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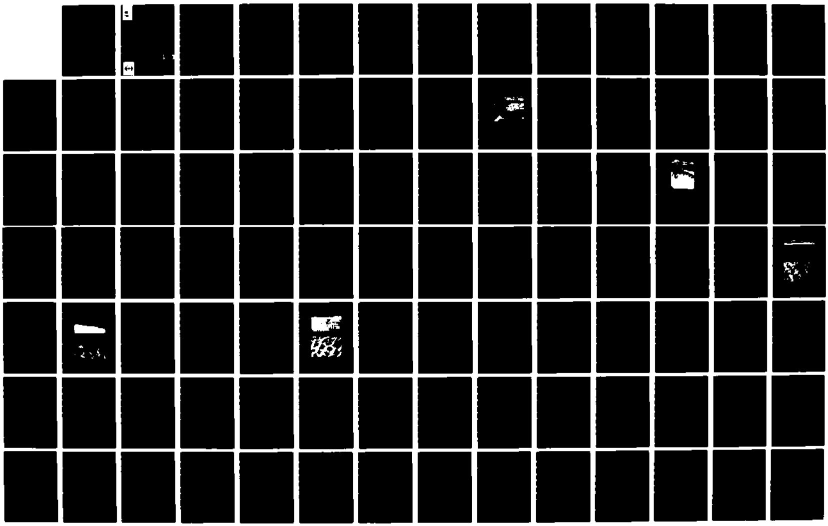

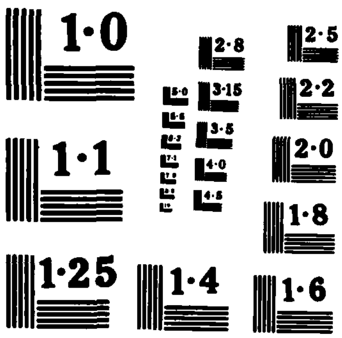

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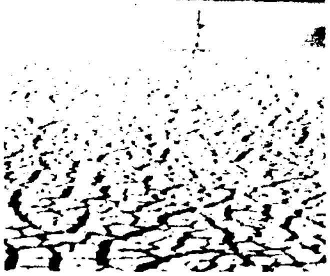
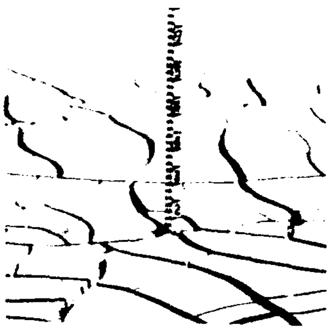
AD-A158 730

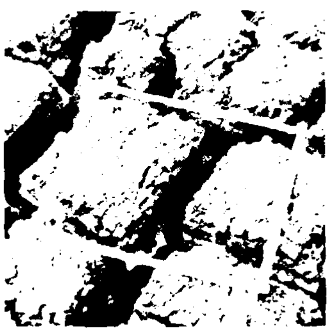
DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

TECHNICAL REPORT D-85-4

MATHEMATICAL MODEL OF THE CONSOLIDATION/DESICCATION PROCESSES IN DREDGED MATERIAL







by

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July 1985

Final Report

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This report documents the development of a mathematical model of the consolidation/desiccation process in soft, fine-grained soils such as dredged material; provides for computer solution of the model; and verifies the solution through comparisons with field measurements.

The consolidation process is modeled through the previously documented finite strain theory of consolidation which accounts for the large strains

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and nonlinear soil properties inherent in the very soft materials commonly found in maintenance dredgings. Pertinent equations necessary for process calculation are given. An empirical description of the desiccation process is presented in terms of the water balance in the uppermost crust in the dredged material layer and generally conforms with previous work. The first and second drying stages along with associated characteristic material properties (saturation limit and desiccation limit) are defined. Procedures for calculation of the effective depths of first and second stage drying, soil evaporation rates, and the surcharge induced by water table lowering are also given. The interaction of the consolidation and desiccation processes is discussed and the mathematical treatment proposed.

The mathematical model is next rewritten for computer solution through the computer program PCDDF. The program uses an explicit finite difference scheme for solving the consolidation portion of the problem and makes monthly adjustments in the top boundary condition and boundary location in accordance with the amount of desiccation which has occurred. In addition to material settlement which comes from a calculation of void ratio distribution, the program also calculates the distribution of stresses and pore pressures through the layer, which can be indicative of soil strength. Any sequence of material deposition as well as consolidation in an underlying foundation layer can be considered.

The model and computer solution are then tested through comparisons of predicted material settlements with measured settlements in three confined disposal areas. The areas include Canaveral Harbor where one layer of material was deposited, Drum Island where two layers were deposited about 1 year apart, and Craney Island where yearly depositions have occurred for a 24-year period. The results of these comparisons show that the proposed model and computer solution offer realistic indications of the material settlements under a wide variety of conditions.

Appendices to the report include a detailed user's manual (Appendix A) for computer program PCDDF along with a program listing (Appendix B) and sample input and output data (Appendix C). Consolidation properties (Appendix D) and the design of a comprehensive field verification site (Appendix E) are also included.

PREFACE

This report was prepared by the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), as part of the Dredging Operation Technical Support Program (DOTS) work unit for verification and refinement of engineering methodologies developed during the Dredged Material Research Program. The DOTS Program is sponsored by the Dredging Division of the Water Resources Support Center, Fort Belvoir, Va., and managed by the Environmental Effects of Dredging Programs (EEDP) in the WES Environmental Laboratory (EL).

Mr. Charles C. Calhoun, Jr., was Manager, EEDP, and Dr. Michael R. Palermo was the work unit Principal Investigator. The report was written by CPT Kenneth W. Cargill during the period June 1982 to March 1983 under the general supervision of Mr. C. L. McAnear, Chief, Soil Mechanics Division, GL; and Dr. William F. Marcuson III, Chief, GL. Dr. John Harrison was Chief, EL, during this period. Revision of the computer model PCDDF to internally determine the simulation time increment and grid size was performed by Mr. Gary Goforth, working for EL under an Intergovernmental Personnel Agreement with the University of Florida.

During the preparation of this report, COL Tilford C. Creel, CE, and COL Robert C. Lee, CE, were Commanders and Directors of WES and Mr. F. R. Brown was Technical Director. At the time of publication, COL Allen F. Grum, CE, was Director and Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

US customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per minute	0.3048	metres per minute
inches	25.4	millimetres
square inches	6.4516	square centimetres
tons (force) per square foot	95.76052	kilopascals

MATHEMATICAL MODEL OF THE CONSOLIDATION/DESICCATION PROCESSES IN DREDGED MATERIAL

PART 1: INTRODUCTION

Background

1. The safe, efficient, and economical disposal of fine-grained material dredged from navigable waterways throughout this country is a problem which must be continually addressed by most Corps Districts. In the recent past, more stringent environmental concerns together with a general decrease in the number of available disposal areas have created the need for maximum utilization of both existing and planned dredged material containment areas. Benefits to be derived from optimal use of containment areas include both economic and environmental factors. By operating and managing the disposal sites in such a manner as to reduce the dredged material surface elevation, the useful service life of the containment areas and the volume of dredged material which can be stored in them will be increased. Thus the number of additional containment areas required in the future will be minimized, as will the environmental impacts of additional containment areas. The authority for site management is recognized in Section 148 of PL 94-587:

> Sec. 148. The Secretary of the Army, acting through the Chief of Engineers, shall utilize and encourage the utilization of such management practices as he determines appropriate to extend the capacity and useful life of dredged material disposal areas such that the need for new dredged material disposal areas is kept to a minimum. Management practices authorized by this section shall include, but not be limited to, the construction of dikes, consolidation and dewatering of dredged material, and construction of drainage and outflow facilities.

As the management of disposal areas has intensified, the need has developed to improve the mainly empirical methods used in the past for containment area design. This report focuses on one of the primary factors in a well-engineered scheme for the disposal of dredged material within confined areas: namely, the prediction of settlements of the fine-grained portion of the dredged material due to consolidation and desiccation.

Problem Statement

2. In order that the maximum benefits can be derived from areas constructed for the confined disposal of dredged material, the areas' design and operation plan must accurately account for the increase in storage capacity resulting from future decreases in the height of dredged fill deposited. The height of the dredged fill decreases by three natural processes: sedimentation, consolidation, and desiccation. The sedimentation process is not covered in this report because its effect is complete within a few hours or few days after material deposition and therefore has no effect on the long-term operation or storage capacity of the disposal area. Tests to ascertain a material's sedimenting nature and procedures for calculating the effects on disposal area filling are described by Montgomery (1978). General guidance on design, operation, and management of disposal areas is given by Palermo, Montgomery, and Poindexter (1978).

3. Increases in the storage capacity of a confined dredged fill disposal site because of the decrease in dredged fill height due to consolidation and desiccation are important considerations when designing a containment area for maximum efficiency and economy. Many soft, fine-grained dredged materials consisting of clays and silts may ultimately undergo upwards of 50-percent strain during self-weight consolidation. If the site is well managed to eliminate surface water so that the material surface can dry through desiccation, much higher strains are possible. The problem then is to determine settlements as a function of time for dredged material subjected to the effects of self-weight consolidation, crust formation due to desiccation, and additional consolidation due to the surcharge created by crust formation.

Objectives

4. There are basically three objectives for this report:

a. Develop a mathematical model which describes the combined processes of consolidation and desiccation within a typical soft, fine-grained dredged fill, and which is based on laboratory-determined material properties and site-specific climatic conditions.

b. Codify the mathematical model in a computer program capable of forecasting dredged material settlements as a function of time for any particular filling history.

c. Verify the mathematical model and computer program by comparing predictions of settlement at various sites with measurements of settlement made at these same sites.

Previous Work

5. A review of the literature revealed some of the past attempts at solving the problem of dredged fill settlements. Casteleiro (1975) presented a mathematical model of consolidation and desiccation which was able to predict settlements of the same order of magnitude as those measured in a field site. The model is based on small strain consolidation theory, purports to calculate consolidation in both saturated and unsaturated layers, and considers evapotranspiration. The report's conclusion that the use of vegetation with high transpiration rates offers the most promise of accelerating dredged fill consolidation leads this author to believe that the model is deficient in its treatment of the consolidation process. Johnson (1976) has also presented a mathematical model for predicting consolidation of dredged material which is based on small strain consolidation theory and includes sedimentation calculations. This model, modified to include an empirical model of desiccation, was used by Palermo, Shields, and Hayes (1981) to make estimates of settlements in the Craney Island disposal area with very good results. Hayden (1978) and Haliburton (1978) have also produced procedures for estimating dredged fill settlements which consider desiccation and use a simplified approach to the consolidation process.

6. Two of the primary drawbacks to all of the above procedures are their reliance on small strain consolidation theory to describe the consolidation process and the unlimited depths through which unrestricted desiccation effects may proceed. The report presented herein is essentially an extension of a previous report by Cargill (1982) which documented a mathematical model for settlement calculation based on the finite strain theory of consolidation. The finite strain theory of consolidation, first proposed by Gibson, England, and Hussey (1967), has been shown to be superior to the conventional small strain consolidation theory in its ability to model the one-dimensional primary consolidation process for soft soils with nonlinear material properties (Gibson, Schiffman, and Cargill 1981; Schiffman and Cargill 1981; and Cargill 1983a). A new version of the mathematical description of the desiccation process to be fully described in Part II of this report will be coupled with

this finite strain model of the consolidation process to provide a state-of-the-art computer program for the prediction of settlements in dredged material.

Need for Field Verification

7. Field verification is a necessity for any analytical procedure before the procedure can be used confidently as a basis for new design. This is especially true where the variances of nature play a major part in the field performance as in the case of desiccation. Therefore, the results of analysis techniques developed in this study will be compared with available field measurements to develop some initial level of confidence in the method. It is recognized that the field sites used were not specifically monitored for the purpose of verifying this consolidation/desiccation calculation procedure, and some of the required input data will have to be assumed.

8. Additional field verification designed specifically for evaluation of the proposed mathematical model and calculation procedure would be particularly advantageous in providing guidelines upon which factors requiring engineering judgment can be based. The design of such a comprehensive field verification site is included as an appendix to this report. Such a program is considered essential before maximum benefits can be derived from this or any other method of dredged fill settlement prediction.

9. Several appendices accompany the main body of this report. Appendix A is a user's manual for the computer program PCDDF. Appendix B provides a source listing of PCDDF. Appendix C presents example input and output of PCDDF. Appendix D contains compressibility and permeability data referenced in the main body. A comprehensive field verification site is described in Appendix E.

PART II: MATHEMATICAL DESCRIPTION OF PROBLEM

10. In general, a problem must be described mathematically before a properly engineered solution can be obtained. The complexity of the mathematical description should conform with the certainty to which its constituent variables can be measured or specified. A rather complex model of the consolidation process is presented here because of the relative certainty with which its variables can be known. That is not to say that they will be absolutely known, but that the opportunity for reliable measurement or specification is great. A somewhat looser description of the desiccation process will be used because the primary factors governing the process are not normally predictable to any large degree of certainty.

The Consolidation Process

11. The mathematical model of one-dimensional primary consolidation used in this report is based on the finite strain theory of consolidation as described in detail by Cargill (1982). Thus, only the main points will be repeated here for ready reference without going into any of the derivations.

Governing equation

12. The governing equation of the consolidation process first presented by Gibson, England, and Hussey (1967) is

$$\left(\frac{\gamma_s}{\gamma_w} - 1\right) \frac{d}{de} \left[\frac{k(e)}{1 + e}\right] \frac{\partial e}{\partial z} + \frac{\partial}{\partial z} \left[\frac{k(e)}{\gamma_w(1 + e)} \frac{d\sigma'}{de} \frac{de}{dz}\right] + \frac{\partial e}{\partial t} = 0 \qquad (1)$$

where

γ_s = unit weight of solids

γ_w = unit weight of water

e = void ratio

$k(e)$ = coefficient of soil permeability as a function of void ratio

z = vertical material coordinate measured against gravity

σ' = effective stress

t = time

This equation is well suited for the prediction of consolidation in thick deposits of very soft, fine-grained dredged material because it provides for:

the effects of self-weight, permeability varying with void ratio, a nonlinear void ratio-effective stress relationship, and large strains.

13. A closed form analytical solution of Equation 1 is probably not possible, but its numerical solution on a computer is quite feasible. Once initial and boundary conditions are defined and appropriate relationships between void ratio and effective stress and between void ratio and permeability are specified, the void ratio distribution in the consolidating layer can be calculated by an explicit finite difference scheme for any future time as fully described in Cargill (1982). In finite differences, Equation 1 can be written

$$e_{i,j+1} = e_{i,j} - \frac{\tau}{\gamma_w} \left(\left\{ \gamma_c \beta(e_{i,j}) + \left[\frac{\alpha(e_{i+1,j}) - \alpha(e_{i-1,j})}{2\delta} \right] \right\} \left[\frac{e_{i+1,j} - e_{i-1,j}}{2\delta} \right] + \alpha(e_{i,j}) \left[\frac{e_{i+1,j} - 2e_{i,j} + e_{i-1,j}}{\delta^2} \right] \right) \tag{2}$$

where

τ = time interval in finite difference mesh

γ_c = buoyant unit weight of solids or

$$\gamma_c = \gamma_s - \gamma_w \tag{3}$$

$\beta(e)$ = a function of the void ratio and permeability defined by

$$\beta(e) = \frac{d}{de} \left[\frac{k(e)}{1 + e} \right] \tag{4}$$

$\alpha(e)$ = a function of the void ratio, permeability, and compressibility defined by

$$\alpha(e) = \frac{k(e)}{1 + e} \frac{d\sigma'}{de} \tag{5}$$

δ = vertical space interval in material coordinates in finite difference mesh

Initial and boundary conditions

14. Typically, the initial conditions of a saturated dredged fill layer can be written as

$$e(z,t) = e_{00} \text{ for } t = 0 \tag{6}$$

where e_{00} = void ratio at zero effective stress. This is an instantaneous condition reached by the dredged material at the end of the sedimentation process just as the solids begin to form a continuous soil matrix. It is actually an approximation since the entire layer does not end sedimentation and begin consolidation at exactly the same instant in time. However, it should be a good approximation if the time to which consolidation is calculated is relatively long in comparison with the total time required for complete sedimentation.

15. In a dredged fill layer not subjected to surface desiccation, the top boundary condition is

$$e(\ell,t) = e_{00} \quad \text{for} \quad t > 0 \tag{7}$$

where ℓ = total layer thickness in material coordinates. The top boundary condition of the consolidating layer in the presence of a desiccated crust will be discussed in a later section.

16. The boundary condition at an impermeable lower interface is

$$\frac{\partial e}{\partial z} = \left(\gamma_w - \gamma_s\right) \frac{de}{d\sigma'} \quad \text{for} \quad t > 0 \quad \text{and} \quad z = 0 \tag{8}$$

and at a semipermeable lower boundary is

$$\frac{\partial e}{\partial z} = \left(\gamma_w - \gamma_s - \frac{\partial u}{\partial z}\right) \frac{de}{d\sigma'} \quad \text{for} \quad t > 0 \quad \text{and} \quad z = 0 \tag{9}$$

where u = excess pore pressure. The impermeable boundary condition is used where the dredged fill overlays a relatively impervious, incompressible foundation layer. The semipermeable condition is used with either a compressible foundation layer which drains through the dredged fill or an incompressible foundation providing impeded drainage from the dredged fill.

17. At a free draining lower boundary, excess pore pressure is zero and the total pore pressure is equal to the static pore pressure or

$$u_w = u_o = h_w \gamma_w \tag{10}$$

where

u_w = total pore pressure

u_o = static pore pressure

h_w = height of the water table above the boundary

Since the total weight of material above the boundary can be calculated, total stresses are known and effective stress may be calculated by the effective stress principle. Thus

$$\sigma'(0,t) = \sigma(0,t) - u_w \tag{11}$$

where σ = total stress and since

$$\sigma'(0,t) = f[e(0,t)] \tag{12}$$

the persistent void ratio at the boundary is known.

18. There are several methods of relating void ratio to effective stress. Among them is

$$e = e_1 - (\sigma' - \sigma_1')a_v \tag{13}$$

where

e_1 = void ratio at effective stress σ_1'

a_v = soil coefficient of compressibility

which is the relationship used deriving the linear small strain theory of consolidation. There is also the well-known relationship for normally consolidated clays

$$e = e_1 - C_c \log\left(\frac{\sigma'}{\sigma_1'}\right) \tag{14}$$

where C_c = compression index for the soil. In linearizing the governing equation of finite strain consolidation theory, Gibson, Schiffman, and Cargill (1981) have proposed the relationship

$$e = (e_{00} - e_\infty) \exp(-\lambda\sigma') + e_\infty \tag{15}$$

where

e_∞ = void ratio at infinite effective stress

λ = a constant describing the change in soil compressibility with void ratio

19. Since none of these methods are completely adequate in representing the void ratio-effective stress relationship throughout the range of void ratios typical of a consolidating dredged fill layer, the mathematical model used here will be based on laboratory-determined curves. This is accomplished in the computer program by interpolating between relatively closely spaced points selected from the laboratory curve.

Coordinates and settlement

20. It is convenient to solve the consolidation governing equation in terms of the vertical material coordinate z. However, since this is a measure of material solids which remains constant throughout the consolidation process, a coordinate transformation is required to obtain the height of points within the dredged fill layer. At any time, the actual coordinate within the layer is

$$\xi(z_1,t) = \int_0^{z_1} \left[1 + e(z,t)\right] dz \qquad (16)$$

where

ξ = convective coordinate

z_1 = material coordinate of any point within the layer

21. Total layer settlement between times t_1 and t_2 is now easily expressed by

$$\delta = \xi(\ell,t_1) - \xi(\ell,t_2) = \int_0^{\ell} \left[e(z,t_1) - e(z,t_2)\right] dz \qquad (17)$$

or if settlement is measured from the initial sedimented dredged fill height h,

$$\delta(t) = e_{00}\ell - \int_{o}^{\ell} e(z,t)dz \tag{18}$$

since

$$h = \ell(1 + e_{00}) \tag{19}$$

Stresses and pore pressures

22. The calculation of stresses and pore pressures within a saturated dredged fill layer is relatively simple once the void ratio distribution and thus effective stress distribution is determined from solution of the governing equation. The total stress at any point in the layer is equal to the total weights in a unit area of all materials above that point. Therefore,

$$\sigma(z,t) = \gamma_w\left[h_1 + \int_{z}^{\ell} e(z,t)dz\right] + \gamma_s \int_{z}^{\ell} dz \tag{20}$$

where h_1 = height of free water surface above the dredged fill layer. The static pore pressure is determined by

$$u_o(z,t) = \gamma_w\left[h_2 - \xi(z,t)\right] \tag{21}$$

where h_2 = height of free water surface above the datum plane $z = 0$, and total pore pressure is

$$u_w(z,t) = \sigma(z,t) - \sigma'(z,t) \tag{22}$$

by the effective stress principle. Then the excess pore pressure is

$$u(z,t) = u_w(z,t) - u_o(z,t) \tag{23}$$

23. With the preceding equations, the state of the dredged fill layer is fully described at all times during the consolidation process. Many of the equations given thus far in this part will be modified when the dredged layer

develops a desiccated crust; therefore, care should be used during application when a crust or other surcharge is present.

The Desiccation Process--An Empirical Approach

24. As previously mentioned, the desiccation process is governed by many factors whose predictability is often difficult. The empirical process description to follow may then seem inconsistent with the rather sophisticated model of the consolidation process. However, by using the more exact model of consolidation, the reliability of the overall settlement calculation should be increased since the major cumulative errors are more likely to be limited to only one part of the calculation.

General process description

25. Desiccation of a dredged material is basically removal of water by changing the state of the water near the surface from a liquid to a gas. This change of state results primarily from evaporation and transpiration. In this report, plant transpiration is considered insignificant due to the recurrent deposition of dredged fill and is therefore disregarded. Evaporation is mainly controlled by such variables as radiation heating from the sun, convective heating from the earth, air temperature, ground temperature, relative humidity, and wind speed. While equations have been proposed which relate evaporation to these and other variables (Gardner and Hillel 1962; Linsley, Kohler, and Paulhus 1978; Ripple, Rubin, and Van Hylckama 1972; Van Bavel 1966), they are not used here due to the uncertainty in describing the variables over any period of time. Instead, evaporation from a dredged material surface will be defined as some function of the average Class A pan evaporation rate (Linsley, Kohler, and Paulhus 1978).

26. Thus, a simple mathematical description of the evaporative flux is

$$E = C_E \, EP \qquad (24)$$

where

E = evaporation from the dredged material surface

C_E = evaporation efficiency

EP = Class A pan evaporation

However, there are other factors which must also be taken into account. For instance, the evaporation efficiency is normally not a constant but some function of depth to which the layer has been desiccated and also is dependent on the amount of water available for evaporation.

Water balance

27. A more accurate equation governing the desiccation process is possible from considering the water balance of a soil element of large areal extent at the surface of the dredged material as illustrated in Figure 1. As

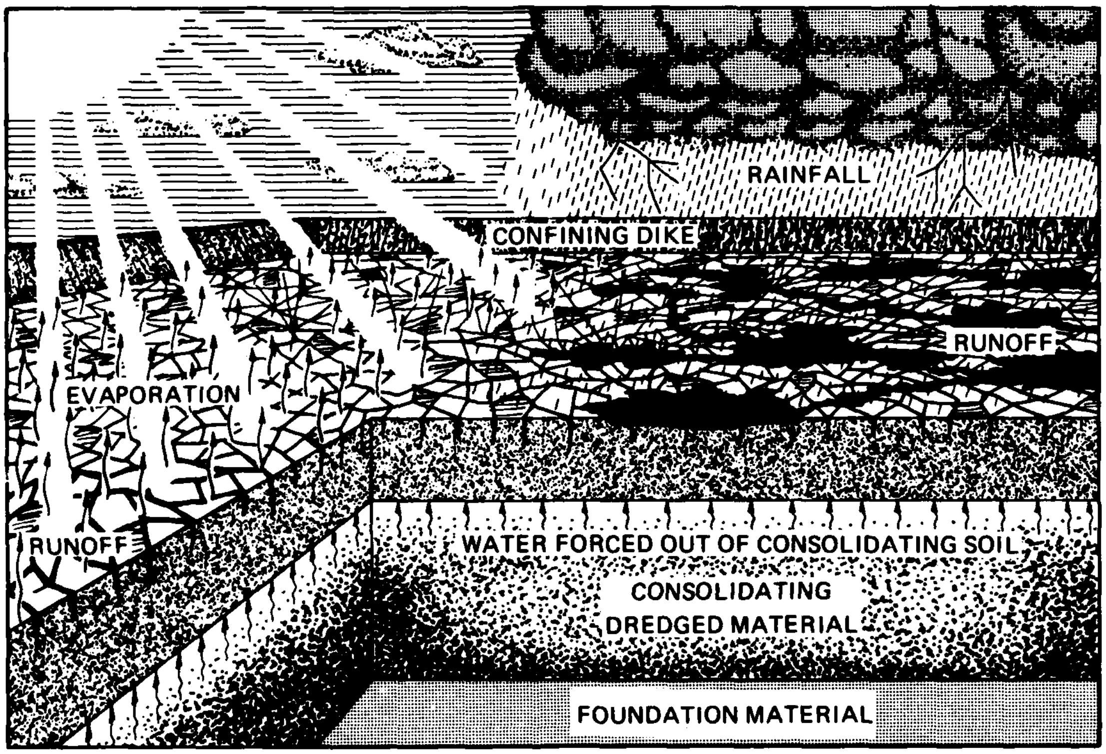


Figure 1. Water balance in a soil element of large areal extent

suggested by the figure, the change in the amount of water contained in the upper crust over a finite period of time can be expressed as

$$\Delta W = RF + CS - OF - E \tag{25}$$

where

ΔW = change in amount of water within crust

RF = rainfall

CS = water supplied from lower consolidating soil

OF = overland outflow of excess rainfall

28. With implementation of an active program to promote surface drainage, most of the water available from rainfall can be removed from the area before it is absorbed by the drying dredged material. The amount of water added to the crust due to RF and OF could then be written

$$RF - OF = \left(1 - \frac{OF}{RF}\right) RF = (1 - C_D)RF \tag{26}$$

where C_D = drainage efficiency.

29. Equation 25 now becomes

$$\Delta W = (1 - C_D)RF + CS - C_E EP \tag{27}$$

for specified periods of time. If ΔW is a positive number, there is excess water available at the dredged material surface which could resaturate previously dried crust. However, a combination of the facts that C_E increases dramatically in the presence of small amounts of free water and that previously dried crust is very slow in adsorbing standing water (Brown and Thompson 1977) leads to the assumption that ΔW can only be zero or less when the crust is exposed to the atmosphere. If ΔW is a negative number, there is a net loss of water which means either that more water is removed from any previously dried crust or that the depth d of dried crust is increased.

30. It is practical to make the calculation of Equation 27 on a monthly basis because of the availability of long-term monthly average rainfall and pan evaporation data. Rainfall and pan evaporation data have been tabulated and published in climatic summaries by the US Weather Bureau for many areas of this country. Tables of average monthly rainfall for select stations are available in National Oceanic and Atmospheric Administration (NOAA) (1980), and Brown and Thompson (1977) have developed maps of monthly pan evaporation. In the absence of more site-specific data, these sources can be used for specification of climatic data.

Drying stages

31. Studies by Brown and Thompson (1977) concluded that evaporation of water from dredged material occurs in two stages. During the first stage, sufficient free water is available at the surface of the material so that evaporation takes place at its full potential rate, i.e. $C_E = 1.0$. In the

second stage of evaporation, drying proceeds at some fraction of the potential rate, i.e. $C_E < 1.0$, and this fraction decreases as the depth of dried crust increases. A statistical analysis of moisture contents taken on the four materials studied led to an equation defining the moisture content at which water can no longer be decanted from the material,

$$w = 2.53\ LL_r \tag{28}$$

where

w = moisture content as a percentage by weight

LL_r = liquid limit of samples which have been dried and reconstituted before testing

They also defined the point dividing first- and second-stage drying as when the top 2 cm of crust reached a moisture content of

$$w = 1.86\ LL_r \tag{29}$$

again by a statistical analysis of moisture contents taken on samples of the four materials studied. They postulated that without the presence of a water table, a crust would form to a depth of about 120 cm and that the moisture content would increase uniformly from 1.86 LL_r at the top to 2.53 LL_r at the bottom. Brown and Thompson see evaporation beyond this second stage occurring at an ever decreasing rate with water being lost from the entire crust due to cracking. They made no further attempts at describing the process other than to say that ultimately the surface will dry to a fraction of the material's plastic limit while 5 to 10 cm deep the material will still be between the plastic and liquid limit.

32. Haliburton (1978) says dewatering by evaporative drying is a three-stage process but describes only the two which are important to fine-grained dredged material. First stage is characterized by free water surface evaporation at the potential rate, and second stage is governed by the capillary resupply potential of the soil and will be at something less than the potential rate. He asserts that, under normal conditions, long-term dredged material evaporative drying is essentially governed by the second-stage process. Haliburton's description of the stages is somewhat different from Brown and Thompson's. He defines the first stage as a period of decantation which

ceases when the moisture content of the top crust reaches 1.8 LL, which is called the "decant point." In the second stage, the crust dries to

$$w = 1.2\ PL \tag{30}$$

where PL = the plastic limit of the dredged material. The calculation of desiccation effects proposed by Haliburton assumes that initially the entire depth of dredged fill exists at 1.8 LL and that evaporation reduces the moisture content of the entire depth to 1.2 PL at the rates of 0.35 EP for a saltwater environment and 0.5 EP for a freshwater environment. No limits are placed on the depths to which these rates are effective.

33. Gardner and Hillel (1962) also characterize soil drying as a two-stage process with the drying rate in the first stage being constant and dependent upon evaporative conditions. During the second stage, the drying rate continuously decreases with time and decreasing moisture content of the soil. The authors point out that previous studies had concluded that during the constant initial stage of drying, the cumulative evaporation from a soil will approach a constant amount which is independent of the evaporation rate, and this conclusion was verified by the reported studies. They additionally report that, after a sufficiently long time, the evaporation rate becomes independent of potential evaporation and depends solely on the water content distribution and water transmitting properties of the soil.

Saturation and desiccation limits

34. Based on the above cited studies, it is concluded that effective evaporative drying of dredged material leading to the formation of a desiccated crust is a two-stage process. The first stage begins when all free water has been decanted or drained from the dredged material surface. In this study, this decant point does not correspond to 1.8 LL as proposed by Haliburton, but is the void ratio (void ratios will be used in lieu of moisture contents so that the desiccation process can be more directly related to the consolidation process as previously described) corresponding to zero effective stress e_{00} as determined by laboratory sedimentation and consolidation testing. This initial void ratio may come very close to Brown and Thompson's decant point of 2.53 LL_r.

35. First-stage drying ends and second stage begins at a void ratio which will be called the saturation limit or e_{SL}. The e_{SL} of typical

dredged material probably comes very close to Haliburton's 1.8 LL. In this model it is assumed that the dredged fill surface material at void ratios higher than e_{SL} will dry to the e_{SL} at a rate equal to some constant percentage of the full evaporation potential. During the first stage, the free water table is expected to remain at the surface of the dredged material even though widely spaced and shallow surface cracks are very likely to develop. This is not to say that the water table will stay constant because the dredged fill surface will be settling due to the effects of primary consolidation and desiccation. It does mean that the material remains saturated and buoyant since any nonsaturated surface film will be negligible; hence, the term "saturation limit."

36. After the saturation limit has been reached to a depth which will be discussed in the next section, water cannot be supplied by the soil fast enough to sustain the first-stage evaporation rate. Two things then happen. First, the dredged material begins to lose saturation starting with the surface. Then, as the free water table begins to drop below the surface, the material develops negative pore pressures which shrink the material to a hard crust having a much lower permeability and thus drastically reduced evaporative rates. The evaporative rate in second-stage drying will depend not only on the water conductivity of the unsaturated crust but also its depth. For this study, it is assumed that second-stage drying will be an effective process until the material reaches a void ratio which will be called the desiccation limit or e_{DL}. When the e_{DL} reaches a limiting depth, evaporation of additional water from the dredged material will effectively cease. What evaporation occurs will be limited to excess moisture from undrained rainfall and that water forced out of the material due to consolidation of material below the crust. The e_{DL} of typical dredged material may roughly correspond to Haliburton's 1.2 PL or a similar quantity. Also associated with the e_{DL} of a material is a particular percent saturation which probably varies from 100 percent to something slightly less, depending on the material.

Desiccation depths

37. The saturation and desiccation limits described above are considered characteristic of the top portions of a dredged fill subjected to evaporative drying. There may be a top film of material dried to less than the e_{SL} or e_{DL} during the first- and second-stage process, respectively, but this film is considered to have negligible influence in the overall calculation of

material settlements. The film, however, is one of the primary factors determining the evaporation rate.

38. To determine the maximum depth of dredged fill which can be desiccated to the e_{SL} at first-stage evaporation rates, it is proposed that one should consider the self-weight consolidation characteristics of the dredged material as deposited. As shown in Figure 2, a saturated dredged fill layer

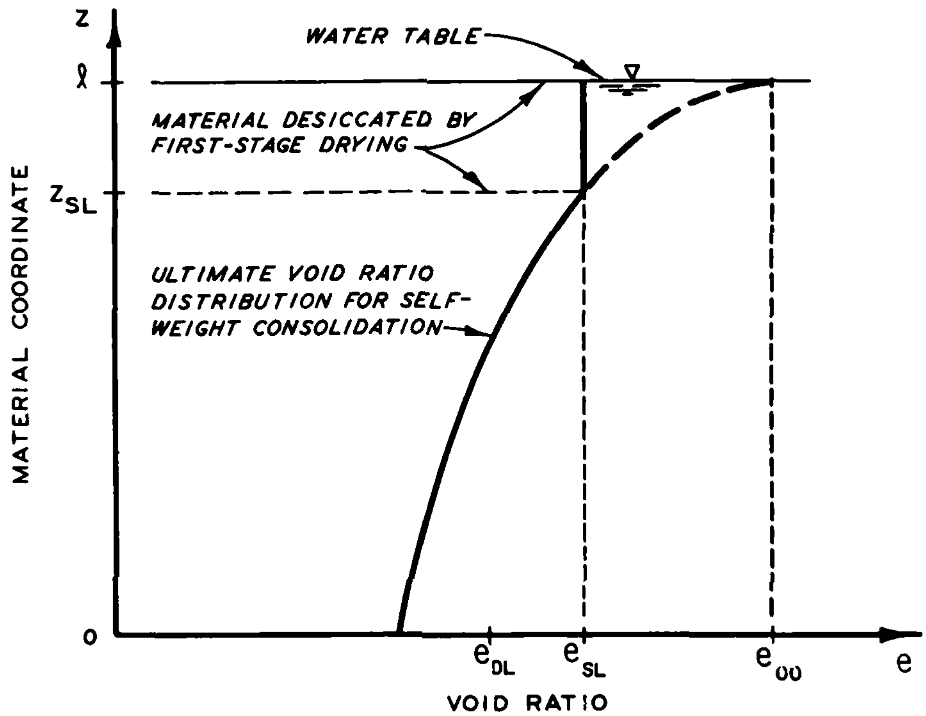


Figure 2. Maximum depth of material desiccated by first-stage drying

with a free water table at or above its surface will undergo self-weight consolidation to an ultimate void ratio distribution as noted. So long as the material remains saturated and the free water table is at the surface, the effects of evaporative drying cannot extend deeper than the intersection of the ordinate denoting e_{SL} and the ultimate void ratio distribution curve. Thus, the maximum depth to which first-stage drying can occur is

$$h_{1st} = (\ell - z_{SL})\ (1 + e_{SL}) \tag{31}$$

where

h_{1st} = maximum depth of first-stage drying

z_{SL} = material coordinate at intersection of e_{SL} and ultimate void ratio distribution curve

While void ratios lower than e_{SL} may exist in the dredged material below z_{SL}, they are due to self-weight consolidation and not surface desiccation during first-stage drying.

39. The absolute maximum depth to which second-stage drying will proceed can also be related to the consolidation characteristics of the material. Figure 3 depicts the situation. As shown, the curve defining the ultimate

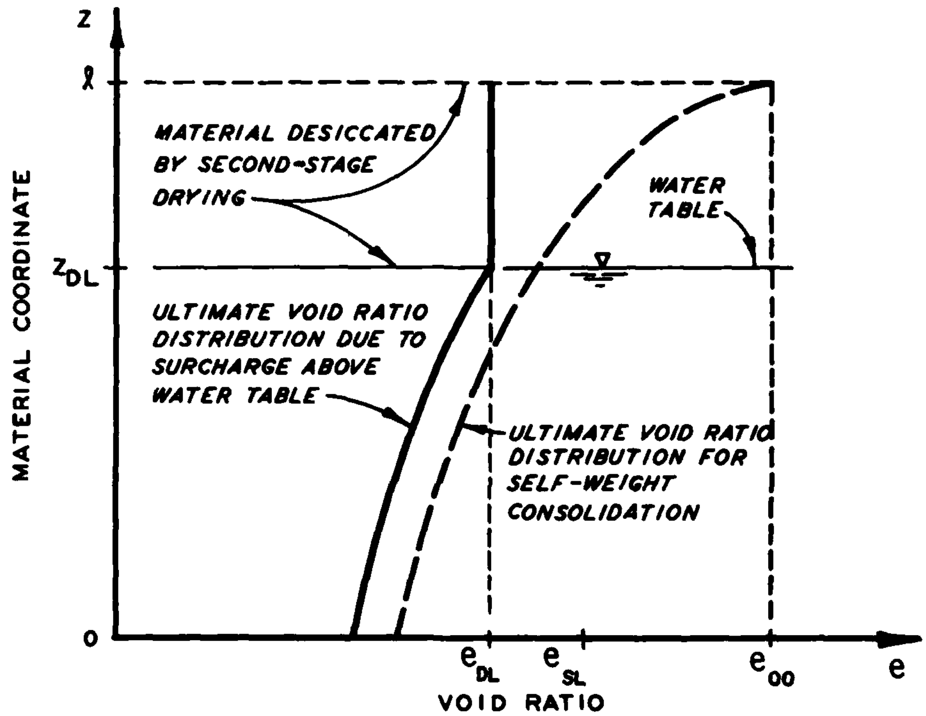


Figure 3. Maximum depth of material desiccated by second-stage drying

void ratio distribution has shifted toward the origin because of a surcharge induced by the water table drop. Thus, the absolute maximum depth to which second-stage drying can occur is the water table depth (which sometimes can be measured in the field) or the intersection of the ordinate denoting e_{DL} with the ultimate void ratio distribution curve which is based on the surcharge induced. In equation form

$$h_{2nd} = (P - z_{DL})(1 + e_{DL}) \tag{32}$$

where

h_{2nd} = maximum depth of second-stage drying

z_{DL} = material coordinate at intersection of e_{DL} and ultimate void ratio distribution curve

Again it can be seen that void ratios lower than e_{DL} may exist below z_{DL} due to consolidation effects. It is also important to note that h_{1st} can be larger than h_{2nd} due to the low void ratio of a completely desiccated dredged material. A field indicator of the depth to which second-stage drying can be effective is the depth of cracks in the dredged material. Of course, cracks subjected to periodic rainfall are probably shallower than they would be under constant evaporative conditions.

40. The preceding two equations form a rational basis for estimating the depths of crust formation in dredged material under first- and second-stage drying. They should be applicable whenever sufficient dredged material is present to provide an intersection between the ultimate void ratio distribution and the appropriate limiting void ratio, and there is no external influence limiting the water table depth. If insufficient material is present, the entire dredged fill layer may be subjected to the first- and second-stage drying processes in turn. If the water table depth is limited, the second-stage drying depth will be similarly limited. Again, the practical maximum depth of second-stage drying is best estimated from the maximum depth of desiccation cracks.

41. The maximum depth of first-stage drying as expressed in Equation 31 should be a realistic measure for most fine-grained soils whose e_{SL} intersects the consolidated void ratio curve above the material coordinate defining the soil's maximum field crust thickness. For those soils whose e_{SL} is so low that z_{SL} is greater than z_{DL} when based on the preceding considerations, the z_{SL} should be limited to no greater than z_{DL}

Evaporation and drainage efficiencies

42. Previous research on evaporation of water from bare soils (Brown and Thompson 1977; Gardner and Hillel 1962; Ripple, Rubin, and Van Hylckama 1972; Ritchie and Adams 1974) suggests that evaporation rates are some constant fraction of the environmental potential rate (in this study, Class A pan potential) during first-stage drying. The rates exponentially decay to a negligible amount during second-stage drying as the water table falls below the surface of the material. This is illustrated graphically in Figure 4

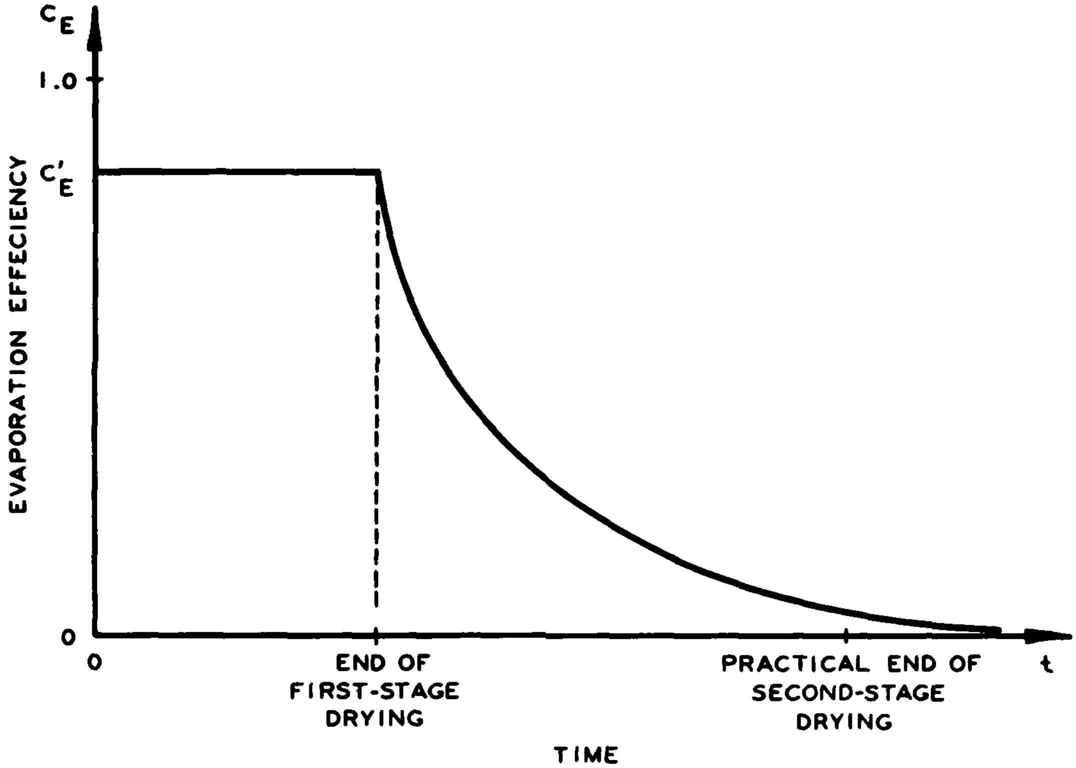


Figure 4. Soil evaporation efficiency as a function of time

where C_E is plotted as a functi n of time. While the maximum value of C_E has been plotted as less than 1.0 in the figure, it should be noted that some data have been presented which require $C_E \geq 1.0$, but these cases are limited to freshwater material and are not considered typical of most dredged material. Equations defining these relationships could be written

$$C_E = C'_E \quad \text{for} \quad 0 \leq t \geq t_1 \tag{33}$$

and

$$C_E = C'_E \exp(-ct) \quad \text{for} \quad t > t_1 \tag{34}$$

where

C'_E = maximum evaporation efficiency for soil type

t_1 = time first-stage drying ends

c = a coefficient dependent on environmental and soil conditions

The literature also suggests that during second-stage drying C_E varies with the depth to water table as shown in Figure 5 for fine-grained materials. The relationship illustrated could be written

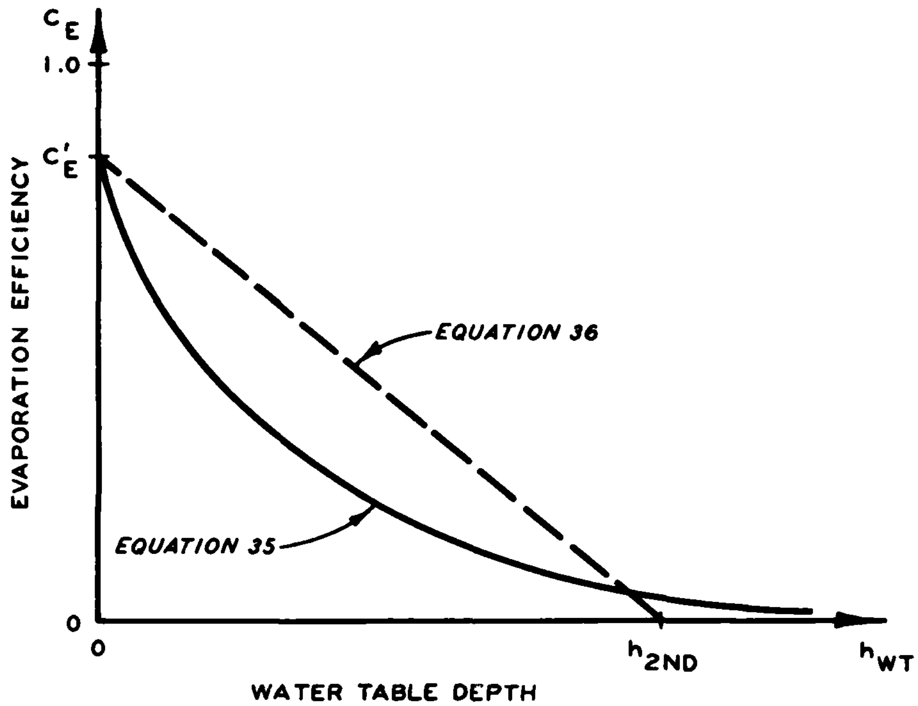


Figure 5. Soil evaporation efficiency as a function of water table depth

$$C_E = C_E' \exp\left(-c_1 h_{wt}\right) \tag{35}$$

where

c_1 = another coefficient dependent on environmental and soil conditions

h_{wt} = depth of water table below surface

43. The relationships given above in Equations 33, 34, and 35 are primarily based on experiments conducted in the laboratory under constant evaporative conditions. It is appropriate to question their applicablility to field situations where a soil layer will experience evaporation extremes every 24 hr and may periodically be rewetted from rainfall. However, based on controlled experiments, Gardner and Hillel (1962) have concluded that one could expect evaporation in the field under diurnally fluctuating conditions to be similar to those under constant conditions. They also describe an experiment which shows that the addition of small amounts of surface water to a soil has no long-term effect on the cumulative water loss from the soil.

44. This latter experiment by Gardner and Hillel together with the previously referenced findings of Brown and Thompson provide an impetus for simplifying Equation 27. A drainage efficiency C_D equal to 1.0 effectively

means that all monthly rainfall is removed from the disposal area while an efficiency equal to 0.0 means that all monthly rainfall must be evaporated before any water can be removed from the dredged material by evaporation. Since all well-managed dredged fill disposal sites are usually sloped to drain as a result of normal placement operations, C_D can be assumed to be 1.0 during periods of management to promote desiccation. Conceivably this period could start as soon as deposition has ceased and outflow weir boards are removed.

45. Owing to the uncertainties in the ability to predict potential evaporation rates at a specific site and the uncertainties associated with defining C'_E, the necessity to use an expression as complex as Equation 35 in this study is not warranted. The expression adopted here for defining the drying rate during second-stage evaporation will be simply a linear function of the water table depth:

$$C_E = C'_E \left(1 - \frac{h_{wt}}{h_{2nd}}\right) \quad \text{for} \quad h_{wt} \leq h_{2nd} \tag{36}$$

This relationship is also shown in Figure 5 for comparison.

<u>Desiccation settlement</u>

46. From the previous discussion, the water lost from a dredged material layer during first-stage drying can be written

$$\Delta W' = CS - C'_E - EP + (1 - C_D)RF \tag{37}$$

where $\Delta W'$ = water lost during first-stage drying. Even though some minor cracks may appear in the surface during this stage, the material will remain saturated and vertical settlement is expected to correspond with water loss or

$$\delta'_D = -\Delta W' \tag{38}$$

where δ'_D = settlement due to first-stage drying.

47. Water lost during second-stage drying can be written

$$\Delta W'' = CS - C'_E \left(1 - \frac{h_{wt}}{h_{2nd}}\right) \cdot EP + (1 - C_D)RF \tag{39}$$

where $\Delta W''$ = water lost during second-stage drying. Two things prevent there being an exact correspondence between water loss and settlement during second-stage drying. First is appearance of an extensive network of cracks which may encompass up to 20 percent (Haliburton 1978) of the volume of the dried layer. Second is the probable loss of saturation within the dried material itself. Combining these two occurrences into one factor enables the vertical settlement to be written

$$\delta''_D = -\Delta W'' - \left(1 - \frac{PS}{100}\right) h_{wt} \qquad (40)$$

where

δ''_D = settlement due to second-stage drying

PS = gross percent saturation of dried crust which includes cracks

In determining the second-stage drying settlement, there are three unknowns and only two equations. Therefore, calculation will have to involve an iterative procedure of trial and error.

Interaction of Consolidation and Desiccation

48. The removal of water by desiccation from a normally consolidating dredged fill layer will affect the upper boundary condition of the consolidating material. The deposition of new material on previously dried material will leave an overconsolidated material forming an interior boundary which will affect future consolidation. At present, there is no rigorous mathematical description of what occurs at these boundaries. Therefore, the succeeding descriptions are proposed as reasonable approximations of the influence of desiccated boundaries on consolidation.

Surcharge induced by water table lowering

49. At the end of the first stage of drying, the water table begins to drop below the surface of the dredged material. The effect of a dropping water table is to increase the effective weight of the material above the water table from a buoyant weight to the full weight of the soil solids plus any water present. The redistribution of stresses and pore pressure due to a lowered water table is illustrated in Figure 6. It should be noted that the distribution shown for pore pressure and effective stress in material below

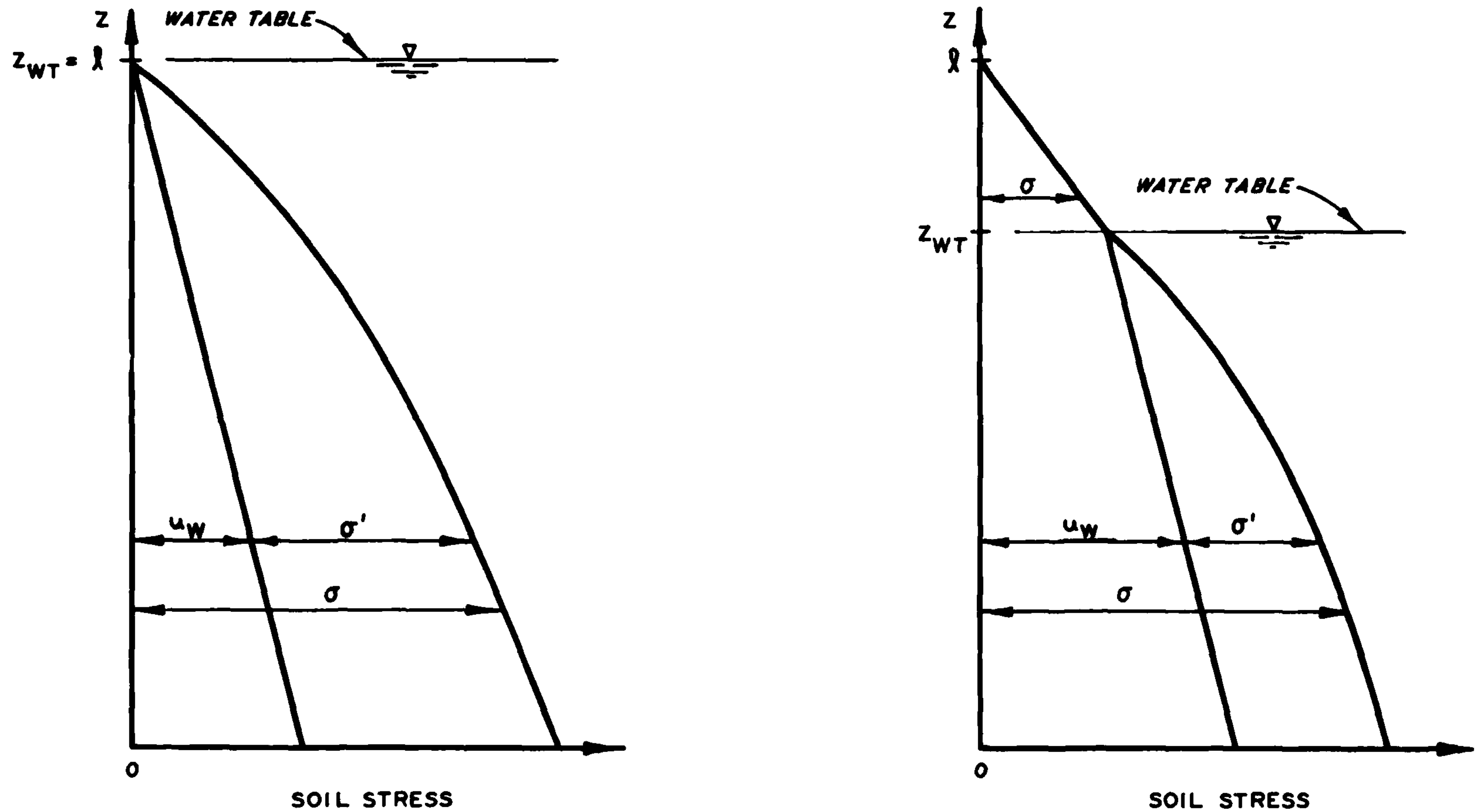


Figure 6. Redistribution of soil stress under a falling water table

the water table is correct only after all excess pore pressures have dissipated.

50. Whereas Equation 20 fully describes the total stress distribution in a dredged fill layer when the water table is at or above its surface, the total stress at any point when the water table is below the surface is

$$\sigma(z,t) = \int_{z}^{\ell} \left[\gamma_s + S\gamma_w e(z,t)\right] dz \quad \text{for} \quad z_{wt} \leq z \leq \ell \tag{41}$$

and

$$\sigma(z,t) = q + \int_{z}^{z_{wt}} \left[\gamma_s + \gamma_w e(z,t)\right] dz \quad \text{for} \quad 0 \leq z < z_{wt} \tag{42}$$

where

S = percent saturation of material above water table

z_{wt} = material coordinate of water table

q = total weight per unit area of material above water table which is Equation 41 evaluated for $z = z_{wt}$ (surcharge due to crust)

51. The surcharge induced by water table lowering causes an increase in the ultimate primary consolidation settlement of dredged material below the water table above that which would occur in a layer due to self-weight consolidation only. The effect of this surcharge can be expressed as a modified boundary condition and is discussed next.

Upper boundary condition

52. During both drying stages, evaporation at the surface tends to pull water from the lower mass of soil. Thus, the removal of water by evaporation will increase the rate of consolidation in the soil below the desiccated surface. This rate increase should be somewhat proportional to the degree of desiccation. In the mathematical model of the consolidation process described previously, boundary conditions are defined in terms of void ratio. Thus, the lower void ratios brought on by desiccation will cause the consolidating material to respond in the correct manner.

53. The series of illustrations in Figure 7 show the proposed process for combining the desiccation/consolidation phenomena during first-stage drying when the water table remains at the material surface. The uniform, intermediate void ratio between e_{00} and e_{SL} in the dried portion is determined by the amount of water evaporated up to the time under consideration.

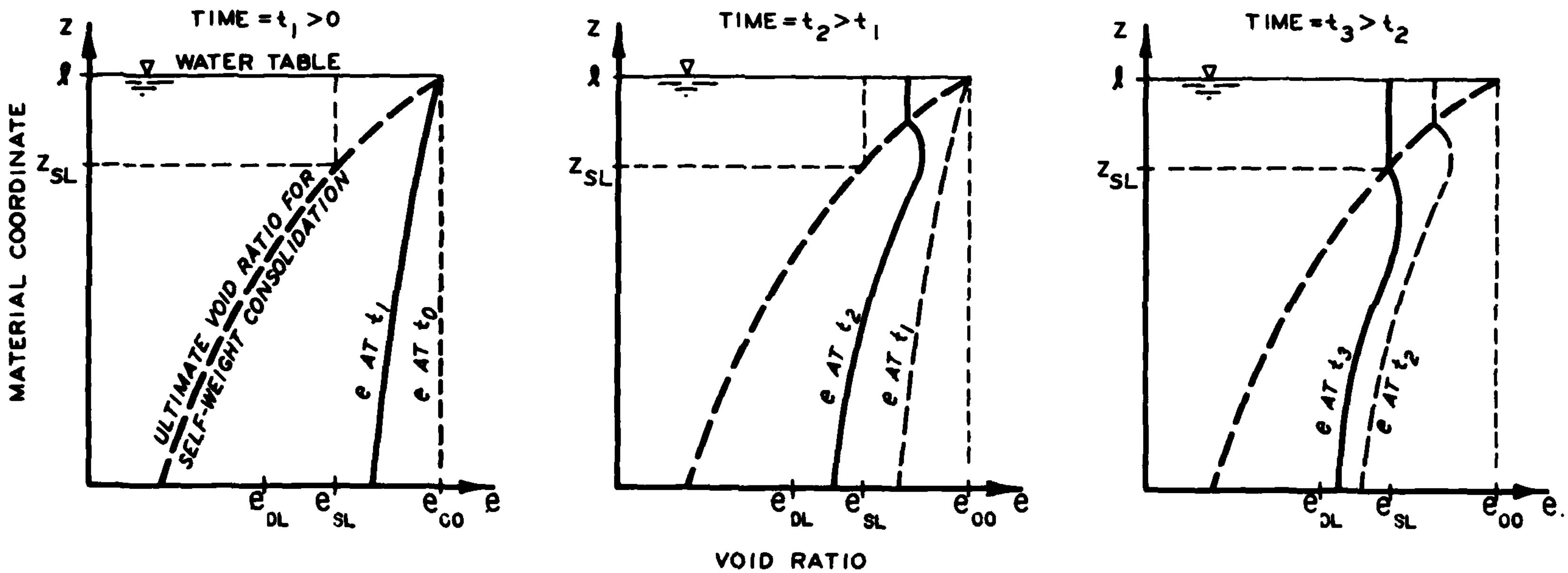


Figure 7. Void ratio distributions during first-stage drying

Intermediate curves in the consolidating portion are dependent on material properties and current boundary conditions. The heavy broken line represents the ultimate void ratio distribution of the total layer normally consolidated by self-weight only. The effect of drying the surface is to cause the effective weight of the dried material to be felt at the top of the consolidating material. Thus, the top boundary of the consolidating material behaves as if it were a drained boundary under a surcharge.

54. Under second-stage drying, the upper boundary condition is also controlled in a manner similar to that for first-stage drying. Differences occur because the water table is being lowered beneath the material surface and the ultimate void ratio distribution is shifting due to loss of buoyancy in the solids above the water table. The series of illustrations in Figure 8 show typical void ratio distributions for increasing times under second-stage drying. The upper boundary of the consolidating layer will follow the water table and its void ratio will be defined as the smaller of either the e_{SL} or the ultimate void ratio at a drained boundary due to the surcharge above the water table.

<u>Deposition of additional material on a previously dried crust</u>

55. A further complication to the already complex mathematical model describing the consolidation/desiccation process in fine-grained dredged material involves the circumstance when additional dredged fill is deposited onto a layer which has previously dried to some degree. Experience indicates that all dredged fill surfaces subjected to desiccation will exhibit cracking, the extent of which depends on material type and the environmental conditions under which drying took place. When additional dredged slurry is deposited on this cracked surface, there is excess water available which will resaturate any material dried to less than saturation, but no vertical swelling of the material will occur. Any tendency for the old material to swell should be proportionate to the amount of cracking and thus will be absorbed by a partial closing of the cracks. There is also evidence which suggests that some of these cracks persist long after many layers of new material have been added and may perform as interior drainage boundaries. The photograph in Figure 9 illustrates how an interior boundary serves to help drain a very well managed dredged fill disposal area near Charleston, S. C.

56. In this study, it is assumed that previously desiccated material

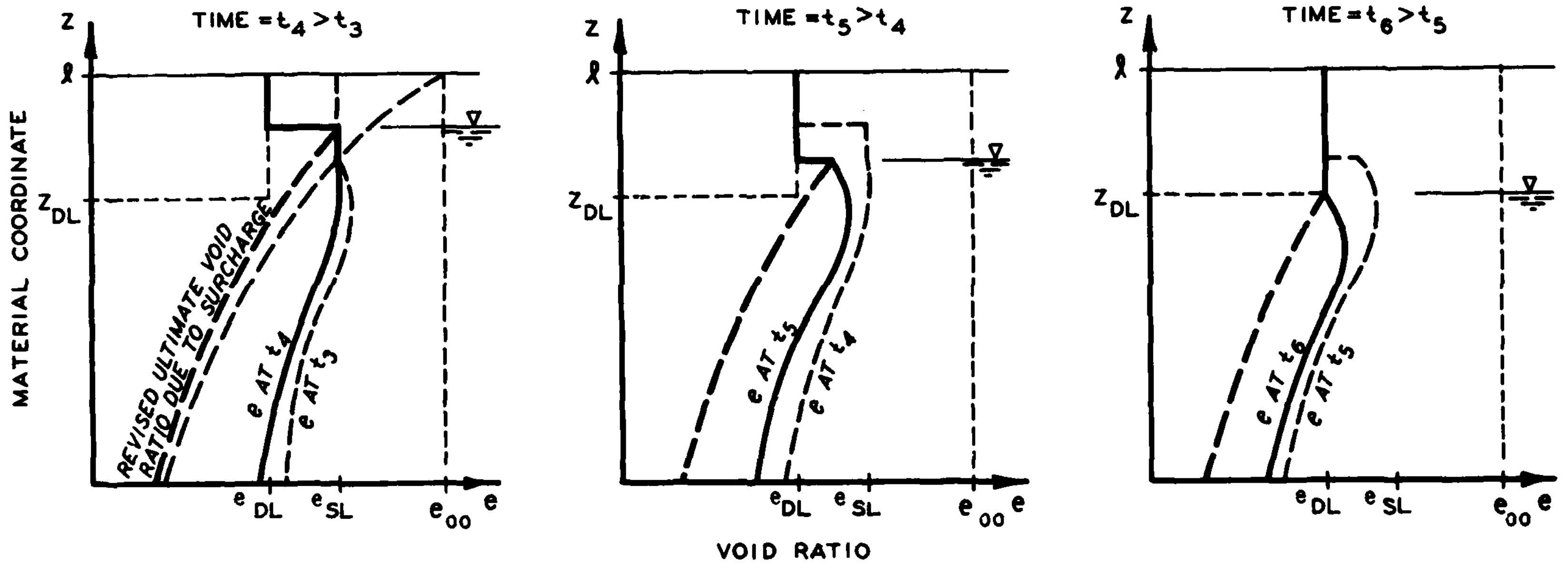


Figure 8. Void ratio distributions during second-stage drying

Figure 9. View of water flowing into ditch from interface of previous dredged material lifts

will remain at its desiccated void ratio when inundated by additional dredged slurry and behave essentially as an overconsolidated material. The effect this has on the normally consolidating material above and below the previously dried crust will be discussed in the next section.

Interior boundary conditions

57. When new dredged fill is placed on top of previously desiccated material, an overconsolidated interior sublayer remains which does not behave as the normally consolidating material above and below. In an intact state this overconsolidated material might be expected to seal the material below and thus impede its future consolidation. However, it is proposed here that this desiccated and overconsolidated material will initially function as a semipermeable drainage boundary due to its cracked and fissured nature developed during the evaporative dewatering process. It is also proposed that

consolidation in the lower overconsolidated material will cease until such time as the effective stresses from higher normally consolidating material cause existing void ratios to again fall above the ultimate void ratios.

58. In the mathematical model, the above postulated behavior of overconsolidated material will be accounted for in the calculation by assigning a temporary "calculation" void ratio commensurate with its effective stress. Effective stress is calculated from the top down by consideration of total material weight and developed pore pressures. Figure 10 illustrates the stresses and pore pressures immediately after additional slurry is placed on a previously desiccated layer and also the actual and calculation void ratios. When the calculation void ratios again equal the actual void ratios, consolidation of the entire layer proceeds in the normal manner as illustrated in Figure 11.

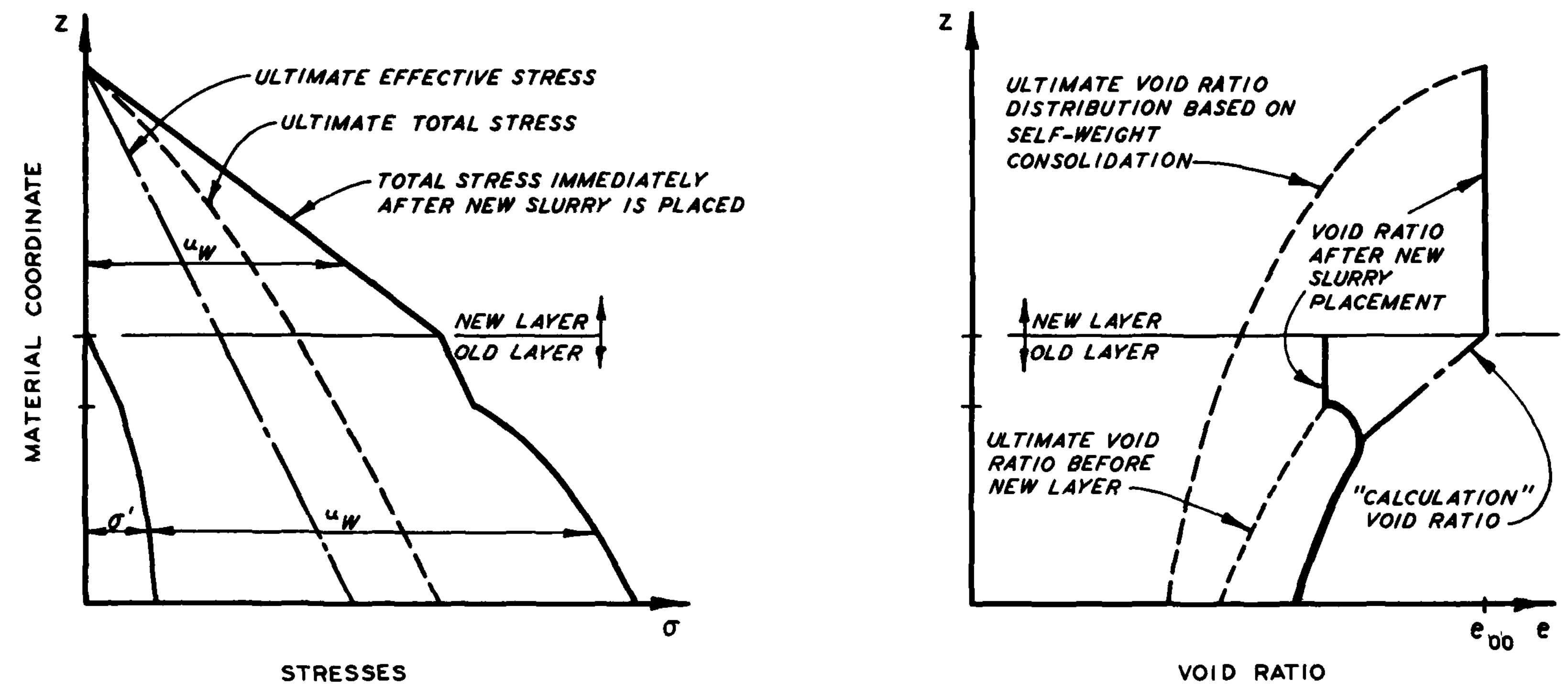


Figure 10. Soil stresses and void ratio distribution immediately after placement of new lift on partially consolidated layer

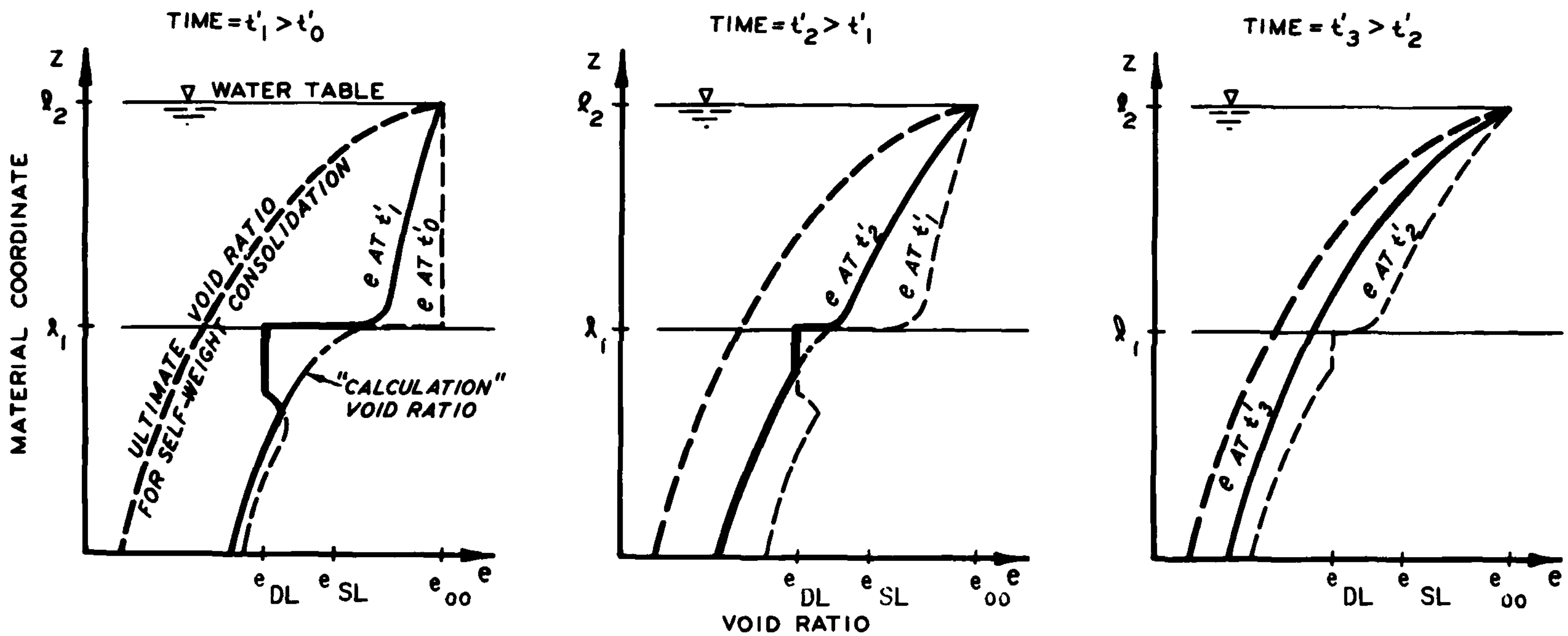


Figure 11. Void ratio distributions after placement of additional dredged material on previously dried material

PART III: COMPUTER PROGRAM PCDDF

59. In this part, solution of the mathematical problem described in the previous part by the computer program Primary Consolidation and Desiccation of Dredged Fill (PCDDF) will be discussed. A user's manual giving specifics of program organization, input requirements, output format, and other information necessary for program use in predicting settlements of actual disposal sites is included as Appendix A to this report. A program listing is contained in Appendix B, and sample input and output are given in Appendix C.

Background

60. PCDDF is basically an extensively revised and expanded version of the computer program CSLFS (Cargill 1982) which solved the self-weight consolidation process through the finite strain consolidation theory by an explicit finite difference solution of the governing equation. The program has retained the features permitting semipermeable drainage boundaries and enabling simultaneous consolidation calculation in a lower compressible foundation layer. The principal alteration is the addition of a subroutine which calculates changes in void ratios due to desiccation and modifies the upper boundary condition of the consolidating material to account for the effective weight of the dried crust.

61. The program is primarily intended as an aid to design of dredged material containment areas where settlements are controlled by the self-weight consolidation characteristics of the material and the material's response to environmental factors causing desiccation of the surface. The calculation scheme is such that any sequence of filling is permissible so long as the basic dredged material properties are unchanged. Compressible foundation properties can be totally different from the dredged material.

62. Another feature of PCDDF is the calculation of soil stresses and pore pressures during the consolidation process. These values are helpful in assessing soil strength and determining when the material can be worked with conventional earthmoving equipment or possibly when the material can support construction loads such as interior dikes. The correlation of dredged material effective stress with load supporting strength is, however, a subject for future research and will not be addressed here.

63. It has been previously shown (Cargill 1983a) that the filling sequence of disposal areas can be safely approximated by lumping all material deposited over a period of time into one total deposition at the beginning of the time period if settlements are being calculated for a time period at least twice the deposition time period. For example, if one is interested in total settlement 2 years after a site is put in operation, for calculation purposes all material deposited throughout the first year can be considered deposited at the beginning of the first year. However, this approximation may introduce error if any desiccation occurs in the incrementally placed material. Thus, the filling sequence used to simulate site filling must be set up to account for all intermediate desiccation periods.

Solution Techniques

64. Closed form analytical solutions of the equations governing the consolidation/desiccation process are not available due to the highly nonlinear nature of the equations' coefficients. However, incremental solutions over relatively short time periods when these coefficients can be assumed practically constant are feasible by computer techniques. In PCDDF the consolidation process and desiccation process are solved separately to a certain point in time when the solutions are combined to determine the net impact on the dredged material. This reconciliation occurs monthly in the program to conform with the availability of reasonably accurate average evaporation and rainfall data.

Consolidation

65. The consolidation process is solved in PCDDF by an explicit finite difference scheme which reduces the governing equation (Equation 1) to a tractable form. The procedure is fully described by Cargill (1982) and the details will not be repeated here. Suffice it to say that the void ratio at nodal points throughout the dredged fill or compressible foundation layer can be calculated for any point in time as illustrated in Figure 12.

66. The consolidation calculation is carried forward from the time of material deposition until the time desiccation starts. At the desiccation start time the void ratio integral for the normally consolidating dredged fill layer is evaluated. Normal consolidation then proceeds until 1 month after the desiccation start time when again the void ratio integral is evaluated. The

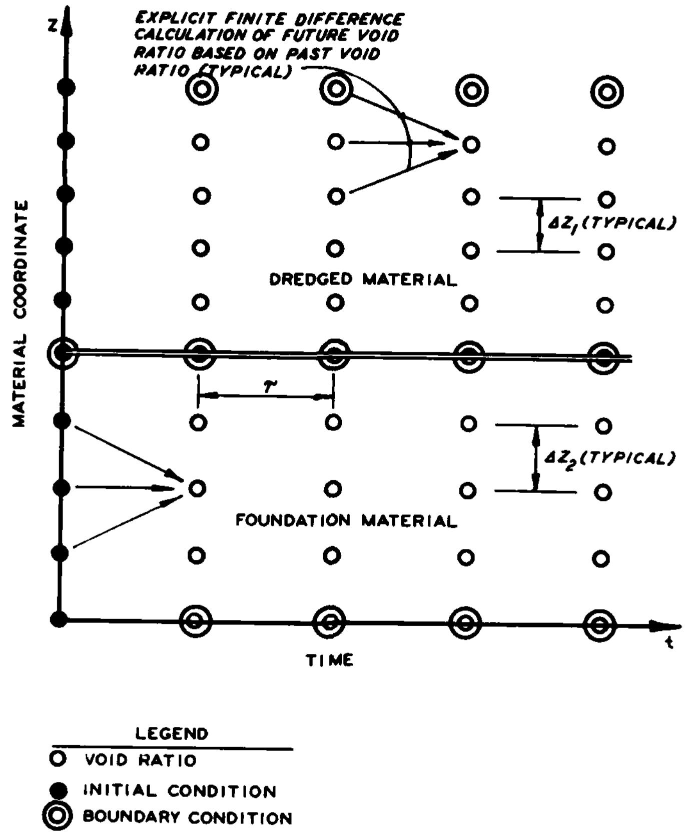


Figure 12. Typical finite difference calculation mesh

difference in these integrals provides the value of CS used in Equations 39 and 41. Adjustments for effective desiccation can then be made. The process is repeated on a monthly basis until new material is placed and desiccation starts anew or until the entire dredged layer is dried and consolidation ceases.

67. At each monthly interval during times when the desiccation process is effective, the material thickness of the consolidating dredged material will decrease by an amount dependent on the amount of effective evaporation. (This will be discussed in the next subsection.) The top boundary condition of the remaining consolidating material is also modified according to the amount of effective evaporation. The void ratio of the top nodal point in the consolidating layer will have a value greater than or equal to its ultimate void ratio as determined by the effective stress induced by desiccated material above. Thus, the consolidating layer behaves as if it were subjected to a drained surcharge at the top boundary.

68. The bottom boundary of the consolidating dredged material and/or compressible foundation is assumed to be unaffected by the desiccation process. Details of how this boundary condition is calculated may be found in the earlier report (Cargill 1982).

69. The use of an explicit finite difference scheme in solving the consolidation governing equation requires that strict stability criteria be observed at all times during the incremental solution process. PCDDF is coded to print an error message when certain criteria are not met in choosing an appropriate time step or material node spacing. Theoretically, the solution should be stable if

$$\tau \leq - \frac{(\Delta z)^2 \gamma_w}{2\alpha(e)_{max}} \tag{43}$$

where

τ = time step

Δz = difference in material coordinates of adjacent nodes

$\alpha(e)_{max} = \frac{k(e)}{1 + e} \frac{d\sigma'}{de}$ (maximum value within layer)

70. Another criterion which has been found to be useful in selecting a time step for input to the program is

$$\tau < \frac{h}{k(e_{oo}) \cdot N} \tag{44}$$

where

h = layer thickness

N = number of material nodes in a layer

71. An instable calculation will usually be characterized by void ratios considerably outside the range of possible values or by zero consolidation when consolidation should be taking place. The cure for an instable calculation is usually to decrease the time step chosen, but other input data should also be checked to ensure consistency.

72. Two options exist for selecting the relationship of the time step and grid size:

a. Based on the compressibility and permeability characteristics entered as input data, PCDDF will determine a simulation time increment and node spacing consistent with the stability criteria presented in Equations 43 and 44. For each problem, the dredged fill (and compressible foundation, if present) is represented by 10 equally spaced nodes, and a stable time step is determined.

b. The user may determine values of the time step and grid size. An algorithm for choosing a stable set is presented in the user's manual.

Desiccation

73. At the end of each monthly period during times when the desiccation process is effective, the effect of the previous month's evaporation is applied to the dredged material. For computational simplicity, changes in void ratio are applied only at nodal points beginning at the surface of the dredged material. Also, to avoid the trial-and-error method of solving Equation 40, the program calculates desiccation settlement as

$$\delta_D = -\Delta W - \delta_D''' \tag{45}$$

where δ_D''' = any carry-over desiccation. Carry-over desiccation normally includes that which is due to the loss of saturation the previous month (a figure which also takes into account the crack network during second-stage drying). It may also include a negative desiccation quantity from the previous month (water lost due to consolidation exceeds potential evaporation desiccation) and/or a quantity from any necessary adjustment in the void ratio at the top of the consolidating layer.

74. With the desiccation settlement from Equation 45, the program next determines the average void ratio reduction within a dredged material sublayer (that material between adjacent nodes) by

$$\Delta\bar{e} = \frac{\delta_D'''}{\Delta z} \tag{46}$$

Starting with the uppermost adjustable node, void ratios are adjusted in turn toward or to the e_{DL} or e_{SL} (depending on whether first- or second-stage drying is effective) until the average required reduction has been achieved.

75. As the dredged material is desiccated below the e_{SL}, the free water table drops below the material's surface. In PCDDF the water table is set at the first calculation nodal point having a void ratio less than e_{SL} but not deeper than the limiting value as defined by Equation 32. The solution of Equation 32 requires a value be known for z_{DL}. Since z_{DL} occurs

at the intersection of the ultimate void ratio distribution curve with e_{DL}, the chosen void ratio-effective stress relationship can be used to define the effective stress at this void ratio. Thus,

$$\sigma'_{DL} = f(e_{DL}) \tag{47}$$

and since

$$\sigma'_{DL} = (\ell - z_{DL})\left[\gamma_s + \left(e_{DL} \cdot PS \cdot \gamma_w\right)\right] \tag{48}$$

z_{DL} is determined.

76. The desiccation subroutine in PCDDF also recalculates a new ultimate void ratio distribution for material in the consolidating layer based on the surcharge created by dried material above the new water table. The uppermost void ratio in the consolidating layer is then set to its ultimate value (which may create some carry-over desiccation) which becomes the top boundary condition for the next series of consolidation calculations.

77. There are obviously some drawbacks to this rather simplistic treatment of the desiccation process in fine-grained dredged material. No attempt has been made to model the complex mechanisms of how a soil gets to its final desiccated volumetric condition nor how and to what magnitude stresses and pore pressures develop in the desiccated portion. As previously stated, such a rigorous explanation is felt not to be warranted due to the paucity of information available on the factors which actually control the process. The mathematical model and solution technique proposed here avoid the necessity of knowing the complex mechanisms at work or the multitude of factors which control them. The overall effect is correctly represented, i.e. desiccation leads to a reduction of voids in the dried material. The presence of a dried surface does change the boundary condition in the consolidating material, and the effect of an extensively cracked crust is to increase the speed and magnitude of consolidation in the underlying material. The accuracy of this method obviously depends on properly defining the proposed quantities e_{SL} and e_{DL} and how well these quantities can be used to represent the true boundary condition of the consolidating layer.

Deposition of additional dredged material

78. PCDDF allows the deposition of additional dredged material at any monthly interval after filling begins. The only program restriction is that

the new material have the same properties as previously placed material. In the absence of any desiccation in prior deposits, there is a natural transition between the old and new since the void ratio at the top of the old matches that of the new. However, when the top of the old layer has been desiccated and extensively cracked, there is no natural transition between the two layers. Again, the program takes a simplistic approach in accordance with the mathematical model previously described.

79. When new material is deposited, there is a discrepancy in the value of the actual void ratio at the boundary node. Due to probable extensive cracking at this point, it appears quite reasonable to approximate the actual void ratio as an average of the zero effective stress void ratio and the desiccated void ratio. Void ratios in the remainder of previously desiccated material are assumed to be maintained at their desiccated values.

80. To calculate consolidation based on these desiccated interior void ratios which may be at or below their ultimate values would be saying that there is a completely free draining interior boundary within the consolidating layer. While evidence does exist to indicate that these old layer boundaries do offer some enhancement to material drainage, it would be overly optimistic to assume they are free draining. Therefore, future consolidation is based on an artificially set initial condition through the previously dried material. The initial condition was previously illustrated in Figure 10 and in the previously dried zone is based on a linear variation of void ratio between the boundary node at the zero effective stress void ratio and the node below the dried zone at a void ratio due to prior consolidation. This scheme of calculation is considered a realistic representation of the effect the previously dried zone has on future consolidation.

<u>Stresses and pore pressures</u>

81. The program calculates stresses and pore pressures by numerical integration of the previous Equations 20 and 23 for all material nodes where the void ratio has not been reduced below its ultimate value due to current or past desiccation. In the consolidating material, effective stress is dependent on the input effective stress-void ratio relationship and exact values are interpolated between input points. At nodes where the void ratio has been desiccated below its ultimate value based on material weights, excess pore pressures are arbitrarily set to zero and effective stress is set equal to the effective weight of material above.

Input Data

82. The variables required for solution of the finite strain theory consolidation governing equation include a relationship between void ratio and effective stress in the form of point values, a void ratio-permeability relationship in the form of point values, and unit weights of material solids and water. The determination of these variables has been previously discussed by Cargill (1982 and 1983a).

83. Input quantities governing the desiccation calculations in PCDDF include the saturation limit (e_{SL}), desiccation limit (e_{DL}), average monthly Class A pan evaporation rates, average monthly rainfall, site drainage efficiency, and maximum potential soil evaporation efficiency. Specification of these quantities will involve considerable engineering judgment until an extensive experience base is developed which compares model predictions against actual site performance. At the present time, NOAA data appear to be the best source for average rainfall and evaporation rates. Sites of interest for a consolidation/desiccation prediction will normally be well managed for drainage of surface water and thus have a drainage efficiency of 1.0, but site-specific conditions may be judged to warrant some lower factor. The e_{SL}, e_{DL}, and maximum evaporation efficiency are soil-related variables for which there is no current convenient method of determination. Recommendations on their specification will be made after some site-specific problems are analyzed in the next section.

PART IV: FIELD VERIFICATION SITES

84. The analysis procedure proposed in the previous parts of this report must be tested against measured field performance before it can be judged useful or appropriate for field design purposes. Therefore, the procedure will be used to predict performance at three dredged material disposal sites where settlements have been measured. These sites are not ideal because they were not monitored as comprehensive field verification sites as recommended in Appendix E. Some assumptions affecting the material's behavior had to be made in order to apply the theory. However, the sites chosen are deemed the best available and sufficient information is considered available to perform valid comparisons of predicted and measured performance.

85. The first site is a confined disposal area for Canaveral Harbor near Cape Canaveral, Fla.; the second site is a confined disposal area for Norfolk Harbor and vicinity called Craney Island which is near Hampton Roads, Va. These two sites were previously used by Cargill (1983a) in verification of procedures for the hand calculation of consolidation only. The third site is a confined disposal area called Drum Island in Charleston Harbor near Charleston, S. C. Settlements at this site were monitored and documented by Mr. Braxton Kyzer of the Charleston District, Corps of Engineers.

Site Descriptions

86. Even though the Canaveral Harbor and Craney Island sites have been previously described (Cargill 1983a; Palermo, Shields, and Hayes 1981), pertinent information will be repeated here for completeness. The description of the Drum Island site is from Kyzer (1981). Tabulated rainfall data are from NOAA (1980), and pan evaporation amounts are estimated from charts by Brown and Thompson (1977).

Canaveral Harbor

87. This disposal site was constructed in 1980 and used for one dredging operation in Canaveral Harbor. The site covers an area of about 20 acres* and was filled with dredged material during or about the last week of September 1980. Although detailed information on dredged volumes and disposal area

* A table of factors for converting US customary units of measurement to metric (SI) units is presented on page 5.

foundation elevations is not available, a sampling program was conducted in conjunction with this study. Two settlement plates were also installed at the interface of the foundation and dredged material prior to filling; thus, good data on material settlement are available after 3 November 1980 when the plates were first read. Surface desiccation at the site was probably nonexistent before outflow weir boards were removed, but was probably a critical factor over the majority of the site afterwards. Project records indicate weir boards were routinely removed beginning in December 1980 and the dike was breached in the summer of 1981 to aid in the removal of surface water from rainfall. Because of its relatively small size, the area around the settlement plates would have been subjected to desiccation when the program of surface water removal was initiated even though the plates were situated toward the lower part of the disposal area.

88. In February 1983, the dredged material deposited at Canaveral Harbor was sampled the full depth of the layer in the vicinity of the settlement plates. Figure 13 shows void ratio profiles developed from water content measurements based on the assumption of saturated samples and a specific gravity of solids of 2.70. From these profiles, an accurate measurement of the depth of material solids can be obtained. The material collected from the fill site was also reconstituted into a slurry with harbor water for the purpose of a self-weight consolidation test as described by Cargill (1983b). From the self-weight consolidation test, the material's zero effective stress void ratio was determined to be 11.5. Using an average height of solids of 0.756 ft, the unconsolidated height of dredged material would have been 9.45 ft. This corresponds reasonably well with the 8.5-ft average height used in a previous analysis (Cargill 1983a) even though the initial void ratio and height of solids do not. The discrepancy is possibly due to the sampling technique used in the survey previously reported.

89. It should also be noted that there were no open desiccation cracks in the area of the settlement plates at the time of the sampling in 1983 while in November 1981, open cracks approximately 8 in. deep were observed. Thus, in the analysis to follow, predicted material height which is based on open desiccation cracks should be slightly higher than measured height.

90. Percent saturation testing conducted on material taken from the top of the desiccated crust showed saturations from 90 to 94 percent. This provided the impetus for assuming 100-percent saturation in lower parts of the

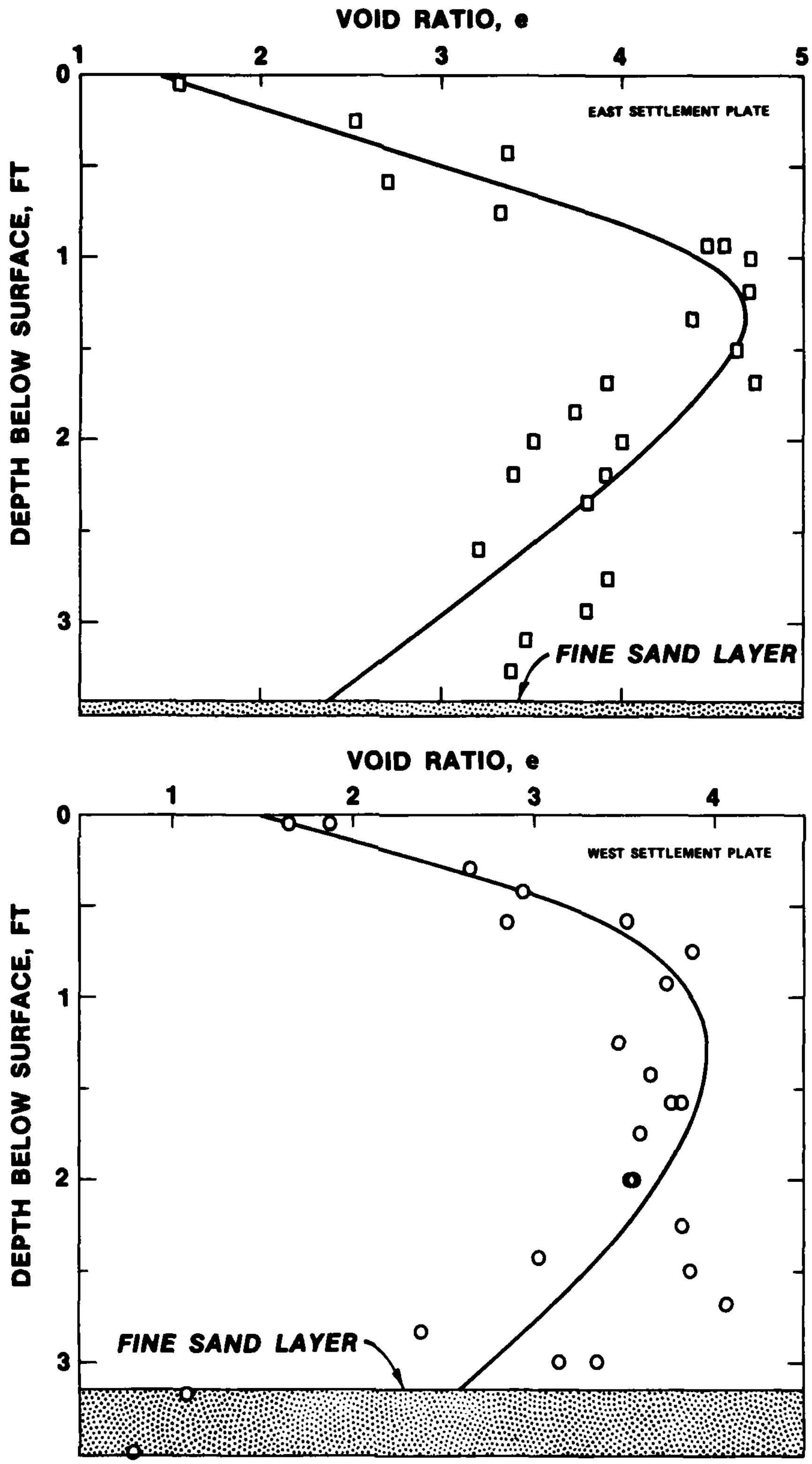


Figure 13. Void ratio profiles at Canaveral Harbor

crust and enabled calculation of void ratio from water content measurements.

91. Average monthly rainfall and pan evaporation data for the site are shown in Table 1 along with the data from other sites to be analyzed. Since the site is generally sloped toward the outflow, a drainage efficiency of 1.0 is probable once the material begins to dry, and the rainfall amounts are not critical to the analysis. They are thus listed as a matter of interest only. For lack of any better specific information, it will be assumed that desiccation in the area of the settlement plates became effective in December 1980 and that prior to that time there was free water at the surface of the dredged material.

Table 1

Average Monthly Rainfall and Pan Evaporation (feet)

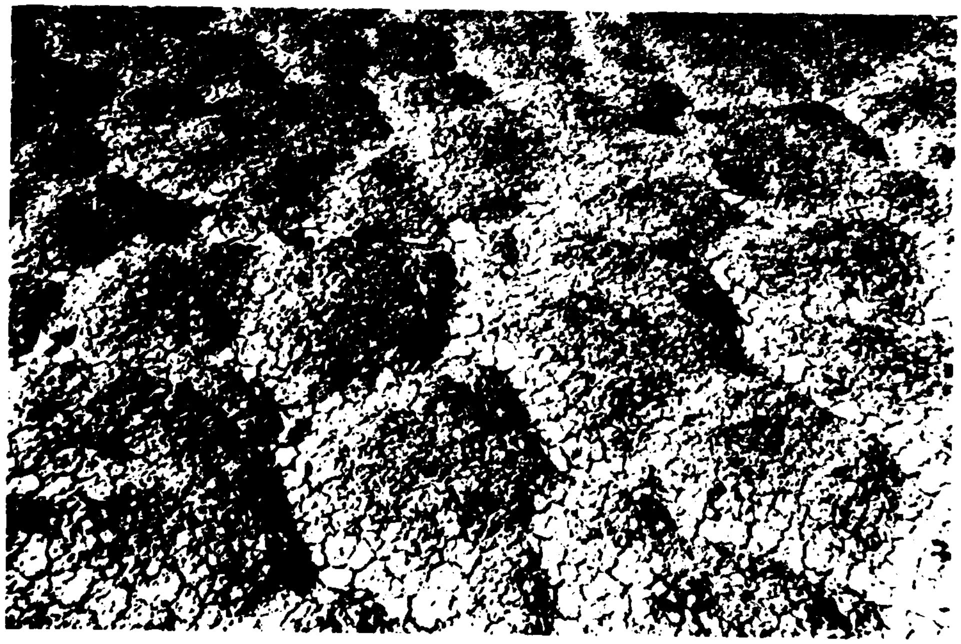
	Canaveral Harbor		Craney Island		Drum Island	
Month	Rainfall	Pan Evaporation	Rainfall	Pan Evaporation	Rainfall	Pan Evaporation
Jan	0.18	0.30	0.28	0.00	0.24	0.18
Feb	0.24	0.30	0.28	0.00	0.27	0.23
Mar	0.29	0.46	0.29	0.00	0.40	0.36
Apr	0.21	0.57	0.23	0.39	0.25	0.36
May	0.23	0.66	0.28	0.57	0.32	0.57
Jun	0.57	0.62	0.30	0.57	0.53	0.49
Jul	0.58	0.57	0.48	0.67	0.68	0.67
Aug	0.57	0.57	0.49	0.51	0.54	0.57
Sep	0.60	0.49	0.35	0.34	0.43	0.41
Oct	0.40	0.41	0.26	0.26	0.25	0.33
Nov	0.16	0.33	0.25	0.00	0.18	0.21
Dec	0.16	0.25	0.26	0.00	0.26	0.16
TOTAL	4.19	5.53	3.75	3.31	4.35	4.54

92. Two recent (February 1983) photographs of the site are shown in Figure 14. It is evident from these pictures that the site has experienced considerable desiccation.

Craney Island

93. The Craney Island disposal site is a 2,500-acre area confined by dikes about 28 ft high. Dike bottom elevation is about -10.0 ft mlw (mean low water), and top elevation averages about +18.0 ft mlw. Dike construction

a. View of area from south dike looking north. East settlement plate in center of photo



b. View of extremely desiccated nature of material. Notice impressions of previous widely spaced cracks

Figure 14. Canaveral Harbor disposal area

started in August 1954 and since 1956 over 130 million cu yd of in situ channel sediments has been deposited in the area almost continuously by both direct pipeline discharge and hopper pumpout. Figure 15 illustrates typical recent conditions at the site. As can be seen from these photographs, the size of the disposal area is sufficient that disposal and desiccation can occur simultaneously.

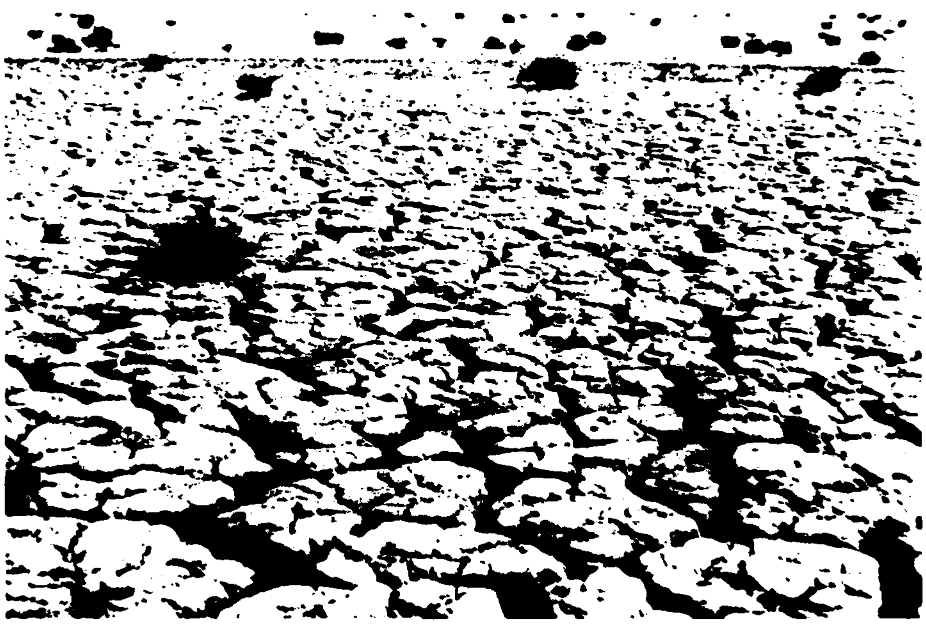
94. Settlement plates have only recently been installed at Craney Island and therefore material settlement at the site had to be inferred from topographic surveys conducted in December 1964, August 1965, October 1968, December 1975, October 1977, and March 1980 as reported by Palermo, Shields, and Hayes (1981). Meaningful comparisons of settlements inferred from site elevations with calculated settlements require detailed information about the volume of solids deposited and the area of deposition.

95. Field sampling and testing reported by Palermo, Shields, and Hayes (1981) indicated that the average in situ void ratio of channel sediments was about 5.93 and that the sediments averaged about 15 percent sand (particle size 0.075 mm). A self-weight consolidation test on material taken from the area in August 1982 indicated the zero effective stress void ratio to be 9.0. If it is assumed that the sand solids will separate and settle immediately after disposition to a void ratio conservatively estimated at about 2.0 (the void ratio would usually be lower), then about 4 percent of the disposal area will be required for sand deposition. Thus, the fine-grained portion will then settle and consolidate in the remaining 2,400 acres. The presence of sand mounds commonly found at the outfall of dredged material discharge pipes verifies the validity of this assumption.

96. It is very unlikely that any of the dredged material deposited in Craney Island spread evenly across the 2,400 acres available for deposition, but the assumption of uniform spreading is the only choice available in the absence of more detailed information. Errors inherent in this assumption should average out over the 24-year disposal history to be examined. Based on this uniform spreading, Table 2 shows the yearly totals of volumes of material deposited, total solids, height of material, and height of solids. The "Height of Solids" column is the equivalent height of solids with no voids in the dredged fill layer and is calculated from the dredged volume, disposal area, and in situ void ratio.

97. Surface desiccation at Craney Island was not possible over a

a. View from west dike looking northeast



b. View from center of disposal area looking north

Figure 15. Craney Island disposal area

Table 2

Annual Volumes and Height of Materials Deposited in Craney Island Disposal Area

Year	Dredged Volume at e = 5.93 10^6 cu yd	Total Solids 10^6 cu yd	Dredged Fill Height* at e = 9.0 ft	Height of Solids ft
1956	0.98	0.14 (0.14)	0.311 (0.311)	0.0311 (0.0311)
1957	4.19	0.60 (0.74)	1.326 (1.637)	0.1326 (0.1637)
1958	5.08	0.73 (1.48)	1.609 (3.246)	0.1609 (0.3246)
1959	10.29	1.49 (2.96)	3.260 (6.506)	0.3260 (0.6506)
1960	5.36	0.77 (3.74)	1.698 (8.204)	0.1698 (0.8204)
1961	3.37	0.49 (4.22)	1.069 (9.272)	0.1069 (0.9272)
1962	4.29	0.62 (4.84)	1.360 (10.633)	0.1360 (1.0633)
1963	1.41	0.20 (5.05)	0.447 (11.080)	0.0447 (1.1080)
1964	3.73	0.54 (5.59)	1.181 (12.261)	0.1181 (1.2261)
1965	6.23	0.90 (6.48)	1.973 (14.234)	0.1973 (1.4234)
1966	6.41	0.93 (7.41)	2.032 (16.266)	0.2032 (1.6266)
1967	10.93	1.58 (8.99)	3.464 (19.727)	0.3464 (1.9727)
1968	4.88	0.70 (9.69)	1.544 (21.274)	0.1544 (2.1274)
1969	5.31	0.77 (10.46)	1.682 (22.956)	0.1682 (2.2956)
1970	6.19	0.89 (11.35)	1.961 (24.916)	0.1961 (2.4916)
1971	20.59	2.97 (14.32)	6.521 (31.437)	0.6521 (3.1437)
1972	2.05	0.30 (14.62)	0.647 (32.086)	0.0647 (3.2086)
1973	4.18	0.60 (15.22)	1.327 (33.411)	0.1325 (3.3411)
1974	4.48	0.65 (15.87)	1.419 (34.830)	0.1419 (3.4830)
1975	5.04	0.73 (16.59)	1.597 (36.427)	0.1597 (3.6427)
1976	4.51	0.65 (17.25)	1.430 (37.857)	0.1430 (3.7857)
1977	2.13	0.31 (17.55)	0.674 (38.531)	0.0674 (3.8531)
1978	6.80	0.98 (18.53)	2.155 (40.686)	0.2155 (4.0686)
1979	1.33	0.19	0.420	0.0420
TOTAL	129.8	18.73	41.106	4.1106

Note: Numbers in parentheses are cumulative totals.
* Considers only fine-grained material, which is 85 percent of the total.

majority of the site until about the end of 1965 when the average surface elevation of the disposal area came above the mean low water elevation of the surrounding harbor. After 1965 surface desiccation was probably limited due to the almost continual input of large volumes of dredged material and the fact that average pan evaporation was zero for nearly half the year as shown in Table 1. However, as previously shown in Figure 15, desiccation does occur at the site. It will therefore be assumed for the purpose of calculation that annual material deposition occurs from August to December and that during the remainder of most years after 1965, desiccation is active. This should approximate an average condition for the entire site and is expected to give full benefit to desiccation which has actually occurred. As shown by Table 2, the years 1967 and 1971 saw exceptionally large amounts of material deposited. Therefore, no desiccation will be assumed to have occurred during those years.

Drum Island

98. This confined disposal area in Charleston Harbor is approximately 125 acres in size and has been used intermittently for storing dredged material since the 1940's. Since 1977 it has been intensively managed by the Charleston District to promote material desiccation. A program of perimeter and interior ditching and even an underdrainage system in a portion of the area has been used. Material taken from the ditches has been thoroughly dried through repeated handling by construction equipment and ultimately used in raising the area's confining dike. This dewatered material has been found to be well suited for dike construction as there has been little loss of dike height due to long-term drying and consolidation of the material.

99. The present study will be concerned only with the two most recent disposal operations at Drum Island because settlement plates were installed just prior to them and have been available for settlement measurements since then. The first disposal operation after settlement plates were installed on the previously placed material occurred between the end of November 1980 and then end of January 1981. Approximately 540,000 cu yd of channel sediments was pumped into the area. Settlement plates were read several times in the months immediately following the first disposal, and readings will be graphically portrayed in a later section.

100. During the month of March 1982, the area was again used for dredged material disposal. Approximately 560,000 cu yd was deposited during this operation. Unfortunately, no settlement plate readings were made in

conjunction with this latest filling operation and until readings were again made in January 1983, the only available data come from interpretation of photographs taken in August 1982.

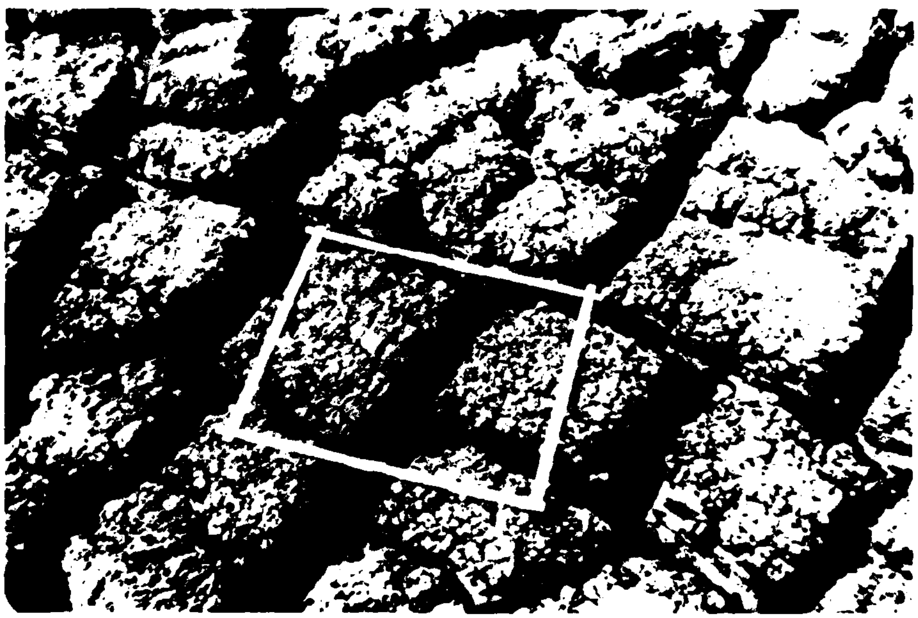
101. At the time of the last settlement plate reading, the dredged material was sampled in the area of each settlement plate through the full depth of the layers resulting from the two latest disposal operations. At the time of the sampling, desiccation cracks about 10 in. deep as shown in Figure 16 were very prominent and completely filled with free water. Figure 17 shows void ratio profiles developed from water content measurements based on saturated samples and a specific gravity of solids of 2.60 for samples taken through undisturbed material between desiccation cracks. From these profiles, an average depth of material solids was determined to be 0.270 ft for the top layer and 0.370 ft for the bottom layer. The gross depth of solids for the top layer calculated from the void ratio profiles was reduced to account for the crack network in arriving at the 0.270-ft figure.

102. A self-weight consolidation test conducted on material from the site reconstituted into a slurry indicated the zero effective stress void ratio to be 12.15. Together with the average solids height, this leads to unconsolidated heights of about 3.6 ft for the top layer and 4.8 ft for the bottom layer.

Material Properties

103. The analysis of consolidation/desiccation settlements accomplished by the computer program PCDDF requires knowledge of the basic material properties controlling or describing the processes. The quantities included in a complete geotechnical description of the material for the purpose of settlement computation are the relationship between void ratio and effective stress for the full range of possible void ratios, the relationship between void ratio and permeability, the specific gravity of soil solids and water, the dredged materials' saturation limit e_{SL}, and its desiccation limit e_{DL} Void ratio-effective stress and void ratio-permeability relationships for each of the field verification sites are given in Appendix D. The relationships for Canaveral Harbor and Craney Island material have been modified from those previously reported by Cargill (1983a) due to information gained from self-weight consolidation testing.

a. View of settlement plate No. 4



b. Reference scale is approximately 18 in.^{2}

Figure 16. Drum Island disposal area

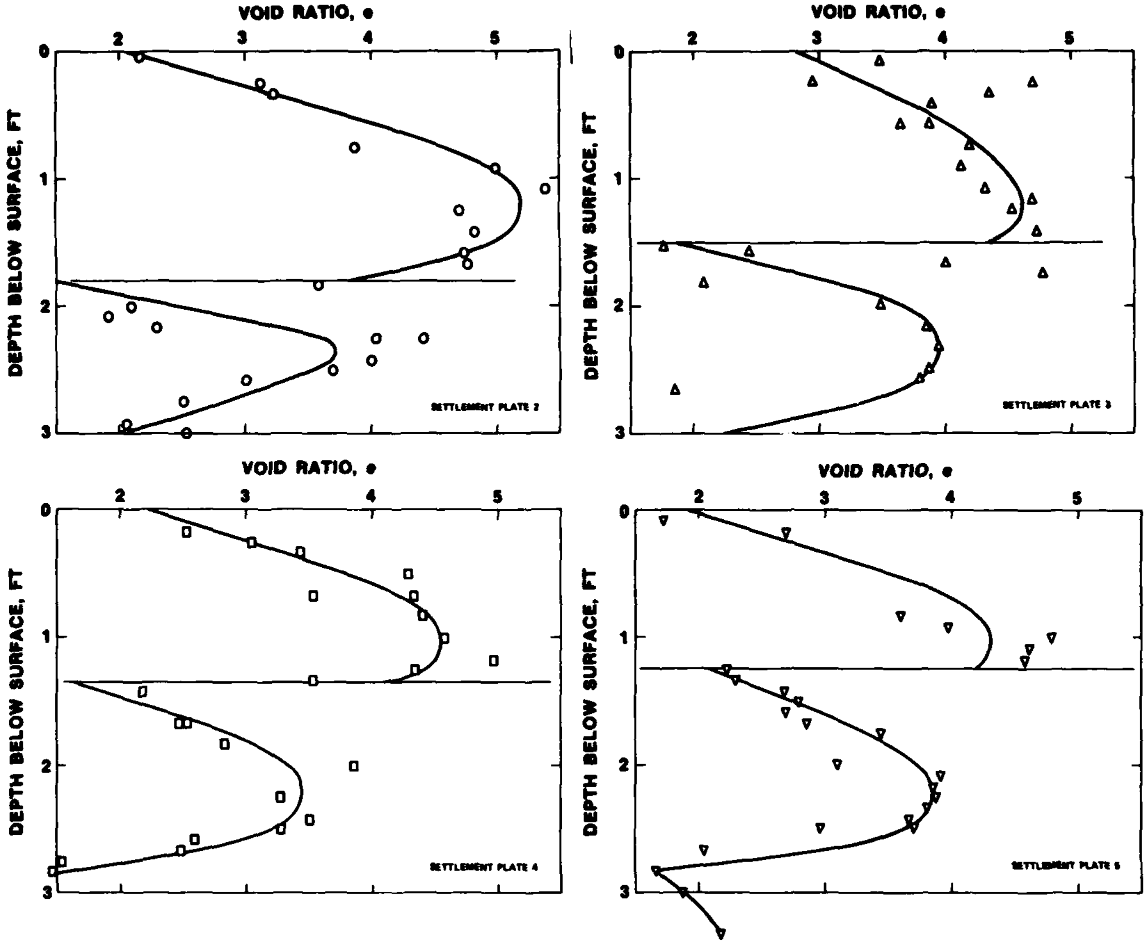


Figure 17. Void ratio profiles at Drum Island

104. Specification of the desiccation variables for the sites is based partially on unpublished water content measurements taken in the dredged material crust during the past few years and partially on the more recent material sampling program. In interpreting the previously collected data, whenever the dredged material was referred to as "at the decant point" (which should correspond to that physical state as described by Haliburton (1978)) it was assumed that the material was saturated, and its void ratio corresponds to the saturation limit e_{SL} . Whenever measurements where made on "dried crust" it was assumed that the material was at the desiccation limit e_{DL} , and it was not necessarily saturated.

105. Calculation of a soils void ratio can be accomplished by the equation

$$e = \frac{w}{PS} \cdot G_s \tag{49}$$

where G_s = specific gravity of solids and other terms are as previously defined. Using this equation and the facts that PS is 100 percent at the e_{SL} and approximately 80 percent (as suggested by Haliburton (1978) and verified through photographs such as shown in Figure 16) at the e_{DL} when the crack network is considered, appropriate void ratios were calculated from all available data and the selected values for the verification sites are shown in Table 3 along with average specific gravity of solids and other information. While the dried material between desiccation cracks may not be completely saturated, it is felt that the approximation of the crack area makes a more accurate calculation of an effective void ratio in the dried crust infeasible.

Table 3

Desiccation Parameters

Parameter	Canaveral Harbor	Craney Island	Drum Island
Specific gravity of solids G_s	2.70	2.75	2.60
Liquid limit LL , %	143	125	140
Plastic limit PL , %	40	42	49
Zero effective stress void ratio e_{oo}	11.5	9.0	12.15
Saturation limit e_{SL}	3.7	6.5	6.7
Desiccation limit e_{DL}	2.5	3.2	3.1
Typical maximum crust depth, in.	11	6	10
Desiccation cracks as percentage of surface area	20	20	20
Maximum evaporation efficiency, %	75	75	75
Site drainage efficiency, %	100	100	100

106. The percentages given for evaporation and drainage efficiencies in Table 3 represent "best estimates" at the present time. Previously cited work supports the 100-percent figure for site drainage efficiency since the chosen sites have been managed to promote drying. The maximum evaporation efficiency represents a compromise between the absolute maximum of 100 percent and the probable minimum of 50 percent. The sensitivity of settlement calculations to the maximum evaporation efficiency was checked for each site by performing the calculations at 50, 75, and 100 percent. The results of this analysis indicated that there are practically no differences in the long-term settlements

calculated by either of the evaporation efficiencies and usually less than about 5 percent differences in the intermediate settlements. Similar checks of drainage efficiency between 0.5 and 1.0 also indicated no differences in long-term settlements and only minor differences for the intermediate times.

107. The reason for this insensitivity to the drainage and evaporation efficiencies lies in the specification of a maximum depth of crust for the particular material. Thus, under most normal drying conditions, a maximum crust will have sufficient time to develop and whether this takes 2 months or 12 months is insignificant over the long term. However, even if the crust does not fully develop, it has also been found that the combined total effect on settlements from desiccation and the additional induced consolidation remains roughly the same magnitude and is mainly dependent on the maximum depth of crust in conjunction with the material's saturation and desiccation limits.

PART V: COMPARISON OF MEASURED WITH PREDICTED PERFORMANCE

108. In this part, the mathematical model of the consolidation/desiccation process in dredged material will be used to predict material settlements at the three verification sites previously described using basic material properties and parameters as determined from field sampling and consolidation testing. In addition to the consolidation/desiccation prediction, a prediction based on the finite strain theory and considering consolidation only will be made to illustrate the differences which desiccation makes in material settlement. This is also an ideal opportunity to illustrate the differences between the finite strain and conventional small strain consolidation theories, and so the results of a small strain analysis for two of the sites are also given. (See Cargill (1983a) for details of calculation procedure for multiple layers.) A small strain consolidation analysis of the Canaveral Harbor site yielded no significant settlement over the period of interest.

Canaveral Harbor

109. Figure 18 shows the predicted height of the dredged material layer at Canaveral Harbor using the mathematical model of the consolidation/desiccation process as proposed in this report. While agreement between the predicted and measured material height is not perfect, there is obviously good correspondence. Differences at the early times when the effects of desiccation become the controlling factor are possibly attributed to more extreme drying conditions at the site than were assigned as problem input. The input pan evaporation rates are average values over many years and thus may seriously underestimate (in this case) the actual pan evaporation rates for any one particular year.

110. Some of the discrepancy between measurements and predictions in the later times is due to the noted fact that the surface of the material has been eroded to fill in the deeper desiccation cracks. However, most of the discrepancy is thought due to the effects of secondary consolidation which is not accounted for in the model. Evidence in support of this hypothesis comes from the measured void ratios in the consolidating material below the crust as shown previously in Figure 13 and the measured relationship between void ratio and effective stress for the material. A calculation of effective weights of

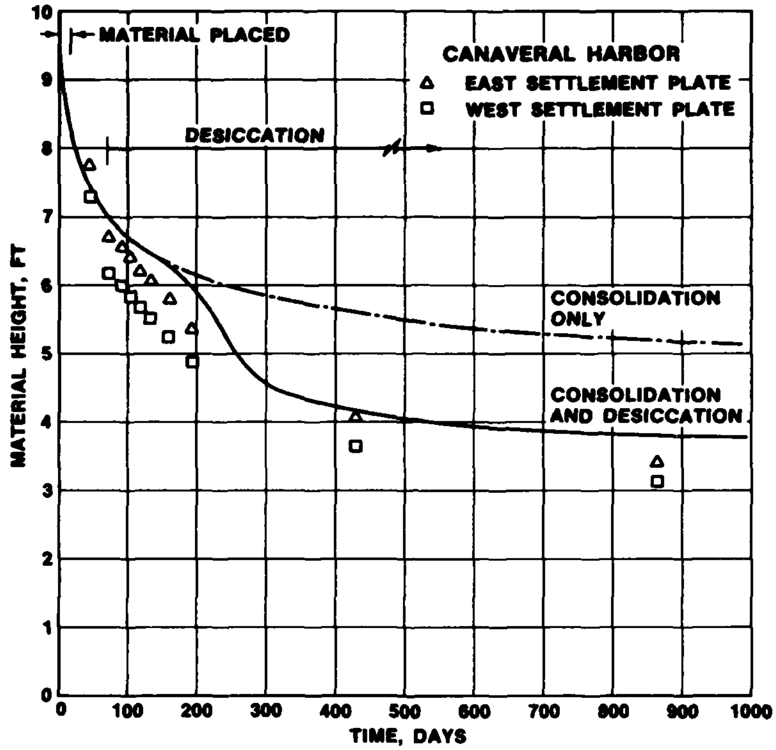


Figure 18. Measured and predicted material heights at Canaveral Harbor

material assuming the water table is at the bottom of desiccation cracks (11 in. below surface) reveals that the void ratio at the bottom of the layer should be about 4.27, yet the void ratio measured was about 3.5. Secondary consolidation is a possible reason for this difference.

Craney Island

111. The average material heights measured and predicted by the various models are shown in Figure 19. It is obvious that again the consolidation/desiccation model developed in this report comes very close to simulating actual field performance. It is also interesting to note that the cumulative amount of desiccation settlement at Craney Island is relatively small compared with overall settlement. This is due to the fact that potential evaporation is zero for much of the year and that regular disposal operations prevent desiccation some of the time when potential evaporation is not zero. The very poor correlation of the small strain theory prediction should also be noted.

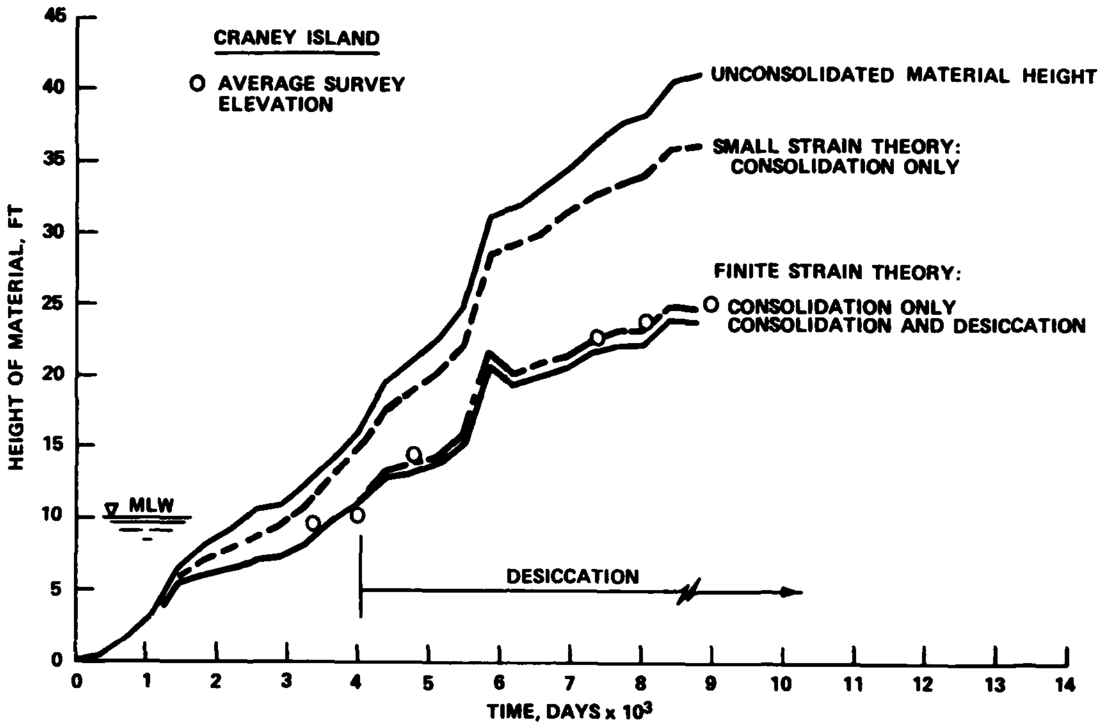


Figure 19. Measured and predicted material heights at Craney Island

112. Considering the 24-year time span covered by the Craney Island disposal history, prediction results are considered very good. The fact that slightly more settlement was predicted than was determined by averaging the topographic survey results is thought to be due mainly to the inherent inaccuracies of trying to characterize average conditions over a 2,500-acre site.

113. Some interesting aspects of the interaction of desiccation and consolidation over a long term are illustrated by Table 4 which lists settlements by type at the end of the 24-year period for various evaporation efficiences. In studying the computer runs for C_E' of 1.00 and 0.75, it became apparent that a higher evaporation efficiency tended to lead to greater desiccation settlement at the earlier times but that this greater early desiccation led to greater consolidation (and increased the water available for evaporation) and thus less later desiccation. However, in comparing the calculations for a C_E' of 0.75 and 0.50, it appeared that the earlier desiccation was not sufficient to trigger greater consolidation and that the expected tendency of greater desiccation for a greater evaporation efficiency was maintained. The overall effect is that calculated total settlements are somewhat insensitive to evaporation efficiency in the long term as shown also in Table 4.

Table 4

Calculated Settlements at Craney Island

Evaporation Efficiency C'_E	Consolidation Settlement ft	Desiccation Settlement ft	Total Settlement ft
0.50	11.86	5.65	17.51
0.75	10.60	6.82	17.51
1.00	14.06	3.48	17.54

Drum Island

114. Predicted versus measured material height during the two latest disposal operations at Drum Island is shown in Figure 20. As can be seen, desiccation causes a relatively major part of the total material settlement, and the consolidation/desiccation model more reliably simulates average material heights throughout the history of the two layers.

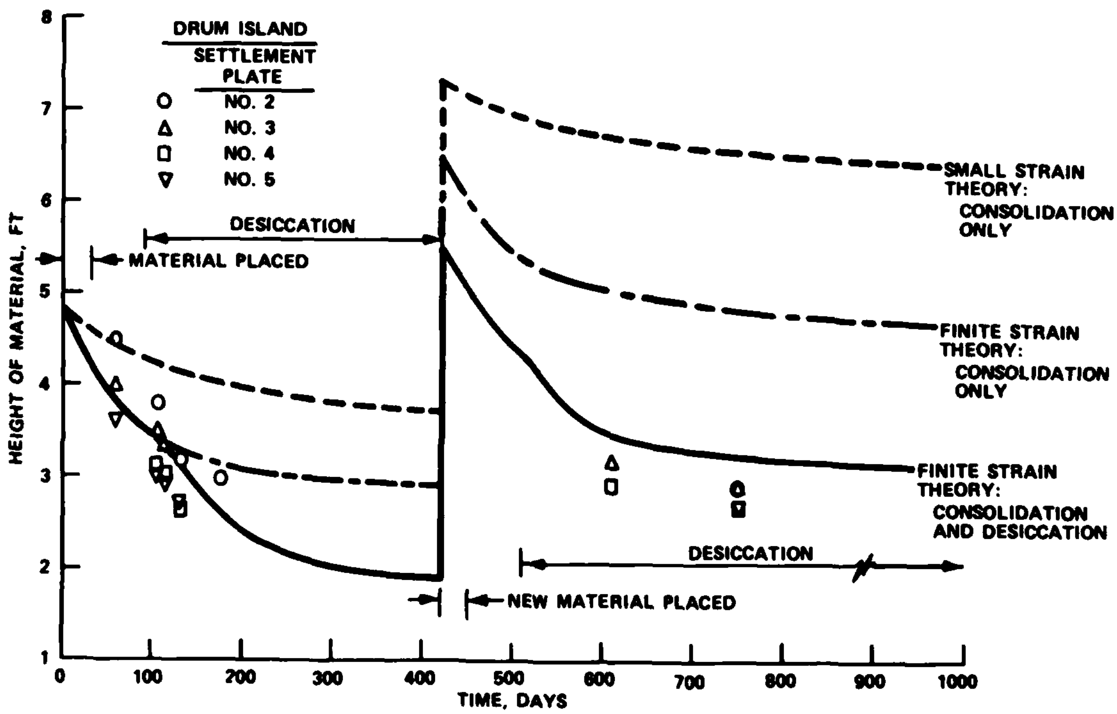


Figure 20. Measured and predicted material heights at Drum Island

115. The discrepancy of about 4 in. toward the end is considered about the limit of the accuracy of settlement plate readings, but the discrepancy is more likely attributable to secondary consolidation in the very soft material. A review of the void ratio profiles in Figure 17 shows void ratios lower than would normally be expected considering the void ratio-effective stress relationship of the material, the effective weight of the material, and a normal water table at the bottom of the desiccation cracks.

PART VI: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

116. In this report, a concise, consistent, and cogent mathematical model of the consolidation/desiccation process in dredged material has been presented. The consolidation portion of the model is well founded on the finite strain theory of consolidation, which is most applicable to the large strains and nonlinear nature of the consolidation process in soft, fine-grained dredged material. The desiccation portion of the model is based on a simplified empirical concept of water evaporation from the dredged material surface. It conforms to observations as documented in previous work by soil scientists and the experimental work of others conducted on dredged material. The coupling of the desiccation process to the consolidation process is accomplished through manipulation of the upper consolidating layer boundary location and the boundary condition.

117. The solution of the mathematical model developed is accomplished by numerical techniques on a computer. The computer program PCDDF as documented herein can calculate dredged material settlements due to consolidation and desiccation for any site-specific application using only the fundamental properties of the dredged material and average site environmental conditions. The fundamental soil properties required are the soil's specific gravity, relationship between void ratio and effective stress, and relationship between void ratio and permeability. Additional soil properties defined in this study and required for modeling the desiccation process are its maximum evaporation efficiency, saturation limit, and desiccation limit. Required environmental conditions include monthly averages of potential Class A pan evaporation and rainfall amounts.

118. Based on the comparisons of predicted with measured field settlements in this report, it is concluded that the proposed mathematical model and solution procedure offer both unique and realistic opportunities for more economical and efficient management of confined dredged material disposal areas. It has been shown that the model can reproduce with a great deal of accuracy material heights resulting from disposal activities involving one lift, two lifts, or even twenty-four lifts of dredged material over relatively short time periods or relatively long time periods. The predictions are based on fundamental soil properties determined during laboratory testing or field sampling and have been shown to be relatively insensitive to those factors

requiring engineering judgment such as site drainage efficiency and soil evaporation efficiency.

119. A logical extension of the research documented in this report involves both theoretical and practical considerations. Improvements in the laboratory determination of the consolidation properties of the very soft, fine-grained soils such as dredged material to include the correlation of some standard consolidation parameters with the standard soil classifiers such as Atterberg limits and activity ratio should be undertaken. Procedures for the laboratory determination of the saturation limit e_{SL}, desiccation limit e_{DL}, and maximum evaporation efficiency C_E' must also be developed to enable before-the-fact predictions in material not previously subjected to field desiccation. Comparisons made here indicate that the role of secondary consolidation in these very soft soils may be more important to ultimate settlement than originally thought. It is therefore recommended that the theory be extended to include appropriate consideration of time-dependent secondary consolidation. Of course, the procedures and equipment required for laboratory determination of the fundamental soil properties governing secondary compression (creep) as a function of the void ratio in these soft materials should proceed concurrently.

120. Special attention is again drawn to the opening assertion that all mathematical problem treatments must be rigorously verified through comparison with field performance. The mathematical model proposed herein should continue to be tested against performance in future comprehensive field verification sites instrumented and monitored as recommended in Appendix E to provide the experience base for any possible refinements necessary to improve its validity.

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APPENDIX A: USER'S GUIDE FOR COMPUTER PROGRAM PCDDF

1. This appendix will provide information useful to users of the computer program Primary Consolidation and Desiccation of Dredged Fill (PCDDF) to include a general description of the program processing sequence, definitions of principal variables, and format requirements for problem input. The program was originally written for use on the US Army Engineer Waterways Experiment Station (WES) time-sharing system but could be readily adapted to batch processing through a card reader and high-speed line printer. Some output format changes would be desirable if the program were used in batch processing to improve efficiency.

2. The program is written in FORTRAN IV computer language with eight-digit line numbers. However, characters 9 through 80 are formatted to conform to the standard FORTRAN statement when reproduced in spaces 1 through 72 of a computer card. Program input is through a quick access type file previously built by the user. Output is either to the time-sharing terminal or to a quick access file at the option of the user. Specific program options will be fully described in the remainder of this appendix.

3. A listing of the program is provided in Appendix B. Typical solution input and output are contained in Appendix C.

Program Description and Components

4. PCDDF is composed of the main program and 12 subroutines. It is broken down into subprograms to make modification and understanding easier. The program is also well documented throughout with comments, so a detailed description will not be given. However, an overview of the program structure is shown in Figure A1, and a brief statement about each part follows:

Main Program. In this part, input data are read according to the option specified and the various subroutines are called to print initial data; calculate consolidation, desiccation, and stresses; and print solution output.

Subroutine INTRO. This subprogram causes a heading to be printed, prints soil and calculation data, and prints initial conditions in each consolidating layer.

Subroutine SETUP1. SETUP1 calculates the time step and grid size, initial and final void ratios, coordinates, stresses, and final settlements in each initial consolidating layer. It also calculates the various void ratio functions

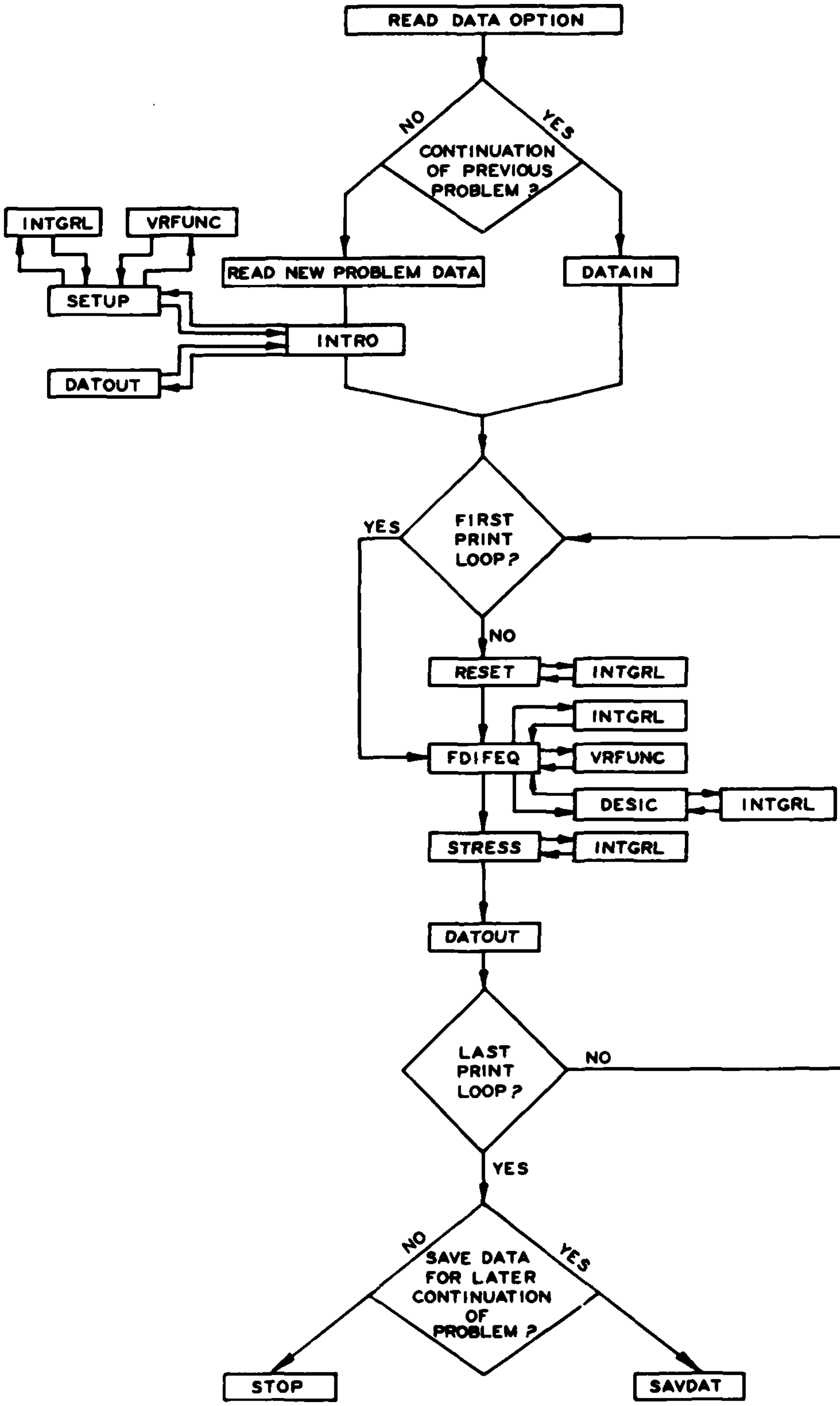

Figure A1. Flow diagram of computer program PCDDF

$$\frac{K(e)}{1 + e} \; \frac{d\sigma'}{de} \quad \alpha(e), \text{ and } \beta(e)$$

where

e = void ratio
$K(e)$ = coefficient of permeability
σ' = effective stress
$\alpha(e)$ = a function of the void ratio, compressibility, and permeability
$\beta(e)$ = a function of the void ratio and permeability

from input relationships between void ratio, effective stress, and permeability.

Subroutine SETUP2. SETUP2 performs the same functions as SETUP1 with the exception of determining the time step and grid size.

Subroutine RESET. In this subroutine initial conditions are modified and certain variables reset each time a new dredged fill layer is added to the consolidating layers. The subprogram also calculates new final settlements and resets the bottom boundary pressure gradient based on the effective weight of the added layer.

Subroutine FDIFEQ. This is where consolidation is actually calculated. A finite difference equation is solved for each nodal point in the consolidating layers at each time step between specified output times. Void ratio functions and pore pressure gradients at layer boundaries are also recalculated at each time step. Subroutine DESIC is called at specified times to modify upper void ratios to account for desiccation. Just before each output time, consistency and stability criteria are checked.

Subroutine DESIC. This subroutine makes adjustments to the top void ratios in a layer based on the amount of desiccation which has been calculated to have occurred during the previous month. The subprogram adjusts toward the e_{SL} or e_{DL} depending on which stage of drying is currently effective (where e_{SL} is the void ratio at the saturation limit and e_{DL} is the void ratio at the desiccation limit). New final void ratios are calculated whenever second-stage drying is in effect. When the entire layer has been dried to the e_{DL} or only four nodes are left in the consolidating layer, a warning message is printed.

Subroutine VRFUNC. The functions $\alpha(e)$ and $\beta(e)$ required at each time step in FDIFEQ are calculated in this subprogram.

Subroutine STRESS. Here, the current convective coordinates, soil stresses, and pore pressures are calculated for each output time.

Subroutine INTGRL. This subroutine evaluates the void ratio integral used in determining convective coordinates, settlements, and soils stresses. The procedure is by Simpson's rule for odd- or even-numbered meshes.

Subroutine DATOUT. DATOUT prints the results of consolidation/desiccation calculations and initial conditions in tabular form. Examples are shown in Appendix C.

Subroutine DATAIN. This routine reads the data from a previous program run so that future consolidation calculations can be continued without having to recalculate previous consolidation.

Subroutine SAVDAT. The data from the current program run is written to a file in the format required to be read by DATAIN.

Variables

5. The following is a list of the principal variables and variable arrays that are used in the computer program PCDDF. The meaning of each variable is also given along with other pertinent information. If the variable name is followed by a number in parentheses, it is an array, and the number denotes the current array dimensions. If these dimensions are not sufficient for the problem to be run, they must be increased throughout the program.

A(101) the Lagrangian coordinate of each space mesh point in the dredged fill layers.

A1(11) the Lagrangian coordinate of each space mesh in the compressible foundation.

AEV the amount of water removed from the dried crust due to a loss of saturation, and which is carried over to the next month and used to adjust the desiccation amount.

AF(101) the function $\alpha(e)$ corresponding to the current void ratios at each space mesh point in the dredged fill layers.

AF1(11) the function $\alpha(e)$ corresponding to the current void ratios at each space mesh point in the compressible foundation.

AHDF(25) the initial height of added dredged fill layers in Lagrangian coordinates.

ALPHA(51) the function $\alpha(e)$ corresponding to the void ratios input when describing the void ratio-effective stress and permeability relationships for the dredged fill.

ALPHA1(51) the function $\alpha(e)$ as above except for the compressible foundation.

ATDS(25) an array which stores the various times at which desiccation starts throughout the current problem.

BETA(51) the function $\beta(e)$ corresponding to the void ratios input when describing the void ratio-effective stress and permeability relationships for the dredged fill.

BETA1(51)	the function $\beta(e)$ as above except for the compressible foundation.
BF(101)	the function $\beta(e)$ corresponding to the current void ratios at each space mesh point in the dredged fill layers.
BF1(11)	the function $\beta(e)$ corresponding to the current void ratios at each space mesh point in the compressible foundation.
CE	the maximum dredged material evaporation efficiency for desiccation drying.
CSET	the consolidation settlement occurring during the most recent monthly period in which desiccation was active.
DA	the difference between the Lagrangian coordinates of space mesh points in the dredged fill layer.
DL	the desiccation limit of the dredged material defined as the lowest void ratio the material will assume under second-stage drying.
DREFF	the drainage efficiency of the dredged material containment area. In practically every case where this program is useful, the value of this variable should be input as 1.0, which signifies a well-drained area.
DSC	the amount of desiccation carried over from the previous month due to a loss of saturation, adjustment to top boundary condition, or evaporation less than consolidation settlement.
DSDE(51)	the calculated value of $d\sigma'/de$ corresponding to the void ratios input when describing the void ratio-effective stress relationship for the dredged fill.
DSDE1(51)	the calculated value of $d\sigma'/de$ as above except for the compressible foundation.
DSET	the desiccation settlement occurring during the most recent monthly period.
DTIM	the next time at which the subroutine DESIC will be called to calculate the results of a month's desiccation.
DUØ	the drainage path length in an incompressible boundary layer used for computing the semipermeable boundary condition. This value is originally input in Lagrangian coordinates but is changed to material coordinates by the program.
DUDZ1Ø	the excess pore pressure gradient in an incompressible foundation at its boundary with the compressible layer.
DUDZ11	the excess pore pressure gradient in the compressible foundation at its boundary with an incompressible foundation.
DUDZ21	the excess pore pressure gradient in the dredged fill layer at its boundary with a compressible foundation or incompressible foundation.

DZ the difference between the material or reduced coordinates of space mesh points in the dredged fill.

DZ1 the difference between the material or reduced coordinates of space mesh points in the compressible foundation.

E(101) the current void ratios at each space mesh point in the dredged fill.

EØ the void ratio in the incompressible foundation at its boundary with the compressible layer.

EØØ the initial void ratio assumed by the dredged fill after initial sedimentation and before consolidation.

E1(101) the initial void ratios at each space mesh point in the dredged fill.

E11(11) the initial void ratios at each space mesh point in the compressible foundation.

EFFSTR(101) the effective stress at each space mesh point in the dredged fill.

EFIN(101) the final (100 percent primary consolidation) void ratios at each space mesh point in the dredged fill.

EFIN1(11) the final (100 percent primary consolidation) void ratios at each space mesh point in the compressible foundation.

EFSTR1(11) the effective stress at each space mesh point in the compressible foundation.

ELL the total depth of the dredged fill in material or reduced coordinates.

ELL1 the depth of the compressible foundation in material or reduced coordinates.

EP(12) the monthly potential evaporation after correction for monthly rainfall and drainage efficiency.

ER(11) the current void ratios at each space mesh point in the compressible foundation.

ES(51) the void ratios input when describing the void ratio-effective stress and permeability relationships in the dredged fill.

ES1(51) the void ratios input when describing the void ratio-effective stress and permeability relationships in the compressible foundation.

ET(101) an array for storing the values of void ratios in the consolidating and desiccating layers just before a new lift of dredged material is placed. These values are used in all calculations except consolidation so long as the corresponding "calculation" void ratios are larger.

F(101) the void ratios at each space mesh point of the previous time step in the dredged fill.

F1(11) the void ratios at each space mesh point of the previous time step in the compressible foundation.

FINT(101) the void ratio integrals evaluated from the bottom to the subscripted space mesh point in the dredged fill.

FINT1(11) the void ratio integrals evaluated from the bottom to the subscripted space mesh point in the compressible foundation.

GC the buoyant unit weight of the dredged fill soil solids.

GC1 the buoyant unit weight of the soil solids of the compressible foundation.

GS the unit weight of the dredged fill soil solids.

GS1 the unit weight of the soil solids of the compressible foundation.

GSBL the specific gravity of the soil solids of the compressible foundation.

GSDF the specific gravity of the dredged fill soil solids.

GW the unit weight of water.

H2 the maximum depth to which second-stage drying will occur in convective coordinates.

HBL the initial height of the compressible foundation in Lagrangian coordinates.

HDF the initial height of the first dredged fill layer in Lagrangian coordinates.

HDF1 the initial height of later dredged fill layers in Lagrangian coordinates.

IMPLY an integer denoting the following options:

1 = program will determine the simulation time increment and grid size to satisfy the stability criteria

2 = user will input TAU, NBDIV, and NBDIV1

IN an integer denoting the input mode or device for initial problem data which has the value "10" in the present program.

INS an integer denoting the input mode or device for problem data from a previous computer run which has the value "12" in the present program.

IOUT an integer denoting the output mode or device for recording the results of program computations in a user's format which has the value "11" in the present program.

IOUTS an integer denoting the output mode or device for recording the results of program computations in a format for continuing the computations in a later run which has the value "13" in the present program.

LBL the number of data points used in describing the void ratio-effective stress and permeability relationships in the compressible foundation. The number should be sufficient to cover the full range of expected or possible void ratios.

LDF the number of data points as above except for the dredged fill.

M an integer used for tracking the month of the year for desiccation calculation purposes.

MM an integer used to flag the start of desiccation and for the purpose of calculating consolidation settlements.

MS the month in which desiccation starts for the current loop to print time.

MTIME the number of additional output times when continuing a previous computer run.

NBDIV the number of parts the initial dredged fill layer is divided into for computation purposes.

NBDIV1 the number of parts the compressible foundation layer is divided into for computation purposes.

NBL an integer denoting the following options:

1 = consolidation calculated for dredged fill layers and compressible foundation.

2 = consolidation calculated for dredged fill layers only.

ND the total number of space mesh points in the dredged fill layers.

NDATA1 an integer denoting the following options:

1 = this is a new problem and data will be read from file "10."

2 = this is a continuation of a previous computer run and data will be read from file "12."

NDATA2 an integer denoting the following options:

1 = do not save data for later computer run.

2 = save data on file "13" so that calculations can be continued in a later computer run.

NDIV the number of space mesh points in the initial dredged fill layer.

NDIV1 the total number of space mesh points in the compressible foundation layer.

NDT the total number of space mesh points in the consolidating portion of the dredged fill layers or "ND" minus those topmost nodes where void ratios have been reduced due to desiccation.

NFLAG an integer denoting the following:

0 = print current conditions heading.

1 = print initial conditions heading.

NM an integer counter which is used in tracking the output times for each computer run.

NMS(25) an array which stores the various months at which desiccation starts throughout the current problem.

NND an integer used to denote the total number of parts into which the dredged fill layers are divided for computation purposes.

NNN an integer counter which is used in tracking the total number of time steps through which consolidation has proceeded.

NNSC(25) an array which stores the various stress print option codes for the current problem. The following values are permissible:

1 = print stress and pore pressure calculations for the succeeding print time.

2 = do not print stress and pore pressure calculations for succeeding print time.

3 = do not print void ratio, stress, and pore pressure calculations.

NPROB an integer used as a label for the current consolidation problem.

NPT an integer denoting the following options:

1 = make a complete computer run, printing soil data, initial conditions, and current conditions for all specified print times.

2 = make a complete computer run but do not print soil data and initial conditions.

3 = terminate computer run after printing soil data and initial conditions.

NSC the value of the stress print option code used in the current loop to print time.

NST an integer line number used on each line of data input and on data lines output for use in a later computer run.

NTIME the number of output times during the initial computer run of a consolidation problem.

PEP(12) the monthly Class A pan or maximum environmental potential evaporation expected at the containment site for each month of the year.

PK(51) the function $k/1 + e$ corresponding to the void ratios input when describing the void ratio-permeability relationship in the dredged fill.

PKØ the function $k/(1 + e)$ for the incompressible foundation layer.

PK1(51) the function $k/(1 + e)$ corresponding to the void ratios input when describing the void ratio-permeability relationship in the compressible foundation.

PRINT(25) the real times at which current conditions in the consolidating layers will be output.

QDF the weight per unit area of the partially saturated dredged material crust which acts as a drained surcharge to lower consolidating material.

RF(12) the monthly rainfall expected at the containment site for each month of the year.

RK(51) the permeabilities input when describing the void ratio-permeability relationship in the dredged fill.

RK1(51) the permeabilities input as above except for the compressible foundation.

RS(51) the effective stresses input when describing the void ratio-effective stress relationship in the dredged fill.

RS1(51) the effective stresses input as above except for the compressible foundation.

SAT the saturation (expressed as a decimal number) of dredged material dried to the desiccation limit which also includes the crack network.

SETC the cumulative total amount of settlement in the dredged material due to consolidation only since the material was placed.

SETD the cumulative total amount of settlement in the dredged material due to desiccation only since the material was placed.

SETT the current total settlement in the dredged fill due to consolidation and desiccation.

SETT1 the current settlement in the compressible foundation.

SFIN the final settlement in the dredged fill layer presently existing without further desiccation effects.

SFIN1 the final settlement in the compressible foundation under present loading conditions.

SL the saturation limit of the dredged material, defined as lowest void ratio the material will assume under first-stage drying and in which the material remains saturated.

TAU the value of the time step in the finite difference calculations.

TDS the time at which desiccation starts in the current loop to print time.

TIME the real time value after each time step.

TPM	the number of basic time periods in a month. Used for counting to desiccation calculation time. If time is measured in days, this will be 30.0.
TPRINT	the real time value of the next output point.
TOSTRI(11)	the current total stress at each space mesh point in the compressible foundation.
TOTSTR(101)	the current total stress at each space mesh point in the dredged fill.
U(101)	the current excess pore pressure at each space mesh point in the dredged fill.
UØ(101)	the current static pore pressure at each space mesh point in the dredged fill.
UØ1(11)	the current static pore pressure at each space mesh point in the compressible foundation.
U1(11)	the current excess pore pressure at each space mesh point in the compressible foundation.
UCON	the current degree of consolidation in the dredged fill.
UCON1	the current degree of consolidation in the compressible foundation.
UW(101)	the current total pore pressure at each space mesh point in the dredged fill.
UW1(11)	the current total pore pressure at each space mesh point in the compressible foundation.
VRI1	the initial total void ratio integral for the compressible foundation.
VRINT	the void ratio integral at the start of each month when desiccation is effective. Used for calculating the amount of consolidation settlement during the month.
XEL	the initial elevation of the top of the incompressible foundation, i.e., bottom of dredged fill if NBL = 2 or bottom of compressible foundation if NBL = 1.
XI(101)	the current convective coordinate of each space mesh point in the dredged fill.
XI1(11)	the current convective coordinate of each space mesh point in the compressible foundation.
Z(101)	the material or reduced coordinate of each space mesh point in the dredged fill.
Z1(11)	the material or reduced coordinate of each space mesh point in the compressible foundation.
ZKØ	the permeability in the incompressible foundation at its boundary with the compressible layer.

Problem Data Input

6. The method of inputting problem data in PCDDF is by a free field data file containing line numbers. The line number must be eight characters or less for ease in file editing and must be followed by a blank space. The remaining items of data on each line must be separated by a comma or blank space. Real data may be either written in exponential or fixed decimal formats, but integer data must be written without a decimal.

7. For an initial problem run (i.e., NDATA1 = 1), the data file should be sequenced in the following manner:

- a. NST, NPROB, NDATA1, NDATA2
- b. NST, NPT, NBL
- c. NST, GSBL, HBL, LBL
- d. NST, ES1(I), RS1(I), RK1(I)
- e. NST, GSDF, HDF, LDF, EØØ, GW
- f. NST, ES(I), RS(I), RK(I)
- g. NST, EØ, ZKØ, DUØ, XEL
- h. NST, IMPLY
- i. NST, NTIME
- j. NST, PRINT(I), AHDF(I), ATDS(I), NMS(I), NNSC(I)
- k. NST, DL, SL, TPM, DREFF, TDS, MS, NSC
- l. NST, PEP(I), RF(I)
- m. NST, CE, SAT, H2

8. It should be pointed out here that NST may be any positive integer but must increase throughout the file so that it will be read in the correct sequence in the time-sharing system.

9. The following exceptions and explanations should also be noted for particular line types:

Line type c: If NBL = 2, all data values are set to zero except NST.

Line type d: There are LBL of these lines unless NBL = 2, and then there will be one line with all values set to zero except NST.

Line type f: There are LDF of these lines.

Line type i: If IMPLY = 2, line type i will contain NST, NBDIV, NBDIV1, TAU, NTIME.

Line type j: There are NTIME of these lines. If AHDF(I) = 0.0 (no additional dredged material is added at this print time), then normally, ATDS(I) = PRINT(I), and NMS(I) = corresponding month.

Line type k: The values input for TDS, MS, and NSC are used in the first loop to print time.

Line type l: There are 12 of these lines corresponding to the 12 months of a year.

10. For the continuation of a previous problem run (i.e., NDATA1 = 2), the data file should be input in the following sequence:

Line type aa. NST, NPROB, NDATA1, NDATA2

Line type bb. NST, MTIME

Line type cc. NST, AHDF(NTIME), ATDS(NTIME), NMS(NTIME), NNSC(NTIME)

Line type dd. NST, PRINT(I), AHDF(I), ATDS(I), NMS(I), NNSC(I)

The following explanations should be noted for particular line types:

Line type cc: AHDF, ATDS, NMS, and NNSC are the values from the last line of the previous computer run.

Line type dd: There are MTIME of these lines.

11. All input data having particular units must be consistent with all other data. For example, if layer thickness is in feet and time is in days, then permeability must be in feet per day. If stresses are in pounds per square foot, then unit weights must be in pounds per cubic foot. Any system of units is permissible so long as consistency is maintained.

12. The following algorithm is offered as guidance for users who wish to determine a stable set of values for the time step and grid size.

a. Determine the maximum value of $\alpha(e)$ where

$$\alpha(e) = \frac{K(e)}{1 + e} \frac{d\sigma'}{de}$$

based on the compressibility and permeability data.

b. Select the number of layers that the dredged fill simulation will employ, NBDIV. A minimum of three layers is required to simulate the desiccation process.

c. Calculate the grid size from

$$\Delta z = \left(\frac{\text{Initial thickness}}{1.0 + e_{oo}} \right) \Big/ \text{NBDIV}$$

d. Calculate the maximum time step from the smaller of:

1. $\tau_{max} = \dfrac{(\Delta z)^2 \gamma \omega}{2\alpha(e)_{max}}$ 2. $\tau_{max} = \dfrac{\Delta z}{K(E\emptyset\emptyset)}$

Select a time step, TAU, that is less than or equal to τ_{max}

e. If a compressible foundation is to be modeled, determine the number of layers, NBDIV1, from

$$\Delta z_{min} = \left[TAU + 2 + \alpha(e)_{max}, \text{ foundation})/\gamma w \right]^{1/2}$$

$$NBDIV1_{max} = \frac{\text{Initial thickness of foundation}}{1 + e_{oo}, \text{ foundation}} \Big/ \Delta z_{min}$$

f. Select an integer value for NBDIV1 that is less than or equal to $NBDIV1_{max}$. If NBDIV1 is less than 1.0, repeat steps 2 through 5 with a larger value of NBDIV.

Program Execution

13. Once an input data file has been built as described in the previous section, the program is executed on the WES time-sharing system by one of the following FORTRAN commands:

a. For an initial run where data are not to be saved for later continuation of the problem

```
RUN RØGEØ33/PCDDF,R#(filename 1)"1Ø";"11"
```

where: (filename 1) = the name of the previously built file in the user's catalog which contains the input data set as described in paragraph 7 above.

b. For an initial run where data are to be saved for later continuation of the problem

```
RUN RØGEØ33/PCDDF,R#(filename 1)"10";"11";(filename 2)"13"
```

where: (filename 2) = the name of the previously built blank file in the user's catalog to which data will be written by the subroutine SAVDAT.

c. For a continuation run where data are not to be saved for later continuation of the problem

```
RUN RØGEØ33/PCDDF,R#(filename 3)"10","11";(filename 4)"12"
```

where: (filename 3) = the name of the previously built file in the user's catalog which contains the input data set as described in paragraph 7 above.

(filename 4) = the name of the file used in the initial run to save data. Should correspond to (filename 2).

d. For a continuation run where data are to be saved for later continuation of the problem.

```
RUN RØGEØ33/PCDDF,R#(filename 3)"10";"11";(filename 4)"12";
(filename 2)"13"
```

14. In the above commands, "11" indicates normal program output is to be printed at the time-sharing terminal. The program is easily modified to utilize other modes of input and output by simply changing the mode identifiers in the main program to whatever is desired.

Computer Output

15. Program output is formatted for the 80-character line of a time-sharing terminal. Since printing at a time-sharing terminal is relatively slow, several options are provided which can be used to eliminate some data which may not be required for the problem at hand or may be repetitions of previous problem runs. These options are fully described in the previous sections of this appendix.

APPENDIX B: PCDDF PROGRAM LISTING

The following is a complete listing of PCDDF as written for the US Army Engineer Waterways Experiment Station time-sharing system.

```
CPCDDF  PRIMARY CONSOLIDATION AND DESICCATION OF DREDGED FILL
C
C         ***********************************************
C         *                                             *
C         *                    PCDDF                    *
C         *                                             *
C         *     ONE-DIMENSIONAL PRIMARY CONSOLIDATION     *
C         *                                             *
C         *             AND DESICCATION OF              
C         *                                             *
C         *         HOMOGENEOUS SOFT CLAY LAYERS        *
C         *                                             *
C         ***********************************************
C
C
C     ********************************************************
C     *                                                      *
C     * PCDDF COMPUTES THE VOID RATIOS, TOTAL AND EFFECTIVE  *
C     * STRESSES, PORE WATER PRESSURES, SETTLEMENTS, AND     *
C     * DEGREES OF CONSOLIDATION FOR HOMOGENEOUS SOFT CLAY   *
C     * LAYERS OF DREDGED FILL DEPOSITED ON A COMPRESSIBLE   *
C     * OR INCOMPRESSIBLE LAYER BY FINITE STRAIN CONSOLIDATION
C     * THEORY AND INCLUDES THE EFFECTS OF ANY DESICCATION.  *
C     * LOWER BOUNDARY OF THE BOTTOM COMPRESSIBLE LAYER MAY  *
C     * BE COMPLETELY FREE DRAINING, IMPERMEABLE, OR NEITHER.*
C     * THE VOID RATIO-EFFECTIVE STRESS AND VOID RATIO-      *
C     * PERMEABILITY RELATIONSHIPS ARE INPUT AS POINT VALUES *
C     * AND THUS MAY ASSUME ANY FORM.  DESICCATION PARAMETERS*
C     * INCLUDE THE LIMITING VOID RATIO OF THE SATURATED AND *
C     * DESICCATED CRUST, MONTHLY CLASS 'A' PAN EVAPORATION  *
C     * POTENTIAL, MONTHLY RAINFALL, AND DRAINAGE AND        *
C     * EVAPORATIVE EFFICIENCIES OF THE DISPOSAL SITE.          *
C     *                                                      *
C     ********************************************************
C
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12),IMPLY
      DIMENSION  AHDF(1000),PRINT(1000),ATDS(1000),NMS(1000),NNSC(1000)
C
```

```
C
C     ...SET INPUT AND OUTPUT MODES
      IN = 10
      IOUT = 11
      INS = 12
      IOUTS = 13
C     ...READ PROBLEM INPUT FROM FREE FIELD DATA FILE
C     .....CONTAINING LINE NUMBERS
  100 FORMAT(V)
C     .....PROBLEM NUMBER, DATA OPTIONS, INTRO OPTION, FDT OPTION
      READ(IN,100) NST,NPROB,NDATA1,NDATA2
      IF (NDATA1 .EQ. 2) GOTO 4
      READ(IN,100) NST,NPT,NBL
C     .....SOIL DATA FOR FOUNDATION LAYER OR SOFT LAYER
      READ(IN,100) NST,GSBL,HBL,LBL
      DO 1  I=1,LBL
      READ(IN,100) NST,ES1(I),RS1(I),RK1(I)
    1 CONTINUE
C     .....SOIL DATA FOR DREDGED FILL
      READ(IN,100)NST,GSDF,HDF,LDF,E00,GW
      DO 2  I=1,LDF
      READ(IN,100) NST,ES(I),RS(I),RK(I)
    2 CONTINUE
C     .....CONSOLIDATION CALCULATION DATA
      READ(IN,100) NST,EO,ZKO,DUO,XEL
      READ(IN,100)NST,IMPLY
      IF(IMPLY.EQ.1)GOTO 10
      READ(IN,100)NST,NBDIV,NBDIV1,TAU,NTIME
      GOTO 20
 10   READ(IN,100) NST,NTIME
      NBDIV=9
      NBDIV1=1
      IF(NBL.EQ.1)NBDIV1=9
 20   DO 3  I=1,NTIME
      READ(IN,100) NST,PRINT(I),AHDF(I),ATDS(I),NMS(I),NNSC(I)
    3 CONTINUE
C
C     ...DESICCATION CALCULATION DATA
      READ(IN,100) NST,DL,SL,TPM,DREFF,TDS,MS,NSC
      DO 9  I=1,12
      READ(IN,100) NST,PEP(I),RF(I)
    9 CONTINUE
      READ(IN,100) NST,CE,SAT,H2
C
C     ...SET INITIAL VARIABLES
      AEV = 0.0 ; DSC = 0.0 ; QDF = 0.0
      M = MS - 1
      DTIM = TDS + TPM
      SETC = 0.0 ; SETD = 0.0
      ELL1=0.0
      TIME = 0.0
      UCON = 0.0 ; UCON1 = 0.0
      SETT = 0.0 ; SETT1 = 0.0
      SFIN = 0.0 ; SFIN1 = 0.0 ; VRI1 = 0.0
      NNN = 1 ; NM = 1 ; MM = 1
      DA = 0.0; HDF1 = 0.0
       DZ=1.0;DZ1=0.0
```

```
C
      DUDZ11 = 0.0 $ DUDZ21 = 0.0
C
C     ...PRINT INPUT DATA AND MAKE INITIAL CALCULATIONS
      CALL INTRO
      IF (NPT .EQ. 3) STOP
      GOTO 6
C
C     ...NEW CONSOLIDATION TIMES AND DATA
    4 READ(IN,100) NST,MTIME
      CALL DATAIN
      READ(IN,100) NST,AHDF(NM-1),ATDS(NM-1),NMS(NM-1),NNSC(NM-1)
      DO 5  I=NM,NTIME
      READ(IN,100) NST,PRINT(I),AHDF(I),ATDS(I),NMS(I),NNSC(I)
    5 CONTINUE
C
C     ...PERFORM CALCULATIONS TO EACH PRINT TIME AND OUTPUT RESULTS
    6 DO 8  K=NM,NTIME
      TPRINT = PRINT(K)
      IF (K .EQ. 1) GOTO 7
      HDF1 = AHDF(K-1)
      TDS = ATDS(K-1)
      MS = NMS(K-1)
      NSC = NNSC(K-1)
      CALL RESET
    7 CALL FDIFEQ
      CALL STRESS
      CALL DATOUT
    8 CONTINUE
C
      IF (NDATA2 .EQ. 2)  CALL SAVDAT
C
      STOP
      END
C
C
      SUBROUTINE INTRO
C
C     ***********************************************
C     * INTRO PRINTS INPUT DATA AND RESULTS OF INITIAL *
C     * CALCULATIONS IN TABULAR FORM.                  *
C     ***********************************************
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &         GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &         IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &         NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &         SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &         A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &         BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &         E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &         ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &         FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &         RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &         UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &         Z(PQ2),Z1(PQ1),
     &         AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
```

```
     &          QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &          EP(12),ET(PQ2),PEP(12),RF(12),IMPLY
C
C     ...PRINT PROBLEM NUMBER AND HEADING
      WRITE(IOUT,100)
      WRITE(IOUT,101)
      WRITE(IOUT,102)
      WRITE(IOUT,103) NPROB
      IF(IMPLY.EQ.1)CALL SETUP1
      IF(IMPLY.EQ.2)CALL SETUP2
      IF (NPT .EQ. 2) RETURN
      IF (NBL .EQ. 2) GOTO 2
C     ...PRINT SOIL DATA FOR COMPRESSIBLE FOUNDATION
      WRITE(IOUT,104)
      WRITE(IOUT,105)
      WRITE(IOUT,106)
      WRITE(IOUT,107) HBL,GSBL
      WRITE(IOUT,108)
      WRITE(IOUT,109)
      DO 1  I=1,LBL
      WRITE(IOUT,110) I,ES1(I),RS1(I),RK1(I),PK1(I),BETA1(I),
     &                DSDE1(I),ALPHA1(I)
    1 CONTINUE
C     ...PRINT SOIL DATA FOR DREDGED FILL
    2 WRITE(IOUT,111)
      WRITE(IOUT,112)
      WRITE(IOUT,113)
      WRITE(IOUT,114) HDF,GSDF,E00,SL,DL
      WRITE(IOUT,108)
      WRITE(IOUT,109)
      DO 3  I=1,LDF
      WRITE(IOUT,110) I,ES(I),RS(I),RK(I),PK(I),BETA(I),
     &                DSDE(I),ALPHA(I)
    3 CONTINUE
C
C     ...PRINT SUMMARY OF RAINFALL AND EVAPORATION POTENTIAL
      WRITE(IOUT,119)
      WRITE(IOUT,120)
      DO 4  I=1,12
      WRITE(IOUT,121) I,RF(I),PEP(I)
    4 CONTINUE
C     ...PRINT CALCULATION DATA
      WRITE(IOUT,115)
      WRITE(IOUT,116)
      WRITE(IOUT,117)
      WRITE(IOUT,118) TAU,EO,ZKO,DUO
C     ...PRINT TABLES OF INITIAL CONDITIONS
      NFLAG = 1
      CALL DATOUT
      NFLAG = 0
C
C     ...FORMATS
  100 FORMAT(1H1/////9X,60(1H*))
  101 FORMAT(9X,47HCONSOLIDATION AND DESICCATION OF SOFT LAYERS---,
     &       12HDREDGED FILL)
  102 FORMAT(9X,60(1H*))
  103 FORMAT(/9X,14HPROBLEM NUMBER,I4)
```

```
 104 FORMAT(/////18(1H*),37HSOIL DATA FOR COMPRESSIBLE FOUNDATION,
    &        17(1H*))
 105 FORMAT(//28X,5HLAYER,9X,16HSPECIFIC GRAVITY)
 106 FORMAT(26X,9HTHICKNESS,11X,9HOF SOLIDS)
 107 FORMAT(/25X,F8.3,12X,F8.3)
 108 FORMAT(//8X,4HVOID,2X,9HEFFECTIVE,3X,5HPERM-,5X,5HK/1+E)
 109 FORMAT(4X,8HI  RATIO,4X,6HSTRESS,3X,8HEABILITY,4X,2HPK,7X,4HBETA,
    &        6X,4HDSDE,5X,5HALPHA)
 110 FORMAT(2X,I3,1X,F6.3,6E10.3)
 111 FORMAT(/////23(1H*),26HSOIL DATA FOR DREDGED FILL,23(1H*))
 112 FORMAT(//4X,5HLAYER,5X,16HSPECIFIC GRAVITY,
    &        5X,7HINITIAL,5X,10HSATURATION,4X,11HDESICCATION)
 113 FORMAT(2X,9HTHICKNESS,7X,9HOF SOLIDS,6X,
    &        10HVOID RATIO,7X,5HLIMIT,9X,5HLIMIT)
 114 FORMAT(/2X,F8.3,8X,F8.3,9X,F8.3,5X,F8.3,6X,F8.3)
 115 FORMAT(/////28(1H*),16HCALCULATION DATA,28(1H*))
 116 FORMAT(//8X,3HTAU,10X,11HLOWER LAYER,7X,11HLOWER LAYER,7X,
    &        13HDRAINAGE PATH)
 117 FORMAT(21X,10HVOID RATIO,8X,12HPERMEABILITY,9X,6HLENGTH)
 118 FORMAT(/4X,E11.5,8X,F8.3,9X,E11.5,7X,3HZ =,F8.3)
 119 FORMAT(1H1///13X,44HSUMMARY OF MONTHLY RAINFALL AND EVAPORATION ,
    &        9HPOTENTIAL)
 120 FORMAT(//20X,5HMONTH,11X,8HRAINFALL,11X,11HEVAPORATION)
 121 FORMAT(/21X,I2,14X,F6.3,15X,F6.3)
C
C
     RETURN
     END
C
C
     SUBROUTINE SETUP1
C
C    ****************************************************
C    * SETUP MAKES INITIAL CALCULATIONS AND MANIPULATIONS *
C    * OF INPUT DATA FOR LATER USE.                       *
C    ****************************************************
C
     PARAMETER PQ1=51, PQ2=501, PQ3=51
     COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
    &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
    &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
    &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
    &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
    &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
    &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
    &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
    &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
    &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
    &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
    &        UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
    &        Z(PQ2),Z1(PQ1),
    &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
    &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
    &        EP(12),ET(PQ2),PEP(12),RF(12)
C
C    ...SET CONSTANTS
     GS = GSDF * GW
```

```
      GC = GS - GW
      GS1 = GSBL * GW
      GC1 = GS1 - GW
      IF( NBL .EQ. 2 ) NDIV1 = NBDIV1 + 1
      PKO = ZKO / (1.0+EO)
      DUO = DUO / (1.0+EO)
      IF (NBL .EQ. 2) GOTO 10
C
      GOTO 10
 2840 CONTINUE
      IF( NBL .EQ. 2 ) GOTO 3891
C     ...CALCULATE ELL FOR COMPRESSIBLE FOUNDATION LAYER
      NDIV1=NBDIV1+1
      DZZ = 0.0
      NBD = 10 * NBDIV1
      DABL = HBL / FLOAT(NBD)
      EFS = 0.0
      DO 4  I=1,NBD
      DO 1  N=2,LBL
      S1 = EFS - RS1(N)
      IF (S1 .LE. 0.0) GOTO 2
    1 CONTINUE
      V = ES1(LBL) ; GOTO 3
    2 NN = N-1
      V = ES1(N) + (S1*(ES1(NN)-ES1(N))/(RS1(NN)-RS1(N)))
    3 TDZ = DABL / (1.0+V)
      EFS = EFS + GC1*TDZ
      DZZ = DZZ + TDZ
    4 CONTINUE
      ELL1 = DZZ
      DZ1 = ELL1 / FLOAT(NBDIV1)
      IF(DZ1.GE.DZ1MIN)GOTO 3040
      IF(NBDIV1.GT.3)GOTO 2565
      NBDIV=NBDIV+1
      GOTO 10
 2565 NBDIV1=NBDIV1-1
      GOTO 2840
C
 3040 CONTINUE
C     ...CALCULATE INITIAL COORDINATES AND VOID RATIOS
C     ...FOR COMPRESSIBLE FOUNDATION LAYER
      Z1(1)=0.0 ; A1(1)=0.0 ; XI1(1)=0.0
      EFS = GC1 * ELL1
      DO 8  I=1,NDIV1
      DO 5  N=2,LBL
      S1 = EFS - RS1(N)
      IF (S1 .LE. 0.0) GOTO 6
    5 CONTINUE
      E11(I) = ES1(LBL) ; GOTO 7
    6 NN = N-1
      E11(I) = ES1(N) + (S1*(ES1(NN)-ES1(N))/(RS1(NN)-RS1(N)))
    7 F1(I) = E11(I)
      ER(I) = E11(I)
      EFS = EFS - GC1*DZ1
    8 CONTINUE
      CALL INTGRL(ER,DZ1,NDIV1,FINT1)
      DO 9  I=2,NDIV1
```

```
          Z1(I) = Z1(I-1) + DZ1
          A1(I) = Z1(I) + FINT1(I)
          XI1(I) = A1(I)
        9 CONTINUE
          GOTO 3891
C
C         ...CALCULATE ELL FOR FIRST DREDGED FILL LAYER
       10 ELL = HDF / (1.0+E00)
          VRINT = ELL * E00
C
C         ...CALCULATE INITIAL COORDINATES AND SET VOID RATIOS
          DZ = ELL / FLOAT( NBDIV )
          GOTO 2679
     2346 TAU=0.99*DZ/RK(1)
          IF(TAU.LT.STAB)GOTO 2351
          TAU=0.99*STAB
     2351 Z(1)=0.0 ; A(1)=0.0 ; XI(1)=0.0
          E1(1)=E00 ; F(1)=E00 ; E(1)=E00 ; ET(1)=E00
          DA = HDF / FLOAT(NBDIV)
          NDIV=NBDIV+1
          ND = NDIV
          NDT=ND
          DO 11  I=2,NDIV
          II = I-1
          Z(I) = Z(II) + DZ
          A(I) = A(II) + DA
          XI(I) = A(I)
          E1(I) = E00
          F(I) = E00
          E(I) = E00
          ET(I) = E00
       11 CONTINUE
C
C         ...CALCULATE FINAL VOID RATIOS FOR DREDGED FILL
          DO 14  I=1,NBDIV
          S1 = GC*(ELL-Z(I))
          IF (S1 .LT. 0.0) S1 = 0.0
          DO 12  N=2,LDF
          S2 = S1 - RS(N)
          IF (S2 .LE. 0.0) GOTO 13
       12 CONTINUE
          EFIN(I) = ES(LDF) ; GOTO 14
       13 NN = N-1
          EFIN(I) = ES(N) + (S2*(ES(NN)-ES(N))/(RS(NN)-RS(N)))
       14 CONTINUE
          EFIN(NDIV) = E00
C
C         ...CALCULATE MAXIMUM SECOND STAGE DRYING DEPTH
          DO 30  N=2,LDF
          C1 = DL - ES(N)
          IF (C1 .GE. 0.0) GOTO 31
       30 CONTINUE
          EFSDL = RS(LDF) ; GOTO 32
       31 NN = N-1
          EFSDL = RS(N) + (C1*(RS(N)-RS(NN))/(ES(N)-ES(NN)))
       32 DZ2 = EFSDL / (GS+(GW*DL*SAT))
          H2MX = DZ2 * (1.0+DL)
```

```
      IF (H2 .GT. H2MX) H2 = H2MX
C
      IF( NBL .EQ. 1 ) GOTO 4640
      GOTO 2840
 3891 CONTINUE
C
C     ...CALCULATE FINAL VOID RATIOS FOR FOUNDATION
      IF (NBL .EQ. 2) GOTO 20
      C1 = ELL1*GC1 $ C2 = ELL*GC
      S1 = C1 + C2
      DO 18  I=1,NDIV1
      S2 = S1 - Z1(I)*GC1
      DO 16  N=2,LBL
      S3 = S2 - RS1(N)
      IF (S3 .LE. 0.0) GOTO 17
   16 CONTINUE
      EFIN1(I) = ES1(LBL) $ GOTO 18
   17 NN = N-1
      EFIN1(I) = ES1(N) + (S3*(ES1(NN)-ES1(N))/(RS1(NN)-RS1(N)))
   18 CONTINUE
C
C     ...CALCULATE INITIAL STRESSES AND PORE PRESSURES
C     .....FOR FOUNDATION LAYER
      WL1 = XI1(NDIV1) + XI(NDIV)
      DO 19  I=1,NDIV1
      U01(I) = GW * (WL1-XI1(I))
      U1(I) = C2
      UW1(I) = U01(I) + U1(I)
      EFSTR1(I) = C1 - GC1*Z1(I)
      TOSTR1(I) = EFSTR1(I) + UW1(I)
   19 CONTINUE
C     .....ULTIMATE SETTLEMENT FOR COMPRESSIBLE FOUNDATION
      VRI1 = FINT1(NDIV1)
      CALL INTGRL(EFIN1,DZ1,NDIV1,FINT1)
      SFIN1 = VRI1 - FINT1(NDIV1)
C
C     .....FOR DREDGED FILL LAYER
   20 DO 21  I=1,NDIV
      U0(I) = GW * (XI(NDIV)-XI(I))
      U(I) = GC * (ELL-Z(I))
      UW(I) = U0(I) + U(I)
      EFFSTR(I) = 0.0
      TOTSTR(I) = UW(I)
   21 CONTINUE
C     .....ULTIMATE SETTLEMENT FOR DREDGED FILL
      CALL INTGRL(EFIN,DZ,NDIV,FINT)
      SFIN = E00*ELL - FINT(NDIV)
      GOTO 2776
C
 2679 CONTINUE
C     ...CALCULATE FUNCTIONS FOR DREDGED FILL
C     .....PERMEABILITY FUNCTION
      DO 22  I=1,LDF
      PK(I) = RK(I) / (1.0+ES(I))
   22 CONTINUE
C     .....SLOPE OF PERMEABILITY FUNCTION -- BETA
C     .....AND SLOPE OF EFF STRESS-VOID RATIO CURVE -- DSDE
```

AD-A158 730 DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM MATHEMATICAL MODEL OF THE C..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR..

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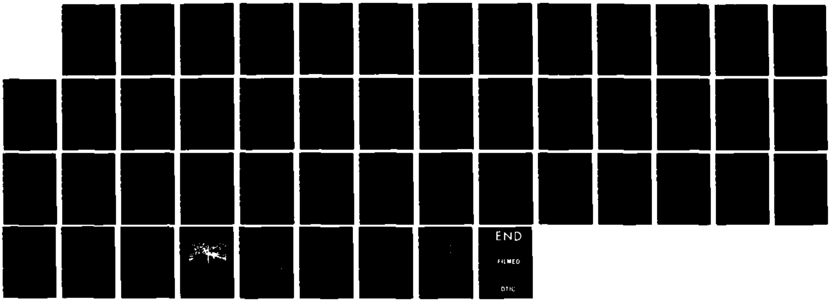
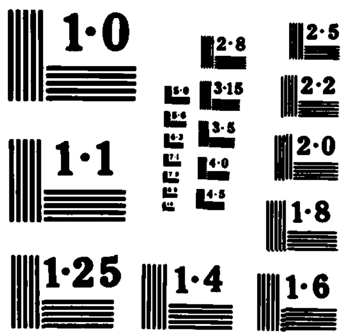
UNCLASSIFIED K W CARGILL JUL 85 WES/TR/D-85-4 F/G 8/13 NL





NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

```
      CD = ES(2) - ES(1)
      BETA(1) = (PK(2)-PK(1)) / CD
      DSDE(1) = (RS(2)-RS(1)) / CD
      L = LDF - 1
      DO 23  I=2,L
      II=I-1 $ IJ=I+1
      CD = ES(IJ) - ES(II)
      BETA(I) = (PK(IJ)-PK(II)) / CD
      DSDE(I) = (RS(IJ)-RS(II)) / CD
   23 CONTINUE
      CD = ES(LDF) - ES(L)
      BETA(LDF) = (PK(LDF)-PK(L)) / CD
      DSDE(LDF) = (RS(LDF)-RS(L)) / CD
C     .....PERMEABILITY FUNCTION TIMES DSDE -- ALPHA
      ALPHMAX=0.0
      DO 24  I=1,LDF
      ALPHA(I) = PK(I) * DSDE(I)
      IF( ABS(ALPHA(I)) .GT. ABS(ALPHMAX) ) ALPHMAX = ALPHA(I)
   24 CONTINUE
 4610 STAB = ABS(( DZ**2 * GW )/( 2.0 * ALPHMAX ))
      GOTO 2346
 2776 IF (NBL .EQ. 2) GOTO 29
      GOTO 4891
C
 4640 CONTINUE
C     ...CALCULATE FUNCTIONS FOR COMPRESSIBLE FOUNDATION
C     .....PERMEABILITY FUNCTION
      DO 26  I=1,LBL
      PK1(I) = RK1(I) / (1.0+ES1(I))
   26 CONTINUE
C     .....SLOPE OF PERMEABILITY FUNCTION -- BETA1
C     .....AND SLOPE OF EFF STRESS-VOID RATIO CURVE -- DSDE1
      CD = ES1(2) - ES1(1)
      BETA1(1) = (PK1(2)-PK1(1)) / CD
      DSDE1(1) = (RS1(2)-RS1(1)) / CD
      L = LBL - 1
      DO 27  I=2,L
      II=I-1 $ IJ=I+1
      CD = ES1(IJ) - ES1(II)
      BETA1(I) = (PK1(IJ)-PK1(II)) / CD
      DSDE1(I) = (RS1(IJ)-RS1(II)) / CD
   27 CONTINUE
      CD = ES1(LBL) - ES1(L)
      BETA1(LBL) = (PK1(LBL)-PK1(L)) / CD
      DSDE1(LBL) = (RS1(LBL)-RS1(L)) / CD
C     .....PERMEABILITY FUNCTION TIMES DSDE -- ALPHA1
      ALPHMAX=0.0
      DO 28  I=1,LBL
      ALPHA1(I) = PK1(I) * DSDE1(I)
      IF(ABS(ALPHA1(I)).GT.ABS(ALPHMAX))ALPHMAX=ALPHA1(I)
   28 CONTINUE
      DZ1MIN=SQRT(TAU*2.0*ABS(ALPHMAX)/GW)
C
      GOTO 2840
 4891 CONTINUE
C     ...CALCULATE BOTTOM BOUNDARY DUDZ
      DUDZ10 = U1(1) / DU0
```

```
   29 IF (NBL .EQ. 2) DUDZ10 = U(1) / DUO
C
C       ...COMPUTE VOID RATIO FUNCTION FOR INITIAL VALUES
        CALL VRFUNC
C
C
        RETURN
        END
C
C
        SUBROUTINE RESET
C
C       ************************************************
C       * RESET UPDATES PREVIOUS CALCULATIONS TO HANDLE *
C       * ADDITIONAL DEPOSITIONS OF DREDGED FILL.       *
C       ************************************************
C
        PARAMETER PQ1=51, PQ2=501, PQ3=51
        COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &          GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &          IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &          NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &          SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &          A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &          BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &          E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &          ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &          FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &          RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &          UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &          Z(PQ2),Z1(PQ1),
     &          AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &          QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &          EP(12),ET(PQ2),PEP(12),RF(12)
C
C       ...RESET DESICCATION VARIABLES
        DTIM = TDS + TPM
        M = MS-1
        IF (HDF1 .LE. ^.0) RETURN
        AEV = 0.0 $ DSC = 0.0
        QDF = 0.0
        MM = 1
C
C       ...CALCULATE ELL FOR NEXT DREDGED FILL LAYER AND RESET CONSTANTS
        EL = HDF1 / (1.0+E00)
        IF (NBL .EQ. 2) U(1) = U(1) + EL*GC
        U1(1) = U1(1) + EL*GC
        NDZ = IFIX((EL/DZ)+0.5)
        ELL = ELL + DZ*FLOAT(NDZ)
        VRINT = (ELL*E00) - SETD - SETC
        NT = ND
        NV = ND + 1
        ND = ND + NDZ
        NB = ND - 1
C
C       ...CALCULATE ADDITIONAL COORDINATES AND SET VOID RATIOS
        DO 1  I=NV,ND
```

```
      II = I-1
      Z(I) = Z(II) + DZ
      A(I) = A(II) + DA
      XI(I) = XI(II) + DA
      E1(I) = E00
      F(I) = E00
      E(I) = E00
    1 CONTINUE
      E(NT) = (E(NT)+E00) / 2.0
      F(NT) = E(NT)
C
C     ...CALCULATE FINAL VOID RATIOS FOR DREDGED FILL
      DO 4  I=1,NB
      S1 = GC*(ELL-Z(I))
      IF (S1 .LT. 0.0) S1=0.0
      DO 2  N=2,LDF
      S2 = S1 - RS(N)
      IF (S2 .LE. 0.0) GOTO 3
    2 CONTINUE
      EFIN(I) = ES(LDF) $ GOTO 4
    3 NN = N-1
      EFIN(I) = ES(N) + (S2*(ES(NN)-ES(N))/(RS(NN)-RS(N)))
    4 CONTINUE
      EFIN(ND) = E00
C
C     ...CALCULATE FINAL VOID RATIOS FOR FOUNDATION
      IF (NBL .EQ. 2) GOTO 9
      C1 = ELL1*GC1 $ C2 = ELL*GC
      S1 = C1 + C2
      DO 8  I=1,NDIV1
      S2 = S1 - Z1(I)*GC1
      DO 6  N=2,LBL
      S3 = S2 - RS1(N)
      IF (S3 .LE. 0.0) GOTO 7
    6 CONTINUE
      EFIN1(I) = ES1(LBL) $ GOTO 8
    7 NN = N-1
      EFIN1(I) = ES1(N) + (S3*(ES1(NN)-ES1(N))/(RS1(NN)-RS1(N)))
    8 CONTINUE
C     .....ULTIMATE SETTLEMENT FOR COMPRESSIBLE FOUNDATION
      CALL INTGRL(EFIN1,DZ1,NDIV1,FINT1)
      SFIN1 = VRI1 - FINT1(NDIV1)
C
C     ...RESET BOTTOM BOUNDARY DUDZ
      IF (NBL .EQ. 3) U1(1) = U1(1) + HDF1
      DUDZ10 = U1(1) / DU0
    9 IF (NBL .EQ. 2) DUDZ10 = U(1) / DU0
C
C     .....ULTIMATE SETLEMENT FOR TOTAL DREDGED FILL
      CALL INTGRL(EFIN,DZ,ND,FINT)
      SFIN = E00*ELL - FINT(ND)
C
C     ...SET VOID RATIO FUNCTIONS FOR RESET VALUES
      DO 10  I=NT,ND
      AF(I) = ALPHA(1)
      BF(I) = BETA(1)
   10 CONTINUE
```

```
C
C      ...SET 'CALCULATION' VOID RATIOS
       DO 11  I=1,ND
       ET(I) = E(I)
    11 CONTINUE
       N = NT-NDT-1
       IF (N .LE. 0) GOTO 13
       DE = (E00-E(NDT-1)) / FLOAT(N)
       DO 12  I=NDT,NT
       II=I-1
       E(I) = E(II) + DE
       F(I) = E(I)
    12 CONTINUE
       NDT = NT
       CALL VRFUNC
    13 NDT = ND
C
C
       RETURN
       END
C
C
       SUBROUTINE FDIFEQ
C
C      *************************************************************
C      * FDIFEQ CALCULATES NEW VOID RATIOS AS CONSOLIDATION PROCEEDS *
C      * BY AN EXPLICIT FINITE DIFFERENCE SCHEME BASED ON PREVIOUS   *
C      * VOID RATIOS.  SOIL PARAMETER FUNCTIONS ARE CONSTANTLY       *
C      * UPDATED TO CORRESPOND WITH CURRENT VOID RATIO.              *
C      *************************************************************
C
       PARAMETER PQ1=51, PQ2=501, PQ3=51
       COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,E0,E00,ELL,ELL1,
      &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
      &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
      &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PK0,SETT,SETT1,
      &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZK0,
      &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
      &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
      &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
      &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
      &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
      &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
      &        U0(PQ2),U01(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
      &        Z(PQ2),Z1(PQ1),
      &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
      &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
      &        EP(12),ET(PQ2),PEP(12),RF(12)
C
C      ...SET CONSTANTS
       CF = TAU/(GW*DZ)
       DZ2 = DZ*2.0
       NND = NDT - 1
       IF (NBL .EQ. 2) GOTO 5
       DZ12 = DZ1*2.0
       CF1 = TAU/(GW*DZ1)
C
```

```
C      .LOOP THROUGH FINITE DIFFERENCE EQUATIONS UNTIL PRINT TIME
C
C      ...CALCULATE VOID RATIO OF IMAGE POINT AND FIRST REAL POINT
C      .....FOR COMPRESSIBLE LAYER
     1 DO 2  I=2,LBL
       C1 = ER(1) - ES1(I)
       IF (C1 .GE. 0.0) GOTO 3
     2 CONTINUE
       DSED = DSDE1(LBL) ; GOTO 4
     3 II = I-1
       DSED = DSDE1(I) + (C1*(DSDE1(I)-DSDE1(II))/(ES1(I)-ES1(II)))
     4 F10 = F1(2) + DZ12*(GC1+DUDZ11)/DSED
       DF = (F1(2)-F10) / 2.0
       DF2DZ = (F1(2)-2.0*F1(1)+F10) / DZ1
       AC = (AF1(2)-AF1(1)) / DZ1
       ER(1) = F1(1) - CF1*(DF*(GC1*BF1(1)+AC)+DF2DZ*AF1(1))
       IF (ER(1) .LT. EFIN1(1))  ER(1) = EFIN1(1)
       IF (ER(1) .GT. E11(1))  ER(1) = E11(1)
C      .....FOR DREDGED FILL
     5 DO 6  I=2,LDF
       C1 = E(1) - ES(I)
       IF (C1 .GE. 0.0) GOTO 7
     6 CONTINUE
       DSED = DSDE(LDF) ; GOTO 8
     7 II = I-1
       DSED = DSDE(I) + (C1*(DSDE(I)-DSDE(II))/(ES(I)-ES(II)))
     8 FO = F(2) + DZ2*(GC+DUDZ21)/DSED
       DF = (F(2)-FO) / 2.0
       DF2DZ = (F(2)-2.0*F(1)+FO) / DZ
       AC = (AF(2)-AF(1)) / DZ
       E(1) = F(1) - CF*(DF*(GC*BF(1)+AC)+DF2DZ*AF(1))
       IF (E(1) .LT. EFIN(1))  E(1) = EFIN(1)
C
C      ...CALCULATE VOID RATIO OF TOP POINT IN COMPRESSIBLE LAYER
       IF (NBL .EQ. 2) GOTO 27
       DO 9  I=2,LDF
       C1 = E(1) - ES(I)
       IF (C1 .GE. 0.0) GOTO 10
     9 CONTINUE
       EST = RS(LDF) ; GOTO 11
    10 II = I-1
       EST = RS(I) + (C1*(RS(I)-RS(II))/(ES(I)-ES(II)))
    11 DEST = EST - EFFSTR(1)
       UT = U(1) - DEST
       EFS1 = EFSTR1(NDIV1) + DEST
       DO 12  I=2,LBL
       C1 = EFS1 - RS1(I)
       IF (C1 .LE. 0.0) GOTO 13
    12 CONTINUE
       ER(NDIV1) = ES1(LBL) ; GOTO 14
    13 II = I-1
       ER(NDIV1) = ES1(I) + (C1*(ES1(II)-ES1(I))/(RS1(II)-RS1(I)))
C
C      ...RESET BOUNDARY DUDZ FOR DREDGED FILL
    14 DO 15  I=2,LBL
       C1 = ER(NBDIV1) - ES1(I)
       IF (C1 .GE. 0.0) GOTO 16
```

```
 15 CONTINUE
    EST1= RS1(LBL) ; GOTO 17
 16 II = I-1
    EST1 = RS1(I) + (C1*(RS1(I)-RS1(II))/(ES1(I)-ES1(II)))
 17 UT1 = U1(NBDIV1) - EST1 + EFSTR1(NBDIV1)
    DUDZ12 = (UT - UT1) / DZ1
    DO 18  I=2,LBL
    C1 = ER(NDIV1) - ES1(I)
    IF (C1 .GE. 0.0) GOTO 19
 18 CONTINUE
    RPKER = PK1(LBL) ; GOTO 20
 19 II = I-1
    RPKER = PK1(I) + (C1*(PK1(I)-PK1(II))/(ES1(I)-ES1(II)))
 20 DO 21  I=2,LDF
    C1 = E(1) - ES(I)
    IF (C1 .GE. 0.0) GOTO 22
 21 CONTINUE
    PKE = PK(LDF) ; GOTO 23
 22 II = I-1
    PKE = PK(I) + (C1*(PK(I)-PK(II))/(ES(I)-ES(II)))
 23 DUDZ21 = DUDZ12 * RPKER / PKE
C
C   ...CALCULATE NEW VOID RATIOS FOR REMAINDER OF MATERIAL
C   .....IN COMPRESSIBLE FOUNDATION
    DO 25  I=2,NBDIV1
    II = I-1 ; IJ = I+1
    DF = (F1(IJ)-F1(II)) / 2.0
    DF2DZ = (F1(IJ)-F1(I)*2.0+F1(II)) / DZ1
    AC = (AF1(IJ)-AF1(II)) / DZ12
    ER(I) = F1(I) - CF1*(DF*(GC1*BF1(I)+AC)+DF2DZ*AF1(I))
 25 CONTINUE
C   .....RESET FOR NEXT LOOP
    DO 26  I=1,NDIV1
    F1(I) = ER(I)
 26 CONTINUE
    IF (NBL .EQ. 3) GOTO 30
    IF (NDT .LT.4) GOTO 30
C
C   ...NEW VOID RATIOS IN DREDGED FILL
 27 DO 28  I=2,NND
    IF (E(I) .LE. EFIN(I)) GOTO 28
    II = I-1 ; IJ = I+1
    DF = (F(IJ)-F(II)) / 2.0
    DF2DZ = (F(IJ)-F(I)*2.0+F(II)) / DZ
    AC = (AF(IJ)-AF(II)) / DZ2
    E(I) = F(I) - CF*(DF*(GC*BF(I)+AC)+DF2DZ*AF(I))
    IF (E(I) .LE. EFIN(I)) E(I) = EFIN(I)
    IF (E(I) .GT. F(I)) E(I) = F(I)
 28 CONTINUE
C   .....RESET FOR NEXT LOOP
    DO 29  I=1,NND
    F(I) = E(I)
 29 CONTINUE
C
C   ...RESET BOTTOM BOUNDARY DUDZ FOR COMPRESSIBLE LAYER
 30 IF (NBL .EQ. 2) GOTO 34
    DO 31  I=2,LBL
```

```
      C1 = ER(1) - ES1(I)
      IF (C1 .GE. 0.0) GOTO 32
   31 CONTINUE
      RPKER = PK1(LBL)
      EST1 = RS1(LBL) $ GOTO 33
   32 II = I-1
      C2 = C1 / (ES1(I)-ES1(II))
      RPKER = PK1(I) + C2*(PK1(I)-PK1(II))
      EST1 = RS1(I) + C2*(RS1(I)-RS1(II))
   33 DUDZ11 = DUDZ10 * PKO / RPKER
      UT1 = U1(1) - EST1 + EFSTR1(1)
      DUDZ10 = UT1 / DUO
      GOTO 38
C
C     ...RESET BOTTOM BOUNDARY DUDZ FOR DREDGED FILL
   34 DO 35  I=2,LDF
      C1 = E(1) - ES(I)
      IF (C1 .GE. 0.0) GOTO 36
   35 CONTINUE
      PKE = PK(LDF)
      EST = RS(LDF) $ GOTO 37
   36 II = I-1
      C2 = C1 / (ES(I)-ES(II))
      PKE = PK(I) + C2*(PK(I)-PK(II))
      EST = RS(I) + C2*(RS(I)-RS(II))
   37 DUDZ21 = DUDZ10 * PKO / PKE
      UT = U(1) - EST + EFFSTR(1)
      DUDZ10 = UT / DUO
C
C     ...CALCULATE ALPHA AND BETA FOR CURRENT VOID RATIOS
   38 CALL VRFUNC
C
C     ...CALCULATE CURRENT TIME AND CHECK AGAINST
C     .....DESICCATION TIME AND PRINT TIME
      TIME = TAU * FLOAT(NNN)
      IF (TIME .GT. TDS .AND. MM .EQ. 1) GOTO 41
   39 IF (TIME .GE. DTIM) CALL DESIC
      NNN = NNN + 1
      IF (TIME .LT. TPRINT .AND. NBL .EQ. 1) GOTO 1
      IF (TIME .LT. TPRINT .AND. NBL .EQ. 2) GOTO 5
C
C     ...RECOVER ACTUAL VOID RATIOS
      DO 44  I=2,NDT
      IF (E(I) .GT. ET(I)) E(I) = ET(I)
   44 CONTINUE
      CALL VRFUNC
C
C     ...CHECK STABILITY AND CONSISTENCY
      IF (NBL .EQ. 2) GOTO 40
      RBF = BF1(1)
      RAF = AF1(1)
      DO 42  I=2,NBDIV1
      II = I+1
      IF (AF1(II) .LE. RAF) GOTO 42
      RAF = AF1(II)
      RBF = BF1(II)
   42 CONTINUE
```

```
      STAB = ABS((DZ1**2*GW)/(2.0*RAF))
      IF (STAB .LT. TAU) WRITE(IOUT,100) NPROB
      CONS = ABS((2.0*RAF)/(GC1*RBF))
C     IF (CONS .LE. DZ1) WRITE(IOUT,101) NPROB
   40 RBF = BF(1)
      RAF = AF(1)
      DO 43  I=2,NND
      II = I+1
      IF (AF(II) .LE. RAF) GOTO 43
      RAF = AF(II)
      RBF = BF(II)
   43 CONTINUE
      STAB = ABS((DZ**2*GW)/(2.0*RAF))
      IF (STAB .LT. TAU) WRITE(IOUT,102) NPROB
      CONS = ABS((2.0*RAF)/(GC*RBF))
C     IF (CONS .LE. DZ) WRITE(IOUT,103) NPROB
      IF (TAU .GE. (A(ND)/(RK(1)*FLOAT(ND)))) WRITE(IOUT,104)
C
C     ...CALCULATE CONSOLIDATION SINCE LAST DESICCATION
      RETURN
   41 MM = 2
      CALL INTGRL(E,DZ,NDT,FINT)
      CSET = VRINT - FINT(NDT)
      SETC = SETC + CSET
      VRINT = FINT(NDT)
      IF (MM .EQ. 2) GOTO 39
C
C     ...FORMATS
  100 FORMAT(/////38HSTABILITY ERROR --FOUNDATION --PROBLEM,I5)
  101 FORMAT(/////40HCONSISTENCY ERROR --FOUNDATION --PROBLEM,I5)
  102 FORMAT(/////40HSTABILITY ERROR --DREDGED FILL --PROBLEM,I5)
  103 FORMAT(/////42HCONSISTENCY ERROR --DREDGED FILL --PROBLEM,I5)
  104 FORMAT(/////40HPOSSIBLE STABILITY PROBLEM--DECREASE TAU)
C
C
      RETURN
      END
C
C
      SUBROUTINE VRFUNC
C
C     ***********************************************
C     * VRFUNC CALCULATES ALPHA AND BETA FUNCTIONS *
C     * FOR CURRENT VOID RATIOS.                    *
C     ***********************************************
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DU0,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,E0,E00,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PK0,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZK0,
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
```

```
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        U0(PQ2),U01(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12)
C
      IF (NBL .EQ. 2) GOTO 4
C     ...FOR COMPRESSIBLE FOUNDATION
      DO 3  I=1,NDIV1
      DO 1  N=2,LBL
      C1 = ER(I) - ES1(N)
      IF (C1 .GE. 0.0) GOTO 2
    1 CONTINUE
      AF1(I) = ALPHA1(LBL)
      BF1(I) = BETA1(LBL) $ GOTO 3
    2 NN = N-1
      CM = C1 / (ES1(N)-ES1(NN))
      AF1(I) = ALPHA1(N) + CM*(ALPHA1(N)-ALPHA1(NN))
      BF1(I) = BETA1(N) + CM*(BETA1(N)-BETA1(NN))
    3 CONTINUE
C
C     ...FOR DREDGED FILL
    4 DO 7  I=1,NDT
      DO 5  N=2,LDF
      C1 = E(I) - ES(N)
      IF (C1 .GE. 0.0) GOTO 6
    5 CONTINUE
      AF(I) = ALPHA(LDF)
      BF(I) = BETA(LDF) $ GOTO 7
    6 NN = N-1
      CM = C1 / (ES(N)-ES(NN))
      AF(I) = ALPHA(N) + CM*(ALPHA(N)-ALPHA(NN))
      BF(I) = BETA(N) + CM*(BETA(N)-BETA(NN))
    7 CONTINUE
C
C
      RETURN
      END
C
C
      SUBROUTINE DESIC
C
C     ***************************************************************
C     * DESIC CALCULATES THE NEW VOID RATIOS DUE TO DESICCATION    *
C     * IN THE UPPER PARTS OF THE DREDGED FILL ON A MONTHLY        *
C     * BASIS.  NEW BOUNDARY CONDITION FOR THE CONSOLIDATING       *
C     * MATERIAL BELOW THE DRIED UPPER CRUST IS ALSO CALCULATED.   *
C     ***************************************************************
C
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
```

```
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        U0(PQ2),U01(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12)
      DIMENSION PS(PQ2)
C
C     ...RECOVER ACTUAL VOID RATIOS
      DO 20  I=2,NDT
      IF (E(I) .GT. ET(I)) E(I) = ET(I)
   20 CONTINUE
C
C     ...CALCULATE NET DESICCATION FOR MONTH
      DTIM = DTIM + TPM
      CALL INTGRL(E,DZ,ND,FINT)
      CT = Z(ND) + FINT(ND) - Z(NDT) - FINT(NDT)
      CSET = VRINT - FINT(NDT)
      SETC = SETC + CSET
      M = M + 1 ; MM = 2
      IF (M .EQ. 13) M=1
      EP(M) = PEP(M) - ((1.0-DREFF)*RF(M))
      EVEFF = CE * (1.0-(CT/H2))
      EP(M) = EP(M) * EVEFF
      DSET = EP(M) - CSET - DSC
      DSC = 0.0
      IF (DSET .LE. 0.0) GOTO 16
      IF (CT .GE. H2) GOTO 16
      SETD = SETD + DSET
      NN = ND-4
      IF (E(ND) .LT. SL) GOTO 5
C
C     ...DETERMINE WHICH POINTS ARE ADJUSTABLE TO SL
    1 DO 2  I=1,NN
      II = ND+1-I
      IF (E(II) .GT. SL .AND. EFIN(II) .GE. SL) GOTO 3
      IF (EFIN(II) .LT. SL) GOTO 5
    2 CONTINUE
      GOTO 5
C
C     ...CHECK CRUST DEPTH
    3 CD = Z(ND) + FINT(ND) - Z(II) - FINT(II)
      H2T = H2 * (SL/DL)
      IF (CD .GT. H2T) GOTO 5
C
C     ...ADJUST VOID RATIOS WHICH ARE ABOVE SL
      DEAV = DSET / DZ
      IF (II .EQ. ND) DEAV = 2.0*DEAV
      V = E(II) - DEAV
      IF (V .LE. SL) GOTO 4
      E(II) = V
      GOTO 16
```

```
    4 RV = DEAV - E(II) +SL
      E(II) = SL
      IF (II .EQ. ND) RV = RV / 2.0
      DSET = RV * DZ
      IF (DSET .GT. 0.0001) GOTO 1
      GOTO 16
C
C     ...DETERMINE WHICH POINTS ARE ADJUSTABLE TO DL
    5 DO 6  I=1,NN
      II = ND+1-I
      IF (E(II) .GT. DL .AND. EFIN(II) .GE. DL) GOTO 7
      IF (EFIN(II) .LT. DL) GOTO 14
    6 CONTINUE
      GOTO 15
C
C     ...ADJUST VOID RATIOS WHICH ARE ABOVE DL
    7 NDT = II
      DEAV = DSET / DZ
      IF (II .EQ. ND) DEAV = DEAV * 2.0
      V = E(II) - DEAV
      IF (V .LE. DL) GOTO 8
      E(II) = V
      IF (EFIN(II) .GT. SL) RL = SL
      IF (EFIN(II) .LE. SL) RL = EFIN(II)
      PC = 0.0
      IF (E(II) .GE. RL) PC = 1.0
      IF (E(II) .LT. RL .AND. RL .GT. DL)
     &          PC = (E(II)-DL) / (RL-DL)
      PS(II) = SAT + ((1.0-SAT)*PC)
      GOTO 9
    8 RV = DEAV - E(II) + DL
      NDT = II - 1
      PS(NDT) = 1.0
      E(II) = DL
      EFIN(II) = DL
      PS(II) = SAT
      IF (II .EQ. ND) RV = RV / 2.0
      DSET = RV * DZ
      SETD = SETD - DSET
C
C     ...CHECK NEW CRUST THICKNESS
      CT = Z(ND) + FINT(ND) - Z(NDT) - FINT(NDT)
      IF (CT .GE. H2) GOTO 9
      REF = CE * (1.0-(CT/H2))
      RAT = REF / EVEFF
      DSET = RAT * DSET
      SETD = SETD + DSET
      IF (DSET .GT. 0.0001) GOTO 5
C
C     ...DETERMINE SURCHARGE DUE TO PARTIALLY SATURATED CRUST
C     .....AND CARRY OVER DESICCATION DUE TO LOSS OF SATURATION
C     .....AND RESET STRESSES IN CRUST
    9 IF (NDT .EQ. ND) GOTO 16
      J = ND-1
      QDF = 0.0
      AEV1 = 0.0
      DO 10  JI=NDT,J
```

```
      I = J + NDT - JI
      IJ = I+1
      EFFSTR(IJ) = QDF
      TOTSTR(IJ) = QDF
      U(IJ) = 0.0
      UO(IJ) = 0.0
      UW(IJ) = 0.0
      EAV = (E(I)+E(IJ)) / 2.0
      SAV = (PS(I)+PS(IJ)) / 2.0
      AEV1 = (DZ*EAV*(1.0-SAV)) + AEV1
      QDF = QDF + (DZ*(GS+(EAV*GW*SAV)))
   10 CONTINUE
      DSC = AEV1 - AEV
      AEV = AEV1
C
C     ...CALCULATE NEW FINAL VOID RATIOS DUE TO LOWER WATER TABLE
C     .....FOR DREDGED FILL
      QD = QDF + GC*Z(NDT)
      DO 13  I=1,NDT
      S1 = QD - GC*Z(I)
      DO 11  N=2,LDF
      S2 = S1 - RS(N)
      IF (S2 .LE. 0.0) GOTO 12
   11 CONTINUE
      EFIN(I) = ES(LDF) ; GOTO 13
   12 NT = N-1
      EFIN(I) = ES(N) + (S2*(ES(NT)-ES(N))/(RS(NT)-RS(N)))
   13 CONTINUE
C
C     ...RESET UPPER BOUNDARY CONDITION FOR DREDGED FILL
      V = E(NDT)
      IF (V .GT. EFIN(NDT)) E(NDT) = EFIN(NDT)
      F(NDT) = E(NDT)
      DSC = (V-E(NDT)) * DZ + DSC
C
C     ...CALCULATE NEW FINAL VOID RATIOS DUE TO LOWER WATER TABLE
C     .....FOR FOUNDATION
      IF (NBL .EQ. 2) GOTO 16
      S1 = (ELL1*GC1) + (Z(NDT)*GC) + QDF
      DO 19  I=1,NDIV1
      S2 = S1 - Z1(I)*GC1
      DO 17  N=2,LBL
      S3 = S2 - RS1(N)
      IF ( S3 .LE. 0.0) GOTO 18
   17 CONTINUE
      EFIN1(I) = ES1(LBL) ; GOTO 19
   18 NT = N-1
      EFIN1(I) = ES1(N) + (S3*(ES1(NT)-ES1(N))/(RS1(NT)-RS1(N)))
   19 CONTINUE
      GOTO 16
C
C     ...PRINT MESSAGE WHEN ALL POINTS ARE AT DL OR EFINAL
   14 WRITE(IOUT,100)
  100 FORMAT(1H1/////5X,39HALL POINTS AT DL OR EFINAL--REFORMULATE)
      GOTO 16
C
C     ...PRINT MESSAGE WHEN LESS THAN 4 POINTS NOT AT DL
```

```
   15 WRITE(IOUT,101)
  101 FORMAT(1H1/////5X,41HLESS THAN 4 POINTS NOT AT DL--REFORMULATE)
C
C       ...RECALCULATE VOID RATIO INTEGRAL FOR NEXT CYCLE
   16 CALL INTGRL(E,DZ,NDT,FINT)
      VRINT = FINT(NDT)
C
C       ...RESET CALCULATION VOID RATIOS
      DO 21  I=2,NDT
      ET(I) = E(I)
      IF (E(I) .LT. EFIN(I)) E(I) = EFIN(I)
      F(I) = E(I)
   21 CONTINUE
C
C
      RETURN
      END
C
C
      SUBROUTINE STRESS
C
C     ************************************************************
C     * STRESS CALCULATES EFFECTIVE STRESSES, TOTAL STRESSES, *
C     * AND PORE WATER PRESSURES BASED ON CURRENT VOID RATIO   *
C     * AND VOID RATIO INTEGRAL.                               *
C     ************************************************************
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12)
C
C       ...CALCULATE VOID RATIO INTEGRAL AND XI COORDINATES
      CALL INTGRL(E,DZ,ND,FINT)
      DO 1  I=1,ND
      XI(I) = Z(I) + FINT(I)
    1 CONTINUE
      IF (NBL .EQ. 2) GOTO 7
      CALL INTGRL(ER,DZ1,NDIV1,FINT1)
      DO 2  I=1,NDIV1
      XI1(I) = Z1(I) + FINT1(I)
    2 CONTINUE
C
C       ...FOR COMPRESSIBLE FOUNDATION
```

```
C     .....CALCULATE STRESSES
      WL1 = XI(NDT) + XI1(NDIV1)
      G1 = QDF + (Z(NDT)*GC)
      W1 = FINT1(NDIV1) + XI(NDT)
      DO 6  I=1,NDIV1
      DO 3  N=2,LBL
      C1 = ER(I) - ES1(N)
      IF (C1 .GE. 0.0) GOTO 4
    3 CONTINUE
      EFSTR1(I) = RS1(LBL) ; GOTO 5
    4 NN = N-1
      EFSTR1(I) = RS1(N) + (C1*(RS1(N)-RS1(NN))/(ES1(N)-ES1(NN)))
    5 UO1(I) = GW * (WL1-XI1(I))
      TOSTR1(I) = GW*(W1-FINT1(I)) + GS1*(ELL1-Z1(I)) + G1
      UW1(I) = TOSTR1(I) - EFSTR1(I)
      U1(I) = UW1(I) - UO1(I)
    6 CONTINUE
C
C     ...FOR DREDGED FILL
C     .....CALCULATE STRESSES
    7 DO 12  I=1,NDT
      IF (E(I) .LE. EFIN(I)) GOTO 11
      DO 9  N=2,LDF
      C1 = E(I) -ES(N)
      IF (C1 .GE. 0.0) GOTO 10
    9 CONTINUE
      EFFSTR(I) = RS(LDF) ; GOTO 11
   10 NN = N-1
      EFFSTR(I) = RS(N) + (C1*(RS(N)-RS(NN))/(ES(N)-ES(NN)))
   11 IF (E(I) .LE. EFIN(I)) EFFSTR(I) = GC*(Z(NDT)-Z(I)) + QDF
      UO(I) = GW * (XI(NDT)-XI(I))
      TOTSTR(I) = GW*(FINT(NDT)-FINT(I)) + GS*(Z(NDT)-Z(I)) + QDF
      UW(I) = TOTSTR(I) - EFFSTR(I)
      U(I) = UW(I) - UO(I)
   12 CONTINUE
C
C     ...CALCULATE SETTLEMENT AND DEGREE OF CONSOLIDATION
      IF (NBL .EQ. 2) GOTO 14
      SETT1 = A1(NDIV1) - XI1(NDIV1)
      UCON1 = SETT1 / SFIN1
   14 SETT = A(ND) - XI(ND)
      UCON = SETT / SFIN
      SETC = SETT - SETD
C
C
      RETURN
      END
C
C
      SUBROUTINE INTGRL(E,DZ,N,F)
C
C     ***********************************************
C     * INTGRL EVALUATES THE VOID RATIO INTEGRAL TO *
C     * EACH MESH POINT IN THE MATERIAL.            *
C     ***********************************************
C
      DIMENSION E(101),F(101)
```

```
C     ...BY SIMPSONS RULE FOR ALL ODD NUMBERED MESH POINTS
      F(1) = 0.0
      DO 1  I=3,N,2
      F(I) = F(I-2) + DZ*(E(I-2)+4.0*E(I-1)+E(I))/3.0
    1 CONTINUE
C     ...BY SIMPSONS 3/8 RULE FOR EVEN NUMBERED MESH POINTS
      DO 2  I=4,N,2
      F(I) = F(I-3) + DZ*(E(I-3)+3.0*(E(I-2)+E(I-1))+E(I))*(3.0/8.0)
    2 CONTINUE
C     ...BY DIFFERENCES FOR FIRST INTERVAL
      F2 = DZ*(E(2)+4.0*E(3)+E(4))/3.0
      F(2) = F(4) -F2
C
C
      RETURN
      END
C
C
      SUBROUTINE DATOUT
C
C     ***********************************************************
C     * DATOUT PRINTS RESULTS OF CONSOLIDATION CALCULATIONS AND *
C     * BASE DATA IN TABULAR FORM.                              *
C     ***********************************************************
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12)
C
C     ...PRINT CONDITIONS IN COMPRESSIBLE FOUNDATION
      IF (NBL .EQ. 2) GOTO 4
      IF (NFLAG .EQ. 1) WRITE(IOUT,100)
      IF (NFLAG .EQ. 0) WRITE(IOUT,108)
      IF (NSC .EQ. 3) GOTO 3
      WRITE(IOUT,101)
      WRITE(IOUT,102)
      DO 1  I=1,NDIV1
      J = NDIV1+1-I
      WRITE(IOUT,103) A1(J),XI1(J),Z1(J),E11(J),ER(J),EFIN1(J)
    1 CONTINUE
      IF (NSC .EQ. 2) GOTO 3
```

```
      WRITE(IOUT,104)
      WRITE(IOUT,105)
      DO 2  I=1,NDIV1
      J = NDIV1+1-I
      WRITE(IOUT,103) XI1(J),TOSTR1(J),EFSTR1(J),UW1(J),UO1(J),U1(J)
    2 CONTINUE
    3 WRITE(IOUT,107) TIME,UCON1
      WRITE(IOUT,110) SETT1,SFIN1
      WRITE(IOUT,111) DUDZ11
C
C     ...PRINT CONDITIONS IN DREDGED FILL
    4 IF (NFLAG .EQ.1) WRITE(IOUT,106)
      IF (NFLAG .EQ. 0) WRITE(IOUT,109)
      IF (NSC .EQ. 3) GOTO 7
      WRITE(IOUT,101)
      WRITE(IOUT,102)
      DO 5  I=1,ND
      J = ND+1-I
      WRITE(IOUT,103) A(J),XI(J),Z(J),E1(J),E(J),EFIN(J)
    5 CONTINUE
      IF (NSC .EQ. 2) GOTO 7
      WRITE(IOUT,104)
      WRITE(IOUT,105)
      DO 6  I=1,ND
      J = ND+1-I
      WRITE(IOUT,103) XI(J),TOTSTR(J),EFFSTR(J),UW(J),UO(J),U(J)
    6 CONTINUE
    7 WRITE(IOUT,107) TIME,UCON
      WRITE(IOUT,110) SETT,SFIN
      IF (TIME .LT. TDS) GOTO 8
      WRITE(IOUT,112) SETC
      WRITE(IOUT,113) SETD
    8 WRITE(IOUT,111) DUDZ21
C
C     ...CALCULATE AND WRITE SURFACE ELEVATION
      ELEV = XEL - SETT1 + XI(ND) + HBL
      WRITE(IOUT,114) ELEV
C
C     ...FORMATS
  100 FORMAT(1H1/////14(1H*),34HINITIAL CONDITIONS IN COMPRESSIBLE,
     &          11H FOUNDATION,13(1H*))
  101 FORMAT(//8X,5(1H*),13H COORDINATES ,5(1H*),13X,5(1H*),
     &          13H VOID RATIOS ,5(1H*))
  102 FORMAT(/7X,1HA,10X,2HXI,11X,1HZ,7X,8HEINITIAL,8X,1HE,8X,
     &          6HEFINAL)
  103 FORMAT(2X,5(F10.4,2X),F10.4)
  104 FORMAT(//15X,5(1H*),10H STRESSES ,5(1H*),7X,5(1H*),
     &          16H PORE PRESSURES ,5(1H*))
  105 FORMAT(/6X,2HXI,9X,5HTOTAL,5X,9HEFFECTIVE,5X,5HTOTAL,6X,
     &          6HSTATIC,6X,6HEXCESS)
  106 FORMAT(1H1/////19(1H*),34HINITIAL CONDITIONS IN DREDGED FILL,
     &          19(1H*))
  107 FORMAT(//10X,7HTIME = ,E10.4,5X,26HDEGREE OF CONSOLIDATION = ,
     &          F10.6)
  108 FORMAT(1H1/////14(1H*),34HCURRENT CONDITIONS IN COMPRESSIBLE,
     &          11H FOUNDATION,13(1H*))
  109 FORMAT(1H1/////19(1H*),34HCURRENT CONDITIONS IN DREDGED FILL,
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```
     &        19(1H*))
 110 FORMAT(/10X,13HSETTLEMENT = ,F10.4,5X,19HFINAL SETTLEMENT = ,
     &        F10.4)
 111 FORMAT(/10X,27HBOTTOM BOUNDARY GRADIENT = ,F12.4)
 112 FORMAT(/10X,34HSETTLEMENT DUE TO CONSOLIDATION = ,F10.4)
 113 FORMAT(/10X,32HSETTLEMENT DUE TO DESICCATION = ,F10.4)
 114 FORMAT(/10X,20HSURFACE ELEVATION = ,F10.4)
C
C
      RETURN
      END
      SUBROUTINE  DATAIN
C
C     ***********************************************************
C     * DATAIN READS THE DATA FROM A PREVIOUS PROGRAM RUN FROM *
C     * FILE SO THAT FUTURE CONSOLIDATION CAN BE CALCULATED    *
C     * WITHOUT REDOING ALL PREVIOUS.                          *
C     ***********************************************************
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12)
C
      READ(INS,100) NST,IN,INS,IOUT,IOUTS,LBL,LDF
      READ(INS,100) NST,NBDIV,NBDIV1,NDIV,NDIV1,NBL
      READ(INS,100) NST,ND,NFLAG,NM,NND,NNN,NTIME
      READ(INS,200) NST,DA,DUDZ11,DUDZ21,DZ,DZ1
      READ(INS,200) NST,EOO,ELL,ELL1,GC,GC1
      READ(INS,200) NST,GS,GS1,GSBL,GSDF,GW
      READ(INS,200) NST,HBL,HDF,HDF1,SETT,SETT1
      READ(INS,200) NST,SFIN,SFIN1,TAU,TIME,TPRINT
      READ(INS,200) NST,UCON,UCON1,VRI1
      READ(INS,200) NST,DUO,DUDZ10,EO
      READ(INS,200) NST,ZKO,PKO,XEL
      READ(INS,100) NST,M,MM,MS,NDT,NSC
      READ(INS,200) NST,AEV,CSET,DL,DREFF
      READ(INS,200) NST,DSC,DSET,DTIM,CE,H2
      READ(INS,200) NST,QDF,SAT,SETC,SETD
      READ(INS,200) NST,SL,TDS,TPM,VRINT
      DO 9  I=1,12
      READ(INS,200) NST,EP(I),PEP(I),RF(I)
    9 CONTINUE
C
```

```
      DO 1  I=1,ND
      READ(INS,200) NST,A(I),AF(I),BF(I),E(I),E1(I)
      READ(INS,200) NST,EFIN(I),EFFSTR(I),F(I),FINT(I),TOTSTR(I)
      READ(INS,200) NST,U(I),UO(I),UW(I),XI(I),Z(I)
      READ(INS,200) NST,ET(I)
    1 CONTINUE
      IF (NBL .EQ. 2) GOTO 4
C
      DO 3  I=1,NDIV1
      READ(INS,200) NST,A1(I),AF1(I),BF1(I),ER(I),E11(I)
      READ(INS,200) NST,EFIN1(I),EFSTR1(I),F1(I),FINT1(I),TOSTR1(I)
      READ(INS,200) NST,U1(I),UO1(I),UW1(I),XI1(I),Z1(I)
    3 CONTINUE
C
    4 DO 5  I=1,LDF
      READ(INS,200) NST,ALPHA(I),BETA(I),DSDE(I),ES(I),PK(I)
      READ(INS,200) NST,RK(I),RS(I)
    5 CONTINUE
      IF (NBL .EQ. 2) GOTO 8
C
    6 DO 7  I=1,LBL
      READ(INS,200) NST,ALPHA1(I),BETA1(I),DSDE1(I),ES1(I),PK1(I)
      READ(INS,200) NST,RK1(I),RS1(I)
    7 CONTINUE
C
C     ...RESET TIME CONTROL
    8 NM = NTIME + 1
      NTIME = NTIME + MTIME
      WRITE(IOUT,300) NPROB
C
C     ...FORMATS
  100 FORMAT(I5,7I9)
  200 FORMAT(I5,5E13.6)
  300 FORMAT(/9X,30HCONTINUATION OF PROBLEM NUMBER,I4)
C
      RETURN
      END
C
C
      SUBROUTINE  SAVDAT
C
      **********************************************************
      * SAVDAT SAVES THE DATA FROM A PREVIOUS PROGRAM RUN ON   *
      * FILE SO THAT FUTURE EXTENSIONS TO THE RUN MAY BE MADE  *
      * WITHOUT RECALCULATING PREVIOUS CONSOLIDATION.          *
      **********************************************************
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
```

```
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        UO(PQ2),UO1(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12)
C
      NST = 1
      WRITE(IOUTS,100) NST,IN,INS,IOUT,IOUTS,LBL,LDF
      NST = NST + 1
      WRITE(IOUTS,100) NST,NBDIV,NBDIV1,NDIV,NDIV1,NBL
      NST = NST + 1
      WRITE(IOUTS,100) NST,ND,NFLAG,NM,NND,NNN,NTIME
      NST = NST + 1
      WRITE(IOUTS,200) NST,DA,DUDZ11,DUDZ21,DZ,DZ1
      NST = NST + 1
      WRITE(IOUTS,200) NST,E00,ELL,ELL1,GC,GC1
      NST = NST + 1
      WRITE(IOUTS,200) NST,GS,GS1,GSBL,GSDF,GW
      NST = NST + 1
      WRITE(IOUTS,200) NST,HBL,HDF,HDF1,SETT,SETT1
      NST = NST + 1
      WRITE(IOUTS,200) NST,SFIN,SFIN1,TAU,TIME,TPRINT
      NST = NST + 1
      WRITE(IOUTS,200) NST,UCON,UCON1,VRI1
      NST = NST + 1
      WRITE(IOUTS,200) NST,DUO,DUDZ10,EO
      NST = NST + 1
      WRITE(IOUTS,200) NST,ZKO,PKO,XEL
      NST = NST + 1
      WRITE(IOUTS,100) NST,M,MM,MS,NDT,NSC
      NST = NST + 1
      WRITE(IOUTS,200) NST,AEV,CSET,DL,DREFF
      NST = NST + 1
      WRITE(IOUTS,200) NST,DSC,DSET,DTIM,CE,H2
      NST = NST + 1
      WRITE(IOUTS,200) NST,QDF,SAT,SETC,SETD
      NST = NST + 1
      WRITE(IOUTS,200) NST,SL,TDS,TPM,VRINT
      DO 8  I=1,12
      NST = NST + 1
      WRITE(IOUTS,200) NST,EP(I),PEP(I),RF(I)
    8 CONTINUE
      DO 1  I=1,ND
      NST = NST + 1
      WRITE(IOUTS,200) NST,A(I),AF(I),BF(I),E(I),E1(I)
      NST = NST + 1
      WRITE(IOUTS,200) NST,EFIN(I),EFFSTR(I),F(I),FINT(I),TOTSTR(I)
      NST = NST + 1
      WRITE(IOUTS,200) NST,U(I),UO(I),UW(I),XI(I),Z(I)
      NST = NST + 1
      WRITE(IOUTS,200) NST,ET(I)
    1 CONTINUE
      IF (NBL .EQ. 2) GOTO 4
C
    2 DO 3  I=1,NDIV1
```

```
      NST = NST + 1
      WRITE(IOUTS,200) NST,A1(I),AF1(I),BF1(I),ER(I),E11(I)
      NST = NST + 1
      WRITE(IOUTS,200) NST,EFIN1(I),EFSTR1(I),F1(I),FINT1(I),TOSTR1(I)
      NST = NST + 1
      WRITE(IOUTS,200) NST,U1(I),U01(I),UW1(I),XI1(I),Z1(I)
    3 CONTINUE
C
    4 DO 5  I=1,LDF
      NST = NST + 1
      WRITE(IOUTS,200) NST,ALPHA(I),BETA(I),DSDE(I),ES(I),PK(I)
      NST = NST + 1
      WRITE(IOUTS,200) NST,RK(I),RS(I)
    5 CONTINUE
      IF (NBL .EQ. 2) RETURN
C
    6 DO 7  I=1,LBL
      NST = NST + 1
      WRITE(IOUTS,200) NST,ALPHA1(I),BETA1(I),DSDE1(I),ES1(I),PK1(I)
      NST = NST + 1
      WRITE(IOUTS,200) NST,RK1(I),RS1(I)
    7 CONTINUE
C
C     ...FORMATS
  100 FORMAT(I5,7I9)
  200 FORMAT(I5,5E13.6)
C
      RETURN
      END
C
      SUBROUTINE SETUP2
C
C     ******************************************************
C     * SETUP MAKES INITIAL CALCULATIONS AND MANIPULATIONS *
C     * OF INPUT DATA FOR LATER USE.                       *
C     ******************************************************
C
      PARAMETER PQ1=51, PQ2=501, PQ3=51
      COMMON  DA,DUO,DUDZ10,DUDZ11,DUDZ21,DZ,DZ1,EO,EOO,ELL,ELL1,
     &        GC,GC1,GS,GS1,GSBL,GSDF,GW,HBL,HDF,HDF1,IN,INS,IOUT,
     &        IOUTS,LBL,LDF,MTIME,NBDIV,NBDIV1,NBL,ND,NDIV,NDIV1,
     &        NFLAG,NM,NPROB,NPT,NND,NNN,NTIME,PKO,SETT,SETT1,
     &        SFIN,SFIN1,TAU,TIME,TPRINT,UCON,UCON1,VRI1,ZKO,
     &        A(PQ2),A1(PQ1),AF(PQ2),AF1(PQ1),ALPHA(PQ3),ALPHA1(PQ3),
     &        BETA(PQ3),BETA1(PQ3),BF(PQ2),BF1(PQ1),DSDE(PQ3),DSDE1(PQ3),
     &        E(PQ2),E1(PQ2),E11(PQ1),EFIN(PQ2),EFIN1(PQ1),ER(PQ1),
     &        ES(PQ3),ES1(PQ3),EFFSTR(PQ2),EFSTR1(PQ1),F(PQ2),F1(PQ1),
     &        FINT(PQ2),FINT1(PQ1),PK(PQ3),PK1(PQ3),RK(PQ3),RK1(PQ3),
     &        RS(PQ3),RS1(PQ3),TOTSTR(PQ2),TOSTR1(PQ1),U(PQ2),U1(PQ1),
     &        U0(PQ2),U01(PQ1),UW(PQ2),UW1(PQ1),XI(PQ2),XI1(PQ1),
     &        Z(PQ2),Z1(PQ1),
     &        AEV,CE,CSET,DL,DREFF,DSC,DSET,DTIM,H2,M,MM,MS,NDT,NSC,
     &        QDF,SAT,SETC,SETD,SL,TDS,TPM,VRINT,XEL,
     &        EP(12),ET(PQ2),PEP(12),RF(12)
C
C     ...SET CONSTANTS
      NDIV = NBDIV + 1
```

```
      ND = NDIV
      NDT = ND
      GS = GSDF * GW
      GC = GS - GW
      GS1 = GSBL * GW
      GC1 = GS1 - GW
      NDIV1 = NBDIV1 + 1
      PKO = ZKO / (1.0+EO)
      DUO = DUO / (1.0+EO)
      IF (NBL .EQ. 2) GOTO 10
C
C     ...CALCULATE ELL FOR COMPRESSIBLE FOUNDATION LAYER
      DZZ = 0.0
      NBD = 10 * NBDIV1
      DABL = HBL / FLOAT(NBD)
      EFS = 0.0
      DO 4  I=1,NBD
      DO 1  N=2,LBL
      S1 = EFS - RS1(N)
      IF (S1 .LE. 0.0) GOTO 2
    1 CONTINUE
      V = ES1(LBL) ; GOTO 3
    2 NN = N-1
      V = ES1(N) + (S1*(ES1(NN)-ES1(N))/(RS1(NN)-RS1(N)))
    3 TDZ = DABL / (1.0+V)
      EFS = EFS + GC1*TDZ
      DZZ = DZZ + TDZ
    4 CONTINUE
      ELL1 = DZZ
      DZ1 = ELL1 / FLOAT(NBDIV1)
C
C     ...CALCULATE INITIAL COORDINATES AND VOID RATIOS
C     ...FOR COMPRESSIBLE FOUNDATION LAYER
      Z1(1)=0.0 ; A1(1)=0.0 ; XI1(1)=0.0
      EFS = GC1 * ELL1
      DO 8  I=1,NDIV1
      DO 5  N=2,LBL
      S1 = EFS - RS1(N)
      IF (S1 .LE. 0.0) GOTO 6
    5 CONTINUE
      E11(I) = ES1(LBL) ; GOTO 7
    6 NN = N-1
      E11(I) = ES1(N) + (S1*(ES1(NN)-ES1(N))/(RS1(NN)-RS1(N)))
    7 F1(I) = E11(I)
      ER(I) = E11(I)
      EFS = EFS - GC1*DZ1
    8 CONTINUE
      CALL INTGRL(ER,DZ1,NDIV1,FINT1)
      DO 9  I=2,NDIV1
      Z1(I) = Z1(I-1) + DZ1
      A1(I) = Z1(I) + FINT1(I)
      XI1(I) = A1(I)
    9 CONTINUE
C
C     ...CALCULATE ELL FOR FIRST DREDGED FILL LAYER
   10 ELL = HDF / (1.0+E00)
      VRINT = ELL * E00
```

```
C
C     ...CALCULATE INITIAL COORDINATES AND SET VOID RATIOS
      DZ = ELL / FLOAT(NBDIV)
      Z(1)=0.0 ; A(1)=0.0 ; XI(1)=0.0
      E1(1)=E00 ; F(1)=E00 ; E(1)=E00 ; ET(1)=E00
      DA = HDF / FLOAT(NBDIV)
      DO 11  I=2,NDIV
      II = I-1
      Z(I) = Z(II) + DZ
      A(I) = A(II) + DA
      XI(I) = A(I)
      E1(I) = E00
      F(I) = E00
      E(I) = E00
      ET(I) = E00
   11 CONTINUE
C
C     ...CALCULATE FINAL VOID RATIOS FOR DREDGED FILL
      DO 14  I=1,NBDIV
      S1 = GC*(ELL-Z(I))
      IF (S1 .LT. 0.0) S1 = 0.0
      DO 12  N=2,LDF
      S2 = S1 - RS(N)
      IF (S2 .LE. 0.0) GOTO 13
   12 CONTINUE
      EFIN(I) = ES(LDF) ; GOTO 14
   13 NN = N-1
      EFIN(I) = ES(N) + (S2*(ES(NN)-ES(N))/(RS(NN)-RS(N)))
   14 CONTINUE
      EFIN(NDIV) = E00
C
C     ...CALCULATE MAXIMUM SECOND STAGE DRYING DEPTH
      DO 30  N=2,LDF
      C1 = DL - ES(N)
      IF (C1 .GE. 0.0) GOTO 31
   30 CONTINUE
      EFSDL = RS(LDF) ; GOTO 32
   31 NN = N-1
      EFSDL = RS(N) + (C1*(RS(N)-RS(NN))/(ES(N)-ES(NN)))
   32 DZ2 = EFSDL / (GS+(GW*DL*SAT))
      H2MX = DZ2 * (1.0+DL)
      IF (H2 .GT. H2MX) H2 = H2MX
C
C
C     ...CALCULATE FINAL VOID RATIOS FOR FOUNDATION
      IF (NBL .EQ. 2) GOTO 20
      C1 = ELL1*GC1 ; C2 = ELL*GC
      S1 = C1 + C2
      DO 18  I=1,NDIV1
      S2 = S1 - Z1(I)*GC1
      DO 16  N=2,LBL
      S3 = S2 - RS1(N)
      IF (S3 .LE. 0.0) GOTO 17
   16 CONTINUE
      EFIN1(I) = ES1(LBL) ; GOTO 18
   17 NN = N-1
      EFIN1(I) = ES1(N) + (S3*(ES1(NN)-ES1(N))/(RS1(NN)-RS1(N)))
```

```
   18 CONTINUE
C
C     ...CALCULATE INITIAL STRESSES AND PORE PRESSURES
C     .....FOR FOUNDATION LAYER
      WL1 = XI1(NDIV1) + XI(NDIV)
      DO 19  I=1,NDIV1
      UO1(I) = GW * (WL1-XI1(I))
      U1(I) = C2
      UW1(I) = UO1(I) + U1(I)
      EFSTR1(I) = C1 - GC1*Z1(I)
      TOSTR1(I) = EFSTR1(I) + UW1(I)
   19 CONTINUE
C     .....ULTIMATE SETTLEMENT FOR COMPRESSIBLE FOUNDATION
      VRI1 = FINT1(NDIV1)
      CALL INTGRL(EFIN1,DZ1,NDIV1,FINT1)
      SFIN1 = VRI1 - FINT1(NDIV1)
C
C     .....FOR DREDGED FILL LAYER
   20 DO 21  I=1,NDIV
      UO(I) = GW * (XI(NDIV)-XI(I))
      U(I) = GC * (ELL-Z(I))
      UW(I) = UO(I) + U(I)
      EFFSTR(I) = 0.0
      TOTSTR(I) = UW(I)
   21 CONTINUE
C     .....ULTIMATE SETTLEMENT FOR DREDGED FILL
      CALL INTGRL(EFIN,DZ,NDIV,FINT)
      SFIN = EOO*ELL - FINT(NDIV)
C
C     ...CALCULATE FUNCTIONS FOR DREDGED FILL
C     .....PERMEABILITY FUNCTION
      DO 22  I=1,LDF
      PK(I) = RK(I) / (1.0+ES(I))
   22 CONTINUE
C     .....SLOPE OF PERMEABILITY FUNCTION -- BETA
C     .....AND SLOPE OF EFF STRESS-VOID RATIO CURVE -- DSDE
      CD = ES(2) - ES(1)
      BETA(1) = (PK(2)-PK(1)) / CD
      DSDE(1) = (RS(2)-RS(1)) / CD
      L = LDF - 1
      DO 23  I=2,L
      II=I-1 $ IJ=I+1
      CD = ES(IJ) - ES(II)
      BETA(I) = (PK(IJ)-PK(II)) / CD
      DSDE(I) = (RS(IJ)-RS(II)) / CD
   23 CONTINUE
      CD = ES(LDF) - ES(L)
      BETA(LDF) = (PK(LDF)-PK(L)) / CD
      DSDE(LDF) = (RS(LDF)-RS(L)) / CD
C     .....PERMEABILITY FUNCTION TIMES DSDE -- ALPHA
      DO 24  I=1,LDF
      ALPHA(I) = PK(I) * DSDE(I)
   24 CONTINUE
      IF (NBL .EQ. 2) GOTO 29
C
C     ...CALCULATE FUNCTIONS FOR COMPRESSIBLE FOUNDATION
C     .....PERMEABILITY FUNCTION
```

```
      DO 26  I=1,LBL
      PK1(I) = RK1(I) / (1.0+ES1(I))
   26 CONTINUE
C     .....SLOPE OF PERMEABILITY FUNCTION -- BETA1
C     .....AND SLOPE OF EFF STRESS-VOID RATIO CURVE -- DSDE1
      CD = ES1(2) - ES1(1)
      BETA1(1) = (PK1(2)-PK1(1)) / CD
      DSDE1(1) = (RS1(2)-RS1(1)) / CD
      L = LBL - 1
      DO 27  I=2,L
      II=I-1 ; IJ=I+1
      CD = ES1(IJ) - ES1(II)
      BETA1(I) = (PK1(IJ)-PK1(II)) / CD
      DSDE1(I) = (RS1(IJ)-RS1(II)) / CD
   27 CONTINUE
      CD = ES1(LBL) - ES1(L)
      BETA1(LBL) = (PK1(LBL)-PK1(L)) / CD
      DSDE1(LBL) = (RS1(LBL)-RS1(L)) / CD
C     .....PERMEABILITY FUNCTION TIMES DSDE -- ALPHA1
      DO 28  I=1,LBL
      ALPHA1(I) = PK1(I) * DSDE1(I)
   28 CONTINUE
C
C     ...CALCULATE BOTTOM BOUNDARY DUDZ
      DUDZ10 = U1(1) / DUO
   29 IF (NBL .EQ. 2) DUDZ10 = U(1) / DUO
C
C     ...COMPUTE VOID RATIO FUNCTION FOR INITIAL VALUES
      CALL VRFUNC
C
C
      RETURN
      END
```

*

LIST GTEST.3

APPENDIX C: SAMPLE PROBLEM LISTINGS

The following pages contain sample data input and calculation results from the Drum Island site previously discussed.

```
100    1    1    1
101    1    2
110    0.    0.    0
111    0.    0.    0.
200    2.6    4.8    36    12.15    62.4
201    12.15   0.00E-00    1.56E-01
202    12.0    5.80E-02    1.44E-01
203    11.5    1.68E-01    1.12E-01
204    11.0    3.56E-01    8.71E-02
205    10.5    6.60E-01    6.77E-02
206    10.0    1.12E+00    5.27E-02
207     9.7    1.50E+00    4.58E-02
208     9.3    2.20E+00    3.74E-02
209     9.0    2.86E+00    3.23E-02
210     8.7    3.68E+00    2.76E-02
211     8.3    4.90E+00    2.29E-02
212     8.0    6.04E+00    1.94E-02
213     7.75   7.16E+00    1.71E-02
214     7.5    8.36E+00    1.47E-02
215     7.25   9.80E+00    1.27E-02
216     7.0    1.14E+01    1.10E-02
217     6.75   1.33E+01    9.36E-03
218     6.5    1.54E+01    7.92E-03
219     6.25   1.79E+01    6.62E-03
220     6.0    2.18E+01    5.57E-03
221     5.75   2.86E+01    4.54E-03
222     5.5    4.02E+01    3.64E-03
223     5.25   5.70E+01    2.87E-03
224     5.0    7.86E+01    2.22E-03
225     4.75   1.11E+02    1.66E-03
226     4.5    1.53E+02    1.25E-03
227     4.25   2.16E+02    9.00E-04
228     4.0    3.00E+02    6.48E-04
229     3.75   4.20E+02    4.57E-04
230     3.5    5.90E+02    3.20E-04
231     3.25   8.20E+02    2.17E-04
232     3.0    1.14E+03    1.48E-04
233     2.75   1.58E+03    9.79E-05
234     2.5    2.20E+03    6.62E-05
235     2.25   3.10E+03    4.39E-05
236     2.0    4.24E+03    2.97E-05
300    1.    1.0E-06    10.    100.
350    1
400    6
403     90.    0.     90.     4    1
404    120.    0.    120.     5    1
405    180.    0.    180.     7    1
406    300.    0.    300.    11    1
407    420.    3.6   510.     6    1
408    450.    0.    510.     6    1
500    3.1    6.7    30.    1.    90.    4    1
601    0.18    0.24
602    0.23    0.27
603    0.36    0.40
604    0.36    0.25
```

605	0.57	0.32	
606	0.49	0.53	
607	0.67	0.68	
608	0.57	0.54	
609	0.41	0.43	
610	0.33	0.25	
611	0.21	0.18	
612	0.16	0.26	
700	.5	.75	.83

*

****

CONSOLIDATION AND DESICCATION OF SOFT LAYERS---DREDGED FILL

****

PROBLEM NUMBER 1

************************SOIL DATA FOR DREDGED FILL***********************

LAYER THICKNESS	SPECIFIC GRAVITY OF SOLIDS	INITIAL VOID RATIO	SATURATION LIMIT	DESICCATION LIMIT
4.800	2.600	12.150	6.700	3.100

I	VOID RATIO	EFFECTIVE STRESS	PERM-EABILITY	K/1+E PK	BETA	DSDE	ALPHA
1	12.150	0.	0.156E 00	0.119E-01	0.524E-02	-0.387E 00	-0.459E-02
2	12.000	0.580E-01	0.144E 00	0.111E-01	0.447E-02	-0.258E 00	-0.286E-02
3	11.500	0.168E 00	0.112E 00	0.896E-02	0.382E-02	-0.298E 00	-0.267E-02
4	11.000	0.356E 00	0.871E-01	0.726E-02	0.307E-02	-0.492E 00	-0.357E-02
5	10.500	0.660E 00	0.677E-01	0.589E-02	0.247E-02	-0.764E 00	-0.450E-02
6	10.000	0.112E 01	0.527E-01	0.479E-02	0.201E-02	-0.105E 01	-0.503E-02
7	9.700	0.150E 01	0.458E-01	0.428E-02	0.166E-02	-0.154E 01	-0.660E-02
8	9.300	0.220E 01	0.374E-01	0.363E-02	0.150E-02	-0.194E 01	-0.705E-02
9	9.000	0.286E 01	0.323E-01	0.323E-02	0.131E-02	-0.247E 01	-0.797E-02
10	8.700	0.368E 01	0.276E-01	0.285E-02	0.110E-02	-0.291E 01	-0.829E-02
11	8.300	0.490E 01	0.229E-01	0.246E-02	0.985E-03	-0.337E 01	-0.830E-02
12	8.000	0.604E 01	0.194E-01	0.216E-02	0.924E-03	-0.411E 01	-0.886E-02
13	7.750	0.716E 01	0.171E-01	0.195E-02	0.852E-03	-0.464E 01	-0.907E-02
14	7.500	0.836E 01	0.147E-01	0.173E-02	0.830E-03	-0.528E 01	-0.913E-02
15	7.250	0.980E 01	0.127E-01	0.154E-02	0.709E-03	-0.608E 01	-0.936E-02
16	7.000	0.114E 02	0.110E-01	0.138E-02	0.663E-03	-0.700E 01	-0.963E-02
17	6.750	0.133E 02	0.936E-02	0.121E-02	0.638E-03	-0.800E 01	-0.966E-02
18	6.500	0.154E 02	0.792E-02	0.106E-02	0.589E-03	-0.920E 01	-0.972E-02
19	6.250	0.179E 02	0.662E-02	0.913E-03	0.521E-03	-0.128E 02	-0.117E-01
20	6.000	0.218E 02	0.557E-02	0.796E-03	0.481E-03	-0.214E 02	-0.170E-01
21	5.750	0.286E 02	0.454E-02	0.673E-03	0.471E-03	-0.368E 02	-0.248E-01
22	5.500	0.402E 02	0.364E-02	0.560E-03	0.427E-03	-0.568E 02	-0.318E-01
23	5.250	0.570E 02	0.287E-02	0.459E-03	0.380E-03	-0.768E 02	-0.353E-01
24	5.000	0.786E 02	0.222E-02	0.370E-03	0.341E-03	-0.108E 03	-0.400E-01
25	4.750	0.111E 03	0.166E-02	0.289E-03	0.285E-03	-0.149E 03	-0.430E-01
26	4.500	0.153E 03	0.125E-02	0.227E-03	0.235E-03	-0.210E 03	-0.477E-01
27	4.250	0.216E 03	0.900E-03	0.171E-03	0.195E-03	-0.294E 03	-0.504E-01
28	4.000	0.300E 03	0.648E-03	0.130E-03	0.150E-03	-0.408E 03	-0.529E-01
29	3.750	0.420E 03	0.457E-03	0.962E-04	0.117E-03	-0.580E 03	-0.558E-01
30	3.500	0.590E 03	0.320E-03	0.711E-04	0.903E-04	-0.800E 03	-0.569E-01
31	3.250	0.820E 03	0.217E-03	0.511E-04	0.682E-04	-0.110E 04	-0.562E-01
32	3.000	0.114E 04	0.148E-03	0.370E-04	0.499E-04	-0.152E 04	-0.562E-01
33	2.750	0.158E 04	0.979E-04	0.261E-04	0.362E-04	-0.212E 04	-0.553E-01
34	2.500	0.220E 04	0.662E-04	0.189E-04	0.252E-04	-0.304E 04	-0.575E-01
35	2.250	0.310E 04	0.439E-04	0.135E-04	0.180E-04	-0.408E 04	-0.551E-01
36	2.000	0.424E 04	0.297E-04	0.990E-05	0.144E-04	-0.456E 04	-0.451E-01

SUMMARY OF MONTHLY RAINFALL AND EVAPORATION POTENTIAL

MONTH	RAINFALL	EVAPORATION
1	0.240	0.180
2	0.270	0.230
3	0.400	0.360
4	0.250	0.360
5	0.320	0.570
6	0.530	0.490
7	0.680	0.670
8	0.540	0.570
9	0.430	0.410
10	0.250	0.330
11	0.180	0.210
12	0.260	0.160

*****************************CALCULATION DATA******************************

TAU	LOWER LAYER VOID RATIO	LOWER LAYER PERMEABILITY	DRAINAGE PATH LENGTH
0.25739E 00	1.000	0.10000E-05	Z = 5.000

**********************INITIAL CONDITIONS IN DREDGED FILL**********************

***** COORDINATES *****			***** VOID RATIOS *****		
A	XI	Z	EINITIAL	E	EFINAL
4.8000	4.8000	0.3650	12.1500	12.1500	12.1500
4.2667	4.2667	0.3245	12.1500	12.1500	8.5789
3.7333	3.7333	0.2839	12.1500	12.1500	7.5545
3.2000	3.2000	0.2433	12.1500	12.1500	6.9016
2.6667	2.6667	0.2028	12.1500	12.1500	6.4203
2.1333	2.1333	0.1622	12.1500	12.1500	6.0996
1.6000	1.6000	0.1217	12.1500	12.1500	5.9082
1.0667	1.0667	0.0811	12.1500	12.1500	5.7594
0.5333	0.5333	0.0406	12.1500	12.1500	5.6682
0.	0.	0.	12.1500	12.1500	5.5810

	***** STRESSES *****		***** PORE PRESSURES *****		
XI	TOTAL	EFFECTIVE	TOTAL	STATIC	EXCESS
4.8000	0.	0.	0.	0.	0.
4.2667	37.3293	0.	37.3293	33.2800	4.0493
3.7333	74.6586	0.	74.6586	66.5600	8.0986
3.2000	111.9878	0.	111.9878	99.8400	12.1478
2.6667	149.3171	0.	149.3171	133.1200	16.1971
2.1333	186.6464	0.	186.6464	166.4000	20.2464
1.6000	223.9757	0.	223.9757	199.6800	24.2957
1.0667	261.3049	0.	261.3049	232.9600	28.3449
0.5333	298.6342	0.	298.6342	266.2400	32.3942
0.	335.9635	0.	335.9635	299.5200	36.4435

TIME = 0. DEGREE OF CONSOLIDATION = 0.

SETTLEMENT = 0. FINAL SETTLEMENT = 1.9465

BOTTOM BOUNDARY GRADIENT 0.

SURFACE ELEVATION = 104.8000

******************CURRENT CONDITIONS IN DREDGED FILL******************

***** COORDINATES *****			***** VOID RATIOS *****		
A	XI	Z	EINITIAL	E	EFINAL
4.8000	3.5013	0.3650	12.1500	12.1500	12.1500
4.2667	3.0230	0.3245	12.1500	9.8932	8.5789
3.7333	2.5897	0.2839	12.1500	9.4944	7.5545
3.2000	2.1711	0.2433	12.1500	9.1463	6.9016
2.6667	1.7669	0.2028	12.1500	8.7835	6.4203
2.1333	1.3780	0.1622	12.1500	8.3869	6.0996
1.6000	1.0060	0.1217	12.1500	7.9517	5.9082
1.0667	0.6521	0.0811	12.1500	7.4979	5.7594
0.5333	0.3167	0.0406	12.1500	7.0399	5.6682
0.	0.	0.	12.1500	6.5776	5.5810

	***** STRESSES *****		***** PORE PRESSURES *****		
XI	TOTAL	EFFECTIVE	TOTAL	STATIC	EXCESS
3.5013	0.	0.	0.	0.	0.
3.0230	33.8911	1.2552	32.6359	29.8419	2.7940
2.5897	64.9820	1.8597	63.1223	56.8834	6.2388
2.1711	95.1511	2.5382	92.6129	83.0032	9.6097
1.7669	124.4235	3.4517	120.9718	108.2264	12.7454
1.3780	152.7414	4.6349	148.1065	132.4950	15.6115
1.0060	180.0032	6.2566	173.7466	155.7075	18.0391
0.6521	206.1340	8.3720	197.7620	177.7891	19.9729
0.3167	231.1111	11.1449	219.9661	198.7169	21.2493
0.	254.9235	14.7484	240.1751	218.4800	21.6951

TIME = 0.9008E 02   DEGREE OF CONSOLIDATION = 0.667211

SETTLEMENT = 1.2987   FINAL SETTLEMENT = 1.9465

SETTLEMENT DUE TO CONSOLIDATION = 1.2987

SETTLEMENT DUE TO DESICCATION = 0.

BOTTOM BOUNDARY GRADIENT = 0.0020

SURFACE ELEVATION = 103.5013

*******************CURRENT CONDITIONS IN DREDGED FILL******************

***** COORDINATES *****			***** VOID RATIOS *****		
A	XI	Z	EINITIAL	E	EFINAL
4.8000	3.3275	0.3650	12.1500	10.9287	12.1500
4.2667	2.8724	0.3245	12.1500	9.6495	8.5789
3.7333	2.4553	0.2839	12.1500	8.9952	7.5545
3.2000	2.0582	0.2433	12.1500	8.5936	6.9016
2.6667	1.6766	0.2028	12.1500	8.2214	6.4203
2.1333	1.3102	0.1622	12.1500	7.8456	6.0996
1.6000	0.9593	0.1217	12.1500	7.4634	5.9082
1.0667	0.6238	0.0811	12.1500	7.0775	5.7594
0.5333	0.3041	0.0406	12.1500	6.6856	5.6682
0.	0.	0.	12.1500	6.3193	5.5810

	***** STRESSES *****		***** PORE PRESSURES *****		
XI	TOTAL	EFFECTIVE	TOTAL	STATIC	EXCESS
3.3275	0.	0.	0.	0.	0.
2.8724	32.4487	1.5884	30.8603	28.3994	2.4609
2.4553	62.5249	2.8730	59.6518	54.4263	5.2255
2.0582	91.3522	4.0045	87.3477	79.2043	8.1434
1.6766	119.2098	5.1988	114.0110	103.0127	10.9983
1.3102	146.1226	6.7317	139.3909	125.8762	13.5147
0.9593	172.0717	8.5707	163.5011	147.7761	15.7250
0.6238	197.0565	10.9041	186.1523	168.7115	17.4408
0.3041	221.0502	13.8413	207.2090	188.6560	18.5530
0.	244.0779	17.2072	226.8706	207.6344	19.2363

TIME = 0.1202E 03   DEGREE OF CONSOLIDATION =   0.756505

SETTLEMENT =   1.4725   FINAL SETTLEMENT =   1.9465

SETTLEMENT DUE TO CONSOLIDATION =   1.4478

SETTLEMENT DUE TO DESICCATION =   0.0248

BOTTOM BOUNDARY GRADIENT =   0.0020

SURFACE ELEVATION =   103.3275

********************CURRENT CONDITIONS IN DREDGED FILL********************

***** COORDINATES *****			***** VOID RATIOS *****		
A	XI	Z	EINITIAL	E	EFINAL
4.8000	2.8161	0.3650	12.1500	5.6754	12.1500
4.2667	2.5193	0.3245	12.1500	6.7000	8.5789
3.7333	2.2014	0.2839	12.1500	6.7000	7.5545
3.2000	1.8948	0.2433	12.1500	6.7000	6.9016
2.6667	1.5597	0.2028	12.1500	7.4644	6.4203
2.1333	1.2227	0.1622	12.1500	7.1500	6.0996
1.6000	0.8986	0.1217	12.1500	6.8334	5.9082
1.0667	0.5874	0.0811	12.1500	6.5160	5.7594
0.5333	0.2885	0.0406	12.1500	6.2296	5.6682
0.	0.	0.	12.1500	6.0113	5.5810

	***** STRESSES *****		***** PORE PRESSURES *****		
XI	TOTAL	EFFECTIVE	TOTAL	STATIC	EXCESS
2.8161	0.	0.	0.	0.	0.
2.5193	22.5640	4.0493	18.5148	18.5148	-0.0000
2.2014	46.4560	8.0986	38.3575	38.3575	-0.0000
1.8948	69.6369	12.1478	57.4891	57.4891	-0.0000
1.5597	94.5950	8.5652	86.0299	78.3979	7.6319
1.2227	119.6686	10.4403	109.2284	99.4223	9.8061
0.8986	143.9463	12.6660	131.2803	119.6506	11.6296
0.5874	167.4160	15.2659	152.1501	139.0711	13.0790
0.2885	190.1138	18.2185	171.8954	157.7196	14.1757
0.	212.1653	21.6235	190.5417	175.7218	14.8200

TIME = 0.1802E 03   DEGREE OF CONSOLIDATION =   1.019244

SETTLEMENT =   1.9839   FINAL SETTLEMENT =   1.9465

SETTLEMENT DUE TO CONSOLIDATION =   1.6416

SETTLEMENT DUE TO DESICCATION =   0.3424

BOTTOM BOUNDARY GRADIENT =   0.0019

SURFACE ELEVATION =   102.8161

********************CURRENT CONDITIONS IN DREDGED FILL********************

***** COORDINATES *****			***** VOID RATIOS *****		
A	XI	Z	EINITIAL	E	EFINAL
4.8000	2.2006	0.3650	12.1500	3.1000	3.1000
4.2667	2.0346	0.3245	12.1500	3.1000	3.1000
3.7333	1.8782	0.2839	12.1500	3.6673	5.8569
3.2000	1.6348	0.2433	12.1500	5.8024	5.7254
2.6667	1.3589	0.2028	12.1500	5.7978	5.6381
2.1333	1.0836	0.1622	12.1500	5.7780	5.5509
1.6000	0.8094	0.1217	12.1500	5.7406	5.4749
1.0667	0.5370	0.0811	12.1500	5.6875	5.4146
0.5333	0.2671	0.0406	12.1500	5.6220	5.3544
0.	0.	0.	12.1500	5.5481	5.2941

	***** STRESSES *****		***** PORE PRESSURES *****		
XI	TOTAL	EFFECTIVE	TOTAL	STATIC	EXCESS
2.2006	0.	0.	0.	0.	0.
2.0346	12.4642	12.4642	0.	0.	0.
1.8782	25.6918	25.6918	0.	0.	0.
1.6348	44.9302	27.1737	17.7565	15.1891	2.5674
1.3589	66.1918	27.2991	38.8927	32.4014	6.4913
1.0836	87.4237	27.8397	59.5840	49.5841	9.9999
0.8094	108.5831	29.0342	79.5489	66.6941	12.8547
0.5370	129.6273	31.5012	98.1261	83.6891	14.4370
0.2671	150.5205	34.5409	115.9796	100.5330	15.4466
0.	171.2365	37.9693	133.2672	117.1997	16.0674

TIME = 0.3001E 03   DEGREE OF CONSOLIDATION =   1.335416

SETTLEMENT =   2.5994   FINAL SETTLEMENT =   1.9465

SETTLEMENT DUE TO CONSOLIDATION =   1.9364

SETTLEMENT DUE TO DESICCATION =   0.6630

BOTTOM BOUNDARY GRADIENT =   -0.0003

SURFACE ELEVATION =   102.2006

*******************CURRENT CONDITIONS IN DREDGED FILL*******************

***** COORDINATES *****			***** VOID RATIOS *****		
A	XI	Z	EINITIAL	E	EFINAL
4.8000	2.0416	0.3650	12.1500	3.1000	3.1000
4.2667	1.8733	0.3245	12.1500	3.1000	3.1000
3.7333	1.7125	0.2839	12.1500	3.1000	3.1000
3.2000	1.5252	0.2433	12.1500	4.2488	5.5250
2.6667	1.2798	0.2028	12.1500	5.4403	5.4570
2.1333	1.0197	0.1622	12.1500	5.3864	5.3968
1.6000	0.7617	0.1217	12.1500	5.3348	5.3365
1.0667	0.5058	0.0811	12.1500	5.2847	5.2762
0.5333	0.2519	0.0406	12.1500	5.2355	5.2235
0.	0.	0.	12.1500	5.1872	5.1767

	***** STRESSES *****		***** PORE PRESSURES *****		
XI	TOTAL	EFFECTIVE	TOTAL	STATIC	EXCESS
2.0416	0.	0.	0.	0.	0.
1.8733	12.4642	12.4642	0.	0.	0.
1.7125	24.9284	24.9284	0.	0.	0.
1.5252	39.0398	39.0398	0.	0.	0.
1.2798	58.4063	43.0891	15.3171	15.3171	0.0000
1.0197	78.6859	47.1384	31.5475	31.5475	0.0000
0.7617	98.8323	51.1877	47.6446	47.6446	-0.0000
0.5058	118.8501	54.6704	64.1797	63.6131	0.5666
0.2519	138.7421	58.2555	80.4866	79.4559	1.0307
0.	158.5108	62.4296	96.0812	95.1753	0.9059

TIME = 0.4201E 03   DEGREE OF CONSOLIDATION =   1.417129

SETTLEMENT =   2.7584   FINAL SETTLEMENT =   1.9465

SETTLEMENT DUE TO CONSOLIDATION =   2.0131

SETTLEMENT DUE TO DESICCATION =   0.7453

BOTTOM BOUNDARY GRADIENT =   -0.0019

SURFACE ELEVATION =   102.0416

********************CURRENT CONDITIONS IN DREDGED FILL********************

***** COORDINATES *****			***** VOID RATIOS *****		
A	XI	Z	EINITIAL	E	EFINAL
8.5333	5.6173	0.6489	12.1500	12.1500	12.1500
8.0000	5.0851	0.6084	12.1500	12.0993	8.5789
7.4667	4.5550	0.5678	12.1500	12.0293	7.5545
6.9333	4.0295	0.5272	12.1500	11.8680	6.9016
6.4000	3.5136	0.4867	12.1500	11.5330	6.4203
5.8667	3.0208	0.4461	12.1500	10.9705	6.0996
5.3333	2.5457	0.4056	12.1500	10.1813	5.9082
4.8000	2.1097	0.3650	12.1500	7.6250	5.7594
4.2667	1.8727	0.3245	12.1500	3.1000	5.6682
3.7333	1.7118	0.2839	12.1500	3.1000	5.5810
3.2000	1.5246	0.2433	12.1500	4.2488	5.4956
2.6667	1.2791	0.2028	12.1500	5.4403	5.4354
2.1333	1.0190	0.1622	12.1500	5.3864	5.3751
1.6000	0.7610	0.1217	12.1500	5.3347	5.3149
1.0667	0.5052	0.0811	12.1500	5.2795	5.2546
0.5333	0.2516	0.0406	12.1500	5.2277	5.2067
0.	0.	0.	12.1500	5.1790	5.1599

	***** STRESSES *****		***** PORE PRESSURES *****		
XI	TOTAL	EFFECTIVE	TOTAL	STATIC	EXCESS
5.6173	0.	0.	0.	0.	0.
5.0851	37.2627	0.0196	37.2430	33.2134	4.0297
4.5550	74.3856	0.0467	74.3390	66.2871	8.0519
4.0295	111.2306	0.0870	111.1435	99.0827	12.0608
3.5136	147.4703	0.1607	147.3096	131.2732	16.0364
3.0208	182.2706	0.3739	181.8967	162.0242	19.8725
2.5457	215.9676	0.9532	215.0144	191.6720	23.3425
2.1097	247.2205	7.7600	239.4605	218.8756	20.5849
1.8727	266.0617	32.3942	233.6675	233.6675	0.
1.7118	280.1475	36.4435	243.7040	243.7040	-0.0000
1.5246	295.8819	40.4928	255.3891	255.3891	0.
1.2791	315.2488	44.2144	271.0344	270.7067	0.3277
1.0190	335.5280	47.8307	287.6972	286.9366	0.7606
0.7610	355.6767	51.3108	304.3658	303.0361	1.3298
0.5052	375.6872	55.0164	320.6708	318.9973	1.6735
0.2516	395.5625	58.9242	336.6383	334.8233	1.8150
0.	415.3106	63.1316	352.1790	350.5222	1.6568

TIME = 0.4502E 03 DEGREE OF CONSOLIDATION = 0.751470

SETTLEMENT = 2.9160 FINAL SETTLEMENT = 3.8804

BOTTOM BOUNDARY GRADIENT = 0.0063

SURFACE ELEVATION = 105.6173

*

APPENDIX D: CONSOLIDATION PROPERTIES

1. Figures D1-D6 show the relationships between void ratio and effective stress and void ratio and permeability used in the settlement calculations discussed in the main text. Cargill (1983a)* provides a complete description of the different tests performed.

2. The g function referenced in Figure D2 is the finite strain coefficient of consolidation

$$g(e) = \frac{K(e)}{\gamma_w(1 + e)} \frac{d\sigma'}{de}$$

which is considered to be a constant over the range of void ratios expected in the containment area (Cargill 1983a).

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* See References at the end of the main text.

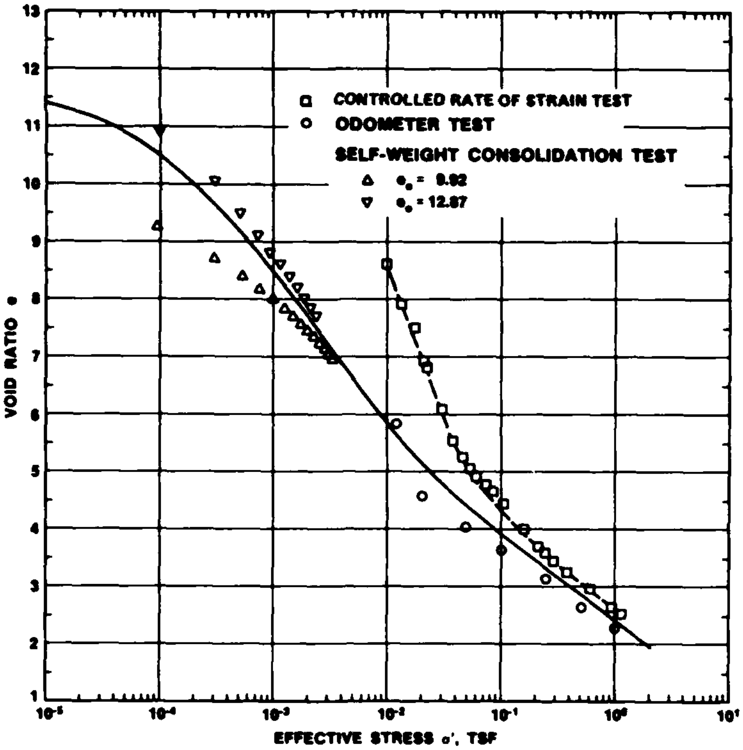

Figure D1. Void ratio-effective stress relationship for Canaveral Harbor material (e_o is the initial void ratio)

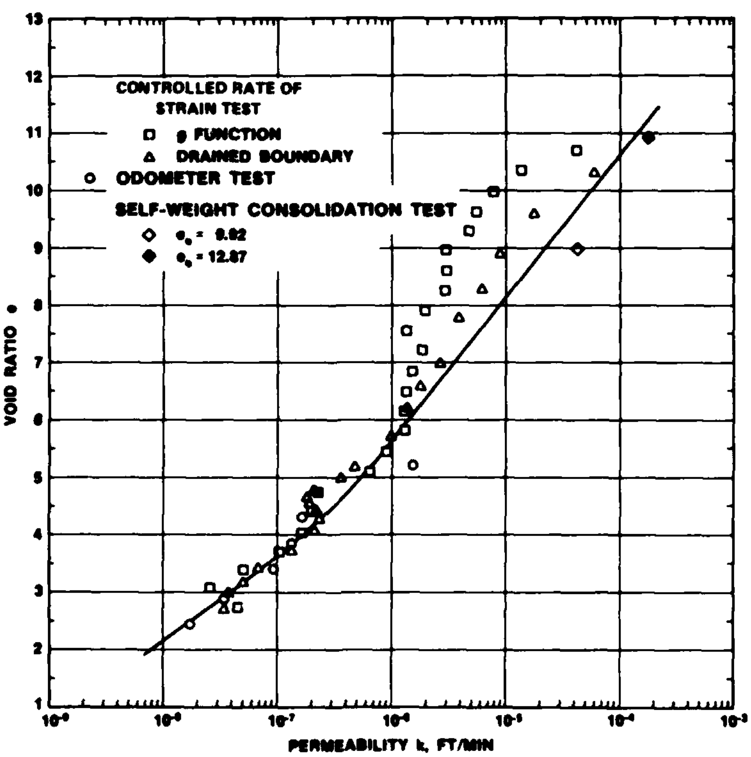

Figure D2. Void ratio-permeability relationship for Canaveral Harbor material

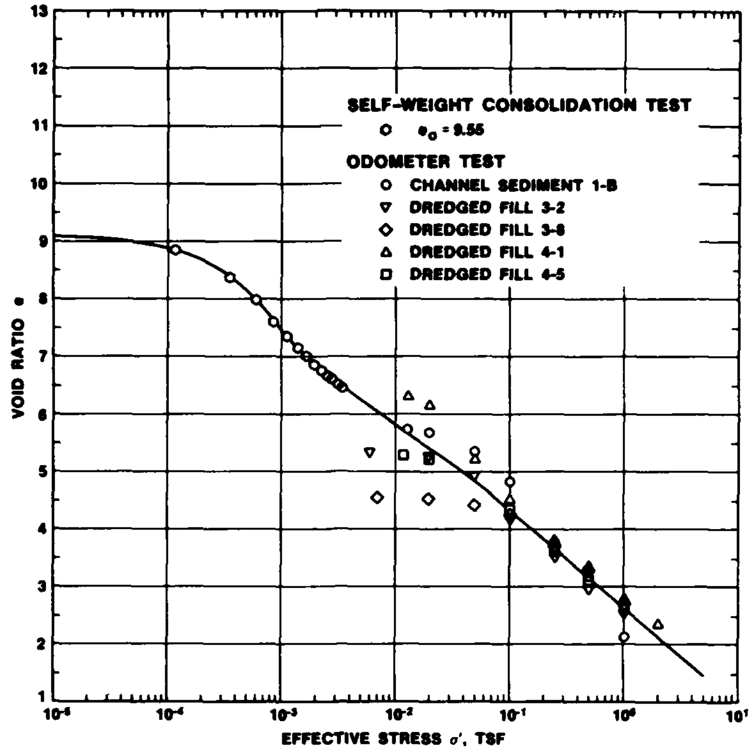

Figure D3. Void ratio-effective stress relationship for Craney Island material

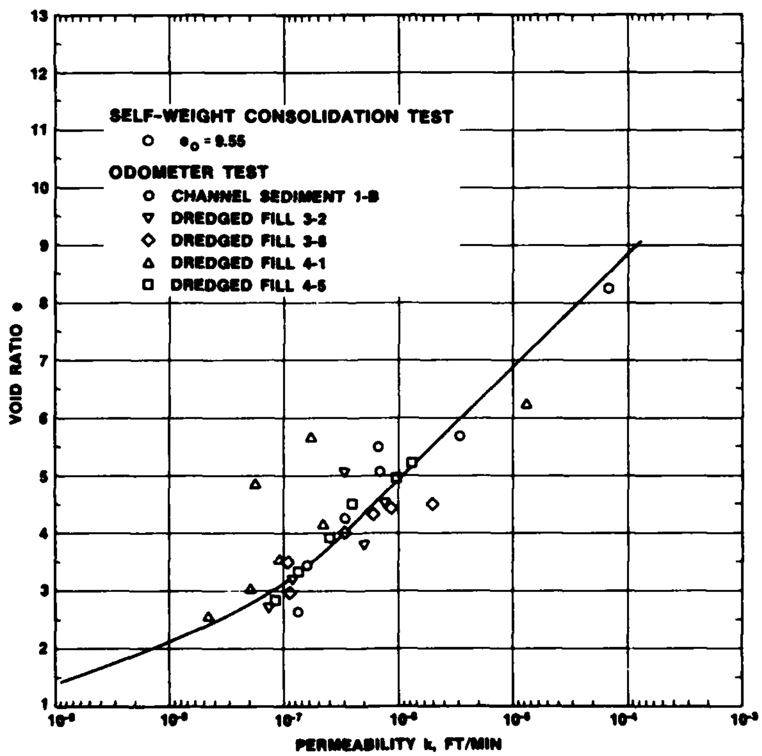

Figure D4. Void ratio-permeability relationship for Craney Island material

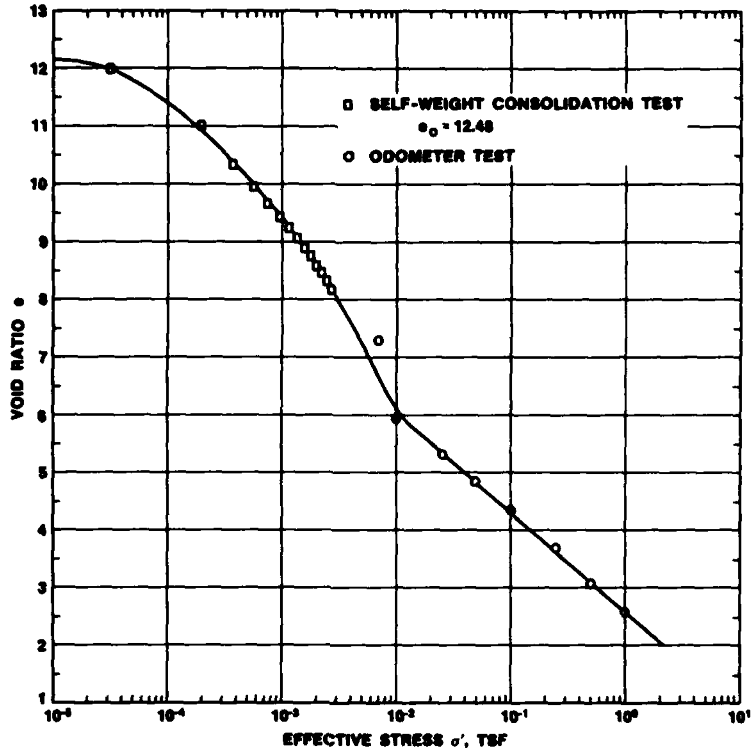

Figure D5. Void ratio-effective stress relationship for Drum Island material

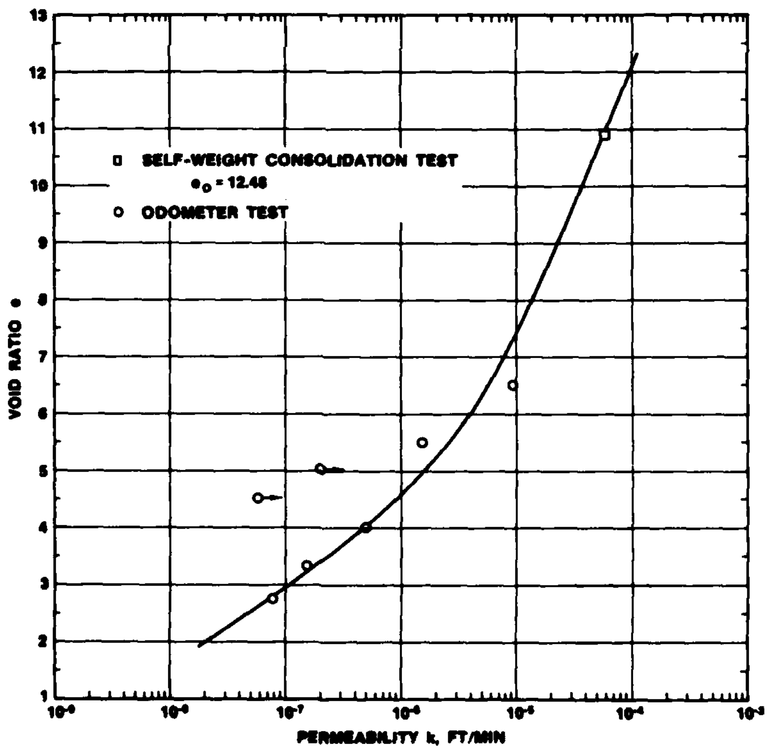

Figure D6. Void ratio-permeability relationship for Drum Island material

APPENDIX E: A COMPREHENSIVE FIELD VERIFICATION SITE

1. This report and others related to dredged material settlement in confined disposal areas have recognized the need for comparing mathematical model predictions to actual field performance. While this and a previous report (Cargill 1982b)* have made some comparisons between theoretically predicted and field measured quantities with good results, the field sites were not specifically monitored for the purposes that they have been used. Therefore, the data have been incomplete and some assumptions have been required in order to make the comparisons. While the data used in this and the previous report have been sufficient to illustrate the validity and usefulness of the procedures and to establish a basic level of confidence in them, there remains a need for additional comparisons at sites specifically monitored for verification purposes. Only then can the analysis procedures be fine tuned and the level of confidence in them be raised to a level acceptable for use in routine design. This appendix documents the measurements and observations which should be made in future contained disposal areas.

General

2. The geometry and size of a comprehensive field verification site are not critical so long as deposited material is able to spread relatively easily and evenly throughout the site and the areal extent or any cross dimension is very large in comparison with the depth of material deposited. The theory is one-dimensional and not applicable where two- or three-dimensional effects are possible.

3. Prior to the commencement of the dredging operation, channel sediments to be dredged should be thoroughly sampled in situ for later correlation with material deposited in the site. Data collected should include in situ void ratio, grain-size distribution, specific gravity of coarse- and fine-grained portions, Atterberg limits, and consolidation parameters of the fine-grained portion. Consolidation testing recommended here and later for material after deposition in the site should be conducted on disturbed samples at a void ratio comparable with the state of the material as it is discharged

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* See References at the end of the main text.

from the dredge pipe. This testing is best accomplished in a controlled rate of strain device (Cargill 1983b) or slurry consolidometer since conventional oedometers cannot accommodate the very high void ratios common to dredged material.

4. A complete initial topographic survey of the containment area and dikes is required to correlate volumes dredged and pumped to volumes stored. While theoretical settlement predictions may be absolutely accurate for known heights of dredged material solids in the disposal area, unless the solids height can be deduced accurately from volume dredged, there is little hope of obtaining a useful settlement prediction.

Foundation Sampling and Testing

5. The material properties of the foundation upon which dredged material is deposited will have some effect on the overall settlement experienced by the surface of the dredged material. Therefore, some sampling and testing of foundation material are required. The specific material will determine how extensive the program of sampling and testing should be.

6. The basic information needed from a sampling program for a comprehensive field verification site includes boring logs identifying the material to a depth from one to two times the maximum height of dredged material to be deposited (so foundation effects can be considered), regular and closely spaced undisturbed samples throughout all compressible layers, and relative density correlations through coarse-grained material along with samples. Correct specification of the boundary condition between foundation and dredged material requires knowledge of the permeability and void ratio at the foundation surface. Undisturbed sampling and field permeability testing should be accomplished to define these variables.

7. A laboratory testing program is needed mainly for the characterization of fine-grained compressible materials. Coarse-grained foundations are normally expected to be relatively incompressible under the loading of typical dredged material thicknesses. Theoretical prediction of foundation settlement requires knowledge of the material's specific gravity, consolidation parameters (derived through testing of material at various depths and reconciled with a measured in situ void ratio distribution when possible), and layer thickness. For completeness and possible use in future correlations, the grain-size distribution and Atterberg limits should also be determined.

Instrumentation

8. Measurement of settlements in both the foundation and dredged material within a confined disposal area is very easy with the aid of a simple settlement plate as illustrated in Figure E1. All comprehensive field verification sites should be initially equipped with at least three settlement plates:

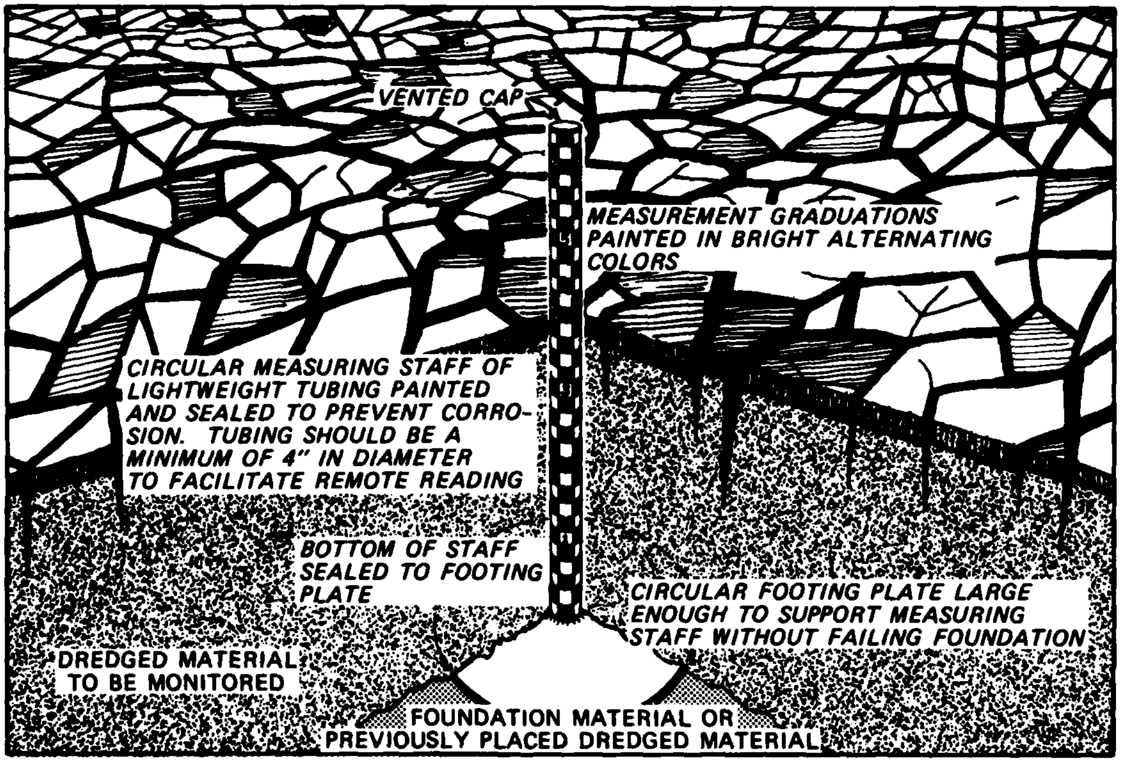

Figure E1. Settlement plate for field verification sites

one located on the inflow side of the area, one near the middle, and one near the effluent discharge side. Since most areas gently slope toward the outflow side and desiccation drying varies across the site, this arrangement allows measurement of settlement under a variety of conditions which can be related to other monitored variables. If a site is used for more than one major dredging disposal operation, additional settlement plates should be placed on top of previously deposited dredged material so that the contribution to total settlement can be individually tracked for all major layers.

9. At sites subjected to extensive evaporative forces, desiccation settlement can be a large part of the total. Theoretical prediction of desiccation settlement is dependent upon knowledge of the environmental potential

evaporation at the site. Therefore, all comprehensive field verification sites should also be equipped with a Class A pan and rain gauge for determining evaporation potential. This equipment should be installed, monitored, and maintained in accordance with the National Weather Service (NWS) standards so that data gathered can be compared with NWS data. After an extended period of favorable correlation between site data and published NWS data for nearby stations, site monitoring can possibly be discontinued, but should be checked periodically throughout the life of the disposal area to ensure consistency of data.

10. The theoretical prediction of consolidation settlement involves very precise calculation of void ratio, effective stress, and pore pressure distributions through the consolidating layer. The accuracy of these calculations at any point in time can be best judged by comparison of predicted and measured pore pressure distributions. Due to the relative impermeability of dredged material and the large unknown relative displacements likely to be experienced by any permanently installed pore pressure measuring device, it is recommended that pore pressure distribution measurements be accomplished with an electronic pore pressure probe such as the one described by Cooper and Franklin (1982). Since the structural integrity of the device is not expected to present a problem in soft dredged fill, a hand-pushed, simplified probe such as shown in Figure E2 may be found to be quite suitable for the intended

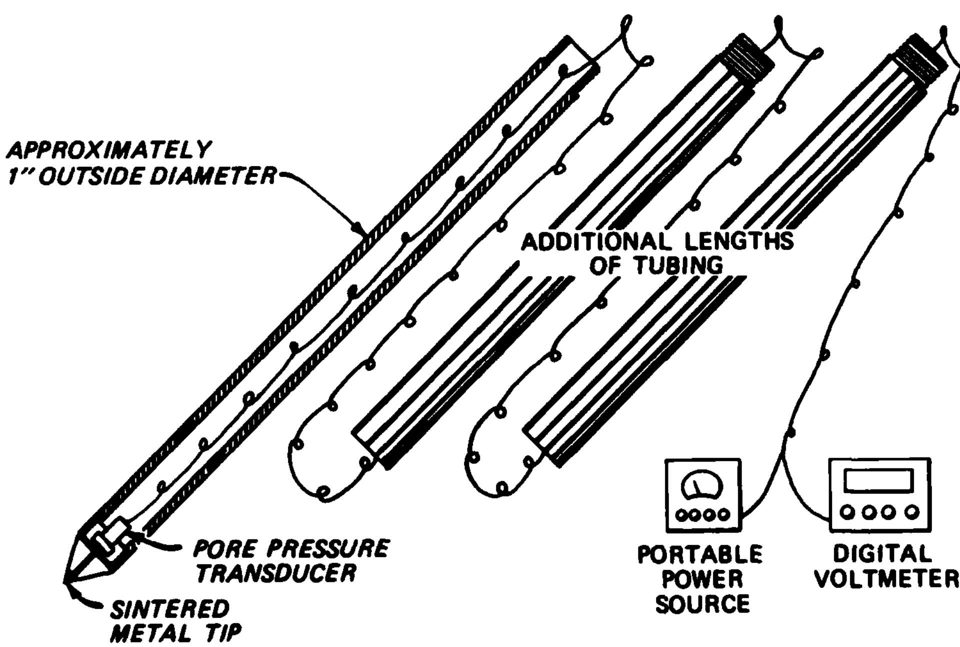

Figure E2. Typical pore pressure measurement probe application. Before the use of any pore pressure probe in dredged material becomes routine, a study on how to account for possible probe-induced pore pressures should be conducted.

Dredged Material Sampling and Testing

11. Immediately upon the completion of dredged material deposition, the entire layer should be sampled on the same foundation contour and in the vicinity of each settlement plate, but not so close as to interfere with the settlement plate. It may be necessary to maintain a pond of water over the site to permit access to the sampling locations by boat since the material will be too soft for foot traffic. This initial sampling is considered crucial to any comprehensive field verification site. From it, an initial void ratio and height of material solids will be determined. The height of material solids is the base number upon which all other calculations are based. If possible, the initial sampling should include well-preserved samples at various depths as well as a tube sample of the entire layer. Techniques for conducting the sampling should recognize the very soft nature of normally consolidated dredged material.

12. Laboratory testing to determine in situ void ratio, grain-size distribution, specific gravity of solids, Atterberg limits, and consolidation parameters should be performed on these initial samples. Correlations between these test results and similar testing on channel sediments should be sought.

13. Once a desiccated crust begins to form in the vicinity of a settlement plate, it should be statistically sampled monthly for determination of thickness, depth and areal percentage of cracks, and void ratio distribution and saturation through the crust. This sampling is crucial for the verification of the saturation limit and desiccation limit concepts and determination of the maximum soil evaporation efficiency and its relationship to water table depth.

Site Monitoring and Operation

14. Once material disposal activities have ended, a regular monitoring program should be initiated to track changes in the material and weather variations over an extended period of time. Settlement plates, evaporation pans,

and rainfall gauges require reading at least monthly and possibly more often in the early stages of consolidation or desiccation. A quarterly determination of pore pressure distribution in the vicinity of settlement plates is considered sufficient for monitoring this aspect of the consolidation phenomenon. A complete topographic survey of the disposal area should be accomplished on a yearly basis to ensure that settlement predictions are correctly translated to volume reduction.

15. At sites operated for field verification purposes, consideration should be given to maintaining the site at various degrees of desiccation through control of surface drainage. For instance, the upper or inflow side of the containment area should be decanted of free surface water as soon as possible to get maximum benefit from evaporative drying; the middle portion of the site should be managed for desiccation starting 3 to 4 months later than the upper end; and the lower or outflow side of the site should be managed to maintain a pond of water so that material desiccation is prevented. Of course, the site must be quite large and positively sloped to enable this type management without benefit of interior dikes. Figure E3 illustrates a comprehensive field verification site as recommended by this appendix.

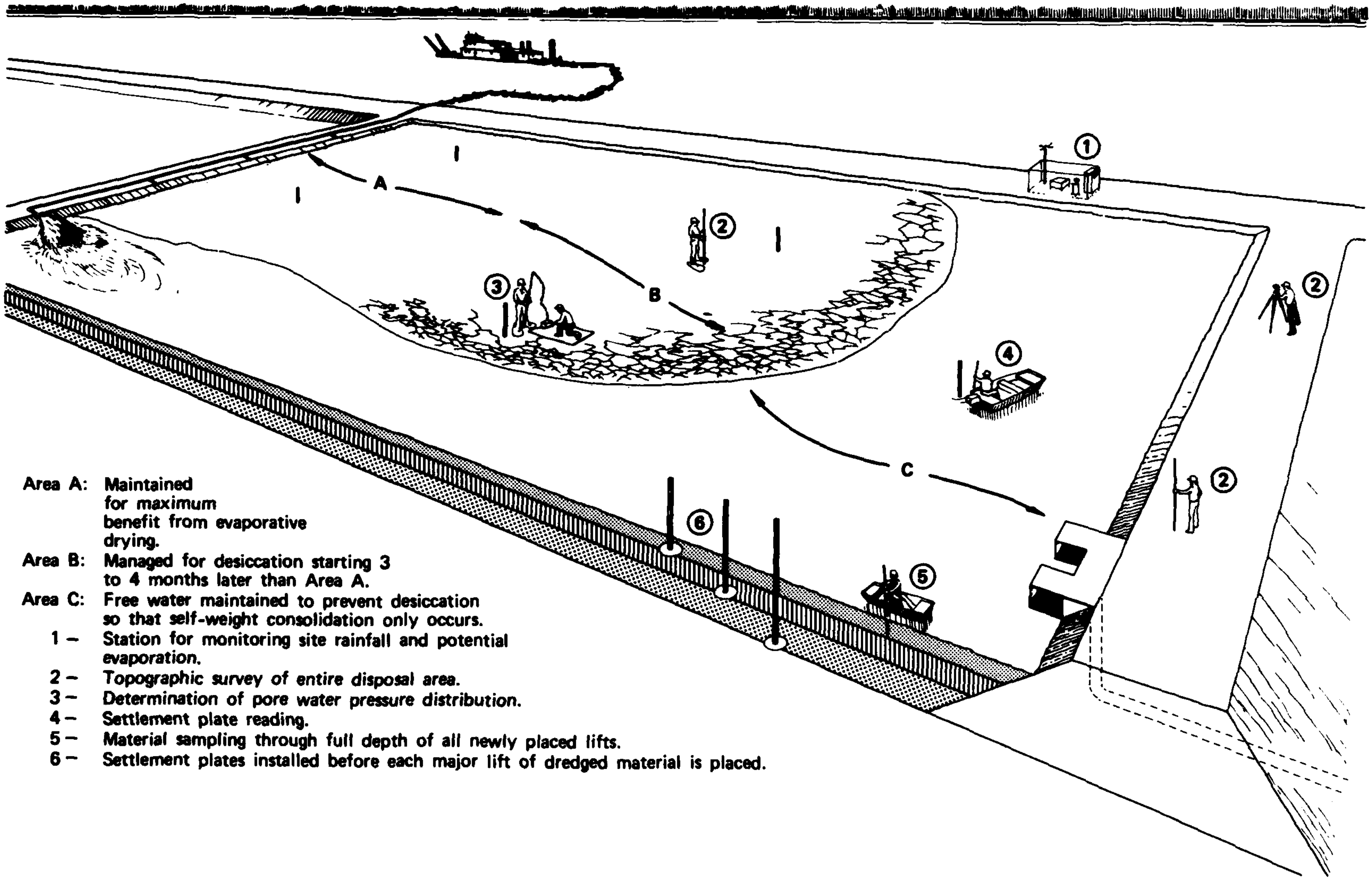

Figure E3. Comprehensive field verification site

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