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CONSOLIDATION CHARACTERISTICS DETERMINATION FOR PHOSPHATIC CLAYS

VOLUME 2: User Manual for Computer Program SICTA

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CONSOLIDATION CHARACTERISTICS DETERMINATION FOR PHOSPHATIC CLAYS

Final Report
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VOLUME 2: User Manual for Computer Program SICTA

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Chapter 1

Introduction

This manual describes the theory and numerical implementation of the seepage induced consolidation test analysis. The computer program SICTA (Seepage Induced-Consolidation Test Analysis) determines the model parameters for soft soil consolidation characteristics from the results of a seepage induced-consolidation test. The analysis procedure includes an optimization scheme for solving the non-linear inverse problem.

The compressibility and permeability functions for soft soils can be expressed as follows (Liu and Znidarcic, 1991) :

$$e = A(\sigma' + Z)^B \tag{1.1}$$

$$k = C e^D \tag{1.2}$$

Where e is the void ratio, σ' is the effective stress and k is the permeability coefficient. The five parameters A, B, C, D and Z are required to describe the consolidation behavior of soft soils.

It is difficult to design a testing program which will provide directly the compressibility and permeability functions for soft soils and a parameter estimation algorithm is needed. Such algorithm requires the numerical simulation of a test performed on a soft soil sample. This algorithm will minimize the difference between the experimentally obtained results and the numerically calculated values.

A testing technique based on the concept of hydraulic consolidation is adopted as a method to provide a reliable experimental data for the need of the parameter estimation analysis. This technique originally proposed by Imai (1981) is modified to obtain more reliable results by performing the test with a constant flux through a soil sample. In this experiment, the soil slurry is poured into the testing apparatus and a constant flow rate is imposed through the sample. The imposed seepage force triggers the consolidation process in the sample during which the sample surface settles and the induced pressure difference across the sample increases. Ultimately , the process reaches the steady state when the settlement and pressure change seize. The ultimate height and pressure difference at steady state are used in the analysis.

The steady state condition in the seepage-induced consolidation test is controlled by the two constitutive relationships : void ratio vs. effective stress and void ratio vs. permeability ; therefore, this state can be used as the basis for determining the parameters in the constitutive relationships.

Two boundary conditions and other data must be specified as input in the process of parameter estimation for which the steady-state flow seepage-induced consolidation is simulated. The boundary conditions are :

- the imposed flow rate, v, which is known from the experiment.

- the free-surface void ratio or the void ratio at zero effective stress, e_o. In order to get the free surface void ratio, a self weight settling column tests must be performed. For this purpose, a graduated cylinder is used to model one dimensional self weight consolidation behavior of soft slurries. The experiment is focused on the determination of the void ratio profile, particularly on the value characterizing the free-surface void ratio at which the effective stress is assumed to be zero.

The other data include :

- initial height of the sample.

- the unit weight of water.

- the specific gravity of the soil solid particles.

The experimental results of the seepage induced consolidation at the steady state are :

- the final height of the sample.

- the bottom effective stress which is equal to the pressure difference across the sample measured using a precision differential transducer.

A loading test, after the seepage induced consolidation test is completed, is needed for providing reference data for parameter estimation algorithm. Under a relatively large load, the soft sample is compressed into an uniform layer. The consolidation properties measured are the permeability, k_s, the effective stress σ'_s and their corresponding void ratio, e_s.

The results of the seepage-induced consolidation test, the loading test and the void ratio at zero effective stress are used to determine the parameters for the models of soil consolidation characteristics.

Numerical simulation of the seepage induced consolidation and parameter estimation algorithm are described in Chapter II of this manual. The input data needed to run program SICTA are described in chapter III. The solution process and the output results are described in chapter IV. Five examples for phosphatic clays are described in chapter V. Four examples of data entry sessions are described in Appendix A. Finally, the computer program is listed in the Appendix B.

Chapter 2

Theory

An efficient algorithm to determine the constitutive parameters is described in this chapter. In the first section, the solution of the seepage induced consolidation test and its numerical computer algorithm are presented. The solution of the parameter estimation problem and its numerical computer algorithm are presented in the second section.

2.1 Solution algorithm of the steady state seepage-induced consolidation

The numerical solution of the steady state seepage-induced consolidation test for any set of constitutive parameters *A, B, C, D, Z,* will determine the calculated bottom effective stress σ_c' and the final calculated height of the sample *hc* at steady state. Then, the normalized difference between the calculated bottom effective stress and the experimentally obtained final bottom effective stress at steady state $hb(1)$ is calculated as :

$$hb(1) = \left|(1. - \frac{\sigma'_c}{\sigma'_f})\right| \tag{2.1}$$

and the normalized difference between the calculated height of the sample and the experimentally obtained final height at the steady state, hb(2) is calculated as :

$$hb(2) = \left|(1 - \frac{hc}{hf})\right| \tag{2.2}$$

Where σ'_f, hf are the experimentally obtained final effective stress and final height at steady state of the seepage induced consolidation test.

Three equations govern the steady state seepage test which can be written in Lagrangian coordinates, a, as follows : :

- The equilibrium equation :

$$\frac{\partial \sigma}{\partial a} - \frac{e\gamma_w + \gamma_s}{1 + eo} = 0.$$

Where σ is the total stress, eo is the initial void ratio, γ_s is the unit weight of the soil solid particles , γ_w is the unit weight of water. Note that the direction of the coordinate axis is with the gravity

- The flow equation

$$v = -\frac{k}{\gamma_w}\frac{\partial u_e}{\partial a}\frac{1 + eo}{1 + e} \tag{2.4}$$

Where v is the apparent relative velocity between the water and the solid phases, u_e is the excess pore water pressure above hydrostatic conditions.

- The principle of the effective stress :

$$\sigma' = \sigma - u_s - u_e \tag{2.5}$$

Where u_s is the static pore water pressure defined at a as :

$$u_s = \frac{1+e}{1+eo}\gamma_w a \tag{2.6}$$

or

$$\frac{\partial u_s}{\partial a} = \frac{1+eo}{1+e}\gamma_w \tag{2.7}$$

These three equations together with the compressibility and the permeability functions defined in Eqs. 1.1, 1.2 will be combined to solve numerically the seepage induced consolidation.

The effective stress at any depth with the lagrangian coordinate a can be obtained in integral form as :

$$\int_0^a \frac{\partial \sigma'}{\partial a} da = \int_0^a [A\frac{\partial \sigma}{\partial a} da - \int_0^a \frac{\partial u_s}{\partial a} da - \int_0^a \frac{\partial u_e}{\partial a} da \tag{2.8}$$

Combining the equilibrium and the flow equation :

$$\sigma'(a) - \sigma'_o = \int_0^a \frac{e\gamma_w + \gamma_s}{1+eo} da - \int_0^a \frac{1+e}{1+eo}\gamma_w da + \int_0^a \frac{v\gamma_w}{k}\frac{1+e}{1+eo} da \tag{2.9}$$

Where $\sigma_o^{'}$ is the effective stress at the top of the sample due to the surcharge load.

The relation between the lagrangian coordinates and the material coordinate z can be expressed as follows :

$$\frac{\partial z}{\partial a} = \frac{1}{1+eo} \tag{2.10}$$

Hence the final governing equation can be written in the material coordinates as follows :

$$\sigma^{'}(z) = \sigma_o^{'} + \int_0^z e\gamma_w + \gamma_s dz - \int_0^z (1+e)\gamma_w da + \int_0^z \frac{v\gamma_w}{k}(1+e)dz \tag{2.11}$$

or

$$\sigma^{'}(z) = \sigma_o^{'} + (\gamma_s - \gamma_w)z + \int_0^z \frac{v\gamma_w}{k}(1+e)dz \tag{2.12}$$

Note that the first two terms represent the effective stress due to the top surcharge load and self weight :

$$\sigma^{'}(z)_{surch+self} = \sigma_o^{'} + (\gamma_s - \gamma_w)z \tag{2.13}$$

and that the third term represents the effective stress due to the seepage force :

$$\sigma^{'}(z)_{seepage} = \int_0^z \frac{v\gamma_w}{k}(1+e)dz \tag{2.14}$$

Note that v is the imposed flow rate that is constant throughout the sample at steady state.

The solution process of the steady state seepage experiment is simulated in the following way : Initially the sample is prepared at a uniform void ratio, e_o, and has a height of H_o. The sample consolidates under the self weight and the top surcharge load in the absence of any externally applied flow and approaches equilibrium at the end of this process. At this stage, the effective stress at any material coordinate z is calculated through equation 2.13 and the corresponding void ratio is obtained as :

$$e = A(\sigma' + Z)^B \tag{2.15}$$

The final height of the sample due to the self weight and the top surcharge load compression is calculated as follows :

$$h_c = \int_0^{Hz} (1+e)dz \tag{2.16}$$

Where $Hz = \frac{H_o}{1+e_o}$

The imposition of the flow rate across the sample causes additional effective stress as described in Eq. 2.14. The effective stress is then calculated from Eq. 2.12.

The effective stress and void ratio distributions and the sample final height at the steady state are calculated using an iterative scheme. In the first iteration, the void ratio distribution due to the self weight and the top surcharge load is used to calculate the permeability distribution as :

$$k = Ce^D \tag{2.17}$$

and then to update the additional effective stress due to seepage force. Once the new effective stress is calculated, the corresponding void ratio distribution is obtained as described before and used again to update new permeability values and seepage stresses. This process is repeated until a predetermined convergence criteria are reached.

The explained iterative algorithm is numerically implemented in the computer program and has been found to be efficient and produce reliable results.

Once the steady state void ratio distribution is found, the ultimate sample height is calculated as described in Eq. 2.16 and the bottom effective stress is calculated as :

$$\sigma_c^{'} = (\frac{e_{bottom}}{A})^{\frac{1}{B}} - Z \tag{2.18}$$

(2.19)

These values are then used to calculate the normalized difference vector, *hb*, as described in Eqs. 2.1, 2.2.

2.2 The Algorithm of the Parameter Estimation Solution

The main purpose of the parameter estimation solution is to find the best set of the constitutive parameters for the compressibility and permeability functions *A, B, C, D, Z* as described in Eqs. 1.1, 1.2.

With the experimental results explained in Chapter I, the number of free parameters needed to be estimated are reduced to two. Parameters *B*, *D* are chosen to be the free parameters to be determined while the others are determined from the void ratio at zero effective stress, e_o and from the data of the step loading as follows :

$$Z = \frac{\sigma_s}{(\frac{e_s}{e_o})^{1/B} - 1} \tag{2.20}$$

$$A = \frac{e_o}{Z^B} \tag{2.21}$$

$$C = \frac{k_s}{(e_s)^D} \tag{2.22}$$

Where e_s, σ'_s, k_s are data from step loading test.

The other data required for the parameter estimation solution are as follows :

1. Initial estimates of the parameters B, D

2. Upper and lower limit values of the parameter B *bl, bh,* and of the parameter D *dl,dh.*

The current parameters B, D are always stored in a vector $x(2)$. At iteration k, parameter B is stored as $a1(k)$ and parameter D is stored as $a2(k)$.

Newton approach has been used to update the old values of *B, D* or vector x toward better estimation. This method is based on linearizing the change in the normalized difference vector hb with respect to the vector x at the current iterate. Note that x, hb are vectors of two data points. Hence, the normalized difference vector at the next iterate, hb_{k+1} can be expanded using Taylor series as follows :

$$hb(1)_{k+1} = hb(1)_k + \frac{\partial hb(1)_k}{\partial a1(k)} da(1) + \frac{\partial hb(1)_k}{\partial a2(k)} da(2) \qquad (2.23)$$

$$hb(2)_{k+1} = hb(2)_k + \frac{\partial hb(2)_k}{\partial a1(k)} da(1) + \frac{\partial hb(2)_k}{\partial a2(k)} da(2) \qquad (2.24)$$

Where the vector da represent the incremental change in B and D respectively. The partial derivatives which appeared in the preceding equations can be approximated by forward finite difference as :

$$\frac{\partial hb(1)_k}{\partial a1(k)} = \frac{hb(1)_k(a1(k) + .0001) - hb(1)_k(a1(k))}{.0001} \qquad (2.25)$$

$$\frac{\partial hb(1)_k}{\partial a2(k)} = \frac{hb(1)_k(a2(k) + .0001) - hb(1)_k(a2(k))}{.0001} \qquad (2.26)$$

$$\frac{\partial hb(2)_k}{\partial a1(k)} = \frac{hb(2)_k(a1(k) + .0001) - hb(2)_k(a1(k))}{.0001} \qquad (2.27)$$

$$\frac{\partial hb(2)_k}{\partial a2(k))} = \frac{hb(2)_k(a2(k) + .0001) - hb(1)_k(a2(k))}{.0001} \qquad (2.28)$$

Setting the difference vector hb_{k+1} to zero in Eqs. 2.23, 2.24,

$$\begin{bmatrix} hb(1)_k \\ hb(2)_k \end{bmatrix} = \begin{bmatrix} \frac{\partial hb(1)_k}{\partial a1(k)} & \frac{\partial hb(1)_k}{\partial a2(k)} \\ \frac{\partial hb(2)_k}{\partial a1(k)} & \frac{\partial hb(2)_k}{\partial a2(k)} \end{bmatrix} \begin{bmatrix} da(1) \\ da(2) \end{bmatrix}$$

(2.29)

This matrix is the Jacobian of the difference vector hb with respect to vector x.

The solution for vector da in matrix form can be written as :

$$\begin{bmatrix} da(1) \\ da(2) \end{bmatrix} = \begin{bmatrix} \frac{\partial hb(1)_k}{\partial a1(k)} & \frac{\partial hb(1)_k}{\partial a2(k)} \\ \frac{\partial hb(2)_k}{\partial a1(k)} & \frac{\partial hb(2)_k}{\partial a2(k)} \end{bmatrix}^{-1} \begin{bmatrix} hb(1)_k \\ hb(2)_k \end{bmatrix} \tag{2.30}$$

The next iterate solution for B, D can now be updated as follows :

$$a1(k+1) = a1(k) + da(1) \tag{2.31}$$

$$a2(k+1) = a2(k) + da(2) \tag{2.32}$$

If the the current estimation of the parameters $a1(k), a2(k)$ exceeded the upper or the lower boundaries of B, D, the step size in the same estimated direction is reduced to bring either one or both $a1(k), a2(k)$ to the specified limits. For example, if the lower limit of parameter $a1(k)$ exceeded the lower limit, initially, the direction represented by the slope $zz1$ will be calculated as :

$$zz1 = \frac{a2(k) - a2(k-1)}{a1(k) - a1(k-1)} \tag{2.33}$$

The incremental change in $a1$ will be taken $a1(k-1) - bl$. The estimation of $a1(k)$ will be taken as bl and the estimation of the parameter $a2(k)$ at iteration k is then determined as follows :

$$a2(k) = a2(k-1) - zz1(a1(k-1) - bl) \tag{2.34}$$

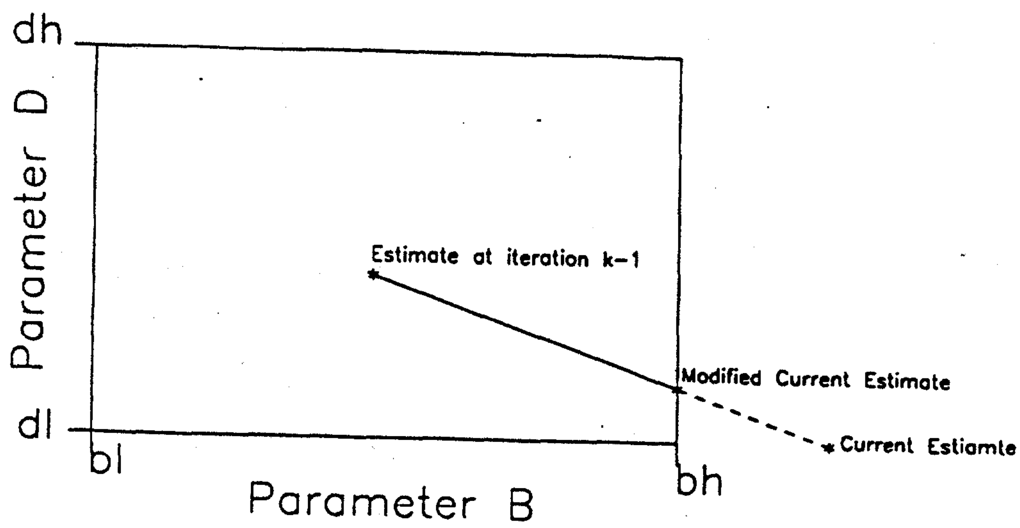

Figure 2.1: Modification Strategy of the Current Estimates

Figure 2.1 shows an example of how the the next iterate will be modified if it exceeded the stated boundaries in the problem.

The total normalized difference between the calculated and measured values *error*(*k*) at iteration *k as :*

$$error(k) = hb(1) + hb(2) \tag{2.35}$$

However ; if the total normalized difference at the current iterate exceed the total normalized difference in the previous iteration according to the following criteria :

$$error(k) > error(k\text{-}1) + .02 \tag{2.36}$$

a search for better estimation of the parameters *B, D* will be initiated. Line search strategy (Dennis and Schnabel, 1983) has been adopted in this study and it requires the estimation of parameters B, D at the current and the previous iterations with their corresponding total normalized differences. The idea of line search algorithm is simple : given a decent direction with slope $s1$, we take a step in that direction that yields an acceptable next iterate. The variable λ is chosen to represent the change in parameters B, D along that direction with $\lambda = 0.$ at their previous estimation , $a1(k-1), a2(k-1)$ and $\lambda = 1$ at their current estimation $a1(k), a2(k)$. The equation of the quadratic interpolation between the total normalized difference and λ can be written as :

$$error(\lambda) = error(k-1) + s1\lambda + s2(\lambda)^{2.} \tag{2.37}$$

$s1$ can be estimated as follows (see Figure 2.2) :

$$s1 = -error(k-1) \tag{2.38}$$

Then, coefficient $s2$ can be found as :

$$s2 = error(k) - error(k-1) - s1 \tag{2.39}$$

The best λ_{opt} at which the error value is minimum can be derived as :

$$\lambda_{opt} = -\frac{s1}{2(s2)} \tag{2.40}$$

and then, the optimal vector x_{op} can be determined as :

$$x(1)_{opt} = a1(k-1) + \lambda(a1(k) - a1(k-1)) \tag{2.41}$$

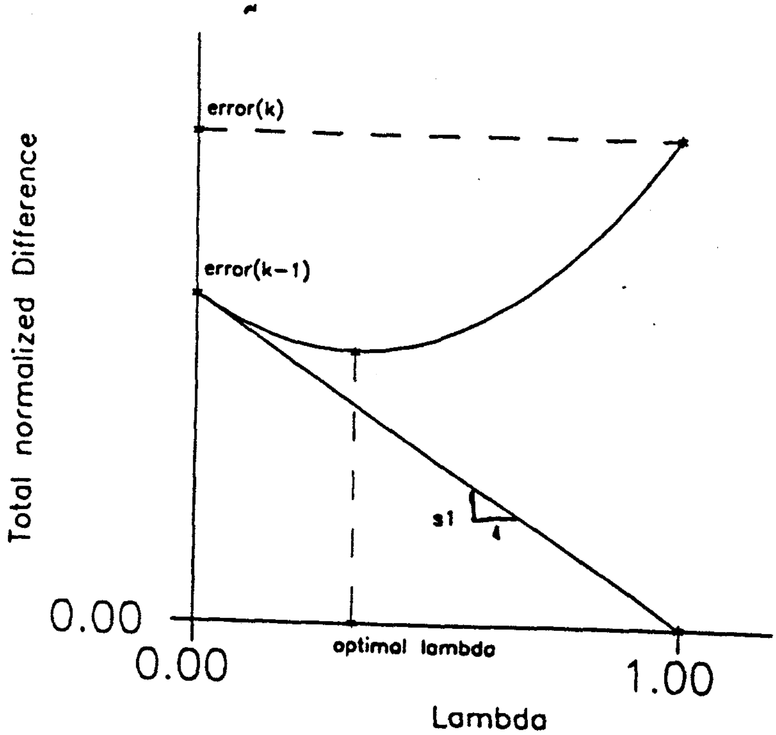

Figure 2.2: Line Search Strategy

$$x(2)_{opt} = a2(k-1) + \lambda(a2(k) - a2(k-1)) \tag{2.42}$$

Then, the results at iteration k are replaced by the results at the optimal vector :

$$a1(k) = x(1)_{opt} \tag{2.43}$$

$$a2(k) = x(2)_{opt} \tag{2.44}$$

$$error(k) = error(x(1)_{opt}, x(2)_{opt}) \tag{2.45}$$

If the criteria defined in Eq.2.36 is still not satisfied with the new estimation of $B, D,$, constant $s2$ will be updated through Eq. 2.39 (note that $s1$ remains constant) and the same cycle of calculations presented in Eqs. 2.40,2.41, 2.42, 2.43, 2.44 will be implemented. This cycle of calculation will be repeated up to ten times until the criteria defined in Eq. 2.36 are satisfied.

If the criteria defined in Eq.2.36 is not satisfied in the tenth cycle (which has not been observed in all the cases analyzed in this study) , the next iterate estimate proceeds as follows :

$$a1(k) = \frac{a1(k-1) + a1(k)}{2.} \tag{2.46}$$

$$a2(k) = \frac{a2(k-1) + a2(k}{2.} \tag{2.47}$$

In this case $a1(k)$, $a2(k)$ are the current estimates of B, D before any search for better estimation of these variables is initiated.

This iterative process of calculation including updating the old estimation, checking the current estimates, and searching for better estimation, if needed, will be continued until a predetermined criteria are satisfied.

Chapter 3

SICTA Input Data

The input data required by program SICTA will be described in this chapter. Initially, how to start program SICTA will be described in the first section. The input data and the program execution will be described in the second and third sections respectively. Samples of data entry session for different cases presented in this chapter are available in Appendix A.

The source code and the execution of program SICTA named as SICTA.FOR, SICTA.EXE respectively are available on the MASTER diskette. Also available on this diskette are input and output files named respectively *Example*1.*dat* and *Example*1.*out*. The discussion presented in this chapter and the following chapter will refer to these data and output files.

The user is recommended to make backup copies of the MASTER diskette. Then, the MASTER diskette or one of the backup copies should be copied into the hard disk.

3.1 Starting program SICTA

Once the executive file of program SICTA is installed correctly on the hard disk, (or any drive) **program SICTA can be started by typing** *SICTA* . Immediately after start up, a message and control menu will be displayed to the user as follows :

```
          WELCOME TO PROGRAM SICTA
 This program will estimate the parameters for void ratio-
 effective stress and void ratio-permeability relationships
 from the result of seepage induced consolidation test.
```

```
          CONTROL MENU
      1. CREATE A NEW DATA FILE
      2. READ AN EXISTING DATA FILE
      3. EXIT
 ENTER YOUR OPTION..?
```

The control menu will give the user the option to create a new data file or to pass the data to the program through an existing data file. The user should respond to the questions displayed by program SICTA by entering the appropriate number and then pressing ENTER.

If the user choose the first option, a new data file will be created through an interactive mode. The user will be asked to give a name for this new file which will store all the data entered :

ENTER A NAME OF FILE TO STORE YOUR DATA

(maximum 30 characters)

Once the user entered a name, SICTA will generate this file which will store all the input data passed through interactive mode.

If the user chooses to pass the data through an existing data file, the name of the file which contains all input data will be requested :

ENTER THE NAME OF EXISTING INPUT DATA FILE

(maximum 30 characters)

The existing data file contains the same order of questions and answers as if the data were entered through the interactive mode.

The user will then be asked to give a name for the output file :

ENTER A NAME OF OUTPUT FILE

(maximum 30 characters)

Once the user entered a name, program SICTA will generate this file which will store the output results.

3.2 INPUT DATA

Data required for program SICTA can be passed through either an interactive mode from an existing data file. For the first time, the user is recommended to create a new data file through an interactive mode. The created data file can be used in a second run , and after any modification, as an existing data file. Full description of input data variables and how to pass them to program SICTA will be described in this section.

The format of the existing data file is shown in Appendix A.1 and the same file is available to the user in the diskette under the file name *Example*1*.dat.* All the input data and the range of the analysis variables shown in this file will be described in this section. The output file for this existing data file is available to the user in the diskette under the file name *Example*1*.out* and is shown in Appendix A.l. The user can run this existing data file by responding to the control menu with number “2 “and entering the name *Example*1*.dat* as an existing data file and name an output file. The generated output file should be the same as *Example1.out*. **The data entry session needed for this case is available in Appendix A.1**

The following discussion will show how to create a new data file that is similar to *Example1.dat*. The data entry session for this case is available in Appendix A.3. Respond to the control menu options as " 1 " and name the new created file which will store all the input data as *Example2.dat* and the output file as *Example2.out*. The values of data that will be entered and stored in the new created data file are similar to the data shown in the existing data file *Example1.dat*.

Three type of data are required by program SICTA :

1. Designation title of the problem : a message will be displayed to the user as follows :

```
------------------------------------------------------------
                 INPUT DATA
------------------------------------------------------------


          ENTER A DESIGNATION TITLE
           ( maximum 70 characters )
```

This title can be passed through an exiting data file as shown in Table 3.1.

This designation title will appear in the output file. Respond to this question as *ChinaClay, TestNo.*1.

2. Test result data.

3. Analysis data.

These data include the seepage induced consolidation and step loading test results and description of the water and soil used in these tests. The user must enter these data. These data are as follows :

1. Water and soil description :

   - gw = unit weight of water.
   - gs = unit weight of soil solid particles.

2. Seepage induced consolidation test results :

   - H_o = initial height of the sample.
   - e_o = void ratio at zero effective stress.
   - $sigmat$ = top effective stress.
   - et = top void ratio that corresponds to the top effective stress.
   - $velo$ = Darcian velocity.

- *sigmaf* = final bottom effective stress.

- *hf* = final height of the sample.

3. Step Loading test results

- *es* = void ratio.

- *sigmas* = effective stress.

- *perms* = permeability coefficient.

The values of these data are passed to program SICTA by responding to the following messages which appear after the designation title is entered as follows :

```
---------------------------------------------------------------

          SEEPAGE INDUCED CONSOLIDATION TEST DATA

---------------------------------------------------------------


   Enter the unit weight of water
9.81
   Enter the unit weight of soil solid particles
26.0946
   Enter the initial height of the sample
.204
```

Enter the initial void ratio of the sample

8.

Enter the top void ratio

8.

Enter the top effective stress

0.

Enter the Darcian velocity

.321e-6

Enter the final height of the sample

.106

Enter the final bottom effective stress

5.574

STEP LOADING TEST DATA

Enter the void ratio

2.22

Enter the effective stress

10.7

```
Enter the coefficient of permeability
.143e-7
```

These data are passed through an existing data file as shown in Appendix A.1.

The values, and more important the units of the test input data should be checked. Any error in the value of the test input data or any inconsistency of the units used will lead to wrong constitutive parameters. Also such an error might cause the numerical solution of the parameter estimation algorithm not to converge.

For example if the force unit is chosen as kN , the length unit as m, the time unit as day, the unit weight of water and solid should be entered in $\frac{kN}{m^3}$ units, the velocity and permeability should be entered in $\frac{m}{day}$ units, the initial and final height should be entered in m units and all the stresses should be entered in $\frac{kN}{m^2}$ (or kPa) units. On the other hand, the obtained constitutive parameters relate the void ratio to the effective stress in $\frac{kN}{m^2}$ (or kPa) units and the void ratio to the permeability in $\frac{m}{day}$ units.

3.2.2 Analysis Data

These data are needed for the analysis of the numerical simulation of the seepage induced consolidation test and the parameter estimation algorithm. **These parameters are set in the program to have default values.**

These can be changed by entering new values or can be accepted by entering 0 **and pressing** *ENTER*.

3.2.3 Analysis data needed for the numerical simulation of the seepage induced consolidation test

The data needed for the analysis of the numerical simulation of the seepage induced consolidation test are as follows :

- *numnod* = number of nodes used to discretize the sample length.
- *error2* = The minimum total approximated error needed to be achieved in the numerical simulation of the seepage induced consolidation test.
- *ni2* = Maximum Number of iterations needed to achieve error2.

The values of these default data are entered by responding to the following messages as follows :

```
-----------------------------------------------------


          ANALYSIS PARAMETERS

     TO USE THE DEFAULT VALUE, JUST PRESS 0


     1. SEEPAGE INDUCED CONSOLIDATION ANALYSIS DATA
-----------------------------------------------------
```

```
  Enter the number of nodes

  (MAX.=100,MIN=30,DEFAULT=41 )

0

  Enter the minimum total approximated error

   (MAX.=1.e-3, MIN =1.e-5, DEFAULT =1.e-4 )

0

  Enter the maximum number of iteration needed

  to achieve this error

       (MAX.=30,MIN.=15,DEFAULT=25 )

0
```

These default data are passed through an existing data file as shown in Appendix A.l. **The default values and the limits of these variables are available to the user in this manual** . The default values can also be entered in an existing data file by typing 0.

If the user entered any value lower than the minimum or higher than the maximum for any of those data, one of the following messages will be displayed into the screen to the user :

ILLEGAL VALUE FOR NUMBER OF NODES, TRY AGAIN

ILLEGAL VALUE FOR error2, TRY AGAIN

```
ILLEGAL VALUE FOR ni2, TRY AGAIN
```

If the data are entered through interactive mode, the user will be given twenty trials to enter data within the specified range. An example for this case is shown in Appendix A.4

If the data are entered through an existing data file and exceed on of the limits, an error message will be displayed to the user as shown before and the program execution will be terminated. An example for this case is shown in Appendix A.2. The user is recommended in this case to fix the variable which exceeds one of the limit and run the program again.

The default values chosen for *numnod*, *ni*2 are found to be suitable for all the cases studied so far and to give good accuracy as can be visualized by the final total approximated error, *error*4 (see the output results). If the *error*4 is found to be larger than *error*2, the user is recommended to enter the maximum values of *numnod*, *ni2* . If *error*4 is still larger than *error*2, the user is recommended to check the test results and change the initial guess of *B*, *D* as will be described later.

The default value chosen for *error*2 gives a very good accuracy and the user is recommended strongly not to change it. The user can choose higher accuracy by choosing smaller value of *error*2 than the default values ; however, the experience shows that a very small change in the output results occurs if higher accuracy than the default value is chosen.

3.2.4 Analysis data needed for the parameter estimation algorithm

The analysis data needed for the parameter estimation algorithm are as follows :

- BL = lower limit value for B.
- BH = upper limit value for B.
- B = initial guess of B.
- DL = lower limit value for D.
- DH = upper limit value for D.
- D = initial guess of D.
- $error1$ = the minimum absolute total normalized difference needed to be achieved in the parameter estimation algorithm.
- $ni1$ = Maximum number of iterations needed to achieve $error1$.

The default values of these data are entered by responding to the following messages as follows :

---

2. PARAMETER ESTIMATION ANALYSIS DATA

```
  Enter the lower limit of parameter B
      (  DEFAULT = MIN. = -5.0 )
0
  Enter the upper limit of parameter B
        (  DEFAULT=MAX. = -.05 )
0
  Enter the initial guess of parameter B
      ( DEFAULT=-.25)
0
  Enter the lower limit of D
    (  DEFAULT = MIN.=.1 )
0
  Enter the upper limit of D
     (  DEFAULT=MAX.=8. )
0
  Enter the initial guess of parameter D
```

```
        ( DEFAULT =3.5 )

0

  Enter the minimum total normalized difference

   ( MAX.=1.e-3, MIN.=1.e-5,DEFAULT= 1.e-4 )

0

  Enter the maximum number of iterations needed

  to achieve the min. total normalized difference

        (MAX.=60,MIN.=40,DEFAULT=50 )

0
```

These default values are passed through an existing data file as shown in Appendix A.1. **The default values and the limits of these variables are available to the user in this manual** . The default values can also be entered in an existing data file by typing 0.

If the user entered any data less than the minimum or larger than the maximum for any of those data, one of the following error messages will be displayed into the screen to the user :

```
ILLEGAL VALUE FOR  BL, TRY AGAIN

ILLEGAL VALUE FOR  BH, TRY AGAIN

ILLEGAL VALUE FOR  B, TRY AGAIN

ILLEGAL VALUE FOR  DL, TRY AGAIN
```

ILLEGAL VALUE FOR DH, TRY AGAIN

ILLEGAL VALUE FOR D, TRY AGAIN

ILLEGAL VALUE FOR error1, TRY AGAIN

ILLEGAL VALUE FOR ni1, TRY AGAIN

If the data are entered in interactive mode , the user will be given twenty trials to enter data within the specified range. Example for this case is shown in Appendix A.4

If the data are entered through an existing data file and any of the data exceed on of the limits, an error message will be displayed to the user as shown before and the program execution will be terminated . The user is recommended for this case to fix the data variable which exceeds one of the limits and run the program again. Example for this case is shown in Appendix A.2.

Once the user entered the lower and the upper limit values for parameters B and D, the user should choose the initial guess for these parameters between the entered lower and upper limit values ; otherwise, an error message will be displayed to the user.

The solution converge if the obtained total normalized difference at the end of the analysis *error*3 (see the output results) is less than the specified minimum total normalized difference *error*1.

The user is recommended strongly not to change the default limits chosen for variables *B*, *D*. These limits give satisfactory results for all the examples studied so far. If other than these default values for the maximum and minimum values for parameters *B* , *D* are entered, it is possible that the solution will not converge toward satisfactory results. The maximum limit of parameter *B* and the minimum limit of parameter *D* are chosen to be near the physical limits of the compressibility and permeability functions ($BH < -.05, DL > .1$). For example, setting these two parameters to zero will imply that the soil is rigid and its permeability is constant which is not the case for soft clays. The minimum limit of parameter *B* and the maximum limit of parameter *D* has been chosen as a large values that will lead to the numerical solution of the parameter estimation algorithm even if the user begins with bad initial guesses.

If the user changes the limits of *B*, *D* and the solution does not converge, the user should enter the default limits and try again.

The default values for the initial guess of parameters *B*, *D* can be changed by the user dependent on the type of the soil under investigation. **If the solution does not converge, the user is strongly recommended to enter a new initial guesses and try again.**

The default value for the minimum total absolute normalized difference gives a very good accuracy and the user is strongly recommended to accept it. The accuracy of the default value chosen for $error1$ can be visualized by comparing the experimentally obtained and the numerically calculated bottom effective stress and final height of the sample at steady state conditions. This condition will also check the obtained constitutive parameters. The experience shows that choosing value for $error1$ less than the default value will not make any significant changes in the final calculated constitutive parameters *A, B, C, D, Z*. If at the end of the analysis, the obtained final total normalized difference *error*3 found to be larger than *error*1, the user is recommended to increase the maximum number of iterations $ni1$, to set the limit parameters of *B, D* to the default values, and to change the initial guesses of *B, D*. If *error*3 is still larger than error1, the user is advised to check the values and the units of the input test data.

The default value for number of iterations, $ni1$ needed to achieve error1 is not recommended to be changed unless the user feels from the screen output that the solution needs more iterations to converge.

3.3 SICTA Processing

Once all input data are passed to program SICTA through either the new created data file or an existing data file, SICTA will pass to the user a summary screen of all test input data followed by question of whether to stop or to continue as follows :

DESCRIPTION OF THE PROBLEM

TITLE OF THE PROBLEM IS

China Clay, Test No.1

Seepage Induced Consolidation Test Data :

Unit Weight of Water	=	9.81000
Unit Weight of Solids	=	26.09460
Initial Height of the Sample	=	0.20400
Initial Void Ratio	=	8.00000
Top Void Ratio	=	8.00000
Top Effective Stress	=	0.00000
Darcian Velocity	=	0.32100E-06
Final Height of the Sample	=	0.10600
Final Bottom Effective Stress	=	5.57400

Loading Test Results :

Void Ratio	=	2.22000
Effective Stress	=	10.70000
Permeability Coefficient	=	0.14300E-07

Do you want to continue (YES/NO)?

This screen summary will give the user the opportunity to check all test results input data before the execution of the program begins. If the user found that some of the test results data should be changed, the user should respond by entering "*N*" or "*n*" and the following message will appear :

PROGRAM EXECUTION HAS BEEN TERMINATED

In this case, the user is recommended to fix any data in the new created file which store input data or in the existing data file and to pass this file to program SICTA as an existing data file.

If the user decides to continue, the execution of the main processor in program SICTA can be initiated by entering " *Y* " or " *y* " . Then, screen output of the execution results are displayed to user as follows :

```
-------------------------------------------------

        THE SOLUTION PROCESS


-----------------------------------------------------

   ITERATION NUMBER  =      1

   PARAMETERS B      =       -0.25000

   PARAMETER  D      =       3.50000
```

```
TOTAL NORMALIZED DIFFERENCE =     0.36894E+00

------------------------------------------------------------

------------------------------------------------------------

ITERATION NUMBER  =     2

PARAMETERS B      =      -0.20581

PARAMETER  D      =      3.55172

TOTAL NORMALIZED DIFFERENCE =     0.69533E-01

------------------------------------------------------------

------------------------------------------------------------

ITERATION NUMBER  =     3

PARAMETERS B      =      -0.20072

PARAMETER  D      =      3.68840

TOTAL NORMALIZED DIFFERENCE =     0.57760E-02

------------------------------------------------------------

------------------------------------------------------------

ITERATION NUMBER  =     4

PARAMETERS B      =      -0.20072

PARAMETER  D      =      3.69466
```

```
TOTAL NORMALIZED DIFFERENCE =      0.91469E-04
```

Many examples for SICTA processing are shown in Appendix A.

Chapter 4

The Solution Process and the Output Results

4.1 The Solution Process

The main purpose of the solution process is to find the constitutive parameters of the compressibility and permeability functions A, B, C, D, Z as defined in Eqs. 1.1, 1.2 using the results of seepage induced consolidation and step loading tests.

The solution process is implemented in main program SICTA with the help of the following subroutines :

- Subroutine CHECK
- Subroutine COMMAND
- Subroutine GRADIENT
- Subroutine SEARCH

- Subroutine SEEP

- Subroutine TESTS

The solution process will be described step by step as appeared in the main program. The source code for program SICTA is given in Appendix and in file SICTA.for on the diskette.

Subroutine INPUT will pass to the main program all the input data described in the third chapter.

At iteration *k*, parameter B will be stored as $a1(k)$ and parameter D will be stored as $a2(k)$. The current parameters *B*, *D* are always stored in a vector 2.

The main program will pass to subroutine COMMAND the current estimates of *B*, *D* stored in vector *x* and all the test results.

Initially subroutine COMMAND will ask subroutine TESTS to estimate the constitutive parameters *A*, *C*, *Z* from the current estimation of *B*, *D* and the tests results as described in Eqs 2.24, 2.25, 2.26. Once all the constitutive parameters *A*, *B*, *C*, *D*, Z are available, subroutine COMMAND will pass these constitutive parameters, and the seepage induced consolidation test results to subroutine SEEP.

Numerical simulation of the seepage induced-consolidation test is then implemented in subroutine SEEP and the final bottom effective stress and final height are then calculated as described in section 2.2. The termination criteria for the numerical simulation of the seepage induced-consolidation are chosen as follows :

- when the total approximated error between two consecutive iterations achieve the following criteria :

$$\sum_{k=1}^{k=numnod} \left| \frac{e(k+1) - e(k)}{e(k)} \right| < error2 \tag{4.1}$$

- when the number of iteration reaches $ni2$.

Subroutine SEEP will then pass the calculated bottom effective stress and final height of the sample to subroutine COMMAND. Subroutine COMMAND will then calculate the absolute normalized difference components $hb(1)$, $hb(2)$ as described in Eqs. 2.1, 2.2 and pass them to the main program.

The absolute total normalized difference at iteration k, $error(k)$ is then calculated in the main program as follows (as in Eq. 2.35) :

$$error(k) = hb(1) + hb(2) \tag{4.2}$$

The main program will pass the estimates of B, D and their maximum and minimum values during all iterations to subroutine CHECK. If the current estimates $a1(k)$, $a2(k)$ exceeded the limits, subroutine CHECK will modify the step size to bring either one or both of the estimates to the specified limits. Eqs 2.33, 2.34 presented earlier in Chapter 2 show how the current estimates are modified if they fall outside the specified limits. Subroutine CHECK will pass to the main program the accepted current estimates of *B, D* that are within the specified limits.

The main program will then pass the current estimates of *B, D* stored in vector *x* and the normalized difference vector *hb* to subroutine GRADIENT. Subroutine GRADIENT will make an estimate of the next step size in parameters *B, D* stored in vector da and will then send them to the main program. The calculations for next step size are described in section 2.2.

The next iterate will then be updated in the main program as (as in Eqs. 2.31, 2.32) :

$$a1(k+1) = a1(k) + da(1) \tag{4.3}$$

$$a2(k+1) = a2(k) + da(2) \tag{4.4}$$

The new iterate will be modified, if needed, by subroutine CHECK

After iteration number one, subroutine SEARCH will be initiated if the total normalized difference at the current iteration exceed the total normalized difference of the preceding iteration according to the following criteria (as in Eq. 2.36) :

$$error(k) > error(k-1) + .02 \tag{4.5}$$

If this is the case, the main program will pass to subroutine SEARCH the following information : iteration number k, the vector estimates $a1$, $a2$ and the total normalized difference vector error during all previous iterations. Subroutine SEARCH will try to obtain a better estimation of the parameter B, D as described in Section 2.2. The better estimation is considered as the next iterate estimation of B, D. The next iterate estimation will be stored in vector z and then will be send back to the main program.

This iterative process of calculation is continued until one of the following termination criteria is achieved :

- When the value of the absolute total normalized difference at any iteration $error(k)$ become less than errorl.
- When the number of iterations reach $ni1$.

For each iteration, screen output of this solution process will be reported to the user through subroutine OUTPUT1. Samples of the screen output results were shown in the third chapter and Appendix A.

4.2 SICTA Output

Once one of the termination criteria for parameter estimation algorithm are achieved, the main program will ask subroutine OUTPUT to write all the output results in the generated output file. The output file generated for the existing data file *Example1.dat* is available in Appendix A.l. It is also available to the user in the the diskette under name *Example1.out*.

The output results are divided into three parts :

- Input data and parameter estimation results.

- Numerical simulation results of self weight and surcharge load consolidation test.

- Numerical simulation results of seepage induced consolidation test.

The parameter estimation results are as follows :

- $x(1), x(2) =$ The best estimation of parameters *B, D.*

- $t(1)$, $t(2)$, $t(3) =$ The best estimation of parameters *A, C, Z*

- *error*3 = the total normalized difference at the the estimated parameters.

- *ich* = number of iterations needed to satisfy the specified minimum total normalized difference *error*1.

The numerical simulation results of the self weight and surcharge load consolidation test are as follows :

- $v1() =$ void ratios at various nodes due to self weight and the surcharge load.

- *height*1()= height of the sample at various nodes due to self weight and the surcharge load.
- *depth*1() : depth of the sample at various nodes due to self weight and the surcharge load.
- *hc*1 = final height of the sample due to the self weight and the surcharge load.
- *sigmat* = top effective stress due to the surcharge load.
- *sigmac*1 = bottom effective stress due to self weight and the surcharge load.

The numerical simulation results of the seepage induced consolidation test are as follows :

- *v*() = void ratios at various nodes due to the seepage induced consolidation.
- *height*() = height of the sample at various nodes due to seepage induced consolidation.
- *depth*()= depth of the sample at various nodes due to seepage induced consolidation.
- h_c= Final height of the sample due to seepage induced consolidation.

- $sigmat$ = top effective stress due to the surcharge load.

- $sigmac$ = bottom effective stress due to the seepage induced consolidation.

- $error4$ = the total approximated error achieved in the numerical simulation of the seepage induced consolidation test.

- kk = number of iterations needed to satisfy the specified total approximated error $error2$.

Before the output results are accepted, the user should compare the experimentally obtained bottom effective stress $sigmaf$ and final height of the sample hf and the calculated numerically bottom effective stress $sigmac$ and final height of the sample h_c. If the differences between the experimentally and numerically obtained results are significant, the user should make use of the output results and check all the input data as described in chapter III.

Chapter 5

Examples Problems for Phosphatic clays

To be added later

References

1. Dennsis, J.E and Schnabel, R.B. (1983) " Numerical Methods for Unconstrained Optimization. " Englewood Cliffs, N.J. : Prentice-Hall Series in Computational Mathmetics.

2. Imai, G., Yano, K., and Aoki, S. (1984). " Applicability of Hydraulic consolidation test for very soft clayey soils. " Soils and Foundations, Jap. Soc. SMFE, 24(2), 29-42.

3. Liu, J.C and Znidarcic, D. (1991). " Modelling 1-D compression characteristics of soils. " J. of geotech. Engrg. Div., ASCE, Vo1.117, No.1, 162-169.

Appendix A : Samples of Data Entry Sessions

A.1 Sample 1

This sample shows how to run the existing data file *Example1.dat* . This file is available to the user in the diskette and is listed as follows :

```
 ENTER A DESIGNATION TITLE
 ( maximum 70 characters )
China Clay , Test No.1
    SEEPAGE INDUCED CONSOLIDATION DATA
 Enter the unit weight of water
 9.81000
 Enter the unit weight of soil solid particles
26.09460
 Enter the initial height of the sample
 0.20400
 Enter the void ratio at zero effective stress
 8.00000
 Enter the top effective stress
 0.00000
 Enter the Darcian velocity
   0.32100E-06
 Enter the final height of the sample
 0.10600
 Enter the final bottom effective stress
 5.57400
    STEP LOADING TEST DATA
 Enter the void ratio
 2.22000
 Enter the effective stress
10.70000
```

```
 Enter the coefficient of permeability
   0.14300E-07
           ANALYSIS PARAMETER , 0 FOR DEFAULT
 1. SEEPAGE INDUCED CONSOLIDATION ANALYSIS DATA
 Enter the number of nodes
    41
 Enter the minimum total approximated error
 0.00010
 Enter maximum number of iterations , ni2 ,
    25
 2. PARAMETER ESTIMATION ANALYSIS DATA
 Enter the lower limit of parameter B
-5.00000
 Enter the upper limit of parameter B
-0.05000
 Enter the initial guess of parameter B
-0.25000
 Enter the lower limit of D
 0.10000
  Enter the upper limit limit of D
 8.00000
 Enter the initial guess of parameter D
 3.50000
 Enter the minimum total normalized difference
 0.00010
 Enter Maximum number of iterations , ni1 ,
    50
```

The data entry session needed to run program SICTA is listed as follows :

```
SICTA
------------------------------------------------------------
          WELCOME TO PROGRAM SICTA
 This program will estimate the parameters for
 void ratio-effective stress and void ratio-
 permeability relations from the result of seepage
 induced consolidation test .

---------------------------------------------------------
          CONTROL MENU
      1. CREATE A NEW DATA FILE
      2. READ AN EXISTING DATA FILE
      3. EXIT
 ENTER YOUR OPTION..?
2
-------------------------------------------------------


     ENTER THE  NAME OF EXISTING INPUT DATA  FILE
         ( maximum 30 characters )
Example1.dat
```

```
-------------------------------------------------------

        ENTER A NAME OF OUTPUT FILE
         (maximum 30 characters )

Example1.out
----------------------------------------------------------
      DESCRIPTION OF THE PROBLEM
       TITLE OF THE PROBLEM  IS
       China Clay , Test No.1
------------------------------------------------------------
    Seepage Induced Consolidation Test Data :
 Unit Weight of Water                 =          9.81000
 Unit Weight of Solids                =         26.09460
 Initial Height of the Sample         =          0.20400
 Void Ratio at zero effective stress =          8.00000
 Top Effective Stress                 =          0.00000
 Darcian Velocity                     =      0.32100E-06
 Final Height of the Sample           =          0.10600
 Final Bottom Effective Stress        =          5.57400
-------------------------------------------------------------
     Loading Test Results :
 Void Ratio                        =          2.22000
 Effective Stress                  =         10.70000
 Permeability Coefficient          =      0.14300E-07
------------------------------------------------------------
     Do you want to continue (YES/NO)?
y
-------------------------------------------------
         THE SOLUTION PROCESS

-------------------------------------------------------
   ITERATION NUMBER   =      1
   PARAMETERS B       =       -0.25000
   PARAMETER  D       =        3.50000
   TOTAL NORMALIZED DIFFERENCE =      0.36894E+00
-------------------------------------------------------

-------------------------------------------------------
   ITERATION NUMBER   =      2
   PARAMETERS B       =       -0.20581
   PARAMETER  D       =        3.55172
   TOTAL NORMALIZED DIFFERENCE =      0.69533E-01
-------------------------------------------------------

-------------------------------------------------------
   ITERATION NUMBER   =      3
   PARAMETERS B       =       -0.20072
   PARAMETER  D       =        3.68840
   TOTAL NORMALIZED DIFFERENCE =      0.57760E-02
-------------------------------------------------------

-------------------------------------------------------
```

```
ITERATION NUMBER  =      4
PARAMETERS B      =       -0.20072
PARAMETER  D      =       3.69466
TOTAL NORMALIZED DIFFERENCE =     0.91469E-04
-------------------------------------------------------
```

SICTA will generate the output file *Example1.out* . This file is available to the user in the diskette and is listed as follows :

```
----------------------------------------------------------
        DESCRIPTION OF THE PROBLEM
         TITLE OF THE PROBLEM  IS
        China Clay , Test No.1
---------------------------------------------------------
         Seepage Induced Consolidation Results :
 Unit Weight of Water                  =          9.81000
 Unit Weight of Solids                 =         26.09460
 Initial Height of the Sample          =          0.20400
 Void Ratio at zero effective stress =            8.00000
 Top Effective Stress                  =          0.00000
 Darcian   Velocity                    =      0.32100E-06
 Final Height of the Sample            =          0.10600
 Final Bottom Effective Stress         =          5.57400
---------------------------------------------------------
        Step Loading Test Results :
 Void Ratio                         =        2.22000
 Effective Stress                   =       10.70000
 Permeability Coefficient           =    0.14300E-07
-------------------------------------------------------

------------------------------------------------------
------------------------------------------------------

       THE OUTPUT RESULTS ARE LISTED AS FOLLOWS :
------------------------------------------------------
             PARAMETER ESTIMATION RESULTS

     Parameter A                  =        3.57366

     Parameter B                  =       -0.20072

     Parameter Z                  =        0.01804

     Parameter C                  =    0.75107E-09

     Parameter D                  =         3.69466

     Number of Iterations         =     4

     Total Normalized Difference  =     0.91469E-04

------------------------------------------------------
```

SELF WEIGHT AND SURCHARGE LOAD CONSOLIDATION RESULTS

Node No.	Void Ratio	Depth	Height
1	8.000	0.00000	0.14018
2	7.363	0.00492	0.13526
3	6.945	0.00952	0.13066
4	6.637	0.01395	0.12623
5	6.397	0.01819	0.12199
6	6.201	0.02234	0.11784
7	6.036	0.02636	0.11382
8	5.894	0.03032	0.10986
9	5.770	0.03417	0.10600
10	5.660	0.03799	0.10219
11	5.562	0.04172	0.09845
12	5.473	0.04543	0.09475
13	5.392	0.04906	0.09112
14	5.317	0.05268	0.08750
15	5.249	0.05622	0.08395
16	5.185	0.05976	0.08042
17	5.126	0.06324	0.07694
18	5.070	0.06670	0.07347
19	5.018	0.07012	0.07006
20	4.969	0.07353	0.06665
21	4.923	0.07688	0.06330
22	4.879	0.08024	0.05994
23	4.838	0.08355	0.05663
24	4.798	0.08686	0.05332
25	4.760	0.09012	0.05006
26	4.724	0.09339	0.04679
27	4.690	0.09661	0.04357
28	4.657	0.09984	0.04034
29	4.625	0.10302	0.03716
30	4.595	0.10621	0.03397
31	4.566	0.10936	0.03082
32	4.538	0.11252	0.02766
33	4.510	0.11564	0.02454
34	4.484	0.11877	0.02141
35	4.459	0.12185	0.01832
36	4.434	0.12495	0.01522
37	4.411	0.12801	0.01216
38	4.388	0.13109	0.00909
39	4.366	0.13412	0.00606
40	4.344	0.13717	0.00301
41	4.323	0.14018	0.00000

Top Effective Stress = 0.00000

Calculated Final Bottom Effective Stress = 0.36912

Calculated Final Height of the Sample = 0.14018

SEEPAGE INDUCED CONSOLIDATION RESULTS

Node No.	Void Ratio	Depth	Height
1	8.000	0.00000	0.10600
2	6.837	0.00477	0.10123
3	6.159	0.00897	0.09703
4	5.689	0.01292	0.09308
5	5.333	0.01658	0.08942
6	5.048	0.02012	0.08588
7	4.813	0.02344	0.08256
8	4.613	0.02671	0.07929
9	4.440	0.02981	0.07619
10	4.288	0.03288	0.07312
11	4.152	0.03581	0.07020
12	4.031	0.03872	0.06728
13	3.920	0.04151	0.06449
14	3.820	0.04430	0.06170
15	3.727	0.04697	0.05903
16	3.642	0.04966	0.05634
17	3.563	0.05224	0.05376
18	3.489	0.05483	0.05117
19	3.420	0.05733	0.04868
20	3.355	0.05984	0.04616
21	3.295	0.06226	0.04374
22	3.237	0.06471	0.04129
23	3.183	0.06707	0.03893
24	3.131	0.06945	0.03655
25	3.083	0.07175	0.03425
26	3.036	0.07408	0.03192
27	2.992	0.07632	0.02968
28	2.950	0.07861	0.02739
29	2.909	0.08080	0.02520
30	2.870	0.08304	0.02296
31	2.833	0.08519	0.02081
32	2.797	0.08738	0.01862
33	2.763	0.08949	0.01651
34	2.730	0.09165	0.01435
35	2.698	0.09372	0.01228
36	2.668	0.09584	0.01016
37	2.638	0.09788	0.00812
38	2.609	0.09997	0.00603
39	2.582	0.10197	0.00403
40	2.555	0.10403	0.00197
41	2.529	0.10600	0.00000

Top Effective Stress = 0.00000

Calculated Final Bottom Effective Stress = 5.57449

Calculated Final Height of the Sample = 0.10600

Number of Iterations	=	10
Total Approximated Error	=	0.15339E-04

The user is recommended to run the same existing data file *Example1.dat* as described before but with different name for the output file .

A.2 Sample 2

This sample shows how to run the existing data file *Example2.dat* which is listed as follows :

```
 ENTER A DESIGNATION TITLE
 ( maximum 70 characters )
  TEST NO
    SEEPAGE INDUCED CONSOLIDATION DATA
 Enter the unit weight of water
 9.81000
 Enter the unit weight of soil solid particles
26.09460
 Enter the initial height of the sample
 0.20400
 Enter the void ratio at zero effective stress
 8.00000
 Enter the top effective stress
 0.00000
 Enter the Darcian velocity
   0.32100E-06
 Enter the final height of the sample
 0.10600
 Enter the final bottom effective stress
 5.57400
    STEP LOADING TEST DATA
 Enter the void ratio
 2.22000
 Enter the effective stress
10.70000
 Enter the coefficient of permeability
   0.14300E-07
              ANALYSIS PARAMETER , 0 FOR DEFAULT
 1. SEEPAGE INDUCED CONSOLIDATION ANALYSIS DATA
 Enter the number of nodes
 0
 Enter the minimum total approximated error
 0
 Enter maximum number of iterations , ni2 ,
 0
 2. PARAMETER ESTIMATION ANALYSIS DATA
 Enter the lower limit of parameter B
 0
 Enter the upper limit of parameter B
 0
 Enter the initial guess of parameter B
```

```
0
Enter the lower limit of D
0
 Enter the upper limit limit of D
0
Enter the initial guess of parameter D
0
Enter the minimum total normalized difference
0.01
Enter Maximum number of iterations , ni1 ,
0
```

In this data file , all the analysis parameters are set to the default value except $error2 = .01$ which exceeds the maximum limit of $error2$. The data entry session for this case is listed as follows :

```
SICTA
------------------------------------------------------------
          WELCOME TO PROGRAM SICTA
 This program will estimate the parameters for
 void ratio-effective stress and void ratio-
 permeability relations from the result of seepage
 induced consolidation test .

---------------------------------------------------------
          CONTROL MENU
      1. CREATE A NEW DATA FILE
      2. READ AN EXISTING DATA FILE
      3. EXIT
 ENTER YOUR OPTION..?
2
-------------------------------------------------------


     ENTER THE  NAME OF EXISTING INPUT DATA  FILE
         ( maximum 30 characters )
Example2.dat
-------------------------------------------------------

         ENTER A NAME OF OUTPUT FILE
          (maximum 30 characters )
Example2.out
  ILLEGAL VALUE FOR  error1 , TRY AGAIN
```

As can be seen in this data entry session , an error message is displayed to the user and the execution of the program has been terminated . The user can fix this data by either entering 0 and so accepting the default value or entering a new value within the specified limits shown before and then run the program as described in Section A.1 .

A.3 Sample 3

Sample 1 shows how to create a new data file similar to the existing data file *Example1.dat* and then to run program SICTA . The new created data file and its corresponding output file will be named respectively as *Example2.dat* and *Example2.out* . The data entry session needed for this case is listed as follows :

```
SICTA
--------------------------------------------------------------
          WELCOME TO PROGRAM SICTA
 This program will estimate the parameters for
 void ratio-effective stress and void ratio-
 permeability relations from the result of seepage
 induced consolidation test .

-----------------------------------------------------------
          CONTROL MENU
      1. CREATE A NEW DATA FILE
      2. READ AN EXISTING DATA FILE
      3. EXIT
 ENTER YOUR OPTION..?
1
---------------------------------------------------------


       ENTER A NAME OF FILE TO STORE YOUR DATA
           ( maximum 30 characters )
Example2.dat
---------------------------------------------------------

         ENTER A NAME OF OUTPUT FILE
          (maximum 30 characters )
Example2.out
---------------------------------------------------------

             INPUT DATA
---------------------------------------------------------

         ENTER A DESIGNATION TITLE
          ( maximum 70 characters )
China Clay , Test No.1
----------------------------------------------------------
          SEEPAGE INDUCED CONSOLIDATION TEST DATA
---------------------------------------------------------


   Enter the unit weight of water
9.81
   Enter the unit weight of soil solid particles
26.0946
   Enter the initial height of the sample
.204
```

```
   Enter the  void ratio at zero effective stress
8.
   Enter the top effective stress
0.
   Enter the Darcian velocity
.321e-6
   Enter the final height of the sample
.106
   Enter the final bottom effective stress
5.574
-------------------------------------------------------

          STEP LOADING TEST DATA
-------------------------------------------------------

   Enter the void ratio
2.22
   Enter the effective stress
10.7
   Enter the coefficient of permeability
.143e-7
-------------------------------------------------------

            ANALYSIS PARAMETERS
     TO USE THE DEFAULT VALUE , JUST PRESS 0

     1. SEEPAGE INDUCED CONSOLIDATION ANALYSIS DATA
-------------------------------------------------------

  Enter the number of nodes
  (MAX.=100,MIN=30,DEFAULT=41 )
0
  Enter the minimum total approximated error
   (MAX.=1.e-3, MIN =1.e-5, DEFAULT =1.e-4 )
0
  Enter the maximum number of iteration needed
  to achieve this error
       (MAX.=30,MIN.=15,DEFAULT=25 )
0
-------------------------------------------------------

   2. PARAMETER ESTIMATION ANALYSIS DATA
-------------------------------------------------------

  Enter the  lower  limit of parameter B
      (  DEFAULT = MIN. = -5.0 )
0
  Enter the upper  limit of parameter B
        (  DEFAULT=MAX. = -.05 )
0
  Enter the initial guess of parameter B
      ( DEFAULT=-.25)
```

```
0
  Enter the lower limit of D
    (  DEFAULT = MIN.= .1 )
0
  Enter the upper limit of D
     (  DEFAULT=MAX.=8. )
0
  Enter the initial guess of parameter D
          ( DEFAULT =3.5 )
0
  Enter the minimum total normalized difference
   ( MAX.=1.e-3, MIN.=1.e-5 ,DEFAULT= 1.e-4 )
0
  Enter the maximum number of iterations needed
  to achieve the min. total normalized difference
        (MAX.=60,MIN.=40,DEFAULT=50 )
0
-----------------------------------------------------------
       DESCRIPTION OF THE PROBLEM
        TITLE OF THE PROBLEM  IS
        China Clay , Test No.1
-------------------------------------------------------------
     Seepage Induced Consolidation Test Data :
 Unit Weight of Water                  =           9.81000
 Unit Weight of Solids                 =          26.09460
 Initial Height of the Sample          =           0.20400
 Void Ratio at zero effective stress =             8.00000
 Top Effective Stress                  =           0.00000
 Darcian Velocity                      =       0.32100E-06
 Final Height of the Sample            =           0.10600
 Final Bottom Effective Stress         =           5.57400
--------------------------------------------------------------
      Loading Test Results :
 Void Ratio                         =         2.22000
 Effective Stress                   =        10.70000
 Permeability Coefficient           =     0.14300E-07
-------------------------------------------------------------
      Do you want to continue (YES/NO)?
y
--------------------------------------------------
         THE SOLUTION PROCESS

------------------------------------------------------
   ITERATION NUMBER  =      1
   PARAMETERS B      =       -0.25000
   PARAMETER  D      =       3.50000
   TOTAL NORMALIZED DIFFERENCE =      0.36894E+00
--------------------------------------------------------

------------------------------------------------------
   ITERATION NUMBER  =      2
   PARAMETERS B      =       -0.20581
```

```
   PARAMETER  D         =         3.55172
   TOTAL NORMALIZED DIFFERENCE =      0.69533E-01
-------------------------------------------------------

-------------------------------------------------------
   ITERATION NUMBER  =       3
   PARAMETERS B      =         -0.20072
   PARAMETER  D      =        3.68840
   TOTAL NORMALIZED DIFFERENCE =      0.57760E-02
-------------------------------------------------------

-------------------------------------------------------
   ITERATION NUMBER  =       4
   PARAMETERS B      =         -0.20072
   PARAMETER  D      =        3.69466
   TOTAL NORMALIZED DIFFERENCE =      0.91469E-04
-------------------------------------------------------
```

The user is recommended to run the same data entry session as described before and then to compare the new created data file *Example2.dat* and *Example2.out* with *Example1.dat* and *Example1.out* respectively .

Once a data file is created , it can be considered , after any modification , as an existing data file .

A.4 Sample 4

This sample shows how to create a data file with the entered analysis parameters different from the default parameters and examples of the error messages which might appear to the user . The data entry session for this case is listed as follows :

```
SICTA
-------------------------------------------------------------
          WELCOME TO PROGRAM SICTA
 This program will estimate the parameters for
 void ratio-effective stress and void ratio-
 permeability relations from the result of seepage
 induced consolidation test .

-------------------------------------------------------------
          CONTROL MENU
      1. CREATE A NEW DATA FILE
      2. READ AN EXISTING DATA FILE
      3. EXIT
 ENTER YOUR OPTION..?
1
-------------------------------------------------------------
```

```
       ENTER A NAME OF FILE TO STORE YOUR DATA
           ( maximum 30 characters )
Example2.dat
--------------------------------------------------------

         ENTER A NAME OF OUTPUT FILE
          (maximum 30 characters )
Example2.out
--------------------------------------------------------

             INPUT DATA
--------------------------------------------------------

         ENTER A DESIGNATION TITLE
          ( maximum 70 characters )

China Clay , Test No.1
---------------------------------------------------------
          SEEPAGE INDUCED CONSOLIDATION TEST DATA
--------------------------------------------------------

   Enter the unit weight of water
9.81
   Enter the unit weight of soil solid particles
26.0946
   Enter the initial height of the sample
.204
   Enter the  void ratio at zero effective stress
8.
   Enter the top effective stress
0.
   Enter the Darcian velocity
.321e-6
   Enter the final height of the sample
.106
   Enter the final bottom effective stress
5.574
--------------------------------------------------------

          STEP LOADING TEST DATA
--------------------------------------------------------

   Enter the void ratio
2.22
   Enter the effective stress
10.7
   Enter the coefficient of permeability
.143e-7
--------------------------------------------------------

            ANALYSIS PARAMETERS
     TO USE THE DEFAULT VALUE , JUST PRESS 0
```

```
     1. SEEPAGE INDUCED CONSOLIDATION ANALYSIS DATA
-------------------------------------------------------

  Enter the number of nodes
  (MAX.=100,MIN=30,DEFAULT=41 )
0
  Enter the minimum total approximated error
   (MAX.=1.e-3, MIN =1.e-5, DEFAULT =1.e-4 )
0
  Enter the maximum number of iteration needed
  to achieve this error
       (MAX.=30,MIN.=15,DEFAULT=25 )
60
  ILLEGAL VALUE FOR ni2 , TRY AGAIN
  Enter the maximum number of iteration needed
  to achieve this error
       (MAX.=30,MIN.=15,DEFAULT=25 )
0
-------------------------------------------------------

   2. PARAMETER ESTIMATION ANALYSIS DATA
-------------------------------------------------------

  Enter the  lower  limit of parameter B
      (  DEFAULT = MIN. = -5.0 )
-4.
  Enter the upper  limit of parameter B
        (  DEFAULT=MAX. = -.05 )
-.1
  Enter the initial guess of parameter B
      ( DEFAULT=-.25)
-.08
  ILLEGAL VALUE FOR B , TRY AGAIN
  Enter the initial guess of parameter B
      ( DEFAULT=-.25)
-.2
  Enter the lower limit of D
    (  DEFAULT = MIN.= .1 )
0
  Enter the upper limit of D
     (  DEFAULT=MAX.=8. )
0
  Enter the initial guess of parameter D
          ( DEFAULT =3.5 )
0
  Enter the minimum total normalized difference
   ( MAX.=1.e-3, MIN.=1.e-5 ,DEFAULT= 1.e-4 )
.01
  ILLEGAL VALUE FOR  error1 , TRY AGAIN
  Enter the minimum total normalized difference
   ( MAX.=1.e-3, MIN.=1.e-5 ,DEFAULT= 1.e-4 )
```

```
0.
  Enter the maximum number of iterations needed
  to achieve the min. total normalized difference
        (MAX.=60,MIN.=40,DEFAULT=50 )
70
  ILLEGAL VALUE FOR ni1 ,TRY AGAIN
  Enter the maximum number of iterations needed
  to achieve the min. total normalized difference
        (MAX.=60,MIN.=40,DEFAULT=50 )
45
----------------------------------------------------------
       DESCRIPTION OF THE PROBLEM
        TITLE OF THE PROBLEM  IS
        China Clay , Test No.1
------------------------------------------------------------
     Seepage Induced Consolidation Test Data :
 Unit Weight of Water                    =         9.81000
 Unit Weight of Solids                   =        26.09460
 Initial Height of the Sample            =         0.20400
 Void Ratio at zero effective stress =             8.00000
 Top Effective Stress                    =         0.00000
 Darcian Velocity                        =     0.32100E-06
 Final Height of the Sample              =         0.10600
 Final Bottom Effective Stress           =         5.57400
-------------------------------------------------------------
      Loading Test Results :
 Void Ratio                          =         2.22000
 Effective Stress                    =        10.70000
 Permeability Coefficient            =     0.14300E-07
------------------------------------------------------------
      Do you want to continue (YES/NO)?
y
-------------------------------------------------
         THE SOLUTION PROCESS

-----------------------------------------------------
   ITERATION NUMBER   =      1
   PARAMETERS B       =       -0.20000
   PARAMETER  D       =        3.50000
   TOTAL NORMALIZED DIFFERENCE =     0.19313E+00
-------------------------------------------------------

-----------------------------------------------------
   ITERATION NUMBER   =      2
   PARAMETERS B       =       -0.20212
   PARAMETER  D       =        3.66862
   TOTAL NORMALIZED DIFFERENCE =     0.76743E-02
-------------------------------------------------------

-----------------------------------------------------
   ITERATION NUMBER   =      3
   PARAMETERS B       =       -0.20073
   PARAMETER  D       =        3.69409
```

```
   TOTAL NORMALIZED DIFFERENCE =      0.37752E-03
-------------------------------------------------------

-----------------------------------------------------
   ITERATION NUMBER   =      4
   PARAMETERS B       =       -0.20070
   PARAMETER  D       =       3.69492
   TOTAL NORMALIZED DIFFERENCE =      0.50662E-05
-------------------------------------------------------
```

Appendix B : Computer Program

```
C*********************************************************************
C= DATE = 2-18-1992
C=DECK SICTA
C=PREPARED BY   : A.NASER A.HEJLEH
C=SUPERVISED BY : DOBROSLAV ZNIDARCIC
C=PURPOSE       : Parameter estimation of void ratio -effective
C                 stress and void ratio-permeability relationships
C                 from the result of seepage induced consolidation test .
C*********************************************************************
C
C    INPUT DATA    :   see  subroutine INPUT   .
C    ------------
C    OUTPUT DATA
C    ------------
C   x(1),x(2)       : values of the estimated parameters B,D during
C                     successive iterations  , and at the end , the
C                     best estimation of parameters B, D  .
C                     At iteration K , x(1),x(2) are stored as
C                     a1(k),a2(k) respectively .
C
C   da(1),da(2)     : step size of the parameters B,D between
C                     successive iterations  .
C   hb(1),hb(2)     : values of the normalized difference vector at
C                     current iterate .
C     error(k)      : absolute total normalized difference at the
C                     current iterate = hb(1) + hb(2)
C     k             : iteration counter  .
C    ich            : number of iterations when stopping criteria
C                     are achieved , zero elsewhere .
C
C     NOTE          :  other output results are presented in
C    ------            subroutine OUTPUT.
C
C*********************************************************************

      PROGRAM SICTA
      integer                MAXETER
      parameter              (MAXETER=60)
      double precision       a1(MAXETER),a2(MAXETER),error(MAXETER)
      double precision       x(2),hb(2),da(2)
      double precision       gw,gs,dle,eo,sigmat,velo,es,sigmas,
     $                        perms,hf,sigmaf,error1,error2
      double precision       B,BL,BH,D,DL,DH
      integer                k,ich,numnod,ni1,ni2
c

      common/nas1/gw,gs,sigmat,dle,velo,numnod,ni2,error2
      common/nas2/eo,es,sigmas,perms
      common/nas3/hf,sigmaf

C---------------------------------------------------------------------
c
c receiving all input data

       call INPUT(gw,gs,dle,eo,sigmat,velo,es,sigmas,perms,
     $             hf,sigmaf,
     $             numnod,B,BL,BH,D,DL,DH,
     $             error1,ni1,error2,ni2 )

      a1(1)=B
```

```
      a2(1)=D
      ich =0.
C-----------------------------------------------------------------
c begin parameter analysis......................
c
      do 1 k=1,60
c  to alter the step size in B,D in the same proportion
c  if one of the current iterate exceed one of the limits.........
       if(k.ne.1)then
        call CHECK(k,a1,a2,BL,BH,DL,DH)
       endif
c
       x(1)=a1(k)
       x(2)=a2(k)
c
c  estimation of the total normalized difference ..
      call COMMAND(x,hb,ich)
      error(k)=abs(hb(1))+abs(hb(2))
      if(k.gt.1.and.error(k).gt.(error(k-1)+.02))then
c
c   search for better estimates
       call SEARCH(k,a1,a2,error,x,hb)
       endif
c
c screen output
       call OUTPUT1 (k,error(k),x)
c
c checking termination criteria
       if(error(k).lt.error1.or.k.eq.ni1) go to 12
c
c calculation of next step size
       call GRADIENT (x,hb,da)
        a1(k+1)=x(1)+da(1)
        a2(k+1)=x(2)+da(2)
  1    continue
  12   continue
       ich=k
       call COMMAND(x,hb,ich)
       stop
       end
C*******************************************************************
C=END FORTRAN
C=DECK INPUT
C=PURPOSE= prepare all input data needed for
C          parameter estimation algorithm .
C=BLOCK FORTRAN
C*******************************************************************
C
C                      ''   STARTING THE PROGRAM  ''
C                           -------------------
C  The execution of program SICTA can be started by typing SICTA .
C  Immediately after start up , the user has the option to create
C  a new data file or to pass the data to the program through
C  an existing data file . A new data file will be created  through
C  an interactive  mode option.If the user choose
C  this  option, the user will be asked to give a name for this
C  file which will store all the data entered . If the user choose
C  to pass the data through an existing file data , he will be
C  asked to give the name of file which contain all input data
C  ;the format of such file are exactly the same as the file
```

```
C  which will store all the data if interactive mode option is
C  is chosen . Hence , after the data in a previous stored file
C  are modified , this file can be used as an existing data file .
C  The  existing data file contains the same order of questions
C  and answers as if the data are entered through interactive
C  mode option .
C  The user will then be  asked to give a name for
C  the output file .
C
C  In the first question , the user will be asked to give
C  a designation title of the  problem  .
C
C  Once all input data are entered , a summary screen of all
C  input data will appear to the user . Then , the user
C  will be asked wether to continue or to stop .
C-----------------------------------------------------------------------
C
C              ''   INPUT DATA    ''
C             -------------------------
C              Two types of data are needed  :
C        A. Data which describe the test results . The
C           user must enter these data .
C        B. Data which are needed to analyze the the numerical
C           solution of the seepage induced consolidation
C           and the parameter estimation algorithm. The
C           user has the option to leave the default recommended
C           data . To go with the default option , the user
C           should respond to the question by entering  0 .
C           The Default value and either  the upper
C           or the lower  values of each of these data
C           will appear to the user in the screen . The user will
C           be given twenty trials to enter suitable values within
C           the specified limits before the program is terminated .
C
C-----------------------------------------------------------------------
C                    A .  TEST RESULT  DATA
C
C        1. Water and soil description :
C              gw      = unit weight of water .
C              gs      = unit weight of soil solid particles
C        2. Seepage induced consolidation test results :
C              Ho      = initial height of the sample .
C              eo      = void ratio at zero effective stress .
C              sigmat  = top effective stress .
C              velo    = Darcian velocity  .
C              sigmaf  = final bottom effective stress at steady
C                        state conditions
C               hf     = final height of the sample
C
C       3.  Step Loading test results
C               es     =  void ratio
C              sigmas  =   effective stress
C               perms  = permeability coefficient
C-----------------------------------------------------------------------
C                    B . ANALYSIS DATA
C
C   1. Seepage induced consolidation analysis data :
C      numnod  = number of nodes used to  discretize
C                 the sample length .
C               (MAX.=100,MIN=30,DEFAULT =41 )
```

```
C     error2  = The minimum  total approximated error needed
C               to be achieved in the numerical simulation
C                of the seepage induced consolidation .
C              (MAX.=1.e-3 , MIN =1.e-5   , DEFAULT =1.e-4 )
C      ni2    = Number of iterations needed  to achieve error2 .
C                  (MAX.=30,MIN=15,DEFAULT=25)
C
C   2. Parameter estimation analysis data :
C      BL     = lower limit value of  B    ( DEFAULT =-5.0 )
C      BH     = upper limit  value of  B    ( DEFAULT =-0.05 )
C      B      = initial  guess of B ( DEFAULT =-.25 )
C      DL     = lower limit value of D (DEFAULT=0.1)
C      DH     = upper limit  value of D (DEFAULT = 8.)
C      D      = initial guess  of D ( DEFAULT =3.5 )
C      error1 = the minimum absolute total normalized
C               difference needed to be achieved in the parameter
C               estimation algorithm .
C            (MAX.=1.e-3, MIN. =1.e-5 ,DEFAULT = 1.e-4 )
C      ni1    = Number of iterations needed to achieve error1 .
C                   (MAX.=60 ,MIN.=40,DEFAULT= 50 )
C
C-----------------------------------------------------------------
C    OUTPUT : dle = Length between any two successive nodes
C                   in material coordinates .
C*****************************************************************
      subroutine INPUT (gw,gs,dle,eo,sigmat,velo,es,sigmas,perms,
     $                  hf,sigmaf,
     $                  numnod,B,BL,BH,D,DL,DH,
     $                  error1,ni1,error2,ni2)

       character dat*30,out*30,data*30,title*70,yesno
     $ ,message*80
       PARAMETER          (MAXNOD=100)
       integer             numnod,ni1,ni2,m1,m2,i,im,k
       double precision   gw,gs,Ho,sigmat,velo ,velo1,eo,
     $                     es,sigmas,perms,hf,sigmaf,dle,
     $                     B,BL,BH,D,DL,DH,error1,error2
       common /nas4/out
       common /nas5/title,Ho
       write (*,20)
 20    format (/,
     $ '--------------------------------------------------------'
     $,/ ,'               WELCOME TO PROGRAM SICTA                 '
     $,/ ,'  This program will estimate the parameters for '
     $ ,/,'  void ratio-effective stress and void ratio- '
     $,/ ,'  permeability relations from the result of seepage '
     $,/ ,'  induced consolidation test . '
     $,/,'                                                        '
     $,/ ,'--------------------------------------------------------')
  1   continue
      do 5 k=1,10
      write(*,21)
 21    format( '          CONTROL MENU              ',
     $/,'        1. CREATE A NEW DATA FILE    '
     $/,'        2. READ AN EXISTING DATA FILE  '
     $/,'        3. EXIT ' ,
     $/, '  ENTER YOUR OPTION..? ' )
      read(*,*)im
      if(im.eq.3 )stop
      if(im.eq.2)go to 2
```

```
      if(im.eq.1)go to 3
5     continue
2      write(*,50)
       write(*,22)
22    format(/,
    $'       ENTER THE  NAME OF EXISTING INPUT DATA  FILE ',/,
    $'            ( maximum 30 characters ) ')
        read'(A)',dat
       open(unit=5,file=dat,status='unknown')
       m2=5
       go to 10
 3     write(*,50)
       write(*,4)
4      format(/,
    $'         ENTER A NAME OF FILE TO STORE YOUR DATA  ',/,
    $'              ( maximum 30 characters )')
        read'(A)',data
        open(unit=4,file=data,status='unknown')
        m1=4
10      write(*,50)
        write(*,*)'            ENTER A NAME OF OUTPUT FILE '
        write(*,*)'             (maximum 30 characters )'
        read'(A)',out
        if(im.eq.2)go to 100
        write(*,50)
        write(*,*)'                INPUT DATA      '
        write(*,50)
        write(*,457)
457     format(
    $           '            ENTER A DESIGNATION TITLE  ' )
        write(*,*)'             ( maximum 70 characters )   '
        write(m1,*)' ENTER A DESIGNATION TITLE  '
        write(m1,*)' ( maximum 70 characters )  '
        read'(A)',title
        write(m1,67)title
 67     format(t2,A70)
        write(*,42)
        write(m1,115)
 115    format(t5,' SEEPAGE INDUCED CONSOLIDATION DATA ')
 42     format(/
    $   '-----------------------------------------------------',
    $   /,T10, '  SEEPAGE INDUCED CONSOLIDATION TEST DATA')
        write(*,50)
        write(*,*) '   Enter the unit weight of water '
        write(m1,*) ' Enter the unit weight of water '
        read(*,*)gw
        write(m1,200)gw
        write(*,*) '   Enter the unit weight of soil solid particles'
        write(m1,*) ' Enter the unit weight of soil solid particles  '
        read(*,*)gs
        write(m1,200)gs
        write(*,*) '   Enter the initial height of the sample '
        write(m1,*) ' Enter the initial height of the sample '
        read (*,*)Ho
        write (m1,200)Ho
        write(*,*) '   Enter the  void ratio at zero effective stress '
        write(m1,*)' Enter the void ratio at zero effective stress'
        read (*,*)eo
        write (m1,200)eo
        write(*,*) '   Enter the top effective stress '
```

```
      write(m1,*) ' Enter the top effective stress '
      read(*,*)sigmat
      write(m1,200)sigmat
       write(*,*) '   Enter the Darcian velocity '
       write(m1,*) ' Enter the Darcian velocity '
      read(*,*)  velo
      write(m1,201)velo
      write(*,*) '   Enter the final height of the sample  '
      write(m1,*) ' Enter the final height of the sample  '
      read(*,*)hf
      write(m1,200)hf
      write(*,*) '   Enter the final bottom effective stress  '
      write(m1,*) ' Enter the final bottom effective stress  '
      read(*,*)sigmaf
      write(*,50)
      write(m1,200)sigmaf
      write(m1,*)'    STEP LOADING TEST DATA  '
      write(*,*)'           STEP LOADING TEST DATA '
      write(*,50)
      write(*,*) '   Enter the void ratio '
      write(m1,*)' Enter the void ratio '
      read (*,*)es
      write (m1,200)es
      write(*,*)'   Enter the effective stress '
      write(m1,*)' Enter the effective stress '
      read(*,200)sigmas
      write(m1,200)sigmas
      write(*,*)'   Enter the coefficient of permeability '
      write(m1,*) ' Enter the coefficient of permeability '
      read(*,*)perms
      write(m1,201)perms
      write(*,50)
      write(*,54)
      write(m1,55)
      write(m1,*)' 1. SEEPAGE INDUCED CONSOLIDATION ANALYSIS DATA '
55    format(T12, ' ANALYSIS PARAMETER , 0 FOR DEFAULT ')
54    format( T12,'  ANALYSIS PARAMETERS ' , /,
     $ t6, ' TO USE THE DEFAULT VALUE , JUST PRESS 0 ',//,
     $ T6, ' 1. SEEPAGE INDUCED CONSOLIDATION ANALYSIS DATA ' )
      write(*,50)
      write(m1,*) ' Enter the number of nodes '
      do 40 i=1,20
      write(*,*) '  Enter the number of nodes '
      write(*,*) '  (MAX.=100,MIN=30,DEFAULT=41 ) '
      read(*,*)numnod
      if(numnod.eq.0)numnod=41
      if(numnod.lt.30.or.numnod.gt.100) then
      write(*,*)'  ILLEGAL VALUE FOR NUMBER OF NODES  , TRY AGAIN '
      else
      go to 41
      endif
40    continue
41    write(m1,202)numnod
      write(m1,*)' Enter the minimum total approximated error '
      do 88 i=1,20
      write(*,*)'  Enter the minimum total approximated error '
      write(*,*)'   (MAX.=1.e-3, MIN =1.e-5, DEFAULT =1.e-4 ) '
      read(*,*)error2
      if(error2.eq.0)error2=1.e-4
      if(error2.lt.1.e-5.or.error2.gt.1.e-3) then
```

```
      write(*,*)'  ILLEGAL VALUE FOR  error2 , TRY AGAIN '
      else
      go to 89
      endif
 88   continue
 89   write(m1,200)error2
      write(m1,*)' Enter maximum number of iterations , ni2 , '
      do 90 i=1,20
      write(*,25)
25    format('   Enter the maximum number of iteration needed',
   $      /,'   to achieve this error')
      write (*,*)'         (MAX.=30,MIN.=15,DEFAULT=25 )'
      read(*,*)ni2
      if(ni2.eq.0)ni2=25
      if(ni2.lt.15.or.ni2.gt.30) then
      write(*,*)'  ILLEGAL VALUE FOR ni2 , TRY AGAIN '
      else
      go to 91
      endif
 90   continue
 91   write(m1,202)ni2
      write(*,50)
      write(*,*)'   2. PARAMETER ESTIMATION ANALYSIS DATA '
      write(m1,*)' 2. PARAMETER ESTIMATION ANALYSIS DATA '
      write(*,50)
      write(m1,*)' Enter the lower limit of parameter B '
      do 112 i=1,20
      write(*,*)'  Enter the  lower  limit of parameter B '
      write(*,*)'      (  DEFAULT = MIN. = -5.0 ) '
      read(*,*)BL
      if(BL.eq.0)BL=-5.0
      if(BL.lt.-5.0.or.BL.gt.-.049999) then
      write(*,*)'  ILLEGAL VALUE FOR  BL , TRY AGAIN '
      else
      go to 113
      endif
 112  continue
 113  write(m1,200)BL
      write(m1,*)' Enter the upper limit of parameter B '
      do 46 i=1,20
      write(*,*)'  Enter the upper  limit of parameter B '
      write(*,*)'        (  DEFAULT=MAX. = -.05 ) '
      read(*,*)BH
      if(BH.eq.0)BH=-.05
      if(BH.lt.-5.0.or.BH.gt.-.049999) then
      write(*,*)'  ILLEGAL VALUE FOR  BH , TRY AGAIN '
      else
      go to 47
      endif
 46   continue
 47   write(m1,200)BH
      write(m1,*) ' Enter the initial guess of parameter B '
      do 110 i=1,20
      write(*,*) '  Enter the initial guess of parameter B '
      write(*,*) '       ( DEFAULT=-.25) '
      read(*,*)B
      if(B.eq.0)B=-.25
      if(B.lt.BL.or.B.gt.BH) then
      write(*,*)'  ILLEGAL VALUE FOR B , TRY AGAIN '
      else
```

```
      go to 111
      endif
110    continue
111    write(m1,200)B
      write(m1,*)' Enter the lower limit of D '
      do 80 i=1,20
      write(*,*)'  Enter the lower limit of D '
      write(*,*)'     (  DEFAULT = MIN.= .1 )'
      read(*,*)DL
      if(DL.eq.0)DL=0.1
      if(DL.lt.0.09999.or.DL.gt.8.0) then
      write(*,*)'  ILLEGAL VALUE FOR DL , TRY AGAIN '
      else
      go to 81
      endif
80    continue
81    write(m1,200)DL
      write(m1,*)'  Enter the upper limit limit of D '
      do 82 i=1,20
      write(*,*)'  Enter the upper limit of D '
      write(*,*)'       (  DEFAULT=MAX.=8. )   '
      read(*,*)DH
      if(DH.eq.0)DH=8.
      if(DH.lt.0.09999.or.DH.gt.8.0) then
      write(*,*)'  ILLEGAL VALUE FOR DH , TRY AGAIN '
      else
      go to 83
      endif
82    continue
83    write(m1,200)DH
      write(m1,*)' Enter the initial guess of parameter D'
      do 48 i=1,20
      write(*,*)'  Enter the initial guess of parameter D'
      write(*,*)'            ( DEFAULT =3.5 )'
      read(*,*)D
      if(D.eq.0)D=3.5
      if(D.lt.DL.or.D.gt.DH) then
      write(*,*)'  ILLEGAL VALUE FOR D , TRY AGAIN '
      else
      go to 49
      endif
48    continue
49    write(m1,200)D
      write(m1,*)' Enter the minimum total normalized difference '
      do 84 i=1,20
      write(*,*)'  Enter the minimum total normalized difference '
      write(*,*)'    ( MAX.=1.e-3, MIN.=1.e-5 ,DEFAULT= 1.e-4 )'
      read(*,*)error1
      if(error1.eq.0)error1=1.e-4
      if(error1.lt.1.e-5.or.error1.gt.1.e-3) then
      write(*,*)'  ILLEGAL VALUE FOR  error1 , TRY AGAIN '
      else
      go to 85
      endif
84    continue
85    write(m1,200)error1
       write(m1,78)
78    format(
     $ '  Enter Maximum number of iterations , ni1 , ')
      do 86 i=1,20
```

```
      write(*,24)
24    format(/,'   Enter the maximum number of iterations needed',
   $         /,'   to achieve the min. total normalized difference ')
      write (*,*)'          (MAX.=60,MIN.=40,DEFAULT=50 )'
      read(*,*)ni1
      if(ni1.eq.0)ni1=50
      if(ni1.lt.40.or.ni1.gt.60) then
      write(*,*)'  ILLEGAL VALUE FOR ni1 ,TRY AGAIN '
      else
      go to 87
      endif
86    continue
87    write(m1,202)ni1

100   if(im.eq.1)go to 101
      read(m2,211)message
      read(m2,211)message
      read(m2,211)title
      read(m2,211)message
      read(m2,211)message
      read(m2,*)gw
      read(m2,211)message
      read(m2,*)gs
      read(m2,211)message
      read  (m2,*)Ho
      read(m2,211)message
      read  (m2,*)eo
      read(m2,211)message
      read(m2,*)sigmat
      read(m2,211)message
      read(m2,*)  velo
      read(m2,211)message
      read(m2,*)hf
      read(m2,211)message
      read(m2,*)sigmaf
      read(m2,211)message
      read(m2,211)message
      read  (m2,*)es
      read(m2,211)message
      read(m2,*)sigmas
      read(m2,211)message
      read(m2,*)perms
      read(m2,211)message
      read(m2,211)message
      read(m2,211)message
      read(m2,*)numnod
      if(numnod.eq.0)numnod=41
      if(numnod.lt.30.or.numnod.gt.100) then
      write(*,*)'  ILLEGAL VALUE FOR  NUMBER OF NODES , TRY AGAIN '
      stop
      endif
      read(m2,211)message
      read(m2,*)error2
      if(error2.eq.0)error2=1.e-4
      if(error2.lt.1.e-5.or.error2.gt.1.e-3) then
      write(*,*)'  ILLEGAL VALUE FOR  error2 , TRY AGAIN '
      stop
      endif
      read(m2,211)message
      read(m2,*)ni2
```

```
if(ni2.eq.0)ni2=25
if(ni2.lt.15.or.ni2.gt.30) then
write(*,*)'  ILLEGAL VALUE FOR  ni2 ,TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,211)message
read(m2,*)BL
if(BL.eq.0)BL=-5.
if(BL.lt.-5.0.or.BL.gt.-.049999) then
write(*,*)'  ILLEGAL VALUE FOR  BL , TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,*)BH
if(BH.eq.0)BH=-.05
if(BH.lt.-5.0.or.BH.gt.-.049999) then
write(*,*)'  ILLEGAL VALUE FOR  BH , TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,*)B
if(B.eq.0)B=-.25
if(B.lt.BL.or.B.gt.BH) then
write(*,*)'  ILLEGAL VALUE FOR  B , TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,*)DL
if(DL.eq.0)DL=0.1
if(DL.lt.0.09999.or.DL.gt.8.) then
write(*,*)'  ILLEGAL VALUE FOR DL , TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,*)DH
if(DH.eq.0)DH=8.
if(DH.lt.0.09999.or.DH.gt.8.) then
write(*,*)'  ILLEGAL VALUE FOR  DH , TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,*)D
if(D.eq.0)D=3.5
if(D.lt.DL.or.D.gt.DH) then
write(*,*)'  ILLEGAL VALUE FOR  D , TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,*)error1
if(error1.eq.0)error1=1.e-4
if(error1.lt.1.e-5.or.error1.gt.1.e-3) then
write(*,*)'  ILLEGAL VALUE FOR  error1 , TRY AGAIN '
stop
endif
read(m2,211)message
read(m2,*)ni1
if(ni1.eq.0)ni1=50
if(ni1.lt.40.or.ni1.gt.60) then
write(*,*)'  ILLEGAL VALUE FOR  ni1 ,TRY AGAIN '
```

```
        stop
        endif
 101    continue
c Calculations of the length between any two
c successive nodes in material coordinates  .
        x1=abs(numnod-1)
        dle=Ho/((1.+eo)*x1)
  50    format(
    $   '----------------------------------------------------------',/)
 200   format(f9.5)
 201   format(e15.5)
 202   format(I7)
       velo1=velo
 211   format( A70)
        write(*,11) title,gw,gs,ho,eo,sigmat,velo,hf,sigmaf,
    $    es,sigmas,perms
  11    format(//,
    $ '-----------------------------------------------------------',
    $    /,'          DESCRIPTION OF THE PROBLEM                    ',
    $   /,'           TITLE OF THE PROBLEM  IS                       ',
    $ /, t10,A50,
    $/,'---------------------------------------------------------------',
    $  /,'       Seepage Induced Consolidation Test Data :           ',
    $  /, '  Unit Weight of Water                  =  ',f15.5,
    $   /,'  Unit Weight of Solids                 =  ',f15.5,
    $   /,'  Initial Height of the Sample          =  ',f15.5,
    $   /,'  Void Ratio at zero effective stress =  ',f15.5,
    $   /,'  Top Effective Stress                  =  ',f15.5,
    $   /,'  Darcian Velocity                      =  ',e15.5,
    $   /,'  Final Height of the Sample            =  ', f15.5,
    $   /,'  Final Bottom Effective Stress         =  ',f15.5,
    $/,'---------------------------------------------------------------',
    $  /,'        Loading Test Results :                  ',
    $   /,'  Void Ratio                         = ',f15.5,
    $   /,'  Effective Stress                   = ',f15.5,
    $   /,'  Permeability Coefficient           = ',e15.5,
    $ /,'---------------------------------------------------------------',
    $         f15.5 )

       write(*,*)'       Do you want to continue (YES/NO)?    '
        read '(A)', yesno
        if(yesno.eq.'Y'.or.yesno.eq.'y') go to 60
       write(*,*) '    PROGRAM  EXECUTION HAS BEEN TERMINATED '
       write(*,50)
       stop
  60   continue
       write(*,61)
  61   format(/,'-----------------------------------------------------',
    $         /,'           THE SOLUTION PROCESS            ' )
       return
       end
C*************************************************************************
C=DECK OUTPUT1
C=PURPOSE : output data on the screen including iteration no ,k,
C           current estimation of B,D , and the corresponding error
C*************************************************************************
      subroutine OUTPUT1 (k,error,x)
      double precision error,x(2)
      write(*,1)k,x(1),x(2),error
  1   format(/,
```

```
     $'-------------------------------------------------------',
     $/,'     ITERATION NUMBER  =', I6   , /,
     $'    PARAMETERS B        =  ', f12.5,/,
     $'    PARAMETER  D        = ',f12.5,/,
     $'    TOTAL NORMALIZED DIFFERENCE = ', e15.5 /,
     $'-------------------------------------------------------')
       return
       end
C**********************************************************************
C=DECK=CHECK
C=PURPOSE= to alter the step size in B,D in the same proportion
C  only if the current iterate exceeded one of the limits
C*********************************************************************
C
C    INPUT DATA
C    -----------
C     BL,BH,DL,DH : as defined in the main program .
C
C    INPUT AND OUTPUT DATA
C    ---------------------
C       a1(k),a2(k)  : current estimate of B,D before any modification
C       a1(k),a2(k)  : current estimates of B,D after step size
C                      is altered if required .
C**********************************************************************
       subroutine CHECK(k,a1,a2,BL,BH,DL,DH)
       double precision      a1(*),a2(*)
       double precision      BL,BH,DL,DH,zz1,dd1,zz2,dd2,
     $                       zz3,dd3,zz4,dd4
       integer               k
c
c check maximum limit of B and if needed altering the step size
       if(a1(k).gt.BH)then
         zz1=(a2(k)-a2(k-1))/(a1(k)-a1(k-1))
         dd1=a1(k-1)-BH
         a2(k)=a2(k-1)-zz1*dd1
         a1(k)=BH
       endif
c
c check minimum limit of B and if needed altering the step size
       if(a1(k).lt.BL)then
         zz2=(a2(k)-a2(k-1))/(a1(k)-a1(k-1))
         dd2=a1(k-1)-BL
         a2(k)=a2(k-1)-zz2*dd2
         a1(k)=BL
       endif
c
c check minimum limit of D and if needed altering the step size
       if(a2(k).lt.DL)then
         zz3=(a1(k)-a1(k-1))/(a2(k)-a2(k-1))
         dd3=a2(k-1)-DL
         a1(k)=a1(k-1)-dd3*zz3
         a2(k)=DL
       endif
c
c check maximum limit of D and if needed altering the step size
       if(a2(k).gt.DH)then
         zz4=(a1(k)-a1(k-1))/(a2(k)-a2(k-1))
         dd4=a2(k-1)-DH
         a1(k)=a1(k-1)-dd4*zz4
         a2(k)=DH
```

```
      endif
c
      return
      end
C***********************************************************************
C=DECK GRADIENT
C=PURPOSE : estimation of the next step size in parameters B , D .
C***********************************************************************
C       INPUT DATA :
C      --------------
C       x(1),x(2)    : current iterate estimation of B,D
C
C       OUTPUT DATA
C      -------------
C       da(1),da(2)    : step size in the parameters B,D
C       ss(2,2)        : Jacopian matrix
C       det            : determinant of the Jacobian matrix
C***********************************************************************
        subroutine GRADIENT (x,hb,da)
        double precision x(2),hb(2),da(2),r(2),ss(2,2)
        double precision f1,f2,f3,f4,det
        r(1)=hb(1)
        r(2)=hb(2)

c  calculation of the Jacobian matrix
        x(1)=x(1)+.1e-4
        call COMMAND(x,hb,ich)
        f1=hb(1)
        f2=hb(2)
        x(1)=x(1)-.1e-4
        x(2)=x(2)+.1e-4
        call COMMAND(x,hb,ich)
        x(2)=x(2)-.1e-4
        f3=hb(1)
        f4=hb(2)
        ss(1,1)=-(f1-r(1))/.1e-4
        ss(2,1)=-(f2-r(2))/.1e-4
        ss(1,2)=-(f3-r(1))/.1e-4
        ss(2,2)=-(f4-r(2))/.1e-4
        det=ss(1,1)*ss(2,2)-ss(1,2)*ss(2,1)

c  calculation of the step size increment in B,D
        da(1)=(1./det)*(ss(2,2)*r(1)-ss(1,2)*r(2))
        da(2)=(1./det)*(-ss(2,1)*r(1)+ss(1,1)*r(2))
c
        return
        end

C***********************************************************************
C=DECK=SEARCH
C=PURPOSE= to search for better estimation of B,D using quadratic
C           interpolation up to 10 times
C***********************************************************************
C     INPUT DATA :
C    --------------
C       a1(k-1) , a2(k-1): the estimated parameters at iteration k-1
C       error(k-1)       : the estimated total normalized difference
C                          at iteration k-1
C       a1(k) , a2 (k)   : the estimated parameters at iteration k
C                          before the  search for better parameters .
```

```
C      error(k)          : the estimated total normalized difference
C                          at iteration k before the search for
C                          better parameters .
C    OUTPUT DATA :
C   --------------
C  a1(k),a2(k): the best B,D parameters at the end of search .
C
C  hb(1),hb(2): the error vector values at the best  parameters .
C
C  error(k)    : = hb(1)+hb(2)
C*************************************************************************
        subroutine SEARCH(k,a1,a2,error,x,hb)
        double precision a1(*),a2(*),error(*),x(*),hb(*)
        double precision s1,s2,fop,err ,d1,d2
        integer i ,k

        d1=a1(k)
        d2=a2(k)
c
c  begins  implementing quadratic interpolation up to ten times .
c  the slope s1 at a1(k-1) , a2(k-1), is always
c  constant for all iterations
           s1=-(error(k-1))
           do 22 i=1,10
c s2 should be estimated from the slope and the
c current approximated errors at the end points .
           s2=error(k)-error(k-1)-s1
c  estimating new B,D at which the error is expected to be minimum
          fop=(-s1)/(2.*s2)
          x(1)=a1(k-1)+fop*(a1(k)-a1(k-1))
          x(2)=a2(k-1)+fop*(a2(k)-a2(k-1))
          call COMMAND(x,hb,ich)
          err=hb(1)+hb(2)
c  if the search is failed  at the first step
       if(err.gt.error(k-1) )then
           a1(k)=x(1)
           a2(k)=x(2)
           error(k)=err
        else
           go to 23
        endif
 22    continue
 23    continue
        if(err.gt.error(k-1))then
           x(1)=(a1(k-1)+d1)/2.
           x(2)=(a2(k-1)+d2)/2.
           call COMMAND(x,hb,ich)
           a1(k)=x(1)
           a2(k)=x(2)
           error(k)=hb(1)+hb(2)
        else
           a1(k)=x(1)
           a2(k)=x(2)
           error(k)=err
        endif
        return
        end
C************************************************************************
C=DECK=COMMAND
C=PURPOSE : To determine the normalized difference vector components .
```

```
C------------------------------------------------------------------------
C   INPUT DATA  : see subroutine INPUT
C   ----------
C   OUTPUT DATA :
C   -----------
C   hb(1)    : The normalized difference error due the difference
C              between the calculated and the experimentally
C              obtained bottom effective stress .
C
C   hb(2)    : The normalized difference error due the difference
C              between the calculated and the experimentally
C              obtained final height of the sample .
C
C------------------------------------------------------------------------
      subroutine COMMAND(x,hb,ich)
      parameter (MAXNOD=100)
      double precision x(2),t(3),hb(2)
      double precision hf,sigmaf,hc,sigmac
      integer ich
      common/nas3/hf,sigmaf
c
      call tests (x,t)
      call seep  (x,t,hc,sigmac,ich)
c
c calculations of error vector values ...

       hb(1)=abs(1.-(sigmac/sigmaf))
       hb(2)=abs(1.-(hc/hf))

       return
       end
C************************************************************************
C=DECK=TESTS
C=PURPOSE : To determine the parameters A,C,Z from the tests
C           results and the current estimation of B,D
C------------------------------------------------------------------------
C    INPUT  DATA :
C            x(1),x(2) : current estimate of B and D
C   -------------
C    OUTPUT DATA
C    -----------
C           t(1) : estimation of the parameter A
C           t(2) : estimation of the parameter D
C           t(3) : estimation of the parameter Z
C
C------------------------------------------------------------------------
        subroutine tests(x,t)
        double precision x(2),t(3),eo,es,sigmas,perms,b,d,gg
        common/nas2/eo,es,sigmas,perms
c
         b=x(1)
         d=x(2)
         gg=(es/eo)**(1./b)
         t(3)=(sigmas)/(gg-1.)
         t(1)=(eo)/(t(3)**b)
         t(2)=(perms)/(es**d)
         return
         end
C************************************************************************
C=DECK SEEP
```

```
C=PURPOSE = This subroutine will numerically simulate the seepage
C           induced consolidation test at steady state conditions
C           and find the bottom effective stress and final height
C           of the sample .
C------------------------------------------------------------------------
C
C     INPUT  :
C    -------
C       x(1),x(2),t(1),t(2),t(3)   : current estimate of B,D,A,C,Z
C       see subroutine INPUT for other input data .
C
C     OUTPUT :
C    -----------
C     v( )       :  void ratio distribution at various nodes .
C     height() :  height distribution at various nodes .
C     sigma()  :  effective stress distribution at various nodes
C     kk          : iterations counter
C
C     weight1  : bottom effective stress of the sample due
C                 self weight and surcharge load
C     weight2 : height of the sample due to self weight
C                 and surcharge load .
C
C     sigmac   : bottom effective stress  due to seepage
C                 induced consolidation at steady state conditions .
C     hc        : final height of the sample due to seepage
C                 induced consolidation at steady state conditions .
C
C**************************************************************************
c
        subroutine SEEP(x,t,hc,sigmac,ich)
        integer                MAXIT, MAXNOD
        parameter             (MAXIT=60, MAXNOD=100 )
        integer                numnod,kk,ich,ni2
        double precision       v(MAXNOD),vave(MAXNOD),
     $                         v1(MAXNOD),height1(MAXNOD),
     $                         naser(MAXIT,MAXNOD),err(MAXIT,MAXNOD),
     $                         sigma(MAXNOD),height(MAXNOD),ra(MAXNOD),
     $                         x(2),t(3)

       double precision        a,b,c,d,z,error4,error2,dd
     $                         ,gw,gs,sigmat,dle,velo,
     $                         hc1,sigmac1,hc,sigmac


        common/nas1/gw,gs,sigmat,dle,velo,numnod,ni2,error2
        b=x(1)
        d=x(2)
        a=t(1)
        c=t(2)
        z=t(3)
        sigma(1)=sigmat
           v(1)=F6(sigma(1),a,b,z)
 c initial estimates of void ratios .
 c  calculations of the effective stresses  and then void ratios
 c  and then effective stresses ..... until convergence
          do 118 kk=1,50
          do 117 i=2,numnod
           vave(i)=(v(i-1)+v(i))/2.
           if(kk.ne.1) then
```

```
          sigma(i)=sigma(i-1)+ (gs-gw)*dle
     $    +((gw*velo)/(F2(vave(i),c,d)))*(1.+vave(i))*dle
        else
c  due to self weight and top effective stress
          sigma(i)=sigma(i-1)+ (gs-gw)*dle
        endif
c the new distribution of void ratios
        v(i)=F6(sigma(i),a,b,z)
 117    continue
c
c checking accuracy of the solution
       error4=0.
        do 121 n=1,numnod
         naser(kk,n)=v(n)
         if(kk.gt.1)then
         err(kk,n)=abs(naser(kk,n)-naser(kk-1,n))/abs(naser(kk-1,n))
         error4=error4+err(kk,n)
         endif
 121    continue
          if(kk.eq.1.and.ich.ne.0) then
          do 16 k=1,numnod
          v1(k)=v(k)
          ra(k)=(1.+v1(k))
 16       continue
          height1(2)=.5*(ra(1)+ra(2))*(dle)
          dd=(1./3.)
          do 1116 k=3,numnod,2
            height1(k)=height1(k-2)
     $    + dd*(ra(k-2)+2*ra(k-1))*(dle)
     $    + dd*(2*ra(k-1)+ra(k))*(dle)
 1116     continue
          do 1136 k=4,numnod,2
          height1(k)=height1(k-2)
     $    + dd*(ra(k-2)+2*ra(k-1))*(dle)
     $    + dd*(2*ra(k-1)+ra(k))*(dle)
 1136     continue
          sigmac1=F1(v(numnod),a,b,z)
          hc1=abs(height1(numnod))
        endif
        if(kk.gt.1) then
          if(error4.lt.error2.or.kk.gt.ni2)go to 122
        endif
 118    continue
 122    continue

c  calculations of the current heights due to self weight
c   or due to seepage induced consolidation

        do 1 k=1,numnod
          ra(k)=(1.+v(k))
 1      continue
c
c       calculation of the settlements at various heights .
        height(2)=.5*(ra(1)+ra(2))*(dle)
        dd=(1./3.)
        do 111 k=3,numnod,2
            height(k)=height(k-2)
     $    + dd*(ra(k-2)+2*ra(k-1))*(dle)
     $    + dd*(2*ra(k-1)+ra(k))*(dle)
 111    continue
```

```
        do 113 k=4,numnod,2
           height(k)=height(k-2)
     $     + dd*(ra(k-2)+2*ra(k-1))*(dle)
     $     + dd*(2*ra(k-1)+ra(k))*(dle)
 113    continue
c
c Accumulation of all output
c storage of the bottom effective stress and final height
          sigmac=F1(v(numnod),a,b,z)
          hc=abs(height(numnod))
          if(ich.ne.0)then
          call OUTPUT(x,t,ich,v1,height1,sigmac1,hc1
     $                ,v,height,sigmac,hc,kk,error4)
          endif
          return
          end
C**************************************************************************
C=DECK=OUTPUT
C=PURPOSE : To store all the output results and then to pass them
C             to the user through a file .
C-------------------------------------------------------------------------
C    OUTPUT DATA
C    ------------
C   x(1),x(2)       : The best estimation of parameters B, D  .
C
C   t(1),t(2),t(3)  :  The best estimation of  parameters A,C,Z
C
C   error3          : the total normalized difference at the
C                     the estimated parameters .
C   ich            : number of iterations needed to satisfy the
C                     specified total normalized difference .
C
C   v1( )         : void ratios at various nodes due to self weight
C   height1 ( )   : height of the sample due to self weight and surcharge
C                   load at various nodes.
C   depth1()      : depth of the sample due to self weight
C                   and surcharge load at various nodes .
C   hc1           : height of the sample due to self weight and
C                   surcharge load.
C   sigmac        : bottom effective stress due to self weight
C                   and surcharge load .
C
C   v  (   )      : void ratios due to the seepage induced
C                   consolidation at various nodes .
C   height  ( )   : height of the sample due to seepage induced
C                   consolidation  at various nodes .
C  depth( )       : depth of the sample due to seepage induced
C                   consolidation .
C   hc            : Final height of the sample due to seepage
C                   induced   consolidation .
C   sigmac        : bottom effective stress due to the seepage
C                   induced   consolidation   .
C  error4         : The total approximated error achieved in the
C                   numerical  simulation of the seepage induced
C                   consolidation test .
C      kk         : number of iterations needed to satisfy the
C                   specified total approximated error .
C-------------------------------------------------------------------------
C
        subroutine OUTPUT(x,t,ich,v1,depth1,sigmac1,hc1,v,depth,
```

```
     $            sigmac,hc,kk,error4)
        character title*70,out*30
        character *1 FORMFD
        parameter  (MAXNOD=100)
        double precision v1(MAXNOD),height1(MAXNOD),v(MAXNOD),
     $  depth(MAXNOD),depth1(MAXNOD),height(MAXNOD)
        double precision sigmac1,sigmac,error3,error4,x(2),t(3),
     $  hc1,hc,hf,sigmaf,Ho,eo,gw,gs,sigmat,dle,
     $  velo,error2,es,sigmas,perms
        integer kk,ich,n,j,numnod,ni2

        common/nas1/gw,gs,sigmat,dle,velo,numnod,ni2,error2
        common/nas2/eo,es,sigmas,perms
        common/nas3/hf,sigmaf
        common /nas4/out
        common /nas5/title,Ho
        open(unit=6,file=out,status='unknown')
        do 112 i=1,numnod
        height1(i)=depth1(numnod)-depth1(i)
        height(i)=depth(numnod)-depth(i)
112     continue
        write(6,11) title,gw,gs,Ho,eo,sigmat,velo,hf,sigmaf,
     $   es,sigmas,perms
 11     format(//,
     $ '-------------------------------------------------------------',
     $    /,'          DESCRIPTION OF THE PROBLEM                     ',
     $    /,'           TITLE OF THE PROBLEM  IS                      ',
     $ /, t10,A70,
     $/,'-------------------------------------------------------------',
     $  /,'          Seepage Induced Consolidation Results :         ',
     $   /,'  Unit Weight of Water                    =  ',f15.5,
     $   /,'  Unit Weight of Solids                   =  ',f15.5,
     $   /,'  Initial Height of the Sample            =  ',f15.5,
     $   /,'  Void Ratio at zero effective stress =  ',f15.5,
     $   /,'  Top Effective Stress                    =  ',f15.5,
     $   /,'  Darcian   Velocity                      =  ',e15.5,
     $   /,'  Final Height of the Sample              =  ', f15.5,
     $   /,'  Final Bottom Effective Stress           =  ',f15.5,
     $/,'-------------------------------------------------------------',
     $  /,'          Step Loading Test Results :                    ',
     $   /,'  Void Ratio                          = ',f15.5,
     $   /,'  Effective Stress                    = ',f15.5,
     $   /,'  Permeability Coefficient            = ',e15.5,
     $ /,'-------------------------------------------------------------',
     $        f15.5 )

        error3=abs(1.-(sigmac/sigmaf)) + abs(1.-(hc/hf))
        write(6,111)t(1),x(1),t(3),t(2),x(2),ich,error3
111     format(/,
     $   '---------------------------------------------------------',
     $ /,'---------------------------------------------------------',
     $//,'        THE OUTPUT RESULTS ARE LISTED AS FOLLOWS :      ',
     $ /,'---------------------------------------------------------',
     $//,'               PARAMETER ESTIMATION RESULTS             ',
     $//,'        Parameter A                   =',F15.5,
     $//,'        Parameter B                   =',F15.5,
     $//,'        Parameter Z                   =',F15.5,
     $//,'        Parameter C                   =',E15.5,
     $//,'        Parameter D                   = ',F15.5,
     $//,'        Number of Iterations          = ',I5,
```

```
    $//,'        Total Normalized Difference   = ',E15.5 ,//
    $ ,'-----------------------------------------------------')

      FORMFD=CHAR(12)
      write(6,*) FORMFD
      write(6,123)
123   format(
    $ ////
    $ ,'---------------------------------------------------',/,
    $  '    SELF WEIGHT AND SURCHARGE LOAD CONSOLIDATION RESULTS '/,
    $ '---------------------------------------------------')
       write(6,1111)
        do 1 n=1,numnod
        write(6,9)n,v1(n),depth1(n),height1(n)
  1     continue
        write(6,73)sigmat,sigmac1,hc1
 73     format(/,
    $   //,t5,'Top Effective Stress                    =',f15.5,
    $   //,t5,'Calculated Final Bottom Effective Stress =', f15.5,
    $   //,t5,'Calculated Final Height of  the Sample   =',f15.5)
         write(6,*)FORMFD
         write(6,124)
 124    format (////,
    $   '-----------------------------------------------------',
    $/,'          SEEPAGE INDUCED CONSOLIDATION RESULTS ' ,/,
    $ '-----------------------------------------------------')
        write(6,1111)
       do 888 j=1,numnod
        write(6,9)j,v(j),depth(j),height(j)
888    continue
1111    format(//,t8, 'Node No. ',t22,'Void Ratio ',t38,
    $   'Depth',t53, 'Height',/)
  9      format(t6,i6,t15,f15.5,t28,f15.5,t45,f15.5)
c
        write(6,2)sigmat,sigmac,hc,kk,error4
  2     format(/,t10,
    $   //,t5,'Top Effective Stress                     =',f15.5,
    $   //,t5,'Calculated Final Bottom Effective Stress =', f15.5,
    $   //,t5,'Calculated Final Height of the Sample    =', f15.5,
    $   //,t5,'Number of  Iterations                    = ',I6,
    $   //,t5,'Total Approximated Error                 = ', E15.5,/,
    $ '-----------------------------------------------------' )
      return
      end
C**********************************************************************
C DECK FUNCTIONS
C PURPOSE To calculate the following functions
C           , F1 : effective stress vs. void ratio .
C           , F6 : void ratio  vs. effective stress .
C           , F2 : Permeability vs. void ratio   .
C BLOCK FORTRAN
C**********************************************************************
      function F1(e,a,b,z)
        double precision  e,a,b,z
        F1=(e/a)**(1/b) - z
      end
      function F6(sig,a,b,z)
       double precision  sig,a,b,z
       F6=a*((sig+z)**b)
      end
```

```
function F2(e,c,d)
 double precision  e,c,d
 F2=c*(e**d)
end
```