PT 2
AEC RESEARCH AND
DEVELOPMENT REPORT

HW-72335 PT2

STEADY DARCIAN TRANSPORT OF FLUIDS IN HETEROGENEOUS PARTIALLY SATURATED POROUS MEDIA

Part 2

THE COMPUTER PROGRAM

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OCTOBER 1963

HANFORD LABORATORIES

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

GENERAL ELECTRIC

HW-72335 PT2

UC-70, Waste Disposal and Processing
(TID-4500, 26th Ed.)

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October 1963

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RICHLAND, WASHINGTON

Work performed under Contract No. AT(45-1)-1350 between the Atomic Energy Commission and General Electric Company

Printed by/for the U. S. Atomic Energy Commission

Printed in USA. Price $2.00. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

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STEADY DARCIAN TRANSPORT OF FLUIDS IN HETEROGENEOUS PARTIALLY SATURATED POROUS MEDIA PART 2 THE COMPUTER PROGRAM

INTRODUCTION

The subject of this document is the generalized computer program written to solve problems involving steady fluid flow through heterogeneous, partially-saturated porous media.[1]

A closely related class of mathematical problems is encountered in analyzing the flow of fluids through porous media. The complexity of the equations requiring solution depends on the conditions of time, saturation, and media uniformity. Traditionally a division of the class has been made between the time dependent and the steady-state flow problems. This is reasonable since in the numerical solution of the transient case the criteria for convergence and stability are far more complex than in the steady state case.

"Steady Darcian Flow in Soils" is a FORTRAN chain-link program based on the theoretical and mathematical development treated in Part 1 of this document subtitled, "Mathematical and Numerical Formulation"[2]

Part 2 gives a complete description of the computer program and discusses solution techniques which are used but not discussed in Part 1. Several appendixes are included as aids to the user and programmer who may wish to use parts of this formulation. In particular, Appendix A can be followed easily without a knowledge of FORTRAN to prepare input for the program.

SUMMARY

The computer program—"Steady Darcian Flow in Soils"—provides a means of obtaining numerical solutions to problems in the general class involving steady flow through porous media. Based on the mathematical and numerical treatment presented in Part 1, the program was designed to handle the widest possible variety of boundary conditions. Potential distributions in saturated and partially-saturated, homogeneous or heterogeneous

soils may be obtained. Combined saturated and partially-saturated flow cases may also be solved, since the equations used for one part are reducible to solve the other. Such a solution proceeds smoothly with little concern for the water table position which can be located easily in the problem solution. Moisture contents may be obtained from the results.

The program was written for the IBM 7090 in FORTRAN and FAP languages. It can solve one-, two-, and three-dimensional and axisymmetrical problems with up to 8000 grid points. As many as 15 different soils may be included in a heterogeneous, partially-saturated flow problem.

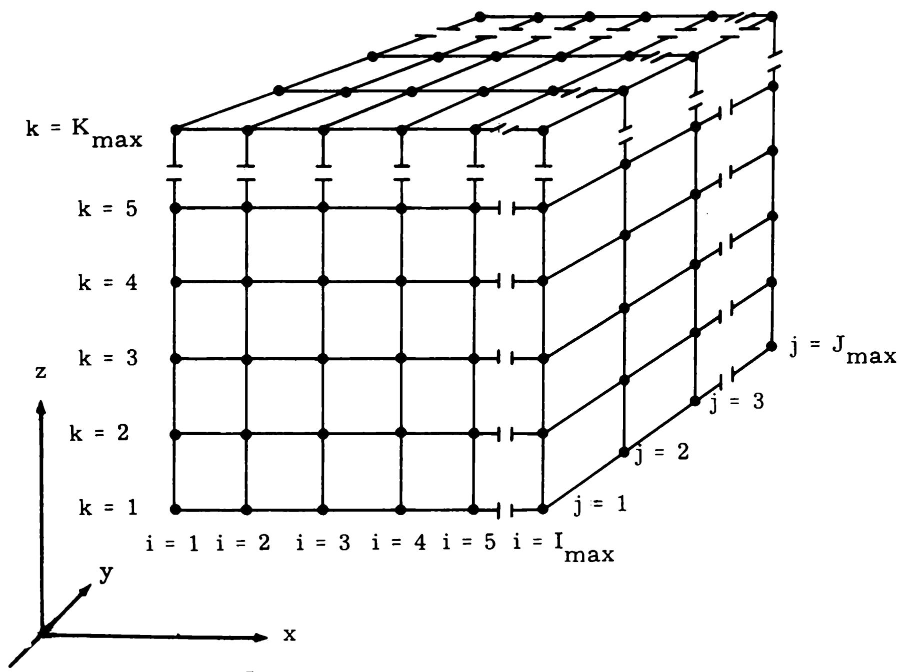
Optimum underrelaxation and overrelaxation techniques are used to increase the speed of convergence and to maintain stability. Other methods of maintaining stability are also discussed.

DESCRIPTION OF THE COMPUTER PROGRAM

The computer program—"Steady Darcian Flow in Soils"—provides a means of obtaining numerical solutions to a wide variety of boundary value problems using the nonlinear, partial differential equation discussed in Part 1, of this report. This equation and its various reduced forms describe the steady-state flow of fluids in soils. The limitations and assumptions of the program, along with an explanation of the numerical methods, are also discussed in Part 1.

The program can solve one-, two-, and three-dimensional and axisymmetrical flow problems using a matrix containing up to 8000 nodes. The soil or porous medium described by the matrix may be heterogeneous or homogeneous, saturated or partially-saturated, since all combinations are special cases of the basic equation.[3]

The description of a physical problem is simplified by visualizing a net of equally-spaced nodes, Figure 1. The matrix size is restricted to less than 501 nodes in the x and z directions and no more than 20 nodes in the y direction; however, the total cannot exceed 8000 nodes. For the two dimensional case the y dimension is reduced to one (Figure 1a), thereby solving for flow in the vertical plane in which gravity is acting. For solutions that require large dimensions in the horizontal plane, i.e., no gravitational



$I_{max} \leq 501$, $J_{max} \leq 20$, $K_{max} \leq 501$

FIGURE 1a

Three Dimensional Array of Node Points

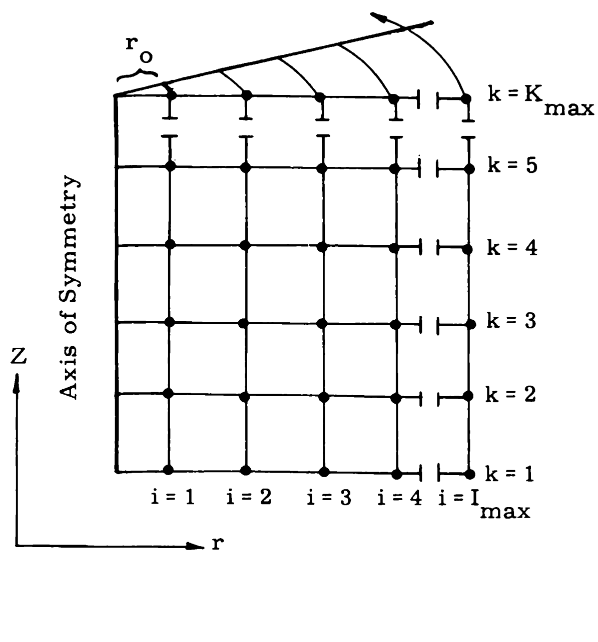


FIGURE 1b

Node Points in Axisymmetrical System

effects, an arbitrary constant is provided in the capillary pressure equation which sets the gravity term equal to zero [parameter D in Equation (18), Part 1]. This permits the use of the x and z coordinates in the horizontal plane. Axisymmetrical cases may be considered as two-dimensional problems, since all of the required equation changes are made internally by the computer program when an axisymmetrical case is designated. In some instances a small increment denoted as r_o, as shown in Figure 1b, is helpful in meeting central boundaries for radial flow problems. In a one-dimensional flow problem the x and y dimensions are reduced to one, and proper control is used to consider gravity effects or to neglect them as desired.

The input information necessary to obtain a solution is dependent upon the type of flow in the problem situation. Partially-saturated flow problems require information describing the functional relationships of capillary conductivity to capillary pressure for each soil in the matrix pattern. The details of treating these laboratory-obtained data for input are discussed in Appendix B. The number of soil types permitted in any one problem is 15. The locations of the soils in this problem type are specified by an integer designation from 1 through 15 at every node. Problems involving only saturated flow require the saturated permeability or hydraulic conductivity of the soil at each point in the matrix; this allows maximum flexibility in modeling the heterogeneous soils pattern.

A calculation control integer is specified at each node to indicate the type of calculation to be performed there. Nodes not lying on a boundary utilize the unmodified point pattern of the finite difference equation as shown in Figure 2. To meet the boundary conditions, nodes lying on a boundary use a modified pattern which reflects the specific boundary conditions at those points. The storage of such integers at every node makes possible complete flexibility in setting up boundary value problems. The designation of each type of piezometric head calculation can be found in Appendix A. The partial differential and finite difference representation for each is included in Part 1.

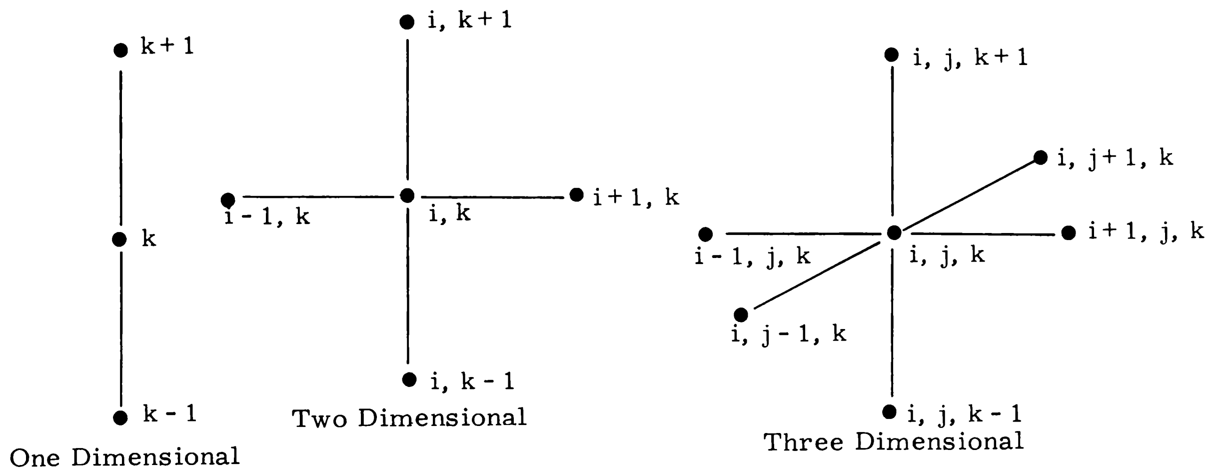


FIGURE 2

Finite Difference Point Pattern Configurations

Computer storage capacity is saved by storing both the calculation-type integer and soil identification in a single computer word. The saving contributes significantly toward enabling all 8000 nodes to be used.

An initial estimate of the piezometric head is needed at every node to start toward a solution. The initial estimate is made heuristically after an examination is made of the source of flow, the flow path length, and the expected final values. In general, good initial estimates reduce the computer time required to reach a satisfactory solution of the difference equations. For saturated flow the conditions are known which assure a stable computational method that will yield a true difference solution from any arbitrary initial start. The same assurance is lacking for the nonlinear, partially-saturated cases, although experience has shown that instabilities are immediately recognizable. Several techniques, to be discussed later, were developed to overcome the instabilities which may arise in partially-saturated flow cases.

Table I shows the major breakdown of input information required for each type of problem.

TABLE I

INPUT AND STORAGE REQUIREMENTS

Type of Problem	Stored Once	Stored at Every Node
Partially saturated	Problem constants Soil relationships	Initial potential Soil identification Calculation type
Saturated	Problem constants	Initial potential Saturated permeability Calculation type

A detailed explanation of the input requirements and card preparation is presented in Appendixes A and B. Examples of input are presented in Appendix C.

Solution Procedure

In general, the solution sequence for the saturated flow case proceeds in the following manner. The initial potential estimates from surrounding nodes and the permeability value are substituted into the appropriate finite difference improvement formula to obtain an improved value for the potential at the central node. The program steps from point to point through the matrix before returning to the initial point to start the second improvement or iteration.

In the partially-saturated case, the initial estimate of potential and the node location are used to calculate the capillary pressure. The calculated capillary pressure is used in a look-up and interpolation procedure of the soils data to obtain an initial capillary conductivity estimate at each node. The potential and conductivity estimates are substituted into the finite difference equation to obtain an improved value for the potential. The capillary conductivity estimate at the node is revised by calculating the new capillary pressure and determining the new value of conductivity from the soils data. The process of improvement proceeds stepwise from node to node through the whole problem to make a complete iteration. Through successive iterations, the initial estimates of potential are improved to as near the solution of the difference equations as desired.

After the potential distribution solution is obtained for a partially-saturated flow problem, it is often desirable to determine the associated soil-moisture distribution. A special feature of the program may be used to evaluate the moisture content of the soil from the final potential values. The capillary conductivity input data are replaced with the relationship of moisture content and capillary pressure for the soils involved (the later experimental relationship is prepared for input as described in Appendixes A and B). One program control integer is changed, and the program solves for the moisture content distribution.

Chain Link 1 (Preparatory Link)

Chain Link 1 of the computer program reads the input data and prepares the problem for calculation. For saturated flow, three matrices equal in size to the whole problem are constructed. These are the initial potential, the conductivity, and the calculation type. For partially-saturated flow, four full-size matrices are filled. The fourth matrix is the soil designation.

Included in Chain Link 1 are the subroutines "Cutter" and "Test" described in Table II.

TABLE II

CHAIN LINK 1 SUBROUTINES

Subroutine Name	Function Performed
Cutter	Provides the ability to convert a large matrix into a smaller one by removing rows and columns. Such a method allows computations on a coarser grid when input originates from a previous solution.
Test	Checks the user's choice of calculation types at all points in the matrix and provides for termination of the problem with an error message if an illogical choice is detected.

Chain Link 1 calls Chain Link 2 and is not entered again during the solution of the problem.

Chain Link 2 (Calculation Link)

Chain Link 2 handles the iteration through the matrix and computes the overrelaxation factor for optimum convergence. All printout from the program is controlled in this link by subroutines "Input" and "Out." There are six FORTRAN subroutines and four FAP subroutines included in this link.

TABLE III

CHAIN LINK 2 SUBROUTINES

Subroutine Name	Function Performed
Step	Controls the origin and the stepwise progress from point to point within the matrix, and selects the grid point pattern for the central node as defined by the calculation type.
Kay	Computes the capillary conductivity from the soils data as a function of the capillary pressure.
Fhi	Calculates the terms of the equation for the potential. The actual calculation occurs in the main link.
Input	Handles the printout for the input data given to the problem.
Out	Writes out all other messages and output from the problem.
Relax	Calculates the overrelaxation factor at specified intervals (chosen by the user) to speed convergence.
Save (FAP)	Provides a means of removing the problem from the computer for inspection between iterations. It enables restarting the program without repeating any of the previously calculated steps. It also permits minor changes in the input data.

TABLE III (contd)

Subroutine	Function Performed
Addrs (FAP)	Merges the integer symbols for the type of calculation and the soil identification into a single computer word.
Gman (FAP)	Retrieves the integer designation for the soil from memory.
Gnl (FAP)	Retrieves the integer designation of the calculation type from memory.

COMPUTATIONAL STABILITY

In any iterative method of successive improvement, computational stability is required if the solution to the difference equations is to be obtained without expending an unreasonable amount of effort. Stability of the Gauss-Seidel method will be discussed cursorily for three problem categories: saturated flow in homogeneous soils, saturated flow in heterogeneous soils, and partially-saturated flow in homogeneous and heterogeneous soils. The single category covering stability for partially-saturated flow should in no way be taken to indicate a lack of importance or need for stability criteria. Rather it is an indication of the near total absence of knowledge on stability conditions for the nonlinear equations of partially-saturated flow.

For saturated flow in homogeneous soil, the Gauss-Seidel method as used in the program is unconditionally stable. That is, the iterations will proceed orderly toward the solution of the difference equations from any reasonable initial estimate.

For saturated flow in heterogeneous soils, the computational method is only conditionally stable for the usual difference equations.[4,5] In other words, the successive improvements will generally proceed smoothly with excellent results; however, stability of the method can not be guaranteed. Since the equations are linear, stability criteria are available. These criteria show that this group of problems can be made unconditionally stable through appropriate averaging of the capillary conductivity. The computer program includes an option for averaging or not averaging at the discretion of the investigator.

The stability criteria for nonlinear equations, i.e., partially-saturated flow problems, are so meager that very little help is available from classical analysis at present. The major guide now available is experience with its associated uncertainties. Experience shows that instability is to be expected in partially-saturated flow problems, but fortunately it is easily detected when it occurs. There are three controls, found by the authors through experience, that effectively overcome instability. They are:

1. appropriate averaging of the capillary conductivity
2. using an underrelaxation factor to dampen instabilities
3. changing the sequence or order of stepping through the nodes in the improvement process.

These three techniques either singularly or in combination have been capable of stabilizing the computational procedure for all steady flow problems encountered by the authors in 3 years of use. The stabilizing methods are applied in the order given. Technique 1 is used for essentially all partially-saturated problems. Technique 2, the underrelaxation factor, is incorporated into the program and is automatically applied when instability occurs. The underrelaxation factor is closely related to the overrelaxation factor used in stable situations to further speed the approach to the solution. Technique 3, stable sequences, is associated with the optimum order in which large systems of equations are solved. A control, called an initial point, sets the order of calculation.

Averaging of Capillary Conductivity

The greater complexity introduced as a result of the nonlinearity of the equations for partially-saturated flow is best described by contrasting the iteration scheme with that for saturated flow. In the saturated case the permeability value, or saturated capillary conductivity, K, is known at each node and therefore is always available. For partially-saturated cases, the capillary conductivity, which is potential dependent, is unknown at any step in the improvement of the potential estimate. In the process of iteration the K value at the node lags behind the potential by one iteration, i.e., the potential must be calculated before a current value for K can be calculated. The stabilizing effect of appropriate averaging of K is illustrated by considering the two-dimensional point pattern in Figure 3. The standard node nomenclature has been changed to indicate the K in existence at each node. K_{new} indicates a current value for K, and K_{old} indicates values associated with the past iteration.

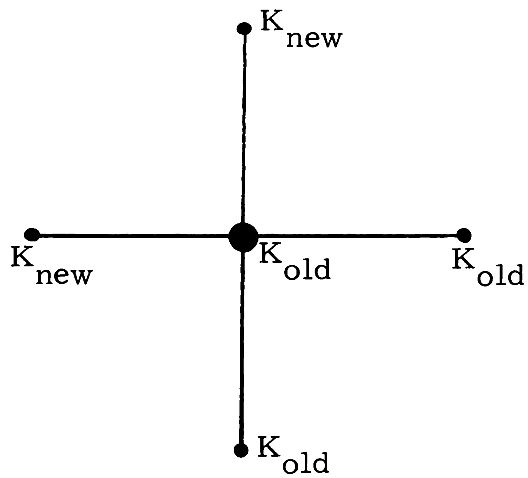


FIGURE 3

Available K in Two-Dimensional Averaging

The values of the surrounding nodes are averaged to get a better estimate of K at the central node; this estimate is then used in the equation for the potential. The average K represents a better estimate of K at the central node than does the value calculated from the previous potential estimate. The finite difference equations, which are unconditionally stable for all saturated flow and may or may not be conditionally stable for partially-saturated flow, are:

(1) One dimensional in the z direction

$$\varphi_k = \frac{1}{2}(\varphi_{k+1} + \varphi_{k-1}) + \frac{1}{4(K_{k+1} + K_{k-1})}(K_{k+1} - K_{k-1})(\varphi_{k+1} - \varphi_{k-1}) \quad (1)$$

(2) Two dimensional in the xz plane

$$\varphi_{i,k} = \frac{1}{4}(\varphi_{i,k+1} + \varphi_{i,k-1} + \varphi_{i+1,k} + \varphi_{i-1,k})$$
$$+ \frac{1}{8(K_{i,k+1} + K_{i,k-1})}(K_{i,k+1} - K_{i,k-1})(\varphi_{i,k+1} - \varphi_{i,k-1})$$
$$+ \frac{1}{8(K_{i+1,k} + K_{i-1,k})}(K_{i+1,k} - K_{i-1,k})(\varphi_{i+1,k} - \varphi_{i-1,k}) \quad (2)$$

(3) Three dimensional in the xyz space

$$\varphi_{i,j,k} = \frac{1}{6}\left[\varphi_{i+1,j,k} + \varphi_{i-1,j,k} + \varphi_{i,j+1,k} + \varphi_{i,j-1,k} + \varphi_{i,j,k+1}\right.$$
$$\left. + \varphi_{i,j,k-1}\right] + \frac{1}{12(K_{i+1,j,k} + K_{i-1,j,k})}\left[K_{i+1,j,k} - K_{i-1,j,k}\right]\left[\varphi_{i+1,j,k}\right.$$
$$\left. - \varphi_{i-1,j,k}\right] + \frac{1}{12(K_{i,j+1,k} + K_{i,j-1,k})}\left[K_{i,j+1,k} - K_{i,j-1,k}\right]\left[\varphi_{i,j+1,k}\right.$$
$$\left. - \varphi_{i,j-1,k}\right] + \frac{1}{12(K_{i,j,k+1} + K_{i,j,k-1})}\left[K_{i,j,k+1} - K_{i,j,k-1}\right]\left[\varphi_{i,j,k+1}\right.$$
$$\left. - \varphi_{i,j,k-1}\right] \quad (3)$$

Changes in the foregoing relationships from Equations (21), (22), and (23) of Part 1, which did not average K's, involved replacing the K of the central node by the average of the two K values at the adjacent nodes which lie in the same coordinate direction as the potential gradient in the term.

In our experience the iterative solution of partially-saturated flow problems will always be unstable without the averaging of K values.

Overrelaxation and Underrelaxation

An optimum overrelaxation factor is used to accelerate convergence and save computer time. The internally-computed optimum factor described by Young[6] and Forsythe and Wascow,[7] works extremely well in saturated flow problems where the basic equations reduce to the linear form. In partially-saturated flow an upper limit of 1.15 is imposed to maintain stability; however, this is not always effective. A method is incorporated in the overrelaxation calculation for detecting instability. When instability occurs the program uses an equation, derived from the authors' experience, which returns to the program an overrelaxation factor less than one; this is referred to as underrelaxation. The result is a tendency toward averaging of the potential values to effectively dampen oscillations.

As the mesh is swept, the sum of the absolute corrections for iteration n,

$$E_n = \sum_{i,j,k} \left| \varphi^{n}_{i,j,k} - \varphi^{n-1}_{i,j,k} \right| \qquad (4)$$

is accumulated, Equation (4), and the highest absolute correction and its location in the matrix are recorded. After each complete passage over the network, the high difference value and its location, the average difference, and the overrelaxation factor applied during the iteration are stored and may be printed.

The high difference value is tested at each iteration against an input value to determine when the solution is reached. The criterion that the greatest correction of the potential at any point on the matrix from the n - 1 to the nth iteration be small is used as the termination condition. In general these corrections should tend to zero in the limit, and the potential should need no further improvement. Experience has shown that 1×10^{-6} is a reasonable iteration limit; however, some problems need not be reduced to this limit.

The overrelaxation correction, ω, is applied after the calculation of φ_n by

$$\varphi_N = \varphi_{n-1} + (\varphi_n - \varphi_{n-1})\omega \ . \tag{5}$$

The optimum ω is calculated by

$$\omega = \frac{2}{1 + \sqrt{1 - \lambda^2}} \tag{6}$$

where $$\lambda^2 = \frac{(Q_n + \omega - 1)^2}{Q_n \omega^2} \tag{7}$$

and $$Q_n = \frac{E^n}{E_{n-1}} \ . \tag{8}$$

The ω calculated during stable sequences is $1 < \omega < 2$.[8]

Large savings in computer time are realized through use of overrelaxation factors generated by the program. Frequently this technique results in greater than a twofold reduction in the number of iterations required for solution.

The program checks the problem type during recalculation of the overrelaxation factor. For partially-saturated flow the ω of Equation (6) is substituted into

$$\omega_p = 1.0 + (\omega - 1.0)\ 0.15 \tag{9}$$

which in the limit permits ω_p to equal 1.15. This does not insure stability, however, for when $Q_n < 1$, the expression $\sqrt{1 - \lambda^2}$ is complex. It was determined empirically that when $Q_n < 1$ an underrelaxation factor can be calculated by reversing the sign of λ^2 and solving Equation (6). The value of the resulting ω is further reduced by

$$\omega_p = 0.65 + 0.175\ \omega \ . \tag{10}$$

The resulting ω_p is used during the next series of iterations.

Initial Point

The use of well-located initial point can save computer solution time and, when required, control instability. Computer time is saved by setting the initial point at a predominant boundary condition. By such placement the large changes in potential, which normally originate at boundaries representing the principal source of flow, are swept quickly toward a far boundary in one iteration. In contrast, positioning the initial point at a minor boundary is less effective in distributing the potential changes from the predominant boundary. The effective distribution of the potential changes is most important early in the solution.

The movable initial point also has utility in overcoming instability. If instability cannot be overcome by the other methods mentioned, then the iteration origin is placed at the node location displaying the greatest disturbance. This in effect reorders the sequence in which the system of equations is solved and sweeps the errors toward the boundaries; the oscillations are dampened and the problem ordinarily converges.

The fixed order of sequencing, which originates at the initial point, proceeds from the initial point row down the initial column until it reaches the boundary; it then returns to the initial row, but left one column, and proceeds again downward. This is termed a "down-left" direction. The order moves down-left, down-right, up-left, and up-right in a two-dimensional plane. In three dimensions the order moves through the initial plane, forward through each plane in like manner than back through the remaining planes.

REFERENCES

1. A. E. Reisenauer. "Methods for Solving Problems of Multidimensional Partially Saturated Steady Flow in Soils," J. Geophys. Res., vol. 68, pp. 5725-5733. 1963.

2. R. W. Nelson. Steady Darcian Transport of Fluids in Heterogeneous Partially Saturated Porous Media, Part 1, Mathematical and Numerical Formulation, HW-72335 PT1. June 4, 1962.

3. R. W. Nelson and A. E. Reisenauer. "Hanford Studies on Flow in Porous Media," Second Ground Disposal of Radioactive Wastes Conference Held at Atomic Energy of Canada Limited, Chalk River, Canada, September 26-29, 1961, USAEC Report TID-7628, pp. 130-144. March 1962.

4. W. J. Karplus. Analog Simulation, McGraw-Hill Book Company, New York, 1958.

5. R. S. Varga. Matrix Iterative Analysis, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1962.

6. D. Young. "Iterative Methods for Solving Partial Difference Equations of Elliptic Type," Trans. Am. Math. Soc., vol. 76, pp. 92-111. 1954.

7. G. E. Forsythe and W. R. Wascow. Finite-Difference Methods for Partial Differential Equations, John Wiley and Sons, New York, 1960.

8. L. A. Schmittroth and A. W. Grimaud. A Two-Dimensional Steady State Temperature Program for the IBM-650, IDO-16644. Idaho Operations Office. April 1961.

APPENDIX A

INPUT PREPARATION

The preparation of input is necessarily complicated by the large number of options available in the program. These options are explained in the text and in the following preparation of data cards. The number and types of data cards used may vary from a few to nearly all of those described, with many duplicates, depending on the options. Sequential order of the input cards is dependent on the boundary value problem and will be found to follow the schematic diagram of Figure 4 (page 34, Appendix A). Listings of sample input are found in Appendix C.

Card Type 1 - Used in all options.

Field A - Five column integer field beginning in Column 1 (contains the case number).

Field B - Sixty column BCD field beginning in Column 6 (contains an identification message).

Card Type 2 - Used in all options. This card contains ten program control integers which are placed in Columns 5, 10, 15, 25, 30, 35, 40, 45, and 50. These integers control the major options in the program.

Field A - NSAT (controls the degree of saturation).

If NSAT is equal to:

1 - Partially saturated soil exists in the problem.

2 - Saturated soil exists everywhere in the problem.

Field B - NINPHI (controls the input method for initial potential head matrix).

If NINPHI is equal to:

1 - The initial head matrix is read in by row input option, using Card Types 10 and 11, or 10 and 13.

2 - The initial head matrix is read in by the matrix input option using Card Type 16.

Field C - NINEK (controls the input method for the initial relative capillary conductivity matrix). This option is not applicable to partially saturated flow problems and no control integer is needed.

If NINEK is equal to:

1 - Initial relative capillary conductivity matrix is read in by row input method using Card Types 10 and 12, or 10 and 14.

2 - The initial relative capillary conductivity matrix is read in by the matrix option using Card Type 17.

Field D - NCUT (controls the matrix cutting option).

If NCUT is equal to:

1 - Rows, columns, and planes will be removed from the initial head matrix provided the matrix dimensions on Card Type 6 are different.

2 - Rows, columns, and planes will be removed from <u>both</u> the initial head and conductivity matrices provided the dimensions on Card Type 6 are different.

Field E - NAVG (controls the denominator in the potential head calculation).

If NAVG is equal to:

1 - The potential head calculation will use the capillary conductivity for the node point in the denominator.

2 - The capillary conductivities will be properly averaged and used in the denominator for the head calculation.

Field F - NAXI (controls the difference between two-dimensional and axisymmetrical cases).

If NAXI is equal to:

1 - Two dimensional case will be calculated

2 - Axisymmetrical case will be calculated.

This integer has no meaning in the one- or three-dimensional cases.

Field G - NPUN (controls the output punching of the cards).

If NPUN is equal to:

1 - The final potential head and relative capillary conductivity matrices are not punched on cards.

2 - The final potential head and relative capillary conductivity matrices are punched on cards using a format compatible with the matrix input option.

Field H - NBUG (controls the program output).

If NBUG is equal to:

1 - The printout will contain:

a. Steady-state potential head values.

b. Relative capillary conductivity values (if flow is unsaturated).

c. The number of iterations for solution.

2 - The printout will contain:

The same as NBUG equal to 1 (above) plus the iteration number, the highest difference between the present and previous iteration, the coordinates of the point of highest difference, the average difference in the matrix, and the relaxation factor used for each iteration.

3 - The printout will contain:

All of the above and, in addition, the piezometric head matrix at each iteration, and the conductivity matrix at each iteration. If partially saturated flow is involved, the printout will also contain pertinent information for each head calculation for each iteration on every point in the matrix. This option is for debugging only since the printout is voluminous.

Field I - NGRAP (controls graphical printout).
If NGRAP is equal to:
1 - Matrices will be printed in compact form.
2 - The matrices will be printed in a graphical form with the decimal points spaced on a nearly equal grid.
Pages may be cut and placed in a manner as to obtain a complete matrix.

Field J - NDUM3 (controls moisture content calculation).
If NDUM3 is equal to:
0 or blank—the program as defined is unchanged and it will calculate potentials.
Any integer—the program calculates moisture content at every node point provided the potential head values are input with the appropriate moisture content soils data substituted into the program.

Card Types 3, 4, and 5 provide the necessary soils input data for solving partially-saturated flow problems. They are not used in the saturated flow case. A detailed explanation of Card Types 4 and 5 will be found in Appendix B.

Card Type 3 - Used when NSAT equals 1. This card contains a two-column integer field, beginning in Column 1, and a 10 column floating point field beginning in Column 3.

Field A - Contains the number of soils used in the problem (limited to 15 or less).

Field B - Contains the scaling factor for the soils data. The purpose of the scaling factor is to control overflow in the computer during the calculation of the soils equation used in Fields D_1 and D_2 on Card Type 5. A test criterion for this factor, f, is: f times the greatest possible capillary pressure, P_g, to the D_2 power must be less than 10^{36}, ($f\, P_g^{D_2} < 10^{36}$).

Card Type 4 - Used when NSAT equals 1. This card contains four 10-column floating point fields beginning in Columns 1, 11, 21, and 31, and a two-digit integer field beginning in Column 41.

Field A - Contains the highest capillary pressure head value for a linear fit on the pressure versus capillary conductivity curve.

Field B - Contains the highest capillary pressure head value of the tabled conductivity values listed in Fields $C_1 \ldots C_n$ of Card Type 5.

Field C - Contains the highest capillary pressure head value for which the exponential fit is used.

Field D - Contains the step between the tabled values of capillary pressure head. This is normally negative since the values are listed in descending order.

Field E - Contains the number of values in the tabled segment of the curve. The table must include values for each end-point pressure. Up to 41 values may be used.

Card Type 5 - Used with Card Type 4. This card contains seven 10-column floating point fields beginning in Column 1, 11, 21, etc.

Field A - Contains the constant relative capillary conductivity value for the pressure head above the linear fit. When more than one soil is used, this value on the first soil is used to relate all values to one soil. (See Permeability Coupling Ratio, page 10, Part 1).

Fields B_1 and B_2 - List the coefficients of the linear equation for computing conductivities for capillary pressures equal to or less than the value in Card Type 4-A and greater than values in Card Type 4-B. The equation is of the form

$$K = B_1(-P_c) + B_2$$

where K is the capillary conductivity and P_c is the capillary pressure. Note: $-P_c = p/\gamma$

Fields $C_1 \ldots C_n$ - Lists the tabled values of capillary conductivity, beginning with the values in Card Type 4-C, in steps of capillary pressure head defined in Card Type 4-D. The n-number of values is set in Card Type 4-E.

Fields D_1 and D_2 - Contain the coefficients of the exponential equation for computing conductivities for pressures equal to or less than the value in Card Type 4-C. The equation of the form

$$K = \frac{D_1}{(-P_c)^{D2}}$$

Sufficient cards of Type 5 are used to read in the necessary information for each soil. Sets of Card Types 4 and 5 are read until the number of soils (Card Type 3, Field A) is satisfied. These same cards are used to input moisture content data in the same manner as the conductivity (See Appendix B).

Card Type 6 - Used in all options. This card contains nine 5-column integer fields beginning in Columns 1, 6, 11, etc.

Fields A, B, and C - List the matrix dimensions in y, z, and x directions respectively before removal of any rows or columns.

Fields D, E, and F - List the matrix dimensions in y, z, and x directions respectively after the removal of rows, columns, and planes. If the two sets of dimensions are equal, no rows, columns or planes will be removed.

Fields G, H, and I - Contain the y, z, and x coordinates of the initial point for stepping through the matrix during calculation of the potential.

These initial point coordinates are in terms of the "uncut" matrix and are "cut" by the program in the routine for removing rows, columns, and planes. To keep the necessary boundaries they must satisfy the equation

$$\text{Whole number} = \frac{N - 1}{M - 1},$$

where N is the large "uncut" boundary and M the final "cut" coordinate of that boundary. The initial point coordinates must also satisfy that condition.

Card Type 7 - Used in all options. This card contains seven 10-column floating point fields beginning in Columns 1, 11, 21, etc.

Field A - Contains the fractional distance between node points; that is, $\frac{L}{n - 1}$ where L is distance and n is the number of nodes used over that distance (Field G, Card 6). This number must have the same dimensional units as the soils data, i.e., length units must be identical to the input capillary pressure head and to L in Field G to follow.

Field B - Contains the translation of the origin in the vertical direction (see page 8, Part 1).

Field C - Contains the angle of inclination of the system in radians. Note: For axisymmetrical cases this angle must be zero or the symmetry will be destroyed.

Field D, E, and F - List the coefficients corresponding to the letters in the equation [Part 1, Equation (24)].

$$p/\gamma = -(P_c)_{i,j,k} = \varphi_{i,j,k} - D(k-1)A \cos C + EA(i-1)\sin C - \frac{FB}{G} G,$$

where the letters A, B, C, D, E, F, and G refer to the fields of Card Type 7.

Field G - Contains the length scaling parameter, L. This must be in the same dimensional units as the soils data and vertical translation.

Card Type 8 - Used in all options. This card contains four 10-column floating point fields beginning in 1, 11, 21, etc.

Field A - Contains the error exit potential head value. If the calculated head equals or exceeds this value, an error exit will occur (usually occurs when iterative solution is unstable).

Field B - Contains a value which defines the completion of the case. If the highest difference between the potential at the n th iteration and the (n-1)th iteration is equal to or less than this value, the case is complete.

Field C - Blank

Field D - Used for axisymmetrical cases only, e.g., if NAXI equals 2. The field contains the fraction of grid space or spaces from the axis of symmetry to the first node [See Part 1, Equation (30)].

Card Type 9 - Used in all options. The card contains one 5-column fixed point field and three 5-column integer fields starting in Columns 1, 6, 11, etc.

Field A - Contains the initial overrelaxation factor to be applied to the potential head calculation through the first number of iterations which appears in Field B.

Field B - Contains the number of the iteration through which the initial overrelaxation in Field A will be applied.

Field C - Contains the number of iteration cycles that will be completed before the calculation of a new overrelaxation factor.

Field D - Contains the number of iteration cycles permitted before the program automatically uses "Save" option.

Since the input preparation for the necessary matrices is complicated by the various options available, a general discussion of these options will first be given.

The row input option is used advantageously with matrices having adjacent rows, in either the Y or Z firections, that are alike. For flexibility two alternatives are available: full row or column of change. The row option always employs two card types. Card Type 10 is used to define the area of the matrix to which the values are to be applied. The second card contains the row of values, but this card will have varying formats, depending on the matrix and the alternative used.

The matrix option is provided for matrices which have different values at nearly every point. In this option, the matrix is read in ordered fashion from (1, 1, 1) to point $(Y_\ell, Z_m \cdot X_n)$. This option uses one card type to describe the matrix. The initial piezometric head and relative capillary conductivity matrices may be read with this option.

1. Row Input Option

Card Type 10 - Used if NINPHI is equal to 1 for capillary pressure heads. Used if NSAT equals 2 and NINEK equals 1 for capillary conductivities. Used if NSAT equals 1 for soil identification.

Used in all options for calculation types.

This card contains five 3-column integer fields beginning in Columns 1, 4, 7, 10, and 13.

Field A - Contains the number of the lowest X-Z plane(s) for which the row of values defined on the following card(s) applies.

Field B - Contains the number of the highest X-Z plane(s) to which the row of values defined on the following card(s) applies.

Field C - Contains the number of the lowest row in the X-Z plane(s) to which the row of values defined on the following card(s) applies.

Field D - Contains the number of the highest row in the X-Z plane(s) to which the row of values defined on the following card(s) applies.

Field E - KKK–Contains the number of changes in the row of values defined on the following card(s). KKK equal to 0 signifies the full row option.

Card Type 11 - Used with Card Type 10 if KKK equals 0. This card contains eight 9-column fixed point fields beginning in Columns 1, 10, 19, etc. Full-row alternative is used to read the initial potential heads at every point on the row(s).

Field

$A_1 \ldots A_8$ - Lists the initial piezometric head values for the row(s); read from left to right. As many cards of this type may be used as necessary to define a row of up to 501 values.

Card Type 12 - Used with Card Type 10 if KKK equals 0. This card contains seven 10-column floating point fields beginning in Columns 1, 11, 21, 31, 41, 51, and 61. The full-row alternative is used to read initial relative capillary conductivity at every point on the row(s).

Field

$A_1 \ldots A_7$ - Lists initial relative capillary conductivities for the row(s) read from left to right. As many cards of this type may be used as necessary to define a row of up to 501 values.

Card Type 13 - Used with Card Type 10 if KKK is greater than 0. The column of change alternative is used to read the initial potential head values. This card contains seven pairs of fields. The pairs begin in Columns 1, 11, 21, etc. Each pair consists of a four-column integer field (Field A) and a six-column fixed point field (Field B).

Field

$A_1 \ldots A_7$ - Lists the numbers of the columns in which the potential head values in the adjacent B field become effective.

Field

$B_1 \ldots B_7$ - Lists the potential head values which become effective in the column indicated in the corresponding A field. Sufficient cards of this type may be used to describe row(s) of up to 501 values.

Card Type 14 - Used with Card Type 10 if KKK is greater than 0. The column of change alternative is used to read the relative capillary conductivity matrix. This card contains four pairs of fields. The pairs begin in Columns 1, 16, 31, and 46. Each pair consists of a five-column integer field and a ten-column floating point field.

Fields A and B - These fields are used in the same manner as those on Card Type 13.

Card Type 15 - Used with Card Type 10 to read in the soil identification and the calculation type matrices using the column of change alternative only. This card contains 14 pairs of fields. The pairs begin in Columns 1, 6, 11, 16, 21, 26, 31, 36, 41, 51, 56, 61, and 66. Each pair consists of a three-column integer field and a two-column fixed point field.

Fields A and B - These fields are used in the same manner as those on Card Type 13.

The calculation type code is listed in Table A-1 below.

TABLE A-1

CODE FOR TYPE OF POTENTIAL HEAD CALCULATION

One-Dimensional Cases

Code	Surrounding Points Used
1	No calculation
2	B-T
3	T-T
4	B-B

Two-Dimensional Cases

Code	Surrounding Points Used	Code	Surrounding Points Used
1	No calculation	6	L-L-B-T
2	L-R-B-T	7	R-R-T-T
3	L-R-T-T	8	L-L-T-T
4	L-R-B-B	9	R-R-B-B
5	R-R-B-T	10	L-L-B-B

TABLE A-1 (contd)

Three-Dimensional Cases

Code	Surrounding Points Used	Code	Surrounding Points Used
1	No calculation	15	L-R-B-B-F-F
2	L-R-B-T-N-F	16	L-R-B-B-N-N
3	L-R-T-T-N-F	17	R-R-B-T-F-F
4	L-R-B-B-N-F	18	R-R-B-T-N-N
5	R-R-B-T-N-F	19	L-L-B-T-F-F
6	L-L-B-T-N-F	20	L-L-B-T-N-N
7	L-R-B-T-F-F	21	R-R-T-T-F-F
8	L-R-B-T-N-N	22	R-R-T-T-N-N
9	R-R-T-T-N-F	23	L-L-T-T-F-F
10	L-L-T-T-N-F	24	L-L-T-T-N-N
11	L-R-T-T-F-F	25	R-R-B-B-F-F
12	L-R-T-T-N-N	26	R-R-B-B-N-N
13	R-R-B-B-N-F	27	L-L-B-B-F-F
14	L-L-B-B-N-F	28	L-L-B-B-N-N

L is the point to the left or in the negative X coordinate direction.

R is the point to the right or in the positive X direction.

B is the point below or in the negative Z direction.

T is the point above or in the positive Z direction.

N is the point in the next "nearer" X-Z plane or in the negative Y direction.

F is the point in the next "farther" X-Z or in the positive Y direction.

2. Matrix Option

Card Type 16 - Used if NINPHI (Card Type 2) equals 2. This card is used to read the initial potential head matrix using the matrix option. The card contains eight 9-column fixed point fields beginning in Columns 1, 10, 19, 28, etc.

Fields

$A_1 \ldots A_8$ - List the initial potential head values read in the following order: (1, 1, 1), (1, 1, 2), . . . , $(1, 1, X_n)$, (1, 2, 1), . . . , $(1, 2, X_n)$, . . . $(1, Z_m X_n)$, (2, 1, 1), . . . , (Y_ℓ, Z_m, X_n). As many cards of this type as necessary are used to read the entire matrix up to 8000 values. This format is compatible with the card output from the program.

Card Type 17 - Used if NINEK (Card Type 2) equals 2 and NSAT equals 2. This card is used to read the initial capillary conductivity by the matrix option. It contains seven 10-column floating point fields beginning in Columns 1, 11, 21, etc. Card Type 17 is used in a manner similar to Card Type 16. This format is also compatible with the output from the program.

It should be noted here that an inconsistency exists between Part 1 and Part 2 documents. The direction in which the Y coordinate increases is lefthanded in Part 1 and righthanded in Part 2. Therefore, if the foregoing table is related to the finite difference representation of the boundary conditions in Part 1, the subscripts $j - 1$ and $j + 1$ should be interchanged. With this change Part 1 becomes consistent with Part 2 and the computer program.

Deck Setup

The deck is set up in standard FORTRAN monitor order:

* IDENT Card
* XEQ Card
Binary Object Deck
* DATA Card
Input Data

Operating Instructions

This is a standard FORTRAN Monitor chain link program; however, the use of two special features will have to be indicated to the operators on the procedures card.

(1) If the matrices indicated in Card Type 2-C are to be punched on cards, the proper note should be made to the operator.

(2) This program may be saved if the maximum execution time is exceeded. Special note to the operator should indicate that in case the specified time limit is exceeded, sense switch one is to be put in the down position, and time allowed for the save. The output is written to Tape Unit B4. The user is advised to check local procedures.

Input Preparation for Startup from the Saved Program

The save feature of the program permits changes to be made in the original input to the problem; the cards needed for startup from save are listed below.

Card Type 1S - Used in all options to indicate if changes in the data are to be made. This card contains a one-column integer field in Column 1.

Field A - The save input control integer. If this integer is zero, no input changes are desired, and no other cards are needed. If the integer is one, input changes are desired and Cards 2S, 3S, 4S, and 5S must follow.

Card Type 2S - This card contains a 60-column BCD field.

Field A - A case identification message. Card Type 1 may be used.

Card Type 3S - This card contains four control integers placed in columns 5, 10, 15, and 20.

Field A - See Program Control Integers–Card 2-E.

Field B - See Program Control Integers–Card 2-G.

Field C - See Program Control Integers–Card 2-H.

Field D - See Program Control Integers–Card 2-I.

Card Type 4S - This card contains two 10-column, floating-point fields beginning in Columns 1 and 11.

Field A - See Card 8-A.

Field B - See Card 8-B.

Card Type 5S - This card contains one 5-column, fixed-point field and three 5-column integer fields starting in Columns 1, 6, 11, and 15.

Field A - See Card 9-A.

Field B - See Card 9-B.

Field C - See Card 9-C.

Field D - See Card 9-D.

The above procedure is applicable to offsite usage where a standard FORTRAN II monitor is used with the exception of the deck setup below for reloading the program.

Deck Setup (for HAPO use only)

The deck for HAPO use is set up in the following order:

* IDENT Card
* XEQ SAVE Card
Binary Save Deck
* DATA Card
Input Data

Deck Setup (for offsite use)

The deck setup for offsite use in in the following order:

* IDENT Card
* XEQ Card
Loader programs (to be provided)
Binary Save Deck
* DATA Card
Input Data

The loader program is a standard FORTRAN program that can easily be modified by the user to meet local operational requirements.

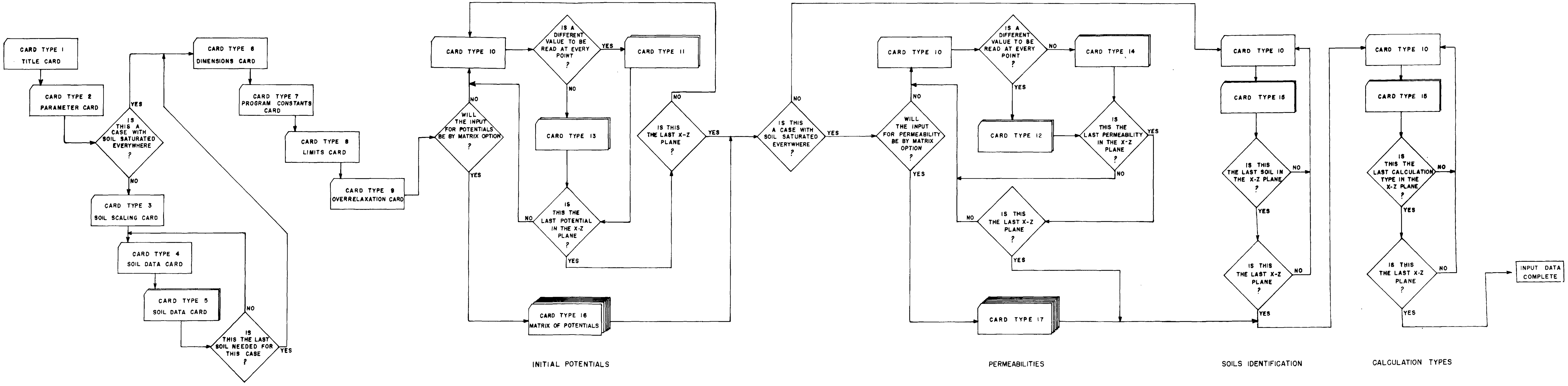


FIGURE 4
Schema of Card Sequence

APPENDIX B

SOILS DATA INPUT PREPARATION

The soils data used in the program for partially-saturated flow problems are obtained experimentally. The treatment of the laboratory data to reduce them to the necessary input on Card Types 4 and 5 is discussed in this Appendix.

In solving for the potentials within the matrix of grid points, the relationship of capillary conductivity, κ, to capillary pressure, $-P_c$, is needed. Once the potential pattern has been obtained the relationship of the moisture content, θ, to $-P_c$ may be used to obtain the moisture content pattern within the matrix.

The input method for the soils data requires that a tabulated set of experimental values be reduced to a systematic set of data that will permit the computer to interpolate between points of information or to evaluate appropriate equations representing the laboratory data. This data reduction step is illustrated graphically in Figure 5 which is a plot of the experimental κ values normalized with the saturated permeability, κ_o. The K plotted on the graph is the relative capillary conductivity. Figure 6 is a plot of moisture content, θ, versus p/γ.

To illustrate the technique used to obtain the necessary soils data from the plot of K versus p/γ (Card Types 4 and 5, Appendix A), a typical soil, G. E.—9, shown on Figure 5 will be used. A complete listing of the input cards for that soil is shown as the first soil of the sample input for the partially saturated case in Appendix C. The same techniques apply for the moisture content relationship, but now the same cards are used in a slightly different manner.

The curve of capillary conductivity shown on Figure 5 is divided into four segments; a constant value, a linear fit, a table of values, and an exponential fit. On the described curve the linear fit segment has been reduced to a point. The highest pressure head, p/γ, of the linear fit is -5.0 cm,

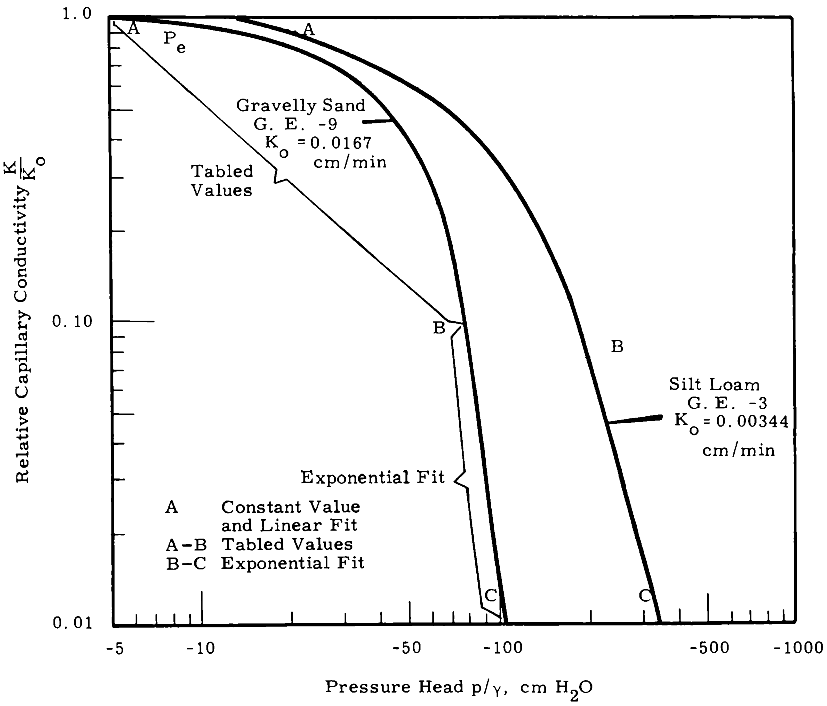


FIGURE 5

Capillary Conductivity-Pressure Relationship
for Typical Hanford Soils

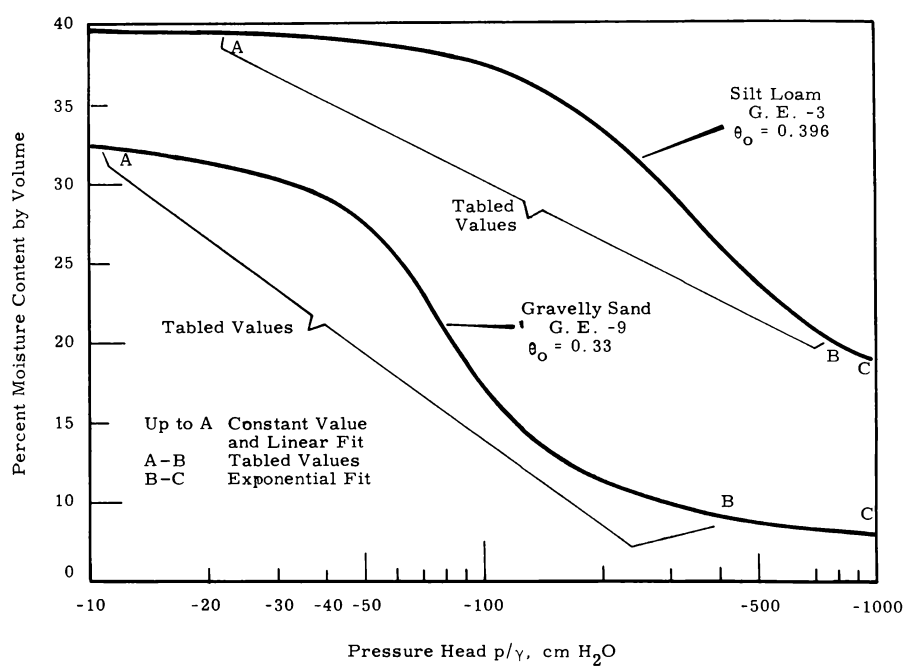


FIGURE 6

Moisture Content-Pressure Relationship
for Typical Hanford Soils

(Field A, Card Type 4). The highest p/γ value of the table of values is chosen where the curve deviates from the straight line description at the point marked A or -5.0 cm, (Field B, Card Type 4). The highest p/γ value of the exponential fit, (Field C, Card Type 4), is chosen arbitrarily and must coincide with the last point of the table of values: for G.E.—9 soil a value of -81.0 cm is used. The pressure head increment between the tabled values of K is chosen as -2.0 cm, (Field D, Card Type 4). The number of K-values between -81.0 cm and -5.0 cm in increments of -2.0 cm is 39 (Field E, Card Type 4).

Card Type 5 inputs the K-values corresponding to the p/γ values on the previous card. The constant K-value normally used in Field A, Card Type 5 is the saturated permeability of the soil; in the example, this value is 0.0167 cm/min. The K-value is used to form the permeability coupling ratio (discussed in Part 1) which correctly interrelates the several soils in any flow problem where each soil has a different saturated conductivity. The first input soil is used as the base soil to which all the other soils are related. When moisture contents are being input, the program does not form this ratio but uses the values directly.

The coefficients of the linear equation for computing the linear fit portion of the curve are B_1 and B_2 in the following equation:

$$K = B_1 (p/\gamma) + B_2 . \tag{1}$$

In this case where no fit was made, $B_1 = 0.0$ and $B_2 = 1.0$ were used (Fields B_1 and B_2, Card Type 5).

The tabled values of capillary conductivity are read from the graph or from tabulated results at every 2.0 cm increment in pressure head. The first value must coincide precisely with the last value at the end of the straight line portion of the curve, i.e., at -5.0 cm the value is 1.0. Additional values for this soil are 0.967, 0.941, 0.916, 0.890, 0.865, etc. These values are entered in Fields $C_1 \ldots C_n$. The straight line portion of the curve, as shown on the logarithmic plot of Figure 5, is described by an exponential equation

$$K = \frac{D_1}{(p/\gamma)^{D_2}} \tag{2}$$

The equation rewritten in logarithmic form is

$$\log_{10} K = \log D_1 - D_2 \log (p/\gamma). \tag{3}$$

Two points from the curve are substituted into the equation to form two equations with two unknowns. Log D_1 is eliminated and the equation is solved for the coefficient D_2. Coefficient D_1 is obtained by substituting D_2 into Equation (2). These values for soil G. E.—9 are 7.3115×10^{13} and 7.842 (Fields D_1 and D_2, Card Type 5). Substitution of the last K-value from the table into Equation (2) must yield the correct p/γ or a discontunity will exist in the curve and erroneous answers will result.

APPENDIX C

PROGRAM SAMPLE INPUT AND RESULTS

The input and solution of two sample problems are included to provide a demonstration of the card preparation and printed results. The cases are not intended to be realistic flow systems but serves to illustrate input options and may be used as standards for checking programs.

The first case is a three dimensional flow problem representing one-quarter of a flow system with the soil only partially saturated. The case demonstrates the soils input data and row input options in initial heads, soils, and calculation types. The soil is heterogeneous with the pattern shown in Figure 7. The flow from a source in the upper corner is outward and downward toward the water table held fixed one node spacing below the bottom of the block. The block of soil being investigated is 30 cm high, 15 cm deep, and 20 cm wide with the nodes spaced at 5 cm intervals throughout.

Case Two illustrates a saturated flow system based on Figure 7, also. The system may be thought of as a thin slice using only the front face on the block. This represents the two dimensional flow system of an infinitely long trench. The pattern is represented by changes in the saturated permeability of the various soils. The origin has been translated a -30 cm to insure saturated conditions.

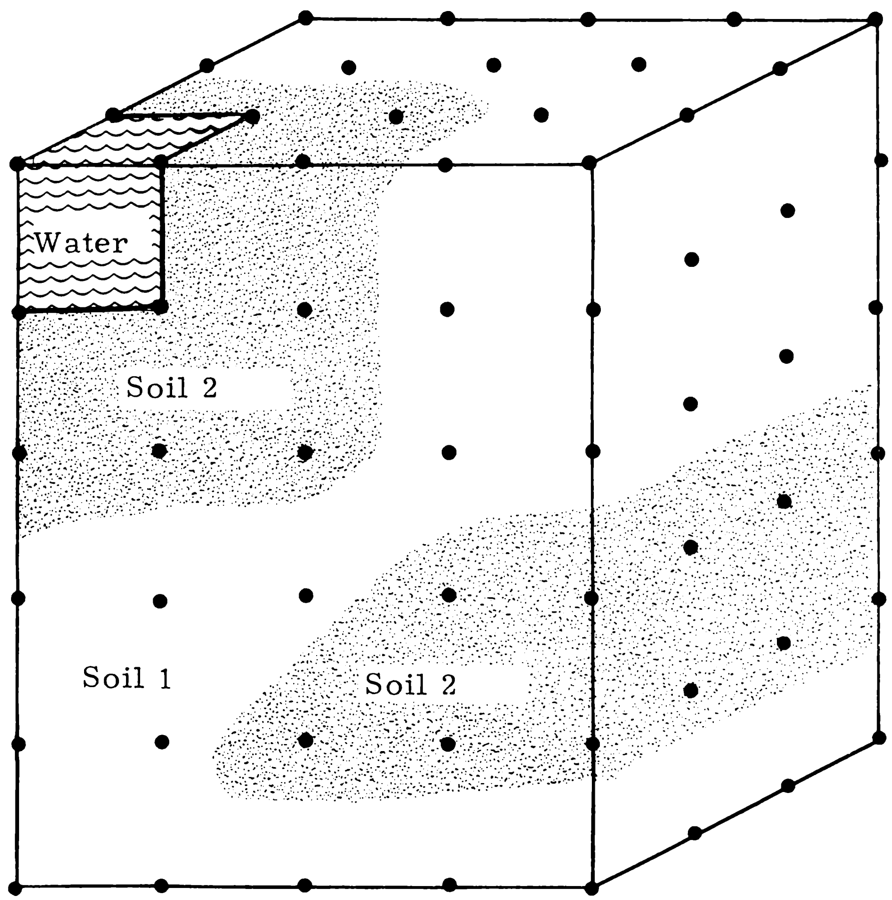


FIGURE 7

Diagram of Test Flow Cases

```
   1 PARTIALLY SATURATED FLOW (3 DIM.) SAMPLE CASE WITH 2 SOILS.          TYPE  1
   1    1        1    2    2    2    2    1                              TYPE  2
COMMENT--SOILS DATA INPUT
 21.0    -02                                                              TYPE  3
-5.     +00-5.     +00-8.1    +01-2.     +0039                            TYPE  4
1.67    -020.      +001.      +001.      +009.67    -019.41    -019.16    -01  TYPE  5
8.9     -018.65    -018.36    -018.12    -017.85    -017.58    -017.32    -01  TYPE  5
7.05    -016.8     -016.53    -016.27    -016.      -015.75    -015.5     -01  TYPE  5
5.23    -014.97    -014.71    -014.46    -014.18    -013.93    -013.66    -01  TYPE  5
3.37    -013.13    -012.88    -012.62    -012.37    -012.14    -011.92    -01  TYPE  5
1.72    -011.54    -011.37    -011.21    -011.07    -019.2     -027.9     -02  TYPE  5
7.3115 +137.842   +00                                                     TYPE  5
-1.4    +01-1.4    +01-2.14   +02-5.0    +0041                            TYPE  4
3.44    -030.0        1.0     +001.0     +009.71    -018.98    -018.03    -01  TYPE  5
7.42    -016.90    -016.50    -016.13    -015.80    -015.5     -015.23    -01  TYPE  5
4.95    -014.68    -014.40    -014.13    -013.88    -013.65    -013.42    -01  TYPE  5
3.22    -013.02    -012.825   -012.625   -012.44    -012.26    -012.09    -01  TYPE  5
1.935   -011.80    -011.665   -011.55    -011.43    -011.33    -011.23    -01  TYPE  5
1.15    -011.075   -011.0     -019.3     -028.6     -027.80    -027.15    -02  TYPE  5
6.4     -025.75    -025.28196+063.4015 +00                                TYPE  5
COMMENT--PROBLEM CONSTANTS
    4    6    5    4    6    5    2    5    2                             TYPE  6
2.0     -016.0        0.0        1.0        1.0        1.0        3.0     +01  TYPE  7
1.3     +001.0     -06                                                    TYPE  8
1.0      15   10   300                                                    TYPE  9
COMMENT--CAPILLARY PRESSURE HEAD LOADED BY ROW INPUT OPTION
  1  4  1  1  1                                                           TYPE 10
   10.2                                                                   TYPE 13
  1  4  2  3  2                                                           TYPE 10
   10.7000    40.5000                                                     TYPE 13
  1  4  4  4  2                                                           TYPE 10
   10.9000    30.7000                                                     TYPE 13
  1  2  5  5  3                                                           TYPE 10
   11.0000    3.98000    4.75000                                          TYPE 13
  3  4  5  5  2                                                           TYPE 10
   10.9800    40.7800                                                     TYPE 13
  1  2  6  6  3                                                           TYPE 10
   11.0000    30.8800    40.7500                                          TYPE 13
  3  4  6  6  0                                                           TYPE 10
0.952000000.910000000.832000000.680000000.62000000                        TYPE 11
COMMENT--CALCULATION TYPE INPUT BY COLUMN OF CHANGE OR ROW INPUT
  1  4  1  1  1                                                           TYPE 10
  11.                                                                     TYPE 15
  1  4  2  2  2                                                           TYPE 10
  11.  32.                                                                TYPE 15
  1  4  3  3  2                                                           TYPE 10
  11.  42.                                                                TYPE 15
  1  2  4  6  2                                                           TYPE 10
  12.  41.                                                                TYPE 15
  3  4  4  6  1                                                           TYPE 10
  11.                                                                     TYPE 15
  1  4  1  1  1                                                           TYPE 10
  11.                                                                     TYPE 15
  1  1  2  4  3                                                           TYPE 10
  117  27.  519                                                           TYPE 15
```

```
  2  3  2  4  3                                                                                              TYPE 10
  15.  22.  56.                                                                                              TYPE 15
  4  4  2  4  3                                                                                              TYPE 10
  118  28.  520                                                                                              TYPE 15
  1  1  5  5  3                                                                                              TYPE 10
  11.  37.  519                                                                                              TYPE 15
  2  2  5  5  3                                                                                              TYPE 10
  11.  32.  56.                                                                                              TYPE 15
  3  3  5  5  3                                                                                              TYPE 10
  15.  22.  56.                                                                                              TYPE 15
  4  4  5  5  3                                                                                              TYPE 10
  118  28.  520                                                                                              TYPE 15
  1  1  6  6  3                                                                                              TYPE 10
  11.  315  527                                                                                              TYPE 15
  2  2  6  6  3                                                                                              TYPE 10
  11.  34.  514                                                                                              TYPE 15
  3  3  6  6  3                                                                                              TYPE 10
  113  24.  514                                                                                              TYPE 15
  4  4  6  6  3                                                                                              TYPE 10
  126  216  528                                                                                              TYPE 15


    2  SATURATED FLOW PROBLEM (2 DIMENSION IN X-Z PLANE)                                                   TYPE  1
    2     2     1     1     1     1     2     2     1                                                      TYPE  2
COMMENT--PROBLEM CONSTANTS
    1     6     5     1     6     5     1     5     1                                                      TYPE  6
2.0     -01-3.0    +010.0     +001.0     +001.0     +001.0     +003.0     +01                              TYPE  7
1.3     +001.0     -06                                                                                     TYPE  8
1.25       8    10    80                                                                                   TYPE  9
COMMENT--PIEZOMETRIC HEAD LOADED BY MATRIX OPTION
0.        0.        0.        0.        0.        0.09056760.08078850.0526355                              TYPE 16
0.03448560.02866330.45925080.39331290.20875630.12100500.09654390.7729132                                   TYPE 16
0.73385700.55597760.29685410.22336061.00000001.00000000.67095760.4631551                                   TYPE 16
0.36174571.00000001.00000000.71804140.54161600.44084580.        0.                                         TYPE 16
COMMENT--HYDRAULIC CONDUCTIVITY OR PERMEABILITY LOADED BY COLUMN OF CHANGE
  1  1  1  1  1                                                                                              TYPE 10
    11.67    -02                                                                                             TYPE 14
  1  1  2  2  2                                                                                              TYPE 10
    11.67    -02     33.44    -03                                                                            TYPE 14
  1  1  3  3  2                                                                                              TYPE 10
    11.67    -02     43.44    -03                                                                            TYPE 14
  1  1  4  6  2                                                                                              TYPE 10
    13.44    -03     41.67    -02                                                                            TYPE 14
COMMENT--CALCULATION TYPE INPUT BY COLUMN OF CHANGE OR ROW INPUT
  1  1  1  1  1                                                                                              TYPE 10
  11.                                                                                                        TYPE 15
  1  1  2  4  3                                                                                              TYPE 10
  15.  22.  56.                                                                                              TYPE 15
  1  1  5  5  3                                                                                              TYPE 10
  11.  32.  56.                                                                                              TYPE 15
  1  1  6  6  3                                                                                              TYPE 10
  11.  34.  510                                                                                              TYPE 15

NOTE--THE COMMENT CARDS ARE FOR INSTRUCTION ONLY NOT PART OF THE DATA
```

```
INITIAL CONDITIONS

CASE NO.    1   PARTIALLY SATURATED FLOW (3 DIM.) SAMPLE CASE WITH 2 SOILS.

   474

INPUT DATA FOR THIS CASE

THIS IS A THREE DIMENSIONAL CASE

UNSATURATED SOIL CONDITIONS EXIST

 SOIL TYPE IDENTIFICATION
    SOIL NUMBER    PERMEABILITY COUPLING RATIO
         1                   1.0000E 00
         2                   2.0599E-01
 THE CAPILLARY PRESSURES ARE SCALED BY 10.0000E-03
 SATURATED PERMEABILITY FOR SOIL NO.1  1.6700E-02

DESCRIPTION OF MATRIX
 MATRIX DIMENSIONS ARE  Y#   4 Z#   6 X#   5
 THE COORDINATES OF THE POINT OF DISTURBANCE ARE Y#   2 Z#   5 X#I  2

PARAMETERS DESCRIBING PROBLEM
 DISTANCE BETWEEN NODE POINTS IS  2.0000E-01
 COLUMN LENGTH IS  3.0000E 01
 VERTICAL TRANSLATION OF THE ORIGIN IS  6.0000E 00
 ANGLE OF INCLINATION OF THE SYSTEM IS  0.
 COEFFICIENTS OF THE CAPILLARY PRESSURE EQUATION ARE  1.0000E 00  1.0000E 00
   1.0000E 00
PIEZOMETRIC HEAD CALCULATION METHOD
 RELATIVE CAPILLARY CONDUCTIVITY VALUES USED IN THE DENOMINATOR OF THE HEAD
  CALCULATION ARE AVERAGED
 OVERRELAXATION CORRECTION
    USED THROUGH ITERATION        FACTOR
              15               1.0000E 00
    OVERRELAXATION FACTOR RECALCULATED EVERY  10 ITERATIONS THEREAFTER UP TO 300

PROGRAM CONTROLS
 IF THE HIGHEST DIFFERENCE IS LESS THAN  1.0000E-06,THE CASE IS COMPLETE
 IF A CALCULATED PIEZOMETRIC HEAD VALUE EXCEEDS  1.3000E 00,AN ERROR EXIT OCCURS

DUMMY INPUT VALUES
     INTEGERS     FLOATING VALUES
        -0           1.6700E-02
        -0          -0.
        -0          -0.


PIEZOMETRIC HEAD

Y#   1

Z#   6   1.00000 1.00000 0.88000 0.75000 0.75000

Z#   5   1.00000 1.00000 0.98000 0.75000 0.75000

Z#   4   0.90000 0.90000 0.70000 0.70000 0.70000

Z#   3   0.70000 0.70000 0.70000 0.50000 0.50000

Z#   2   0.70000 0.70000 0.70000 0.50000 0.50000

Z#   1   0.20000 0.20000 0.20000 0.20000 0.20000
```

Y# 2

Z#	6	1.00000	1.00000	0.88000	0.75000	0.75000
Z#	5	1.00000	1.00000	0.98000	0.75000	0.75000
Z#	4	0.90000	0.90000	0.70000	0.70000	0.70000
Z#	3	0.70000	0.70000	0.70000	0.50000	0.50000
Z#	2	0.70000	0.70000	0.70000	0.50000	0.50000
Z#	1	0.20000	0.20000	0.20000	0.20000	0.20000

Y# 3

Z#	6	0.95200	0.91000	0.83200	0.68000	0.62000
Z#	5	0.98000	0.98000	0.98000	0.78000	0.78000
Z#	4	0.90000	0.90000	0.70000	0.70000	0.70000
Z#	3	0.70000	0.70000	0.70000	0.50000	0.50000
Z#	2	0.70000	0.70000	0.70000	0.50000	0.50000
Z#	1	0.20000	0.20000	0.20000	0.20000	0.20000

Y# 4

Z#	6	0.95200	0.91000	0.83200	0.68000	0.62000
Z#	5	0.98000	0.98000	0.98000	0.78000	0.78000
Z#	4	0.90000	0.90000	0.70000	0.70000	0.70000
Z#	3	0.70000	0.70000	0.70000	0.50000	0.50000
Z#	2	0.70000	0.70000	0.70000	0.50000	0.50000
Z#	1	0.20000	0.20000	0.20000	0.20000	0.20000

SOIL IDENTIFICATION

Y# 1

Z#	6	2	2	2	1	1
Z#	5	2	2	2	1	1
Z#	4	2	2	2	1	1
Z#	3	1	1	1	2	2
Z#	2	1	1	2	2	2
Z#	1	1	1	1	1	1

Y= 2					
Z= 6	2	2	2	1	1
Z= 5	2	2	2	1	1
Z= 4	2	2	2	1	1
Z= 3	1	1	1	2	2
Z= 2	1	1	2	2	2
Z= 1	1	1	1	1	1
Y= 3					
Z= 6	1	1	1	1	1
Z= 5	1	1	1	1	1
Z= 4	1	1	1	1	1
Z= 3	1	1	1	2	2
Z= 2	1	1	2	2	2
Z= 1	1	1	1	1	1
Y= 4					
Z= 6	1	1	1	1	1
Z= 5	1	1	1	1	1
Z= 4	1	1	1	1	1
Z= 3	1	1	1	2	2
Z= 2	1	1	2	2	2
Z= 1	1	1	1	1	1

TYPE OF PIEZOMETRIC HEAD CALCULATION

Y= 1					
Z= 6	1	1	15	15	27
Z= 5	1	1	7	7	19
Z= 4	17	7	7	7	19
Z= 3	17	7	7	7	19
Z= 2	17	7	7	7	19
Z= 1	1	1	1	1	1

Y# 2

Z# 6	1	1	4	4	14
Z# 5	1	1	2	2	6
Z# 4	5	2	2	2	6
Z# 3	5	2	2	2	6
Z# 2	5	2	2	2	6
Z# 1	1	1	1	1	1

Y# 3

Z# 6	13	4	4	4	14
Z# 5	5	2	2	2	6
Z# 4	5	2	2	2	6
Z# 3	5	2	2	2	6
Z# 2	5	2	2	2	6
Z# 1	1	1	1	1	1

Y# 4

Z# 6	26	16	16	16	28
Z# 5	18	8	8	8	20
Z# 4	18	8	8	8	20
Z# 3	18	8	8	8	20
Z# 2	18	8	8	8	20
Z# 1	1	1	1	1	1

CASE IS COMPLETE

CASE NO. 1 PARTIALLY SATURATED FLOW (3 DIM.) SAMPLE CASE WITH 2 SOILS.
PIEZOMETRIC HEAD

Y# 1

Z# 6	1.00000	1.00000	0.68414	0.58546	0.56752
Z# 5	1.00000	1.00000	0.65100	0.56601	0.55161
Z# 4	0.58298	0.57172	0.51234	0.51499	0.51222
Z# 3	0.39890	0.39947	0.40939	0.42722	0.43072
Z# 2	0.30072	0.30080	0.30053	0.28375	0.28075
Z# 1	0.20000	0.20000	0.20000	0.20000	0.20000

Y# 2

Z#	6	1.00000	1.00000	0.67066	0.58199	0.56549
Z#	5	1.00000	1.00000	0.63963	0.56324	0.54999
Z#	4	0.57597	0.56589	0.51215	0.51445	0.51169
Z#	3	0.40185	0.40258	0.41291	0.42858	0.43128
Z#	2	0.30234	0.30244	0.30212	0.28440	0.28111
Z#	1	0.20000	0.20000	0.20000	0.20000	0.20000

Y# 3

Z#	6	0.72902	0.70865	0.62219	0.57533	0.56142
Z#	5	0.69028	0.67263	0.59497	0.55770	0.54673
Z#	4	0.54655	0.53889	0.51702	0.51418	0.51086
Z#	3	0.41874	0.41957	0.43110	0.43332	0.43293
Z#	2	0.30740	0.30751	0.30704	0.28611	0.28198
Z#	1	0.20000	0.20000	0.20000	0.20000	0.20000

Y# 4

Z#	6	0.67546	0.65812	0.60600	0.57055	0.55888
Z#	5	0.63924	0.62469	0.58102	0.55377	0.54467
Z#	4	0.53398	0.52793	0.51428	0.51300	0.51005
Z#	3	0.41997	0.42115	0.43370	0.43437	0.43335
Z#	2	0.30868	0.30884	0.30844	0.28670	0.28231
Z#	1	0.20000	0.20000	0.20000	0.20000	0.20000

RELATIVE CAPILLARY CONDUCTIVITY

Y# 1

Z#	6	2.0599E-01	2.0599E-01	2.0422E-01	8.1877E-01	8.1231E-01
Z#	5	2.0599E-01	2.0599E-01	2.0599E-01	8.8975E-01	8.8435E-01
Z#	4	2.0599E-01	2.0599E-01	2.0599E-01	9.4685E-01	9.4576E-01
Z#	3	9.8296E-01	9.8324E-01	9.8815E-01	2.0599E-01	2.0599E-01
Z#	2	1.0000E 00	1.0000E 00	2.0599E-01	2.0599E-01	2.0599E-01
Z#	1	1.0000E 00	1.0000E 00	1.0000E 00	1.0000E 00	1.0000E 00

```
Y#  2
Z#  6 2.0599E-01 2.0599E-01 2.0374E-01 8.1752E-01 8.1152E-01
Z#  5 2.0599E-01 2.0599E-01 2.0599E-01 8.8872E-01 8.8375E-01
Z#  4 2.0599E-01 2.0599E-01 2.0599E-01 9.4663E-01 9.4556E-01
Z#  3 9.8442E-01 9.8478E-01 9.8989E-01 2.0599E-01 2.0599E-01
Z#  2 1.0000E 00 1.0000E 00 2.0599E-01 2.0599E-01 2.0599E-01
Z#  1 1.0000E 00 1.0000E 00 1.0000E 00 1.0000E 00 1.0000E 00
Y#  3
Z#  6 8.7588E-01 8.6825E-01 8.3199E-01 8.1512E-01 8.0987E-01
Z#  5 9.3735E-01 9.3074E-01 9.0104E-01 8.8664E-01 8.8253E-01
Z#  4 9.5916E-01 9.5617E-01 9.4764E-01 9.4653E-01 9.4523E-01
Z#  3 9.9278E-01 9.9319E-01 9.9890E-01 2.0599E-01 2.0599E-01
Z#  2 1.0000E 00 1.0000E 00 2.0599E-01 2.0599E-01 2.0599E-01
Z#  1 1.0000E 00 1.0000E 00 1.0000E 00 1.0000E 00 1.0000E 00
Y#  4
Z#  6 8.5433E-01 8.4678E-01 8.2616E-01 8.1340E-01 8.0885E-01
Z#  5 9.1822E-01 9.1263E-01 8.9560E-01 8.8516E-01 8.8175E-01
Z#  4 9.5425E-01 9.5189E-01 9.4657E-01 9.4607E-01 9.4492E-01
Z#  3 9.9338E-01 9.9397E-01 1.0000E 00 2.0599E-01 2.0599E-01
Z#  2 1.0000E 00 1.0000E 00 2.0599E-01 2.0599E-01 2.0599E-01
Z#  1 1.0000E 00 1.0000E 00 1.0000E 00 1.0000E 00 1.0000E 00
```

```
INITIAL CONDITIONS

CASE NO.    2    SATURATED FLOW PROBLEM (2 DIMENSION IN X-Z PLANE)

   474

INPUT DATA FOR THIS CASE

THIS IS A TWO DIMENSIONAL CASE

SATURATED SOIL CONDITIONS EXIST
 SATURATED PERMEABILITY FOR SOIL NO.1 -0.

DESCRIPTION OF MATRIX
 MATRIX DIMENSIONS ARE  Y=   1 Z=   6 X=   5
 THE COORDINATES OF THE POINT OF DISTURBANCE ARE Y=   1 Z=   5 X=I  1

PARAMETERS DESCRIBING PROBLEM
 DISTANCE BETWEEN NODE POINTS IS  2.0000E-01
 COLUMN LENGTH IS  3.0000E 01
 VERTICAL TRANSLATION OF THE ORIGIN IS -3.0000E 01
 ANGLE OF INCLINATION OF THE SYSTEM IS  0.
 COEFFICIENTS OF THE CAPILLARY PRESSURE EQUATION ARE  1.0000E 00  1.0000E 00
   1.0000E 00
PIEZOMETRIC HEAD CALCULATION METHOD
 RELATIVE CAPILLARY CONDUCTIVITY VALUES USED IN THE DENOMINATOR OF THE HEAD
 CALCULATION ARE NOT AVERAGED
 OVERRELAXATION CORRECTION
    USED THROUGH ITERATION        FACTOR
              8                 1.2500E 00
    OVERRELAXATION FACTOR RECALCULATED EVERY  10 ITERATIONS THEREAFTER
    UP TO  80 ITERATIONS MAXIMUM
PROGRAM CONTROLS
 IF THE HIGHEST DIFFERENCE IS LESS THAN  1.0000E-06,THE CASE IS COMPLETE
 IF A CALCULATED PIEZOMETRIC HEAD VALUE EXCEEDS  1.3000E 00,AN ERROR EXIT OCCURS

DUMMY INPUT VALUES
     INTEGERS     FLOATING VALUES
         -0          -0.
         -0          -0.
         -0           0.
         -0          -0.

 PIEZOMETRIC HEAD

 Y=  1

 Z=  6  1.00000 1.00000 0.71804 0.54162 0.44085

 Z=  5  1.00000 1.00000 0.67096 0.46316 0.36175

 Z=  4  0.77291 0.73366 0.55598 0.29685 0.22336

 Z=  3  0.43923 0.39331 0.20876 0.12100 0.09654

 Z=  2  0.09057 0.08079 0.05264 0.03449 0.02866

 Z=  1  0.      0.      0.      0.      0.
```

RELATIVE CAPILLARY CONDUCTIVITY

Y= 1

Z= 6	3.4400E-03	3.4400E-03	3.4400E-03	1.6700E-02	1.6700E-02
Z= 5	3.4400E-03	3.4400E-03	3.4400E-03	1.6700E-02	1.6700E-02
Z= 4	3.4400E-03	3.4400E-03	3.4400E-03	1.6700E-02	1.6700E-02
Z= 3	1.6700E-02	1.6700E-02	1.6700E-02	3.4400E-03	3.4400E-03
Z= 2	1.6700E-02	1.6700E-02	3.4400E-03	3.4400E-03	3.4400E-03
Z= 1	1.6700E-02	1.6700E-02	1.6700E-02	1.6700E-02	1.6700E-02

TYPE OF PIEZOMETRIC HEAD CALCULATION

Y= 1

Z= 6	1	1	4	4	10
Z= 5	1	1	2	2	6
Z= 4	5	2	2	2	6
Z= 3	5	2	2	2	6
Z= 2	5	2	2	2	6
Z= 1	1	1	1	1	1

CASE IS COMPLETE

CASE NO. 2 SATURATED FLOW PROBLEM (2 DIMENSION IN X-Z PLANE)
PIEZOMETRIC HEAD

Y= 1

Z= 6	1.00000	1.00000	0.05993	0.04860	0.04627
Z= 5	1.00000	1.00000	0.05398	0.04545	0.04394
Z= 4	0.03842	0.03708	0.03041	0.03727	0.03860
Z= 3	0.02199	0.02198	0.02298	0.02992	0.03393
Z= 2	0.01102	0.01104	0.01120	0.00360	0.00211
Z= 1	0.	0.	0.	0.	0.

APPENDIX D

PROGRAM AND SUBROUTINE LISTINGS

```
C     STEADY DARCIAN FLOW IN SOILS

      CHAIN LINK 1

C     ONE,TWO,OR THREE DIMENSIONAL STEADY STATE FLOW IN SOIL PROGRAM
C     UP TO 8000 NODE POINTS
C     CHAIN LINK 1 READS INPUT AND PREPARES FOR ITERATIONS THRU MATRIX
C     PROGRAMMER NOTE THE COORDINATE INDICES USED INTERNALLY DO NOT
C     CONFORM TO USUAL MATHEMATICAL CONVENTION.
C     COORDINATE        INTERNAL INDEX       EXTERNAL (DOCUMENT) INDEX
C         X                    K                        I
C         Y                    J                        J
C         Z                    I                        K
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON DEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
 5001 FORMAT (44HERROR EXIT ON LOADING BY COLUMN OF CHANGE Y= I3, 5HTO Y
     1= I3,5X,2HZ=I3,6H TO Z= I3, 2X,8HCHANGES=I5,2X,22HFIRST NUMBER LOA
     1DED IS ,A6)
    1 FORMAT (I5,10A6)
    2 FORMAT (I2,E10.4)
    3 FORMAT (14I5)
    4 FORMAT (14(I3,F2.0))
   30 FORMAT (F5.0,3I5)
   60 FORMAT (7(I4,F6.0))
   70 FORMAT (7E10.4)
   71 FORMAT (4E10.4,I2)
  300 FORMAT (5I3)
  752 FORMAT (8F9.7)
 3009 FORMAT (4(I5,E10.4))
C     CASE IDENTIFICATION AND SWITCH SETTERS READ IN
      READ INPUT TAPE 2,1,NCASE,CODE
      READ INPUT TAPE 2,3,NSAT,NINPHI,NINEK,NCUT,NAVG,NAXI,NPUN,NBUG,
     1NGRAP,NDUM3
C     READ-IN SOIL DATA FOR K CALCULATION ON NSAT=1
      GO TO (600,2000),NSAT
  600 READ INPUT TAPE 2,2,NUM,CUNIT
      DO 705  M=1,NUM
      READ INPUT TAPE 2,71,UK1(M),UK2(M),UK3(M),STEK3(M),MEK3
```

```
      READ INPUT TAPE 2,70,CK1(M),(CK2(M,N),N=1,2),(CK3(M,N),N=1,MEK3),
     1(CK4(M,N),N=1,2)
      IF(NDUM3)705,640,705
C     CALCULATE PERMEABILITY COUPLING RATIO FOR HETEROGENIOUS SOILS
  640 IF(M-1)650,650,655
  650 RWN=CK1(1)
  655 CK1(M)=CK1(M)/RWN
      CK2(M,1)=CK2(M,1)*CK1(M)
      CK2(M,2)=CK2(M,2)*CK1(M)
      DO 675 N=1,MEK3
  675 CK3(M,N)=CK3(M,N)*CK1(M)
      CK4(M,1)=CK4(M,1)*CK1(M)
C     UNIT CORRECT SOIL DATA IF NECESSARY
      IF (CUNIT-1.) 706,705,706
  706 UK1(M)=UK1(M)*CUNIT
      UK2(M)=UK2(M)*CUNIT
      UK3(M)=UK3(M)*CUNIT
      CK2(M,1)=CK2(M,1)/CUNIT
      CK4(M,1)=CK4(M,1)*CUNIT**CK4(M,2)
      STEK3(M)=STEK3(M)*CUNIT
  705 CONTINUE
C     READ CASE INPUT
 2000 READ INPUT TAPE 2,3,NCMAXJ,NCMAXI,NCMAXK,ICMAXJ,ICMAXI,ICMAXK,
     1JJ,II,KK,NDUM1,NDUM2,NDUM4
      READ INPUT TAPE 2,70,DELZ,H,ANGLE,BEE,DEE,AYE,ELENG
      READ INPUT TAPE 2,70,PHIMAX,PI,DUM1,DUM2,DUM4
      READ INPUT TAPE 2,30,COR1,N1,N2,N3
C     SET-UP UNCUT DIMENSIONS FOR PHI READ-IN
      MAXJ=NCMAXJ
      MAXI=NCMAXI
      MAXK=NCMAXK
C     COMPUTE SINE AND COSINE OF ANGLE OF SYSTEM INCLINATION
      CANGLE=COSF(ANGLE)
      SANGLE=SINF(ANGLE)
      DDUM4=H
      DDUM5=ELENG
      GO TO (4000,4001),NSAT
C     UNIT CORRECT COLUMN LENGTH
 4000 ELENG=ELENG*CUNIT
      DUM1=RWN
      H=H*CUNIT
C     DETERMINE IF AND HOW MATRIX IS TO BE CUT-UP
 4001 IF(NCMAXI-ICMAXI) 2070,2071,2070
 2071 ICUT=1
      GO TO 2072
 2070 ICUT=NCMAXI/ICMAXI+1
C     READ INITIAL PHI,K,MATERIAL,AND CALC TYPE MATRICES
 2072 III=1
   15 GO TO (7,3000,21,21),III
C     INITIAL K IN
 3000 GO TO (3006,     3001),NINEK
 3006 READ INPUT TAPE 2,300,JB,JT,IB,IT,KKK
      IF(KKK) 3050,3050,3007
C     INITIAL K-WHOLE LINE
 3050 READ INPUT TAPE 2, 70,(PLOP(K),K=1,MAXK)
      GO TO 2050
```

```
C     INITIAL K-BY POINTS OF CHANGE
 3007 READ INPUT TAPE 2,3009,((KEY(JJJ),PLOP(JJJ)),JJJ=1,KKK)
      GO TO 20
C     MATERIAL AND CALC TYPES-BY POINTS OF CHANGE
   21 READ INPUT TAPE 2,300,JB,JT,IB,IT,KKK
      READ INPUT TAPE 2,4,((KEY(JJJ),PLOP(JJJ)),JJJ=1,KKK)
      GO TO 20
C     INITIAL PHIS
    7 GO TO   (750,3001),NINPHI
  750 READ INPUT TAPE 2,300,JB,JT,IB,IT,KKK
      IF(KKK) 3051,3051,8
C     INTIAL PHI-WHOLE LINE
 3051 READ INPUT TAPE 2,752,(PLOP(K),K=1,MAXK)
C     WHOLE LINE IN ROUTINE
 2050 DO 751 J=JB,JT
      DO 751 I=IB,IT
      DO 751 K=1,MAXK
      JAM=MAXI*MAXK*(J-1)+MAXK*(I-1)+K
      IF(III-2) 2004,2005,2005
 2004 PHI(JAM)=PLOP(K)
      GO TO 751
 2005 EK (JAM)=PLOP(K)
  751 CONTINUE
      GO TO 22
C     WHOLE MATRIX IN ROUTINE
 3001 KIJTOT=MAXI*MAXK*MAXJ
      IF(III-2) 3002,3003,3003
 3002 READ INPUT TAPE 2, 752,(PHI(JAM),JAM=1,KIJTOT)
      GO TO 2008
 3003 READ INPUT TAPE 2,  70,( EK(JAM),JAM=1,KIJTOT)
      GO TO 2009
C     INTIAL PHI-BY POINTS OF CHANGE
    8 READ INPUT TAPE2,60,((KEY(JJJ),PLOP(JJJ)),JJJ=1,KKK)
C     POINT OF CHANGE ROUTINE
   20 KEY(KKK+1)=0
      IF(KKK-501)4100,5000,5000
 4100 IF(IT-501) 4111,5000,5000
 4111 IF(JT-21)3888,5000,5000
 5000 WRITE OUTPUT TAPE 3, 5001, JB, JT,IB,IT, KKK,PLOP(1)
      LSW=9
      GO TO 2080
 3888 DO 9 J=JB,JT
      DO 9I=IB,IT
      JJJ=1
      DO 9 K=1,MAXK
      IF(K-KEY(JJJ+1)) 10,11,10
   11 JJJ=JJJ+1
   10 JAM=MAXI*MAXK*(J-1)+MAXK*(I-1)+K
      GO TO (12,2006,13,105),III
   12    PHI(JAM)=PLOP(JJJ)
      GO TO 9
 2006 EK(JAM)=PLOP(JJJ)
      GO TO 9
   13 MAT(JAM)=PLOP(JJJ)
      GO TO 9
  105 NO(JAM)=PLOP(JJJ)
    9 CONTINUE
C     GET ALL OF MATRICES
   22 IF(MAXI-IT) 14,14,15
   14 IF(MAXJ-JT) 2007,2007,15
```

```
C     SET-UP FOR NEXT MATRIX-PICK-UP PROPER MATRIX DIMENSIONS
 2007 GO TO (2008,2009,2010,2011),III
 2008 GO TO (2012,2013),NSAT
 2012 III=3
      NCUT=1
      GO TO 2022
 2013 III=2
      IF(ICUT-1) 2020,2020,2021
 2021 IF(NCUT-2) 2022,2020,2020
 2009 III=4
      GO TO 2022
 2010 III=4
      GO TO 2022
C     SIZE OF UNCUT MATRIX
 2020 MAXJ=NCMAXJ
      MAXI=NCMAXI
      MAXK=NCMAXK
      GO TO 15
C     SIZE OF CUT MATRIX
 2022 MAXJ=ICMAXJ
      MAXI=ICMAXI
      MAXK=ICMAXK
      GO TO 15
C     SET-UP TO CUT MATRIX IF NECESSARY
 2011 IDUMP=1
      IF (ICUT-1) 2014,2014,2023
 2023 MAXJ=NCMAXJ
      MAXI=NCMAXI
      MAXK=NCMAXK
C     SUBROUTINE CUTTER REMOVES ROWS AND COLUMNS FROM A MATRIX
      CALL CUTTER
      IDUMP=IDUMP
      GO TO (2014,2015),IDUMP
C     ERROR EXIT-ON FAILURE IN CUTTER ROUTINE
 2015 GO TO 2080
C     DETERMINE IF 1,2,OR 3D MATRIX
 2014 IF(MAXJ-1) 400,400,2030
  400 IF(MAXK-1) 2031,2031,401
 2031 NSIZE=1
      GO TO 402
  401 NSIZE=2
      GO TO 402
 2030 NSIZE=3
C     SUBROUTINE TESTS FOR ILLOGICAL CALC TYPE CHOICES
  402 CALL TEST
      IDUMP=IDUMP
      GO TO(306,403),IDUMP
C     ERROR EXIT-ILLOGICAL CALC TYPE CHOICE
  403 LSW=6
      GO TO 2080
C     PRINT INITIAL CONDITIONS
  306 LSW=1
      IKTOT=MAXI*MAXK
      KIJTOT=MAXI*MAXK*MAXJ
C     CHAIN LINK 2          HANDLES ITERATION THRU THE MATRIX AND
C     CALCULATES PHI AT EACH POINT
 2080 CALL CHAIN (2,8)
      END
```

SUBROUTINE TEST

```
      SUBROUTINE TEST
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON PHI,EK,NO
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KTOTOT,NDOC,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NORAP,L,MI,JMI,IMI,KMI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON DEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(6000),EK(6000),NO(6000),MAT(6000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
      DO 600J=1,MAXJ
      DO 600I=1,MAXI
      DO 600K=1,MAXK
      JAM=MAXI*MAXK*(J-1)+MAXK*(I-1)+K
      IMAG=NO(JAM)
      IF(IMAG)500,500,40
   40 GO TO (50,60,70),NSIZE
   50 IF(IMAG-4)89,89,500
   60 IF (IMAG-10)89,89,500
   70 IF(IMAG-28)89,89,500
   89 IF (J-1) 90,90,91
   90 IF (K-1)  100,100,101
  100 IF (I-1)  102,102,103
  102 GO TO (401,402,403),NSIZE
  401 GO TO (600,500,600,500),IMAG
  402 GO TO (600,500,500,500,500,500,600,500,500,500),IMAG
  403 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,500,500,500,600,500,500,500,500,500,500,500),IMAG
  103 IF (I-MAXI) 104,105,105
  104 GO TO (404,405,406),NSIZE
  404 GO TO 600
  405 GO TO (600,500,500,500,600,500,600,500,600,500),IMAG
  406 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,600,500,500,500,600,500,500,500,600,500,500,500),IMAG
  105 GO TO (407,408,409),NSIZE
  407 GO TO (600,500,500,600),IMAG
  408 GO TO (600,500,500,500,500,500,500,500,600,500),IMAG
  409 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
     1,500,500,500,500,500,500,500,500,500,600,500,500,500),IMAG
  101 IF (K-MAXK) 106,107,107
  106 IF (I-1)  108,108,109
  108 GO TO (500,410,411),NSIZE
  410 GO TO (600,500,600,500,500,500,600,600,500,500),IMAG
```

```
411 GO TO (600,500,500,500,500,500,500,500,500,500,600,500,500,500,500
   1,500,500,500,500,500,600,500,600,500,500,500,500,500),IMAG
109 IF (I-MAXI) 110,111,111
110 GO TO (500,412,413),NSIZE
412 GO TO 600
413 GO TO (600,500,500,500,500,500,600,500,500,500,600,500,500,500,600
   1,500,600,500,600,500,600,500,600,500,600,500,600,500),IMAG
111 GO TO (500,414,415),NSIZE
414 GO TO (600,500,500,600,500,500,500,500,600,600),IMAG
415 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,600
   1,500,500,500,500,500,500,500,500,500,600,500,600,500),IMAG
107 IF (I-1)  112,112,113
112 GO TO (500,416,417),NSIZE
416 GO TO (600,500,500,500,500,500,500,600,500,500),IMAG
417 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,500,500,500,500,600,500,500,500,500,500),IMAG
113 IF (I-MAXI) 114,115,115
114 GO TO (500,418,419),NSIZE
418 GO TO (600,500,500,500,500,600,500,600,500,600),IMAG
419 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,600,500,500,500,600,500,500,500,600,500),IMAG
115 GO TO (500,420,421),NSIZE
420 GO TO (600,500,500,500,500,500,500,500,500,600),IMAG
421 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,500,500,500,500,500,500,500,500,600,500),IMAG
 91 IF (J-MAXJ)  92,93,93
 92 IF (K-1)  200,200,201
200 IF (I-1)  202,202,203
202 GO TO (600,500,500,500,500,500,500,500,600,500,500,500,500,500,500
   1,500,500,500,500,500,600,600,500,500,500,500,500,500),IMAG
203 IF (I-MAXI) 204,205,205
204 GO TO (600,500,500,500,600,500,500,500,600,500,500,500,600,500,500
   1,500,600,600,500,500,600,600,500,500,600,600,500,500),IMAG
205 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,600,500,500
   1,500,500,500,500,500,500,500,500,500,600,600,500,500),IMAG
201 IF (K-MAXK) 206,207,207
206 IF (I-1)  208,208,209
208 GO TO (600,500,600,500,500,500,500,500,600,600,600,600,500,500,500
   1,500,500,500,500,500,600,600,600,600,500,500,500,500),IMAG
209 IF (I-MAXI) 210,211,211
210 GO TO 600
211 GO TO (600,500,500,600,500,500,500,500,500,500,500,500,600,600,600
   1,600,500,500,500,500,500,500,500,500,600,600,600,600),IMAG
207 IF (I-1)  212,212,213
212 GO TO (600,500,500,500,500,500,500,500,500,600,500,500,500,500,500
   1,500,500,500,500,500,500,500,600,600,500,500,500,500),IMAG
213 IF (I-MAXI) 214,215,215
214 GO TO (600,500,500,500,500,600,500,500,500,600,500,500,500,600,500
   1,500,500,500,600,600,500,500,600,600,500,500,600,600),IMAG
215 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,600,500
   1,500,500,500,500,500,500,500,500,500,500,500,600,600),IMAG
 93 IF (K-1)  300,300,301
300 IF (I-1)  302,302,303
302 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,500,500,500,600,500,500,500,500,500,500),IMAG
303 IF (I-MAXI) 304,305,305
```

```
304 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,600,500,500,500,600,500,500,500,600,500,500),IMAG
305 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,500,500,500,500,500,500,500,600,500,500),IMAG
301 IF (K-MAXK) 306,307,307
306 IF (I-1)  308,308,309
308 GO TO (600,500,500,500,500,500,500,500,500,500,500,600,500,500,500
   1,500,500,500,500,500,500,600,500,600,500,500,500,500),IMAG
309 IF (I-MAXI) 310,311,311
310 GO TO (600,500,500,500,500,500,500,600,500,500,500,600,500,500,500
   1,600,500,600,500,600,500,600,500,600,500,600,500,600),IMAG
311 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,600,500,500,500,500,500,500,500,500,500,600,500,600),IMAG
307 IF (I-1)  312,312,313
312 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,500,500,500,500,500,600,500,500,500,500),IMAG
313 IF (I-MAXI) 314,315,315
314 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,500,600,500,500,500,600,500,500,500,600),IMAG
315 GO TO (600,500,500,500,500,500,500,500,500,500,500,500,500,500,500
   1,500,500,500,500,500,500,500,500,500,500,500,500,600),IMAG
600 CONTINUE
    GO TO 700
500 IDUMP=2
    LSW=6
700 RETURN
    END
```

SUBROUTINE CUTTER

```
      SUBROUTINE CUTTER
C     SUBROUTINE CUTTER REMOVES ROWS AND COLUMNS FROM A MATRIX
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,PI,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
      ICOUNT=0
```

```
    1 ICOUNT=ICOUNT+1
      GO TO (2,3,4,16,17,18,7),ICOUNT
C     TEST IF PROPOSED MATRIX CUT INCLUDES BOUNDARIES
    2 NDUM1=MAXK
      NDUM2=KK
      GO TO 5
    3 NDUM1=MAXI
      NDUM2=II
      GO TO 5
    4 NDUM1=MAXJ
      NDUM2=JJ
      GO TO 5
   16 NDUM1=KK
      NDUM2=1
      GO TO 5
   17 NDUM1=II
      NDUM2=1
      GO TO 5
   18 NDUM1=JJ
      NDUM2=1
    5 DIFF=(FLOATF(NDUM1)-FLOATF(NDUM2))/FLOATF(ICUT)
      IDIFF=XFIXF(DIFF)
      XDIFF=FLOATF(IDIFF)
      IF(XDIFF-DIFF) 6,1,6
C     ERROR EXIT-CUTTER ROUTINE-PROPOSED CUT DOES NOT INCLUDE BOUNDARY
C     LSW=7
    6 LSW=7
      IDUMP=2
      GO TO 15
C     MATRIX ROWS AND COLUMNS CUT OUT
    7 DO 8 M=1,NCUT
      JAM=0
      DO 8 J=1,MAXJ,ICUT
      DO 8 I=1,MAXI,ICUT
      KLEFT=MAXI*MAXK*(J-1)+MAXK*(I-1)+1
      KRIGHT=KLEFT+MAXK-1
      DO 8 K=KLEFT,KRIGHT,ICUT
      JAM=JAM+1
      GO TO (9,10),M
    9 PHI(JAM)=PHI(K)
      GO TO 8
   10 EK(JAM)=EK(K)
    8 CONTINUE
C     CALCULATE CUT DIMENSIONS
      MAXK=MAXK/ICUT+1
      MAXI=MAXI/ICUT+1
      MAXJ=MAXJ/ICUT+1
      JJ=JJ/ICUT+1
      II=II/ICUT+1
      KK=KK/ICUT+1
C     CHECK CALC CUT DIMENSIONS AGAINST INPUT CUT DIMENSIONS
      IF(MAXK-ICMAXK) 11,12,11
   12 IF(MAXI-ICMAXI) 11,13,11
   13 IF(MAXJ-ICMAXJ) 11,14,11
   14 DELZ=DELZ*FLOATF(ICUT)
      GO TO 15
C     ERROR EXIT-CUTTER ROUTINE-CALCULATED CUT DIMENSIONS DO NOT AGREE
C     WITH INPUT CUT DIMENSIONS-LSW=8
   11 LSW=8
      IDUMP=2
   15 RETURN
      END
```

CHAIN LINK 2

```
C     CHAIN LINK 2   HANDLES ITERATION THRU THE MATRIX AND CALCULATES
C     PHI AT EACH POINT
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
  209 FORMAT (I1)
  401 FORMAT (3HOL=I3,3H Y=I3,3H Z=I3,3H X=I3,23H TERMS OF THE EQUATION
     11P5E12.4/13H DENOMINATORS1P3E12.4,9H CONSTANT1PE12.4/7I5)
 1000 FORMAT (10A6)
 1001 FORMAT (14I5)
 1003 FORMAT (F5.0,3I5)
 2090 FORMAT (2I5)
 2091 FORMAT (8F9.7)
 2094 FORMAT (7E10.4)
C     SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
      IF(LSW-6)1004,2,2
 1004 CALL OUT
C     INITIALIZE
      LSW=2
      NDY=0
      L=1
      HI=0.
C     CALCULATE INITIAL K ON NSAT=1
      GO TO (2016,2017),NSAT
C     ADDRS SUBROUTINE MERGES  MATERIAL AND TYPE OF CALC MATRIX INTO
C     ONE SET OF MEMORY LOCATIONS
 2016 CALL ADDRS (MAT ,NO)
      DO 17 J=1,MAXJ
      DO 17 I=1,MAXI
   63 DO 17 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(I-1)+K
C     SUBROUTINE GMAN PICKS UP MATERIAL MATRIX FROM MERGED MATRIX
      CALL GMAN (MAN,NO,JAM)
  760 FRACT=(PHI(JAM)-BEE*CANGLE*DELZ*FLOATF(I-1)+DEE*SANGLE*DELZ*
     1FLOATF(K-1)-(AYE*H        /ELENG))*ELENG
C     SUBROUTINE KAY COMPUTES K A FUNCTION OF FRACT-(PHI)
      CALL       KAY
       EK(JAM)=FK
```

```
   17 CONTINUE
 2017 CORR=COR1
      NSKIP=1
      HTERM=0.
      VTERM=0.
      OTERM=0.
      AX TERM=0.
      DUM3=0.
C     ROUTINE TO SELECT TYPE  OF STEPPING
      IF (KK-1) 2030,2030,2031
 2030 IF (II-1) 2032,2032,2033
 2032 NTYPE=2
      GO TO 31
 2033 IF(II-MAXI) 2034,2035,2035
 2034 NTYPE=3
      GO TO 31
 2035 NTYPE=4
      GO TO 31
 2031 IF(KK-MAXK) 2036,2037,2037
 2036 IF (II-1) 2038,2038,2039
 2038 NTYPE=9
      GO TO 31
 2039 IF(II-MAXI) 2040,2041,2041
 2040 NTYPE=1
      GO TO 31
 2041 NTYPE=5
      GO TO 31
 2037 IF (II-1) 2042,2042,2043
 2042 NTYPE=8
      GO TO 31
 2043 IF(II-MAXI) 2044,2045,2045
 2044 NTYPE=7
      GO TO 31
 2045 NTYPE=6
C     ITERATION THRU MATRIX FROM THIS POINT
   31 PSDIFE=SDIFE
      SDIFE=0.
      DO 15JPLANE=1,MAXJ
C     ROUTINE TO PICK-UP PROPER I,K MATRIX
      IF(JPLANE-1) 1,1,3
    1 J=JJ
      GO TO 4
    3 IF (JJ-J) 6,5,5
    5 J=J-1
      IF (J-1) 7,4,4
    7 J=JJ+1
      GO TO 4
    6 J=J+1
    4 INIT=1
      ICOUNT=1
      MDUM1=IKTOT*(J-1)
      DO 15IP=1,MAXI
      DO 15KP=1,MAXK
C     SUBROUTINE STEP SETS-UP STEPPING THRU MATRIX AND INDICES OF
C     SURROUNDING POINTS
      CALL        STEP
```

```
      I=(JAM-MDUM1       )/MAXK+1
      K=JAM-MDUM1       -MAXK*(I-1)
      IF(K) 6000,6000,6001
 6000 K=MAXK
      I=I-1
 6001 INIT=INIT
      ICOUNT=ICOUNT
      JAM=JAM
      NSKIP=NSKIP
C     NSKIP CONTROLS SKIPPING OF A POINT ON TYPE OF CALC=1
      GO TO(44,15),NSKIP
   44 BEFORE=PHI(JAM)
      IF(NDUM3)2021,314,2021
C     SUBROUTINE FHI COMPUTES TERMS OF PHI EQUATION
  314 CALL       FHI
      PHI(JAM)=AVTERM+HTERM+VTERM+OTERM+AXTERM
C     OVER-RELAXATION CORRECTION
      PHI(JAM)=BEFORE+(PHI(JAM)-BEFORE)*CORR
      GO TO (2021,2022),NSAT
C     CALCULATE K IF NSAT=1
C     SUBROUTINE GMAN PICKS UP MATERIAL MATRIX FROM MERGED MATRIX
 2021 CALL GMAN (MAN,NO,JAM)
      FRACT=(PHI(JAM)-BEE*CANGLE*DELZ*FLOATF(I-1)+DEE*SANGLE*DELZ*FLOATF
     1(K-1)-(AYE*H/ELENG))*ELENG
C     SUBROUTINE KAY COMPUTES K A FUNCTION OF FRACT-(PHI)
      CALL KAY
      EK(JAM)=FK
 2022 GO TO (83,83,84),NBUG
C     TERMWISE DEBUG PRINTOUT
   84 WRITE OUTPUT TAPE 3,401,L,J,I,K,AVTERM,HTERM,VTERM,OTERM,AXTERM,
     1DENOM1,DENOM2,DENOM3,DENCON,JAM,MH1,MH2,MV1,MV2,MO1,MO2
C     FIND HIGHEST DIFFERENCE POINT IN ITERATION
   83 DIFE=ABSF((PHI(JAM)-BEFORE)/CORR)
      SDIFE=SDIFE+DIFE
      IF(HI-DIFE) 46,504,504
   46 HI=DIFE
      IHI=I
      KHI=K
      JHI=J
C     TEST PHI AGAINST INPUT VALUE
  504 IF(ABSF(PHI(JAM))-ABSF(PHIMAX))  15,301,301
C     ERROR EXIT-CALCULATED PHI BIGGER THAN INPUT MAX VALUE-LSW=9
  301 LSW=9
      GO TO 2
   15 CONTINUE
      DUM3=SDIFE/FLOATF(KIJTOT)
C     DEBUG PRINTOUT
C     SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
   71 CALL OUT
C     INTERROGATE SS TO.SEE IF TIME LIMIT EXCEEDED
   70 IF (SENSE SWITCH 1) 202,250
C     NEED TO ITERATE AGAIN
  250 IF(HI-P1) 19,19,20
C     NO MORE ITERATION
   19 LSW=3
C     PUNCH PHI AND K MATRIX IF DESIRED
```

```
      GO TO (2,2093),NPUN
 2093 PUNCH 2090,NCASE,KIJTOT
      PUNCH 2091,(PHI(JAM),JAM=1,KIJTOT)
      GO TO (2092,2),NSAT
 2092 PUNCH 2094,(EK(JAM),JAM=1,KIJTOT)
C     END OF CASE PRINTOUT-LSW=3
C     SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
    2 CALL OUT
 5000 CALL EXIT
C     ITERATE AGAIN
C     RE-INITIALIZE
   20 HI=0.
      DUM3=0.
      L=L+1
 4000 LSW=2
C     SET UP OVER-RELAXATION CORRECTION
      IF(L-N1)28,28,22
   22 CALL RELAX (NSAT,SDIFE,PSDIFE,CORR,NDY)
   34 COR1=CORR
   35 N1=N1+N2
      GOTO 31
   28 IF(L-N3)31,31,30
C     GO TO SAVE ROUTINE-ITERATION LIMIT EXCEEDED
   30 LSW=4
      GO TO 602
C     GO TO SAVE ROUTINE-TIME RUN OUT
  202 LSW=5
C     PRINT BEFORE SAVE
  602 CALL OUT
C     SAVE ROUTINE
  600 CALL SAVE (0)
C     START-UP AFTER SAVE
      READ INPUT TAPE 2,209,NCHG
      IF (NCHG) 50,50,210
  210 READ INPUT TAPE 2,1000,CODE
      READ INPUT TAPE 2,1001,NAVG,NPUN,NBUG,NGRAP,NDUM1,NDUM2,NDUM4
      READ INPUT TAPE 2,2094,PHIMAX,P1,DUM1,DUM4
      READ INPUT TAPE 2,1003,COR1,N1,N2,N3
   50 WRITE OUTPUT TAPE 3,4100,NCASE
 4100 FORMAT (9H1CASE NO.I5,28H RESTARTED AFTER BEING SAVED)
      IF (LSW-4) 4000,4000,250
      END
```

SUBROUTINE FHI

```
      SUBROUTINE FHI
C     SUBROUTINE FHI COMPUTES TERMS OF PHI EQUATION
C     THIS VERSION OF FHI WILL HANDLE ONLY EQUAL GRID SPACING
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
      GO TO (1,2),NAVG
    1 DENOM1=EK(JAM)
      DENOM2=EK(JAM)
      DENOM3=EK(JAM)
      GO TO 3
C     AVG K IN DENOMINATOR
    2 DENOM1=(EK(MV2)+EK(MV1))/2.
      DENOM3=        (EK(MO2)+EK(MO1))/2.
      DENOM2=        (EK(MH1)+EK(MH2))/2.
    3 GO TO (4,5,6),NSIZE
C     1-D
    4 AV TERM=(PHI(MV1)+PHI(MV2))/2.
      DENCON=8.
      GO TO 7
C     2-D
    5 AV TERM=(PHI(MH1)+PHI(MH2)+PHI(MV1)+PHI(MV2))/4.
      DENCON=16.
      GO TO (8,9),NAXI
C     AXISYMMETRICAL
    9 AX TERM=(PHI(MH2)-PHI(MH1))/(8.*(FLOATF(K)+DUM2-1.))
      GO TO 8
C     3-D
    6 AV TERM=(PHI(MH1)+PHI(MH2)+PHI(MV1)+PHI(MV2)+PHI(MO1)+PHI(MO2))/6.
      DENCON=24.
      OTERM=((EK(MO2)-EK(MO1))*(PHI(MO2)-PHI(MO1)))/(DENCON*DENOM3)
    8 HTERM=((EK(MH2)-EK(MH1))*(PHI(MH2)-PHI(MH1)))/(DENCON*DENOM2)
    7 VTERM=((EK(MV2)-EK(MV1))*(PHI(MV2)-PHI(MV1)))/(DENCON*DENOM1)
      RETURN
      END
```

SUBROUTINE KAY

```
      SUBROUTINE KAY
C     SUBROUTINE KAY COMPUTES K A FUNCTION OF FRACT-(PHI)
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,P1,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
   10 IF(UK1(MAN)-FRACT) 21,22,22
   21 FK=CK1(MAN)
      GO TO 20
   22 IF(UK2(MAN)-FRACT) 23,24,24
   23 FK=CK2(MAN,1)*FRACT+CK2(MAN,2)
      GO TO 20
   24 IF(UK3(MAN)-FRACT) 25,26,26
   25 M=((FRACT-UK2(MAN))/STEK3(MAN))+1.
      FK=CK3(MAN,M)+(CK3(MAN,M+1)-CK3(MAN,M))*((FRACT-
     1(STEK3(MAN)*FLOATF(M-1)+UK2(MAN)))/STEK3(MAN))
      GO TO 20
   26 FK=CK4(MAN,1)/(FRACT**CK4(MAN,2))
   20 RETURN
      END
```

SUBROUTINE RELAX

```
      SUBROUTINE RELAX (NSAT,SDIFE,PSDIFE,CORR,NDY)
   22 QM=SDIFE/PSDIFE
      FLAMSQ=(QM+CORR-1.)**2/(QM*CORR**2)
      IF(1.-FLAMSQ)26,25,25
   26 FLAMSQ=-FLAMSQ
      NDY=NDY+1
   25 CORR=2./(1.+SQRTF(1.-FLAMSQ))
      IF(NSAT-1)29,29,34
   29 IF(1-NDY)27,23,23
   23 IF(FLAMSQ)27,27,32
   27 CORR=0.65+CORR*0.175
      GO TO 34
   32 CORR=1.+(CORR-1.)*.15
   34 RETURN
       END
```

SUBROUTINE ADDRS

```
       COUNT    20
       ENTRY    ADDRS
ADDRS  SXA      START+5,4
       CLA      1,4
       ADD      WONE
       STA      START+1
       CLA      2,4
       ADD      WONE
       STA      START+3
START  AXT      8000,4
       CLA      **,4
       ARS      18
       STA      **,4
       TIX      START+1,4,1
       AXT      **,4
       TRA      3,4
 WONE  OCT      1
       END
```

SUBROUTINE GMAN

```
      COUNT   20
      ENTRY   GMAN
GMAN  SXA     MLOD+1,4
      CLA     1,4
      STA     MLOD
      CLA     2,4
      ADD     WONE
      STA     LOAD
      CLA     3,4
      STA     *+1
      LXD     **,4
LOAD  CLA     **,4
      ALS     19
      ARS     1
      TOV     *+1
MLOD  STO     **
      AXT     **,4
      TRA     4,4
WONE  OCT     1
      END
```

SUBROUTINE GNO

```
      COUNT   20
      ENTRY   GNO
 GNO  SXA     MLOD+1,4
      CLA     1,4
      STA     MLOD
      CLA     2,4
      ADD     WONE
      STA     LOAD
      CLA     3,4
      STA     *+1
      LXD     **,4
LOAD  CLA     **,4
      ARS     18
      ALS     18
MLOD  STO     **
      AXT     **,4
      TRA     4,4
WONE  OCT     1
      END
```

SUBROUTINE OUT

```
      SUBROUTINE  OUT
      SUBROUTINE OUT HANDLES ALL PRINTOUT-WELL NEARLY
      COMMON PHI,EK,NO
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINER,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,PI,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
      DIMENSION  KROW(14)
  101 FORMAT (19H1INITIAL CONDITIONS)
  102 FORMAT (22H1ITERATION IS COMPLETE)
  103 FORMAT (17H1CASE IS COMPLETE)
  104 FORMAT (58H1NUMBER OF ITERATIONS HAS EXCEEDED THE LIMIT-PROGRAM SA
     1VED)
  105 FORMAT (34H1TIME LIMIT EXCEEDED-PROGRAM SAVED)
  106 FORMAT (62H1ERROR EXIT-AN ILLOGICAL CHOICE OF CALCULATION TYPE HAS
     1 BEEN MADE-CHECK INPUT DATA)
  107 FORMAT (59H1ERROR EXIT-PROPOSED MATRIX CUT DOES NOT INCLUDE BOUNDA
     1RIES)
  108 FORMAT (90H1ERROR EXIT-CALCULATED CUT MATRIX DIMENSIONS DO NOT AGR
     1EE WITH INPUT CUT MATRIX DIMENSIONS)
  109 FORMAT (76H1ERROR EXIT-A CALCULATED PIEZOMETRIC HEAD VALUE HAS EXC
     1EEDED THE INPUT LIMIT)
  301 FORMAT (1H0, 8HCASE NO.I5,2X,10A6)
  322 FORMAT (17H PIEZOMETRIC HEAD)
   66 FORMAT(20H SOIL IDENTIFICATION)
  206 FORMAT (37H TYPE OF PIEZOMETRIC HEAD CALCULATION)
  324 FORMAT (32H RELATIVE CAPILLARY CONDUCTIVITY)
  325 FORMAT (30H MOISTURE CONTENT DISTRIBUTION)
 2000 FORMAT (3H0Y=I3)
  306 FORMAT (3H0Z=I3)
  600 FORMAT (5H0    14I8)
 3006 FORMAT (1H0,I12,9I11)
   14 FORMAT (1H+F14.5,13F8.5/(F15.5,13F8.5))
   68 FORMAT (1H+I10,27I4/(I11,27I4))
 3011 FORMAT (1H+,5X,1P10E11.4/(6X,1P10E11.4))
 4011 FORMAT (1H+,5X,1P10E11.4)
 4000 FORMAT (1H0)
 4001 FORMAT (1H )
```

```
 1010 FORMAT (1H1)
  115 FORMAT (45H0THE NUMBER OF ITERATIONS IN THIS CASE EQUALSI5)
   72 FORMAT (11H0ITERATION=,I3,15H HI DIFFERENCE=,1PE11.4,3H Y=,I3,3H Z
     1=,I3,3H X=,I3,22H   AVERAGE DIFFERENCE=,E11.4,17H   O-RELAX. COR.=
     2,E11.4)
      GO TO (1,2,3,4,5,6,7,8,9),LSW
C     INITIAL CONDITIONS PRINTED OUT-LSW=1
    1 WRITE OUTPUT TAPE 3,101
      GO TO 15
C     ITERATION PRINTOUT-LSW=2
C       NBUG=1-NOTHING
C       NBUG=2-HI DIFFERENCE AND POINT AND AVDIFE
C       NBUG=3-ABOVE PLUS PHI AND K
    2 GO TO (100,10,30), NBUG
   30 WRITE OUTPUT TAPE 3,102
      GO TO 15
C     END OF CASE PRINTOUT-LSW=3
    3 WRITE OUTPUT TAPE 3,103
      GO TO 15
C     SAVE-TOO MANY ITERATIONS-LSW=4
    4 WRITE OUTPUT TAPE 3,104
      GO TO 31
C     SAVE-EXCEEDED TIME LIMIT-LSW=5
    5 WRITE OUTPUT TAPE 3,105
   31 GO TO (15,15,100),NBUG
C     ERROR EXIT-ILLOGICAL TYPE OF CALC CHOICE-LSW=6
    6 WRITE OUTPUT TAPE 3,106
      GO TO 15
C     ERROR EXIT-CUTTER ROUTINE-PROPOSED CUT DOES NOT INCLUDE BOUNDARY
C     LSW=7
    7 WRITE OUTPUT TAPE 3,107
      GO TO 15
C     ERROR EXIT-CUTTER ROUTINE-CALCULATED CUT DIMENSIONS DO NOT AGREE
C     WITH INPUT CUT DIMENSIONS-LSW=8
    8 WRITE OUTPUT TAPE 3,108
      GO TO 15
C     ERROR EXIT-CALCULATED PHI BIGGER THAN INPUT MAX VALUE-LSW=9
    9 WRITE OUTPUT TAPE 3,109
C     CASE NO. AND CASE IDENT PRINTED OUT
   15 WRITE OUTPUT TAPE 3,301,NCASE,CODE
      GO TO (16,19,18,19,19,18,18,18,19),LSW
C     INPUT PRINTOUT
   16 CALL INPUT
      WRITE OUTPUT TAPE 3,1010
      IF (LSW-6) 19,19,100
   18 GO TO (19,20),NGRAP
C     NON GRAPHICAL PHI MATRIX PRINTOUT
   19 WRITE OUTPUT TAPE3,322
      DO 2041 J=1,MAXJ
      WRITE OUTPUT TAPE 3,2000,J
      DO 41  I=1,MAXI
      IREV=MAXI+1-I
      WRITE OUTPUT TAPE 3,306,IREV
      DO 211 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  211 DUM(K)=   PHI(JAM)
```

```
   41 WRITE OUTPUT TAPE 3, 14,(DUM(K),K=1,MAXK)
 2041 WRITE OUTPUT TAPE 3,1010
      GO TO (22,703,703,703,703,22,100,100,25),LSW
   22 GO TO (1000,1050),NSAT
C     MATERIAL MATRIX PRINTOUT
 1000 WRITE OUTPUT TAPE 3,66
      DO 2213 J=1,MAXJ
      WRITE OUTPUT TAPE 3,2000,J
      DO 213 I=1,MAXI
      IREV=MAXI+1-I
      WRITE OUTPUT TAPE 3,306,IREV
      DO 212 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  212 MUM(K)=MAT(JAM)
  213 WRITE OUTPUT TAPE 3,68,(MUM(K),K=1,MAXK)
 2213 WRITE OUTPUT TAPE 3,1010
C     TYPE OF CALC MATRIX PRINTOUT
 1001 WRITE OUTPUT TAPE 3,206
      DO 2207 J=1,MAXJ
      WRITE OUTPUT TAPE 3,2000,J
      DO 207 I=1,MAXI
      IREV=MAXI+1-I
      WRITE OUTPUT TAPE 3,306,IREV
      DO 208 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  208 MUM(K)=NO(JAM)
  207 WRITE OUTPUT TAPE 3,68,(MUM(K),K=1,MAXK)
 2207 WRITE OUTPUT TAPE 3,1010
      GO TO 100
C     GRAPHICAL PHI AND K MATRIX PRINTOUT
   20 NPR=1
 3013 GO TO (3000,3001),NPR
 3000 NCOL=14
      GO TO 3002
 3001 NCOL=10
 3002 LL=NCOL
  514 IF(LL-MAXK) 511,512,513
  511 LL=LL+NCOL
      GO TO 514
  512 LINE=MAXK/NCOL
      GO TO 503
  513 LINE=MAXK/NCOL+1
  503 GO TO(3503,3003),NPR
 3503 WRITE OUTPUT TAPE 3,322
      GO TO 3004
 3003 WRITE OUTPUT TAPE 3,324
 3004 DO 2011 J=1,MAXJ
      WRITE OUTPUT TAPE 3,2000,J
  515 DO 11 LL=1,LINE
      K1=(LL-1)*NCOL+1
      IF(LL-LINE) 516,517,517
  516 K2=K1+NCOL-1
      GO TO 518
  517 K2=MAXK
  518 DO 610 K=K1,K2
      K3=K-(LL-1)*NCOL
```

```
  610 KROW(K3)=K
      GO TO (611,3005),NPR
  611 WRITE OUTPUT TAPE 3,600,(KROW(K),K=1,K3)
      GO TO 618
 3005 WRITE OUTPUT TAPE 3,3006,(KROW(K),K=1,K3)
  618 DO 11 I=1,MAXI
      IREV=MAXI+1-I
      WRITE OUTPUT TAPE 3,306,IREV
  519 DO 526 K=K1,K2
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
      K3=K-(LL-1)*NCOL
      GO TO (3007,3008),NPR
 3007 DUM(K3)=PHI    (JAM)
      GO TO 526
 3008 DUM(K3)=EK(JAM)
  526 CONTINUE
      GO TO (3009,3010),NPR
 3009 WRITE OUTPUT TAPE 3,14,(DUM(K),K=1,K3)
      WRITE OUTPUT TAPE 3,4000
      WRITE OUTPUT TAPE 3,4001
      GO TO 11
 3010 WRITE OUTPUT TAPE 3,4011,(DUM(K),K=1,K3)
      WRITE OUTPUT TAPE 3,4000
      WRITE OUTPUT TAPE 3,4000
      WRITE OUTPUT TAPE 3,4001
   11 CONTINUE
 2011 WRITE OUTPUT TAPE 3,1010
      GO TO (3012,702),NPR
 3012 NPR=2
      GO TO (3013,702),NSAT
  703 GO TO (1050,702),NSAT
C     NON GRAPHICAL K MATRIX PRINTOUT
 1050 IF(NDUM3)1052,1051,1052
 1051 WRITE OUTPUT TAPE 3,324
      GO TO 1053
 1052 WRITE OUTPUT TAPE 3,325
 1053 DO 2309 J=1,MAXJ
      WRITE OUTPUT TAPE 3,2000,J
      DO 309I=1,MAXI
      IREV=MAXI+1-I
      WRITE OUTPUT TAPE 3,306,IREV
      DO 202 K=1,MAXK
      JAM=IKTOT*(J-1)+MAXK*(IREV-1)+K
  202 DUM(K)= EK(JAM)
  309 WRITE OUTPUTTAPE3,3011,(DUM(K),K=1,MAXK)
 2309 WRITE OUTPUT TAPE 3,1010
  702 GO TO (1001,10, 24,24,24,1001,100,100,100),LSW
   24 GO TO (25,100,100),NBUG
C     NO OF ITERATIONS PRINTED OUT
   25 WRITE OUTPUT TAPE 3,115,L
      GO TO 100
C     HI DIFFERENCE AND POINT PRINTED OUT
   10 WRITE OUTPUT TAPE 3,72,L,HI,JHI,IHI,KHI,DUM3,COR1
  100 RETURN
      END
```

SUBROUTINE INPUT

```
      SUBROUTINE INPUT
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NBUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,HI,JHI,IHI,KHI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINEK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON BEE,CANGLE,DELZ,SANGLE,DEE,AYE,H,ELENG,PI,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
   99 FORMAT (1H0,I6)
      WRITE OUTPUT TAPE 3,100
  100 FORMAT (25H0INPUT DATA FOR THIS CASE)
      GO TO (1,2,3),NSIZE
    1 WRITE OUTPUT TAPE 3,50
   50 FORMAT (31H0THIS IS A ONE DIMENSIONAL CASE)
      GO TO 4
    2 GO TO (5,6),NAXI
    5 WRITE OUTPUT TAPE 3,51
   51 FORMAT (31H0THIS IS A TWO DIMENSIONAL CASE)
      GO TO 4
    6 WRITE OUTPUT TAPE 3,52
   52 FORMAT (31H0THIS IS AN AXISYMMETRICAL CASE)
      GO TO 4
    3 WRITE OUTPUT TAPE 3,53
   53 FORMAT (33H0THIS IS A THREE DIMENSIONAL CASE)
    4 GO TO (7,8),NSAT
    7 WRITE OUTPUT TAPE 3,54
   54 FORMAT (34H0UNSATURATED SOIL CONDITIONS EXIST)
      WRITE OUTPUT TAPE 3,112
  112 FORMAT(26H0 SOIL TYPE IDENTIFICATION)
      WRITE OUTPUT TAPE 3,55
   55 FORMAT (47H      SOIL NUMBER     PERMEABILITY COUPLING RATIO)
      WRITE OUTPUT TAPE 3,56,((M,CK1(M   )),M=1,NUM)
   56 FORMAT (I12,1PE28.4)
      WRITE OUTPUT TAPE 3,57,CUNIT
   57 FORMAT (40H  THE CAPILLARY PRESSURES ARE SCALED BY 1PE11.4)
      GO TO 9
    8 WRITE OUTPUT TAPE 3,58
   58 FORMAT (32H0SATURATED SOIL CONDITIONS EXIST)
    9 WRITE OUTPUT TAPE 3,200,DUM1
  200 FORMAT (39H  SATURATED PERMEABILITY FOR SOIL NO.1  ,1PE11.4)
```

```
      WRITE OUTPUT TAPE 3,62
   62 FORMAT (22H0DESCRIPTION OF MATRIX)
      GO TO (10,11,11,11,11,11,11),ICUT
   10 WRITE OUTPUT TAPE 3,59,NCMAXJ,NCMAXI,NCMAXK
   59 FORMAT(28H  MATRIX DIMENSIONS ARE  Y= I3,4H Z= I3,4H X= I3)
      GO TO 12
   11 WRITE OUTPUT TAPE 3,60,NCMAXJ,NCMAXI,NCMAXK,ICMAXJ,ICMAXI,ICMAXK
   60 FORMAT(37H  MATRIX DIMENSIONS ARE  CUT FROM Y= I3,4H Z= I3,4H X= I
     13,7H TO Y= I3,4H Z= I3,4H X= I3)
   12 WRITE OUTPUT TAPE 3,201,JJ,II,KK
  201 FORMAT (55H  THE COORDINATES OF THE POINT OF DISTURBANCE ARE Y= I3
     1,4H Z= I3,3H X=I3)
      WRITE OUTPUT TAPE 3,115
  115 FORMAT (30H0PARAMETERS DESCRIBING PROBLEM)
      WRITE OUTPUT TAPE 3,116,DELZ
  116 FORMAT(33H  DISTANCE BETWEEN NODE POINTS IS1PE12.4)
      WRITE OUTPUT TAPE 3,117,DDUM5
  117 FORMAT(18H  COLUMN LENGTH IS1PE12.4)
      WRITE OUTPUT TAPE 3,118,DDUM4
  118 FORMAT(39H  VERTICAL TRANSLATION OF THE ORIGIN IS1PE12.4)
      WRITE OUTPUT TAPE 3,119,ANGLE
  119 FORMAT(39H  ANGLE OF INCLINATION OF THE SYSTEM IS1PE12.4)
      WRITE OUTPUT TAPE 3,120,BEE,DEE,AYE
  120 FORMAT(47H  COEFF. OF THE CAPILLARY PRESSURE EQUATION ARE1P3E12.4)
      WRITE OUTPUT TAPE 3,61
   61 FORMAT (36H0PIEZOMETRIC HEAD CALCULATION METHOD)
      GO TO (13,14),NAVG
   13 WRITE OUTPUT TAPE 3,63
   63 FORMAT ( 81H  RELATIVE CAPILLARY CONDUCTIVITY VALUES USED IN THE D
     1ENOMINATOR ARE NOT AVERAGED)
      GO TO 15
   14 WRITE OUTPUT TAPE 3,64
   64 FORMAT ( 77H  RELATIVE CAPILLARY CONDUCTIVITY VALUES USED IN THE D
     1ENOMINATOR ARE AVERAGED)
   15 WRITE OUTPUT TAPE 3,128
  128 FORMAT (27H0 OVERRELAXATION CORRECTION)
      WRITE OUTPUT TAPE 3,129
  129 FORMAT (41H     USED THROUGH ITERATION         FACTOR)
      WRITE OUTPUT TAPE 3,130,N1,COR1
  130 FORMAT (I17,16X,1PE11.4)
      WRITE OUTPUT TAPE 3,131,N2,N3
  131 FORMAT (46H     OVERRELAXATION FACTOR RECALCULATED EVERY ,I3,16H I
     1TERATIONS UP TO ,I3,16H ITERATIONS MAX.)
      WRITE OUTPUT TAPE 3,202
  202 FORMAT (17H0PROGRAM CONTROLS)
      WRITE OUTPUT TAPE 3,126,P1
  126 FORMAT(51H  IF THE HI. DIFF. BETWEEN ITERATIONS  IS LESS THAN 1PE1
     X2.4,21H,THE CASE IS COMPLETE)
      WRITE OUTPUT TAPE 3,65,PHIMAX
   65 FORMAT(49H  IF A CALCULATED PIEZOMETRIC HEAD VALUE EXCEEDS 1PE11.4
     1,21H,AN ERROR EXIT OCCURS)
      WRITE OUTPUT TAPE 3,66
   66 FORMAT (19H0DUMMY INPUT VALUES)
      WRITEOUTPUT TAPE 3,68
   68 FORMAT (34H      INTEGERS      FLOATING VALUES)
      WRITE OUTPUT TAPE 3,67,NDUM1,DUM1
```

```
67 FORMAT (I12,1PE20.4)
   WRITE OUTPUT TAPE 3,67,NDUM2,DUM2
   WRITE OUTPUT TAPE 3,67,NDUM4,DUM4
   RETURN
   END
```

SUBROUTINE STEP

```
      SUBROUTINE STEP
C     SUBROUTINE STEP SETS-UP STEPPING THRU MATRIX AND FINDS SURROUNDING
C     POINTS
      COMMON PHI,EK,NO
      COMMON UK1,UK2,UK3,STEK3,CK1,CK2,CK3,CK4
      COMMON  KK,II,JJ,MAXI,MAXK,MAXJ,IKTOT,KIJTOT,NDUG,NPUN,NCASE,NSAT,
     1N1,N2,N3,N4,N5,NAVG,NSIZE,NAXI,LSW,NGRAP,L,MI,JMI,IMI,KMI,NDUM1,
     2NDUM2,NDUM3,NDUM4,MDUM1,MDUM2,MDUM3,MDUM4,KEY
      COMMON IDUMP,ICUT,NCUT,ICMAXJ,ICMAXI,ICMAXK,MAN,INIT,NTYPE,ICOUNT,
     1JAM,MH1,MH2,MV1,MV2,MO1,MO2,NSKIP,J,K,I,NINCK,NINPHI,NCMAXJ,
     2NCMAXI,NCMAXK,NUM
      COMMON DEE,CANGLE,DELZ,SANGLE,DEL,AYE,M,ELENG,PI,COR1,COR2,COR3,
     1COR4,COR5,CODE,PHIMAX,DUM1,DUM2,DUM3,DUM4,DDUM1,DDUM2,DDUM3,
     2DDUM4,DDUM5,ANGLE,PLOP
      COMMON FRACT,FK,X,DENOM1,DENOM2,DENOM3,DENCON,AVTERM,HTERM,VTERM,
     1AXTERM,OTERM,CUNIT
      EQUIVALENCE (PLOP,DUM),(KEY,MUM)
      EQUIVALENCE (MAT,EK)
      DIMENSION PHI(8000),EK(8000),NO(8000),MAT(8000)
      DIMENSION UK1(15),UK2(15),UK3(15),STEK3(15)
      DIMENSION CK1(15),CK2(15,2),CK3(15,41),CK4(15,2)
      DIMENSION PLOP(501),KEY(502),DUM(501),MUM(502),CODE(10)
      NSKIP=1
    9 GO TO (10,11),INIT
   10 GO TO (12,13,14,15,16,17,18,19,20),NTYPE
C     INITIALIZE STARTING COORDINATES DEPENDING ON TYPE OF STEPPING
   12 III=II
      KKK=KK
      GO TO (21,22,23,24),ICOUNT
   13 III=II-1
      KKK=KK-1
      GO TO 24
   14 III=II
      KKK=KK-1
      GO TO (22,24),ICOUNT
   15 III=II
      KKK=KK-1
      GO TO 22
   16 III=II
      KKK=KK
      GO TO (21,22),ICOUNT
   17 III=II
      KKK=KK
      GO TO 21
   18 III=II
```

```
      KKK=KK
      GO TO (21,23),ICOUNT
   19 III=II-1
      KKK=KK
      GO TO 23
   20 III=II-1
      KKK=KK
      GO TO (23,24),ICOUNT
C     STEPPING DOWN-LEFT -COMPUTE LIMITS
   21 ISIGN=-1
      KSIGN=-1
      NBT=MDUM1      +KKK
      NMID=MDUM1      +MAXK*(III-1)+KKK
      NEND=MDUM1+1
      GO TO 25
C     STEPPING DOWN-RIGHT-COMPUTE LIMITS
   22 ISIGN=-1
      KSIGN=+1
      NBT=MDUM1      +KKK+1
      NMID=MDUM1      +MAXK*(III-1)+KKK+1
      NEND=MDUM1+MAXK
      GO TO 25
C     STEPPING UP-LEFT   -COMPUTE LIMITS
   23 ISIGN=+1
      KSIGN=-1
      NBT=MDUM1      +MAXK*(MAXI-1)+KKK
      NMID=MDUM1      +MAXK*III+KKK
      NEND=MDUM1      +MAXK*(MAXI-1)+1
      GO TO 25
C     STEPPING UP-RIGHT  -COMPUTE LIMITS
   24 ISIGN=+1
      KSIGN=+1
      NBT=MDUM1      +MAXK*(MAXI-1)+KKK+1
      NMID=MDUM1      +MAXK*(III)+KKK+1
      NEND=IKTOT*J
   25 JAM=NMID
      INIT=2
      GO TO 26
C     COMPUTE AND TEST PHI INDEX
   11 JAM=JAM+ISIGN*MAXK
      IF(ISIGN*(JAM-NBT)) 26,26,27
   27 NBT=NBT+KSIGN
      NMID=NMID+KSIGN
      JAM=NMID
      IF(KSIGN*(NBT-NEND)) 26,26,28
   28 ICOUNT=ICOUNT+1
      INIT=1
      GO TO 9
C     ROUTINE TO FIND SURROUNDING POINTS
C     SIX NORMAL SURROUNDING POINTS
   26 MH1=JAM-1
      MH2=JAM+1
      MV1=JAM-MAXK
      MV2=JAM+MAXK
      MO1=JAM-IKTOT
      MO2=JAM+IKTOT
```

```
C     SPECIAL CASES ON SURROUNDING POINTS
      GO TO (200,201),NSAT
  200 CALL GNO (IMAGE,NO,JAM)
      GO TO 202
  201 IMAGE=NO(JAM)
  202 GO TO (100,101,102),NSIZE
C     1-D
  100 GO TO (103,131,105,106),IMAGE
C     2-D
  101 GO TO (103,131,105,106,107,108,111,112,115,116),IMAGE
C     3-D
  102 GO TO (103,131,105,106,107,108,109,110,111,112,113,114,115,116,
     1117,118,119,120,121,122,123,124,125,126,127,128,129,130),IMAGE
  103 NSKIP=2
      GO TO131
  105 MV1=MV2
      GO TO131
  106 MV2=MV1
      GO TO131
  107 MH1=MH2
      GO TO131
  108 MH2=MH1
      GO TO131
  109 MO1=MO2
      GO TO131
  110 MO2=MO1
      GO TO131
  111 MV1=MV2
      MH1=MH2
      GO TO131
  112 MV1=MV2
      MH2=MH1
      GO TO131
  113 MV1=MV2
      MO1=MO2
      GO TO131
  114 MV1=MV2
      MO2=MO1
      GO TO131
  115 MV2=MV1
      MH1=MH2
      GO TO131
  116 MV2=MV1
      MH2=MH1
      GO TO131
  117 MV2=MV1
      MO1=MO2
      GO TO131
  118 MV2=MV1
      MO2=MO1
      GO TO131
  119 MH1=MH2
      MO1=MO2
      GO TO131
  120 MH1=MH2
      MO2=MO1
```

```
      GO TO131
121   MH2=MH1
      MO1=MO2
      GO TO131
122   MH2=MH1
      MO2=MO1
      GO TO131
123   MV1=MV2
      MH1=MH2
      MO1=MO2
      GO TO131
124   MV1=MV2
      MH1=MH2
      MO2=MO1
      GO TO131
125   MV1=MV2
      MH2=MH1
      MO1=MO2
      GO TO131
126   MV1=MV2
      MH2=MH1
      MO2=MO1
      GO TO131
127   MV2=MV1
      MH1=MH2
      MO1=MO2
      GO TO131
128   MV2=MV1
      MH1=MH2
      MO2=MO1
      GO TO131
129   MV2=MV1
      MH2=MH1
      MO1=MO2
      GO TO131
130   MV2=MV1
      MH2=MH1
      MO2=MO1
131   RETURN
      END
```

```
C       SUBROUTINE SAVE
C       SUBROUTINE SAVE WRITES THE CONTENTS OF MEMORY TO SPECIFIED TAPE OR
        TO CARDS.  THIS ENABLES START UP AT TIME BREAK.
*       FAP
        COUNT   350
        REM     THE SAVE SUBROUTINE USES EXIT,(IOU),(FPT) AND (TES)
        REM     THE CALL LIST IS VARIABLE IN LENGTH
        REM     CALL SAVE (N,T1,T2,.....TN) WHERE
        REM     N IS THE NO. OF TAPES (IF ZERO IT IS THE ONLY ENTRY IN
        REM     THE CALL LIST)
        REM     TN IS THE LOGICAL TAPE NUMBER
        REM
        REM     SAVE THE REGISTERS
        REM
        ENTRY   SAVE
SAVE    STO     ACSTO                   STORE AC
        ARS     35
        STO     PQSTO                   STORE P,Q BITS OF AC
        STQ     MQSTO                   STORE MQ
        STI     SISTO                   STORE SF
        SXA     XR1,1                   STORE IRS
        SXA     XR2,2                   *
        SXA     XR4,4                   *
        AXT     23,1                    ESTABLISH A GROUP
        STZ     ZEROS+23,1                    OF 23 ZEROS
        TIX     *-1,1,1                       IN COMMON
        AXT     4,1                     SAVE SENSE LIGHTS
        STZ     LIGHTS+4,1
        TIX     *-1,1,1
        CLA     L(2)
        SLT     1
        STO     LIGHTS
        SLT     2
        STO     LIGHTS+1
        SLT     3
        STO     LIGHTS+2
        SLT     4
        STO     LIGHTS+3
        REM
        REM     DETERMINE TAPE POSITIONS
        REM
        CLA*    1,4
        STO     STAPE                   SAVE NO. TAPES TO BE PROCESSED
        ARS     18
        ADD     L(2)
        STA     RET                     ESTABLISH RETURN ADDRESS
        LXD     STAPE,1
        TXL     WLP,1,0                 IF NO. TAPES EQUAL ZERO
        PXA     0,4
        SUB     RET
        STA     TAPU                    INIALIZE ADDRESS OF CALL LIST
        XEC*    $(TES)
        BTTA                            TURN OFF BT INDICATORS
        NOP
        BTTB                            *
        NOP
TAPU    CLA*    ..,1                    PICK UP TAPE UNIT AND
        TZE     ZERO                    TRA IF ZERO
        ARS     18
```

```
       ADD    $(IOU)                                                      120-0 56
       STA    *+1                  ADDRESS OF TAPE UNIT CODE.              120-0 57
       LXA    ..,4                 UNIT CODE TO XR4                        120-0 58
       TXH    *+2,4,0              AND CONTINUE UNLESS                     120-0 59
       HPR    1,6                  UNIT CODE IS ZERO.                      120-0 60
       PXA    0,4                                                          120-0 61
       STA    STAPE,1              STORE UNIT CODE IN STAPE TABLE.         120-0 62
       SXA    BSR,4                INITIALIZE TAPE MOVER ADDRESSES         120-0 63
       AXT    3072,2               TCOA COMMAND                            120-0 64
       CLA    L(1000                                                       120-0 65
       TXH    *+2,4,1023                                                   120-0 66
       TRA    *+3                                                          120-0 67
       ADD    L(1000                                                       120-0 68
       AXT    3136,2               TCOB COMMAND                            120-0 69
       STA    BTT                                                          120-0 70
       SXD    TCO,2                                                        120-0 71
       AXT    0,2                                                          120-0 72
 BSR   BSR    ..                                                           120-0 73
 TCO   TCOA   *                                                            120-0 74
 BTT   BTT    ..                                                           120-0 75
       TRA    *+2                  FOUND IT                                120-0 76
       TXI    BSR,2,1              KEEP LOOKING                            120-0 77
       TXL    *+2,2,0                                                      120-0 78
       TXI    *+1,2,-1             CORRECT FOR STACKING EFFECT             120-0 79
       PXD    0,2                                                          120-0 80
       STD    STAPE,1              SAVE TAPE POSITIONIN STAPE TABLE        120-0 81
 ENDLP TIX    TAPU,1,1                                                     120-0 82
       TEFA   *+1                  TURN OFF INDICATORS                     120-0 83
       TEFB   *+1                  *                                       120-0 84
       TRA    WLP                                                          120-0 85
 ZERO  STZ    STAPE,1                                                      120-0 86
       TRA    ENDLP                                                        120-0 87
       BSS    10                                                           120-0 88
 STAPE PZE                                                                 120-0 89
 L(2)  OCT    2                                                            120-0 90
L(1000 OCT    1000                                                         120-0 91
LIGHTS OCT    0,0,0,0                                                      120-0 92
       REM                                                                 120-0 93
       REM    WRITE LOADER PROGRAM - 2 CARDS                               120-0 94
       REM                                                                 120-0 95
       HTR    RELOAD                                                       120-0 96
 WLP   CAL    *-1                  ESTABLISH THE                           120-0 97
       STA    LRET                 RETURN ADDRESS                          120-0 98
       AXT    5,2                  RED. ERR. CTR.                          120-0 99
 WT4   WTBB   4                                                            120-0100
       RCHB   CD1                                                          120-0101
       LCHB   CD2                                                          120-0102
       TCOB   *                                                            120-0103
       TRCB   LERR                                                         120-0104
       TRA    CSAVE                                                        120-0105
 LERR  BSRB   4                                                            120-0106
       BSRB   4                                                            120-0107
       TIX    WT4,2,1                                                      120-0108
       HPR    3,7                                                          120-0109
       TRA    WT4-1                                                        120-0110
 CD1   IOCP   CARD1,,24                                                    120-0111
       IORT   ID,,3                                                        120-0112
 CD2   IOCP   CARD2,,18                                                    120-0113
       IOCP   ZEROS,,6                                                     120-0114
```

```
        REM                                                      120-0116
        REM     LOADER PROGRAM                                   120-0117
        READ    ID,,3                                            120-0118
CARD1   OCT     000526077670,0                                   120-0119
        AXT     32596,1               32696    77670             120-0120
        STZ     32696,1               32697    77671             120-0121
        TIX     32697,1,1             32698    77672             120-0122
        AXT     5,4                   32699    77673             120-0123
        RTBA    2                     32700    77674             120-0124
        RCHA    32733                 32701    77675             120-0125
        TCOA    32702                 32702    77676             120-0126
        TRCA    32725                 32703    77677             120-0127
        TEFA    32729                 32704    77700             120-0128
        CAL     32734                 32705    77701             120-0129
        ERA     32731                 32706    77702             120-0130
LRET    TZE     ..                    32707    77703             120-0131
        ALS     2                     32708    77704             120-0132
        CAL     32734                 32709    77705             120-0133
        ANA     32732                 32710    77706             120-0134
        PDX     0,1                   32711    77707             120-0135
        STA     32716                 32712    77710             120-0136
        AXT     0,2                   32713    77711             120-0137
        CAL     32734                 32714    77712             120-0138
        LDQ     32736,2               32715    77713             120-0139
        STQ     ..,2                  32716    77714             120-0140
        ACL     32736,2               32717    77715             120-0141
CARD2   OCT     000520077716,0                                   120-0142
        TXI     32719,2,-1            32718    77716             120-0143
        TIX     32715,1,1             32719    77717             120-0144
        ERA     32735                 32720    77720             120-0145
        TZE     32700                 32721    77721             120-0146
        TOV     32700                 32722    77722             120-0147
        HPR     0,7                   32723    77723             120-0148
        TRA     32700                 32724    77724             120-0149
        BSRA    2                     32725    77725             120-0150
        TIX     32700,4,1             32726    77726             120-0151
        HPR     1,7                   32727    77727             120-0152
        TRA     32699                 32728    77730             120-0153
        HPR     2,7                   32729    77731             120-0154
        TRA     32729                 32730    77732             120-0155
        OCT     000500077777          32731    77733             120-0156
        OCT     000037077777          32732    77734             120-0157
        IOCD    32734,,24             32733    77735             120-0158
        REM                                                      120-0159
        REM     SAVE MEMORY TO B4 ON CARD RECORDS                120-0160
        REM                                                      120-0161
CSAVE   CLA     C+5                                              120-0162
        STO     C+2                   INIT ADD FOR SUCCESSIVE SAVES 120-0163
        LXA     C+1,1                 NO. WORDS TO XR1           120-0164
        LXA     C+3,2                                            120-0165
        SXD     TT3+1,2               INITIALIZE IOCP AND        120-0166
        SXA     CKSUM,2               CHECK SUM INSTR TO 22 WORDS 120-0167
        CLA     CC                                               120-0168
        STO     CC1                   SET 1ST OUTPUT WORD TO 22 WORDS 120-0169
TT      TIX     *+2,1,22                                         120-0170
        TRA     TT2                   IF LESS THAN 22 WORDS REMAIN 120-0171
        CLA     C+2                                              120-0172
        STA     TT3+1                 INITIALIZE IOCP ADDRESS    120-0173
        STA     CC1                                              120-0174
```

```
         STA    GO                          AND ACL ADDRESS                 120-0175
CKSUM    AXT    ..,2                        NO. WORDS THIS CARD TO XR2      120-0176
         AXT    0,4                         ZERO TO XR4 FOR CKSUM CALC      120-0177
         CAL    CC1                                                         120-0178
GO       ACL    ..,4                                                        120-0179
         TXI    *+1,4,-1                                                    120-0180
         TIX    GO,2,1                                                      120-0181
         SLW    CC1+1                                                       120-0182
         CAS    CC1                                                         120-0183
         TRA    *+2                                                         120-0184
         TRA    UPDAT                       IF ALL WORDS IN CARD ARE ZERO   120-0185
         AXT    5,4                         IF NON ZERO -                   120-0186
WTBEG    WTBB   4                           WRITE CARD RECORD               120-0187
         RCHB   TT3                                                         120-0188
         TCOB   *                                                           120-0189
         TRCB   TT4                                                         120-0190
UPDAT    CLA    C+2                         UPDATE WRITE ADDRESS            120-0191
         ADD    C+3                         *                               120-0192
         STA    C+2                         *                               120-0193
         MSE    97                          IS SENSE LIGHT 1 ON             120-0194
         TRA    TT                          NO.                             120-0195
         WTBB   4                           YES                             120-0196
         RCHB   TT8                         WRITE END CARD                  120-0197
         TCOB   *                                                           120-0198
         TRCB   *+1                                                         120-0199
         WPDA                               WRITE PAUSE MESSAGE             120-0200
         RCHA   PAU                             *                           120-0201
         TCOA   *                               *                           120-0202
         HPR    4681,1                                                      120-0203
         CALL   EXIT                                                        120-0204
PAU      IOCD   PAUSE,,24                                                   120-0205
TT2      SXD    TT3+1,1                     NO. WORDS LESS THAN 22          120-0206
         SXA    CKSUM,1                                                     120-0207
         PXD    0,1                                                         120-0208
         SUB    L22D                                                        120-0209
         STD    TT3+2                                                       120-0210
         PXD    0,1                                                         120-0211
         ORA    CC+1                                                        120-0212
         STD    CC1                                                         120-0213
         PSE    97                          TURN ON LITE 1                  120-0214
         TRA    TT+2                                                        120-0215
TT3      IOCP   CC1,0,2                                                     120-0216
         IOCP   ......                                                      120-0217
         IOCP   ZEROS,,...                                                  120-0218
         IOCD   ID,,3                                                       120-0219
TT4      BSRB   4                                                           120-0220
         TIX    WTBEG,4,1                                                   120-0221
         HPR    1,5                                                         120-0222
         TRA    UPDAT                                                       120-0223
TT8      IOCP   CC3,0,1                                                     120-0224
         IOCP   ZEROS,,23                                                   120-0225
         IOCD   ID,,3                                                       120-0226
C        OCT    77462                       ADDRESS OF ARRAY TO BE SAVED    120-0227
         OCT    77317                       NO. OF WORDS TO BE SAVED        120-0228
         OCT    144                         INITIAL WORD                    120-0229
         OCT    26                                                          120-0230
         OCT    1                                                           120-0231
         OCT    144                                                         120-0232
CC       OCT    000526000000                                                120-0233
```

```
       OCT    000500000000
L22D   OCT    000026000000
CC3    OCT    000500077777
PAUSE  OCT    204100400200,100000000000,000010000100,020000000000,0,0
       OCT    010200200000,0,102004064010,0,000000000004,0
       OCT    020060010000,460000000000,040402003001,0
       OCT    000000000420,200000000000,060642003101,440000000000
       OCT    214000040210,100000000000,102134634424,220000000000
       REM
       REM    RESTORE REGISTERS AND CONTINUE
       REM
RELOAD RTDA   2
       RCHA   DATCD
       TCOA   *
       TRCA   *+1
       CAL    DATCD+1
       ARS    30
       SUB    L(54)
       TZE    CONT
NODAT  WTDA   3
       RCHA   NDMSG
       TCOA   *
       TRCA   *+1
       CALL   EXIT
NDMSG  IOCD   *+1,0,4
       BCI    4,0 DATA CARD IS MISSING
DATCD  IOCD   *+1,0,2
       PZE
       PZE
L(54)  OCT    54                        ASTERISK
       REM
       REM    STOP TO LOAD TAPES
       REM
CONT   WPDA
       RCHA   PAZ
       TCOA   *
       WPRA
       SPRA   4
       SPRA   4
       SPRA   4
       SPRA   4
       TCOA   *
       HPR    9362,2
       REM
       REM    POSITION TAPES
       REM
       LXD    STAPE,1
       TXL    LDREG,1,0                 IF NO TAPES USED
       TEFA   *+1
       TEFB   *+1
TPADV  CAL    STAPE,1
       PDX    0,2
       STA    *+2
       STA    *+2
       REW    ..
       RDS    ..
       TIX    *-1,2,1
       TIX    TPADV,1,1
       REM
```

```
        REM     LOAD REGISTERS
        REM
LDREG   CAL     $(FPT)
        STO     8                       RESTORE FPT
        NZT     LIGHTS                  RESTORE SENSE LIGHTS
        SLN     1
        NZT     LIGHTS+1
        SLN     2
        NZT     LIGHTS+2
        SLN     3
        NZT     LIGHTS+3
        SLN     4
        LDI     SISTO                   LOAD SI
        CLA     PQSTO
        LDQ     ACSTO
        LLS     35                      LOAD AC
        TOV     *+1
        LDQ     MQSTO                   LOAD MQ
        TCOA    *
        TCOB    *
        TRCA    *
        TRCB    *
XR1     AXT     ..,1
XR2     AXT     ..,2
XR4     AXT     ..,4
RET     TRA     ..,4
PAZ     IOCD    PAZE,,24
ACSTO   PZE
PQSTO   PZE
MQSTO   PZE
SISTO   PZE
PAZE    OCT     2000050000,100000000000,11000001,2000000000
        OCT     40010,0,100000002000,0,2100420404,0,21020000200,0
        OCT     200002010041,460000000000,100002,100000000000
        OCT     440400000020,200000000000,12100042,144000000000
        OCT     302200040010,100000000000,65161437625,220000000000
ZEROS   SYN     32696                   OUTPUT ZEROS
CC1     SYN     32720                   OUTPUT WORDS 1 + 2.
..      SYN     0
ID      SYN     5
        END
```

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