PIT SLOPE MANUAL

supplement 4-1

COMPUTER MANUAL FOR SEEPAGE ANALYSIS

This supplement has been prepared as part of the

PIT SLOPE PROJECT

of the
Mining Research Laboratories
Canada Centre for Mineral and Energy Technology
Energy, Mines and Resources Canada

MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
CANMET REPORT 77-30

Available by mail from:

Printing and Publishing
Supply and Services Canada,
Ottawa, Canada K1A 0S9

CANMET
Energy, Mines and Resources Canada,
555 Booth St.
Ottawa, Canada K1A 0G1

or through your bookseller.

Catalogue No. M38-14/4-1977-1 Price: Canada $3.50
ISBN 0-660-01007-2 Other countries: $4.20

Price subject to change without notice.

En vente par la poste:

Imprimerie et Édition
Approvisionnements et Services Canada,
Ottawa, Canada K1A 0S9

CANMET
Énergie, Mines et Ressources Canada,
555, rue Booth
Ottawa, Canada K1A 0G1

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N° de catalogue M38-14/4-1977-1 Prix: Canada $3.50
ISBN 0-660-01007-2 Autres Pays: $4.20

Prix sujet à changement sans avis préalable.

THE PIT SLOPE MANUAL

The Pit Slope Manual consists of ten chapters, published separately. Most chapters have supplements, also published separately. The ten chapters are:

1. Summary
2. Structural Geology
3. Mechanical Properties
4. Groundwater
5. Design
6. Mechanical Support
7. Perimeter Blasting
8. Monitoring
9. Waste Embankments
10. Environmental Planning

The chapters and supplements can be obtained from the Publications Distribution Office, CANMET, Energy, Mines and Resources Canada, 555 Booth Street, Ottawa, Ontario, K1A 0G1, Canada.

Reference to this supplement should be quoted as follows:

Marlon-Lambert, J. Pit Slope Manual Supplement 4-1 - Computer Analysis of Groundwater Seepage; CANMET (Canada Centre for Mineral and Energy Technology, formerly Mines Branch, Energy, Mines and Resources Canada), CANMET REPORT 77-30; 97 p.; December 1977.

ABSTRACT

FEFPM performs a steady-state seepage analysis to determine fluid pressures, flow quantities, rates and direction of groundwater slopes. It assumes either planar or radially symmetric flow, linear in a finite element in a porous medium. It computes the location of phreatic surface for unconfined flow problems, material type and permeability for a specific soil element, and fluid potential and stream function values. The program generates nodes and elements of a finite element mesh during iterations to locate a phreatic surface and automatically limits the flow regime to the slope profile.

ACKNOWLEDGEMENTS

Roy Sage was responsible for the production of the Groundwater chapter and the supplement on Seepage. Address enquiries to him at: 555 Booth Street, Ottawa, Ontario K1A 0G1.

The finite element seepage computer program was developed by J. Marlon-Lambert from an original seepage program produced by the U.S. Bureau of Mines. J. Marlon-Lambert wrote the supplement and provided the sample data and results. The program was modified to run on the CDC Cyber 70 of the Department of Energy, Mines and Resources by A-S Wong and staff of the Computer Science Centre in the department. The text was edited by Sysdoc International.

Contractors: Golder Associates
Sysdoc International

The Pit Slope Project is the result of five years' research and development cooperatively funded by the Canadian Mining Industry and the Government of Canada.

The Pit Slope Group has been led successively by D.F. Coates, M. Gyenge and R. Sage; their colleagues have been G. Herget, B. Hoare, G. Larocque, D. Murray and M. Service.

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PROGRAM IDENTIFICATION

PROGRAM TITLE: Seepage: Finite Element analysis of Flow in Porous Media.

PROGRAM CODE NAME: FEFPM

WRITER: Golder Associates

ORGANIZATION: Energy, Mines and Resources
Canadian Centre for Mineral and Energy Technology.

DATE: January, 1976

UPDATES: This program was converted in December, 1976, from Univac 1108 FORTRAN to Control Data CYBER FORTRAN.

SOURCE LANGUAGE: Originally written in FORTRANV for the UNIVAC 1108, EXEC-8. The version supplied by CANMET has been converted to CDC CYBER FORTRAN.

AVAILABILITY: Pit Slope Group, Mining Research Laboratories,
Canada Centre for Mineral and Energy Technology,
Department of Energy, Mines and Resources,
555 Booth Street,
Ottawa, Canada K1A 0G1

DISCLAIMER: Neither the authors nor the Mining Research Laboratories can accept any responsibility for the accuracy of results generated by this program.

ENGINEERING DOCUMENTATION

NARRATIVE DESCRIPTION

1. The user prepares scaled drawings, based on geological samples, of the seepage area in terms of a finite element mesh. The salient features that must be included are:

material boundaries
boundary conditions
an assumed initial phreatic surface.

2. The properties of the area must be related to the co-ordinates of this mesh. Units and dimensions of the co-ordinate system must be consistent and chosen carefully for a good solution. The following measurements must be used for material permeability and fluid properties:

Property	measured as
pressure (head)	length
permeability	length/time
flow rate (velocity)	length/time
flow quantity	length^3/time

A knowledge of fluid and soil/rock mechanics is required to apply realistic boundary conditions.

3. The grid is usually drawn with quadrilateral elements, but triangular elements may be added. Areas of significant changes in velocity or pressure should have a finer mesh.

4. Most of the input data is obtained from this scale model. It includes:

a. a title for the problem
b. parameters describing the type of problem and the desired results. These are entered as a FORTRAN NAMELIST, and default values are provided to minimize input.
c. definition of nodes; locations, boundary conditions and generation parameters for significant points are entered. The program will extrapolate from and interpolate between significant points as required.
d. material properties: type, directional permeabilities and the extent of zoning in the problem area
e. element definitions in terms of nodes and material types
f. fluid inflows described along edges of elements (optional)
g. pipes describing a string of elements linking any internal sources or sinks to a boundary (optional).

5. Intermediate results can be saved and used in a program restart. This is useful to monitor partial results before the program goes through numerous iterations with bad data that will never converge. It also permits iterated data to be restarted with different output parameters to produce different reports without changing

original data. Output includes a listing of the input data, detailed intermediate results of each iteration, including extrapolated and interpolated nodes, potential flow values defining the final phreatic surface, and optionally mesh and nodal pressures between iterations. Options are available for reducing the output printed.

METHOD OF SOLUTION

Finite Element Formulation of Groundwater Seepage

The Mathematical Problem

6. The general equation for steady-state Darcy type fluid flow in a two-dimensional porous medium, ie, wherein the rate of flow is proportional to the potential head gradient, is:

$$\frac{\partial}{\partial x}\left(k_x \cdot \frac{\partial\phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \cdot \frac{\partial\phi}{\partial y}\right) = Q(x,y) = 0 \qquad \text{eq 1}$$

in which ϕ is the potential head function; k_x, k_y are the material permeabilities in the x- and y-directions, respectively; and Q(x, y) is the rate of flow influx to the region per unit volume.

7. The solution to this equation must satisfy the boundary conditions for the actual porous media flow (or seepage) problem under study. The physical conditions of the particular problem and the region considered will commonly impose boundary conditions where:

i) the value of ϕ is specified, or

ii) the rate of flow is specified across the boundary

8. Boundary condition case (ii) is governed by the following equation:

$$k_x \cdot \frac{\partial\phi}{\partial x} \cdot l_x + k_y \cdot \frac{\partial\phi}{\partial y} \cdot l_y + q = 0 \qquad \text{eq 2}$$

where l_x, l_y are the direction cosines of the outward normal to the boundary surface and q is the flow per unit area across the surface. In the case of a non-conducting boundary, the value of q is simply set to zero.

9. Equation 1, together with the boundary conditions, specifies the problem uniquely. By using the Euler conditions of the calculus of variations it is possible to show that the problem is identical to that of determining the minimum value of a function, E, where:

$$E = \int_{\text{volume}} \frac{1}{2}\left(k_x \left(\frac{\partial\phi}{\partial x}\right)^2 + k_y \left(\frac{\partial\phi}{\partial y}\right)^2 + Q\cdot\phi\right)\cdot d(\text{volume}) \qquad \text{eq 3}$$
$$+ \int_{\text{area}} q\cdot\phi\cdot d\ (\text{area})$$

and with ϕ specified on a boundary region. The expression within the volume integral represents the rate at which energy is being dissipated in a unit volume and thus the integral becomes the energy dissipation rate for the entire flow region.

The Finite Element Procedure

10. In the finite element procedure, the continuous region under analysis is divided into a number of discrete areas or elements. The shape of each element is determined, in general, by the number of nodes associated with it. The potential head at each of the nodes in the region under consideration must be defined by the vector.

$$\{\phi\} = \{\phi_1, \phi_2 \cdots \phi_n\}^T \qquad \text{eq 4}$$

where n is the total number of nodes. The variation of the potential head function within any particular element is defined by the nodal values of ϕ, by letting the elemental potential head vector $\{\phi\}^e$ be:

$$\{\phi\}^e = \{\phi_i, \ldots \phi_m\}^T \qquad \text{eq 5}$$

where i to m are the nodes associated with this element. The potential head function variation then becomes:

$$\phi\ (x,y) = [n]\ \{\phi\}^e \qquad \text{eq 6}$$

11. Equation 6 now defines the function ϕ uniquely within the element in terms of the elemental vector $\{\phi\}^e$, and the functional E can now be minimized with respect to these values by writing equations as follows:

$$\frac{\partial E}{\partial \phi_i} = 0 \quad \vdots \quad \frac{\partial E}{\partial \phi_m} = 0 \qquad \text{eq 7}$$

12. As the function ϕ is single-valued throughout each of the elemental volumes, then to minimize the total integral, it is necessary only to minimize the integral as it pertains to each element and to sum the resultants. If E^e is the contribution of an element to the total integral then:

$$E = \sum_e E^e \qquad \text{eq 8}$$

13. One necessary condition is that E does not become infinite at the element interfaces, but this is obviously satisfied as E only involves the first derivatives of and there is no discontinuity in ϕ between elements.

14. Differentiating eq 3 with respect to each of the nodal values of ϕ gives:

$$\begin{aligned}\frac{\partial E^e}{\partial \phi_i} &= \int_{volume} [k_x \cdot \frac{\partial \phi}{\partial x} \cdot \frac{\partial}{\partial \phi_i} (\frac{\partial \phi}{\partial x}) + k_y \cdot \frac{\partial \phi}{\partial y} \cdot \frac{\partial}{\partial \phi_i} \cdot (\frac{\partial \phi}{\partial y})] d(\text{volume}) \\ &\quad + \int_{volume} Q . \frac{\partial}{\partial \phi_i} (\phi) . d(\text{volume}) + \int_{area} q \frac{\partial}{\partial \phi_i} (\phi) . d(\text{area}) \qquad \text{eq 9} \\ &= [S]^e . \{\phi\}^e + \{F\}^e\end{aligned}$$

where the first integral is equal to $[S]^e . \{\phi\}^e$ and the two last one equal to $\{F\}^e$. It can be shown that $\{S\}^e$ is symmetric.

15. Differentiating eq 8 then gives:

$$\frac{\partial E}{\partial \phi_i} = \sum_e . \frac{\partial E^e}{\partial \phi_i} \qquad \text{eq 10}$$

with the summation taken over all the elements. Thus the final set of equations becomes:

$$[S] . \{\phi\} + \{F\} = \{0\} \qquad \text{eq 11}$$

where typical terms are

$$S_{ij} = \sum_e . S_{ij}^e$$

and

$$F_i = \sum_e . F_i^e$$

in which the summation is taken over all the elements connected with node i.

16. Equation 11 is in fact a set of linear equations describing the seepage through a porous media and is directly analogous to the equation set produced for a structural analysis. As the [S] matrix and the [F] vector are completely known, standard linear equation solution techniques can be used to determine the potential head distribution ie, $\{\phi\}$ throughout the flow region.

Finite Element Flow Matrix Development

17. The individual finite element flow matrix $[S]^e$ has been derived previously as:

$$[S]^e = \int_{volume} [k_x \cdot \frac{\partial \phi}{\partial x} \cdot \frac{\partial}{\partial \phi_i} (\frac{\partial \phi}{\partial x}) + k_y \cdot \frac{\partial \phi}{\partial y} \cdot \frac{\partial}{\partial \phi_i} (\frac{\partial \phi}{\partial y})] d(\text{volume}) \qquad \text{eq 12}$$

18. It is seen that the terms $\partial\phi/\partial x$, $\partial\phi/\partial y$ are needed to evaluate the integral, thus from eq 1 and introducing matrix notation

$$\begin{Bmatrix}\partial\phi/\partial x \\ \partial\phi/\partial y\end{Bmatrix} = \begin{bmatrix}\frac{\partial}{\partial x} & \frac{\partial}{\partial y}\end{bmatrix} [n] \{\phi\}^e = [B] \{\phi\}^e \qquad \text{eq 13}$$

19. The expression for $[S]^e$ can then be rewritten as:

$$\int_{volume} \frac{\partial}{\partial \phi_i} \begin{bmatrix}\frac{\partial \phi}{\partial x} & \frac{\partial \phi}{\partial y}\end{bmatrix} [K] \begin{Bmatrix}\partial\phi/\partial x \\ \partial\phi/\partial y\end{Bmatrix} . d(\text{volume})$$

where [K] is the permeability matrix and thus

$$[S]^e = \{\frac{\partial \phi_e}{\partial \phi_i}\} \int_{volume} [B]^T [K] [B] . d(\text{volume})$$

where $\{\frac{\partial\phi_e}{\partial\phi_i}\}$ is a unit matrix such that now

$$[S]^e = \int_{volume} [B]^T\ [K]\ [B]\ .\ d(volume) \qquad \text{eq 14}$$

Finite Element Forcing Vector

20. The individual finite element forcing vector $\{F\}^e$ has been previously determined as:

$$\{F\}^e = \int_{volume} Q.\ \frac{\partial\phi}{\partial\phi_i}\ .\ d(volume)+\int q.\ \frac{\partial\phi}{\partial\phi_i}\ .\ d(area)$$

$$= \int_{volume} Q.d(volume)+\int_{area} q.d(area) \qquad \text{eq 15}$$

where Q represents the prescribed rate of flow of influx or efflux to the element volume, and q represents the prescribed rates of flow across the element boundaries. In physical terms, Q could represent the amount of fluid pumped out of the element.

Alternative Formulation Using Fluid Pressures

21. An alternative finite element formulation using fluid pressures as the variable in the energy function presents a number of advantages to the computational process. Potential function magnitudes are defined in terms of the arbitrary coordinate system assigned to a problem, whereas fluid pressure magnitudes are independent of the coordinate system. Boundary conditions are thus readily specified in terms of pressure distributions.

22. The potential head function may be expressed in terms of the fluid pressure as:

$$\phi = h + p/\rho g \qquad \text{eq 16}$$

where the quantities h and $p/\rho g$ are the elevation head and the pressure head, respectively. This definition holds for all points within the flow region, where the elevation head is the elevation of the point in question above a certain horizontal datum level. The differentials of the potential head function, assuming that $h = y-y_0$, where y_0 is the reference datum, then are

$$\frac{\partial\phi}{\partial x} = \frac{1}{\rho g}\ .\ \frac{\partial p}{\partial x} \qquad \text{eq 17}$$

and

$$\frac{\partial\phi}{\partial y} = 1 + \frac{1}{\rho g}\ .\ \frac{\partial p}{\partial y} \qquad \text{eq 18}$$

23. Substituting into the energy functional expression eq 3 yields

$$E = \int_{volume} (\tfrac{1}{2}(k_x.(\frac{1}{\rho g}.\frac{\partial p}{\partial x})^2+k_y(1+\frac{1}{\rho g}.\frac{\partial p}{\partial y})^2+Q(y-y_o+\frac{p}{\rho g}))d(volume)$$

$$+ \int_{area} q(y-y_o+\frac{p}{\rho g}).\ d(area) \qquad \text{eq 19}$$

24. The pressure heads at each of the nodes in the flow region are defined by the vector $\{p\}$ where

$$\{p\} = \{p_1,p_2...p_m\}^T \qquad \text{eq 20}$$

25. The variation of the pressure head within any particular element is defined by the nodal pressures. The elemental pressure head vector is then

$$\{p\}^e = \{P_i,...p_n\}^T \qquad \text{eq 21}$$

where i to n are the element nodes, and the pressure head variation becomes

$$p(x,y) = [N]\ \{p\}^e \qquad \text{eq 22}$$

26. Equation 22 defines the pressure head variation uniquely within the element in terms of the elemental vector $\{p\}^e$ and the energy function is now minimized with respect to these values as follows:

$$\begin{array}{l} \frac{\partial E}{\partial p_i} = 0 \\ \quad \vdots \\ \frac{\partial E}{\partial p_m} = 0 \end{array} \qquad \text{eq 23}$$

27. Differentiating eq 19 with respect to each of the nodal values of p for each elemental area gives:

$$[S*]^e.\{p\}^e = \int_{volume} [k_x(\frac{1}{\rho g}.\frac{\partial p}{\partial x}).\frac{\partial}{\partial p_i}(\frac{1}{\rho g}.\frac{\partial p}{\partial x}) + k_y(\frac{1}{\rho g}.\frac{\partial p}{\partial x}).\frac{\partial}{\partial p_i}(1+\frac{1}{\rho g}.\frac{\partial p}{\partial y})].d(volume)$$

$$\begin{aligned}\frac{\partial E}{\partial p_i} &= \int_{volume}(k_x(\frac{1}{\rho g}.\frac{\partial p}{\partial x}).\frac{\partial}{\partial p_i}(\frac{1}{\rho g}.\frac{\partial p}{\partial x})+k_y(\frac{1}{\rho g}.\frac{\partial p}{\partial y}).\frac{\partial}{\partial p_i}(1+\frac{1}{\rho g}\frac{\partial p}{\partial y})).d(volume)\\ &+\int_{volume} Q.\frac{\partial}{\partial p_i}(1+\frac{1}{\rho g}.\frac{\partial p}{\partial y}).d(volume)\\ &+\int_{volume} Q.\frac{\partial}{\partial p_i}(y-y_o+\frac{p}{\rho g}).d(volume)+\int_{area} q\frac{\partial}{\partial p_i}(y-y_o+\frac{p}{\rho g}).d(area)\\ &= [S*]^e.\{p\}^e+[F*]^e\end{aligned} \qquad \text{eq 24}$$

where the first integral is equal to $[S*]^e.\{p\}^e$ and the last three are equal to $\{F*\}^e$. $\{S*\}^e$ can be shown to be symmetric and is known as the flow matrix while $\{F*\}^e$ is known as the seepage forcing vector.

28. Differentiating eq 7 with respect to the nodal pressures gives

$$\frac{\partial E}{\partial p_i} = \sum_e \frac{\partial E_e}{\partial p_i} \qquad \text{eq 25}$$

with the summation taken over all the elements. The final set of equations thus becomes:

$$[S*]^e.\{p\}+\{F*\} = \{0\} \qquad \text{eq 26}$$

29. This set of equations is in fact a set of linear equations and can be solved for the unknown nodal pressure vector {p} by standard matrix solution techniques. The individual finite element flow matrix {F} has been derived above in terms of nodal pressures as:

30. The terms ∂p/∂x, ∂p/∂y are needed to evaluate the integral, thus from eq 22 and introducing the matrix notation

$$\{\begin{matrix}\partial p/\partial x\\ \partial p/\partial y\end{matrix}\} = \begin{bmatrix}\frac{\partial}{\partial x} & \frac{\partial}{\partial y}\end{bmatrix} [N]\ \{p\}^e = [B]\ \{p\}^e \qquad \text{eq 27}$$

31. The expression for $[S*]^e.\{p\}^e$ can then be written as

$$\frac{1}{(\rho g)^2}\int_{volume}\frac{\partial}{\partial p_i}\begin{bmatrix}\frac{\partial p}{\partial x} & \frac{\partial p}{\partial y}\end{bmatrix}[K]\ \frac{\partial p/\partial x}{\partial p/\partial y}\ .d(volume) \qquad \text{eq 28}$$

where [K] is the permeability matrix.

32. The partial differential operation of the above expression

$$\frac{\partial}{\partial\{p_i\}}\quad \frac{\partial p}{\partial x}\ \frac{\partial p}{\partial y} = \frac{\partial}{\partial\{p_i\}}\ \{p\}^T$$

follows standard matrix differentiation in that the differentiation of a vector {p} with respect to another vector $\{p_i\}$ yields a matrix of the following form:

$$\frac{\partial}{\partial\{p_i\}}\{p\}^T = \frac{\partial}{\partial\{p_i\}}\{p\}^{eT}\ [B]^T$$

$$= \begin{bmatrix}\frac{\partial p_1}{\partial p_2} & \frac{\partial p_1}{\partial p_2} & \cdots & \frac{\partial p_1}{\partial p_m}\\ \frac{\partial p_2}{\partial p_1} & \frac{\partial p_2}{\partial p_2} & \cdots & \frac{\partial p_2}{\partial p_m}\\ \vdots & \vdots & & \vdots\\ \frac{\partial p_m}{\partial p_1} & \frac{\partial p_m}{\partial p_2} & \cdots & \frac{\partial p_m}{\partial p_m}\end{bmatrix} [B]^T = [U]\ [B]^T \qquad \text{eq 29}$$

since, however

$$\frac{\partial p_k}{\partial p_j} = \begin{matrix} 0 \text{ if } k \neq j \\ 1 \text{ if } k = j \end{matrix} \qquad \text{eq 30}$$

then [U] must be an identity matrix, therefore

$$\frac{\partial}{\partial \{p_i\}} \{p\}^T = \frac{\partial}{\partial \{p_i\}} \{p\}^{eT} [B]^T = [I] [B]^T = [B]^T \qquad \text{eq 31}$$

33. Thus the element flow matrix is determined by:

$$[S*]^e = \frac{1}{(\rho g)^2} \cdot \int_{\text{volume}} [B]^T [K] [B] \ . \ d(\text{volume}) \qquad \text{eq 32}$$

34. The expansions for the terms in the forcing vector $\{F\}^e$ of eq 24 are straightforward. Letting

$$\{F*\}^e = \{F_1\}^e + \{F_2\}^e + \{F_3\}^e \qquad \text{eq 33}$$

where

$$\{F_1\}^e = \int_{\text{volume}} 2k_y \cdot \frac{\partial}{\partial p_i} \left(\frac{1}{\rho g} \cdot \frac{\partial p}{\partial y}\right) . \ d(\text{volume})$$

$$\{F_2\}^e = \int_{\text{volume}} Q \cdot \frac{\partial}{\partial p_i} \left(y - y_o + \frac{p}{\rho g}\right) . \ d(\text{volume})$$

and

$$\{F_3\}^e = \int_{\text{area}} q \cdot \frac{\partial}{\partial p_i} (y - y_o + \frac{p}{\rho g} . \ d(\text{volume})$$

35. The first term in the series, $\{F_1\}^e$ can be evaluated in the same manner as the flow matrix, in that

$$\frac{\partial p}{\partial y} = \frac{\partial}{\partial y} [N] \{p\}^e = \lceil C \rfloor \{p\}^e = \{C\}^T \{p\}^e$$

and thus

$$\frac{\partial}{\partial p_i} \left(1 + \frac{1}{\rho g} \cdot \frac{\partial p}{\partial y}\right) = \frac{1}{\rho g} \cdot \frac{\partial}{\partial p_i} \left(\frac{\partial p}{\partial y}\right)$$
$$= \frac{1}{\rho g} \cdot \left[\frac{\partial p_e}{\partial p_i}\right] \{C\}$$

Therefore

$$\begin{aligned} \{F_1\}^e &= \frac{2k_y}{\rho g} \int_{\text{volume}} \left[\frac{\partial p_e}{\partial p_i}\right] \{C\} . \ d(\text{volume}) \\ &= \frac{2k_y}{\rho g} \int_{\text{volume}} \{C\} \ . \ d(\text{volume}) \end{aligned} \qquad \text{eq 34}$$

36. The second term is simpler to evaluate in that

$$\frac{\partial}{\partial p_i} \left(y - y_o + \frac{p}{\rho g}\right) = \frac{1}{\rho g} \left[\frac{\partial p_e}{\partial p_i}\right]$$

thus

$$(F_2)^e = \frac{1}{\rho g} \int_{\text{volume}} Q . d(\text{volume}) \qquad \text{eq 35}$$

where

$$Q = Q(x,y)$$

37. It therefore follows that the third term in the series is

$$\{F_3\}^e = \frac{1}{\rho g} \int_{\text{area}} q \ . \ d(\text{area}) \qquad \text{eq 36}$$

where

$$q = q(x,y)$$

Derivation of Triangular Element Flow Matrix

38. The simplest form of finite element which can be used to model a continuous region is the triangle (Fig 1).

39. The elemental pressure head vector for this element is:

$$\{p\}^e = \{p_i, p_j, p_k\}^T \qquad \text{eq 37}$$

40. Assuming a linear variation of pressure head throughout the element

$$p(x,y) = A_1 + A_2 . (x - x_i) + A_3 . (y - y_i) \qquad \text{eq 38}$$

which in matrix form becomes

$$\begin{Bmatrix} p_i \\ p_j \\ p_k \end{Bmatrix} = \begin{bmatrix} 1 & \cdot & \cdot \\ 1 & x_j-x_i & y_j-y_i \\ 1 & x_k-x_i & y_k-y_i \end{bmatrix} \cdot \begin{bmatrix} A_1 \\ A_2 \\ A_3 \end{bmatrix} = [\Psi]\ \{A\} \qquad \text{eq 39}$$

41. The constants {A} can be expressed in terms of $\{p\}^e$ as:

$$\{A\} = [\psi]^{-1}\ \{p\}^e = [N]\ \{p\}^e \qquad \text{eq 40}$$

42. The matrix [N] can be evaluated directly as

$$[N] = \frac{1}{\Delta} \begin{bmatrix} \Delta & \cdot & \cdot \\ b_j-b_k & b_k & -b_j \\ d_k-d_j & -d_k & d_j \end{bmatrix} \qquad \text{eq 41}$$

where $\Delta = d_j\ b_k - d_k\ b_j$, (twice the area of the triangle);

$$d_j = x_j - x_i$$

$$d_k = x_k - x_i$$

$$b_j = y_j - y_i,$$

and $b_k = y_k - y_i$

thus

$$p = \lceil 1 \quad x-x_i \quad y-y_i \rfloor \begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix}$$

and

$$\frac{\partial p}{\partial x} = \begin{vmatrix} \cdot & 1 & \cdot \end{vmatrix} \{A\}$$

$$\frac{\partial p}{\partial y} = \begin{vmatrix} \cdot & \cdot & 1 \end{vmatrix} \{A\} \qquad \text{eq 42}$$

thus

$$[B] = \frac{1}{\Delta} \begin{bmatrix} \cdot & 1 & \cdot \\ \cdot & \cdot & 1 \end{bmatrix} \begin{bmatrix} \Delta & \cdot & \cdot \\ b_j-b_k & b_k & -b_j \\ d_k-d_j & -d_k & d_j \end{bmatrix}$$

$$= \frac{1}{\Delta} \begin{bmatrix} b_j-b_k & b_k & -b_j \\ d_k-d_j & -d_k & d_j \end{bmatrix} \qquad \text{eq 43}$$

43. Due to limitations imposed by available permeability testing procedures, permeabilities are measured parallel with and perpendicular to rock strata or soil layering. As the layering directions do not coincide, in general, with the coordinate directions, a transformation of the permeability coefficients from the layer coordinate system is required. Figure 1 indicates the nature of this problem with the primed axes representing the layer coordinate system.

44. The measured directional permeabilities are k_x^1 and k_y^1 with the stratification angle being ϕ. Darcy's Law may be expressed in terms of the layer coordinate system as

$$\begin{Bmatrix} V_x^1 \\ V_y^1 \end{Bmatrix} = - \begin{bmatrix} k_x^1 & \cdot \\ \cdot & k_y^1 \end{bmatrix} \begin{Bmatrix} \partial\phi/\partial x^1 \\ \partial\phi/\partial y^1 \end{Bmatrix} \qquad \text{eq 44}$$

where V_x^1, V_y^1 are flow velocities along the layer coordinate directions. Using standard transformation techniques it can be shown that

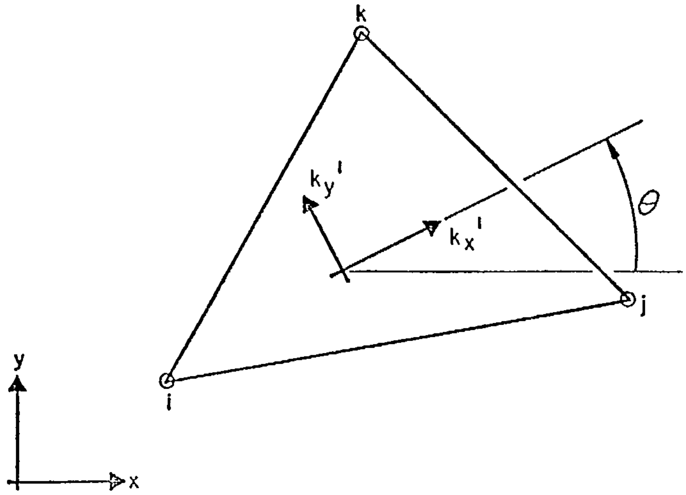
$$\begin{Bmatrix} V_x \\ V_y \end{Bmatrix} = \begin{vmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{vmatrix} \begin{Bmatrix} V_x^1 \\ V_y^1 \end{Bmatrix}$$

and that

$$\begin{Bmatrix} \frac{1}{\rho g}\frac{\partial p}{\partial x} \\ 1+\frac{1}{\rho g}\frac{\partial p}{\partial y} \end{Bmatrix} = \begin{vmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{vmatrix} \begin{Bmatrix} \partial\phi/\partial x^1 \\ \partial\phi/\partial y^1 \end{Bmatrix} \qquad \text{eq 45}$$

45. Combining the above transformations to give Darcy's Law in terms of the general coordinate system yields

$$\begin{Bmatrix} V_x \\ V_y \end{Bmatrix} = \begin{vmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{vmatrix} \begin{vmatrix} k_x^1 & \cdot \\ \cdot & k_y^1 \end{vmatrix} \begin{vmatrix} \cos\theta\ \sin\theta \\ -\sin\theta\ \cos\theta \end{vmatrix} \begin{Bmatrix} \rho\frac{1}{g} \cdot \frac{\partial p}{\partial x} \\ 1+\frac{1}{\rho g} \cdot \frac{\partial p}{\partial x} \end{Bmatrix}$$



i, j, k - Element nodes
k_x^1, k_x^1 - Element material permeabilities
ϵ - Element material orientation or stratification angle

Fig 1 - Triangular finite element.

or

$$\{V\} = - [L]^T [K^1] [L] \{\phi\} = - [K] \{\phi\} \qquad \text{eq 46}$$

46. Note that the permeability matrix is now

$$[K] = \begin{bmatrix} k_{xx} & k_{xy} \\ k_{yx} & k_{yy} \end{bmatrix} = [L] [K^1] [L] \qquad \text{eq 47}$$

where [L] is a transformation matrix containing direction cosines.

47. Now that the [B] and [K] matrices have been defined for this element, the flow matrix is determined from the equation

$$[S^*]^e = \frac{1}{(\rho g)^2} \int_{\text{volume}} [B]^T [K] [B] \cdot d(\text{volume}) \qquad \text{eq 48}$$

48. However, as shown above, all the quantities in the above integral are constants within the element and integration is indicated by replacing the integral over the element by the volume V^e of the element,

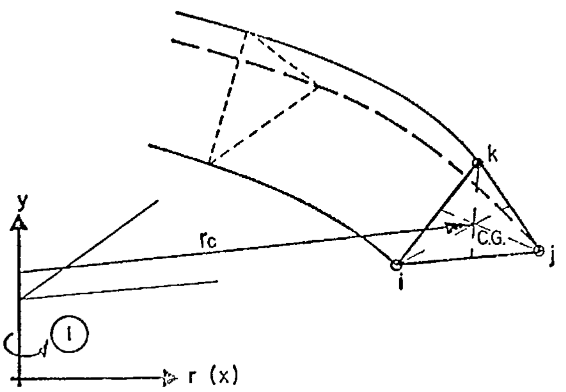
$$[S^*]^e = \frac{V_e}{(\rho g)^2} \cdot [B]^T [K] [B] \qquad \text{eq 49}$$

49. Both axi-symmetric, ie, radial, and plane flow conditions are described by the above expression if the basic elemental volumes are taken accordingly. For plane flow, the elemental volume utilized is the area of the basic triangular region times a unit thickness, thus

$$V_{pl}^e = \frac{\Delta}{2} = \frac{d_j b_k - d_k b_j}{2} \qquad \text{eq 50}$$

where d_j, d_k, b_j, b_k have been defined previously. For an axi-symmetric or radial flow element (Fig 2) the elemental volume is that of a ring whose cross section is triangular, thus

$$V_{ax}^e = \pi \cdot r_c \cdot \Delta \qquad \text{eq 51}$$



(1) Axis of symmetry

i, j, k - element nodal circles

r_c - radius to element centroid

k_x^1, k_y^1, θ - same as for planar element

Fig 2 - Axi-symmetric finite element.

where r_c is the radius of the centroid of the element. Thus if the axis is to be the axis of symmetry then

$$r_c = \frac{x_i + x_j + x_k}{3} \qquad \text{eq 52}$$

Formation of Quadrilateral Element Flow Matrix

50. In applications to seepage analysis problems, it is often expedient to combine four triangular elements into a basic quadrilateral shape as shown on Fig 3.

$$x_m = \frac{x_i + x_j + x_k + x_e}{4}$$

and

$$y_m = \frac{y_i + y_j + y_k + y_e}{4} \qquad \text{eq 53}$$

51. The quadrilateral element flow matrix will then be assembled from the individual element flow matrices as follows:

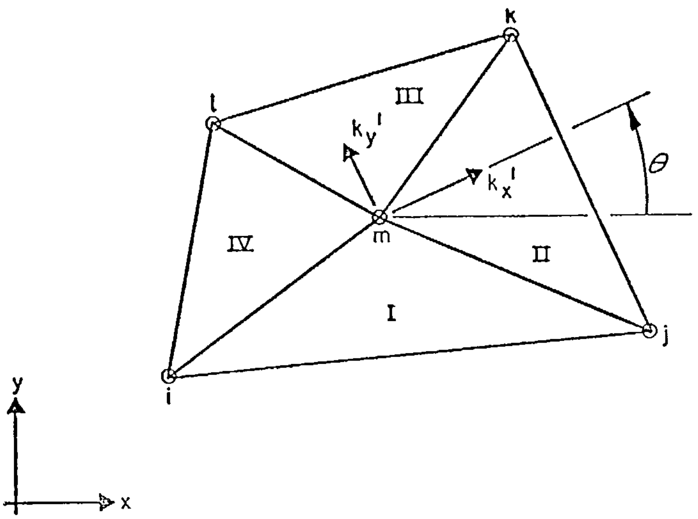
$$[S*]^e = [S*_I]^e + [S*_{II}]^e + [S*_{III}]^e + [S*_{IV}]^e \qquad \text{eq 54}$$

52. Each individual flow matrix is a 3 x 3 matrix and has coefficients of the following general form for a triangle with nodes n, p and q

$$[S*]^e = \begin{bmatrix} S_{nn} & S_{np} & S_{nq} \\ S_{pn} & S_{pp} & S_{pq} \\ S_{qn} & S_{qp} & S_{qq} \end{bmatrix} \qquad \text{eq 55}$$

53. The composite element flow matrix will then be a 5 x 5 matrix and will have the following general form.

$$[S*]^e = \left[\begin{array}{cccc|c} S_{ii} & S_{ij} & \cdot & S_{il} & S_{im} \\ S_{ji} & S_{jj} & S_{jk} & \cdot & S_{jm} \\ \cdot & S_{kj} & S_{kk} & S_{kl} & S_{km} \\ S_{li} & \cdot & S_{lk} & S_{ll} & S_{lm} \\ \hline S_{mi} & S_{mj} & S_{mk} & S_{ml} & S_{mm} \end{array}\right] = \begin{bmatrix} S_{AA} & S_{AB} \\ S_{BA} & S_{BB} \end{bmatrix}$$



i, j, k, l	- element exterior nodes
m	- element interior node
I, II, III, IV	- element constituent triangles
k_x^1, k_y^1	- element material permeabilities
θ	- element material orientation or stratification angle

Fig 3 - Quadrilateral finite element.

where the partition index A relates to those terms associated with the pressures at the exterior nodes i, j, k, l and the partition index B relates to those terms associated with the fluid pressure at the interior node m.

54. If the fluid pressure and the fluid flow at the interior node m do not constitute boundary conditions ie, if the nodal pressure is not specified and if there is no prescribed quantity of flow through the node, it is possible to eliminate the dependence of the central node. This is done by using the static condensation algorithm which is an extension of the Gaussian elimination process. In matrix terms, this operation is

$$[S^*]^e = [S_{AA}]-[S_{AB}].[S_{BB}]^{-1}.[S_{AA}] \qquad \text{eq 56}$$

This reduced flow matrix is a 4 x 4 matrix. The use of this form of element flow matrix reduces the overall size and bandwidth of the resulting set of equations without loss of accuracy.

Derivation of Seepage Forcing Vector

55. Equation 38 contains a description of the various constituents of the element seepage forcing vector. The seepage forcing vector for the problem is then simply the sum of the element forcing vectors

$$\{F^*\} = \sum_m \{F^*\}^e$$

56. For each triangular element, the constituent parts of the forcing vector are evaluated separately using eq 34, 35 and 36. Thus, the first item $\{F_1\}^e$, is found from

$$\{F_1\}^e = \frac{2k_y}{\rho g} \cdot \int_{\text{volume}} \{C\} \cdot d(\text{volume})$$

where {C} can be interpreted directly from eq 43 as

$$\{C\} = \frac{1}{\Delta} \left\{ \begin{matrix} d_k - d_j \\ -d_k \\ d_j \end{matrix} \right\} \qquad \text{eq 57}$$

57. As all the quantities in the above integral are constant within the element, the integration process becomes

$$\{F_1\}^e = \frac{2k_y}{\rho g} \cdot V^e \cdot \{C\} \qquad \text{eq 58}$$

Thus, for planar flow elements

$$\{F_1\}^e = \frac{k_y}{\rho g} \begin{Bmatrix} d_k - d_j \\ -d_k \\ d_j \end{Bmatrix} \qquad \text{eq 59}$$

and for axi-symmetric flow elements

$$\{F_1\}^e = \frac{2\pi . k_y . r_c}{\rho g} \begin{Bmatrix} d_k - d_j \\ -a_k \\ a_j \end{Bmatrix} \qquad \text{eq 60}$$

58. The second term in the seepage forcing vector, $\{F_2\}^e$ is found from

$$\{F_2\}^e = \frac{1}{\rho g} \int_{\text{volume}} Q \cdot d(\text{volume})$$

where Q represents the rate of flow influx to the element. For most practical analyses it is more convenient to apply a specific quantity of inflow per unit time to an individual node rather than to specify an influx rate over an element area. Thus, this equation reduces to

$$\{F_2\}^e = \frac{1}{\rho g} \begin{Bmatrix} Q_i \\ \vdots \\ Q_m \end{Bmatrix} \qquad \text{eq 61}$$

and as integration over the element is not required, this operation need no longer be performed as an elemental procedure, but simply as an addition to the problem seepage forcing vector.

59. The third term in the seepage forcing vector is

$$\{F_3\}^e = \frac{1}{\rho g} \int_{\text{area}} q \cdot d(\text{area})$$

where q represents the flow rate normal to the boundary surface. As both the triangular and quadrilateral elements are constant velocity elements (thus implying constant flow) only a constant rate of flow may be specified. Normally, only one side of an element is assumed to have a specified flow and thus $\{F_3\}^e$ becomes

$$\{F_3\}^e = \frac{q}{2\rho g} \begin{Bmatrix} 1_n \\ \vdots \\ 1_p \\ \vdots \end{Bmatrix} \text{area } n\text{-}p \qquad \text{eq 62}$$

where n, p are the nodes at the ends of the side. For planar flow elements where a unit thickness element is presumed, the area term becomes

$$\text{Area}_{n-p} = [(x_n - x_p)^2 + (y_n - y_p)^2]^{V}{}_{2} \qquad \text{eq 63}$$

For axi-symmetric elements, the area term becomes

$$\text{Area}_{n-p} = \pi[x_p . y_p - x_p y_n + x_n y_p - x_n y_n](1 + (\frac{x_p - x_n}{y_p - y_n})^2)^{V}{}_{2} \qquad \text{eq 64}$$

60. It should be noted that the above derivations apply to the quadrilateral element equally well.

Boundary Conditions

61. Three types of boundary conditions occur in the solution of seepage problems. These are:

a. surfaces with known or specified fluid pressures
b. surfaces with known or specified flow rates
c. free or phreatic surfaces where the atmospheric pressure is taken to be zero and the flow rate normal to the surface is known and is usually zero.

62. The first boundary condition is satisfied by computing the nodal fluid pressures at the nodes along the surface with the known or specified fluid pressure, and then modifying the equations in the flow matrix corresponding to these nodes so as to produce the nodal pressures as the

solution. The values of the other nodal pressures are obtained by solving the set of simultaneous equations represented by eq 24.

63. The second boundary condition is handled by computing the equivalent nodal flows along the surface with known or specified flow rates, then calculating the elemental contributions to the forcing vector {F} using eq 36 and finally adding these quantities to the forcing vector prior to solving the set of equations.

64. The inclusion of the above two types of boundary conditions permits the solution of confined flow seepage problems. Unconfined flow problems are much more difficult to solve as the location of the phreatic surface is not known. This indefiniteness is offset by the third type of boundary condition, which is, in effect, a combination of the first two boundary condition types. It is not possible, however, to solve for a simultaneous combination of these conditions on a surface by the finite element method. Instead, an iterative approach must be used in which a free surface position is estimated, one of the boundary conditions is applied, and the other is disregarded. Upon solving the set of equations, the resulting conditions along the free surface are investigated to see if the disregarded boundary conditions have been approximately satisfied. If not, then a new position of the phreatic surface is calculated from the resulting conditions and the solution process repeated. This iteration procedure continues until the disregarded boundary condition is satisfied.

Calculation of Flow Velocities

65. From eq 44, the flow velocities are determined from Darcy's Law as

$$\{V\} = -[K]\{\dot{\phi}\} \qquad \text{eq 65}$$

66. The vector V , however, represents the flow velocities along the general coordinate directions. In general, the flows parallel with and perpendicular to the material layering are of greater interest and are calculated by

$$\{V^1\} = [K]\{\dot{\phi}'\} \qquad \text{eq 66}$$

Thus

$$\begin{matrix} V_x^{\,1} \\ V_y^{\,1} \end{matrix} = -\begin{bmatrix} k_x^{\,1} & \cdot \\ \cdot & k_y^{\,1} \end{bmatrix} \begin{Bmatrix} \partial\phi/\partial x^1 \\ \partial\phi/\partial y^1 \end{Bmatrix} \qquad \text{eq 67}$$

Using the transformations presented earlier (eq 45, 46)

$$V_x^{\,1} = -\begin{vmatrix} k_x^{\,1} & \cdot \\ \cdot & k_y^{\,1} \end{vmatrix} \begin{vmatrix} \cos\theta & -\sin\theta \\ \sin\theta & -\cos\theta \end{vmatrix} \begin{Bmatrix} \frac{1}{\rho g}\cdot\frac{\partial p}{\partial x} \\ 1+\frac{1}{\rho g}\cdot\frac{\partial p}{\partial y} \end{Bmatrix}$$

$$= [K]\,[L]^T\left(\{\{1\} + \frac{1}{\rho g}\cdot[B]\;\{\rho\}^e\}\right) \qquad \text{eq 68}$$

67. For a triangular element with nodes i, j, k this becomes

$$\begin{matrix} V_x^{\,1} \\ V_y^{\,1} \end{matrix} = -\frac{1}{\Delta}\begin{bmatrix} k_x^{\,1} & \cdot \\ \cdot & k_y^{\,1} \end{bmatrix} \begin{bmatrix} \text{COS } \theta & -\text{SIN } \theta \\ \text{SIN } \theta & \text{COS } \theta \end{bmatrix} \left(\begin{Bmatrix} 1 \end{Bmatrix} + \frac{1}{\rho g}\begin{bmatrix} b_j-b_k & b_k-b_j \\ d_k-d_j-d_k & d_j \end{bmatrix} \begin{Bmatrix} p_i \\ p_j \\ p_k \end{Bmatrix}\right) \qquad \text{eq 69}$$

68. In the case of a quadrilateral element, the pressure at the interior node is calculated as the average of the corner node pressures. The flows in each constituent triangular element are computed and averaged to provide flow values for the quadrilateral element.

Solution for Stream Function

69. In finite element seepage analyses, the solution is generally found in terms of the velocity potential or potential head function ϕ. For two-dimensional and axi-symmetric flow situations another function exists which can be very useful for determining the amount or rate of fluid flow. This function is known as the stream function ψ and has the following properties:

a. it is constant along a streamline, a line which is tangential at all points to the third velocity vectors at an instant

b. $\frac{\partial\psi}{\partial y} = V_x, \quad \frac{\partial\psi}{\partial x} = V_y$

$$(\partial\psi = V_x\partial y - V_y\partial x) \qquad \text{eq 70}$$

c. the volume flow rate between any two streamlines i and j is constant and is completely defined by the differences in stream function values,

$$Q_{ij} = \psi_j - \psi_i \qquad \text{eq 71}$$

d. it is a linear function of the boundary conditions.

70. Thus, it can be seen that the stream function ψ is particularly useful for calculation of seepage rates and quantities.

71. Now, if flow velocity or head potential function distributions are known exactly throughout a continuum then the stream function could readily be found, since from eq 46

$$\begin{aligned} V_x &= k_{xx}\frac{\partial\phi}{\partial x} + k_{xy}\frac{\partial\phi}{\partial y} = \frac{\partial\psi}{\partial y} \\ V_x &= k_{yx}\frac{\partial\phi}{\partial x} + k_{yy}\frac{\partial\phi}{\partial y} = \frac{\partial\psi}{\partial x} \end{aligned} \qquad \text{eq 72}$$

72. Unfortunately, the finite element method provides only estimates of V_x and V_y which by definition are not continuous across element boundaries. Thus, different estimates of the total fluid flow across an inter-element boundary will be found if $\partial\psi/\partial y$ and $\partial\psi/\partial x$ are integrated along paths on either side of the boundary. It is possible to directly formulate the finite element method in terms of the stream function ψ in much the same manner as outlined earlier. However, in this case the inverse problem occurs in that instead of ψ it is ϕ that is ambiguously defined.

73. A simple least-squares technique can be utilized to obtain a set of stream function values at the nodes in a finite element mesh from the elemental flow velocities. This least-squares technique minimizes the sum of the weighted squares of the differences between the total flow across each element boundary and the flows based on the velocity within each element.

74. The least-squares technique is described as follows. Integrating eq 72 within each element for each pair of nodes i and j describing the sides of the element will yield m sets of total flow estimates $\hat{Q}_{ij}$. The flow discrepancy that occurs in the estimation for path k is then

$$\varepsilon^{(k)} = Q_{ij} - \hat{Q}_{ij}^{(k)} \qquad \text{eq 73}$$

which from eq 71 can be shown to be

$$\varepsilon^{(k)} = \psi_j - \psi_i - \hat{Q}_{ij}^{(k)} \qquad \text{eq 74}$$

(Note that at this point ψ_j and ψ_i are unknown.) The weighted squared discrepancy is then formulated as:

$$\omega^{(k)}\,\varepsilon^{(k)2} = \omega^{(k)}\,(\psi_j - \psi_i - \hat{Q}_{ij}^{(k)})^2 \qquad \text{eq 75}$$

75. Summing the weighted squared discrepancies for all m sets of flow estimates gives

$$\mathcal{Z} = \sum_m \omega^{(k)}\,\varepsilon^{(k)2} \qquad \text{eq 76}$$

76. Minimizing $\mathcal{Z}$ with respect to each nodal stream function value ψ_n gives a series of relationships

$$\frac{\partial\mathcal{Z}}{\partial\psi_n} = 0 \qquad \text{eq 77}$$

which when expanded become

$$\begin{aligned} \frac{\partial\mathcal{Z}}{\partial\psi_n} &= 2\sum_m \omega^{(k)} \cdot \varepsilon^{(k)} \cdot \frac{\partial\varepsilon^{(k)}}{\partial\psi_n} \\ &= 2\sum_m \omega^{(k)} \cdot (\psi_j - \psi_i - \hat{Q}_{ij}^{(k)}) \cdot \left(\frac{\partial\psi_i}{\partial\psi_n} - \frac{\partial\psi_i}{\partial\psi_n}\right) = 0 \end{aligned} \qquad \text{eq 78}$$

Now, it is obvious that

$$\frac{\partial\psi_j}{\partial\psi_n} - \frac{\partial\psi_i}{\partial\psi_n} = \left\{ \begin{array}{ll} +1 & \text{if } n = j \\ -1 & \text{if } n = i \\ 0 & \text{if } n \neq i \text{ and } n \neq j \end{array} \right\}$$

77. Putting eq 78 into matrix form yields the linear relationship

$$[W]\ \{\psi\} = \{\bar{Q}\} \qquad \text{eq 79}$$

where [W] is a matrix of summed weighting factors,

$\{\psi\}$ is a vector of (unknown) nodal stream function estimates, and

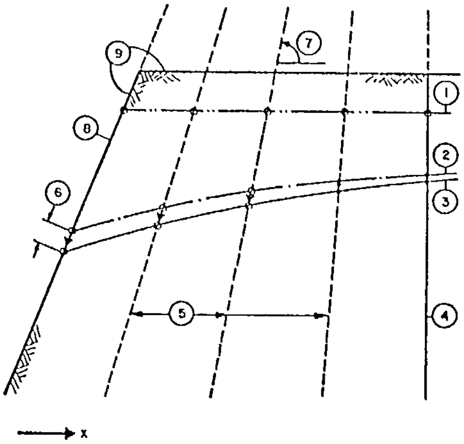
$\{\overline{Q}\}$ is a vector of summed and weighted total flow estimates.

78. Equation 79 can then be solved for the nodal stream function estimates $\{\psi\}$ using a standard linear equation solution process once a suitable datum is provided for the stream function.

79. If a source or sink exists within the continuum region the stream function cannot be defined. In mining practice, a drainage adit behind a pit wall will often act as a sink. This difficulty can be removed by connecting the source or sink to the surrounding boundary by an imaginary conduit.

Location of Phreatic Surface in Unconfined Flow Problems

80. Unconfined flow problems, in which the location of the phreatic surface is not known at the start of the analysis, are solved using an iterative procedure. As outlined earlier, an initial position of the phreatic surface is estimated. After applying the boundary condition of known constant flow across this initial boundary (most often zero flow) the nodal pressures throughout the finite element mesh are calculated. The pressures along the phreatic surface are then interrogated and related to zero with subsequent adjustment of their location. The boundary conditions of known constant flow are then applied to the distorted mesh and a new solution for nodal pressures is then obtained. The pressures along the phreatic surface are interrogated again and another new location of the phreatic surface is estimated. Figure 4 illustrates this iterative procedure which continues until the total change in phreatic surface location between iterations is less than a specified amount.



(1) Initial assumed phreatic surface location C_I^1
(2) C_I^{n-1} - phreatic surface location after n-1 iterations
(3) C_I^n - phreatic surface location after n iterations
(4) Material interface
(5) Nodal correction directions
(6) D_j^{n-1} - correction distance for node j
(7) k - nodal correction angle
(8) Slope face
(9) Slope outline

For convergence $d_j^{n-1} \leq$ tolerance

Fig 4 - Finite element program: phreatic surface adjustment procedure.

81. The procedure involved in phreatic surface location adjustment requires an estimate of the derivative of the third pressure gradient normal to the direction along which a node is to be moved. Two methods are available for the assessment of this quantity. The first and simplest method takes the vertical component for correction of a nodal position as being $-p_i/\rho g$ and leads to a correction distance of

$$D_i = \frac{-p_i/\rho g}{\sin k} \qquad \text{eq 80}$$

where p_i = fluid pressure at node i and

k = nodal correction angle.

82. This method is not theoretically correct as the horizontal component of the pressure gradient has been omitted, however, it can be used safely for many practical seepage analysis problems.

83. The second method uses a least squares process to determine the fluid pressure gradient at a node and is useful for situations in which the first method fails to provide a converged solution. The difference in fluid pressure between a node and a point some distance away can be found through a Taylor series expansion, provided that the gradient is known, as

$$\Delta p = \{\nabla p\}^T \begin{Bmatrix} \Delta x \\ \Delta y \end{Bmatrix} + \frac{1}{2} \{\nabla^2 p\}^T \begin{Bmatrix} \Delta x \\ \Delta y \end{Bmatrix}^2 + \ldots \qquad \text{eq 81}$$

where $\{\nabla p\} = \begin{Bmatrix} \partial p/\partial x \\ \partial p/\partial y \end{Bmatrix}$ is the pressure gradient, and

Δx, Δy are the distance components between the two points.

84. As only a linear variation of fluid pressure is allowed within the finite elements described in this report, it is reasonable to use a linear variation for fluid pressure about a nodal point. Furthermore, if a local co-ordinate system originating at the nodal point is chosen then the pore pressure at some distance from it is found through

$$p = p_i + Bx + Cy \qquad \text{eq 82}$$

where B and C are parameters to be determined.

85. Equation 81 then reduces to

$$\nabla p = \{\nabla p\}^T \begin{Bmatrix} \Delta x \\ \Delta y \end{Bmatrix} = \{\nabla p\}^T \begin{Bmatrix} x \\ y \end{Bmatrix}$$

and the pressure gradient becomes

$$\{\nabla p\} = \begin{Bmatrix} \partial p/\partial x \\ \partial p/\partial y \end{Bmatrix} = \begin{Bmatrix} B \\ C \end{Bmatrix}$$

thus giving

$$\Delta p = \begin{Bmatrix} B \\ C \end{Bmatrix}^T \begin{Bmatrix} x \\ y \end{Bmatrix} = Bx + Cy \qquad \text{eq 83}$$

86. The discrepancy in fluid pressure that occurs between a set of nodes i and j is then

$$\varepsilon j = p_j - p_i - \Delta p = p_j - p_i - Bx_j - Cy_j \qquad \text{eq 84}$$

The weighted squared discrepancy becomes

$$\omega_j \varepsilon_j^2 = \omega_j (p_j - p_i - Bx_j - Cy_j)^2 \qquad \text{eq 85}$$

which when summed over j nodal connections gives the total error as

$$Z = \sum_j \omega_j \varepsilon_j^2 = \sum_j \omega_j (p_j - p_i - Bx_j - Cy_j)^2 \qquad \text{eq 86}$$

Minimizing Z with respect to the unknown parameters B and C gives two relationships

$$\begin{aligned} \frac{\partial Z}{\partial B} &= \sum_j \omega_j (p_j - p_i - Bx_j - Cy_j)(-x_j) \\ \frac{\partial Z}{\partial C} &= \sum_j \omega_j (p_j - p_i - Bx_j - Cy_j)(-y_j) \end{aligned} \qquad \text{eq 87}$$

which when put in matrix form yield the linear relationships.

$$\begin{bmatrix} \sum_j \omega_j x_j^2 & \sum_j \omega_j x_j y_j \\ \sum_i \omega_j y_j x_j & \sum_i \omega_j y_j^2 \end{bmatrix} \begin{Bmatrix} B \\ C \end{Bmatrix} = \begin{Bmatrix} \sum_j \omega_j (p_j - p_i) x_j \\ \sum_i \omega_j (p_j - p_i) y_j \end{Bmatrix}$$

87. After equating the weighting function ω_j to the distance between the two points the parameters B and C can be readily determined and thus the average fluid pressure gradient at the node has been obtained. The calculation of the

derivative of the gradient normal to the nodal correction is then a trivial matter using the chain value. The correction distance is thus found to be

$$D_i = \frac{-p_i/\rho g}{C.\cos k - B.\sin k} \qquad \text{eq 88}$$

88. In practice, it has sometimes been found necessary to underestimate the next location of the phreatic surface. This action, known more properly as under-relaxation, generally assumes monotonic convergence of the above iteration procedures.

89. An ambiguity in the specification of the boundary conditions along the phreatic surface exists when the surface intersects the geometric boundary of the continuum. As the nodal flow at this point cannot be specified directly it becomes difficult to predict its location precisely. Retaining the finite element mesh in the region of this intersection point reduces the effect of the ambiguity. The most satisfactory practical treatment has been to fit a parabola through the three closest phreatic surface points and then extrapolate it to determine the location of the intersection point.

PROGRAM CAPABILITIES

90. The finite element seepage analysis computer program is known acronymically as FEFPM (Finite Element analysis of Flow in Porous Media). The FEFPM computer program is used to determine fluid pressures as well as flow quantities, rates and directions in steady-state ground water regimes. These ground water regimes are vertical sections in which fluid movement patterns conform reasonably well to either planar or radially symmetric flow conditions. It is further assumed that geological conditions existing throughout the section are known.

91. The analytical capabilities of the FEFPM computer program permit the analysis of groundwater flow subject to the following conditions:

- flow is planar or radially symmetric on vertical sections
- flow is linear within a finite element (Darcy flow rules)
- material permeabilities may be isotropic or anisotropic
- flow regime may be confined or unconfined.

The program itself has been developed to the extent that it will automatically compute:

- the location of the phreatic surface for unconfined flow problems
- the material type and permeability for an element from soil region definition lines and zones
- fluid potential and stream function values.

92. To minimize user involvement in data set-up and control of an analysis, the FEFPM computer program can:

- generate nodes and elements
- re-generate automatically the finite element mesh during phreatic surface location iterations
- automatically limit the flow regime to the slope profile.

In addition the FEFPM computer program is structured and coded to utilize available computer resources efficiently and minimize computer time required by analysis. Some means by which this efficiency is accomplished are:

- expanding and contracting computer memory (core storage) allocations as required by particular problems
- using a Choleski decomposition algorithm for the iterative solution of the flow equations
- using a bandwidth reduction process to re-order mode sequences and thus minimize the size of the global flow matrix.

93. Because the FEFPM computer program has the ability to set and adjust its internal core storage allocation, there is only one limitation to the size of the problem. This simply is that the

computer memory required to store all node, element, and material data as well as the global flow matrix, flow forcing and solution vectors does not exceed the available core storage. Most practical seepage analysis problems with about 500 nodes, 500 elements and 10 different materials are well within core storage limits on modern large high-speed computers.

94. Intermediate and final results of FEFPM analyses can also be automatically saved on computer peripheral storage units such as disks or magnetic tapes. Thus, for an unconfined seepage analysis problem in which the final location of the phreatic surface is determined by an iterative procedure, it is possible to stop the run after, say, only five iterations have been completed. The user would then check intermediate results and ascertain that the analysis was correct up to that point. He would then restart the analysis using the saved results of the fifth iteration and instruct the program to carry on iterating until the solution converged.

95. These capabilities and limits are controlled with parameters in the NAMELIST input.

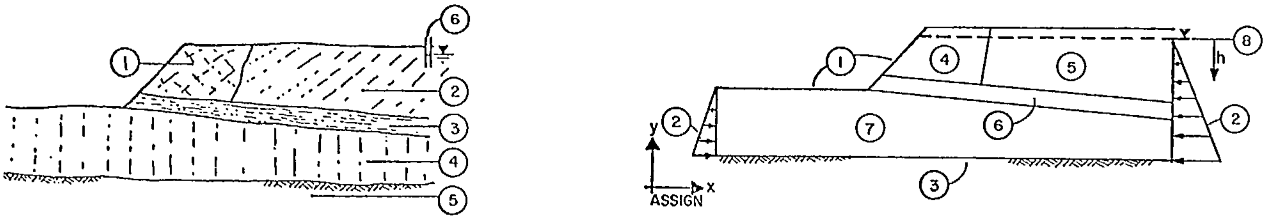
DATA INPUT

96. The seven types of possible input are coded on the forms shown in Fig 5. The order of input is approximately the order of the forms. All these inputs are assumed read from logical unit 5, the card reader (INPUT).

Setting the Analysis

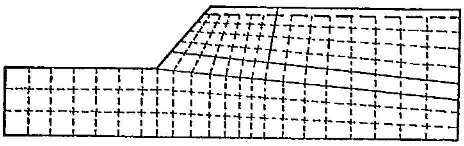
97. Setting up a finite element analysis of seepage problems is a precise, yet straightforward procedure as outlined graphically in Fig 5. Initially, all data pertinent to the seepage problem must be collected. The best method is to prepare a geological section and mark the known geological and hydraulic/hydrologic data on it.

98. From this rough chart, the next step is to prepare a scaled drawing of the problem geometry including such features as material boundaries, boundary conditions and an assumed initial phreatic surface. Input units and dimensions for the co-ordinate system, fluid properties and material permeabilities must be carefully and consistently chosen. The following dimensions must be used throughout.



1. Seepage Problem
   - (1) Fractured rock K
   - (2) Intact rock K_2
   - (3) Mineral layer K_3
   - (4) Underlying strata K_4
   - (5) Assumed impervious bedrock
   - (6) Known piezometer reading

2. Layout Problem Geometry, Material Boundaries and Boundary Conditions
   - (1) Set $p = 0$
   - (2) Set $p = \gamma_w h$
   - (3) Set $q = o$
   - (4) Type 1
   - (5) Type 2
   - (6) Type 3
   - (7) Type 4
   - (8) Assumed initial phreatic surface



3. Develop Finite Element Mesh
4. Prepare Data
5. Check Data
6. Run FEFPM Computer Program
7. Plot Results

Fig 5 - Finite element analysis procedure.

Quantity	Measured in
pressure (head)	lenght (L)
permeability (velocity)	length/time (L/T)
flow rate (velocity)	length/time (L/T)
flow quantity	$\text{length}^3/\text{time}$ (L^3/T)

The user must understand fluid and soil/rock mechanics sufficiently well that realistic boundary condtions are applied.

99. The finite element mesh itself must then be developed on the scaled drawing. As the FEFPM computer program permits node and element generation, nodes should be regularly spaced, wherever possible, and the node number scheme kept as systematic as possible. The use of quadrilateral elements allows most problems with irregular geometries to be modelled easily, however the user can include triangular elements into the mesh if desired. In areas where significant changes in pressure or velocities are anticipated the grid mesh should be made finer.

100. The next phase involves the coding of the input data for the program. This must be done very carefully as an error in a coordinate location or material type would likely not be detected by the program and erroneous but apparently acceptable results would be obtained. The importance of checking and re-checking the input data cannot be over-emphasized.

101. Finally, when the user is sure that his data is correct, the FEFPM computer program can be run. Should an error occur during execution, the program will print out an error message stating the cause and location, and will then stop. The user will be able to correct the situation from the error message description and re-submit the run. Upon successful completion of the analysis, the complete report of all nodal and elemental results should be studied carefully prior to plotting flow nets and fluid pressure contours.

Data Preparation

102. Data cards detailing regime geometric material permeabilities and boundary conditions are prepared using fixed formats. When the data cards have been keypunched, checked and verified, the system control cards are added to the card deck. The complete run deck is then submitted to the computer through the card reader on a batch terminal.

103. There are seven distinct input items in the data for FEFPM.

a. Title card(s) and START card. These cards are used for problem title input and job initialization.
b. Control parameters input through Namelist $FPM cards. These cards set values for various parameters describing the type of problem, how it is to be solved and the level of output required.
c. Node definition cards. These cards define the locations, boundary conditions and generation parameters for nodes.
d. Material properties cards. These define for each material, the directional permeabilities, and the extent or zoning throughout the problem geometry.
e. Element definition cards. These define the elements in terms of their nodes and material types.
f. Distributed inflow cards (optional). These cards define fluid inflows distributed along the edges of finite elements.
g. Pipe card (optional). This card defines a string of elements linking any internal sources or sinks to a boundary.

Note that while the last two data input items are optional, depending on the type of problem, the first five items are always essential for initial or START runs. For RESTART runs only data items a. and b. are input.

Input Data Card Formats

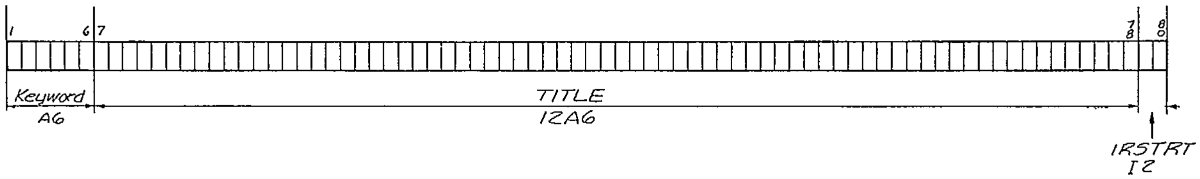
Title Card(s) and START Card

104. The format of the title cards and the START, RESTART or STOP card are shown in Fig 6.

Namelist $FPM Cards

105. Figure 7 illustrates the manner in which the control parameters are entered through the Namelist SFPM cards. A list and description of

Title Cards and Start Card



Keyword - START means data for a new problem follow. The TITLE (72 chars) on the START card is printed on each output page.

- RESTART means an interrupted problem is to be restarted. A check point file created in a previous run must be attached to unit 13. (usually a card deck). A restarted job can add only Namelist data, no other kind.

- STOP means terminate execution.

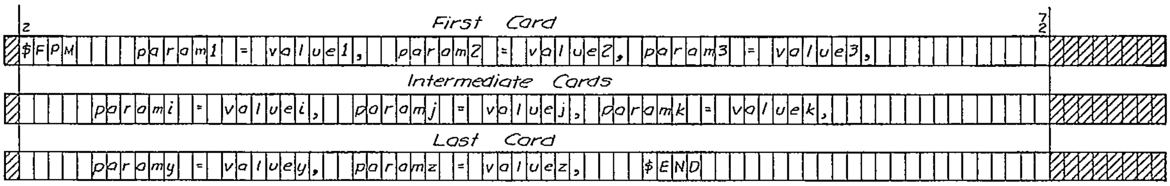
Anything else: the card will be printed, and the next card read.

Variable - IRSTRT is a two digit number entered only for a RESTART run. The input unit will be positioned forward of IRSTRT files.

Comment - After completion of each problem, the input stream returns to Card 1 to look for the next problem, or a STOP card.

Fig 6 - Title cards and start card.

NAMELIST $FPM Cards



These cards contain control parameters for the problem. Each parameter itemized on the following pages has a default value so that only those having a value different from their default need be entered.

Format - free format in card columns 2 through 72 as outlined above (Card columns 1 and 73 through 80 must be blank).

- the first card must contain $FPM in columns 2 through 5. the last card must contain $END after the last parameter specification.

- each parameter is specified by a phrase of the form PARAM = VALUE, (the comma must directly follow the value).
  for numeric parameters value is the appropriate real or integer number, and
  for logical parameters, value is .TRUE. (or .T.) for true, or .FALSE. (or .F.) for false.
- the last card must contain a $END.

Fig 7 - NAMELIST $FPM cards.

all control parameters are contained in Table 1.

106. Namelist input is a convenient means to input program control parameter values as only those parameters that require to be reset from their default values need be entered. The form in which the parameter values are entered is in a phrase equivalent to:

PARAM = VALUE,

for example, to specify that the solution is to pass through ten iterations would be accomplished by including: NUMIT = 10, in the Namelist.

107. The user should note that although Namelist input is free-format there are a number of conventions that must be strictly adhered to (Fig 7).

108. For a RESTART problem only thoes control parameters connected with the iterative solution procedure and the form of output should be altered. The remaining Namelist parameters will have been set in the initial run and saved along with the previous results, now attached to logical unit 13.

Node Definition Cards

109. The general card format with which nodes are defined is shown below (Fig 11). The node definition cards are the most complicated of all the data input. Three types of nodes are used in seepage finite element analyses. These are as follows:

1) ordinary nodes,
2) phreatic surface nodes, and
3) pseudo-phreatic surface or linked nodes.

Variations of the illustrated format are used to input data for the different node types. The first column on the card contains a character which identifies the node type.

110. The co-ordinate system to be used for problems is an orthogonal pair of axes in which the x-axis is horizontal, increasing towards the right, and the y-axis is vertical and increasing upwards. For axi-symmetric problems the y-axis is the axis of symmetry and the x-axis values are the radial measurements (Fig 8).

Table 1: $FPM namelist parameter description

Parameter	Type	Default	Description
* IACCEL	integer	1000	do an Aitken acceleration every IACCEL iteration (IACCEL>2)
* IDEBUG(50)	integer	0	debugging codes (see note on following page)
LUIN	integer	5	logical unit for input of nodal and elemental information
* LUPNCH	integer	13	logical unit to which to assign punched output
* MAXIT	integer	1	maximum number of iterations
* NEWNOD	integer	0	if reset to a positive number <NUMNP then it will be the starting node number for internal node renumbering to reduce proble bandwidth
NFLCD	integer	0	number of cards defining the distributed element boundary flow
NPIPE	integer	0	number of elements connecting internal source/sinks to the exterior boundary (see notes on PIPE cards)
NTYPE	integer	0	type of problem 0 - axi-symmetric 1 - planar flow
NUMEL	integer		number of finite elements in prob
NUMFSC	integer	0	total number of phreatic surface
NUMMAT	integer	1	number of materials and soil region lines (see material properties cards)
NUMNP	integer		number of nodal points in problem
* BETA	real	1.0	overrelaxation factor for convergence of phreatic surface
HITE	real	0.0	reference for calculating potenti
QY	real	0.0	vertical infiltration into phreat surface rare
RO	real	1.0	unit weight of fluid
SCALXY	real	1.0	scale factor for nodal co-ordinat
* TOL	real	0.1	tolerance criterion on R.M.S. mov of phreatic surface nodes. Itera cease when this criterion is sati
* BRIEF	logical	.FALSE.	if BRIEF = T, a short form of printout is obtained, without nodal stream function values
ECHOIN	logical	.TRUE.	print out initial node and elemen information
* IFGRAD	logical	.FALSE.	if EFGRAD = T, use nodal fluid pressure gradients in calculating phreatic surface corrections
* NOTNSN	logical	.FALSE.	NOTNSN = T prevents continuity nodes from going into tension
* PRINT	logical	.FALSE.	PRINT = T causes intermediate printout of mesh and nodal pressures between iterations
* PUNCH	logical	.FALSE.	PUNCH = T causes final iteration data to be punched to peripheral unit LUPNCH for subsequent use in a RESTART run

Notes on Namelist $FPM Parameters

IDEBUG - this is an array of 50 integers normally set to zero (0). If individually reset to one (1) then specific processing and debugging information may be printed out. Not all 50 items have assigned purposes. The active parameters are:

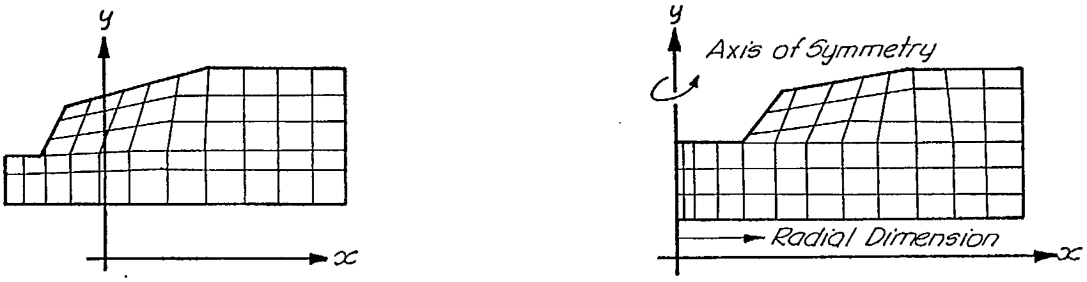
IDEBUG(1) - will print array MESH (in subroutine FORM).
IDEBUG(2) - will print out the fluid flow in each finite element (calculated in subroutine ELFLOW)
IDEBUG(3) - print most of the steps involved in computing the global flow matrix (in subroutine TRIFL)
IDEBUG(4) - print element material type chosen when automatic soil zone location is involved (in subroutine TRIFL)
IDEBUG(7) - print global flow matrix and the RHS vector before and after boundary conditions are applied (in subroutine MODIFY)
IDEBUG(11) - print the re-ordered phreatic surface nodes (in subroutine SORTPS)
IDEBUG(25) - print finite element properties (in subroutine BLDMAT)
IDEBUG(37) - print core addresses (entry points) in the expandable memory portion of the program. (Array C in COMMON block/MATRIX/ in the main routine FEFPM)

NEWNOD - when the value of this parameter is set to a positive number less than or equal to the number of nodes in the problem (NUMNP) then a bandwidth reduction process will be initiated. This bandwidth reduction process takes the node specified by NEWNOD and uses it to start a revised node number sequence that has the minimum bandwidth. This new sequence is completely internal to the FEFPM computer and is not apparent to the user. Note that this sequence may not represent the actual absolute minimum bandwidth but it is likely to be an improvement over that resulting from the input node sequence. For problems that are to be solved iteratively this minimized bandwidth will generally result in less computer time being required for the analysis and thus will be more economic. For large confined flow problems with only one solution iteration it may still prove more economic to minimize the bandwidth than to leave it as originally specified.

The value assigned to NEWNOD should be chosen with care. Suggested nodes to try are those at geometrical extremes (corners) of the finite element mesh.

SCALXY - very often gridded paper is used to draw up finite element meshes. When entering nodal co-ordinates it is then more convenient to use grid square values rather than actual co-ordinate values. In such a case, SCALXY may readily be used to convert input (ie, grid) node co-ordinates to real co-ordinates.

QY - normally in unconfined flow problems the boundary conditions on the phreatic surface are zero fluid pressure and no flow across it. In some cases, though, water, usually resulting from precipitation on the slope surface, infiltrates across the phreatic surface at a known rate. As the location of the phreatic surface changes between iterations equivalent nodal flow rates also change. Thus, if this infiltration was specified by distributed flow cards serious errors in flow quantities could arise at the end of the iterative solution. The FEFPM computer program will calculate the correct phreatic surface node infoltration quantities when QY is specified in the Namelist $FPM cards.



a) Planar Problem

b) Axi-symmetric Problem

Fig 8 - Finite element co-ordinate systems.

111. All phreatic surface nodes must be defined, but ordinary or linked nodes can be automatically generated by defining only the nodes at the ends of a line of sequential nodes (Fig 9). Note that the example shown in Fig 9 indicates that the nodes are equally spaced. This node generation line has a geometric progression ratio for node spacing of 1.0. It is possible to vary the spacing of the line using a non-unitary geometric progression ratio (RGP) as shown in Fig 10. The ratio of the distance between successive nodes is the geometric progression ratio. This ability to generate non-equally spaced nodes can reduce the amount of time required to code nodal input

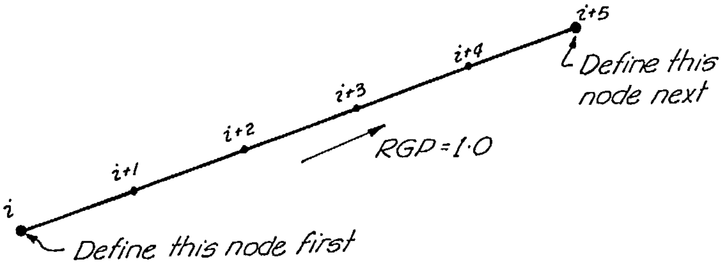


Fig 9 - Simple node generation.

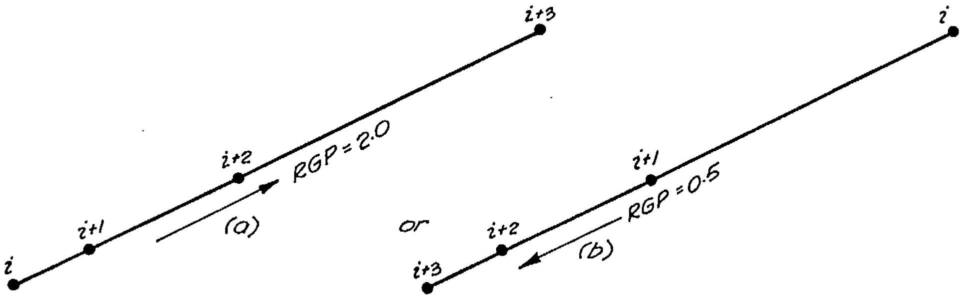
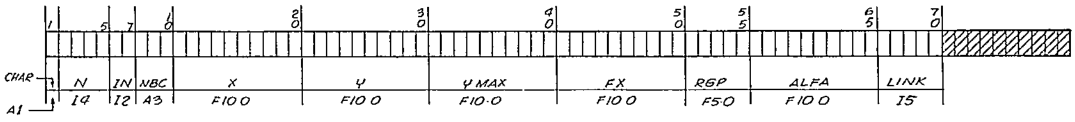


Fig 10 - Node generation with non-unitary geometric progression ratios.

data for a problem. In most problems the geometric progression ratios used to generate nodes should be limited to the range of 0.8 to 1.25 to maintain reasonably shaped and sized finite elements.

112. When nodes on finite element mesh boundaries are generated, the variation of the boundary condition values must follow in a similar manner. Note 1 of Fig 11 contains full details on the ways in which boundary conditions can be generated.

Node Definition Cards.



CHAR - node type identifier - "blank" indicates an ordinary node
* is used to define a phreatic surface node
L is for a pseudo-phreatic or linked node
N - node number
IN - boundary condition generation code (see Note 1)
NBC - boundary condition code (see Note 1)
X,Y - nodal co-ordinate values
YMAX - upper bound for movement of a phreatic surface node (see Note 2)
FX - boundary condition value
RGP - geometric progression ratio for generation to next defined node
ALFA - is the correction direction for phreatic surface nodes (default = 90°) (see Note 2) and fractional movement coefficient for pseudo-phreatic nodes (default = 1.0) (see Note 3)
LINK - is the phreatic surface node to which pseudo-phreatic nodes are linked (see Note 3)

Notes on Node Definition Cards

1. Boundary condition codes and generation characteristics.
   - as outlined previously in the finite element theory section, sufficient boundary conditions must be applied to the mesh to permit solution for the flow characteristics. Four variations of boundary conditions are possible for unconfined flow problems. These boundary conditions are always applied at nodes, and their type is indicated by the variable NBC on the node definition card.
   - for a node with known fluid pressure (Pressure Node), set NBC = "ƀƀP", ie, place a P in column 10, and set FX = fluid pressure.
   - for a node with a known fluid influx (Continuity Node) set NBC = "ƀƀQ", ie, place a Q in column 10, and set FX = the flow influx (make FX negative if flow is out of the mesh). Most nodes in a finite element mesh will have zero influx but will still be in this category. If flow rates across a boundary are known, use distributed inflow cards to provide details of flow quantities.
   - phreatic surface nodes are defined completely by the character in the first column and thus NBC should be left blank or zero.
   - a special feature in the FEFPM program allows nodes to be set at the same fluid potential function value, which will be determined at part of the solution. To do this select one node (I) to which others will be referenced, then when one of these other nodes is defined set NBC = I on the data card. This feature is very useful when defining nodes along a well (see sample problem no. 2). The boundary condition value FX is ignored for this case.
   - boundary conditions and values can be generated along with the nodes. However, boundary condition generation must follow one of six possible forms (specified by the boundary condition generation code IN on the node definition card) as indicated in the table below.

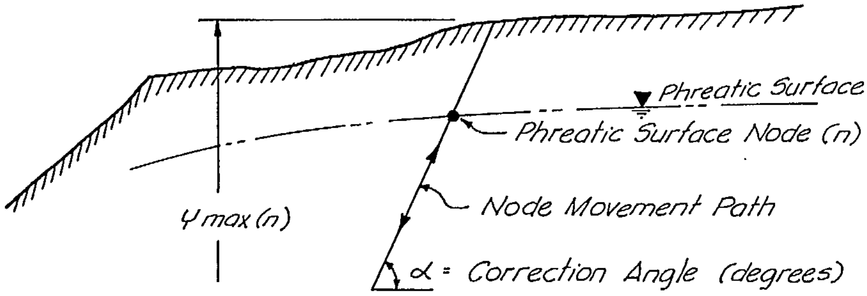
Boundary condition generation codes

Conditions assigned to generated nodes.

IN	Type (NBC)	Value (FX)
-1	NBC(n)	0.0
0	"Q"	0.0
1	NBC(n)	Linearly varying between specified values at the end of the line.
2	NBC(n)	Linearly varying from FX(n) to 0.0 at the end of the line.
3	NBC(n)	Linearly varying between specified values at the ends of the line. However, if the line distorts, the gradient of FX along the line is held constant, and values are generated from FX(n).
4	NBC(n)	Linearly varying as for IN = 3 but values are generated from the other end of the line if the line distorts.

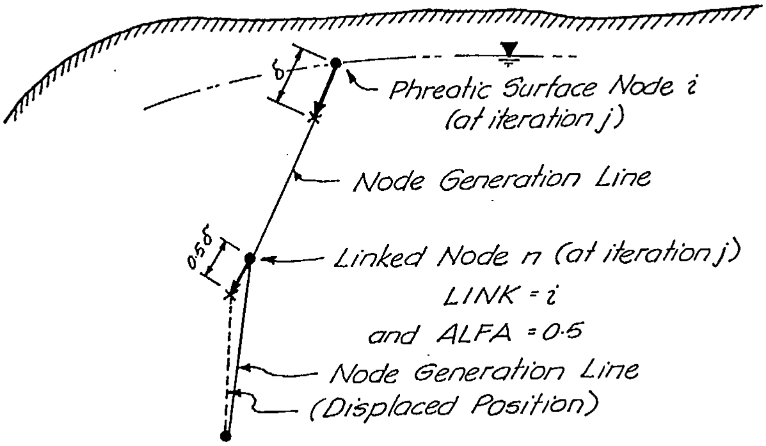
Fig 11 - Node definition cards.

2. Phreatic surface node movement directions and limits (see diagram).
   - each phreatic surface node should have a correction direction assigned and also a limit to ensure that the flow regime stays within the slope profile.



   - note if the correction angle (α) is not specified it is set so that the node movement is vertical (ie, α = 90°).

3. Pseudo-phreatic surface or linked nodes.
   - linked phreatic surface nodes are used principally to prevent severe mesh distortion during iterative solutions of unconfined flow problems. This is illustrated in the diagram below.



   - in the above figure, node n is linked to phreatic surface node i and is to have half the movement of i during each iteration. If ALFA had not been specified it would have been defaulted to 1.0 and thus node n would then have the same movement as node i.

Fig 11 (cont) - Node definition cards.

Ordinary Node Definition

- Ordinary nodes are all nodes which are not phreatic surface or pseudo-phreatic surface card column blank.
- The following parameters are to be input:
  - the node number (N)
  - the boundary condition generation code (IN)
  - the boundary condition code for the node (NBC)
  - the co-ordinates of the node (X,Y)
  - the boundary condition value (FX)
  - the geometric progression ratio for distances

between nodes to be generated (RGP)

Phreatic Surface Node Definition

- Phreatic surface nodes define the upper limit of the groundwater regime for unconfined flow problems. The final location of the phreatic surface will be computed during the iterative procedure. Phreatic surface nodes are indicated by punching an asterisk '*' in the first column of the card.
- The following parameters are to be input:
  - the node number (N)
  - the co-ordinates (X,Y)
  - the upper bound for phreatic surface movement (YMAX)
  - the correction direction for node movement (ALFA) (angle in degrees measured counterclockwise from the x-axis)

Pseudo-Phreatic Surface or Linked Node Definition

- Pseudo-phreatic surface or linked nodes are nodes which are constrained to move in concert with specified phreatic surface nodes to prevent severe mesh distortion in unconfined flow problems. Linked nodes are identified by punching L in the first column of the card.
- The following parameters are to be input:
  - the node number (N)
  - the boundary condition generation code (IN)
  - the boundary condition code for the node (NBC)
  - the coordinates of the node (X,Y)
  - the boundary condition value (FX)
  - the geometric progression ratio for subsequent node generation (RGP)
  - the correction distance factor (ALFA), and
  - the phreatic-surface node that this node is linked to (LINK)

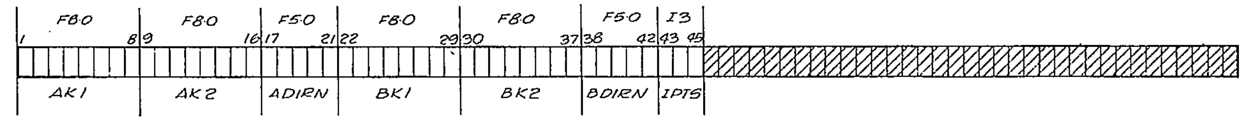
Material Definition Cards

113. The material definition cards define both the properties and the locations of the various material zones. The various card formats used to input material properties and locations are shown in Fig 12.

114. Individual finite element material types can be defined in one of two ways, ie,

1. by explicitly coding a material type number (MAT) on the element definition card, or
2. by having the FEFPM program do an automatic search through defined material zones and lines to find the applicable material type for the

MATERIAL DEFINITION CARDS



Each card represents the boundary between two materials where

AK1 - maximum permeability just above the line
AK2 - minimum permeability just above the line (if left blank it will be set equal to AK1)
ADIRN - counterclockwise direction (degrees) from the X axis to the maximum permeability above the line

BK1, BK2, BDIRN - as above for just below the line

IPTS - 0 no points entered, line is set to default values and all elements not defined by any other line will have the just above the line properties
<0: the next card(s) contains the X, Y co-ordinates of the co-ordinate locations defining the boundary
>0: the next card contains IPTS node numbers for nodes defining the boundary

Fig 12 - Material definition cards.

MATERIAL ZONE OR LINE DEFINITION CARDS (by co-ordinate locations)
Input only if IPTS is set negative

F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0
1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 80
XLIN(1)	YLIN(1)	XLIN(2)	YLIN(2)	XLIN(3)	YLIN(3)	XLIN(4)	YLIN(4)

- Up to 14 co-ordinate locations may be used to define a material zone or line. To define a zone, ie, a closed loop, the first and last co-ordinate locations entered must be the same.
- Enter /IPTS/ co-ordinate locations in X,Y pairs as indicated above. Use as many cards as required up to a maximum of 4.

MATERIAL ZONE OR LINE DEFINITION CARDS (by defined nodes)
Input only if IPTS is set positive

I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	I5	
1 5	6 10	11 15	16 20	21 25	26 30	31 35	36 40	41 45	46 50	51 55	56 60	61 65	66 70	▨
NODES(1)						NODES(7)							NODES(14)	

- Up to 14 nodes may be used to define a material zone or line. To define a zone, ie, a closed loop, the first and last nodes entered must be the same.
- Enter IPTS node numbers starting from the left of the card.

Fig 12 (cont) - Material definition cards.

element centroid.

115. Material type numbers are not defined explicitly on the material definition cards but are generated in the order in which they are placed in the input card deck. Care must be exercised when coding data and setting up card decks to ensure that the material definition cards are sequenced correctly.

116. The location of a particular material is defined by a series of connected line segments in the plane of the mesh. If the series of lines forms a closed loop, then all the material enclosed within the loop is considered to be the material zone. The points defining the ends of the line segments may be referenced as either:

1. finite element mesh nodes (original locations for moving phreatic surface problems), or
2. co-ordinate locations input as part of the material definition data.

Different input card formats exist for the alternate definitions of material zone or line segments.

117. All materials defined for the FEFPM computer program are defined in terms of lines to which values of permeability are set for just above and just below the line. If a line is not explicitly defined for a material type, then the FEFPM program generates a line composed of three segments as shown in Fig 13. Any element in the

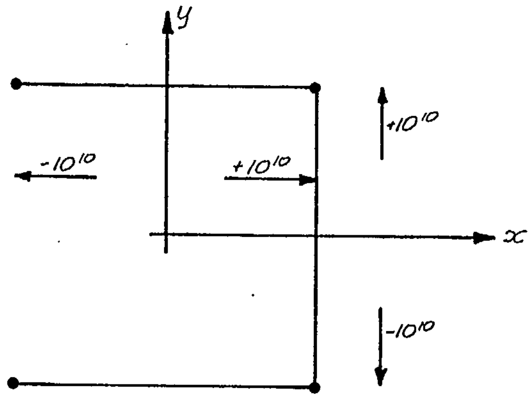


Fig 13 - Default material definition line.

mesh which is then not explicitly typed or defined by a material line or zone will have the material properties defined as those just above the default line. Thus, if there is only one material involved in the finite element mesh, a single card with the maximum permeability, AK1, the minimum permeability, AK2, and direction, ADIRN, for anisotropic problems is needed.

118. It is possible to define different material properties for just above and just below the line. This feature is very useful when a line represents the boundary between two different geological materials. The following conditions apply when the FEFPM computer program searches for material types:

- if the element centroid is found to lie within a material definition loop, then the material properties used are those that were set for just above the line. If it lies within more than one loop then the closest loop is selected.
- if the element centroid is found to lie between two material definition lines then the material properties are linearly interpreted from those set just above the closest line segment directly below and those set just below the closest line segment directly above the point. Any ambiguities about the closest line segment are settled by setting the lower sequences lines above the others.
- if the element centroid is found to lie below the lowest line, the material properties set just below the line are used.
- if the element centroid lies above the highest line, an error message is printed and FEFPM program execution is terminated.

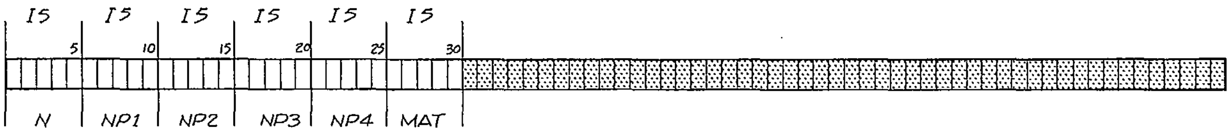
119. Users should be careful about mixing line and zone definitions for material properties. Wherever possible, it is recommended that the zone definition be used throughout a problem in which automatic material searching will be required.

Element Definition Cards

120. Figure 14 illustrates the format of the element definition cards. The data required to define a finite element are essentially the nodes at the corners, and the material type. As indicated below, element nodes are entered as they occur in clockwise order about the centroid of the element. If the material type is not defined, an automatic soil zone search will be initiated to determine the zone in which the element centroid lies.

121. Element input data may be automatically generated by the FEFPM program. For element data generation, the general requirement is that if a string of elements lies between two lines of sequenced nodes, as shown in Fig 15, then only the

Element Definition Cards



N	is the element number. Element cards must be entered in ascending order. The first and last elements must have cards. Elements which are not defined will be generated from the previous element by increasing all node numbers by 1. The material properly typed MAT will be unchanged.
NP1, NP2, NP3, NP4	are the nodes, in counterclockwise order. For triangular elements set NP4 blank.
MAT	is the material number for the element. If zero or blank, the appropriate material will automatically be selected, based on the soil zone in which the element centroid lies.

Fig 14 - Element definition cards.

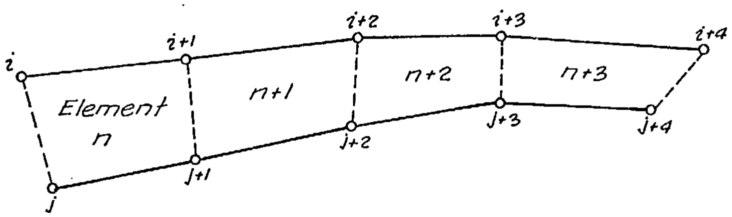


Fig 15 - Element generation procedure.

first element in the sequence need be coded.

122. Element data generation is accomplished by incrementing the element number and all attached node numbers by 1 until the end of the string is reached. The material type number remains unchanged throughout this operation. Refer to the sample problem data input lists for examples of element generation.

Distributed Boundary Inflow Cards

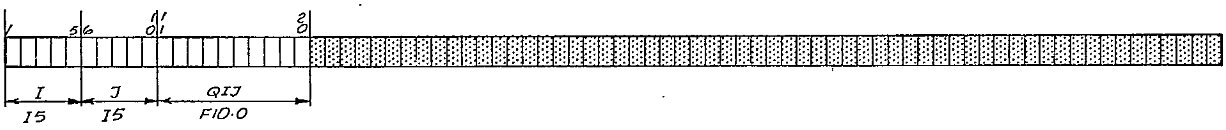
123. Figure 16 illustrates the format used for distributed boundary inflow cards. Distributed inflow occurs when fluid is injected or pumped along a boundary of a seepage element area. Most of the distributed boundary inflow occurs along the top surface of the problem area due to infiltration of precipitation. This is in contrast to a problem in which a defined rate of fluid influx or efflux can be assigned to a particular node. In the case of distributed boundary inflow, rates of flow per unit area are known and the FEFPM computer program calculates equivalent nodal flow rates by integrating the unit area flow rates over the appropriate boundary surface area. For planar problems, a unit thickness is assumed for the mesh while for axi-symmetric problems, the boundary surface area corresponds to a one-radian sector (Fig 17).

124. The number of distributed boundary inflow cards to be read is specified by the parameter NFLCD set with the Namelist $FPM cards.

Pipe Cards

125. Figure 18 illustrates the format used for pipe element definition cards. Pipe cards must be input if flow sources or sinks exist within the body of the finite element mesh. The stream function can only be calculated for problems having a single outer boundary in the topological sense. Thus if an internal boundary exists, it must be connected to the outer boundary. This is accomplished for the FEFPM computer program by specifying a string of elements that connect the internal source or sink to the external boundary. Figure 19 illustrates this procedure for a problem in which an adit serves as a flow sink. Up to 16

DISTRIBUTED BOUNDARY INFLOW CARDS (Format - 2I5,F10.0)



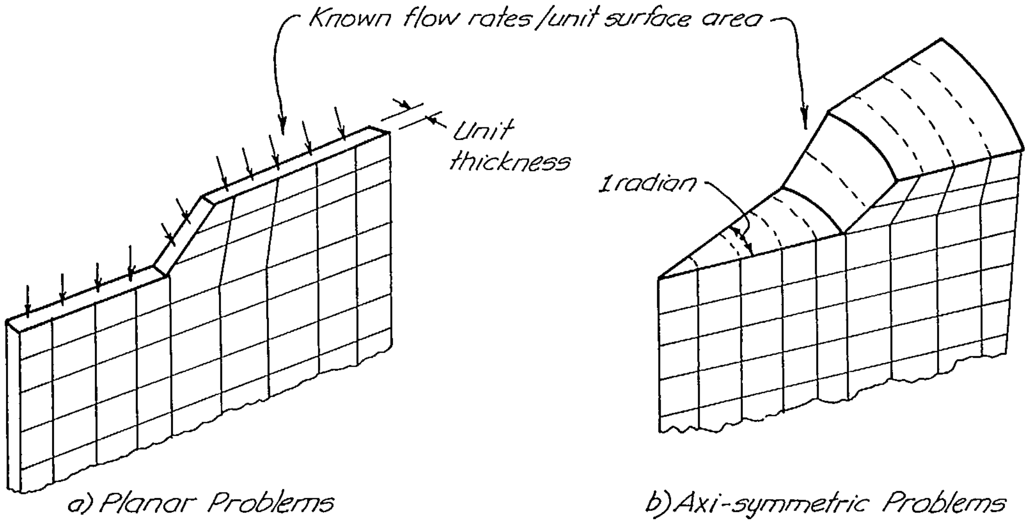
I - Nodal point I

J - Nodal point J

QIJ - Fluid flow across boundary I-J. Flow/unit area.
- if QIJ > 0 - QIJ represents a flow influx.
- if QIJ < 0 - QIJ represents a flow efflux.

Note For steady-state solutions, flows across the phreatic surface must be input as a distributed boundary flow.

Fig 16 - Distributed boundary inflow cards.

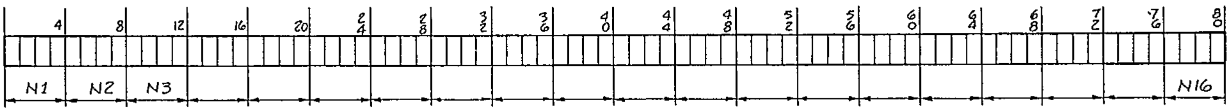


a) Planar Problems

b) Axi-symmetric Problems

Fig 17 - Boundary surface areas.

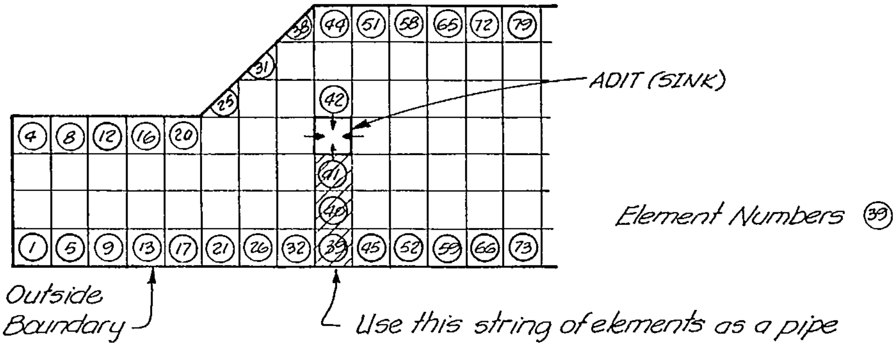
Pipe - card. Only submitted if NPIPE>0.



The terms N1-N2 .... (NPIPE terms) are element numbers in a string that connects the internal source/sinks to the boundary. The stream-function Ψ will be discontinuous across this line of elements.

Up to 16 element numbers may be input per card. Use as many cards as required to input NPIPE numbers.

Fig 18 - Pipe card - only submitted if NPIPE > 0.



The 'pipe' element string is then ㊴→㊵→㊶
and NPIPE = 3

Fig 19 - Pipe elements.

pipe elements can be listed per pipe card.

Input Data Card Sequence

126. The card sequence must permit the following machine actions.

a. read one card
  - if it is a START card, go to b
  - if it is a RESTART card, go to l
  - if it is a STOP card, terminate execution
  - otherwise, print the card and read next card
b. read $FPM cards
c. read node cards
d. read material cards
e. read element cards
f. read any distributed inflow cards
g. read a pipe card if required
h. do a steady-state solution
i. read a pipe card if required
j. do a steady-state solution
k. go to a
l. read in the checkpoint file produced by an earlier run
m. read any changes to the $FPM Namelist
n. go to h.

Program Options

127. The only options available are those set by the NAMELIST parameters.

Sample Runs

128. Appendix A gives the input data and results for three sample runs.

SYSTEM DOCUMENTATION

Computer Equipment

129. FEFPM, as modified for CANMET, runs on a CDC 6400 with card reader, line printer and tape drive.

Source Program

130. A source deck on magnetic tape is obtainable from: Mining Research Laboratories (Pit Slope Group), CANMET, Energy, Mines and Resources Canada, 555 Booth Street, Ottawa, Ontario, K1A 0G1, Canada.

Storage Requirements

131. The following are the core storage requirement on the CDC 6400 (see list of subroutines below).

	bytes:	words:
Main program FEFPM	3637	1951
	14307 (buffers)	6343
CONTROL,SLINES,ELMT labelled common	2712	1482
216-142 1260 BO		
blank common	1	1
BLKBLK common area 62 - 50		
TIME 1-1 Function NCORE	13	11
MESHIN	2263	1203
RENUM	730	472
SORTPS	310	200
FORM	2412	1290
GETFLO	130	88
SETNOT	256	174
BLDMAT	765	501
BMULT	114	76
DECOMP	635	413
FINDCN	134	92
GRADNT	172	122
MODIFY	503	323
TRIFL	506	326
ELFLOW	1072	570
FIX	41	33
SZONE	165	117
CROSS	50	40
EXTINT	1177	639
WRMESH	3y0	248
BLK	6747	3559
GBTTL	1070	568
(not used) MCORE	32	26
LCORE*	14	12
SYFDBN	103	67
TOD	243	163
ETIME*	10	8
ETIMEF*	14	12
ERTRAN*	20	16
NTRAN*	2061	1073

Compass:			
	FLD*		7
	SETFLD*		11
	FLDLNTH*		11
		451	297
	Totals:	44408.	24078.

Main Program FEFPM

132. The main program is used to:

a. control the data input, analysis and output sections of the system

b. allocate central memory (core) locations as required

c. increase as well as decrease central memory core size as required

d. assign temporary scratch files (logical units 14 and 15).

Common Block Allocation

133. This main program when compiled automatically includes the labelled CØMMØN blocks/ CØNTRL/,/SLINES/ and /ELMT/ as outlined in detail in the documentation for the procedural element PDPFPM.

134. In addition, the labelled CØMMØN block /MATRIX/ is allocated only in the main program. It is the array C in this block which is expanded and contracted as required to provide the correct amount of memory for a particular problem.

135. COMMON BLØCK MATRIX contains the expanding array C used to store the bulk of the data in FEFPM. Each section of data is defined by its starting location value, as listed in Table 2.

Internal Calls

136. As this is the main routine many calls are made to subroutines and functions. It must be noted that all references to array storage locations in array C of the labelled CØMMØN block /MATRIX/ are made through defined starting locations passed in individual subroutine argument lists. See Subroutine list below.

Sequence of Steps

1. Various FEFPM parameters are initialized.
2. The problem title is read from cards and the problem keyword is decoded.
3. The appropriate title and run description is printed (CALL GBTTL).
4. The namelist $FPM is read from cards.
5. The element information block handling routine is initialized (CALL BLK).
6. According to the parameters read in through the namelist $FPM, the entry points and lengths for the various arrays required are calculated using internal function NCØRE.
7. The array C in common block /MATRIX/ is expanded (CALL MCØRE).
8. The node, element and material data is read in and a finite element mesh generated and checked (CALL MESHIN).
9. The nodes are renumbered to minimize the problem flow matrix bandwidth (CALL RENUM).
10. The nodal and elemental connectives are determined (CALL EXTINT).
11. The phreatic surface nodes are sorted (CALL SØRTPS).
12. The required core storage (size of array C) is checked and increased CAS002.
13. The scratch drum file, logical unit 14, for element information blocks is allocated.
14. The elemental and problem flow matrices are set up and solved iteratively, if necessary (CALL FØRM).
15. If requested, all problem data is written to the punch file (LUPNCH).
16. The matrix C is reduced to its minimum amount (CALL LCØRE).

137. Minor variations in the above sequence occur if the problem to be analyzed is a RESTART from a previous run.

Common Block Variables

CØMMØN BLØCK - CØNTRL

GFEFPM

program description - ('GFEFPM')

HED(18)

title of problem

NUMNP

number of nodal points

NUMEL

number of elements

NUMMAT

number of soil region lines (not to exceed 30)

NUMFSC

number of phreatic surface cards

NDMP

errør return variable

RØ

unit weight of fluid

BETA

Table 2: Location of variables in common block/MATRIX/

Starting location	Length		Description
N2	NUMFSC	NPFS	- phreatic surface nodes - contiguously sorted from end to end
N222	NUMFSC	MPFS	- phreatic surface nodes as entered
N3	NUMFSC	ALPHA	- the correction direction for phreatic surface nodes (measured counter-clockwise from x-axis)
N33	NUMFSC	YMAX	- upper limit for y values for phreatic surface nodes
N34	NUMFSC	ICØDFS	- phreatic surface node codes
N4	NUMNP	MESH	- input nodal numbers
N41	NUMNP	NEWNUM	- new internal node numbers
N5	NUMNP	X	- x coordinates of node points
N6	NUMNP	Y	- y coordinates of node points
N7	NUMNP	NBC	- boundary condition codes
N8	NUMNP	FX if	- function determined by NBC NBC = 0 FX = net nodal inflow NBC = 1 FX = pressure NBC < 0 FX = same potential as the linked node /NBC/
N81	NUMNP	R	- solution vector
N82	NUMNP	PSI	- flow function
N93	NUMNP	SCR	- scratch array
N96	NUMNP	PRESS	- fluid pressure at nodes
N99	$\frac{\text{NUMNP}+35}{36}$	ZERØP	- flags for no tension (NO TNSN controlled)
N10	5*NUMEL	NP NP(1,I) NP(5,I)	- element array - NP(4,I) - nodes forming the element - soil associated with element
* N122	$\frac{\text{NUMNP}+35}{36}$	NØDFLG	- flags to indicate if node is exterior (1) or interior (0)
N124	NPIPE	IPIPE	- pipe elements
* N12	3*NUMNP	NRAYS (3,1)	- node indexes connected to each node
* N13	2*NLS	LNESEG(2,1)	- line segments and related elements
N14	NUMNP*MAXBAN	C) Last wørd of C)	Flow matrix

correction factor

HITE
reference for potentials

T/L
error tolerance

MAXIT
maximum number of iterations

MAXMSH
number of node cards read

NFLCD
number of cards defining boundary flows

PI
constant (3.1415926/180.0)

MAXBAN
maximum bandwidth

IFGRAD
logical variable indicating use of phreatic nodal pressures in calculating corrections

PUNCH
logical variable - output to be punched upon completion of the job

LUPNCH
logical unit for output

IACCEL
no. of steps between Aitken accelerations

QY
vertical infiltration rate into phreatic surface

LUIN
logical unit of input

ECHOIN
logical variable signalling a printout of input mesh data

SCALXY
scale factor applied to x and y coordinates after input (note: this does not apply to soil zone boundaries)

PRINT
logical variable signalling intermediate printout between iterations

NUMIT
number of the current iteration

BRIEF
logical variable signalling a short form of output is desired (no flow function data)

ROOF
Not used.

IFEXT
logical variable signalling the use of 'EXTINT'

NOTNSN
indicator to prevent continuity nodes from going into tension

N41
entry point (in MATRIX) for internal node numbers (NEWNUM)

N99
entry point for the flags which indicate a node is being held at zero pressure to satisfy the no tension criterion

N81
entry point for R - solution vector

N82
entry point for PSI - the flow function

N2
entry point for NPFS - the phreatic surface nodes as input

N222
entry point for MPFS - the phreatic surface nodes as returned from SORTPS - contiguous from one end to another (there may be a problem if SORTPS - contiguous from one end to another (there may be a problem if SORTPS tries to sort more than one phreatic surface)

N61
entry points for Z - coordinates

NTYPE
indicator of problem type - 0 Axisymmetric flow
- 1 Plane flow

N3
entry point for ALPHA

N33
entry point for upper limits on Y values

N4
entry point for MESH - nodal numbers of input nodes

N5
entry point for X coordinates

N6
entry point for Y coordinates

N7
entry point for NBC - boundary condition code

N8
entry point for FX where FX is determined by NBC eg, NBC = 0 NBC eg,

NBC = 0 FX = not nodal inflow (continuity)
NBC = 1 FX = pressure
NBC = < 0 same potential as linked node

N93
entry point for the scratch array (SCR)

N96
entry point for the pore pressure array PRESS

N10
entry point for NP - element nodal conductivity and material

N122
entry point for N0DFLG, the array which indicates if a node is on the boundary

N123
not used

N124
entry point for array of elements which form a pipe and are not used in computing the flow function

N12
entry point for NRAYS - returned from EXTINT

N13
entry point for LNESEG - returned from EXTINT

N14
entry point for flow matrix C

N16
last word in matrix C

NLS
number of line segments

NPIPE
number of pipe elements

IDEBUG(50)
debugging codes

XXX
dummy variables

C0MM0N BL0CK - SLINES (MATERIAL PR0PERTIES BL0CK - up to 30 different material types allowed)

LPTS (30)
number of points defining material region

IL00P (30)
logical variable

IL00P (30)
true if the points form a closed loop

XLIN (14,30)
x-coordinates of points on region lines

YLIN (14,30)
y-coordinates of points on region lines

AK1 (30)
maximum permeability above region line

AK2 (30)
minimum permeability above region line

ADIRN (30)
counterclockwise direction from the x-axis to the maximum permeability above the region line

AK11 (30), AK12 (30, AK22 (30)
permeabilities in the x-y coordinate system above the region line

BK1 (30)
maximum permeability below the region line

BK2 (30)
minimum permeability below the region line

BDIRN (30)
counterclockwise direction from the x-axis to the maximum permeability below the region line

BK11 (30, BK12 (30), BK22 (30)
permeabilities in the x-y coordinate system below the region line

C0MM0N BL0CK - ELMT

(common block retaining data to the current element)

XX (5)
element's nodal x-coordinates

YY (5)
element's nodal y-coordinates

S (5,5)
element flow matrix

GG (5)
initial R.H.S. for flow equation

FLOW (6,4)
real nodal flows

XCENT (4)
x-coordinates of centroid

EPRESS (5)
element nodal pressure

IS0IL
soil type

NELT
element number

Subroutines and Functions

138. Due to the conversion of this program some confusion may exist in the use of the term "field

length".

139. Field length is used on control data systems to describe the size of central memory required to run a program. The subroutines CAS002 and FLDLNTH are concerned with evaluating and setting memory size, and refer to this as the field length, the functions (or subroutines) FLD and SETFLD are converted from or used in conjunction with the UNIVAC 1100 series function FLD, a bit manipulation function. The 'field length' described here is the number of bits in a word. Neither of these is the usual use of the word "field", meaning a subset of a computer record.

140. Below are listed the subroutines called by the main program and other subroutines. Those marked with a ✓ use routines written in Assembler (Compass) or use CDC functions. Those marked * use ENCODE or DECODE.

FEFPM
calls: FLD (compass)
NTRAN (FORTRAN with intrinsic CDC routines)
CAS002 (EMRLIB, compass)
SETFLD (compass)
BLK✓
GBTTL✓
MESHIN*✓
REMI✓
SORTPS
EXTINT✓
FORM✓
NCORE
LCORE✓
PAGBA(GBTTL)✓

MESHIN*✓
calls: ETIMEF✓
WRMESH✓
BLKOUT(BLK)✓
PAGBA(GBTTL)✓

RENUM✓
calls: FLD
SETFLD
ETIME✓
ETIMEF✓

SORTPS
calls: FINDCN✓

FORM*✓
calls: FLD
SETFLD
ELFLOW✓
ETIMEF✓
GRADNT
PAGBA (GBTTL)✓
SETNOT✓
BLDMAT✓
DECOMP
ETIME✓
FINDCN✓
GETFLO
MODIFY✓
SUBST (DECOMP)
WRMSH (WRMESH)✓

GETFLO
calls: BMULT

SETNOT✓
calls: FLD
SETFLD

BLDMAT✓
calls: BLKOUT (BLK)✓
ETIMEF✓
ETIME✓
TRIFL

BMULT
calls: None.

DECOMP
FORTRAN library only

FINDCN✓
SETFLD

GRADNT
FORTRAN library only

MODIFY✓
- FLD

TRIFL
- SZONE

ELFLOW✓
- FLD
- DECOMP
- ETIMEF✓
- BLKIN (BLK)✓
- ETIME✓
- FIX
- PAGBA (GBTTL)✓
- SUBST (DECOMP)

FIX
- None

SZONE
- CROSS

CROSS

EXTINT✓
- FLD
- SETFLD

WRMESH✓
- PAGBA (GBTTL)✓

BLK✓ uses CDC BUFFER statement
- NTRAN
- FLD
- SETFLD
- EXIT

GBTTL✓
- ERTRAN
- SETFLD
- FLD

MCORE (not used)
- FLDLNTH
- LOCF

LCORE✓
- FLDLNGTH
- LOCF

SYFDBN✓
- FLD

TOD✓
- FLD
- ERTRAN
- SETFLD
- ABORT✓
- SYFDBN✓

ETIME✓
- SECOND (CDC intrinsic function)

ETIMEF✓
- SECOND

ERTRAN✓
- DATE } CDC intrinsic functions
- TIME }

FLD✓
- Compass routine

SETFLD✓
- Compass

FLDLNTH
- Compass - same as CAS002

NTRAN*
- BUFFER IN and BUFFER OUT } CDC FORTRAN functions
- READMS
- WRITEMS
- LENGTH
- OPENMS
- UNIT

Subroutine: MESHIN

PURP0SE

Subroutine MESHIN is used to read all input data describing the problem finite element mesh configuration.

CALLING SEQUENCE

CALL MESHIN (NPFS, ALPHA, YMAX, MESH, X, Y, NBC, FX, NP, PRESS, IPIPE, Z, IC0DFS).

DESCRIPTI0N OF ARGUMENTS

NPFS(1): Integer array - Phreatic suface nodes.

ALPHA(1): Real array - Correction directions for phreatic surface nodes.

YMAX(1): Real array - Upper limit for y-values of phreatic surface nodes. (To ensure that the phreatic surface remains within the bounds of the continuum).

MESH(1): Integer array - Node numbers as input.

X(1): Real array - x-coordinates of nodal points.

Y(1): Real array - y-coordinates of nodal points.

NBC(1): Integer array - Nodal boundary condition codes.

FX(1): Real array - Nodal function value.

NP(5,1): Integer array - Element node and material type array.

PRESS(1): Real array - Nodal fluid pressures.

IPIPE(1): Integer array - Pipe elements used in calculation of stream function for problems with a source or sink within the mesh.

Z(1): Real array.

IC0DFS(1): Integer array - Phreatic surface node codes.

C0MM0N BL0CK ALL0CATION

When compiled, this routine automatically includes the labelled C0MM0N blocks /C0NTRL/, /SLINES/ and /ELMT/ as outlined in COMMON blocks.

INTERNAL CALLS

See Subroutine list.

SEQUENCE OF STEPS

1. Read node information and generate intermediate nodal data if required.
2. Print complete nodal information (CALL WRMESH).
3. Read material properties information (including zone descriptions).
4. Print material properties data.
5. Read and write element information. Generate and write intermediate elements if required. Write out element information blocks to element file (CALL BLK0UT).
6. Read and write distributed flow input data.
7. Read and write phreatic surface nodal data.
8. Read and write pipe element data.
9. Return to calling program.

Subroutine: RENUM

PURPOSE

To renumber the nodal points in a finite element mesh to give a reduced problem bandwidth.

CALLING SEQUENCE

CALL RENUM (NUMEL, NP, NEWNUM, NC0NS, IAVAIL, IHAVE, MEMJTX, NUMNP, KNEXT, MAXBAN, NBC).

DESCRIPTION OF ARGUMENTS

NUMEL: Integer - No. of finite elements in mesh.

NP(5,1): Integer array - Elemental nodal points and material type numbers.

NEWNUM(1): Integer array - Elemental nodal points and material type numbers.

NC0NS(1): Integer array - Scratch area (no. of node connections per node).

IAVAIL(1): Integer array - Scratch area (availability, numbers for a node).

IHAVE(1): Integer array - Scratch area (renumbered nodes).

MEMJTX(1): Integer array - Scratch area (nodes connected to a node).

NUMNP: Integer - No. of nodal points in mesh.

KNEXT: Integer - The number of the node from which the renumbering process is to start.

MAXBAN: Integer - Maximum half-bandwidth of renumbered finite element mesh.

NBC(1): Integer array - Nodal boundary condition indicators.

INTERNAL CALLS

See Subroutine list.

SEQUENCE OF STEPS

1. Set up arrays NO0NS and MEMJT for all nodes as

follows:

a. NCØNS (I) is the number of nodes (included linked nodes) that are connected to node I.

b. MEMJT (J,I) is the Jth node connected to node I. Three node numbers are packed into each word of this array and a maximum of 30 nodes can be connected to any one node.

2. The availability numbers of all nodes are initialized to indicate that these nodes have not yet been renumbered:
   IAVAIL(I) = -NCØNS(I) - 100,000
3. If KNEXT (the starting node number) is less than or equal to zero, then return to the calling program.
4. Start the numbering procedure with node KNEXT. Set IHAVE(1) to KNEXT and change IAVAIL) of all the nodes connected to KNEXT to indicate that they should have priority in renumbering - IAVAIL(J) = -50 -NCØNS(I)
   Note that the availability numbers for nodes connected to node KNEXT are much greater than for unconnected nodes.
5. The only nodes considered for renumbering at this stage are those connected to KNEXT. Find the neighbour with the highest availability number. In case of a tie, pick the neighbouring node first encountered in the search. Assume it is node J, set the neighbour's availability number to zero and set IHAVE(2) to J. Then reset the availability numbers of all the unrenumbered nodes connected to J as:
   IAVAIL(K) = -50*(2) -NCØNS(K)
   Note that these availability numbers for nodes connected to new node 2 are less than those for new node 1.
6. Continue finding the neighbours of KNEXT (new node 1), renumbering them, resetting IAVAIL for the node found and making IHAVE for the node equal to INEXT, where INEXT is the next sequence number in the new node array. Then reset the availability numbers for each of the unrenumbered nodes connected to INEXT as:
   IAVAIL(L) = -50*INEXT -NCØNS(L)
7. When all neighbouring nodes for node KNEXT have been found, move on to newnode 2 and repeat the process outlined in step 6.
8. Repeat step 6 for each renumbered node until all nodes have been renumbered.
9. Transfer contents of IHAVE scratch array to NEWNUM array.
10. Return to the calling program.

Note:

The basic node renumbering algorithm can be described simply as:

Number from the earliest renumbered node which has unrenumbered neighbours.

Number to the neighbour who is connected to the earliest other renumbered node. In the case of a tie number to the neighbour found first.

Subroutine: SØRTPS

PURPOSE

SORTPS is used to sort phreatic surface nodes into a contiguous sequence from end to end.

CALLING SEQUENCE

CALL SØRTPS (NPFS, MPFS, NUMFSC, ALPHA, LNESEG, NLS, NBC, IDEBUG, YMAX, ICØDFS)

DESCRIPTION OF ARGUMENTS

NPFS(1): Integer array - Output sorted phreatic surface node array.

MPFS(1): Integer array - Input phreatic surface node array.

NUMFSC: Integer - Number of true plus dummy phreatic surface nodes in set.

ALPHA(1): Real array - Nodal correction direction array (sorted when output).

LNESEG(2,1): Integer array - Double dimensioned array containing indices of the nodal points defining each line segment present within the set of elements, along with the indexes to the elements to which they are common.

NLS: Integer - Number of line segments in finite element mesh.

NBC(1): Integer array - Array of nodal boundary condition indicators.

IDEBUG: Integer - Debug flag (pIDEBUG(11) from main program). If set >0 will cause SØRTPS to print out contents of NPFS array after sorting.

YMAX: Real array - Array of maximum permitted y-coordinates for phreatic surface nodes (sorted when output).

ICODFS(1): Integer array - Array containing indicator flags for phreatic surface nodes.

If ICØDFS (i)

= 0 - true phreatic surface node

> 0 - then ICØDFS(i) is the node to which the pseudo phreatic surface node is linked.

(Sorted when output)

INTERNAL CALLS

SØRTPS calls subroutine FINDCN.

SEQUENCE OF STEPS

1. Transfer the contents of the NPFS array to the MPFS array.
2. Search the MPFS array until a true phreatic surface node is found with only one connecting line segment. This node is then one end of the phreatic surface and is placed at the beginning of the MPFS array.
3. Search the MPFS array for the true phreatic surface node connected to the last one found. Move it to the appropriate location.
4. Repeat step 3 for all true phreatic surface nodes.
5. All pseudo-phreatic surface nodes are now located in the MPFS array after the end of the true phreatic surface nodes.
6. Return to the calling program.

Subroutine: FØRM

PURPOSE

Subroutine FØRM controls and conducts all phases of the actual seepage analysis. These phases consist of:

1. mesh generation
2. problem flow matrix construction
3. modification of flow matrix for nodal boundary conditions
4. solution of flow matrix equations
5. computation of phreatic-surface movement
6. mesh regeneration
7. solution iteration, phases 6, then 3 through 5, as required to converge results
8. calculation of nodal stream function values as well as individual finite element flows.

CALLING SEQUENCE

CALL FØRM (NPFS, MPFS, ALPHA, MESH, X, Y, NBC, FX, NP, R, C, RAYS, LNESEG, PSI, IFPIPE, NØDFLG, YMAX, SCR, PRESS, Z, NEWMUM, ZERØP, ICØDFS).

DESCRIPTION OF ARGUMENTS

NPFS(1): Integer array - Input phreatic surface nodes.

MPFS(1): Integer array - Sorted phreatic surface nodes.

ALPHA(1): Real array - Correction directions for phreatic surface nodes.

MESH(1): Integer array - Node numbers as input (used to generate F.E. geometry).

X(1): Real array - x-coordinates of nodal points.

Y(1): Real array - y-coordinates of nodal points.

NBC(1): Integer array - Nodal boundary condition codes.

FX(1): Real array - Nodal boundary condition values.

NP(5,1): Integer array - Array of elemental node and material type numbers.

R(1): Real array - Right hand side (R.H.S.) vector (used initially to store flow forcing vector).

C(MAXBAN,1): Real array - Matrix area for storage of global ie, problem, flow matrix.

RAYS(3, 1): Real array - Double-dimensioned array space for integer array containing linkage indexes for each node point.

LNESEG(2,1): Integer array - Double-dimensioned array containing the indices of the nodal points defining each line segment present within the set of elements along with the indexes to elements to which they are common.

PSI(1): Real array - Nodal stream function values.

IFPIPE(1): Integer array - Pipe element array (used in calculation of stream function values).

NØDFLG(1): Integer array - Nodal condition flags to indicate if node is exterior (=1) or interior (=0) to a finite element mesh.

YMAX(1): Real array - Upper limit of y-values to phreatic surface nodes.

SCR(1): Real array - Scratch array used to contain net nodal flows.

PRESS(1): Real array - Nodal fluid pressures.

Z(1): Real array - Nodal elevations.

NEWNUM(1): Integer array - New node position numbers.

ZER0P(1): Bit array - Flags for no-tension conditions.

IC0DES(1): Integer array - Indicator flags for phreatic surface nodes.

C0MM0N BLOCK ALLOCATION

When compiled, this routine automatically includes the labelled C0MM0N blocks/C0NTRL/, /SLINES/ and /ELMT/ as outlined in COMMON blocks.

INTERNAL CALLS

See Subroutine list.

SEQUENCE OF STEPS

1. Set no-tension flags for phreatic surface nodes.
2. Generate, or re-generate, finite element mesh node geometry by proceeding through the MESH array as follows:
   a. look at the end of each node generation line
      - if it is not a phreatic surface node go to (c)
      - if this is the first iteration go to (c)
      - if the end node is not a pseudo-phreatic surface node go to (b)
      - calculate the fraction of movement of true phreatic surface node that this node is to have
      - go to (c)
   b. retrieve the true phreatic surface node movements previously stored
   c. check to see if nodes are to be generated along the node generation line - if not go to (e)
      - back-figure the geometric progression ratio from the first two line segments
      - calculate the sum of the geometric ratios for all line segments and then determine movements of the node at the end of the first line segment
      - if node generation line has continuity boundary condition go to (d)
      - calculate difference in previous values of nodal condition function along generation line and make appropriate adjustments for boundary condition generation type (IN on node care)
   d. start generating the nodal co-ordinates and boundary condition values along the line from the first segment
   e. add increments (change in geometry) to the starting node on the line. If this is the first iteration go to (f), if not, and the end node is a true phreatic surface node, print the movement details
   f. set conditions for next line segment.
3. If mesh report is to be printed, calculate the net nodal flows (S/R GETFL0) and print the report (S/R WRMESH).
4. Build the global, ie, problem, flow matrix and the flow forcing vector (R.H.S.) (S/R BLDMAT).
   - then set correct inflows for phreatic surface nodes (S/R FINDCN)
   - then modify the global flow matrix and the flow forcing vector for specified boundary conditions (S/R M0DIFY)
5. Solve the linear equations represented by the global flow matrix and the flow forcing vector for the nodal fluid pressure (S/R DECOMP and S/R SUBST). If no-tension conditions on phreatic surface are set and phreatic surface node pressures are less than zero re-set them to zero (S/R SETN0T). If this iteration is the last one to be done, ie, = MAXIT, or if it is a confined flow problem, to to Step 13.
6. Calculate net nodal flows (S/R GETFL0).
7. Cycle through the true phreatic surface nodes and calculate their movements as follows.
   a. if the node is on either end of the phreatic surface node string, leave it for later.
   b. if the node has not previously tried to leave the slope, ie, go outside it or daylight, then go to (c) - If the node then has a net third inflow its location is in error and the convergency flag for the iteration is set to false. Go back to the

start of this step for the next phreatic surface node.

   c. Set the node correction direction and vertical component. If specified by data input in NAMELIST $FPM calculate the fluid pressure gradient at the node. Calculate and store the component movements and gradients. Also sum total phreatic surface movement.

8. If the total phreatic surface movement is less than the pre-set tolerance, the analysis has converged. Then go to Step 13.
9. Calculate solution acceleration factor.
10. Cycle through the true phreatic surface nodes again and calculate accelerated movements for the next iteration as follows.
    a. If the node has not previously daylighted the slope, go to (b), otherwise check to see if there is a net nodal inflow. If so, switch the node to have a continuity boundary condition it should drop after the next iteration - and go back to the start of this step
    b. Is the node moving down? If so, go to (c). Otherwise, check to ensure that the accelerated node movement will not cause it to leave or daylight the slope. If it does, then change the node to a zero pressure boundary condition and reset its co-ordinates so that it is on the slope outline.
    c. Calculate and store the accelerated movements for the true phreatic surface node points.
11. Compute the movements of the ends of the phreatic surface. Fit a parabola to the second, third and fourth node from each end and use the slope calculated at the second node to estimate the new position of the end node. Ensure that the end nodes will not leave the slope as in Step 10.
12. Cycle through steps 2 to 11 as required to converge or finish the analysis.
13. Solve for the individual element flows and the nodal stream function values (S/R ELFL0W). Then print a nodal result report.
14. Return to the main program.

Subroutine: GETFL0

Is used to compute net nodal outflows which are returned to F0FRM in the array SCR. To do this the original global flow matrix is retrieved from disk storage and is multiplied by the nodal potential array.

Subroutine: SETN0T

Is used to set a zero pressure flag for nodes with negative third pressures (tension) and also to indicate to F0RM that the solution then cannot have converged.

Subroutine: BLDMAT

PURPOSE

To compute flow matrices for individual quadrilateral and triangular elements and assemble these into the global (or master) flow matrix.

CALLING SEQUENCE

CALL BLDMAT (X, Y, Z, NP, PRESS, R, C, NEWNUM, NBC).

DESCRIPTION OF ARGUMENTS

X(1): Real array - x-coordinates of nodal points.

Y(1): Real array - y-coordinates of nodal points.

Z(1): Real array - Elevations of nodal points (not used).

NP(5,1): Integer array - Element nodal points and material type numbers.

PRESS(1): Real array - Nodal pressures.

R(1): Real array - Solution rector

C(MAXBAN,1): Real array - Matrix area for storage of global flow matrix.

NEWNUM(1): Integer array - New internal node numbers (after bandwidth minimization).

NBC(1): Integer array - Nodal boundary condition codes.

COMMON BLOCK ALLOCATION

Labelled C0MM0N blocks /C0NTRL/, /SLINES/ and /ELMT/ are automatically included on compilation. See COMMON blocks.

INTERNAL CALLS

See Subroutine list.

SEQUENCE OF STEPS

1. Initialize solution vector R and global flow matrix C to zeros.
2. For each element in the mesh:
   a. initialize pressure vector and flow matrix to zeros
   b. find and store element nodal co-ordinates and determine element centroid
   c. if element is quadrilateral, locate and define sub-elements (triangles)
   d. build nodal position number array
   e. if a quadrilateral, form flow matrix from triangular sub-element flow matrices (4 calls to TRIFL) and reduce the centre node
   f. if a triangle, form flow matrix (CALL TRIFL)
   g. add the element flow matrix using the internal node numbers carried in the NEWNUM array
3. Store the complete global flow matrix on logical unit 14 (CALL NTRAN).
4. Store the right hand side (flow forcing vector) on logical unit 14 (CALL NTRAN).
5. Return to calling program.

Subroutine: BMULT

PURPOSE

This subroutine multiplies a symmetric matrix by a vector. Only the elements of the lower half-band of the matrix, including the diagonal, are required.

CALLING SEQUENCE

CALL BMULT (A, B, C, N, M)

DESCRIPTION OF ARGUMENTS

A: - Real input one-dimensional array containing the lower half-band only including the diagonal of the symmetric multiplicand matrix of order, N, and half-bandwidth, M, stored by columns. A must be dimensioned at least (N-1)*M+1. For a diagram showing the arrangement of the elements of A, see documentation of Golder Associates library subroutine DECOMP.

B: - Real input one-dimensional array of length at least N containing the multiplier vector.

C: - Real output one-dimensional array of length at least N to contain the product vector.

N: - Integer input argument containing the order of the multiplicand matrix, which is also the length of vectors B and C.

M: - Integer input argument containing the width of the half-band of the matrix, including the diagonal.

INTERNAL CALLS

See Subroutine list.

Subroutine: DECOMP

PURPOSE

This subroutine is used to solve a system of linear equations represented by the matrix equation A.x=b for the vector x, where A is a positive-definite symmetric banded matrix. Entry DECOMP decomposes A by Cholesky's method to L, a lower triangular matrix such that $L.L^T=A$. Entry SUBST then solves for x by forward and backward substitution.

CALLING SEQUENCES

CALL DECOMP (A, N, M, RATIO)

ALTERNATE ENTRY POINT

CALL SUBST (A, B, N, M)

DESCRIPTION OF ARGUMENTS

A: - Real input and output one-dimensional array, dimensioned at least (N-1)*M+1. Contains, on input to entry DECOMP, the lower half-band of the positive-definite symmetric matrix A, stored columnwise. Each column is of length, M, the bandwidth, so some array locations may not be used, ie, those which protrude below the last row of the matrix.

On output from entry DECOMP, and for input to entry SUBST, A contains L, the lower triangular matrix such that $L.L^T=A$.

N: - Integer input argument containing the order of matrix, A, which is also the length of vectors x and b.

M: - Integer input argument containing the width of the half-band, including the diagonal.

RATIO: - Real output argument which acts as a condition word. For a normal return, RATIO>0. and is the ratio of the smallest to the largest diagonal element of L. If RATIO is positive but extremely small - less than, say, 1.E-7, matrix A is probably ill-conditioned. If matrix A is not positive-definite, or if $M \leq 0$, RATIO is returned <0., and an error message is printed.

B: - Real input and output one-dimensional array dimensioned at least N. On input, B should contain the vector b from the matrix equation A.x=b. On output, B contains vector x, the solution to the system of linear equations.

SEQUENCE OF STEPS

ENTRY DECOMP: DECOMP replaces each element of A with the corresponding element of L as it calculates it. First, it tests for a diagonal matrix, and if true, calculates the terms of L, calculates RATIO, and returns. For a non-diagonal matrix, the diagonal term of any empty (all-zero) row is replaced by 1. Then L(1), L(2) and the second diagonal term of L are calculated separately and explicitly by Cholesky's method. DECOMP then loops through the rest of the matrix row by row, each time calculating by Cholesky's method, first the left-most non-zero term of the row, then in an inner loop the next term in the row through the term immediately to the left of the diagonal, and finally, the diagonal term in the row. The minimum and maximum values for diagonals of L are carried throughout the loop. When the last row is complete, RATIO is equated to minimum over maximum diagonal term, and control is returned to the calling program.

ENTRY SUBST: Having decomposed A to $L.L^T$, we get $L.L^T.x=b$. Setting $y \equiv L^T.x$, we get $L.y=b$. Since L is lower triangular, y can be solved by forward substitution, then knowing y, we can solve $L^T.x = y$ for x by backward substitution. Entry SUBST accomplishes this, first working downward replacing the elements of B one by one by y, then from the bottom up in turn replacing these elements by x, the solution for the system A.x = b. Control is then returned to the calling program.

ERROR CONDITIONS

A value of RATIO $\leq$ 0. on return always indicates an error condition, and will always cause a printout of one of the following error messages:

"DECOMP - IMPROPER BANDWIDTH = [bandwidth]"
"**SYSTEM IS NOT POSITIVE-DEFINITE** ERROR OCCURRED IN ROW [row number]"

COMMENTS

For an explanation of Cholesky's method, see "Solving Large Systems of Linear Equations with Applications in Engineering", June 1970, by A.G. Fowler - pages 1-3.

Subroutine: FINDCN

PURPOSE

FINDCN is used to determine whether two nodes defining a line segment are attached to the same finite element.

CALLING SEQUENCE

CALL FINDCN (I, J, ICON, LNESEG, NLS, *)

DESCRIPTION OF ARGUMENTS

Argument: Type - Description

I: Integer - Input node number at start of line segment.

J: Integer - Input node number at end of line segment.

ICON: Integer - Output of connection in array LNESEG if common element found.

LNESEG (2,1): Integer array - Double dimensioned array containing the indices of the nodal points defining each line segment present within the set of elements along with the indexes to elements to which they are common.

NLS: Integer - Maximum number of line segments in finite element mesh.

*: - Error return entry if no element connection is found.

INTERNAL CALLS

See Subroutine list.

Subroutine: GRADNT

PURPOSE

To estimate the fluid pressure gradient at any node.

CALLING SEQUENCE

CALL GRADNT (NØDE, X, Y, NP, NUMEL, PRESS, GRADX, GRADY).

DESCRIPTION OF ARGUMENTS

NØDE: Integer - No. of node at which pressure gradient is to be estimated.

X(1): Real array - Array of nodal x-coordinates.

Y(1): Real array - Array of nodal y-coordinates.

NP(5,1): Integer array - Array of element node and material type numbers.

NUMEL: Integer - Total no. of finite elements in problem.

PRESS: Real array - Array of nodal fluid pressures.

GRADX: Real - Estimated fluid pressure gradient of selected node in X-direction.

GRADY: Real - Estimated fluid pressure gradient of selected node in Y-direction.

SEQUENCE OF STEPS

1. Subroutine GRADNT searches through all elements to find those connected to NØDE.
2. For elements connected to NØDE, the subroutine calculates their contribution to the least square terms for the gradient estimation process.
3. The fluid pressure gradient components on the coordinate directions are estimated and returned to the calling program.

Subroutine: MØDIFY

PURPOSE

To modify the global flow matrix equations remating to nodes with prescribed pressures or flows.

CALLING SEQUENCE

CALL MØDIFY (MM, NBC, FX, R, C, MPFS, ICØDFS, NEWNUM, Z, ZERØP).

DESCRIPTION OF ARGUMENTS

MM: Integer - Maximum half-bandwidth of global flow matrix.

NBC(1): Integer array - Nodal boundary condition indicators.

FX(1): Real array - Nodal boundary condition values.

R(1): Real array - R.H.S. solution vector.

C(MM,1): Real array - Global flow matrix.

MPFS(1): Integer array - Phreatic surface node numbers.

ICØDFS(1): Integer array - Indicator flags for phreatic surface nodes.

NEWNUM(1): Integer array - New nodal position numbers, after bandwidth reduction).

Z(1): Real array - Reference elevations for linked node potential value calculations.

ZERØP(1): Bit array - Flags for no-tension conditions.

COMMON BLOCK ALLOCATION

When compiled, this routine automatically includes the labelled CØMMØN blocks /CØNTRL/, /SLINES/ and /ELMT/ as outlined in COMMON blocks.

INTERNAL CALLS

1. If the debug flag (IDEBUG(7)) is set greater than zero, print out
   - the renumbered nodes (NEWNUM)
   - the original global flow matrix (C)
   - the original R.H.S. (R)
2. For each node:
   a. check if it is to be held at zero pressure, if so, go to the next element
   b. check boundary condition indicator - if it is a continuity node, add the nodal flow to the forcing rector and go to the next node. If it is a node with fixed pressure, go the next node. For a linked potential node, calculate the new potential value and place it in the R.H.S.
3. For each node, again:
   a. check for known pressure condition - if not, go to the next element

   b. add the term summed from the operation

$$R(n) = P\ (n) \cdot \sum_{i} S(i,n)$$

   (where i = no. of equations) to the R.H.S.
   c. clear out the row and column associated with node n and set the diagonal term to one.

4. If the debug flag (IDEBUG(7)) is set greater than zero, print out
   - the modified global flow matrix (C)
   - the modified R.H.S. (R)
5. Return to the calling routine.

Subroutine: TRIFL

PURPØSE

To compute flow matrices for triangular finite elements.

CALLING SEQUENCE

CALL TRIFL (I, J., K, AREA, XC, YC)

DESCRIPTION OF ARGUMENTS

I,J,K: Integers - Node numbers for corners of triangular element, entered counter-clockwise.

AREA: Real - Area of finite element

XC: Real - x-coordinate of centroid of finite element.

YC: Real - y-coordinate of centroid of finite element.

CØMMØN BLØCK ALLØCATIØN

When compiled, this routine automatically includes by labelled CØMMØN blocks /CØNTRL/, /SLINES/ and /SLINES/ /ELMT/ as outlined in COMMON blocks.

INTERNAL CALLS

See Subroutine list.

SEQUENCE OF STEPS

1. Calculate geometry and check area of finite element.
2. If material type unknown, determine region in which the finite element lies (CALL SZØNE).
3. Compute rotated permeability and flow matrices.
4. Return to calling routine.

Subroutine: ELFLØW

PURPOSE

To compute flow velocities in finite elements and stream functions at the nodes.

CALLING SEQUENCE

CALL ELFLØW (X,Y,NP,R,PSI,C,IFPIPE,NRAYS, NØDFLG,NBC,FX,NEWNUM)

DESCRIPTION OF ARGUMENTS

X(1): Real array - Nodal x-coordinates.

Y(1): Real array - Nodal y-coordinates.

NP(5,1): Integer array - Element node and material type array.

R(1): Real array - Nodal solution vector.

PSI(1): Real array - Nodal steam function array.

C(MAXBAN,1): Real array - Double-dimensioned scratch array used to contain terms in least squares matrix for calculation of stream function.

IFPIPE(1): Integer array - Pipe element array.

NRAYS(3,1): Integer array - Double-dimensioned array which provides linkage indexes for each node point to all other directly connected nodes.

NØDFLG(1): Integer array - Array containing condition flags for each node to indicate if the node is exterior (=1) or interior (=0) for a finite element mesh.

NBC(1): Integer array - Nodal boundary condition codes.

FX(1): Real array - Nodal function values.

NEWNUM*1): Integer array - New to the program, internal node numbers after bandwidth minimization.

COMMON BLOCK ALLOCATION

When compiled, this routine automatically includes the labelled CØMMØN blocks /CØNTRL/, /SLINES/ and /ELMT/ as outlined in COMMON blocks.

INTERNAL CALLS

See Subroutine list.

SEQUENCE OF STEPS

1. Initialize PSI and C arrays to zero.
2. For each element in the mesh:

  - a. read in element information block (CALL BLKIN)
  - b. if a quadrilateral element, back calculate fluid pressure at the central node
  - c. reset flow matrix
  - d. calculate flow across each side and add value to PSI array, then add terms to the least squares matrix
  - e. calculate average flow velocity at centroid of element and print results
3. Search for a node on an impermeable boundary - if found, set nodal stream function value to datum of 0.0 and modify the least squares array (CALL FIX). Then search for neighbouring boundary nodes and set their stream function values to the datum of 0.0 as well (CALL FIX again).
4. Solve the least-squares matrix using the Choleski linear equation solver by:
  - a. decomposing the matrix (CALL DECØMP) and
  - b. backsubstituting to calculate the nodal stream function value vector (CALL SUBST)
5. Return to the calling routine.

NOTE: Subroutine ELFLØW has an internal subroutine FIX which is used to modify the least squares matrix, C, so that a real datum for the stream function can be set and thus the equations solved.

Subroutine: SZØNE

PURPOSE

SZØNE determines the material region or zone in which a specified point lies, generally the centroid of a finite element.

CALLING SEQUENCE

CALL SZØNE (X, Y, LABØVE, LBELØW, FRACTN,*)

DESCRIPTION OF ARGUMENTS

X: Real - x-coordinate of point.

Y: Real - y-coordinate of point.

LABØVE: Integer - No. of closest material zone definition line directly above the point.

LBELØW: Integer - No. of closest material zone definition line directly below the point.

FRACTN: Real - Fraction of vertical distance between LBELØW and LABØVE that exists between LBELØW and Y if point not within a looped zone.

*: - Error return location.

COMMON BLOCK ALLOCATION

Labelled CØMMØN blocks /CØNTRL/, /SLINES/ and /ELMT/ are automatically included on compilation. (See COMMON blocks).

INTERNAL CALLS

See Subroutine list.

SEQUENCE OF STEPS

1. Cycle through all material zone definition lines to see if a segment is intersected by a vertical line drawn through the point.
2. If a segment is intersected, save the line number and compare crossing y-coordinate with previous value. If latest y-coordinate is closer to the point, store line number and y-coordinate value.
3. Continue cycling through material zone definition lines.
4. At the end of cycling operation, compare line number above and line number below. If they are the same then the point is within a material loop, FRACTN is set equal to 1.0×10^{20}, and control is returned to the calling program. If the line numbers are both greater than zero but different, compute the fractional vertical distance as:

$$\text{FRACTN} = \frac{\text{Y - YBELØW}}{\text{YABØVE - YBELØW}}$$

and return to the calling program. If the line number above is zero, then the point has left the continuum and the error return location is taken.

Subroutine: CROSS

PURPOSE

CROSS is used by the material region interrogation procedure (S/R SZONE) to determine if a vertical line drawn vertically through a point, which is usually the centroid of a finite element, cuts the line segment joining two other points.

CALLING SEQUENCE

CALL CR0SS (IFAB0V, YCR0SS, XP, YP, X, Y)

DESCRIPTION OF ARGUMENTS

IFAB0V: Integer - Output crossing indicator
= 0 if vertical line does not cross
= +1 if vertical line crosses above YP
= -1 if vertical line crosses below YP

YCR0SS: Real - y-coordinate of vertical line intersection

XP: Real - x-coordinate of point

YP: Real - y-coordinate of point

X(2): Real array - x-coordinates of line segment points

Y(2): Real array - y-coordinates of line segment points

SEQUENCE OF STEPS

1. XP is checked to ensure that it falls within the range XL<XP<XR where XL is the end of the line segment with the lower, ie, left, x-coordinate, and XR is the other end. If not, return to the calling program.
2. Calculate YCR0SS and determine if it is greater than or less than YP. Return to the calling program.

Subroutine: EXTINT

PURPOSE

To find and flag all nodal points which lie on the boundaries of a finite element mesh. These nodal points may define either the external perimeter of the mesh or any interior perimeters or holes in the mesh. In addition, subroutine EXTINT builds an array of line segments that define edges of finite elements within the mesh and also constructs an array of rays which defines all possible line segments from a given nodal point.

CALLING SEQUENCES

CALL EXTINT (NEL, NELM, LNESEG, MAXSEG, NLS, NRAYS, N0DFLG, MAXN0D, NUMN0D, IERR).

ALTERNATE ENTRY POINT

CALL EXTIAN (NEL, NELM, LNESEG, MAXSEG, NLS, NRAYS, N0DFLG, MAXN0D, NUM0D, NELX, IERR).

DESCRIPTION OF ARGUMENTS

NEL(5,1): Integer array - Elemental nodal points and material type code.

NELM: Integer - Number of finite elements in mesh.

LNESEG(2,1): Integer array - Array returned containing indices of the nodal points defining each line segment present within the set of elements along with the indexes to the elements to which they are common.

MAXSEG: Integer - Maximum number of line segments allowed.

NLS: Integer - Number of unique line segments found by this subroutine.

NRAYS(3,1): Integer array - Array returned containing linkages from each nodal point to all other nodes to which it is connected.

N0DFLG(1): Integer array (bit usage) - Condition bit flags for each node indicating if the node is on a boundary (=1) or not (=0).

MAXN0D: Integer - Maximum number of nodal points allowed.

NUMN0D: Integer - Number of nodal points found by this subroutine.

NELX(2,1): Integer array - Special array containing the neighbouring elements for each element in the mesh.

IERR: Integer - Returned error flag.
= 0, no errors
= 1, errors encountered.

SEQUENCE OF STEPS

1. Initialize NRAYS and N0DFLG arrays.
2. For each element in the mesh:
   a. determine if it is a special finite element eg, bar, joint, etc. and if so, go to the next element
   b. for each side in the finite element, store the line segment in NRAYS and LNESEG if it has not already been found. If the line segment has already been defined, check back to see that it has only been defined once

before.

3. Commence to find the exterior line segments and nodes by performing a simple sort on the data.

Subroutine: WRMESH

PURPØSE

To print nodal input data and nodal analysis results.

CALLING SEQUENCES

CALL WRMESH (X, Y, Z, NBC, FX)

ALTERNATE ENTRY POINT

CALL WRMSH (X, Y, Z, NBC, FX, PRESS, SCR)

DESCRIPTION OF ARGUMENTS

X(1): Real array - Nodal x-coordinates.

Y(1): Real array - Nodal y-coordinates.

Z(1): Real array - Nodal elevations.

NBC: Integer array - Nodal boundary condition indicators.

FX: Real array - Nodal boundary condition values.

PRESS: Real array - Nodal pressures.

SCR: Real array - Net nodal flows.

COMMON BLOCK ALLOCATION

When compiled, this routine automatically includes the labelled CØMMØN blocks /CØNTRL/, /SLINES/ and /ELMT/ as outlined in COMMON blocks.

Subroutine: BLK

PURPOSE

To block-buffer short records onto a data file. This allows the packing of more than one record into each block, and can substantially reduce I/Ø time.

CALLING SEQUENCES

CALL BLK (LU, BUFFER, NBUFF, NREC, IFTEMP)

The above call initializes the routine. Input/Output of individual records is then handed by:
CALL BLKOUT (IREC, FROM) to write record IREC, and
CALL BLKIN (IREC, TO) to read it; which are auxiliary entry points in BLK.

DESCRIPTION OF ARGUMENTS

LU: Integer input variable - Fortran logical unit number. If LU≥0 a scratch file called TEMPLU will be created ancd attached to fortran unit 15, ie, for LU=15, the file name is TEMP15. If BLK has previously been called with the same value of LU, and the file has not been deleted or freed, the previous file will be DELETEd AND FREEd.

If it is desired to use a file created by BLK in a previous run, this is indicated by setting the value of LU negative. The file must be assigned and attached to unit LU before BLK is called.

BUFFER: Real input or output array - Array provided for use as a buffer for the block being accessed.

NBUFF: Integer input argument - Length of array BUFFER.

NRECS: Integer input argument - Maximum number of records anticipated.

NREC: Integer input argument - Record length, in words.

NREC is also used to FREE or DELETE a file:

NREC=0 to complete and FREE the file.

NREC<0 to DELETE and FREE the file.

IFTEMP: Logical input argument - If IFTEMP is •TRUE• a scratch file will be used; otherwise a permanent file will be used. A permanent file will not be readable by a subsequent run unless BLK is called with NREC=0 at the end of the original run.

IREC: Integer input argument - The record number to be read/written.

FROM: Real input array - Array from which the record to be written is to come.

TO: Real output array - Array to which the record to be read is to be copied.

INTERNAL CALLS

See Subroutine list.

INTERNAL DOCUMENTATION

Internal variables and logic are described by comment cards within the program.

OUTPUT

CALL BLK for NREC>0 creates a new file, destroying any previous existing file assigned to LU. CALL BLKOUT eventually causes a write of the block containing IREC to the file assigned to LU.

LIMITATIONS

No more than 1080 records may be used.

ERROR MESSAGES

1. XXX FATAL ERROR IN S/R BLK - TOO MANY BLOCKS - nnnnnn
   - the program will stop.
2. ERROR IN S/R BLK: IREC=nnnn IERR=nn IN=nnnnmm IM=nnnnmm IFOUT=nn IPACK=nnn
   - an NTRAN operation has failed.
   - the program will stop.
3. WARNING - YOU HAVE ATTEMPTED TO READ BLOCK nnnn WHICH WAS NOT PREVIOUSLY WRITTEN
   - the record in question will be zero-filled.
4. There are several other self-explanatory and fatal messages.

Notes: BLK will only handle one logical unit at a time. If an attempt is made to read a record which has not previously been written, a record of 0.0's will be sent.

Subroutine: GBTTL

PURPOSE

This is a heading routine which creates a title block and page headers containing title and page numbers.

CALLING SEQUENCES

CALL GBTTL (NAME, ILEN) - for title block

ALTERNATE ENTRY POINTS

CALL PAGBA (IPAGE) - to print a page header

CALL SPAGA (IPAGE) - CSTS and DIGITECH only - to print a shorter page header

CALL SGBTTL (PNAME) - for a short title block ($\leq$6 characters).

DESCRIPTION OF ARGUMENTS

NAME: Alphanumeric input argument. Array containing the title in A6 format. Up to 72 characters may be printed.

ILEN: Integer input argument. This controls the combination of header record, title, and trailer record to be printed.

The title block consists of three separable parts:

HEADER - This contains the title.

TITLE - A printout of the title starting at NAME.

TRAILER - This contains the day of year and time of day.

ILEN controls what is printed thus:

ILEN	HEADER PRINTED?	TITLE PRINTED? (N CHARACTERS)	TRAILER PRINTED?
n	yes	yes	yes
-1000	yes	no	no
-(1000+N)	yes	yes	no
-N	no	yes	no
0	no	no	yes
1000	no	no	no

A CALL GBTTL for ILEN=1000 prints nothing, but merely sets up the title for future calls to PAGBA & SPAGA.

Note: The number of characters printed is limited or truncated to 72 characters. If N is greater than or equal to 90, the run date and time are returned to the calling program in characters 73 to 90 (words 13-15 of NAME) as:

MO/DA/YR-HH:MM:SS

However, the title printed will still be truncated at 72 characters.

IPAGE: Integer input argument containing the page number to be printed at the top of the new page, or may be input as 0 which causes an automatic increment by 1 of the page number, starting with 1, eg, if for the first call to PAGBA or SPAGA, IPAGE is input as 0, a page number of '2' will be printed.

PNAME: Alphanumeric input argument which is a one-word 'short' title (of 1-6 characters) to be printed by SGBTTL in a title block.

OUTPUT: The title block produced by GBTTL is 79 print positions wide +1 for carriage control. Calls to GBTTL for all in-range values of ILEN except 1000 will produce, printed at the top of a new page, some or all of the title block as indicated in the above table. If ILEN=1000, nothing is printed, but the title for future calls to PAGBA and SPAGA is changed to contain up to 72 characters beginning at NAME. A call to PAGBA will cause a page header to be printed at the top of the next page containing the current title, time and date. This page header is 122 print positions wide (+1 for carriage control). Entry point SPAGA is identical to PAGBA except that the page header is split into two lines, only 79 print positions wide (+1 for carriage control).

If the title input starting at NAME contains no more than 36 characters ignoring (trailing blanks), it will be double-spaced horizontally in both title block and page header.

The title block produced by SGBTTL is 59 print positions wide (+1 for carriage control) and contains the heading desired, followed by run time and date.

INTERNAL CALLS

See Subroutine list.

MOD - FORTRAN V library function

MINO - FORTRAN V library function

IABS - FORTRAN V library function

DOY - CSCX library utility subroutine: return day of year

DOY - DIGITECH system library routine: return day of year

DOYF - CSTS library utility entry point: return day of year

TOD - CSCX library utility subroutine: return time of day in hours, minutes and seconds

TOD - DIGITECH system library routine: return time of day in hours, minutes and seconds

TODF - CSTS library utility entry point: return time of day in hours, minutes and seconds.

Subroutine: MCORE

SOURCE LANGUAGE

UNIVAC 1100 series SLEUTH II Assembler on Digitech's UNIVAC 1106 with EXEC 8 operating system.

PURPOSE

This routine performs dynamic expansion and contraction of a user's DBANK.

ENTRY POINTS

MCORE - gets more core

LCORE - releases core previously obtained by MCORE

CALLING SEQUENCE

```
CALL MCORE (ADR, N, ISTAT)
CALL LCORE (ADR)
```

COMMON BLOCK

Each pre-processor must define a labelled COMMON block which is forced by collector directives to be positioned at the end of the systems DBANK. It is this COMMON block which is expanded and contracted by MCORE/LCORE.

DESCRIPTION OF ARGUMENTS

ADR - Input argument of any type giving, for MCORE, the starting location within the labelled COMMON block from which expansion is to begin. For LCORE, ADR is the highest location to be retained after core contraction.

N - Integer input argument - number of core words of DBANK to be added to ADR.

ISTAT - Integer output argument - acts as a status word. For a successful expansion, ISTAT is returned = 0. If ISTAT = 1, core has not been expanded due to size limitations.

LIMITATIONS

MCORE will not allow DBANK to exceed 65K.

LCORE can only release core acquired by MCORE. If LCORE is called with ADR lower than the highest collection time DBANK address, DBANK will be reduced to its original size.

Since LCORE$, the executive request used by LCORE, releases core in blocks of 512 words, DBANK will probably extend past ADR after a call to LCORE by an amount no greater than 511 words.

ERROR CONDITIONS

If a call to MCORE requests expansion of DBANK over 65K, argument ISTAT is returned = 1, and no expansion is performed.

Subroutine: TOD

PURPOSE

This subroutine retrieves the current time of day and day of year.

CALLING SEQUENCES

CALL TOD (ITIME)
DOY (IDAY) (alternate entry point)

DESCRIPTION OF ARGUMENTS

ITIME - Alphanumeric 2-word output array which contains on output the current time in the format. HH.MM.SS, where HH represents hours (00-24), MM represents minutes (00-59) and SS represents seconds (00-59)

IDAY - Alphanumeric 2-word output array containing on output the date in the format DD,MM,YY where DD represents day of month (0-31), MON represents month (first three letters) YY represents year (last two digits)

INTERNAL CALLS

FLD - FORTRAN V library function
ERTRAN - FORTRAN V library subroutine
SYFDBN - Golder Associates library subroutine

ERROR CONDITIONS

The only possible error return is a RETURN 0, which will occur only if the system data word containing the date is in error.

Subroutine: SYFDBN

SOURCE LANGUAGE

FORTRAN V on Digitech's UNIVAC 1106 with EXEC 8 operating system. SYFDBN uses compiler option FLD=R.

PURPOSE

SYFDBN converts a field data character string to an integer. Leading blanks in the string are considered as zero; all other characters encountered which are not 0, 1, 2, 3, 4, 5, 6, 7, 8 or 9 cause an error return.

ENTRY POINT

SYFDBN

CALLING SEQUENCE

CALL SYFDBN (INP, CHAR, BIN, $)

DESCRIPTION OF ARGUMENTS

INP - Alphanumeric input word or array containing character string to be converted. The first character is considered to be the first digit.

CHAR - Integer input argument giving the number of characters, beginning with the first character in the first word of INP, to be included in the conversion.

BIN - Integer output argument to contain the integer equivalent of the character string.

$ - Statement number in calling program to which control is transferred in case of an error condition ie, if an invalid character is encountered.

LIMITATIONS

The maximum value of the number to be converted is 2^{35}-1. Negative numbers are not allowed, as characters other than '0' - '9' cause an error return.

INTERNAL CALLS

FLD - FORTRAN V library function

This subroutine uses DEFINE procedures, a feature of FORTRAN V.

Subroutine: ERTRAN

PURPOSE

Returns the date and time and accepts a dummy value.

CALLING SEQUENCE

CALL ERTRAN(DUMMY,DAT,TM)

DAT returns the data in the format: dd/mm/yy

TM returns the time in the format: hh.mm.ss.

Comments: The original routine is a UNIVAC 1100 series FORTRAN interface with the operating system. In FEFPM, only ABORT$ (operation code 1) and DATE$ (operation code 9) are used. Thus, the Control Data FORTRAN intrinsic routines DATE, TIME and ABORT are used to convert it. Most other systems have means of returning this information from FORTRAN.

Subroutine: NTRAN

PURPOSE

NTRAN perfomrs binary reading and writing of tape or disk and permits I/O buffering.

CALLING SEQUENCE

CALL NTRAN(LU,OP,LEN,BUF,STAT)

LU is the logical unit to be read or written, the default is 15.

OP is one of the operation codes:

Code	Meaning
1	write
2	read
8	position-sequential file
9	write End-of-file
10 or 11	rewing
6	position random file
22	does nothing

LEN Length of the data to be read or written, in words.

BUF is the name of the variable to be read or written

STAT is a variable that NTRAN uses to return a device status:

-2 end of tape or disk file

-3 device error

or STAT will return a positive value which should be the number of words transmitted.

Comments: This, although written in FORTRAN, performs I/O with routines written in Compass, since they are Control Data intrinsic functions (BUFFER IN, BUFFER OUT, LOCF). The original of this routine is a special UNIVAC subroutine that handles the access of a UNIVAC drum with 28 word sectors, and it permits the queuing of I/O. Operation 22 is intended to cause a wait until the stack is empty. The routine documented here cannot handle I/O queuing or all of the operations of the original NTRAN. The conversion of this subroutine would depend upon the I/O devices of a particular system and would require assembler or operating system routines on most systems.

Subroutine: FLDLNTH

PURPOSE

This routine returns the current memory being used (field length), requests a new field length or requests the maximum field length available.

CALLING SEQUENCE

CALL FLDLNTH(LENGTH)

If LENGTH = 0 the current memory size is returned in the variable.

If LENGTH = -1 the maximum available field length is returned (this is the value available on the job card as the CM specification).

otherwise the value specified as LENGTH will be the number of words that will become the new field length.

Comments: This program is written in Compass, the assembler language of the CNC CYBER series computers. It uses a system macro to allocate the new central memory storage or to determine the amount already in use.

Conversion of this program requires assembler level reprogramming.

Subroutine/Function: SETFLD

PURPOSE

To move a bit string from one word to another without affecting the rest of the output word. The input word (WORD 2) contains the bit string right justified. The specified number of bits (N) are moved to the specified position (starting at bit IPOS) of the output word (WORD 1). The value of the final value of the output word (WORD 1) is also returned in an arithmetic register (X6) so that this routine can be used as either a Subroutine or a function.

CALLING SEQUENCE

CALL SETFLD (IPOS,N,WORD1,WORD2) or
JJ = SETFLD (IPOS,N,WORD1,WORD2)
Function: FLD
Type: Integer

PURPOSE

To perform bit string manipulation. Specifcally, FLD is used to access the bytes of a computer word. The position and width of the byte and the word to be accessed are the arguments of the function.

CALLING SEQUENCE

FLD(IPOS,N,WORD)

IPOS is an integer, between 0 and 35 (the length of an 1108 word, hence the upper limit in these programs) and is the first bit to be accessed in the word.

N is an integer between 1 and 36 (see note above), and are the number of bits to be accessed.

WORD is an integer, real, logical or (on the 1108) typeless and is the word to be accessed.

Bits are counted from left to right in the word. The first bit is zero. The contents of the byte extracted from the word are right-adjusted in the arithmetic register and the remaining bits are set to zero. The result is considered an integer.

Examples of use: NI = FLD(35,1,STRING)

NI then contains one bit, bit 35, of the contents of variable STRING. That one bit is right justified in the variable NI, the rest of which is zero.

Comments: This is a routine written in Compass to replace an intrinsic function of UNIVAC 1100 series FORTRAN V. For conversion of this routine, a knowledge of assembly language of a computer will probably be necessary, or the use of the ANSI standard (1977) function.

Subroutine: CAS002

PURPOSE

To query the system to determine the amount of core taken by the program (field length). It can be used to change the core allocated to the program, as long as the program stays within the upper limit set on the job card (CM).

CALLING SEQUENCE

CALL CAS002(IFL)

If IFL = 0, the current field length is returned in IFL. (IFL will be number of words.)

If IFL is unsigned and greater than zero, the field length is set to the value of IFL

If IFL is a signed integer, the current field length will be increased or decreased by the value of IFL.

Comments: This FORTRAN callable subroutine is written in Compass. CDC's assembler language for the CYBER series computers. It is part of the Department of Energy, Mines and Resources Library (EMRLIB). It performs the same functions as MCORE and LCORE routines in the original 1108 version of these programs, and functions similarly to FLDLNTH.

Programs of this kind usually require an interface with the operating system, so that program conversion for another computer system will require an expert programmer.

Subroutine: LCORE

PURPOSE

To contract core to the specified address (a variable name)

CALLING SEQUENCE

CALL LCORE (ADR)

ADR - this is the last variable to have core.

Comments: This routine uses the CDC intrinsic function LOCF, finds the location of the variable

(ADR), and then calls FLDLNTH to change the size of the core allocated to the program. See FLDLNTH for additional comments.

Subroutine: ETIMEF

PURPOSE

Used to return the CPU time since the last call to subroutine ETIME.

CALLING SEQUENCE

```
CALL ETIMEF(SEC)
```

Comments: This subroutine picks up the variable TO in the labelled COMMON block TIME, and calls the Control Data intrinsic function SECOND.

Subroutine: ETIME

PURPOSE

Obtains the number of elapsed CPU seconds (as a real number) since the start of the job.

The time is stored in a variable TO in a labelled COMMON block called TIME.

CALLING SEQUENCE

```
CALL ETIME
```

Comments: This subroutine uses the Control Data FORTRAN intrinsic function SECOND.

APPENDIX A

SAMPLE PROBLEMS

1. Three sample problems illustrating typical use of most features of the FEFPM computer program are presented. Drawings of each problem showing finite element mesh layouts, complete listings of input data and the entire FEFPM computer program output are included for each sample problem.

SAMPLE PROBLEM 1 - DUPUIT PARABOLA

2. The first sample problem presented is one of the program validation examples reported earlier in this supplement. The problem geometry and finite element mesh used in the analysis are shown in Fig A-1. The purpose of this problem was to check the capabilities and accuracy of the FEFPM computer program; geometries and permeability values used are not necessarily realistic.

3. The problem involves planar flow through an isotropic material zone with vertical sides situated on an impermeable base. Constant hydrostatic pressure conditions with different surface levels exist on the vertical sides. The object of the analysis is to determine the steady-state groundwater flow regime. This involves determining location of the steady state phreatic surface.

4. The nodes and elements used to define the finite element mesh are illustrated in Fig A-1. Note that these nodes and elements are sequentially numbered in the vertical direction, thus facilitating data generation. The actual data cards used for this problem are reproduced below with annotations and the data generation procedures for both nodes and elements are obvious. The outlined areas on the input data listing are the bounds of the respective formats for each type of data card.

5. The printout from the FEFPM program for this sample problem follows the input data card listing. The headings for each output section describe the printout but some additional annotations have been made to facilitate understanding. The final phreatic surface location determined in the analysis is shown in Fig A-1.

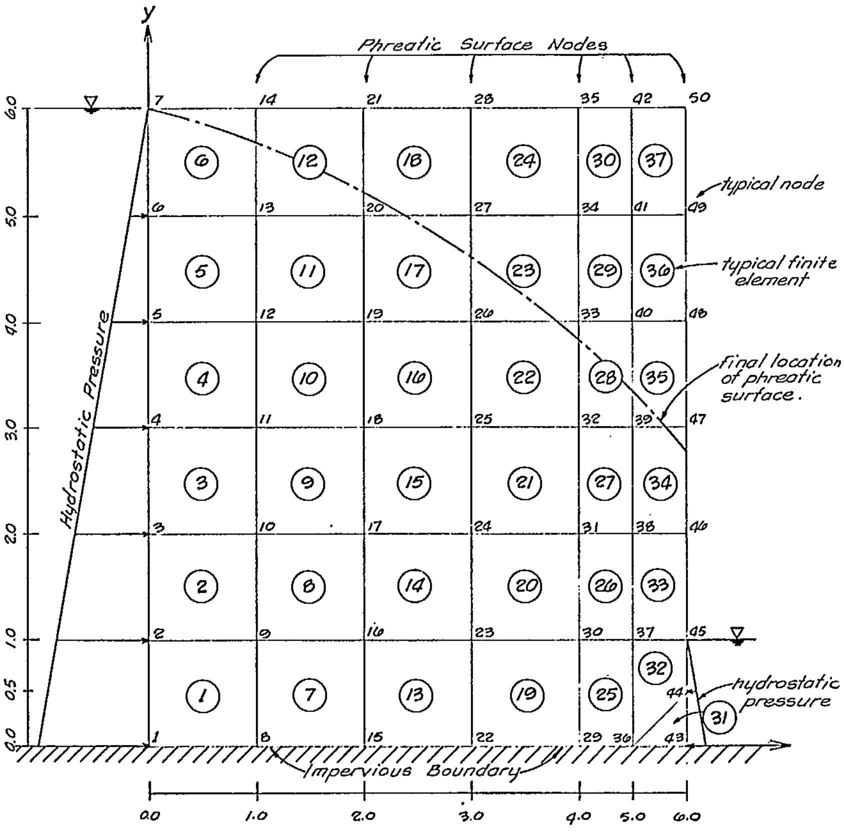
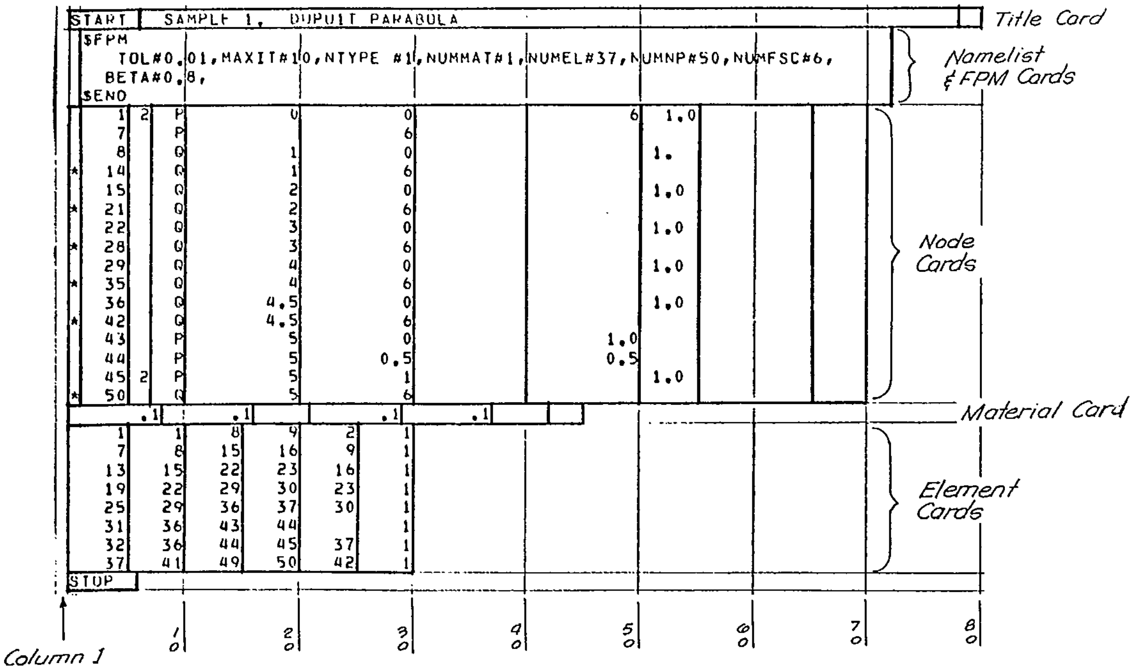


Fig A-1 - Sample problem 1 - geometry and mesh.

SAMPLE PROBLEM 1 - INPUT DATA



```
START     SAMPLF 1,  DUPUIT PARABOLA
 $FPM
   TOL#0.01,MAXIT#10,NTYPE #1,NUMMAT#1,NUMEL#37,NUMNP#50,NUMFSC#6,
  BETA#0.8,
 $END
    1 2   P         0         0                   6  1.0
    7     P                   6
    8     Q         1         0                      1.
*  14     Q         1         6
   15     Q         2         0                      1.0
*  21     Q         2         6
   22     Q         3         0                      1.0
*  28     Q         3         6
   29     Q         4         0                      1.0
*  35     Q         4         6
   36     Q       4.5         0                      1.0
*  42     Q       4.5         6
   43     P         5         0                 1.0
   44     P         5       0.5                 0.5
   45 2   P         5         1                      1.0
*  50     Q         5         6
       .1        .1                .1        .1
    1    1    8    9    2    1
    7    8   15   16    9    1
   13   15   22   23   16    1
   19   22   29   30   23    1
   25   29   36   37   30    1
   31   36   43   44         1
   32   36   44   45   37    1
   37   41   49   50   42    1
STOP
```

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 1

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                             *
*                                                                             *
*                 S E E P A G E   A N A L Y S I S                             *
*                                                                             *
*         S A M P L E   1 ,    D U P U I T   P A R A B O L A                  *
*                                                                             *
*                                                                             *
*                      01/30/76-14:57:23                                      *
*                                                                             *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
 NUMBER OF NODAL POINTS------ 50

 NUMBER OF ELEMENTS---------- 37

 NUMBER OF DIFF. MATERIALS---  1

 UNIT WEIGHT OF FLUID--------   1.0000+00

 REFERENCE FOR POTENTIALS----   0.0000


 CORRECTION FACTOR-----------    .80000

 MAX. NO. ITERATIONS---------  10

 ERROR TOLERANCE-------------    .01000


 PLANE FLOW PROBLEM

ASGIO DYNAMIC E.R. - @ASG,T      TEMP15,017/   3410/TRK/   3410 .
ASGIU DYNAMIC E.R. - @USE     15,TEMP15 .
```

Input Control Parameters

← Assignment of temporary file (logical unit 15)

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 2

```
*              S A M P L E   1 .   D U P U I T   P A R A B O L A                **    01/30/76-14:57:23    **    PAGE  2

NODE B.C.          X-ORD       Y-ORD        F
  1 PRESS.         .0000       .0000    6.0000+00    0.0000        *
  2 PRESS.         .0000      1.0000    5.0000+00    0.0000        *
  3 PRESS.         .0000      2.0000    4.0000+00    0.0000        *
  4 PRESS.         .0000      3.0000    3.0000+00    0.0000        *
  5 PRESS.         .0000      4.0000    2.0000+00    0.0000        *
  6 PRESS.         .0000      5.0000    1.0000+00    0.0000        *
  7 PRESS.         .0000      6.0000    0.0000       0.0000        *
  8  CONT         1.0000       .0000    0.0000       0.0000        *
  9  CONT         1.0000      1.0000    0.0000       0.0000        *
 10  CONT         1.0000      2.0000    0.0000       0.0000        *
 11  CONT         1.0000      3.0000    0.0000       0.0000        *
 12  CONT         1.0000      4.0000    0.0000       0.0000        *
 13  CONT         1.0000      5.0000    0.0000       0.0000        *
 14  CONT         1.0000      6.0000    0.0000       0.0000        *
 15  CONT         2.0000       .0000    0.0000       0.0000        *
 16  CONT         2.0000      1.0000    0.0000       0.0000        *
 17  CONT         2.0000      2.0000    0.0000       0.0000        *
 18  CONT         2.0000      3.0000    0.0000       0.0000        *
 19  CONT         2.0000      4.0000    0.0000       0.0000        *
 20  CONT         2.0000      5.0000    0.0000       0.0000        *
 21  CONT         2.0000      6.0000    0.0000       0.0000        *
 22  CONT         3.0000       .0000    0.0000       0.0000        *
 23  CONT         3.0000      1.0000    0.0000       0.0000        *
 24  CONT         3.0000      2.0000    0.0000       0.0000        *
 25  CONT         3.0000      3.0000    0.0000       0.0000        *
 26  CONT         3.0000      4.0000    0.0000       0.0000        *
 27  CONT         3.0000      5.0000    0.0000       0.0000        *
 28  CONT         3.0000      6.0000    0.0000       0.0000        *
 29  CONT         4.0000       .0000    0.0000       0.0000        *
 30  CONT         4.0000      1.0000    0.0000       0.0000        *
 31  CONT         4.0000      2.0000    0.0000       0.0000        *
 32  CONT         4.0000      3.0000    0.0000       0.0000        *
 33  CONT         4.0000      4.0000    0.0000       0.0000        *
 34  CONT         4.0000      5.0000    0.0000       0.0000        *
 35  CONT         4.0000      6.0000    0.0000       0.0000        *
 36  CONT         4.5000       .0000    0.0000       0.0000        *
 37  CONT         4.5000      1.0000    0.0000       0.0000        *
 38  CONT         4.5000      2.0000    0.0000       0.0000        *
 39  CONT         4.5000      3.0000    0.0000       0.0000        *
 40  CONT         4.5000      4.0000    0.0000       0.0000        *
 41  CONT         4.5000      5.0000    0.0000       0.0000        *
 42  CONT         4.5000      6.0000    0.0000       0.0000        *
 43 PRESS.        5.0000       .0000    1.0000+00    0.0000        *
 44 PRESS.        5.0000       .5000    5.0000-01    0.0000        *
 45 PRESS.        5.0000      1.0000    0.0000       0.0000        *
 46 PRESS.        5.0000      2.0000    0.0000       0.0000        *
 47 PRESS.        5.0000      3.0000    0.0000       0.0000        *
 48 PRESS.        5.0000      4.0000    0.0000       0.0000        *
 49 PRESS.        5.0000      5.0000    0.0000       0.0000        *
 50  CONT         5.0000      6.0000    0.0000       0.0000        *
```

Initial Node Geometry
and Boundary Conditions

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 3

```
*              S A M P L E   1 .   D U P U I T   P A R A B O L A             **    01/30/76-14:57:23    **    PAGE  3
                                    MATERIAL   PROPERTIES
LINE *      PROPERTIES       ABOVE         *       PROPERTIES       BELOW        *      DELIMITING NODE STRING
 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     *                                     *                                     *
  1  *      1.00-01     1.00-01      .0    *      1.00-01     1.00-01      .0    *   -1.000+10  1.000+20          1.000+10  1.000+20
     *                                     *                                     *    1.000+10 -1.000+10         -1.000+10 -1.000+10
     *                                     *                                     *
 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 4

```
*              S A M P L E   1 .    D U P U I T   P A R A B O L A             **    01/30/76-14:57:23    **     PAGE  4

ELMT         I          J          K          L        MAT

   1         1          8          9          2          1
   2         2          9         10          3          1
   3         3         10         11          4          1
   4         4         11         12          5          1
   5         5         12         13          6          1
   6         6         13         14          7          1
   7         8         15         16          9          1
   8         9         16         17         10          1
   9        10         17         18         11          1
  10        11         18         19         12          1
  11        12         19         20         13          1
  12        13         20         21         14          1
  13        15         22         23         16          1
  14        16         23         24         17          1
  15        17         24         25         18          1
  16        18         25         26         19          1
  17        19         26         27         20          1
  18        20         27         28         21          1
  19        22         29         30         23          1
  20        23         30         31         24          1
  21        24         31         32         25          1
  22        25         32         33         26          1
  23        26         33         34         27          1
  24        27         34         35         28          1
  25        29         36         37         30          1
  26        30         37         38         31          1
  27        31         38         39         32          1
  28        32         39         40         33          1
  29        33         40         41         34          1
  30        34         41         42         35          1
  31        36         43         44         44          1
  32        36         44         45         37          1
  33        37         45         46         38          1
  34        38         46         47         39          1
  35        39         47         48         40          1
  36        40         48         49         41          1
  37        41         49         50         42          1
```

Finite Element List

```
  *   *   *   *   *  F R E E   S U R F A C E  *   *   *   *   *   *

     NODF     CORR. ANGLE         Y(MAX)

       14        90.0        ************
       21        90.0        ************
       28        90.0        ************
       35        90.0        ************
       42        90.0        ************
       50        90.0        ************

CPU TIME USED IN S/R MESMIN =  1.358 SECONDS
```

Phreatic surface node details.

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 5

```
TOTAL SPACE ACQUIRED FOR /MATRIX/ IS  1541

MAXIMUM BANDWIDTH =  10
ASGIO DYNAMIC F.R. - @ASG,T      TEMP14,F17/       1/TRK/       1 .
ASGIO DYNAMIC F.R. - @USE      14,TEMP14 .
```

← *Assignment of temporary file (Logical unit 14)*

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 6

```
*              S A M P L E   1 .    D U P U I T   P A R A B O L A              **     01/30/76-14157123     **     PAGE  5
TOTAL MESH AREA=  3.0000000+01    CPU TIME TO BUILD FLOW MATRIX =    3.300 SECONDS.


 * * * * *  ITERATION  1
```

Details of phreatic surface node movements during iterative solution.

```
TIME TO SOLVE MATRIX =  .109 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       8.85-01
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.2985  DX,DY=   1.4901-08  -3.6493-01
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  .0536  DX,DY=   0.0000      -9.4278-01

     NODE     X-ORD      Y-ORD       PRESSURE         POTENTIAL        DX         DY       DP/DX      DP/DY
       14    1.0000     6.0000     -.43816+00        .55618+01      .0000     -.3649     .0000      .0000
       21    2.0000     6.0000     -.82929+00        .51707+01     -.0000     -.6634     .0000    -1.0000
       28    3.0000     6.0000     -.11144+01        .48856+01     -.0000     -.8915     .0000    -1.0000
       35    4.0000     6.0000     -.12235+01        .47765+01     -.0000     -.9788     .0000    -1.0000
       42    4.5000     6.0000     -.12120+01        .47880+01     -.0000     -.9696     .0000    -1.0000
       50    5.0000     6.0000     -.12482+01        .47518+01      .0000     -.9428     .0000      .0000
TOTAL MESH AREA=  2.6625503+01    CPU TIME TO BUILD FLOW MATRIX =    3.140 SECONDS.


 * * * * *  ITERATION  2


TIME TO SOLVE MATRIX =  .127 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       5.24-01
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.5507  DX,DY=   7.4506-09   5.4345-02
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0047  DX,DY=   0.0000      -7.0533-01

     NODE     X-ORD      Y-ORD       PRESSURE         POTENTIAL        DX         DY       DP/DX      DP/DY
       14    1.0000     5.6351     -.18158-01        .56169+01      .0000      .0543     .0000      .0000
       21    2.0000     5.3366     -.24730+00        .50893+01     -.0000     -.1978     .0000    -1.0000
       28    3.0000     5.1085     -.54217+00        .45663+01     -.0000     -.4337     .0000    -1.0000
       35    4.0000     5.0212     -.79633+00        .42249+01     -.0000     -.6371     .0000    -1.0000
       42    4.5000     5.0304     -.85106+00        .41793+01     -.0000     -.6808     .0000    -1.0000
       50    5.0000     5.0572     -.91312+00        .41441+01      .0000     -.7053     .0000      .0000
TOTAL MESH AREA=  2.5053712+01    CPU TIME TO BUILD FLOW MATRIX =    3.170 SECONDS.


 * * * * *  ITERATION  3


TIME TO SOLVE MATRIX =  .100 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       3.17-01
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.6729  DX,DY=   7.4506-09   1.2761-01
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.1688  DX,DY=   0.0000      -5.6637-01
```

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 7

```
      NODE     X-ORD      Y-ORD       PRESSURE        POTENTIAL       DX        DY      DP/DX     DP/DY
        14    1.0000     5.6894     -.15253-01       .56742+01     .0000     .1276     .0000      .0000
        21    2.0000     5.1387      .67882-02       .51455+01     .0000     .0054     .0000   -1.0000
        28    3.0000     4.6747     -.19175+00       .44830+01    -.0000    -.1534     .0000   -1.0000
        35    4.0000     4.3841     -.48192+00       .39022+01    -.0000    -.3855     .0000   -1.0000
        42    4.5000     4.3496     -.59952+00       .37500+01    -.0000    -.4796     .0000   -1.0000
        50    5.0000     4.3519     -.65831+00       .36936+01     .0000    -.5664     .0000      .0000

TOTAL MESH AREA=  2.4362804+01   CPU TIME TO BUILD FLOW MATRIX =   2.850 SECONDS.


 * * * * *  ITERATION  4


TIME TO SOLVE MATRIX =  .101 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      1.91-01
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.6670  DX,DY=   7.4506-09   5.1275-02
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.4390  DX,DY=   0.0000     -4.5727-01

      NODE     X-ORD      Y-ORD       PRESSURE        POTENTIAL       DX        DY      DP/DX     DP/DY
        14    1.0000     5.8170     -.11162+00       .57054+01     .0000     .0513     .0000      .0000
        21    2.0000     5.1442      .71430-01       .52156+01     .0000     .0571     .0000   -1.0000
        28    3.0000     4.5213     -.42333-02       .45171+01    -.0000    -.0034     .0000   -1.0000
        35    4.0000     3.9986     -.24590+00       .37527+01    -.0000    -.1967     .0000   -1.0000
        42    4.5000     3.8699     -.40274+00       .34672+01    -.0000    -.3222     .0000   -1.0000
        50    5.0000     3.7855     -.43944+00       .33461+01     .0000    -.4573     .0000      .0000

TOTAL MESH AREA=  2.4040886+01   CPU TIME TO BUILD FLOW MATRIX =   3.050 SECONDS.


 * * * * *  ITERATION  5


TIME TO SOLVE MATRIX =  .105 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      1.02-01
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.5912  DX,DY=   7.4506-09  -3.2808-02
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.7233  DX,DY=   0.0000     -3.2412-01

      NODE     X-ORD      Y-ORD       PRESSURE        POTENTIAL       DX        DY      DP/DX     DP/DY
        14    1.0000     5.8683     -.15765+00       .57106+01     .0000    -.0328     .0000      .0000
        21    2.0000     5.2013      .53748-01       .52551+01     .0000     .0430     .0000   -1.0000
        28    3.0000     4.5179      .68678-01       .45866+01     .0000     .0549     .0000   -1.0000
        35    4.0000     3.8019     -.76049-01       .37258+01    -.0000    -.0608     .0000   -1.0000
        42    4.5000     3.5477     -.22743+00       .33203+01    -.0000    -.1819     .0000   -1.0000
        50    5.0000     3.3283     -.24832+00       .30799+01     .0000    -.3241     .0000      .0000

TOTAL MESH AREA=  2.3892390+01   CPU TIME TO BUILD FLOW MATRIX =   2.750 SECONDS.


 * * * * *  ITERATION  6
```

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 8

```
TIME TO SOLVE MATRIX =  .102 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      4.55-02
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.5098  DX,DY=   7.4506-09  -6.7055-02
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.9446  DX,DY=   0.0000     -1.7733-01

      NODE      X-ORD     Y-ORD       PRESSURE        POTENTIAL       DX        DY       DP/DX      DP/DY
       14      1.0000    5.8355     -.13336+00      .57021+01      .0000    -.0671     .0000      .0000
       21      2.0000    5.2443      .17957-01      .52623+01      .0000     .0144     .0000    -1.0000
       28      3.0000    4.5729      .70841-01      .46437+01      .0000     .0567     .0000    -1.0000
       35      4.0000    3.7410      .25941-01      .37670+01      .0000     .0208     .0000    -1.0000
       42      4.5000    3.3658     -.83382-01      .32824+01     -.0000    -.0667     .0000    -1.0000
       50      5.0000    3.0041     -.11010+00      .28940+01      .0000    -.1773     .0000      .0000

TOTAL MESH AREA=  2.3834255+01   CPU TIME TO BUILD FLOW MATRIX =   2.860 SECONDS.


 * * * * *  ITERATION  7


TIME TO SOLVE MATRIX =  .094 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      2.86-02
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.4599  DX,DY=   7.4506-09  -5.7462-02
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE= -1.0713  DX,DY=   0.0000     -6.1587-02

      NODE      X-ORD     Y-ORD       PRESSURE        POTENTIAL       DX        DY       DP/DX      DP/DY
       14      1.0000    5.7684     -.78301-01      .56901+01      .0000    -.0575     .0000      .0000
       21      2.0000    5.2587     -.94781-02      .52492+01     -.0000    -.0076     .0000    -1.0000
       28      3.0000    4.6296      .38844-01      .46684+01      .0000     .0311     .0000    -1.0000
       35      4.0000    3.7618      .59110-01      .38209+01      .0000     .0473     .0000    -1.0000
       42      4.5000    3.2991      .22316-02      .33013+01      .0000     .0018     .0000    -1.0000
       50      5.0000    2.8268     -.36515-01      .27903+01      .0000    -.0616     .0000      .0000

TOTAL MESH AREA=  2.3821244+01   CPU TIME TO BUILD FLOW MATRIX =   2.500 SECONDS.


 * * * * *  ITERATION  8


TIME TO SOLVE MATRIX =  .091 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      2.36-02
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.4462  DX,DY=   7.4506-09  -2.9894-02
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE= -1.1177  DX,DY=   0.0000      6.8914-04

      NODE      X-ORD     Y-ORD       PRESSURE        POTENTIAL       DX        DY       DP/DX      DP/DY
       14      1.0000    5.7110     -.29897-01      .56811+01      .0000    -.0299     .0000      .0000
       21      2.0000    5.2511     -.20284-01      .52308+01     -.0000    -.0162     .0000    -1.0000
       28      3.0000    4.6606      .49334-02      .46656+01      .0000     .0039     .0000    -1.0000
       35      4.0000    3.8091      .46417-01      .38555+01      .0000     .4371     .0000    -1.0000
       42      4.5000    3.3009      .29856-01      .33307+01      .0000     .0239     .0000    -1.0000
       50      5.0000    2.7652     -.94854-02      .27557+01      .0000     .0007     .0000      .0000

TOTAL MESH AREA=  2.3819036+01   CPU TIME TO BUILD FLOW MATRIX =   2.690 SECONDS.
```

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 9

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 * * * * *  ITERATION  9


TIME TO SOLVE MATRIX =  .099 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      1.55-02
PHREATIC SURFACE END-NODE  14 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  -.4551  DX,DY=   7.4506-09  -4.6220-03
PHREATIC SURFACE END-NODE  50 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE= -1.1180  DX,DY=   0.0000      1.9601-02

      NODE      X-ORD     Y-ORD       PRESSURE        POTENTIAL       DX        DY       DP/DX      DP/DY
       14      1.0000    5.6811     -.36742-02      .56774+01      .0000    -.0046     .0000      .0000
       21      2.0000    5.2349     -.16905-01      .52180+01     -.0000    -.0135     .0000    -1.0000
       28      3.0000    4.6646     -.13087-01      .46515+01     -.0000    -.0105     .0000    -1.0000
       35      4.0000    3.8462      .20623-01      .38668+01      .0000     .0165     .0000    -1.0000
       42      4.5000    3.3248      .24693-01      .33495+01      .0000     .0198     .0000    -1.0000
       50      5.0000    2.7659     -.57666-02      .27601+01      .0000     .0196     .0000      .0000

TOTAL MESH AREA=  2.3817574+01   CPU TIME TO BUILD FLOW MATRIX =   2.500 SECONDS.


 * * * * *  ITERATION 10


TIME TO SOLVE MATRIX =  .133 SECONDS.

MAX. NUMBER OF ITERATIONS REACHED
```

← Note that the solution has not fully converged. However the phreatic surface node movements (DY above) are now quite small and thus the results of iteration 10 are presumed to be accurate enough for program validation purposes.

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 10

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*           S A M P L E   1 .    D U P U I T   P A R A B O L A              **    01/30/76-14:57:23     **    PAGE  6

  ELMT     X-ORD     Y-ORD     Z-ORD        X-FLOW          Y-FLOW         TOTAL FLOW  DIRN   MATERIAL

    1      .500      .487      .487      7.7569-02     -1.0076-03       7.7576-02    -.74       1
    2      .500     1.460     1.460      7.3707-02     -2.8126-03       7.3760-02   -2.19       1
    3      .500     2.433     2.433      6.6754-02     -4.0997-03       6.6880-02   -3.51       1
    4      .500     3.406     3.406      5.7829-02     -4.8334-03       5.8031-02   -4.78       1
    5      .500     4.379     4.379      4.7772-02     -5.2726-03       4.8062-02   -6.30       1
    6      .500     5.352     5.352      3.6291-02     -6.1381-03       3.6806-02   -9.60       1
    7     1.500      .454      .454      8.1958-02     -3.1222-03       8.2017-02   -2.18       1
    8     1.500     1.362     1.362      7.7744-02     -8.7207-03       7.8231-02   -6.40       1
    9     1.500     2.270     2.270      7.0318-02     -1.2674-02       7.1451-02  -10.22       1
   10     1.500     3.179     3.179      6.1187-02     -1.4788-02       6.2949-02  -13.59       1
   11     1.500     4.087     4.087      5.1644-02     -1.5711-02       5.3980-02  -16.92       1
   12     1.500     4.945     4.995      4.2774-02     -1.6627-02       4.5892-02  -21.24       1
   13     2.500      .411      .411      9.1840-02     -5.5618-03       9.2008-02   -3.47       1
   14     2.500     1.234     1.234      8.6559-02     -1.5677-02       8.7967-02  -10.27       1
   15     2.500     2.057     2.057      7.7293-02     -2.2791-02       8.0583-02  -16.43       1
   16     2.500     2.880     2.880      6.6496-02     -2.6089-02       7.1431-02  -21.42       1
   17     2.500     3.703     3.703      5.6218-02     -2.6717-02       6.2244-02  -25.42       1
   18     2.500     4.526     4.526      4.7688-02     -2.6262-02       5.3916-02  -29.15       1
   19     3.500      .355      .355      1.0976-01     -7.8874-03       1.1004-01   -4.11       1
   20     3.500     1.065     1.065      1.0369-01     -2.4109-02       1.0646-01  -13.09       1
   21     3.500     1.774     1.774      9.0762-02     -3.7174-02       9.8080-02  -22.27       1
   22     3.500     2.484     2.480      7.5669-02     -4.2077-02       8.6253-02  -29.50       1
   23     3.500     3.194     3.194      6.1768-02     -4.1535-02       7.4434-02  -33.92       1
   24     3.500     3.904     3.904      5.2002-02     -3.8769-02       6.4863-02  -36.71       1
   25     4.250      .300      .300      1.3026-01     -7.9167-03       1.3050-01   -3.48       1
   26     4.250      .901      .901      1.2960-01     -2.7704-02       1.3252-01  -12.07       1
   27     4.250     1.502     1.502      1.1286-01     -5.3985-02       1.2511-01  -25.56       1
   28     4.250     2.102     2.102      8.8331-02     -6.2227-02       1.0805-01  -35.16       1
   29     4.250     2.703     2.703      6.6914-02     -6.0476-02       9.0193-02  -42.11       1
   30     4.250     3.303     3.303      5.5115-02     -5.2171-02       7.5891-02  -43.43       1
   31     4.833      .167      .167      1.4114-01      0.0000          1.4114-01     .00       1
   32     4.750      .514      .514      1.4834-01     -3.5170-03       1.4838-01   -1.36       1
   33     4.750     1.007     1.007      1.6641-01     -5.9161-02       1.7661-01  -19.57       1
   34     4.750     1.465     1.465      1.2760-01     -7.8946-02       1.5005-01  -31.75       1
   35     4.750     1.922     1.922      9.9135-02     -8.4326-02       1.3015-01  -40.39       1
   36     4.750     2.379     2.379      7.4064-02     -8.3671-02       1.1174-01  -48.49       1
   37     4.750     2.836     2.836      4.9948-02     -7.5638-02       9.0641-02  -56.56       1

CPU TIME IN S/R ELFLOW =    .855 SECONDS.
```

Resulting Element Flows

FEFPM - SAMPLE PROBLEM NO. 1 - OUTPUT - 11

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*           S A M P L E   1 .    D U P U I T   P A R A B O L A              **    01/30/76-14:57:23     **    PAGE  7

NODE  B.C.      X-ORD     Y-ORD      Z-ORD    PRESSURE     POTENTIAL     FLOW FN      OUTFLOW

   1 PRESS       .00       .00        .00   6.0000+00    6.0000+00   -8.3893-04   -3.8771-02
   2 PRESS       .00      1.00       1.00   5.0000+00    6.0000+00    7.6912-02   -7.5506-02
   3 PRESS       .00      2.00       2.00   4.0000+00    6.0000+00    1.5034-01   -6.9826-02
   4 PRESS       .00      3.00       3.00   3.0000+00    6.0000+00    2.1657-01   -6.1539-02
   5 PRESS       .00      4.00       4.00   2.0000+00    6.0000+00    2.7373-01   -5.1682-02
   6 PRESS       .00      5.00       5.00   1.0000+00    6.0000+00    3.2093-01   -4.0427-02
   7 PRESS       .00      6.00       6.00   0.0000       6.0000+00    3.5788-01   -1.2471-02
   8 CONT.      1.00       .00        .00   5.2144+00    5.2144+00    0.0000       5.5879-09
   9 CONT.      1.00       .95        .95   4.2676+00    5.2337+00    7.5000-02    0.0000
  10 CONT.      1.00      1.89       1.89   3.3955+00    5.2877+00    1.4640-01   -5.0291-08
  11 CONT.      1.00      2.84       2.84   2.5281+00    5.3665+00    2.1110-01   -2.0489-08
  12 CONT.      1.00      3.78       3.78   1.6708+00    5.4591+00    2.6742-01   -1.3039-08
  13 CONT.      1.00      4.73       4.73   8.2986-01    5.5602+00    3.1478-01   -4.0978-08
  14 CONT.      1.00      5.68       5.68   1.5580-03    5.6780+00    3.5278-01   -2.6077-08
  15 CONT.      2.00       .00        .00   4.3848+00    4.3848+00    0.0000       2.7940-09
  16 CONT.      2.00       .87        .87   3.5515+00    4.4218+00    7.4919-02   -3.3528-08
  17 CONT.      2.00      1.74       1.74   2.7846+00    4.5250+00    1.4597-01   -2.9802-08
  18 CONT.      2.00      2.61       2.61   2.0642+00    4.6749+00    2.0989-01   -2.4214-08
  19 CONT.      2.00      3.48       3.48   1.3679+00    4.8488+00    2.6528-01   -2.6077-08
  20 CONT.      2.00      4.35       4.35   6.7992-01    5.0310+00    3.1220-01   -4.8429-08
  21 CONT.      2.00      5.22       5.22  -7.7005-03    5.2136+00    3.5139-01   -4.0978-08
  22 CONT.      3.00       .00        .00   3.4555+00    3.4555+00    0.0000      -1.1176-08
  23 CONT.      3.00       .78        .78   2.7556+00    3.5092+00    7.6937-02   -2.7940-09
  24 CONT.      3.00      1.55       1.55   2.1108+00    3.6622+00    1.4973-01   -1.3039-08
  25 CONT.      3.00      2.33       2.33   1.5577+00    3.8847+00    2.1389-01   -2.7940-08
  26 CONT.      3.00      3.10       3.10   1.0345+00    4.1372+00    2.6806-01   -5.0291-08
  27 CONT.      3.00      3.88       3.88   5.1350-01    4.3919+00    3.1335-01    7.4506-09
  28 CONT.      3.00      4.65       4.65  -1.5115-02    4.6390+00    3.5178-01   -1.8626-08
  29 CONT.      4.00       .00        .00   2.3508+00    2.3508+00    0.0000      -2.7940-09
  30 CONT.      4.00       .64        .64   1.7644+00    2.4082+00    7.8500-02   -1.2107-08
  31 CONT.      4.00      1.29       1.29   1.3069+00    2.5945+00    1.5504-01   -7.4506-09
  32 CONT.      4.00      1.93       1.93   9.6235-01    2.8937+00    2.2077-01   -1.8626-08
  33 CONT.      4.00      2.58       2.58   6.6215-01    3.2373+00    2.7316-01   -2.2352-08
  34 CONT.      4.00      3.22       3.22   3.4724-01    3.5662+00    3.1423-01   -1.1176-08
  35 CONT.      4.00      3.86       3.86   1.9157-03    3.8646+00    3.4768-01    3.7253-09
  36 CONT.      4.50       .00        .00   1.7057+00    1.7057+00    0.0000      -6.5193-09
  37 CONT.      4.50       .56        .56   1.1864+00    1.7439+00    7.5398-02   -6.5193-09
  38 CONT.      4.50      1.11       1.11   7.7609-01    1.8909+00    1.5535-01   -2.0489-08
  39 CONT.      4.50      1.67       1.67   5.6454-01    2.2368+00    2.2374-01   -1.3039-08
  40 CONT.      4.50      2.23       2.23   4.0704-01    2.6367+00    2.7665-01   -1.8626-08
  41 CONT.      4.50      2.79       2.79   2.4298-01    3.1301+00    3.1544-01   -1.8626-08
  42 CONT.      4.50      3.34       3.34   1.1174-02    3.3557+00    3.4479-01   -7.4506-09
  43 PRESS      5.00       .00        .00   1.0000+00    1.0000+00    2.5838-03    3.5284-02
  44 PRESS      5.00       .50        .50   5.0000-01    1.0000+00    7.5737-02    7.4320-02
  45 PRESS      5.00      1.00       1.00   0.0000       1.0000+00    1.5646-01    9.3217-02
  46 PRESS      5.00      1.36       1.36   0.0000       1.3571+00    2.2423-01    4.9059-02
  47 PRESS      5.00      1.71       1.71   0.0000       1.7142+00    2.7028-01    4.0152-02
  48 PRESS      5.00      2.07       2.07   0.0000       2.0713+00    3.0599-01    3.2649-02
  49 PRESS      5.00      2.43       2.43   0.0000       2.4284+00    3.3296-01    2.5540-02
  50 CONT.      5.00      2.79       2.79  -1.0367-02    2.7751+00    3.4844-01   -1.4901-08

  SUMMARY  OF  EXTERNAL  FLOWS        INFLOW     OUTFLOW
PRESSURE NODES:                      3.502-01    3.502-01
```

Resulting node geometrics as well as potential and flow (stream) function valves.

```
CONTINUITY NODES:  SPECIFIED FLOW  0.000        0.000
                   OTHER FLOW      6.584-07     1.956-08

ASGIO DYNAMIC E.R. - *FREE TEMP14.        .
ASGIO DYNAMIC E.R. - *FREE TEMP15.        .


*FIN
```

← *Release of temporary files.*

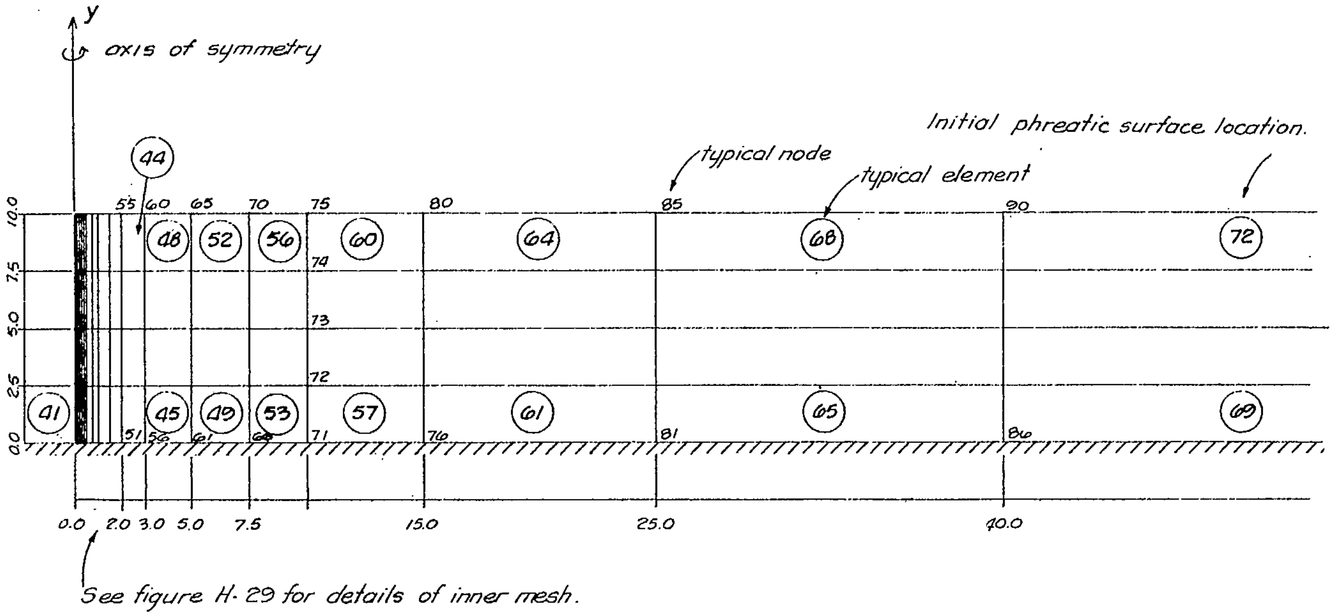


Fig A-2 - Sample problem 2 - finite element mesh.

SAMPLE PROBLEM 2 - WELL DRAWDOWN

6. The second sample problem is a simulation of a well of known flow in a homogeneous water-table type aquifer. For this problem, finite element modelling of the flow close to the well requires careful analysis if accurate results are to be produced. Fortunately, when the well flow is specified, even a poor model of the behaviour close to the well does not cause bad results further away from the well. When the well water level rather than the flow is specified, this is not the case and a good model must be constructed. Fig A-2 and A-3 illustrate the geometry of the problem and also the finite element mesh used. Note that node and element data are generated along vertical lines.

7. Figure A-4 depicts schematically the behaviour of a well. Sketches (a) and (b) show the effect of low and high pumping rates. For the low capacity pump, the phreatic surface exits just above the level of the water in the well. For the high capacity pump, the phreatic surface exits high above the well water level. The FEFPM program could be used to compute formation characteristic curves which, combined with the pump characteristic curves as shown in Fig A-4 (a), (d) and (e), would give a prediction of the well's performance. Such an analysis could be misleading if the head loss due to existing the formation and passing through the well casing were significant.

8. In sample problem 2, there is a fairly low pumping rate and therefore it is assumed that the phreatic surface exits at the well water level. As discussed above, minor errors near the well do not affect accuracy of results further away, so the error due to this assumption is negligible.

9. A problem arises when designing the mesh for this case - the node at the intersection of the phreatic surface and the well is both zero-pressure and has an unknown net outflow. The FEFPM program is designed only to handle phreatic surface nodes with a known net flow based on QY, the surface infiltration rate. The solution is to insert a layer of finite elements within the well and withdraw the well outflow from the centre. Provided these elements have a high vertical permeability, the potentials of the nodes on the well-soil interface will all be the same, and the solution will be valid. In this problem the dummy elements are numbers 1-4, and a high effective vertical permeability is ensured by giving nodes 1-5 at the centre identical potentials. The line of dummy nodes is linked to the movements of node 10 at the intersection of the phreatic surface and the well. The inner portion of the mesh is shown schematically in Fig A-5.

10. A listing of the data input cards used in the analysis and a complete printout follows. The final phreatic surface location in the region of the well is shown in Fig A-5.

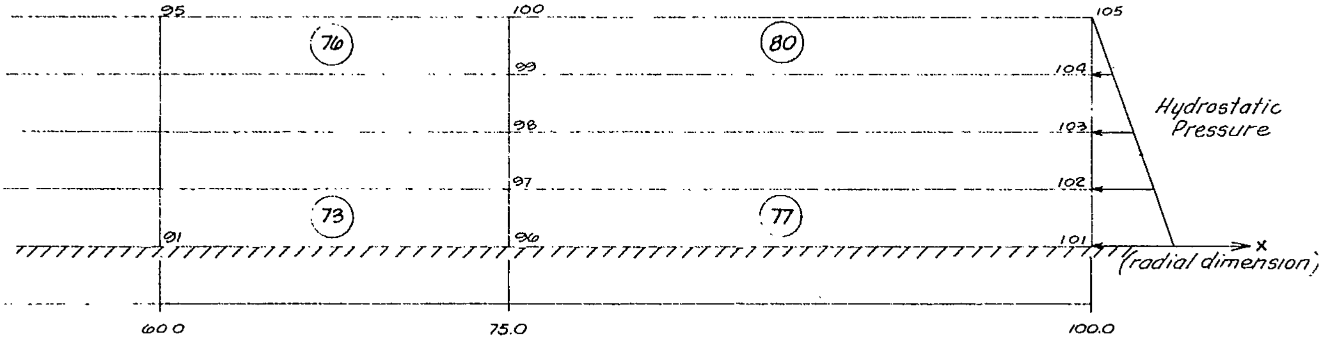


Fig A-2 (cont) - Sample problem 2 - finite element mesh.

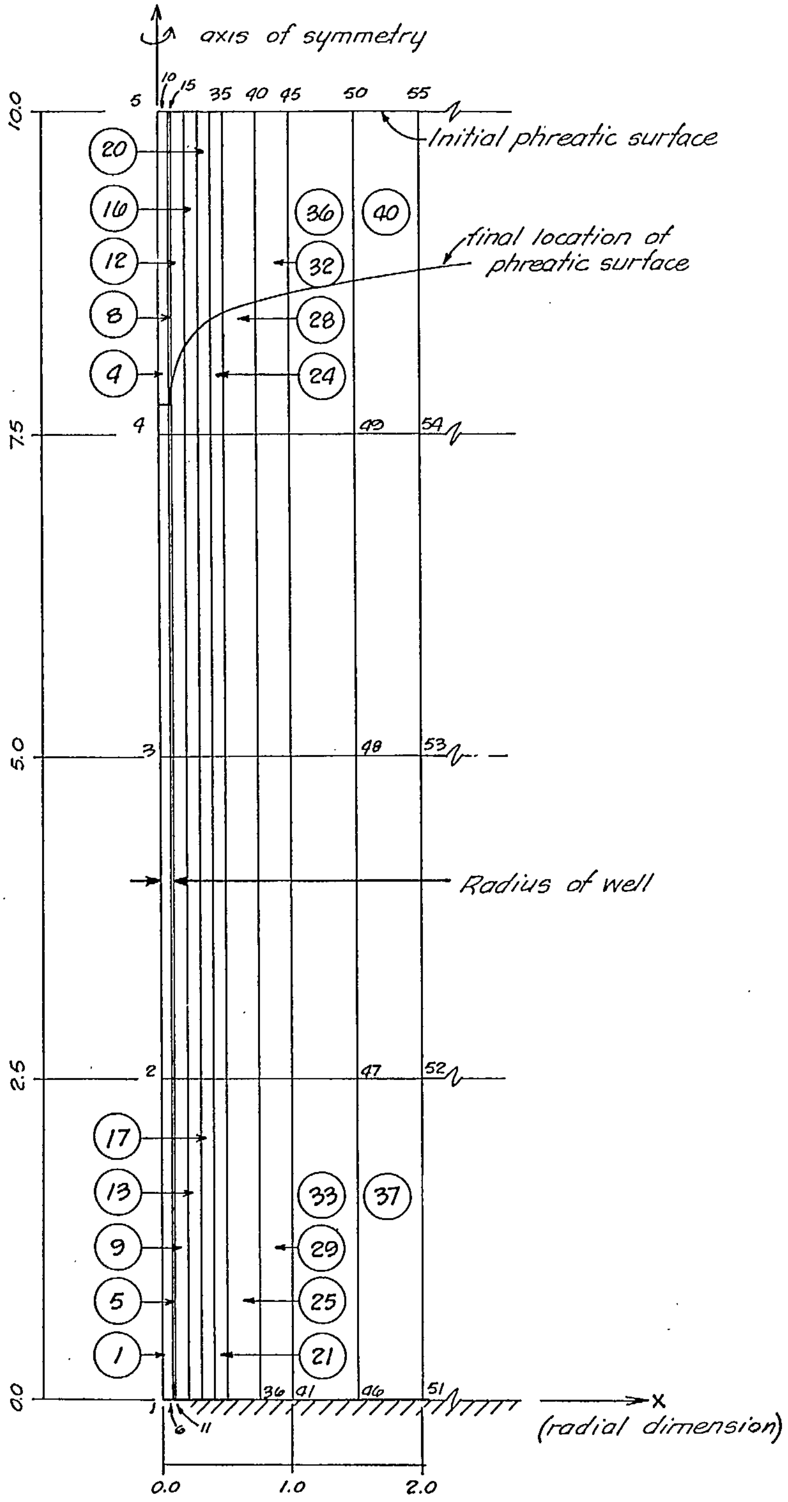
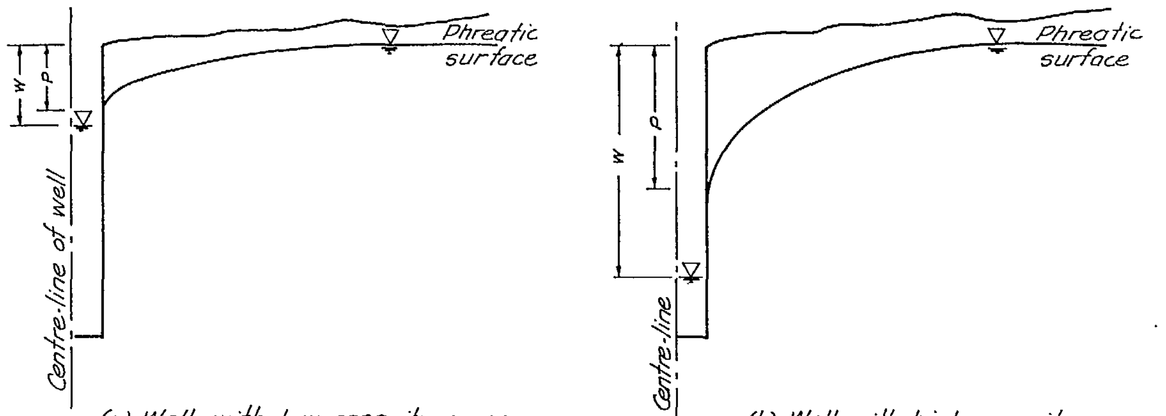
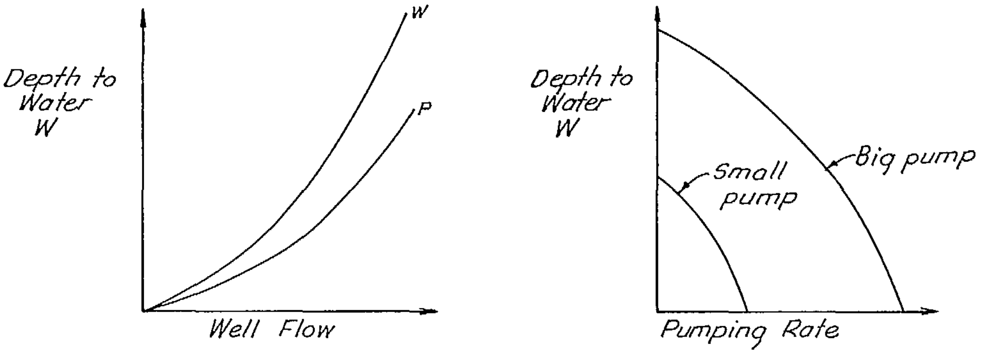


Fig A-3 - Sample problem 2 - inner mesh.



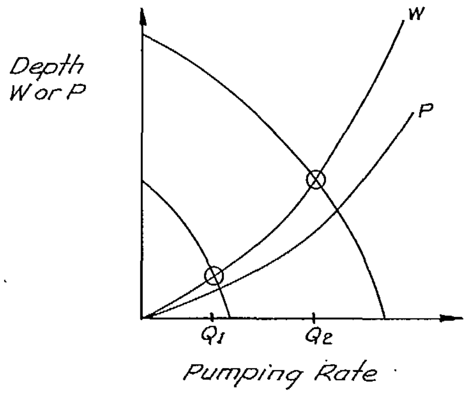
(a) Well with low capacity pump.

(b) Well with high capacity pump



(c) Formation characteristic curves.

(d) Pump characteristic curves



(e) Superimposed characteristic rate.

Fig A-4 - Well behaviour.

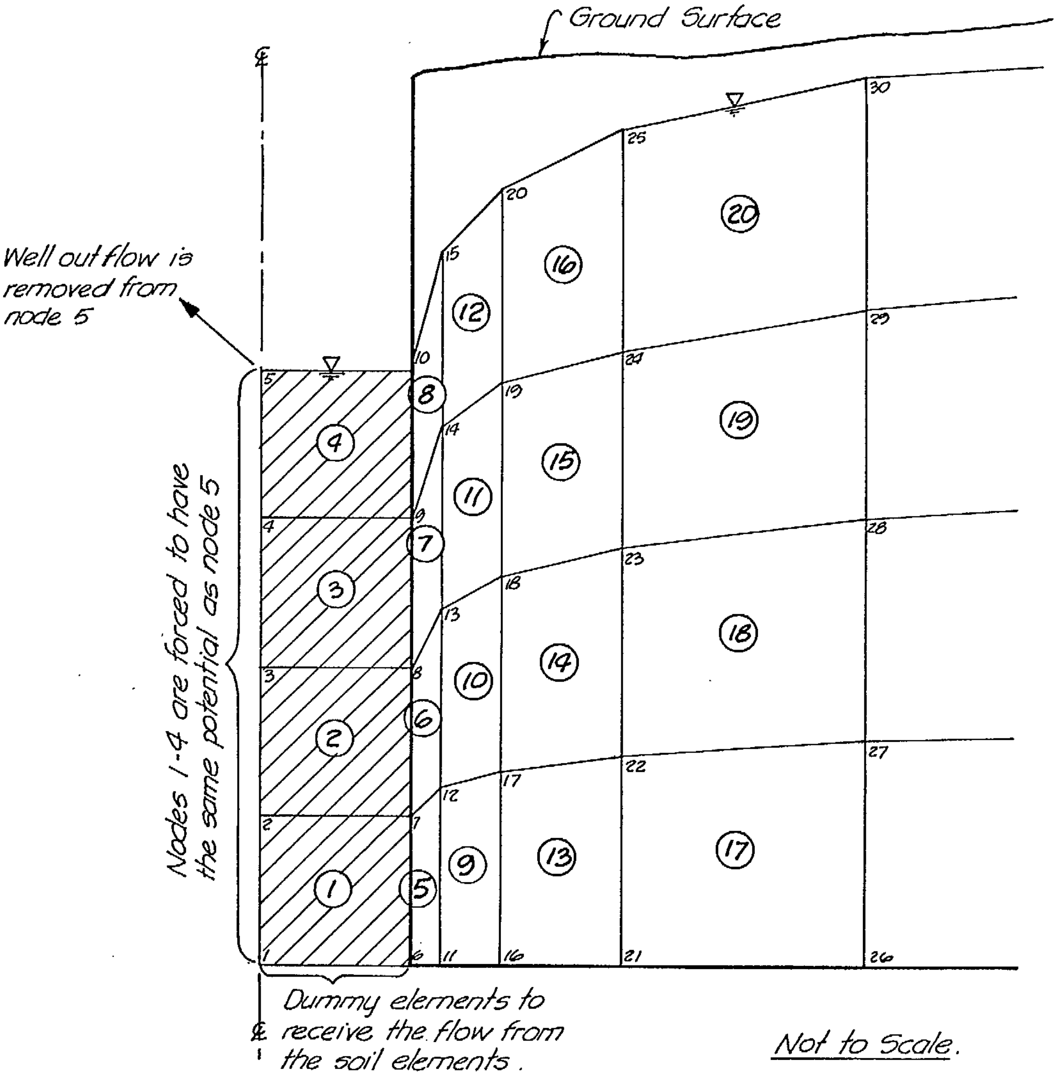


Fig A-5 - Finite element and boundary conditions used to model characteristics of the well.

SAMPLE PROBLEM 2 - INPUT DATA

```
START   SAMPLE 2     WELL DRAWDOWN WITH PHREATIC SURFACE
 $FPM
  NUMFSC#23,NUMEL#80,NUMNP#105,TOL#0.01,MAXIT#10,NTYPE#0
 $END
```

Name list $ FPM Cards

```
    1    5        0        0                                 
L   2    5        0      2.5                          0.25   10
L   3    5        0        5                          0.5    10
L   4    5        0      7.5                          0.75   10
L   5    Q        0       10      -3,183-6            1      10
    6    Q    .0762
*  10    Q    .0762       10
   11    Q       .1
*  15    Q       .1       10
   16    Q       .2
*  20    Q       .2       10
   21    Q       .3
*  25    Q       .3       10
   26    Q       .4
*  30    Q       .4       10
   31    Q       .5
*  35    Q       .5       10
   36    Q      .75
*  40    Q      .75       10
   41    Q      1.0
*  45    Q      1.0       10
   46           1.5
*  50           1.5       10
   51           2.0
*  55    Q      2.0       10
   56    Q      3.0
*  60    Q      3.0       10
   61    Q      5.0
*  65    Q      5.0       10
   66    Q      7.5
*  70    Q      7.5       10
   71    Q     10.0
*  75    Q     10.0       10
   76    Q     15.0
*  80    Q     15.0       10
   81    Q     25.0
*  85    Q     25.0       10
   86    Q     40.0
*  90    Q     40.0       10
   91    Q     60.0
*  95    Q     60.0       10
   96    Q     75.0
* 100    Q     75.0       10
  101  2 P      100                      10
  105    P      100       10
```

Node Cards

```
 .000001  .000001
```

Material Properties Card

```
    1    1    6    7    2    1
    5    6   11   12    7    1
    9   11   16   17   12    1
   13   16   21   22   17    1
   17   21   26   27   22    1
   21   26   31   32   27    1
   25   31   36   37   32    1
   29   36   41   42   37    1
   33   41   46   47   42    1
   37   46   51   52   47    1
   41   51   56   57   52    1
   45   56   61   62   57    1
   49   61   66   67   62    1
   53   66   71   72   67    1
   57   71   76   77   72    1
   61   76   81   82   77    1
   65   81   86   87   82    1
   69   86   91   92   87    1
   73   91   96   97   92    1
   77   96  101  102   97    1
   80   99  104  105  100    1
```

Element Cards

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 1

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                               *
*                                                                               *
*                    S E E P A G E   A N A L Y S I S                            *
*                                                                               *
*               SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE                 *
*                                                                               *
*                                                                               *
*                          01/26/76-15:13:59                                    *
*                                                                               *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 NUMBER OF NODAL POINTS-------105

 NUMBER OF ELEMENTS---------- 80

 NUMBER OF DIFF. MATERIALS---  1

 UNIT WEIGHT OF FLUID--------   1.0000+00

 REFERENCE FOR POTENTIALS----   0.0000

 CORRECTION FACTOR-----------   1.00000

 MAX. NO. ITERATIONS---------  10

 ERROR TOLERANCE-------------    .01000

 AXISYMMETRIC FLOW PROBLEM

ASGIO DYNAMIC E.R. - @ASG,T      TEMP15,017/   6770/TRK/   6770 .
ASGIO DYNAMIC E.R. - @USE     15,TEMP15 .
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 2

```
*                 SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE                          **    01/26/76-15:13:59      **      PAGE  2

NODE B.C.           X-ORD      Y-ORD      F                              NODE B.C.         X-ORD       Y-ORD      F

  1 (   5)          .0000      .0000   0.0000       0.0000       *    51  CONT        2.0000       .0000   0.0000        0.0000
  2 (   5)          .0000     2.5000   0.0000       0.0000       *    52  CONT        2.0000      2.5000   0.0000        0.0000
  3 (   5)          .0000     5.0000   0.0000       0.0000       *    53  CONT        2.0000      5.0000   0.0000        0.0000
  4 (   5)          .0000     7.5000   0.0000       0.0000       *    54  CONT        2.0000      7.5000   0.0000        0.0000
  5  CONT           .0000    10.0000  -3.1830-06    0.0000       *    55  CONT        2.0000     10.0000   0.0000        0.0000
  6  CONT           .0762      .0000   0.0000       0.0000       *    56  CONT        3.0000       .0000   0.0000        0.0000
  7  CONT           .0762     2.5000   0.0000       0.0000       *    57  CONT        3.0000      2.5000   0.0000        0.0000
  8  CONT           .0762     5.0000   0.0000       0.0000       *    58  CONT        3.0000      5.0000   0.0000        0.0000
  9  CONT           .0762     7.5000   0.0000       0.0000       *    59  CONT        3.0000      7.5000   0.0000        0.0000
 10  CONT           .0762    10.0000   0.0000       0.0000       *    60  CONT        3.0000     10.0000   0.0000        0.0000
 11  CONT           .1000      .0000   0.0000       0.0000       *    61  CONT        5.0000       .0000   0.0000        0.0000
 12  CONT           .1000     2.5000   0.0000       0.0000       *    62  CONT        5.0000      2.5000   0.0000        0.0000
 13  CONT           .1000     5.0000   0.0000       0.0000       *    63  CONT        5.0000      5.0000   0.0000        0.0000
 14  CONT           .1000     7.5000   0.0000       0.0000       *    64  CONT        5.0000      7.5000   0.0000        0.0000
 15  CONT           .1000    10.0000   0.0000       0.0000       *    65  CONT        5.0000     10.0000   0.0000        0.0000
 16  CONT           .2000      .0000   0.0000       0.0000       *    66  CONT        7.5000       .0000   0.0000        0.0000
 17  CONT           .2000     2.5000   0.0000       0.0000       *    67  CONT        7.5000      2.5000   0.0000        0.0000
 18  CONT           .2000     5.0000   0.0000       0.0000       *    68  CONT        7.5000      5.0000   0.0000        0.0000
 19  CONT           .2000     7.5000   0.0000       0.0000       *    69  CONT        7.5000      7.5000   0.0000        0.0000
 20  CONT           .2000    10.0000   0.0000       0.0000       *    70  CONT        7.5000     10.0000   0.0000        0.0000
 21  CONT           .3000      .0000   0.0000       0.0000       *    71  CONT       10.0000       .0000   0.0000        0.0000
 22  CONT           .3000     2.5000   0.0000       0.0000       *    72  CONT       10.0000      2.5000   0.0000        0.0000
 23  CONT           .3000     5.0000   0.0000       0.0000       *    73  CONT       10.0000      5.0000   0.0000        0.0000
 24  CONT           .3000     7.5000   0.0000       0.0000       *    74  CONT       10.0000      7.5000   0.0000        0.0000
 25  CONT           .3000    10.0000   0.0000       0.0000       *    75  CONT       10.0000     10.0000   0.0000        0.0000
 26  CONT           .4000      .0000   0.0000       0.0000       *    76  CONT       15.0000       .0000   0.0000        0.0000
 27  CONT           .4000     2.5000   0.0000       0.0000       *    77  CONT       15.0000      2.5000   0.0000        0.0000
 28  CONT           .4000     5.0000   0.0000       0.0000       *    78  CONT       15.0000      5.0000   0.0000        0.0000
 29  CONT           .4000     7.5000   0.0000       0.0000       *    79  CONT       15.0000      7.5000   0.0000        0.0000
 30  CONT           .4000    10.0000   0.0000       0.0000       *    80  CONT       15.0000     10.0000   0.0000        0.0000
 31  CONT           .5000      .0000   0.0000       0.0000       *    81  CONT       25.0000       .0000   0.0000        0.0000
 32  CONT           .5000     2.5000   0.0000       0.0000       *    82  CONT       25.0000      2.5000   0.0000        0.0000
 33  CONT           .5000     5.0000   0.0000       0.0000       *    83  CONT       25.0000      5.0000   0.0000        0.0000
 34  CONT           .5000     7.5000   0.0000       0.0000       *    84  CONT       25.0000      7.5000   0.0000        0.0000
 35  CONT           .5000    10.0000   0.0000       0.0000       *    85  CONT       25.0000     10.0000   0.0000        0.0000
 36  CONT           .7500      .0000   0.0000       0.0000       *    86  CONT       40.0000       .0000   0.0000        0.0000
 37  CONT           .7500     2.5000   0.0000       0.0000       *    87  CONT       40.0000      2.5000   0.0000        0.0000
 38  CONT           .7500     5.0000   0.0000       0.0000       *    88  CONT       40.0000      5.0000   0.0000        0.0000
 39  CONT           .7500     7.5000   0.0000       0.0000       *    89  CONT       40.0000      7.5000   0.0000        0.0000
 40  CONT           .7500    10.0000   0.0000       0.0000       *    90  CONT       40.0000     10.0000   0.0000        0.0000
 41  CONT          1.0000      .0000   0.0000       0.0000       *    91  CONT       60.0000       .0000   0.0000        0.0000
 42  CONT          1.0000     2.5000   0.0000       0.0000       *    92  CONT       60.0000      2.5000   0.0000        0.0000
 43  CONT          1.0000     5.0000   0.0000       0.0000       *    93  CONT       60.0000      5.0000   0.0000        0.0000
 44  CONT          1.0000     7.5000   0.0000       0.0000       *    94  CONT       60.0000      7.5000   0.0000        0.0000
 45  CONT          1.0000    10.0000   0.0000       0.0000       *    95  CONT       60.0000     10.0000   0.0000        0.0000
 46  CONT          1.5000      .0000   0.0000       0.0000       *    96  CONT       75.0000       .0000   0.0000        0.0000
 47  CONT          1.5000     2.5000   0.0000       0.0000       *    97  CONT       75.0000      2.5000   0.0000        0.0000
 48  CONT          1.5000     5.0000   0.0000       0.0000       *    98  CONT       75.0000      5.0000   0.0000        0.0000
 49  CONT          1.5000     7.5000   0.0000       0.0000       *    99  CONT       75.0000      7.5000   0.0000        0.0000
 50  CONT          1.5000    10.0000   0.0000       0.0000       *   100  CONT       75.0000     10.0000   0.0000        0.0000
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 3

```
*              SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE               **    01/26/76-15:13:59     **    PAGE  3

NODE B.C.        X-ORD          Y-ORD         F
101 PRESS.     100.0000        .0000    1.0000+01    0.0000        *
102 PRESS.     100.0000       2.5000    7.5000+00    0.0000        *
103 PRESS.     100.0000       5.0000    5.0000+00    0.0000        *
104 PRESS.     100.0000       7.5000    2.5000+00    0.0000        *
105 PRESS.     100.0000      10.0000    0.0000       0.0000        *
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 4

```
*              SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE              **    01/26/76-15:13:59     **    PAGE  4

                                   MATERIAL   PROPERTIES
LINE *      PROPERTIES      ABOVE          *       PROPERTIES      BELOW       *     DELIMITING NODE STRING
 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     *                                     *                                   *
  1  *     1.00-06     1.00-06      .0     *     1.00-06     1.00-06     .0    *  -1.000+10  1.000+20        1.000+10  1.000+20
     *                                     *                                   *   1.000+10 -1.000+10       -1.000+10 -1.000+10
     *                                     *                                   *
 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 5

```
*              SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE               **    01/26/76-15:13:59     **    PAGE  5

 ELMT        I         J         K         L        MAT

   1         1         6         7         2         1
   2         2         7         8         3         1
   3         3         8         9         4         1
   4         4         9        10         5         1
   5         6        11        12         7         1
   6         7        12        13         8         1
   7         8        13        14         9         1
   8         9        14        15        10         1
   9        11        16        17        12         1
  10        12        17        18        13         1
  11        13        18        19        14         1
  12        14        19        20        15         1
  13        16        21        22        17         1
  14        17        22        23        18         1
  15        18        23        24        19         1
  16        19        24        25        20         1
  17        21        26        27        22         1
  18        22        27        28        23         1
  19        23        28        29        24         1
  20        24        29        30        25         1
  21        26        31        32        27         1
  22        27        32        33        28         1
  23        28        33        34        29         1
  24        29        34        35        30         1
  25        31        36        37        32         1
  26        32        37        38        33         1
  27        33        38        39        34         1
  28        34        39        40        35         1
  29        36        41        42        37         1
  30        37        42        43        38         1
  31        38        43        44        39         1
  32        39        44        45        40         1
  33        41        46        47        42         1
  34        42        47        48        43         1
  35        43        48        49        44         1
  36        44        49        50        45         1
  37        46        51        52        47         1
  38        47        52        53        48         1
  39        48        53        54        49         1
  40        49        54        55        50         1
  41        51        56        57        52         1
  42        52        57        58        53         1
  43        53        58        59        54         1
  44        54        59        60        55         1
  45        56        61        62        57         1
  46        57        62        63        58         1
  47        58        63        64        59         1
  48        59        64        65        60         1
  49        61        66        67        62         1
  50        62        67        68        63         1
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 6

```
*             SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE                **    01/26/76-15:13:59    **    PAGE  6

ELMT          I          J          K          L         MAT

 51          63         68         69         64          1
 52          64         69         70         65          1
 53          66         71         72         67          1
 54          67         72         73         68          1
 55          68         73         74         69          1
 56          69         74         75         70          1
 57          71         76         77         72          1
 58          72         77         78         73          1
 59          73         78         79         74          1
 60          74         79         80         75          1
 61          76         81         82         77          1
 62          77         82         83         78          1
 63          78         83         84         79          1
 64          79         84         85         80          1
 65          81         86         87         82          1
 66          82         87         88         83          1
 67          83         88         89         84          1
 68          84         89         90         85          1
 69          86         91         92         87          1
 70          87         92         93         88          1
 71          88         93         94         89          1
 72          89         94         95         90          1
 73          91         96         97         92          1
 74          92         97         98         93          1
 75          93         98         99         94          1
 76          94         99        100         95          1
 77          96        101        102         97          1
 78          97        102        103         98          1
 79          98        103        104         99          1
 80          99        104        105        100          1


 * * * * * F R E E   S U R F A C E * * * * * *

   NODE    CORR. ANGLE       Y(MAX)

     2                  WILL HAVE  .25 TIMES THE MOVEMENTS OF NODE  10
     3                  WILL HAVE  .50 TIMES THE MOVEMENTS OF NODE  10
     4                  WILL HAVE  .75 TIMES THE MOVEMENTS OF NODE  10
     5                  WILL HAVE 1.00 TIMES THE MOVEMENTS OF NODE  10
    10        90.0        ************
    15        90.0        ************
    20        90.0        ************
    25        90.0        ************
    30        90.0        ************
    35        90.0        ************
    40        90.0        ************
    45        90.0        ************
    50        90.0        ************
    55        90.0        ************
    60        90.0        ************
    65        90.0        ************
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 7

```
      70        90.0        ************
      75        90.0        ************
      80        90.0        ************
      85        90.0        ************
      90        90.0        ************
      95        90.0        ************
     100        90.0        ************

CPU TIME USED IN S/R MESHIN =  2.234 SECONDS

TOTAL SPACE ACQUIRED FOR /MATRIX/ IS  2989

MAXIMUM BANDWIDTH =   7
ASGIO DYNAMIC E.R. - @ASG,T      TEMP14,F17/       1/TRK/       1 .
ASGIO DYNAMIC E.R. - @USE      14,TEMP14 .
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 8

```
*              SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE                  **    01/26/76-15:13:59     **     PAGE  7
TOTAL MESH AREA=  9.9999999+02   CPU TIME TO BUILD FLOW MATRIX =   6.030 SECONDS.


 * * * * *  ITERATION  1

TIME TO SOLVE MATRIX =  .187 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      1.32+00
PHREATIC SURFACE END-NODE 100 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0044  DX,DY=  -1.1921-07  -9.5604-02
PHREATIC SURFACE END-NODE  10 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  2.6212  DX,DY=   0.0000      -2.2410+00

      NODE      X-ORD     Y-ORD       PRESSURE       POTENTIAL       DX        DY       DP/DX     DP/DY
        10      .0762   10.0000     -.22649+01      .77351+01      .0000   -2.2410     .0000      .0000
        15      .1000   10.0000     -.21786+01      .78214+01     -.0000   -2.1786     .0000   -1.0000
        20      .2000   10.0000     -.19610+01      .80390+01     -.0000   -1.9610     .0000   -1.0000
        25      .3000   10.0000     -.18325+01      .81675+01     -.0000   -1.8325     .0000   -1.0000
        30      .4000   10.0000     -.17412+01      .82588+01     -.0000   -1.7412     .0000   -1.0000
        35      .5000   10.0000     -.16703+01      .83297+01     -.0000   -1.6703     .0000   -1.0000
        40      .7500   10.0000     -.15418+01      .84582+01     -.0000   -1.5418     .0000   -1.0000
        45     1.0000   10.0000     -.14505+01      .85495+01     -.0000   -1.4505     .0000   -1.0000
        50     1.5000   10.0000     -.13220+01      .86780+01     -.0000   -1.3220     .0000   -1.0000
        55     2.0000   10.0000     -.12307+01      .87693+01     -.0000   -1.2307     .0000   -1.0000
        60     3.0000   10.0000     -.11024+01      .88976+01     -.0000   -1.1024     .0000   -1.0000
        65     5.0000   10.0000     -.94189+00      .90581+01     -.0000    -.9419     .0000   -1.0000
        70     7.5000   10.0000     -.81400+00      .91860+01     -.0000    -.8140     .0000   -1.0000
        75    10.0000   10.0000     -.72285+00      .92772+01     -.0000    -.7228     .0000   -1.0000
        80    15.0000   10.0000     -.59530+00      .94047+01     -.0000    -.5953     .0000   -1.0000
        85    25.0000   10.0000     -.43602+04      .95640+01     -.0000    -.4360     .0000   -1.0000
        90    40.0000   10.0000     -.28906+00      .97109+01     -.0000    -.2891     .0000   -1.0000
        95    60.0000   10.0000     -.16171+00      .98383+01     -.0000    -.1617     .0000   -1.0000
       100    75.0000   10.0000     -.90965-01      .99090+01     -.0000    -.0956     .0000      .0000

TOTAL MESH AREA=  9.6807415+02   CPU TIME TO BUILD FLOW MATRIX =   6.230 SECONDS.


 * * * * *  ITERATION  2

TIME TO SOLVE MATRIX =  .205 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      5.42-02
PHREATIC SURFACE END-NODE 100 EXTRAPULATED FROM NEIGHBOUR AT SLOPE=   .0044  DX,DY=  -1.1921-07  -8.8401-04
PHREATIC SURFACE END-NODE  10 EXTRAPULATED FROM NEIGHBOUR AT SLOPE=  4.0286  DX,DY=   2.3283-10  -6.5304-02

      NODE      X-ORD     Y-ORD       PRESSURE       POTENTIAL       DX        DY       DP/DX     DP/DY
        10      .0762    7.7590     -.11491+00      .76441+01      .0000    -.0653     .0000      .0000
        15      .1000    7.8214     -.31807-01      .77896+01     -.0000    -.0318     .0000   -1.0000
        20      .2000    8.0390      .70980-01      .81100+01      .0000     .0710     .0000   -1.0000
        25      .3000    8.1675      .97856-01      .82653+01      .0000     .0979     .0000   -1.0000
        30      .4000    8.2588      .10299+00      .83618+01      .0000     .1030     .0000   -1.0000
        35      .5000    8.3297      .99909-01      .84296+01      .0000     .0999     .0000   -1.0000
        40      .7540    8.4582      .81662-01      .85398+01      .0000     .0817     .0000   -1.0000
        45     1.0000    8.5495      .61920-01      .86115+01      .0000     .0619     .0000   -1.0000
        50     1.5000    8.6780      .31163-01      .87091+01      .0000     .0312     .0000   -1.0000
        55     2.0000    8.7693      .10334-01      .87796+01      .0000     .0103     .0000   -1.0000
        60     3.0000    8.8976     -.11877-01      .88857+01     -.0000    -.0119     .0000   -1.0000
        65     5.0000    9.0581     -.24033-01      .90341+01     -.0000    -.0240     .0000   -1.0000
        70     7.5000    9.1860     -.24684-01      .91613+01     -.0000    -.0247     .0000   -1.0000
        75    10.0000    9.2772     -.22369-01      .92548+01     -.0000    -.0224     .0040   -1.0000
        80    15.0000    9.4047     -.16648-01      .93881+01     -.0000    -.0166     .0000   -1.0000
        85    25.0000    9.5640     -.91413-02      .95548+01     -.0000    -.0091     .0000   -1.0000
        90    40.0000    9.7109     -.39960-02      .97069+01     -.0000    -.0040     .0000   -1.0000
        95    60.0000    9.8383     -.12180-02      .98371+01     -.0000    -.0012     .0000   -1.0000
       100    75.0000    9.9044      .42938-02      .99087+01     -.0000    -.0009     .0000      .0000

TOTAL MESH AREA=  9.6761249+02   CPU TIME TO BUILD FLOW MATRIX =   6.440 SECONDS.


 * * * * *  ITERATION  3

TIME TO SOLVE MATRIX =  .175 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      2.88-02
PHREATIC SURFACE END-NODE 100 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0044  DX,DY=  -1.1921-07  -2.1281-05
PHREATIC SURFACE END-NODE  10 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=  4.2710  DX,DY=   2.3283-10   4.8677-02

      NODE      X-ORD     Y-ORD       PRESSURE       POTENTIAL       DX        DY       DP/DX     DP/DY
        10      .0762    7.6937     -.76215-02      .76861+01      .0000     .0487     .0000      .0000
        15      .1000    7.7896      .54446-01      .78441+01      .0000     .0544     .0000   -1.0000
        20      .2000    8.1100      .66951-01      .81769+01      .0000     .0670     .0000   -1.0000
        25      .3000    8.2653      .55987-01      .83213+01      .0000     .0560     .0000   -1.0000
        30      .4000    8.3618      .44251-01      .84060+01      .0000     .0443     .0000   -1.0000
        35      .5000    8.4296      .34404-01      .84640+01      .0000     .0344     .0000   -1.0000
        40      .7500    8.5398      .18108-01      .85580+01      .0000     .0181     .0000   -1.0000
        45     1.0000    8.6115      .89613-02      .86204+01      .0000     .0090     .0000   -1.0000
        50     1.5000    8.7091      .10011-02      .87101+01      .0000     .0010     .0000   -1.0000
        55     2.0000    8.7796     -.16115-02      .87780+01     -.0000    -.0016     .0000   -1.0000
        60     3.0000    8.8857     -.23312-02      .88834+01     -.0000    -.0023     .0000   -1.0000
        65     5.0000    9.0341     -.15695-02      .90325+01     -.0000    -.0016     .0000   -1.0000
        70     7.5000    9.1613     -.90988-03      .91604+01     -.0000    -.0009     .0000   -1.0000
        75    10.0000    9.2548     -.58652-03      .92542+01     -.0000    -.0006     .0000   -1.0000
        80    15.0000    9.3881     -.31070-03      .93877+01     -.0000    -.0003     .0000   -1.0000
        85    25.0000    9.5548     -.12157-03      .95547+01     -.0000    -.0001     .0000   -1.0000
        90    40.0000    9.7069     -.37218-04      .97069+01     -.0000    -.0000     .0000   -1.0000
        95    60.0000    9.8371     -.77802-05      .98371+01     -.0000    -.0000     .0000   -1.0000
       100    75.0000    9.9035      .51776-02      .99087+01     -.0000    -.0000     .0000      .0000

TOTAL MESH AREA=  9.6763348+02   CPU TIME TO BUILD FLOW MATRIX =   6.220 SECONDS.
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FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 9

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* * * * *  ITERATION  4

TIME TO SOLVE MATRIX =  .173 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =      5.64-03
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FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 10

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CONVERGENCE.
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FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 11

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*            SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE                  **     01/26/76-15:13:59       **     PAGE  8

    ELMT     X-ORD       Y-ORD      Z-ORD          X-FLOW           Y-FLOW        TOTAL FLOW   DIRN   MATERIAL

      1       .038        .968      4.355       -1.3324-05       -3.9676-10       1.3324-05 -180.00       1
      2       .038       2.903      5.323       -1.3387-05       -2.0686-09       1.3387-05 -179.99       1
      3       .038       4.839      6.291       -1.3340-05        3.8923-09       1.3340-05  179.98       1
      4       .038       6.775      7.259       -1.5417-05       -8.5652-08       1.5418-05 -179.68       1
      5       .068        .974       .974       -4.5058-06       -9.0889-10       4.5058-06 -179.99       1
      6       .088       2.922      2.922       -4.5033-06       -4.0322-09       4.5033-06 -179.95       1
      7       .088       4.871      4.871       -4.6256-06        6.4554-09       4.6256-06  179.92       1
      8       .088       6.819      6.819       -4.9824-06       -1.8174-07       4.9858-06 -177.91       1
      9       .150       1.001      1.001       -2.7079-06       -1.3313-09       2.7079-06 -179.97       1
     10       .150       3.004      3.004       -2.7008-06       -3.3512-09       2.7008-06 -179.93       1
     11       .150       5.007      5.007       -2.8553-06       -3.2293-09       2.8553-06 -179.94       1
     12       .150       7.009      7.009       -2.5921-06       -1.9459-07       2.5994-06 -175.71       1
     13       .250       1.031      1.031       -1.5954-06       -1.7048-09       1.5954-06 -179.94       1
     14       .250       3.093      3.093       -1.5992-06       -2.9207-09       1.5992-06 -179.90       1
     15       .250       5.156      5.156       -1.6819-06       -1.5763-08       1.6819-06 -179.46       1
     16       .250       7.218      7.218       -1.3530-06       -1.8562-07       1.3656-06 -172.19       1
     17       .350       1.045      1.045       -1.1338-06       -1.7943-09       1.1338-06 -179.91       1
     18       .350       3.136      3.136       -1.1398-06       -3.3410-09       1.1398-06 -179.83       1
     19       .350       5.227      5.227       -1.1852-06       -2.2341-08       1.1854-06 -178.92       1
     20       .350       7.318      7.318       -9.1065-07       -1.6317-07       9.2515-07 -169.84       1
     21       .450       1.054      1.054       -8.7991-07       -1.8164-09       8.7991-07 -179.88       1
     22       .450       3.163      3.163       -8.8605-07       -3.9292-09       8.8606-07 -179.75       1
     23       .450       5.272      5.272       -9.1223-07       -2.5847-08       9.1260-07 -178.38       1
     24       .450       7.381      7.381       -6.8543-07       -1.4247-07       7.0008-07 -168.26       1
     25       .625       1.064      1.064       -6.3725-07       -1.8231-09       6.3725-07 -179.84       1
     26       .625       3.192      3.192       -6.4250-07       -4.8800-09       6.4252-07 -179.56       1
     27       .625       5.319      5.319       -6.5164-07       -2.8025-08       6.5224-07 -177.54       1
     28       .625       7.447      7.447       -4.8362-07       -1.1505-07       4.9712-07 -166.62       1
     29       .875       1.074      1.074       -4.5279-07       -1.8332-09       4.5279-07 -179.77       1
     30       .875       3.221      3.221       -4.5657-07       -5.9895-09       4.5661-07 -179.25       1
     31       .875       5.368      5.368       -4.5477-07       -2.8616-08       4.5567-07 -176.40       1
     32       .875       7.516      7.516       -3.3769-07       -8.5235-08       3.4828-07 -165.83       1
     33      1.250       1.083      1.083       -3.1774-07       -1.6683-09       3.1774-07 -179.66       1
     34      1.250       3.249      3.249       -3.1963-07       -6.9152-09       3.1971-07 -178.76       1
     35      1.250       5.416      5.416       -3.1147-07       -2.6324-08       3.1258-07 -175.17       1
     36      1.250       7.582      7.582       -2.3672-07       -5.8874-08       2.4393-07 -166.03       1
     37      1.750       1.093      1.093       -2.2523-07       -1.9125-09       2.2524-87 -179.51       1
     38      1.750       3.279      3.279       -2.2542-07       -7.4459-09       2.2554-07 -178.11       1
     39      1.750       5.465      5.465       -2.1529-07       -2.2225-08       2.1643-07 -174.11       1
     40      1.750       7.651      7.651       -1.6975-07       -3.6680-08       1.7367-07 -167.81       1
     41      2.500       1.104      1.104       -1.5694-07       -1.8890-09       1.5695-07 -179.31       1
     42      2.500       3.312      3.312       -1.5569-07       -7.0495-09       1.5585-07 -177.41       1
     43      2.500       5.519      5.519       -1.4645-07       -1.6569-08       1.4739-07 -173.55       1
     44      2.500       7.727      7.727       -1.2191-07       -2.1296-08       1.2375-07 -170.09       1
     45      4.000       1.120      1.120       -9.5974-08       -1.5710-09       9.5987-08 -179.06       1
     46      4.000       3.359      3.359       -9.4104-08       -5.2500-09       9.4250-08 -176.81       1
     47      4.000       5.599      5.599       -8.6411-08       -9.4609-09       8.8916-08 -173.89       1
     48      4.000       7.838      7.838       -7.9492-08       -9.4938-09       8.0057-08 -173.19       1
     49      6.250       1.137      1.137       -5.9099-08       -9.8248-10       5.9108-08 -179.05       1
     50      6.258       3.411      3.411       -5.7852-08       -2.8875-09       5.7924-08 -177.14       1
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FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 12

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*            SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE              **    01/26/76-15:13:59     **     PAGE  9

   ELMT     X-ORD      Y-ORD      Z-ORD         X-FLOW          Y-FLOW       TOTAL FLOW   DIRN   MATERIAL

    51      6.250      5.685      5.685      -5.5342-06      -4.1694-09      5.5499-08 -175.69        1
    52      6.250      7.959      7.959      -5.2498-08      -3.7004-09      5.2629-08 -175.97        1
    53      8.750      1.151      1.151      -4.0872-08      -4.9715-10      4.0875-08 -179.30        1
    54      8.750      3.453      3.453      -4.0250-08      -1.3649-09      4.0273-08 -178.06        1
    55      8.750      5.755      5.755      -3.9179-08      -1.8218-09      3.9221-08 -177.34        1
    56      8.750      8.056      8.056      -3.8044-08      -1.6737-09      3.8081-08 -177.48        1
    57     12.500      1.165      1.165      -2.7762-08      -2.0475-10      2.7763-08 -179.58        1
    58     12.500      3.495      3.495      -2.7558-08      -5.5739-10      2.7563-08 -178.84        1
    59     12.500      5.826      5.826      -2.7219-08      -7.5440-10      2.7229-08 -178.41        1
    60     12.500      8.156      8.156      -2.6867-08      -7.4991-10      2.6878-08 -178.40        1
    61     20.000      1.184      1.184      -1.6867-08      -5.3916-11      1.6867-08 -179.82        1
    62     20.000      3.552      3.552      -1.6838-08      -1.5244-10      1.6838-08 -179.48        1
    63     20.000      5.920      5.920      -1.6786-08      -2.2628-10      1.6788-08 -179.23        1
    64     20.000      8.287      8.287      -1.6726-08      -2.7059-10      1.6728-08 -179.07        1
    65     32.500      1.204      1.204      -1.0177-08      -1.4552-11      1.0177-08 -179.92        1
    66     32.500      3.612      3.612      -1.0173-08      -4.3372-11      1.0173-08 -179.76        1
    67     32.500      6.019      6.019      -1.0164-08      -7.1196-11      1.0165-08 -179.60        1
    68     32.500      8.427      8.427      -1.0152-08      -9.7529-11      1.0153-08 -179.45        1
    69     50.000      1.221      1.221      -6.5155-09      -5.8975-12      6.5156-09 -179.95        1
    70     50.000      3.664      3.664      -6.5145-09      -1.7676-11      6.5145-09 -179.84        1
    71     50.000      6.107      6.107      -6.5124-09      -2.9104-11      6.5124-09 -179.74        1
    72     50.000      8.550      8.550      -6.5093-09      -4.0245-11      6.5094-09 -179.65        1
    73     67.500      1.234      1.234      -4.7790-09      -3.0269-12      4.7790-09 -179.96        1
    74     67.500      3.701      3.701      -4.7786-09      -9.1660-12      4.7786-09 -179.89        1
    75     67.500      6.169      6.169      -4.7776-09      -1.5234-11      4.7777-09 -179.82        1
    76     67.500      8.636      6.636      -4.7763-09      -2.1245-11      4.7763-09 -179.75        1
    77     87.500      1.244      1.244      -3.6565-09      -1.1795-12      3.6565-09 -179.98        1
    78     87.500      3.732      3.732      -3.6561-09      -3.5243-12      3.6561-09 -179.94        1
    79     87.500      6.220      6.220      -3.6551-09      -5.8549-12      3.6551-09 -179.91        1
    80     87.500      8.708      8.708      -3.6537-09      -8.2565-12      3.6537-09 -179.87        1

CPU TIME IN S/R ELFLOW =  1.478 SECONDS.
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FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 13

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*            SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE              **    01/26/76-15:13:59     **     PAGE 10

NODE  B.C.      X-ORD      Y-ORD      Z-ORD    PRESSURE    POTENTIAL     FLOW FN      OUTFLOW

   1(   5)       .00        .00        .00   6.3502+00   6.3502+00  -9.6112-08   0.0000
   2(   5)       .00       1.94       1.94   4.4146+00   6.3502+00  -7.3677-07   0.0000
   3(   5)       .00       3.87       3.87   2.4790+00   6.3502+00  -1.4155-06   0.0000
   4(   5)       .00       5.81       5.81   5.4343-01   6.3502+00  -2.0855-06   0.0000
   5 CONT.       .00       7.74       7.74  -1.3922+00   6.3502+00  -2.7818-06   3.1830-06
   6 CONT.       .08        .00        .00   7.3648+00   7.3648+00   0.0000    -8.5265-14
   7 CONT.       .08       1.94       1.94   5.4367+00   7.3663+00  -7.1898-07   0.0000
   8 CONT.       .08       3.87       3.87   3.5031+00   7.3743+00  -1.4190-06   3.4106-13
   9 CONT.       .08       5.81       5.81   1.5524+00   7.3593+00  -2.1146-06  -5.6843-14
  10 CONT.       .08       7.74       7.74  -5.1588-02   7.6908+00  -2.8478-06   1.4211-13
  11 CONT.       .10        .00        .00   7.4718+00   7.4718+00   0.0000     0.0000
  12 CONT.       .10       1.96       1.96   5.5127+00   7.4738+00  -7.3133-07  -1.0232-12
  13 CONT.       .10       3.92       3.92   3.5594+00   7.4815+00  -1.4561-06  -1.0800-12
  14 CONT.       .10       5.88       5.88   1.5883+00   7.4714+00  -2.2062-06  -1.4779-12
  15 CONT.       .10       7.84       7.84   4.0506-03   7.6481+00  -2.9612-06   0.0000
  16 CONT.       .20        .00        .00   7.7413+00   7.7413+00   0.0000     2.2737-13
  17 CONT.       .20       2.04       2.04   5.7004+00   7.7447+00  -7.7253-07  -5.1159-13
  18 CONT.       .20       4.09       4.09   3.6619+00   7.7503+00  -1.5447-06  -6.5370-13
  19 CONT.       .20       6.13       6.13   1.6410+00   7.7737+00  -2.3636-06  -6.5370-13
  20 CONT.       .20       8.18       8.18  -4.7520-04   8.1764+00  -3.0870-06  -1.7053-13
  21 CONT.       .30        .00        .00   7.9006+00   7.9006+00   0.0000    -1.1369-13
  22 CONT.       .30       2.08       2.08   5.8240+00   7.9043+00  -7.9484-07  -1.2506-12
  23 CONT.       .30       4.16       4.16   3.7500+00   7.9107+00  -1.5946-06   1.7053-12
  24 CONT.       .30       6.24       6.24   1.7114+00   7.9524+00  -2.4390-06  -4.5475-13
  25 CONT.       .30       8.32       8.32  -6.2535-03   8.3150+00  -3.1155-06   1.2506-12
  26 CONT.       .40        .00        .00   8.0139+00   8.0139+00   0.0000     2.2737-13
  27 CONT.       .40       2.10       2.10   5.9162+00   8.0177+00  -8.0939-07   6.8212-13
  28 CONT.       .40       4.20       4.20   3.6223+00   8.0254+00  -1.6260-06   9.6634-13
  29 CONT.       .40       6.30       6.30   1.7725+00   8.0771+00  -2.4773-06   1.7053-12
  30 CONT.       .40       8.41       8.41  -9.3864-03   8.3967+00  -3.1302-06  -1.3074-12
  31 CONT.       .50        .00        .00   8.1019+00   8.1019+00   0.0000    -6.8212-13
  32 CONT.       .50       2.12       2.12   5.9697+00   8.1058+00  -8.1909-07  -1.1369-12
  33 CONT.       .50       4.23       4.23   3.8827+00   8.1147+00  -1.6465-06   2.2737-13
  34 CONT.       .50       6.35       6.35   1.8240+00   8.1720+00  -2.4966-06   1.0232-12
  35 CONT.       .50       8.46       8.46  -1.0813-02   8.4532+00  -3.1367-06   6.8212-13
  36 CONT.       .75        .00        .00   8.2612+00   8.2612+00   0.0000    -2.2737-13
  37 CONT.       .75       2.14       2.14   6.1256+00   8.2651+00  -8.2997-07   2.2737-13
  38 CONT.       .75       4.28       4.28   3.9979+00   8.2769+00  -1.6681-06  -1.7053-13
  39 CONT.       .75       6.42       6.42   1.9204+00   8.3388+00  -2.5134-06  -1.8190-12
  40 CONT.       .75       8.56       8.56  -1.0926-02   8.5470+00  -3.1427-06  -1.5348-12
  41 CONT.      1.00        .00        .00   8.3743+00   8.3743+00   0.0000    -4.5475-13
  42 CONT.      1.00       2.16       2.16   6.2232+00   8.3783+00  -8.3618-07  -2.0464-12
  43 CONT.      1.00       4.31       4.31   4.0620+00   8.3922+00  -1.6795-06  -5.6843-13
  44 CONT.      1.00       6.47       6.47   1.9676+00   8.4531+00  -2.5134-06  -6.2528-13
  45 CONT.      1.00       8.62       8.62  -9.5365-03   8.6109+00  -3.1418-06  -6.2528-13
  46 CONT.      1.50        .00        .00   8.5331+00   8.5331+00   0.0000    -4.5475-13
  47 CONT.      1.50       2.18       2.18   6.3597+00   8.5372+00  -8.4207-07   5.6843-14
  48 CONT.      1.50       4.36       4.36   4.1942+00   8.5533+00  -1.6870-06  -4.5475-13
  49 CONT.      1.50       6.53       6.53   2.0738+00   8.6064+00  -2.5037-06  -1.4779-12
  50 CONT.      1.50       8.71       8.71  -6.6056-03   8.7035+00  -3.1370-06  -1.4779-12
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 14

```
*              SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE              **    01/26/76-15:13:59     **     PAGE 11

NODE  B.C.      X-ORD      Y-ORD      Z-ORD    PRESSURE   POTENTIAL    FLOW FN     OUTFLOW

  51 CONT.      2.00        .00        .00   8.6456+00   8.6456+00   0.0000      -2.2737-13
  52 CONT.      2.00       2.19       2.19   6.4554+00   8.6499+00  -8.4445-07   -9.0949-13
  53 CONT.      2.00       4.39       4.39   4.2773+00   8.6664+00  -1.6857-06   -1.2506-12
  54 CONT.      2.00       6.58       6.58   2.1269+00   8.7104+00  -2.4831-06   -2.8422-12
  55 CONT.      2.00       8.78       8.78  -4.4725-03   8.7735+00  -3.1258-06   -1.7053-12
  56 CONT.      3.00        .00        .00   8.8026+00   8.8026+00   0.0000      -6.8212-13
  57 CONT.      3.00       2.22       2.22   6.5859+00   8.8067+00  -8.4376-07   -2.2737-12
  58 CONT.      3.00       4.44       4.44   4.3796+00   8.8213+00  -1.6751-06   -3.1832-12
  59 CONT.      3.00       6.66       6.66   2.1879+00   8.8504+00  -2.4530-06   -1.9327-12
  60 CONT.      3.00       8.88       8.88  -2.1993-03   8.8812+00  -3.1125-06   -1.6485-12
  61 CONT.      5.00        .00        .00   8.9951+00   8.9951+00   0.0000      -1.0232-12
  62 CONT.      5.00       2.26       2.26   6.7399+00   8.9980+00  -8.3272-07   -1.3642-12
  63 CONT.      5.00       4.52       4.52   4.4906+00   9.0069+00  -1.6077-06   -2.7285-12
  64 CONT.      5.00       6.77       6.77   2.2458+00   9.0201+00  -2.4189-06   -1.2506-12
  65 CONT.      5.00       9.03       9.03  -7.2116-04   9.0318+00  -3.1287-06   -1.7053-12
  66 CONT.      7.50        .00        .00   9.1435+00   9.1435+00   0.0000       2.2737-13
  67 CONT.      7.50       2.29       2.29   6.8550+00   9.1451+00  -8.1697-07   -4.0927-12
  68 CONT.      7.50       4.58       4.58   4.5691+00   9.1493+00  -1.6190-06   -3.4106-12
  69 CONT.      7.50       6.87       6.87   2.2847+00   9.1550+00  -2.3928-06   -4.6612-12
  70 CONT.      7.50       9.16       9.16  -2.3943-04   9.1602+00  -3.1392-06   -1.3642-12
  71 CONT.     10.00        .00        .00   9.2461+00   9.2461+00   0.0000      -2.5011-12
  72 CONT.     10.00       2.31       2.31   6.9333+00   9.2468+00  -8.0700-07   -1.1369-12
  73 CONT.     10.00       4.63       4.63   4.6216+00   9.2489+00  -1.6024-06   -2.2737-13
  74 CONT.     10.00       6.94       6.94   2.3109+00   9.2516+00  -2.3757-06   -1.8190-12
  75 CONT.     10.00       9.25       9.25  -9.3784-05   9.2541+00  -3.1180-06   -1.1369-12
  76 CONT.     15.00        .00        .00   9.3852+00   9.3852+00   0.0000       3.2969-12
  77 CONT.     15.00       2.35       2.35   7.0384+00   9.3854+00  -7.9918-07   -9.0949-13
  78 CONT.     15.00       4.69       4.69   4.6921+00   9.3859+00  -1.5927-06    2.2737-12
  79 CONT.     15.00       7.04       7.04   2.3460+00   9.3868+00  -2.3744-06   -1.0459-11
  80 CONT.     15.00       9.39       9.39  -2.6250-05   9.3877+00  -3.1353-06   -1.3168-11
  81 CONT.     25.00        .00        .00   9.5539+00   9.5539+00   0.0000       4.5475-12
  82 CONT.     25.00       2.39       2.39   7.1653+00   9.5540+00  -7.9664-07    4.5475-12
  83 CONT.     25.00       4.78       4.78   4.7768+00   9.5541+00  -1.5964-06    4.5475-12
  84 CONT.     25.00       7.17       7.17   2.3883+00   9.5544+00  -2.3921-06    2.7285-12
  85 CONT.     25.00       9.55       9.55  -1.8531-05   9.5547+00  -3.1854-06   -3.0013-11
  86 CONT.     40.00        .00        .00   9.7066+00   9.7066+00   0.0000      -1.4552-11
  87 CONT.     40.00       2.43       2.43   7.2799+00   9.7066+00  -8.0290-07   -6.1846-11
  88 CONT.     40.00       4.85       4.85   4.8532+00   9.7067+00  -1.6075-06   -5.4570-11
  89 CONT.     40.00       7.28       7.28   2.4266+00   9.7068+00  -2.4141-06   -1.6735-10
  90 CONT.     40.00       9.71       9.71  -1.7361-05   9.7069+00  -3.2236-06   -7.2760-11
  91 CONT.     60.00        .00        .00   9.8369+00   9.8369+00   0.0000      -8.0036-11
  92 CONT.     60.00       2.46       2.46   7.3776+00   9.8369+00  -8.0556-07    1.4552-11
  93 CONT.     60.00       4.92       4.92   4.9184+00   9.8369+00  -1.6166-06   -2.1828-10
  94 CONT.     60.00       7.38       7.38   2.4592+00   9.8370+00  -2.4330-06   -7.2760-12
  95 CONT.     60.00       9.84       9.84  -1.5114-05   9.8370+00  -3.2593-06   -1.4552-10
  96 CONT.     75.00        .00        .00   9.9086+00   9.9086+00   0.0000       1.8190-11
  97 CONT.     75.00       2.48       2.48   7.4327+00   9.9086+00  -8.0299-07   -3.6380-11
  98 CONT.     75.00       4.95       4.45   4.9569+00   9.9086+00  -1.6206-06   -1.3097-10
  99 CONT.     75.00       7.43       7.43   2.4810+00   9.9086+00  -2.4022-06   -1.8917-10
 100 CONT.     75.00       9.90       9.90   5.1672-03   9.9087+00  -3.2574-06   -1.5280-10
```

FEFPM - SAMPLE PROBLEM NO. 2 - OUTPUT - 15

```
*              SAMPLE 2    WELL DRAWDOWN WITH PHREATIC SURFACE              **    01/26/76-15:13:59     **     PAGE 12

NODE  B.C.      X-ORD      Y-ORD      Z-ORD    PRESSURE   POTENTIAL    FLOW FN     OUTFLOW

 101 PRESS    100.00        .00        .00   1.0000+01   1.0000+01   8.1812-08   -3.9948-07
 102 PRESS    100.00       2.50       2.50   7.5000+00   1.0000+01  -7.8919-07   -7.9896-07
 103 PRESS    100.00       5.00       5.00   5.0000+00   1.0000+01  -1.6272-06   -7.9875-07
 104 PRESS    100.00       7.50       7.50   2.5000+00   1.0000+01  -2.4678-06   -7.9839-07
 105 PRESS    100.00      10.00      10.00   0.0000      1.0000+01  -3.3438-06   -3.8810-07

  SUMMARY  OF  EXTERNAL  FLOWS          INFLOW      OUTFLOW
PRESSURE NODES:                        3.184-06    0.000
CONTINUITY NODES:  SPECIFIED FLOW     0.000        3.183-06
                   OTHER FLOW         1.454-09     6.438-11

ASGIO DYNAMIC E.R. - #FREE TEMP14.          .
ASGIO DYNAMIC E.R. - #FREE TEMP15.          .


#FIN
```

SAMPLE PROBLEM 3 - OPEN PIT INFLOW

11. This sample case illustrates the application of the FEFPM program to a hypothetical open pit mine inflow problem. The general cross section geometry of the pit and the finite element mesh used in the analysis are illustrated in Fig A-6. Flow is assumed to be planar through this vertical cross section. The pit outline and the geology involved are typical of actual mines.

12. The size of this sample problem and the number of nodes and elements in the mesh should not be considered typical for seepage analyses. This sample problem was purposely set up to illustrate FEFPM program features and capabilities and was limited in size so that it could be included in this appendix. The node and element data is generated along vertical lines in the same manner as for the first two sample problems. The nodes, however, are no longer equally spaced to refine the element size close to the phreatic surface.

13. The geological domains are specified with material definition lines and thus the appropriate material type for each element is automatically determined by the location of its centroid. A material region with anisotropic permeabilities runs as an inclined band across the flow regime. The y-axis is the centre-line of the pit and is presumed to be a streamline, ie, a non-conducting boundary. The base of the problem is at some distance below the pit and is assumed to be impermeable. Also included in this analysis is the effect of horizontal drains at the toe of the slope.

14. A listing of the complete set of input data cards as well as a copy of the printout from the analysis are included. The final phreatic surface location is indicated in Fig A-6 and the marked effect on it of the anisotropic material zone should be noted. It should also be noted that the horizontal toe drains do not contribute significantly to drainage of the pit slope.

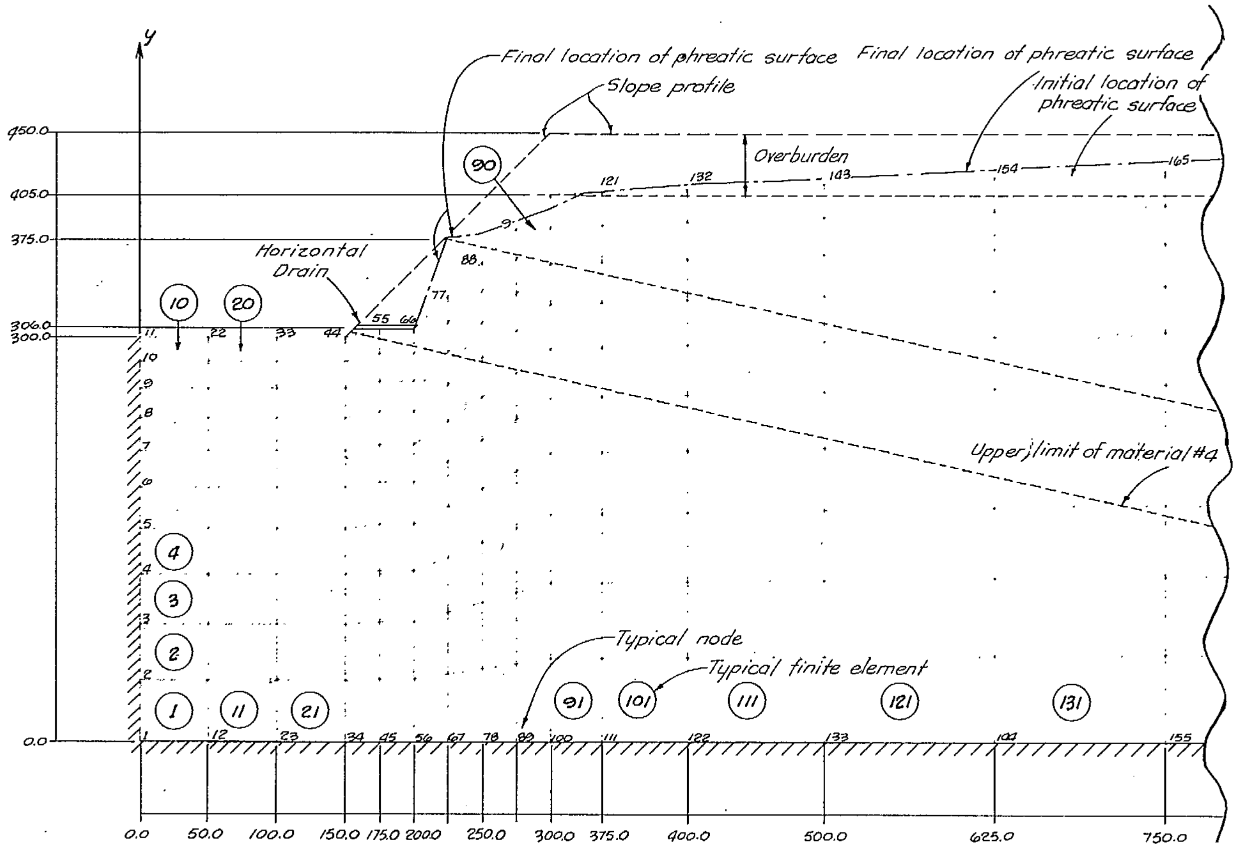

Fig A-6 - Sample problem 3 - mesh geometry and boundary conditions.

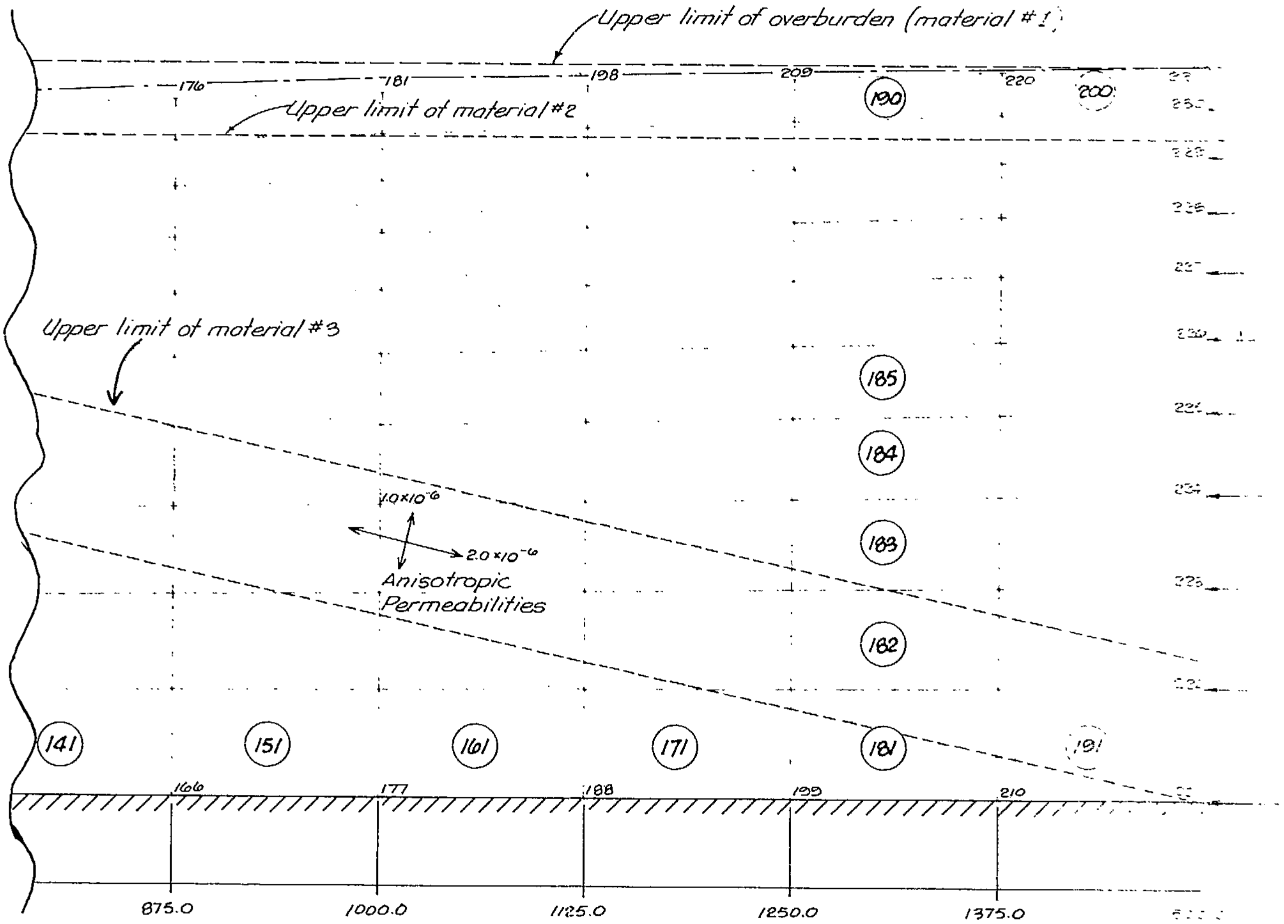

Fig A-6 (cont) - Sample problem 3 - mesh geometry and boundary conditions.

SAMPLE PROBLEM 3 - INPUT DATA

```
START  SAMPLE 3      OPEN PIT INFLOW
 $FPM
    TOL#0.1,MAXIT#10,NUMFSC#15,NUMNP#231,NUMEL#200,NUMMAT#4,NTYPE#0,
 $END
```

Name list
$FPM Cards

```
    1    Q        0         0                        0.9
   11    P        0       300
   12    Q       50         0                        0.9
   22    P       50       300
   23    Q      100         0                        0.9
   33    P      100       300
   34    Q      150         0                        0.9
   44    P      150       300
   45    Q      175         0                        0.9
   55    Q      175       306      325
   56    Q      200         0                        0.9
   66    P      200       306
   67    Q      225         0                        0.9
*  77    Q      225    330.75      375
   78    Q      250         0                        0.9
*  88    Q      250    355.55      400
   89    Q      275         0                        0.9
*  99    Q      275    380.25      425
  100    Q      300         0                        0.9
* 110    Q      300       405      450
  111    Q    337.5         0                        0.9
* 121    Q    337.5    406.41      450
  122    Q      400         0                        0.9
* 132    Q      400    408.75      450
  133    Q      500         0                        0.9
* 143    Q      500    412.50      450
  144    Q      625         0                        0.9
* 154    Q      625    417.19      450
  155    Q      750         0                        0.9
* 165    Q      750    421.88      450
  166    Q      875         0                        0.9
* 176    Q      875    426.56      450
  177    Q     1000         0                        0.9
* 187    Q     1000    431.25      450
  188    Q     1125         0                        0.9
* 198    Q     1125    435.94      450
  199    Q     1250         0                        0.9
* 209    Q     1250    440.63      450
  210    Q     1375         0                        0.9
* 220    Q     1375    445.31      450
  221  2 P     1500         0               450      0.9
  231    P     1500       450
```

Node
Cards

```
                          2.0-05   2.0-05       -3
         255        405      300        450    1500      450
   2.0-05                 2.5-06   2.5-06       -3
         225        375      255        405    1500      405
   2.5-06  2.5-06         2.0-06   1.0-06 167.2 -3
         155        305      225        375    1500    85.87
   2.0-06  1.0-06 167.2   5.0-07   5.0-07 1.0-8 -4
           0        300      150        300     155      305     1500        0
```

Material
definition
(Line)
Cards

```
    1     1    12    13     2
   11    12    23    24    13
   21    23    34    35    24
   31    34    45    46    35
   41    45    56    57    46
   51    56    67    68    57
   61    67    78    79    68
   71    78    89    90    79
   81    89   100   101    90
   91   100   111   112   101
  101   111   122   123   112
  111   122   133   134   123
  121   133   144   145   134
  131   144   155   156   145
  141   155   166   167   156
  151   166   177   178   167
  161   177   188   189   178
  171   188   199   200   189
  181   199   210   211   200
  191   210   221   222   211
  200   219   230   231   220
```

Element
Cards

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 1

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                             *
*                                                                             *
*                      S E E P A G E    A N A L Y S I S                       *
*                                                                             *
*          S A M P L E   3          O P E N   P I T   I N F L O W             *
*                                                                             *
*                                                                             *
*                           01/28/76-11:52:12                                 *
*                                                                             *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 NUMBER OF NODAL POINTS-------231

 NUMBER OF ELEMENTS-----------200

 NUMBER OF DIFF. MATERIALS---  4

 UNIT WEIGHT OF FLUID---------   1.0000+00

 REFERENCE FOR POTENTIALS----   0.0000


 CORRECTION FACTOR-----------   1.00000

 MAX. NO. ITERATIONS---------  10

 ERROR TOLERANCE-------------    .10000


 AXISYMMETRIC FLOW PROBLEM

ASGIO DYNAMIC E.R. - @ASG,T       TEMP15*,017/  16850/TRK/  16850 .
ASGIO DYNAMIC F.R. - @USE      15,TEMP15 .
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 2

```
*         S A M P L E   3         O P E N   P I T   I N F L O W              **    01/28/76-11:52:12     **     PAGE  2

NODE B.C.        X-ORD       Y-ORD        F                                 NODE B.C.       X-ORD       Y-ORD        F

  1   CONT       .0000       .0000    0.0000      0.0000       *     51  CONT     175.0000    220.1356   0.0000       0.0000
  2   CONT       .0000     46.0602    0.0000      0.0000       *     52  CONT     175.0000    245.1034   0.0000       0.0000
  3   CONT       .0000     87.5144    0.0000      0.0000       *     53  CONT     175.0000    267.5745   0.0000       0.0000
  4   CONT       .0000    124.8231    0.0000      0.0000       *     54  CONT     175.0000    287.7984   0.0000       0.0000
  5   CONT       .0000    158.4010    0.0000      0.0000       *     55  CONT     175.0000    306.0000   0.0000       0.0000
  6   CONT       .0000    188.6211    0.0000      0.0000       *     56  CONT     200.0000       .0000   0.0000       0.0000
  7   CONT       .0000    215.8192    0.0000      0.0000       *     57  CONT     200.0000     46.9814   0.0000       0.0000
  8   CONT       .0000    240.2975    0.0000      0.0000       *     58  CONT     200.0000     89.2647   0.0000       0.0000
  9   CONT       .0000    262.3279    0.0000      0.0000       *     59  CONT     200.0000    127.3196   0.0000       0.0000
 10   CONT       .0000    282.1553    0.0000      0.0000       *     60  CONT     200.0000    161.5690   0.0000       0.0000
 11 PRESS.       .0000    300.0000    0.0000      0.0000       *     61  CONT     200.0000    192.3935   0.0000       0.0000
 12   CONT     50.0000       .0000    0.0000      0.0000       *     62  CONT     200.0000    220.1356   0.0000       0.0000
 13   CONT     50.4000     46.0602    0.0000      0.0000       *     63  CONT     200.0000    245.1034   0.0000       0.0000
 14   CONT     50.0000     87.5144    0.0000      0.0000       *     64  CONT     200.0000    267.5745   0.0000       0.0000
 15   CONT     50.0000    124.8231    0.0000      0.0000       *     65  CONT     200.0000    287.7984   0.0000       0.0000
 16   CONT     50.0000    158.4010    0.0000      0.0000       *     66 PRESS.    200.0000    306.0000   0.0000       0.0000
 17   CONT     50.0000    188.6211    0.0000      0.0000       *     67  CONT     225.0000       .0000   0.0000       0.0000
 18   CONT     50.0000    215.8192    0.0000      0.0000       *     68  CONT     225.0000     50.7814   0.0000       0.0000
 19   CONT     50.0000    240.2975    0.0000      0.0000       *     69  CONT     225.0000     96.4846   0.0000       0.0000
 20   CONT     50.0000    262.3279    0.0000      0.0000       *     70  CONT     225.0000    137.6175   0.0000       0.0000
 21   CONT     50.0000    282.1553    0.0000      0.0000       *     71  CONT     225.0000    174.6371   0.0000       0.0000
 22 PRESS.     50.0000    300.0000    0.0000      0.0000       *     72  CONT     225.0000    207.9548   0.0000       0.0000
 23   CONT    100.0000       .0000    0.0000      0.0000       *     73  CONT     225.0000    237.9407   0.0000       0.0000
 24   CONT    100.0000     46.0602    0.0000      0.0000       *     74  CONT     225.0000    264.9280   0.0000       0.0000
 25   CONT    100.0000     87.5144    0.0000      0.0000       *     75  CONT     225.0000    289.2165   0.0000       0.0000
 26   CONT    100.0000    124.8231    0.0000      0.0000       *     76  CONT     225.0000    311.0763   0.0000       0.0000
 27   CONT    100.0000    158.4010    0.0000      0.0000       *     77  CONT     225.0000    330.7500   0.0000       0.0000
 28   CONT    100.0000    188.6211    0.0000      0.0000       *     78  CONT     250.0000       .0000   0.0000       0.0000
 29   CONT    100.0000    215.8192    0.0000      0.0000       *     79  CONT     250.0000     54.5890   0.0000       0.0000
 30   CONT    100.0000    240.2975    0.0000      0.0000       *     80  CONT     250.0000    103.7191   0.0000       0.0000
 31   CONT    100.0000    262.3279    0.0000      0.0000       *     81  CONT     250.0000    147.9362   0.0000       0.0000
 32   CONT    100.0000    282.1553    0.0000      0.0000       *     82  CONT     250.0000    187.7316   0.0000       0.0000
 33 PRESS.    100.0000    300.0000    0.0000      0.0000       *     83  CONT     250.0000    223.5475   0.0000       0.0000
 34   CONT    150.0000       .0000    0.0000      0.0000       *     84  CONT     250.0000    255.7817   0.0000       0.0000
 35   CONT    150.0000     46.0602    0.0000      0.0000       *     85  CONT     250.0000    284.7926   0.0000       0.0000
 36   CONT    150.0000     87.5144    0.0000      0.0000       *     86  CONT     250.0000    310.9023   0.0000       0.0000
 37   CONT    150.0000    124.8231    0.0000      0.0000       *     87  CONT     250.0000    334.4011   0.0000       0.0000
 38   CONT    150.0000    158.4010    0.0000      0.0000       *     88  CONT     250.0000    355.5500   0.0000       0.0000
 39   CONT    150.0000    188.6211    0.0000      0.0000       *     89  CONT     275.0000       .0000   0.0000       0.0000
 40   CONT    150.0000    215.8192    0.0000      0.0000       *     90  CONT     275.0000     58.3813   0.0000       0.0000
 41   CONT    150.0000    240.2975    0.0000      0.0000       *     91  CONT     275.0000    110.9245   0.0000       0.0000
 42   CONT    150.0000    262.3279    0.0000      0.0000       *     92  CONT     275.0000    158.2133   0.0000       0.0000
 43   CONT    150.0000    282.1553    0.0000      0.0000       *     93  CONT     275.0000    200.7733   0.0000       0.0000
 44 PRESS.    150.0000    300.0000    0.0000      0.0000       *     94  CONT     275.0000    239.0773   0.0000       0.0000
 45   CONT    175.0000       .0000    0.0000      0.0000       *     95  CONT     275.0000    273.5508   0.0000       0.0000
 46   CONT    175.0000     46.9814    0.0000      0.0000       *     96  CONT     275.0000    304.5771   0.0000       0.0000
 47   CONT    175.0000     89.2647    0.0000      0.0000       *     97  CONT     275.0000    332.5007   0.0000       0.0000
 48   CONT    175.0000    127.3196    0.0000      0.0000       *     98  CONT     275.0000    357.6319   0.0000       0.0000
 49   CONT    175.0000    161.5690    0.0000      0.0000       *     99  CONT     275.0000    380.2500   0.0000       0.0000
 50   CONT    175.0000    192.3935    0.0000      0.0000       *    100  CONT     300.0000       .0000   0.0000       0.0000
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 3

```
*          S A M P L E   3          O P E N   P I T   I N F L O W              **    01/28/76-11:52:12     **      PAGE  3

NODE B.C.        X-ORD       Y-ORD        F                                NODE B.C.        X-ORD       Y-ORD        F

101  CONT      300.0000     62.1813   0.0000        0.0000        *    151  CONT      625.0000    334.1657   0.0000        0.0000
102  CONT      300.0000    118.1444   0.0000        0.0000        *    152  CONT      625.0000    364.8020   0.0000        0.0000
103  CONT      300.0000    168.5112   0.0000        0.0000        *    153  CONT      625.0000    392.3746   0.0000        0.0000
104  CONT      300.0000    213.8414   0.0000        0.0000        *    154  CONT      625.0000    417.1900   0.0000        0.0000
105  CONT      300.0000    254.6385   0.0000        0.0000        *    155  CONT      750.0000       .0000   0.0000        0.0000
106  CONT      300.0000    291.3559   0.0000        0.0000        *    156  CONT      750.0000     64.7729   0.0000        0.0000
107  CONT      300.0000    324.4016   0.0000        0.0000        *    157  CONT      750.0000    123.0686   0.0000        0.0000
108  CONT      300.0000    354.1427   0.0000        0.0000        *    158  CONT      750.0000    175.5346   0.0000        0.0000
109  CONT      300.0000    380.9097   0.0000        0.0000        *    159  CONT      750.0000    222.7541   0.0000        0.0000
110  CONT      300.0000    405.0000   0.0000        0.0000        *    160  CONT      750.0000    265.2516   0.0000        0.0000
111  CONT      337.5000       .0000   0.0000        0.0000        *    161  CONT      750.0000    303.4994   0.0000        0.0000
112  CONT      337.5000     62.3978   0.0000        0.0000        *    162  CONT      750.0000    337.9223   0.0000        0.0000
113  CONT      337.5000    118.5557   0.0000        0.0000        *    163  CONT      750.0000    368.9030   0.0000        0.0000
114  CONT      337.5000    169.0979   0.0000        0.0000        *    164  CONT      750.0000    396.7856   0.0000        0.0000
115  CONT      337.5000    214.5859   0.0000        0.0000        *    165  CONT      750.0000    421.8800   0.0000        0.0000
116  CONT      337.5000    255.5250   0.0000        0.0000        *    166  CONT      875.0000       .0000   0.0000        0.0000
117  CONT      337.5000    292.3703   0.0000        0.0000        *    167  CONT      875.0000     65.4915   0.0000        0.0000
118  CONT      337.5000    325.5310   0.0000        0.0000        *    168  CONT      875.0000    124.4338   0.0000        0.0000
119  CONT      337.5000    355.3757   0.0000        0.0000        *    169  CONT      875.0000    177.4819   0.0000        0.0000
120  CONT      337.5000    382.2358   0.0000        0.0000        *    170  CONT      875.0000    225.2251   0.0000        0.0000
121  CONT      337.5000    406.4100   0.0000        0.0000        *    171  CONT      875.0000    268.1941   0.0000        0.0000
122  CONT      400.0000       .0000   0.0000        0.0000        *    172  CONT      875.0000    306.8661   0.0000        0.0000
123  CONT      400.0000     62.7570   0.0000        0.0000        *    173  CONT      875.0000    341.6710   0.0000        0.0000
124  CONT      400.0000    119.2383   0.0000        0.0000        *    174  CONT      875.0000    372.9953   0.0000        0.0000
125  CONT      400.0000    170.0715   0.0000        0.0000        *    175  CONT      875.0000    401.1673   0.0000        0.0000
126  CONT      400.0000    215.6214   0.0000        0.0000        *    176  CONT      875.0000    426.5600   0.0000        0.0000
127  CONT      400.0000    256.9963   0.0000        0.0000        *    177  CONT     1000.0000       .0000   0.0000        0.0000
128  CONT      400.0000    294.0537   0.0000        0.0000        *    178  CONT     1000.0000     66.2115   0.0000        0.0000
129  CONT      400.0000    327.4053   0.0000        0.0000        *    179  CONT     1000.0000    125.8019   0.0000        0.0000
130  CONT      400.0000    357.4218   0.0000        0.0000        *    180  CONT     1000.0000    179.4333   0.0000        0.0000
131  CONT      400.0000    384.4367   0.0000        0.0000        *    181  CONT     1000.0000    227.7015   0.0000        0.0000
132  CONT      400.0000    408.7500   0.0000        0.0000        *    182  CONT     1000.0000    271.1429   0.0000        0.0000
133  CONT      500.0000       .0000   0.0000        0.0000        *    183  CONT     1000.0000    310.2401   0.0000        0.0000
134  CONT      500.0000     63.3328   0.0000        0.0000        *    184  CONT     1000.0000    345.4276   0.0000        0.0000
135  CONT      500.0000    120.3323   0.0000        0.0000        *    185  CONT     1000.0000    377.0964   0.0000        0.0000
136  CONT      500.0000    171.6318   0.0000        0.0000        *    186  CONT     1000.0000    405.5983   0.0000        0.0000
137  CONT      500.0000    217.8014   0.0000        0.0000        *    187  CONT     1000.0000    431.2500   0.0000        0.0000
138  CONT      500.0000    259.3540   0.0000        0.0000        *    188  CONT     1125.0000       .0000   0.0000        0.0000
139  CONT      500.0000    296.7514   0.0000        0.0000        *    189  CONT     1125.0000     66.9316   0.0000        0.0000
140  CONT      500.0000    330.4090   0.0000        0.0000        *    190  CONT     1125.0000    127.1701   0.0000        0.0000
141  CONT      500.0000    360.7009   0.0000        0.0000        *    191  CONT     1125.0000    181.3847   0.0000        0.0000
142  CONT      500.0000    387.9636   0.0000        0.0000        *    192  CONT     1125.0000    230.1778   0.0000        0.0000
143  CONT      500.0000    412.5000   0.0000        0.0000        *    193  CONT     1125.0000    274.0916   0.0000        0.0000
144  CONT      625.0000       .0000   0.0000        0.0000        *    194  CONT     1125.0000    313.6141   0.0000        0.0000
145  CONT      625.0000     64.0528   0.0000        0.0000        *    195  CONT     1125.0000    349.1843   0.0000        0.0000
146  CONT      625.0000    121.7004   0.0000        0.0000        *    196  CONT     1125.0000    381.1975   0.0000        0.0000
147  CONT      625.0000    173.5832   0.0000        0.0000        *    197  CONT     1125.0000    410.0093   0.0000        0.0000
148  CONT      625.0000    220.2777   0.0000        0.0000        *    198  CONT     1125.0000    435.9400   0.0000        0.0000
149  CONT      625.0000    262.3028   0.0000        0.0000        *    199  CONT     1250.0000       .0000   0.0000        0.0000
150  CONT      625.0000    300.1254   0.0000        0.0000        *    200  CONT     1250.0000     67.6517   0.0000        0.0000
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 4

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*          S A M P L E   3 .        O P E N   P I T   I N F L O W              **    01/28/76-11:52:12     **      PAGE  4

NODE B.C.        X-ORD       Y-ORD        F
201  CONT     1250.0000    128.5382   0.0000        0.0000        *
202  CONT     1250.0000    183.3361   0.0000        0.0000        *
203  CONT     1250.0000    232.6542   0.0000        0.0000        *
204  CONT     1250.0000    277.0494   0.0000        0.0000        *
205  CONT     1250.0000    316.9881   0.0000        0.0000        *
206  CONT     1250.0000    352.9409   0.0000        0.0000        *
207  CONT     1250.0000    385.2985   0.0000        0.0000        *
208  CONT     1250.0000    414.0204   0.0000        0.0000        *
209  CONT     1250.0000    440.6300   0.0000        0.0000        *
210  CONT     1375.0000       .0000   0.0000        0.0000        *
211  CONT     1375.0000     68.3702   0.0000        0.0000        *
212  CONT     1375.0000    129.9034   0.0000        0.0000        *
213  CONT     1375.0000    185.2833   0.0000        0.0000        *
214  CONT     1375.0000    235.1252   0.0000        0.0000        *
215  CONT     1375.0000    279.9629   0.0000        0.0000        *
216  CONT     1375.0000    320.3548   0.0000        0.0000        *
217  CONT     1375.0000    356.6896   0.0000        0.0000        *
218  CONT     1375.0000    389.3908   0.0000        0.0000        *
219  CONT     1375.0000    418.8220   0.0000        0.0000        *
220  CONT     1375.0000    445.3100   0.0000        0.0000        *
221 PRESS.    1500.0000       .0000   4.5000+02     0.0000        *
222 PRESS.    1500.0000     69.0903   3.8091+02     0.0000        *
223 PRESS.    1500.0000    131.2716   3.1873+02     0.0000        *
224 PRESS.    1500.0000    187.2347   2.6277+02     0.0000        *
225 PRESS.    1500.0000    237.6015   2.1240+02     0.0000        *
226 PRESS.    1500.0000    282.9517   1.6707+02     0.0000        *
227 PRESS.    1500.0000    323.7288   1.2627+02     0.0000        *
228 PRESS.    1500.0000    360.4462   8.9554+01     0.0000        *
229 PRESS.    1500.0000    393.4919   5.6508+01     0.0000        *
230 PRESS.    1500.0000    423.2330   2.6767+01     0.0000        *
231 PRESS.    1500.0000    450.0000   0.0000        0.0000        *
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 5

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*          S A M P L E   3          O P E N   P I T   I N F L O W            **    01/28/76-11:52:12     **     PAGE  5

                                 MATERIAL   PROPERTIES
LINE *      PROPERTIES       ABOVE          *        PROPERTIES       BELOW          *       DELIMITING NODE STRING
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     *                                      *                                        *
  1  *      0.00        0.00          .0    *     2.00-05      2.00-05      .0       *     2.550+02  4.050+02          3.000+02  4.500+02
     *                                      *                                        *     1.500+03  4.500+02
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     *                                      *                                        *
  2  *      2.00-05     2.00-05       .0    *     2.50-06      2.50-06      .0       *     2.250+02  3.750+02          2.550+02  4.050+02
     *                                      *                                        *     1.500+03  4.050+02
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     *                                      *                                        *
  3  *      2.50-06     2.50-06       .0    *     2.00-06      1.00-06   167.2       *     1.550+02  3.050+02          2.250+02  3.750+02
     *                                      *                                        *     1.500+03  8.587+01
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     *                                      *                                        *
  4  *      2.00-06     1.00-06   167.2     *     5.00-07      5.00-07      .0       *     0.000     3.000+02          1.500+02  3.000+02
     *                                      *                                        *     1.550+02  3.050+02          1.500+03  0.000
     *                                      *                                        *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 6

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*          S A M P L E   3          O P E N   P I T   I N F L O W            **    01/28/76-11:52:12     **     PAGE  6

ELMT        I         J         K         L        MAT

  1         1        12        13         2         0
  2         2        13        14         3         0
  3         3        14        15         4         0
  4         4        15        16         5         0
  5         5        16        17         6         0
  6         6        17        18         7         0
  7         7        18        19         8         0
  8         8        19        20         9         0
  9         9        20        21        10         0
 10        10        21        22        11         0
 11        12        23        24        13         0
 12        13        24        25        14         0
 13        14        25        26        15         0
 14        15        26        27        16         0
 15        16        27        28        17         0
 16        17        28        29        18         0
 17        18        24        30        19         0
 18        19        30        31        20         0
 19        20        31        32        21         0
 20        21        32        33        22         0
 21        23        34        35        24         0
 22        24        35        36        25         0
 23        25        36        37        26         0
 24        26        37        38        27         0
 25        27        38        39        28         0
 26        28        39        40        29         0
 27        29        40        41        30         0
 28        30        41        42        31         0
 29        31        42        43        32         0
 30        32        43        44        33         0
 31        34        45        46        35         0
 32        35        46        47        36         0
 33        36        47        48        37         0
 34        37        48        49        38         0
 35        38        49        50        39         0
 36        39        50        51        40         0
 37        40        51        52        41         0
 38        41        52        53        42         0
 39        42        53        54        43         0
 40        43        54        55        44         0
 41        45        56        57        46         0
 42        46        57        58        47         0
 43        47        58        59        48         0
 44        48        59        60        49         0
 45        49        60        61        50         0
 46        50        61        62        51         0
 47        51        62        63        52         0
 48        52        63        64        53         0
 49        53        64        65        54         0
 50        54        65        66        55         0
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 7

```
*          SAMPLE 3          OPEN PIT INFLOW          **   01/28/76-11:52:12   **   PAGE 7

ELMT       I          J          K          L        MAT

  51       56         67         68         57         0
  52       57         68         69         58         0
  53       58         69         70         59         0
  54       59         70         71         60         0
  55       60         71         72         61         0
  56       61         72         73         62         0
  57       62         73         74         63         0
  58       63         74         75         64         0
  59       64         75         76         65         0
  60       65         76         77         66         0
  61       67         78         79         68         0
  62       68         79         80         69         0
  63       69         80         81         70         0
  64       70         81         82         71         0
  65       71         82         83         72         0
  66       72         83         84         73         0
  67       73         84         85         74         0
  68       74         85         86         75         0
  69       75         86         87         76         0
  70       76         87         88         77         0
  71       78         89         90         79         0
  72       79         90         91         80         0
  73       80         91         92         81         0
  74       81         92         93         82         0
  75       82         93         94         83         0
  76       83         94         95         84         0
  77       84         95         96         85         0
  78       85         96         97         86         0
  79       86         97         98         87         0
  80       87         98         99         88         0
  81       89        100        101         90         0
  82       90        101        102         91         0
  83       91        102        103         92         0
  84       92        103        104         93         0
  85       93        104        105         94         0
  86       94        105        106         95         0
  87       95        106        107         96         0
  88       96        107        108         97         0
  89       97        108        109         98         0
  90       98        109        110         99         0
  91      100        111        112        101         0
  92      101        112        113        102         0
  93      102        113        114        103         0
  94      103        114        115        104         0
  95      104        115        116        105         0
  96      105        116        117        106         0
  97      106        117        118        107         0
  98      107        118        119        108         0
  99      108        119        120        109         0
 100      109        120        121        110         0
 101      111        122        123        112         0              PAGE  8
 102      112        123        124        113         0
 103      113        124        125        114         0
 104      114        125        126        115         0
 105      115        126        127        116         0
 106      116        127        128        117         0
 107      117        128        129        118         0
 108      118        129        130        119         0
 109      119        130        131        120         0
 110      120        131        132        121         0
 111      122        133        134        123         0
 112      123        134        135        124         0
 113      124        135        136        125         0
 114      125        136        137        126         0
 115      126        137        138        127         0
 116      127        138        139        128         0
 117      128        139        140        129         0
 118      129        140        141        130         0
 119      130        141        142        131         0
 120      131        142        143        132         0
 121      133        144        145        134         0
 122      134        145        146        135         0
 123      135        146        147        136         0
 124      136        147        148        137         0
 125      137        148        149        138         0
 126      138        149        150        139         0
 127      139        150        151        140         0
 128      140        151        152        141         0
 129      141        152        153        142         0
 130      142        153        154        143         0
 131      144        155        156        145         0
 132      145        156        157        146         0
 133      146        157        158        147         0
 134      147        158        159        148         0
 135      148        159        160        149         0
 136      149        160        161        150         0
 137      150        161        162        151         0
 138      151        162        163        152         0
 139      152        163        164        153         0
 140      153        164        165        154         0
 141      155        166        167        156         0
 142      156        167        168        157         0
 143      157        168        169        158         0
 144      158        169        170        159         0
 145      159        170        171        160         0
 146      160        171        172        161         0
 147      161        172        173        162         0
 148      162        173        174        163         0
 149      163        174        175        164         0
 150      164        175        176        165         0
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 8

```
*          S A M P L E   3          O P E N   P I T   I N F L O W                 **    01/28/76-11:52:12     **     PAGE  9

ELMT         I          J          K          L         MAT

 151        166        177        178        167          0
 152        167        178        179        168          0
 153        168        179        180        169          0
 154        169        180        181        170          0
 155        170        181        182        171          0
 156        171        182        183        172          0
 157        172        183        184        173          0
 158        173        184        185        174          0
 159        174        185        186        175          0
 160        175        186        187        176          0
 161        177        188        189        178          0
 162        178        189        190        179          0
 163        179        190        191        180          0
 164        180        191        192        181          0
 165        181        192        193        182          0
 166        182        193        194        183          0
 167        183        194        195        184          0
 168        184        195        196        185          0
 169        185        196        197        186          0
 170        186        197        198        187          0
 171        188        199        200        189          0
 172        189        200        201        190          0
 173        190        201        202        191          0
 174        191        202        203        192          0
 175        192        203        204        193          0
 176        193        204        205        194          0
 177        194        205        206        195          0
 178        195        206        207        196          0
 179        196        207        208        197          0
 180        197        208        209        198          0
 181        199        210        211        200          0
 182        200        211        212        201          0
 183        201        212        213        202          0
 184        202        213        214        203          0
 185        203        214        215        204          0
 186        204        215        216        205          0
 187        205        216        217        206          0
 188        206        217        218        207          0
 189        207        218        219        208          0
 190        208        219        220        209          0
 191        210        221        222        211          0
 192        211        222        223        212          0
 193        212        223        224        213          0
 194        213        224        225        214          0
 195        214        225        226        215          0
 196        215        226        227        216          0
 197        216        227        228        217          0
 198        217        228        229        218          0
 199        218        229        230        219          0
 200        219        230        231        220          0
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 9

```
 * * * * * F R E E   S U R F A C E * * * * * *

   NODE     CURR. ANGLE          Y(MAX)

     77        90.0            375.000
     88        90.0            400.000
     99        90.0            425.000
    110        90.0            450.000
    121        90.0            450.000
    132        90.0            450.000
    143        90.0            450.000
    154        90.0            450.000
    165        90.0            450.000
    176        90.0            450.000
    187        90.0            450.000
    198        90.0            450.000
    209        90.0            450.000
    220        90.0            450.000

CPU TIME USED IN S/R MESHIN =  4.961 SECONDS

TOTAL SPACE ACQUIRED FOR /MATRIX/ IS  7955

MAXIMUM BANDWIDTH =  13
ASGIO DYNAMIC F.R. = @ASG,T      TEMP14,F17/       2/TRK/       2 .
ASGIO DYNAMIC F.R. = @USE      14,TEMP14 .
```

FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 10

```
*          S A M P L E   3           O P E N   P I T   I N F L O W              **    01/28/76-11:52:12     **     PAGE.10
TOTAL MESH AREA=  6.0877680+05   CPU TIME TO BUILD FLOW MATRIX =  38.370 SECONDS.


 * * * * *  ITERATION  1

TIME TO SOLVE MATRIX = 1.292 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       1.55+01
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .4578  DX,DY=   2.1257-07   4.4250+01
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0116  DX,DY=  -9.5367-07   3.3710+00

     NODE      X-ORD      Y-ORD         PRESSURE        POTENTIAL        DX         DY.       DP/DX      DP/DY
       77   225.0000   330.7500        .38556+02       .36931+03      .0000    44.2500      .0000      .0000
       88   250.0000   355.5500        .36276+02       .39183+03      .0000    36.2757      .0000    -1.0000
       99   275.0000   380.2500        .20488+02       .40074+03      .0000    20.4884      .0000    -1.0000
      110   300.0000   405.0000      -.41412+00        .40459+03     -.0000     -.4141      .0000    -1.0000
      121   337.5000   406.4100        .18282+01       .40824+03      .0000     1.8282      .0000    -1.0000
      132   400.0000   408.7500        .84417+01       .41719+03      .0000     8.4417      .0000    -1.0000
      143   500.0000   412.5000        .11772+02       .42427+03      .0000    11.7720      .0000    -1.0000
      154   625.0000   417.1900        .15479+02       .43267+03      .0000    15.4794      .0000    -1.0000
      165   750.0000   421.8800        .14980+02       .43666+03      .0000    14.9799      .0000    -1.0000
      176   875.0000   426.5600        .13973+02       .44053+03      .0000    13.9730      .0000    -1.0000
      187  1000.0000   431.2500        .11929+02       .44318+03      .0000    11.9289      .0000    -1.0000
      198  1125.0000   435.9400        .95515+01       .44549+03      .0000     9.5515      .0000    -1.0000
      209  1250.0000   440.6300        .65998+01       .44723+03      .0000     6.5998      .0000    -1.0000
      220  1375.0000   445.3100        .34752+01       .44879+03     -.0000     3.3710      .0000      .0000

TOTAL MESH AREA=  6.2287634+05   CPU TIME TO BUILD FLOW MATRIX =  36.880 SECONDS.


 * * * * *  ITERATION  2

TIME TO SOLVE MATRIX = 1.225 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       5.42+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .2657  DX,DY=   9.9288-13   3.8147-06
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0153  DX,DY=  -9.5367-07  -1.8323-01

     NODE      X-ORD      Y-ORD         PRESSURE        POTENTIAL        DX         DY        DP/DX      DP/DY
       77   225.0000   375.0000        .00000          .37500+03      .0000      .0000      .0000      .0000
       88   250.0000   391.8257      -.92677+01        .38256+03     -.0000    -9.2677      .0000    -1.0000
       99   275.0000   400.7384      -.11690+02        .38905+03     -.0000   -11.6898      .0000    -1.0000
      110   300.0000   404.5854      -.93501+01        .34524+03     -.0000    -9.3501      .0000    -1.0000
      121   337.5000   408.2382      -.13299+01        .40691+03     -.0000    -1.3299      .0000    -1.0000
      132   400.0000   417.1417      -.22531+01        .41494+03     -.0000    -2.2531      .0000    -1.0000
      143   500.0000   424.2720      -.20458+01        .42223+03     -.0000    -2.0458      .0000    -1.0000
      154   625.0000   432.6694      -.38445+01        .42882+03     -.0000    -3.8445      .0000    -1.0000
      165   750.0000   436.8599      -.25977+01        .43426+03     -.0000    -2.5977      .0000    -1.0000
      176   875.0000   440.5330      -.23828+01        .43815+03     -.0000    -2.3828      .0000    -1.0000
      187  1000.0000   443.1789      -.17100+01        .44147+03     -.0000    -1.7100      .0000    -1.0000
      198  1125.0000   445.4915      -.11402+01        .44435+03     -.0000    -1.1402      .0000    -1.0000
      209  1250.0000   447.2298      -.64343+00        .44659+03     -.0000     -.6434      .0000    -1.0000
      220  1375.0000   448.6810      -.30315+00        .44838+03     -.0000     -.1832      .0000      .0000

TOTAL MESH AREA=  6.2001770+05   CPU TIME TO BUILD FLOW MATRIX =  36.660 SECONDS.


 * * * * *  ITERATION  3

TIME TO SOLVE MATRIX = 1.214 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       1.34+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .3050  DX,DY=   2.3842-07  -3.5710+00
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0180  DX,DY=  -9.5367-07   4.7039-01

     NODE      X-ORD      Y-ORD         PRESSURE        POTENTIAL        DX         DY        DP/DX      DP/DY
       77   225.0000   375.0000        .00000          .37500+03      .0000    -3.5710      .0000      .0000
       88   250.0000   382.5581      -.35052+01        .37905+03     -.0000    -3.5052      .0000    -1.0000
       99   275.0000   389.0485      -.23350+01        .38671+03     -.0000    -2.3350      .0000    -1.0000
      110   300.0000   395.2358      -.78845+00        .39445+03     -.0000     -.7885      .0000    -1.0000
      121   337.5000   406.9083      -.87594+00        .40603+03     -.0000     -.8759      .0000    -1.0000
      132   400.0000   414.9386      -.14004+01        .41354+03     -.0000    -1.4004      .0000    -1.0000
      143   500.0000   422.2262      -.26688+00        .42196+03     -.0000     -.2669      .0000    -1.0000
      154   625.0000   428.8249        .52806+00       .42935+03      .0000      .5281      .0000    -1.0000
      165   750.0000   434.2622        .30530+00       .43457+03      .0000      .3053      .0000    -1.0000
      176   875.0000   438.1503        .16524+00       .43832+03      .0000      .1652      .0000    -1.0000
      187  1000.0000   441.4689        .51557-01       .44152+03      .0000      .0516      .0000    -1.0000
      198  1125.0000   444.3513      -.61996-01        .44429+03     -.0000     -.0620      .0000    -1.0000
      209  1250.0000   446.5864        .12825+00       .44671+03      .0000      .1283      .0000    -1.0000
      220  1375.0000   448.4978      -.54332-01        .44844+03     -.0000      .4704      .0000      .0000

TOTAL MESH AREA=  6.1976854+05   CPU TIME TO BUILD FLOW MATRIX =  39.270 SECONDS.
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 11

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 * * * * *  ITERATION  4

TIME TO SOLVE MATRIX = 1.282 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       2.95+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .2386  DX,DY=  1.0359-07   3.5710+00
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0141  DX,DY= -9.5367-07  -3.4272-01

       NODE      X-ORD      Y-ORD        PRESSURE        POTENTIAL       DX         DY       DP/DX      DP/DY
         77   225.0000   371.4290       .12802+02       .38423+03     .0000     3.5710      .0000      .0000
         88   250.0000   379.0529       .85590+01       .38561+03     .0000     6.5590      .0000    -1.0000
         99   275.0000   386.7135       .50999+01       .39181+03     .0000     5.0999      .0000    -1.0000
        110   300.0000   394.4474       .40423+01       .39849+03     .0000     4.0423      .0000    -1.0000
        121   337.5000  '406.0324       .27552+01       .40879+03     .0000     2.7552      .0000    -1.0000
        132   400.0000   413.5382       .21994+01       .41574+03     .0000     2.1994      .0000    -1.0000
        143   500.0000   421.9593       .16948+01       .42365+03     .0000     1.6948      .0000    -1.0000
        154   625.0000   429.3530       .12651+01       .43062+03     .0000     1.2651      .0000    -1.0000
        165   750.0000   434.5675       .97543+00       .43554+03     .0000      .9754      .0000    -1.0000
        176   875.0000   438.3155       .78424+00       .43910+03     .0000      .7842      .0000    -1.0000
        187  1000.0000   441.5204       .63518+00       .44216+03     .0000      .6352      .0000    -1.0000
        198  1125.0000   444.2893       .52040+00       .44481+03     .0000      .5204      .0000    -1.0000
        209  1250.0000   446.7147       .15220+00       .44687+03     .0000      .1522      .0000    -1.0000
        220  1375.0000   448.4682      -.45720+00       .44851+03    -.0000     -.3427      .0000      .0000

TOTAL MESH AREA=  6.2128151+05   CPU TIME TO BUILD FLOW MATRIX =  36.940 SECONDS.


 * * * * *  ITERATION  5

TIME TO SOLVE MATRIX = 1.277 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       2.47+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .3117  DX,DY=  2.3842-07  -2.8748+00
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0150  DX,DY= -9.5367-07  -9.6918-02

       NODE      X-ORD      Y-ORD        PRESSURE        POTENTIAL       DX         DY       DP/DX      DP/DY
         77   225.0000   375.0000       .00000          .37500+03     .0000    -2.8748      .0000      .0000
         88   250.0000   385.6119      -.56947+01       .37992+03    -.0000    -5.6947      .0000    -1.0000
         99   275.0000   391.8135      -.42026+01       .38761+03    -.0000    -4.2026      .0000    -1.0000
        110   300.0000   398.4897      -.33824+01       .39511+03    -.0000    -3.3824      .0000    -1.0000
        121   337.5000   408.7876      -.22036+01       .40658+03    -.0000    -2.2036      .0000    -1.0000
        132   400.0000   415.7376      -.14863+01       .41425+03    -.0000    -1.4863      .0000    -1.0000
        143   500.0000   423.6541      -.78596+00       .42287+03    -.0000     -.7860      .0000    -1.0000
        154   625.0000   430.6180      -.14285+01       .42919+03    -.0000    -1.4285      .0000    -1.0000
        165   750.0000   435.5029      -.10004+01       .43454+03    -.0000    -1.0004      .0000    -1.0000
        176   875.0000   439.0997      -.73618+00       .43836+03    -.0000     -.7362      .0000    -1.0000
        187  1000.0000   442.1556      -.52626+00       .44163+03    -.0000     -.5263      .0000    -1.0000
        198  1125.0000   444.8097      -.34919+00       .44446+03    -.0000     -.3492      .0000    -1.0000
        209  1250.0000   446.8669      -.21287+00       .44665+03    -.0000     -.2129      .0000    -1.0000
        220  1375.0000   446.6255      -.21502+00       .44841+03    -.0000     -.0969      .0000      .0000

TOTAL MESH AREA=  6.1999328+05   CPU TIME TO BUILD FLOW MATRIX =  38.010 SECONDS.


 * * * * *  ITERATION  6

TIME TO SOLVE MATRIX = 1.247 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =       2.22+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .2665  DX,DY=  1.1198-07   2.8748+00
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0171  DX,DY= -9.5367-07   4.9008-01

       NODE      X-ORD      Y-ORD        PRESSURE        POTENTIAL       DX         DY       DP/DX      DP/DY
         77   225.0000   372.1252       .12143+02       .38427+03     .0000     2.8748      .0000      .0000
         88   250.0000   379.9173       .49921+01       .38491+03     .0000     4.9921      .0000    -1.0000
         99   275.0000   387.6108       .39696+01       .39158+03     .0000     3.9696      .0000    -1.0000
        110   300.0000   395.1073       .31592+01       .39827+03     .0000     3.1592      .0000    -1.0000
        121   337.5000   406.5840       .20098+01       .40859+03     .0000     2.0098      .0000    -1.0000
        132   400.0000   414.2514       .13012+01       .41555+03     .0000     1.3012      .0000    -1.0000
        143   500.0000   422.8681       .57738+00       .42345+03     .0000      .5774      .0000    -1.0000
        154   625.0000   429.1896       .12125+01       .43040+03     .0000     1.2125      .0000    -1.0000
        165   750.0000   434.5426       .79644+00       .43534+03     .0000      .7964      .0000    -1.0000
        176   875.0000   438.3636       .53113+00       .43889+03     .0000      .5311      .0000    -1.0000
        187  1000.0000   441.6294       .30926+00       .44194+03     .0000      .3093      .0000    -1.0000
        198  1125.0000   444.4606       .10944+00       .44457+03     .0000      .1094      .0000    -1.0000
        209  1250.0000   446.6540       .22174+00       .44688+03     .0000      .2217      .0000    -1.0000
        220  1375.0000   448.5286      -.89154-02       .44852+03    -.0000      .4901      .0000      .0000

TOTAL MESH AREA=  6.2111791+05   CPU TIME TO BUILD FLOW MATRIX =  37.630 SECONDS.
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 12

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 * * * * *  ITERATION  7

TIME TO SOLVE MATRIX = 1.243 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =        2.27+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .3208  DX,DY=   2.3842-07  -3.2894+00
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0150  DX,DY=  -9.5367-07  -4.8538-01

     NODE      X-ORD      Y-ORD       PRESSURE       POTENTIAL      DX        DY       DP/DX      DP/DY
      77   225.0000   375.0000      .00000        .37500+03     .0000   -3.2894     .0000      .0000
      88   250.0000   384.9094     -.51789+01     .37973+03    -.0000   -5.1789     .0000    -1.0000
      99   275.0000   391.5805     -.40044+01     .38758+03    -.0000   -4.0044     .0000    -1.0000
     110   300.0000   398.2665     -.31935+01     .39507+03    -.0000   -3.1935     .0000    -1.0000
     121   337.5000   408.5938     -.20293+01     .40656+03    -.0000   -2.0293     .0000    -1.0000
     132   400.0000   415.5526     -.13155+01     .41424+03    -.0000   -1.3155     .0000    -1.0000
     143   500.0000   423.4455     -.58648+00     .42286+03    -.0000    -.5865     .0000    -1.0000
     154   625.0000   430.4020     -.12177+01     .42918+03    -.0000   -1.2177     .0000    -1.0000
     165   750.0000   435.3390     -.79894+00     .43454+03    -.0000    -.7989     .0000    -1.0000
     176   875.0000   438.8947     -.53203+00     .43836+03    -.0000    -.5320     .0000    -1.0000
     187  1000.0000   441.9386     -.30875+00     .44163+03    -.0000    -.3087     .0000    -1.0000
     198  1125.0000   444.5700     -.10681+00     .44446+03    -.0000    -.1068     .0000    -1.0000
     209  1250.0000   446.8757     -.21765+00     .44666+03    -.0000    -.2178     .0000    -1.0000
     220  1375.0000   449.0186     -.60707+00     .44641+03    -.0000    -.4854     .0000      .0000

TOTAL MESH AREA=  6.1997352+05   CPU TIME TO BUILD FLOW MATRIX =  39.080 SECONDS.


 * * * * *  ITERATION  8

TIME TO SOLVE MATRIX = 1.268 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =        2.53+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .2349  DX,DY=   9.5481-08   3.2894+00
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0171  DX,DY=  -9.5367-07   4.8767-01

     NODE      X-ORD      Y-ORD       PRESSURE       POTENTIAL      DX        DY       DP/DX      DP/DY
      77   225.0000   371.7106      .12586+02     .38430+03     .0000    3.2894     .0000      .0000
      88   250.0000   379.7305      .60668+01     .38580+03     .0000    6.0668     .0000    -1.0000
      99   275.0000   387.5761      .43254+01     .39190+03     .0000    4.3254     .0000    -1.0000
     110   300.0000   395.0731      .33950+01     .39847+03     .0000    3.3950     .0000    -1.0000
     121   337.5000   406.5645      .21537+01     .40872+03     .0000    2.1537     .0000    -1.0000
     132   400.0000   414.2371      .14085+01     .41565+03     .0000    1.4085     .0000    -1.0000
     143   500.0000   422.8590      .65281+00     .42351+03     .0000     .6528     .0000    -1.0000
     154   625.0000   429.1804      .12650+01     .43045+03     .0000    1.2650     .0000    -1.0000
     165   750.0000   434.5401      .83386+00     .43537+03     .0000     .8339     .0000    -1.0000
     176   875.0000   438.3627      .55831+00     .43892+03     .0000     .5583     .0000    -1.0000
     187  1000.0000   441.6299      .32777+00     .44196+03     .0000     .3278     .0000    -1.0000
     198  1125.0000   444.4632      .11960+00     .44458+03     .0000     .1196     .0000    -1.0000
     209  1250.0000   446.6579      .22520+00     .44688+03     .0000     .2252     .0000    -1.0000
     220  1375.0000   448.5333     -.10151-01     .44852+03    -.0000     .4877     .0000      .0000

TOTAL MESH AREA=  6.2119445+05   CPU TIME TO BUILD FLOW MATRIX = 38.050 SECONDS.


 * * * * *  ITERATION  9

TIME TO SOLVE MATRIX = 1.211 SECONDS.

RMS PHREATIC SURFACE NODE MOVEMENT =        2.48+00
PHREATIC SURFACE END-NODE  77 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .3088  DX,DY=   2.3842-07  -2.7601+00
PHREATIC SURFACE END-NODE 220 EXTRAPOLATED FROM NEIGHBOUR AT SLOPE=   .0150  DX,DY=  -9.5367-07  -4.8780-01

     NODE      X-ORD      Y-ORD       PRESSURE       POTENTIAL      DX        DY       DP/DX      DP/DY
      77   225.0000   375.0000      .00000        .37500+03     .0000   -2.7601     .0000      .0000
      88   250.0000   385.7973     -.58375+01     .37996+03    -.0000   -5.8375     .0000    -1.0000
      99   275.0000   391.9015     -.43012+01     .38760+03    -.0000   -4.3012     .0000    -1.0000
     110   300.0000   398.4681     -.33862+01     .39508+03    -.0000   -3.3862     .0000    -1.0000
     121   337.5000   408.7182     -.21531+01     .40657+03    -.0000   -2.1531     .0000    -1.0000
     132   400.0000   415.6455     -.14086+01     .41424+03    -.0000   -1.4086     .0000    -1.0000
     143   500.0000   423.5118     -.65325+00     .42286+03    -.0000    -.6532     .0000    -1.0000
     154   625.0000   430.4494     -.12656+01     .42918+03    -.0000   -1.2656     .0000    -1.0000
     165   750.0000   435.3739     -.83450+00     .43454+03    -.0000    -.8345     .0000    -1.0000
     176   875.0000   438.9210     -.55890+00     .43836+03    -.0000    -.5589     .0000    -1.0000
     187  1000.0000   441.9576     -.32827+00     .44163+03    -.0000    -.3283     .0000    -1.0000
     198  1125.0000   444.5828     -.11999+00     .44446+03    -.0000    -.1200     .0000    -1.0000
     209  1250.0000   446.6831     -.22546+00     .44666+03    -.0000    -.2255     .0000    -1.0000
     220  1375.0000   449.0209     -.60950+00     .44841+03    -.0000    -.4878     .0000      .0000

TOTAL MESH AREA=  6.1999298+05   CPU TIME TO BUILD FLOW MATRIX =  36.870 SECONDS.


 * * * * *  ITERATION 10

TIME TO SOLVE MATRIX = 1.216 SECONDS.

MAX. NUMBER OF ITERATIONS REACHED
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 13

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*          S A M P L E   3          O P E N   P I T   I N F L O W             **    01/28/76-11:52:12     **      PAGE 11

     ELMT     X-ORD      Y-ORD      Z-ORD          X-FLOW           Y-FLOW        TOTAL FLOW   DIRN   MATERIAL

       1     25.000     23.030     23.030      -1.3520-08       1.6672-08       2.1465-08   129.04        4
       2     25.000     66.787     66.787      -1.3849-08       4.9011-08       5.0930-08   105.78        4
       3     25.000    106.169    106.169      -1.4208-08       7.9396-08       8.0657-08   100.15        4
       4     25.000    141.612    141.612      -1.4199-08       1.0760-07       1.0853-07    97.52        4
       5     25.000    173.511    173.511      -1.3528-08       1.3278-07       1.3347-07    95.82        4
       6     25.000    202.220    202.220      -1.2088-08       1.5401-07       1.5449-07    94.49        4
       7     25.000    228.058    228.058      -9.9137-09       1.7066-07       1.7094-07    93.32        4
       8     25.000    251.313    251.313      -7.1860-09       1.8241-07       1.8255-07    92.26        4
       9     25.000    272.242    272.242      -4.3293-09       1.8946-07       1.8951-07    91.31        4
      10     25.000    291.078    291.078      -1.4701-09       1.9286-07       1.9286-07    90.44        4
      11     75.000     23.030     23.030      -2.8298-08       1.6142-08       3.2579-08   150.30        4
      12     75.000     66.787     66.787      -2.9528-08       4.7719-08       5.6116-08   121.75        4
      13     75.000    106.169    106.169      -3.1167-08       7.8154-08       8.4139-08   111.74        4
      14     75.000    141.612    141.612      -3.2146-08       1.0753-07       1.1224-07   106.64        4
      15     75.000    173.511    173.511      -3.1567-08       1.3492-07       1.3856-07   103.17        4
      16     75.000    202.220    202.220      -2.9046-08       1.5892-07       1.6155-07   100.36        4
      17     75.000    228.058    228.058      -2.4711-08       1.7850-07       1.8020-07    97.88        4
      18     75.000    251.313    251.313      -1.8711-08       1.9350-07       1.9440-07    95.52        4
      19     75.000    272.242    272.242      -1.1020-08       2.0374-07       2.0404-07    93.10        4
      20     75.000    291.078    291.078      -3.3736-09       2.0643-07       2.0646-07    90.94        4
      21    125.000     23.030     23.030      -4.4238-08       1.4896-08       4.6679-08   161.39        4
      22    125.000     66.787     66.787      -4.6903-08       4.4406-08       6.4589-08   136.57        4
      23    125.000    106.169    106.169      -5.1079-08       7.4042-08       8.9952-08   124.60        4
      24    125.040    141.612    141.612      -5.5016-08       1.0478-07       1.1835-07   117.70        4
      25    125.000    173.511    173.511      -5.6586-08       1.3634-07       1.4761-07   112.54        4
      26    125.000    202.220    202.220      -5.4015-08       1.6671-07       1.7524-07   107.95        4
      27    125.000    228.058    228.058      -4.7286-08       1.9245-07       1.9817-07   103.80        4
      28    125.000    251.313    251.313      -3.6690-08       2.1113-07       2.1465-07   100.38        4
      29    125.000    272.242    272.242      -2.9745-08       2.2610-07       2.2805-07    97.49        4
      30    125.000    291.078    291.078      -1.2575-08       2.5112-07       2.5143-07    92.87        4
      31    162.500     23.260     23.260      -5.0283-08       1.3590-08       5.5959-08   165.94        4
      32    162.500     67.455     67.455      -5.8413-08       4.0765-08       7.1232-08   145.09        4
      33    162.500    107.230    107.230      -6.5611-08       6.9011-08       9.5222-08   133.55        4
      34    162.500    143.028    143.028      -7.4210-08       1.0047-07       1.2490-07   126.45        4
      35    162.500    175.246    175.246      -8.1022-08       1.3671-07       1.5891-07   120.65        4
      36    162.500    204.242    204.242      -8.0759-08       1.7679-07       1.9437-07   114.55        4
      37    162.500    230.334    230.339      -6.8484-08       2.1399-07       2.2468-07   107.75        4
      38    162.500    253.826    253.826      -4.8744-08       2.3315-07       2.3819-07   101.81        4
      39    162.500    274.964    274.964      -4.9074-08       2.2046-07       2.2579-07   102.55        4
      40    162.500    293.988    293.988      -1.2940-07       1.8117-07       2.2263-07   125.54        4
      41    187.500     23.491     23.491      -6.0290-08       1.2410-08       6.1554-08   168.37        4
      42    187.500     68.123     68.123      -6.5377-08       3.7209-08       7.5225-08   150.35        4
      43    187.500    108.292    108.292      -7.4908-08       6.3255-08       9.8043-08   139.82        4
      44    187.500    144.444    144.444      -8.8055-08       9.3261-08       1.2826-07   133.36        4
      45    187.500    176.981    176.981      -1.0228-07       1.3137-07       1.6649-07   127.91        4
      46    187.500    206.265    206.265      -1.0973-07       1.8172-07       2.1228-07   121.13        4
      47    187.500    232.620    232.620      -9.5788-08       2.4130-07       2.5961-07   111.65        4
      48    187.500    256.339    256.339      -4.0265-08       2.9076-07       2.9354-07    97.88        4
      49    187.500    277.686    277.686       4.1523-08       2.5372-07       2.5709-07    80.71        4
      50    187.500    296.899    296.899       1.1694-07       5.1166-08       1.2764-07    23.63        4
      51    212.500     26.033     26.033      -6.4379-08       1.1895-08       6.5469-08   169.53        4                PAGE 12
      52    212.500     75.496     75.496      -7.2297-08       3.5807-08       8.0678-08   153.65        4
      53    212.500    120.013    120.013      -8.7735-08       6.1213-08       1.0698-07   145.10        4
      54    212.500    160.078    160.078      -1.1352-07       9.0405-08       1.4512-07   141.47        4
      55    212.500    196.137    196.137      -1.5890-07       1.2324-07       2.0109-07   142.20        4
      56    212.500    228.590    228.590      -2.4287-07       1.5164-07       2.8632-07   148.02        4
      57    212.500    257.797    257.797      -3.9663-07       1.6540-07       4.2973-07   157.36        4
      58    212.500    284.084    284.084      -1.0720-06       1.4734-07       1.0821-06   172.17        4
      59    212.500    307.742    307.742      -1.8458-06       3.7291-08       1.8462-06   178.84        4
      60    212.500    329.034    329.034      -2.4303-06      -2.6655-07       2.4449-06  -173.74        3
      61    237.500     28.872     28.872      -6.8598-08       1.1122-08       6.9493-08   170.79        4
      62    237.500     83.729     83.729      -7.8279-08       3.3434-08       8.5120-08   156.87        4
      63    237.500    133.100    133.100      -9.8458-08       5.6540-08       1.1354-07   150.13        4
      64    237.500    177.534    177.534      -1.3332-07       8.0696-08       1.5584-07   148.81        4
      65    237.500    217.525    217.525      -1.6909-07       9.8943-08       2.1377-07   152.43        4
      66    237.500    253.517    253.517      -2.7207-07       8.6625-08       2.8552-07   162.34        4
      67    237.500    285.909    285.909      -8.6330-07       1.6074-07       8.7818-07   169.45        4
      68    237.500    315.062    315.062      -1.4557-06      -4.2643-08       1.4563-06  -178.32        3
      69    237.500    341.300    341.300      -1.1442-06      -4.6388-07       1.2346-06  -157.93        3
      70    237.500    364.914    364.914      -2.7319-07      -7.2021-07       7.7028-07  -110.77        3
      71    262.500     29.462     29.462      -7.0542-08       9.2006-09       7.1139-08   172.57        4
      72    262.500     85.439     85.439      -8.0405-08       2.7167-08       8.4871-08   161.33        4
      73    262.500    135.818    135.818      -1.0059-07       4.4046-08       1.0981-07   156.35        4
      74    262.500    181.168    181.168      -1.3312-07       5.7806-08       1.4513-07   156.53        4
      75    262.500    221.967    221.967      -1.7597-07       6.2029-08       1.8659-07   160.58        4
      76    262.500    258.694    258.694      -2.1377-07       3.4544-08       2.1654-07   170.82        4
      77    262.500    291.747    291.747      -9.9758-07       9.0857-08       1.0017-06   174.80        3
      78    262.500    321.496    321.496      -9.7687-07      -1.4377-07       9.8938-07  -171.64        3
      79    262.500    348.270    348.270      -6.5070-07      -3.3526-07       7.3199-07  -152.74        3
      80    262.500    372.366    372.366      -6.4129-07      -2.7327-07       6.9708-07  -156.92        2
      81    287.500     30.042     30.042      -7.1135-08       7.2857-09       7.1508-08   174.15        4
      82    287.500     87.122     87.122      -8.0582-08       2.0966-08       8.3265-08   165.42        4
      83    287.500    138.494    138.494      -9.9256-08       5.2061-08       1.0431-07   162.10        4
      84    287.500    184.729    184.729      -1.2706-07       3.7755-08       1.3255-07   163.45        4
      85    287.500    226.340    226.340      -1.6260-07       3.4294-08       1.6598-07   168.00        4
      86    287.500    263.790    263.790      -3.3286-07       2.7231-08       3.3398-07   175.32        4
      87    287.500    297.495    297.495      -7.8264-07      -8.3744-09       7.8269-07  -179.39        3
      88    287.500    327.830    327.830      -7.1111-07      -1.6719-07       7.3049-07  -166.77        3
      89    287.500    355.131    355.131      -5.9051-07      -2.0452-07       6.2492-07  -160.90        3
      90    287.500    379.702    379.702      -6.2176-07      -1.9768-07       6.5243-07  -162.36        2
      91    318.750     30.770     30.770      -7.0258-08       5.0778-09       7.0442-08   175.87        4
      92    318.750     89.233     89.233      -7.8575-08       1.3974-08       7.9807-08   169.92        4
      93    318.750    141.850    141.850      -9.4173-08       1.9318-08       9.6134-08   168.41        4
      94    318.750    189.205    189.205      -1.1551-07       1.8464-08       1.1698-07   170.92        4
      95    318.750    231.824    231.824      -1.4098-07       7.5999-09       1.4118-07   176.91        4
      96    318.750    270.182    270.182      -3.8308-07       2.9204-08       3.8419-07   175.64        4
      97    318.750    304.704    304.704      -5.9189-07      -4.6503-08       5.9372-07  -175.51        3
      98    318.750    335.773    335.773      -4.6848-07      -1.4285-07       4.8978-07  -163.04        3
      99    318.750    363.736    363.736      -5.9884-07      -2.4006-07       6.4516-07  -158.16        2
     100    318.750    388.903    388.903      -5.9006-07      -2.3054-07       6.3350-07  -158.66        2
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 14

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*        S A M P L E   3          O P E N   P I T   I N F L O W                **    01/28/76-11:52:12      **      PAGE 13

   ELMT    X-ORD      Y-ORD      Z-ORD          X-FLOW           Y-FLOW        TOTAL FLOW   DIRN   MATERIAL

   101   368.750     31.505     31.505      -6.5955-08        2.2703-09        6.5994-08  178.03        4
   102   368.750     91.365     91.365      -7.1695-08        5.4928-09        7.1905-08  175.62        4
   103   368.750    145.239    145.239      -8.1668-08        5.1589-09        8.1830-08  176.39        4
   104   368.750    193.726    193.726      -9.3442-08       -6.8027-11        9.3442-08 -179.96        4
   105   368.750    237.364    237.364      -1.0160-07       -1.0311-08        1.0212-07 -174.20        4
   106   368.750    276.638    276.638      -4.0295-07        6.1022-09        4.0299-07  179.13        3
   107   368.750    311.985    311.985      -3.7750-07       -5.6046-08        3.8164-07 -171.56        3
   108   368.750    343.797    343.797      -3.5912-07       -1.0151-07        3.7319-07 -164.22        3
   109   368.750    372.427    372.427      -3.5194-07       -1.4867-07        3.8205-07 -157.10        2
   110   368.750    398.195    398.195      -7.6863-07       -2.9122-07        8.2195-07 -159.25        2
   111   450.000     32.131     32.131      -5.5233-08       -3.3739-10        5.5234-08 -179.65        4
   112   450.000     93.179     93.179      -5.7484-08       -1.7870-09        5.7511-08 -178.22        4
   113   450.000    148.122    148.122      -6.0592-08       -5.0870-09        6.0805-08 -175.20        4
   114   450.000    197.571    197.571      -6.3740-08       -1.2305-08        6.4917-08 -169.07        4
   115   450.000    242.076    242.076      -1.5225-07        8.9006-10        1.5225-07  179.67        4
   116   450.000    282.129    282.129      -2.3210-07       -1.3557-08        2.3250-07 -176.66        3
   117   450.000    318.178    318.178      -2.2808-07       -4.6618-08        2.3280-07 -168.45        3
   118   450.000    350.621    350.621      -2.3325-07       -6.2576-08        2.4150-07 -164.96        2
   119   450.000    379.820    379.820      -2.1496-07       -7.9433-08        2.2917-07 -159.72        2
   120   450.000    406.100    406.100      -8.7592-07       -5.6002-08        8.7771-07 -176.34        2
   121   562.500     32.704     32.704      -4.0072-08       -1.5699-09        4.0102-08 -177.76        4
   122   562.500     94.843     94.843      -4.0327-08       -4.9236-09        4.0626-08 -173.04        4
   123   562.500    150.767    150.767      -4.0783-08       -8.9226-09        4.1747-08 -167.66        4
   124   562.500    201.099    201.099      -6.3321-08       -8.4065-09        6.3876-08 -172.44        4
   125   562.500    246.398    246.398      -1.3615-07       -5.3325-10        1.3615-07 -179.78        3
   126   562.500    287.167    287.167      -1.3472-07       -1.0935-08        1.3517-07 -175.36        3
   127   562.500    323.859    323.859      -1.5435-07       -1.8159-08        1.5542-07 -173.29        2
   128   562.500    356.862    356.882      -1.4922-07       -2.7136-08        1.5167-07 -169.69        2
   129   562.500    386.602    386.602      -1.4350-07       -3.3366-08        1.4733-07 -166.91        2
   130   562.500    413.351    413.351      -8.7408-07       -5.8756-08        8.7605-07 -176.15        1
   131   687.500     53.153     53.153      -2.7067-08       -1.4044-09        2.7106-08 -176.95        4
   132   687.500     96.143     96.143      -2.6397-08       -4.2902-09        2.6743-08 -170.77        4
   133   687.500    152.834    152.834      -2.4505-08       -6.4849-09        2.5349-08 -165.18        4
   134   687.500    203.856    203.856      -8.9737-08        4.2768-09        8.9839-08  177.28        3
   135   687.500    249.776    249.776      -8.5799-08        3.2735-10        8.5800-08  179.78        3
   136   687.500    291.104    291.104      -1.0665-07       -5.7881-09        1.0680-07 -176.89        2
   137   687.500    328.299    328.299      -1.0398-07       -7.8519-09        1.0428-07 -175.68        2
   138   687.500    361.774    361.774      -1.0201-07       -1.2417-08        1.0276-07 -173.06        2
   139   687.500    391.902    391.902      -9.9699-08       -1.6117-08        1.0099-07 -170.82        2
   140   687.500    419.018    419.018      -7.9100-07       -1.9708-08        7.9124-07 -178.57        1
   141   812.500     33.505     33.505      -1.8956-08       -8.6821-10        1.8976-08 -177.38        4
   142   812.500     97.165     97.165      -1.8446-08       -2.5271-09        1.8618-08 -172.20        4
   143   812.500    154.458    154.458      -4.1689-08        1.5285-09        4.1717-08  177.90        4
   144   812.500    206.022    206.022      -6.4948-08        2.7456-09        6.5006-08  177.58        3
   145   812.500    252.430    252.430      -7.5651-08        5.3348-10        7.5653-08  179.60        2
   146   812.500    294.197    294.197      -7.7656-08        9.8902-10        7.7662-08  179.27        2
   147   812.500    331.787    331.787      -7.6424-08       -2.0993-09        7.6453-08 -178.43        2
   148   812.500    365.619    365.619      -7.4473-08       -4.2529-09        7.4595-08 -176.73        2
   149   812.500    396.067    396.067      -1.9627-07       -1.0268-08        1.9653-07 -177.01        2
   150   812.500    423.470    423.470      -5.6822-07       -1.3574-08        5.6838-07 -178.63        1
   151   937.500     33.777     33.777      -1.4244-08       -5.5018-10        1.4255-08 -177.79        4           PAGE 14
   152   937.500     97.954     97.954      -1.3913-08       -1.1653-09        1.3962-08 -175.21        4
   153   937.500    155.713    155.713      -5.1874-08        4.1578-09        5.2040-08  175.42        3
   154   937.500    207.696    207.696      -5.6095-08        3.9410-09        5.6233-08  175.98        3
   155   937.500    254.480    254.480      -6.1883-08        3.9111-09        6.2006-08  176.38        2
   156   937.500    296.587    296.587      -6.1933-08        2.3400-09        6.1977-08  177.84        2
   157   937.500    334.482    334.482      -6.1670-08        1.3249-09        6.1684-08  178.77        2
   158   937.500    368.588    368.588      -6.1331-08        5.8003-10        6.1334-08  179.46        2
   159   937.500    399.284    399.284      -1.6791-07       -1.7767-09        1.6792-07 -179.39        2
   160   437.500    426.910    426.910      -4.8749-07       -1.2502-08        4.8765-07 -178.53        1
   161  1062.500     34.011     34.011      -1.0838-08       -4.2066-10        1.0846-08 -177.78        4
   162  1062.500     98.633     98.633      -2.5304-08        2.8064-09        2.5438-08  174.12        4
   163  1062.500    156.792    156.792      -4.0610-08        4.3582-09        4.0844-08  173.87        3
   164  1062.500    209.136    209.136      -5.1636-08        4.2052-09        5.1807-08  175.34        2
   165  1062.500    256.245    256.245      -5.1669-08        3.0845-09        5.1761-08  176.58        2
   166  1062.500    298.643    298.643      -5.1945-08        2.1184-09        5.1988-08  177.66        2
   167  1062.500    336.801    336.801      -5.2217-08        1.4386-09        5.2237-08  178.42        2
   168  1062.500    371.144    371.144      -5.2356-08        1.1431-09        5.2369-08  178.75        2
   169  1062.500    402.052    402.052      -1.4458-07       -1.9115-09        1.4460-07 -179.24        2
   170  1062.500    429.869    429.869      -4.2093-07       -9.2887-09        4.2104-07 -178.74        1
   171  1187.500     34.204     34.204      -8.6885-09       -2.3228-11        8.6886-09 -179.85        4
   172  1187.500     99.193     90.193      -3.3221-08        3.8772-09        3.3446-08  173.34        3
   173  1187.500    157.682    157.682      -3.7159-08        3.8895-09        3.7362-08  174.02        3
   174  1187.500    210.322    210.322      -4.1920-08        3.2334-09        4.2044-08  175.59        2
   175  1187.500    257.699    257.699      -4.2760-08        1.6514-09        4.2792-08  177.79        2
   176  1187.500    300.338    300.338      -4.3580-08        2.2067-10        4.3580-08  179.71        2
   177  1187.500    338.712    338.712      -4.4654-08       -1.1875-09        4.4669-08 -178.48        2
   178  1187.500    373.250    373.250      -4.6244-08       -2.6574-09        4.6320-08 -176.71        2
   179  1187.500    404.333    404.333      -1.2833-07       -1.6860-10        1.2833-07 -179.92        2
   180  1187.500    432.309    432.309      -3.7061-07       -1.5179-09        3.7062-07 -179.77        1
   181  1312.500     34.361     34.361      -1.5493-08        1.5155-09        1.5567-08  174.41        4
   182  1312.500     99.646     94.646      -2.6478-08        2.8439-09        2.6630-08  173.87        3
   183  1312.500    158.402    158.402      -3.4465-08        2.6876-09        3.4568-08  175.54        2
   184  1312.500    211.283    211.283      -3.4680-08        1.6777-09        3.4721-08  177.23        2
   185  1312.500    258.876    258.876      -3.4838-08        5.4047-10        3.4842-08  179.11        2
   186  1312.500    301.709    301.709      -3.4661-08       -6.1806-10        3.4667-08 -178.98        2
   187  1312.500    340.260    340.260      -3.4018-08       -1.8471-09        3.4068-08 -176.89        2
   188  1312.500    374.955    374.955      -3.2726-08       -3.2142-09        3.2883-08 -174.39        2
   189  1312.500    406.180    406.180      -2.0226-07        3.4800-09        2.0229-07  179.01        1
   190  1312.500    434.283    434.283      -2.6190-07        5.4752-10        2.6190-07  179.88        1
   191  1437.500     34.489     34.489      -1.8497-08        1.3625-09        1.8547-08  175.79        3
   192  1437.500    100.018    100.018      -2.5130-08        1.4926-09        2.5175-08  176.60        3
   193  1437.500    158.994    158.994      -2.8786-08        1.2619-09        2.8813-08  177.49        2
   194  1437.500    212.072    212.072      -2.9609-08        6.4932-10        2.9616-08  178.74        2
   195  1437.500    259.842    259.842      -2.9958-08        2.4880-10        2.9959-08  179.52        2
   196  1437.500    302.836    302.836      -3.0036-08       -3.0923-11        3.0036-08 -179.94        2
   197  1437.500    341.530    341.530      -2.9979-08       -1.5552-10        2.9980-08 -179.70        2
   198  1437.500    376.355    376.355      -2.9925-08       -3.6152-11        2.9925-08 -179.93        2
   199  1437.500    407.697    407.697      -1.8630-07       -1.5484-09        1.8630-07 -179.52        1
   200  1437.500    435.905    435.905      -2.3743-07       -2.5257-09        2.3744-07 -179.39        1

CPU TIME IN S/R ELFLOW =  4.767 SECONDS.
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 15

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*          SAMPLE 3          OPEN PIT INFLOW                  **   01/28/76-11:52:12     **     PAGE 15

NODE  B.C.      X-ORD      Y-ORD      Z-ORD    PRESSURE    POTENTIAL    FLOW FN     OUTFLOW

   1 CONT.        .00        .00        .00   3.6527+02   3.6527+02   0.0000      -1.4552-11
   2 CONT.        .00      46.06      46.06   3.1766+02   3.6372+02   0.0000      -5.8208-11
   3 CONT.        .00      87.51      87.51   2.7212+02   3.5960+02   0.0000      -1.4552-11
   4 CONT.        .00     124.82     124.82   2.2888+02   3.5370+02   0.0000      -8.0036-11
   5 CONT.        .00     158.40     158.40   1.8809+02   3.4649+02   0.0000      -4.3656-11
   6 CONT.        .00     188.62     188.62   1.4989+02   3.3852+02   0.0000      -8.7311-11
   7 CONT.        .00     215.82     215.82   1.1441+02   3.3023+02   0.0000      -2.9104-11
   8 CONT.        .00     240.30     240.30   8.1703+01   3.2200+02   0.0000       4.3656-11
   9 CONT.        .00     262.33     262.33   5.1782+01   3.1411+02   0.0000       1.4552-11
  10 CONT.        .00     282.16     282.16   2.4581+01   3.0674+02   0.0000      -1.0186-10
  11 PRESS        .00     300.00     300.00   0.0000      3.0000+02   6.7217-05    8.0084-05
  12 CONT.      50.00        .00        .00   3.6661+02   3.6661+02   0.0000       1.2369-10
  13 CONT.      50.00      46.06      46.06   3.1903+02   3.6509+02  -3.3678-05   -4.0745-10
  14 CONT.      50.00      87.51      87.51   2.7353+02   3.6104+02  -6.1231-05   -2.9104-10
  15 CONT.      50.00     124.82     124.82   2.3031+02   3.5513+02  -8.1276-05   -6.8394-10
  16 CONT.      50.00     158.40     158.40   1.8949+02   3.4789+02  -9.1101-05   -6.5484-10
  17 CONT.      50.00     188.62     188.62   1.5119+02   3.3982+02  -8.8757-05    2.9104-11
  18 CONT.      50.00     215.82     215.82   1.1553+02   3.3135+02  -7.5855-05    2.4738-10
  19 CONT.      50.00     240.30     240.30   8.2568+01   3.2287+02  -6.0900-05   -6.1118-10
  20 CONT.      50.00     262.33     262.33   5.2354+01   3.1468+02  -6.0588-05    2.3283-10
  21 CONT.      50.00     282.16     282.16   2.4875+01   3.0703+02  -8.7813-05   -5.9663-10
  22 PRESS      50.00     300.00     300.00   0.0000      3.0000+02  -1.0679-04    5.0098-04
  23 CONT.     100.00        .00        .00   3.6940+02   3.6940+02   0.0000      -2.6193-10
  24 CONT.     100.00      46.06      46.06   3.2189+02   3.6795+02  -1.4878-04   -3.4925-10
  25 CONT.     100.00      87.51      87.51   2.7657+02   3.6408+02  -2.8293-04   -1.7462-10
  26 CONT.     100.00     124.82     124.82   2.3351+02   3.5833+02  -4.0050-04   -8.1491-10
  27 CONT.     100.00     158.40     158.40   1.9273+02   3.5113+02  -4.9381-04   -1.2224-09
  28 CONT.     100.00     188.62     188.62   1.5427+02   3.4290+02  -5.5368-04   -9.0222-10
  29 CONT.     100.00     215.82     215.82   1.1826+02   3.3408+02  -5.7682-04   -1.3970-09
  30 CONT.     100.00     240.30     240.30   8.4781+01   3.2508+02  -5.7725-04   -1.3388-09
  31 CONT.     100.00     262.33     262.33   5.3883+01   3.1621+02  -5.9966-04   -7.5670-10
  32 CONT.     100.00     282.16     282.16   2.5549+01   3.0770+02  -7.0881-04   -1.2224-09
  33 PRESS     100.00     300.00     300.00   0.0000      3.0000+02  -8.4769-04    1.1315-03
  34 CONT.     150.00        .00        .00   3.7375+02   3.7375+02   0.0000      -1.7462-10
  35 CONT.     150.00      46.06      46.06   3.2639+02   3.7245+02  -3.3512-04   -6.9849-10
  36 CONT.     150.00      87.51      87.51   2.8145+02   3.6896+02  -6.5006-04   -1.1059-09
  37 CONT.     150.00     124.82     124.82   2.3884+02   3.6367+02  -9.4727-04   -1.9209-09
  38 CONT.     150.00     158.40     158.40   1.9839+02   3.5679+02  -1.2155-03   -1.3388-09
  39 CONT.     150.00     188.62     188.62   1.5992+02   3.4855+02  -1.4309-03   -1.2806-09
  40 CONT.     150.00     215.82     215.82   1.2341+02   3.3923+02  -1.5653-03   -1.2806-09
  41 CONT.     150.00     240.30     240.30   8.9085+01   3.2938+02  -1.6105-03   -1.7462-09
  42 CONT.     150.00     262.33     262.33   5.7317+01   3.1965+02  -1.6508-03   -8.1491-10
  43 CONT.     150.00     282.16     282.16   2.8064+01   3.1022+02  -1.9966-03   -8.1491-10
  44 PRESS     150.00     300.00     300.00   0.0000      3.0000+02  -2.6341-03    1.6553-03
  45 CONT.     175.00        .00        .00   3.7642+02   3.7642+02   0.0000      -9.3132-10
  46 CONT.     175.00      46.98      46.98   3.2821+02   3.7519+02  -4.6322-04   -3.4925-10
  47 CONT.     175.00      89.26      89.26   2.8259+02   3.7185+02  -9.0548-04   -1.2224-09
  48 CONT.     175.00     127.32     127.32   2.3943+02   3.6675+02  -1.3368-03   -9.8453-10
  49 CONT.     175.00     161.57     161.57   1.9842+02   3.5999+02  -1.7452-03   -5.8208-11
  50 CONT.     175.00     192.39     192.39   1.5416+02   3.5155+02  -2.0914-03   -2.3283-10
  51 CONT.     175.00     220.14     220.14   1.2130+02   3.4144+02  -2.3025-03   -2.3283-09                  PAGE 16
  52 CONT.     175.00     245.10     245.10   8.5013+01   3.3012+02  -2.2710-03   -2.0955-09
  53 CONT.     175.00     267.57     267.57   5.1523+01   3.1910+02  -1.9691-03   -1.9209-09
  54 CONT.     175.00     287.80     287.80   2.3077+01   3.1088+02  -2.4922-03   -1.4552-09
  55 CONT.     175.00     306.00     306.00   2.0719+00   3.0807+02  -4.5569-03    9.8953-10
  56 CONT.     200.00        .00        .00   3.7937+02   3.7937+02   0.0000      -2.3283-10
  57 CONT.     200.00      46.98      46.98   3.3129+02   3.7827+02  -5.9689-04   -3.0268-09
  58 CONT.     200.00      89.26      89.26   2.8604+02   3.7531+02  -1.1768-03   -9.3132-10
  59 CONT.     200.00     127.32     127.32   2.4346+02   3.7078+02  -1.7620-03    9.3132-10
  60 CONT.     200.00     161.57     161.57   2.0314+02   3.6476+02  -2.3501-03   -2.7940-09
  61 CONT.     200.00     192.39     192.39   1.6461+02   3.5701+02  -2.9023-03   -5.1223-09
  62 CONT.     200.00     220.14     220.14   1.2682+02   3.4695+02  -3.3244-03   -1.5134-09
  63 CONT.     200.00     245.10     245.10   8.9075+01   3.3418+02  -3.3105-03   -6.9849-10
  64 CONT.     200.00     267.57     267.57   5.1487+01   3.1906+02  -1.6082-03   -8.4401-09
  65 CONT.     200.00     287.80     287.80   1.8961+01   3.0676+02  -1.3625-03   -1.2515-08
  66 PRESS     200.00     306.00     306.00   0.0000      3.0600+02  -9.7677-03    2.8943-02
  67 CONT.     225.00        .00        .00   3.8260+02   3.8260+02   0.0000      -1.3970-09
  68 CONT.     225.00      57.15      57.15   3.2407+02   3.8122+02  -9.0271-04   -2.0955-09
  69 CONT.     225.00     108.59     108.59   2.6887+02   3.7746+02  -1.8295-03    1.6298-09
  70 CONT.     225.00     154.88     154.88   2.1677+02   3.7165+02  -2.8770-03   -1.2951-09
  71 CONT.     225.00     196.54     196.54   1.6738+02   3.6392+02  -4.1689-03   -3.2451-09
  72 CONT.     225.00     234.04     234.04   1.2081+02   3.5485+02  -5.9139-03   -2.7721-09
  73 CONT.     225.00     267.74     267.74   7.8640+01   3.4643+02  -8.4747-03   -1.5425-09
  74 CONT.     225.00     298.16     298.16   4.3203+01   3.4136+02  -1.2983-02   -1.5737-08
  75 CONT.     225.00     325.50     325.50   2.0130+01   3.4563+02  -2.5676-02    5.1223-09
  76 CONT.     225.00     350.10     350.10   1.1284+01   3.6138+02  -3.3117-02   -1.2107-08
  77 CONT.     225.00     372.24     372.24   1.2052+01   3.8429+02  -3.4088-02   -1.2107-08
  78 CONT.     250.00        .00        .00   3.8592+02   3.8592+02   0.0000       4.6566-10
  79 CONT.     250.00      58.34      58.34   3.2640+02   3.8473+02  -1.0782-03   -2.9104-09
  80 CONT.     250.00     110.84     110.84   2.7071+02   3.8155+02  -2.1882-03   -2.0955-09
  81 CONT.     250.00     158.09     158.09   2.1870+02   3.7679+02  -3.4430-03   -2.7940-09
  82 CONT.     250.00     200.62     200.62   1.7031+02   3.7093+02  -4.9515-03   -1.6298-09
  83 CONT.     250.00     238.89     238.89   1.2613+02   3.6503+02  -6.7851-03   -1.9791-09
  84 CONT.     250.00     273.34     273.34   8.8321+01   3.6166+02  -8.7583-03   -3.6671-09
  85 CONT.     250.00     304.34     304.34   5.6274+01   3.6062+02  -1.6436-02   -9.1386-09
  86 CONT.     250.00     332.25     332.25   3.5112+01   3.6736+02  -2.4994-02   -1.2456-08
  87 CONT.     250.00     357.36     357.36   2.2872+01   3.8023+02  -2.9955-02   -1.8510-08
  88 CONT.     250.00     379.96     379.96   4.9234+00   3.8488+02  -3.1555-02   -1.0477-08
  89 CONT.     275.00        .00        .00   3.8933+02   3.8933+02   0.0000      -1.3970-09
  90 CONT.     275.00      59.51      59.51   3.2884+02   3.8835+02  -1.2381-03   -2.3283-10
  91 CONT.     275.00     113.07     113.07   2.7271+02   3.8578+02  -2.5085-03   -2.0955-09
  92 CONT.     275.00     161.27     161.27   2.2086+02   3.8213+02  -3.9318-03   -1.6298-09
  93 CONT.     275.00     204.65     204.65   1.7341+02   3.7807+02  -5.6095-03   -7.7998-09
  94 CONT.     275.00     243.70     243.70   1.3070+02   3.7439+02  -7.6076-03   -8.2655-09
  95 CONT.     275.00     278.84     278.84   9.4120+01   3.7296+02  -9.7550-03   -4.4238-09
  96 CONT.     275.00     310.46     310.46   6.4759+01   3.7522+02  -1.7675-02   -3.3760-09
  97 CONT.     275.00     338.93     338.93   4.3426+01   3.8235+02  -2.4337-02   -1.0827-08
  98 CONT.     275.00     364.54     364.54   2.5066+01   3.8961+02  -2.8803-02   -1.5832-08
  99 CONT.     275.00     387.60     387.60   3.4481+00   3.9155+02  -3.2231-02   -6.5193-09
 100 CONT.     300.00        .00        .00   3.9278+02   3.9278+02   0.0000      -4.6566-10
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 16

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*          S A M P L E   3          O P E N   P I T   I N F L O W             **     01/28/76-11:52:12      **       PAGE 17

NODE  B.C.       X-ORD       Y-ORD      Z-ORD     PRESSURE     POTENTIAL     FLOW FN      OUTFLOW

 101 CONT.      300.00       60.66      60.66   3.3135+02    3.9201+02   -1.3760-03   -5.8208-09
 102 CONT.      300.00      115.25     115.25   2.7479+02    3.9005+02   -2.7752-03   -5.5879-09
 103 CONT.      300.00      164.38     164.38   2.2307+02    3.8746+02   -4.3139-03   -3.3760-09
 104 CONT.      300.00      208.60     208.60   1.7631+02    3.8492+02   -6.0772-03   -3.2596-09
 105 CONT.      300.00      248.40     248.40   1.3479+02    3.8319+02   -8.1620-03   -6.8685-09
 106 CONT.      300.00      284.22     284.22   9.8852+01    3.8307+02   -1.1051-02   -1.7579-08
 107 CONT.      300.00      316.46     316.46   7.0282+01    3.8674+02   -1.8242-02   -2.1420-08
 108 CONT.      300.00      345.47     345.47   4.7929+01    3.9340+02   -2.3741-02   -1.1758-08
 109 CONT.      300.00      371.58     371.58   2.4918+01    3.9650+02   -2.8000-02   -2.4214-08
 110 CONT.      300.00      395.08     395.08   3.1606+00    3.9824+02   -3.2142-02   -8.8476-09
 111 CONT.      337.50         .00        .00   3.9789+02    3.9789+02    0.0000      -1.3970-09
 112 CONT.      337.50       62.42      62.42   3.3499+02    3.9741+02   -1.5358-03   -4.1910-09
 113 CONT.      337.50      118.60     118.60   2.7768+02    3.9628+02   -3.0686-03   -4.0745-09
 114 CONT.      337.50      169.16     169.16   2.2587+02    3.9503+02   -4.6888-03   -5.1223-09
 115 CONT.      337.50      210.67     214.67   1.7960+02    3.9427+02   -6.4067-03   -6.5193-09
 116 CONT.      337.50      255.62     255.62   1.3916+02    3.9478+02   -8.0286-03   -7.9162-09
 117 CONT.      337.50      292.48     292.48   1.0347+02    3.9595+02   -1.3320-02   -1.5134-08
 118 CONT.      337.50      325.66     325.66   7.3777+01    3.9943+02   -1.8658-02   -1.2806-08
 119 CONT.      337.50      355.51     355.51   4.8430+01    4.0394+02   -2.2900-02   -3.0268-09
 120 CONT.      337.50      382.38     382.38   2.3538+01    4.0592+02   -2.7367-02   -3.5856-08
 121 CONT.      337.50      406.57     406.57   2.0144+00    4.0858+02   -3.1230-02   -2.1420-08
 122 CONT.      400.00         .00        .00   4.0594+02    4.0594+02    0.0000      -3.2596-09
 123 CONT.      400.00       63.60      63.60   3.4224+02    4.0584+02   -1.6510-03   -6.5193-09
 124 CONT.      400.00      120.84     120.84   2.8489+02    4.0573+02   -3.2437-03   -6.9849-10
 125 CONT.      400.00      172.35     172.35   2.3358+02    4.0594+02   -4.8437-03   -2.0955-09
 126 CONT.      400.00      218.72     218.72   1.8800+02    4.0672+02   -6.5201-03   -6.0536-09
 127 CONT.      400.00      260.45     260.45   1.4747+02    4.0791+02   -8.3298-03   -7.4506-09
 128 CONT.      400.00      298.00     298.00   1.1155+02    4.0955+02   -1.3374-02   -2.3283-10
 129 CONT.      400.00      331.80     331.80   8.0656+01    4.1246+02   -1.7345-02    4.1910-09
 130 CONT.      400.00      362.22     362.22   5.1300+01    4.1352+02   -2.0794-02   -3.6787-08
 131 CONT.      400.00      389.60     389.60   2.5167+01    4.1476+02   -2.3418-02   -1.0245-08
 132 CONT.      400.00      414.24     414.24   1.3051+00    4.1554+02   -2.5215-02   -1.6019-07
 133 CONT.      500.00         .00        .00   4.1685+02    4.1685+02    0.0000      -2.9104-09
 134 CONT.      500.00       64.92      64.92   3.5210+02    4.1703+02   -1.6286-03   -2.3283-10
 135 CONT.      500.00      123.35     123.35   2.9420+02    4.1756+02   -3.1239-03   -7.6834-09
 136 CONT.      500.00      175.94     175.94   2.4247+02    4.1841+02   -4.4615-03   -3.7253-09
 137 CONT.      500.00      223.27     223.27   1.9667+02    4.1994+02   -5.7416-03   -7.2177-09
 138 CONT.     ·500.00      265.87     265.87   1.5477+02    4.2064+02   -9.3369-03   -1.7695-08
 139 CONT.      500.00      304.20     304.20   1.1771+02    4.2191+02   -1.2596-02   -4.6566-09
 140 CONT.      500.00      338.71     338.71   8.3557+01    4.2226+02   -1.5790-02    1.1176-08
 141 CONT.      500.00      369.76     369.76   5.2975+01    4.2273+02   -1.8402-02   -1.1176-08
 142 CONT.      500.00      397.71     397.71   2.5538+01    4.2320+02   -2.0132-02    2.4214-08
 143 CONT.      500.00      422.86     422.86   5.7951-01    4.2344+02   -3.5697-02   -2.4214-07
 144 CONT.      625.00         .00        .00   4.2684+02    4.2684+02    0.0000      -1.8626-09
 145 CONT.      625.00       65.89      65.89   3.6118+02    4.2707+02   -1.4314-03    2.7940-09
 146 CONT.      625.00      125.20     125.20   3.0250+02    4.2770+02   -2.7112-03   -1.8626-09
 147 CONT.      625.00      178.57     178.57   2.5016+02    4.2874+02   -3.8051-03    2.3283-09
 148 CONT.      625.00      226.61     226.61   2.0236+02    4.2898+02   -5.8644-03   -6.5193-09
 149 CONT.      625.00      269.84     269.84   1.5974+02    4.2958+02   -9.0525-03   -1.4901-08
 150 CONT.      625.00      308.75     308.75   1.2101+02    4.2976+02   -1.1928-02   -1.4901-08
 151 CONT.      625.00      343.77     343.77   8.6141+01    4.2991+02   -1.4784-02   -9.6858-08                          PAGE 18
 152 CONT.      625.00      375.29     375.29   5.4831+01    4.3012+02   -1.7195-02   -1.8626-08
 153 CONT.      625.00      403.65     403.65   2.6706+01    4.3036+02   -1.9207-02    1.4529-07
 154 CONT.      625.00      429.18     429.18   1.2131+00    4.3040+02   -3.4189-02    3.2037-07
 155 CONT.      750.00         .00        .00   4.3365+02    4.3365+02    0.0000       2.7940-09
 156 CONT.      750.00       66.72      66.72   3.6708+02    4.3380+02   -1.2162-03    9.3132-10
 157 CONT.      750.00      126.76     126.76   3.0743+02    4.3419+02   -2.3464-03    2.7940-09
 158 CONT.      750.00      180.80     180.80   2.5375+02    4.3455+02   -3.5190-03   -1.4901-08
 159 CONT.      750.00      229.44     229.44   2.0541+02    4.3484+02   -6.3204-03   -4.2841-08
 160 CONT.      750.00      273.21     273.21   1.6160+02    4.3501+02   -9.1314-03   -3.2596-08
 161 CONT.      750.00      312.61     312.61   1.2241+02    4.3501+02   -1.1887-02   -1.4901-08
 162 CONT.      750.00      348.06     348.06   8.7023+01    4.3509+02   -1.4462-02   -5.2154-08
 163 CONT.      750.00      379.97     379.97   5.5221+01    4.3519+02   -1.6836-02   -5.5879-08
 164 CONT.      750.00      408.69     408.69   2.6628+01    4.3532+02   -1.9147-02    2.2724-07
 165 CONT.      750.00      434.54     434.54   7.9580-01    4.3534+02   -3.2898-02   -1.7881-07
 166 CONT.      875.00         .00        .00   4.3842+02    4.3842+02    0.0000      -3.8999-09
 167 CONT.      875.00       67.30      67.30   3.7120+02    4.3850+02   -1.0141-03    6.5193-09
 168 CONT.      875.00      127.88     127.88   3.1084+02    4.3872+02   -1.8158-03    4.6566-10
 169 CONT.      875.00      182.39     182.39   2.5647+02    4.3886+02   -4.3546-03   -3.4459-08
 170 CONT.      875.00      231.46     231.46   2.0753+02    4.3899+02   -6.8348-03    0.0000
 171 CONT.      875.00      275.61     275.61   1.6330+02    4.3891+02   -9.5872-03   -5.5879-09
 172 CONT.      875.00      315.36     315.36   1.2352+02    4.3888+02   -1.2124-02    6.3330-08
 173 CONT.      875.00      351.12     351.12   8.7744+01    4.3887+02   -1.4485-02   -1.0803-07
 174 CONT.      875.00      383.32     383.32   5.5554+01    4.3887+02   -1.6729-02    0.0000
 175 CONT.      875.00      412.29     412.29   2.6584+01    4.3887+02   -1.9053-02    7.0035-07
 176 CONT.      875.00      438.36     438.36   5.2979-01    4.3889+02   -3.1721-02   -5.9605-08
 177 CONT.     1000.00         .00        .00   4.4199+02    4.4194+02    0.0000      -4.0745-10
 178 CONT.     1000.00       67.81      67.81   3.7425+02    4.4206+02   -9.7429-04   -4.6566-09
 179 CONT.     1000.00      128.83     128.83   3.1329+02    4.4212+02   -1.9993-03   -2.4214-08
 180 CONT.     1000.00      183.75     183.75   2.5840+02    4.4215+02   -4.7088-03   -3.3528-08
 181 CONT.     1000.00      233.18     233.18   2.0889+02    4.4207+02   -7.5216-03   -1.1176-07
 182 CONT.     1000.00      277.67     277.67   1.6434+02    4.4201+02   -1.0105-02   -4.6429-08
 183 CONT.     1000.00      317.71     317.71   1.2426+02    4.4197+02   -1.2505-02    3.3528-08
 184 CONT.     1000.00      353.74     353.74   8.8201+01    4.4194+02   -1.4776-02   -2.9802-08
 185 CONT.     1000.00      386.17     386.17   5.5754+01    4.4193+02   -1.7007-02    5.9605-08
 186 CONT.     1000.00      415.36     415.36   2.6564+01    4.4192+02   -1.9253-02    1.9372-07
 187 CONT.     1000.00      441.63     441.63   3.0723-01    4.4194+02   -3.1412-02   -2.3842-07
 188 CONT.     1125.00         .00        .00   4.4471+02    4.4471+02    0.0000      -5.2387-09
 189 CONT.     1125.00       68.24      68.24   3.7652+02    4.4476+02   -7.0777-04   -2.9802-08
 190 CONT.     1125.00      129.66     124.66   3.1509+02    4.4475+02   -3.0095-03   -1.9558-08
 191 CONT.     1125.00      184.93     184.93   2.5980+02    4.4474+02   -5.3641-03    1.8626-09
 192 CONT.     1125.00      234.68     234.68   2.0997+02    4.4465+02   -8.0633-03   -3.7253-09
 193 CONT.     1125.00      279.45     279.45   1.6515+02    4.4460+02   -1.0517-02   -3.3528-08
 194 CONT.     1125.00      319.75     319.75   1.2463+02    4.4457+02   -1.2786-02   -6.7055-08
 195 CONT.     1125.00      356.01     356.01   8.8547+01    4.4456+02   -1.4931-02   -7.4506-08
 196 CONT.     1125.00      388.65     388.65   5.5894+01    4.4454+02   -1.7038-02   -5.9605-08
 197 CONT.     1125.00      418.03     418.03   2.6531+01    4.4456+02   -1.9755-02   -5.2154-07
 198 CONT.     1125.00      444.46     444.46   1.0586-01    4.4457+02   -3.1533-02    5.9605-07
 199 CONT.     1250.00         .00        .00   4.4693+02    4.4693+02    0.0000      -1.6044-09
 200 CONT.     1250.00       68.58      68.58   3.7831+02    4.4689+02   -9.9642-04   -3.7253-08
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FEFPM - SAMPLE PROBLEM NO. 3 - OUTPUT - 17

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*         S A M P L E   3        O P E N   P I T   I N F L O W          **   01/28/76-11:52:12    **    PAGE 19

NODE  B.C.      X-ORD      Y-ORD      Z-ORD     PRESSURE    POTENTIAL     FLOW FN     OUTFLOW

 201 CONT.    1250.00     130.30     130.30    3.1657+02   4.4687+02  -3.4583-03  -3.1665-08
 202 CONT.    1250.00     185.84     185.84    2.6096+02   4.4681+02  -6.0602-03  -2.7940-08
 203 CONT.    1250.00     235.84     235.84    2.1093+02   4.4677+02  -8.4652-03  -3.7253-09
 204 CONT.    1250.00     280.83     280.83    1.6593+02   4.4676+02  -1.0667-02  -2.9802-08
 205 CONT.    1250.00     321.32     321.32    1.2545+02   4.4677+02  -1.2666-02  -7.4506-09
 206 CONT.    1250.00     357.77     357.77    8.9055+01   4.4682+02  -1.4469-02  -7.4506-08
 207 CONT.    1250.00     390.57     390.57    5.6338+01   4.4691+02  -1.6084-02   8.1956-08
 208 CONT.    1250.00     420.09     420.09    2.6794+01   4.4688+02  -2.1781-02   1.0282-06
 209 CONT.    1250.00     446.66     446.66    2.1735-01   4.4687+02  -3.2365-02   7.7486-07
 210 CONT.    1375.00        .00        .00    4.4849+02   4.4849+02   0.0000      1.0747-08
 211 CONT.    1375.00      68.87      68.87    3.7970+02   4.4856+02  -1.8916-03  -6.3330-08
 212 CONT.    1375.00     130.84     130.84    3.1775+02   4.4859+02  -3.9932-03   5.2154-08
 213 CONT.    1375.00     186.62     186.62    2.6191+02   4.4853+02  -6.4452-03  -4.0978-08
 214 CONT.    1375.00     236.83     236.83    2.1168+02   4.4851+02  -8.6658-03   7.4506-09
 215 CONT.    1375.00     282.01     282.01    1.6649+02   4.4850+02  -1.0655-02   1.4901-08
 216 CONT.    1375.00     322.67     322.67    1.2583+02   4.4850+02  -1.2400-02   5.2154-08
 217 CONT.    1375.00     359.27     359.27    8.9232+01   4.4850+02  -1.3866-02  -6.7055-08
 218 CONT.    1375.00     392.21     392.21    5.6295+01   4.4850+02  -1.4994-02   1.6391-07
 219 CONT.    1375.00     421.85     421.85    2.6659+01   4.4851+02  -2.4027-02  -6.7055-07
 220 CONT.    1375.00     448.53     448.53   -1.3855-02   4.4852+02  -3.3290-02  -7.1526-07
 221 PRESS    1500.00        .00        .00    4.5000+02   4.5000+02   1.5499-04  -8.7135-04
 222 PRESS    1500.00      69.09      69.09    3.8091+02   4.5000+02  -2.0944-03  -2.1092-03
 223 PRESS    1500.00     131.27     131.27    3.1873+02   4.5000+02  -4.3945-03  -2.3114-03
 224 PRESS    1500.00     187.23     187.23    2.6277+02   4.5000+02  -6.6586-03  -2.2091-03
 225 PRESS    1500.00     237.60     237.60    2.1240+02   4.5000+02  -8.7783-03  -2.0334-03
 226 PRESS    1500.00     282.93     282.93    1.6707+02   4.5000+02  -1.0697-02  -1.8460-03
 227 PRESS    1500.00     323.73     323.73    1.2627+02   4.5000+02  -1.2383-02  -1.6668-03
 228 PRESS    1500.00     360.45     360.45    8.9550+01   4.5000+02  -1.3792-02  -1.5068-03
 229 PRESS    1500.00     393.49     393.49    5.6508+01   4.5000+02  -1.4817-02  -3.7195-03
 230 PRESS    1500.00     423.23     423.23    2.6767+01   4.5000+02  -2.4486-02  -9.6160-03
 231 PRESS    1500.00     450.00     450.00    0.0000      4.5000+02  -3.3732-02  -4.4227-03

  SUMMARY  OF  EXTERNAL  FLOWS            INFLOW      OUTFLOW
 PRESSURE NODES:                          3.231-02    3.231-02
 CONTINUITY NODES:  SPECIFIED FLOW        0.000       0.000
                    OTHER FLOW            4.842-06    4.596-06

 ASGIO DYNAMIC E.R. - *FREE TEMP14.         .
 ASGIO DYNAMIC E.R. - *FREE TEMP15.         .


*FIN
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