David Sego

THE UNIVERSITY OF ALBERTA

COMPARISON OF CONSOLIDATION ANALYSES
FOR FILL ON VERY SOFT DEPOSITS

BY

LUDMILA STEPANEK

A RESEARCH PROJECT REPORT

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

AND RESEARCH IN PARTIAL FULFILLMENT OF THE

REQUIREMENT FOR THE DEGREE OF

MASTER OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

DECEMBER 1984

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a research project report entitled COMPARISON OF CONSOLIDATION ANALYSES FOR FILL ON VERY SOFT DEPOSITS, submitted by Ludmila Stepanek in partial fulfilment of the requirements for the degree of Master of Engineering.

____

Dr. Z. Eisenstein, Supervisor

____

Dr. S. Thomson

Date______________________

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

This report compares two methods of calculating the consolidation settlement of highly compressible submerged clay deposits subjected to a free draining surcharge. As shown by Baligh and Fuleihan (1978) settlements of 0.9 to 1.2 m occurred in a layer of clay 30.5 m thick on which was placed a 3.0 m layer of sand. Under these conditions the conventional Terzaghi (1943) method of predicting the magnitude and progress of settlement is inappropriate, because of its assumption of small strains.

The two methods that are being compared have been put forward by Baligh and Fuleihan (op. cit.), and by Eisenstein and Sandroni (1979) respectively. These methods modify the conventional Terzaghi's theory of consolidation by taking into account the changes in the magnitude of the imposed load as the fill sinks below the water level and the changes in the length of the drainage path. The practical importance of these analyses is in the prediction of the magnitude and the time rate of settlement of reclamation fills placed over lacustrine deposits in coastal lagoons and estuarine deposits.

CONVENTIONAL ANALYSIS

The classical Terzaghi's one-dimensional consolidation theory for saturated clays has been found to generally overestimate the time of consolidation. This theory is based on the following set of simplifying assumptions, regarding material properties and the dimensionality of compression (Terzaghi, op. cit.). These assumptions, in reality only approximately satisfied, are:

1. The soil is saturated.
2. The water and soil constituents are incompressible.
3. Darcy's law is valid.
4. The coefficient of permeability (k) is constant.
5. The time lag during consolidation is only due to low permeability of the soil.
6. The strains of the soil skeleton are controlled by a linear time dependent relationship (m_v is independent of strain).
7. The soil skeleton is homogeneous.
8. The strains, velocities and stress increments are small, and the theory is quasi-static.
9. Secondary compression is neglected.
10. The surcharge load is applied rapidly.

For the soil conditions considered in this paper, it is assumption (8) that is not complied with. The other assumptions are retained and are assumed to be valid. The final settlements of these normally consolidated, highly compressible soft clay deposits are large, and therefore the changes in the vertical stress are large. Consequently the thickness of these clay layers is considered a variable rather than a constant. The problem then becomes one of a moving boundary.

During consolidation,the settlement of the soil layer is governed by the vertical strains generated by an increment of loading. In the conventioanl analysis, for each layer i, the magnitude of the settlement is calculated as follows

$$p = \sum_i m_v H_i \Delta\sigma_i \tag{1}$$

The governing field equation for the time rate of consolidation settlement, due to time-independent loading, is

$$C_v \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} \tag{2}$$

The solution to equation (2) is usually given in the form of

$$u = f(T) \tag{3}$$

where

$$T = C_v \frac{t}{(H_o/2)^2} \tag{4}$$

These two separated parts of the analysis are connected by the assumption that the developed strains are related to the corresponding excess pore pressure. That is

$$\Delta\sigma_i{}' = \sigma - \Delta u_i \tag{5}$$

SOIL CONDITIONS

A schematic diagram of the soil and loading conditions is shown in Figure 1. A highly compressible, soft clay deposit, with an initial height H_o, is overlaying a free draining and incompressible stratum. On this clay layer is instantaneously placed an incompressible sand fill with a thickness H_f. The water level is above the top of the clay, and remains constant due to the external environment.

David Segu

During consolidation the thickness of the clay layer decreases, the sand fill becomes increasingly more submerged and the lenght of the drainage path increases. This settlement is large compared to the initial height of the clay stratum.

ANALYSIS ACCORDING TO EISENSTEIN AND SANDRONI

Eisenstein and Sandroni (op. cit.) analysis is briefly summarized below. Only the main equations are noted. Their derivations can be found in reference 3. A schematic diagram of the soil conditions is shown in Figure 1.

The aim of this analysis is to evaluate the amount of fill that will be required to obtain a specified final elevation. The total height of required fill is

$$H_f = H_s + H_d + p_f \qquad (6)$$

The time rate of consolidation will be analysed for the height of fill H_f.

1. Change in Load

The change in load due to submergence of the sand fill is taken into account by considering the amount of water that is squeezed out during consolidation. The total stresses at the top and bottom of the clay layer are calculated. The average change in load across the consolidation layer then is

$$\Delta\sigma_p = \tfrac{1}{2}(\Delta\sigma_{tp} + \Delta\sigma_{bp}) = \tfrac{1}{2}p_t(\gamma_s - \gamma_d - \gamma_w + \gamma_s - \gamma_d) \quad (7)$$
$$= p_t(\gamma_s - \gamma_d - \gamma_w/2)$$

2. Change in Thickness

The change in thickness of the clay layer during consolidation is expressed as

$$H = H_o - P_t \quad (8)$$

The settlement of the layer is calculated using Terzaghi's equation

$$p = H_o m_v \Delta\sigma' \quad (9)$$

3. Modification of Settlement Calculation

The initial and final effective stresses in the middle of the consolidating layer are calculated. The decrease in the thickness of the consolidating layer is taken into consideration by using equation (8) in the evaluation of the final effective stress. The initial effective stress is calculated based on the soil conditions prior to the placement of fill. The average effective stress change is then obtained using

$$\Delta\sigma'_f = \sigma'_f - \sigma'_i \qquad (10)$$

then

$$\Delta\sigma'_f = H_s(\gamma_s - \gamma_w) + H_d\gamma_d + p_f(\gamma_s - \gamma_w) \qquad (11)$$

By rearranging this equation together with equation (9) the final settlement is

$$p_f = \frac{H_o m_v[H_s(\gamma_s - \gamma_w) + H_d\gamma_d]}{1 - H_o m_v(\gamma_s - \gamma_w)} \qquad (12)$$

4. Modification of Consolidation Theory

The change in load during consolidation is taken into account by modifying the Terzaghi field equation according to Gibson (1958).

$$C_v\frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} - \bar{B}\frac{\partial\sigma}{\partial t} \qquad (13)$$

where $\bar{B}$ is a pore pressure coefficient defined by Bishop (1954). By using equation (9) p is established. Then by substituting equation (7) and the p term into equation (13) and rearranging, the following is obtained

$$C_v\frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t}\left[1 - \bar{B}\frac{H_o m_v(\gamma_s - \gamma_d - \gamma_w/2)}{H_o m_v(\gamma_s - \gamma_d - \gamma_w/2) - 1}\right] \qquad (14)$$

A modified coefficient of consolidation (C_v*) is introduced

$$C_v^* = \frac{C_v}{1 - \bar{B}\dfrac{H_o m_v(\gamma_s - \gamma_d - \gamma_w/2)}{H_o m_v(\gamma_s - \gamma_d - \gamma_w/2) - 1}} \qquad (15)$$

The conventional Terzaghi's field equation is then retained using the modified coefficient of consolidation.

$$C_v^* \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} \qquad (16)$$

The modified time factor T* then is

$$T^* = C_v^* \frac{t}{(H_o/2 - p_t/2)^2} \qquad (17)$$

It is used in evaluating the progress of consolidation with time. However since T* is a function of settlement it has to be reevaluated during the consolidation calculations as the magnitude of settlement changes.

The computation procedure for this method of analysing consolidation settlement is shown in the examples.

ANALYSIS ACCORDING TO BALIGH AND FULEIHAN

Baligh and Fuleihan (op. cit.) consider the effects of large settlements by means of a small strain one dimensional theory. Their analysis is briefly summarized below. Only the final equations are noted. Their derivations can be found in reference 1. A schematic diagram of the site conditions is shown in Figure 1.

1. Modification of Settlement Calculation

The authors introduce two parameters, β and C where

$$\beta = 1 - (\gamma_s - \gamma_d)/\gamma_w = 1 - n(1 - S) \tag{18}$$

and

$$C = m_v H_o \gamma_w \tag{19}$$

the parameter β deals with the properties of the fill, while parameter C measures the flexibility of the consolidating clay layer.

Using β and C the consolidation settlement equation is modified as follows

$$p_f = \frac{C}{1 + \beta C} \frac{\Delta q}{\gamma_w} \tag{20}$$

When C is small, such that $C << 1$, the settlement equation (20) reduces to the classical Terzaghi equation.

2. Modification of Consolidation Theory

Terzaghi's field equation (3) is modified to take into account the settlement effect. The resulting expression is

$$C_v \frac{\partial^2 h}{\partial z^2} = \frac{\partial h}{\partial t} - \frac{\beta C}{1 + \beta C} \frac{1}{H_o} \int_0^{H_o} \frac{\partial h}{\partial t}\, dz \tag{21}$$

This linear integro-differential equation reduces to the classical Terzaghi's equation when the flexibility parameter C is negligible.

Equation (21) is solved by converting it to a normalized equation and then using the perturbation method. The following boundary conditions apply

$$t = 0^+ \qquad h(z,0) = \frac{\Delta q}{\gamma_w} + H_w$$

$$z = 0 \qquad h(0,t) = H_w$$

$$z = H_o \qquad h(H_o,t) = H_w$$

The terms in the expansion are as follows

$$W_o = 2\sum_{n=1,3,5}^{\infty} \frac{1}{n'} \exp(-n'^2 T)\sin(n'Z) \tag{22}$$

$$\bar{W}_o = 2\sum_{n=1,3,5}^{\infty} \frac{1}{n'} \exp(-n'^2 T) \tag{23}$$

$$W_1 = -4\sum_{n=1,3,5}^{\infty} \frac{1}{n'} \exp(-n'^2 T)[T + \sum_{\substack{m=1,3,5\\ n\neq m}}^{\infty} \frac{\exp(n'^2 - m'^2)T - 1]}{n'^2 - m'^2} \sin(n'Z) \tag{24}$$

$$\bar{W}_1 = -4\sum_{n=1,3,5}^{\infty} \frac{1}{n'} \exp(-n'^2 T)[T + \sum_{\substack{m=1,3,5\\ n\neq m}}^{\infty} \frac{\exp(n'^2 - m'^2)T - 1]}{n'^2 - m'^2} \tag{25}$$

where

$$n' = n\pi/2 \qquad m' = m\pi/2$$

both n and m consist of odd integers only.

and

$$Z = \frac{z}{H_o/2} \qquad T = \frac{C_v t}{(H_o/2)^2}$$

To obtain the total excess head at time t

$$\Delta h = \frac{\Delta q}{\gamma_w}[W_o(Z,T) + \frac{\beta C}{1 + \beta C} W_1(Z,T)] \tag{26}$$

The term W_o corresponds to Terzaghi's solution and W_1 is a modifying factor for the changes in stress.

The degree of consolidation is given by

$$\bar{U}(T) = 1 - \bar{W}_o(T) - \frac{\beta C}{1 + \beta C}\bar{W}_1(Z) \tag{27}$$

or

$$\bar{U}(T) = \bar{U}(T)_{Terzaghi} - \frac{\beta C}{1 + \beta C}\bar{W}_1(T) \tag{28}$$

The computation procedure is shown in the following examples.

EXAMPLES

Two typical examples are presented to illustrate and compare the proposed methods of evaluating consolidation of soft clays.

EXAMPLE 1

This example is taken out of Baligh and Fuleihan's paper. The relevant soil properties are listed below and the soil conditions are shown in Figure 2.

Properties of the clay:

$C_v = 8.0 \times 10^{-4}\ cm^2/s$

$m_v = 2.23 \times 10^{-6}\ m^2/N$

$= 0.223\ cm^2/kg$

Properties of the sand fill:

$\gamma_s = 2.0\ g/cm^3$

$\gamma_d = 1.84\ g/cm^3$

$S = 0.25$

$n = 0.333$

$\Delta q = 0.886\ kg/cm^2$

1. Terzaghi's Method

Time factor:

$$T = \frac{C_v t}{(H_o/2)^2}$$

$$= \frac{(8.0 \times 10^{-4})(3600)(24)t}{(1830/2)^2} = 8.26 \times 10^{-5}\ t/day$$

Degree of Consolidation:

for $0 < \bar{U} < 50\%$ $\quad \bar{U} = \frac{2}{\sqrt{\pi}} \sqrt{\frac{C_v t}{(H_o/2)^2}}$ (29)

for $\bar{U} > 50\%$ $\quad \bar{U} = 1 - \frac{8}{\pi^2} \exp(-\pi^2 T/4)$ (30)

Final total settlement:

$\rho_f = m_v \bar{H}_o \Delta q$

$\Delta q = 305(0.002 - 0.001) + 305(0.00184)$

$= 0.866\ kg/cm^2$

$\rho_f = (0.223)(1830)(0.866) = 353.41\ cm$

The results of the Terzaghi's analysis are summarized in Table 1 and shown in Figure 3.

2. Eisenstein and Sandroni's Method

Final total settlement:

In order to evaluate the final settlement it is necessary to know H_d. Since H_f and H_s are known, H_d can be obtained by substituting equation (6) into equation (12).

$$p_f = \frac{(1830)(0.223)[305(0.001) + 0.00184H_d]}{1 - (1830)(0.223)(0.001)}$$

$$= 689.45[0.305 + 0.00184H_d]$$

and using equation (6)

$$H_f = H_s + H_d + p_f \quad \text{then} \quad 610 = 305 + H_d + p_f$$

then $$p_f = 689.45[0.305 + 0.00184(305 - p_f)]$$

solving for p_f and H_d we get $p_f = 263.3$ cm

$H_d = 41.7$ cm

First iteration:

The following calculations are shown in Table 2.

The time factor and the degree of consolidation are calculated using Terzaghi's analysis. The settlement at time t is calculated using the modified p_f, as obtained above. That is

$$p_t = \bar{U}\% \; p_f$$

Second iteration:

The modified time factor T* and coefficient of consolidation C_v* are calculated. Using equation (15)

$$C_v^* = 9.11 \times 10^{-4} \text{ cm/s}$$

The pore pressure coefficient $\bar{B}$ is assumed to equal one, then using equation (17)

$$T^* = \frac{9.11 \times 10^{-4} t}{\left(\frac{1830 - p_t}{2}\right)^2}$$

The degree of consolidation $\bar{U}$* is evaluated using equations (29) and (30) together with the modified time factor and the coefficient of consolidation.

Third iteration:

The modified time factor is calculated using p_t obtained in the second iteration. A new value for the degree of consolidation and the amount of settlement at time t is determined.

Since the change in the degree of consolidation between the second and the third iterations is negligible another iteration is not necessary.

The final iteration is presented in Table 1 and shown in Figure 3.

3. Baligh and Fuleihan's Method

Modifying parameters:

$$C = (0.223)(1830)(0.001) = 0.40$$

$$\beta = 1 - 0.333(1 - 0.25) = 0.75$$

and $\beta C = 0.30$

Final total settlement, using equation (20):

$$\rho_f = \frac{0.4}{1 + 0.30}\,\frac{0.866}{0.001} = 266.46 \text{ cm}$$

Degree of consolidation, using equation (28):

$$\bar{U} = \bar{U}_{Terzaghi} - \frac{0.30}{1 + 0.30}\,\bar{W}_1$$

The values obtained using the above equation and the amount of settlement at time t are summarized in Table 1 and shown in Figure 3.

EXAMPLE 2

This example is taken out of Eisenstein and Sandroni's paper (op. cit.). The relevant soil properties are listed below and the soil conditions are shown in Figure 4.

Properties of the clay:

$$C_v = 0.01 \text{ cm}^2/\text{s}$$

$$m_v = 0.5 \text{ cm}^2/\text{kg}$$

Properties of the sand fill:

$\gamma_s = 2.05\ g/cm^3$

$\gamma_d = 1.75\ g/cm^3$

$S = 0.25$ (assumed)

$n = 0.30$

$\Delta q = 0.796\ kg/cm^2$

1. Terzaghi's Method

Time factor:

$$T = \frac{(0.01)(3600)(24)t}{(1000/2)^2} = 3.46 \times 10^{-3}\ t/day$$

Degree of Consolidation:

$$\text{for } 0 < \bar{U} < 50\% \quad \bar{U} = \frac{2}{\sqrt{\pi}} \sqrt{\frac{C_v t}{(H_o/2)^2}} \qquad (29)$$

$$\text{for } \bar{U} > 50\% \quad \bar{U} = 1 - \frac{8}{\pi^2} \exp(-\pi^2 T/4) \qquad (30)$$

Final total settlement:

$$p_f = m_v H_o \Delta q$$

$$\Delta q = 100(0.00205 - 0.001) + (1000 + 495 - 1100)0.00175$$

$$= 0.796\ kg/cm^2$$

$$p_f = (0.5)(1000)(0.796) = 398\ cm$$

The results of the Terzaghi's analysis are summarized in Table 3 and shown in Figure 5.

2. Eisenstein and Sandroni's Method

Final total settlement, using equation (12):

$$\rho_f = \frac{(1000)(0.5)[100(0.00205 - 0.001) + 100(0.00175)]}{1 - 1000(0.5)(0.00205 - 0.001)}$$

$$= 294.74 \text{ cm}$$

then using equation (6)

$$H_f = 100 + 100 + 294.7 = 494.7 \text{ cm}$$

First iteration:

The following calculations are shown in Table 4.

The time factor and the degree of consolidation are calculated using Terzaghi's analysis. The settlement at time t is calculated using the modified ρ_f, as obtained above. That is

$$\rho_t = \bar{U}\% \rho_f$$

Second and third iterations:

The modified time factor T* and coefficient of consolidation C_v* are calculated. Using equation (15)

$$C_v^* = 0.011 \text{ cm/s}$$

The pore pressure coefficient $\bar{B}$ is assumed to equal one. Then using equation (17)

$$T^* = \frac{0.011\ t}{\left(\frac{1000 - p_t}{2}\right)^2}$$

The degree of consolidation $\bar{U}^*$ is evaluated using equations (29) and (30) together with the modified time factor and the coefficient of consolidation. The amount of settlement at time t is determined.

Since the change in the degree of consolidation between the second and the third iterations is negligible another iteration is not necessary.

The final iteration is presented in Table 3 and shown in Figure 5.

3. Baligh and Fuleihan's Method

Modifying parameters:

$$C = (0.5)(1000)(0.001) = 0.50$$

$$\beta = 1 - 0.30(1 - 0.25) = 0.78$$

and $\beta C = 0.39$

Final total settlement, using equation (20):

$$p_f = \frac{0.50}{1 + 0.39} \frac{0.796}{0.001} = 286.3 \text{ cm}$$

Degree of consolidation, using equation (28):

$$\bar{U} = \bar{U}_{Terzaghi} - \frac{0.39}{1 + 0.39} \bar{W}_1$$

The values obtained using the above equation and the amount of settlement at time t are summarized in Table 3 and shown in Figure 5.

DISCUSSION

The two methods that are compared in this report are only applicable to cases where the water table is and remains, during consolidation, within the fill layer. Once the fill sinks below the water table the classical Terzaghi solution would be used.

Both of these methods, of analysing consolidation settlements of soft compressible clay deposits, provide basically the same results. This is shown by the degree of consolidation graphs in Figures 3 and 5 and in Tables 1 and 3. The maximum difference in the degree of consolidation is 4% in example 1 and 10% in example 2, while there is only a 1.2% and 2.9% difference, respectively, in the final settlement values. These analyses predict a faster time rate of consolidation than that predicted by Terzaghi's analyses. There also is a decrease of one third in the final settlement values.

The method proposed by Eisenstein and Sandroni is simple to use since it utilizes Terzaghi's classical field equation.

The degree of consolidation and the time factor have been modified but the rest of the analysis has retained the shape of the field equation. Therefore the solutions that have been worked out for many common situations are applicable.

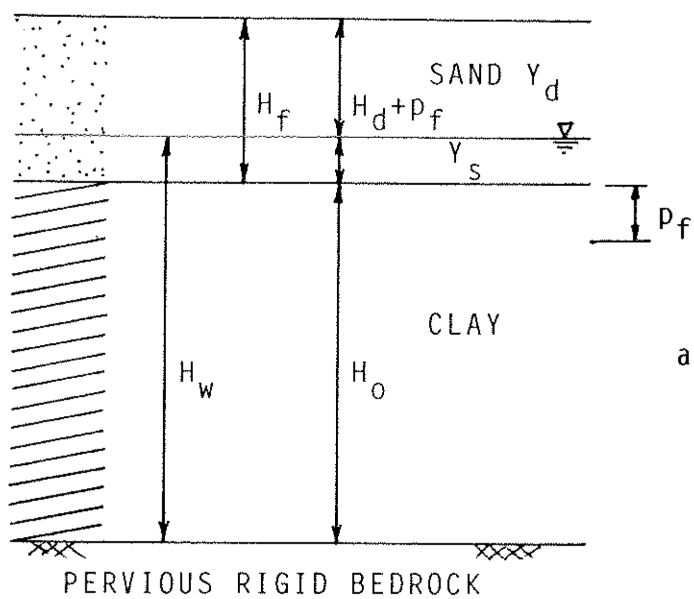
The analysis proposed by Baligh and Fuleihan is more difficult to use. This analysis establishes a new integro-differential equation, whose evaluation is time consuming. If large size graphs were available of the solutions, then this method would be relatively easy to use. This analysis also requires that the degree of saturation of the fill be known. This value is not needed in Eisenstein and Sandroni's analysis.

Eisenstein and Sandroni's analysis provides solutions to consolidation cases where the final desired ground elevation is known, such as during reclamation projects. If only the amount of fill that has been placed is known, such as during preloading, then Baligh and Fuleihan's analysis is more appropriate. If the former analysis is used, the amount of fill that will be above the water table at 100% consolidation must be estimated and calculated by a trial and error method, as seen in example 1. Should Baligh and Fuleihan's analysis be used for a reclamation project then the amount of fill that would be required to obtain a final ground elevation would have to be calculated by a trial and error method.

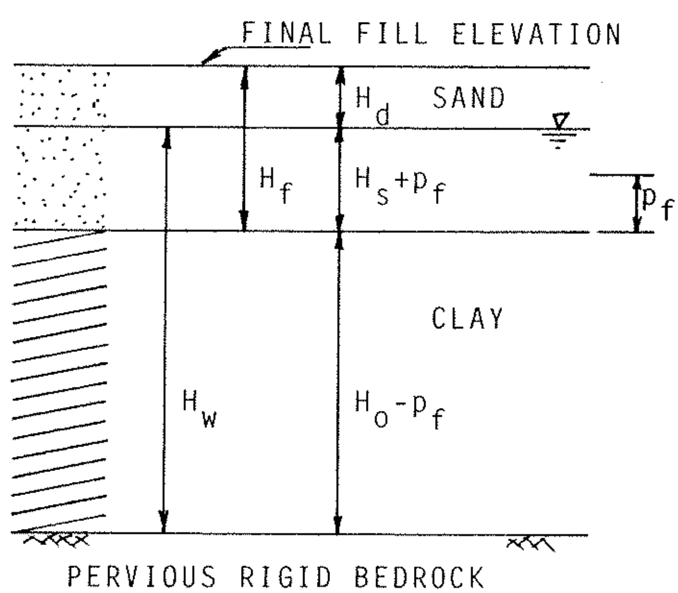
Both of the methods compared in this report provide similar results. However since field data were not available to compare these methods to, it is not known whether they accurately represent actual field conditions. It would be very usefull to carry out a comparison with field data.

ACKNOWLEDGEMENT

The valuable assistance and guidance provided by Dr. Z. Eisenstein throughout this work was greatly appreciated.



a. Immediately after surcharge application



b. After consolidation

FIGURE 1. Schematic Diagram of Soil Conditions

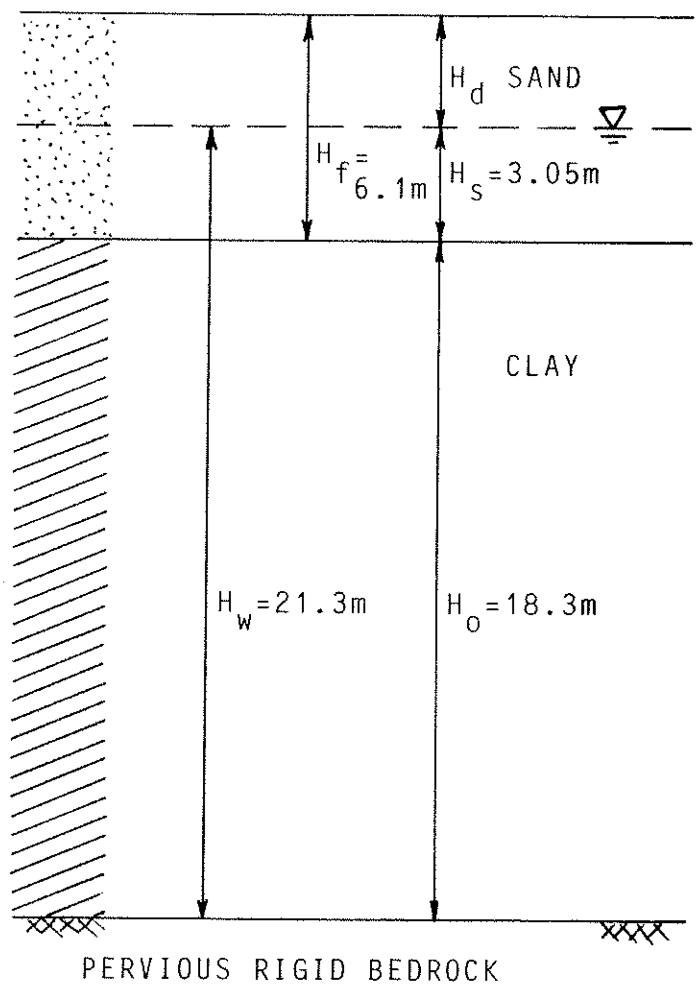


FIGURE 2. Soil Conditions for Example 1

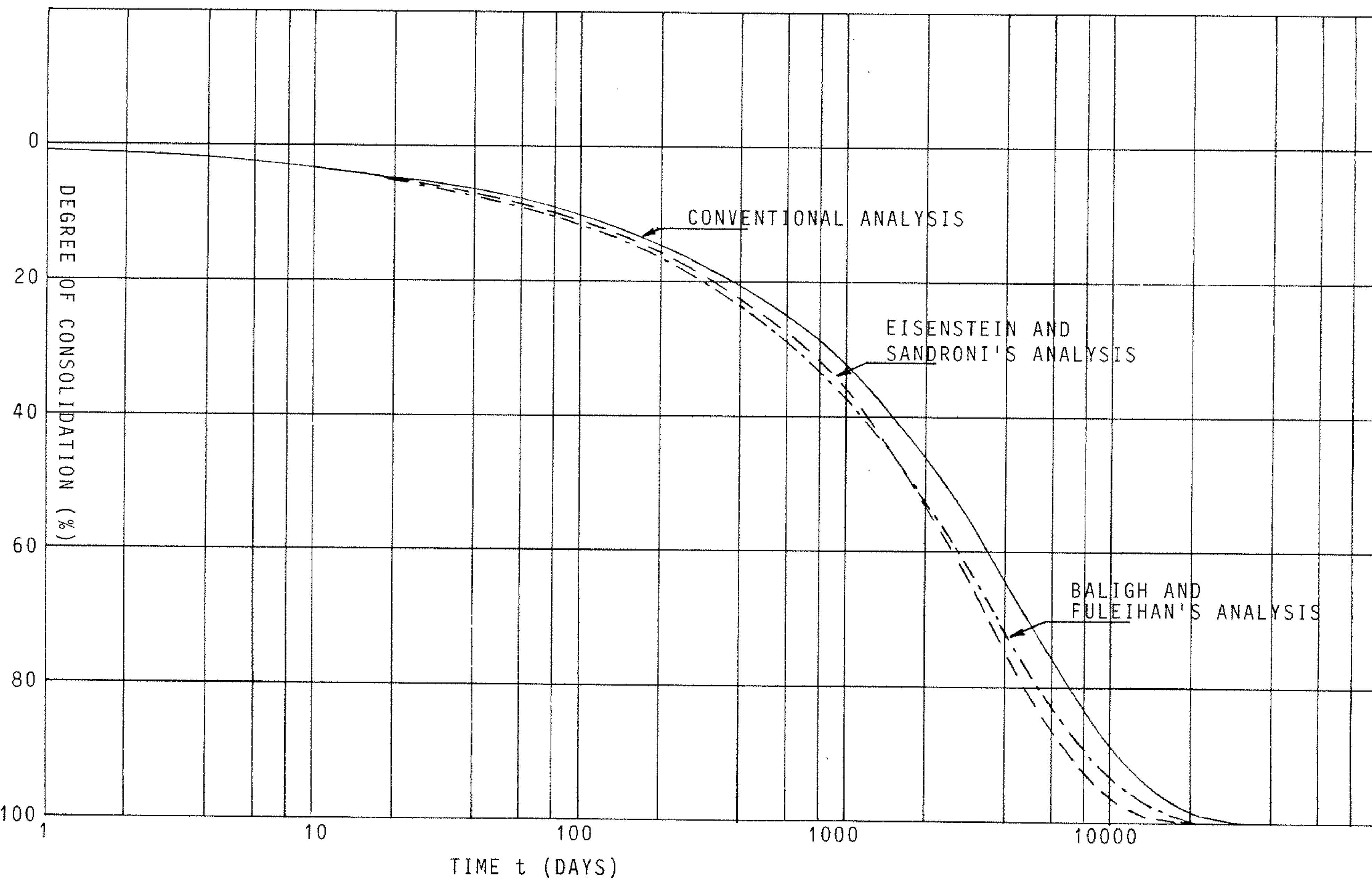
TABLE 1 Example 1 - Comparison of Consolidation Calculations

time t (days)	1	2	5	10	20	50	100	200	500	1825	3650	7300	18250	36500
Terzaghi's Analysis														
Time Factor T	0.00008	0.00017	0.00041	0.00083	0.00165	0.00413	0.00826	0.01651	0.04128	0.15067	0.30134	0.60268	1.5066	3.01338
Deg. of consol. $\bar{U}$%	1.0	1.5	2.3	3.3	4.6	7.3	10.3	14.5	22.9	43.8	61.5	81.7	98.0	100
p_t (cm) = $\bar{U}$% p_f	3.5	5.3	8.1	11.7	16.3	25.8	36.4	51.3	81.0	154.8	217.4	288.8	346.4	353.5
Eisenstein and Sandroni's Analysis														
Mod. Time Factor T*	0.00009	0.00019	0.00047	0.00095	0.00191	0.00481	0.00971	0.01969	0.05062	0.19915	0.42529	0.90809	2.33851	4.68180
Mod. Deg. of Consol. $\bar{U}$%	1.1	1.6	2.4	3.5	4.9	7.8	11.1	15.8	25.4	50.4	71.6	91.4	99.7	100
p_t (cm) = $\bar{U}$% p_f	2.9	4.2	6.3	9.2	12.9	20.5	29.2	41.6	66.9	132.7	188.5	240.7	262.5	263.3
Baligh and Fuleihan's Analysis														
Mod. Factor $\bar{W}_1$	-0.0007	-0.0013	-0.004	-0.009	-0.017	-0.033	-0.058	-0.093	-0.161	-0.264	-0.302	-0.254	-0.063	-0.003
Mod. Deg. of Consol. $\bar{U}$%	1.0	1.5	2.4	3.5	5.0	8.1	11.6	16.6	26.6	49.9	68.5	87.6	99.5	100
p_t (cm) = $\bar{U}$% p_f	2.7	4.1	6.4	9.3	13.3	21.5	31.0	44.4	70.9	132.9	182.4	233.3	265.0	266.5

TABLE 2 Example 1 - Eisenstein and Sandroni's Analysis

time t (days)	1	2	5	10	20	50	100	200	500	1825	3650	7300	18250	36500
First Iteration														
Time Factor T	0.00008	0.00017	0.00041	0.00083	0.00165	0.00413	0.00826	0.01651	0.04128	0.15067	0.30134	0.60268	1.50669	3.01338
Deg. of Consol. $\bar{U}\%$	1.0	1.5	2.3	3.3	4.6	7.3	10.3	14.5	22.9	43.8	61.5	81.7	98.0	100
p_t (cm) $= \bar{U}\% \, p_f$	2.6	3.9	6.1	8.7	12.1	19.2	27.1	38.2	60.3	115.3	161.9	215.1	258.0	263.3
Second Iteration														
Mod. Time Factor T*	0.00009	0.00019	0.00047	0.00095	0.00191	0.00480	0.00969	0.01961	0.05026	0.19542	0.41299	0.88130	2.3214	4.68180
Mod. Deg.of Consol. $\bar{U}\%$	1.1	1.6	2.4	3.5	4.9	7.8	11.1	15.8	25.3	49.9	70.7	90.8	99.7	100
p_t (cm) $= \bar{U}\% \, p_f$	2.9	4.2	6.3	9.2	12.9	20.5	29.2	41.6	66.6	131.4	186.2	239.1	262.5	263.3
Third Iteration														
Mod. Time Factor T*	0.00009	0.00019	0.00047	0.00095	0.00191	0.00481	0.00971	0.01969	0.05062	0.19915	0.42529	0.90809	2.33851	4.68180
Mod. Deg.of Consol. $\bar{U}\%$	1.1	1.6	2.4	3.5	4.9	7.8	11.1	15.8	25.4	50.4	71.6	91.4	99.7	100
p_t (cm) $= \bar{U}\% \, p_f$	2.9	4.2	6.3	9.2	12.9	20.5	29.2	41.6	66.9	132.7	188.5	240.7	262.5	263.3

FIGURE 3. Example 1 - Results of Consolidation Analyses



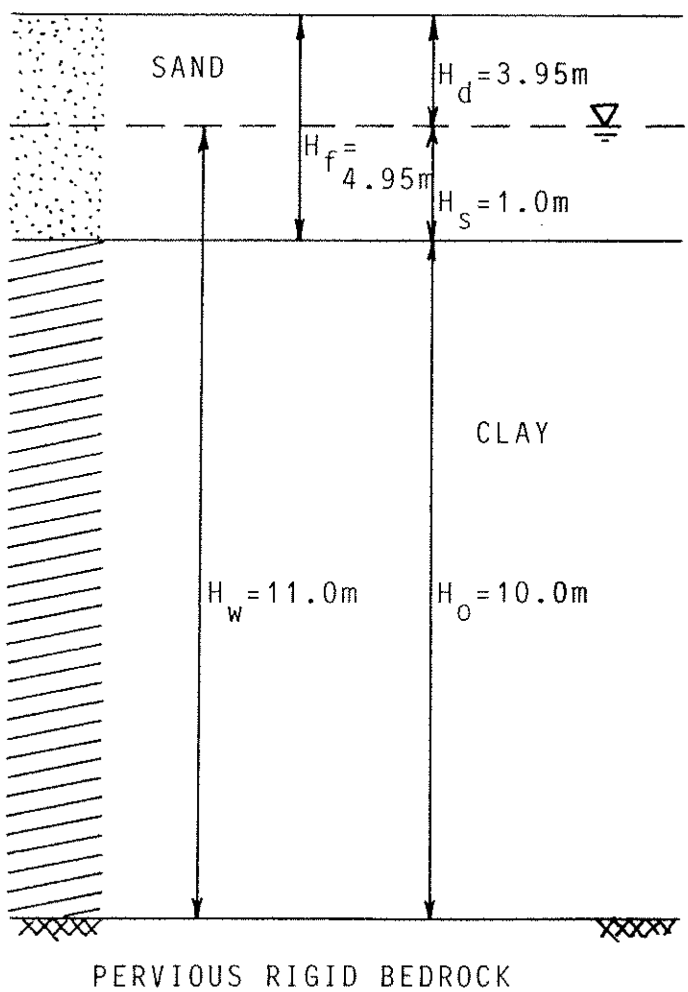


FIGURE 4. Soil Conditions for Example 2

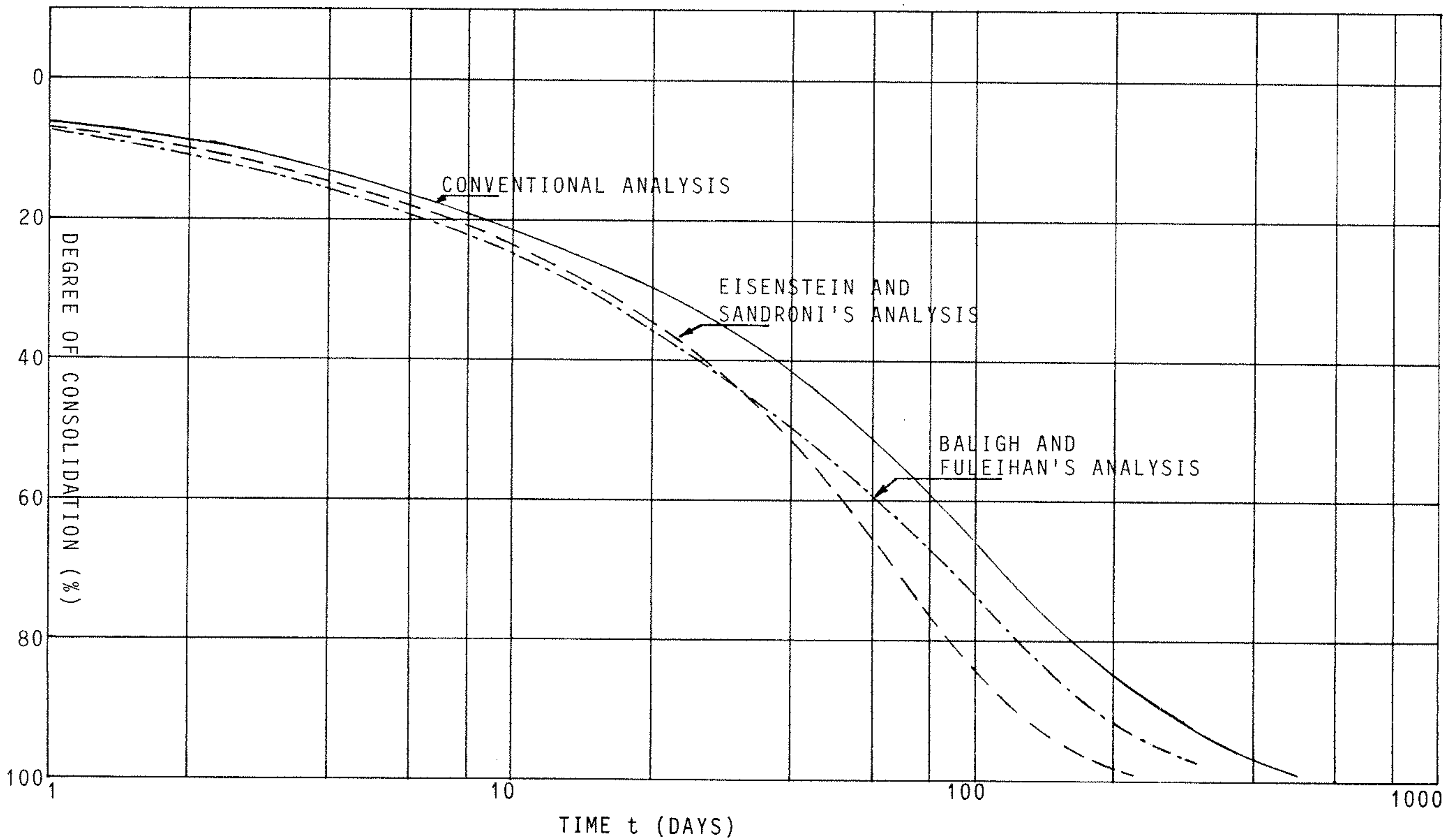
TABLE 3 Example 2 - Comparison of Consolidation Calculations

time t (days)	1	2	5	10	20	50	100	200	500
			Terzaghi's Analysis						
Time Factor T	0.00346	0.00691	0.01728	0.03456	0.06912	0.17280	0.34560	0.69120	1.72800
Deg. of Consol. $\bar{U}\%$	6.6	9.4	14.8	21.0	29.7	46.9	65.4	85.3	98.9
ρ_t (cm) $= \bar{U}\% \, \rho_f$	26.3	37.4	58.9	83.6	118.2	186.7	260.3	339.5	393.6
			Eisenstein and Sandroni's Analysis						
Mod. Time Factor T*	0.00397	0.00808	0.02097	0.04389	0.09397	0.27440	0.65489	1.49226	3.82110
Mod. Deg. of Consol. $\bar{U}\%$	7.1	10.1	16.3	23.6	34.6	58.8	83.9	98.0	~100
ρ_t (cm) $= \bar{U}\% \, \rho_f$	20.9	29.8	48.0	69.5	102.0	173.3	247.3	288.8	294.7
			Baligh and Fuleihan's Analysis						
Time Factor T	0.00346	0.00691	0.01728	0.03456	0.06912	0.17280	0.34560	0.69120	1.72800
Mod. Factor $\bar{W}_1$	-0.028	-0.050	-0.095	-0.142	-0.198	-0.274	-0.299	-0.229	-0.041
Deg. of Consol. $\bar{U}\%$	7.4	10.8	17.5	25.0	35.3	54.6	73.8	91.7	~100
ρ_t (cm) $= \bar{U}\% \, \rho_f$	21.1	30.9	50.0	71.5	100.9	156.3	211.3	262.6	286.3

TABLE 4 Example 2 - Eisenstein and Sandroni's Analysis

time t (days)	1	2	5	10	20	50	100	200	500
			First Iteration						
Time Factor T	0.00346	0.00691	0.01728	0.03456	0.06912	0.17280	0.34560	0.69120	1.72800
Deg. of Consol. $\bar{U}$%	6.6	9.4	14.8	21.0	29.7	46.9	65.4	85.3	98.9
p_t (cm) = $\bar{U}$% p_f	19.5	27.7	43.6	61.9	87.5	138.2	192.8	251.4	291.5
			Second Iteration						
Mod. Time Factor T*	0.00395	0.00804	0.02078	0.04320	0.09131	0.25591	0.58339	1.35660	3.78625
Mod. Deg. of Consol. $\bar{U}$%	7.1	10.1	16.3	23.5	34.1	56.9	80.8	97.1	100
p_t (cm) = $\bar{U}$% p_f	20.9	29.8	48.0	69.3	100.5	167.7	238.1	286.2	294.7
			Third Iteration						
Mod. Time Factor T*	0.00397	0.00808	0.02097	0.04389	0.09397	0.27440	0.65489	1.49226	3.82110
Mod. Deg. of Consol. $\bar{U}$%	7.1	10.1	16.3	23.6	34.6	58.8	83.9	98.0	100
p_t (cm) = $\bar{U}$% p_f	20.9	29.8	48.0	69.5	102.0	173.3	247.3	288.8	294.7

FIGURE 5. Example 2 - Results of Consolidation Analyses



LIST OF SYMBOLS

$\bar{B}$ pore pressure coefficient defined by Bishop (1954)

C flexibility parameter (Baligh and Fuleihan (op.cit.))

C_v coefficient of consolidation

H_d thickness of fill above the water table

H_f thickness of fill

H_i thickness of given layer i

H_o initial thickness of clay layer

H_s thickness of fill below the water table

H_w height of water level

h total head, sum of elevation and pressure heads

k coefficient of permeability

m_v coefficient of volume compressibility

n porosity

q surcharge load

S degree of saturation

T time factor

T^* modified time factor (Eisenstein and Sandroni (op.cit.))

t time

u pore pressure

$\bar{U}\%$ degree of consolidation

$W_1, \bar{W}_1, W_o, \bar{W}_o$ modifying factors (Baligh and Fuleihan (op.cit.))

z thickness of consolidating layer

β saturation parameter (Baligh and Fuleihan (op.cit.))

Δ increment

γ_d unit weight of fill

γ_s unit weight of submerged fill

γ_w unit weight of water

ρ_f final surface settlement

ρ_t settlement at time t

σ' effective stress

σ total stress

REFERENCES

1. Baligh, M.M. and Fuleihan,N.N., 1978. "Consolidation Theory with Stress Reduction Due to Settlement." Journal of the Geotechnical Engineering Division, ASCE, Vol. 104, No. GT5, pp. 519 - 534.

2. Bishop, A.W., 1954. "The use of pore pressure coefficients in practice." Geotechnique, 4, pp. 148 - 152.

3. Eisenstein, Z. and Sandroni, S.S., 1979. "Settlement Analysis for a Reclamation Fill on Very Soft Deposits." Proceedings of the 32nd Canadian Geotechnical Conference, Quebec, P.Q., pp. 3.104 - 3.114.

4. Gibson, R.E., 1958. "The Progress of Consolidation in a Clay Layer Increasing in Thickness with Time." Geotechnique, 8, pp. 171 - 182.

5. Schiffman, R.L., Chen, A.T-F. and Jordan, J.C., 1969. "An Analysis of Consolidation Theories." Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 95, No. SM1, pp. 285 - 312.

6. Terzaghi,K., 1943. Theoretical Soil Mechanics, John Wiley and Sons, Inc., New York, N.Y.