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FMG, RENUM, LINEL, ELLFMG, ELLP and DIMES: Chain of Programs for Calculating and Analyzing Fluid Flow through Two-Dimensional Fracture Networks. Users Manuals and Listings

D. Billaux, J. Peterson, S. Bodea, and J. Long

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FMG, RENUM, LINEL, ELLFMG, ELLP and DIMES: Chain of Programs for Calculating and Analyzing Fluid Flow through Two-Dimensional Fracture Networks. Users Manuals and Listings

Daniel Billaux, John Peterson, Sorin Bodea and Jane Long

Earth Sciences Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720

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Table of Contents

List of Tables

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1.0 Introduction

The purpose of this report is to provide the user with sufficient information to run the programs FMG, RENUM, LINEL, and ELLFMG. A previous report explained the theory and the design of these programs, so that by using the two reports, a thorough understanding of the codes is possible. This report should familiarize the user with program options and modes of operation, input variables, input and output files. Information not strictly needed to run the programs, but useful in understanding their internal structure is provided in appendices. The appendices cover program variables and arrays, subroutine outlines, a short description of each subroutine, and finally listings of codes. The additional information on FMG, RENUM, LINEL, and ELLFMG is in Appendices A, C, E, G respectively, and the listings are in Appendices B, D, F, and H.

An addition program TRINET which calculates the steady state or transient flow should be used in place of LINEL. LINEL is being phased out and will not be maintained. A complete description of TRINET is in a forthcoming report.

Two simple additional programs, ELLP and DIMES, are not considered in this manual. These two programs are used to plot the networks (DIMES) output by FMG and RENUM or the permeability ellipses (ELLP) obtained by ELLFMG. These programs are machine dependent and interactive, the user specifying if he wants a plot on his screen or on a plotter.

The codes are written in FORTRAN-77 for use on a CONVEX computer. Large arrays are dimensioned by constants set in "parameter" statements. An overall maximum dimensioning parameter statement is inserted in each main program and the appropriate subroutines. For each program, the allowable problem size, controlled by the maximum number of fractures, nodes, etc., can be changed simply by editing the parameter statement and recompiling the program.

2.0 Program FMG

Several options are available for the output generated by program FMG. First, the user selects one of four modes of operation, or ways in which the program can be executed, using the input control variable icont:

1. Generation of primary fracture system (icont = 1).
2. Generation of a primary fracture system and determination of the conducting fracture system in one or more flow regions (icont = 2)
3. Determination of the conducting fracture system in one or more flow regions from a previously generated primary fracture system (icont = 4)
4. Generation of a primary fracture system, and search of a connection between sides 1 and 3 (icont = 5).

The shape of the generation region and the flow region are controlled by the parameter igene:

- Rectangular generation and flow region for directional permeability measurements
- Circular generation and flow region, with a circular hole in the flow region to model well tests.

The user then controls the computation of one or more fluid flow meshes, one for each flow region, with the input variable imesh.

Table 2-1 lists the input variables and their formats by groups. The input groups required to run the program depend on the selected mode of operation. Table 2-1 indicates also which input groups are read for each value of the variable icont. Except for the group 2 and 3, all input variables are read from FMG.INP file. The Group 2 may also be read in the main program from the STUDY.DAT file. The group number 3 may also be read in the main program from the FRAC.DAT file, and it is unformatted; Groups 1,4,10 are read by the main program. Groups

5,6,7,8 are read by subroutine FRAGEN; Group 9 is read in subroutine SPATIA and Group 11 is read in subroutine WRENUM. Data Group 7 is repeated for each flow region; any number of flow regions can be designated for a given primary fracture system. The flow regions may be of various sizes as long as they fit within the generation rectangle, and of various orientations. Input variables are described in Table 2-1.

Table 2-3 lists the Input/Output units used by the program, describes the contents of each file, and identifies the subroutines that read or write the data.

Further information about the program is given in Appendix A: description of the program variables and arrays (Table A-1 and Table A-2); a subroutine outline (Table A-3) and description of the program subroutines (Table A-4). Appendix B is a listing of the code.

Table 2-1. FMG - Input Variables and Formats

Group	Variable	Format	Input.Unit
1	icont,iplot,imesh,iprnt	10x,i5,3(15x,i5)	1
	ikeep,iunits,igene	"	
	iranf,dseed	10x,i5,15x,d15.0	
2	istud	i2	20
	xstud(i),ystud(i), i = 1,istud	2(f6.2)	
3*	oray,odate,title		2
icont = 3	nsets,nfrac,xgene,ygene		
	(iseti(i,j),j=1,8), i=1,nsets	unformatted	
	(rseti(i,j),j=1,10),i=1,nsets		
	frac(i,j),j=1,10)kut(i),i=1,nfrac		
4	title	a	1
	xgene,ygene,nsgene(igene=0)	2(10x,f10.4),10x,i5	
	rgene,nsgene(igene=1)	10x,f10.4,30x,i5	
	nsets,itole	2(10x,i5)	
5	icent,idens	3(10x,i5)	1
6	nfrac	10x,i5,15x,f10.4	1
icent = 1	frac(m,j),j=1,5;m=1,nfrac	5(f10.4)	
7	nfrac (idens = 1)	10x,i5,15x,f10.4	1
	or		
	rlamb, (idens = 0)	10x,e10.3,10x,f10.4	
repeat for each	ichar	10x,i5	
characteristic:	const(ichar = 2)	10x,f10.4	
orientation	or		
length, and	idist,ev,sd(ichar = 3)	10x,i5,15x,f10.4,10x,f10.4	
aperture	or		
	ycept,slope,sd(ichar = 4)**	3(10x,f10.4)	
8	rlamb	10x,e10.3,10x,f10.4	1
icent = 3			
	ichar	10x, i5	
	idist,ev,sd(ichar = 3, 6, or 7)	10x,i5,15x,f10.4,10x,f10.4	
	or		
	ycept,slope,sd(ichar = 4 or 5)**	3(10x,f10.0)	

9	rlambmn (idens = 0)	10x,e10.3	7
icent = 3	or		
	rlbar,rlambmn(idens = 2)	10x,e10.3,10x,f10.4	
	or		
	nfracmn(idens = 1)	10x,i5,15x,f10.4	
	const(ichar = 2)	10x,f10.4	
	or		
	ev,sd(ichar = 3)	2(10x,f10.0)	
	or		
	ycept,slope,sd(ichar = 4 or 5**)	3(10x,f10.0)	
	or		
	sd(ichar = 7)	10x,f10.0	
10	xmesh,ymesh,rotan(igene = 0)	3(10x,f10.4)	
(icont=2 or 3)	rmesh,rhole,xhole,yhole(igene = 1)	4(10x,f10.4)	
11	bcode(i),i = 1,4	4i10	1
	bvalu(i),i = 1,4	4f10.4	

*This group, which can be written by a previous generation, is read from a unformatted file FRAC.DAT.

**The variables ycept, slope, sd(ichar = 4) are read only when generating the apertures.

Table 2-2. FMG - Description of Input Variables

Variable	Description
bcode(i),i=1,4	Boundary codes for side i of the flow region = -1 - constant flux = 0 - internal node = 1 - constant head = 2 - constant linearly distributed head
bvalu(i),i=1,4	Values of the boundary head or flux on side i of the flow region
const	Constant orientation, length, or aperture; const is read when ichar=2
dseed	Seed for random number generator (double-precision)
ev	Expected value (i.e., mean) of a statistical distribution
icent	Code for determining fracture characteristics; A negative value indicates that transmissivities are to be input instead of apertures. = 1 - read orientation, length, aperture and coordinates of fracture center = 2 - statistically generate coordinates of fracture center; set orientation, length, and aperture to a constant value or else statistically generate these characteristics = 3 - statistically generate fractures by zones
ichar	Code for determining individual fracture characteristics; ichar is read for each of orientation, length, and aperture/transmissivity = 2 - read constant values = 3 - generate statistically independent values = 4 - correlate aperture with log length (for aperture only) = 5 - correlate aperture with length (for aperture only)
icont	Code for controlling program execution = 1 - generate fracture system only = 2 - generate fracture system and compute the mesh = 3 - option no longer valid = 4 - read primary fracture system from local file called "frac" and compute mesh
idens	Code for reading either the density per set (rlamb) or the number of fractures per set (nfrac) = 0 - input rlamb, compute nfrac = 1 - input nfrac, compute rlamb = 2 - calculate rlamb from rlbar & rlambdal (used when generating fractures by zones)

idist	Code for statistical distributions = 1 - normal distribution = 2 - lognormal distribution = 3 - exponential distribution = 4 - gamma distribution (disabled) = 5 - uniform distribution
igene	Code for the shape of the generation and flow regions = 0 - rectangular regions = 1 - circular regions, with a circular hole in the flow region.
ikeep	Code for discarding dead-ends = 0 - keep only conducting fracture network = 1 - keep dead-ends = 2 - keep dead-ends and isolated clusters
imesh	Code for producing a finite element mesh = 0 - no mesh = 1 - generate mesh
iplot	Code for producing input files for the plotting program DIMES or COPLOT = 0 - no plot = 1 - generate plot files after RENUM only = 2 - generate plot files after both FMG and RENUM
iprnt	Code for printing output in LINEL = 0 - normal output = 1 - (used only in CHANGE) = 2 - print detailed output
iranf	Code for duplicating the random number generation of a previous run = 0 - "random" choice of dseed = 1 - read dseed to duplicate previous run
istud	Number of study regions
itole	Number of decimal places in the coordinates of fracture centers
iunits	Type of units = 0 - cgs = 1 - mks
nfrac	Number of fractures per set
nfracmn	Number of fractures in a given subregion
nsets	Number of fracture sets
nsgene	Number of generation sub-regions in each direction. The total number of subregions is $(nsgene)^2$
rgene	radius of the generation region (igene = 1)
rhole	radius of the circular hole in the flow region (igene = 1) for well-test modeling

rlamb	Number of fractures per unit area (fracture density)
rlambmn	Density of fractures (i.e. number of fracture per unit area) in a subregion
rlbar	Mean fracture length in a subregion
rmesh	radius of the flow region (igene = 1)
rotan	Angle of rotation of the flow region
sd	Standard deviation of a statistical distribution
slope	Slope of correlation line between variables
title(2)	Title of the problem to be solved
xgene	Dimension of the generation region in x direction
xhole	x-coordinate of the center of the hole in the flow region
xmesh	Dimension of the flow region in x direction
xstud(i)	Dimension of the study region in x direction
ycept	The y intercept of correlation line between two variables
ygene	Dimension of the generation region in y direction
yhole	y-coordinate of the center of the hole in the flow region
ymesh	Dimension of the flow region in y direction
ystud(i)	Dimension of the study region in y direction

Table 2-3. FMG - Input/Output Files

Unit	Name	Read/ Write	Main Prog./ Subroutine	Description
1	FMG.INP	Read	FMG	Input data groups: 1,2,3,4,10
			FRAGEN	Input data groups: 5,6,7,8
			SPATIA	Input data group: 9
			WRENUM	Input data group: 11
				Input data for plotting program:
3	LINESGR.DAT	Write	PLOCOO	Fractures in generation region (if iplot = 1 or 2)
3	LINES00.DAT	Write	PLOCOO	Fractures in first flow region before discarding anything (if iplot = 1 or 2)
3	LINESnn.DAT	Write	PLOCOO	Fractures in flow region for each rotation (if iplot = 2)
4	RENUMGR.DAT	Write	PLOCOO	Header for generation region
4	RENUM00.DAT	Write	PLOCOO	Header for first flow region
4	RENUMnn.DAT	Write	WRENUM	Input data for RENUM program for each flow region
5	FRAC.TXT	Write	WRENUM	Arrays frac(mfrac,10) and kut(mfrc)
6	FMG.OUT	Write	PFS	Statistics on characteristics of fractures by sets
			WRENUM	Titles and data about flow region
7	SUBREG.DAT	Read	SPATIA	Input data group: 9

FRAGEN

8	FRAC.DAT	Write	FMG	All primary fracture system data: file is written when icont = 1 or 2
8	FRAC.DAT	Read	FMG	All primary fracture system data: file is read in for each flow region in the run when icont = 1 or 2 or in subsequent runs when icont = 4, input data group 3
20	STUDY.DAT	Read	FMG	Input data group: 2
50	CONNECTIONS	Read/Write	CONNEC	Number of runs for which a connection has been found (icont = 5)

3.0 Program RENUM

The user does not need to write any input to RENUM. All the information the program needs is contained in the files RENUMnn.DAT created by FMG or CHANGE. Subroutine RDATA reads input from RENUM01.DAT, RENUM02.DAT, RENUM03.DAT, etc. MERGE then discards zero length elements, by combining nodes very close together into one node. Paths connected to the boundaries are traced in subroutine PATHS, in order to discard any complex dead-ends. Then the nodes are renumbered using a modified Cuthill-McKee method preparing them for output. This is done in subroutine MCGEE. A plot file is written by subroutine PLOT and the input file for the finite element program LINEL, LINEL.INP, is then output.

Alternatively, if the input file INTER.INP exists in the directory the input files for TRINET are written: CTRL.INP, ELMT.INP, NODE.INP. See TRINET manual for description of program.

Table 3-1 lists the input variables and their formats. These variables are described in Table 3-2. Table 3-3 lists the Input/Output units and files used by the program, describes succinctly the content of each file, and identifies the subroutines that read or write data. Further information about the program is given in Appendix C: description of the program variables and arrays (Table C-1 and Table C-2); a subroutine outline (Table C-3) and a description of each subroutine (Table C-4). Appendix D is a listing of the code.

Table 3-1. RENUM - Input Variables and Formatting

Variable	Format	Input Unit
title	10(a/)	1
neleme,nnodes,maxd,	3(10x,i6,5x)	
ikeep,iplot	2(10x,i5,5x)	
(ibs(1,m),ibs(2,m),ifrac(m),(xyzphi(i,m),i=1,6),m=1,nnodes)	5x,3i5,6f10.0	
(inode(1,n),inode(2,n),aptdis(1,n),aptdis(2,n),ifr(1,n), ifr(2,n),n=1,neleme)	5x,2i5,5x,2e10.4,5x,2i5	
If INTER.INP exists: (control variable for TRINET)		3
title2	a80	
imode,bmod,mxstep	3(10x,i5)	
time0,tmax,dtini	3(10x,f10.0)	
prr,theta,tole	3(10x,f10.0)	
dcint,dcon,dcoff	3(10x,f10.0)	
rhor,rmur,gravr	3(10x,f10.0)	
ssubs,dispc	2(10x,f10.0)	

Table 3-2. RENUM - Description of Input Variables and Arrays

Variable/Array	Description
aptdis(2,mxelem)	Fracture characteristics: aptdis(1,m)= transmissivity of element m aptdis(2,m)= length of element m
dcint	If the concentration difference is less than **dcint** between two adjacent nodes found during upstream search in **btrack.f**, cubic spline interpolation is used in **cubeint.f** to obtain the concentration of the originating fixed node, otherwise upwind scheme is used.
dcoff	When the concentration difference between two nodes becomes less than **dcoff**, and if one of them is a moving node, it is deleted in **pluck.f.**
dcon	When the concentration difference between the node and an adjacent node is larger than **decon**, a moving node(s) is originated from the node in **ftrack.f.**
dtini	Initial time step increment, Δt.
gravr	Gravitational constant. Default is 9.8067 m/sec^2.
ibs(2,mxnode)	Node information; n = 1, nnodes ibs(1,n) = node type = 0 internal node = 1 imposed head boundary node = -1 imposed flux boundary node ibs(2,n) = boundary side number for boundary nodes
ibmode	Used in **renum.f** to determine the boundary from which Cuthil-Mckee renumbering scheme starts: ibmode = 0 Radial boundary (start from side 5 only), 1 Square boundary (start from side 2 only), 2 Square boundary (start from all four sides: 1, 2, 3, 4).
ifrac(mxnode)	Number of fractures on which the node exists (3-D only).
ifr(2,mxelem)	Fracture numbers ie = 1, neleme

ifr(1,ie) = number of the fracture on which lies an element (fracture line in 2-D; fracture disc in 3-D)
ifr(2,ie) = number of other fracture disc on which lies an element, if relevant (3-D only)

ikeep — Code for discarding dead-ends
= 0 - keep only conducting fracture network
= 1 - keep dead-ends
= 2 - keep dead-ends and isolated clusters

imode — Used to control types of problems:
imode = -2 Steady-state flow only (theta = 1.0),
-1 Transient flow only,
0 Test data deck,
1 Transport in transient flow field,
2 Transport in steady-state flow field (theta = 1.0).

iplot — Code for producing input files for (fracture) the plotting program DIMES
= 0 - no plot
= 1 - generate plot files after RENUM only
= 2 - generate plot files after both FMG and RENUM

inode(2,mxelem) — Node number of the two nodes defining an element
m = 1, neleme
inode(1,m)= node number of the first node of element m
inode(2,m)= node number of the second node of element m

maxd — Number of sets of boundary conditions

mxstep — Maximum time step desired in the simulation.

neleme — Number of elements

nnodes — Number of nodes

prr — By default, the time step Δt is increased geometrically using the following formula:

$$\Delta t_{n+1} = \Delta t_n \times prr$$

rhor — Density of fluid. Default value is 1000 m^3/kg.

rmur — Dynamic viscosity of fluid. Default value is 0.001 kg/m·sec.

theta

Time weighting constant used in the following manner. Recommended value is 0.66. For steady-state flow problem, it is set to 1 internally.

$$\left[\frac{[A]^t}{\Delta t} + [B]^t\right] \cdot \{h\}^{t+\Delta t} = \{F\} + \left[\frac{[A]^t}{\Delta t} - (1-\Theta)\cdot[B]^t\right] \cdot \{h\}^t ,$$

where [A] is the storage coefficient matrix, [B] is the permeability matrix, {F} contains boundary conditions, {h} is the head vector. **theta** is used analogously for mass diffusion equation.

time0

Initial time of the start of simulation. time0 is other than zero when restarting a simulation which is stopped in the middle.

title

Title of the simulation run. Three lines are used. Two title lines are inherited from the mesh generator. One line is added from **INTER**.

title(10)

First ten lines read from RENUM%%.DAT then written to LINEL.INP: information needed by LINEL but not by RENUM. (character*80)

tmax

Maximum simulation time allowed (in real time).

tole

Tolerance to allow for numerical round off. For example, if the distance between two nodes are less than **tole** they are merged to one node.

xyzphi(6,mxnode)

Node information:
n = 1, nnodes
xyzphi(1,n)= x-coordinate of node n
xyzphi(2,n)= y-coordinate of node n
xyzphi(3,n)= z-coordinate of node n
xyzphi(4,n)= value of imposed head at node n, first boundary conditions
xyzphi(5,n)= value of imposed head at node n, second boundary conditions
xyzphi(6,n)= value of imposed head at node n, third boundary conditions

Table 3-3. RENUM - Input/Output Files

Unit	Name	Read/ Write	Main. Prog./ Subroutine	Description
1	RENUM%%.DAT	Read	RDATA	Input to program RENUM written by program FMG (see Table 1-1)
3	INTER.INP	Read	RCNTRL	Control variables for input to program TRINET
4	LINEL.INP	Write	PROUT	Node and element information; input to program LINEL
7	LINES%%.DAT	Write	PLOT	Plotting files used by program DIMES to make fracture plots of the flow regions
8	CTRL.INP	Write	TRIOUT	Control variables; input to program TRINET
9	NODE.INP	Write	TRIOUT	Node information; input to program TRINET
10	ELMT.INP	Write	TRIOUT	Element information; input to program TRINET
11	RENUM.ERR	Write	WERROR	Run-time error messages
12	NPN.INP	Read	RNPN	Read only if NPN.INP exists (see TRINET manual)

4.0 Program LINEL

In the same way as RENUM, the user does not need to write any input to LINEL. All the information the program needs is contained in the files LINEL.INP and STUDY.DAT. First, the study regions data is read by RSTUD. The header of the data file is read by RHEAD, and the nodes and elements information is read by RMESH. SORTIJ sorts the two nodes that form each element and then sorts the elements by their first node number. CPHI fills the matrix and vector constituting the linear system of equations to be solved. Then SYMSOL solves the system using a banded lower triangle decomposition. From the head at each node, the flux entering or leaving the network at each imposed head boundary node is computed by CUNK. PINFO print the header of the output file LINEL.OUT. SFLUX sums up and prints the fluxes on the various boundaries. The head at imposed flux boundary nodes is also output. If study regions were specified, the heads and fluxes at their boundaries are computed and printed by subroutine STUDY. This program is being phased out in favor of the transient flow program TRINET. See TRINET manual for details.

Table 4-1 lists the input variables and their formats. These variables are described in Table 4-2. Table 4-3 lists the Input/Output units and files used by the program, describes succinctly the content of each file, and identifies the subroutines that read or write data. Further information about the program is given in Appendix E: Description of the Program Variables and Arrays (Tables E-1 and E-2); a subroutine outline (Table E-3) and a description of each subroutine (Table E-4). Appendix F is a listing of the code.

Table 4-1. LINEL - Input Variables and Formats

Group	Variable	Format	Input.Unit
1	istud,igrad	2i2	20
	(xstud(k),ystud(k),k=1,istud)	2f6.2	
2	jobnam,date,iprnt	a19,3x,a9,i1	1
	title	a/a	
	nfrac	10x,i5	
	xgene,ygene,zgene	3(10x,f10.4)	
	xmesh,ymesh,zmesh	3(10x,f10.4)	
	rotan,rotan2	2(10x,f10.4)	
	ibcode	10x,6i10	
	bvalu	10x,6f10.0	
	visc,spgr	2(10x,f10.0)	
	neleme,nnodes,maxd	3(10x,i6,4x)	
	ibwth	50x,i5	
3	(ib(m),side(m),(coord(i,m),i=1,3) (phi(m,irot),irot=1,maxd),m=1,nnodes)	5x,2i5,5x,6f10.4	1
	(inode(1,n),inode(2,n),trans(n), dist(n),n=1,neleme)	5x,2i5,5x,2e10.4	1

Table 4-2. LINEL - Description of Input Variables and Arrays

Variable	Description
bvalu(i),i=1,6	Values of the boundary head or flux on side i of the flow region (bvalu(5) = bvalu(6) = 0 for 2-D cases)
coord(3,mxnode)	node coordinates, n=1, nnodes coord(1,n) = x coordinate of node n coord(2,n) = y coordinate of node n coord(3,n) = z coordinate of node n (0 if 2-D)
dist (mxelem)	Element length array ie=1, neleme dist(ie) = length of element number ie
ib(mxnode)	node type, n=1, nnodes ib(n) = 0 internal node = 1 imposed head boundary node = -1 imposed flux boundary node
ibcode(i),i=1,6	Boundary codes for side i of the flow region (ibcode(5) = ibcode(6) = 0 for 2-D cases) = -1 - constant flux = 0 - internal node = 1 - constant head = 2 - constant linearly distributed head
ibwth	Bandwidth of the linear system
igrad	Type of gradient to be used for study region permeability calculations = 0 use both types of gradients = 1 use global gradient only = 2 use local gradient only
inode(2,mxelem)	Element-node reference array, ie = 1,neleme inode(1,ie) = number of the node making up the first endpoint of element number ie inode(2,ie) = number of the node making up the second endpoint of element number ie
iprnt	Code for printing output = 0 print normal output in LINEL.OUT = 1 print normal output plus heads at disc intersections in LINEL.OUT (3D only) = 2 print detailed output in LINELALL.OUT
istud	Number of study regions

jdate	Character variable containing the date at which the line network was generated
jobnam	Character variable identifying the program that generated the line network
maxd	Number of different boundary conditions to be solved for the same network
neleme	Number of elements in the network
nfrac	Number of fractures in the flow region
nnodes	Number of nodes in the network
phi(mxnode,3)	Imposed head or flux on a node, if relevant, n = 1,nnodes; irot = 1,maxd phi(n,irot) = 0 if node n is internal phi(n,irot) = value of imposed head or flux for boundary node number n for set number irot of boundary conditions
rotan,rotan2	Rotation angles of the flow region(rotan2 = 0 for 2-D cases) For circular flow region, rotan and rotan2 are the coordinates of the center of the hole
side(mxnode)	Boundary side number, n=1, nnodes side(n) = side on which boundary node is lying = 0 if internal node
spgr	Specific gravity in the unit system chosen by the user
title(2)	Character*80, title of the problem to be solved
trans(mxelem)	Element transmissivities array ie = 1, neleme trans(ie) = transmissivity of element number ie
visc	Dynamic viscosity of water in the unit system chosen by the user
xgene,ygene,zgene	Size of the generation region (zmesh = 0 for 2-D cases) for circular generation regions, ygene = 0, and the radius is read in xgene
xmesh,ymesh,zmesh	Size of the flow region (z mesh = 0 for 2-D cases) for circular flow regions, xmesh = radius of flow region ymesh = radius of hole
xstud(20)	Size of the study regions in the x direction
ystud(20)	Size of the study regions in the y direction

Table 4-3. LINEL - Input/Output Files

Unit	Name	Read/ Write	Main Prog./ Subroutine	Description
1	LINEL.INP	READ	RHEAD RMESH	Input data Group: 3,4,5
6	LINEL.OUT	WRITE	CPHI,PINFO	-
8	LINELALL.OUT	WRITE	PINFO RMESH	-
10	LINEL.ERR	WRITE	WERROR	-
11	ELLIPSE.INP	WRITE	SFLUX	-
20	STUDY.DAT	READ	RSTUD	Input data group: 1,2
31	ELLIPSEG01.INP	WRITE	STUDY	
32	ELLIPSEG02.INP	"	"	
.	"	"	"	
.	"	"	"	
.	"	"	"	
[istud+30]	ELLIPSEG[istud].INP	"	"	
51	ELLIPSEl01.INP	WRITE	STUDY	
52	ELLIPSEl02.INP	"	"	
.	"	"	"	
.	"	"	"	
.	"	"	"	
[istud+50]	ELLIPSEl[istud].INP	"	"	

5.0 Program ELLFMG

The user does not need to write any input to ELLFMG. All the information the program needs is contained in the files ELLIPSE.INP, ELLIPSEG01.INP, ELLIPSEL01.INP, etc. These files are written by program LINEL. ELLFMG computes the best fit ellipse for a given set of directional permeability measurements. Table 5-1 lists the input variables and their formats. These variables are described in Table 5-2. Table 5-3 lists the input and output files used by the program. A description of the program variables and arrays is given in Appendix G (Table G1 and G-2). Appendix H is a listing of the code.

Table 5-1. ELLFMG - Input Variables and Formats

Group	Variable	Format	Input Unit
1	iray,idate jobname,jdate title(4)	a7,5x,a9 a7,5x,a9 a80	11
2	angle,xkganre,pkganre (as many lines as there are permeability measurements)	3e15.5	11

Table 5-2. ELLFMG - Description of Input Variables

Variable	Description
angle	Angle between x-axis and the direction of the gradient for a permeability measurement
idate	Date of creation of the fracture network
iray	Name of the program which created the network
jdate	Date the flow was computed
jobname	Name of the job which computed the flow
pkganre	Inverse of the square root of permeability for gradient direction "angle"
title(4)	Title lines for identifying the run
xkganre	Permeability for gradient direction "angle"

Table 5-3. ELLFMG - Input/Output Files

Unit	Name	Read/ Write	Main Program Subroutine	Description
6	ELLFMG.OUT	WRITE	Main	Output file for ELLFMG.
7	ELLIPSE.PLT	WRITE	Main	File containing plotting information
7	ELLIPSEG01.PLT ELLIPSEG02.PLT 03 PLT 04 : (istud)	WRITE WRITE	Main Main	Files containing plotting information for global gradients study regions if relevant*
7	ELLIPSEL01.PLT 02 03 : (istud)	WRITE	Main	Files containing plotting information for local gradient study regions if relevant*
11	ELLIPSE.INP (if ngrad = 0)	READ	Main	Input file for ELLFMG (flow region)
11	ELLIPSEG01.INP 02 03 : (istud) if(ngrad=1)	READ	Main	Input file for ELLFMG (global gradient study regions if relevant*)
11	ELLIPSEL01.INP 02 03 : (istud) if (ngrad = 2)	READ	Main	Input file for ELLFMG(local gradient study region if relevant*)

* see Theory and Design report, Chapter 4 (LINEL), for definition of local and global gradient study regions

Appendix A

FMG - Program Organization and Arrays

Table A-1. FMG - Description of Program Variables

Variable	Description	How Value is Assigned
Global:		
idate	Current date, character*9	Set by calling FORTRAN subroutine DATE
igene	Code for the shape of the generation and flow regions = 0 rectangular regions = 1 circular regions, with a circular hole in the flow region	Read from FMG.INP in main program
ikeep	Code for discarding dead-ends = 0 - keep only conducting fracture network = 1 - keep dead-ends = 2 - keep dead-ends and isolated clusters	Read from FMG.INP in main program
imesh	Code for producing a finite element mesh = 0 - no mesh = 1 - generate mesh	Read from FMG.INP in main program
iprnt	Parameter for LINEL passed to RENUM %%.DAT	Read from FMG.INP in main program
iranf	Code for duplicating the random number generation of a previous run = 0 - "random" choice of dseed = 1 - read dseed to duplicate previous run	Read from FMG.INP in main program
iray	Label for output file (FMG.OUT), character*19	Set in main program
istud	The number of study regions	Main program, PLOCOO
itole	Number of decimal places in the coordinates of fracture centers	Read from FMG.INP in main program
iunits	Type of units	Read from FMG.INP in

		main program
	= 0 - cgs = 1 - mks	
lplot	Keeps track of the number of the file where to write the plot information	Subroutine WRENUM
lrenum	Keeps track of the number of the file where to write mesh data for RENUM	Subroutines WRENUM, PLOCOO
mfrc	Maximum number of fractures	Set in a parameter statement in main program
mnod	Maximum number of nodes	Set in a parameter statement in main program
mkey	mnod*2	Set in a parameter statement in main program
nfrac	Number of fractures per set, then total number of fractures	Read from FMG.INP if idens=1; calculated in FRAGEN if idens=0 reset in limit, connec
nsets	Number of fracture sets	Read from FMG.INP in main program
nsgene	Number of sub-generation regions in each direction. The total number of subregions is $(nsgene)^2$	Read from FMG.INP in main program
pi180	Conversion factor from degrees to radians	Set in main program
qc	Factor which multiplied by the cubic power of the aperture gives the transmissivity	Set in main program
rmesh	Radius of the flow region. Set to rgene for the first call to subroutine CLIMIT in order to truncate fractures at the generation region boundaries	Read from FMG.INP in main program
rgene	Radius of the generation region (igene = 1)	Read from FMG.INP in main program
rhole	Radius of the circular hole in the flow region (igene = 1, for well-test modelling)	Read from FMG.INP in main program

rotan	Angle of rotation of the flow region	Read from FMG.INP in main program
spgr	Specific gravity	Set in main program according with the type of units used
visc	Viscosity	Set in main program
xgene	Width of the generation region in x-direction	Read from FMG.INP in main program
xhole	x-coordinate of the center of the hole in the flow region (igene = 1)	Read from FMG.INP in main program
xmesh	Width of the flow region in x-direction Set to xgene for the first call to subroutine RLIMIT in order to truncate fractures at the generation region boundaries	Read from FMG.INP in main program
ygene	Width of generation region in y-direction	Read from FMG.INP in main program
yhole	y-coordinate of the center of the hole in the flow region (igene = 1)	Read from FMG.IMP in main program
ymesh	Width of flow mesh region in y-direction Set to ygene for the first call to subroutine RLIMIT in order to truncate fractures at the generation region boundaries	Read from FMG.INP in main program

Local:

ai	Variable assigned to frac(i,8). See arrays description	Defined in CONNEC
ainf	Minimum of the range of a uniform distribution	Computed in UNIFOD
aj	Variable assigned to frac(j,8) See arrays description	Defined in CONNEC
alen	Length of the fracture	CLIMIT
bi	Variable assigned to frac(i,9) - see array description	Defined in subroutine CONNEC
bj	Variable assigned to frac(j,9) - see array description	Defined in subroutine CONNEC

delt	Discriminant of second order equation	CLIMIT
file	Char*7 File name	Defined in main program, subroutine SPATIA and WRENUM
filel	Char*7 File name	Used in subroutine PLOCOO
filer	Char*7 File name	Used in subroutine PLOCOO
ci	Variable assigned to frac(i,10). See array description.	Defined in subroutine CONNEC
cj	Variable assigned to frac(j,10).	Defined in subroutine CONNEC
cosr	Variable assigned to the cosine of the rotation angle of the flow region	Defined in WRENUM
cov	Covariance between two variables	Dummy argument in subroutine FRSTA1
crc	Correlation coefficient	Appear in subroutine FRSTA1
dist	The length of the element	Used in subroutine WRENUM
dx	One half of the projection of the length of fracture i on the x axis	Defined in subroutine ENDPTS
dy	One half of the projection of the length of fracture i on the y axis, taken with minus sign	Defined in subroutine ENDPTS
eapt	Dummy argument in subroutine FRSTA1 which takes the expected value of the statistical distribution for k = 1	
elen	Dummy argument in sub FRSTA1 which has the value of the expected statistical distribution for k = 2	
emin	Minimum value of the parameter	Set and used in NORMD1
flen	Length of fracture i	Subroutine LIMIT
hlen	Half of the length of fracture i	Defined in subroutine ENDPTS
ialpha	Integer form of [alpha]	Subroutine ORIEST
ibkey1	Value of boundary codes for sides i=1,4	Subroutine WRENUM

ibkey2	Value of boundary code for sides i = 1,4	Subroutine WRENUM
ieleme	Element number	Subroutine WRENUM
ier	Error code on return from the subroutine RLLAV	Subroutine FRSTA1
ifrc	Other fracture of intersection	Subroutine CONNEC
ifrc1	The number assigned to the first fracture in the current level	Subroutine CONNEC
ifrc2	Last fracture in current level	Subroutine CONNEC
ifrc3	Last fracture in next level	Subroutine CONNEC
ilevel	Current level	Subroutine CONNEC
in1	Node number 1 of current element	Subroutine WRENUM
in2	Node number 2 of the current element	Subroutine WRENUM
ind	Number of the fracture to be discarded	Subroutine CONNEC
indint	Index into the k node array	Subroutine CONNEC
inext	Pointer used to build the array next	Subroutine LIMIT
inode	Node number counter	Subroutine WRENUM
int1	First index in the [knode] array	Subroutine WRENUM
int2	Last index in the [knode] array	
io	Old number for fracture i	Subroutine CONNEC and WRENUM
iside	Side for the boundary codes	Defined in subroutine WRENUM
jint1	Index used in computing the intersections with previous fractures	Subroutine CONNEC
jint2	Index used in computing the intersections with previous fractures	Subroutine CONNEC

k0	Index of the first fracture in the next level	Subroutine CONNEC
k1	The new fracture number	Subroutine CONNEC
k2	Keeps track of the index of the next fracture to be considered	Subroutine CONNEC
ku	Truncation code (see array kut)	CLIMIT
maxd	Number of sets of boundary conditions output by the program (2 if constant gradient boundary conditions are specified, 1 if any imposed flux condition is specified)	Subroutine WRENUM
maxfrc	Maximum number of fractures	
msk1	Integer*2. Variable assigned to mask (1,i) while checking for intersections with fractures not previously included	Subroutine CONNEC
msk2	Integer*2. Variable assigned to mask (2,i) while checking for intersections with fractures not previously included	Subroutine CONNEC
ncon	Number of runs with connections	CONNEC
neleme	Number of elements	Subroutine CONNEC
nextra	Number of extra elements and nodes for non-truncated meshes (ikeep > 0)	Subroutine CONNEC
nslice	Dimensioning parameter for local arrays	Parameter statement in ORIEST
nf	Number of fractures in a set	Subroutine PFS
nfracmn	Number of fractures in a given subregion	Subroutine SPATIA
nnodes	Number of nodes	Subroutine CONNEC
nt	The number of intersections of a fracture line with the boundary lines of the flow region	Subroutine LIMIT
prtx	The new x coordinate of one end of the fracture	Subroutine LIMIT

prty	The new y coordinate of one end of the fracture	Subroutine LIMIT
ran	Random number	Subroutine RANDXY
rlambdal	Linear density, used to compute rlambmn if dens = 2	Subroutine SPATIA
rlambmn	Number of fractures in a subregion	Subroutine SPATIA
rlbar	Mean fracture length in a subregion. Read from the file SUBREG.DAT.	Used in subroutine FRAGEN
rhsq	rhole*rhole	CLIMIT
rmsq	rmesh*rmesh	CLIMIT
rs	Radius of generation region	CIRCXY
sdn	Standard deviation of normal distribution associated to log normal distribution with parameters ev,sd	Subroutine LOGNOD
sinr	Dummy variable assigned to sine of the rotation angle	Defined in subroutine WRENUM
slen	Standard deviation of the fracture length for the set under consideration	Subroutine FRSTA1
sn	Sum of 25 random variables distributed uniformly in (0,1)	Subroutine NORMAD
t1	Distance between the first end point of the fracture and a node	Subroutine WRENUM
t1,t2	Relative coordinates along the fracture line of its intersections with a circle (generation region, flow region, or hole). The relative coordinate is zero at the first endpoint and one at the second endpoint.	CLIMIT
told	[t] value of previous node used to compute element length	Subroutine WRENUM
toler	Tolerance in the minimum distance between points	Subroutine CIRCXY, RECTXY, CONNEC, WRENUM

transm	Transmissivity	Subroutine WRENUM
u0	x coordinates of the resultant vector in computing the standard deviation of orientation	Subroutine ORIEST
v0	y coordinate of the resultant vector in computing the standard deviation of orientation	Subroutine ORIEST
x1	x coordinate of first endpoint of fracture	CLIMIT
x2	xcoordinate of second endpoint of fracture	CLIMIT
xc	x coordinate of fracture center	Subroutine ENDPTS
xg2	Half of the width of the generation region in the x direction	Subroutine SPATIA
xm2	Half of the width of the flow mesh region in the x direction	Subroutine LIMIT
xsubgene	Width of the generation subregion in x direction	Subroutine SPATIA
y1	y coordinate of first endpoint of fracture	CLIMIT
y2	y coordinate of second endpoint of fracture	CLIMIT
yc	y coordinate of fracture center	Subroutine ENDPTS
yg2	Half of the width of the generation region in the y direction	Subroutine SPATIA
ym2	Half of the width of the flow mesh region in the y direction	Subroutine LIMIT
ysubgene	Width of the generation subregion in y direction	Subroutine SPATIA

Table A-2. FMG - Description of Program Arrays

Array	Description
Global:	
frac(mfrc,10)	Fracture characteristics, read, set, or generated in subroutine FRAGEN, n=1,nfrac frac(i,1) = orientation frac(i,2) = length frac(i,3) = aperture frac(i,4) = x1, x coordinate of fracture center or end frac(i,5) = y1, y coordinate of fracture center or end frac(i,6) = x2, x coordinate of fracture end frac(i,7) = y2, y coordinate of fracture end frac(i,8) = a, = -sin(orientation) frac(i,9) = b, = cos(orientation) frac(i,10) = c, = -(a*x1 + b*y1) so that ax + by + c = 0 is the equation of the line supporting the fracture. Note that frac(i,4) and frac(i,5) are first the fracture center coordinates during generation. They are then set to the coordinates of the first end-point of the fracture in subroutine ENDPTS.
ifrac(2,mnod)	The numbers of the two fractures that determine a node. Used in subroutines CONNEC and WRENUM.
iseti(20,8)	Used in subroutines FRAGEN and SPATIA to store the values of nfrac, icent, and idist for each set.
kut(mfrc)	Truncation code for each fracture. Set up in CLMIT or RLIMIT. If fracture in cuts sides i and j (where i and j are 0 when no side is cut), then kut(in) = 16*i + j. In subroutine CONNEC, [kut] is then transformed into an index for the array [knode].
knode(mkey)	Index into the arrays [ifrac] and [tint].
mask(2,mfrc)	Mask resulting from bit mapping of fractures. Used to save time in computing intersections.
next(mfrc)	Pointer keeping track of the fractures that intersect the flow region sides.

rseti(20,11)	Used in subroutines FRAGEN and SPATIA to store the values of const, ev, and sd for each set.
tint(2,mnod)	Distance between the first endpoint of a fracture and the node.
xstud(10)	Dimension of the study region in x direction.
ystud(10)	Dimension of the study region in y direction.

Local:

a(n)	Array used to store the random distribution once this is created. Used in subroutine DISTRI and in all the random generation subroutines.
bcode(i)	Boundary codes for sides i=1,4 of the flow region which are read from FMG.INP = -1 - constant flux = 0 - internal node = 1 - constant head = 2 - constant, head linearly distributed
bval(2)	The heads for the rotation and for rotation plus 90° of the boundary node.
bvalu(4)	Boundary values of the head or flux on side i=1,4 of the flow region.
corner(2,5)	Coordinates of the corners of the flow region.
is(4)	The number attached to each flow region boundary line. Can take the values 1,2,3 and 4.
mseed(3)	Seeds for random number generator.
ola(3)	Character *11 array to store the words "orientation", "length", "aperture".
rseed(3)	Seeds for random number generator.
rseti(20,11)	Used in subroutines FRAGEN, SPATIA to store the constant value (ichar = 2); or expected value and standard deviation of each parameter for each set.
type(5)	Stores the name of the type of distribution.
wk(4000)	Temporary working storage for IMSL.

x(n)	X coordinate of randomly distributed fracture centers in RECTXY and CIRCXY.
xy(mfrc,6)	Contains two variables (length and aperture) and three work spaces for RLLAV.
y(n)	Y coordinates of randomly distributed fracture centers in RECTXY and CIRCXY.

Table A-3. FMG - Subroutine Outline

FMG	FRAGEN	SPATIA	RANDXY	
			NORMD1	
			DISTRI	NORMAD
				LOGNOD
				EXPOND
				UNIFOD
		RECTXY		
		CIRCXY		
		NORMD1		
		DISTRI	NORMAD	
			LOGNOD	
			EXPOND	
			UNIFOD	
	EQLINE			
	ENDPTS			
	PFS	ORIEST		
		FRSTAT		
		FRSTA1	RLLAV	
	RLIMIT			
	CLIMIT	MOVE		
	PLOCOO			
	CONNEC			
	WRENUM			

Table A-4. FMG - Description of Subroutines

CIRCXY

Generates the coordinates of the fracture centers according to a random distribution in a circle.

given: n,dseed,rs,itole

returns: x(n),y(n)

CLIMIT

Truncates the portions of the fractures lying
- outside of the generation region at the first call; or
- outside of the flow region or inside of the hole at the second call.

Recalculates the fracture endpoints and length. Fills the [mask(2,mfrc)] and [kut(mfrc)] arrays.

given: nfrac,nsets,iseti(nsets,2),maxfrc, (frac(nfrac,i), i=4 to 7),rmesh

returns: frac(nfrac,2),(frac(nfrac,i),i=4 to 7), kut(nfrac),mask(2,nfrac)

uses: MOVE

CONNEC

Searches for intersections between fractures. Starts with the initial fractures selected by subroutine RLIMIT or CLIMIT. Looks for fractures intersecting the initial ones, then fractures intersecting the ones it found, and so on. If icont is not 5, stops when there is no more intersection to be found (ikeep = 0) or when all fractures have been checked (ikeep ≥ 1). If icont is 5, stops whenever boundary side 3 is reached, or when there is no more intersection to be found. Calculates the number of nodes and elements.

given: maxfrc,frac(mfrc,10),kut(mfrc),nfrac,itole,ikeep
mask(2,mfrc),ifrac(2,mnod),next(mfrc)

returns: tint(2,mnod), modified kut, next

prints: ncon

DISTRI

Calls the appropriate distribution routine to be used in the generation of values, based upon the value of the code [idist] such that if:

idist = 1 - normal distribution
= 2 - lognormal distribution
= 3 - exponential distribution

= 4 - gamma distribution (disabled)
= 5 - uniform distribution

given: idist

returns: a(n)

uses subroutines: NORMAD
LOGNOD
EXPOND
UNIFOD

ENDPTS — Takes the fracture characteristics (orientation, length and center coordinates) and computes the coordinates of each endpoint of the fracture.

given: maxfrc,nfrac,frac(i,1),frac(i,2),frac(i,4),frac(i,5)

returns: frac(i,4),frac(i,5),frac(i,6),frac(i,7)

Note that frac(i,4) and frac(i,5) are modified in ENDPTS.

EQLINE — Calculates the coefficients a, b and c of the line which supports each fracture.

given: maxfrc,nfrac,frac(i,1),frac(i,4),frac(i,5)

returns: frac(i,8),frac(i,9),frac(i,10)

EXPOND — Generates random variables distributed exponentially with expected value ev.

given: n,dseed,ev

returns: a(n)

FRAGEN — Reads in or generates the following fracture characteristics: orientation, length, aperture, and the coordinates of the fracture center.

given: maxfrc,dseed,nsets,xgene,ygene,nsgene,iranf,
icent,idens,ipois,itole,iseti(i,j),rseti(i,j),rgene,igene

reads: icent,idens,ipois,nfrac,theta
[frac(m,j); j=1,5; m = n1,n2],rlamb,ichar,const,
idist,ev,sd,ycept,slope,sd

returns: nfrac, (frac(i,j), j = 1,5), i = 1, nfrac

uses subroutines:

SPATIA	RECTXY	
	NORMD1	
	DISTRI	NORMAD
		LOGNOD
		EXPOND
		UNIFOD
RECTXY		
CIRCXY		
NORMD1		
DISTRI	NORMAD	
	LOGNOD	
	EXPOND	
	UNIFOD	

FRSTAT — Calculates a mean [ev] and a standard deviation [sd]

given: a(n),n,k

returns: ev,sd

FRSTA1 — Calculates the covariance [cov] and correlation coefficient [crc] if the index ichar = 4 or ichar = 5 (which corresponds with having aperture and length correlated when the fracture characteristics are generated).

given: n,a(n),b(n),ichar,elen,slen,eapt,sapt,beta(1), beta(2)

returns: cvc,crc,ycept,slope

GGUBFS: — random number generator

given: dseed

returns: ggubfs, modified dseed

LOGNOD — Generates random variables distributed lognormally with mean [ev] and standard deviation [sd].

given: ev,sd,dseed,n

returns: a(n)

MOVE — Moves the information in the array frac for all fractures with number greater than i. This subroutine is used to make room for boundary fractures newly created because of the splitting of fractures at an inner boundary (hole).

given: i,nfrac,n2,frac(nfrac,10)

returns: modified i,nfrac,n2,frac

NORMAD — Generates random variables distributed normally with expected value [ev] and standard deviation [sd].

given: ev,sd,dseed,n

returns: a(n)

NORMD1 — Generates random variables distributed normally with expected value [ev] and standard deviation [sd], where [ev] for one parameter (i.e. aperture) is proportional to the logarithm of another parameter (i.e. length) or to the parameter itself depending upon the value of the parameter [ichar] (i.e., if ichar = 4 use log (length), if ichar = 5 use length).

given: ev,sd,dseed,ichar,ycept,slope,b(n)

returns: a(n)

ORIEST — Calculates the basic statistic elements (mean and circular standard deviation) for orientation distributions.

given: a(n),b(n),d(n),nslice

returns: ev,sd

PFS — Calculates and prints the fracture statistics for each set in order to compare them to the specified fracture statistics.

given: frac(maxfrc,10),nsets,iseti(20,8),rseti(20,11)

prints: ev,sd

uses subroutines: ORIEST
FRSTAT
FRSTA1

PLOCOO — Writes the input decks for the plotting programs DIMES or COPLOT

given: maxfrc,frac(maxfrc,10),itole,iranf, iunits,ikeep,imesh,iskip8,nfrac,
iplot,lplot,xgene,ygene,xmesh,ymesh,
rotan,nsgene,istud,xstud(10),ystud(10)

prints: fracture endpoints

RECTXY — Generates the coordinates of the fracture centers according to a random distribution in a rectangle.

given: n,dseed,xs,ys,itole,ipois,slcos,slsin

returns: x(n),y(n)

RLIMIT — Truncates the portion of the fractures lying outside of the flow or generation region and recalculates the fracture endpoints and length if needed. Fills the [mask (2,mfrc)] and [kut(mfrc)] arrays.

given: nfrac,nsets,iseti(1,2),maxfrc,frac(nfrac,8),
frac(nfrac,9),frac(nfrac,10),xmesh,ymesh,rotan.

returns: frac(nfrac,2),frac(nfrac,4),frac(nfrac,5),frac(nfrac,6)
frac(nfrac,7),kut(nfrac),mask(2,nfrac)

SPATIA — Reads fracture information by subregions and then generates fractures by subregions.

given: maxfrc,dseed,frac(maxfrc,10),icent,itole,
iranf,iunits,ikeep,imesh,nfrc,iplot,
xgene,ygene,xmesh,ymesh,rotan,nsgene, nsets,iseti(20,8)

reads: rseti(i,11),ichar,idist,ev,sd,ycept,slope,
rlambmn,rlbar,nfracm,theta,const

returns: frac(i,j), j = 1,5

UNIFOD — Generates random variables distributed uniformly between (center -range) and (center +range)

given: n,dseed,center,range

returns: a(n)

WRENUM — Computes boundary conditions, and writes the input decks RENUM%%.DAT for the mesh optimization program RENUM.

given: frac(maxfrc,10),kut(mfrc),knode(mkey),
tint(2,1),ifrac(2,1),xgene,ygene,xmesh,
ymesh,rotan,nsgene,itole,iranf,kenzi,

imesh,nfrac,iplot,nnodes,neleme,iray,
idate,lrenum,visc,spgr,ikeep,transm

reads: [bcode(i),i=1,4],[bvalu(i),i=1,4]

prints: complete mesh specification

Appendix B

FMG - Program Listing

```
      program fmg
c     ************************* s e t u p ***************************
c
      parameter (mfrc=100000)
      parameter (mnod=70000)
      parameter (mkey=90000)
      common/files/ lplot,lrenum
      common/frac/  frac(mfrc,10)
      common/ifrac/ ifrac(2,mnod)
      common/inew/  inew(mfrc)
      common/iold/  iold(mfrc)
      common/iwk/   iwk(mfrc)
      common/kind/  kind(mnod)
      common/knode/ knode(mkey)
      byte kind
      common/kut/   kutone,kut(mfrc)
      common/mask/  mask(2,mfrc)
      integer*2 mask
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     '              rmesh,xhole,yhole,rhole,nsgene
      common/next/  next(mfrc)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     '              iplot,igene
      common/pi/    pi180
      common/qc/    visc,spgr,qc,itrans
      common/seti/  nsets,iseti(20,8),rseti(20,11)
      common/stud/  istud,xstud(10),ystud(10)
      common/tint/  tint(2,mnod)
      common/title/ title,iray,idate
      common/xy/    xy(mfrc,6)
      integer*2 iside(mfrc)
      dimension nfrs(4)
      character*80 title(2)
      character*10 faccs(2)
      character*9 idate,odate
      character*19 iray,oray
      character*3 cgsmks(2),fstat(2)
      double precision dseed
      data cgsmks/'cgs','mks'/
      data faccs,fstat/'sequential','append','new','old'/
      data lplot,lrenum/-2,0/
c
c  define pi/180.
c
      pi180 = atan(1.)/45.
c
c *** open files
c
      open (unit=1,readonly,file='fmg.inp',status='old')
      open (unit=6,file='fmg.out',status='unknown')
c     open (unit=15,readonly,file='plot.dat',status='old')
      istud=0
      open (unit=20,readonly,file='study.dat',status='old',err=19)
      istud=1
c
c *** set maxfrc & maxkey to dimension the whole program
c
   19 maxfrc= mfrc
      maxnod= mnod
      maxkey= mkey
c
c *** request job information.
c
      iray = 'fmgrun Version 1.00'
      call date (idate)
c
c     ************************* i n p u t ***************************
c
c *** read control variables
c
c
      read (1,260) icont,iplot,imesh,iprnt
      read (1,260) ikeep,iunits,igene
      read (1,270) iranf,dseed
      write(6,410) cgsmks(iunits+1)
      write(6,290) icont,iplot,imesh
c
      if (iunits.eq.0) then
        visc=.01
        spgr=980.66
       else
        visc=.001
        spgr=9806.6
c
c
       endif
      qc=spgr/(12.*visc)
c
      if (istud.ne.0) read(20,'(12)') istud
      if (istud.ne.0) then
        do 1130 i=1,istud
          read(20,1140)xstud(i),ystud(i)
 1140     format(2f6.2)
 1130   continue
       endif
      if (icont.eq.4) go to 49
      if (icont.eq.3) then
        stop ' option icont=3 is no longer valid'
       endif
c
c *** read input variables
c
      read (1,330) title
      if(igene.eq.0)then
        read (1,250) xgene,ygene,nsgene
       else
        read(1,250) rgene,dumy,nsgene
        xgene=2.*rgene
        ygene=2.*rgene
       endif
      read (1,280) nsets,itole
c
c     ********** f r a c t u r e   g e n e r a t i o n **********
c
c *** call subroutine fragen to read in or generate fracture
c *** characteristics and store them in array frac
c
      call fragen (maxfrc,dseed,frac)
c *** program stop if nfrac greater than maxfrc
c
      if (nfrac.gt.maxfrc) then
        write(6,140) nfrac,maxfrc
        stop
       endif
c
c *** print the contents of frac.
c
```

```
      write(6,210) iray,idate
      write(6,450)
      write(6,470) nfrac
      do 30 m=1,nsets
        write(6,220)
        write(6,230) m,iseti(m,2),rseti(m,10)
        write(6,240)
   30   continue
c
c *** fill array frac ---
c *** 1.  call subroutine eqline to calculate coefficients of the
c ***     equation of the line on which the fracture lies,
c *** 2.  call subroutine endpts to calculate fracture endpoints,
c
      call eqline(maxfrc,frac)
      call endpts(maxfrc,frac)
c
c *** calculate and print fracture statistics for each set
c
      write(6,540)
      call pfs (maxfrc,frac,xy)
c
c *** 3.  call subroutine rlimit or climit to truncate any fractures
c ***     falling outside of the generation block.
c
      if(igene.eq.0)then
        rotan=0.
        xmesh=xgene
        ymesh=ygene
        call rlimit(icont,maxfrc,frac)
       else
        rmesh=rgene
        rhole=0.
        xhole=2.*rmesh
        yhole=2.*rmesh
        call climit(icont,maxfrc,frac)
       endif
c
c *** print the contents of frac and kut.
c
      write(6,210) iray,idate
      write(6,480)
      write(6,460) xgene,ygene,nsgene**2
      write(6,470) nfrac
c
c
c *** write frac and kut to tape5.
c
        open (unit=5,file='frac.txt',status='unknown')
        write (5,300) iray,idate
        write (5,330) title
        write (5,420) nsets
        write (5,350) ((iseti(i,j),j=1,8),i=1,nsets)
        write (5,370) ((rseti(i,j),j=1,10),i=1,nsets)
        write (5,430) nfrac,xgene,ygene
        write (5,380) ((frac(i,j),j=1,7),kut(i),i=1,nfrac)
        close (unit=5)
c
c *** calculate and print fracture statistics for each set
c
      write(6,550)
      call pfs (maxfrc,frac,xy)
c
c *** write data to unit 8
c
      open (unit=8,file='frac.dat',status='unknown',form='unformatted')
      write (8) iray,idate,title
      if (igene.eq.0)then
        write (8) nsets,nfrac,xgene,ygene
       else
        write (8) nsets,nfrac,rgene
       endif
      write (8) ((iseti(i,j),j=1,8),i=1,nsets),
     1          ((rseti(i,j),j=1,10),i=1,nsets)
      do i1=1,nfrac,1000
        i2=min0(nfrac,i1+999)
        write (8) ((frac(i,j),j=1,10),kut(i),i=i1,i2)
       enddo
      close (unit=8)
c
c
c *** if iplot = 1, write an input file for a plotting program on tape3
c
      if (iplot.ge.1.and.icont.ne.5)call plocoo(maxfrc,frac)
c
      if (icont.eq.1) then
        write(6,150)
        stop
       endif
c
c *** open data in unit 8
c
   49 open (unit=8,file='frac.dat',status='old',readonly,form='unformatted')
c
c     ******************** f l o w   r e g i o n **********************
c
   50 if (igene.eq.0)then
        read (1,440,end=130) xmesh,ymesh,rotan
       else
        read (1,445,end=130) rmesh,rhole,xhole,yhole
        xmesh=rmesh*2.
        ymesh=rmesh*2.
       endif
c
c
c *** read data from unit 8
c
      read (8) oray,odate,title
      if (igene.eq.0)then
        read (8) nsets,nfrac,xgene,ygene
       else
        read (8) nsets,nfrac,rgene
       endif
      read (8) ((iseti(i,j),j=1,8),i=1,nsets),
     1          ((rseti(i,j),j=1,10),i=1,nsets)
      do i1=1,nfrac,1000
        i2=min0(nfrac,i1+999)
        read (8) ((frac(i,j),j=1,10),kut(i),i=i1,i2)
       enddo
      rewind (unit=8)
c
      if ((xmesh.ne.xgene).or.(ymesh.ne.ygene).or.(rotan.ne.0.).or.
     1    (rmesh.ne.rgene).or.(rhole.ne.0.)) then
c
c *** call subroutine rlimit or climit to eliminate or truncate
c *** fractures falling outside of the flow region.
c
       if (igene.eq.0)then
```

```
          call rlimit(icont,maxfrc,frac)
         else
          call climit(icont,maxfrc,frac)
         endif
        endif
       if (nfrac.eq.0) write(6,170) rotan
c
c *** print the contents of frac and kut.
c
       write(6,210) iray,idate
       write(6,490)
       write(6,500)
       write(6,510) xmesh,ymesh,rotan
       write(6,530) nfrac
c
c *** calculate and print fracture statistics for each set
c
       write(6,560)
       call pfs (maxfrc,frac,xy)
c
c
c *** if iplot = 1, write an input file for a plotting program on tape3
c
c
       if (iplot.ge.1.and.nfrac.ne.0.and.rotan.eq.0..and.icont.ne.5) then
         call plocoo(maxfrc,frac)
        else
         if(iplot.lt.0)iplot=0
        endif
       call connec(icont,maxfrc,iside,frac)
       if (icont.eq.5)goto 50
       call wrenum(maxfrc,frac)
c
c *** if iplot = 2, write an input file for a plotting program on tape3
c
       if (iplot.eq.2.and.nfrac.ne.0) call plocoo(maxfrc,frac)
       go to 50
c
  130 write(6,160)
       stop
c
c      *************** f o r m a t   s t a t e m e n t s ****************
c
c
c
  140 format('1',39('-')/
     1  ' program stop,nfrac is greater than maxfrc,nfrac = ',16/
     2  ' maxfrc= ',16/1x,55('-'))
  150 format('0normal program stop,icont=1')
  160 format('0normal program stop,end of input')
  170 format('0no fractures in flow region for rotan=',f6.2)
  210 format('0',a19,' - ',a9)
  220 format('0',10(/),6x,'set       number of fractures',6x,
     1  'density of fractures'/)
  230 format('0',5x,i5,15x,i5,15x,i5,15x,1p,e10.3)
  240 format(10(/))
  250 format(2(10x,f10.4),10x,i5)
  260 format(10x,i5,3(15x,i5))
  270 format(10x,i5,15x,d15.8)
  280 format(3(10x,i5))
  290 format('0icont=  ',i5,10x,'iplot =  ',i5,10x,'imesh = ',i5)
  300 format(a19,' - ',a9)
  330 format(a)
  350 format(8i10)
  370 format(1p,5e12.4)
  380 format(2f10.4,1p,e10.3,0p,4f10.2,3x,z2)
  410 format('*** units are ',a,' ***')
  420 format('--nsets---',i5)
  430 format('--nfrac---',i5,'--xgene---',f10.4,'--ygene---',f10.4)
  440 format(3(10x,f10.4),7x,i1)
  445 format(4(10x,f10.4))
  450 format('0f r a c t u r e   g e n e r a t i o n')
  460 format('0the size of the generation region is ',f8.1,' by ',f8.1/
     1  ' the number of subregions is ',i3)
  470 format('0the number of fractures generated or read in is ',i5)
  480 format('0t r u n c a t e d   f r a c t u r e s   o f',
     1  '   g e n e r a t i o n   s t a g e')
  490 format('0f r a c t u r e s   i n   f l o w   r e g i o n')
  500 format(' ( a l l   f r a c t u r e s   i n c l u d e d )')
  510 format('0the size of the flow region is ',f8.1,' by ',f8.1/
     1  ' the angle of rotation is ',f6.2)
  530 format('0the number of fractures in the flow region is ',i5)
  540 format('0f r a c t u r e   s t a t i s t i c s')
  550 format('0f r a c t u r e   s t a t i s t i c s'/
     1  ' o f   t r u n c a t e d   f r a c t u r e s')
  560 format('0f r a c t u r e   s t a t i s t i c s'/
     1  ' o f   f r a c t u r e s   i n   f l o w   r e g i o n')
      end
```

```
      subroutine circxy (x,y,n,dseed,rs,itole)
c
c *** this subroutine generates random fracture centers
c *** in a circle with radius rs
c
      dimension x(n),y(n)
      double precision dseed
c
      toler=10.**itole
      rt=2*rs*toler
      do i=1,n
   10   a=ggubfs(dseed)-0.5
        b=ggubfs(dseed)-0.5
        if(a*a+b*b.gt.0.25)goto 10
        x(i)=float(int(rt*a))/toler
        y(i)=float(int(rt*b))/toler
       enddo
c
      return
      end
```

```
      subroutine climit (icont,maxfrc,frac)
      parameter (nc=10)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     ,              iplot,igene
      common/inew/  inew(100)
      common/iold/  iold(100)
      common/kut/   kutone,kut(100)
      common/mask/  mask(2,100)
      integer*2 mask
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     ,              rmesh,xhole,yhole,rhole,nsgene
      common/next/  next(100)
      common/pi/    pi180
      common/seti/  nsets,iseti(20,8),rseti(20,11)
c
c     ****************************************************************
c
c     this subroutine truncates a fracture if one or both of its
c     endpoints fall outside of the circle of radius rmesh,
c     and discards the fracture if it is outside the block.
c
c     if the fracture is truncated, the coordinate of the endpoints
c     and the length of the fracture are recalculated.
c
c     nfrac is the number of fractures.
c
c     one components of frac may be recalculated in this subroutine -
c       frac(i,2) = length,
c       frac(i,4) = x1, x coordinate of endpoint 1,
c       frac(i,5) = y1, y coordinate of endpoint 1,
c       frac(i,6) = x1, x coordinate of endpoint 2,
c       frac(i,7) = y1, y coordinate of endpoint 2.
c
c     the components of frac used in this subroutine are ---
c       frac(i, 8) = a = -sin of orientation,
c       frac(i, 9) = b =  cos of orientation,
c       frac(i,10) = c,
c     where a, b, and c are the coefficients in the equation of the
c     line, ax + by + c = 0, on which fracture i lies.
c
c       kut(i) = truncation code.
c       next(i) = where the next truncated fracture sits
c
      dimension frac(maxfrc,10)
      dimension t(4),is(4)
c
      toler=10.**-itole
      k=1
      n2=0
      inext=0
      rmsq=rmesh*rmesh
      rm2=rmesh*2.
      rhsq=rhole*rhole
c
c
      do 170 l=1,nsets
c
        m=0
c
        n1=n2+1
        n2=n1+iseti(1,2)-1
        if (n2.lt.n1) go to 170
c
        i=n1
        do while (i.le.n2)
c
c     calculate intersection with outer disc
c
          1160=0
          next(i)=0
          x1=frac(i,4)
          y1=frac(i,5)
          x2=frac(i,6)
          y2=frac(i,7)
          alen=frac(i,2)
          ku=0
          a=alen*alen
          b=x1*(x2-x1)+y1*(y2-y1)
          c=x1*x1+y1*y1-rmsq
          delt=b*b-a*c
          if(delt.le.0.)goto 150
          delt=sqrt(delt)
          t1=(-b-delt)/a
          if(t1.ge.1.)goto 150
          t2=(-b+delt)/a
          if(t2.le.0.)goto 150
          if(t1.gt.0.)then
            x1=x1+t1*(x2-x1)
            y1=y1+t1*(y2-y1)
            t2=(t2-t1)/(1.-t1)
            alen=alen*(1.-t1)
            if(alen.lt.toler)goto 150
            ku=ku+48
          endif
          if(t2.lt.1.)then
            x2=x1+t2*(x2-x1)
            y2=y1+t2*(y2-y1)
            alen=alen*t2
            if(alen.lt.toler)goto 150
            ku=ku+3
          endif
c
c     calculate intersection with inner disc
c
          a=alen*alen
          xx1=x1-xhole
          yy1=y1-yhole
          xx2=x2-xhole
          yy2=y2-yhole
          b=xx1*(xx2-xx1)+yy1*(yy2-yy1)
          c=xx1*xx1+yy1*yy1-rhsq
          delt=b*b-a*c
          if(delt.le.0.)goto 140
          delt=sqrt(delt)
          t1=(-b-delt)/a
          if(t1.ge.1.)goto 140
          t2=(-b+delt)/a
          if(t2.le.0.)goto 140
          if(t1.lt.0..and.t2.gt.1.)goto 150
          if(t1.gt.0.)then
            ku2=ku-16*(ku/16)
            kuplus=1-ku2
            if(t2.lt.1.)then
              frac(i,4)=x1+(t1+t2)*(x2-x1)/2.
              frac(i,5)=y1+(t1+t2)*(y2-y1)/2.
              if (ku2.ne.0)then
                frac(i,2)=sqrt( (frac(i,6)-frac(i,4))**2 +
     ,                          (frac(i,7)-frac(i,5))**2 )
```

```
            else
              frac(i,2)=alen*(1.-(t1+t2)/2.)
              frac(i,6)=x2
              frac(i,7)=y2
            endif
            x2=x1+t1*(x2-x1)
            y2=y1+t1*(y2-y1)
            alen=alen*t1
            ku=ku+kuplus
            i160=1
            if (k.eq.i)call move(i,nfrac,n2,frac,maxfrc)
            goto 140
          endif
          x2=x1+t1*(x2-x1)
          y2=y1+t1*(y2-y1)
          alen=alen*t1
          ku=ku+kuplus
        endif
        if(t2.lt.1.)then
          kul=ku/16
          kuplus=16*(1-kul)
          x1=x1+t2*(x2-x1)
          y1=y1+t2*(y2-y1)
          alen=alen*(1.-t2)
          ku=ku+kuplus
        endif
c
c *** store information about fractures part or all of which fall into
c *** the flow region.
c
  140   ix1=(x1+rmesh)*nc/rm2
        ix2=(x2+rmesh)*nc/rm2
        iy1=(y1+rmesh)*nc/rm2
        iy2=(y2+rmesh)*nc/rm2
        ix=min(ix1,ix2)
        iy=min(iy1,iy2)
        ix2=ix1+ix2-ix+1
        iy2=iy1+iy2-iy+1
        ix2=2**min(ix2,nc)
        iy2=2**min(iy2,nc)
        ix=max(ix,0)
        iy=max(iy,0)
        ix1=2**min(nc-1,ix)
        iy1=2**min(nc-1,iy)
        mask(1,k)=ix2-ix1
        mask(2,k)=iy2-iy1
        kut(k)=ku
        frac(k,1)=frac(i,1)
        frac(k,2)=alen
        frac(k,3)=frac(i,3)
        frac(k,4)=x1
        frac(k,5)=y1
        frac(k,6)=x2
        frac(k,7)=y2
        do j=8,10
          frac(k,j)=frac(i,j)
        enddo
c
        next(k)=0
        k16=kut(k)/16
        if(k16.eq.1.or.kut(k)-16*k16.eq.1) then
          next(k)=inext
          inext=k
        endif
          k=k+1
          m=m+1
  150     if(i160.eq.0)i=i+1
c
        enddo
c
        iseti(1,2)=m
c
  170   continue
c
      nfrac=k-1
      k16=kut(nfrac)/16
      if(k16.ne.1.and.kut(nfrac)-16*k16.ne.1)next(nfrac)=inext
c
      return
      end
```

```
      subroutine connec(icont,maxfrc,iside,frac)
c
c     this subroutine sets up intersection information
c     and uses the following arrays
c       frac - array of fracture information
c       kut  - which sides are crossed by this fracture
c       next - next fracture which crosses a side
c
c     during processing next and kut are destroyed
c     the arrays created are
c       next - array of initial fracture (negative means more than one)
c       kut  - index into arrays tint and ifrac
c       tint - t value of intersection
c       ifrac- other fracture in intersection
c
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     ,              iplot,igene
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     ,              rmesh,xhole,yhole,rhole,nsgene
      common/kut/   kutone,kut(1)
      common/mask/  mask(2,1)
      integer*2 mask,msk1,msk2
      common/next/  next(1)
      common/knode/ knode(1)
      common/iold/  iold(1)
      common/inew/  inew(1)
      common/ifrac/ ifrac(2,1)
      common/linel/ nnodes,neleme
      common/kind/  kind(1)
      byte kind
      common/tint/  tint(2,1)
      common/pi/    pi180
c
      dimension frac(maxfrc,10)
      dimension is(2)
      integer*2 iside(maxfrc)
      OPEN (99,status='unknown')
c
c     this is to make it unnecessary to move fracture informaton
c
      do i=1,nfrac
        iold(i)=i
        inew(i)=i
        iside(i)=kut(i)
       enddo
c
      toler=10.**(-itole-1)
      inext=nfrac
      k=1
      if (icont.lt.5.and.igene.eq.0)then
        if (iside(iold(nfrac)).eq.0) inext=next(nfrac)
       else
        k16=iside(iold(nfrac))/16
        if(k16.ne.1.and.iside(iold(nfrac))-16*k16.ne.1)inext=next(nfrac)
       endif
c
      do while (inext.ne.0)
        if (icont.ne.5.and.igene.eq.0)then
          do while (iside(iold(k)).ne.0.and.k.lt.inext)
            k=k+1
            next(k)=0
           enddo
         else
          do while ((iside(iold(k))/16.eq.1.or.
     ,               mod(iside(iold(k)),16).eq.1)
     ,              .and.k.lt.inext)
            k=k+1
            next(k)=0
           enddo
         endif
        i=inext
        inext=0
        if (i.gt.k) then
          inew(k)=i
          iold(i)=k
          inew(i)=k
          iold(k)=i
          inext=next(i)
          next(i)=0
          next(k)=0
         endif
       enddo
      next(nfrac)=0
      if (icont.ne.5.and.igene.ne.1)then
        if(iside(iold(k)).eq.0) k=k-1
       else
        k16=iside(iold(k))/16
        if(k16.ne.1.and.iside(iold(k))-16*k16.ne.1)k=k-1
       endif
c
      if (k.eq.0) then
        if (ikeep.le.1) then
          nfrac=0
          go to 60
         endif
        k=1
       endif
      kutone=0
      nnodes=0
      nvoid=0
      ivoid=0
      neleme=0
      nextra=0
      indint=0
      ilevel=0
      ifrc1=1
      ifrc2=k
      k1=0
      k2=1
   10 ifrc3=ifrc2+1
      k0=ifrc3
      do ii=ifrc1,ifrc2
        inext=0
        k1=k1+1
        i=k2
        if (i.lt.ifrc1) then
          ifrc3=ifrc3-1
          i=ifrc3
         endif
        io=iold(i)
        k2=k1+1
        int1=indint+1
        jfrc=next(i)
        next(i)=0
        next(k1)=0
        if (ilevel.eq.0.or.igene.eq.1) then
c
c       include intersections with a side
```

```
c
        is(1)=iside(io)/16
        is(2)=iside(io)-16*is(1)
        if (icont.eq.5.and.(is(1).eq.3.or.is(2).eq.3))goto 25
        do j=1,2
          if (is(j).ne.0) then
            indint=indint+1
            nnodes=nnodes+1
            knode(indint)=nnodes
            ifrac(1,nnodes)=k1
            ifrac(2,nnodes)=-is(j)
            tint(1,nnodes)=(3*j-4)*frac(io,2)
            tint(2,nnodes)=0.
            kind(nnodes)=0
          endif
        enddo
      endif
c
c     include intersections with previous fractures
c
      do while (jfrc.ne.0)
        jint1=kut(jfrc-1)+1
        jint2=kut(jfrc)
        do while (knode(jint2).eq.0)
          jint2=jint2-1
        enddo
        do jj=jint1,jint2
          j=knode(jj)
          if (ifrac(1,j).eq.i) go to 20
        enddo
        stop ' sync lost - jfrc points to fracture w/o backpointer'
20      indint=indint+1
        knode(indint)=j
        jl=jfrc
        jfrc=-ifrac(2,j)
        ifrac(1,j)=jl
        ifrac(2,j)=k1
      enddo
c
c     check for intersections with fractures not previously included
c
      jfrc=max0(k1+1,ifrc1)
      if (jfrc.le.nfrac) then
        ai=frac(io,8)
        bi=frac(io,9)
        ci=frac(io,10)
        x1i=frac(io,4)
        y1i=frac(io,5)
        x2i=frac(io,6)
        y2i=frac(io,7)
        msk1=mask(1,io)
        msk2=mask(2,io)
c
        jl=jfrc-1
        nfraco=nfrac
        do 30 jj=jfrc,nfraco
          jl=jl+1
          if (jl.ge.ifrc3.and.jl.lt.k0) go to 30
          j=jl
          jo=iold(jl)
          IF (frac(io,1).EQ.frac(jo,1)) GOTO 30
          if ((mask(1,jo).and.msk1).eq.0) go to 30
          if ((mask(2,jo).and.msk2).eq.0) go to 30
          aj=frac(jo,8)
          bj=frac(jo,9)
          cj=frac(jo,10)
c
c     check to see if (x1i,y1i) and (x2i,y2i) are on different sides of
c     the line of the jth fracture.
c
          d1i = aj*x1i + bj*y1i + cj
          d2i = aj*x2i + bj*y2i + cj
          if (d1i*d2i.gt.0) go to 30
          x1j=frac(jo,4)
          y1j=frac(jo,5)
          x2j=frac(jo,6)
          y2j=frac(jo,7)
c
c     check to see if (x1j,y1j) and (x2j,y2j) are on different sides of
c     the line of the ith fracture.
c
          d1j = ai*x1j + bi*y1j + ci
          d2j = ai*x2j + bi*y2j + ci
          if (d1j*d2j.gt.0) go to 30
c
c     they intersect
c
          d1i=abs(d1i)
          d2i=abs(d2i)
          denomi=d1i+d2i
          d1j=abs(d1j)
          d2j=abs(d2j)
          denomj=d1j+d2j
          if (denomi*denomj.eq.0) go to 30
          if (icont.eq.5)then
            if(iside(jo)/16.eq.3.or.mod(iside(jo),16).eq.3)then
25            ncon=0
              open(unit=50,file='connections',status='unknown')
              read(50,*,end=26)ncon
26            ncon=ncon+1
              rewind(unit=50)
              write(50,*)ncon
              close (unit=50)
              goto 60
            endif
          endif
          if (j.gt.k) then
            if (ifrc3.lt.k0.and.i+1.lt.k0) then
              k0=k0-1
              iold(k0)=jo
              inew(jo)=k0
              ko=iold(nfrac)
              iold(jl)=ko
              inew(ko)=jl
              jl=jl-1
              j=k0
              nfrac=nfrac-1
            else
              k=k+1
              ko=iold(k)
              iold(k)=jo
              inew(jo)=k
              iold(jl)=ko
              inew(ko)=jl
              j=k
            endif
            next(j)=0
          endif
```

```
          if (ivoid.ne.0) then
            nvoid=nvoid-1
            jnode=ivoid
            ivoid=ifrac(1,ivoid)
           else
            nnodes=nnodes+1
            jnode=nnodes
           endif
          indint=indint+1
          knode(indint)=jnode
          ifrac(1,jnode)=j
          ifrac(2,jnode)=-next(j)
          tint(1,jnode)=dli*frac(io,2)/denomi
          tint(2,jnode)=dlj*frac(jo,2)/denomj
          kind(jnode)=0
          next(j)=k1
30        continue
        endif
      neleme=neleme+indint-int1
      if (indint.eq.int1) then
        if (ikeep.eq.0) then
          lnext=0
          indint=indint-1
          l=int1
          ind=k1
          k1=k1-1
          ifrc3=ifrc3-1
          k2=ifrc3
40        jnode=knode(l)
          knode(l)=0
          jfrc=ieor(ind,ieor(ifrac(1,jnode),ifrac(2,jnode)))
          if (jnode.eq.nnodes) then
            nnodes=nnodes-1
           else
            nvoid=nvoid+1
            ifrac(1,jnode)=ivoid
            ivoid=jnode
            kind(jnode)=-1
           endif
          if (jfrc.gt.0) then
            neleme=neleme-1
            jint2=kut(jfrc)
            jint1=kut(jfrc-1)+1
            l=jint1-1
            do j=jint1,jint2
              lnode=knode(j)
              if (lnode.eq.jnode) then
                knode(j)=0
               elseif (lnode.ne.0) then
                l=l+1
                knode(j)=0
                knode(l)=lnode
               endif
             enddo
            ind=jfrc
            if (l.le.jint1) go to 40
           endif
         endif
       elseif (int1.lt.indint) then
c
c     sort elements by ascending tint's
c
          i2=indint
          j1=int1+1
        do while (i2.ge.j1)
          j2=i2
          i0=1
          i1=0
          i2=0
          jj2=knode(j1-1)
          kj2=(k1-ifrac(1,jj2))/(ifrac(2,jj2)-ifrac(1,jj2))
          if ((kj2.and..not.1).ne.0) stop ' kj2 error 1'
          do j=j1,j2
            jj1=jj2
            kj1=kj2
            jj2=knode(j)
            kj2=(k1-ifrac(1,jj2))/(ifrac(2,jj2)-ifrac(1,jj2))
            if ((kj2.and..not.1).ne.0) stop ' kj2 error 2'
            if (tint(kj2+1,jj2).lt.tint(kj1+1,jj1)) then
              knode(j-1)=jj2
              knode(j)=jj1
              jj2=jj1
              kj2=kj1
              i2=j-1
              i1=i1+i0*i2
              i0=0
             endif
           enddo
          j1=max0(i1,int1+1)
         enddo
        if (i.ne.k1) then
          iold(i)=0
          iold(k1)=io
          inew(io)=k1
         endif
       endif
      kut(k1)=indint
              if (int1.gt.indint) then
                nextra=nextra+2
       else
        inode=knode(int1)
        kj2=(k1-ifrac(1,inode))/(ifrac(2,inode)-ifrac(1,inode))
        if ((kj2.and..not.1).ne.0) stop ' kj2 error 3'
        if (tint(kj2+1,inode).gt.toler) then
          nextra=nextra+1
         elseif (tint(kj2+1,inode).lt.0.) then
          tint(kj2+1,inode)=0.
         endif
        inode=knode(indint)
        kj2=(k1-ifrac(1,inode))/(ifrac(2,inode)-ifrac(1,inode))
        if ((kj2.and..not.1).ne.0) stop ' kj2 error 4'
        if (tint(kj2+1,inode).lt.frac(io,2)-toler) then
          nextra=nextra+1
         elseif (tint(kj2+1,inode).gt.frac(io,2)) then
          tint(kj2+1,inode)=frac(io,2)
         endif
       endif
     enddo
    ilevel=ilevel+1
    if (k.ge.k0) then
      ifrc1=k0
      ifrc2=k
      go to 10
     else
      if (ikeep.ge.2.and.k.lt.nfrac) then
        k=k+1
        ifrc1=k
        ifrc2=k
```

```
          go to 10
        endif
       nfrac=kl
      endif
c
      nnodes=nnodes+nextra-nvoid
      neleme=neleme+nextra
c
      if (ikeep.ne.0) return
      nnodes=nnodes-nextra
      neleme=neleme-nextra
c
   60 return
      end
```

```
      subroutine distri (idist,a,n,dseed,ev,sd)
c
c *** this subroutine calls the appropriate distribution routine
c     based upon the idist argument
c     idist = 1 - normal
c             2 - lognormal
c             3 - exponential
c             4 - gamma
c             5 - uniform
c
      dimension a(n)
      if (idist*(idist-6).ge.0) stop 'unknown distribution'
      go to (10,20,30,40,50),idist
   10 call normad (a,n,dseed,ev,sd)
      return
   20 call lognod (a,n,dseed,ev,sd)
      return
   30 call expond (a,n,dseed,ev)
      return
   40 stop 'gamma distribution disabled'
c     call gammad (a,n,dseed,ev,sd)
c     return
   50 call unifod (a,n,dseed,ev,sd)
      return
      end
```

```
      subroutine endpts(maxfrc,frac)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     *              iplot,igene
c
c     ****************************************************************
c
c     this subroutine calculates the coordinates of the endpoints of a
c     fracture given the center, orientation and length of the fracture.
c
c     nfrac is the number of fractures.
c
c     the components of frac used in this subroutine are ---
c       frac(i,1) = orientation,
c       frac(i,2) = length,
c       frac(i,4) = xc, x coordinate of fracture center,
c       frac(i,5) = yc, y coordinate of fracture center.
c
c     the components of frac that are calculated in this subroutine
c     are ---
c       frac(i,4) = x1, x coordinate of endpoint 1,
c       frac(i,5) = y1, y coordinate of endpoint 2,
c       frac(i,6) = x2, x coordinate of endpoint 2,
c       frac(i,7) = y2, y coordinate of endpoint 2.
c
c     the endpoint (x1,y1) lies on the ray which forms an angle =
c     frac(i,1) with the positive x-axis.  (x2,y2) lies on the ray
c     forming an angle = frac(i,1) + 180 with the positive x-axis.
c
c     ****************************************************************
c
      dimension frac(maxfrc,10)
c
      do 110 i=1,nfrac
c
c     calculate coordinates of endpoints
c
        hlen=.5*frac(i,2)
        dx=hlen*frac(i,9)
        dy=hlen*frac(i,8)
        xc=frac(i,4)
        yc=frac(i,5)
        frac(i,4)=xc-dx
        frac(i,5)=yc+dy
        frac(i,6)=xc+dx
        frac(i,7)=yc-dy
c
  110   continue
c
      return
      end
```

```
      subroutine eqline (maxfrc,frac)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
                    iplot,igene
      common/pi/    pi180
c
c                       version 1.1 (oct 1981)
c     ****************************************************************
c
c     this subroutine calculates the coefficients, a, b and c, of
c     the line through the fracture center with the given orientation.
c
c     nfrac is the number of fractures.
c
c     the general form of the line is ax + by + c = 0.
c     a, b and c are stored in the array frac ---
c       frac(i,8) = a,
c       frac(i,9) = b,
c       frac(i,10) = c.
c
c     the components of frac used in this subroutine are ---
c       frac(i,1) = orientation,
c       frac(i,4) = xc, x coordinate on fracture,
c       frac(i,5) = yc, y coordinate on fracture.
c
c     ****************************************************************
c
      dimension frac(maxfrc,10)
c
      do 140 i=1,nfrac
c
c     set local variables.
c
        orie=frac(i,1)
        xc=frac(i,4)
        yc=frac(i,5)
c
c     convert orie from degrees to radians.
c
        orie=orie*pi180
c
c     line on which fracture lies is neither horizontal nor vertical
c
        a=-sin(orie)
        b=cos(orie)
c
        frac(i,8)=a
        frac(i,9)=b
        frac(i,10)=-b*yc-a*xc
c
  140   continue
c
      return
      end
```

```
      subroutine expond (a,n,dseed,ev)
c
c *** this subroutine generates random variables distributed
c *** exponentially with expected value ev.
c
c *** if x is distributed uniformly in (0,1), then y = -ln(1-x)*ev
c *** is distributed exponentially with parameter lambda = 1/ev.
c *** the expected value of y is ev.
c
      dimension a(n)
c
      do 110 i=1,n
        a(i)=-alog(1.-ggubfs(dseed))*ev
  110   continue
c
      return
      end
```

```
      subroutine fragen (maxfrc,dseed,frac)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     *              iplot,igene
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     *              rmesh,xhole,yhole,rhole,nsgene
      common/seti/  nsets,iseti(20,8),rseti(20,11)
      common/pi/    pi180
      common/qc/    visc,spgr,qc,itrans
c
c     ****************************************************************
c
c     this subroutine reads in fracture information and then either
c     reads in or generates the following fracture characteristics -
c     orientation, length, aperture, and the coordinates of the
c     fracture center.
c
c     the following variables or arrays from the main program are
c     used ---
c
c       nsets = number of fracture sets,
c
c       xgene = x dimension of generation region,
c       ygene = y dimension of generation region,
c       nsgene**2 = number of subregions for generation
c
c       frac(i, 1) = orientation,
c       frac(i, 2) = length,
c       frac(i, 3) = aperture,
c       frac(i, 4) = x1, x coordinate of fracture center or end,
c       frac(i, 5) = y1, y coordinate of fracture center or end.
c       frac(i, 6) = x2, x coordinate of fracture end,
c       frac(i, 7) = y2, y coordinate of fracture end.
c       frac(i, 8) = a, coeff. = -sin(orientation)
c       frac(i, 9) = b, coeff. =  cos(orientation)
c       frac(i,10) = c, coeff. = -(a*x1 + b*y1)
c
c     the 'randomness' of the generation is controlled by iranf and
c     dseed ---
c
c       iranf = 0 - 'random' generation,
c       iranf = 1 - use dseed from previous generation,
c
c       dseed - seed for random number generator.
c
c     the variables which control the read or generation are given
c     below ---
c
c       icent = 1 - read in all fracture characteristics,
c               2 - generate fracture center coordinates,
c               3 - generate fracture center coordinates in subregions
c
c       idens = 0 - read and use rlamb
c               1 - read nfrac directly
c               2 - calculate rlamb for rlbar & rlambdal
c
c       ipois = 0 - generate fracture centers in whole gen. region
c               1 - generate frctr centers along line at angle theta
c       ichar - read value for each of orientation, length and
c               aperture,
c             = 2 - set characteristic equal to a constant value,
c             = 3 - generate characteristics values according to a
c                   distribution,
c             = 4 - generate apertures correlated to log of length
c             = 5 - generate apertures correlated to length
c
c       idist = 1 - normal distribution,
c               2 - lognormal distribution,
c               3 - exponential distribution.
c               4 - gamma distribution (DISABLED)
c               5 - uniform distribution.
c
c     in addition, the following variables are read in ---
c
c       nfrac = number of fractures,
c
c       rlamb = no. of fractures per square unit,
c
c       theta = angle of poisson generation line
c
c       itole - number of decimal places in fracture center coordinates
c
c       const - see ichar = 2,
c
c       ev - expected value of statistical distribution,
c
c       sd - standard deviation of statistical distribution.
c
c     the array iseti is used to store the values of nfrac, icent, and
c     ichar and idist for each set.  the array rseti is used to store
c     the values of const, ev and sd for each set.
c
c     ****************************************************************
c
      dimension frac(maxfrc,10)
c
      double precision dseed
c
c *** if iranf = 0, pick a random dseed
c
      if (iranf .eq. 0) dseed = secnds(0.0) * 100.0
      write(6,80)dseed
c
c
c *** zero information matrices
c
      do 20 i=1,nsets
        do 10 j=1,8
          iseti(i,j)=0
          rseti(i,j)=0.
   10     continue
        rseti(i,9)=0.
   20   continue
c
c     open subreg.dat to read in information about subregions
c
      if(nsgene.ne.0)then
        open (unit=7,readonly,file='subreg.dat',status='old')
       endif
c
      if(igene.eq.0)then
        xg2=xgene/2
        yg2=ygene/2
        genare=xgene*ygene
       else
        xg2=0.
        yg2=0.
        genare=pi180*180.*rgene*rgene
       endif
```

```
      n1=1
c
      itrans = 0
      do 70 i=1,nsets
c
        read (1,140) icent,idens,ipois
        if(icent.lt.0) then
          itrans = 1
          icent = -icent
        end if
        iseti(i,1)=icent
c
        if (icent.eq.1) then
c
c *** read in all fracture characterictics
c
          read (1,100) nfrac,theta
          iseti(i,2)=nfrac
          n2=nfrac+n1-1
          read (1,150) ((frac(m,j),j=1,5),m=n1,n2)
          do m=n1,n2
            frac(m,4)=frac(m,4)-xg2
            frac(m,5)=frac(m,5)-yg2
           enddo
          n1=n2+1
          iseti(i,3)=1
          iseti(i,5)=1
          iseti(i,7)=1
          rlamb=nfrac/genare
          rseti(i,10)=rlamb
c
        elseif (icent.eq.3) then
         call spatia(maxfrc,dseed,frac,i,n1,n2,idens)
        else
         if (idens.ne.0) then
           read (1,100) nfrac,theta
           rlamb=float(nfrac)/genare
          else
           read (1,110) rlamb,theta
           rseti(i,10)=rlamb
           nfrac=int(genare*rlamb)
          endif
c
c
         if (ipois.eq.1) then
c
           if ((xgene.ne.ygene).and.(idens.eq.0)) write(6,90)
c
           theta = theta*pi180
           slcos = cos(theta)
           slsin = sin(theta)
           if (abs(xgene*slsin).le.abs(ygene*slcos)) then
             scanl = xgene/cos(theta)
            else
             scanl = ygene/sin(theta)
            endif
           slcos = scanl*slcos
           slsin = scanl*slsin
           if (idens.eq.0) nfrac=int(scanl*rlamb)
          endif
c
         n2=nfrac+n1-1
         iseti(i,2)=nfrac
         rseti(i,10)=rlamb
         if (igene.eq.0)then
           call rectxy (frac(n1,4),frac(n1,5),n2-n1+1,dseed,
     1                  xgene,ygene,itole,ipois,slcos,slsin)
          else
           call circxy (frac(n1,4),frac(n1,5),n2-n1+1,dseed,
     ,                  rgene,itole)
          endif
c
         l=1
         m=-2
         do 60 k=1,3
           l=l+2
           m=m+3
c
           read (1,100) ichar
           iseti(i,l)=ichar
c
c *** set fracture characteristic to a constant
c
           if (ichar.lt.3) then
             read (1,160) const
             rseti(i,m)=const
             do 50 j=n1,n2
               frac(j,k)=const
  50           continue
c
c *** read in code for statistical distribution and read in
c *** statistical parameters
c
            elseif (ichar.eq.3) then
             read (1,120) idist,ev,sd
             iseti(i,l+1)=idist
             rseti(i,m+1)=ev
             rseti(i,m+2)=sd
             call distri (idist,frac(n1,k),n2-n1+1,dseed,ev,sd)
            else
             read (1,130) ycept,slope,sd
             iseti(i,l+1)=1
             rseti(i,m)=ycept
             rseti(i,m+1)=slope
             rseti(i,m+2)=sd
             call normdl (frac(n1,k),n2-n1+1,dseed,ycept,sd,slope,
     1          frac(n1,2),ichar)
            endif
c
  60       continue
c
         n1=n2+1
        endif
c
c *** generate locations of fracture centers
c
c
  70   continue
c
      nfrac=n2
c
      if (icent.ne.3) rseti(i,11)=rseti(i,10)
c
c     close subregion file
c
      if(nsgene.ne.0)close (unit=7)
c
      return
```

```
c
   80 format ('0the initial seed used in the random number generator',
     1   ' is ',d15.8)
   90 format ('0xgene.ne.ygene.use nfrac')
  100 format (10x,15,15x,f10.4)
  110 format (10x,e10.3,10x,f10.4)
  120 format (10x,15,15x,f10.4,10x,f10.4)
  130 format (3(10x,f10.4))
  140 format (3(10x,15))
  150 format (5f10.4)
  160 format (10x,f10.4)
      end
```

```
      subroutine frstal(a,b,n,elen,slen,eapt,sapt,cov,crc,ycept,slope,
     1                  ichar,xy)
      common/iwk/   iwk(1)
c
c     a=frac(*,2)
c     b=frac(*,3)
c
c *** this subroutine calculates the mean and standard deviation.
c
      dimension a(n),b(n),xy(n,6),beta(2),wk(6)
c
      sl=0.
c
      do 110 j=1,n
        c=a(j)*b(j)
        sl=sl+c
        if (a(j).le.0.) write(6,*) j,a(j)
        xy(j,1) = a(j)
        if (ichar.ne.5) xy(j,1) = alog10(a(j))
        xy(j,2) = b(j)
  110   continue
      call rllav(xy,n,n,1,0,beta,sumre,iter,irank,iwk,wk,ier)
      slope = beta(1)
      ycept = beta(2)
      if (ier.eq.33) then
        write(6,300)
       elseif (ier.eq.129) then
        write(6,301)
       endif
      continue
c
      d=float(n)
      elna=sl/d
      cov = (elna - elen * eapt)
      if (slen.eq.0..or.sapt.eq.0.) then
        crc = 99.
       else
        crc = cov/(slen*sapt)
       endif
      return
c
  300 format(' the best fit curve is likely to be nonunique')
  301 format(' calculation terminated prematurely due to rounding',
     1  ' errors')
      end
```

```
      subroutine frstat (a,n,ev,sd)
c
c *** this subroutine calculates the mean and standard deviation.
c
      dimension a(n)
ccc if orientation is being examined use stator instead
      if (k.eq.1) stop ' frstat called with k=1'
c
      s1=0.
      s2=0.
c
      do 110 i=1,n
        c=a(i)
        s1=s1+c
        s2=s2+c*c
  110   continue
c
      d=float(n)
      ev=s1/d
      sd=sqrt(abs(s2/d-ev*ev))
c
      return
      end
```

```
      FUNCTION ggubfs(dDUM)
      DIMENSION R(97)
      real*8 ddum
      PARAMETER (M1=259200,IA1=7141,IC1=54773,RM1=3.8580247E-6)
      PARAMETER (M2=134456,IA2=8121,IC2=28411,RM2=7.4373773E-6)
      PARAMETER (M3=243000,IA3=4561,IC3=51349)
      DATA IFF /0/
      idum=int(ddum)
      IF (IDUM.LT.0.OR.IFF.EQ.0) THEN
c
c     "quick fix" to make sure that idum is initialized in
c     the proper range
c
        do while (idum.gt.ic1)
          idum=mod(idum,ic1)
         enddo
        IFF=1
        IX1=MOD(IC1-IDUM,M1)
        IX1=MOD(IA1*IX1+IC1,M1)
        IX2=MOD(IX1,M2)
        IX1=MOD(IA1*IX1+IC1,M1)
        IX3=MOD(IX1,M3)
        DO 11 J=1,97
          IX1=MOD(IA1*IX1+IC1,M1)
          IX2=MOD(IA2*IX2+IC2,M2)
          R(J)=(FLOAT(IX1)+FLOAT(IX2)*RM2)*RM1
11      CONTINUE
        dDUM=1.d0
      ENDIF
      IX1=MOD(IA1*IX1+IC1,M1)
      IX2=MOD(IA2*IX2+IC2,M2)
      IX3=MOD(IA3*IX3+IC3,M3)
      J=1+(97*IX3)/M3
      IF(J.GT.97.OR.J.LT.1)stop ' seed too big, should be < 54773 '
      ggubfs=R(J)
      R(J)=(FLOAT(IX1)+FLOAT(IX2)*RM2)*RM1
      RETURN
      END
```

```
      subroutine lognod (a,n,dseed,ev,sd)
c
c *** this subroutine generates random variables distributed
c *** lognormally with expected value ev and standard distribution sd.
c
c *** step 1.  sn = sum of 25 random variables distributed uniformly
c ***          in (0,1),
c *** step 2.  sn = (sn-12.5)*sqrt(.48) is distributed normally
c ***          with mean = 0 and standard deviation = 1,
c *** step 3.  exp(sd*sn+ev) is distributed lognormally with mean =
c ***          exp(ev)*exp(sd*sd/2) and standard deviation =
c ***          exp(sd*sd+2*ev)*(exp(sd*sd)-1).
c
      dimension a(n)
      data s48/0./
c
      if (s48.eq.0) s48=sqrt(.48)
      a2evsd=alog(ev*ev+sd*sd)
      aev=alog(ev)
c
      evn=2.*aev-0.5*a2evsd
      sdn=sqrt(a2evsd-2.*aev)
c
      do 120 i=1,n
        sn=0.
        do 110 j=1,25
          sn=sn+ggubfs(dseed)
  110     continue
        sn=s48*(sn-12.5)
  120   a(i)=exp(sdn*sn+evn)
c
      return
      end
```

```
      subroutine move(i,nfrac,n2,frac,maxfrc)
c
      dimension frac(maxfrc,10)
c
      if (nfrac.eq.maxfrc)stop ' too many fractures split in climit'
      idif=jmin0(nfrac/10+1,maxfrc-nfrac)
      do ifrac=nfrac,i,-1
        do j=1,10
          frac(ifrac+idif,j)=frac(ifrac,j)
        enddo
       enddo
      n2=n2+idif
      nfrac=nfrac+idif
      i=i+idif
      return
      end
c
```

```
      subroutine normad (a,n,dseed,ev,sd)
c
c *** this subroutine generates random variables distributed
c *** normally with expected value ev and standard distribution sd.
c
c *** step 1.  sn = sum of 25 random variables distributed uniformly
c ***          in (0,1),
c *** step 2.  sn = (sn-12.5)*sqrt(.48) is distributed normally
c ***          with mean = 0 and standard deviation = 1,
c *** step 3.  sd*sn+ev is distributed normally with mean ev and
c ***          standard deviation sd.
c
      dimension a(n)
      double precision dseed
      data s48/0./
c
      if (s48.eq.0) s48=sqrt(.48)
      do 120 i=1,n
        sn=0.
        do 110 j=1,25
  110     sn=sn+ggubfs(dseed)
        sn=s48*(sn-12.5)
  120   a(i)=sd*sn+ev
c
      return
      end
```

```
      subroutine normdl (a,n,dseed,ycept,sd,slope,b,ichar)
c
c *** this subroutine generates random variables distributed
c *** normally with expected value ev and standard distribution sd.
c *** where ev is proportional to the logarithm of another
c *** parameter or the parameter itself
c
c *** step 1.  sn = sum of 25 random variables distributed uniformly
c ***          in (0,1),
c *** step 2.  sn = (sn-12.5)*sqrt(.48) is distributed normally
c ***          with mean = 0 and standard deviation = 1,
c *** step 3.  sd*sn+ev is distributed normally with mean ev and
c ***          standard deviation sd. where ev is proportional
c ***          to a parameter or the log of the parameter.
c *** step 4.  the value of sd*sn+ev is set so that it is never
c ***          less than a minimum value
c
      dimension a(n),b(n)
      double precision dseed
      data emin/1.e-8/
      data s48/0./
c
      if (s48.eq.0) s48=sqrt(.48)
      do 120 i=1,n
        sn=0.
        do 110 j=1,25
  110     sn=sn+ggubfs(dseed)
        sn=s48*(sn-12.5)
        fl=b(i)
        ev=ycept+slope*fl
        if (ichar.ne.5) ev=ycept+slope*alog10(fl)
        a(i)=sd*sn+ev
        if (a(i).lt.emin) a(i)=emin
  120   continue
c
      return
      end
```

```
      subroutine oriest(d,a,b,n,ev,sd)
      parameter (nslice=180)
      common/pi/    pi180
c
c     basic statistics for orientation distributions.
c
c        a=-sin(orie)
c        b=cos(orie)
c
      dimension a(n),b(n),d(n)
      dimension ssum(nslice),csum(nslice)
      if (n.eq.0) then
        ev=0.
        sd=0.
        return
       endif
      do i=1,nslice
        ssum(i)=0.
        csum(i)=0.
       enddo
      do i=1,n
        alpha=amod(d(i),360.)+360.
        alpha=(nslice*alpha)/180
        ialpha=alpha
        alpha=alpha-ialpha
        is1=ialpha/nslice
        is2=(ialpha+1)/nslice
        i1=ialpha-nslice*is1+1
        i2=ialpha-nslice*is2+2
        ssum(i1)=ssum(i1)+(-1)**is1*a(i)*(1.-alpha)
        csum(i1)=csum(i1)-(-1)**is1*b(i)*(1.-alpha)
        ssum(i2)=ssum(i2)+(-1)**is2*a(i)*alpha
        csum(i2)=csum(i2)-(-1)**is2*b(i)*alpha
       enddo
      u0=0.
      v0=0.
      do i=1,nslice
        u0=u0+csum(i)
        v0=v0+ssum(i)
       enddo
      r0=u0*u0+v0*v0
      u=u0
      v=v0
      do i=2,nslice
        u=u-2*csum(i-1)
        v=v-2*ssum(i-1)
        r=u*u+v*v
        if (r.gt.r0) then
          u0=u
          v0=v
          r0=r
         endif
       enddo
      ev=0.
      if (r0.gt.0) ev=atan2(v0,u0)/pi180
      ev=amod(ev+225.,180.)-45.
      sd=1.-sqrt(r0)/n
      return
      end
```

```
c
      subroutine pfs (maxfrc,frac,xy)
      common/iwk/   iwk(1)
      common/seti/  nsets,iseti(20,8),rseti(20,11)
c
c *** calculate and print fracture statistics for each set
c
c
      dimension frac(maxfrc,10),
     1          elen(20), slen(20), eapt(20), sapt(20),
     2          xy(maxfrc,6)
      character*11 ola(3)
      character*7 type(5)
      data ola/'orientation','length','aperture'/
      data type/'normal','lognor.','expon.','gamma.','uniform'/
      data ion/0/
c
      write(6,60) nsets
      write(6,160)
      write(6,170) (i,rseti(i,10),rseti(i,11),i=1,nsets)
      do 10 i=1,nsets
        if (iseti(i,7).eq.4.or.iseti(i,7).eq.5) ion=1
   10   continue
      do 30 k=1,3
        write(6,70) ola(k)
        if (ion.eq.1.and.k.eq.3) then
          write(6,90)
         else
          write(6,80)
         endif
c
        n2=0
        do 20 i=1,nsets
          nf=iseti(i,2)
          if (nf.le.0) then
            write(6,50) i,nf
           else
            n1=n2+1
            n2=n1+nf-1
            l=k*2+1
            ichar=iseti(i,1)
            if (ichar.eq.1) then
              write(6,100) i,nf
             elseif (ichar.eq.2) then
              m=k*3-2
              write(6,110) i,nf,rseti(i,m)
             else
              m=k*3-2
              idist=iseti(i,1+1)
              if (k.eq.1) then
                call oriest(frac(n1,1),frac(n1,8),frac(n1,9),
     1                      n2-n1+1,ev,sd)
               else
                call frstat (frac(n1,k),n2-n1+1,ev,sd)
                if (k.eq.2) then
                  elen(i) = ev
                  slen(i) = sd
                 elseif (k.eq.3) then
                  eapt(i) = ev
                  sapt(i) = sd
                 endif
               endif
              if ((ichar.eq.4).or.(ichar.eq.5)) then
                call frstal (frac(n1,2),frac(n1,3),n2-n1+1,
     1                       elen(i),slen(i),eapt(i),sapt(i),
     2                       cov,crc,ycept,slope,ichar,xy)
                write(6,130) i,nf,cov,crc,rseti(i,8),rseti(i,7),
     1                       slope,ycept
               else
                write(6,120)i,nf,type(idist),rseti(i,m+1),rseti(i,m+2),
     1            ev,sd
               endif
c
             endif
           endif
   20     continue
   30   continue
      if (ion.eq.1) then
        write(6,80)
        do 40 i=1,nsets
          write(6,140) i,eapt(i),sapt(i)
   40     continue
       endif
      write(6,150)
      return
c
   50 format(1x,i3,4x,15)
   60 format('0the number of sets is',i3)
   70 format('0'/' the following table contains statistical',
     1  ' information on the fracture ',a,' of each set')
   80 format('0set  no. of  meth. of  const.    type of  ev',8x,'sd',
     1  8x,'ev',8x,'sd'/6x,'frac    gen.      value     dist. ',
     2  2('   read in'),1x,2('  computed')/)
   90 format(' -- correlation between length and aperture'/
     1  '0set  no. of  meth. of  covari    correl.  1/n',7x,'c',
     2  9x,'1/n',7x,'c'/6x,'frac    gen.      ance      coef. ',
     3  2('  read in'),1x,2('  computed')/)
  100 format(1x,i3,4x,15,'  read in')
  110 format(1x,i3,4x,15,'  set to',4x,f8.4)
  120 format(1x,i3,4x,15,'  generated',11x,a,4(1x,1p,e9.2e2))
  130 format(1x,i3,4x,15,'  generated',1p,e9.2e2,0p,2x,f7.4,
     1  1p,4(1x,e9.2))
  140 format(1x,i3,12x,'same as above',12x,'   n/a       n/a   ',
     1  1p,2(1x,e9.2))
  150 format(10(/))
  160 format('0density for set     calculated     global')
  170 format(13x,i3,5x,f10.6,5x,f10.6)
      end
```

```
      subroutine plocoo(maxfrc,frac)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     '              iplot,igene
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     '              rmesh,xhole,yhole,rhole,nsgene
      common/stud/  istud,xstud(10),ystud(10)
      common/pi/    pi180
      common/files/ lplot,lrenum
      common/title/ title,iray,idate
      character*80 title(2)
      character*11 filel,filer
      dimension corner(2,5)
      dimension frac(maxfrc,10)
      data filel,filer/'linesgr.dat','renumgr.dat'/
c
      lplot=lplot+1
      if(lplot.ge.0)write(filel(6:7),10) lplot
   10 format(i2.2)
      open (unit=3,file=filel,status='unknown',
     1      carriagecontrol='list')
c
c     draw study regions
c
      if (istud*lplot.gt.0) then
        cosr=cos(rotan*pi180)
        sinr=sin(rotan*pi180)
c
        do i=1,istud
          corner(1,4)=cosr*xstud(i)/2 - sinr*ystud(i)/2
          corner(2,4)=cosr*ystud(i)/2 + sinr*xstud(i)/2
          corner(1,2)=-corner(1,4)
          corner(2,2)=-corner(2,4)
          corner(1,1)=cosr*xstud(i)/2 + sinr*ystud(i)/2
          corner(2,1)=-cosr*ystud(i)/2 + sinr*xstud(i)/2
          corner(1,3)=-corner(1,1)
          corner(2,3)=-corner(2,1)
          corner(1,5)=corner(1,1)
          corner(2,5)=corner(2,1)
          do j=1,4
            write(3,580)((corner(k,l),k=1,2),l=j,j+1)
           enddo
         enddo
       endif
c
      write (3,580) ((frac(k,j),j=4,7),k=1,nfrac)
      close(unit=3)
c
      if(lplot.eq.-1)then
        open (unit=3,file=filer,status='unknown',
     '        carriagecontrol='list')
        write(filer(6:7),20)0
   20   format(i2.2)
        if (igene.eq.0)then
          write(3,300)title,xgene,ygene,xgene,ygene,0.
         else
          write(3,310)title,rgene,rgene,0.,0.
         endif
        close(unit=3)
       elseif(lplot.eq.0)then
        open (unit=3,file=filer,status='unknown',
     '        carriagecontrol='list')
        if (igene.eq.0)then
          write(3,300)title,xgene,ygene,xmesh,ymesh,rotan
         else
          write(3,310)title,rmesh,rhole,xhole,yhole
         endif
        close(unit=3)
       endif
c
      return
  300 format(/a/a//1p,'xgene- - -',e10.3,'ygene- - -',e10.3/
     1               'xmesh- - -',e10.3,'ymesh- - -',e10.3/
     2               'rotan- - -',e10.3)
  310 format(/a/a///1p,'rmesh- - -',e10.3,'rhole- - -',e10.3/
     '               'xhole- - -',e10.3,'yhole- - -',e10.3)
  580 format(1p,2(2e10.3,10x))
      end
```

```
      subroutine rectxy (x,y,n,dseed,xs,ys,itole,ipois,slcos,slsin)
c
c *** this subroutine generates random fracture centers
c
      dimension x(n),y(n)
      double precision dseed
c
      toler=10.**itole
      xt=xs*toler
      yt=ys*toler
      x2=xs/2
      y2=ys/2
      if (ipois.ne.1) then
c
        do 290 i=1,n
          x(i)=float(int(xt*ggubfs(dseed)))/toler-x2
          y(i)=float(int(yt*ggubfs(dseed)))/toler-y2
  290     continue
c
       else
c
c *** fracture centers randomly located on scanline passing
c *** through center of generation region
c
        xt=xt/2
        yt=yt/2
        do 300 i = 1,n
c
          ran = toler*(ggubfs(dseed)-.5)
          x(i)=float(int(ran*slcos + xt))/toler-x2
          y(i)=float(int(ran*slsin + yt))/toler-y2
  300     continue
       endif
c
      return
      end
```

```
      subroutine rlimit (icont,maxfrc,frac)
      parameter (nc=10)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     *              iplot,igene
      common/inew/  inew(100)
      common/iold/  iold(100)
      common/kut/   kutone,kut(100)
      common/mask/  mask(2,100)
      integer*2 mask
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     *              rmesh,xhole,yhole,rhole,nsgene
      common/next/  next(100)
      common/pi/    pi180
      common/seti/  nsets,iseti(20,8),rseti(20,11)
c
c     ****************************************************************
c
c     this subroutine truncates a fracture if one or both of its
c     endpoints fall outside of the block of dimension xmesh by ymesh,
c     and discards the fracture if it is outside the block.
c
c     if the fracture is truncated, the coordinate of the endpoints
c     and the length of the fracture are recalculated.
c
c     nfrac is the number of fractures.
c
c     one components of frac may be recalculated in this subroutine -
c       frac(i,2) = length,
c       frac(i,4) = x1, x coordinate of endpoint 1,
c       frac(i,5) = y1, y coordinate of endpoint 1,
c       frac(i,6) = x1, x coordinate of endpoint 2,
c       frac(i,7) = y1, y coordinate of endpoint 2.
c
c     the components of frac used in this subroutine are ---
c       frac(i, 8) = a = -sin of orientation,
c       frac(i, 9) = b =  cos of orientation,
c       frac(i,10) = c,
c     where a, b, and c are the coefficients in the equation of the
c     line, ax + by + c = 0, on which fracture i lies.
c
c       kut(i) = truncation code.
c       next(i) = where the next truncated fracture sits
c
      dimension frac(maxfrc,10)
      dimension t(4),is(4)
c
      k=1
      n2=0
      inext=0
      r=rotan*pi180
      cosr=cos(r)
      sinr=sin(r)
      xm2=xmesh/2
      ym2=ymesh/2
c
c
      do 170 l=1,nsets
c
        m=0
c
        n1=n2+1
        n2=n1+iseti(1,2)-1
        if (n2.lt.n1) go to 170
c
        do 160 i=n1,n2
c
c     calculate array t of intersection values
c
          nt=0
          next(i)=0
          flen=frac(i,2)
          x=frac(i,4)
          y=frac(i,5)
          denomx=cosr*frac(i,8)+sinr*frac(i,9)
          denomy=sinr*frac(i,8)-cosr*frac(i,9)
          prtx=cosr*y-sinr*x
          prty=cosr*x+sinr*y
          if (denomx.ne.0.) then
            is(1)=1
            is(2)=3
            t(1)=(prtx+ym2)/denomx
            t(2)=(prtx-ym2)/denomx
            nt=2
          else
            if (abs(prtx).ge.xm2) go to 160
          endif
          if (denomy.ne.0.) then
            is(nt+1)=2
            is(nt+2)=4
            t(nt+1)=(prty+xm2)/denomy
            t(nt+2)=(prty-xm2)/denomy
            nt=nt+2
          else
            if (abs(prty).ge.ym2) go to 160
          endif
c
c     sort array t of intersection values
c
          j1=2
          i2=nt
          do while (i2.ge.j1)
            j2=i2
            i0=1
            i1=0
            i2=0
            do 20 j=j1,j2
              if (t(j-1).le.t(j)) go to 20
              tt=t(j-1)
              t(j-1)=t(j)
              t(j)=tt
              it=is(j-1)
              is(j-1)=is(j)
              is(j)=it
              i2=j-1
              i1=i1+i0*i2
              i0=0
   20         continue
            j1=max0(i1,2)
          enddo
          i1=nt/2
          if (mod(is(1)+is(2)+i1,2).eq.0) go to 160
          if (t(i1).ge.flen.or.t(i1+1).le.0.) go to 160
c
c       truncate fracture to block
c
          kut(i)=0
          if (t(i1+1).le.flen) then
            kut(i)=is(i1+1)
```

```
            frac(i,2)=t(il+1)
            frac(i,6)=x+frac(i,9)*t(il+1)
            frac(i,7)=y-frac(i,8)*t(il+1)
          endif
          if (t(il).ge.0.) then
            kut(i)=kut(i)+16*ls(il)
            frac(i,2)=frac(i,2)-t(il)
            frac(i,4)=x+frac(i,9)*t(il)
            frac(i,5)=y-frac(i,8)*t(il)
          endif
c
c *** store information about fractures part or all of which fall into
c *** the flow region.
c
          ix1=(cosr*frac(i,4)+sinr*frac(i,5)+xm2)*nc/xmesh
          ix2=(cosr*frac(i,6)+sinr*frac(i,7)+xm2)*nc/xmesh
          iy1=(-sinr*frac(i,4)+cosr*frac(i,5)+ym2)*nc/ymesh
          iy2=(-sinr*frac(i,6)+cosr*frac(i,7)+ym2)*nc/ymesh
          ix=min(ix1,ix2)
          iy=min(iy1,iy2)
          ix2=ix1+ix2-ix+1
          iy2=iy1+iy2-iy+1
          ix2=2**min(ix2,nc)
          iy2=2**min(iy2,nc)
          ix=max(ix,0)
          iy=max(iy,0)
          ix1=2**min(nc-1,ix)
          iy1=2**min(nc-1,iy)
          mask(1,k)=ix2-ix1
          mask(2,k)=iy2-iy1
          kut(k)=kut(i)
          do 150 j=1,10
  150       frac(k,j)=frac(i,j)
c
          next(k)=0
          if(icont.lt.5)then
            if (kut(k).ne.0) then
              next(k)=inext
              inext=k
            endif
          elseif(icont.eq.5)then
            k16=kut(k)/16
            if(k16.eq.1.or.kut(k)-16*k16.eq.1) then
              next(k)=inext
              inext=k
            endif
          endif
          k=k+1
          m=m+1
c
  160     continue
c
        iseti(1,2)=m
c
  170   continue
c
      nfrac=k-1
      if (icont.lt.5)then
        if (kut(nfrac).eq.0) next(nfrac)=inext
      elseif(icont.eq.5)then
        k16=kut(nfrac)/16
        if(k16.ne.1.and.kut(nfrac)-16*k16.ne.1)next(nfrac)=inext
      endif
c
      return
      end
```

```
      subroutine spatia (maxfrc,dseed,frac,i,n1,n2,idens)
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     *              iplot,igene
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     *              rmesh,xhole,yhole,rhole,nsgene
      common/seti/  nsets,iseti(20,8),rseti(20,11)
c
c     ****************************************************************
c
c     this subroutine is called by fragen when generation is done
c     by subregions.
c
c       icent = 1 - read in all fracture characteristics,
c               2 - generate fracture center coordinates,
c               3 - generate fracture center coordinates by subregions
c
c       idens = 0 - read and use rlamb
c               1 - read nfrac directly
c               2 - calc. rlamb from lbar & rlambdal
c
c       ipois = 0 - generate fracture centers in whole gen. region
c       ichar - read value for each of orientation, length and
c               aperture,
c             = 2 - set characteristic equal to a constant value,
c             = 3 - generate characteristics values according to a
c                   distribution, (local if icent=3)
c             = 4 - generate apertures correlated to log of length
c             = 5 - generate apertures correlated to length
c             = 6 - generate subregion data using global parameters
c                   from tape1
c             = 7 - generate a mean value using the global parameters,
c                   read a local standard deviation to generate local
c                   values.
c
c       idist = 1 - normal distribution,
c               2 - lognormal distribution,
c               3 - exponential distribution.
c               4 - gamma distribution.
c
c     in addition, the following variables are read in ---
c
c       nfrac = number of fractures,
c
c       rlambmn = no. of fractures per square subunit,
c
c       itole - number of decimal places in fracture center coordinates
c
c       const - see ichar = 2,
c
c       ev - expected value of statistical distribution,
c                    or lambdai for gamma distr.
c
c       sd - standard deviation of statistical distribution,
c                    or alphai for gamma distr.
c
c     the array iseti is used to store the values of nfrac, icent, and
c     ichar and idist for each set.  the array rseti is used to store
c     the global values of const, ev and sd for each set.
c
c     ****************************************************************
c
      dimension frac(maxfrc,10)
      real nev(1,1)
c
      double precision dseed,rseed(3),mseed(3)
c
c     initialise seeds
c
c     dseed is used to generate fracture centers.
c     mseed is used to generate means for local distributions.
c     rseed is used to generate orientation,length,or aperture.
c
      xg2=xgene/2
      yg2=ygene/2
      rseed(1)=dseed
      mseed(1)=dseed
      do 170 ll=2,3
        rseed(ll)=rseed(ll-1)-1.d0
        mseed(ll)=rseed(ll)
  170 continue
c     read global data on tape1
c
      read(1,250)rseti(1,11)
c
      l=1
      m=-2
      do 180 k=1,3
        l=l+2
        m=m+3
c
        read (1,240) ichar
        iseti(1,l)=ichar
c
c *** read in code for statistical distribution and read in
c *** statistical parameters
c
        if (ichar.eq.3.or.ichar.ge.6) then
          read (1,260) idist,ev,sd
          iseti(1,l+1)=idist
          if (idist.eq.3) sd=ev
          rseti(1,m+1)=ev
          rseti(1,m+2)=sd
        elseif (ichar.gt.3) then
          read (1,270) ycept,slope,sd
          iseti(1,l+1)=1
          rseti(1,m)=ycept
          rseti(1,m+1)=slope
          rseti(1,m+2)=sd
        endif
c
  180 continue
c
c *** generate locations of fracture centers
c     spatia fills the subregions moving to the
c     right starting from top left corner, ie top
c     row 1 to r, 2nd row 1 to r etc.
c
      xsubgene=xgene/nsgene
      ysubgene=ygene/nsgene
      iseti(1,2)=0
      rseti(1,10)=0.
      do 230 nn=1,nsgene
        do 220 mm=1,nsgene
          if (idens.eq.0) then
            read (7,250) rlambmn
            nfracmn=nint(xgene*ygene*rlambmn/nsgene**2)
          elseif (idens.eq.2) then
            read(7,250) rlbar, rlambdal
```

```
          if(rlbar.le.1.e-20)stop
     '      'mean length in subregion should be strictly positive'
          rlambmn= rlambdal / rlbar
          nfracmn=nint(xgene*ygene*rlambmn/nsgene**2)
         else
          read (7,240) nfracmn,theta
          rlambmn=nfracmn/(xgene*ygene*nsgene**2)
         endif
c
        if (nfracmn.eq.0)goto 220
        if (ipois.eq.1) stop 'ipois cannot be 1 here'
        n2=nfracmn+n1-1
        iseti(i,2)=nfracmn+iseti(i,2)
        rseti(i,10)=rlambmn/nsgene**2+rseti(i,10)

        call rectxy (frac(n1,4),frac(n1,5),nfracmn,dseed,
     1      xsubgene,ysubgene,itole,ipois,dumb1,dumb2)
c
c     adjust centers
c
        do 190 kk=n1,n2
          frac(kk,4)=frac(kk,4)+(xg2*(2*mm-nsgene-1))/nsgene
          frac(kk,5)=frac(kk,5)+(yg2*(nsgene+1-2*nn))/nsgene
  190     continue
c
        l=1
        m=-2
        do 210 k=1,3
          l=l+2
          m=m+3
c
          ichar=iseti(i,l)
          idist=iseti(i,l+1)
          ev=rseti(i,m+1)
          sd=rseti(i,m+2)
c
          if (ichar.eq.4.or.ichar.eq.5) then
            read (7,270) ycept,slope,sd
            call normdl (frac(n1,k),n2-n1+1,rseed(k),ycept,sd,slope,
     1        frac(n1,2),ichar)
           elseif (ichar.ge.3.and.ichar.le.7) then
c
c *** read in code for statistical distribution and read in
c *** statistical parameters
c
            if (ichar.eq.3) then
              read (7,270) ev,sd
c
c     otherwise keep global values
c
             elseif (ichar.eq.7) then
c
              call distri (idist,nev,1,mseed(k),ev,sd)
              ev=nev(1,1)
              read(7,270)sd
             endif
c
c *** patch to allow ev=lambda & sd=alpha
c
            if (idist.eq.4) then
              ev=sd/ev
              sd=sqrt(ev*ev/sd)
             endif
c
             call distri (idist,frac(n1,k),n2-n1+1,rseed(k),ev,sd)
            else
c
c *** set fracture characteristic to a constant
c
             read (7,280) const
             do 200 j=n1,n2
               frac(j,k)=const
  200          continue
            endif
c
  210       continue
c
          n1=n2+1
c
  220     continue
c
  230   continue
        return
c
  240 format(10x,15,15x,f10.4)
  250 format(10x,e10.3,10x,f10.4)
  260 format(10x,15,15x,f10.4,10x,f10.4)
  270 format(3(10x,f10.0))
  280 format(10x,f10.4)
      end
```

```
      subroutine unifod (a,n,dseed,center,range)
c
c     this subroutine generates random variables uniformly
c     distributed between center-range and center+range
c
      dimension a(n)
      double precision dseed
c
      ainf=center-range
      span=2*range
      do 10 i=1,n
        a(i)=ainf+ggubfs(dseed)*span
   10   continue
      return
      end
```

Pages 84-90 intentionally removed.

```
      subroutine wrenum(maxfrc,frac)
c
c     this subroutine writes renum??.dat
c     and uses the following arrays
c       frac - array of fracture information
c       kut  - index into array knode
c       knode- index array into tint and ifrac
c       tint - t value of intersection
c       ifrac- fractures in intersection
c
      common/files/ iplot,lrenum
      common/param/ itole,iranf,iunits,ikeep,imesh,iprnt,nfrac,
     *              iplot,igene
      common/qc/    visc,spgr,qc,itrans
      common/mesh/  xgene,ygene,rgene,xmesh,ymesh,rotan,
     *              rmesh,xhole,yhole,rhole,nsgene
      common/title/ title,iray,idate
      common/kut/   kutone,kut(1)
      common/knode/ knode(1)
      common/iold/  iold(1)
      common/inew/  inew(1)
      common/ifrac/ ifrac(2,1)
      common/linel/ nnodes,neleme
      common/kind/  kind(1)
      byte kind
      common/tint/  tint(2,1)
      common/pi/    pi180
c
      dimension frac(maxfrc,10)
      dimension nintside(4)
      character*80 title(2)
      dimension bvalu(5),is(2),a1(4),b1(4),a2(4),b2(4),c(5),bval(2)
      character*9 idate
      character*19 iray
      character*11 file
      integer bcode(5)
c
      toler=10.**(-itole-1)
      do i=1,4
        nintside(i)=0
       enddo
c
c *** read in the types and values of the boundary conditions.
c
      read (1,100) (bcode(i),i=1,4)
      read (1,110) (bvalu(i),i=1,4)
c
      if (nfrac.eq.0) write(6,120) rotan
      lrenum=lrenum+1
      write(file,125) lrenum
  125 format('renum',i2.2,'.dat')
      open (unit=4,file=file,status='unknown',
     1      carriagecontrol='list')
c
c *** print the contents of frac and kut.
c
      write(6,130) iray,idate
      write(6,140)
      write(6,150)
      write(6,160) xmesh,ymesh,rotan
      write(6,170) nfrac
c
      write(6,180)
      write(6,190)
c
      if (imesh.eq.0) then
        write(6,200)
        stop
       endif
c
c     ************ f i n i t e   e l e m e n t   m e s h **************
c
c *** write input deck for finite element program.
c
c *** set coeff. for calculating linear potential boundary
c *** conditions.
c
      if (igene.eq.0)then
        bcode(5)=bcode(1)
        bvalu(5)=bvalu(1)
c
        r=rotan*pi180
        cosr=cos(r)
        sinr=sin(r)
        a1(1)=(bvalu(4)-bvalu(2))*cosr
        b1(1)=(bvalu(4)-bvalu(2))*sinr
        a2(2)=-b1(1)/ymesh
        b2(2)=a1(1)/ymesh
        a1(1)=a1(1)/xmesh
        b1(1)=b1(1)/xmesh
        c(1)=(bvalu(2)+bvalu(4))/2
        a1(2)=-(bvalu(3)-bvalu(1))*sinr
        b1(2)=(bvalu(3)-bvalu(1))*cosr
        a2(1)=-b1(2)/xmesh
        b2(1)=a1(2)/xmesh
        a1(2)=a1(2)/ymesh
        b1(2)=b1(2)/ymesh
        c(2)=(bvalu(3)+bvalu(1))/2
        do i=1,2
          a1(i+2)=a1(i)
          b1(i+2)=b1(i)
          a2(i+2)=a2(i)
          b2(i+2)=b2(i)
          c(i+2)=c(i)
         enddo
        c(5)=c(1)
c
c *** write out arrays on tape4 in format for finite element program.
c
        maxd=2
        ibkey1=bcode(4)
        if (ibkey1.eq.2) ibkey1=1
        do i=1,4
          ibkey2=bcode(i)
          if (ibkey2.eq.2) ibkey2=1
          if (ibkey1.ne.ibkey2) maxd=1
          ibkey1=ibkey2
         enddo
       else
        maxd=1
       endif
       write (4,210) iray,idate,iprnt
       write (4,220) title
       write (4,230) nfrac
       if (igene.eq.0)then
         write (4,240) xgene,ygene
         write (4,250) xmesh,ymesh,rotan
        else
```

```
      write (4,330) rgene
      write (4,340) rmesh,rhole,xhole,yhole
     endif
    write (4,260) (bcode(i),i=1,4)
    write (4,270) (bvalu(i),i=1,4)
    write (4,280) visc,spgr,neleme,nnodes,maxd,ikeep,iplot
c
    write (6,290) rotan,neleme,nnodes
c
c   write nodes
c
    inode=0
    int3=0
    lfrac=nfrac
    do i=1,nfrac
      io=iold(i)
      told=-2*toler
      int1=int3+1
      int2=kut(i)
      int3=int2
      do while (knode(int2).eq.0.and.int2.ge.int1)
        int2=int2-1
       enddo
      k=knode(int1)
      if (int2.lt.int1) then
        k=0
       else
        kj2=(i-ifrac(1,k))/(ifrac(2,k)-ifrac(1,k))
        if ((kj2.and..not.1).ne.0) stop ' kj2 error 6'
        t=tint(kj2+1,k)
       endif
      if (ikeep.ne.0.and.(k.eq.0.or.t.gt.toler)) then
        inode=inode+1
        ibkey1=0
        iside=0
        told=0.
        x=frac(io,4)
        y=frac(io,5)
        write (4,300) inode,ibkey1,iside,x,y
       endif
      if (k.ne.0) then
        do k1=int1,int2
          k=knode(k1)
          kj2=(i-ifrac(1,k))/(ifrac(2,k)-ifrac(1,k))
          if ((kj2.and..not.1).ne.0) stop ' kj2 error 7'
          t=tint(kj2+1,k)
          ifrc=ifrac(2-kj2,k)
          if (t.gt.told+toler) then
            x=frac(io,4)+frac(io,9)*t
            y=frac(io,5)-frac(io,8)*t
           endif
          told=t
          if (ifrc.lt.0) then
            inode=inode+1
            iside=-ifrc
            nintside(iside)=nintside(iside)+1
            ibkey1 = bcode(iside)
            bval(1) = bvalu(iside)
            if (igene.eq.1.and.iside.eq.1.and.ibkey1.eq.-1)then
              iside=7
              x=xhole
              y=yhole
             else
              ibkey2 = bcode(iside+1)
              bval(2) = bvalu(iside+1)
             endif
c
ccc   linear potential on sides
c
            if (ibkey1.eq.2) then
              bval(1)=a1(iside)*x+b1(iside)*y+c(iside)
              ibkey1 = 1
             endif
c
            if (ibkey2.eq.2) then
              bval(2)=a2(iside)*x+b2(iside)*y+c(iside+1)
             endif
            write (4,300) inode,ibkey1,iside,x,y,
     1                    (bval(ib),ib=1,maxd)
            kind(k)=-2
           elseif (kind(k).ne.-2) then
            inode=inode+1
            ibkey1=0
            iside=0
            write (4,300) inode,ibkey1,iside,x,y
            kind(k)=-2
           endif
         enddo
       endif
      if (ikeep.ne.0.and.(k.eq.0.or.told+toler.lt.frac(io,2))) then
        inode=inode+1
        ibkey1=0
        iside=0
        write (4,300) inode,ibkey1,iside,frac(io,6),frac(io,7)
       endif
     enddo
c
c   write elements
c
    inode=0
    int3=0
    ieleme=0
    do i=1,nfrac
      io=iold(i)
      transm = frac(io,3)
      if(itrans.eq.0) transm=qc*transm**3
      int1=int3+1
      int2=kut(i)
      int3=int2
      do while (knode(int2).eq.0.and.int1.le.int2)
        int2=int2-1
       enddo
      in2=0
      told=0.
      k=knode(int1)
      if (int2.lt.int1) then
        k=0
       else
        kj2=(i-ifrac(1,k))/(ifrac(2,k)-ifrac(1,k))
        if ((kj2.and..not.1).ne.0) stop ' kj2 error 9'
        t=tint(kj2+1,k)
        t1=t
        t2=t
       endif
      if (ikeep.ne.0.and.(k.eq.0.or.t.gt.toler)) then
        inode=inode+1
        in2=inode
       endif
```

```
c       *
        if (k.ne.0) then
c       *
          do k1=int1,int2
            k=knode(k1)
            if (ifrac(1,k)*ifrac(2,k).ne.0) then
              kj2=(1-ifrac(1,k))/(ifrac(2,k)-ifrac(1,k))
              if ((kj2.and..not.1).ne.0) stop ' kj2 error 10'
              t=tint(kj2+1,k)
              ifrc=ifrac(2-kj2,k)
              ifrac(1,k)=ifrc
c       *
              tint(1,k)=tint(2-kj2,k)
              t2=t
              if (in2.eq.0) t1=t2
              in1=in2
              if (kind(k).eq.-2) then
                inode=inode+1
                in2=inode
                ifrac(2,k)=-in2
                kind(k)=-3
c       *
               else
                in2=-ifrac(2,k)
               endif
              if (in1.ne.0) then
                dist=t-told
                if (dist.le.toler) dist=0
                ieleme=ieleme+1
c
c     write out element number with the two node numbers and aperture
c
c       *
                write (4,320) ieleme,in1,in2,transm,dist,i
               endif
              told=t
             endif
c
           enddo
          if (ikeep.eq.0) then
            frac(io,7)=frac(io,5)-frac(io,8)*t2
            frac(io,6)=frac(io,4)+frac(io,9)*t2
c       *
            frac(io,5)=frac(io,5)-frac(io,8)*t1
            frac(io,4)=frac(io,4)+frac(io,9)*t1
           endif
         endif
c       *
        if (ikeep.ne.0) then
          if (k.eq.0.or.told+toler.lt.frac(io,2)) then
            inode=inode+1
            dist=frac(io,2)-told
            ieleme=ieleme+1
c
c     write out element number with the two node numbers and transmissivity
c
            write (4,320) ieleme,in2,inode,transm,dist,i
           endif
         else
c       *
c
c     this next if block moves all discarded fractures outside of the plotting
c     region
c
c       *
          if (t1.eq.t2) then
            frac(io,7)=ygene
            frac(io,6)=xgene
            frac(io,5)=ygene
            frac(io,4)=xgene
           endif
c       *
         endif
        enddo
c
c       write the number of boundary nodes per side on fmg.out
c
        write(6,6001)nintside
        close (unit=4)
        return
c
  100 format(4i10)
  110 format(4f10.4)
  120 format('0there are no conducting fractures for rotan=',f6.2)
  130 format('0',a19,' - ',a9)
  140 format('0f r a c t u r e s  i n  f l o w  r e g i o n')
  150 format('0( n o n - i n t e r s e c t i n g  f r a c t u r e s',
     1 '  h a v e  b e e n  d r o p p e d )')
  160 format('0the size of the flow region is ',f8.1,' by ',f8.1/
     1 ' the angle of rotation is ',f6.2)
  170 format('0the number of fractures in the flow region is ',i5)
  180 format('0f r a c t u r e  s t a t i s t i c s'/
     1 'o f  f r a c t u r e s  i n  f l o w  r e g i o n')
  190 format('0isolated fractures have been eliminated')
  200 format('0normal end of generation,imesh =0')
  210 format(a19,' - ',a9,i1)
  220 format(a)
  230 format('nfrac- - -',i5)
  240 format('xgene- - -',f10.4,'ygene- - -',f10.4)
  250 format('xmesh- - -',f10.4,'ymesh- - -',f10.4/'rotan- - -',f10.4)
  260 format('bcode(s) -',4i10)
  270 format('bvalu(s) -',4f10.4)
  280 format('viscosity-',f10.4,'spgr - - -',f10.4/
     1       'nelements-',i6,5x,'nnodes - -',i6,5x,'nboundary-',i6,5x/
     2       'trunc.code',i5,5x,'plot code-',i5)
  290 format('rotan=',f10.4,5x,'nelem=',i6,5x,'nnode=',i6)
  300 format(3i5,5x,2f10.4,10x,2f10.4)
  320 format(3i5,5x,1p,2e10.3,5x,i5)
  330 format('rgene- - -',f10.4)
  340 format('rmesh- - -',f10.4,'rhole- - -',f10.4/
     '       'xhole- - -',f10.4,'yhole- - -',f10.4)
 6001 format(//' number of boundary intersections per side:'/
     '         ' side one   ',i10/
     '         ' side two   ',i10/
     '         ' side three ',i10/
     '         ' side four  ',i10)
      end
```

Appendix C

RENUM - Program Organization and Arrays

Table C-1. RENUM - Description of Program Variables

Variable	Description	How Value is Assigned
Global:		
ikeep	Code for discarding dead-ends = 0 - keep only conducting fracture network = 1 - keep dead-ends = 2 - keep dead-ends and isolated clusters	Read in RDATA
iplot	Code for producing input files for the plotting program DIMES = 0 no plot = 1 - generate plot files after RENUM only = 2 - generate plot files after both FMG and RENUM	Read in RDATA
maxd	Number of boundary conditions	Read in RDATA
mxelem	Maximum number of elements, used for dimensioning arrays	Set in parameter statement in main program
mxnode	Maximum number of nodes, used for dimensioning arrays	Set in parameter statement in main program
neleme	Number of elements	Read in RDATA
nflow	Number of current flow region	Initialized to zero incremented in RDATA
newnel	Number of elements after mesh optimization	Calculated in MCGEE
nnodes	Number of nodes	Read in RDATA, modified in PATHS
Local:		
ibwth	Bandwidth of the linear system after mesh optimization	Computed in PROUT
ie	Current element number	Indexed in MCGEE, MERGE PATHS, PLOT, PROUT
ihole	Number of parallelepiped with constant flux boundary conditions, or "hole"	Computed and used in MERGE

ilasd	Last node added in the current list of nodes for the downward search	Set and incremented in PATHS
ilasf	Last node added in the current list of nodes for the forward search	Set, incremented in PATHS
in	Current node new number	Indexed in MCGEE, MERGE, PATHS, PLOT and PROUT
ind	Number of nodes already connected	Calculated in PATHS
ind1	First node of the current level	Determined in PATHS
ind2	Last node of current level	Determined in PATHS
io	Old number of the current node, **in**	Set in MCGEE, MERGE, PATHS, PLOT and PROUT
is	Source number of the current node, **in**	Determined and used in PATHS
isour	Flag for marking a node as a source for the next forward search, used during downward searches	Set in PATHS
jn	New number of node connected to **in** by element ie	Used McGee, PATHS, PLOT and PROUT
jo	Old number for node **jn**	Set in MCGEE, PATHS, PLOT and PROUT
js	Source number of the node **jn** connected to the current node **in**	Determined and used in PATHS
knode	Number of nodes already connected	Initialized and incremented in MCGEE
knode1	First node of the current level	Determined in MCGEE
knode2	Last node of the current level	Determined in MCGEE
next0	Dummy variable used to set up the "next" common property	Used in PATHS
nodeso	Initial number of nodes	Set in PATHS

Table C-2. RENUM - Description of Program Arrays

Array	Description
aptdis(2,mxelem)	Element characteristics; read in subroutine RDATA; m = 1, neleme aptdis(1,m) = transmissivity aptdis(2,m) = element length
ibeg(10)	Number of the first boundary node encountered on a given imposed flux parallelepiped or circle ("hole") ihole = 1, 10 ibeg(ihole) = number of first node on hole number ihole. All subsequent nodes on hole ihole will be shrunk into node ibeg(ihole) Defined and used in MERGE
ibs(2,mxnode)	Node information; n = 1, nnodes ibs(1,n) = node type = 0 internal node = 1 imposed head boundary node = -1 imposed flux boundary node ibs(2,n) = boundary side number for boundary nodes
ielte(2,mxelem)	element connections array, ie = 1, neleme; i = 1, 2 ielte (i, ie) = number of the next element connected to element ie through its endpoint number i
ieltn(mxnode)	Element connection pointer, n = 1, nnodes ieltn(n) = number of first element in the list of elements connected to node n
ifr(2,mxelem)	fracture numbers, ie = 1, neleme ifr(1,ie) = number of the fracture on which lies an element (fracture line in 2-D; fracture disc in 3-D) ifr(2,ie) = number of other fracture disc on which lies an element, if relevant (3-D only)
iold(mxnode)	Reference array for old node numbers, in = 1, nnodes iold(in) = old number of node number in

inew(mxnode)	Back reference in array for new node numbers, io = 1, nnode iold(io) = 0 if node with old number io is discarded iold(io) = new node number otherwise
inode(2,mxelem)	Node numbers of the two nodes defining an element ie = 1, neleme inode(1,ie) = number of the first node of element ie inode(2,ie) = number of the second node of element ie
isrc(mxnode)	source number array, in = 1,nnodes isrc(in)= source of node in
next (mxnode)	Pointer array used for searches in PATH n = 1, nnodes next(n) = node to be screened after node n in the current search.
title(10)	First ten lines read from RENUM%%.inp then written to linel.inp: information needed by LINEL but not by RENUM. (character*80)
xyzphi(6,mxnode)	Node information, n = 1, nnodes xyzphi(1,n)= x-coordinate of node n xyzphi(2,n)= y-coordinate of node n xyzphi(3,n)= z-coordinate of node n xyzphi(4,n)= value of the imposed head at node n, first boundary conditions xyzphi(5,n)= value of the imposed head at node n, second boundary conditions xyzphi(6,n)= value of the imposed head at node n, third boundary conditions

Table C-3. RENUM - Subroutine Outline

RENUM RDATA WERROR

MERGE

PATHS

MCGEE

PLOT

PROUT

or

RCNTRL

RNPN

TRIOUT

Table C-4. RENUM - Description of Subroutines

Subroutine	Description
MCGEE	Sorts nodes by coordinates and then renumbers them using the Cutill-McKee method. given: inew(nnodes), iold(nnodes), ielte(2,neleme), ieltn(nnodes), ibs(2,nnodes), nnodes, ikeep, xyzphi(6,nnodes), inode(2, neleme) returns: rewnel, modified nnodes, inew, iold
MERGE	Eliminates zero-length elements, and merges no flow boundary nodes given: inew(nnodes), iold(nnodes), ieltn(nnodes), ibs(2,nnodes), nnodes, neleme, xyzphi(6,nnodes), inode(2,neleme), aptdis(2,neleme), ifr(2,neleme) returns: ielte, modified ibs, inew, iold, inode, aptdis, ifr, neleme, ieltn
PATHS	Traces connected paths from the boundaries in order to detect and discard complex dead-ends given: inew(nnodes), iold(nnodes), nnodes, ibs(2,nnodes), ielte(2,neleme), ieltn(nnodes), inode(2,neleme) returns: modified inew, iold, nnodes
PLOT	Writes plotting files, lines%%.dat, which are used by program DIMES to produce fracture plots given: nnodes, ielte(2,neleme), ieltn(nnodes), inode(2, neleme), ifr(2,neleme), xyzphi(6,nnodes), inew(nnodes), iold(nnodes) prints: endpoints coordinates and fracture(s) number(s) for each element in the optimized network.
PROUT	Prints program output to the file linel.inp. given: title, newnel, nnodes, maxd, ikeep, iplot, ibwth, inew(nnodes), iold(nnodes), ibs(2, nnodes), xyzphi(6, nnodes), ielte(2, neleme), ieltn (nnodes), inode (2, neleme), ifr (2, neleme), aptdis(2, neleme) prints: - a header containing title, newnel, nnodes, maxd, ikeep iplot, ibwth - a list of nodes with a node number, and the information in ibs and xyzphi

- a list of elements with element number, numbers of the two nodes making up the element, and the information contained in aptdis and ifr

RCNTRL Reads control variables from inter.inp

returns: title2, imode, ibmode, mxstep, iue, iui, nstep, time0, dtini, prr, tmax, theta, fsys, tole, dcint, dcon, dcoff, rhor, rmur, gravr, ssubs, dispc

RDATA Reads in data from renum%%.inp and also checks the problem size against the array dimensions.

given: nflow
reads: all input (see Table 3-1)
returns: all it reads, and incremented nflow
uses subroutine: WERROR

TRIOUT Prints program out put to files ctrl,inp, node.inp and elmt.inp

given: type in the "givens" for PROUT and the "returns" for RCNTRL

prints: - a control file ctrl,inp for input to TRINET to node.inp
- a list of nodes with a node number, and the information in ibs and xyzphi
- to elmt.inp a list of elements with element number members of the two nodes making up the element, and the information contained in aptdis and ifr

WERROR Prints error messages in sys$error file.

given: character*(*) line
prints: error message contained in line

Appendix D

RENUM - Program Listing

```
      program renum
      parameter (mxnode=60000)
      parameter (mxelem=90000)
      common/aptdis/ aptdis(2,mxelem)
      common/control/maxele,maxnod
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/ibs/    ibs(2,mxnode)
      common/ielte/  ielte(2,mxelem)
      common/ieltn/  ieltn(mxnode)
      common/ifr/    ifr(2,mxelem)
      common/ifrac/  ifrac(mxnode)
      common/inew/   inew(mxnode)
      common/inode/  inode(2,mxelem)
      common/iold/   iold(mxnode)
      common/isrc/   isrc(mxnode)
      common/next/   next(0:mxnode)
      common/title/  title
      common/xyzphi/ xyzphi(6,mxnode)
      common /cgeo/  dc(mxelem),ss(mxelem),w(mxelem)
      common /contrl/  title2,imode,ibmode,mxstep,iuo,iui,
     $                 nstep,time0,dtini,prr,tmax,theta,fsys,
     $                 tole,dcint,dcon,dcoff,rhor,rmur,gravr,
     $                 ssubs,dispc
      character*80 title(10),title2
      logical*1 fxl
      maxnod=mxnode
      maxele=mxelem
      open (unit=4,file='linel.inp',status='unknown')
      nflow=0
      do while (.true.)
        call rdata
c
        do i=1,nnodes
          ieltn(i)=0
          iold(i)=i
          inew(i)=i
         enddo
c
c       Merge inner constant
c       flux boundary nodes and get rid of zero length elements
c
        call merge
c
c       trace connected paths
c
        if(ikeep.eq.0)call paths
c
c       renumber the nodes using Cuthill-McKee's method
c
        call mcgee
c
c       write a file for plotting
c
        if(iplot.ge.1)call plot
c
c       write linel input deck
c
        inquire(file='inter.inp',exist=fxl)
        if(.not.fxl) then
          call prout
          else
            call rcntrl
            call rnpn
            call triout
          end if
         enddo
        end
```

```
 parameter (maxno=18000,maxel=34000,maxbn=4000)
 common /fmgb/     ibcode(6),bvalufmg(6)
 common /bound/    ib(maxno),ibc(maxno),bvalu(maxno),cbvalu(maxno),
$                  isc(maxno),nboun,kb(6)
 common /cgeo/     dc(maxel)
 common /conc/     cold(maxno)
 common /contrl/   title1,title2,imode,ibmode,mxstep,iuo,iui,
$                  nstep,time0,dtini,prr,tmax,theta,fsys,
$                  tole,dcint,dcon,dcoff
 common /geo/      ne,nn,ibw,icat(2,maxel),xyz(3,maxno),
$                  rl(maxel),w(maxel),ss(maxel),transm(maxel),
$                  ssubs,dispc
 common /head/     h(maxno)
 common /para/     rhor,rmur,gravr
 character         title1(3)*80,title2*80
 logical*1         finit,fxl
```

```
      subroutine mcgee
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/xyzphi/xyzphi(6,1)
      common/ieltn/ieltn(1)
      common/iold/iold(1)
      common/inew/inew(1)
      common/ielte/ielte(2,1)
      common/ibs/ibs(2,1)
      common/inode/inode(2,1)
c
      knode2=0
      knode=0
      j=0
      do while (knode.lt.nnodes.and.j.le.500)
        j=j+1
        j9=500
        knode3=knode+2
        knp11=knode+1
        do in=knp11,nnodes
          io=iold(in)
          if (ibs(2,io).ne.0.and.ieltn(io).ne.0) then
            if (ibs(2,io).eq.j) then
              knode=knode+1
              ko=iold(knode)
              iold(knode)=io
              inew(io)=knode
              iold(in)=ko
              inew(ko)=in
             else
              j9=min(j9,ibs(2,io)-1)
             endif
          endif
        enddo
        if (ikeep.gt.1.and.j.eq.501) then
          j=500
          do while (nnodes.gt.knode.and.knode.lt.knp11)
            io=iold(knp11)
            if (ieltn(io).eq.0) then
              ko=iold(nnodes)
              iold(nnodes)=io
              inew(io)=nnodes
              iold(knp11)=ko
              inew(ko)=knp11
              nnodes=nnodes-1
             else
              knode=knp11
             endif
          enddo
        endif
c
c       sort array by coordinates
c
          j1=knode3
          i2=knode
          do while (i2.ge.j1)
            j2=i2
            i0=1
            i1=0
            i2=0
            in1=iold(j1-1)
            do j0=j1,j2
              in2=iold(j0)
              xt=xyzphi(1,in2)
              yt=xyzphi(2,in2)
              zt=xyzphi(3,in2)
              if (xt.gt.xyzphi(1,in1).or.
     2           (xt.eq.xyzphi(1,in2).and.(yt.gt.xyzphi(2,in2).or.
     3           (yt.eq.xyzphi(2,in2).and.zt.gt.xyzphi(3,in2))))) then
                i2=j0-1
                iold(j0)=in1
                iold(i2)=in2
                inew(in1)=j0
                inew(in2)=i2
                i1=i1+i0*i2
                i0=0
               else
                in1=in2
               endif
            enddo
            j1=max0(i1,knode3)
          enddo

        do while (knode.gt.knode2)
          knode1=knode2+1
          knode2=knode

          do in=knode1,knode2
            knode3=knode+2
            io=iold(in)
            ie=ieltn(io)
            do while (ie.ne.0)
              k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
              jo=inode(2-k,ie)
              jn=inew(jo)
              if (jn.gt.knode.and.jn.le.nnodes) then
                knode=knode+1
                ko=iold(knode)
                iold(knode)=jo
                inew(jo)=knode
                iold(jn)=ko
                inew(ko)=jn
               endif
              ie=ielte(k+1,ie)
             enddo
c
c   sort array by coordinates
c
            j1=knode3
            i2=knode
            do while (i2.ge.j1)
              j2=i2
              i0=1
              i1=0
              i2=0
              in1=iold(j1-1)
              do j0=j1,j2
                in2=iold(j0)
                xt=xyzphi(1,in1)
                yt=xyzphi(2,in1)
                zt=xyzphi(3,in1)
                if (xt.gt.xyzphi(1,in2).or.
     2             (xt.eq.xyzphi(1,in2).and.(yt.gt.xyzphi(2,in2).or.
     3             (yt.eq.xyzphi(2,in2).and.zt.gt.xyzphi(3,in2))))) then
                  i2=j0-1
                  iold(j0)=in1
                  iold(i2)=in2
                  inew(in1)=j0
                  inew(in2)=i2
```

```
            i1=i1+10*i2
            i0=0
           else
            in1=in2
           endif
          enddo
         j1=max0(i1,knode3)
        enddo
       enddo
     enddo
    j=max(j,j9)
  enddo

nnodes=knode
newnel=0
do i=1,neleme
  n1=inode(1,i)
  n2=inode(2,i)
  n1=inew(n1)
  n2=inew(n2)
  if (n1*n2.ne.0) newnel=newnel+1
 enddo
return
end
```

```
      subroutine merge
      common/title/title
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/control/maxele,maxnod
      common/ieltn/ieltn(1)
      common/iold/iold(1)
      common/inew/inew(1)
      common/ielte/ielte(2,1)
      common/xyzphi/xyzphi(6,1)
      common/ibs/ibs(2,1)
      common/inode/inode(2,1)
      common/aptdis/aptdis(2,1)
      common/ifr/ifr(2,1)
      character*80 title(10)
      integer ibeg(20)
c
c     merge inner constant flux boundary elements
c
c     initialize flag
c
      do i=1,20
        ibeg(i)=0
       enddo
c
c     loop over nodes
c
      do in=1,nnodes
        if(ibs(1,in).eq.-1)then
          ihole=(ibs(2,in)-1)/6
          if(ihole.ne.0)then
            if(ibeg(ihole).eq.0)then
              ibeg(ihole)=in
             else
              inew(in)=ibeg(ihole)
              ibs(2,in)=0
             endif
           endif
         endif
       enddo
c
c     get rid of zero length elements
c
      i=0
      do while (i.lt.neleme)
        i=i+1
        n1=inode(1,i)
        n2=inode(2,i)
        do while (inew(n1).ne.n1)
          n1=inew(n1)
         enddo
        do while (inew(n2).ne.n2)
          n2=inew(n2)
         enddo
        if (aptdis(2,i).eq.0..or.n1.eq.n2)then
          if (ibs(2,n2).eq.0) then
            inew(n2)=n1
           elseif (n1.ne.n2) then
            inew(n1)=n2
            ibs(2,n1)=0
           endif
          inode(1,i)=inode(1,neleme)
          inode(2,i)=inode(2,neleme)
          aptdis(1,i)=aptdis(1,neleme)
          aptdis(2,i)=aptdis(2,neleme)
          ifr(1,i)=ifr(1,neleme)
          ifr(2,i)=ifr(2,neleme)
          i=i-1
          neleme=neleme-1
         endif
       enddo
      i=1
      do while (i.le.neleme)
c
c     get read of element if it is a loop on one node
c
        n1=inode(1,i)
        do while(inew(n1).ne.n1)
          n1=inew(n1)
         enddo
        inode(1,i)=n1
        n2=inode(2,i)
        do while (inew(n2).ne.n2)
          n2=inew(n2)
         enddo
        inode(2,i)=n2
        if(n1.eq.n2)then
          inode(1,i)=inode(1,neleme)
          inode(2,i)=inode(2,neleme)
          aptdis(1,i)=aptdis(1,neleme)
          aptdis(2,i)=aptdis(2,neleme)
          ifr(1,i)=ifr(1,neleme)
          ifr(2,i)=ifr(2,neleme)
          neleme=neleme-1
          goto 20
         endif
c
c     get rid of elements in parallel
c
        ie=ieltn(n2)
        do while (ie.ne.0)
          k=(n2-inode(1,ie))/(inode(2,ie)-inode(1,ie))
          n1=inode(2-k,ie)
          if (n1.eq.inode(1,i)) then
            if(aptdis(2,i).ne.0)
     ,        aptdis(1,ie)=aptdis(1,ie)+aptdis(1,i)*
     ,                     aptdis(2,ie)/aptdis(2,i)
            inode(1,i)=inode(1,neleme)
            inode(2,i)=inode(2,neleme)
            aptdis(1,i)=aptdis(1,neleme)
            aptdis(2,i)=aptdis(2,neleme)
            ifr(1,i)=ifr(1,neleme)
            ifr(2,i)=ifr(2,neleme)
            neleme=neleme-1
            go to 20
           endif
          ie=ielte(k+1,ie)
         enddo
        do j=1,2
          n2=inode(j,i)
          ielte(j,i)=ieltn(n2)
          ieltn(n2)=i
         enddo
        i=i+1
   20   enddo
c
      return
      end
```

```
      subroutine paths
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/control/maxele,maxnod
      common/ieltn/ieltn(1)
      common/ielte/ielte(2,1)
      common/iold/iold(1)
      common/inew/inew(1)
      common/isrc/isrc(1)
      common/ibs/ibs(2,1)
      common/inode/inode(2,1)
      common/next/next0,next(1)
      nodeso=nnodes
c
c     initialize search. Put boundary nodes as sources for 1st search
c
      ilasf=0
      do i=1,nnodes
        if (ibs(2,i).ne.0) then
          next(ilasf)=i
          ilasf=i
         endif
        isrc(i)=i
       enddo
      next(ilasf)=0
c
c     begin loop over searches
c
      i = next(0)
      do while (i.ne.0)
c
c       forward search
c
c       put sources for search in level one
c
        ind=0
        do while(i.ne.0)
          ind=ind+1
          if (ind.ne.inew(i)) then
            io=iold(ind)
            in=inew(i)
            iold(ind)=i
            inew(i)=ind
            iold(in)=io
            inew(io)=in
           endif
          i=next(i)
         enddo
        ind1=1
        ind2=ind
        ilasd=0
c
c       loop over levels
c
        do while (ind1.lt.ind2)
c
c         loop over nodes in level
c
          do in=ind1,ind2
            io=iold(in)
            ie=ieltn(io)
            is=isrc(io)
            if (is.eq.0)is=io
c
c           loop over nodes connected to node in by a line element,
c           skipping active nodes.
c
            indsav = ind
            do while (ie.ne.0)
              k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
              jo=inode(2-k,ie)
              ie=ielte(k+1,ie)
              js=isrc(jo)
              if(js.ne.0)then
                jn=inew(jo)
                if (jn.gt.ind) then
                  ind=ind+1
                  indo=iold(ind)
                  iold(ind)=jo
                  inew(jo)=ind
                  iold(jn)=indo
                  inew(indo)=jn
                  isrc(jo) = is
                elseif (jn.gt.indsav) then
                  isrc(jo) = is
                elseif (js.ne.is.and.jn.gt.in)then
                  isrc(jo)=0
                  next(ilasd)=jo
                  ilasd=jo
                 endif
               elseif (is.ne.jo.and.isrc(io).ne.0) then
                isrc(io) = 0
                is = io
                next(ilasd) = io
                ilasd = io
                ie = ieltn(io)
               endif
             enddo
           enddo
          ind1=ind2+1
          ind2=ind
         enddo
        next(ilasd)=0
c
c       downward search
c
        io=next(0)
        ilasf=0
c
c       loop over nodes as long as there are new ones to be screened
c
        do while (io.ne.0)
c
          in=inew(io)
          ie=ieltn(io)
          isour=0
c
c         loop over nodes connected to node in by a line element
c
          do while (ie.ne.0)
            k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
            jo=inode(2-k,ie)
            if (isrc(jo).ne.0)then
              jn=inew(jo)
              if(jn.le.in)then
c
c               flag node jn as active and mark to be
c               screened later in the downward search
c
```

```
              next(ilasd)=jo
              isrc(jo)=0
              ilasd=jo
              next(ilasd)=0
             else
c
c             flag node in to be marked as a source for
c             the next forward search
c
              isour=1
             endif
            endif
            ie=ielte(k+1,ie)
           enddo
c
c        mark node as a source for next forward search
c
         if(isour.ne.0)then
           next(ilasf)=io
           ilasf=io
          endif
c
         io=next(io)
        enddo
       next(ilasf)=0
       i=next(0)
      enddo
c
c     take active nodes
c
      nnodes=0
      do io=1,nodeso
        in=inew(io)
        if (isrc(io).eq.0) then
          nnodes=nnodes+1
          jo=iold(nnodes)
          iold(in)=jo
          inew(jo)=in
          iold(nnodes)=io
          inew(io)=nnodes
        endif
       enddo
      do in=nnodes+1,nodeso
        io=iold(in)
        inew(io)=0
       enddo
      return
      end
```

```
      subroutine plot
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/control/maxele,maxnod
      common/ieltn/ieltn(1)
      common/iold/iold(1)
      common/inew/inew(1)
      common/ielte/ielte(2,1)
      common/inode/inode(2,1)
      common/ifr/ifr(2,1)
      common/xyzphi/xyzphi(6,1)
      character*11 file
c
      write(file,10)nflow
   10 format('lines',i2.2,'.dat')
      open(unit=7,file=file,status='unknown')
      do in=1,nnodes
        io=iold(in)
        ie=ieltn(io)
        do while (ie.ne.0)
          k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
          jo=inode(2-k,ie)
          jn=inew(jo)
          if (in.lt.jn) then
            x1=xyzphi(1,io)
            y1=xyzphi(2,io)
            z1=xyzphi(3,io)
            x2=xyzphi(1,jo)
            y2=xyzphi(2,jo)
            z2=xyzphi(3,jo)
            write (7,710) x1,y1,z1,x2,y2,z2,ifr(1,ie),ifr(2,ie)
           endif
          ie=ielte(k+1,ie)
         enddo
       enddo
      close (unit=7)
      return
  710 format(6f10.4,2i5)
      end
```

```
      subroutine prout
      common/title/title
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/control/maxele,maxnod
      common/ieltn/ieltn(1)
      common/iold/iold(1)
      common/inew/inew(1)
      common/ielte/ielte(2,1)
      common/xyzphi/xyzphi(6,1)
      common/ibs/ibs(2,1)
      common/inode/inode(2,1)
      common/aptdis/aptdis(2,1)
      common/ifr/ifr(2,1)
      common/ifrac/ifrac(1)
      character*80 title(10)
c
c     compute bandwidth ibwth
c
      ibwth=0
      do in=1,nnodes
        io=iold(in)
        if (ibs(1,io).ne.1)then
          ie=ieltn(io)
          do while (ie.ne.0)
            k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
            jo=inode(2-k,ie)
            if (ibs(1,jo).ne.1)then
              jn=inew(jo)
              ibwth=max(jn-in,ibwth)
             endif
            ie=ielte(k+1,ie)
           enddo
         endif
       enddo
      ibwth=ibwth+1
c
      write (4,30) title,newnel,nnodes,maxd,ikeep,iplot,ibwth
      do m=1,nnodes
        n=iold(m)
        if (ibs(2,n).eq.0) then
          write(4,40) m,ibs(1,n),ibs(2,n),ifrac(n),(xyzphi(i,n),i=1,3)
         else
          write(4,40) m,ibs(1,n),ibs(2,n),ifrac(n),(xyzphi(i,n),i=1,3+maxd)
         endif
       enddo
      m=0
      do in=1,nnodes
        io=iold(in)
        ie=ieltn(io)
        do while (ie.ne.0)
          k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
          jn=inew(inode(2-k,ie))
          if (in.lt.jn) then
            m=m+1
            write (4,50) m,in,jn,aptdis(1,ie),aptdis(2,ie),
     2                   ifr(1,ie),ifr(2,ie)
           endif
          ie=ielte(k+1,ie)
         enddo
       enddo
      return
c
   30 format(10(a/),
     1  'nelements-',i6,4x,'nnodes - -',i6,4x,'nboundary-',i6/
     2  'trunc.code',i5,5x,'plot code-',i5,5x,'bandwidth-',i5)
   40 format(4i5,6f10.4)
   50 format(3i5,5x,1p,2e10.4,0p,5x,2i5)
      end
```

```
      subroutine rcntrl
c-------------------------------------------------------------
c     imode= -2    Flow only (Steady-state, theta=1.0)
c            -1              (Transient)
c             0    Test data deck
c             1    Transport (Transient flow)
c             2              (Steady-state flow, theta=1.0)
c     ibmode= 0    Radial boundary (start from side 5 only)
c             1    Square boundary (start from side 2 only)
c             2    Square boundary (start from all four sides
c                                   1, 2, 3, 4.)
c-------------------------------------------------------------
      common /contrl/  title2,imode,ibmode,mxstep,iuo,iui,
     $                 nstep,time0,dtini,prr,tmax,theta,fsys,
     $                 tole,dcint,dcon,dcoff,rhor,rmur,gravr,
     $                 ssubs,dispc
      character        title2*80
c
      iui=3
      open (unit=iui,readonly,file='inter.inp',status='old')
      read(iui,501) title2
      read(iui,521) imode,ibmode,mxstep
c
      read(iui,511) time0,tmax,dtini
c
      read(iui,511) prr,theta,tole
c
      read(iui,511) dcint,dcon,dcoff
c
      read(iui,511) rhor,rmur,gravr
c
      read(iui,512) ssubs,dispc
c
  501 format(a80)
  511 format(3(10x,f10.0))
  512 format(2(10x,f10.0))
  521 format(3(10x,i5))
c
      return
      end
```

```
      subroutine rdata
      common/title/title
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/control/maxele,maxnod
      common/iold/iold(1)
      common/inew/inew(1)
      common/xyzphi/xyzphi(6,1)
      common/ibs/ibs(2,1)
      common/inode/inode(2,1)
      common/aptdis/aptdis(2,1)
      common/ifr/ifr(2,1)
      common/ifrac/ifrac(1)
      character*80 title(10)
      character*11 file
c
c               read input data
c
      nflow=nflow+1
      write(file,10)nflow
   10 format('renum',i2.2,'.dat')
c     open (unit=1,readonly,file=file,status='old',err=60)
      open (unit=1,file=file,status='old',err=60)
c
      read (1,70,end=60) title,neleme,nnodes,maxd,ikeep,iplot
      if (neleme .gt. maxele) then
        write(6,*) maxele
        call werror('neleme .gt. mxelem')
       endif
      if (nnodes .gt. maxnod) then
        write(6,*) maxnod
        call werror('nnodes .gt. mxnode')
       endif
      if (neleme .lt. 1) then
        write(6,*) neleme
       elseif (nnodes.gt.0) then
c
        read(1,80) (ibs(1,m),ibs(2,m),ifrac(m),
     2              (xyzphi(i,m),i=1,6),m=1,nnodes)
        read(1,90) (inode(1,n),inode(2,n),aptdis(1,n),aptdis(2,n),
     1              ifr(1,n),ifr(2,n),n=1,neleme)
       endif
      return
   60 stop
c
   70 format(10(a/),3(10x,i6,5x)/2(10x,i5,5x))
   80 format(5x,3i5,6f10.0)
   90 format(5x,2i5,5x,2e10.4,5x,2i5)
      end
```

```
      subroutine rnpn
c
      common /ibs/ ibs(2,1)
      logical*1 fx4
c
      inquire(file='npn.inp',exist=fx4)
      if(.not.fx4) return
      open(unit=12,file='npn.inp',status='old')
    1 read(12,700,end=99) listp
      if(ibs(1,listp).eq.0) then
        ibs(1,listp)=-99
      else
        ibs(1,listp)=-abs(ibs(1,listp))
      endif
  700 format(i5)
      go to 1
   99 close(unit=12)
      return
      end
```

```
      subroutine triout
      common/title/title
      common/forward/nnodes,neleme,maxd,newnel,nflow,ikeep,iplot
      common/control/maxele,maxnod
      common/ieltn/ieltn(1)
      common/iold/iold(1)
      common/inew/inew(1)
      common/ielte/ielte(2,1)
      common/xyzphi/xyzphi(6,1)
      common/ibs/ibs(2,1)
      common/inode/inode(2,1)
      common/aptdis/aptdis(2,1)
      common/ifr/ifr(2,1)
      common/ifrac/ifrac(1)
      common /cgeo/     dc(1),ss(1),w(1)
      common /contrl/   title2,imode,ibmode,mxstep,iuo,iui,
     $                  nstep,time0,dtini,prr,tmax,theta,fsys,
     $                  tole,dcint,dcon,dcoff,rhor,rmur,gravr,
     $                  ssubs,dispc
      character*80 title(10),title2
c
      cube = 1./3.
      open(unit=8,status='unknown',file='ctrl.inp',
     $     carriagecontrol='list')
      open(unit=9,status='unknown',file='node.inp',
     $     carriagecontrol='list')
      open(unit=10,status='unknown',file='elmt.inp',
     $     carriagecontrol='list')
      write(8,620) title(1),title(2),title2
      write(8,621) imode,ibmode,mxstep
      write(8,631) time0,tmax,dtini
      write(8,641) prr,theta,tole
      write(8,651) dcint,dcon,dcoff
      write(8,661) rhor,rmur,gravr
      write(9,670) nnodes,title(1)
c
c     compute bandwidth ibwth
c
      ibwth=0
      do in=1,nnodes
        io=iold(in)
        if (ibs(1,io).ne.1)then
          ie=ieltn(io)
          do while (ie.ne.0)
            k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
            jo=inode(2-k,ie)
            if (ibs(1,jo).ne.1)then
              jn=inew(jo)
              ibwth=max(jn-in,ibwth)
            endif
            ie=ielte(k+1,ie)
          enddo
        endif
      enddo
      ibwth=ibwth+1
      print *, 'bandwidth =',ibwth
c
      ibc = 0
      do m=1,nnodes
        n = iold(m)
        if(xyzphi(3,n).eq.0.and.xyzphi(4,n).eq.0.) then
          write(9,674) m,ibs(2,n),ibs(1,n),ibc,(xyzphi(j,n),j=1,2)
        elseif(xyzphi(4,n).eq.0.) then
          write(9,673) m,ibs(2,n),ibs(1,n),ibc,(xyzphi(j,n),j=1,3)
        else
          write(9,671) m,ibs(2,n),ibs(1,n),ibc,(xyzphi(j,n),j=1,4)
        endif
      end do
      write(10,680) newnel,title(1)
      m=0
      do in=1,nnodes
        io=iold(in)
        ie=ieltn(io)
        do while (ie.ne.0)
          k=(io-inode(1,ie))/(inode(2,ie)-inode(1,ie))
          jn=inew(inode(2-k,ie))
          if (in.lt.jn) then
            m=m+1
c! currently, the cubic law is assumed
            w(ie)=(aptdis(1,ie)*12.*rmur/rhor/gravr)**cube
c! currently, Ss and D are constant value
            ss(ie)=ssubs
            dc(ie)=dispc
            if(dispc.eq.0.) then
              write(10,682) m,in,jn,aptdis(1,ie),w(ie),
     $                      aptdis(2,ie),ss(ie)
            else
              write(10,681) m,in,jn,aptdis(1,ie),w(ie),
     $                      aptdis(2,ie),ss(ie),dc(ie)
            endif
          endif
          ie=ielte(k+1,ie)
        enddo
      enddo
c
      close(unit=7)
      close(unit=8)
      close(unit=9)
      return
c
  620 format(a)
  621 format('imode    =',i5,'ibmode   =',i5,'mxstep   =',i5)
  631 format('time0    =',1pe10.4,'tmax     =',1pe10.4,
     $       'dtini    =',1pe10.4)
  641 format('prr      =',1pe10.4,'theta    =',1pe10.4,
     $       'tole     =',1pe10.4)
  651 format('dcint    =',1pe10.4,'dcon     =',1pe10.4,
     $       'dcoff    =',1pe10.4)
  661 format('rhor     =',1pe10.4,'rmur     =',1pe10.4,
     $       'gravr    =',1pe10.4)
  670 format('nn       =',i5,1x,a)
  671 format(i5,i3,2i2,5f12.4)
  673 format(i5,i3,2i2,3f12.4)
  674 format(i5,i3,2i2,2f12.4)
  680 format('ne       =',i5,1x,a)
  681 format(3i5,1p,5e12.4)
  682 format(3i5,1p,4e12.4)
c
      end
```

```
      subroutine werror(line)
c
c
      character*(*) line
c
      open (unit=11,file='sys$error',access='append',status='unknown')
      write (11,100) line
      close (unit=11)
      stop
  100 format(' error ',a)
      end
```

Appendix E

LINEL - Program Organization and Arrays

Table E-1. LINEL - Description of Program Variables

Variable	Description	How Value is Assigned
ibwth	Bandwidth of the linear system	Read by RHEAD
idate	Current date, character*9	Call to the date subroutine
igrad	Type of gradient to be used for study region permeability calculations = 0 use both types of gradients = 1 use global gradient only = 2 use local gradient only	Read by RSTUD
impflx	Flag for the presence of imposed flux nodes	Set in RMESH
iprnt	Code for printing output = 0 print normal output in LINEL.OUT = 1 print normal output plus heads at disc intersections in LINEL.OUT (3D only) = 2 print detailed output in LINELALL.OUT	Read LINEL.INP
istud	Number of study regions	Read by RSTUD
i8open	Flag which says if LINELALL.OUT is open or not	Subroutine RDATA
jdate	Character variable containing the date at which the line network was generated	Read from LINEL.INP
jobnam	Character variable identifying the program that generated the line network	Read from LINEL.INP
maxd	Number of different boundary conditions to be solved for the same network	Read by RHEAD
maxele	Maximum number of elements used to check the size of the problem	Set in main
maxnod	Maximum number of nodes used to check the size of the problem	Set in main

mxelem	Maximum number of elements used to dimension arrays	Parameter statement in main
mxnode	Maximum number of nodes used to dimension arrays	Parameter statement in main
neleme	Number of elements in the network	Read by RHEAD
nfrac	Number of fractures in the flow region	Read by RHEAD
ngrad	Index for the do loops for global and local gradients	Used in KSTUD and SFLUX
nnodes	Number of nodes in the network	Read by RHEAD
noddim	Dummy parameter in subroutines (noddim = maxnod)	
nside	Number of sides, depending on the type of problem (2-dimensional rectangle or circle, or 3-dimensional)	Set in RHEAD
rotan rotan2	Rotation angles of the flow region (rotan2 = 0 for 2-D cases) For circular flow region, rotan and rotan2 are the coordinates of the center of the hole	Read by RHEAD
spgr	Specific gravity in the unit system chosen by the user	Read by RHEAD
visc	Dynamic viscosity of water in the unit suystem chosen by the user	Read by RHEAD
xgene,ygene,zgene	Size of the generation region (zmesh = 0 for 2-D cases) for circular generation regions, y-gene = 0, and the radius is read in xgene	Read by RDATA
xmesh,ymesh,zmesh	Size of the flow region (z mesh = 0 for 2-D cases) for circular flow regions, xmesh = radius of flow region, ymesh = radius of hole	Read from RDATA

Table E-2. LINEL - Description of Program Arrays

Array	Description	How Value is Assigned
a(ndima)	Matrix representing the linear system, stored in banded form. a(i) = an element of the matrix Note that a is passed as a two-dimensional routine to subroutines CPHI and SYMSOL	Built by CPHI
b(mxnode,3)	Right-hand side vector of the linear system, contains the solution after SYMSOL. i = 1 nnodes; irot = 1, maxd b(i,irot) = value of the right-hand side for line i of the linear system under boundary conditions number irot (irot = 1 or 2 for two-dimensional cases)	Build by CPHI, modified by SYMSOL
bvalu(i),i=1,6	Values of the boundary head or flux on side i of the flow region (bvalu(5) = bvalu(6) = 0 for 2-D cases)	Read by RDATA
coord(3,mxnode)	node coordinates; n=1 nnodes coord(1,n) = x coordinate of node n coord(2,n) = y coordinate of node n coord(3,n) = z coordinate of node n (0 if 2-D)	Read by RDATA
dist(mxelem)	Element length; ie=1 neleme dist(ie) = length of element number ie	Read by RDATA
flx(mxelem)	Flux solution vector; ie = 1, neleme flx(ie) = flux in element ie	Computed by CUNK
ibcode(6)	The boundary code for side i of the flow region (ibcode(5) = ibcode(6) = 0 for 2-D cases) = -1 - constant flux = 0 - internal node = 1 - constant head = 2 - constant linearly distributed head	Read by RDATA
ib(mxnode)	Node type; n=1, nnodes ib(n) = 0 internal node = 1 imposed head boundary node = -1 imposed flux boundary node	Read by RDATA

inode(2,mxelem)	Element-node reference array; ie = 1,neleme inode(1,ie) = number of the node making up the first endpoint of element number ie inode(2,ie) = number of the node making up the second endpoint of element number ie	Read by RDATA
phi(mxnode,3)	Imposed head or flux if relevant, and then head solution vector; n = 1, nnodes irot = 1,maxd	
	phi(n,irot) = 0 if node n is internal phi(n,irot) = value of imposed head or flux	Read by RDATA
	phi(n,irot) = head computed or imposed at node n	Assigned by CUNK
side(mxnode)	Boundary side number, n=1, nnodes side(n) = side on which boundary node is lying = 0 if internal node	Read by RDATA
sgrad(2)	Character array which stores "g" (standing for global gradient) and "l" (standing for local gradient)	
title(2)	The title of the problem to be solved. Character*80. Read from LINEL.INP.	Read by RDATA
trans(mxelem)	Element transmissivities array; ie = 1, neleme trans(ie) = transmissivity of element number ie	Read by RDATA
xstud(20)	Size of the study regions in the x direction	Read by main
ystud(20)	Size of the study regions in the y direction	Read by main

Table E-3. LINEL - Subroutine Outline

LINEL	RSTUD	
	RHEAD	WERROR
	RMESH	
	WERROR	
	SORTIS	
	CPHI	WERROR
	SYMSOL	
	CUNK	
	PINFO	
	SFLUX	
	STUDY	

Table E-4. LINEL - Description of Subroutines

Subroutine	Description
CPHI	Fills the matrix and the right-hand side vector b.
	given: flx(nnodes), ib(nnodes), inode(2,neleme), nnodes, neleme, idima, ibwth, maxd, phi(nnodes,maxd), dist(neleme), coord(3,nnodes), trans(nnodes)
	returns: a(ndima), b(nnodes,maxd)
CUNK	Transfers the solution to the head vector phi, and computes the flux through each element.
	given: nnodes, neleme, b(nnodes,maxd), inode(2,neleme), ib(nnodes), trans(neleme), dist(neleme)
	returns: phi(nnodes,maxd), flx(neleme)
PINFO	Prints the headers for the output files and the "dump" file if specified
	given: nside, iray, idate, jobnam, date, title, nfrac, ibwth, xgene, ygene, zgene, xmesh, ymesh, zmesh, rotan, rotan2, neleme,nnodes, ibcode(6), bvalu(6) bound(6,3), iskip8, spgr, visc, inode(2,neleme), trans(neleme), dist(neleme), phi(nnodes,maxd),
	writes: part or all of the above, depending on iskip8
RHEAD	Reads the header of the input file LINEL.INP (group 2, Table 4-1)
	reads: all input from group 2 (file LINEL.INP) as specified in Table 4-1
	returns: everything it reads plus nside
RMESH	Reads the nodes and elements making up the network (group 3 in Table 4-1)
	given: all the parameters read by RHEAD (group 2 in Table 4-1)
	reads: nodes and elements definition (group 3 in Table 4-1)
	returns: everything it reads, plus flx (nnodes), maxd,impflx
	writes: everything read by RHEAD or itself on a dump file named LINELALL.OUT, depending on parameter iskip8

RSTUD Reads study regions data (group 1 in Table 4-1)

reads: input group 1

returns: what it reads, except ngrad which is modified

SFLUX Computes and prints out the flux through each side.

given: istud, igrad, iray, idate, jobnam, date, title(2) xstud(istud), ystud(istud), flx(neleme), iskip8, rotan, irot, nside, xmesh, ymesh, zmesh

writes: total fluxes through the two, four or six boundaries, depending on nside; number of fractures per unit area or per unit length on each boundary

SORTIJ Sorts elements, and nodes within elements, to insure that the two nodes in an element are in increasing order, and that the elements are in non-decreasing order with regard to their first node.

given: neleme, inode(2,neleme), trans(neleme), dist(neleme)

returns: modified inode, trans, dist

STUDY Looks for intersections between fractures and the study region boundaries. Then computes the average head at these boundaries, and the flux through these boundaries.

given: rotan, istud, neleme, nnodes, inode(2,neleme), coord(3,nnodes), xstud(istud), ystud(istud), trans(neleme), phi(nnodes)

writes: equivalent permeability for each direction of each study region

SYMSOL Linear equation solver

given: ibwth, a(ndima), nnodes, b(nnodes, maxd)

returns: modified b containing the solution of the linear system

WERROR Prints out error messages on file LINEL.ERR

given: line

prints it.

Appendix F

LINEL - Program Listing

```
      program linel
      implicit real*8 (a-h,o-z)
c
c           version 3.0 (jan 1986)
c       this program is used to calculate the flux
c          through line elements
c
c       a = the coeff matrix
c
c       title = the title of the problem to be solved
c       iray = array to store the jobcard information
c       ibcode = the boundary code
c              -1 = flux specified
c               0 = internal node
c               1 = phi specified
c       bvalu = code used to determine the value of phi
c               on the boundary
c       idate = variable to store the date of program run
c       jobnam = the name of the job
c       jdate = the date of creation of input to linel
c       inode = the node numbers for the element
c       trans = the transmissivity of the element
c       coord = coordinates of the node
c       side = the side on which the node is located
c       phi = the potential of the node
c       flx = net flux into or out of node n
c               0 = an internal node
c       b = the solution array
c
      parameter (mxnode=75000,mxelem=85000,ndima=6000000)
      common/trans/ trans(mxelem)
      common/bcode/ ibcode(6),bvalu(6)
      common/coord/ coord(3,mxnode)
      common/dist/  dist(mxelem)
      common/flux/  flx(mxnode)
      common/ib/    ib(mxnode)
      byte ib
      common/inode/ inode(2,mxelem)
      common/ifrac/ ifrac(2,mxnode)
      common/mesh/  xmesh,ymesh,zmesh,xgene,ygene,zgene,
     1              rotan,rotan2,nfrac
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/pi/    pi180
      common/side/  side(mxnode)
      byte side
      common/stud/  istud,xstud(20),ystud(20)
c
c     array a is a two-dimensional array of columns by rows,
c     however the number of columns is unknown until the bandwidth
c     has been calculated
c
      dimension a(ndima),b(mxnode,2),phi(mxnode,2),inew(mxnode)
      common/title/ title(2)
      character*80 title
      common/titles/iray,idate,jobnam,jdate
      character*7 iray,jobnam
      character*9 idate,jdate
      common/vispg/ visc,spgr
c
c     calculate pi/180 once
c
      pi180=atan(1.d0)/45.d0
      maxele=mxelem
      maxnod=mxnode
c
      iray = 'linel'
      call date(idate)
c
c if maxd is 2 linel will attempt to find a second column in
c the b vector and calculate fluxes for rotan+90.
c if ib(iside) is .le. 0, maxd is set to 1 in rdata
c
      maxd=2
c
c read data for study regions
c
      call rstud
c
      open(unit=1,file='linel.inp',readonly,status='old')
      open(unit=6,file='linel.out',status='unknown')
      open(unit=11,file='ellipse.inp',status='unknown',
     1     carriagecontrol='list')
   10 call rhead(ibwth)
      if (nnodes.lt.0) stop
      call rmesh(phi,maxnod,ibwth,inew,na)
      if (na*ibwth .gt. ndima) call werror('array a is too small-lin')
c
      if (nnodes.ne.0) then
        call sortij
c
        start=cputime(0.0)
c
        call cphi(ibwth,na,a,maxnod,b,phi,inew)
        call symsol(ibwth,na,a,maxnod,b)
       endif
c
      aver = 0.d0
c$dir scalar
      do irot=1,maxd
        if(na.ne.0)then
c
          call cunk(phi(1,irot),b(1,irot),inew)
         endif
c
        call pinfo(phi(1,irot),b(1,irot),ibwth,irot,inew)
        call sflux(phi(1,irot),b(1,irot),irot,inew)
c
        if (istud.ne.0) call study (phi(1,irot))
        rotan = rotan + 90.d0
       enddo
      time=cputime(0.0)-start
      write(6,20)time
   20 format(///' Time spent filling the matrix and solving the'/
     1        ' linear system (in cpu seconds):',f15.2///)
      go to 10
c
      end
```

```
      subroutine cphi(ibwth,na,a,noddim,b,phi,inew)
      implicit real*8 (a-h,o-z)
c
c            version 4.0 ( Dec 1987 )
c
c *** method of solution to [a] x = [b]
c
c *** if node(i) is prescribed, the inew(i)-th row and
c *** column of [a] are set to zero and, hence, contributes
c *** nothing to the solution, placing these nodes last (using
c *** inew) allows us to omit them from the matrix solver and
c *** still leave them in b. b(inew(i)) is replaced by
c *** the known value of x(i). each of the affected
c *** terms of b is modified by subtracting from it the value
c *** of the prescribed nodal variable multiplied by the
c *** appropriate column term from the original [a] matrix.
c
      common/trans/ trans(1)
      common/coord/ coord(3,1)
      common/dist/  dist(1)
      common/flux/  flx(1)
      common/ib/    ib(1)
      byte ib
      common/inode/ inode(2,1)
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/side/  side(1)
      byte side
      common/vispg/ visc,spgr
      dimension phi(noddim,2),b(noddim,2),inew(*)
      dimension a(ibwth,na)
c
c *** initialize a & b
c
c  the following loop is to initialize the entire a array
c  it is done in this manner to prevent the compiler from
c  vectorizing just the column stores (ibwth direction)
c
      do i = 1, ibwth*na
        a(i,1) = 0.d0
       enddo
      do j=1,nnodes
        b(j,1)=0.0d0
        b(j,2)=0.0d0
       enddo
      do j=1,nnodes
        if (ib(j).lt.0) b(inew(j),1)=flx(j)
       enddo
c
c       calculate banded coefficient matrix and modify [b]
c       fill banded matrix [a] with lower triangle values where:
c       number of rows = number of non-boundary nnodes
c       number of columns = bandwidth
c       and the first column is the diagonal
c       and the other columns are the non-zeros off-diagonals
c       of the coefficient matrix
c
      izero = 0
      do n=1,neleme
        if (dist(n).eq.0.d0) then
          write(6,70) n
          izero = 1
        endif
       enddo
      if (izero.ne.0) then
        call werror('there is an element with zero length')
        return
       endif
      do n=1,neleme
        n1 = inode(1,n)
        n2 = inode(2,n)

c
c *** calculate element term (e) of coefficient matrix
c
        e=trans(n)/dist(n)
c
c
        if (ib(n1).ne.1) then
          a(1,inew(n1)) = a(1,inew(n1)) + e
          if (ib(n2).ne.1) then
            a(1,inew(n2)) = a(1,inew(n2)) + e
c
c *** head not prescribed at either node of element so put
c *** e into its off diagonal position in band storage
c      save storage in [a] for all diagonal elements
c
            a(inew(n2)-inew(n1)+1,inew(n1)) = -e
          else
c
c *** else if node n2 prescribed head modify [b] only
c
c$dir scalar
            do irot=1,maxd
              b(inew(n1),irot)=b(inew(n1),irot)+e*phi(n2,irot)
            enddo
          endif
        elseif (ib(n2).ne.1) then
          a(1,inew(n2)) = a(1,inew(n2)) + e
c
c *** else if node n1 prescribed head modify [b] only
c
c$dir scalar
          do irot=1,maxd
            b(inew(n2),irot)=b(inew(n2),irot)+e*phi(n1,irot)
          enddo
        endif
       enddo
c
c   put the prescribed-head into [b].
c   (this is the one place where iold would have been useful)
c
c$dir scalar
      do irot = 1,maxd
        do ir=1,nnodes
          if (ib(ir).eq.1) b(inew(ir),irot) = phi(ir,irot)
        enddo
       enddo
      return
   70 format('element ',i5,' has zero length, try cphi2')
      end
```

```
      subroutine cunk(phi,b,inew)
      implicit real*8 (a-h,o-z)
c
c           version 3.0 (jan 1986)
c    this subroutine calculates values of phi
c
      common/trans/ trans(1)
      common/coord/ coord(3,1)
      common/dist/  dist(1)
      common/flux/  flx(1)
      common/ib/    ib(1)
      byte ib
      common/inode/ inode(2,1)
      common/side/  side(1)
      byte side
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/vispg/ visc,spgr
c     only the column of phi and b for this rotation are passed
      dimension phi(1),b(1),inew(1)
c
      do i = 1, nnodes
        phi(i) = b(inew(i))
       enddo
c
c               calculate flux of constant head boundary nodes
c
      do i=1,nnodes
        if (ib(i) .eq. 1) flx(i) = 0.d0
       enddo
      do i = 1, neleme
        n1 = inode(1,i)
        n2 = inode(2,i)
        if (ib(n1) .eq. 1)
     1    flx(n1) = flx(n1) + trans(i)*(phi(n1)-phi(n2))/dist(i)
        if (ib(n2) .eq. 1)
     1    flx(n2) = flx(n2) + trans(i)*(phi(n2)-phi(n1))/dist(i)
       enddo
      return
      end
```

```
      subroutine pinfo(phi,b,ibwth,irot,inew)
      implicit real*8 (a-h,o-z)
c
c            version 3.0 (jan 1986)
c
      common/trans/ trans(1)
      common/bcode/ ibcode(6),bvalu(6)
      common/coord/ coord(3,1)
      common/dist/  dist(1)
      common/flux/  flx(1)
      common/ib/    ib(1)
      byte ib
      common/inode/ inode(2,1)
      common/ifrac/ ifrac(2,1)
      common/mesh/  xmesh,ymesh,zmesh,xgene,ygene,zgene,
     1              rotan,rotan2,nfrac
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/side/  side(1)
      byte side
      common/title/title(2)
      character*80 title
      common/titles/iray,idate,jobnam,date
      character*7 iray,jobnam
      character*9 idate,date
      common/vispg/ visc,spgr
      dimension phi(1),b(1),inew(1)
      dimension boun(6,3)
      data boun/ 1.d0, -1.d0,  0.d0, -1.d0, -1.d0, -1.d0,
     1          -1.d0, -1.d0, -1.d0, -1.d0,  1.d0,  0.d0,
     2          -1.d0,  1.d0, -1.d0,  0.d0, -1.d0, -1.d0/
c
      if(nside.eq.2)then
        write(6,80) iray,idate,jobnam,date,title,nfrac,ibwth,
     1              xgene,xmesh,ymesh,rotan,rotan2,neleme,nnodes
       ibc=ibcode(1)
       if (ibc.eq.-1)then
         write(6,210)bvalu(1)
        elseif (ibc.eq.1)then
         write(6,220)bvalu(1)
        endif
       ibc=ibcode(3)
       if(ibc.eq.-1)then
         write(6,230)bvalu(2)
        elseif(ibc.eq.1)then
         write(6,240)bvalu(2)
        endif
c
        if (iprnt.lt.2)then
          if (impflx.ne.0)goto 1000
          return
         endif
       elseif(nside.eq.4)then
        write(6,90) iray,idate,jobnam,date,title,nfrac,ibwth,
     1              xgene,ygene,xmesh,ymesh,rotan,neleme,nnodes
c
c$dir scalar
        do i=1,nside
          ibc = ibcode(i)
          if (ibc .eq. -1) then
            write(6,110) i,bvalu(i)
           elseif (ibc .eq. 0) then
            write(6,120) i
           elseif (ibc .eq. 1) then
            write(6,130) i,bvalu(i)
           elseif (ibc .eq. 2) then
            write(6,140) i
           endif
         enddo
c
cccc write on tape 8 if iprnt is 2
c
        if (iprnt.lt.2)then
          if (impflx.ne.0)goto 1000
          return
         endif
c
        write(8,90) iray,idate,jobnam,date,title,nfrac,ibwth,
     1        xgene,ygene,xmesh,ymesh,rotan,neleme,nnodes
c
c$dir scalar
        do i=1,nside
          ibc = ibcode(i)
          if (ibc .eq. -1) then
            write(8,110) i,bvalu(i)
           elseif (ibc .eq.  0) then
            write(8,120) i
           elseif (ibc .eq.  1) then
            write(8,130) i,bvalu(i)
           elseif (ibc .eq.  2) then
            write(8,140) i
           endif
         enddo
c
       else
        write(6,100) iray,idate,jobnam,date,title,nfrac,ibwth,
     1               xgene,ygene,zgene,xmesh,ymesh,zmesh,
     2               rotan,rotan2,neleme,nnodes
c
        ibc = ibcode(irot)
c$dir scalar
        do i=1,nside
          if(boun(i,ibc).ge.0.)then
            write(6,130) i,bvalu(irot)*boun(i,ibc)
           else
            write(6,140) i
           endif
         enddo
c
cccc write on tape 8 if iprnt is 2.
c
        if (iprnt.lt.2)then
          if (impflx.ne.0)goto 1000
          return
         endif
c
        write(8,100) iray,idate,jobnam,date,title,nfrac,ibwth,
     1               xgene,ygene,zgene,xmesh,ymesh,zmesh,
     2               rotan,rotan2,neleme,nnodes
c
c$dir scalar
        do i=1,nside
          if(boun(i,ibc).ge.0.)then
            write(8,130) i,bvalu(irot)*boun(i,ibc)
           else
            write(8,140) i
           endif
         enddo
```

```
      endif
c
c     calculate flux and velocity in each fracture
c
      write(8,150)
c
      qc=spgr/(12.d0*visc)
      do i = 1, neleme
        n1 = inode(1,i)
        n2 = inode(2,i)
        fr = trans(i)*(phi(n1) - phi(n2))/dist(i)
        re = fr/visc
        aper = (trans(i)/qc)**(1.d0/3.d0)
        vel= fr/aper
        write(8,160) i,aper,vel,fr,re
       enddo
c
      write(8,170)
      do i = 1, nnodes
        write(8,181) i,phi(i),flx(i),ifrac(1,i),ifrac(2,i), ! jep 1jul88
     1                  (coord(j,i),j=1,3),side(i)           ! add coord
       enddo
c
      if(impflx.eq.0)return
c
 1000 write(6,185)
      do i = 1, nnodes
        if(ib(i).lt.0)then
          write(6,181)i,phi(i),flx(i),ifrac(1,i),ifrac(2,i), !jep 1jul88
     1                  (coord(j,i),j=1,3),side(i)           !add coord
        endif
       enddo
      write(6,190)
c
      return
c
   80 format(//' --- ',a7,' --- ',a9//
     1  ' jobname and date of finite element mesh creation --- ',a7,
     2  ', ',a9//1x,a80/1x,a80//
     3  ' the number of fractures in the flow region is',18/
     4  ' the bandwidth for the matrix is',17x,15/
     5  ' the radius of the generation region is',8x,f7.2/
     6  ' the radius of the flow region is      ',8x,f7.2/
     7  ' the radius of the inner hole is       ',8x,f7.2/
     8  ' the coordinates of the hole are  x=',8x,f10.4,' and y=',f10.4//
     8  ' neleme = ',15,10x,'nnodes = ',15)
   90 format(//' --- ',a7,' --- ',a9//
     1  ' jobname and date of finite element mesh creation --- ',a7,
     2  ', ',a9//1x,a80/1x,a80//
     3  ' the number of fractures in the flow region is',18/
     4  ' the bandwidth for the matrix is',17x,15/
     5  ' the size of the generation region is',f7.2,' by',f7.2/
     6  ' the size of the flow region is      ',f7.2,' by',f7.2/
     7  ' the angle of rotation is',19x,f10.2//
     8  ' neleme = ',15,10x,'nnodes = ',15)
  100 format('1 --- ',a7,' --- ',a9//
     1  ' jobname and date of finite element mesh creation --- ',a7,
     2  ', ',a9//1x,a80/1x,a80//
     3  ' the number of fractures in the flow region is',18/
     4  ' the bandwidth for the matrix is',17x,15/
     5  ' the size of the generation region is',f7.2,2(' by',f7.2)/
     6  ' the size of the flow region is      ',f7.2,2(' by',f7.2)/
     7  ' the rotation angles phi and theta are',f4.0,' and ',f5.0//
     8  ' neleme = ',15,10x,'nnodes = ',15)
  110 format(' side ',i1,' is a constant flowrate boundary with value',
     1       ' = ',f10.4)
  120 format(' side ',i1,' is a no flow boundary')
  130 format(' side ',i1,' is a constant pressure boundary',
     1       ' with value = ',f10.4)
  140 format(' side ',i1,' is a constant pressure boundary' ,
     1       ' - the pressure varies linearly')
  150 format('0element number  fracture width(cm)  velocity(cm/sec)'
     1       '   flow rate(cc/sec)    reynolds number')
  160 format(1x,i8,1pe24.5,1p3e20.5)
  170 format('0node number   head(cm)     flow rate(cc/sec)  side')
  180 format(1x,17,1p2e17.5,6x,i1)
  181 format(1x,i6,2e13.5,2i6,3f10.4,i3)
  185 format(//' Imposed flux node(s)'/
     1       ' node number   head        flow rate          side')
  190 format(/)
  210 format(/' The center hole has an imposed flux of  ',f10.4)
  220 format(/' The center hole has an imposed head of  ',f10.4)
  230 format(/' The outer circle has an imposed flux of ',f10.4)
  240 format(/' The outer circle has an imposed head of ',f10.4)
      end
```

```
      subroutine rhead(ibwth)
      implicit real*8 (a-h,o-z)
c
c             version 3.0 (jan 1986)
c
c       this subroutine reads in the header of the data file
c
      common/trans/ trans(1)
      common/bcode/ ibcode(6),bvalu(6)
      common/coord/ coord(3,1)
      common/dist/  dist(1)
      common/flux/  flx(1)
      common/ib/    ib(1)
      byte ib
      common/inode/ inode(2,1)
      common/mesh/  xmesh,ymesh,zmesh,xgene,ygene,zgene,
     1              rotan,rotan2,nfrac
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/side/  side(1)
      byte side
      common/title/title(2)
      character*80 title
      common/titles/iray,idate,jobnam,date
      character*7 iray,jobnam
      character*9 idate,date
      common/vispg/ visc,spgr
      data i8open/0/
c
c               read input data
c
      read(1,200,end=190) jobnam,date,iprnt,title,nfrac,
     1         xgene,ygene,zgene,xmesh,ymesh,zmesh,rotan,
     2         rotan2,ibcode,bvalu,visc,spgr,neleme,nnodes,
     3         maxd,ibwth
      if (neleme .gt. maxele) then
        write(6,*) maxele
        call werror('neleme .gt. mxelem')
       endif
      if (nnodes .gt. maxnod) then
        write(6,*)  maxnod
        call werror('nnodes .gt. mxnode')
       endif
      if (ygene.eq.0)then
        nside=2
       elseif(zgene.eq.0.)then
        nside=4
       else
        nside=6
       endif
c
      return
  190 stop
c
  200 format(a19,3x,a9,i1/2(a/)10x,i5/2(3(10x,f10.4)/),2(10x,f10.4)/
     1  10x,6i10/10x,6f10.0/2(10x,f10.0)/3(10x,i6,4x)/50x,i5)
      end
```

```
      subroutine rmesh(phi,noddim,ibwth,inew,na)
      implicit real*8 (a-h,o-z)
c
c           version 3.0 (jan 1986)
c
c       this subroutine reads in the input data
c
      common/trans/ trans(1)
      common/bcode/ ibcode(6),bvalu(6)
      common/coord/ coord(3,1)
      common/dist/  dist(1)
      common/flux/  flx(1)
      common/ib/    ib(1)
      byte ib
      common/inode/ inode(2,1)
      common/ifrac/ ifrac(2,1)
      common/mesh/  xmesh,ymesh,zmesh,xgene,ygene,zgene,
     1              rotan,rotan2,nfrac
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/side/  side(1)
      byte side
      common/title/title(2)
      character*80 title
      common/titles/iray,idate,jobnam,date
      character*7 iray,jobnam
      character*9 idate,date
      common/vispg/ visc,spgr
      dimension phi(noddim,2),inew(noddim)
      data i8open/0/
c
c  set up indices for in & out of matrix
      iim = 0
      iom = nnodes
      if (nnodes.ge.1) then
c
        do i = 1, nnodes
          read(1,210) ib(i),side(i),(coord(j,i),j=1,3),
     1           (phi(i,irot),irot=1,maxd)
         enddo
c
c check to see that a 90 deg rotation is appropriate
c if all boundaries are not constant head, the a matrix will
c be different, also set inew to record whether or not this
c node will be recorded in the matrix.
c
        do i = 1, nnodes
          if (ib(i).le.0) then
            iim = iim + 1
            inew(i) = iim
            flx(i) = phi(i,1)
            if (ib(i).lt.0)impflx=1
            if (side(i).ne.0) maxd = 1
           else
            inew(i) = iom
            iom = iom - 1
           endif
          enddo
        endif
       na=iim
c
      if (neleme .lt. 1) then
        write(6,*)  neleme
       else
```

```
c ***********************************************
c  jep 1jul88 - change boundary cond. to print out fracture intersection heads
c
        do n = 1,neleme
          read(1,220) inode(1,n),inode(2,n),trans(n),dist(n),if1,if2
          if(if1.ne.if2.and.iprnt.eq.1) then
            do ii = 1,2
              in0 = inode(ii,n)
              if(ib(in0).le.0) then
                ib(in0) = -1
                if(ii.eq.1) ifrac(ii,in0) = if1
                if(ii.eq.2) ifrac(ii,in00) = if2
                impflx = 1
              end if
              in00 = in0
            end do
            write(30,*) ifrac(1,in00),ifrac(2,in00)
          end if
         end do
        endif
c
c        write output information on tape8 if iprnt=2
c
       if (iprnt.lt.2) return
       if (i8open.eq.0) open (unit=8,file='linelall.out',
      1  status='unknown',carriagecontrol='list')
       i8open=1
       write(8,230) iray,idate,jobnam,date,title,nfrac,
      1         xgene,ygene,zgene,xmesh,ymesh,zmesh,rotan,
      2         rotan2,ibcode,bvalu,visc,spgr,nnodes
c
       write(8,240) (m,ib(m),side(m),(coord(i,m),i=1,3),
      1              phi(m,1),flx(m),m=1,nnodes)
       write(8,250) neleme
c
       write(8,260) (n,inode(1,n),inode(2,n),trans(n),dist(n),n=1,neleme)
c
       return
c
  210 format(5x,2i5,5x,6f10.4)
  220 format(5x,2i5,5x,2e10.4,5x,2i5)
  230 format('1 --- ',a7,' --- ',a9//' input data'//
     1  ' jobname and date of finite element mesh creation ---',a7,
     2  ', ',a9/1x,a80/1x,a80//
     3  ' nfrac =',i5/
     4  ' xgene,ygene,zgene =',3f11.4/
     5  ' xmesh,ymesh,zmesh =',3f11.4/
     6  ' rotan ='2f10.4/
     7  '0bcodes =',6i2//
     8  ' bvalues =',6f11.4//
     9  ' visc =',f11.4/' spgr =',f11.4///
     1  1x,80('-')///
     1  ' node information'///' nnodes =',i5///
     2  '0',6x,'i     code    side',8x,'x',13x,'y',13x,'z',
     3  12x,'phi',10x,'flux'/)
  240 format(1x,3i8,5f14.4)
  250 format(1x,80('-')///' element information'///' numel = ',i9///
     1  7x,'i    node1   node2   transmissivity',7x,'length'/)
  260 format(1x,3i9,2g18.6)
      end
```

```
      subroutine rstud
      implicit real*8 (a-h,o-z)
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/stud/  istud,xstud(20),ystud(20)
      character*14 file
      character*1  sgrad(2)
      data sgrad/'g','l'/
c
c the following lines read data for study regions
c
      open(unit=20,readonly,file='study.dat',status='old',
     1  err=270)
      read(20,280)istud,igrad
      igrad=3-igrad
c$dir scalar
      do k = 1,istud
        read(20,290) xstud(k),ystud(k)
c$dir scalar
        do ngrad=1,2
          if(igrad.ne.ngrad)then
            kk=k+10+ngrad*20
            write(file,300) sgrad(ngrad),k
            open (unit=kk,file=file,status='unknown',
     1            carriagecontrol='list')
          endif
        enddo
      enddo
  270 return
  280 format(2i2)
  290 format(2f6.2)
  300 format('ellipse',a1,i2.2,'.inp')
      end
```

```
      subroutine sflux(phi,b,irot,inew)
      implicit real*8 (a-h,o-z)
c
c            version 3.0 (jan 1986)
c
      common/bcode/ ibcode(6),bvalu(6)
      common/coord/ coord(3,1)
      common/flux/  flx(1)
      common/mesh/  xmesh,ymesh,zmesh,xgene,ygene,zgene,
     1              rotan,rotan2,nfrac
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/side/  side(1)
      byte side
      common/stud/  istud,xstud(20),ystud(20)
      common/title/title(2)
      character*80 title
      common/titles/iray,idate,jobnam,date
      character*7 iray,jobnam
      character*9 idate,date
      dimension phi(*),b(*),inew(*)
      dimension sum(6),dl(6)
      character*4 glbloc(2)
      data glbloc/'glob',' loc'/
      data iread/0/
c
      if(iread.eq.0) then
        iread=1
        write(11,310) iray,idate,jobnam,date,title
        write(11,320)xmesh,ymesh
        if (istud.ne.0) then
c$dir scalar
          do ngrad=1,2
            if(ngrad.ne.igrad)then
c$dir scalar
              do n=1,istud
                k=n+10+ngrad*20
                write(k,310) iray,idate,jobnam,date,title
                write(k,340) glbloc(ngrad),xstud(n),ystud(n)
                write(k,330) xmesh,ymesh
              enddo
            endif
          enddo
        endif
       endif
c$dir scalar
      do i=1,nside
        sum(i) = 0.d0
        dl(i) = 0.d0
       enddo
c
      if (nside.eq.2)then
        do m=1,nnodes
          if (side(m).eq.1.or.side(m).eq.7)then
            sum(1) = sum(1) + flx(m)
           elseif (side(m).eq.3)then
            sum(2) = sum(2) + flx(m)
           endif
         enddo
        write(6,420)sum(1),sum(2)
        return
       else
        do m=1,nnodes
          j=side(m)
          if (j.ne.0) then
            sum(j) = sum(j) + flx(m)
            dl(j) = dl(j) + 1.d0
           endif
         enddo
       endif
c
      write(6,'(1x)')
      if (iprnt.eq.2) write(8,'(1x)')
      rot=rotan-180.d0
      jrot=irot*(6-nside)/2
c$dir scalar
      do i=1,nside
        j=mod(i-jrot+nside,nside)+1
        rot=rot+90.d0
        flux=abs(sum(j))
        if (flux.ne.0.0d0) then
          vsqrtp = sqrt(1.d0/flux)
          write(6,350) i,sum(j),vsqrtp
          if(iprnt.eq.2)write(8,350) i,sum(j),vsqrtp
         else
          vsqrtp=1.d20
          write(6,360) i,sum(j)
          if(iprnt.eq.2)write(8,360) i,sum(j)
         endif
c
c*** write tape 11 for plotting ellipses
c
        if (mod(i,2).eq.0) write(11,370)rot,flux,vsqrtp
       enddo
ccc calculate the number of fractures/unit length or area
c   intersecting each side
c
      fpul=0.d0
      do i=1,nside
        fpul=fpul+dl(i)
       enddo
      if(nside.eq.4)then
        fpul = (dl(1)+dl(2)+dl(3)+dl(4))/(2*(xmesh+ymesh))
        dl(1) = dl(1)/xmesh
        dl(2) = dl(2)/ymesh
        dl(3) = dl(3)/xmesh
        dl(4) = dl(4)/ymesh
        write(6,380)
        if (irot.gt.1) then
          dlsave=dl(1)
c$dir scalar
          do i=1,3
            dl(i)=dl(i+1)
           enddo
          dl(4)=dlsave
         endif
       else
        fpul = (dl(1)+dl(2)+dl(3)+dl(4)+dl(5)+dl(6))/
     1         (2*(xmesh*ymesh+xmesh*zmesh+ymesh*zmesh))
        dl(1) = dl(1)/(ymesh*zmesh)
        dl(2) = dl(2)/(xmesh*zmesh)
        dl(3) = dl(3)/(ymesh*zmesh)
        dl(4) = dl(4)/(xmesh*ymesh)
        dl(5) = dl(5)/(xmesh*zmesh)
        dl(6) = dl(6)/(xmesh*zmesh)
        write(6,390)
       endif
      write(6,400) (iside,dl(iside),iside=1,nside)
```

```
      write(6,410) fpul
c
      return
c
  310 format(a7,' --- ',a9/a7,' --- ',a9/a80/a80)
  320 format(' flow region',22x,' xmesh=',f7.2,' ymesh=',f7.2/)
  330 format(' flow region',22x,' xmesh=',f7.2,' ymesh=',f7.2)
  340 format(' study region,',a4,'al gradient',6x,'xstud=',f7.2,
     1' ystud=',f7.2)
  350 format(' side',i1,' --- the sum of the fluxes =',1pe14.6,
     1       ' --- sqrt(1/sum) =',1pe14.6)
  360 format(' side',i1,' --- the sum of the fluxes =',1pe14.6,
     1       ' --- sqrt(1/sum) = infinity')
  370 format(3g15.5)
  380 format(/' number of fractures per unit length'/
     1  '   side       fractures')
  390 format(/' number of fractures per unit area  '/
     1  '   side       fractures')
  400 format(i7,f16.4)
  410 format('   global',f14.4/)
  420 format(' inner hole ----- the sum of the fluxes =',1pe14.6/
     1       ' outside circle - the sum of the fluxes =',1pe14.6)
      end
```

```
      subroutine sortij
      implicit real*8 (a-h,o-z)
c
c            version 3.0 (jan 1986)
c     insure that i .lt. j and that i is in increasing order
c
      common/trans/ trans(1)
      common/dist/  dist(1)
      common/inode/ inode(2,1)
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
c
      do i = 1, neleme
c
        nl = inode(1,i)
        if (nl .gt. inode(2,i)) then
          inode(1,i) = inode(2,i)
          inode(2,i) = nl
        endif
      enddo
c
      nmax=neleme
      nmin2=2
      do while (nmax.ge.nmin2)
        nmax2=nmax
        nfirst=1
        nmin=0
        nmax=0
        do n=nmin2,nmax2
          it=inode(1,n-1)
          if (it.gt.inode(1,n)) then
            inode(1,n-1)=inode(1,n)
            inode(1,n)=it
            it=inode(2,n-1)
            inode(2,n-1)=inode(2,n)
            inode(2,n)=it
            rt=trans(n-1)
            trans(n-1)=trans(n)
            trans(n)=rt
            rt=dist(n-1)
            dist(n-1)=dist(n)
            dist(n)=rt
            nmax=n-1
            nmin=nmin+nfirst*nmax
            nfirst=0
          endif
        enddo
        nmin2=max0(nmin,2)
      enddo
      return
      end
```

```
      subroutine study(phi)
      implicit real*8 (a-h,o-z)
c
c            version 3.0 (jan 1986)
c   handle study regions
c
      common/trans/ trans(1)
      common/coord/ coord(3,1)
      common/inode/ inode(2,1)
      common/mesh/  xmesh,ymesh,zmesh,xgene,ygene,zgene,
     1              rotan,rotan2,nfrac
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      common/pi/    pi180
      common/stud/  istud,xstud(20),ystud(20)
      common/vispg/ visc,spgr
      dimension phi(1)
      dimension nfrc(4,20),flux(4,20),fluxl(4)
      double precision sumphi(4,20),sumphi2(4,20),avphi(4),ddphi
c
      dimension t(4),is(4),s(4)
c
      r=rotan*pi180
      cosr2=2*cos(r)
      sinr2=2*sin(r)
c
c  the following 2-d arrays are initialized as 1-d for vectorization
      do i = 1, 4*istud
        nfrc(i,1)=0.d0
        flux(i,1)=0.d0
        sumphi(i,1)=0.d0
        sumphi2(i,1)=0.d0
       enddo
c
      do i=1,neleme
        n1=inode(1,i)
        n2=inode(2,i)
        x1=coord(1,n1)
        y1=coord(2,n1)
        dx=coord(1,n2)-x1
        dy=coord(2,n2)-y1
c
c   calculate array t of intersection values
c
        nt=0
        flen2=dx*dx+dy*dy
        denomx=  sinr2*dx-cosr2*dy
        denomy=-(sinr2*dy+cosr2*dx)
        prtx=cosr2*y1-sinr2*x1
        prty=cosr2*x1+sinr2*y1
        do 420 k=1,istud
          if (denomx.ne.0.) then
            is(1)=1
            is(2)=3
            t(1)=(prtx+xstud(k))/denomx
            t(2)=(prtx-xstud(k))/denomx
            nt=2
           else
             if (abs(prty).ge.ystud(k)) go to 420
           endif
          if (denomy.ne.0.) then
            is(nt+1)=2
            is(nt+2)=4
            t(nt+1)=(prty+ystud(k))/denomy
            t(nt+2)=(prty-ystud(k))/denomy
            nt=nt+2
           else
            if (abs(prtx).ge.xstud(k)) go to 420
           endif
c
c   sort array t of intersection values
c
          j1=2
          i2=nt
          do while (i2.ge.j1)
            j2=i2
            i0=1
            i1=0
            i2=0
            do j=j1,j2
              if (t(j-1).gt.t(j)) then
                tt=t(j-1)
                t(j-1)=t(j)
                t(j)=tt
                it=is(j-1)
                is(j-1)=is(j)
                is(j)=it
                i2=j-1
                i1=i1+i0*i2
                i0=0
               endif
             enddo
            j1=max0(i1,2)
           enddo
          i1=nt/2
          if (mod(is(1)+is(2)+i1,2).eq.0) go to 420
          if (t(i1).ge.1.d0.or.t(i1+1).le.0.d0) go to 420
c
c     element is partially inside study region
c
          nt=0
          if (t(i1).ge.0.d0) then
            is(1)=is(i1)
            t(1)=t(i1)
            s(1)=1.d0
            nt=1
           endif
          if (t(i1+1).le.1.) then
            nt=nt+1
            is(nt)=is(i1+1)
            t(nt)=t(i1+1)
            s(nt)=-1.d0
           endif
          if (nt.gt.0) then
            phi1=phi(n1)
            dphi=phi1-phi(n2)
            fluxe=trans(i)*(dphi)/sqrt(flen2)
c$dir scalar
            do i1=1,nt
              iside=is(i1)
              nfrc(iside,k)=nfrc(iside,k)+1
              flux(iside,k)=flux(iside,k)+s(i1)*fluxe
              ddphi=phi1-t(i1)*dphi
              sumphi(iside,k)=sumphi(iside,k)+ddphi
              sumphi2(iside,k)=sumphi2(iside,k)+ddphi*ddphi
             enddo
           endif
c
```

```
c *** store information about fractures part or all of which fall into
c *** the flow region.
c
  420     continue
c
       enddo
c
c$dir scalar
      do k=1,istud
        write(6,430) k,xstud(k),ystud(k),rotan
        nfrct=0
c$dir scalar
        do iside=1,4
          n=nfrc(iside,k)
          nfrct=nfrct+n
          if (n.ne.0) then
            avphi(iside)=sumphi(iside,k)/n
            sdphi=sqrt(sumphi2(iside,k)/n-avphi(iside)**2)
            write(6,440) iside,avphi(iside),sdphi
           else
            write(6,450) iside
           endif
         enddo
c$dir scalar
        do iside=1,3,2
          t(iside  )=nfrc(iside  ,k)/xstud(k)
          t(iside+1)=nfrc(iside+1,k)/ystud(k)
          if (nfrc(2,k).ne.0.and.nfrc(4,k).ne.0)
     1      fluxl(iside+1)=flux(iside+1,k)*ymesh/
     2          (xmesh*(avphi(2)-avphi(4)))
          flux(iside  ,k)=flux(iside  ,k)*xmesh/xstud(k)
          flux(iside+1,k)=flux(iside+1,k)*ymesh/ystud(k)
         enddo
        fpul=nfrct/(2*(xstud(k)+ystud(k)))
        write(6,'(1x)')
c$dir scalar
        do iside=1,4
          aflux=abs(flux(iside,k))
          if (aflux.gt.1.d-20) then
            s(iside)=sqrt(1.d0/aflux)
            write(6,460) iside,flux(iside,k),s(iside)
           else
            s(iside)=1.d10
            write(6,470) iside,flux(iside,k)
           endif
          flux(iside,k)=aflux
         enddo
        write(6,480) (iside,t(iside),iside=1,4),fpul
        if (igrad.ne.1) then
          kk=k+30
          write(kk,490) rotan       ,flux(2,k),s(2)
          write(kk,490) rotan+180.d0,flux(4,k),s(4)
         endif
        if (igrad.ne.2) then
          write(6,500)
          if (nfrc(2,k).ne.0.and.nfrc(4,k).ne.0)then
c$dir scalar
            do iside=2,4,2
              aflux=abs(fluxl(iside))
              if (aflux.gt.1.d-20) then
                s(iside)=sqrt(1.d0/aflux)
                write(6,460) iside,fluxl(iside),s(iside)
               else
                s(iside)=1.d10
                write(6,470) iside,fluxl(iside)
               endif
              fluxl(iside)=aflux
             enddo
           else
            write(6,510)
            fluxl(2)=flux(2,k)
            fluxl(4)=flux(4,k)
           endif
          kk=k+50
          write(kk,490) rotan       ,fluxl(2),s(2)
          write(kk,490) rotan+180.d0,fluxl(4),s(4)
         endif
       enddo
      return
c
  430 format(//' study region number',i3/
     1  ' the size of study region is',f7.2,' by',f7.2/
     2  ' the angle of rotation is',f20.2/)
  440 format(' side',i2,': average head is',1pe14.6,' , standard ',
     1       'deviation is',1pe14.6)
  450 format(' side',i2,' intersects no fracture')
  460 format(' side',i1,' --- the sum of the fluxes =',1pe14.6,
     1  ' --- sqrt(1/sum) =',1pe14.6)
  470 format(' side',i1,' --- the sum of the fluxes =',1pe14.6,
     1  ' --- sqrt(1/sum) = infinity')
  480 format(' number of fractures per unit length'/
     1  '   side       fractures'/
     2  4(6x,i1,f16.4/),
     3  '   global',f14.4/)
  490 format(3g15.5)
  500 format(/' normalized fluxes -- local gradient')
  510 format(' average head could not be calculated for side',
     1  ' 2 or side 4'/
     2  '   because no fracture intersected that side'/
     3  '   values writen for ellfmg are those for global',
     4  ' gradient')
      end
```

```
      subroutine symsol(ibwth,na,a,noddim,b)
      implicit real*8 (a-h,o-z)
c
c            version 3.0 (jan 1986)
c    matrix solver
c
      common/param/ maxele,maxnod,neleme,nnodes,iprnt,maxd,igrad,
     1              nside,impflx
      dimension b(noddim,2),a(ibwth,na)
c
c               reduce matrix
c
      do n=1,na
c
c if a(1,n) is 0, symsol will fail, force soln. by letting a=1e-20
c
        if (a(1,n).eq.0.d0) then
          a(1,n) = 1.d-20
          write(6,370) n, a(1,n)
         endif
        an = 1.0d0 / a(1,n)
        l1=n
        do l=2,ibwth
          cc=a(l,n)*an
          i = n + l - 1
          if (i.le.na) then
            j = l - 1
            do k=1,ibwth
              a(k-j,i) = a(k-j,i) - cc*a(k,n)
             enddo
           endif
          a(l,n) = cc
         enddo
       enddo

c
c               reduce vector
c
c$dir scalar
      do irot = 1,maxd
        do n=1,na
          an = 1.0d0 / a(1,n)
          do l=2,ibwth
            i = n + l - 1
c
c  removed test, although it will perform operations on b(i,*) with
c  i beyond the desired index, the a(*,*) involved should be zero
c  and there will be no net effect
c           if (i.gt.na) go to 360
            b(i,irot) = b(i,irot) - a(l,n)*b(n,irot)
           enddo
c 360     continue
          b(n,irot) = b(n,irot) * an
         enddo
c
c               back substitution
c
        do n = na-1, 1, -1
          do k=2,ibwth
            l = n + k - 1
c
c  removed test, although it will perform operations using b(l,*) with
c  l beyond the desired index, the a(*,*) involved should be zero
c  and there will be no net effect
c           if (na.ge.l) then
            b(n,irot) = b(n,irot) - a(k,n)*b(l,irot)
c           endif
           enddo
         enddo
       enddo
      return
  370 format(' n=',i5,5x,'a(n,1)= ',e10.5)
      end
```

```
      subroutine werror(line)
      character*(*) line
      open (unit=10,file='line1.err',status='unknown',
     1      carriagecontrol='list')
      write(10,520) line
      stop
  520 format( 'error ',a)
      end
```

Appendix G

ELLFMG - Program Organization and Arrays

Table G-1. ELLFMG - Description of Program Variables

angle	Angle between the gradient and the x axis for the directional permeability measurements
ellname	Character variable which contains character string "ELLFMG" - the name of the program. Character *7.
edate	Date on which the program is executed. Character *9.
e1ix e1iy e2jx e2jy	Coordinates of eigenvectors
file	Character variable that contains the name of the file to be opened for input: "ELLIPSE.INP", "ELLIPSE01.INP", etc. Character *14.
file1	Character variable that contains the name of the file to be opened for output: plotting information for the program "ELLP". Character *14.
idate	Date of fracture mesh generation by FMG. Character *9.
iray	Label for program output. Character *7.
istud	Maximum number of study regions.
jobname*7	The name of the job read from unit 11. Character *7.
jdate	Date the flow program LINEL was executed. Character *9.
kij	Directional permeability.
maxn	Maximum number of angles.
maxnr	Maximum number of runs.
n	Number of angles per run.
nr	Number of runs.
ngrad	Gradient type ngrad = 0 specified flow region gradient = 1 global gradient = 2 local gradient.
ne	Number of points for plotting the best fit ellipse.

nd	Total number of permeability measurements: number of angles times number of runs.
pkganre	$1/\sqrt{K}$ for one angle
r2	Radius for plotting in polar coordinates.
sum1 - sum7	Different terms in the equation for calculating K11, K12, K22 (see Theory and Design Report, Equations 5-18, 5-19 and 5-20).
theta1	Angle between first eigenvector and x axis.
theta2	Angle between second eigenvector and x axis.
nkganre	The element (i,nr) of the array [xkgan].
xk11 xk12 xk22	Components of the permeability tensor.
xk1	First principal permeability.
xk2	Second principal permeability.
xmse	Mean square error.
xgnmse	Normalized geometric mean square error.
xanmse	Normalized arithmetic mean square error.
xmeank	Mean permeability.

Table G-2. ELLFMG - Description of Program Arrays

an(maxn)	Angle in degrees of a directional permeability as output by LINEL
ella(180)	Angle in degrees for plotting best fit ellipses.
ello(180)	Values of the directional permeability for the best fit ellipse, for plotting.
ellp(180)	$1/\sqrt{r2}$ for each angle if r2>0; 10^{20} if r2≤0.
pkgan(50,25)	One over the square root of the directional permeability as output by LINEL.
pkijnn(50)	One over the square root of the direction permeability for the best fit ellipse.
pkav (50)	One over the square root of the average permeability when several runs are input for each angle.
title(4)*80	Title, input variable read from unit 11.
xkgan(50,25)	Directional permeability as calculated by LINEL.
x1(50,25)	x coordinate of a point in rectangular coordinate system.
x2(50)	x coordinate of a best fit point in rectangular coordinate system.
y1(50,25)	y coordinate of a data point in rectangular coordinate system.
y2(50)	y coordinate of a best fit point in rectangular coordinate system.

Appendix H

ELLFMG - Program Listing

```
      program ellfmg
c     an = evenly spaced angles from 0 degrees to 360 degrees
c     xkgan = k = prmeability as calculated by linel
c        pkgan = 1/(sqrt k )
c        xl and yl are all data points in rectangular coor.
c      x2 and y2 are best fit points in rectangular coor.
c        pkijnn = 1/(kij) or best fit
c     xkav = avg k
c        pkav = 1/(sqrt xkav)
c        n = no. of angles = i
c        nr = no. of runs = j
c
c
c           this program calculates,
c                1) permeability tensors
c                2) principal permeability
c                3) coordinates of eigenvectors
c                4) mean square error
c                5) normalized mean square error
c                6) angle of theta 1 (between e1 and x axis)
c                7) angle of theta 2 (between e2 and x axis)
c           and generates plotting input file.
c
      dimension an(50), xkgan(50,25),pkgan(50,25)
      character*80 line(20)
      dimension xkav (50),pkav(50)
      character*80 title(4)
      dimension x1(50,25),y1(50,25),x2(50),y2(50),pkijnn(50)
      dimension ellp(180),ella(180),ello(180)
      character idate*9,iray*7,jobname*7,jdate*9,ellname*7,edate*9
      character file*14,filel*14,sgrad(2)*1
      integer istud
      data sgrad/'g','l'/
c
      file='ellipse.inp'
      open(unit=6,file='ellfmg.out',status='new')
      istud=1
      do ngrad=0,2
        do nstud=1,istud
          if(ngrad.gt.0) then
            write(file,20)sgrad(ngrad),nstud
   20       format('ellipse',a1,i2.2,'.inp')
           endif
          open (unit=11,readonly,file=file,status='old',err=60)
          if(ngrad.gt.0) then
            filel=file
            filel(12:14)='plt'
           else
            filel='ellipse.plt'
           endif
          open (unit=7,file=filel,status='new')
c
          maxn=50
          maxnr=25
          ne = 180
          jlag=0
          iflag0=0
c
c         read program i.d.s and dates from fmg and linel
c         and title as input to fmg
c
          read(11,240) iray,idate,jobname,jdate,title
          jlag=0
          i2=1
c
c         read directional permeability data from linel
c
          read(11,260)angle,xkganre,pkganre
          xkmin = 1.0e20
          absmin= 1.0e-20
          maxnr1=maxnr+1
          do nr = 1,maxnr1
            do i = 1,maxn
              an(i)=angle
              xkgan(i,nr)=xkganre
              pkgan(i,nr)=pkganre
              if (xkgan(i,nr) .lt.xkmin) then
                xkmin = xkgan(i,nr)
                anmin = an(i)
               end if
              read(11,260,end=50)angle,xkganre,pkganre
              i2=i2+1
              if(angle.eq.an(1))goto 40
             enddo
            write(6,6001)maxn
 6001       format(' more than',i3,' angles given for one region ')
            stop
   40       n=i
           enddo
          write(6,6002)maxnr
 6002     format(' more than',i3,' runs given for one region ')
          stop
   50     if(nr.eq.1)n=i
          nd=n*nr
          if(xkmin.le.absmin)iflag0=1
c
c         check to see if input file contained the correct
c         number of data points
c
          if (i2.ne.nd) then
            write(6,270) nd,i2,file
            stop
           endif
           ellname='ellfmg '
           call date (edate)
           write(6,280) ellname,edate,iray,idate,jobname,jdate
           write(6,290) title
           write(6,300) file,i2,n,nr
c
           calculate avg kgan values for each angle
           initialize average
c
           do i = 1,n
             xkav(i) = 0
            enddo
           do i = 1,n
             do j = 1,nr
               xkav(i) = xkav(i) + xkgan(i,j)/nr
              enddo
             write(6,310) an(i),xkav(i)
            enddo
           call sum(an,xkgan,maxn,maxnr,n,nr,sum1,sum2,
     1              sum3,sum4,sum5,sum6,sum7,jlag,theta1)
c
c          compute k11,k12,k22 --- permeability tensor
c
           xk22=(sum1*sum5 - sum2*sum3) / (sum4*sum5 - sum2*sum2)
           xk11 = sum3/sum5-sum2*xk22/sum5
```

```
      xk12=sum6/sum7
c
c     compute lambda 1 and lambda 2 --- principal permeability
c
      z=sqrt((xk11+xk22)**2.-4.*((xk11*xk22)-(xk12)**2))/2
      xk1=((xk11+xk22)/2.)+z
      xk2=((xk11+xk22)/2.)-z
      if (xk2.lt.0) then
        write(6,6003)
 6003   format(2x,'REGRESSION FAILED')
        jlag=5
       end if
c
c     compute coordinates of eigenvectors
c
      elix=1./sqrt(1.+((xk1-xk11)/xk12)**2.)
      eliy=((xk1-xk11)/xk12)/sqrt(1.+((xk1-xk11)/xk12)**2.)
      e2jx=1./sqrt(1.+((xk2-xk11)/xk12)**2)
      e2jy=((xk2-xk11)/xk12)/sqrt(1.+((xk2-xk11)/xk12)**2.)
c
c      compute angles between e1 and e2 and x-axis
c
      theta1=atan2(eliy,elix)*180/3.14159
      theta2=atan2(e2jy,e2jx)*180/3.14159
c
c
cccc  If k2<0 let k2=kmin,redo regression to find k1
cccc  assuming the eigenvectors are not changed
c
c
      if (jlag.eq.5) then
c
c       these eqns from V-36 Long phd, insure const. eigenvectors
c
        yy1 = (xk1-xk11)/xk12
        yy2 = (xk2-xk11)/xk12
c
        xk2 = xkmin
c
ccc     call sum again, this time let an = an -theta1 to put
ccc     data into principal coord's
ccc     In this case, K2 is know = kmin
ccc          K12 is zero
ccc     Only need to calculate K1 with eqn.V-22 Long phd
c
        call sum(an,xkgan,maxn,maxnr,n,nr,sum1,sum2,
     1            sum3,sum4,sum5,sum6,sum7,jlag,theta1)
        xk1 = (sum3-xk2*sum2)/sum5
        xk11 = ((yy1*xk2)-yy2*xk1)/(yy1-yy2)
        xk12 = (xk1-xk11)/yy1
        xk22 = ((yy1*xk1)-xk12)/yy1
       end if
c
c     compute coordinates for plotting ellipses in polar
c     and rectangular systems
c     compute sum8 for mean square error
c     compute x1 and y1 for all values
c     compute x2 and y2 for best fit ellipse
c
      pi180=3.14159/180.
      sum8=0.0
      do i=1,n
        ani=an(i)*pi180
        sinan=sin(ani)
        cosan=cos(ani)
        r2 = xk11*cosan*cosan+2*xk12*sinan*cosan+
     1       xk22*sinan*sinan
        if(r2.gt.0.)then
          pkijnn(i) = 1.0/sqrt(r2)
         else
          pkijnn(i) = 1.0e20
         end if
        x2(i) = pkijnn(i)*cosan
        y2(i) = pkijnn(i)*sinan
        if (xkav(i) .eq. 0.0) then
          pkav(i)=1.0e20
         else
          pkav(i) = 1.0/sqrt(xkav(i))
         endif
        do j = 1,nr
          sum8=sum8+(xkgan(i,j)-r2)**2
          x1(i,j) = pkgan(i,j)*cosan
          y1(i,j) = pkgan(i,j)*sinan
         enddo
       enddo
c
c     compute mean square error and normalized mean square error
c
      xmse=sum8/nd
      if(iflag0.eq.0)then
        xgnmse=xmse/(abs(xk1)*abs(xk2))
       else
        xgnmse=0.
       endif
      xmeank=(abs(xk1)+abs(xk2))/2.
      xanmse=xmse/xmeank**2
      write(6,320) xk11,xk12,xk22,xk1,xk2,elix,eliy,
     1             e2jx,e2jy,xmse,xgnmse,xanmse,theta1,
     2             theta2
c
      write(6,330)
      do i=1,n
        write(6,350) an(i)
        do j = 1,nr
          write(6,360)pkgan(i,j),xkgan(i,j)
         enddo
       enddo
      write(6,340)
      do i = 1,n
        write(6,370)an(i),pkijnn(i),pkav(i)
       enddo
c
c     write data for ellipses in rectangular coordinates
c
      write(6,380)
      do i=1,n
        write(6,350)an(i)
        do j = 1,nr
          write(6,400)x1(i,j),y1(i,j)
         enddo
       enddo
      write(6,390)
      do i = 1,n
        write(6,370) an(i),x2(i),y2(i)
       enddo
c
```

```
      prepare data for plotting an ellipse ---

      do i=1,ne
        ella(i)=2.*i
        pi180=3.14159/180.
        ani=ella(i)*pi180
        sinan=sin(ani)
        cosan=cos(ani)
        r2=xk11*cosan*cosan+2*xk12*sinan*cosan+
     1     xk22*sinan*sinan
        ello(i)=r2
        if (r2.gt.0.)ellp(i)=1.0/sqrt(r2)
        if (r2.le.0.)ellp(i)=1.0e20
       enddo
      write(7,410) icontp, nr
      write(7,'(a80)') title
       if (jlag.eq.5) then
         write(7,210)
210     format('  Regression Failed')
        else
         write(7,220)
220     format('Successful Regression')
       end if
      write(7,410) nd
      write(7,200) jlag
200   format(' jlag= - -',i1)
      write(7,430) ((pkgan(i,j),j=1,nr),i=1,n)
      write(7,430) ((an(i),j=1,nr),i=1,n)
      write(7,410) ne

      write (7,430) (ellp(i),i=1,ne)
      write(7,430) (ella(i),i=1,ne)

      write(7,430) theta1,xgnmse




      write(7,430) ((xkgan(i,j),j=1,nr),i=1,n)
      write(7,430) (ello(i),i=1,ne)
      close(unit=7)
     enddo
60   istud=20
    enddo
    stop
240 format(2(a7,5x,a9/),(a80))
250 format(215)
260 format(3e15.5)
270 format('1 The number of data points should be',i4,'.'/
   1  ' There are',i5,' data points on ',a,' -- run terminated.')
280 format('1 --- ',a7,' --- ',a9//'  --- ',a7,' --- ',a9//
   1  '  --- ',a7,' --- ',a9/)
290 format('0',a/(1x,a))
300 format('0The number of data points in ',a,' is',i5,'.'/
   1  '1 Permeability was calculated in',i5,' directions.'/
   2  '0the number of runs is',i5///
   3  11x,'an (deg)',13x,'xkav(cm/sec)'//)
310 format(10x,f9.2,10x,e15.5)
320 format('1 permeability tensors'//10x,'k11=',e20.10/
   1  10x,'k12=',e20.10/10x,'k22=',e20.10///
   2  ' principal permeability'//10x,'k1 (lambda1)=',e20.10/
   3  10x,'k2 (lambda2)=',e20.10///' coordinates of eigenvectors'//
   4  14x,'e1ix=',e20.10/14x,'e1iy=',e20.10/14x,'e2jx=',e20.10/
   5  14x,'e2jy=',e20.10///' mean square error=',8x,e20.10//
   6  ' geom. normalized mean sqr error=  ',g20.10///
   7  ' arithm. normalized mean sqr error=',g20.10///
   8  ' angle of theta 1(between e1 and x-axis)=',f10.5//
   9  ' angle of theta 2(between e2 and x-axis)=',f10.5///)
c
c 321 format(//10x,'ab data fmg 0013 (64x64)'/10x,'units are cm. sec.'/
c    1 10x,'parameters constant'/10x,'two sets randomly located')
c
  330 format('1 parameters for plotting data points in polar',
     1  ' coordinates'//
     2  10x,'angle alpha',10x,'1/sqrt(kgan)',13x,'xkgan'//)
  340 format('1best fit values'//
     1  10x,'angle alpha',21x,'1/sqrt(kijnn)',14x,'1/sqrt(xkav)'//)
  350 format('0'/11x,f7.2)
  360 format(25x,e15.5,11x,e15.5)
  370 format(10x,f7.2,11x,e15.5,12x,e15.5)
  380 format('1 parameters for plotting data points in cartesian',
     1  ' coordinates'//10x,'angle alpha',13x,' x&y from kgan'//)
  390 format('1cartesian coordinates of best fit ellipse'//
     1  5x,'angle alpha',13x,'x&y from xijn'//)
  400 format(25x,2e15.5)
  410 format(1615)
  430 format(8e10.4)
      end
      subroutine sum(an,xkgan,maxn,maxnr,n,nr,sum1,sum2,sum3,sum4,sum5,
     1  sum6,sum7,jlag,theta1)
      dimension an(maxn),xkgan(maxn,maxnr)
      pi180=3.14159/180.0
      sum1=0.
      sum2=0.
      sum3=0.
      sum4=0.
      sum5=0.
      sum6=0.
      sum7=0.
      do 450 i=1,n
        ani=an(i)*pi180
ccc if k2<0, go to principal coord's
c
        if(jlag.eq.5)ani = (an(i)-theta1)*pi180
c
        sinan=sin(ani)
        cosan=cos(ani)
        sum2=sum2+(cosan*sinan)**2
        sum4=sum4+sinan**4
        sum5=sum5+cosan**4
        sum7=sum7+2*((sinan*cosan)**2)
        do 440 j = 1,nr
          sum1=sum1+xkgan(i,j)*sinan**2
          sum3=sum3+xkgan(i,j)*cosan**2
          sum6=sum6+xkgan(i,j)*cosan*sinan
  440     continue
  450   continue
      xnr=nr
      sum1=sum1/xnr
      sum3=sum3/xnr
      sum6=sum6/xnr
      return
      end
```

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720