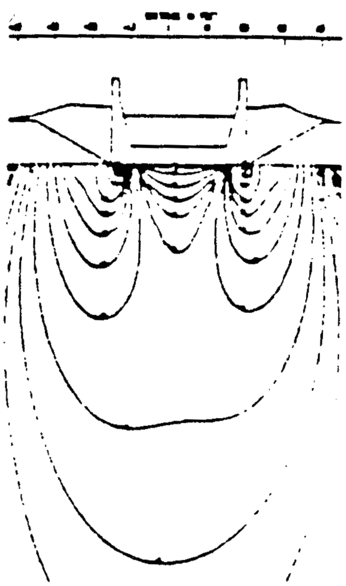

COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

INSTRUCTION REPORT K-84-7

USER'S GUIDE: COMPUTER PROGRAM FOR DETERMINING INDUCED STRESSES AND CONSOLIDATION SETTLEMENTS (CSETT)

by

Alexis E. Templeton

US Army Engineer District, Vicksburg
PO Box 60
Vicksburg, Mississippi 39180-0060

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Final Report

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Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Monitored by Automation Technology Center
US Army Engineer Waterways Experiment Station
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CATEGORY A

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM CSETT - Determining Induced Stresses and Consolidation Settlements of Clay (I0019)	PROGRAM NO. 741-F3-R0109
PREPARING AGENCY U. S. Army Engineer Waterways Experiment Station, Automatic Data Processing Center, P. O. Box 631, Vicksburg, MS 39180	

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
Eddie Templeton	April 1983	FINAL	OP

A. PURPOSE OF PROGRAM

CSETT is designed to compute induced stresses under general shaped loads and to calculate consolidation settlement resulting from these stresses. The program is capable of modeling the following loading and foundation conditions: (1) loads defined in two or three dimension; (2) instantaneous loads and ramp loads; (3) single or double draining strata; (4) stratified compressible and incompressible materials; (5) normally consolidated and overconsolidated deposits; and (6) soil rebound due to excavations occurring prior to loading.

B. PROGRAM SPECIFICATIONS

This program is written in FORTRAN 66. The CORPS system library time-sharing file name is I0019.

C. METHODS

Stresses are computed using the Boussinesq or Westergaard stress induction equation for a point load integrated over general shaped regions using the technique developed by J. V. Flack and M. E. Pittman, New Orleans District. Ultimate settlement is determined using classical stress-volume relationships. Time-rate of consolidation is computed using Terzaghi's theory of one-dimensional consolidation. CSETT provides results at the horizonal locations and to the depth specified by the user.

D. EQUIPMENT DETAILS

Time-sharing computer (Honeywell level 66, CDC Cyber, or Harris 500).

E. INPUT-OUTPUT

Input data may be supplied interactively from the terminal or from a predefined data file. If data are supplied interactively from the terminal, prompting is available to indicate the type of data to be entered. Interactive input is also possible without prompting using a keyword format. Output includes the ultimate settlement and time-rate of settlement for each soil stratum and for the sum of the soil strata. Time-rate information is given for each time specified by the user.

F. ADDITIONAL REMARKS

Documentation can be obtained from the Engineering Computer Programs Library, WES, P. O. Box 631, Vicksburg, MS 39180; telephone (601)634-2581 or FTS 542-2581.

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REPORT DOCUMENTATION PAGE

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18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. This report was prepared under the Computer-Aided Structural Engineering (CASE) Project. A list of published CASE reports is printed on the inside of the back cover.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Boussinesq and Westergaard Formulae	Stress induction
Instantaneous loading	Stress volume relationship
Nonuniform loads	Time-rate of consolidation
One-dimensional consolidation	Ultimate consolidation
Ramp loading	Uniform loads

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents CSETT, a computer program designed to compute consolidation settlement of compressible soils resulting from simple and complex loading conditions. The program provides ultimate settlement and time-rate of consolidation for the total soil mass specified and for the individual compressible soil layers within the soil mass. Additionally, it provides the in situ overburden pressures and the induced stresses.

(Continued)

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20. ABSTRACT (Continued).

Induced stresses are determined by integration of either Boussinesq or Westergaard point load equations over general shaped loaded regions. Loaded regions may consist of simple or complex geometric shapes for singular or multiple loads entered as two-dimensional pressure profiles, two-dimensional soil embankment profiles, or three-dimensional polygons.

Settlement computations are based on strain versus effective stress or void ratio versus effective stress relationships. The rate of consolidation is determined using Terzaghi's one-dimensional consolidation theory. The program provides for analyses of multiple soil layers and a variety of drainage conditions.

Data can be input interactively or by entering a predefined data file. Data files are created using command words that identify corresponding data items. Interactive input can be accomplished by a question-and-answer session or by using command words. Output consists of a total settlement, settlement of individual layers, and degree of consolidation for each time and location specified by the user.

PREFACE

This instruction report documents the computer program CSETT that can be used to compute induced stresses under irregular loads and the resulting consolidation settlements. Funds to modify the computer program and to write the user's guide were provided to the US Army Engineer Waterways Experiment Station (WES) by the Civil Works Directorate of the Office, Chief of Engineers, US Army (OCE), under the Geotechnical Aspects of the Computer-Aided Structural Engineering (GCASE) Project.

Specifications for the program were provided by members of the GCASE Task Group:

Mr. Phillip Napolitano, New Orleans District (Chairman)
Dr. Roger Brown, South Atlantic Division
Mr. Larry Cooley, Vicksburg District
Mr. Frank Coppinger, North Atlantic Division
Mr. Lavane D. Dempsay, St. Paul District
Mr. Ed Demsky, St. Louis District
Mr. Charles Trahan, LMVD
Mr. Thomas Wolff, St. Louis District
Mr. Reed Mosher, WES
Dr. N. Radhakrishnan, WES
Mr. Bill Strohm, WES
Mr. Dennis Williams, WES
Mr. Richard Davidson, OCE
Mr. Don Dressler, OCE
Mr. Rixby Hardy, OCE

CSETT, by Mr. Alexis E. Templeton, US Army Engineer District, Vicksburg (VXD), is a modified version of a computer program developed by Mr. James G. Flock and Dr. Micheal E. Pittman, New Orleans District (NOD), during the period November 1978 to March 1979. The original program was developed under the direction of Mr. Leonard Manson, Chief, Engineering Systems and Programming Section, NOD.

This report was written by Mr. Templeton. The report and program modifications were made under the guidance and supervision of Messrs. Robert L. Fleming, Chief, Analytical Section, Foundation and Materials Branch, and Larry A. Cooley, Chief, Foundation and Materials Branch, VXD. Technical assistance was provided by Messrs. Mosher and Williams, Automation Technology (AT) Center, WES. Appendix B was provided by Mr. Flock and Dr. Pittman. The work was managed and coordinated by Dr. Radhakrishnan, Chief, AT Center, WES, and CASE Project Manager. Mr. Hardy and, later, Mr. Davidson, Geotechnical Branch, Civil Works Directorate, were the OCE points of contact.

Commanders and Directors of WES during the development of the program and the publication of this instruction report were Colonel Nelson P. Conover, CE, and Colonel Tilford C. Creel, CE. Technical Director was Mr. Frederick R. Brown.

CONTENTS

CONVERSION FACTORS, INCH-POUND TO SI (METRIC) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
kips (1000 lb force)	4.448222	kilonewtons
kips (force) per square foot	47.880263	kilopascals
pounds (force) per square foot	47.880263	pascals
pounds (mass) per cubic foot	16.018463	kilograms per cubic meter
square feet per year	0.0939	square meters per year

USER'S GUIDE: COMPUTER PROGRAM FOR DETERMINING INDUCED STRESSES AND CONSOLIDATION SETTLEMENT (CSETT)*

PART I: INTRODUCTION

Purpose of Program CSETT

1. The computer program CSETT is designed to compute induced stresses under general-shaped loads and to evaluate resulting consolidation settlements in underlying clay strata. The program is capable of modeling the following loading and foundation conditions.

   a. Loads defined in two or three dimensions.

   b. Ramp loads and instantaneous loads.

   c. Single or double drainage conditions.

   d. Stratified compressible and incompressible materials.

   e. Normally consolidated or overconsolidated deposits.

   f. Soil rebound due to excavations occurring prior to loading.

Organization of Report

2. The remainder of this report is divided into the following parts:

   a. Part II presents a brief description of the theory and assumptions utilized in the program.

   b. Part III describes the mechanics of the solution procedure.

   c. Part IV presents instructions for the input and execution of the program.

   d. Part V presents example problems to illustrate data input and program capabilities.

   e. Appendix A presents example solutions with hand verifications.

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* Three pages entitled "Program Information" have been hand-inserted inside the front cover of this report. They present general information on the program and describe how it can be accessed. If procedures used to access this and other CORPS library programs should change, recipients of this report will be furnished a revised version of the "Program Information."

f. Appendix B describes the derivation of the general equations for vertical stress induction for the two- and three-dimensional load cases.

PART II: THEORETICAL CONSIDERATIONS

3. The theory and assumptions employed in the program CSETT, including stress induction, ultimate settlements, and time-rate of settlement, are discussed below.

Stress Induction

4. Stress induction equations used in CSETT for computing vertical stresses due to imposed loads were derived from the Boussinesq and Westergaard point load formulae integrated over general-shaped regions. These equations are applicable to any two-dimensional load defined by straight line segments and for three-dimensional rectangular or irregular loads of uniform pressure (Flock and Pittman 1979).

5. The Boussinesq and Westergaard stress induction equations are based on the theory of elasticity. The assumptions used in the development of these equations are as follows:

- a. The soil is a semi-infinite half space.
- b. The soil is elastic and homogeneous and obeys Hooke's law.
- c. The soil is weightless.
- d. The soil volume remains constant.
- e. There is stress continuity.
- f. Stress distribution is symmetrical about the vertical axis.
- g. The loads are perfectly flexible.
- h. The loads are applied to a horizontal surface.
- i. The loads maintain a constant shape.

In addition, the Boussinesq theory assumes that the soil is isotropic, and the Westergaard theory assumes there are no lateral deflections.

6. In most cases the assumptions are not so restrictive as to prohibit the use of these theories. However, the assumption of a perfectly flexible load is valid only for earth structures and flexible foundations and is not valid for structures with rigid foundations. Therefore, when analyzing rigid structures, the engineer should give particular attention to determining the applicability of these theories.

7. Flock and Pittman's discussion of the development of the stress

induction equations derived from Boussinesq and Westergaard formulae is presented in Appendix B.

Ultimate Settlement

8. The ultimate settlement for a soil layer of a given thickness and loading condition is dependent on the stress-volume relationship of the soil. CSETT allows the user to define this relationship either in terms of pressure and void ratio or in terms of pressure and strain.* In addition, the stress-volume data may be input by means of a piecewise linear curve or a bilinear curve as described below.

a. The piecewise linear curve is defined by a series of stress-strain points over the range of stresses to be considered in the analysis. The stress-strain behavior is assumed to vary linearly between defined points.

b. The bilinear curve is defined by a compression slope (C_c) for stresses greater than the in situ stress and a recompression slope (C_R) for stresses less than the in situ stress.

For each method a rebound-recompression slope (C_R) defines the behavior of the material during unloading and recompression (i.e., at stresses less than the in situ stress). See Figure 1.

9. Assuming the stress-strain curve represents the field response of the soil to loading and unloading, the user can determine the change in strain resulting from an increased effective stress due to loading directly from the curve by taking the difference between the strain associated with in situ stress and the strain resulting from the increase in effective stress due to loading as shown below:

$$\text{change in strain } (\Delta\varepsilon) = \text{in situ strain} - \text{final strain} \tag{1}$$

10. The ultimate settlement ΔH is then defined as

$$\Delta H = \frac{\Delta e}{1 + e_o} H \tag{2a}$$

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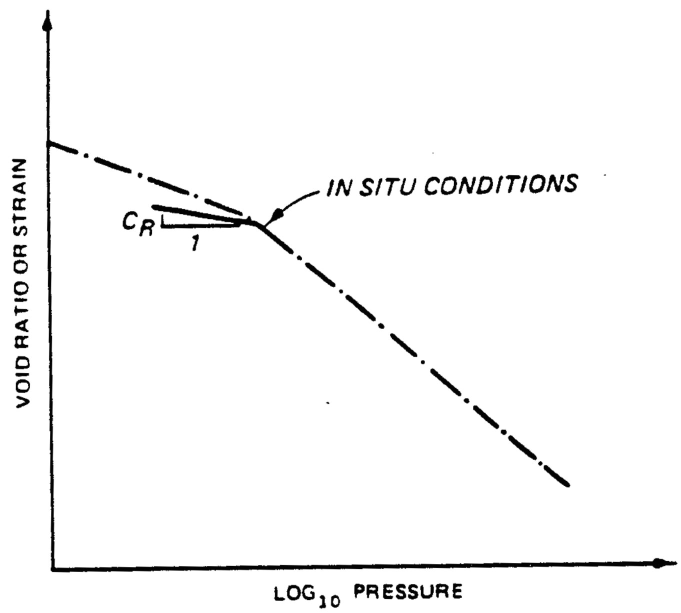
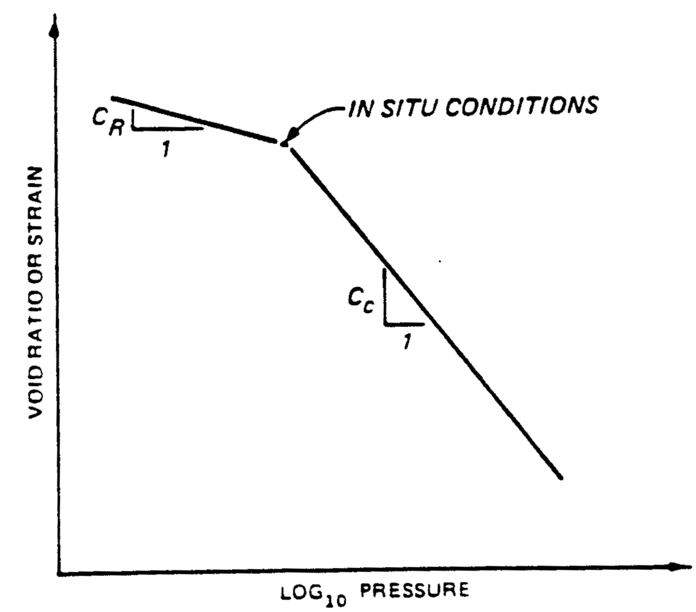
* Throughout this report the pressure-void ratio or pressure-strain relationship will be referred to as the stress-strain relationship.



a. Piecewise linear stress-strain relationship



b. Bilinear stress-strain relationship

Figure 1. Piecewise and bilinear stress-strain relationships

or

$$\Delta H = \Delta \varepsilon H \tag{2b}$$

where

Δe = change in void ratio

e_o = in situ void ratio

$\Delta \varepsilon$ = change in strain

H = thickness of compressible stratum

11. The stress-strain relationships are generally based on laboratory compression tests. Conventional interpretation of these tests considers only primary consolidation (that compression occurring during which time the rate of compression is controlled by the resistance to flow of water out of the soil voids) and neglects secondary compression and creep (compression occurring after excess hydrostatic pressures have dissipated). CSETT considers only primary consolidation and is not recommended for analyzing settlements in soils which exhibit significant secondary compression.

Time-Rate of Consolidation

12. The basic equations used in time-rate of consolidation computations are derived from Terzaghi's classical theory of one-dimensional consolidation (Taylor 1948). The following assumptions are used in the derivation:

a. Homogeneous soil.

b. Saturated material.

c. Negligible compression of soil grains and water.

d. Continuous behavior of the soil.

e. One-dimensional compression.

f. One-dimensional flow.

g. The validity of Darcy's law.

h. Constant soil properties.

i. Constant rate of change of void ratio with pressure.

The time-rate of consolidation theory provides a means of evaluating at any time the degree of consolidation (U) that has occurred within the consolidating strata. CSETT computes time-rate solutions for instantaneous loading and time-dependent loading assuming constant initial excess hydrostatic pressure.

13. For the case of instantaneous loading the degree of consolidation at any time is:

$$U = 1 - \sum_{m=0}^{m=\infty} M^2 \; EXP(-M^2 T) \qquad (3)$$

where

$M = \frac{\pi(2m + 1)}{2}$

$m = 0, 1, 2, 3, \ldots$

T = time factor = $\frac{c_v t}{H^2}$

c_v = coefficient of consolidation

t = time at which U is desired

H = length of longest drainage path

14. For time-dependent loading (Figure 2), the degree of consolidation at any time is:

For $T \leq T_c$

$$U = \left(\frac{T}{T_c}\right)\left\{1 - \frac{2}{T} \sum_{m=0}^{\infty} \frac{1}{M^4} \left[1 - EXP(-M^2 T)\right]\right\} \qquad (4)$$

For $T \geq T_c$

$$U = 1 - \left(\frac{2}{T_c}\right) \sum_{m=0}^{\infty} \left(\frac{1}{M^4}\right) \left\{\left[EXP(M^2 T_c) - 1\right] EXP(-M^2 T)\right\} \qquad (5)$$

where

$$T_c = \frac{c_v t_c}{H^2}$$

t_c = time at end of loading (Figure 2)

All other terms are as defined previously.

Further discussions on the degree of consolidation for instantaneous and time-dependent loading may be found in Taylor (1948) and Olson.*

15. Any sequential combination of instantaneous and/or time-dependent loads may be defined using the two-dimensional soil load, two-dimensional pressure load or three-dimensional rectangular load options. When applying the three-dimensional irregular load option, the user assumes all loads to be applied as specified for the first load defined (see "Load Definitions," pp 19-25).

16. The length of the longest drainage path, H , is determined for each stratum according to the drainage condition specified for that particular stratum (Figure 3).

a. If the stratum is designated double drained, H equals 1/2 the stratum thickness.

b. If the stratum is designated single drained, H is taken as the total stratum thickness.

c. If a stratum is designated contiguous, H is found by combining the thicknesses of the contiguous strata and treating them as single or double drained as specified for the upper stratum in the group of contiguous strata.

17. It should be emphasized that the analyses of this program are based on the assumptions of one-dimensional compression and one-dimensional drainage. For loading cases that will result in significant horizontal displacements and/or horizontal drainage the settlements and time-rate of settlement will be underestimated by CSETT.

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* R. E. Olson. 1977. Unpublished Notes, "Consolidation under Time-Dependent Loading," University of Texas, Austin, Texas.

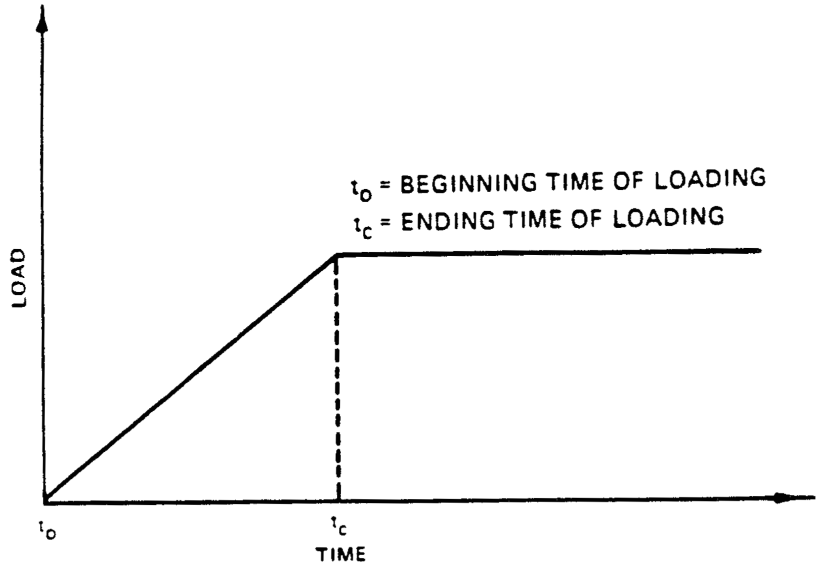

Figure 2. Time-dependent loading

STRATUM NO.	DRAINAGE CONDITION	STRATUM THICKNESS	H	ISOCHROME AT T > 0
1	INCOMPRESSIBLE	TH_1	–	
2	DOUBLE DRAINED	TH_2	$\frac{TH_2}{2}$	
3	INCOMPRESSIBLE	TH_3	–	
4	SINGLE DRAINED	TH_4	TH_4+TH_5	
5	CONTIGUOUS	TH_5	TH_4+TH_5	

Figure 3. Definition of drainage conditions

PART III: MECHANICS OF SOLUTION PROCEDURE

Introduction

18. The mechanics of the solution procedure employed in CSETT are described below. The user should be familiar with available options to ensure that loading and consolidation conditions are modeled correctly.

Stratification

19. Each stratum must be designated as compressible or incompressible. Compressible strata are designated as having single drainage or double drainage or being contiguous with adjacent strata. If a stratum is designated as contiguous, its consolidation characteristics (i.e., length of drainage path) are determined as if it were part of the stratum with which it is contiguous.

20. Each compressible stratum is internally subdivided into layers 3 ft* thick or less to increase the accuracy of settlement calculations. The original stratification as supplied by the user is retained for output purposes.

In Situ Properties

21. The stress-strain relationship supplied by the user is utilized in computing the in situ properties of each stratum.** The procedure varies depending on the type of stress-strain relationship supplied (see paragraph 8) and whether an excavation precedes loading.

22. If the stress-strain relationship is defined by a piecewise linear curve and no excavation precedes loading, the in situ properties are determined as follows:

- a. The in situ overburden stress (P_{ON}) is found by summing the stress contribution of each material from the ground surface to the midheight of the stratum of interest (Figure 4).
- b. The in situ strain is determined by interpolating between appropriate points on the stress-strain curve (Figure 5).

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* A table of factors for converting inch-pound units of measurement to SI (metric) units is presented on page 4.

** Unless noted otherwise "stratum" refers to internally generated stratification described in paragraph 20.

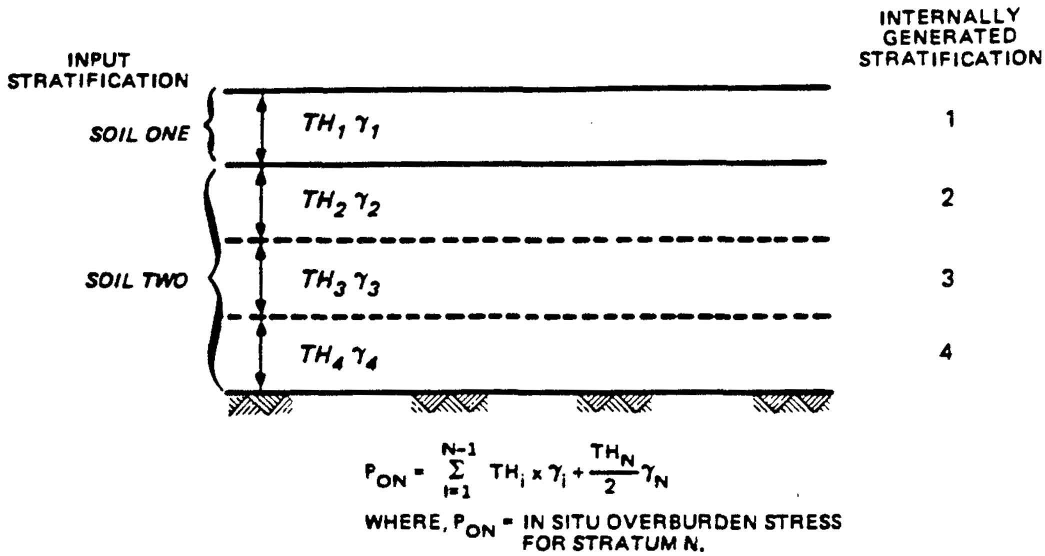


Figure 4. In situ stress for the case of no excavation

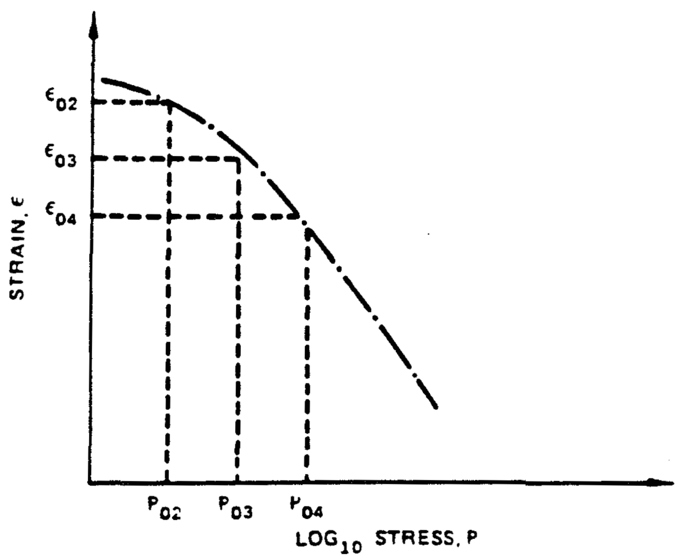
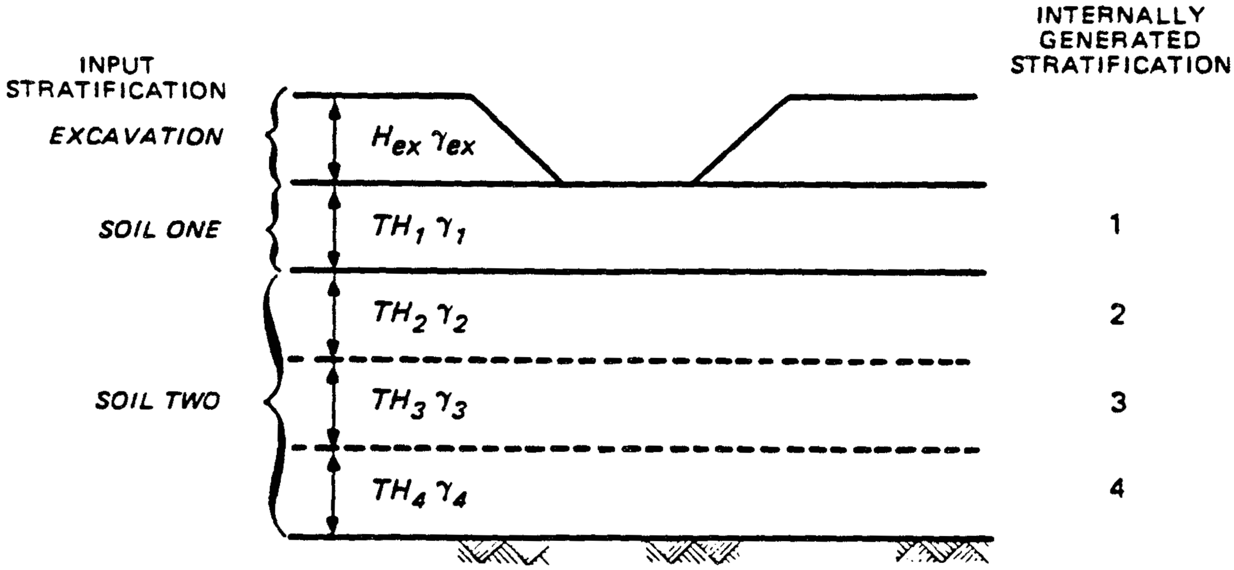


Figure 5. In situ strain for strata 2, 3, and 4 from piecewise linear stress-strain relationship and the case of no excavation (soil profile is shown in Figure 4)

23. If the stress-strain relationship is defined as a piecewise linear curve and an excavation precedes loading, the in situ properties are determined as follows:

a. The pre-excavation overburden stress (P_{ON}) is found by summing the contribution of all material from the pre-excavation ground surface to the midheight of the stratum of interest (see Figure 6).



$$P_{ON} = \left[\sum_{i=1}^{N-1} TH_i \times \gamma_i\right] + \frac{TH_N}{2}\gamma_N + H_{EX}\gamma_{EX} \qquad \text{EQ. 7}$$

$$P_{POSTN} = P_{ON} - \Delta P_N \qquad \text{EQ. 8}$$

WHERE, P_{ON} = PRE-EXCAVATION IN SITU OVERBURDEN STRESS FOR STRATUM N

P_{POSTN} = POST EXCAVATION OVERBURDEN STRESS FOR STRATUM N

ΔP_N = STRESS RELIEF FOR STRATUM N DUE TO EXCAVATION

Figure 6. Calculation of pre-excavation and post-excavation overburden stresses

b. The pre-excavation strain (ε_{ON}) is found by interpolating between appropriate points on the stress-strain curve (Figure 7).

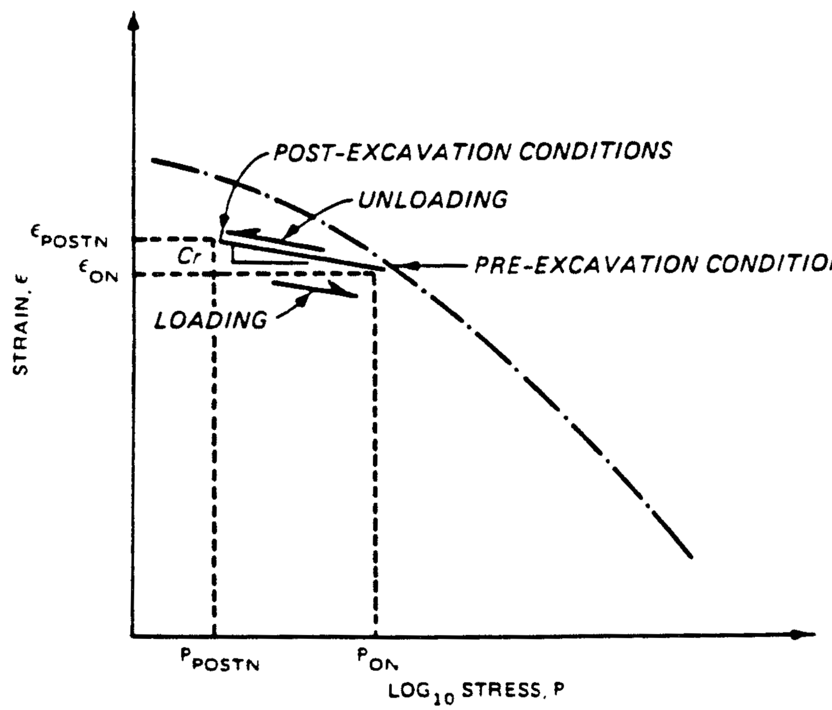


Figure 7. Pre-excavation and post-excavation strains from piecewise linear stress-strain relationship for soil profile shown in Figure 6

c. The stress relief (ΔP_N) due to the excavation is determined by the Boussinesq or the Westergaard formula. The post-excavation stress (P_{POSTN}) is then found by subtracting this stress relief from the pre-excavation overburden (see Figure 6).

d. The post-excavation strain (ε_{POSTN}) is found by computing the change in strain along the recompression slope (C_R) due to the stress relief and adding it to the pre-excavation strain (ε_{ON}) (Figure 7).

24. If the stress-strain relationship is defined as a bilinear curve and no excavation precedes loading, in situ properties are determined as follows:

a. The in situ overburden stress (P_{ON}) is found by summing the contributions of all materials from the ground surface to the midheight of the stratum of interest (Figure 4).

b. The in situ strain (ϵ_{ON}) is found by calculating the strain corresponding to the in situ stress along the bilinear curve. It should be noted that if the in situ overburden stress is less than the stress defining the intersection of the recompression slope and the compression slope, the in situ strain will be located along the recompression slope (Figure 8).

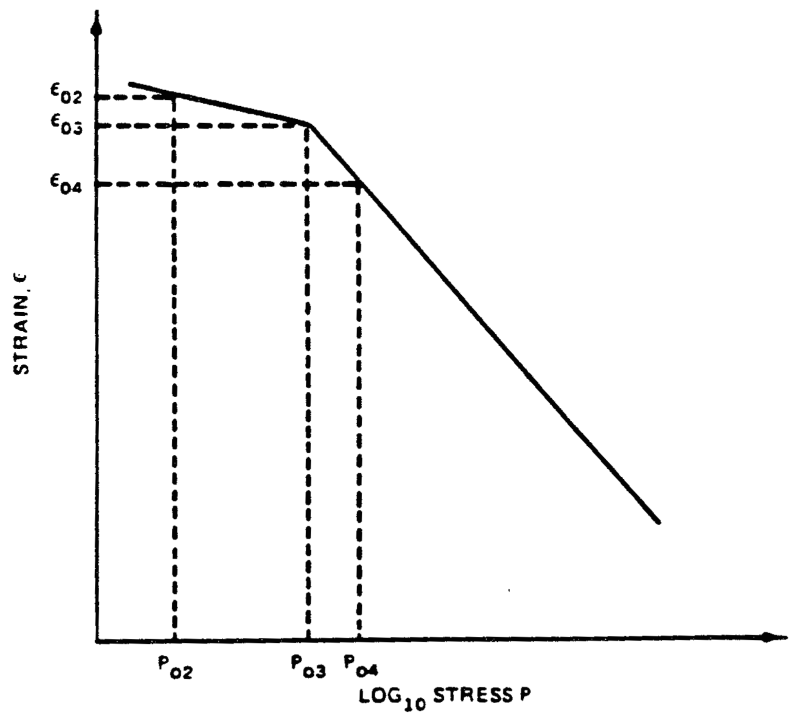


Figure 8. Determination of in situ strain for strata 2, 3, and 4 from bilinear stress-strain relationship and the case of no excavation (soil profile is shown in Figure 4)

25. If the stress-strain relationship is defined as a bilinear curve and an excavation precedes loading, the following procedure is used to determine the in situ properties.

a. The pre-excavation in situ stress (P_{ON}) is found by summing the contributions of all materials from the pre-excavation ground surface to the midheight of the stratum of interest (Figure 6).

b. The pre-excavation strain (ε_{ON}) is found by calculating the strain corresponding to the pre-excavation stress on the bilinear curve (Figure 9).

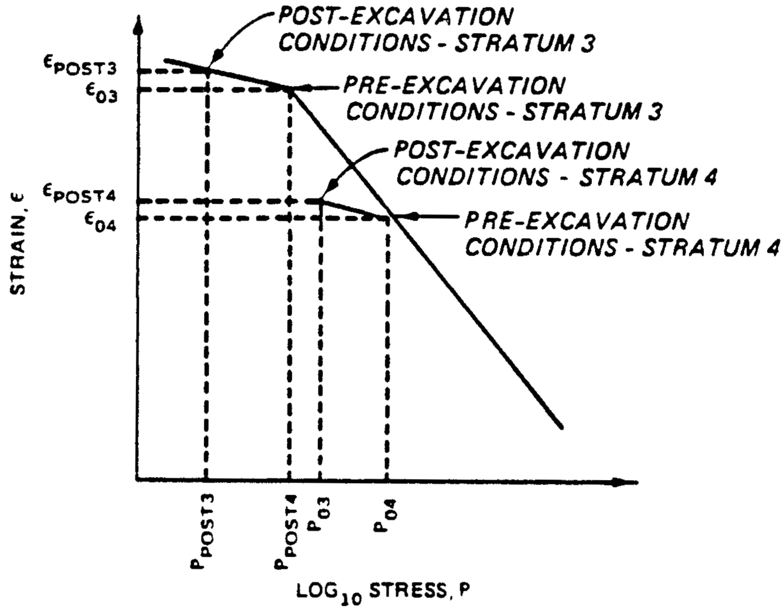


Figure 9. Determination of pre-excavation and post-excavation strains for strata 3 and 4 from bilinear stress-strain relationship

c. The stress relief due to the excavation is determined by the Boussinesq or the Westergaard formula. The post-excavation stress (P_{POSTN}) is found by subtracting this stress relief from the pre-excavation stress (Figure 6).

d. The post-excavation strain (ε_{POSTN}) is found by computing the change in strain along the recompression slope due to the stress relief and adding it to the pre-excavation strain (see Figure 9).

Load Definition

26. Four options are available for defining loads:

a. Two-dimensional soil loads which are load density profiles defined in the X-Z plane (Figure 10). The load is assumed to extend infinitely in the Y direction, plane-strain conditions.

b. Two-dimensional pressure loads which are pressure diagrams defined in the X-Z plane (Figure 11). Again, the load is assumed to extend infinitely in the Y-direction, plane-strain conditions.

c. Three-dimensional rectangular loads which are rectangular regions of uniform pressure defined in the X-Y plane (Figure 12).

d. Three-dimensional irregular loads which are piecewise linear regions of uniform pressure defined in the X-Y plane (Figure 13).

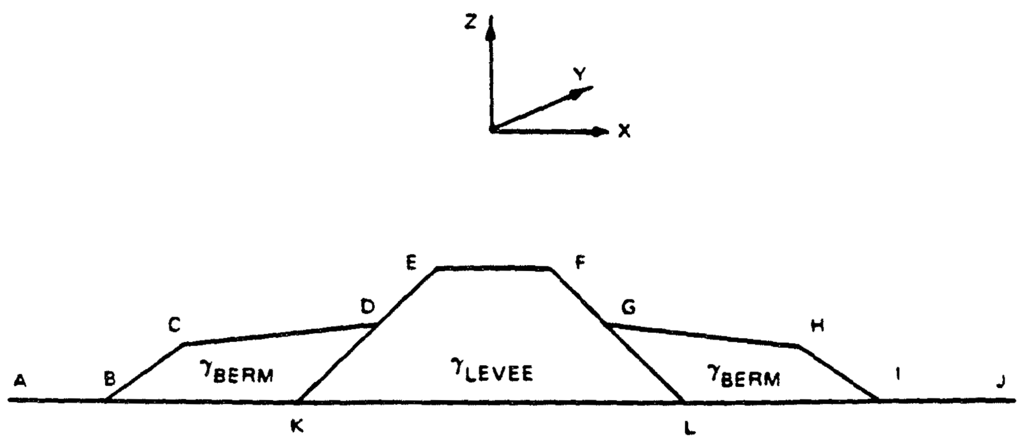


Figure 10. Example of two-dimensional soil load

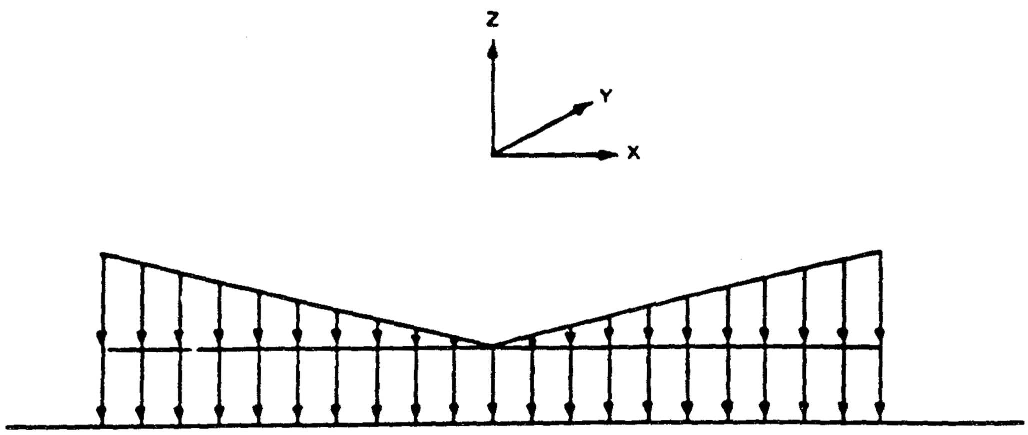


Figure 11. Example of two-dimensional pressure loads

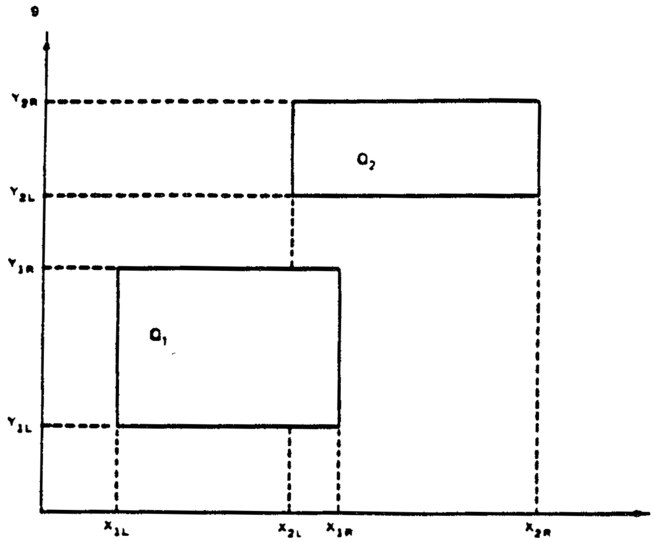


Figure 12. Example of three-dimensional rectangular loads

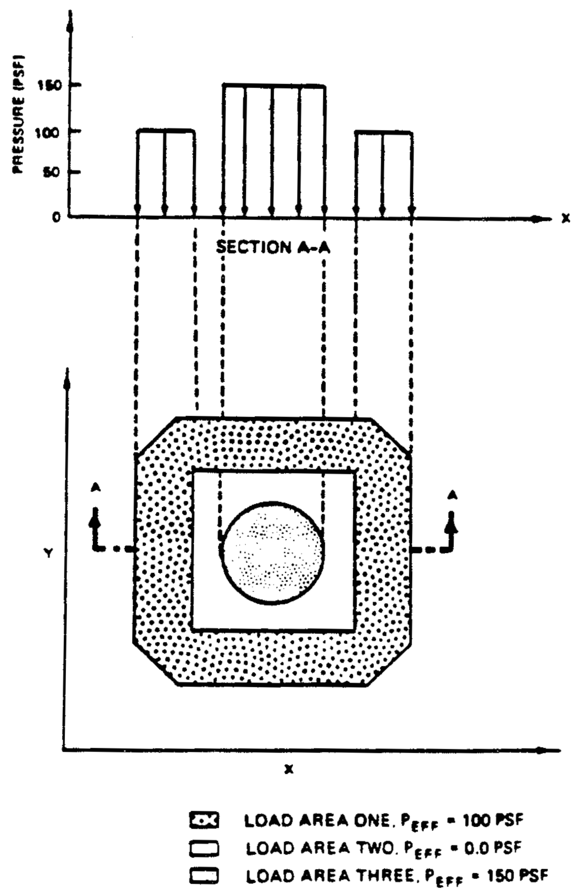


Figure 13. Example of three-dimensional irregular loads

27. Two-dimensional pressure loads and two-dimensional soil loads may be combined ("mixed") to define a loading case. When mixed loads are defined, they should be numbered consecutively with all pressure loads preceding the soil loads. The three-dimensional load options cannot be used concurrently with two-dimensional loading.

28. The superposition techniques employed in CSETT require that certain guidelines be followed when defining loads. These guidelines will be explained in the following paragraphs and are illustrated in the example problems in Part V and in Appendix A. It should be noted that the load number associated with the load profile is not indicative of the time of load application. The load profile number indicates the order required by the program to read the load data. The time of load application is supplied as a separate variable for each load.

29. Two-dimensional soil load profiles are defined by X-Z coordinates bounding layers of constant unit weight. Coordinate pairs defining each load profile should be input in a left to right order. When ordering sets of profiles, the user places the topmost layer first and follows with subsequent layers in order. To define a uniform loading condition extending to infinity in all directions, two points at x-coordinates of -9999 and 9999 are entered along with the appropriate load elevation. The explanation below and the examples in Appendix A should aid the user in coding difficult loading cases.

30. Consider the levee and berm sections shown in Figure 10.

a. Load profile 1 is defined by coordinates A, B, C, D, E, F, G, H, I, and J and is assigned a unit weight of γ_{berm} where points A and J have x-coordinates of -9999 and +9999, respectively.

b. Load profile 2 is defined by coordinates A, K, E, F, L, and J and is assigned a unit weight of γ_{levee} .

31. The induced stresses due to each load are determined as follows:

a. The induced stress at the point of interest is first computed assuming that the entire area is enclosed by profile 1 and that the ground surface contains material with a unit weight γ_{berm} .

b. The actual induced stress due to the berms is determined by computing the stress induced by a material of unit weight γ_{berm} within the area enclosed by load profile 2 and subtracting this stress from that determined in a above.

c. The stress induced by the levee is then computed using a material of unit weight γ_{levee} within the area enclosed by load profile 2.

32. Two-dimensional pressure loads are defined by coordinates and pressures input in a left to right order (Figure 11). To define a uniform load extending to infinity in all directions, two points at x-coordinates of -9999 and +9999 with the appropriate pressure should be supplied. Multiple pressure profiles may be entered. Each is considered individually to determine induced stresses. The total induced stress for a given location is the sum of stresses computed for individual loads.

33. Three-dimensional rectangular loads are defined by supplying the X-Y coordinates of the lower left corner and upper right corner (plan view) of each rectangular region of uniform pressure (Figure 12). The stress induced by each region is calculated separately. The total induced stress for a given location is the sum of the stresses contributed by individual loads.

34. The three-dimensional irregular load option allows the user to define multiple areas by piecewise linear perimeters in the X-Y plane (plan view) with uniform pressure loads. The stress at each location is determined by summing the individual stresses computed for each load area. Loads must be defined in a clockwise order, and the pressure assigned to each area must represent the resultant pressure after considering any overlying loads. A superposition code has been included as an optional means of controlling pressures assigned to each area during the stress computations. When a superposition code is assigned to a load area the pressure assigned to that area during stress induction computations is

$$P_{eff}\ (NL) = P_{input}\ (NL) - P_{input}\ (NS) \tag{9}$$

where

NL = load number of the load being considered

NS = superposition code which is the load number of the load immediately surrounding the load being considered

P_{input} (NL) = pressure assigned to load NL by user

P_{input} (NS) = pressure assigned to load NS by user

P_{eff} (NL) = pressure used to compute stresses induced by load NL

The following example illustrates the uses of the three-dimensional irregular load option with and without using the superposition code (Figure 13).

35. If the loads are to be input using superposition codes:

a. Load one is assigned a pressure of 100 psf and a superposition code of zero (0).

b. Load two is assigned a pressure of 0.0 psf and a superposition code of one (1).

c. Load three is assigned a pressure of 150 psf and a superposition code of two (2).

36. The induced stress at the point being considered is computed as described below.

a. First a stress is computed assuming a 100-psf pressure over the entire area bounded by the perimeter of load one. Note that this area includes areas occupied by loads two and three whose associated pressures are not 100 psf.

b. Next, stresses induced by a pressure of

P_{eff} (2) = P_{input} (2) - P_{input} (1) = 0 - 100 = -100 psf

acting over the area bounded by the perimeter of load two are added to the stresses computed in Step a. This effectively superimposes a zero (0) load region within the 100-psf load region one.

c. Lastly, stresses induced by a pressure of

P_{eff} (3) = P_{input} (3) - P_{input} (2) = 150 - 0 = 150 psf

acting over the area bounded by the perimeter of load three are added to the stresses computed in Step b. The resulting stress is the total induced stress resulting from the three loads.

37. If the loads are to be input without using superposition codes:

a. Load one is assigned a pressure of 100 psf and a superposition code of zero (0).

b. Load two is assigned a pressure of -100 psf and a superposition code of zero (0).

c. Load three is assigned a pressure of 150 psf and a superposition code of zero (0).

38. The induced stress at a point being considered is computed by

summing the values computed using the assigned pressure associated with each area. Note that when superposition codes are not used, the user is manually accomplishing the same results generated internally with the superposition codes.

PART IV: INPUT GUIDE

Source of Input

39. Input data may be supplied interactively from the terminal or from a predefined data file. Data supplied interactively from the terminal may be entered by following a prompting sequence or by using the same keyword format as that used to create a predefined data file.

Data Format

40. All input data (interactive or data file) are read in free-field format.

- a. Data items must be separated by one or more blanks (comma separators are not permitted).
- b. Integer numbers must be in the form NNNN.
- c. Real numbers may be in the form ± xxxx, ±xx.xx, or ± xx.xxE±rr.

Data Entry from Terminal

41. Data are entered from the terminal using the prompt or no-prompt mode. In the prompt mode, the user is queried for the required data. In the no-prompt mode, data are input by using keywords followed by the associated data. A description of the keyword format is described in the section titled Input Description. Note that the format for the no-prompt mode is the same as that for a data file except that line numbers are not used when entering data from the terminal.

Data Entry from File

42. Using a data file allows the user to create a permanent file of the input data prior to executing the program. To create a data file, follow the guidelines provided in the section Input Description.

43. In addition to the general format requirements given in paragraph 40, the following pertain to data being entered using the Input Description guide.

a. Each line of a data file must begin with a nonzero, positive line number, denoted by LN. Line numbers are not used when entering data from the terminal.

b. A line of input may require a keyword. The acceptable abbreviation for the keyword is indicated by underlined capital letters, e.g., the acceptable abbreviation for the keyword BOUSsinesq is BOUS.

c. Alphanumeric data items are enclosed in quotes.

d. Items designated by upper case letters and numbers without quotes indicate numeric data values. Numeric data values are either real or integer according to standard FORTRAN variable naming conventions.

e. Data items enclosed in brackets [] may be omitted if default values are to be used. Data items in parentheses () indicate that a special note follows.

f. Input data are divided into the sections listed in paragraph 44 below. Each section consists of a keyword line and may be followed by one or more data lines.

g. Each input line is limited to 70 characters including LN.

Sections of Input

44. Input data are divided into the following sections:

a. Title.

b. Applied loads.

c. Excavation.

d. Soil stratification.

e. Stress-strain properties.

f. Type and extent of stress analysis.

g. Time sequence for consolidation calculations.

h. Location of planes of interest.

i. Termination.

Units

45. All data must be in feet, pounds, and years.

Input Description

46. Title

a. Keyword line--one (1) per analysis

[LN] "TITLe"

b. Data lines--one (1) per analysis

b(1) Contents

[LN] title

b(2) Definition

title = alphanumeric information up to 70 characters including LN.

47. Applied Loads

a. 2-Dimensional Pressure Load

a(1) Keyword line--one (1) per load (max of 20 loads)

(a) Contents

[LN] "2DPRessure" NL N TIM1 TIM2

(b) Definitions

"2DPRessure" = keyword

NL = load number

N = number of points defining load NL (max of 50)

TIM1 = beginning time of load application (yrs)

TIM2 = ending time of load application (yrs)

a(2) Data lines--one (1) to fifty (50) points per load

(a) Contents

[LN] X1 P1 X2 P2 ...

(b) Definitions

X1 = x-coordinate of point 1 defining pressure load (ft)

P1 = pressure corresponding to location 1 defining pressure load (psf) etc.,

b. 2-Dimensional Soil Load Profile

b(1) Keyword line--one (1) per load (max of 20 loads)

(a) Contents

[LN] "2DSOil" (NL) N TIM1 TIM2 GAM

(b) Definitions

"2DSOil" = keyword

(NL) = load profile number

N = number of points defining load NL (max of 50)

T1M1 = beginning time of load application (yrs)

T1M2 = ending time of load application (yrs)

GAM = effective unit weight of soil load (pcf)

(c) Discussion

As noted previously, the load profile number, NL, indicates a superposition sequence and should not be mistaken for the chronological order of load application.

b(2) Data line--One (1) to fifty (50) lines per load

(a) Contents

[LN] X1 Z1 X2 Z2 ...

(b) Definitions

X1 = x-coordinate of point 1 defining soil load NL (ft)

Z1 = z-coordinate of point 1 defining soil load NL (ft), etc.

c. 3-Dimensional Rectangular Load

c(1) Keyword line-one (1) per load (max of 25 loads)

(a) Contents

[LN] "3DREctangular" NL T1M1 T1M2 PRES

(b) Defintions

"3DREctangular" = keyword

NL = load number

T1M1 = beginning time of load application (yrs)

T1M2 = ending time of load application (yrs)

PRES = pressure of load region (psf)

c(2) Data lines--one (1) line per load

(a) Contents

[LN] XL YL XR YR

(b) Definitions

XL = x-coordinate (ft) defining lower left corner of load region (PLAN VIEW)

YL = y-coordinate (ft) defining lower left corner of load region (PLAN VIEW)

XR = x-coordinate (ft) defining upper-right corner of load region (PLAN VIEW)

YR = y-coordinate (ft) defining upper right corner of load region (PLAN VIEW)

d. 3-Dimensional Irregular Load

d(1) Keyword line--one (1) per load (max of 20 loads)

(a) Contents

[LN] "3DIRregular" NL (NS) N T1M1 T1M2 PRES

(b) Definitions

"3DIRregular" = keyword

NL = load number

(NS) = superposition code

N = number of points defining load region (max of 50)

T1M1 = beginning time of load application (yrs)

T1M2 = ending time of load application (yrs)

PRES = pressure of load region (psf)

(c) Discussion

The superposition code is the load number of the surrounding load. For external loads, the superposition code is zero (0). For interior loads, the superposition code is the number corresponding to the load region immediately outside (surrounding) the load.

d(2) Data lines--one (1) to fifty (50) points per load

(a) Contents

[LN] X1 Y1 X2 Y2...

(b) Definitions

X1 = x-coordinate of point 1 defining load region (ft)

Y1 = y-coordinate of point 1 defining load region (ft) etc.

(c) Discussion

All loads must be entered in a clockwise order.

48. Excavation

a. Keyword line--one (1) per analysis

a(1) Contents

[LN] "EXCAvation" N GAM

a(2) Definitions

"EXCAvation" = keyword

N = number of points defining excavated profile (max of 50)

GAM = effective unit weight of excavated material (pcf)

b. Data line--one (1) to fifty (50) lines

b(1) Contents

[LN] X1 Z1 X2 Z2...

b(2) Definitions

X1 = x-coordinate of point 1 defining excavation profile (ft)

Z1 = z-coordinate of point 1 defining excavation profile (ft) etc.

c. Comments

For excavations assumed to extend infinitely in all directions, the excavation profile must be defined with two points at the pre-excavation ground surface elevation at infinite x-coordinates. This format is also used to define excavations for 3-D Load Cases (X1 = -9999 X2 = 9999).

49. Soil Stratification

a. Keyword line--one (1) per stratum

a(1) Contents

[LN] "SOIL" N EL ("NDC") GM [CR] [CV] [ST]

a(2) Definition

"SOIL" = keyword

N = stratum number

EL = elevation of top stratum (ft)

(NDC) = drainage condition

GM = effective unit weight of stratum (pcf)

[CR] = recompression index (not required if NDC = N)

[CV] = coefficient of consolidation (ft^2/yr) (not required if NDC = N)

[ST] = Poisson's ratio (default = 0.32)

a(3) Discussion

(a) Each soil stratification line must be immediately followed by the stress-strain information for that stratum (see paragraph 50) unless an incompressible stratum is input. No stress-strain information is required for incompressible strata.

(b) The drainage condition indicates the drainage assumption for time-rate of consolidation calculations. A value of S indicates single drainage, D indicates double drainage, and C indicates the stratum should be combined with the previous stratum. A value of N indicates an incompressible stratum.

b. Data lines - none

50. Stress-Strain Properties

a. Void Ratio-Pressure Curve

a(1) Keyword line--one (1) per stratum

(a) Contents

[LN] "VOID" NP

(b) Definitions

"VOID" = keyword

NP = number of points defining curve (max of 10 pts)

a(2) Data lines--one (1) to five (5) lines

(a) Contents

[LN] OR1 AB1 OR2 AB2...

(b) Definitions

OR1 = void ratio value of first point on curve

AB1 = pressure value of first point on curve (psf), etc.

b. Strain-Pressure Curve

b(1) Keyword line--one (1) per stratum

(a) Contents

[LN] "STRAin" NP

(b) Definitions

"STRAin" - keyword

NP = number of points defining curve (max of 10 pts)

b(2) Data line--one (1) to five (5) lines

(a) Contents

[LN] OR1 AB1 OR2 AB2....

(b) Definitions

OR1 = strain value of first point on curve

AB1 = pressure value of first point on curve (psf)

c. Index Properties

c(1) Keyword line--one (1) line per stratum

(a) Contents

[LN] "INDEx" CC PO EO

(b) Definitions

"INDEx" = keyword

CC = compression index

PO = in situ pressure (psf)

EO = in situ void ratio

c(2) Data lines - none

51. Type of Stress Analysis - one (1) line per analysis

a. Boussinesq Analysis

a(1) Keyword line--one (1) per analysis

(a) Contents

[LN] "BOUSsinesq" DMAX

(b) Definitions

"BOUSsinesq" = keyword

DMAX = maximum depth below top of strata 1 to which analysis will be extended (ft)

a(2) Data lines - none

b. Westergaard Analysis

b(1) Keyword line--one (1) per analysis

(a) Contents

[LN] "WESTergaard" DMAX

(b) Definitions

"WESTergaard" = keyword

DMAX = Maximum depth below top of stratum 1 to which the analysis will extend

b(2) Data lines - none

52. Time Sequence for Consolidation Calculations

a. Geometric Progression

a(1) Keyword line--one (1) per analysis

(a) Contents

[LN] "TIMI" [VTS][ALF]

(b) Definitions

"TIMI" = keyword

[VTS] = initial time period (default = 1 week = 0.0192 yrs)

[ALF] = multiplicative factor for the geometric progression algorithm (default = 2.0)

(2) Data lines - none

(3) Discussion - a total of thirteen (13) computation times are generated

b. Specified Times

b(1) Keyword line--one (1) line per analysis

(a) Contents

[LN] "TIMS" T1 T2...

(b) Definitions

"TIMS" = keyword

T1 = first time for which time-rate of consolidation will be determined (yrs).

T2 = second time for which time-rate of consolidation will be determined (yrs), etc.

b(2) Data lines - none

53. Location of Planes of Interest

a. 2-Dimensional Cases

a(1) Keyword line--one (1) per analysis

(a) Contents

[LN] "OUTPut" XL XR SP

(b) Definitions

"OUTPut" = keyword

XL = leftmost point defining plane of interest (ft)

XR = rightmost point defining plane of interest (ft)

SP = spacing along plane of interest where output is desired (ft)

a(2) Data lines - none

b. 3-Dimensional Case

b(1) Keyword line--one (1) to the number of planes at which output is desired

(a) Contents

[LN] "OUTPut" X1 Y1 X2 Y2 SP

(b) Definitions

"OUTPut" = keyword

X1 = x-coordinate (ft) defining lower (or left) corner of plane of interest (plan view)

Y1 = y-coordinate (ft) defining lower (or left) corner of plane of interest (plan view)

X2 = x-coordinate (ft) defining upper (or right) corner of plane of interest (plan view)

Y2 = y-coordinate (ft) defining upper (or right) corner of plane of interest (plan view)

SP = spacing along plane of interest where output is desired (ft)

b(2) Data lines - none

54. Termination of Input Sequence

a. Keyword line-one (1) line required

a(1) Contents

[LN] "END"

Abbreviated Input Guide

55. Title--one (1) line identifying problem

a. Keyword line -- one (1) per analysis

[LN] "TITLe" title

b. Data line--one (1) per analysis

[LN] title

56. Applied Loads

a. 2-Dimensional Pressure Load

a(1) Keyword line--one (1) per load (max of 20 loads)

[LN] "2DPRessure" NL N T1M2 T1M2

a(2) Data lines--one (1) to fifty (50) lines per load.

[LN] X1 P1 X2 P2....

b. 2-Dimensional Soil Load Profile

b(1) Keyword line--one (1) per load (max of 20 loads)

[LN] "2DSOil" (NL) N T1M1 T1M2 GAM

b(2) Data line--one (1) to fifty (50) lines per load

[LN] X1 Z1 X2 Z2....

c. 3-Dimensional Rectangular Load

c(1) Keyword line--one (1) line per load (max of 25 loads)

[LN] "3DREctangular" NL T1M1 T1M2 PRES

c(2) Data lines--one (1) line per load

[LN] XI YI XL YL

d. 3-Dimensional Irregular Load

d(1) Keyword line--one (1) line per load (max of 20 loads)

[LN] "3DIRregular" NL (NS) N T1M1 T1M2 PRES

d(2) Data lines--one (1) to fifty (50) lines per load

[LN] X1 Y1 X2 Y2...

57. Excavation (2-Dimensional Analyses Only)

a. Keyword--one (1) line per analysis

[LN] "EXCAvation" N GAM

b. Data line--one (1) to fifty (50) lines

[LN] X1 Z1 X2 Z2...

58. Soil Stratification

a. Keyword--one (1) line per stratum

[LN] "SOIL" N EL ("NDC") GM [CR] [CV] [ST]

b. Data lines - none

59. Stress-Strain Properties

a. Void Ratio--Pressure Curve

a(1) Keyword--one (1) line per stratum

[LN] "VOID" NP

a(2) Data lines--one (1) to five (5) lines

[LN] OR1 AB1 OR2 AB2...

b. Strain-Pressure Curve

b(1) Keyword--one (1) line per stratum

[LN] "STRAin" NP

b(2) Data line--one (1) to five (5) lines

[LN] OR1 AB1 OR2 AB2...

c. Index Properties

c(1) Keyword--one (1) line per stratum

[LN] "INDEx" CC PO EO

c(2) Data lines - none

60. Type of Stress Analysis--one (1) line per analysis

a. Boussinesq Analysis

a(1) Keyword--one (1) line per analysis

[LN] "BOUSsinesq" DMAX

a(2) Data lines - none

b. Westergaard Analysis

b(1) Keyword--one (1) line per analysis

[LN] "WESTergaard" DMAX

b(2) Data lines - none

61. Time Sequence For Consolidation Calculations

a. Geometric Progression

a(1) Keyword--one (1) line per analysis

[LN] "TIMI" [VTS] [ALF]

a(2) Data lines - none

b. Specified Times

b(1) Keyword--one (1) line per analysis

[LN] "TIMS" T1 T2 T3...

b(2) Data lines - none

62. Location of Plane of Interest

a. 2-Dimensional Case

a(1) Keyword-one (1) line per analysis

[LN] "OUTPut" XL XR SP

a(2) Data lines - none

b. 3-Dimensional Case

b(1) Keyword--one (1) to the number of planes at which output is desired

[LN] "OUTPut" X1 Y1 X2 Y2 SP

b(2) Data lines - none

63. Termination of Input Sequence

[LN] "END"

PART V: EXAMPLE PROBLEMS

64. The following example problems are solved using the program CSETT. These examples illustrate the input requirements for the program.

Example Problem 1

65. In this problem the ultimate settlement and time-settlement rates resulting from a 9-ft-high uniform fill are determined. The soil profile and soil properties are shown in Figure 14. The input data are presented in Figure 15. The clay stratum is assumed to be drained only at its upper boundary. The soil is normally consolidated. Results of this analysis can be compared to those presented by Hough (1957).

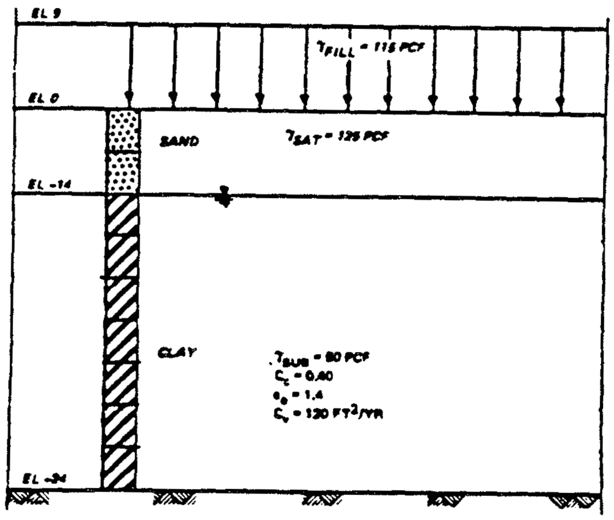


Figure 14. Soil profile and properties for Example Problem 1

```
LIST ETH

010 TITLE
020 EXAMPLE PROBLEM FROM HOUGH
030 2DSO 1 2 0 0 115 (2-DIMENSIONAL SOIL LOAD DATA NL N TIM1 TIM2 GAM)
040 -9999 9 9999 9 (X_i Z_i .... i = 1,N)
050 SOIL 1 0 N 125 (SOIL DATA N EL NDC GM)
060 SOIL 2 -14 S 50 .4 120 (SOIL DATA N EL NDC GM CR CV)
070 INDEX .4 2000 1.4 (INDEX PROPERTIES CC PO EO)
080 SOIL 3 -24 N 52.5 (SOIL DATA N EL NDC GM)
090 BOUS 25 (BOUSSINESQ SOLUTION DMAX)
100 TIMI (GEOMETRIC PROGRESSION)
110 OUTPUT 0 5 10 (OUTPUT XL XR SP)
120 END (TERMINATION)
```

Figure 15. Input data file for Example Problem 1

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE:   7/ 5/83                                     TIME: 16: 3:22


I.  INPUT DATA


1. TITLE - EXAMPLE PROBLEM FROM HOUGH


2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
   THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
   IS   25.00 FEET.


3. 2-DIMENSIONAL PRESSURE LOAD DATA
   NONE


4. 2-DIMENSIONAL SOIL LOAD DATA

  PROFILE NUMBER  1 :NUMBER OF POINTS=  2
                     BEGINNING TIME OF APPLICATION = 0.      YRS.
                     ENDING TIME OF APPLICATION = 0.      YRS.
                     EFFECTIVE UNIT WEIGHT OF SOIL LOAD=  115.00 PCF

                     POINT NO.     X          Y
                                 (FT.)      (FT.)

                         1    -9999.00      9.00
                         2     9999.00      9.00


5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
   NONE


6. 3-DIMENSIONAL IRREGULAR LOAD DATA
   NONE
```

7. EXCAVATION DATA
NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	0.	N	125.00			
2	-14.00	S	50.00	0.40000	120.00000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

STRATUM NO. 2

COMPRESSION INDEX= 0.40000
RECOMPRESSION INDEX= 0.40000
INSITU VOID RATIO= 1.40000
INSITU OVERBURDEN= 2000.00 PSF

10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS

A GEOMETRIC PROGRESSION WITH AN INITIAL TIME PERIOD OF 0.0192 YEARS AND A MULTIPLICATIVE FACTOR OF 2.0000 WILL BE USED IN THE TIME RATE OF CONSOLIDATION CALCULATIONS.

11. OUTPUT CONTROL DATA

XXL= 0. FT.
XUL= 5.0000 FT.
DELX= 10.0000 FT.

WILL OUTPUT GO TO TERMINAL, FILE, OR BOTH?
ENTER T, F, OR B
=

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 5/83 TIME: 16: 4:24

II. OUTPUT SUMMARY.

1. TITLE- EXAMPLE PROBLEM FROM HOUGH

POSITION: X= 0.
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	7.00	875.00	1035.00	0.
2	19.00	2000.00	1035.00	0.303

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.02 (YRS.)	0.04 (YRS.)	0.08 (YRS.)	0.15 (YRS.)	0.31 (YRS.)	0.61 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.303	0.052	0.074	0.103	0.146	0.205	0.262
TOTALS:	0.303	0.052	0.074	0.103	0.146	0.205	0.262

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	1.23 (YRS.)	2.45 (YRS.)	4.91 (YRS.)	9.82 (YRS.)	19.64 (YRS.)	39.28 (YRS.)	78.55 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.296	0.303	0.303	0.303	0.303	0.303	0.303
TOTALS:	0.296	0.303	0.303	0.303	0.303	0.303	0.303

Solution by Hough (1957)
ΔH = 3.6 in.

Example Problem 2

66. In this example the ultimate settlement and time-settlement rates resulting from a uniform load of 1500 psf are determined. The soil profile consists of two homogeneous clays above an impervious layer separated by a free-draining layer of incompressible sand. The soil profile and soil properties are shown in Figure 16. The input data file is shown in Figure 17. Results of this analysis can be compared to those presented by Means and Parcher (1963).

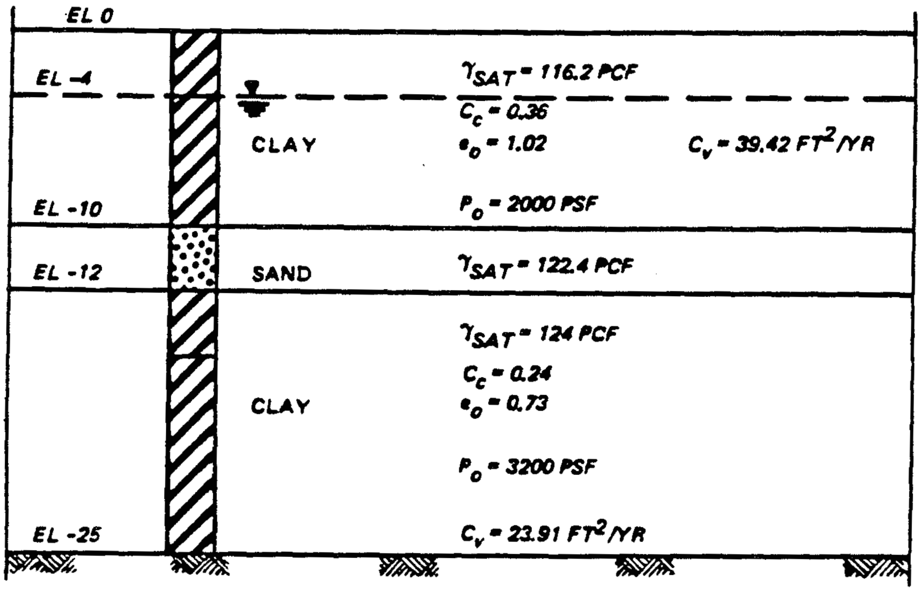


Figure 16. Soil profile and properties for Example Problem 2

```
010 TITLE
020 EXAMPLE PROBLEM FROM MEANS & PARCHER
030 2DPR 1 2 0 0 (2-DIMENSIONAL PRESSURE LOAD DATA NL N TIM1 TIM2)
040 -9999 1500 9999 1500 (Xi Zi .... I = 1,N)
050 SOIL 1 0 D 116.2 .36 39.42 (SOIL DATA N EL NDC GM CR CV)
060 INDEX .36 2000 1.02 (INDEX PROPERTIES CC PO EO)
070 SOIL 2 -4 C 53.8 .36 39.42 (SOIL DATA N EL NDC GM CR CV)
080 INDEX .36 2000 1.02 (INDEX PROPERTIES CC PO EO)
090 SOIL 3 -10 N 60 (SOIL DATA N EL NDC GM)
100 SOIL 4 -12 S 61.6 .24 23.91 (SOIL DATA N EL NDC GM CR CV)
110 INDEX .24 3200 .73 (INDEX PROPERTIES CC PO EO)
120 SOIL 5 -25 N 60 (SOIL DATA N EL NDC GM)
130 BOUS 30 (BOUSSINESQ SOLUTION DMAX)
140 TIMI (GEOMETRIC PROGRESSION)
150 OUTPUT 0 10 20 (OUTPUT XL XR SP)
160 END (TERMINATION)

*
```

Figure 17. Input data for Example Problem 2

1PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 5/83 TIME: 15:44:44

I. INPUT DATA

1. TITLE - EXAMPLE PROBLEM FROM MEANS & PARCHER

2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
IS 30.00 FEET.

3. 2-DIMENSIONAL PRESSURE LOAD DATA

LOAD NUMBER 1 : NUMBER OF POINTS= 2
BEGINNING TIME OF APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.

POINT NO.	X (FT.)	PRESSURE (PSF)
1	-9999.00	1500.00
2	9999.00	1500.00

4. 2-DIMENSIONAL SOIL LOAD DATA
NONE

5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
NONE

6. 3-DIMENSIONAL IRREGULAR LOAD DATA
NONE

7. EXCAVATION DATA
NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	0.	D	116.20	0.36000	39.42000	0.32000
2	-4.00	C	53.80	0.36000	39.42000	0.32000
3	-10.00	N	60.00			
4	-12.00	S	61.60	0.24000	23.91000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

COMPRESSION INDEX= 0.36000
RECOMPRESSION INDEX= 0.36000
INSITU VOID RATIO= 1.02000
INSITU OVERBURDEN= 2000.00 PSF

STRATUM NO. 2

COMPRESSION INDEX= 0.36000
RECOMPRESSION INDEX= 0.36000
INSITU VOID RATIO= 1.02000
INSITU OVERBURDEN= 2000.00 PSF

STRATUM NO. 3

INCOMPRESSIBLE STRATUM

STRATUM NO. 4

COMPRESSION INDEX= 0.24000
RECOMPRESSION INDEX= 0.24000
INSITU VOID RATIO= 0.73000
INSITU OVERBURDEN= 3200.00 PSF

10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS

A GEOMETRIC PROGRESSION WITH AN INITIAL TIME PERIOD OF 0.0192 YEARS AND A MULTIPLICATIVE FACTOR OF 2.0000 WILL BE USED IN THE TIME RATE OF CONSOLIDATION CALCULATIONS.

11. OUTPUT CONTROL DATA

XXL= 0. FT.
XUL= 10.0000 FT.
DELX= 20.0000 FT.

1
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 5/83 TIME: 15:41: 4

II. OUTPUT SUMMARY.

1. TITLE- EXAMPLE PROBLEM FROM MEANS & PARCHER

POSITION: X= 0.
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	2.00	232.40	1500.00	0.561
2	7.00	626.20	1500.00	0.524
3	11.00	847.60	1500.00	0.
4	18.50	1308.00	1500.00	0.575

3. TIME-SETTLEMENT SUMMARY.

STRATA NO	(SETTLEMENT IN FEET AT SPECIFIED TIMES) ULT	0.02 (YRS.)	0.04 (YRS.)	0.08 (YRS.)	0.15 (YRS.)	0.31 (YRS.)	0.61 (YRS.)
1	0.561	0.111	0.156	0.220	0.311	0.424	0.520
2	0.524	0.103	0.145	0.205	0.289	0.395	0.484
3	0.	0.	0.	0.	0.	0.	0.
4	0.575	0.034	0.047	0.068	0.096	0.136	0.192
TOTALS:	1.660	0.248	0.348	0.493	0.696	0.955	1.196

STRATA NO	(SETTLEMENT IN FEET AT SPECIFIED TIMES) 1.23 (YRS.)	2.45 (YRS.)	4.91 (YRS.)	9.82 (YRS.)	19.64 (YRS.)	39.28 (YRS.)	78.55 (YRS.)
1	0.558	0.561	0.561	0.561	0.561	0.561	0.561
2	0.520	0.524	0.524	0.524	0.524	0.524	0.524
3	0.	0.	0.	0.	0.	0.	0.
4	0.271	0.377	0.491	0.562	0.575	0.575	0.575
TOTALS:	1.349	1.462	1.576	1.647	1.660	1.660	1.660

Table 1. Ultimate Settlements*

Elev. Top Layer	Initial Void Ratio	Consolidation Coefficient	Induced Stress psf	Final Stress psf	Ultimate Settlement in.
0	1.356		1500	1732	6.43
		0.36			
4	1.201		1500	2126	6.25
10	--	--	--	--	--
12	0.826		1500	2594	3.52
		0.24			
18	0.787		1500	2993	3.40

Total Settlement = 19.60 in.

= 1.63 ft

* From Means and Parcher.

Example Problem 3

67. In this example the ultimate settlement and time-settlement rates resulting from a 4- by 4-ft footing carrying a 2000-psf load are determined. The soil profile and soil properties are presented in Figure 18. Settlements are computed under the center of the footing. The input data are presented in Figure 19.

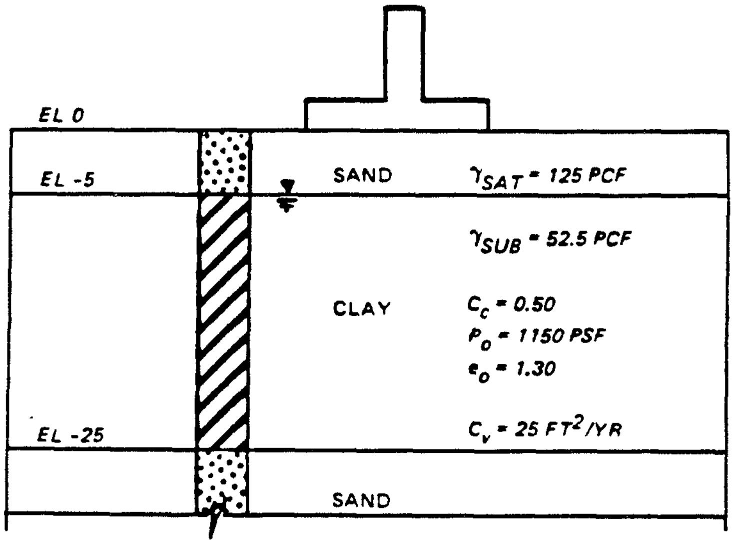


Figure 18. Soil profile and soil properties for Example Problem 3

```
010 TITLE
020 SETTLEMENT UNDER A 4X4 FOOTING
030 3DRE 1 0 0 2000 (3-DIMENSIONAL RECTANGULAR LOAD DATA NL TIMI TIM2 PRES)
040 0 0 4 4 (XI YI XL YL)
050 SOIL 1 0 N 125 (SOIL DATA N EL NDC GM)
060 SOIL 2 -5 D 52.5 .5 25 (SOIL DATA N EL NDC GM CR CV)
070 INDEX .5 1150 1.3 (INDEX PROPERTIES CC PO EO)
080 SOIL 3 -25 N 57.5 (SOIL DATA N EL NDC GM)
090 BOUS 30 (BOUSSINESQ SOLUTION DMAX)
095 TIMI (GEOMETRIC PROGRESSION)
100 OUTP 2 2 4 2 5 (OUTPUT XI YI X2 Y2 SP)
110 END (TERMINATION)
```

*

Figure 19. Input data for Example Problem 3

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE:   7/ 6/83                                       TIME:   9:11: 1


I.   INPUT DATA


1. TITLE - SETTLEMENT UNDER A 4X4 FOOTING


2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
   THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
   IS    30.00 FEET.


3. 2-DIMENSIONAL PRESSURE LOAD DATA
   NONE


4. 2-DIMENSIONAL SOIL LOAD DATA
   NONE


5. 3-DIMENSIONAL RECTANGULAR LOAD DATA

  LOAD NUMBER    1     BEGINNING TIME OF LOAD APPLICATION = 0.    YRS.
                       ENDING TIME OF APPLICATION = 0.       YRS.
                       PRESSURE =   2000.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =     0.   ,     0.

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =     4.00,     4.00


6. 3-DIMENSIONAL IRREGULAR LOAD DATA
   NONE
```

7. EXCAVATION DATA
NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	0.	N	125.00			
2	-5.00	D	52.50	0.50000	25.00000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

STRATUM NO. 2

```
   COMPRESSION INDEX= 0.50000
 RECOMPRESSION INDEX= 0.50000
    INSITU VOID RATIO= 1.30000
   INSITU OVERBURDEN= 1150.00 PSF
```

10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS

A GEOMETRIC PROGRESSION WITH AN INITIAL TIME PERIOD OF 0.0192 YEARS AND A MULTIPLICATIVE FACTOR OF 2.0000 WILL BE USED IN THE TIME RATE OF CONSOLIDATION CALCULATIONS.

11. OUTPUT CONTROL DATA

```
PLANE  1        XA=    2.0000 FT.
                YA=    2.0000 FT.
                XB=    4.0000 FT.
                YB=    2.0000 FT.
              DELX=    5.0000 FT.
```

WILL OUTPUT GO TO TERMINAL, FILE, OR BOTH?
ENTER T, F, OR B
=

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 6/83 TIME: 9:11:43

II. OUTPUT SUMMARY.

1. TITLE- SETTLEMENT UNDER A 4X4 FOOTING

POSITION: X= 2.0 Y= 2.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	2.50	312.50	1248.25	0.
2	15.00	1150.00	108.14	0.205

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.02 (YRS.)	0.04 (YRS.)	0.08 (YRS.)	0.15 (YRS.)	0.31 (YRS.)	0.61 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.205	0.017	0.024	0.032	0.044	0.063	0.090
TOTALS:	0.205	0.017	0.024	0.032	0.044	0.063	0.090

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	1.23 (YRS.)	2.45 (YRS.)	4.91 (YRS.)	9.82 (YRS.)	19.64 (YRS.)	39.28 (YRS.)	78.55 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.127	0.167	0.196	0.204	0.205	0.205	0.205
TOTALS:	0.127	0.167	0.196	0.204	0.205	0.205	0.205

DO YOU WANT A PLOT OF STRESS BULBS ?
ENTER Y OR N.
=

Example Problem 4

68. In this example the ultimate settlement and time-settlement rates resulting from a building load are determined. The structure is 40 by 100 ft in plan and applies a uniform load of 2000 psf. Settlements are computed under the center of the building. The soil profile and soil properties are presented in Figure 20. The input data for this example is shown in Figure 21. Results of this analysis can be compared to those presented by Winterkorn and Fang (1975).

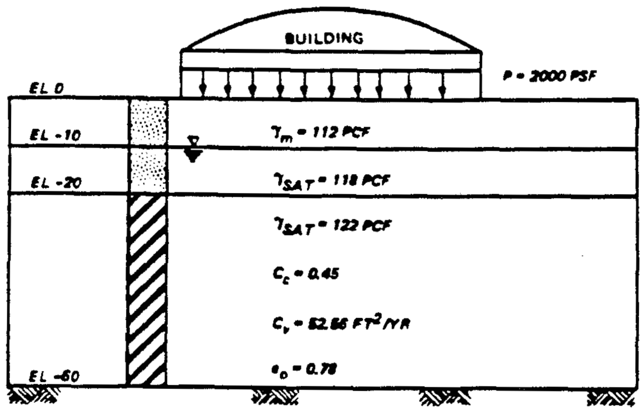


Figure 20. Soil profile and soil properties for Example Problem 4

```
010 TITLE
020 EXAMPLE FROM WINTERKORN & FANG
030 3DIR 1 0 5 0 0 2000  (3-D IRREGULAR LOAD DATA NL NS N TIM1 TIM2 PRES)
040 0 0 0 40 100 40 100 0 0 0 (Xi Yi .... i = 1iN)
050 SOIL 1 0 N 112  (SOIL DATA N EL NDC GM)
060 SOIL 2 -10 N 55.5 (SOIL DATA N EL NDC GM)
070 SOIL 3 -20 S 59.5 .45 52.56 (SOIL DATA N EL NDC GM CR CV)
080 INDEX .45 1970 .78 (INDEX PROPERTIES CC PO EO)
090 SOIL 4 -30 C 59.5 .45 52.56 (SOIL DATA N EL NDC GM CR CV)
100 INDEX .45 2550 .78  (INDEX PROPERTIES CC PO EO)
110 SOIL 5 -40 C 59.5 .45 52.56 (SOIL DATA N EL NDC GM CR CV)
120 INDEX .45 3480 .78  (INDEX CC PO EO)
130 SOIL 6 -60 N 60  (SOIL DATA N EL NDC GM)
140 BOUS 65  (BOUSSINESQ SOLUTION DMAX)
150 TIMI  (GEOMETRIC PROGRESSION)
160 OUTP 50 20 60 20 20  (OUTPUT X1 Y1 X2 Y2 SP)
170 END  (TERMINATION)
```

Figure 21. Input data for Example Problem 4

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 5/83 TIME: 16: 9:22

I. INPUT DATA

1. TITLE - EXAMPLE FROM WINTERKORN & FANG

2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
IS 65.00 FEET.

3. 2-DIMENSIONAL PRESSURE LOAD DATA
NONE

4. 2-DIMENSIONAL SOIL LOAD DATA
NONE

5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
NONE

6. 3-DIMENSIONAL IRREGULAR LOAD DATA

LOAD NUMBER 1 BEGINNING TIME OF LOAD APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.
PRESSURE = 2000.000 PSF

POINT NO.	X (FT.)	Y (FT.)
1	0.	0.
2	0.	40.00
3	100.00	40.00
4	100.00	0.
5	0.	0.

7. EXCAVATION DATA
NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	0.	N	112.00			
2	-10.00	N	55.50			
3	-20.00	S	59.50	0.45000	52.56000	0.32000
4	-30.00	C	59.50	0.45000	52.56000	0.32000
5	-40.00	C	59.50	0.45000	52.56000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

STRATUM NO. 2

INCOMPRESSIBLE STRATUM

STRATUM NO. 3

COMPRESSION INDEX= 0.45000
RECOMPRESSION INDEX= 0.45000
INSITU VOID RATIO= 0.78000
INSITU OVERBURDEN= 1970.00 PSF

STRATUM NO. 4

COMPRESSION INDEX= 0.45000
RECOMPRESSION INDEX= 0.45000
INSITU VOID RATIO= 0.78000
INSITU OVERBURDEN= 2550.00 PSF

```
            STRATUM NO.   5
            ---------------
         COMPRESSION INDEX= 0.45000
       RECOMPRESSION INDEX= 0.45000
         INSITU VOID RATIO= 0.78000
         INSITU OVERBURDEN= 3480.00 PSF


10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS


      A GEOMETRIC PROGRESSION WITH AN INITIAL TIME PERIOD OF   0.0192
      YEARS AND A MULTIPLICATIVE FACTOR OF   2.0000 WILL BE USED IN
      THE TIME RATE OF CONSOLIDATION CALCULATIONS.


11. OUTPUT CONTROL DATA


   PLANE  1        XA=   50.0000 FT.
                   YA=   20.0000 FT.
                   XB=   60.0000 FT.
                   YB=   20.0000 FT.
                 DELX=   20.0000 FT.

WILL OUTPUT GO TO TERMINAL, FILE, OR BOTH?
ENTER T, F, OR B
=
```

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 5/83 TIME: 16:11:12

1. TITLE- EXAMPLE FROM WINTERKORN & FANG

POSITION: X= 50.0 Y= 20.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	5.00	560.00	1977.80	0.
2	15.00	1397.50	1778.60	0.
3	25.00	1972.50	1451.13	0.607
4	35.00	2567.50	1148.80	0.407
5	50.00	3460.00	818.50	0.473

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.02 (YRS.)	0.04 (YRS.)	0.08 (YRS.)	0.15 (YRS.)	0.31 (YRS.)	0.61 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.
3	0.607	0.018	0.025	0.035	0.050	0.069	0.097
4	0.407	0.013	0.017	0.024	0.033	0.046	0.066
5	0.473	0.015	0.019	0.027	0.037	0.053	0.077
TOTALS:	1.487	0.046	0.061	0.086	0.120	0.168	0.240

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	1.23 (YRS.)	2.45 (YRS.)	4.91 (YRS.)	9.82 (YRS.)	19.64 (YRS.)	39.28 (YRS.)	78.55 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.
3	0.138	0.195	0.276	0.386	0.508	0.587	0.607
4	0.092	0.130	0.185	0.258	0.341	0.396	0.407
5	0.106	0.150	0.214	0.300	0.395	0.457	0.473
TOTALS:	0.336	0.475	0.675	0.944	1.244	1.440	1.487

Table 2. Ultimate Settlement at Center of Structure*

Layer Number	Mid-Depth of Layer ft	Layer Thickness ft	In-Situ Stress psf	Induced Stress	Ultimate Settlement ft
1	25	10	1970	1430	0.600
2	35	10	2550	1140	0.377
3	50	20	3480	810	0.463

Total Settlement = 1.440 ft

* As computed in Winterkorn and Fang.

Example Problem 5

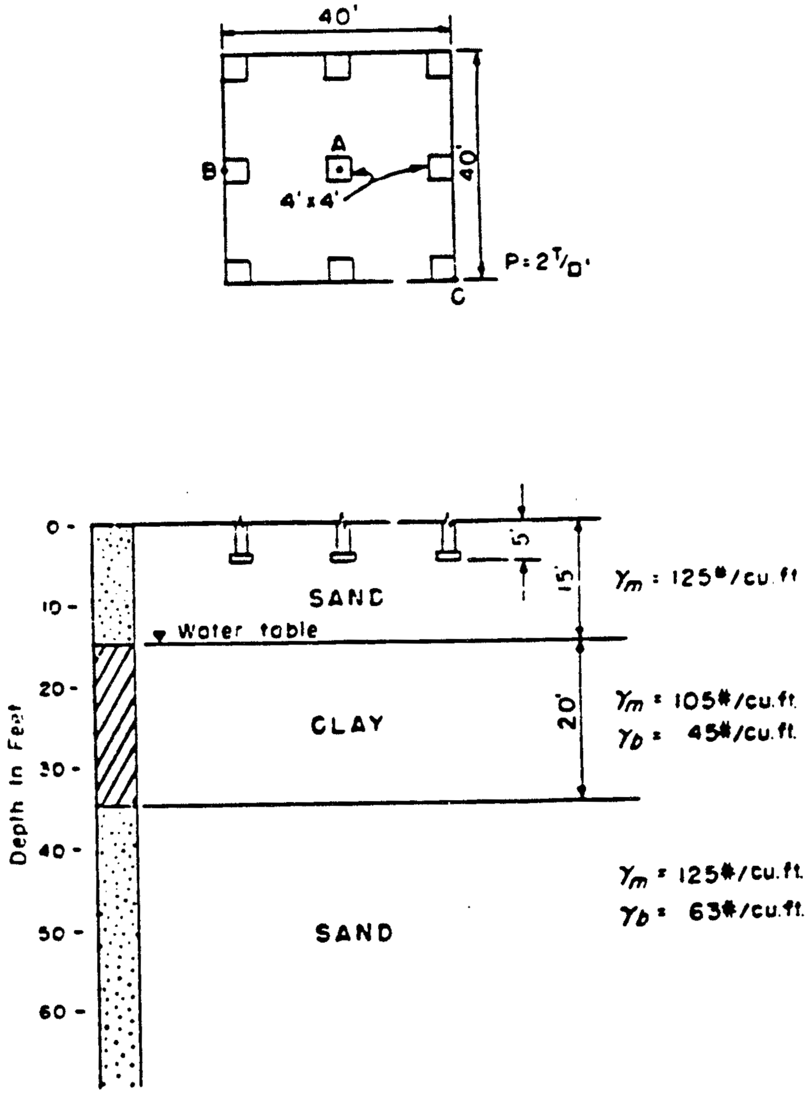
69. Overview

Example 5 was taken from EM 1110-2-1904 (HQUSACE 1953). The description of the problem is given below. A sketch of the foundation system and soil profile is included as Plate 1. Input data are shown in Figure 22. Output is generated for points A, B, and C shown in Plate 1.

70. Computed time-settlement rates and ultimate settlements compare favorably with those shown in this EM. Predicted time-settlement rates are compared in Plate 12. Ultimate settlements are compared in Table 3.

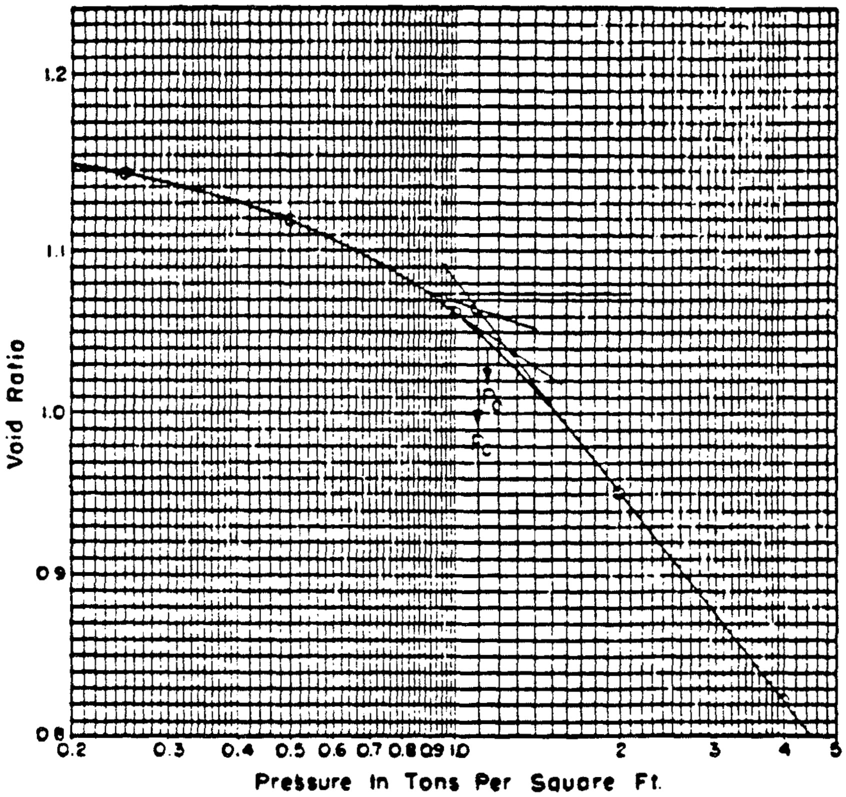
71. The following is quoted from EM 1110-2-1904:

> The Problem. Determine the total settlement resulting from a buried clay stratum and the time-settlement rate for a structure supported by nine 4- by 4-ft footings located at an elevation 5 ft below the natural ground surface. The foundation plan for the structure and the soil conditions beneath the structure are shown in Plate No. 1. The gross unit load on each footing is 2 tons per square foot. The construction rate of load will be applied uniformly during the next 30 days. The amount of rebound, resulting from the excavation before the construction load is applied, is assumed to be negligible. Consolidation test data for a representative sample of the clay stratum are shown on Plates Nos. 2 and 8 on which are plotted pressure-void ratio and time-settlement data, respectively, for the sample tested. Examination of the consolidation data shows the clay to be normally consolidated.



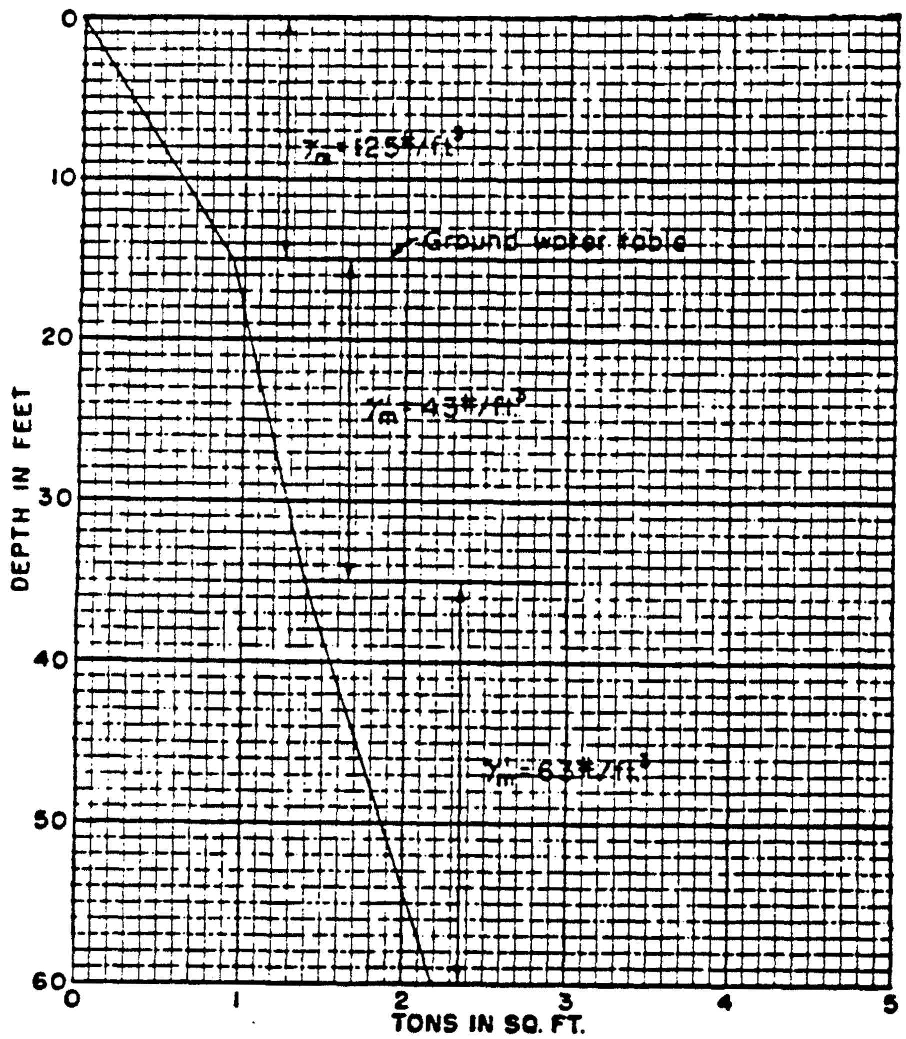
GENERAL PLAN
SHOWING STRUCTURE AND SOIL PROFILE

ENGINEERING MANUAL PART CXIX CHAPTER 4 PLATE NO. 1



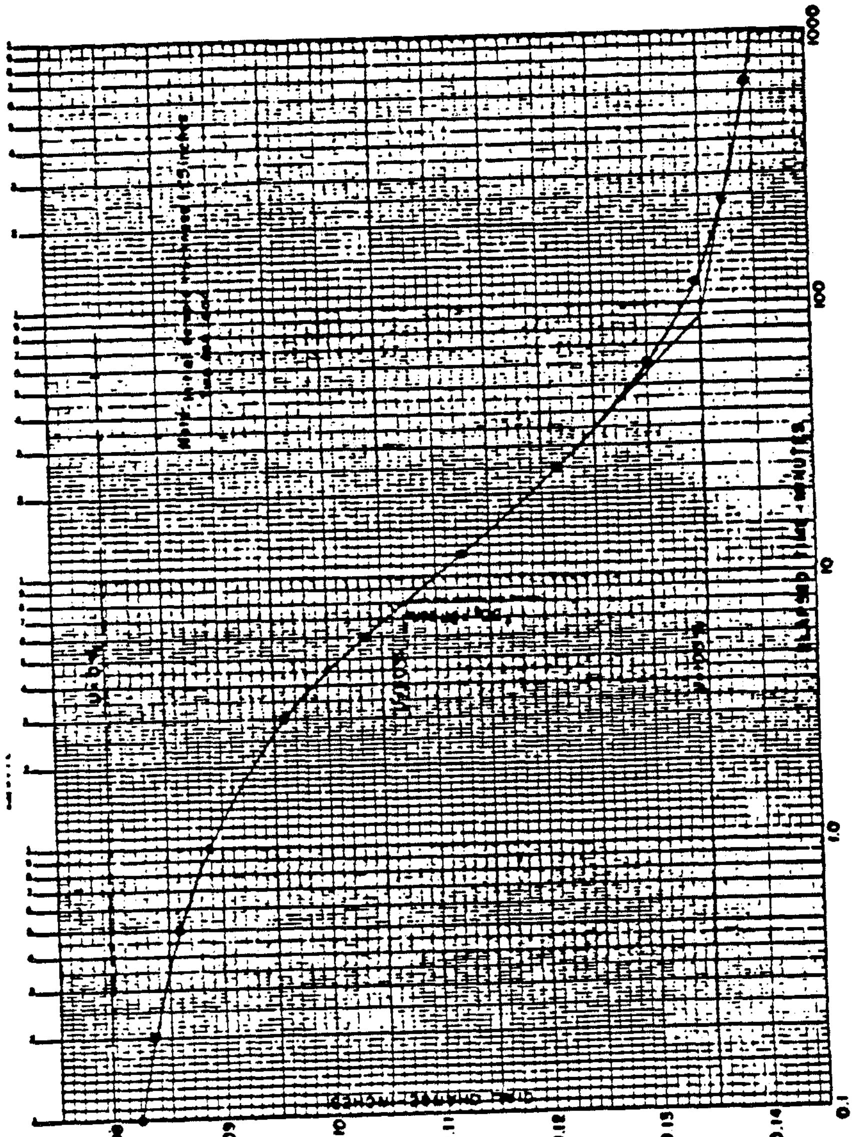
Note:
Initial thickness of sample 1.25 inches.

PRESSURE - VOID RATIO CURVE
FOR CLAY STRATUM BELOW
STRUCTURE ON PLATE NO. 1



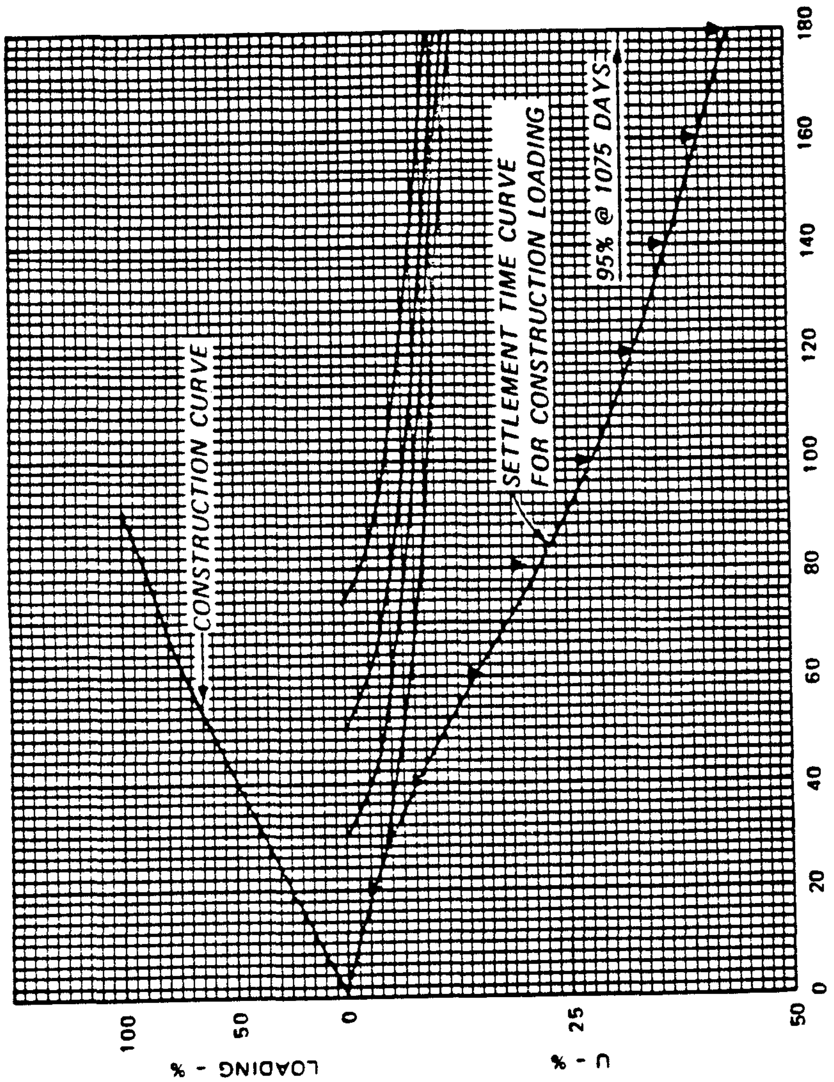
LOAD DEPTH DIAGRAM

OVERBURDEN PRESSURE



TIME COMPRESSION CURVE

LOGARITHMIC FITTING METHOD



TIME - SETTLEMENT CURVE
FOR CONSTRUCTION RATE OF LOADING

LEGEND

▼ = CSETT SOLUTION

```
005 TITLE
010 EXAMPLE PROBLEM -- EM 1110-2-1904
020 3DRE 1 0 .1644 2531 (3-DIMENSIONAL RECTANGULAR LOAD NL TIM1 TIM2 PRES)
030 0 0 4 4 (X1 Y1 XL YL)
040 3DRE 2 0 .1644 2531
050 18 0 22 4
060 3DRE 3 0 .1644 2531
070 36 0 40 4
080 3DRE 4 0 .1644 2531
090 0 18 4 22
100 3DRE 5 0 .1644 2531
110 18 18 22 22
120 3DRE 6 0 .1644 2531
130 36 18 40 22
140 3DRE 7 0 .1644 2531
150 0 36 4 40
160 3DRE 8 0 .1644 2531
170 18 36 22 40
180 3DRE 9 0 .1644 2531
190 36 36 40 40
200 3DRE 10 .1644 .2466 844
210 0 0 4 4
220 3DRE 11 .1644 .2466 844
230 18 0 22 4
240 3DRE 12 .1644 .2466 844
250 36 0 40 4
260 3DRE 13 .1644 .2466 844
270 0 18 4 22
280 3DRE 14 .1644 .2466 844
290 18 18 22 22
300 3DRE 15 .1644 .2466 844
310 36 18 40 22
320 3DRE 16 .1644 .2466 844
330 0 36 4 40
340 3DRE 17 .1644 .2466 844
350 18 36 22 40
360 3DRE 18 .1644 .2466 844
370 36 36 40 40
400 SOIL 1 -5 N 125 (SOIL DATA N EL NDC GM)
410 SOIL 2 -15 D 45 0 34.5 (SOIL DATA N EL NDC GM CR CV)
420 VOID 5 (VOID RATIO - PRESSURE CURVE NP)
430 1.15 500 1.12 1000 1.06 2000 .95 4000 .82 8000 (ORi ABi ... i = 1,NP)
440 SOIL 3 -35 N 63 (SOIL DATA N EL NDC GM)
450 BOUS 40 (BOUSSINESQ SOLUTION DMAX)
460 TIMS .0223 .0899 .205 .365 .568 .829 1.17 1.64 2.46 3.27 (SPECIFIED
                                                              TIMES T1 T2...
470 OUTPUT 0 20 20 20 20 (OUTPUT X1 Y1 X2 Y2 SP)
480 OUTPUT 40 0 50 0 20 (OUTPUT X1 Y1 X2 Y2 SP)
490 END (TERMINATION)
```

Figure 22. Input data for Example Problem 5

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE:   7/ 5/83                                          TIME: 15:56:20


I.  INPUT DATA


1. TITLE - EXAMPLE PROBLEM -- EM 1110-2-1904


2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
   THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
   IS   40.00 FEET.


3. 2-DIMENSIONAL PRESSURE LOAD DATA
   NONE


4. 2-DIMENSIONAL SOIL LOAD DATA
   NONE


5. 3-DIMENSIONAL RECTANGULAR LOAD DATA

  LOAD NUMBER    1     BEGINNING TIME OF LOAD APPLICATION = 0.   YRS.
                       ENDING TIME OF APPLICATION = 0.1644 YRS.
                       PRESSURE =  2531.000 PSF

       COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
       CORNER OF LOAD REGION - X , Y =     0.   ,     0.

       COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
       CORNER OF LOAD REGION - X , Y =    4.00,     4.00


  LOAD NUMBER    2     BEGINNING TIME OF LOAD APPLICATION = 0.   YRS.
                       ENDING TIME OF APPLICATION = 0.1644 YRS.
                       PRESSURE =  2531.000 PSF

       COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
       CORNER OF LOAD REGION - X , Y =   18.00,     0.

       COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
       CORNER OF LOAD REGION - X , Y =   22.00,     4.00
```

```
LOAD NUMBER    3     BEGINNING TIME OF LOAD APPLICATION = 0.      YRS.
                     ENDING TIME OF APPLICATION = 0.1644 YRS.
                     PRESSURE =  2531.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =    36.00,     0.

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =    40.00,     4.00

LOAD NUMBER    4     BEGINNING TIME OF LOAD APPLICATION = 0.      YRS.
                     ENDING TIME OF APPLICATION = 0.1644 YRS.
                     PRESSURE =  2531.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =     0.  ,    18.00

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =     4.00,    22.00

LOAD NUMBER    5     BEGINNING TIME OF LOAD APPLICATION = 0.      YRS.
                     ENDING TIME OF APPLICATION = 0.1644 YRS.
                     PRESSURE =  2531.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =    18.00,    18.00

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =    22.00,    22.00

LOAD NUMBER    6     BEGINNING TIME OF LOAD APPLICATION = 0.      YRS.
                     ENDING TIME OF APPLICATION = 0.1644 YRS.
                     PRESSURE =  2531.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =    36.00,    18.00

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =    40.00,    22.00

LOAD NUMBER    7     BEGINNING TIME OF LOAD APPLICATION = 0.      YRS.
                     ENDING TIME OF APPLICATION = 0.1644 YRS.
                     PRESSURE =  2531.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =     0.  ,    36.00

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =     4.00,    40.00
```

```
LOAD NUMBER   8     BEGINNING TIME OF LOAD APPLICATION = 0.      YRS.
                    ENDING TIME OF APPLICATION = 0.1644 YRS.
                    PRESSURE =  2531.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =   18.00,   36.00

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =   22.00,   40.00

LOAD NUMBER   9     BEGINNING TIME OF LOAD APPLICATION = 0.      YRS.
                    ENDING TIME OF APPLICATION = 0.1644 YRS.
                    PRESSURE =  2531.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =   36.00,   36.00

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =   40.00,   40.00

LOAD NUMBER  10     BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
                    ENDING TIME OF APPLICATION = 0.2466 YRS.
                    PRESSURE =   844.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =    0.   ,    0.

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =    4.00,    4.00

LOAD NUMBER  11     BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
                    ENDING TIME OF APPLICATION = 0.2466 YRS.
                    PRESSURE =   844.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =   18.00,    0.

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =   22.00,    4.00

LOAD NUMBER  12     BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
                    ENDING TIME OF APPLICATION = 0.2466 YRS.
                    PRESSURE =   844.000 PSF

      COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
      CORNER OF LOAD REGION - X , Y =   36.00,    0.

      COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
      CORNER OF LOAD REGION - X , Y =   40.00,    4.00
```

LOAD NUMBER 13 BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
ENDING TIME OF APPLICATION = 0.2466 YRS.
PRESSURE = 844.000 PSF

COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
CORNER OF LOAD REGION - X , Y = 0. , 18.00

COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
CORNER OF LOAD REGION - X , Y = 4.00, 22.00

LOAD NUMBER 14 BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
ENDING TIME OF APPLICATION = 0.2466 YRS.
PRESSURE = 844.000 PSF

COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
CORNER OF LOAD REGION - X , Y = 18.00, 18.00

COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
CORNER OF LOAD REGION - X , Y = 22.00, 22.00

LOAD NUMBER 15 BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
ENDING TIME OF APPLICATION = 0.2466 YRS.
PRESSURE = 844.000 PSF

COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
CORNER OF LOAD REGION - X , Y = 36.00, 18.00

COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
CORNER OF LOAD REGION - X , Y = 40.00, 22.00

LOAD NUMBER 16 BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
ENDING TIME OF APPLICATION = 0.2466 YRS.
PRESSURE = 844.000 PSF

COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
CORNER OF LOAD REGION - X , Y = 0. , 36.00

COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
CORNER OF LOAD REGION - X , Y = 4.00, 40.00

LOAD NUMBER 17 BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
ENDING TIME OF APPLICATION = 0.2466 YRS.
PRESSURE = 844.000 PSF

COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
CORNER OF LOAD REGION - X , Y = 18.00, 36.00

COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
CORNER OF LOAD REGION - X , Y = 22.00, 40.00

LOAD NUMBER 18   BEGINNING TIME OF LOAD APPLICATION = 0.1644 YRS.
ENDING TIME OF APPLICATION = 0.2466 YRS.
PRESSURE = 844.000 PSF

COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
CORNER OF LOAD REGION - X , Y = 36.00, 36.00

COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
CORNER OF LOAD REGION - X , Y = 40.00, 40.00

6. 3-DIMENSIONAL IRREGULAR LOAD DATA
NONE

7. EXCAVATION DATA
NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	-5.00	N	125.00			
2	-15.00	D	45.00	0.	34.50000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

STRATUM NO. 2

VOID RATIO	PRESSURE (PSF)
1.1500	500.0000
1.1200	1000.0000
1.0600	2000.0000
0.9500	4000.0000
0.8200	8000.0000

10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS

TIME RATE OF CONSOLIDATION CALCULATIONS WILL BE MADE
AT TIMES (YRS):

```
                    0.02
                    0.09
                    0.21
                    0.36
                    0.57
                    0.83
                    1.17
                    1.64
                    2.46
                    3.27
```

11. OUTPUT CONTROL DATA

```
PLANE  1       XA=   0.        FT.
               YA=   20.0000   FT.
               XB=   20.0000   FT.
               YB=   20.0000   FT.
             DELX=   20.0000   FT.

PLANE  2       XA=   40.0000   FT.
               YA=   0.        FT.
               XB=   50.0000   FT.
               YB=   0.        FT.
             DELX=   20.0000   FT.
```

WILL OUTPUT GO TO TERMINAL, FILE, OR BOTH?

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 5/83 TIME: 15:37:55

II. OUTPUT SUMMARY.

1. TITLE- EXAMPLE PROBLEM -- EM 1110-2-1904

POSITION: X= 0. Y= 20.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	5.00	625.00	799.25	0.
2	20.00	1700.00	127.89	0.071

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.02 (YRS.)	0.09 (YRS.)	0.21 (YRS.)	0.36 (YRS.)	0.57 (YRS.)	0.83 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.071	0.	0.004	0.013	0.024	0.031	0.039
TOTALS:	0.071	0.	0.004	0.013	0.024	0.031	0.039

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	1.17 (YRS.)	1.64 (YRS.)	2.46 (YRS.)	3.27 (YRS.)
1	0.	0.	0.	0.
2	0.046	0.054	0.062	0.066
TOTALS:	0.046	0.054	0.062	0.066

POSITION: X= 20.0 Y= 20.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	5.00	625.00	1282.28	0.
2	20.00	1700.00	156.79	0.086

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.02 (YRS.)	0.09 (YRS.)	0.21 (YRS.)	0.36 (YRS.)	0.57 (YRS.)	0.83 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.086	0.	0.006	0.016	0.029	0.038	0.048
TOTALS:	0.086	0.	0.006	0.016	0.029	0.038	0.048

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	1.17 (YRS.)	1.64 (YRS.)	2.46 (YRS.)	3.27 (YRS.)
1	0.	0.	0.	0.
2	0.060	0.068	0.078	0.081
TOTALS:	0.060	0.068	0.078	0.081

POSITION: X= 40.0 Y= 0.
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	5.00	625.00	524.05	0.
2	20.00	1700.00	105.13	0.057

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.02 (YRS.)	0.09 (YRS.)	0.21 (YRS.)	0.36 (YRS.)	0.57 (YRS.)	0.83 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.057	0.	0.002	0.010	0.019	0.027	0.032
TOTALS:	0.057	0.	0.002	0.010	0.019	0.027	0.032

STRATA NO	(SETTLEMENT IN FEET AT SPECIFIED TIMES) 1.17 (YRS.)	1.64 (YRS.)	2.46 (YRS.)	3.27 (YRS.)
1	0.	0.	0.	0.
2	0.039	0.046	0.051	0.055
TOTALS:	0.039	0.046	0.051	0.055

Table 3. Comparison of Ultimate Settlements

Point	X (ft)	X (ft)	Ultimate Settlement, ft EM 110-2-1904 Hand Solution	CSETT
A	20	20	0.09	0.086
B	0	20	0.07	0.071
C	40	0	0.06	0.057

REFERENCES

Flock, J. G., and Pittman, M. E. 1979. "Vertical Stress Induction and Settlement Analysis Program," U. S. Army Engineer District, New Orleans, Corps of Engineers, New Orleans, Louisiana.

Headquarters, Department of the Army, Office of the Chief of Engineers. 1953. "Soil Mechanics Design, Settlement Analysis," Engineer Manual 1110-2-1904, Washington, D. C.

Hough, B. K. 1957. Basic Soils Engineering, The Ronald Press Company, New York, N.Y.

Means, R. E., and Parcher, J. V. 1963. Physical Properties of Soils, Charles E. Merrill Publishing Co., Columbus, Ohio.

Taylor, D. W. 1948. Fundamentals of Soil Mechanics, John Wiley and Sons, New York, N.Y.

Winterkorn, H. F., and Fang, H. 1975. Foundation Engineering Handbook, Van Nostrand Reinhold Co., New York, N.Y.

APPENDIX A: EXAMPLE RUNS WITH HAND VERIFICATIONS

Example Problem A1

1. This example provides a solution for uniform loads extending infinitely in all directions. Soil stratification and loading are shown in Figure A1, and input soil properties are listed in Table A1. A combination of ramp loads and an instantaneous load are applied as indicated graphically in Figure A2.

2. The problem was run using a data file which is given in Figure A3. Time-rate calculations are performed at 0.10, 0.25, 0.50, 0.80, 0.90, 1.00, 1.20, 1.50, 1.75, 2.00, 4.00, and 8.00 years. Full and abbreviated output listings are shown. A hand solution is supplied (Tables A2-A5), and the results are compared with the solution by CSETT in Table A6.

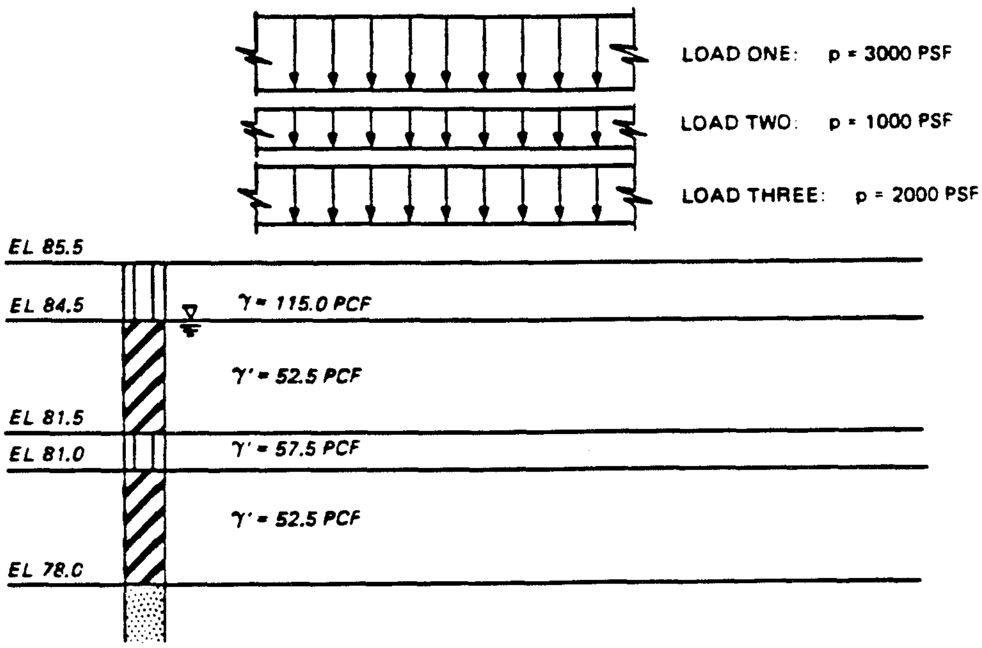


Figure A1. Soil stratification for Example Problem A1

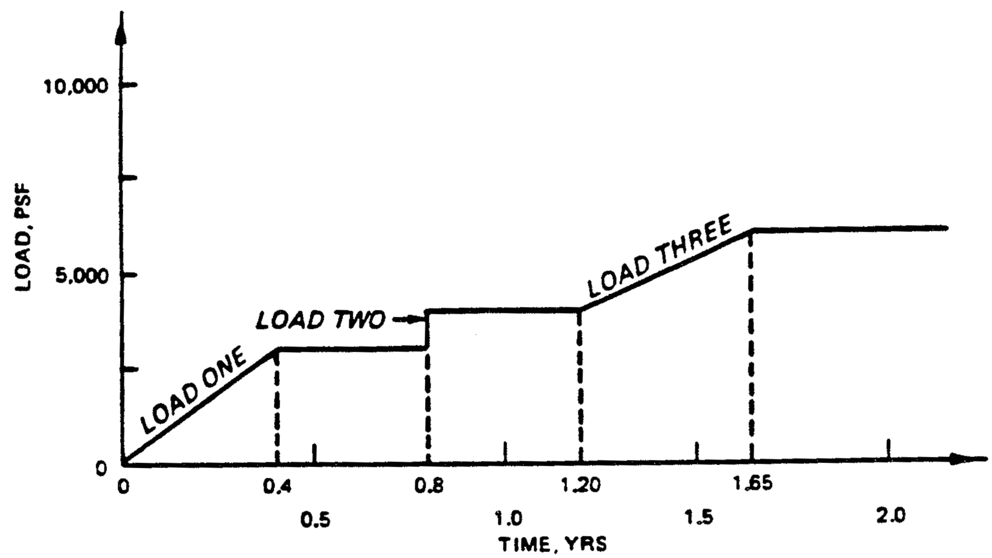


Figure A2. Loading sequence for Example Problem A1

Table A1

Soil Properties for Example Problem A1

Stratum No.	El of Top of Stratum ft NGVD	Eff Unit Weight pcf	Consolidation Data C_v ft^2/yr	e_o	P_o psf	C_R	C_C
1	85.5	115.0	--	--	--	--	--
2	84.5	52.5	8.0	1.6	193.75	0.04	0.35
3	81.5	57.5	--	--	--	--	--
4	81.0	52.5	12.0	1.3	380.00	0.045	0.48
5	78.0	57.5	--	--	--	--	--

SOLUTION BY CSETT

```
LIST UNI1

010  TITLE
020  UNIFORMLY DISTRIBUTED LOADS
030  2DPR 1 2 1.20 1.65 (2DPRESSURE LOAD DATA NL N T1M1 T1M2)
040  -9999.  2000  9999.  2000 (Xi Yi ... , i=1,N)
050  2DPR 2 2  .8  .8 (2DPRESSURE LOAD DATA NL N T1M1 T1M2)
060  -9999.  1000  9999.  1000 (Xi Yi ... , i=1,N)
070  2DPR 3 2 0.0  .4 (2DPRESSURE LOAD DATA NL N T1M1 T1M2)
080  -9999.  3000  9999.  3000 (Xi Yi ... , i=1,N)
090  BOUS 7.5 (BOUSSINESQ ANALYSIS DMAX)
100  SOIL 1 85.5 N 115. (SOIL DATA N EL NDC GM)
120  SOIL 2 84.5 D 52.5 .04 8.0 (SOIL DATA N EL NDC GM CR CV)
130  INDEX .35  193.75  1.6  (INDEX PROPERTIES CC PO EO)
140  SOIL 3  81.5  N  57.5  (SOIL DATA N EL NDC GM)
160  SOIL 4  81.0  D  52.5  .045  12.0 (SOIL DATA N EL NDC GM CR CV)
170  INDEX .48  380.0  1.3 (INDEX PROPERTIES CC PO EO)
180  SOIL 5  78.0  N  57.5 (SOIL DATA IN EL NDC GM)
200  T1MS  .1 .25 .5 .8 .9 1.0 1.2 1.5 1.75 2.0 4.0 8.0 (SPECIFIED TIMES T1 T2)
210  OUTP 0.0 5.0 10.0 (OUTPUT XL XR SP)
220  END (TERMINATION)
```

Figure A3. Input data file for Example Problem A1

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/12/83 TIME: 10: 9:34

I. INPUT DATA

1. TITLE - UNIFORMLY DISTRIBUTED LOADS

2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
IS 7.50 FEET.

3. 2-DIMENSIONAL PRESSURE LOAD DATA

LOAD NUMBER 1 : NUMBER OF POINTS= 2
BEGINNING TIME OF APPLICATION = 1.2000 YRS.
ENDING TIME OF APPLICATION = 1.6500 YRS.

POINT NO.	X (FT.)	PRESSURE (PSF)
1	-9999.00	2000.00
2	9999.00	2000.00

LOAD NUMBER 2 : NUMBER OF POINTS= 2
BEGINNING TIME OF APPLICATION = 0.8000 YRS.
ENDING TIME OF APPLICATION = 0.8000 YRS.

POINT NO.	X (FT.)	PRESSURE (PSF)
1	-9999.00	1000.00
2	9999.00	1000.00

LOAD NUMBER 3 : NUMBER OF POINTS= 2
BEGINNING TIME OF APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0.4000 YRS.

POINT NO.	X (FT.)	PRESSURE (PSF)
1	-9999.00	3000.00
2	9999.00	3000.00

4. 2-DIMENSIONAL SOIL LOAD DATA
   NONE

5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
   NONE

6. 3-DIMENSIONAL IRREGULAR LOAD DATA
   NONE

7. EXCAVATION DATA
   NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF. OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	85.50	N	115.00			
2	84.50	D	52.50	0.04000	8.00000	0.32000
3	81.50	N	57.50			
4	81.00	D	52.50	0.04500	12.00000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

```
            STRATUM NO.  2
            --------------
   COMPRESSION INDEX= 0.35000
 RECOMPRESSION INDEX= 0.04000
   INSITU VOID RATIO= 1.60000
   INSITU OVERBURDEN=  193.75 PSF

            STRATUM NO.  3
            --------------
        INCOMPRESSIBLE STRATUM

            STRATUM NO.  4
            --------------
   COMPRESSION INDEX= 0.48000
 RECOMPRESSION INDEX= 0.04500
   INSITU VOID RATIO= 1.30000
   INSITU OVERBURDEN=  380.00 PSF


10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS


     TIME RATE OF CONSOLIDATION CALCULATIONS WILL BE MADE
     AT TIMES (YRS):
                          0.10
                          0.25
                          0.50
                          0.80
                          0.90
                          1.00
                          1.20
                          1.50
                          1.75
                          2.00
                          4.00
                          8.00


11. OUTPUT CONTROL DATA


      XXL=     0.      FT.
      XUL=     5.0000  FT.
     DELX=    10.0000  FT.


DO YOU WANT TO EDIT DATA? ENTER 'Y' OR 'N'.
=
```

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 11/17/82                                            TIME:   9:57:39


II.   OUTPUT SUMMARY.


1. TITLE- UNIFORMLY DISTRIBUTED LOADS


2. SUMMARY OF TIME SETTLEMENT DATA.


                  PLANE OF INTEREST: XRIGHT=    0.
                                      XLEFT=    5.0
                                       DELX=   10.0


   TIME   X=    0.
   (YR)
   ----   --------
   ULT.      1.375
   0.10      0.086
   0.25      0.309
   0.50      0.644
   0.80      0.685
   0.90      0.853
   1.00      0.895
   1.20      0.914
   1.50      1.148
   1.75      1.349
   2.00      1.373
   4.00      1.375
   8.00      1.375

DO YOU WANT A PLOT OF STRESS BULBS ?
ENTER Y OR N.
=N


DO YOU WANT TO MAKE ANOTHER RUN?
ENTER Y OR N
=Y
```

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/12/83 TIME: 10:11:34

II. OUTPUT SUMMARY.

1. TITLE- UNIFORMLY DISTRIBUTED LOADS

POSITION: X= 0.
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	6000.00	0.
2	2.50	193.75	6000.00	0.608
3	4.25	286.88	6000.00	0.
4	6.00	380.00	6000.00	0.767

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.10 (YRS.)	0.25 (YRS.)	0.50 (YRS.)	0.80 (YRS.)	0.90 (YRS.)	1.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.608	0.034	0.127	0.276	0.302	0.370	0.391
3	0.	0.	0.	0.	0.	0.	0.
4	0.767	0.052	0.182	0.368	0.383	0.483	0.504
TOTALS:	1.375	0.086	0.309	0.644	0.685	0.853	0.895

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	1.20 (YRS.)	1.50 (YRS.)	1.75 (YRS.)	2.00 (YRS.)	4.00 (YRS.)	8.00 (YRS.)
1	0.	0.	0.	0.	0.	0.
2	0.403	0.501	0.591	0.606	0.608	0.608
3	0.	0.	0.	0.	0.	0.
4	0.511	0.647	0.758	0.767	0.767	0.767
TOTALS:	0.914	1.148	1.349	1.373	1.375	1.375

HAND VERIFICATION: SETTLEMENTS UNDER UNIFORMLY DISTRIBUTED LOADS

Table A2

Internally Generated Stratification For Example Problem A1

Input Stratum No.	Internally Generated Stratum No.	Thickness For Compression Calculations ft	Eff Thickness For Consolidation Calculations ft	Drainage Condition
1	1	--	--	N
2	2	3.0	3.0	D
3	3	--	--	N
4	4	3.0	3.0	D
5	5	--	--	N

Note: Since all strata thicknesses are less than or equal to 3 ft, the internally generated stratification is the same as the input stratification.

Table A3

Summary of Stresses and Ultimate Settlements for Example Problem A1

Stratum No.	P_o psf	e_o	ΔP_{Loads} psf	P_{Final} psf	ΔH_{ult} ft
1	--	--	--	--	--
2	193.75	1.6	6000.0	6193.75	0.608
3	--	--	--	--	--
4	380.00	1.30	6000.0	6380.00	0.767
5	--	--	--	--	--

Calculations for Table A3

a. Calculation of in situ overburden (P_o) and void ratio (e_o):

Stratum 2

$$P_o = 1.0 \times 115 + 1.5 \times 52.5 = 193.75 \text{ psf}$$

Since $P_o = P_{OINPUT}$, $e_o = e_{OINPUT} = 1.6$

Stratum 4

$$P_o = 1.0 \times 115 + 3.0 \times 52.5 + 0.5 \times 57.5 + 1.5 \times 52.5 = 380.0 \text{ psf}$$

Since $P_o = P_{OINPUT}$, $e_o = e_{OINPUT} = 1.3$

b. Calculation of ultimate settlements:

Stratum 2

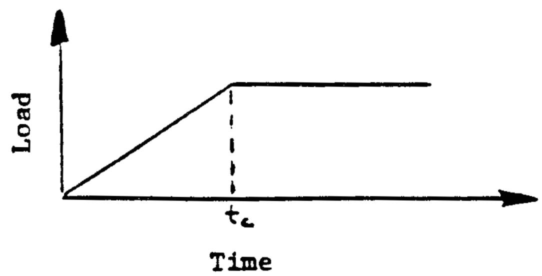
$$\Delta H_{ULT} = \frac{HC_c}{1 + \bar{e}_o} \log_{10} \frac{P_{final}}{P_o} = \frac{3.0(0.35)}{1 + 1.60} \log_{10} \frac{6193.75}{193.75} = 0.608 \text{ ft}$$

Stratum 4

$$\Delta H_{ULT} = \frac{3.0(0.48)}{1 + 1.30} \log_{10} \frac{6380.00}{380.00} = 0.767 \text{ ft}$$

c. Time-rate of consolidation calculations:

(1) Time-dependent loading



$$T = \frac{C_{vt}}{H^2}$$ where, C_v = coefficient of consolidation

t = time of interest

$$T_c = \frac{C_v t_c}{H^2}$$ t_c = time at end of loading

H = length of longest drainage path

for $T \geq T_c$ $$U = 1 - \left(\frac{2}{T_c}\right) \sum_{M=0}^{\infty} \left(\frac{1}{M^4}\right) \left[\text{EXP}\left(M^2 T_c\right) - 1\right] \text{EXP}\left(-M^2 T\right)$$

for $T \leq T_c$ $$U = \left(\frac{T}{T_c}\right) \left\{1 - \frac{2}{T} \sum_{M=0}^{\infty} \frac{1}{M^4} \left[1 - \text{EXP}(-M^2 T)\right]\right\} \times 100$$

where U = % consolidation

$$M = \frac{\pi(2m + 1)}{2} \quad M = 0,1,2,...$$

(2) Instantaneous loading

$$U = \left[1 - \sum_{M=0}^{\infty} \frac{2}{M^2} \text{ EXP } -M^2 T_c \right] \times 100$$

where U = % consolidation

$$M = \frac{(2m + 1)\pi}{2} \quad ,M = 0,1,2,...$$

Table A4

Time-Rate Calculations for Stratum 2

Load No.	T1M1 yr	T1M2 yr	T_c	Time yr	Relative Time yr	T	U %
1	1.20	1.65	1.60	0.10	0	0	0
				0.25	0	0	0
				0.50	0	0	0
				0.80	0	0	0
				0.90	0	0	0
				1.0	0	0	0
				1.20	0	0	0
				1.50	0.30	1.07	47.3
				1.75	0.55	1.96	91.6
				2.0	0.80	2.84	99.1
				4.0	2.80	9.96	100.0
2	0.80	0.80	0.0	0.10	0	0	0
				0.25	0	0	0
				0.50	0	0	0
				0.80	0	0	0
				0.90	0.10	0.36	66.3
				1.0	0.20	0.71	86.0
				1.2	0.40	1.42	97.6
				1.5	0.70	2.49	99.8
				1.75	0.95	3.38	100.0
				2.0	1.20	4.27	100.0
				4.0	3.20	11.38	100.0
3	0.00	0.40	1.42	0.10	0.10	0.36	11.2
				0.25	0.25	0.89	41.7
				0.50	0.50	1.78	90.7
				0.80	0.80	2.84	99.3
				0.90	0.90	3.20	99.7
				1.00	1.00	3.56	99.9
				1.20	1.20	4.27	100.0
				1.50	1.50	5.33	100.0
				1.75	1.75	6.22	100.0
				2.00	2.00	7.11	100.0
				4.00	4.00	14.22	100.0

Note:

Stratum 2

$C_v = 8.0\ ft^2/yr$

$H = 1.5\ ft$

Table A5

Time-Rate Calculations for Stratum 4

Load No.	T1M1 yr	T1M2 yr	T_c	Time yr	Relative Time yr	T	U %
1	1.20	1.65	2.40	0.10	0	0	0
				0.25	0	0	0
				0.50	0	0	0
				0.80	0	0	0
				0.90	0	0	0
				1.0	0	0	0
				1.20	0	0	0
				1.50	0.30	1.60	53.0
				1.75	0.55	2.93	96.3
				2.0	0.80	4.27	99.9
				4.0	2.80	14.93	100.0
2	0.80	0.80	0.0	0.10	0	0	0
				0.25	0	0	0
				0.50	0	0	0
				0.80	0	0	0
				0.90	0.10	0.53	78.3
				1.00	0.20	1.067	94.2
				1.20	0.40	2.13	99.6
				1.50	0.70	3.73	100.0
				1.75	0.95	5.07	100.0
				2.0	1.20	6.40	100.0
				4.0	3.20	17.07	100.0
3	0.00	0.40	2.13	0.10	0.10	0.53	13.5
				0.25	0.25	1.33	47.5
				0.50	0.50	2.67	95.9
				0.80	0.80	4.27	99.9
				0.90	0.90	4.80	100.0
				1.00	1.00	5.33	100.0
				1.20	1.20	6.40	100.0
				1.50	1.50	8.00	100.0
				1.75	1.75	9.33	100.0
				2.00	2.00	10.67	100.0
				4.00	4.00	21.3	100.0

Note:

Stratum 4

$C_v = 12.0\ ft^2/yr$

$H = 1.5\ ft$

Table A6

Summary of Settlements for Example Problem A1*

Stratum No.	Load No.	ΔP_{Loads} psf	ΔP_{Loadi} psf	ΔH_{ULT} ft	$\Delta H_{ULT} \times \frac{\Delta P_{Loadi}}{\Delta P_{Loads}}$ ft	Settlement In Feet At Specified Time: 0.10 yrs	0.25 yrs	0.50 yrs	0.80 yrs	0.90 yrs	1.00 yrs	1.20 yrs	1.50 yrs	1.75 yrs	2.00 yrs	4.00 yrs
2	1	6000.0	2000.0	0.608	0.203	0	0	0	0	0	0	0	0.096	0.186	0.201	0.203
	2	6000.0	1000.0	0.608	0.101	0	0	0	0	0.067	0.087	0.099	0.101	0.101	0.101	0.101
	3	6000.0	3000.0	0.608	0.304	0.034	0.127	0.276	0.302	0.303	0.304	0.304	0.304	0.304	0.304	0.304
				Total	0.608	0.034	0.127	0.276	0.302	0.370	0.391	0.403	0.501	0.591	0.606	0.608
					(0.608)	(0.034)	(0.127)	(0.276)	(0.302)	(0.370)	(0.391)	(0.403)	(0.501)	(0.591)	(0.606)	(0.608)
4	1	6000.0	2000.0	0.767	0.256	0	0	0	0	0	0	0	0.136	0.247	0.256	0.256
	2	6000.0	1000.0	0.767	0.128	0	0	0	0	0.100	0.121	0.127	0.128	0.128	0.128	0.128
	3	6000.0	3000.0	0.767	0.384	0.052	0.182	0.368	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
				Total	0.768	0.052	0.182	0.368	0.384	0.484	0.505	0.511	0.648	0.759	0.768	0.768
					(0.767)	(0.052)	(0.182)	(0.368)	(0.383)	(0.483)	(0.504)	(0.511)	(0.647)	(0.758)	(0.767)	(0.767)
				Total	1.376	0.086	0.309	0.644	0.686	0.854	0.896	0.914	1.149	1.350	1.374	1.376
					(1.375)	(0.086)	(0.309)	(0.644)	(0.686)	(0.853)	(0.895)	(0.914)	(1.148)	(1.349)	(1.373)	(1.375)

* Results from CSETT are shown in parentheses for comparison.

Example Problem A2

3. In this example, settlements are computed under a levee and berm fill. Soil stratification and load cross sections are shown in Figure A4. Loads are assumed to be instantaneous. Void ratio-$\log_{10}$ pressure curves used in the analysis are plotted in Figure A5. Soil properties are summarized in Table A7.

4. The input data file used to generate the CSETT solution is listed in Figure A6. Output is requested at 20-ft intervals extending 60 ft from the levee centerline in both directions. A geometric progression is used to generate times for time-rate calculations using the default parameters.

5. A hand solution of settlement at the levee centerline is provided for comparison (Tables A8-A10). Results of the hand solution and the CSETT solution are compared in Table A11.

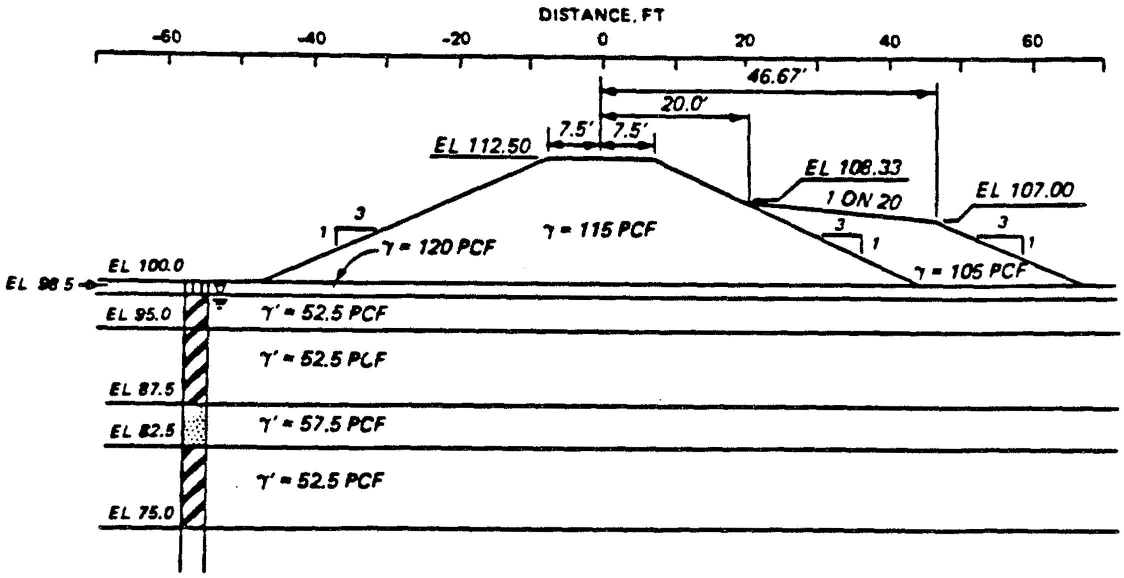


Figure A4. Soil stratification and loads for Example Problem A2

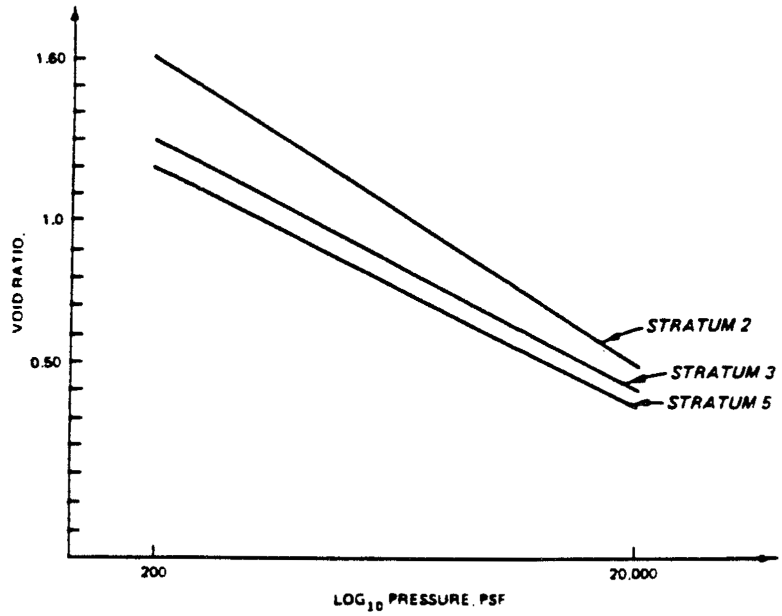


Figure A5. Field compression curves for Example Problem A2

Table A7

Soil Properties for Example Problem A2

Stratum No.	El of top of Stratum ft NGVD	Eff Unit Weight pcf	Consolidation Data C_v (ft^2/yr)	e_o	P_o psf	C_R	C_c
1	100.00	120.00	--	--	--	--	--
2	98.50	52.50	20.0	*	*		*
3	95.00	52.50	15.0	*	*		*
4	87.50	57.50	--	--	--	--	--
5	82.50	52.50	50.0	*	*		*
6	75.00	57.50	--	--	--	--	--

* Input curve (see Figure A5).

SOLUTION BY CSETT

```
*LIST LEVE

010  TITLE
020  SETTLEMENT UNDER LEVEE SECTION
030  2DSO 1  8  0.0  0.0  105.0 (2DSOIL LOAD DATA NL N T1ML TLM2 GAM)
040  -9999. 100.0  -45.0  100.0  -7.5 112.5  7.5  112.5  20.0  108.33
050  46.67  107.0  67.67  100.0  9999.  100.0 (Xi Yi ..., i=1, N)
060  2DSO  2  6  0.0  0.0  115.0 (2DSOIL LOAD DATA NL N TLML TLM2 GAM)
070  -9999.  100.0  -45.0  100.0  -7.5  112.5  7.5  112.5  45.0  100.0
080  9999.  100.0  (Xi Yi ... i=1, N)
090  SOIL  1 100.0 N 120.0 (SOIL DATA N EL NDC GAM)
100  SOIL 2  98.5  S  52.5  .07  20.0 (SOIL DATA N EL NDC GM CR CV)
110  VOID 2  (VOID RATIO PRESSURE CURVE NP)
120  1.6  200.0  .50  20000.0  (ORi ABi ..., i=1, NP)
130  SOIL 3  95.0  S  52.5  .05  10.0  (SOIL DATA N EL NDC GM CR CV)
140  VOID 2 (VOID RATIO PRESSURE CURVE NP)
150  1.3  200.0  .40  20000.0 (ORi ABi ..., i=1, NP)
160  SOIL 4  87.5  N  57.5 (SOIL DATA N EL NDC GM)
170  SOIL 5  82.5  D  52.5  .04  16.0 (SOIL DATA N EL NDC GM CR CV)
180  VOID 2  (VOID RATIO PRESSURE CURVE NP)
190  1.2  200.0  .35  20000.0 (ORi ABi ..., i=1, NP)
200  SOIL 6  75.0  N 57.5 (SOIL DATA N EL NDC GM)
210  BOUS 25.0 (BOUSSINESQ DMAX)
220  TIMI (GEOMETRIC PROGRESSION W/DEFAULT VALUES)
230  OUTP -60  60  20  (OUTPUT XL XR SP)
240  END (TERMINATION)
```

Figure A6. Input data file for Example Problem A2

```
IS INPUT FROM TERMINAL OR A FILE
ENTER T OR F
=F


ENTER DATA FILE NAME
=LEVE


INPUT COMPLETE. DO YOU WANT INPUT DATA
ECHOPRINTED TO YOUR TERMINAL, A FILE,
BOTH, OR NEITHER? (ENTER T, F, B, OR N)
=T
```

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE:   7/12/83                                        TIME:   9:41:55


I.   INPUT DATA


1. TITLE - SETTLEMENT UNDER LEVEE SECTION


2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
   THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
   IS   25.00 FEET.


3. 2-DIMENSIONAL PRESSURE LOAD DATA
   NONE
```

4. 2-DIMENSIONAL SOIL LOAD DATA

PROFILE NUMBER 1 :NUMBER OF POINTS= 8
BEGINNING TIME OF APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.
EFFECTIVE UNIT WEIGHT OF SOIL LOAD= 105.00 PCF

POINT NO.	X (FT.)	Y (FT.)
1	-9999.00	100.00
2	-45.00	100.00
3	-7.50	112.50
4	7.50	112.50
5	20.00	108.33
6	46.67	107.00
7	67.67	100.00
8	9999.00	100.00

PROFILE NUMBER 2 :NUMBER OF POINTS= 6
BEGINNING TIME OF APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.
EFFECTIVE UNIT WEIGHT OF SOIL LOAD= 115.00 PCF

POINT NO.	X (FT.)	Y (FT.)
1	-9999.00	100.00
2	-45.00	100.00
3	-7.50	112.50
4	7.50	112.50
5	45.00	100.00
6	9999.00	100.00

5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
NONE

6. 3-DIMENSIONAL IRREGULAR LOAD DATA
NONE

7. EXCAVATION DATA
NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	100.00	N	120.00			
2	98.50	S	52.50	0.07000	20.00000	0.32000
3	95.00	S	52.50	0.05000	10.00000	0.32000
4	87.50	N	57.50			
5	82.50	D	52.50	0.04000	16.00000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

STRATUM NO. 2

VOID RATIO	PRESSURE (PSF)
1.6000	200.0000
0.5000	20000.0000

STRATUM NO. 3

VOID RATIO	PRESSURE (PSF)
1.3000	200.0000
0.4000	20000.0000

STRATUM NO. 4

INCOMPRESSIBLE STRATUM

STRATUM NO. 5

VOID RATIO	PRESSURE (PSF)
1.2000	200.0000
0.3500	20000.0000

10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS

A GEOMETRIC PROGRESSION WITH AN INITIAL TIME PERIOD OF 0.0192 YEARS AND A MULTIPLICATIVE FACTOR OF 2.0000 WILL BE USED IN THE TIME RATE OF CONSOLIDATION CALCULATIONS.

11. OUTPUT CONTROL DATA

```
  XXL=    0.      FT.
  XUL=    5.0000  FT.
 DELX=   10.0000  FT.
```

DO YOU WANT TO EDIT DATA? ENTER 'Y' OR 'N'.
=N

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 11/17/82 TIME: 9:54:26

II. OUTPUT SUMMARY.

1. TITLE- SETTLEMENT UNDER LEVEE SECTION

2. SUMMARY OF TIME SETTLEMENT DATA.

```
PLANE OF INTEREST: XRIGHT=    0.
                    XLEFT=    5.0
                     DELX=   10.0
```

TIME (YR)	X= 0.
ULT.	1.995
0.02	0.265
0.04	0.374
0.08	0.528
0.15	0.747
0.31	1.030
0.61	1.329
1.23	1.563
2.45	1.752
4.91	1.912
9.82	1.985
19.64	1.995
39.28	1.995
78.55	1.995

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/12/83 TIME: 9:43: 3

II. OUTPUT SUMMARY.

1. TITLE- SETTLEMENT UNDER LEVEE SECTION

POSITION: X= 0.
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.75	90.00	1437.40	0.
2	3.25	271.88	1432.65	0.610
3	8.75	560.63	1385.40	0.879
4	15.00	901.25	1299.10	0.
5	21.25	1241.88	1204.80	0.506

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.02 (YRS.)	0.04 (YRS.)	0.08 (YRS.)	0.15 (YRS.)	0.31 (YRS.)	0.61 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.610	0.122	0.173	0.244	0.344	0.467	0.569
3	0.879	0.058	0.082	0.116	0.164	0.231	0.327
4	0.	0.	0.	0.	0.	0.	0.
5	0.506	0.085	0.119	0.168	0.239	0.332	0.433
TOTALS:	1.995	0.265	0.374	0.528	0.747	1.030	1.329

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	1.23 (YRS.)	2.45 (YRS.)	4.91 (YRS.)	9.82 (YRS.)	19.64 (YRS.)	39.28 (YRS.)	78.55 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.608	0.610	0.610	0.610	0.610	0.610	0.610
3	0.462	0.636	0.796	0.869	0.879	0.879	0.879
4	0.	0.	0.	0.	0.	0.	0.
5	0.493	0.506	0.506	0.506	0.506	0.506	0.506
TOTALS:	1.563	1.752	1.912	1.985	1.995	1.995	1.995

HAND VERIFICATION: SETTLEMENTS UNDER ℄ LEVEE SECTION

Table A8

Internally Generated Stratification for Example Problem A2

Input Stratum No.	Internally Generated Stratum No.	Thickness for Compression Calculations ft	Eff Thickness for Consolidation Calculations ft	Drainage Condition
1	2	--	--	N
2	3	1.75	3.5	S
	4	1.75	3.5	S
3	5	2.50	7.5	S
	6	2.50	7.5	S
	7	2.50	7.5	S
4	8	--	--	N
	9	--	--	N
5	10	2.50	7.5	D
	11	2.50	7.5	D
	12	2.50	7.5	D

Note: The stratification generated by CSETT will be used in this solution.

Table A9

Summary of Stresses and Settlements for Example Problem A2

Stratum No.	P_o psf	e_o	ΔP_{Loads} psf	P_{Final} psf	ΔH_{ULT} ft
2	--	--	--	--	--
3	225.94	1.571	1436	1662	0.324
4	317.81	1.489	1430	1748	0.286
5	429.38	1.151	1414	1843	0.331
6	560.63	1.099	1388	1949	0.290
7	691.88	1.057	1354	2046	0.258
8	--	--	--	--	--
9	--	--	--	--	--
10	1110.63	0.884	1242	2353	0.184
11	1241.88	0.863	1204	2446	0.168
12	1373.13	0.844	1168	2541	0.154

Note: P_o = in situ overburden (see previous calculations)

e_o = in situ void ratio (see previous calculations)

ΔP_{Loads} = induced stresses (from CSETT)

$P_{Final} = P_o + \Delta P_{Loads}$

ΔH_{ULT} = Ultimate settlements (see following computations)

Calculations for Table A9

a. Computation of in situ overburden (P_o) and void ratio (e_o):

Stratum 3

$$P_o = 1.5 \times 120.0 + \frac{1.75}{2.0} \times 52.5 = 225.94 \text{ psf}$$

$$e_o = e_1 - C_c \log_{10} \frac{P_o}{P_1}$$

$$C_c = \frac{e_1 - e_2}{\log_{10} P_2 - \log_{10} P_1} = \frac{1.60 - 0.50}{\log_{10} 20{,}000 - \log_{10} 200} = 0.550$$

$$e_o = 1.60 - 0.55 \log_{10} \frac{225.94}{200.0} = 1.571$$

Stratum 4

$$P_o = 225.94 + 1.75\ (57.5) = 317.81 \text{ psf}$$

$$e_o = 1.6 - 0.55 \log_{10} \frac{317.81}{200} = 1.489$$

Stratum 5

$$P_o = 1.5 \times 120 + 3.5 \times 52.5 + \frac{2.50}{2.0} \times 52.5 = 429.38 \text{ psf}$$

$$C_c = \frac{1.30 = 0.40}{\log_{10} 20000 - \log_{10} 200} = 0.450$$

$$e_o = 1.30 - 0.45 \log_{10} \frac{429.38}{200.0} = 1.151$$

Stratum 6

$$F_o = 429.38 + 2.5(52.5) = 560.63 \text{ psf}$$

$$e_o = 1.3 - 0.45 \log_{10} \frac{560.63}{200.0} = 1.099$$

Stratum 7

$$P_o = 560.63 + 2.5(52.5) = 691.88 \text{ psf}$$

$$e_o = 1.3 - 0.450 \log_{10} \frac{691.88}{200.0} = 1.057$$

Stratum 10

$$P_o = 1.5 \times 120 + 11.0 \times 52.5 + 5.0 \times 57.5 + 1.25 \times 52.5 = 1110.63 \text{ psf}$$

$$C_c = \frac{1.20 - 0.35}{\log_{10} 20000 - \log_{10} 200} = 0.425$$

$$e_o = 1.20 - \log_{10} \frac{1110.63}{200.0} = 0.884$$

Stratum 11

$$P_o = 110.63 + 2.5(52.5) = 1241.88 \text{ psf}$$

$$e_o = 1.20 - 0.425 \log_{10} \frac{1241.88}{200.0} = 0.863$$

Stratum 12

$$P_o = 1241.88 + 2.5(52.5) = 1373.13 \text{ psf}$$

$$e_o = 1.20 - 0.425 \log_{10} \frac{1373.13}{200.0} = 0.844$$

b. Computation of ultimate settlements:

Stratum 3

$$\Delta H_{ULT} = \frac{HC_c}{1 + e_o} \log_{10} \frac{P_{final}}{P_o} = \frac{1.75(0.550)}{1 + 1.571} \log_{10} \frac{1662}{225.74} = 0.324 \text{ ft}$$

Stratum 4

$$\Delta H_{ULT} = \frac{1.75(0.55)}{1 + 1.489} \log_{10} \frac{1748}{317.8} = 0.286 \text{ ft}$$

Stratum 5

$$\Delta H_{ULT} = \frac{2.50(0.45)}{1 + 1.151} \log_{10} \frac{1843}{429.4} = 0.331 \text{ ft}$$

Stratum 6

$$\Delta H_{ULT} = \frac{2.5(0.45)}{1 + 1.099} \log_{10} \frac{1949}{560.6} = 0.290 \text{ ft}$$

Stratum 7

$$\Delta H_{ULT} = \frac{2.5(0.45)}{1 + 1.057} \log_{10} \frac{2046}{691.9} = 0.258 \text{ ft}$$

Stratum 10

$$\Delta H_{ULT} = \frac{2.5(0.425)}{1 + 0.884} \log_{10} \frac{2353}{1110.6} = 0.184 \text{ ft}$$

Stratum 11

$$\Delta H_{ULT} = \frac{2.5(0.425)}{1 + 0.863} \log_{10} \frac{2446}{1242} = 0.168 \text{ ft}$$

Stratum 12

$$\Delta H_{ULT} = \frac{2.5(0.425)}{1 + 0.844} \log_{10} \frac{2541}{1373} = 0.154 \text{ ft}$$

Table A10

Time-Rate of Consolidation Calculations for Example Problem A2

Stratum* No.	ΔH_{ULT}** ft	H ft	C_v ft^2/yr	t yr	T	U %	Settlement ft
3&4 (2)	0.610	3.5	20.0	0.019	0.031	19.9	0.121
				0.077	0.126	40.0	0.244
				0.307	0.501	76.5	0.466
				1.227	2.003	99.4	0.606
				4.910	8.016	100.0	0.610
				19.638	32.06	100.0	0.610
5,6,& 7 (3)	0.879	7.5	10.0	0.019	0.003	6.6	0.058
				0.077	0.014	13.2	0.116
				0.307	0.055	26.4	0.232
				1.227	0.218	52.6	0.462
				4.910	0.873	90.6	0.796
				19.638	3.491	100.0	0.879
10,11, & 12 (5)	0.506	3.75	16.0	0.019	0.022	16.6	0.084
				0.077	0.088	33.4	0.169
				0.307	0.349	65.8	0.333
				1.227	1.396	97.4	0.493
				4.910	5.586	100.0	0.506
				19.638	22.34	100.0	0.506

* Numbers in parentheses indicate input stratification.

** Total settlement for indicated stratum.

Note: For instantaneous loading and a linear initial distribution of excess pore pressure:

$$U\% = \left[1 - \sum_{m=o}^{\geq} \frac{2}{m^2} \, EXP^{-M^2 T_y} \right] \times 100$$

where

$$M = \frac{(2m + 1)\pi}{2} \;, m = o, 1, 2, \ldots .$$

$$T_v = \frac{C_{vt}}{H^2}$$

Table A11

Summary of Time-Settlement Data for Example Problem A2*

Stratum. No.	ΔH_{ULT} ft	Settlement, ft, At Indicated Time 0.019 yr	0.077 yr	0.307 yr	1.227 yr	4.910 yr	19.638 yr
2	(0.610) 0.610	(0.122) 0.121	(0.244) 0.244	(0.467) 0.466	(0.608) 0.606	(0.610) 0.610	(0.610) 0.610
3	(0.879) 0.879	(0.058) 0.058	(0.116) 0.116	(0.231) 0.232	(0.462) 0.462	(0.796) 0.796	(0.879) 0.879
5	(0.506) 0.506	(0.085) 0.084	(0.168) 0.169	(0.332) 0.333	(0.493) 0.493	(0.506) 0.506	(0.506) 0.506
Total	(1.995) 1.995	(0.265) 0.263	(0.528) 0.529	(1.030) 1.031	(1.563) 1.561	(1.912) 1.912	(1.995) 1.995

* Results of the CSETT solution are shown in parentheses for comparison.

Example Problem A3

6. This example is provided to illustrate the analysis of irregular two-dimensional loads combined with a construction excavation. Soil stratification and load cross sections are shown in Figure A7. The load due to a U-frame lock system is shown in Figures A8 and A9. Input soil properties are listed in Table A12. The void ratio-$\log_{10}$ pressure curve for stratum 1 is plotted in Figure A10. Ramp loads are used to simulate the construction and backfill sequence as shown in Figure A11.

7. The input data file used to generate the CSETT solution is listed in Figure A12. Output is generated at 30-ft intervals extending 120 ft either side of the centerline of the U-frame section. Time-rate calculations are made at 0.10, 0.25, 0.50, 1.00, 2.00, 2.25, 2.50, 5.00, and 10.00 years.

8. A hand solution of settlements under the centerline of the U-frame is provided for comparison (Tables A13-A17). Results of the hand solution and the CSETT solution are compared in Table A18.

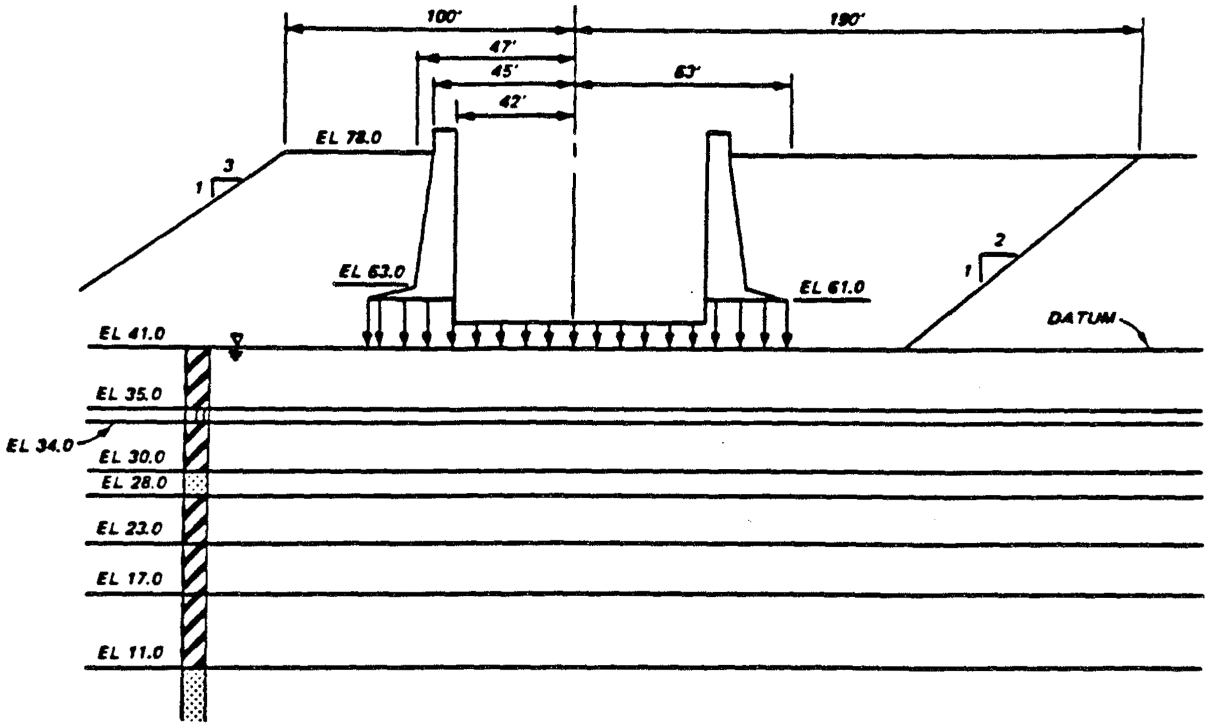


Figure A7. Soil stratification and loads for Example Problem A3 (not to scale)

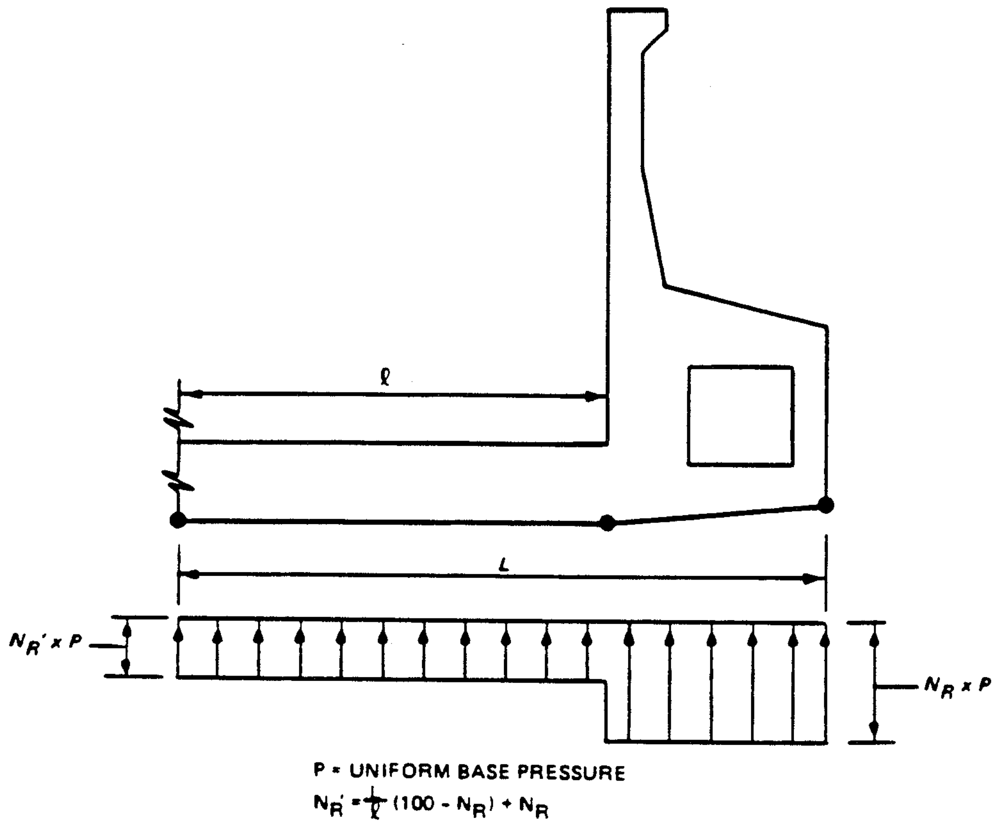


Figure A8. Assumed pressure distribution for U-frame section

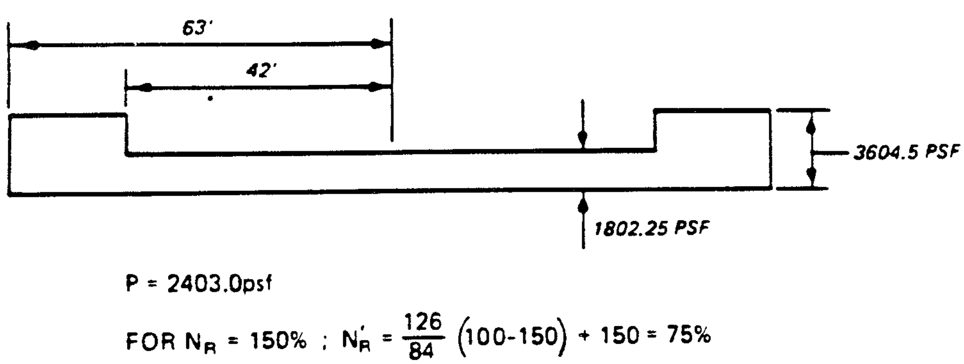


Figure A9. Pressures under U-frame section

Table A12

Soil Properties for Example Problem A3

Stratum No.	El of Top of Stratum ft NGVD	Eff Unit Weight pcf	Consolidation Data				
			C_v ft^2/yr	e_o	P_o psf	C_r	C_c
1	41.0	52.5	17.0	*	*	0.110	*
2	35.0	57.5	--	--	--	--	--
3	34.0	52.5	16.0	1.40	4917.50	0.072	0.52
4	30.0	57.5	--	--	--	--	--
5	28.0	52.5	11.0	1.60	5268.75	0.040	0.41
6	23.0	52.5	11.0	1.51	5557.50	0.035	0.35
7	17.0	52.5	11.0	1.30	5872.50	0.028	0.30
8	11.0	57.5	--	--	--	--	--

* Input curve (see Figure A10).

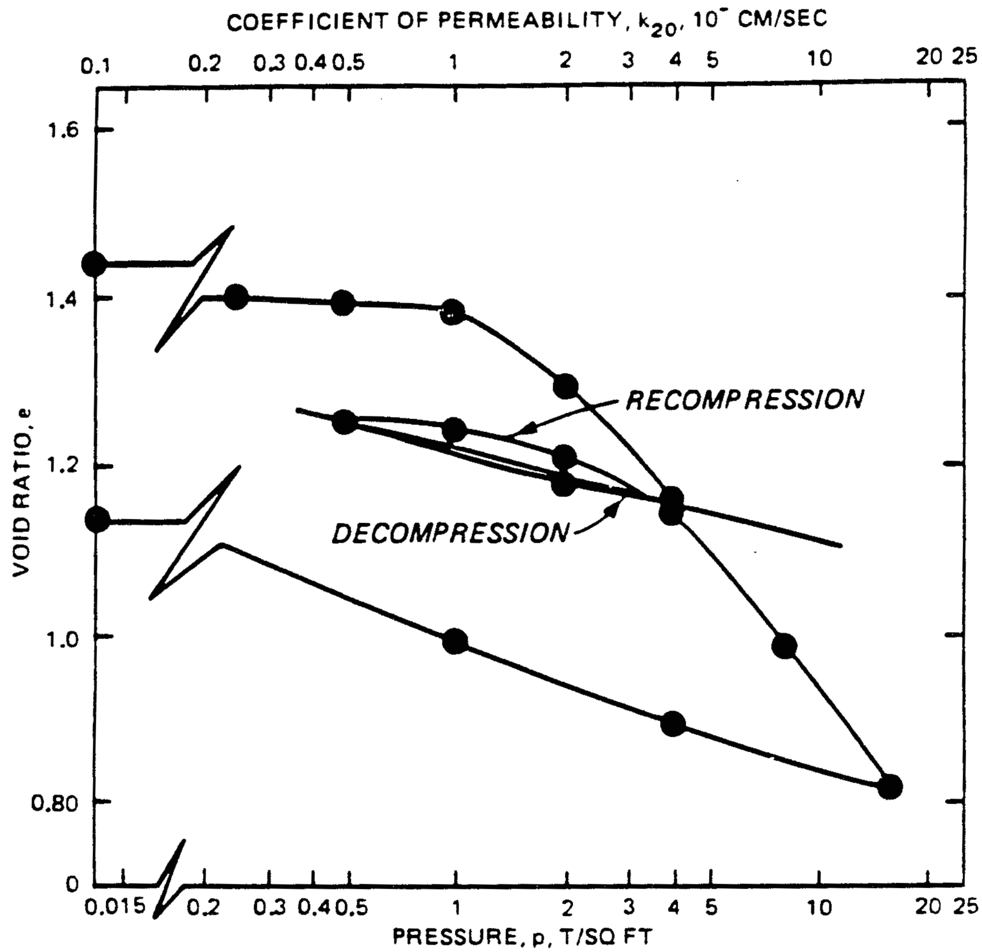


Figure A10. Laboratory compression curve for stratum 1

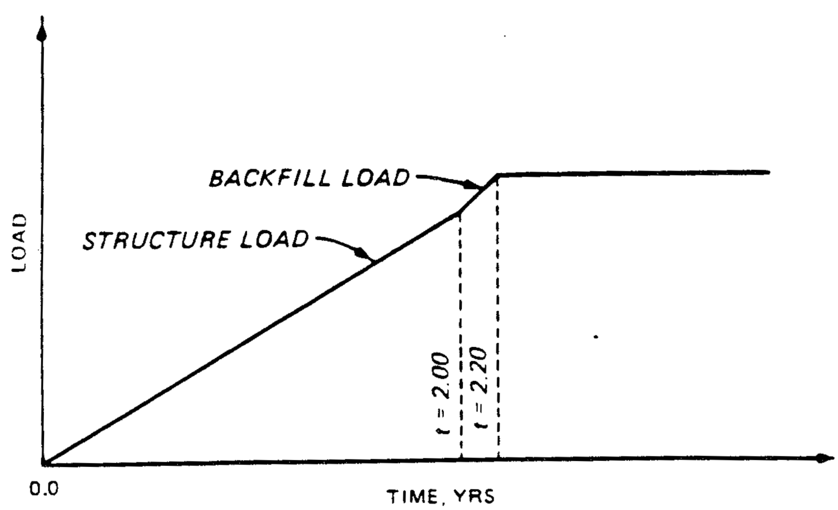


Figure A11. Loading sequence for Example Problem A3

SOLUTION BY CSETT

```
10 TITLE
20 CALION LOCK SETTLEMENTS
30 2DPR 1 10 0 2 (2DPRESSURE LOAD DATA NL N TIM1 TIM2)
40 -9999 0 -63 0 -63 3604.5 -42 3604.5 -42 1802.25 (Xi, Yi...., i = 1,N)
50 42 1802.25 42 3604.5 63 3604.5 63 0 9999 0
60 2DSO 2 14 2 2.2 130 (2DSOIL LOAD DATA NL N TIM1 TIM2 GAM)
70 -9999 41 -211 41 -100 78 -45 78 -47 63
80 -63 61 -63 41 63 41 63 61
90 47 63 45 78 190 78 116 41 9999 41   (Xi, Yi .... i = 1,N)
100 EXCA 4 120 (EXCAVATION DATA N GAM)
110 -9999 41 116 41 190 78 9999 78 (Xi Yi.... i = 1,N)
120 SOIL 1 41 D 52.5 .11 17 (SOIL DATA N EL NDC GM CR CV ST)
130 VOID 8 (VOID RATIO - PRESSURE CURVE DATA NP)
140 1.44 30 1.4 500 1.39 1000 1.38 2000
150 1.3 4000 1.15 7000 .9 16000 .82 32000 (ORi ABi...., i = 1,NP)
160 SOIL 2 35 N 57.5 (SOIL DATA N EL NDC GM CR CV ST)
170 SOIL 3 34 D 52.5 .072 16 (SOIL DATA N EL NDC GM CR CV ST)
180 INDEX .52 4917.5 1.4 (INDEX PROPERTIES CC PO EO)
190 SOIL 4 30 N 57.5 (SOIL DATA N EL NDC GM CR CV ST)
200 SOIL 5 28 D 52.5 .04 11 (SOIL DATA N EL NDC GM CR CV ST)
210 INDEX .41 5268.75 1.6 (INDEX PROPERTIES CC PO EO)
220 SOIL 6 23 C 52.5 .035 11 (SOIL DATA N EL NDC GM CR CV ST)
230 INDEX .35 5557.5 1.51 (INDEX PROPERTIES CC PO EO)
240 SOIL 7 17 C 52.5 .028 11 (SOIL DATA N EL NDC GM CR CV ST)
250 INDEX .3 5872.5 1.3 (INDEX PROPERTIES CC PO EO)
260 SOIL 8 11 N 57.5 (SOIL DATA N EL NDC GM CR CV ST)
270 BOUS 35 (BOUSSINESQ DMAX)
280 TIMS .1 .25 .5 1. 2. 2.25 2.5 5. 10. (SPECIFIED TIMES T1 T2 T3....)
290 OUTP 0 5 10 (OUTPUT XL XR SP)
300 END (TERMINATION)
```

Figure A12. Input data file for Example Problem A3

```
IS INPUT FROM TERMINAL OR A FILE
ENTER T OR F
=F


ENTER DATA FILE NAME
=CALION


INPUT COMPLETE. DO YOU WANT INPUT DATA
ECHOPRINTED TO YOUR TERMINAL, A FILE,
BOTH, OR NEITHER? (ENTER T, F, B, OR N)
=T
```

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 6/83 TIME: 9: 1:60

I. INPUT DATA

1. TITLE - CALION LOCK SETTLEMENTS

2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES . THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED IS 35.00 FEET.

3. 2-DIMENSIONAL PRESSURE LOAD DATA

LOAD NUMBER 1 : NUMBER OF POINTS= 10
BEGINNING TIME OF APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 2.0000 YRS.

POINT NO.	X (FT.)	PRESSURE (PSF)
1	-9999.00	0.
2	-63.00	0.
3	-63.00	3604.50
4	-42.00	3604.50
5	-42.00	1802.25
6	42.00	1802.25
7	42.00	3604.50
8	63.00	3604.50
9	63.00	0.
10	9999.00	0.

4. 2-DIMENSIONAL SOIL LOAD DATA

PROFILE NUMBER 2 :NUMBER OF POINTS= 14
BEGINNING TIME OF APPLICATION = 2.0000 YRS.
ENDING TIME OF APPLICATION = 2.2000 YRS.
EFFECTIVE UNIT WEIGHT OF SOIL LOAD= 130.00 PCF

POINT NO.	X (FT.)	Y (FT.)
1	-9999.00	41.00
2	-211.00	41.00
3	-100.00	78.00
4	-45.00	78.00
5	-47.00	63.00
6	-63.00	61.00
7	-63.00	41.00
8	63.00	41.00
9	63.00	61.00
10	47.00	63.00
11	45.00	78.00
12	190.00	78.00
13	116.00	41.00
14	9999.00	41.00

5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
NONE

6. 3-DIMENSIONAL IRREGULAR LOAD DATA
NONE

7. EXCAVATION DATA

NUMBER OF POINTS DEFINING EXCAVATED PROFILE= 4
EFFECTIVE UNIT WEIGHT OF EXCAVATED MATERIAL= 120.00 PCF

POINT NO.	X (FT.)	Y (FT.)
1	-9999.00	41.00
2	116.00	41.00
3	190.00	78.00
4	9999.00	78.00

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	41.00	D	52.50	0.11000	17.00000	0.32000
2	35.00	N	57.50			
3	34.00	D	52.50	0.07200	16.00000	0.32000
4	30.00	N	57.50			
5	28.00	D	52.50	0.04000	11.00000	0.32000
6	23.00	C	52.50	0.03500	11.00000	0.32000
7	17.00	C	52.50	0.02800	11.00000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

VOID RATIO	PRESSURE (PSF)
1.4400	30.0000
1.4000	500.0000
1.3900	1000.0000
1.3800	2000.0000
1.3000	4000.0000
1.1500	7000.0000
0.9000	16000.0000
0.8200	32000.0000

STRATUM NO. 2

INCOMPRESSIBLE STRATUM

STRATUM NO. 3

COMPRESSION INDEX= 0.52000
RECOMPRESSION INDEX= 0.07200
INSITU VOID RATIO= 1.40000
INSITU OVERBURDEN= 4917.50 PSF

STRATUM NO. 4

INCOMPRESSIBLE STRATUM

```
          STRATUM NO.   5
          ---------------
   COMPRESSION INDEX= 0.41000
 RECOMPRESSION INDEX= 0.04000
    INSITU VOID RATIO= 1.60000
    INSITU OVERBURDEN= 5268.75 PSF

          STRATUM NO.   6
          ---------------
   COMPRESSION INDEX= 0.35000
 RECOMPRESSION INDEX= 0.03500
    INSITU VOID RATIO= 1.51000
    INSITU OVERBURDEN= 5557.50 PSF

          STRATUM NO.   7
          ---------------
   COMPRESSION INDEX= 0.30000
 RECOMPRESSION INDEX= 0.02800
    INSITU VOID RATIO= 1.30000
    INSITU OVERBURDEN= 5872.50 PSF


10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS


     TIME RATE OF CONSOLIDATION CALCULATIONS WILL BE MADE
     AT TIMES (YRS):
                          0.10
                          0.25
                          0.50
                          1.00
                          2.00
                          2.25
                          2.50
                          5.00
                         10.00


11. OUTPUT CONTROL DATA


      XXL=     0.       FT.
      XUL=     5.0000 FT.
     DELX=    10.0000 FT.


WILL OUTPUT GO TO TERMINAL, FILE, OR BOTH?
ENTER T, F, OR B
=
```

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/ 6/83 TIME: 9:10: 8

II. OUTPUT SUMMARY.

1. TITLE- CALION LOCK SETTLEMENTS

POSITION: X= 0.
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	3.00	4597.50	1803.05	0.314
2	6.50	4783.75	1806.80	0.
3	9.00	4917.50	1814.50	0.080
4	12.00	5080.00	1829.20	0.
5	15.50	5268.75	1857.75	0.039
6	21.00	5557.50	1924.25	0.036
7	27.00	5872.50	2023.75	0.027

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.10 (YRS.)	0.25 (YRS.)	0.50 (YRS.)	1.00 (YRS.)	2.00 (YRS.)	2.25 (YRS.)
1	0.314	0.005	0.020	0.053	0.129	0.286	0.305
2	0.	0.	0.	0.	0.	0.	0.
3	0.080	0.002	0.007	0.017	0.036	0.076	0.080
4	0.	0.	0.	0.	0.	0.	0.
5	0.039	0.	0.	0.002	0.006	0.016	0.019
6	0.036	0.	0.	0.002	0.005	0.014	0.017
7	0.027	0.	0.	0.002	0.004	0.010	0.012
TOTALS:	0.496	0.007	0.027	0.076	0.180	0.402	0.433

```
              (SETTLEMENT IN FEET AT SPECIFIED TIMES)
STRATA       2.50    5.00   10.00
   NO       (YRS.)  (YRS.)  (YRS.)
------      ------  ------  ------

   1        0.311   0.314   0.314
   2        0.      0.      0.
   3        0.080   0.080   0.080
   4        0.      0.      0.
   5        0.021   0.031   0.038
   6        0.019   0.029   0.035
   7        0.014   0.022   0.027

TOTALS:     0.445   0.476   0.494

DO YOU WANT A PLOT OF STRESS BULBS ?
ENTER Y OR N.
=N


DO YOU WANT TO MAKE ANOTHER RUN?
ENTER Y OR N
=
```

HAND SOLUTION OF SETTLEMENTS UNDER ℄
OF U-FRAME

Table A13

Internally Generated Stratification for Example Problem A3

Input Stratum No.	Internally Generated Stratum No.	Thickness for Compression Calculations ft	Eff Thickness for Consolidation Calculations ft	Drainage Condition
1	2	3.0	6.0	D
	3	3.0	6.0	D
2	4	1.0	--	N
3	5	2.0	4.0	D
	6	2.0	4.0	D
4	7	2.0	--	N
5	8	2.5	17.0	D
	9	2.5	17.0	D
6	10	3.0	17.0	D
	11	3.0	17.0	D
7	12	3.0	17.0	D
	13	3.0	17.0	D

Note: The stratification generated by CSETT will be used in this solution.

Table A14

Summary of Stresses and Ultimate Settlements for Example Problem A3

Stratum No.	P_o psf	e_o	ΔP_{EXC} psf	P_{Post} psf	e_{post}	ΔP_{Load} psf	ΔP_{Final} psf	ΔH_{ULT} ft
2	4519	1.267	4440	79	1.460	1802	1881	0.185
3	4676	1.258	4440	236	1.401	1804	2040	0.129
4	--	--	--	--	--	--	--	--
5	4865	1.400	4440	425	1.476	1811	2236	0.042
6	4970	1.398	4440	530	1.468	1818	2348	0.038
7	--	--	--	--	--	--	--	--
8	5203	1.600	4439	764	1.633	1846	2610	0.020
9	5334	1.598	4439	895	1.629	1903	2798	0.019
10	5478	1.510	4438	1040	1.535	1903	2943	0.019
11	5636	1.508	4437	1199	1.532	1946	3145	0.017
12	5794	1.300	4435	1359	1.318	1996	3355	0.014
13	5951	1.298	4433	1518	1.315	2052	3570	0.013

Note: P_o = pre-excavation overburden (see computations)

e_o = pre-excavation void-ratio (see computations)

ΔP_{EXC} = stress relief due to excavation (from CSETT)

P_{Post} = post-excavation stress = P_o - P_{EXC}

e_{post} = post-excavation void ratio (see computations)

ΔP_{Load} = induced stress due to loads (from CSETT)

ΔP_{Final} = stress after excavation and load application = P_{Post} + P_{Load}

ΔH_{ULT} = total settlement under applied loads (see computations)

Calculations for Table A14

a. Calculation of pre-excavation overburden (P_o) and void ratio (e_o):

Stratum 2

$$P_o = (78 - 41)\ 120 + \frac{3.0}{2}\ (52.5) = 4519 \text{ psf}$$

Interpolate between appropriate points on input curve for e_o

e	Log_{10} P
1.30	3.6021
1.30-x	3.6550
1.15	3.8451

$$\frac{1.30 - (1.30-X)}{1.30 - 1.15} = \frac{3.6021 - 3.6550}{3.6021 - 3.8451}$$

$$X = 0.0327$$

$$e_o = 1.30\text{-}X = 1.267$$

Stratum 3

$$P_o = 4519 + 3.0\ (52.5) = 4676 \text{ psf}$$

e	Log_{10} P
1.30	3.6021
1.30-X	3.6699
1.15	3.8451

$$\frac{1.30 - (1.30-X)}{1.30 - 1.15} = \frac{3.6021 - 3.6699}{3.6021 - 3.8451}$$

$$X = 0.0418$$

$$e_o = 1.30\text{-}\ X = 1.258$$

Stratum 5

$$P_o = 4676 + 1.5\ (52.5) + 1.0\ (57.5) + 1.0\ (52.5) = 4865 \text{ psf}$$

Since $P_o < P_{OINPUT}$, compute e_o using C_R

$$e_o = e_{OINPUT} - C_R\ Log_{10} \frac{Po}{P_{OINPUT}} = 1.40 - 0.072\ \log_{10} \frac{4865}{4917.5} = 1.400$$

Stratum 6

$$P_o = 4865 + 2.0\ (52.5) = 4970 \text{ psf}$$

$P_o > P_{OINPUT}$, so compute e_o using C_c

$$e_o = e_{OINPUT} \quad C_c\ \log_{10} \frac{P_o}{P_{OINPUT}} = 1.40 - 0.52\ \log_{10} \frac{4970}{4917.5} = 1.398$$

Stratum 8

$$P_o = 4970 + 1.0\ (52.5) + 2.0\ (57.5) + 1.25\ (52.5) = 5203 \text{ psf}$$

$P_o < P_{OINPUT}$, so e_o found on recompression slope

$$e_o = 1.6 - 0.040 \log_{10} \frac{5263}{5268.75} = 1.600$$

Stratum 9

$$P_o = 5203 + 2.5\ (52.5) = 5334 \text{ psf}$$

$P_o > P_{OINPUT}$, so use C_c

$$e_o = 1.6 - 0.41 \log_{10} \frac{5334}{5268.75}\quad 1.598$$

Stratum 10

$$P_o = 5334 + 2.75\ (52.5) = 5478 \text{ psf}$$

$P_o < P_{OINPUT}$, use C_R

$$e_o = 1.51 - 0.035 \log \frac{5478}{5557.5} = 1.51$$

Stratum 11

$$P_o = 5478 + 3.0\ (52.5) = 5636$$

$$e_o = 1.51 - 0.35 \log_{10} \frac{5636}{5557} = 1.508$$

Stratum 12

$$P_o = 5636 + 3.0\ (52.5) = 5794$$

$$e_o = 1.30 - 0.028 \log_{10} \frac{5794}{5872} = 1.300$$

Stratum 13

$$P_o = 5794 + 3.0\ (52.5) = 5951 \text{ psf}$$

$$e_o = 1.30 - 0.30 \log_{10} \frac{5951}{5872} = 1.298$$

b. Calculation of post-excavation void ratio (e_{post}) and ultimate settlement (ΔH_{ULT}):

Stratum 2

$$e_{Post} = e_o + \Delta e_{Rebound} = e_o - C_r \log_{10} \frac{P_{post}}{P_o} = 1.267 - 0.11 \log_{10} \frac{79}{4519} = 1.460$$

$$\Delta H_{ULT} = \frac{H}{1 + e_{post}} C_r \log_{10} \frac{P_{Final}}{P_{post}} = \frac{3.0}{1 + 1.460} \; 0.11 \log_{10} \frac{1881}{79} = 0.185$$

Stratum 3

$$e_{Post} = 1.258 - 0.11 \log_{10} \frac{236}{4676} = 1.401$$

$$\Delta H_{ULT} = \frac{3.0}{1 + 1.401} \; 0.11 \log_{10} \frac{2040}{236} = 0.129$$

Stratum 5

$$e_{Post} = 1.400 - 0.072 \log_{10} \frac{425}{4865} = 1.476$$

$$\Delta H_{ULT} = \frac{2.0}{1 + 1.476} \; 0.072 \log_{10} \frac{2236}{425} = 0.042$$

Stratum 6

$$e_{Post} = 1.398 - 0.072 \log_{10} \frac{530}{4970} = 1.468$$

$$\Delta H_{ULT} = \frac{2.0}{1 + 1.468} \; 0.072 \log_{10} \frac{2348}{530} = 0.038$$

Stratum 8

$$e_{Post} = 1.600 - 0.040 \log_{10} \frac{764}{5203} = 1.633$$

$$\Delta H_{ULT} = \frac{2.5}{1 + 1.633} \; 0.040 \log_{10} \frac{2610}{764} = 0.020$$

Stratum 9

$$e_{Post} = 1.598 - 0.040 \log_{10} \frac{895}{5334} = 1.627$$

$$\Delta H_{ULT} = \frac{2.5}{1 + 1.629} \; 0.040 \log_{10} \frac{2798}{895} = 0.019$$

Stratum 10

$$e_{Post} = 1.51 - 0.035 \log_{10} \frac{1040}{5478} = 1.535$$

$$\Delta H_{ULT} = \frac{3.0}{1 + 1.535} 0.035 \log_{10} \frac{2943}{1040} = 0.019$$

Stratum 11

$$e_{Post} = 1.508 - 0.035 \log_{10} \frac{1199}{5636} = 1.532$$

$$\Delta H_{ULT} = \frac{3.0}{1 + 1.532} 0.035 \log_{10} \frac{3145}{1199} = 0.017$$

Stratum 12

$$e_{Post} = 1.300 - 0.028 \log_{10} \frac{1357}{5794} = 1.318$$

$$\Delta H_{ULT} = \frac{3.0}{1 + 1.318} 0.028 \log_{10} \frac{3355}{1359} = 0.014$$

Stratum 13

$$e_{Post} = 1.298 - 0.028 \log_{10} \frac{1518}{5951} = 1.315$$

$$\Delta H_{ULT} = \frac{3.0}{1 + 1.315} 0.028 \log_{10} \frac{3570}{1518} = 0.013$$

Table A15

Time-Rate Calculations for Strata 2 and 3

Load No.	T1M1 yr	T1M2 yr	T_c	TIME yr	Relative Time yr	T	U %
1	0.0	2.00	3.778	0.10	0.10	0.189	1.6
				0.25	0.25	0.472	6.4
				0.50	0.50	0.994	17.0
				1.00	1.00	1.889	41.3
				2.00	2.00	3.778	91.3
				2.25	2.25	4.250	97.3
				2.50	2.50	4.772	99.2
				5.00	5.00	9.444	100.0
				10.00	10.00	18.888	100.0
2	2.00	2.20	0.378	0.10	0.0	0.0	0.0
				0.25	0.0	0.0	0.0
				0.50	0.0	0.0	0.0
				1.00	0.0	0.0	0.0
				2.00	0.0	0.0	0.0
				2.25	0.25	0.472	58.1
				2.50	0.50	0.944	87.0
				5.00	3.00	5.667	100.0
				10.00	8.00	15.111	100.0

Note:

$C_v = 17 ft^2/yr$

$H = 3.0$ ft

Table A16

Time-Rate Calculations for Strata 5 and 6

Load No.	T1M1 yr	T1M2 yr	T_c	TIME yr	Relative Time yr	T	U %
1	0.00	2.00	8.00	0.10	0.10	0.400	2.4
				0.25	0.25	1.00	8.7
				0.50	0.50	2.00	20.9
				1.00	1.00	4.00	45.8
				2.00	2.00	8.00	95.8
				2.25	2.25	9.00	99.7
				2.50	2.50	10.00	100.0
				5.00	5.00	20.00	100.0
				10.00	10.00	40.00	100.0
2	2.00	2.20	0.80	0.10	0.0	0.0	0.0
				0.25	0.0	0.0	0.0
				0.50	0.0	0.0	0.0
				1.00	0.0	0.0	0.0
				2.00	0.0	0.0	0.0
				2.25	0.25	1.00	78.4
				2.50	0.50	2.00	98.2
				5.00	3.00	12.00	100.0
				10.00	8.00	32.00	100.0

Note:

C_v = 16.0 ft^2/yr

H = 2.0 ft.

Table A17

Time-Rate Calculations for Strata 8 Through 13

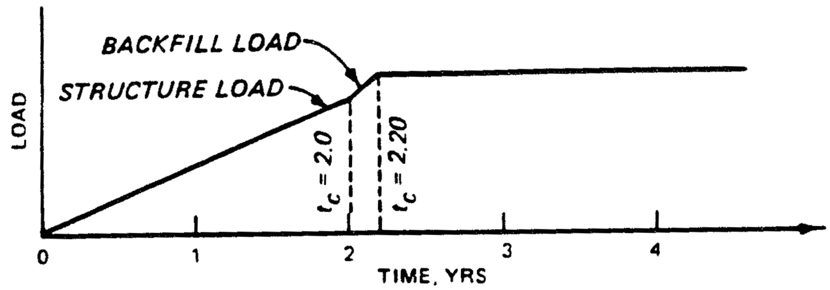
Load No.	T1M1 yr	T1M2 yr	T_c	TIME yr	Relative Time yr	T	U %
1	0.00	2.00	0.304	0.10	0.10	0.015	0.5
				0.25	0.25	0.038	1.9
				0.50	0.50	0.076	5.3
				1.00	1.00	0.152	14.7
				2.00	2.00	0.304	41.5
				2.25	2.25	0.343	47.5
				2.50	2.50	0.381	52.5
				5.00	5.00	0.761	81.5
				10.00	10.00	1.522	97.2
2	2.00	2.20	0.03	0.10	0.0	0.0	0.0
				0.25	0.0	0.0	0.0
				0.50	0.0	0.0	0.0
				1.00	0.0	0.0	0.0
				2.00	0.0	0.0	0.0
				2.25	0.25	0.038	16.9
				2.50	0.50	0.076	27.9
				5.00	3.00	0.457	72.7
				10.00	8.00	1.218	95.8

Note:

C_v = 11.0 ft^2/yr

H = 8.5 ft.

c. Calculations for Tables A15, A16, and A17. Time-rate of consolidation computations (time-dependent loading)



$$T = \frac{C_{vt}}{H^2}$$

$$T_c = \frac{C_v t_c}{H^2}$$

where

C_v = coefficient of consolidation

t_c = length of construction period (i.e., TIM2-TIM1)

H = length of drainage path

for

$$T \leq T_c \quad U = \left(\frac{T}{T_c}\right) \left\{1 - \frac{2}{T} \sum_{m=o}^{\infty} \frac{1}{M^4} \left[1 - EXP(-M^2T)\right]\right\} \times 100$$

$$T \geq T_c \quad U = \left\{1 - \left(\frac{2}{T_c}\right) \sum_{m=o}^{\infty} \frac{1}{M^4} \left[EXP(M^2T_c) - 1\right] EXP(-M^2T)\right\} \times 100$$

where

U = % consolidation

$M = \frac{(2m + 1)\pi}{2}$,m=o, 1, 2, ...

For time-dependent loading, it is assumed that the settlement attributed to each load is proportional to the stress induced by that load, or

$$\frac{\Delta H_i}{\Delta H_{ULT}} = \frac{\Delta P_{Loadi}}{\Delta P_{Load}}$$

Table A18

Summary of Settlements for Example Problem A3*

Stratum** No.	Load No.	ΔP_{Loads} psf	ΔP_{Loadi} psf	ΔH_{ULT} ft	$\Delta H_{ULT} \times \frac{\Delta P_{Loadi}}{\Delta P_{Loads}}$ ft	Settlement, ft, At Specified Time 0.10 yr	0.25 yr	0.50 yr	1.00 yr	2.00 yr	2.25 yr	2.50 yr	5.00 yr	10.00 yr
1_2	2	1802	0.0435	0.185	0.00	0	0	0	0	0	0	0	0	0
	1	1802	1802	0.185	0.185	0.003	0.012	0.031	0.076	0.169	0.180	0.184	0.185	0.185
1_3	2	1804	1.17	0.129	0.00	0	0	0	0	0	0	0	0	0
	1	1804	1803	0.129	0.129	0.002	0.008	0.022	0.053	0.118	0.126	0.128	0.129	0.129
1				Total:	0.314	0.005	0.020	0.053	0.129	0.287	0.306	0.312	0.314	0.314
					(0.314)	(0.005)	(0.020)	(0.053)	(0.129)	(0.286)	(0.305)	(0.311)	(0.314)	(0.314)
3_5	2	1811	6.42	0.042	0.00	0	0	0	0	0	0	0	0	0
	1	1811	1804	0.042	0.042	0.001	0.004	0.009	0.019	0.040	0.042	0.042	0.042	0.042
3_6	2	1818	12.3	0.038	0.00	0	0	0	0	0	0	0	0	0
	1	1818	1806	0.038	0.038	0.001	0.003	0.008	0.017	0.036	0.038	0.038	0.038	0.038
				Total:	0.080	0.002	0.007	0.017	0.036	0.076	0.080	0.080	0.080	0.080
					(0.080)	(0.002)	(0.007)	(0.017)	(0.036)	(0.076)	(0.080)	(0.080)	(0.080)	(0.080)
5_8	2	1846	34.0	0.020	0.00	0	0	0	0	0	0	0	0	0
	1	1846	1812	0.020	0.020	0	0	0.001	0.003	0.008	0.009	0.010	0.015	0.018
5_9	2	1870	53.0	0.019	0.001	0	0	0	0	0	0	0	0.001	0.001
	1	1870	1817	0.019	0.018	0	0	0.001	0.003	0.007	0.009	0.009	0.015	0.017
				Total:	0.039	0	0	0.002	0.006	0.015	0.018	0.019	0.031	0.036
					(0.039)	(0)	(0)	(0.002)	(0.006)	(0.016)	(0.019)	(0.021)	(0.031)	(0.038)
6_{10}	2	1903	81	0.019	0.001	0	0	0	0	0	0	0	0.001	0.001
	1	1903	1822	0.019	0.018	0	0	0.001	0.003	0.007	0.009	0.009	0.015	0.017
6_{11}	2	1946	117	0.017	0.001	0	0	0	0	0	0	0	0.001	0.001
	1	1946	1829	0.017	0.016	0	0	0.001	0.002	0.007	0.008	0.008	0.013	0.016
				Total:	0.036	0	0	0.002	0.005	0.014	0.017	0.017	0.030	0.035
					(0.036)	(0)	(0)	(0.002)	(0.005)	(0.014)	(0.017)	(0.019)	(0.029)	(0.035)
7_{12}	2	1996	161	0.014	0.001	0	0	0	0	0	0	0	0.001	0.001
	1	1996	1835	0.014	0.013	0	0	0.001	0.002	0.005	0.006	0.007	0.011	0.013
7_{13}	2	2052	212	0.013	0.001	0	0	0	0	0	0	0	0.001	0.001
	1	2052	1840	0.013	0.012	0	0	0.001	0.002	0.005	0.006	0.006	0.010	0.012
				Total:	0.027	0	0	0.002	0.004	0.010	0.012	0.013	0.023	0.027
					(0.027)	(0)	(0)	(0.002)	(0.004)	(0.010)	(0.012)	(0.014)	(0.022)	(0.027)
			Total for all Strata:		0.498	0.007	0.027	0.076	0.180	0.402	0.433	0.441	0.477	0.494
					(0.496)	(0.027)	(0.076)	(0.076)	(0.180)	(0.402)	(0.433)	(0.445)	(0.476)	(0.479)

* Stratum designated as input; subscript indicates internal stratification.
** Results of the CSETT solution are shown in parentheses for comparison.

Example Problem A4

9. This example illustrates the use of a three-dimensional rectangular load option. The soil stratification is shown in Figure A13. A strip footing and two square footings, each with a uniform load, are located as shown in Figure A14. Soil properties are summarized in Table A19.

10. The input file is listed in Figure A15. Output is generated along the centerline of the strip footing and along a diagonal between the strip footing and the square footings as shown in Figure A14. Time-rate calculations were made at times 0.25, 0.50, 1.0, 2.0, 4.0, and 8.0 years.

11. A hand solution at position (X,Y) = (35.0, 32.5) is provided for comparison (Tables A20-A22). Results of the hand solution and the CSETT solution are compared in Table A23.

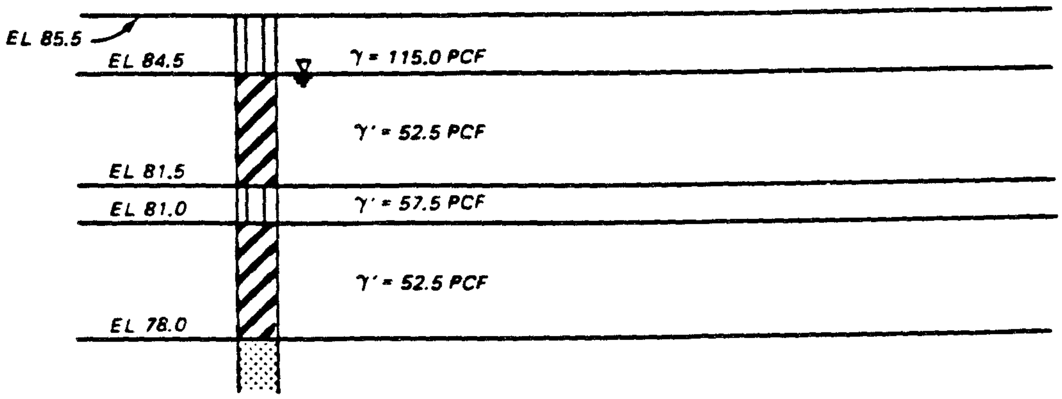


Figure A13. Soil stratification for Example Problem A4

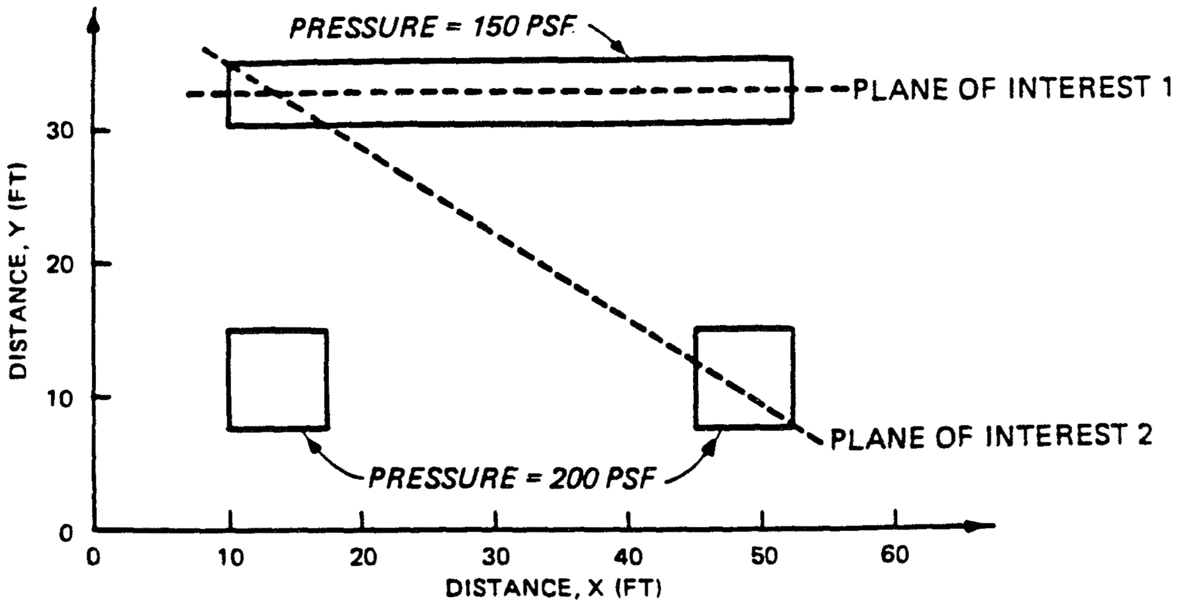


Figure A14. Plan view of footing loads for Example Problem A4

Table A19

Soil Properties for Example Problem A4

Stratum No.	El of Top of Strata ft NGVD	Eff Unit Weight pcf	Consolidation Data				
			C_v ft^2/yr	e_o	P_o psf	C_R	C_c
1	85.5	115.0	--	--	--	--	--
2	84.5	52.5	8.0	1.6	193.75	0.04	0.35
3	81.5	57.5	--	--	--	--	--
4	81.0	52.5	12.0	1.3	380.00	0.045	0.48
5	78.0	57.5	--	--	--	--	--

SOLUTION BY CSETT

```
LIST RECT

10 TITLE
20 3-DIMENSIONAL RECTANGULAR LOADS - THREE FOOTINGS
30 3DRE 1 0.0 0 150.0
40 10.0 30.0 50.0 35.0
50 3DRE 2 0.0 0 200.0
60 10.0 7.5 17.5 15.0
70 3DRE 3 0.0 0.0 200.0
80 45.0 7.5 52.5 15.0
90 BOUS 7.5
100 SOIL 1 85.5 N 115.
110 SOIL 2 84.5 D 52.5 .04 8.0
120 INDEX .35 193.75 1.6
130 SOIL 3 81.5 N 57.5
140 SOIL 4 81.0 D 52.5 .045 12.0
150 INDEX .48 380.0 1.3
160 SOIL 5 78.0 N 57.5
170 TIMS .25 .50 1.0 2.0 4.0 8.0
180 OUTPUT 10.0 32.5 60.0 32.5 25.0
190 OUTPUT 10.0 35.0 52.5 7.5 10
200 END


*
```

Figure A15. Input data file for Example Problem A4.

```
IS INPUT FROM TERMINAL OR A FILE
ENTER T OR F
=F

ENTER DATA FILE NAME
=RECT

INPUT COMPLETE. DO YOU WANT INPUT DATA
ECHOPRINTED TO YOUR TERMINAL, A FILE,
BOTH, OR NEITHER? (ENTER T, F, B, OR N)
=T
```

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE:   7/12/83                                        TIME:   9:55:29


I.   INPUT DATA


1. TITLE - 3-DIMENSIONAL RECTANGULAR LOADS - THREE FOOTINGS


2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
   THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
   IS     7.50 FEET.


3. 2-DIMENSIONAL PRESSURE LOAD DATA
   NONE


4. 2-DIMENSIONAL SOIL LOAD DATA
   NONE


5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
```

```
LOAD NUMBER    1     BEGINNING TIME OF LOAD APPLICATION = 0.        YRS.
                     ENDING TIME OF APPLICATION = 0.        YRS.
                     PRESSURE =    150.000 PSF

       COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
       CORNER OF LOAD REGION - X , Y =    10.00,    30.00

       COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
       CORNER OF LOAD REGION - X , Y =    50.00,    35.00


LOAD NUMBER    2     BEGINNING TIME OF LOAD APPLICATION = 0.        YRS.
                     ENDING TIME OF APPLICATION = 0.        YRS.
                     PRESSURE =    200.000 PSF

       COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
       CORNER OF LOAD REGION - X , Y =    10.00,     7.50

       COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
       CORNER OF LOAD REGION - X , Y =    17.50,    15.00


LOAD NUMBER    3     BEGINNING TIME OF LOAD APPLICATION = 0.        YRS.
                     ENDING TIME OF APPLICATION = 0.        YRS.
                     PRESSURE =    200.000 PSF

       COORDINATE PAIR (PLAN VEIW) DEFINING LOWER-LEFT
       CORNER OF LOAD REGION - X , Y =    45.00,     7.50

       COORDINATE PAIR (PLAN VEIW) DEFINING UPPER-RIGHT
       CORNER OF LOAD REGION - X , Y =    52.50,    15.00


6. 3-DIMENSIONAL IRREGULAR LOAD DATA
   NONE


7. EXCAVATION DATA
   NONE
```

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	85.50	N	115.00			
2	84.50	D	52.50	0.04000	8.00000	0.32000
3	81.50	N	57.50			
4	81.00	D	52.50	0.04500	12.00000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

STRATUM NO. 2

COMPRESSION INDEX= 0.35000
RECOMPRESSION INDEX= 0.04000
INSITU VOID RATIO= 1.60000
INSITU OVERBURDEN= 193.75 PSF

STRATUM NO. 3

INCOMPRESSIBLE STRATUM

STRATUM NO. 4

COMPRESSION INDEX= 0.48000
RECOMPRESSION INDEX= 0.04500
INSITU VOID RATIO= 1.30000
INSITU OVERBURDEN= 380.00 PSF

10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS

TIME RATE OF CONSOLIDATION CALCULATIONS WILL BE MADE

AT TIMES (YRS):

0.25
0.50
1.00
2.00
4.00
8.00

11. OUTPUT CONTROL DATA

PLANE 1	XA=	10.0000	FT.
	YA=	32.5000	FT.
	XB=	60.0000	FT.
	YB=	32.5000	FT.
	DELX=	25.0000	FT.
PLANE 2	XA=	10.0000	FT.
	YA=	35.0000	FT.
	XB=	52.5000	FT.
	YB=	7.5000	FT.
	DELX=	10.0000	FT.

Complete Output

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/12/83 TIME: 9:56:38

II. OUTPUT SUMMARY.

1. TITLE- 3-DIMENSIONAL RECTANGULAR LOADS - THREE FOOTINGS

POSITION: X= 10.0 Y= 32.5
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	74.80	0.
2	2.50	193.75	61.40	0.048
3	4.25	286.88	46.30	0.
4	6.00	380.00	36.00	0.025

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.25 (YRS.)	0.50 (YRS.)	1.00 (YRS.)	2.00 (YRS.)	4.00 (YRS.)	8.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.048	0.044	0.048	0.048	0.048	0.048	0.048
3	0.	0.	0.	0.	0.	0.	0.
4	0.025	0.024	0.025	0.025	0.025	0.025	0.025
TOTALS:	0.073	0.068	0.073	0.073	0.073	0.073	0.073

Abbreviated Output

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 11/17/82                                             TIME: 10: 0: 7


II.   OUTPUT SUMMARY.


1. TITLE- 3-DIMENSIONAL RECTANGULAR LOADS - THREE FOOTINGS


2. SUMMARY OF TIME SETTLEMENT DATA.


           PLANE OF INTEREST    1:  XA=   35.0   YA=   32.5
                                    XB=   40.0   YB=   32.5
                                       DELX=   10.0


  TIME   X=   35.0
  (YR)   Y=   32.5
  ----   --------
  ULT.       0.133
  0.25       0.123
  0.50       0.132
  1.00       0.133
  2.00       0.133
  4.00       0.133
  8.00       0.133
```

POSITION: X= 35.0 Y= 32.5
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	149.50	0.
2	2.50	193.75	122.70	0.086
3	4.25	286.88	92.40	0.
4	6.00	380.00	71.40	0.047

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.25 (YRS.)	0.50 (YRS.)	1.00 (YRS.)	2.00 (YRS.)	4.00 (YRS.)	8.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.086	0.078	0.085	0.086	0.086	0.086	0.086
3	0.	0.	0.	0.	0.	0.	0.
4	0.047	0.045	0.047	0.047	0.047	0.047	0.047
TOTALS:	0.133	0.123	0.132	0.133	0.133	0.133	0.133

POSITION: X= 60.0 Y= 32.5
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	0.	0.
2	2.50	193.75	0.10	0.
3	4.25	286.88	0.60	0.
4	6.00	380.00	1.30	0.001

3. TIME-SETTLEMENT SUMMARY.

STRATA NO	ULT	(SETTLEMENT IN FEET AT SPECIFIED TIMES) 0.25 (YRS.)	0.50 (YRS.)	1.00 (YRS.)	2.00 (YRS.)	4.00 (YRS.)	8.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.
4	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TOTALS:	0.001	0.001	0.001	0.001	0.001	0.001	0.001

DO YOU WANT A PLOT OF STRESS BULBS ?
ENTER 'Y' OR 'N'.
= N

HAND VERIFICATION POINT SETTLEMENT AT (X,Y) = (35, 32.5)

Table A20

Internally Generated Stratification for Example Problem A4*

Input Stratum No.	Internally Generated Strata No.	Thickness for Compression Calculations ft	Eff Thickness for Consolidation Calculations ft	Drainage Condition
1	1	--	--	N
2	2	3.0	3.0	D
3	3	--	--	N
4	4	3.0	3.0	D
5	5	--	--	N

* Note: Since all strata thicknesses are less than or equal to 3 ft, the internally generated stratification is the same as the input stratification.

Table A21

Summary of Stresses and Ultimate Settlements

Stratum No.	P_o psf	e_o	ΔP_{Loads*} psf	ΔP_{Final} psf	ΔH_{ULT} ft
1	--	--	--	--	--
2	193.75	1.60	122.73	316.48	0.086
3	--	--	--	--	--
4	380.0	1.30	71.42	451.42	0.047
5	--	--	--	--	--

* From CSETT

Note: Calculation of in situ void ratio (e_o) and overburden (P_o)

Stratum 2

$P_o = 1.0 \times 115 + 1.5 \times 52.5 = 193.75$ psf

Since $P_o = P_{OINPUT}$, $e_o = e_{OINPUT} = 1.60$

Stratum 4

$P_o = 1.0 \times 115.0 + 3.0 \times 52.5 + 0.50 \times 57.5 + 1.5 \times 52.5 = 380.0$ psf

Since $P_o = P_{OINPUT}$, $e_o = 1.30$

Table A22

Time-Rate of Consolidation and Ultimate Settlement Calculations

Stratum No.	H_{ULT} ft	H ft	C_v ft^2/yr	t yr	T_v	U %	Settlement ft
2	0.086	1.50	18.0	0.25	0.889	91.0	0.078
				0.50	1.78	99.0	0.085
				1.00	3.56	100.0	0.086
				2.00	7.11	100.0	0.086
				4.00	14.22	100.0	0.086
				8.00	28.44	100.0	0.086
4	0.047	1.50	12.0	0.25	1.33	97.0	0.045
				0.50	2.67	100.0	0.047
				1.00	5.33	100.0	0.047
				2.00	10.67	100.0	0.047
				4.00	21.33	100.0	0.047
				8.00	42.67	100.0	0.047

Note: Calculation of ultimate settlements.

Stratum 2

$$\Delta H_{ULT} = \frac{HC_c}{1 + e_o} \log_{10} \frac{P_f}{P_o} = \frac{3.0(0.35)}{1 + 1.60} \log_{10} \frac{316.48}{193.75} = 0.086 \text{ ft}$$

Stratum 4

$$\Delta H_{ULT} = \frac{3.0(0.48)}{1 + 1.30} \log_{10} \frac{451.42}{380.0} = 0.047 \text{ ft}$$

Table A23

Summary of Time-Rate Calculations*

Stratum No.	ΔH_{ULT} ft	Settlement in Feet at Specified Time 0.25 yr	0.50 yr	1.00 yr	2.00 yr	4.00 yr	8.00 yr
2	(0.086) 0.086	(0.078) 0.078	(0.085) 0.085	(0.086) 0.086	(0.086) 0.086	(0.086) 0.086	(0.086) 0.086
4	(0.047) 0.047	(0.045) 0.045	(0.047) 0.047	(0.047) 0.047	(0.047) 0.047	(0.047) 0.047	(0.047) 0.047
Total	(0.133) 0.133	(0.123) 0.123	(0.132) 0.132	(0.133) 0.133	(0.133) 0.133	(0.133) 0.133	(0.133) 0.133

* Results from the CSETT solution are shown in parentheses for comparison.

Example Problem A5

12. This example provides an illustration of three-dimensional irregular loads. The loading consists of a fill and a storage tank as shown in Figure A16. The soil stratification is shown in Figure A17, and the soil properties are summarized in Table A24.

13. The input data file is listed in Figure A18. Output is generated at 20-ft intervals along the plane of interest shown in Figure A16. Time-rate calculations are made at times of 0.10, 0.20, 0.40, 0.80, 1.50, 3.0, 6.0, and 12 years.

14. A hand solution at position (x,y) = (30,30) is provided (Tables A25-A27). Results of the hand solution and the CSETT solution are compared in Table A28.

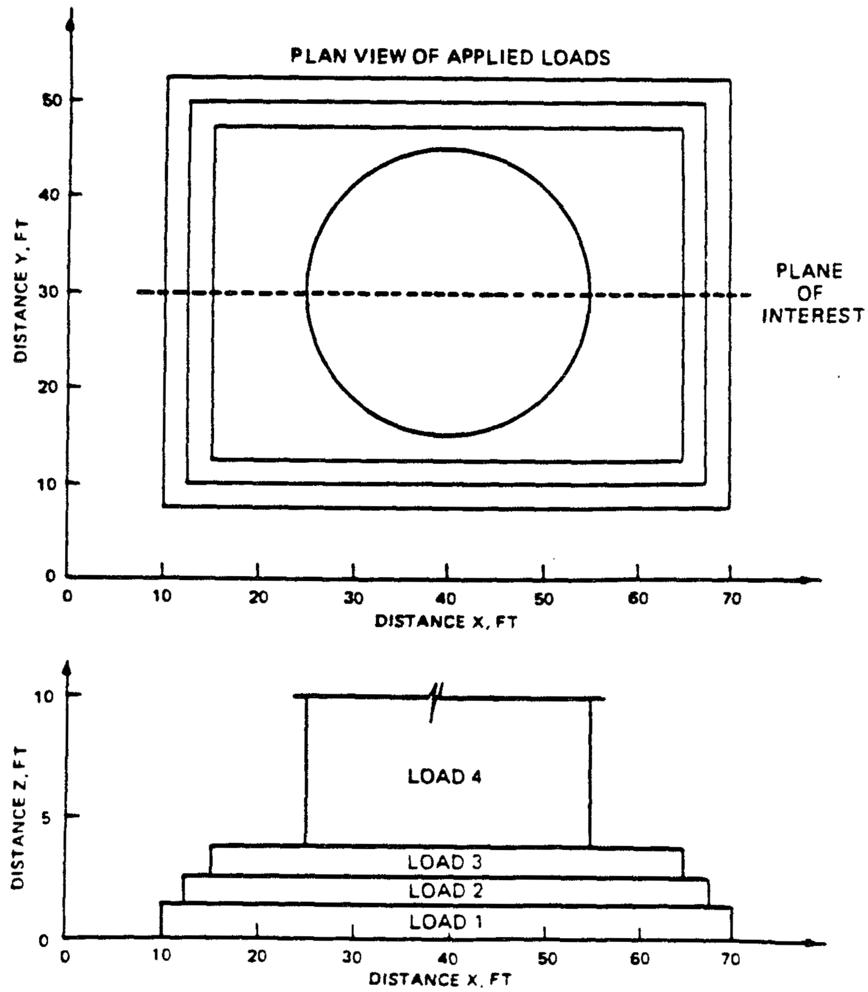


Figure A16. Plan and elevation views of loads for Example Problem A5

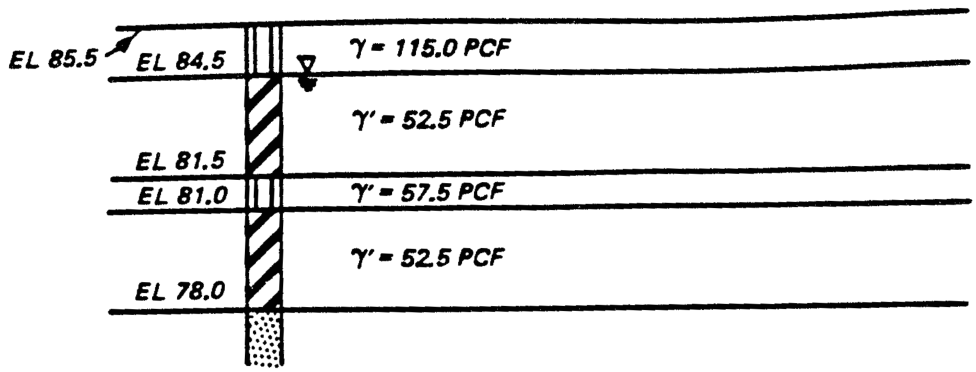


Figure A17. Soil stratification for Example Problem A5

Table A24

Soil Properties for Example Problem A5

Stratum No.	El of Top of Stratum ft NGVD	Eff Unit Weight pcf	Consolidation Data C_v ft^2/yr	e_o	P_o psf	C_R	C_c
1	85.5	115.0	--	--	--	--	--
2	84.5	52.5	8.0	1.6	193.75	0.04	0.35
3	81.5	57.5	--	--	--	--	--
4	81.0	52.5	12.0	1.3	380.00	0.045	0.48
5	78.0	57.5	--	--	--	--	--

SOLUTION BY CSETT

LIST IRR

```
10   TITLE
20   3-DIM. IRREGULAR LOADS - FILL AND STORAGE TANK
30   3DIR 1 0 5 0.0 0.0 150.0 (3-D IRREGULAR LOAD DATA NL NS N T1M1 T1M2 PRES)
40   10.0  7.5 10.0 52.5 70.0 52.5 70.0 7.5 10.0 7.5 (Xi Yi , i=1,N)
50   3DIR 2 1 5 0.0 0.0 300.0 (3-D IRREGULAR LOAD DATA NL NS N T1M1 T1M2 PRES)
60   12.5 10.0 12.5 50.0 67.5 50.0 67.5 10.0 12.5 10.0 (Xi Yi , i=1,N)
70   3DIR 3 2 5 0.0 0.0 450.0 (3-D IRREGULAR LOAD DATA NL NS N T1M1 T1M2 PRES)
80   15.0 12.5 15.0 47.5 65.0 47.5 65.0 12.5 15.0 12.5 (Xi Yi , i=1,N)
90   3DIR 4 0 17 0.0 0.0 1250.0 (3-D IRREGULAR LOAD DATA NL NS N T1M1 T1M2 PRES)
100  25.0 30.0 26.0 35.0 29.0 40.0 34.0 44.0
110  40.0 45.0 46.0 44.0 51.0 40.0 54.0 35.0  Xi Yi , i=1,N
120  55.0 30.0 54.0 25.0 51.0 20.0 46.0 16.0
130  40.0 15.0 34.0 16.0 29.0 20.0 26.0 25.0
140  25.0 30.0
150  BOUS 7.5 (BOUSSINESQ SOLUTION DMAX)
160  SOIL 1 85.5 N 115. (SOIL DATA N EL NDC GM)
170  SOIL 2 84.5 D 52.5 .04 8.0 (SOIL DATA N EL NDC GM CR CV)
180  INDEX .35 193.75 1.6 (INDEX PROPERTIES CC PO EO)
190  SOIL 3 81.5 N 57.5 (SOIL DATA NEL NDC GM)
200  SOIL 4 81.0 D 52.5 .045 12.0 (SOIL DATA N EL NDC GM CR CV)
210  INDEX .48 380.0 1.3 (INDEX PROPERTIES CC PO EO)
220  SOIL 5 78.0 N 57.5 (SOIL DATA N EL NDC GM)
230  T1MS .1 .2 .4 .8 1.5 3.0 6.0 12.0 (SPECIFIED TIME T1 T2 T3 ...)
240  OUTPUT 10 30 70 30 20  (OUTPUT X1 Y1 X2 Y2 SP)
250  END (TERMINATION)
```

Figure A18. Input data file for Example Problem A5

```
IS INPUT FROM TERMINAL OR A FILE
ENTER T OR F
=F

ENTER DATA FILE NAME
=TRR

INPUT COMPLETE. DO YOU WANT INPUT DATA
ECHOPRINTED TO YOUR TERMINAL, A FILE,
BOTH, OR NEITHER? (ENTER T, F, B, OR N)
=T
```

```
PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE:  7/12/83                                         TIME: 10: 0:17


I.   INPUT DATA


1. TITLE - 3-DIM. IRREGULAR LOADS - FILL AND STORAGE TANK


2. BOUSSINESQ SOLUTION WILL BE USED TO COMPUTE INDUCED STRESSES .
   THE MAXIMUM DEPTH TO WHICH THE ANALYSIS WILL BE EXTENDED
   IS     7.50 FEET.


3. 2-DIMENSIONAL PRESSURE LOAD DATA
   NONE


4. 2-DIMENSIONAL SOIL LOAD DATA
   NONE


5. 3-DIMENSIONAL RECTANGULAR LOAD DATA
   NONE
```

6. 3-DIMENSIONAL IRREGULAR LOAD DATA

LOAD NUMBER 1 BEGINNING TIME OF LOAD APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.
PRESSURE = 150.000 PSF

POINT NO.	X (FT.)	Y (FT.)
1	10.00	7.50
2	10.00	52.50
3	70.00	52.50
4	70.00	7.50
5	10.00	7.50

LOAD NUMBER 2 BEGINNING TIME OF LOAD APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.
PRESSURE = 300.000 PSF

POINT NO.	X (FT.)	Y (FT.)
1	12.50	10.00
2	12.50	50.00
3	67.50	50.00
4	67.50	10.00
5	12.50	10.00

LOAD NUMBER 3 BEGINNING TIME OF LOAD APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.
PRESSURE = 450.000 PSF

POINT NO.	X (FT.)	Y (FT.)
1	15.00	12.50
2	15.00	47.50
3	65.00	47.50
4	65.00	12.50
5	15.00	12.50

LOAD NUMBER 4 BEGINNING TIME OF LOAD APPLICATION = 0. YRS.
ENDING TIME OF APPLICATION = 0. YRS.
PRESSURE = 1250.000 PSF

POINT NO.	X (FT.)	Y (FT.)
1	25.00	30.00
2	26.00	35.00
3	29.00	40.00
4	34.00	44.00
5	40.00	45.00
6	46.00	44.00
7	51.00	40.00
8	54.00	35.00
9	55.00	30.00
10	54.00	25.00
11	51.00	20.00
12	46.00	16.00
13	40.00	15.00
14	34.00	16.00
15	29.00	20.00
16	26.00	25.00
17	25.00	30.00

7. EXCAVATION DATA
NONE

8. SOIL DATA

STRATA NO.	EL. OF TOP OF STRATUM (FEET NGVD)	DRAINAGE CONDITION	EFF UNIT WEIGHT (PCF)	RECOMPR. INDEX	COEF.OF CONSOL. (SQFT/YR)	POISSON'S RATIO
1	85.50	N	115.00			
2	84.50	D	52.50	0.04000	8.00000	0.32000
3	81.50	N	57.50			
4	81.00	D	52.50	0.04500	12.00000	0.32000

9. STRESS-STRAIN DATA

STRATUM NO. 1

INCOMPRESSIBLE STRATUM

```
            STRATUM NO.  2
            --------------
   COMPRESSION INDEX= 0.35000
 RECOMPRESSION INDEX= 0.04000
   INSITU VOID RATIO= 1.60000
   INSITU OVERBURDEN=  193.75 PSF

            STRATUM NO.  3
            --------------
       INCOMPRESSIBLE STRATUM

            STRATUM NO.  4
            --------------
   COMPRESSION INDEX= 0.48000
 RECOMPRESSION INDEX= 0.04500
   INSITU VOID RATIO= 1.30000
   INSITU OVERBURDEN=  380.00 PSF


10. TIME SEQUENCE FOR CONSOLIDATION CALCULATIONS


     TIME RATE OF CONSOLIDATION CALCULATIONS WILL BE MADE
     AT TIMES (YRS):
                             0.10
                             0.20
                             0.40
                             0.80
                             1.50
                             3.00
                             6.00
                            12.00


11. OUTPUT CONTROL DATA


   PLANE  1        XA=    10.0000 FT.
                   YA=    30.0000 FT.
                   XB=    70.0000 FT.
                   YB=    30.0000 FT.
                 DELX=    20.0000 FT.


DO YOU WANT TO EDIT DATA? ENTER 'Y' OR 'N'.
```

PROGRAM CSETT - VERTICAL STRESS INDUCTION AND SETTLEMENT PROGRAM
DATE: 7/12/83 TIME: 10: 2:25

II. OUTPUT SUMMARY.

1. TITLE- 3-DIM. IRREGULAR LOADS - FILL AND STORAGE TANK

POSITION: X= 10.0 Y= 30.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	75.30	0.
2	2.50	193.75	92.10	0.068
3	4.25	286.88	115.80	0.
4	6.00	380.00	137.50	0.084

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.10 (YRS.)	0.20 (YRS.)	0.40 (YRS.)	0.80 (YRS.)	1.50 (YRS.)	3.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.068	0.045	0.059	0.067	0.068	0.068	0.068
3	0.	0.	0.	0.	0.	0.	0.
4	0.084	0.066	0.079	0.084	0.084	0.084	0.084
TOTALS:	0.152	0.111	0.138	0.151	0.152	0.152	0.152

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	6.00 (YRS.)	12.00 (YRS.)
1	0.	0.
2	0.068	0.068
3	0.	0.
4	0.084	0.084
TOTALS:	0.152	0.152

POSITION: X= 30.0 Y= 30.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	1699.60	0.
2	2.50	193.75	1661.00	0.396
3	4.25	286.88	1569.90	0.
4	6.00	380.00	1458.60	0.429

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.10 (YRS.)	0.20 (YRS.)	0.40 (YRS.)	0.80 (YRS.)	1.50 (YRS.)	3.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.396	0.263	0.341	0.387	0.396	0.396	0.396
3	0.	0.	0.	0.	0.	0.	0.
4	0.429	0.335	0.404	0.427	0.429	0.429	0.429
TOTALS:	0.825	0.598	0.745	0.814	0.825	0.825	0.825

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	6.00 (YRS.)	12.00 (YRS.)
1	0.	0.
2	0.396	0.396
3	0.	0.
4	0.429	0.429
TOTALS:	0.825	0.825

POSITION: X= 50.0 Y= 30.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	1699.60	0.
2	2.50	193.75	1661.00	0.396
3	4.25	286.88	1569.90	0.
4	6.00	380.00	1458.60	0.429

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.10 (YRS.)	0.20 (YRS.)	0.40 (YRS.)	0.80 (YRS.)	1.50 (YRS.)	3.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.396	0.263	0.341	0.387	0.396	0.396	0.396
3	0.	0.	0.	0.	0.	0.	0.
4	0.429	0.335	0.404	0.427	0.429	0.429	0.429
TOTALS:	0.825	0.598	0.745	0.814	0.825	0.825	0.825

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	6.00 (YRS.)	12.00 (YRS.)
1	0.	0.
2	0.396	0.396
3	0.	0.
4	0.429	0.429
TOTALS:	0.825	0.825

POSITION: X= 70.0 Y= 30.0
****

2. SUMMARY OF ULTIMATE SETTLEMENTS.

STRATA NO.	MID-DEPTH OF STRATA (FEET)	IN-SITU OVERBURDEN (LB/SQ FT)	DELTA SIGMA (LB/SQ FT)	ULTIMATE SETTLEMENT (FEET)
1	0.50	57.50	75.30	0.
2	2.50	193.75	92.10	0.068
3	4.25	286.88	115.80	0.
4	6.00	380.00	137.50	0.084

3. TIME-SETTLEMENT SUMMARY.

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	ULT	0.10 (YRS.)	0.20 (YRS.)	0.40 (YRS.)	0.80 (YRS.)	1.50 (YRS.)	3.00 (YRS.)
1	0.	0.	0.	0.	0.	0.	0.
2	0.068	0.045	0.059	0.067	0.068	0.068	0.068
3	0.	0.	0.	0.	0.	0.	0.
4	0.084	0.066	0.079	0.084	0.084	0.084	0.084
TOTALS:	0.152	0.111	0.138	0.151	0.152	0.152	0.152

(SETTLEMENT IN FEET AT SPECIFIED TIMES)

STRATA NO	6.00 (YRS.)	12.00 (YRS.)
1	0.	0.
2	0.068	0.068
3	0.	0.
4	0.084	0.084
TOTALS:	0.152	0.152

HAND VERIFICATION AT SETTLEMENT UNDER (X,Y) = (30,30)

Table A25

Internally Generated Stratification for Example Problem A5

Input Stratum No.	Internally Generated Stratum No.	Thickness for Compression Calculations ft	Eff Thickness for Consolidation Calculations ft	Drainage Condition
1	1	--	--	N
2	2	3.0	3.0	D
3	3	--	--	N
4	4	3.0	3.0	D
5	5	--	--	N

Note: Since all strata thicknesses are less than or equal to three (3) ft, the internally generated stratification is the same as the input stratification.

Table A26

Summary of Stresses and Ultimate Settlements for Example Problem A5

Stratum No.	P_o psf	e_o	ΔP_{Loads}* psf	P_{Final} psf	ΔH_{ULT} ft
1	--	--	--	--	--
2	193.75	1.60	1661.00	1845.75	0.396
3	--	--	--	--	--
4	380.0	1.30	1458.60	1838.60	0.429
5	--	--	--	--	--

Note: Calculation of in situ void ratio (e_o) and overburden (P_o).

Stratum 2

$P_o = 1.0 \times 115 + 1.5 \times 52.5 = 193.75$ psf

Since $P_o = P_{OINPUT}$, $e_o = e_{OINPUT} = 1.60$

Stratum 4

$P_o = 1.0 \times 115.0 + 3.0 \times 52.5 + 0.5 \times 57.5 + 1.5 \times 52.5 = 380.0$ psf

Since $P_o = P_{OINPUT}$, $e_o = e_{OINPUT} = 1.30$

* From CSETT.

Table A27

Time-Rate of Consolidation Calculations for Example Problem A5

Stratum No.	ΔH_{ULT} ft	H ft	C_v ft^2/yr	t yr	T_v	U %	Settlement ft
2	0.396	1.50	8.0	0.10	0.356	66.3	0.262
				0.20	0.711	86.0	0.340
				0.40	1.422	97.6	0.386
				0.80	2.844	99.9	0.396
				1.50	5.333	100.0	0.396
				3.00	10.67	100.0	0.396
				6.00	21.33	100.0	0.396
				12.00	42.67	100.0	0.396
4	0.429	1.50	12.0	0.10	0.533	78.3	0.336
				0.20	1.067	94.2	0.404
				0.40	2.133	99.6	0.427
				0.80	4.267	100.0	0.429
				1.50	8.00	100.0	0.429
				3.00	16.00	100.0	0.429
				6.00	32.00	100.0	0.429
				12.00	64.00	100.0	0.429

Note: Calculation of ultimate settlements.

Stratum 2

$$\Delta H_{ULT} = \frac{HC_c}{1 + e_o} \log_{10} \frac{P_f}{P_o} = \frac{3.0(0.35)}{1 + 1.60} \log_{10} \frac{1854.75}{193.75} = 0.396 \text{ ft}$$

Stratum 4

$$\Delta H_{ULT} = \frac{3.0(0.48)}{1 + 1.30} \log_{10} \frac{1838.6}{380.0} = 0.429 \text{ ft}$$

Table A28

Summary of Time-Settlement Data for Example Problem A5*

Stratum No.	ΔH_{ULT} ft	Settlement, FT, at Specified Time 0.10 yr	0.20 yr	0.40 yr	0.80 yr	1.50 yr	3.00 yr
2	(0.396) 0.396	(0.263) 0.262	(0.341) 0.340	(0.387) 0.386	(0.396) 0.396	(0.396) 0.396	(0.396) 0.396
4	(0.429) 0.429	(0.335) 0.336	(0.404) 0.404	(0.427) 0.427	(0.429) 0.429	(0.429) 0.429	(0.429) 0.429
Total	(0.825) 0.825	(0.598) 0.598	(0.745) 0.744	(0.814) 0.813	(0.825) 0.825	(0.825) 0.825	(0.825) 0.825

* Results of the CSETT solution are shown in parentheses for comparison.

APPENDIX B: GENERAL EQUATIONS FOR STRESS INDUCTION*

INTRODUCTION

Although much literature exists on settlement caused by stresses induced when a load is placed on the surface of a soil mass, few texts contain expanded formulas for computing the induced vertical stresses. The equation found in the classical texts on soils mechanics and foundation design are normally those for point loads, distributed line loads, "nice" geometric shapes, and, in general, very limited loading conditions. These equations were created by integration of the Boussinesq or Westergaard point load formulas over the shapes to be considered. Applying the same techniques to more general elemental regions, the formulas can be expanded to do the most general two- or three-dimensional problems.

In recent years, many digital programs have been created using either finite element methods or finite difference testers to approximate induced stresses. No one is, nor should be, concerned about the approximations, since even "exact" solutions are merely academics. However, the user is burdened by having to input much of the bookkeeping necessary to adequately describe the loading condition. Also, a program burdened with the required secretarial logic can do little more than compute vertical stresses. Thus, the ultimate goal of settlement analysis must be done by subsequent activities, if all of the aspects of consolidation such as ultimate, time-rate, graphics, etc., are to be included.

The purpose of this paper is to present the general equations of vertical stress induction for the two- and three-dimensional Boussinesq and Westergaard theories, discuss techniques for their application, and present FORTRAN subroutines which can be used in the computation of vertical stresses. These subroutines are excerpted from an all-purpose settlement analysis program designed and coded by the authors. The program handles stratified soil and nonhomogeneous loads, computes ultimate and time-rate of consolidations, provides graphics capability for displaying lines of equal stress intensity, and allows the user to select either Boussinesq or Westergaard analysis.

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* J. G. Flock and M. E. Pittman. 1979. "Vertical Stress Induction and Settlement Analysis Program", U. S. Army Engineer District, New Orleans, Corps of Engineers, New Orleans, Louisiana.

Discussion

The Boussinesq theory yields the following formula for a point load, P, acting on a homogeneous soil:

$$\Delta\sigma_Z = \frac{3P}{2\pi Z^2}\left[1 + \left(\frac{r}{Z}\right)^2\right]^{-\frac{5}{2}}$$

and the Westergaard theory gives

$$\Delta\sigma_Z = \frac{P}{2\pi\mu^2 Z^2}\left[\left(\frac{r}{\mu Z}\right)^2 + 1\right]^{-\frac{3}{2}}$$

where

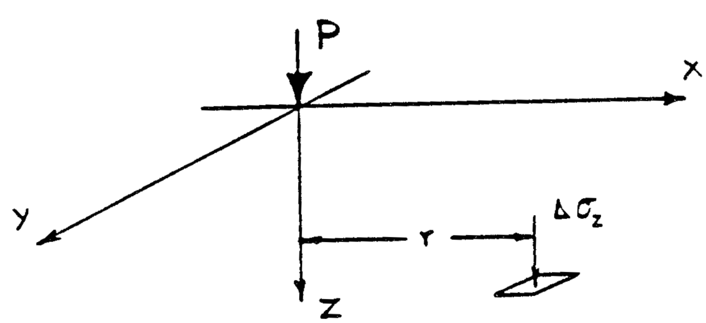
$\mu^2 = (1-2\mu)/2(1-\mu)$

and

μ is the Poisson's ratio for the soil.

If we substitute Z' for μZ,

$$\Delta\sigma_Z = \frac{P}{2\pi Z'^2}\left[\left(\frac{r}{Z'}\right)^2 + 1\right]^{-\frac{3}{2}}$$ results



For the two-dimensional case, these equations must be integrated from $y = -\infty$ to $y = +\infty$ to achieve the equations for a distributed line load of infinite extent. This has been done by many authors (at least for the Boussinesq theory) and the following equations are obtained:

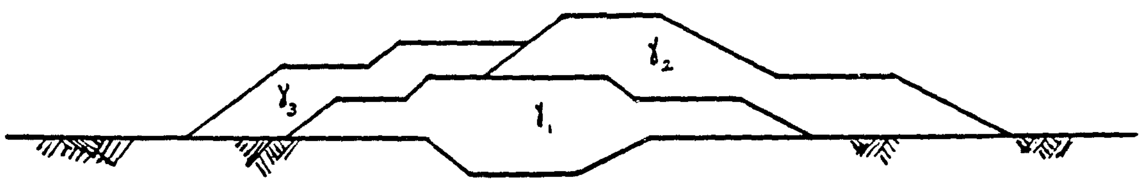
Boussinesq, distributed line load:

$$\Delta\sigma_Z = \frac{2PZ^3}{\pi(X^2 + Z^2)^2}$$

Westergaard, distributed line load:

$$\Delta\sigma_Z = \frac{PZ'}{\pi(X^2 + Z'^2)}$$

Also, for the two-dimensional case, the most general loading condition may appear as:



In this sketch, the load is not homogeneous nor geometrically "visa," and the virgin ground is not horizontal since there was an excavation prior to subsequent loading. The design engineer would either have to approximate the load or prepare to input the load as a large set of finite elements.

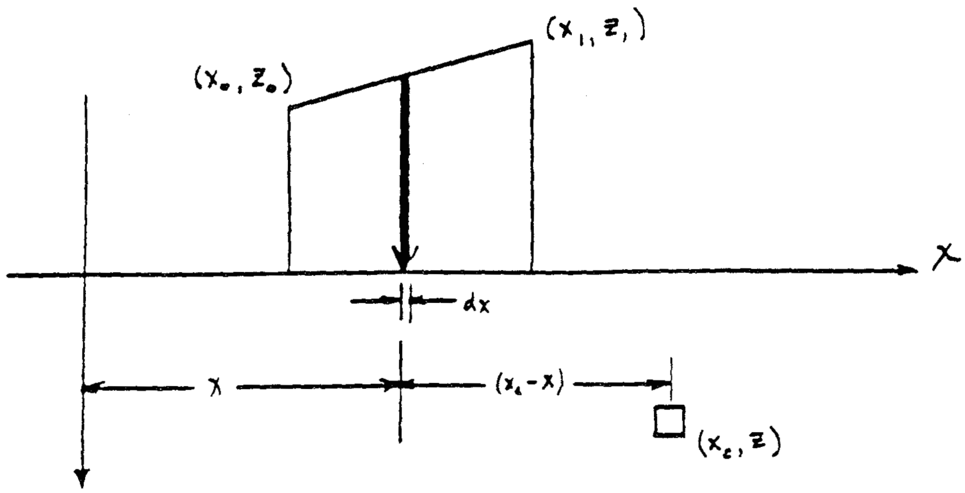
Consider the natural ground prior to subsequent loading activity, which includes the excavation as a loading activity. From some datum below the natural ground (conveniently, the bottom of the proposed excavation), if one were to remove all the above material (assign negative stress values to the soil continuum) and add all but the excavated material back, the natural ground appears as a homogeneous irregular area on a horizontal surface (datum). Each subsequent load, using judicial superpositioning techniques, appears the same way because each layer shows a common region with the layer immediately below it. Only the effective density of the load is altered. Thus, superposition techniques can be applied vertically as well as horizontally, which establishes the game plan for general analysis.

If there are i layered loads, each piecewise-linearly defined, having ji homogeneous areas between adjacent coordinates defining the region, then $\Delta\sigma_{Z_{i,ji}}$ is the stress contribution by this elemental region at a point (X_c, Z) in the soil continuum. The total vertical stress, $\Delta\sigma_Z$, is therefore given by:

$$\Delta\sigma_Z = \sum_{n=1}^{i} \sum_{m=1}^{ji} \Delta\sigma_{Z_{i,ji}}$$

Further discussion will develop the equations for $\Delta\sigma_{Z_{i,ji}}$ for the most general case. For facility, the symbol N_Z will be used for the stress contribution by an elemental region.

The elemental region is defined to be a homogeneous region between adjacent coordinates defining a load layer. Since the element extends down to the datum, it shows areas with previously defined regions of different densities; but the difference in areas and densities can be taken care of by application technique. The elemental region extends infinitely through the page and appears in the sketch below.



P is a linear function of X, given by

$$P = \gamma \frac{y_o X_1 - {}_1 X_o}{X_1 - X_o} + \frac{y_1 - y_o}{X_1 - X_o} X$$

where γ is the unit weight of the soil.

Writing the equations for a line load with the substitution for P and using the elemental figure, we get the following formulas for the line loads.

Boussinesq line load:

$$dN_Z = \frac{dx^2 \gamma Z^3}{\pi} \left[\frac{y_o X_1 - y_o X_o}{X_1 - X_o} + \frac{y_1 - y_o}{X_1 - X_o} X \right] \left[(X_i - X)^2 + Z^2 \right]^2$$

Westergaard line load:

$$dN_Z = \frac{dx Z' \gamma}{\pi} \left[\frac{y_o X_1 - y_o X_o}{X_1 - X_o} + \frac{y_1 - y_o}{X_1 - X_o} X \right] \left[(X_i X)^2 + Z'^2 \right]^{-1}$$

Integrating both equations with respect to X between X_o and X_1, yields the equations for the elemental trapezoidal region. Thus, we finally achieve the following two equations for a general two-dimensional homogeneous region of trapezoidal shape.

Boussinesq

$$N_Z = \frac{Z\gamma}{\pi (X_1 - X_o)} \left[Y_1 + Y_o - Y_1 \frac{(X_1 X_o - X_c X_o - X_c X_1 + X_c^2 + Z^2)}{(X_1 - X_c)^2 + Z^2} - Y_o \frac{(X_1 X_o - X_c X_o - X_c X_1 + X_c^2 + Z^2)}{(X_o - X_1)^2 + Z^2} + \frac{y_o (X_1 - X_c) - y_1 (X_o - X_c)}{Z} \left\{ \tan^{-1} \frac{X_1 - X_c}{Z} - \tan^{-1} \frac{X_o - X_c}{Z} \right\} \right]$$

Westergaard

$$N_Z = \frac{\gamma Z'}{\pi} \quad \frac{y_o X_1 - y_1 X_o}{2(X_1 - X_o)} + \frac{y_1 - y_o}{X_1 - X_o} \frac{X_c}{Z'} \quad \tan^{-1} \frac{X_1 - X_c}{Z'} - \tan^{-1} \frac{X_o \quad X_c}{Z'}$$

$$+ \frac{y_1 \quad y_o}{2(X_1 - X_o)} \quad (\mu (X_1 - X_c)^2 + Z'^2) - \mu((X_o - X_c)^2 + Z'^2)$$

The following two FORTRAN subroutines are provided for computing values of vertical stress (SIG) for the Boussinesq (subroutine BOUS2) or Westergaard (subroutine WEST2) theories for the two-dimensional case. It is assumed that a mainline will be written by the users to supply the calling arguments whose definition are given preceding the listings.

It should be noted that in the event of an excavation, the amount of material above the datum (normally selected to be the bottom of the excavation) is relieved from the stress values by a value equaling the height of material in feet times its effective density. This is a calling argument. The profile above the datum is then considered as a load placed back upon the soil as a load (minus the excavated region). Also, for excavations, the X-coordinates will tend to infinity, represented as 9999 and given the appropriate sign. The equations have been computed for these limiting conditions and are built into the subroutines.

Calling Argument Definitions

X - abscissa value (feet) defining point in soil continuum at which vertical stress is to be computed.

Z - depth in feet from the datum at which stress is to be computed.

XL(i,j) - abscissa (feet) value for the jth coordinate defining the ith load strata.

YL(i,j) - ordinate value, defined as above.

GAM(i) - effective density (lb/ft^3) of the ith load strata.

LL - total number of layered loads.

KS(i) - number of coordinates defining ith load.

SIGU - value of stress (lb/ft^3) to be relieved from calculated value due to excavation-type loading.

SIG - returned value of stress (lb/ft^3) computed at (X,Z).

UMU - Poisson's ratio for the soil; Westergaard routine only.

The subroutines assume a mainline exists which has read the input into the argument arrays.

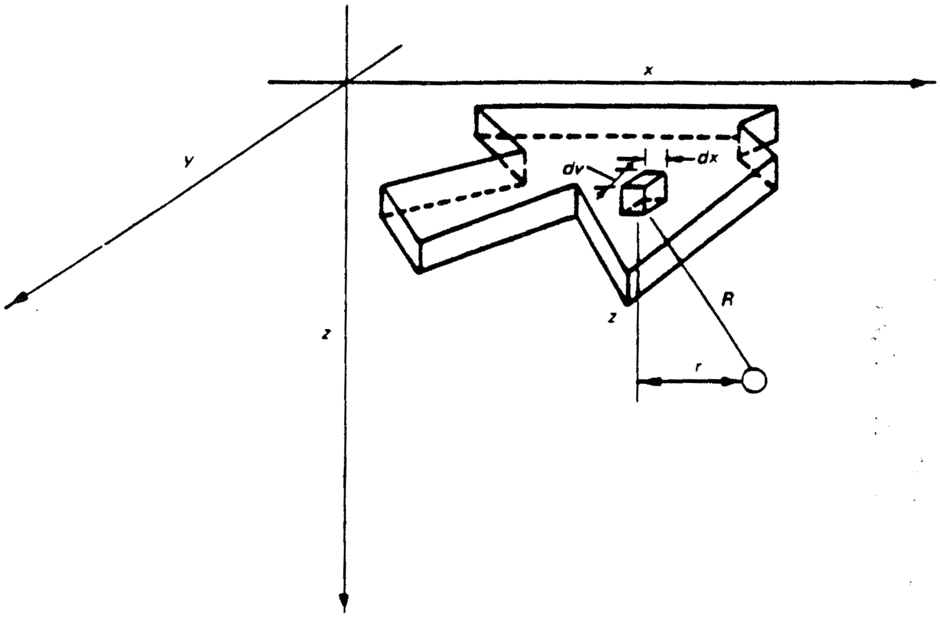
When using these subroutines, the load layers should be entered into the coordinate arrays defining the load with the topmost layer first. Otherwise, the equations, which account for the effects of layering on the effective density, will not yield the proper results. The soil continuum may be stratified; this presents no difficulty with the Boussinesq equations since soil properties are not a factor, but with the Westergaard analysis the mainline program should provide bookkeeping to account for changes in the Poisson's ratio. The mainline and subroutines are small enough to fit on even very small processors, if only the values of vertical stress are desired. However, large programs can be written using these routines to do a multitude of computation and bookkeeping to do most desirable end products for settlement analysis and stress induction activity.

```
      SUBROUTINE BOUS2 (X, Z, XL, YL, GAM, LL, KS, SIGU, SIG)
      DIMENSION XL (20, 50), YL (20, 50), GAM (20), KS (20)
      2-DIMENSIONAL BOUSSINESQ
      GAML = 0.0
      SI = 0.0
      DØ 200 I = 1, LL
      LØØP PERFØRMED FØR EACH LØAD LAYER
      SIG = 0.0
      KM = KS(I)
      DØ 100 J = 2, KM
      LØØP PERFØRMED FØR EACH LAYER ELEMENT
      CH = ABS (XL (I, J) - XL (I, J-1))
      IF (CH. LT. 0.001) GØ TØ 100
      IF (XL(I, J-1). LE. -9998.) GØ TØ 50
      IF (XL(I, J). GE. 9998) GØ TØ 80
      NEITHER X0 ØR X1 GØ TØ INFINITY
      A = XL(I, J) * XL(I, J-1) - X* XL(I, J-I) - X*XL(I, J) + X**2 + Z**2
      B = YL(I, J) * A/((XL(I, J) - X)**2 + Z**2)
      C = YL(I, J-1) *A/((XL(I, J-1) - X) **2 + Z**2)
      D = ATAN2 ((XL(I, J)-X), Z) - ATAN2((XL(I, J-1)-X)), Z)
      E = (YL(I, J-1) * (XL(I, J) - X) - YL (I, J) * (XL(I, J-1)-X))/Z
      F = YL(I, J-1) + YL(I, J)
      G = Z/(3.14159 + (XL(I, J) - XL(I, J-1)))
      G = G/(GAM(I) - GAML)
      SIG = G*(F-B-C+E*b) + SIG
      GØ TØ 100
      LEFT X GØES TØ MINUS INFINITY
 50   A = (XL(I, J) - X)
      B = YL(I, J)
      C = ATAN2 (A, Z) + 1.5708
      A = -A
      GØ TØ 90
      RIGHT X GØES TØ INFINITY
 80   A = (XL(I, J-1) - X)
      B = YL(I, J-1)
      C = 1.5708 - ATAN2 (A, Z)
 90   G = Z/3.14159 * (B/Z*C - B*A/(A**2 + Z**2))
      C = G* (GAM(I) - GAML)
      SIG = SIG + G
100   CØNTINUE
      GAML = GAM(I)
      SI + SI + SIG
```

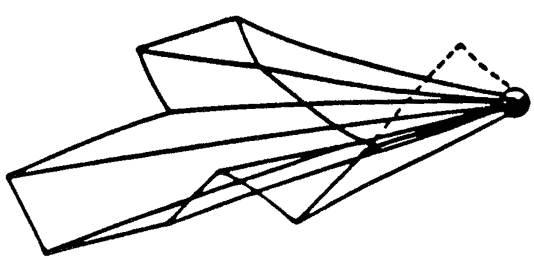
```
 200  CØNTINUE
      SUBTRACT RELIEVED PRESSURE FRØM CØMPUTED
      SIG = SI - SIGU
      RETURN
      END

      SUBRØUTINE WEST2 (X, Z, XL, YL, GAM, LL, KS, SIGU, UMU, SIG)
      DIMENSION XL (20, 50), YL (20, 50), GAM (20), KS (20)
C     2-DIMENSIONAL WESTERGAARD
      GAML = 0.0
      ETA = SQRT ((1. - 2.*UMU)/(2.*(1. - UMU)))
      SI = 0.0
      DØ 100 I = 1, LL
      LØØP PERFØRMED FØR EACH LØAD LAYER
      SIG = 0.0
      KM = KS(I)
      DØ 100 J = 2, KM
C     LØØP PERFØRMED FØR EACH ELEMENTAL REGIØN
      IF (XL(I, J-1). LE. -9998.) GØ TØ 80
      IF (XL (I,J) .GE. 9998.) GØ TØ 50
C     IF HERE, REGIØN FINITE
      IF (ABS (XL(I, J) - XL(I, J-1)). LT. 0.001) GØ TØ 100
      A = (YL(I, J-1)*XL(I, J) - YL(I, J) * XL(I, J-1))/(XL(I, J) - XL(I, J1))
      B = (YL(I, J) - YL(I, J-1))/(XL(I, J) - XL(I, J-1))
      C = (A + B*X)/(Z*ETA)
      D = ATAN2 ((XL(I, J) - X), (Z*ETA)) - ATAN2 ((XL(I, J-1) -X), (Z*ETA))
      E = B/2.* (ALØG((XL(I, J) - X)**2 + (Z*ETA)**2) - ALØG((XL(I, J-1) - X)**2
      $ + (Z *ETA)**2))
      W = (GAM(I) - GAML) *ETA/3.14159
      SIG = W * Z*(C *D + E) + SIG
      GØ TØ 100
C     LEFT X GØES TØ INFINITY
 50   SIG = (GAM(I) - GAML)*YL(I, J-1)/3.14159*(1.570796 - ATAN2((XL(I, J-1) -X),
      $ (Z * ETA))) + SIG
      GØ TØ 100
C     RIGHT X GØES TØ INFINITY
 80   SIG = (GAM(I) - GAML) * YL(I,J)/3.14159 *(1.570796 + ATAN2((XL(I, J) -X),
      $ (Z *ETA))) + SIG
100   CØNTINUE
      GAML = GAM(I)
      SI = SI + SIG
200   CØNTINUE
      SIG = SI - SIGU
      RETURN
      END
```

For the three-dimensional case, the starting point is the equation for a point load vertical to a horizontal surface, and again superposition will be used. The load need not be homogeneous, although the analysis will assume that it is, simply since a non-homogeneous load can be separated into homogeneous regions and superpositioning will allow summing of the regions. Each homogeneous region is assumed to be definable by (X,Y) coordinate pairs in plan view; i.e., the region boundaries are piecewise linear. The most general case is therefore a homogeneous polygon as a horizontal surface as shown by the sketch below:

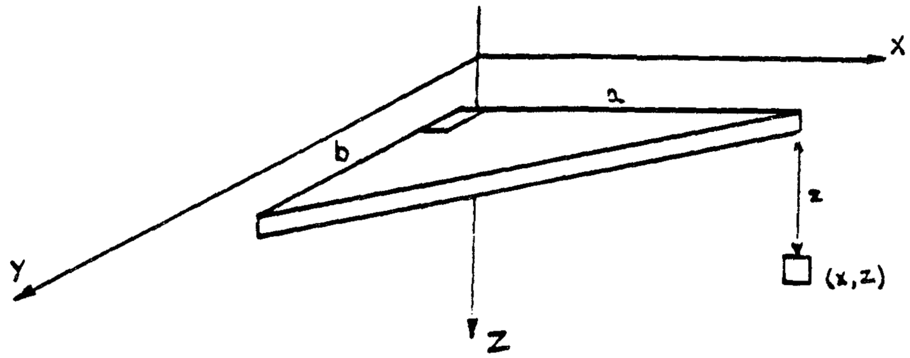


To analyze this case, consider the plan view to uncover the elemental region.



Using superpositioning, the region can be analyzed by considering each region defined by (X_i,Y_i), (X_{j+1},Y_{j+1}), (X_c,Y_c) incrementally. Thus, the incremental region to be considered is further reduced to triangular regions. In fact, since any triangular region can be considered as a combination of two right triangles, the right triangle becomes the most elemental region for formulae derivations.

Hence, the three-dimensional equation will be developed using a right-triangular, homogeneous load on a horizontal surface for a point immediately beneath one corner of the load and at a depth Z.



The total vertical stress is the algebraic sum of contributions by all such triangular regions, summed over all regions of homogeneous density.

For the three-dimensional Boussinesq case, the following equation holds.

$$N_Z = \frac{3PZ^3}{2\pi} \int_0^a dx \int_0^{b\, x/a} (X^2 + y^2 + Z^2)^{5/2} \, dy$$

For the three-dimensional Westergaard case, the following equation holds.

$$N_Z = \frac{P}{2\pi\mu^2 Z^2} \int_0^a dx \int_0^{b\, x/a} \left(\frac{X^2+y^2}{\mu^2 Z^2} + 1\right)^{3/2} dy$$

In the Westergaard case, if we replace μZ by Z', as was previously done in the two-dimensional problem, the equation simplifies.

$$N_Z = \frac{P}{2\pi Z'^2} \int_0^a dx \int_0^{b\, x/a} \left(\frac{X^2+y^2}{Z'^2} + 1\right)^{3/2} dy$$

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