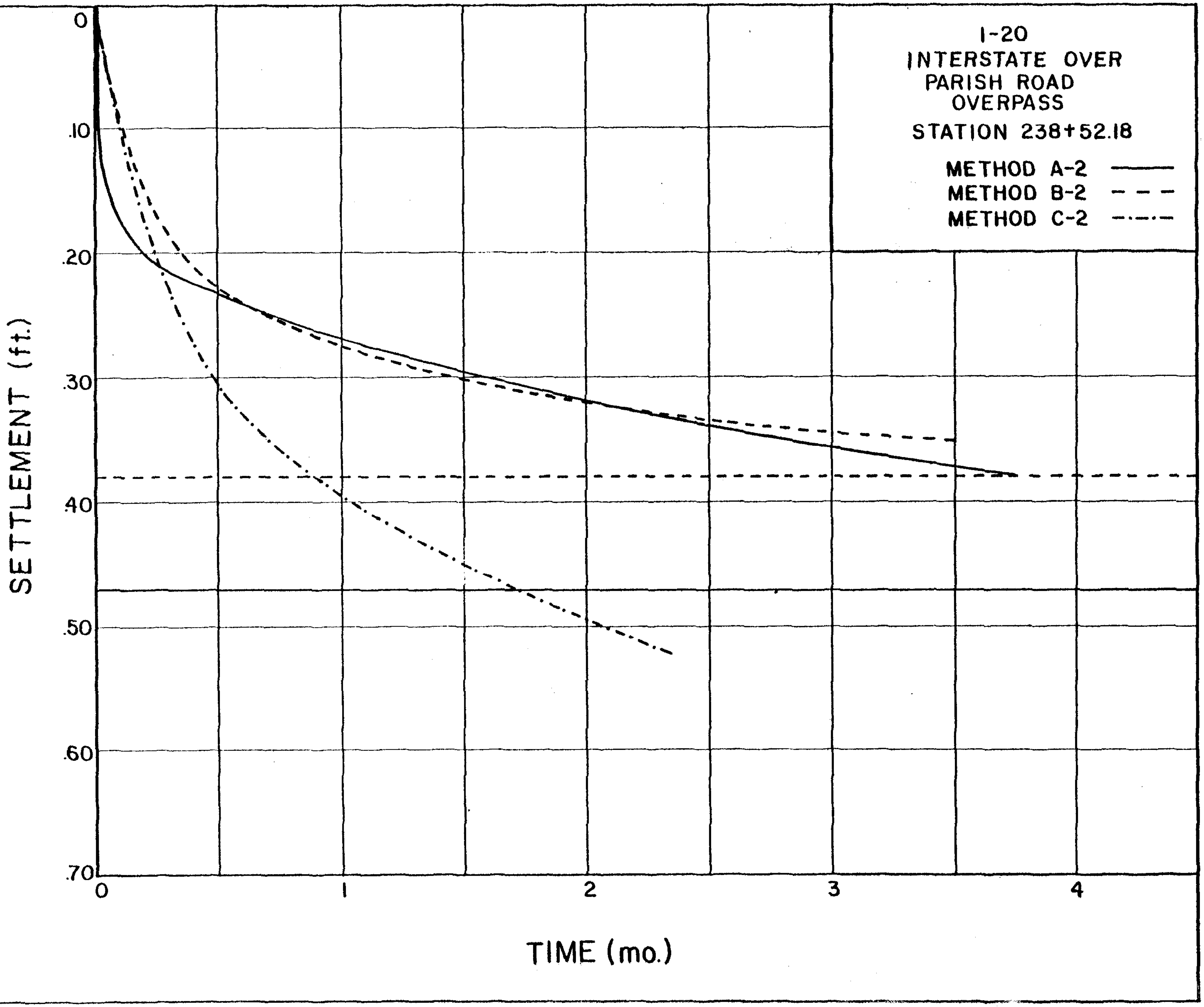


FIGURE 7

Rate of Settlement (Parish Road Overpass)

Location 2

The next location was I-20 over the Missouri Pacific Railroad, U.S. 65 and Walnut Bayou. This was the largest embankment on I-20 checked. The height was 32 feet (9.75 m), with a crown of 132 feet (40.25 m) and 4:1 side slopes, a large fill indeed. In fact, it had a depressed median. This fill was used as the example for calculations in the Appendix.

Two holes were computed at this structure. It can be seen from Figures 8 and 9 that Method B-2 was in close agreement but A-2 and C-2 were not, even though the two borings were only approximately 400 feet (122 m) apart. The reason can be found in the way the two borings divided themselves. The boring at Station 904+00 (Boring 3) had three drainage layers to drain 36 feet (11 m) while the boring at Station 908+00 (Boring 4) was interpreted to have four layers draining 35 feet (10.7 m) of compressible material. None of the top three compressible strata were over 6 feet (1.8 m) thick in B-4, while in Boring 3 a corresponding unit was 15 feet (4.8 m) thick. It should be remembered that the time in the field, $t_F$, is proportional to the square of the distance of the shortest drainage path, $H_F$.

The selection of drainage layers was predicated on the time to reach $U_{100}$. Those cores that required less than 10 minutes to reach 100% consolidation were chosen as drainage layers. This approach of choosing drainage was unique to this study but seemed like a worthwhile technique. No matter what the soil classification, if $t_{100}$ was less than 10 minutes, that layer was considered to act as drainage for those whose $t_{100}$ was greater than 10 minutes. But during the calculations even this technique had its drawbacks.

For instance, in Boring 3 (at Station 904+00) unit 2 was composed of cores 46, 47, ....... 52. All cores had a $t_{50}$ ranging between 14.5 and 23.5 minutes except C-48 whose $t_{50}$ was 1.6 minutes. Yet the

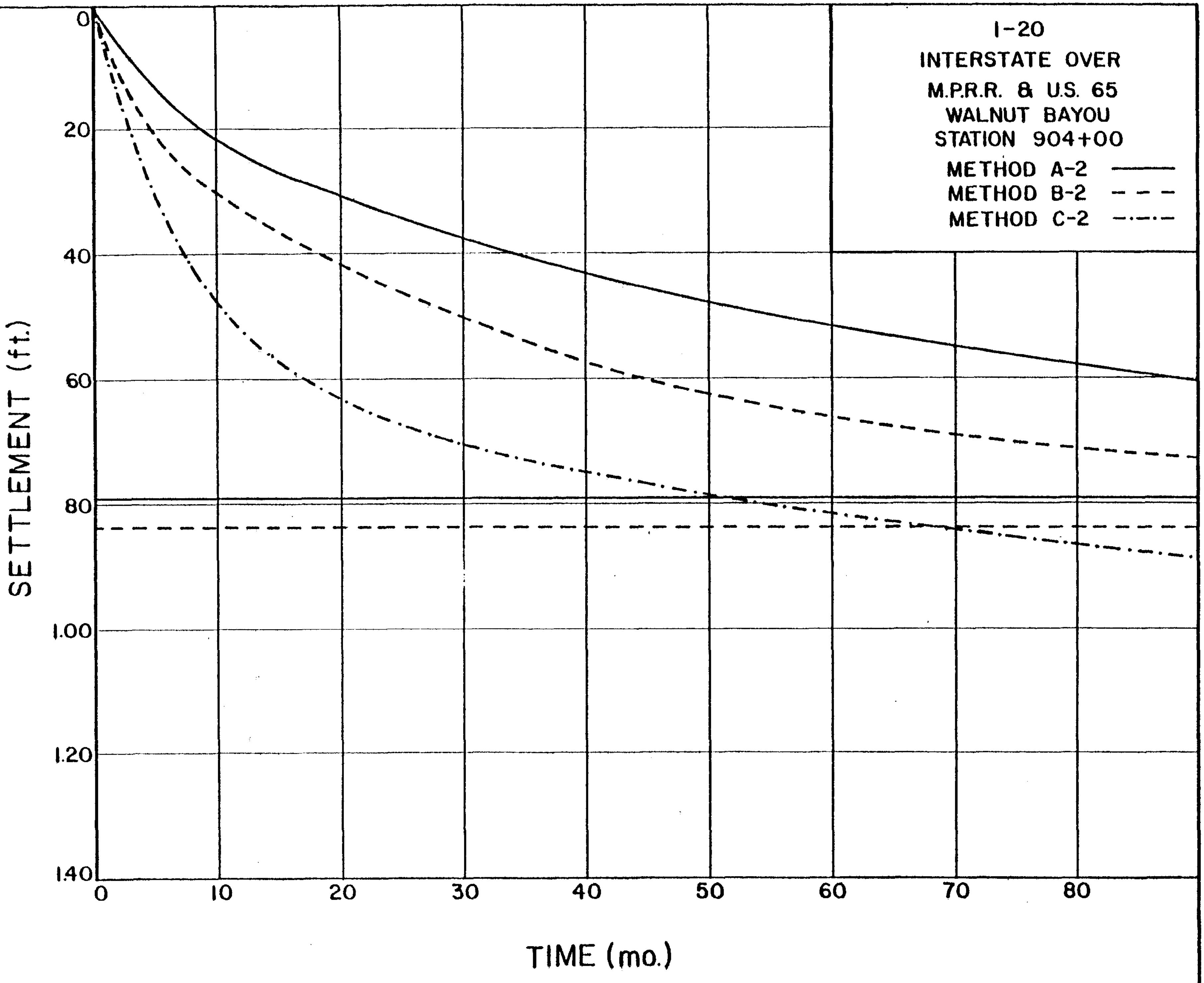


FIGURE 8

Rate of Settlement (Walnut Bayou)

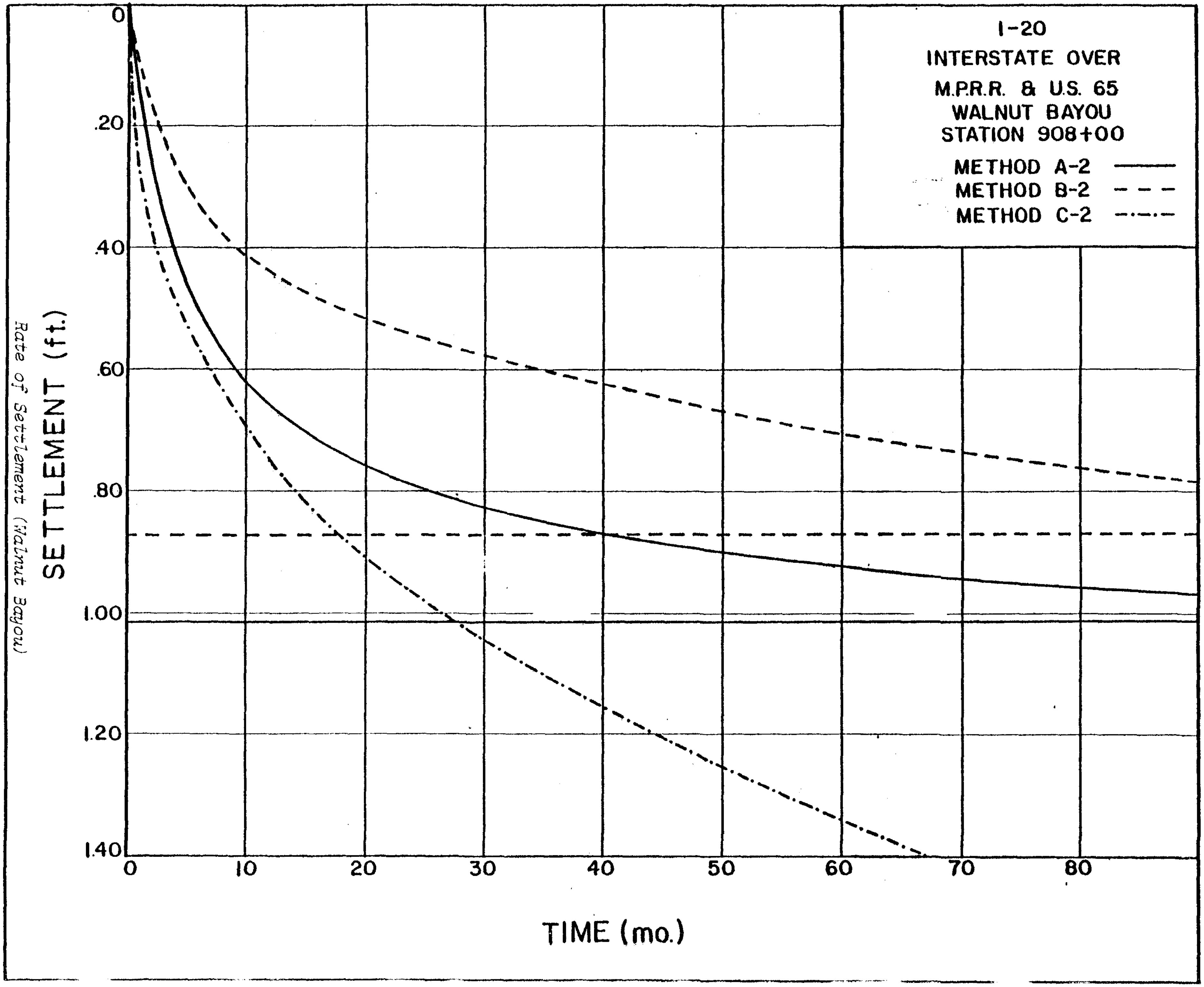


FIGURE 9

Rate of Settlement (Walnut Bayou)

$t_{100}$ was 35.2 minutes, above the 10 minute minimum. So it is likely that the layer represented by core 48 would act as a drainage layer since $t_{100}$ of all cores except 48 were about 92% above 48's.

Another fact is that the log of Boring 3 showed C-48 to be a stiff blue-gray and brown heavy clay with a Group Index (G.I.) of 20 and a Plasticity Index (P.I.) of 54 sandwiched in with soils with similar classification. It is known that such soils do not reach $U_{100}$ as rapidly as 35.5 minutes. In Boring 4, 400 feet (122 m) away, core 74 at the approximately same elevation was also a heavy clay also sandwiched in with similar soils, but it had a $t_{100}$ of 114.4 minutes and a $t_{50}$ of 24.0 minutes. Therefore, all evidence indicated that either there was a small silty or sandy seam tested in Boring 3 and not tested or even present in Boring 4, or C-48 was disturbed in some way.

Conversely, attention should be paid to the fact that DOTD Method B-2 was so similar in the two borings. Methods B-1 and B-2, it should be recalled, used all cores to compute both total settlement (B-1) and rate of settlement (B-2). The total settlements, represented by the horizontal dashed line on both Figures 8 and 9, were in close agreement, 0.82 feet (0.25 m) for Boring 3 and 0.84 feet (0.26 m) for B-4. It is natural, then, that the rates were similar. In contrast, the total (solid line) settlements of the two borings were not in close agreement (0.79 feet (10.21 m) for Boring 3 and 1.01 feet (0.31 m) for Boring 4). There was a trend for Boring 4 to consolidate more rapidly than Boring 3 even for the B-2 method. That was because of the disparity in the number of drainage layers already mentioned.

Location 3

The next location was a parish road overpass at Interstate Station 96+50. Two holes were drilled at this location, one north of I-20 and one south. Figures 10 and 11 represent the rates and amounts of settlement. These holes were approximately 460 feet (139.8 m) apart yet the curves were not similar at all. Again, the way these holes were set up tells the story.

As with the preceding locations, Boring 5, at parish road Station 51+25, had three drainage layers while Boring 6, Station 55+85, had four. In Figure 11, representing Boring 6, the embankment induced a settlement rate that was faster than its neighbor, represented by Figure 10. It should also be pointed out that there was about 0.1-foot (0.03-m) difference between Methods A-1 and B-1 in Boring 6, while in Boring 5 there was only a 0.01-foot (0.0003-m) difference. This is explained by testing error.

Method C-2 by far was the fastest in both holes. In fact, in Boring 6 the amount of settlement had to be changed from feet to inches in order to depict the rate without getting the curves tangled.

### Location 4

Last among the test sites along I-20 studied was the La. 577 overpass south of Waverly. Again two locations (borings) were investigated--one north of the interstate and the other to the south. The embankment was proposed to be 25 feet (7.6 m) high with a 44-foot (13.3-m) crown and 4:1 side slopes. Figures 12 and 13 represent the settlement rate for these two holes and as can be seen the rates were very similar for all three methods, i.e., the borings correlated well, especially the C-2 curves. Methods A-2 and B-2 were within 0.6 inches (1.52 cm) of one another between holes.

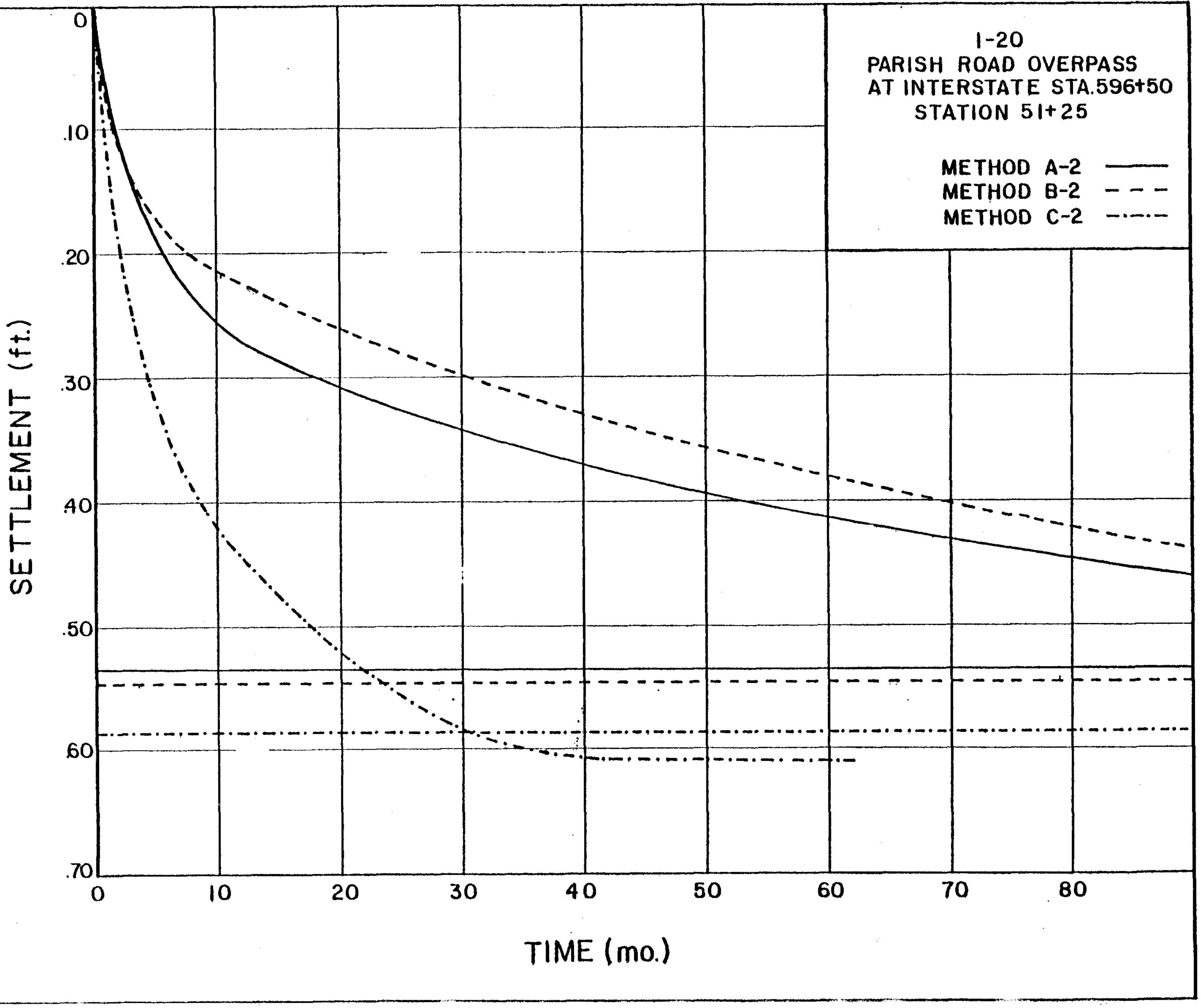


FIGURE 10
Rate of Settlement (Parish Road Overpass)

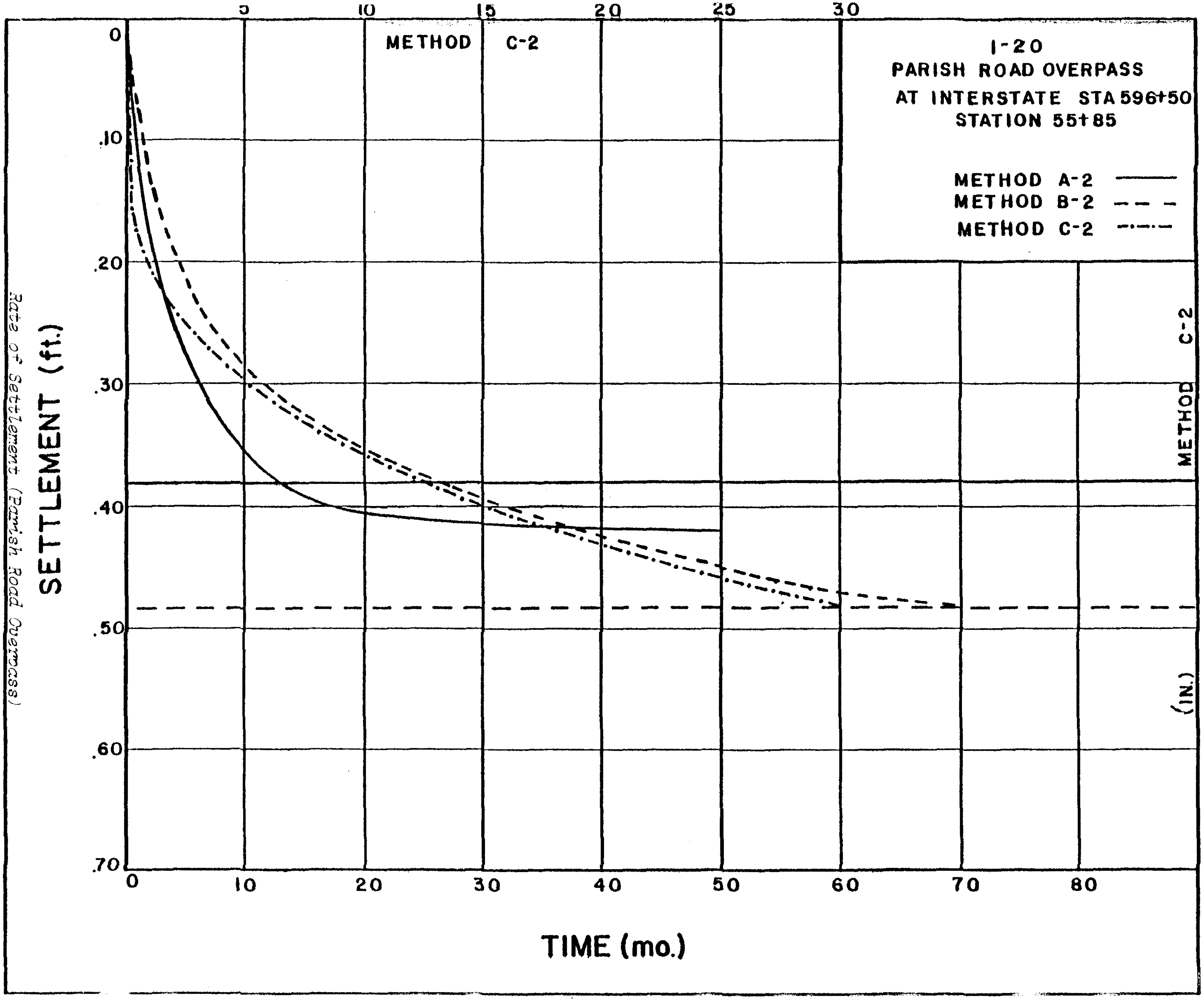
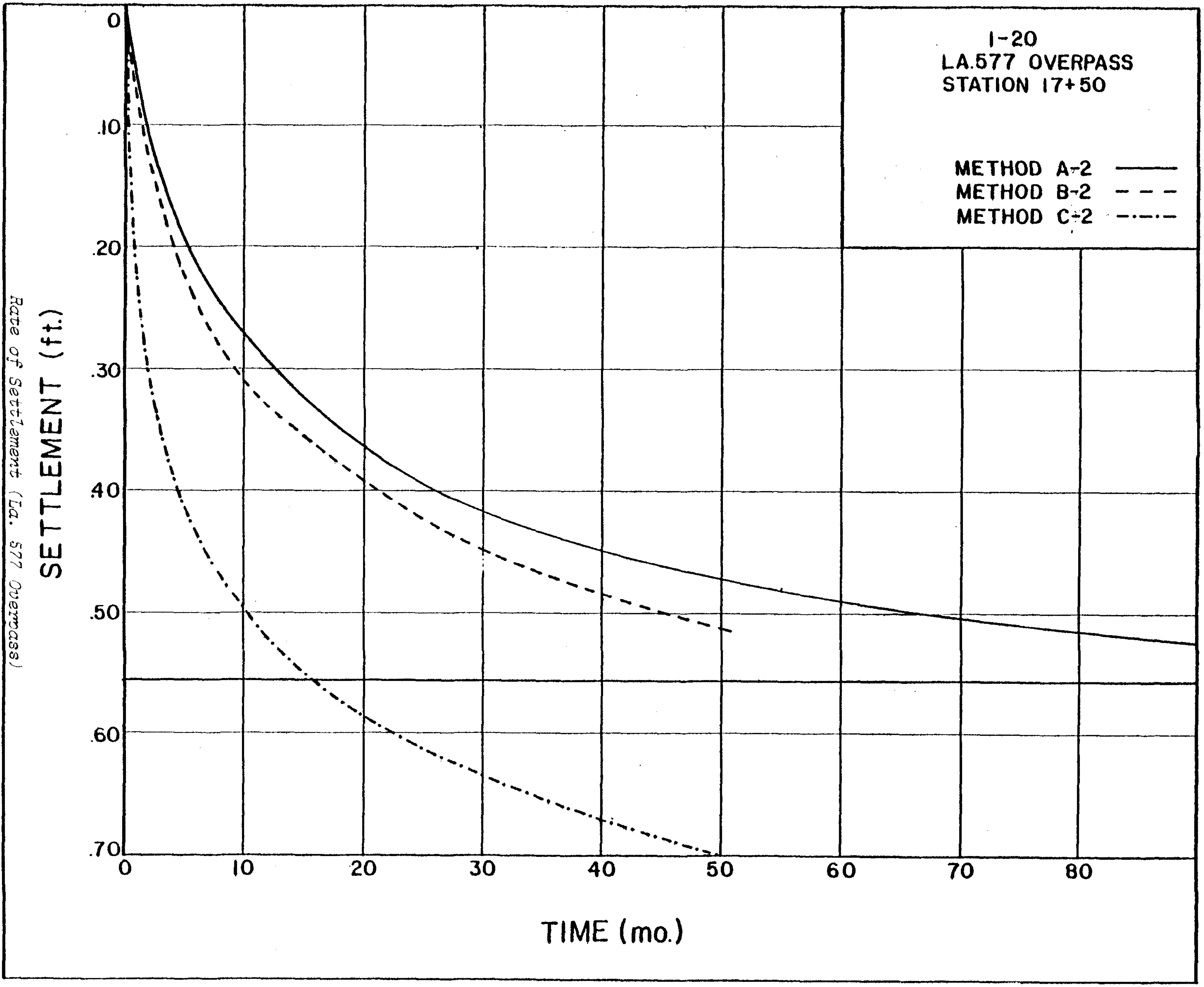


Figure 11

Rate of Settlement (Parish Road Overpass)



Rate of Settlement (La. 577 Overpass)

FIGURE 12

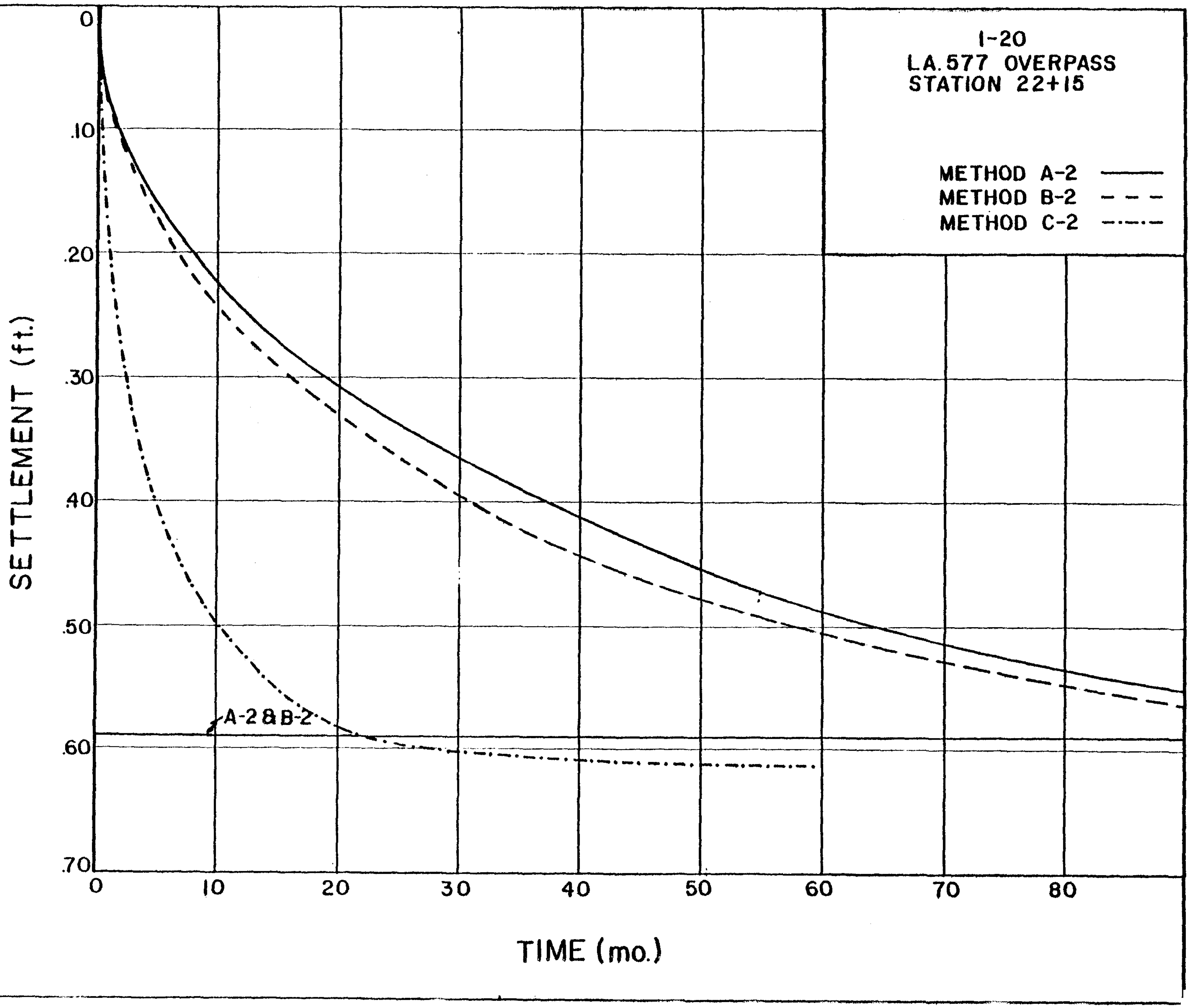


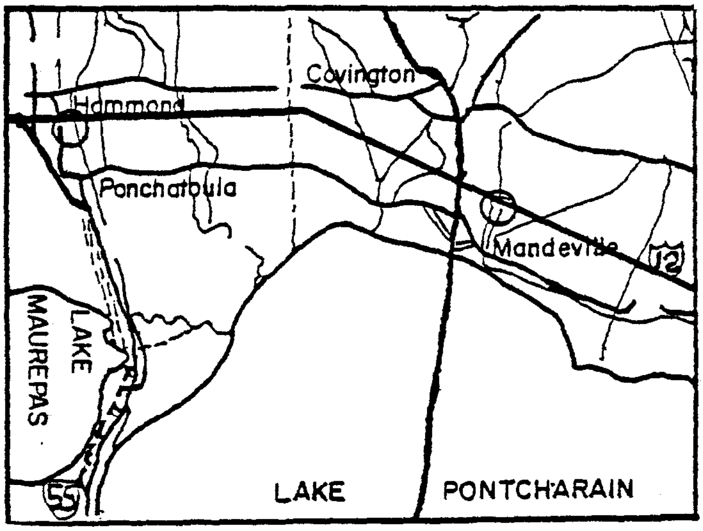
FIGURE 13

Rate of Settlement (La. 577 Overpass)

## I-12 Results

### General Location

Two embankments were studied on I-12. Figure 14 is a vicinity map with the locations shown. The general shape and geometry of these two embankments are shown in the Appendix. They were large fills, both taking the interstate over a railroad and a state highway. Four holes were drilled, three at one and one at the other.



*Vicinity Map of I-12 Locations*

*FIGURE 14*

### Location A

The first of the two embankments to be discussed was at Station 244+00 south of Hammond (one hole). This was to be I-12 over U.S. 51 and I.C.R.R. where the proposed fill was 30 feet (9.1 m) high, with a crown width of 140 feet (42.5 m) and 4:1 side slopes. Figure 15 presents the rate of settlement of this embankment.

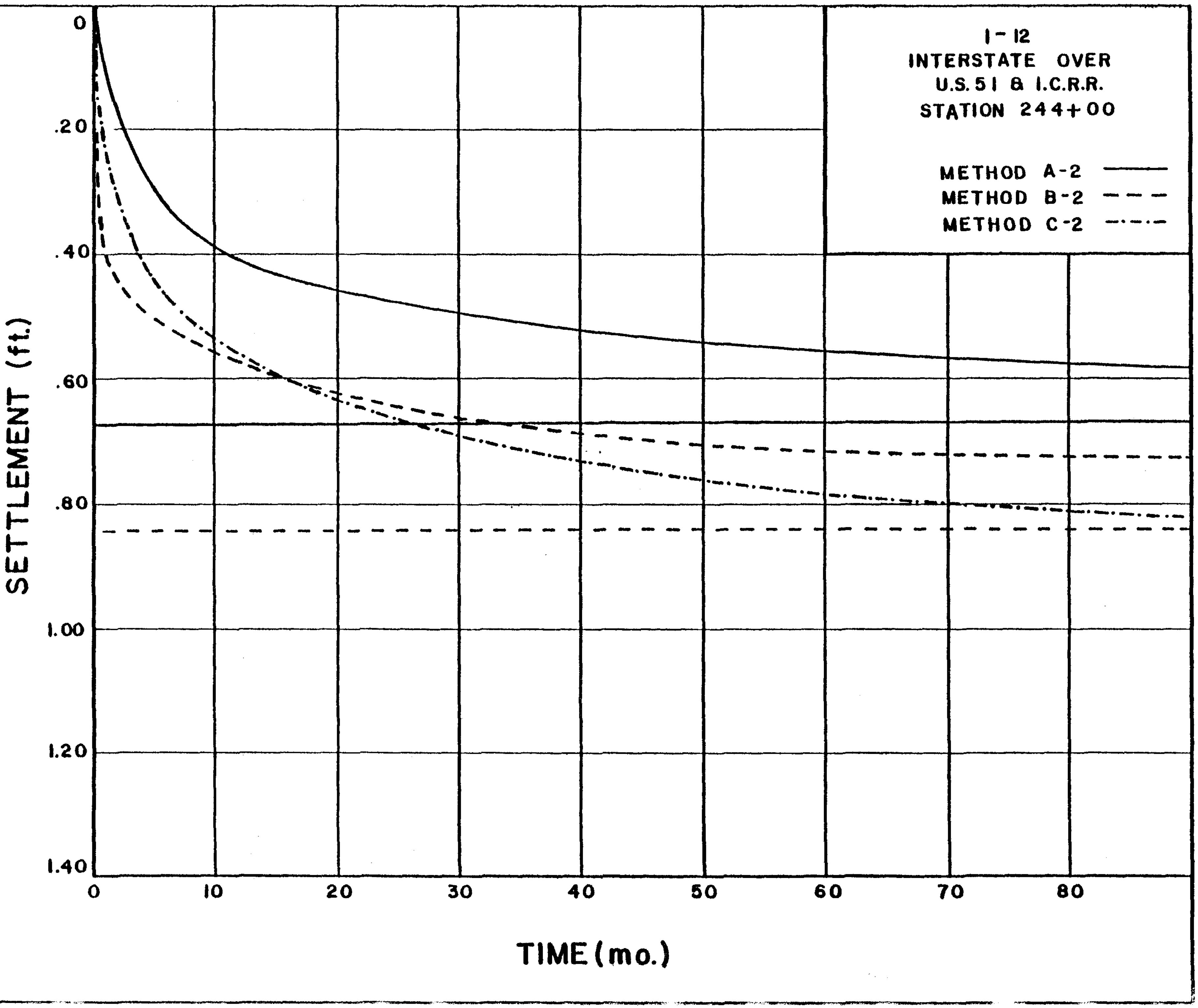
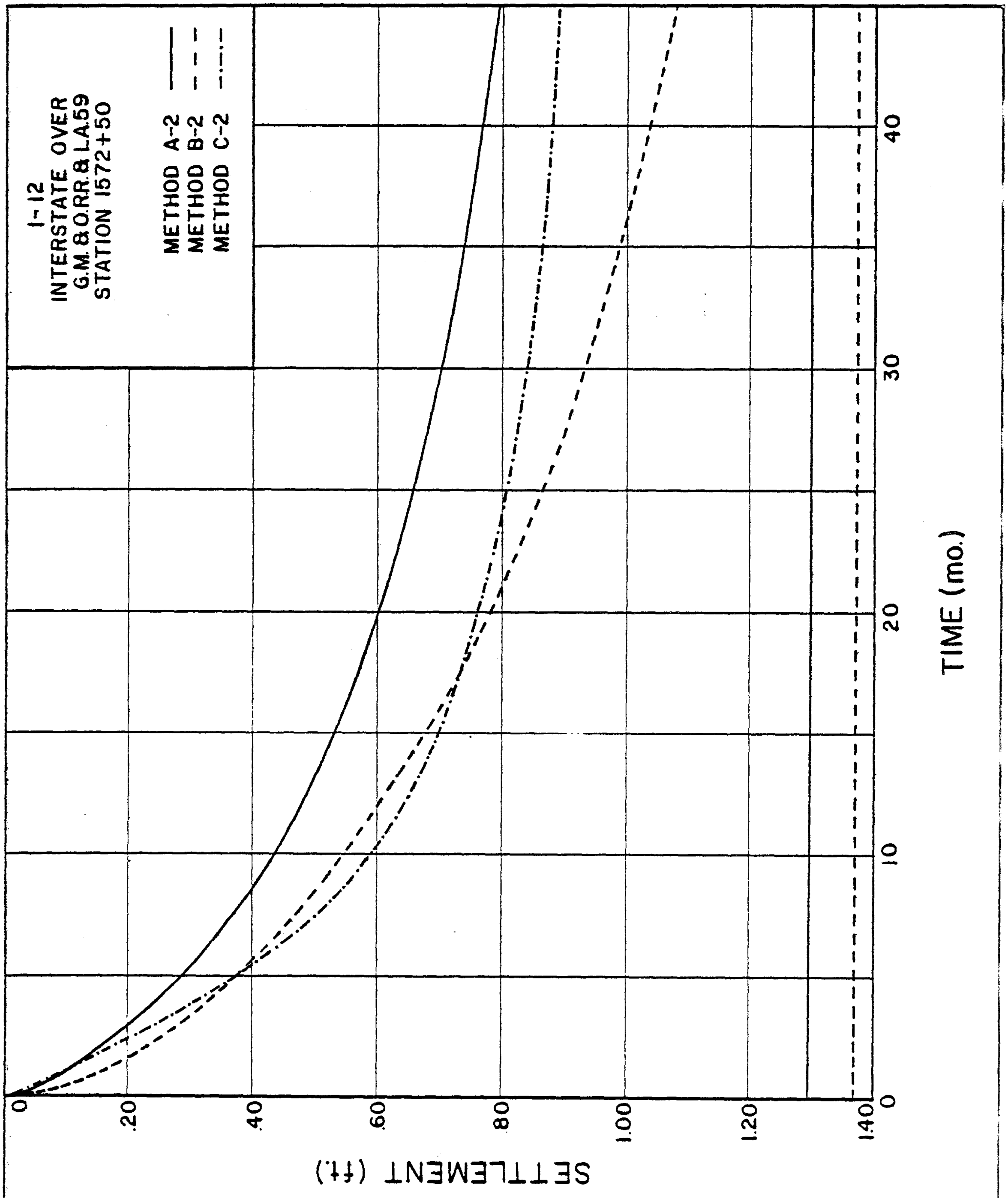


FIGURE 15
Rate of Settlement (U.S. 51 Overpass)

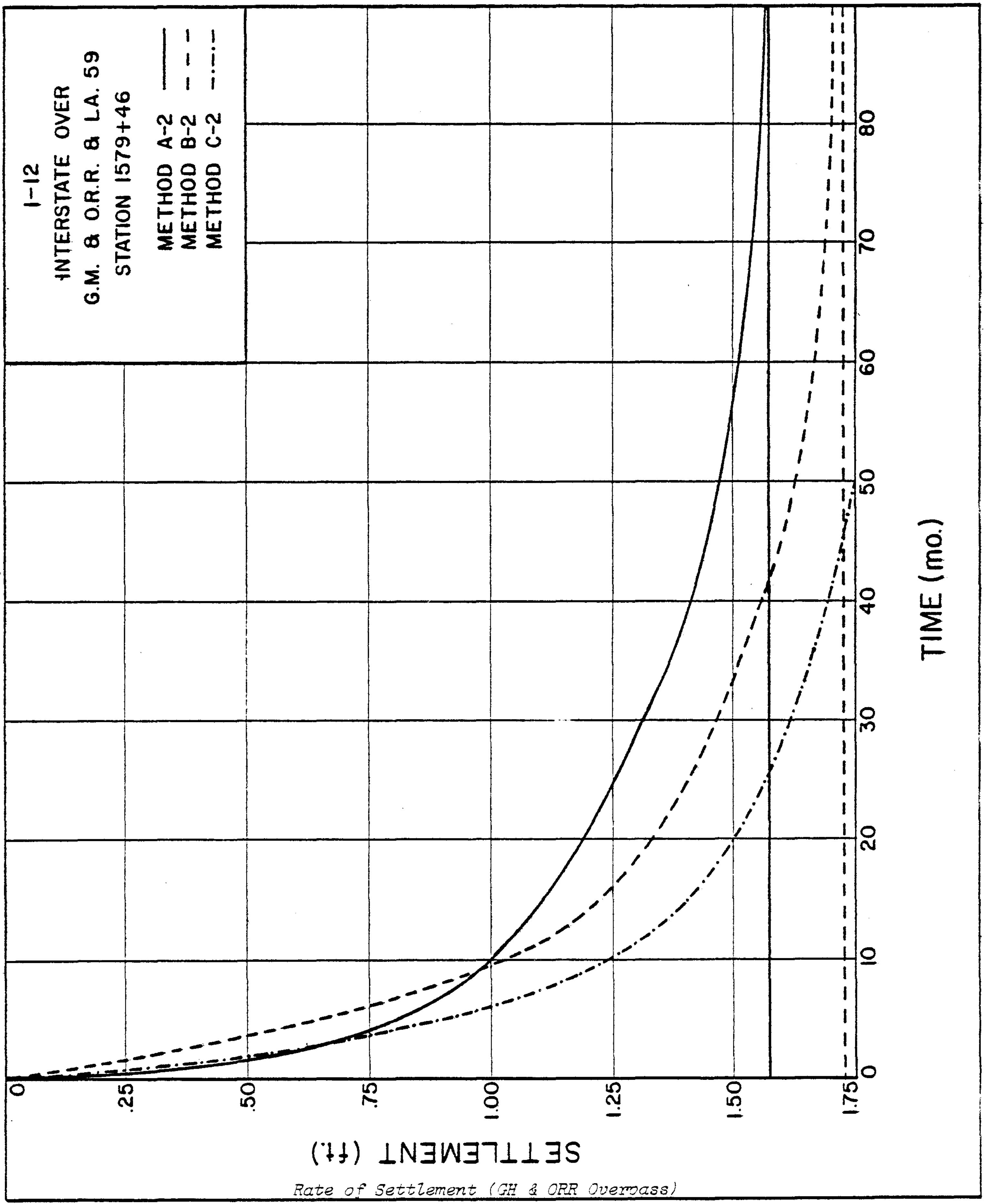
### Location B

The other fill carried Interstate 12 over the G.M.& O. Railroad and La. 59 (Figure 4-A in the Appendix) at approximate Station 1580+00. Here three holes were drilled at Stations 1572+50, 1579+46 and 1597+00 and are represented by Figures 16, 17 and 18. The total settlements vary from 0.55 feet (0.17 m) at Station 1597+00 to 1.70 feet (0.52 m) at Station 1579+46. This can be explained by the fact that the fill heights were variable. Table 1 indicates some of the important dimensions at this location.



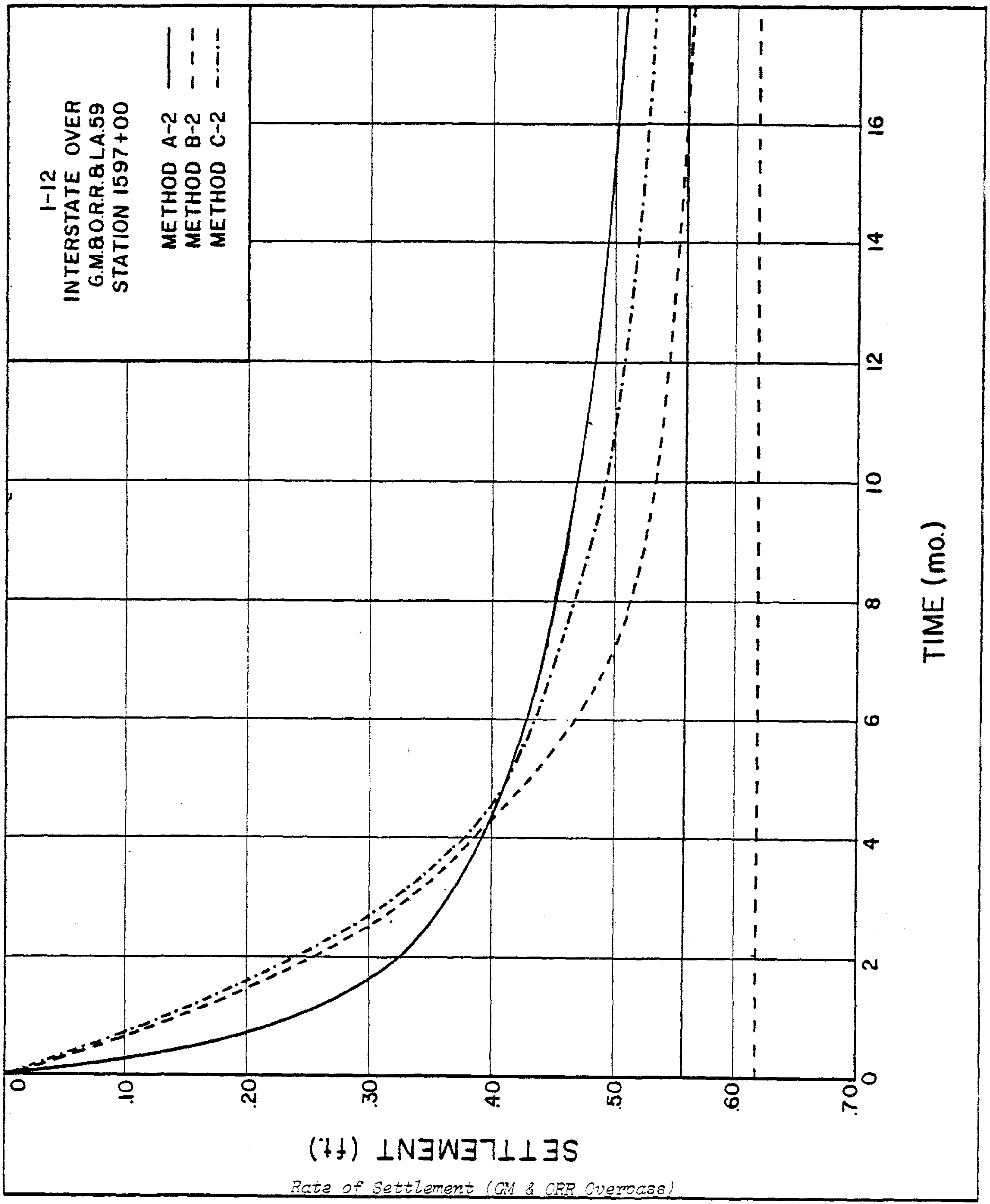
*Rate of Settlement (GM & ORR Overpass)*

*FIGURE 16*



*Rate of Settlement (GH & ORR Overpass)*

*FIGURE 17*



*Rate of Settlement (GM & ORR Overpass)*

*FIGURE 18*

## TABLE 1

## SUMMARY OF SETTLEMENT AT STATION 1580

| Hole Station | 1572+50 | 1579+46 | 1597+00 |
|---|---|---|---|
| Fill Height | 21' | 39' | 18' |
| Compressible Material | 74' | 64' | 52' |
| Settlement* | 1.4' | 1.7' | 0.61' |
| Time to Reach 75% of Total* | 36 mo. | 12 mo. | 8 mo. |

1 foot = 0.304 m

*Using Method B-2

As can be seen, the total settlement was greatest at Station 1579+46 where the fill height was 39 feet (11.8 m), but settlement time was longest at Station 1572+46 where there was 74 feet (22.5 m) of compressible material. Here again the length of drainage path governed the rate, while the height of fill was the controlling factor in the amount of settlement.

# SUMMARY

This report dealt strictly with the laboratory work involved in computing settlements and their rates in some relatively high fills along Interstates 20 and 12 in Louisiana. It is recognized that some of the methods are somewhat antiquated due to the use of the computer and computer programs currently available. Computer use would have taken tedious labor out of these computations. However, if the research would have been done through some "canned" program, the logic of the computations would have been lost within such a program.

In a recent publication by Arman and McManis (9) it was shown that the 2.8-inch (7.1-cm)-diameter core, the conventional sample size and the size used in this study, was subject to disturbance. That is, when the core was trimmed only 0.15 inch (3.8 mm) to fit in a 2.5-inch (6.3-cm) consolidometer ring, much of the distorted soil, which became that way during sampling, was left in the specimen during testing. They state:

> Variation of the shape of the e-log $\bar{\sigma}$ curve produced from various types of samples [2.5 inches (6.3 cm) were trimmed from 1 foot$^3$ (.028 m$^3$) blocks and 8 inches (20.3 cm) ranging down to 2.8-inch (7.1 cm) cores] was also observed to be significant and resulted in large discrepancies in settlement predictions in some instances.

This fact may have had some bearing on the discrepancies in the predicted amount of settlement in two adjacent holes on the same structure even though these inconsistencies have been explained by differences in the depth of compressible material or the number of drainage layers. The amount of disturbance was also proportional to the looseness of the soil.

As was pointed out, the two large embankments at Walnut Bayou on I-20 and at approximate Station 1584+00 on I-12 had the most pronounced discrepancies. These were explained by the nature of the foundation materials, unfortunately, for these two fills offered the best geometry to study. At any rate, a summary of the fill heights, predicted amounts and rates appears in the table below.

# TABLE 2
## SUMMARY OF PREDICTED SETTLEMENTS

| Structure Type | Parish Road Over I-20 | | I-20 Over Walnut B., U.S. 65 & M.P.R.R. | | Parish Road Over I-20 | | La. 577 Over I-20 | | I-12 Over U.S. 51 & M.P.R.R. | I-12 Over G.M.& O.R.R. And La. 59 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boring Number | 1(20) | 2(20) | 3(20) | 4(20) | 5(20) | 6(20) | 7(20) | 8(20) | 1(12) | 2(12) | 3(12) | 4(12) |
| Station Location | 238+15 | Not Shown | 904+00 | 908+00 | 596+50 @ 51+25 | 596+50 @ 55+85 | 235+40 @ 17+50 | 232+40 @ 22+15 | 244+00 | 1572+50 | 1579+46 | 1597+00 |
| Fill Height | 23' | Not Shown | 32' | 32' | 22' | 22' | 25' | 25' | 30' | 21' | 39' | 48' |
| Amount Compressible Material | | Not Shown | 36' | 35' | | | | | | 74' | 64' | 52' |
| Method A-1 | 0.48' | Not Shown | 0.79' | 1.10' | 0.54' | 0.38' | 0.56' | 0.59' | 0.68' | 1.30' | 1.55' | 0.56' |
| Method B-1 | 0.38' | Not Shown | 0.81' | 0.87' | 0.55' | 0.49' | 0.66' | 0.59' | 0.84' | 1.38' | 1.73' | 0.61 |
| Method A-2* | 3 mos. | Not Shown | 80 mos. | 20 mos. | 58 mos. | 5 mos. | 29 mos. | 45 mos. | 36 mos. | <40 mos. | 10 mos. | 5½ mos. |
| Method B-2* | 3½ mos. | Not Shown | 45 mos. | 36 mos. | 73 mos. | 19 mos. | 45 mos. | 33 mos. | 20 mos. | 38 mos. | 12 mos. | 8 mos. |
| Method C-2* | 3/4 mos. | Not Shown | 18 mos. | 8 mos. | 9½ mos. | 8 mos. | 10 mos. | 7 mos. | 18 mos. | <40 mos. | 10 mos. | 6½ mos. |

*Time to Reach 75% Consolidation.

# REFERENCES

1. Ray, J. R., B. J. Covington, and Ara Arman, "Consolidation Study," Louisiana State University, Baton Rouge, Louisiana, 1964.

2. Corps of Engineers, U. S. Army, "Investigations of Foundation, Borrow Material and Embankment Design for the Relocation of U. S. 190 and 71 - West Atchafalaya Floodway Crossing." T. M. No. 3-284, 1949.

3. Shockley, W. G., and C. I. Mansur, "Settlement of a Railroad Embankment Crossing the Morganza Floodway, Louisiana," Symposium on Consolidation Testing of Soils, Tech. Pub. No. 126, Am. Soc. for Testing Mats., 1951, pp 34-41.

4. Fisk, H. N., "Geological Investigation of the Alluvial Valley of the Lower Mississippi River," conducted for the Miss. R. Commission, Corps of Eng., U.S. Army, 1944.

5. Casagrande, A., "The Determination of the Pre-consolidation Load and Its Practical Significance," Prog. Int. Conf. Soil Mechanics, Vol. III, Harvard Univ., 1936.

6. Taylor, D. W., "Fundamentals of Soil Mechanics," John Wiley and Sons, Inc., New York, 1962, p. 278 (Twelfth Printing).

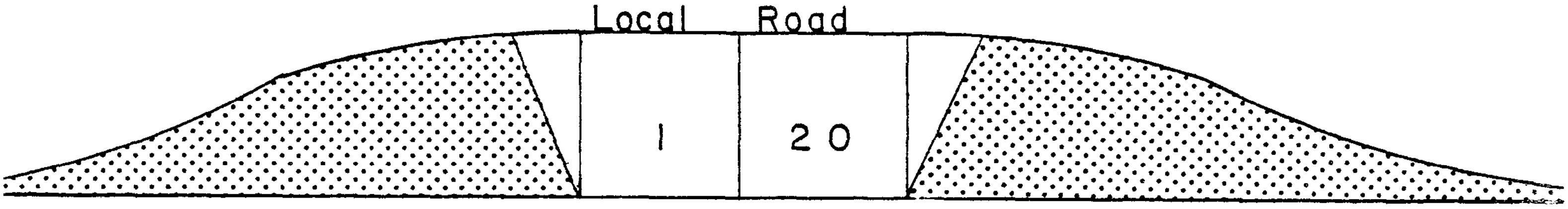
7. Carothers, S. D., "Stresses Due to a Loaded Surface When the Earth Is Treated As an Elastic Solid," Engineering, London, Vol. CXVIII, July 4, 1924.

8. Palmer, L. A. and Barber, E. S., "Principles of Soils Mechanics Involved in Fill Construction," Proc. 19th Annual Meeting, Hwy. Resh. Board, 1937.

9. Arman, Ara and McManis, K. L., "The Effects of Conventional Soil Sampling Methods on the Engineering Properties of Cohesive Soils in Louisiana," Louisiana State Univ., Div. of Eng. Resh., Engr. Resh. Bull. 117, July 1977.

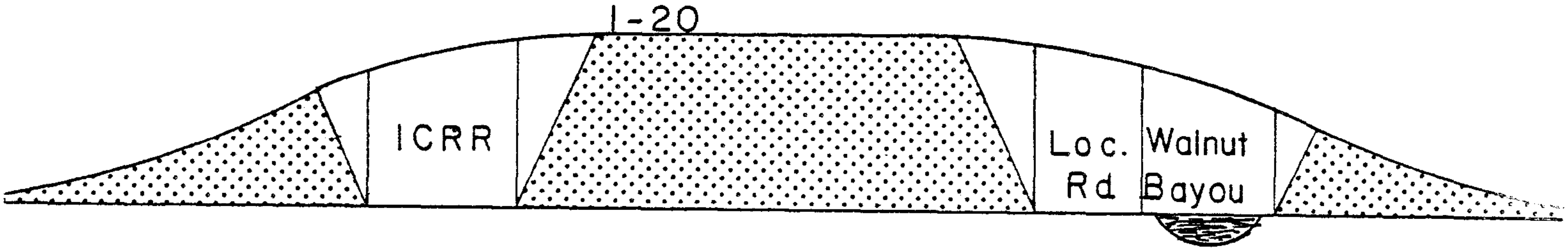
# APPENDIX A

## GENERALIZED SKETCHES OF THE OVERPASSES INVESTIGATED



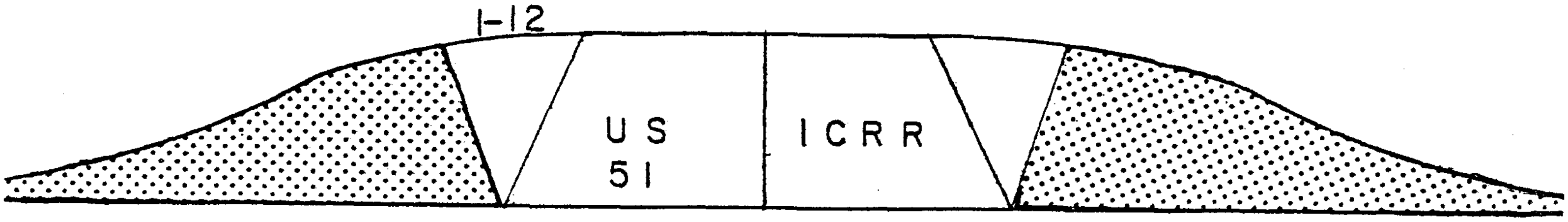
GENERAL SKETCH FOR LOCAL ROAD OVERPASSES
FAP NOS. I-20-4(4)154 STATION 238+32
FAP NOS. I-20-3(25)48 STATION 596+50
FAP NOS. I-20-3(25)48 STATION 232+40

*FIGURE 1-A*



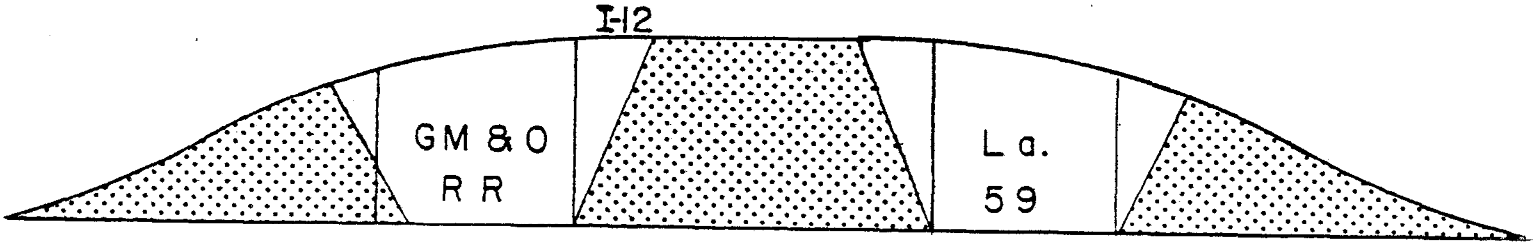
SKETCH FOR
FAP NO. I-20-4(4)154 STATION 906+00

*FIGURE 2-A*



SKETCH FOR
I-12-1(9)39 STATION 248+40

*FIGURE 3-A*

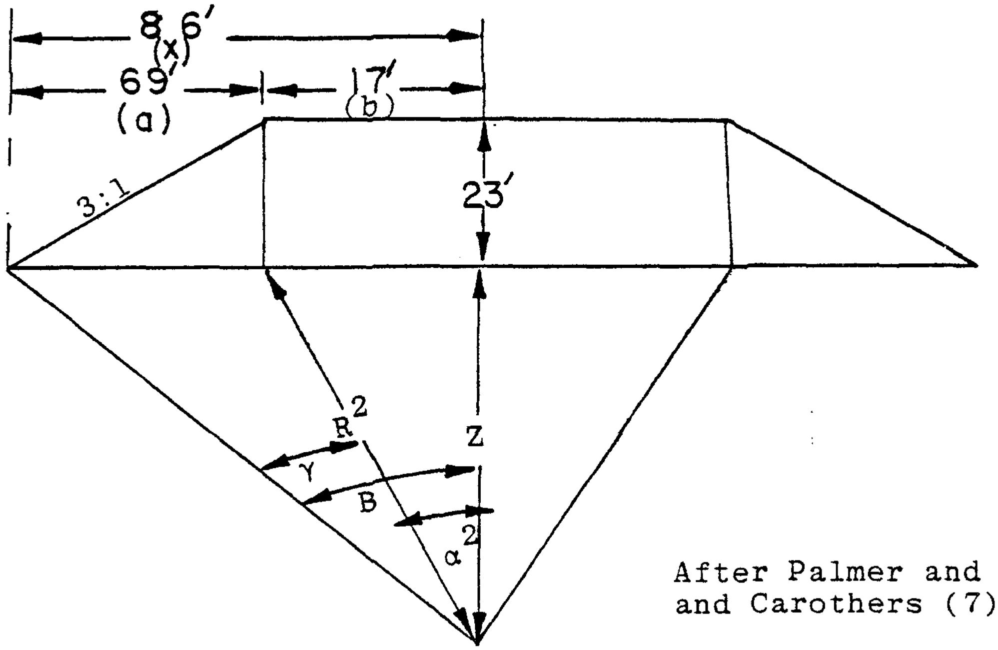


SKETCH FOR
I-12-1(9)39 STATION 1580+00

*FIGURE 4-A*

# APPENDIX B

# EXAMPLE CALCULATIONS OF A PRESSURE DISTRIBUTION CURVE



After Palmer and Barber (8) and Carothers (7).

$$P_o = \frac{120\ \#/ft^2}{2000} \times 23' = 1.38\ \text{tsf}$$

For Sq. Sec. $P_z = \frac{P_o}{¶}(\alpha + \text{Sin}\ \alpha)$

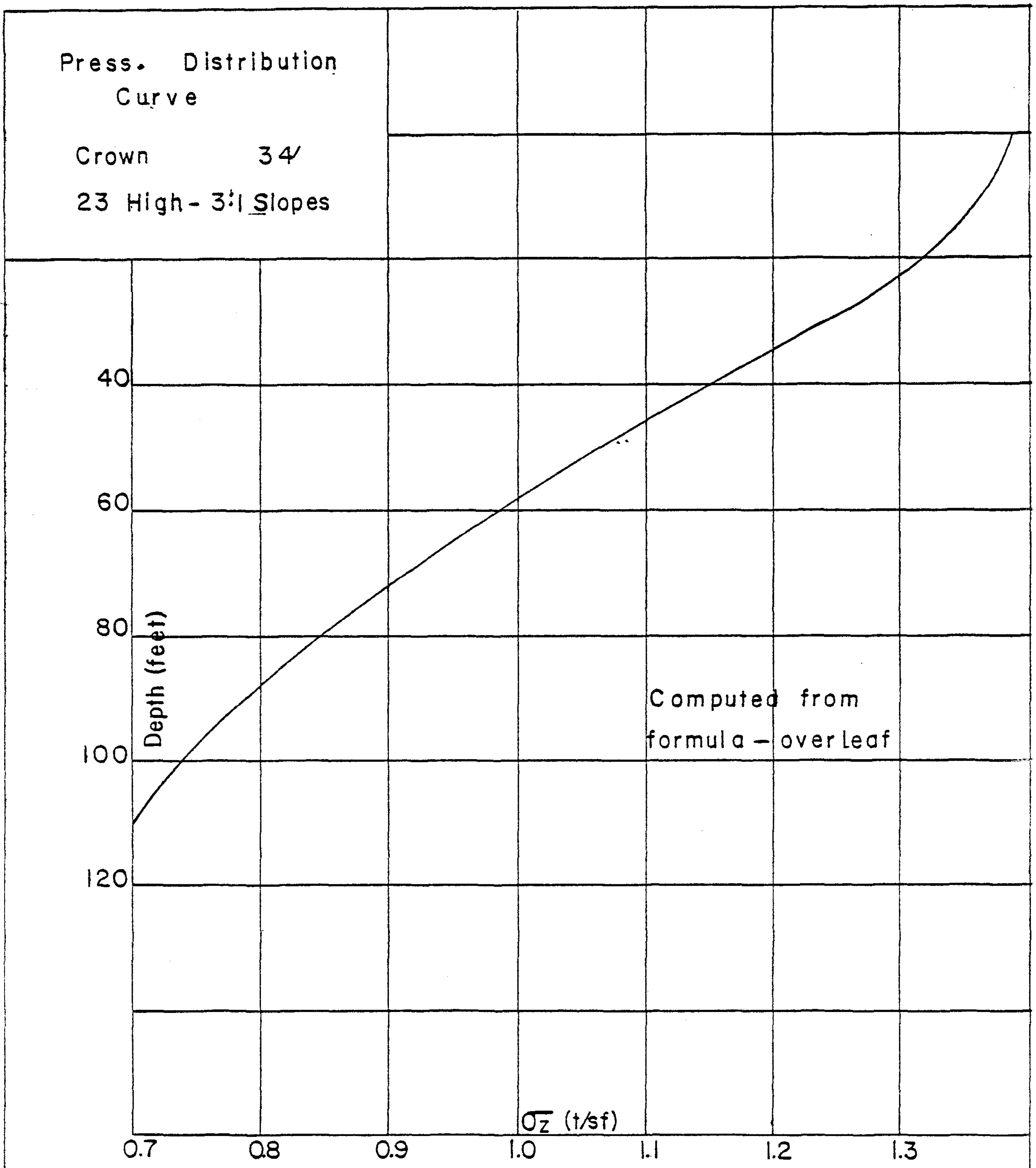
| z | α=2 tan$^{-1}$ 17/z | α(rad) | Sin α | α + Sin α | $\frac{P_o}{¶}(\alpha + \text{Sin}\ \alpha)$ |
|---|---|---|---|---|---|
| 0 | 180° | ¶ | 0 | ¶ | 1.380 |
| 15 | (48°30')2<br>97°00' | 1.694 | .990 | 2.684 | 1.180 |
| 30 | (29°34')2<br>59°08' | 1.014 | .860 | 1.874 | 0.824 |
| 45 | (20°42')2<br>41°24' | 0.724 | .663 | 1.387 | 0.608 |
| 60 | (15°50')2<br>31°40' | 0.525 | .526 | 1.051 | 0.462 |
| 75 | (12°46')2<br>25°32' | 0.445 | .432 | .877 | 0.386 |
| 90 | (10°42')2<br>21°12' | 0.370 | .363 | .733 | 0.322 |
| 105 | (09°12')2<br>18°24' | 0.321 | .317 | .638 | 0.280 |
| 120 | (08°04')2<br>16°08' | 0.282 | .279 | .561 | 0.246 |

*Example Calculations of Pressure Distribution*
*FIGURE 1-B*

For 2 Tr. Sec. $P_{z_{Tr}} = \frac{2P_o}{\P a} [x\gamma \text{ (rad)} - \frac{azb}{R^2}$

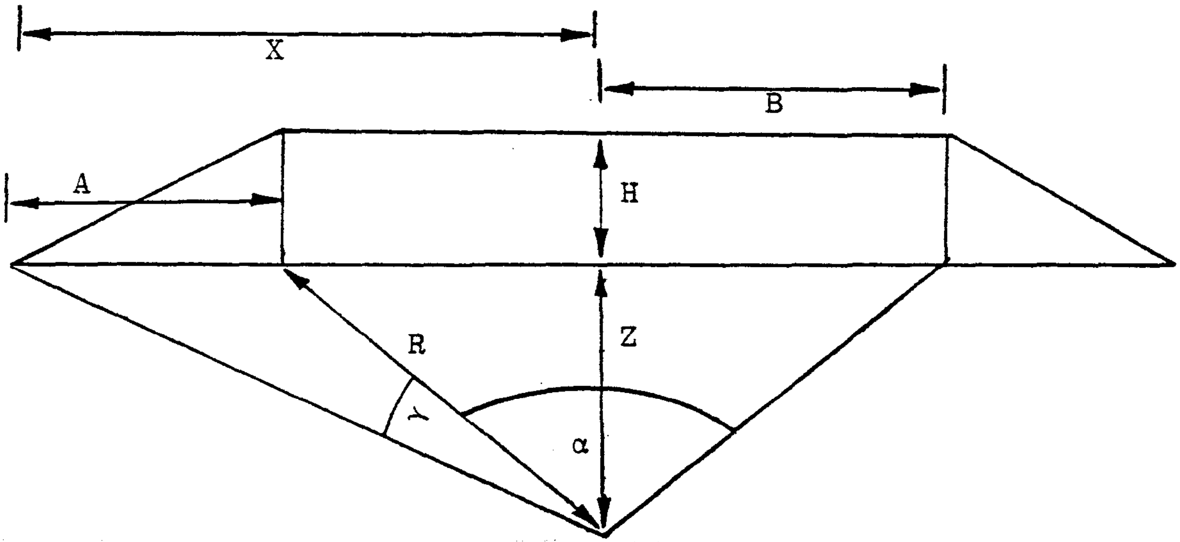
| $z$ | $B = \tan^{-1} 86/z$ | $\gamma = B-\alpha/2$ | $\chi\gamma$(rad) | $e^2 = 17^2+z^2$ | az | $\frac{azb}{R^2}$ | $x\gamma - \frac{azb}{R^2}$ | $P_z$ | Depth (Feet) | $P_z$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 180° | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1.380 |
| 15 | 80°07' | 31°37' | 47.40 | 514 | 1,035 | 34.20 | 13.20 | .168 | 15 | 1.348 |
| 30 | 70°47' | 41°13' | 61.75 | 1,189 | 2,070 | 29.65 | 32.10 | .408 | 30 | 1.232 |
| 45 | 62°21' | 41°39' | 62 50' | 2,314 | 3.105 | 22.85 | 39.65 | .505 | 45 | 1.103 |
| 60 | 55°06' | 39°16' | 59.00 | 3,889 | 4,140 | 18.10 | 40.90 | .520 | 60 | .982 |
| 75 | 48°52' | 36°06' | 54.20 | 5,914 | 5,175 | 14.90 | 39.30 | .500 | 75 | .886 |
| 90 | 44°41' | 33°59' | 51.10 | 8,389 | 6,210 | 12.60 | 38.50 | .490 | 90 | .812 |
| 105 | 39°20' | 30°08' | 45.20 | 11,314 | 7,245 | 10.86 | 34.34 | .436 | 105 | .716 |
| 120 | 35°35' | 27°31' | 41.25 | 14,689 | 8,280 | 9.60 | 31.65 | .425 | 120 | .671 |

*FIGURE 1-B (Continued)*



*Pressure Distribution Curve*

FIGURE 2-B



*Shortened Version of Pressure Distribution*

*FIGURE 3-B*

The original formula from Carothers (7) and Palmer and Barber (8) is

$$P_z = \frac{P_o}{\P} (\alpha + \text{Sin } \alpha) + \frac{2P_o}{\P A} (x\gamma - \frac{AZB}{R^2}$$

Where

$$P_o = \frac{120}{2000} \text{ H,T/fr}^2$$

$A, B, H, R, X, Z, \alpha, \gamma$ = as shown in Figure 3-B.

But it can be shown that:

$$P_z = \frac{P_o}{\P} \alpha + \frac{2P_o x}{\P A} \gamma$$

Because the function $\frac{P_o}{\P} \text{ Sin } \alpha = \frac{2P_o}{\P A} (\frac{AZB}{R^2})$

By cancellation $\text{Sin } \alpha = 2(\frac{ZB}{R^2})$

Looking at the right side only $2(\frac{Z}{R} \cdot \frac{B}{R})$

But from the figure $\frac{Z}{R} = \text{Cos } \frac{\alpha}{2}$ and $\frac{B}{R} = \text{Sin } \frac{\alpha}{2}$

Thus the right side becomes 2 Cos $\frac{\alpha}{2}$ Sin $\frac{\alpha}{2}$ which is Sin $^{\alpha}$.

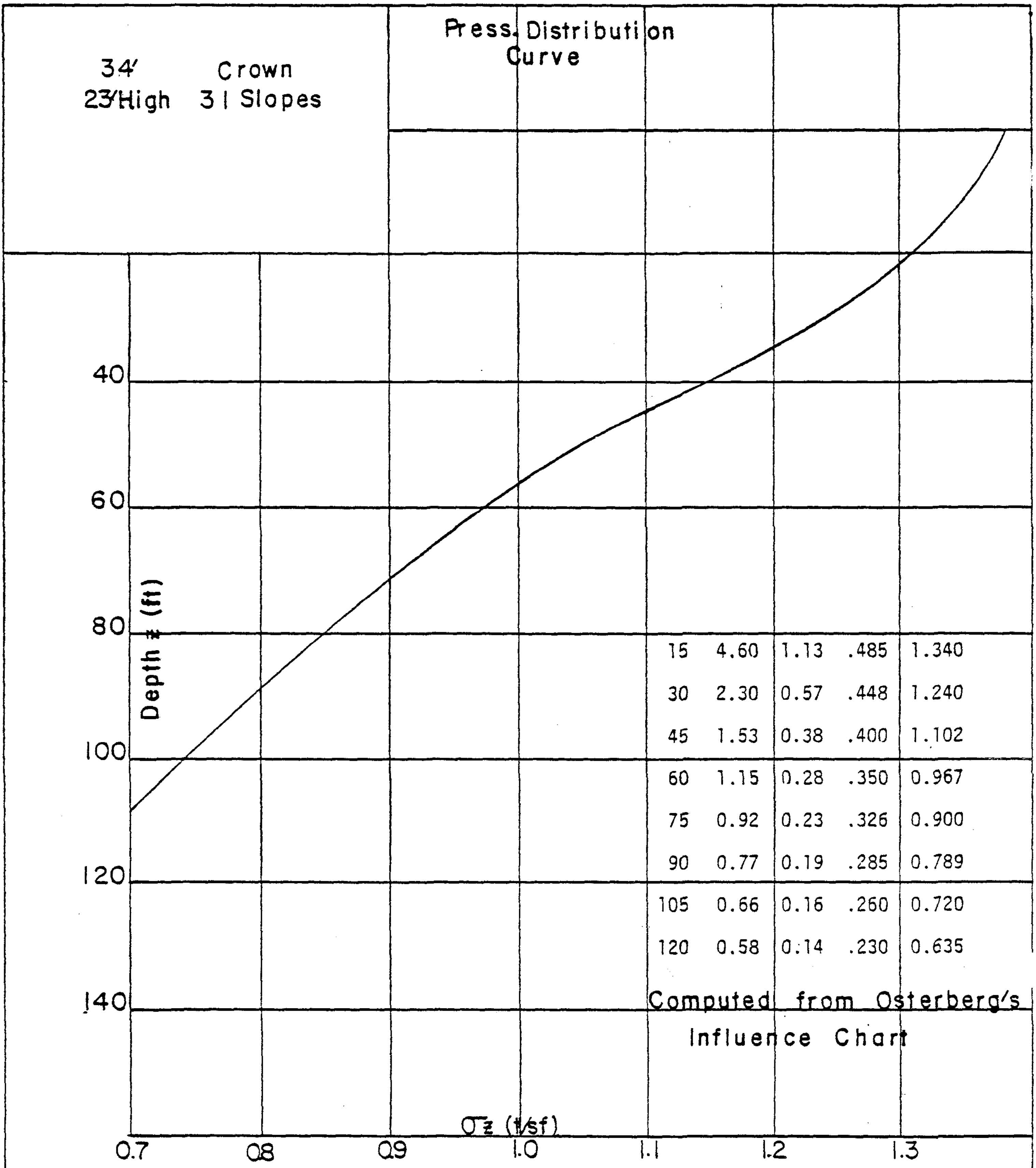
Since $\frac{P_1}{\P}$ (Sin $\alpha$) is plus and $\frac{2P_o}{\P A}$ $(\frac{AZB}{R^2})$ is minus, they cancel.

Therefore

$$P_z = \frac{P_o}{\P} (\alpha + \frac{2X\gamma}{a})$$ is a shortened version of

$$P_z = \frac{P_o}{\P} (\alpha + \text{Sin } \alpha) + \frac{2P_o}{\P a} [X\gamma - \frac{azb}{R}],$$ the equation solved

here. The formula is rather obscure and probably unfamiliar to the reader. For a comparison to a method using an "Influence Chart for Vertical Stress Embankment Loading - Infinite Extent - Boussinesq Case" prepared by Osterberg, J. O., see the following example.



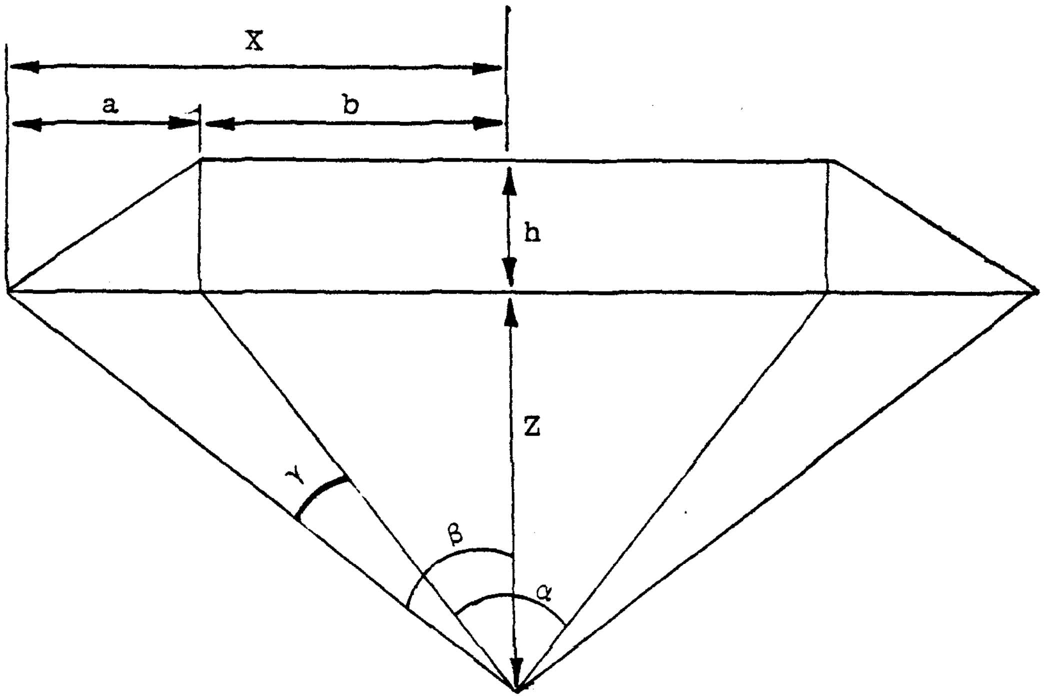
| | | | | |
|---|---|---|---|---|
| 15 | 4.60 | 1.13 | .485 | 1.340 |
| 30 | 2.30 | 0.57 | .448 | 1.240 |
| 45 | 1.53 | 0.38 | .400 | 1.102 |
| 60 | 1.15 | 0.28 | .350 | 0.967 |
| 75 | 0.92 | 0.23 | .326 | 0.900 |
| 90 | 0.77 | 0.19 | .285 | 0.789 |
| 105 | 0.66 | 0.16 | .260 | 0.720 |
| 120 | 0.58 | 0.14 | .230 | 0.635 |

*Pressure Distribution Curve (Osterberg Influence Chart)*

*FIGURE 4-B*

# APPENDIX C

## INTERSTATE STATIONS 904+00 AND 908+00
## INTERSTATE OVERPASS OVER RAILROAD
## SOUTH OF TALLULAH, LOUISIANA



Data:
$a = 128'$
$b = 66'$
$x = 194'$
$h = 32'$

$$P_o = \frac{\text{density } (\#/\text{ft}^3)}{2000\ \#/\text{T}}\ h(\text{ft.})$$

Revised Formula $P_z = \frac{P_o}{\P}\alpha + \frac{2P_oX}{\P a}\gamma^{(7)}$

$$\frac{P_o}{\P} = 0.611 \qquad \frac{2P_ox}{\P a} = 1.850$$

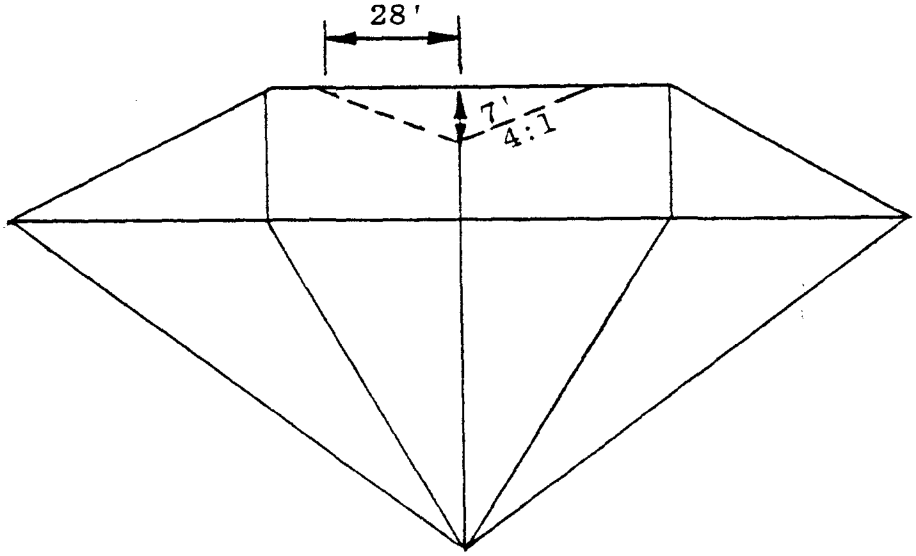
$$\frac{\alpha}{z} - \tan^{-1}\frac{b}{z}\ ,\ \beta = \tan^{-1}\frac{x}{z}\ ,\ \gamma = \beta - \frac{\alpha}{z}$$

| Z (ft.) | α/2° | α° | $\alpha_{rad}$ | β° | α° | $\gamma_{rad}$ | $P'_z$ |
|---|---|---|---|---|---|---|---|
| 0 | 90 | 180 | 3.14 | 90 | 0 | 0.00 | 1.920 |
| 15 | 77.2 | 154 | 2.69 | 85.6 | 8.4 | 0.147 | 1.913 |
| 30 | 65.6 | 131.2 | 2.288 | 81.2 | 15.6 | 0.273 | 1.903 |
| 45 | 55.7 | 111.3 | 1.945 | 76.9 | 21.3 | 0.371 | 1.874 |
| 60 | 48.9 | 97.7 | 1.666 | 72.8 | 24.0 | 0.438 | 1.829 |
| 75 | 41.3 | 82.5 | 1.443 | 68.9 | 27.6 | 0.480 | 1.773 |
| 90 | 36.2 | 72.4 | 1.264 | 64.6 | 28.3 | 0.504 | 1.706 |
| 105 | 32.2 | 64.3 | 1.123 | 61.6 | 29.4 | 0.513 | 1.637 |
| 120 | 28.8 | 57.6 | 1.006 | 58.3 | 29.5 | 0.515 | 1.568 |

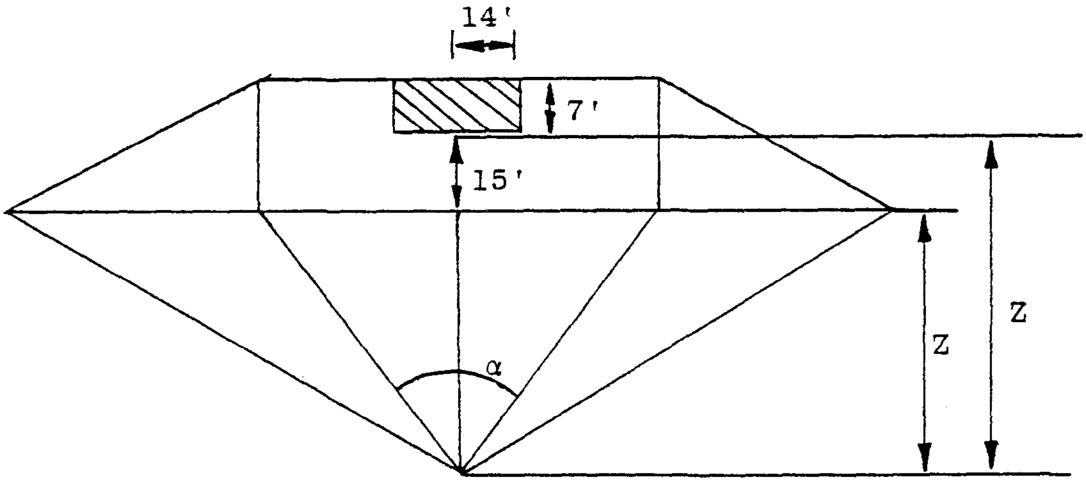
COMPUTED VALUES OF PRESSURE DUE TO
PROPOSED FILL AT STATIONS 904+00 AND 908+00

*FIGURE 1-C*

## Influence of Median on Fill



Assume that rectangular section has the same effect as the triangular section.



The rectangular section has the same depth as the triangular section and a width equal to one-half (1/2) that of the triangular section. However, the total cross-sectional areas are equal.

*FIGURE 1-C (CONTINUED)*

## Values of $P''_z$ (Influence of Median)

$$P''_z = \frac{P''_o}{Z} (\alpha + \text{Sin } \alpha)$$

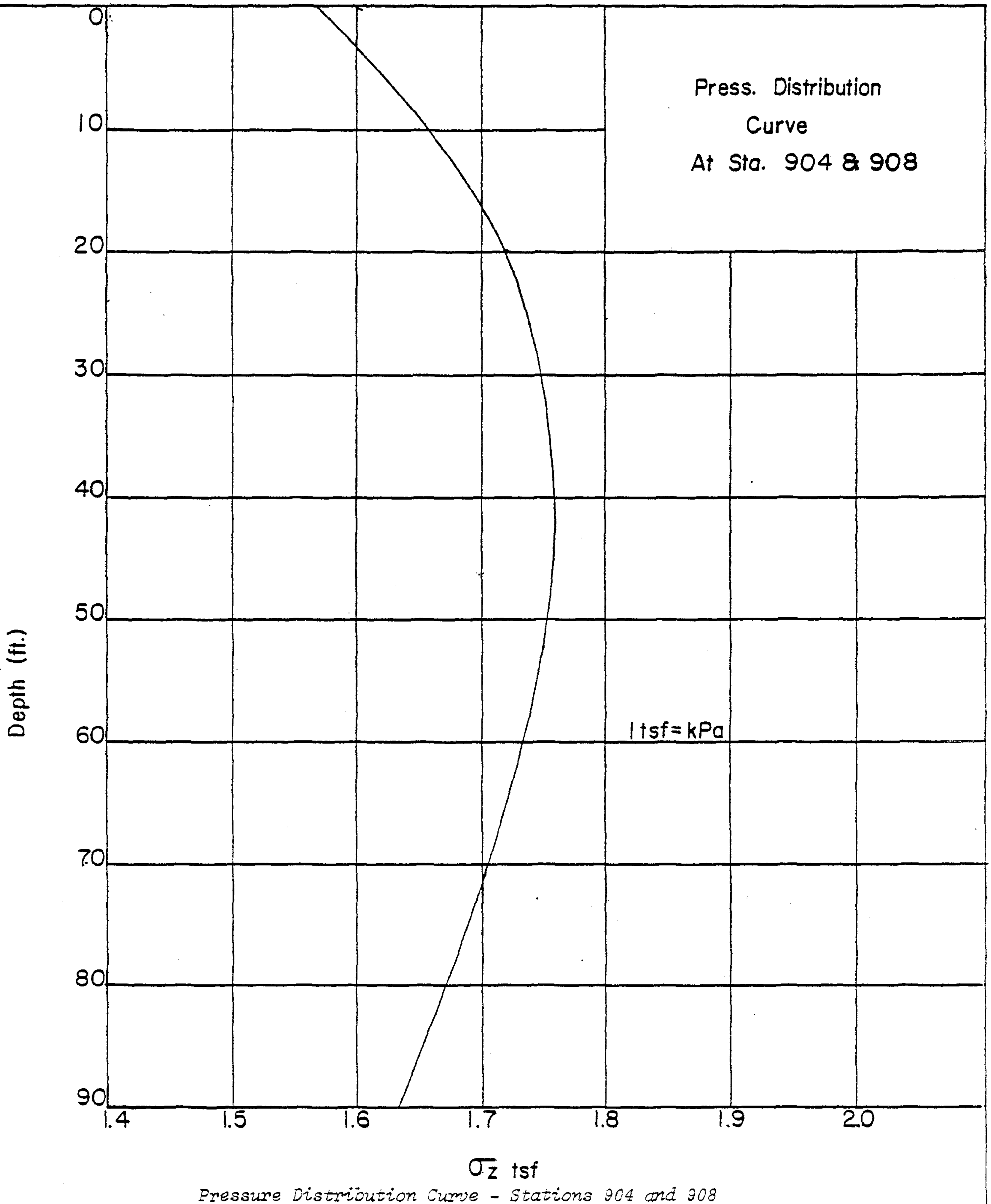
$$\alpha'' = 2\text{Tan}^{-1} \frac{14}{Z}$$

$$P_o = \frac{\text{Den}}{2000} h \text{ (ft.)} = \frac{120}{2000} \cdot 7$$

$$\frac{P_o}{\P} = 0.1337$$

| Z | α" | Sin α | α + Sin α | $P''_z$ | $P'_z$ | $P_z$ |
|---|---|---|---|---|---|---|
| 0/15 | 1.502 | 0.998 | 2.499 | 0.334 | 1.920 | 1.586 |
| 15/30 | 0.873 | 0.776 | 1.640 | 0.219 | 1.913 | 1.695 |
| 30/45 | 0.603 | 0.567 | 1.171 | 0.156 | 1.903 | 1.747 |
| 45/60 | 0.458 | 0.443 | 0.901 | 0.120 | 1.874 | 1.754 |
| 60/75 | 0.369 | 0.360 | 0.730 | 0.098 | 1.829 | 1.731 |
| 75/90 | 0.309 | 0.304 | 0.612 | 0.082 | 1.773 | 1.691 |
| 90/105 | 0.265 | 0.262 | 0.527 | 0.070 | 1.706 | 1.636 |

*FIGURE 1-C (CONTINUED)*



*Pressure Distribution Curve - Stations 904 and 908*

*FIGURE 2-C*

## EXAMPLE PROCEDURES

It was decided that the boring divided itself into four compressible units and that all units would be drained both at top and bottom.

An explanation of the calculations are given as follows (Methods A2 and B2):

1. Calculations for weight average $t_{50}$ and $h_L$

$h_F$ = height of the strata in the field, feet

$t_{50}$ = time required to reach 50% consolidation ($U_{50}$) in the lab

$\frac{t_{50} h_F}{h_F \text{ for unit}}$ = weighted average $t_{50}$ in the lab, minutes

$h_L$ = height of soil cake in the lab at $U_{50}$, inches

$\frac{h_L h_F}{h_R \text{ for unit}}$ = weighted average $h_L$, inches

2. Calculation of $C_V = \frac{TH_L^2}{t_L}$

T = Terzaghi's Factor at $U_{50}$

$H_L = \frac{h_L}{2}$ since the soil was drained at top and bottom, inches

$t_L$ = time for unit in the lab to reach $U_{50}$ (weight average $L_{50}$), minutes

$C_V$ = Coefficient of consolidation, in$^2$/min.

3. Calculations for primary consolidation

$H_F = \frac{h_F}{2}$ feet since the unit in the field was drained at the top and bottom, inches

$\Delta H$ = change in height of the unit due to the influence or $\Delta\sigma$, inches

$K = \frac{(H_F)^2}{C_v(4.32x10^4}$ when K is multiplied by T, in this case T at $U_{25}$, $U_{50}$, and $U_{75}$, the time in the field ($t_F$) is obtained.

$t_{25}$, etc. = time in the field, months

These numbers ($t_{25}$, etc.) were plotted as the abscissa and 25%, 50%, etc. of the total settlement for the unit under consideration were plotted as the ordinate of time versus settlement curves. This was done for each unit encountered. For Method C-2 the grouping of samples as in Method A-2 is used, but the $\sqrt{t}$ is used rather than Log L plus.

4. Secondary consolidation: After computing the settlement rate for 100% primary consolidation ($U_{100}$), an arbitrary 0.001 inches (0.0254 mm) past on the $U_{100}$ was observed the time it takes to reach 0.001 inches (0.0254 mm) past $U_{100}$ and the $h_L$ at 0.001 inches (0.0254 mm) past. The average values for t (secondary) and $h_L$ were computed as it was in #1 above. From these values

$$\Delta H_F = \Delta H_L \left(\frac{H_F}{H_L}\right)$$

$$= 0.001 \left(\frac{H_F}{H_L}\right)$$

and

$$t_F \text{ (secondary)} = \frac{t_L \text{ (secondary)}}{4.32 \times 10^4} \left(\frac{H_F}{H_L}\right)^2$$

The summation of the curves for each unit in primary consolidation plus what is obtained for secondary consolidation was plotted as the rate of settlement, L.S.U. Method C-2. Examples can be seen in Figures

## TABLE 1-C

Research Project No. 64-1S
Station No. 908+00
Boring 4

### METHOD A1

| Representative Core Number | $\gamma$,T/ft.$^2$ | Depth to Mid-pt.,ft. | Depth of Layer,ft. | $\sigma_o$, T/ft$^2$ | $\Delta\sigma$,T/ft.$^2$ |
|---|---|---|---|---|---|
| 61 | 0.0602 | 1.5 | 3 | 0.090 | 1.496 |
| 62 | 0.0578 | 4.5 | 3 | 0.267 | 1.520 |
| 63 | 0.0263 | 7.5 | 3 | 0.393 | 1.542 |
| 64 | 0.0239 | 15.0 | 12 | 0.576 | 1.596 |
| 68 | 0.0258 | 22.5 | 3 | 0.758 | 1.645 |
| 69 | 0.0267 | 24.5 | 1 | 0.810 | 1.658 |
| 70 | 0.0229 | 26.0 | 2 | 0.847 | 1.669 |
| 71 | 0.0251 | 28.5 | 3 | 0.907 | 1.680 |
| 72 | 0.0271 | 31.5 | 3 | 0.986 | 1.697 |
| 73 | 0.0254 | 34.5 | 3 | 1.064 | 1.709 |
| 74 | 0.0269 | 42.0 | 12 | 1.264 | 1.733 |
| 78 | 0.0269 | 52.0 | 8 | 1.533 | 1.738 |
| 81 | 0.0310 | 58.0 | 4 | 1.702 | 1.729 |
| 83 | 0.0297 | 61.5 | 3 | 1.809 | 1.721 |

## TABLE 1-C (CONTINUED)

## METHOD A1 (CONTINUED)

| Representative Core Number | $\sigma o+\Delta\sigma$,(T/ft.$^2$) | 1 + e. | $\Delta e$ | $h_f$ | $\frac{\Delta e}{1+e}\cdot h_f$ |
|---|---|---|---|---|---|
| 61 | 1.675 | 1.649 | 0.010 | 3 | 0.018 |
| 62 | 1.882 | 1.807 | 0.028 | 3 | 0.047 |
| 63 | 2.033 | 1.937 | 0.102 | 3 | 0.158 |
| 64 | 2.266 | 2.104 | 0.069 | 12 | 0.393 |
| 68 | 2.488 | 1.979 | 0.056 | 3 | 0.085 |
| 69 | 2.547 | 1.924 | 0.029 | 1 | 0.015 |
| 70 | 2.587 | 1.994 | 0.070 | 2 | 0.070 |
| 71 | 2.653 | 2.010 | 0.042 | 3 | 0.063 |
| 72 | 2.737 | 1.873 | 0.066 | 3 | 0.106 |
| 73 | 2.819 | 1.964 | 0.083 | 3 | 0.127 |
| 74 | 3.024 | 1.833 | 0.036 | 12 | 0.236 |
| 78 | 3.283 | 1.897 | 0.074 | 8 | 0.312 |
| 81 | 3.441 | 1.706 | 0.017 | 4 | 0.040 |
| 83 | 3.539 | 1.687 | 0.010 | 3 | 0.018 |

Total Settlement 1.688' or 20.26'

NOTE: Cores 62, 63, 69, 78, 81, 83, even though compressible, were considered drainage layers having a $t_{100}$ of less than 10 min. Therefore, total settlement of this foundation shows up as 1.098 feet when the A-2 method is completed.

## TABLE 2-C

## METHOD A2

Research Project No. 64-1S
Station Number 908+00
Boring 4

| Core No. | $h_f$ (ft) | $t_{50}$ | $t_{50} \times \frac{h_f}{h_f \text{ for Unit}}$ | $h_L$ | $h_L \times \frac{h_f}{h_f \text{ for Unit}}$ | $H_L$ |
|---|---|---|---|---|---|---|
| 61 | 3 | 16.4 | 16.4 | 0.9895 | 0.9895 | |
| Unit I | 3 | | 16.4 | | 0.9895 | 0.4947 |
| 64 | 6 | 30.8 | 30.8 | 0.9864 | 0.9864 | |
| Unit II | 6 | | 30.8 | | 0.9864 | 0.4932 |
| 68 | 3 | 17.3 | 17.3 | 0.9855 | 0.9855 | |
| Unit III | 3 | | 17.3 | | 0.9855 | 0.4927 |
| 70 | 2 | 23.8 | 2.07 | 0.9516 | 0.0828 | |
| 71 | 3 | 20.8 | 2.72 | 0.9812 | 0.1280 | |
| 72 | 3 | 10.3 | 1.34 | 0.9512 | 0.1240 | |
| 73 | 3 | 24.0 | 3.13 | 0.9517 | 0.1241 | |
| 74 | 12 | 7.45 | 3.88 | 0.9902 | 0.5160 | |
| Unit IV | 23 | | 13.14 | | 0.9749 | 0.4875 |

$$Cv = \frac{TH_L^2}{t_L}$$

| Unit No. | T | $H^2_L$ | $t_L$ | $C_v$ |
|---|---|---|---|---|
| I | 0.197 | 0.245 | 16.4 | 0.00294 |
| II | 0.197 | 0.243 | 30.8 | 0.00155 |
| III | 0.197 | 0.242 | 17.3 | 0.00276 |
| IV | 0.197 | 0.238 | 13.4 | 0.00349 |

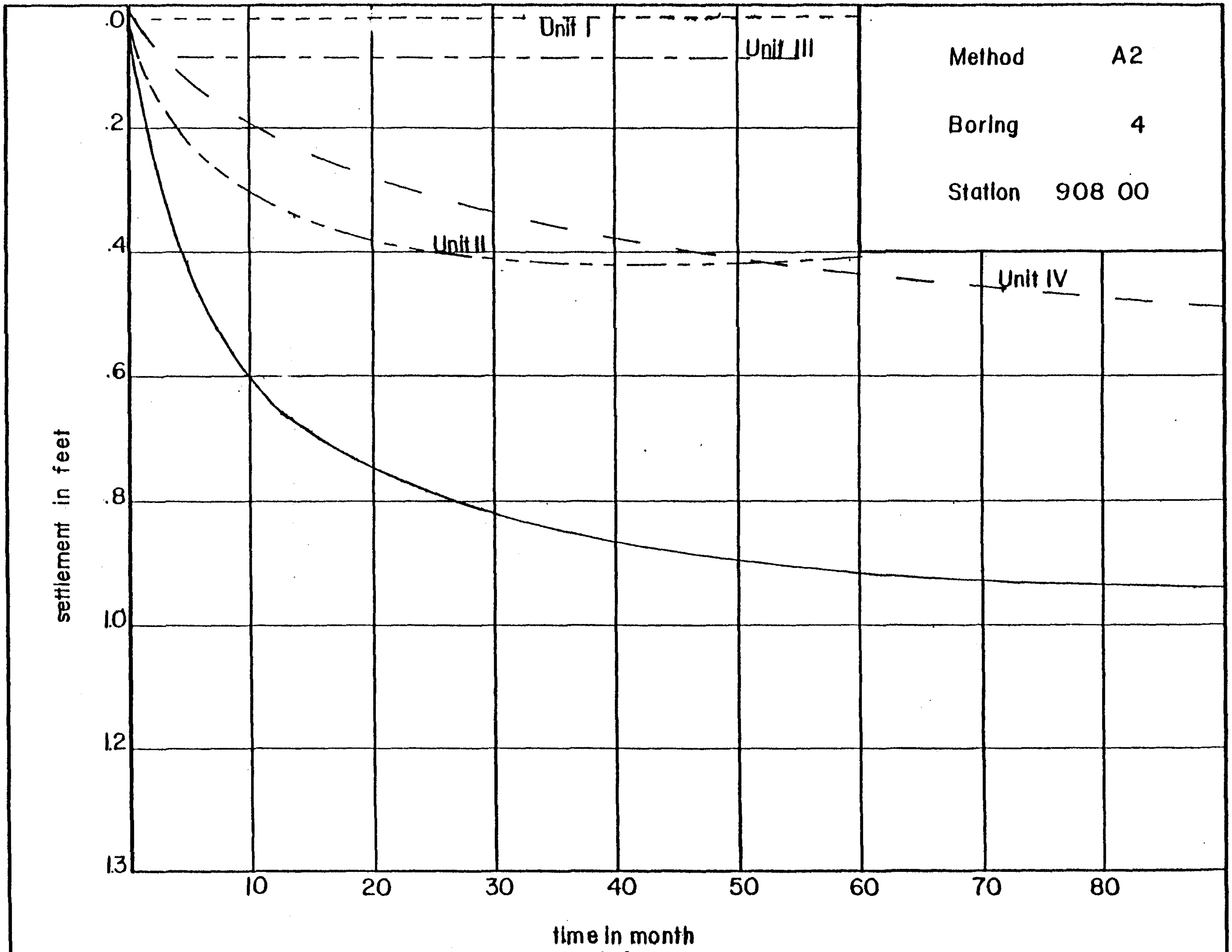
## TABLE 2-C (CONTINUED)

## METHOD A2 (CONTINUED)

|  |  |  |  |  | $t_f = KT$ |  |  |
|---|---|---|---|---|---|---|---|
| Unit No. | $C_v$ | $h^2_f$(in.$^2$) | $\Delta h$,ft. | $K=\frac{h^2_f}{Cv(4.32 \times 10^4)}$ | $t_{f\ 25\%}$ | $t_{f\ 50\%}$ | $t_{f\ 75\%}$ |
| I | 0.00294 | 324 | 0.018 | 2.55 | 0.127 | 0.503 | 1.22 |
| II | 0.00155 | 1296 | 0.393 | 19.35 | 0.968 | 3.82 | 9.49 |
| III | 0.00276 | 324 | 0.085 | 2.72 | 0.136 | 0.535 | 1.33 |
| IV | 0.00349 | 19044 | 0.602 | 126.0 | 6.3 | 24.8 | 61.7 |
|  |  |  | 1.098 |  |  |  |  |

$T_{25} = 0.050$, $T_{50} = 0.197$, $T_{75} = 0.490$

$(4.32 \times 10^4)$ = Minutes/Month



Method A2
FIGURE 3-C

Research Project No. 64-1S
Station No. 908+00
Boring 4

## TABLE 3-C

### METHOD B1

| Representative Core Number | $\gamma$,T/ft.$^2$ | Depth to Mid-pt.,ft. | Depth of Layer,ft. | $\sigma_o$, T/ft$^2$ | $\Delta\sigma$,T/ft.$^2$ |
|---|---|---|---|---|---|
| 61 | 0.0602 | 1.5 | 3 | 0.090 | 1.496 |
| 62 | 0.0578 | 4.5 | 3 | 0.267 | 1.520 |
| 63 | 0.0263 | 7.5 | 3 | 0.393 | 1.542 |
| 64 | 0.0239 | 10.5 | 3 | 0.469 | 1.596 |
| 65 | 0.0243 | 13.5 | 3 | 0.541 | 1.586 |
| 66 | 0.0231 | 16.5 | 3 | 0.612 | 1.606 |
| 67 | 0.0256 | 19.5 | 3 | 0.685 | 1.627 |
| 68 | 0.0258 | 22.5 | 3 | 0.762 | 1.645 |
| 69 | 0.0267 | 24.5 | 1 | 0.814 | 1.658 |
| 70 | 0.0229 | 26.0 | 2 | 0.850 | 1.669 |
| 71 | 0.0251 | 28.5 | 3 | 0.911 | 1.680 |
| 72 | 0.0271 | 31.5 | 3 | 0.989 | 1.697 |
| 73 | 0.0254 | 34.5 | 3 | 1.068 | 1.709 |
| 74 | 0.0269 | 37.5 | 3 | 1.147 | 1.733 |
| 75 | 0.0254 | 40.5 | 3 | 1.225 | 1.730 |
| 76 | 0.0215 | 43.5 | 3 | 1.295 | 1.735 |
| 77 | 0.0251 | 46.5 | 3 | 1.365 | 1.738 |
| 78 | 0.0269 | 49.5 | 3 | 1.443 | 1.739 |
| 79 | 0.0265 | 52.5 | 3 | 1.523 | 1.736 |
| 80 | 0.0283 | 55.0 | 2 | 1.592 | 1.733 |
| 81 | 0.0310 | 56.5 | 1 | 1.635 | 1.731 |
| 82 | 0.0302 | 58.5 | 3 | 1.696 | 1.728 |
| 83 | 0.0297 | 61.5 | 3 | 1.786 | 1.721 |

## TABLE 3-C (CONTINUED)

## METHOD B1 (CONTINUED)

| Representative Core Number | σo+Δσ,(T/ft.$^2$) | 1 + e. | Δe | $h_f$,ft. | $\frac{\Delta e}{1 + e} \cdot h_f$ |
|---|---|---|---|---|---|
| 61 | 1.586 | 1.6488 | 0.010 | 3 | 0.018 |
| 62 | 1.787 | 1.8066 | 0.028 | 3 | 0.047 |
| 63 | 1.935 | 1.9370 | 0.102 | 3 | 0.015 |
| 64 | 2.065 | 2.1039 | 0.064 | 3 | 0.091 |
| 65 | 2.127 | 2.0629 | 0.050 | 3 | 0.073 |
| 66 | 2.218 | 2.1507 | 0.041 | 3 | 0.057 |
| 67 | 2.312 | 1.9698 | 0.033 | 3 | 0.050 |
| 68 | 2.407 | 1.9786 | 0.056 | 3 | 0.085 |
| 69 | 2.472 | 1.9239 | 0.026 | 1 | 0.014 |
| 70 | 2.519 | 1.9942 | 0.070 | 2 | 0.070 |
| 71 | 2.591 | 2.0095 | 0.042 | 3 | 0.063 |
| 72 | 2.686 | 1.8728 | 0.071 | 3 | 0.113 |
| 73 | 2.777 | 1.9642 | 0.083 | 3 | 0.126 |
| 74 | 2.880 | 1.8327 | 0.033 | 3 | 0.054 |
| 75 | 2.95[illegible] | 1.9198 | 0.030 | 3 | 0.047 |
| 76 | 3.030 | 1.9990 | 0.053 | 3 | 0.079 |
| 77 | 3.103 | 2.0508 | 0.032 | 3 | 0.048 |
| 78 | 3.182 | 1.8969 | 0.067 | 3 | 0.106 |
| 79 | 3.259 | 1.9245 | 0.048 | 3 | 0.075 |
| 80 | 3.325 | 1.8408 | 0.046 | 2 | 0.050 |
| 81 | 3.366 | 1.7062 | 0.016 | 1 | 0.009 |
| 82 | 3.424 | 1.7492 | 0.006 | 3 | 0.010 |
| 83 | 3.507 | 1.6968 | 0.010 | 3 | 0.018 |
| | Total Settlement | | | | *1.318' or 15.816" |

*Method B-1 yielded less total settlement than A-1 because of cores selection in A-1.

## TABLE 4-C

## METHOD B2

Research Project No. 64-1S
Station Number 908+00
Boring 4

| Core No. | $h_f$. ft. | $t_{50}$ | $\frac{t_{50}h_f}{h_f \text{ for Unit}}$ | $h_L$ | $\frac{h_L h_f}{h_f \text{ for Unit}}$ | $H_L$ |
|---|---|---|---|---|---|---|
| 61 | 3 | 16.4 | | 0.9895 | 0.9895 | |
| Unit I | 3 | | 16.4 | | 0.9895 | 0.4947 |
| 64 | 3 | 30.8 | 15.4 | 0.9864 | 0.4932 | |
| 65 | 3 | 29.0 | 14.5 | 0.9892 | 0.4946 | |
| Unit II | 6 | | 29.9 | | 0.9878 | 0.4939 |
| 68 | 3 | 17.3 | 17.3 | 0.9855 | 0.9855 | |
| Unit III | 3 | | 17.3 | | 0.9855 | 0.4927 |
| 70 | 2 | 23.8 | 2.09 | 0.9516 | 0.0828 | |
| 71 | 3 | 20.8 | 2.72 | 0.9812 | 0.1278 | |
| 72 | 3 | 10.3 | 1.34 | 0.9512 | 0.1240 | |
| 73 | 3 | 24.0 | 3.13 | 0.9517 | 0.1241 | |
| 74 | 3 | 7.45 | 0.97 | 0.9902 | 0.1291 | |
| 75 | 3 | 14.5 | 1.89 | 0.9876 | 0.1288 | |
| 76 | 3 | 11.5 | 1.50 | 0.9849 | 0.1283 | |
| 77 | 3 | 6.4 | 0.83 | 0.9960 | 0.1299 | |
| Unit IV | 23 | | 14.47 | | 0.9748 | 0.4874 |

$$Cv = \frac{Th_L^2}{t_L}$$

| Unit No. | T | $H_L^2$ | $t_L$ | $C_v$ |
|---|---|---|---|---|
| I | 0.197 | 0.245 | 16.4 | 0.00293 |
| II | 0.197 | 0.244 | 29.9 | 0.00161 |
| III | 0.197 | 0.243 | 17.3 | 0.00277 |
| IV | 0.197 | 0.238 | 14.5 | 0.00323 |

## TABLE 4-C (CONTINUED)

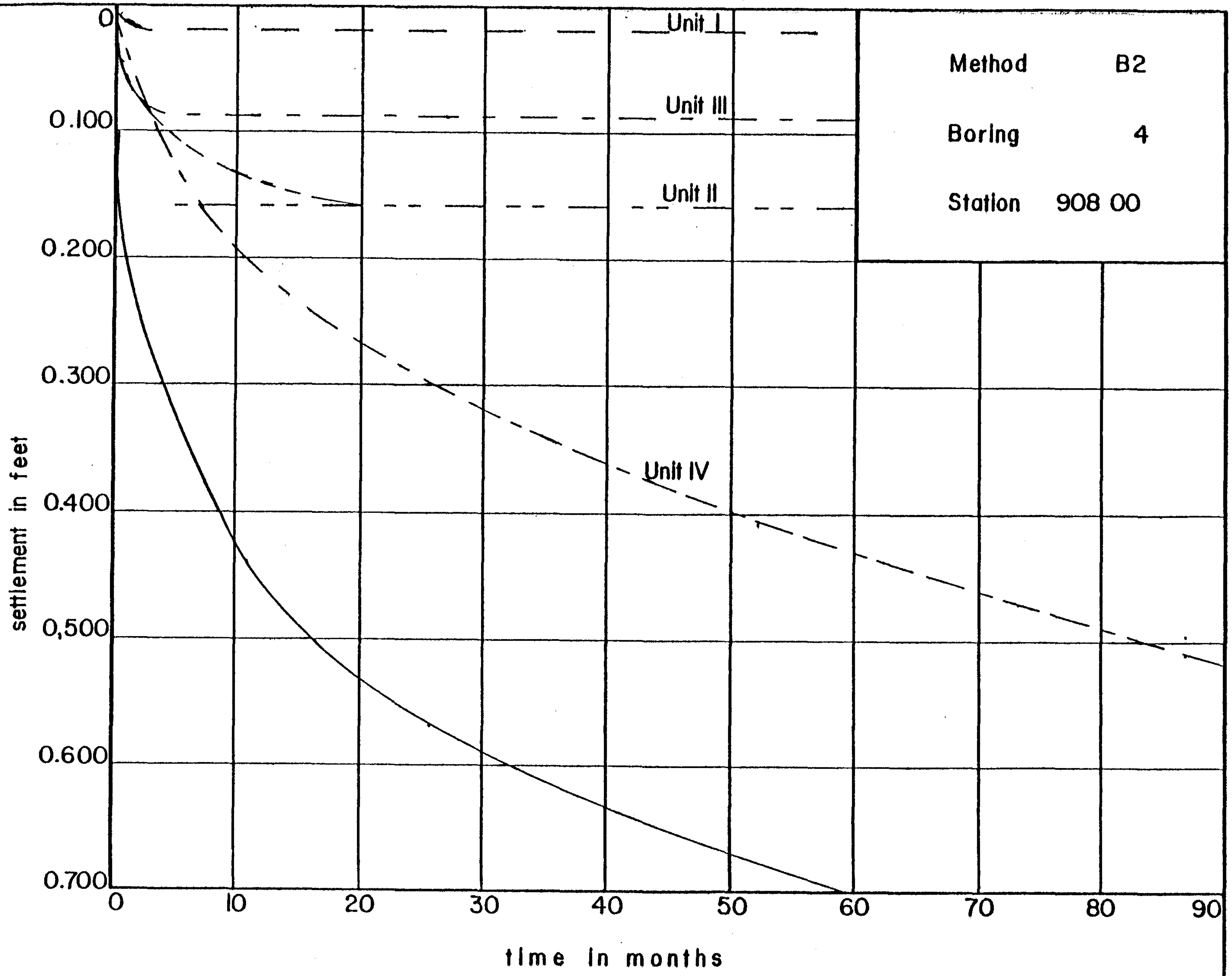
## METHOD B2 (CONTINUED)

$t_f = KT$

| Unit No. | $C_v$ | $h^2_f$(in.$^2$) | $\Delta h_c$,ft. | $K = \frac{h^2_f}{Cv(4.32 \times 10^4)}$ | $t_{f\ 25\%}$ | $t_{f\ 50\%}$ | $t_{f\ 75\%}$ |
|---|---|---|---|---|---|---|---|
| I | 0.00293 | 324 | 0.018 | 2.56 | 0.128 | 0.504 | 1.25 |
| II | 0.00161 | 1296 | 0.164 | 18.62 | 0.931 | 3.67 | 9.12 |
| III | 0.00277 | 324 | 0.085 | 2.71 | 0.0136 | 0.534 | 1.33 |
| IV | 0.00323 | 19044 | 0.600 | 136.5 | 6.82 | 26.9 | 66.9 |
| | | | 0.867 | | | | |

$T_{25} = 0.050$, $T_{50} = 0.197$, $T_{75} = 0.490$

$(4.32 \times 10^4)$ = Minutes/Month



*Method B2*
*Figure 4-C*

## TABLE 5-C

## METHOD C2

| Core No. | $h_f$ | $t_{90}$ | $\frac{t_{90}h_f}{h_f \text{ for Unit}}$ | $h_L$ | $\frac{h_L h_f}{h_f \text{ for Unit}}$ |
|---|---|---|---|---|---|
| 61 | 3 | 1.96 | 1.96 | 0.9912 | 0.9912 |
| Unit I | 3 | | 1.96 | | 0.9912 |
| 64 | 6 | 115.56 | 115.56 | 0.9841 | 0.9841 |
| Unit II | 6 | | 115.56 | | 0.9841 |
| 68 | 3 | 51.84 | 51.84 | 0.9796 | 0.9796 |
| Unit III | 3 | | 51.84 | | 0.9796 |
| 70 | 2 | 102.01 | 8.87 | 0.9423 | 0.0820 |
| 71 | 3 | 72.25 | 9.42 | 0.9777 | 0.1275 |
| 72 | 3 | 34.81 | 4.54 | 0.9446 | 0.1232 |
| 73 | 3 | 90.25 | 11.77 | 0.9455 | 0.1233 |
| 74 | 12 | 8.41 | 4.39 | 0.9900 | 0.5165 |
| Unit IV | 23 | | 38.99 | | 0.9725 |

## CALCULATIONS FOR $C_v$

| Unit No. | T | $H_L^2$ | $t_L$ | $C_v$ |
|---|---|---|---|---|
| I | 0.848 | 0.247 | 1.96 | 0.107 |
| II | 0.848 | 0.242 | 115.56 | 0.00178 |
| III | 0.848 | 0.242 | 51.84 | 0.00396 |
| IV | 0.848 | 0.236 | 38.99 | 0.00513 |

## TABLE 5-C (CONTINUED)

### METHOD C2
### CALCULATIONS FOR $C_v$ (CONTINUED)

| Unit No. | $C_v$ | $H_f^2$ | ΔH(ft.) | $k=\dfrac{H_f^2}{C_v(4.32x10^4)}$ | $t_{25}$ | $t_{50}$ | $t_{75}$ | $t_{90}$ |
|---|---|---|---|---|---|---|---|---|
| I | 0.107 | 324 | 0.018 | 0.0701 | 0.0035 | 0.0138 | 0.0344 | 0.0595 |
| II | 0.00178 | 1,296 | 0.393 | 16.82 | 0.84 | 3.32 | 8.25 | 14.28 |
| III | 0.00396 | 324 | 0.085 | 1.89 | 0.094 | 0.37 | 0.96 | 1.60 |
| IV | 0.00513 | 19,044 | 0.602 | 86.0 | 4.30 | 16.9 | 42.1 | 72.9 |
|  |  |  | 1.098 |  |  |  |  |  |

$T_{25} = 0.050$, $T_{50} = 0.197$, $T_{75} = 0.490$, $T_{90} = 0.848$

## TABLE 5-C (CONTINUED)

## USING SECONDARY CONSOLIDATION

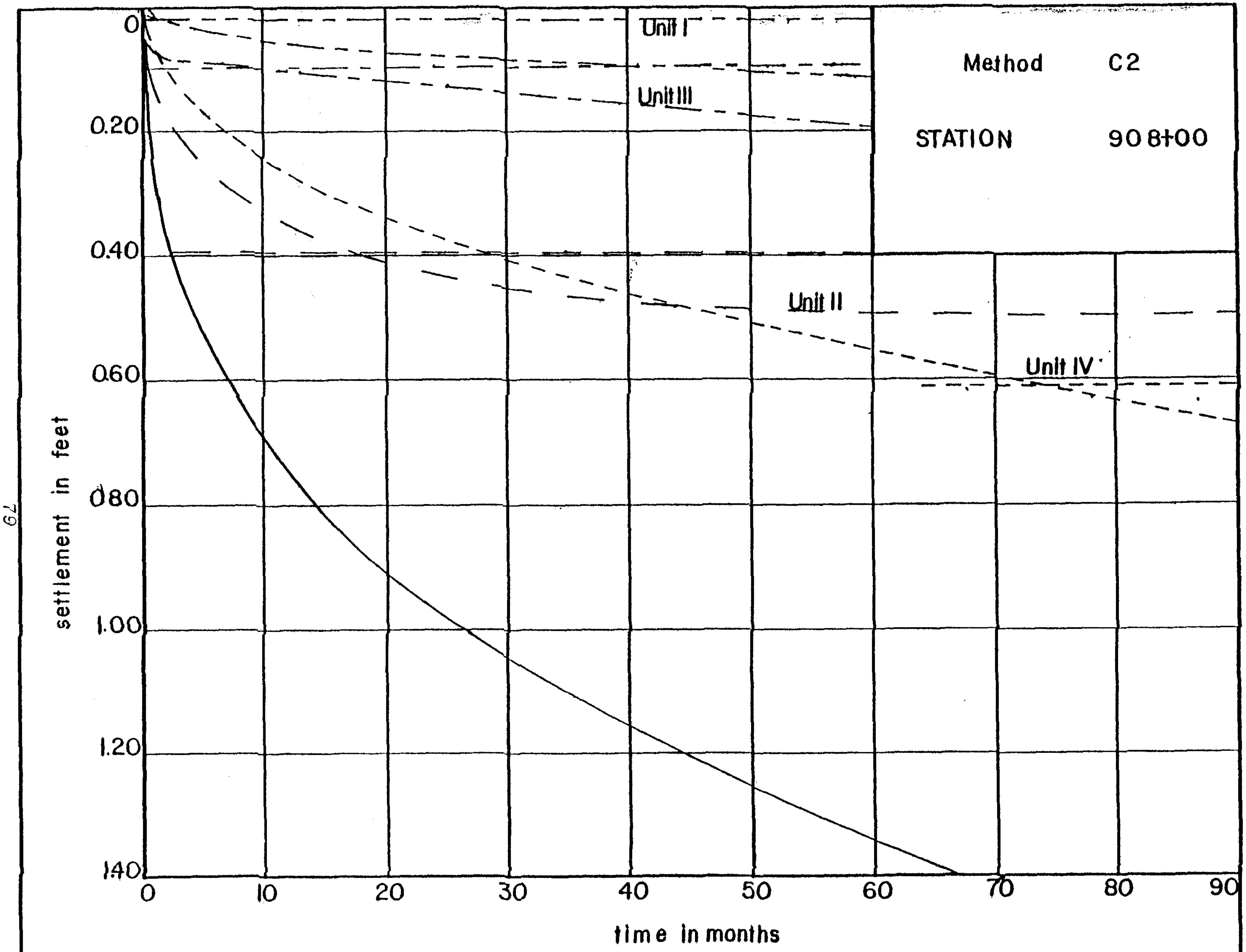
| Core No. | $h_f$ | $h_L$ | $\frac{h_L h_f}{h_f \text{ for Unit}}$ | $t_{L(\text{secondary})}$ | $\frac{t_{L(\text{secondary})} h_f}{h_f \text{ for Unit}}$ |
|---|---|---|---|---|---|
| 61 | 3 | 0.9912 | 0.9912 | 5.22 | 5.22 |
| Unit I | 3 | | 0.9912 | | 5.22 |
| 64 | 6 | 0.9841 | 0.9841 | 108.36 | 108.36 |
| Unit II | 6 | | 0.9841 | | 108.36 |
| 68 | 3 | 0.9796 | 0.9796 | 9.00 | 9.00 |
| Unit III | 3 | | 0.9796 | | 9.00 |
| 70 | 2 | 0.9423 | 0.0820 | 21.20 | 1.84 |
| 71 | 3 | 0.9777 | 0.1275 | 35.91 | 4.68 |
| 72 | 3 | 0.9446 | 0.1231 | 5.51 | 0.72 |
| 73 | 3 | 0.9455 | 0.1232 | 30.75 | 4.01 |
| 74 | 12 | 0.9900 | 0.5220 | 10.51 | 5.49 |
| Unit IV | 23 | | 0.9778 | | 16.74 |

| Unit | $H_f$(ft.) | $H_L$(in.) | $\Delta H_L$(in.) | $\Delta H_f$(in.) | $\Delta H_f$(ft.) |
|---|---|---|---|---|---|
| I | 18 | 0.9912 | 0.001 | 0.218 | 0.0182 |
| II | 36 | 0.9841 | 0.001 | 0.439 | 0.0366 |
| III | 18 | 0.9796 | 0.001 | 0.221 | 0.0184 |
| IV | 138 | 0.9778 | 0.001 | 0.169 | 0.141 |

$$\Delta H_f = \Delta H_L \left(\frac{H_f}{H_L}\right)$$

| Unit | $H_f$(ft.) | $H_L$(in.) | $t_{L(\text{secondary})}$ | $t_{f(\text{secondary})}$ |
|---|---|---|---|---|
| I | 18 | 0.9912 | 5.22 | 5.74 |
| II | 36 | 0.9841 | 108.36 | 4.84 |
| III | 18 | 0.9796 | 9.00 | 10.2 |
| IV | 138 | 0.9778 | 16.74 | 11.1 |

$$t_{f(\text{secondary})} = \frac{t_{L(\text{secondary})}}{4.32 \times 10^4} \left(\frac{H_f}{H_L}\right)^2$$



Method C2
FIGURE 5-C