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A COMPUTER PROGRAM FOR AUTOMATIC MESH GENERATION FOR THE 2-D FINITE ELEMENT PROGRAM WILAX

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A COMPUTER PROGRAM FOR AUTOMATIC MESH GENERATION FOR THE 2-D FINITE ELEMENT PROGRAM WILAX

by

N.A. Toews* and Y.S. Yu*

ABSTRACT

This report describes a system of three computer programs (MSHGEN, MSHPLT and WXCONV), developed at the Mining Research Centre (MRC), for 'automatic' input data generation for the two-dimensional finite element program WILAX (1). These programs have been successfully used at MRC for the stress analysis of mining oriented problems, such as the analysis of open-pit slopes or underground openings. Meshes that formerly took several weeks of tedious work to prepare and check can now often be finished in a day or two. With some minor modifications this system can be easily adapted to most two dimensional finite element programs.

KEY WORDS: Finite element, mesh generator, mesh plotter, WILAX.

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Direction des mines

Rapport de recherches R-272

PROGRAMME MACHINE POUR LA GÉNÉRATION AUTOMATIQUE DE TREILLIS DESTINÉS AU PROGRAMME WILAX À ÉLÉMENT FINI

par

N.A. Toews* et Y.S. Yu*

RÉSUMÉ

L'auteur décrit un système comportant trois programmes machines (MSHGEN, MSHPLT et WXCONV), mis au point au Centre de recherches minières (CRM) pour l'entrée automatique de données destinées à l'usage du programme WILAX (1) bi-dimensionnel à élément fini. Ces programmes ont été utilisés avec succès au CRM pour l'analyse des contraintes relatives à des problèmes miniers, comme l'analyse des pentes des exploitations à ciel ouvert ou des ouvertures souterraines. L'établissement de treillis qui demandait autrefois plusieurs semaines de travail ardu de préparation et de vérification peut maintenant se faire en un jour ou deux. Avec quelques modifications mineures, ce système peut être facilement adapté à la plupart des programmes bi-dimensionnels à élément fini.

MOTS CLÉS: Élément fini, générateur de treillis enrégistrement graphique de treillis, WILAX.

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CONTENTS

1. Introduction

The finite element (F.E.) method has become a very useful tool for analyzing engineering and geotechnical problems in the field of rock mechanics.

The structures modelled,by the finite element method, in rock mechanics tend to be large. Thus a very time-consuming data preparation problem is created. In particular the specification of nodal co-ordinates and the specification of elements is tedious and error prone. Therefore any computer program that automated all or part of the finite element input information would be very useful.

The finite element program that has been most extensively used at MRC for handling plane and axisymmetric structures is a program called WILAX (a modified version of Wilson's axisymmetric program) (1). This report describes a 2-D mesh generating program, "MSHGEN", developed at MRC in the fall of 71, to automate WILAX input preparation. This program closely follows the concepts and terminology introduced by Zienkiewicz and Phillips (2).

Two companion programs, MSHPLT and WXCONV are also described in this report. MSHPLT is a program for plotting the MSHGEN produced finite element mesh so that a visual inspection of the generated mesh can be carried out. WXCONV performs the final conversion of the MSHGEN output to the format demanded by WILAX as well asinputting material properties, boundary pressures, etc., to produce an input file for WILAX. This system can be easily adapted, with some minor modification to most finite element programs.

Two years experience with this WILAX data preparation system, at least for the type of problems commonly encountered at MRC, has been good. Meshes that formerly took several weeks of tedious work to prepare and check can now often be finished in a day or two.

2. MSHGEN

2.1 Fundamental Concepts and Terminology

This section will introduce the basic concepts involved in MSHGEN as well as the terminology needed to understand the discussion of the program.

Consider the continuous quadratic mapping defined by $X = \sum_{i=1}^{8} X_i N_i(\xi,\eta)$, $Y = \sum_{i=1}^{8} Y_i N_i(\xi,\eta)$. Here $N_1(\xi,\eta)$, $N_2(\xi,\eta)$ ....., $N_8(\xi,\eta)$ are eight interpolating functions defined in Appendix A. (For typing convenience the notation (EPS, ETA) will be used for (ξ,η) in much of this report.) This mapping (under certain restrictions) defines a one-to-one correspondence between points in a 2 by 2 square, called a key diagram zone (key zone), and points in a curvilinear quadrilateral with possibly parabolic sides, called a model diagram zone (model zone) (see Figure 1). This mapping is completely defined when the co-ordinates of the eight points (X1, Y1), (X2, Y2), ... (X8, Y8), as shown on the model zone in Figure 1, are given. These points are called the specified points. Points 1 to 4 are the corner specified points and points 5 to 8 are the intermediate specified points.

If the EPS span of the key zone is subdivided, for example into 4 subintervals and the ETA span is divided into 3 subintervals then the key diagram zone is subdivided into rectangles as shown in Figure 2a. The 20 points defined by this subdivision (Figure 2a) are mapped onto the 20 points (nodal points) on the model zone (Figure 2b). If these points are connected by straight lines (Figure 2c) then a finite element (F.E.) discretization of the model zone is produced. By increasing the number of subdivisions it is possible to approximate the parabolic sides of the model zone as closely as desired. (Figure 2d).

Different mesh grading can be achieved by proper choice of the intermediate specified points. Figure 3a shows the F.E. discretization of a straight sided quadrilateral when mid-point intermediate points are used. Figure 3b shows an example of the mesh grading that can be achieved with a different choice of intermediate specified points but with the same number of subdivisions.

Define α to be the fraction of the side length at which the inter-

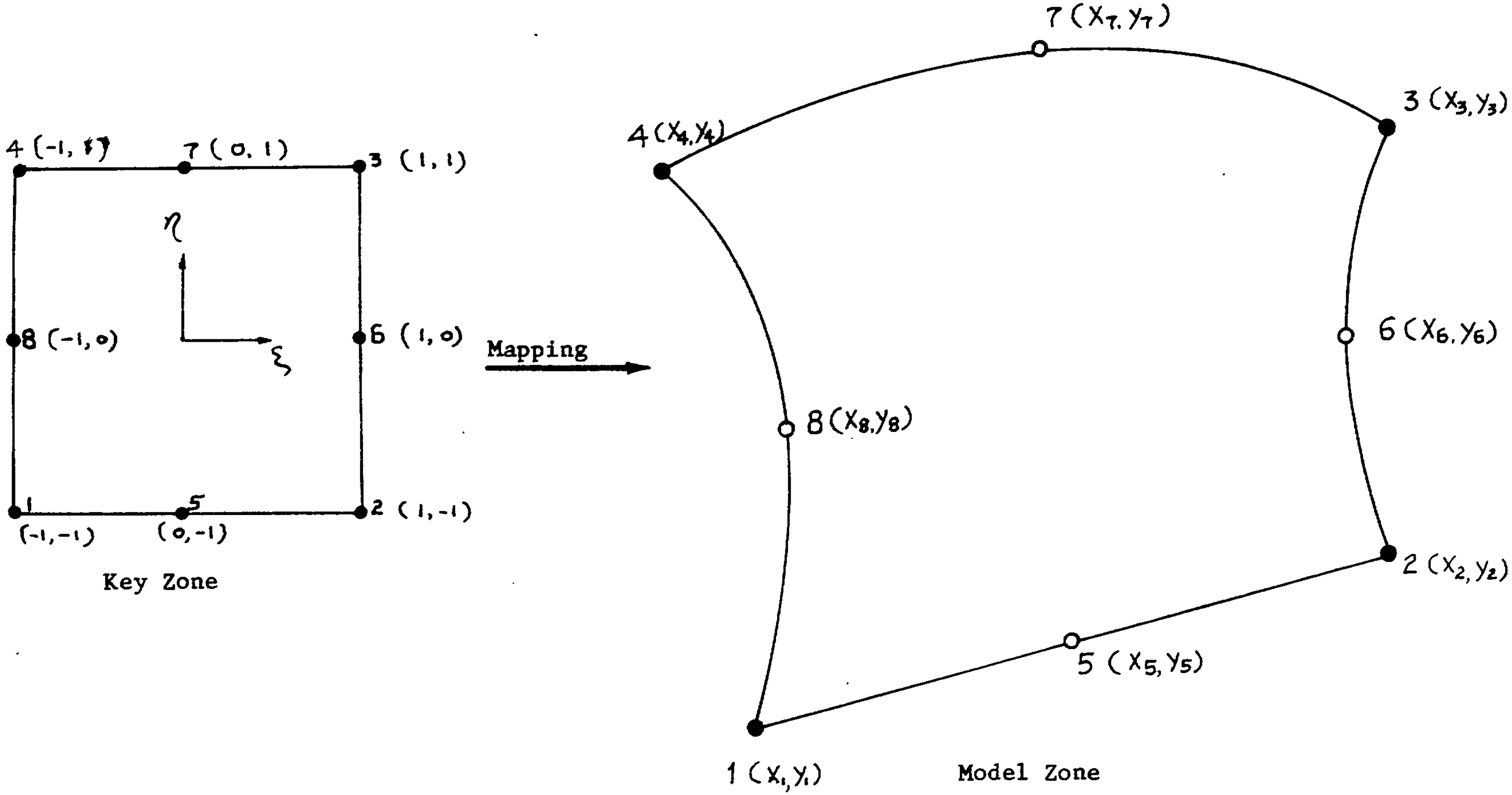


Figure 1: Fundamental Mapping of Key Zone onto Model Zone.

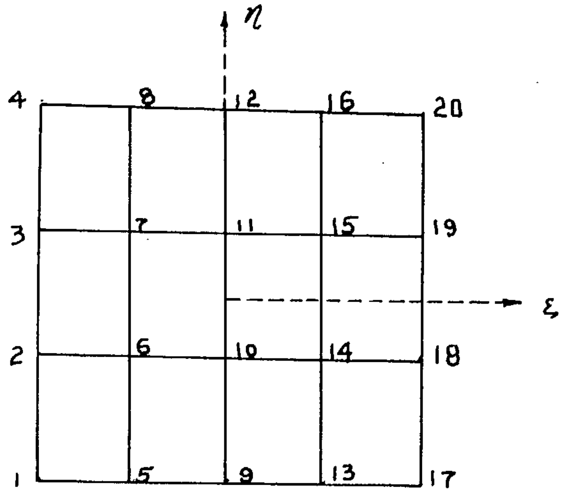


Figure 2a: Subdivision of Key Zone

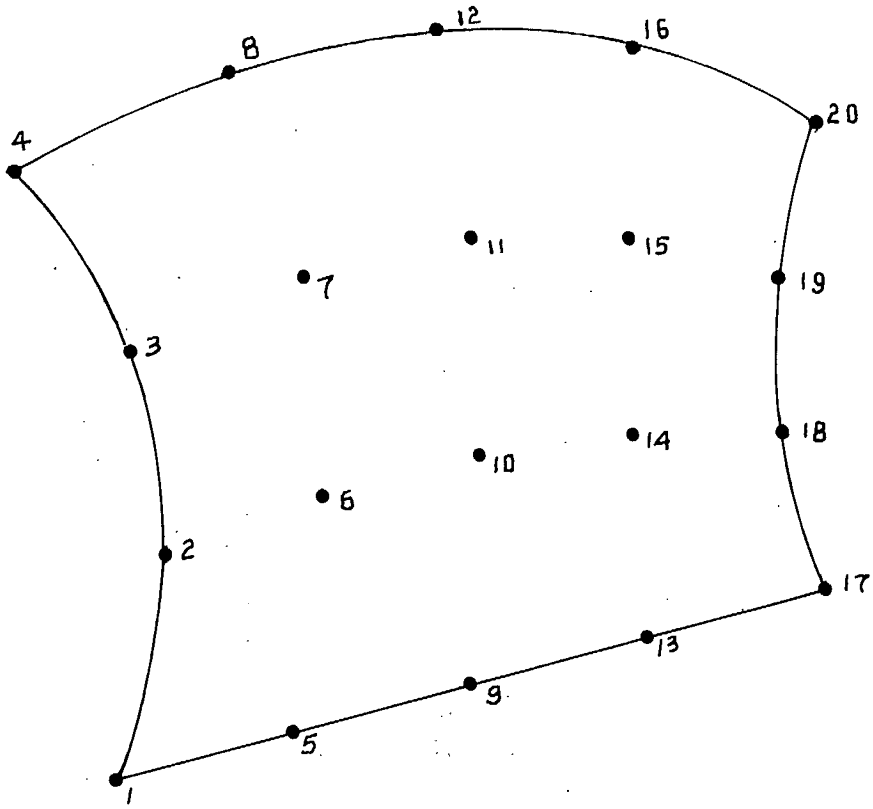


Figure 2b: Nodal Points in Model Zone.

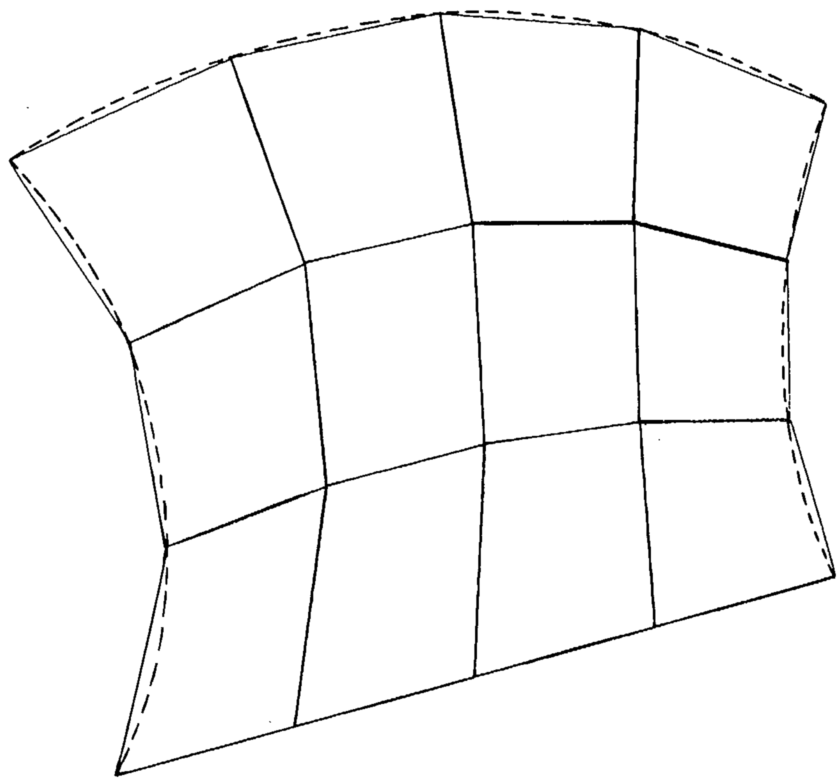


Figure 2c: Discretization of Model Zone.

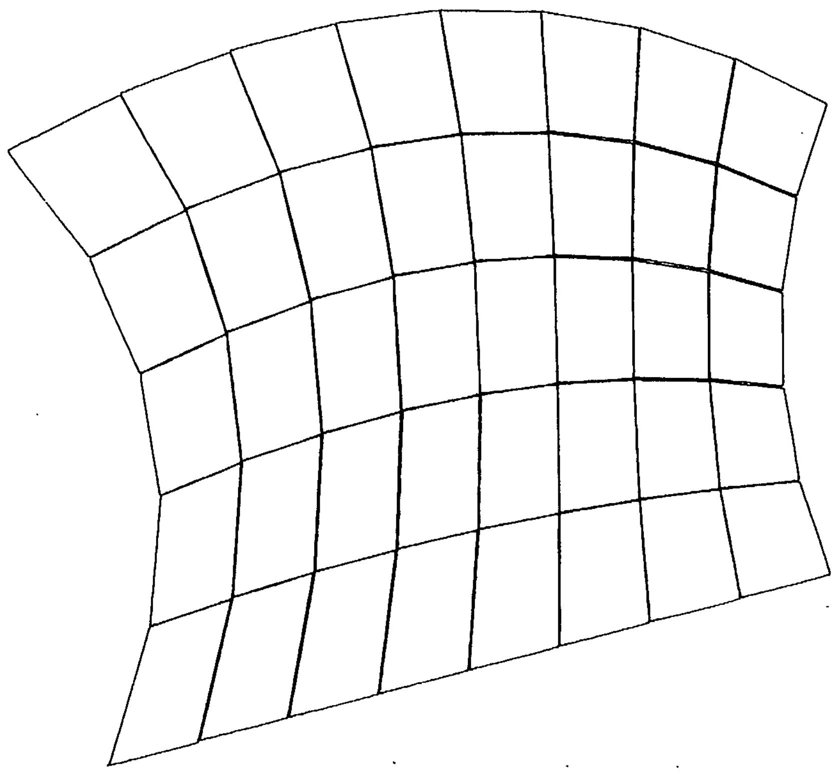


Figure 2d: Refined F.E. Discretization of Model Zone.

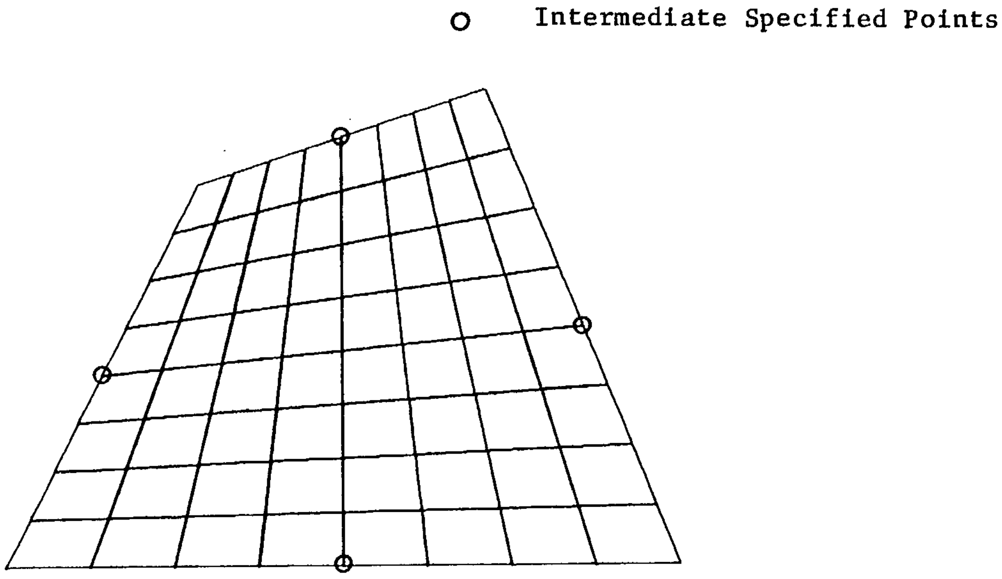


Figure 3a: Mesh Grading with Mid-point Intermediate points.

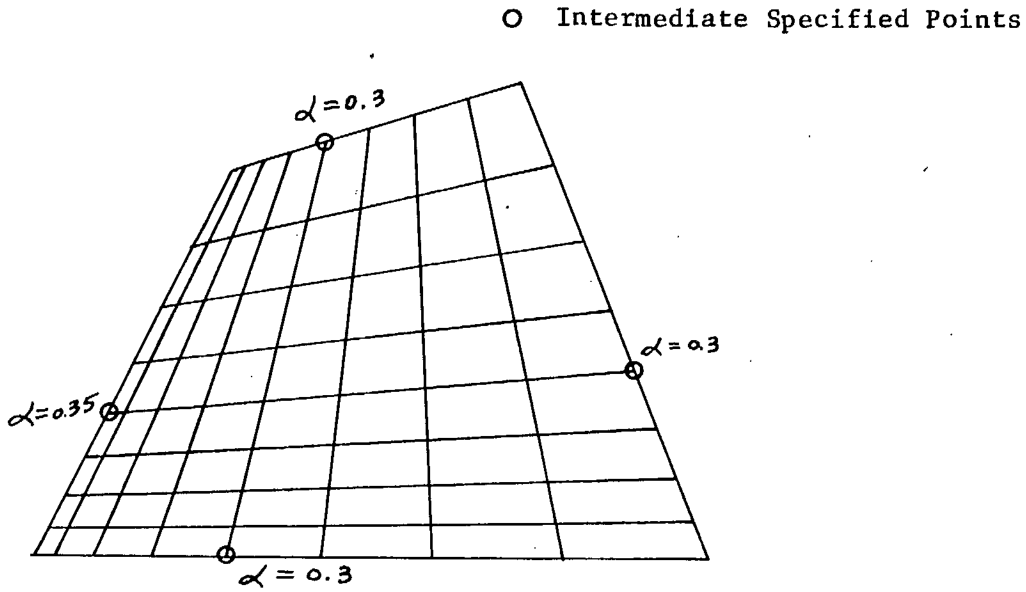


Figure 3b: Mesh Grading with Non Mid-point intermediate points.

mediate point is selected. Thus Figure 3a has $\alpha=\frac{1}{2}$ on all 4 sides whereas Figure 3b has α's as shown. It can be shown that the following restriction, $1/4 < \alpha < 3/4$, is necessary if the given mapping is to remain a one-to-one correspondence. Figure 4 shows for a one dimensional case, the grading that is achieved when α is varied from .5 to .25 in steps of .05. Note that α=.25 still gives a valid discretization and for sufficiently coarse subdivisions even larger values of α could do so. The explanation is, that while the mapping may be nonunique (i.e. certain points of key zone map outside the model zone), as long as none of the 'nodal points' selected on the key zone belong to these then an acceptable discretization could still result.

A further restriction on the model zone is that no interior angle of a model zone can be greater than 180 degrees. Thus a model zone as shown in Figure 5a is illegal. Triangular zones (zones with interior angles equal 180 degrees) are however possible. Figure 5b gives an example of a F.E. discretization of such a zone.

Most models for which we want an F.E. discretization are considerably more complex than a curvilinear quadrilateral. The assumption is made in MSHGEN that the given model can be subdivided into a number (hopefully few) of interconnected model zones and that a corresponding key diagram, made up of key zones, can be set up. The procedure for doing this will be fully described in the next section.

2.2 MSHGEN Preliminary Input Preparation Procedure

It is recommended that the following set of procedures be followed prior to preparing MSHGEN input data. Throughout this section it will be assumed that the no IDENTIFICATION option of MSHGEN (this is a feature that will be discussed later) is in effect. To illustrate the recommended procedure a simple example (Figure 6a) will be used. More realistic models, with less detail are shown in Figures 8 to 10.

Step 1. SKETCH OF STRUCTURE

First a sketch of the structure to be analyzed should be drawn to some appropriate scale. (Figure 6a).

Step 2. SUBDIVISION OF MODEL INTO MODEL ZONES

This is the most critical step in the procedure if an adequate well-graded F.E. discretization is to be achieved. Experience with the program

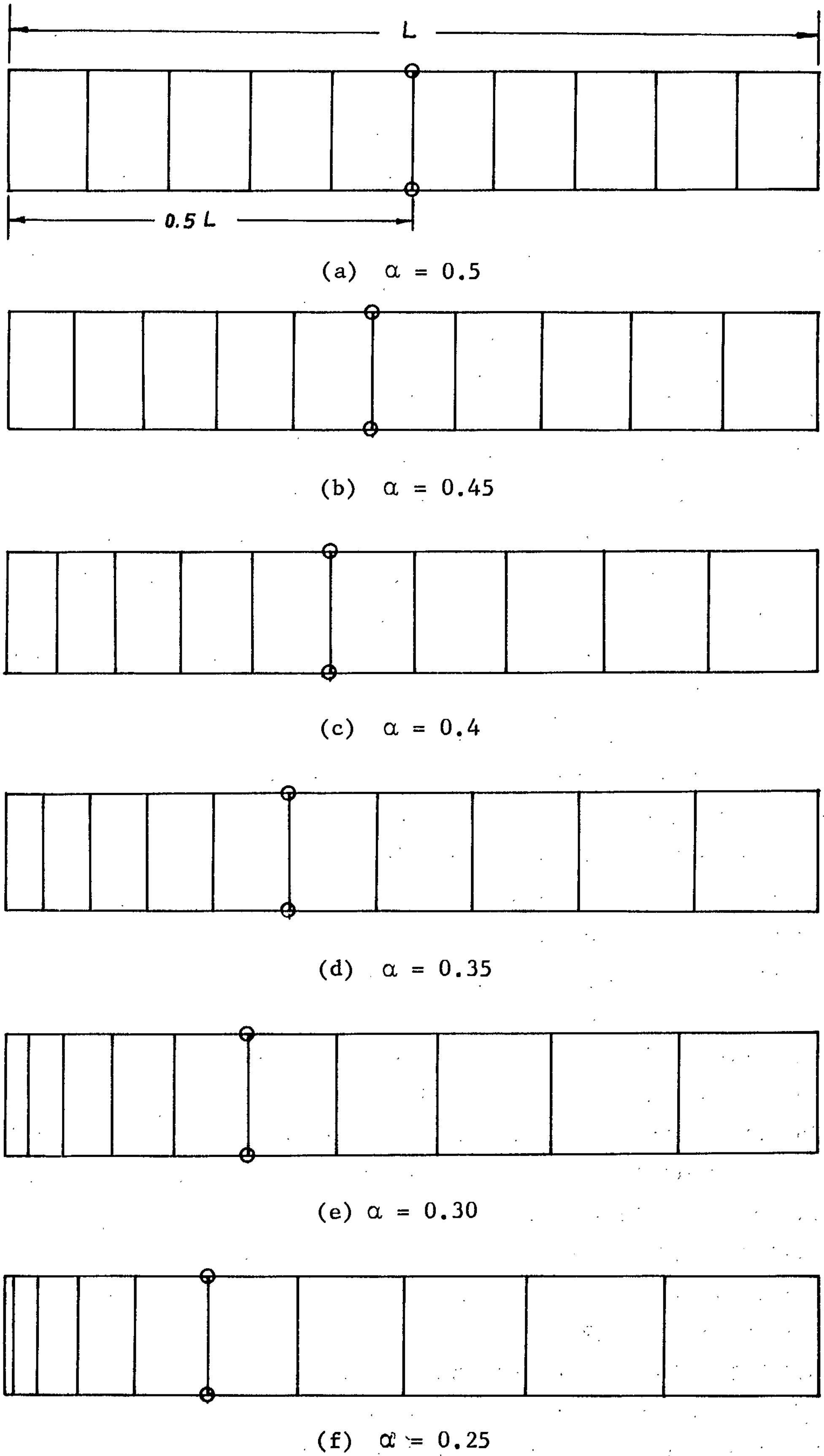


Figure 4: Grading achieved by different intermediate points.

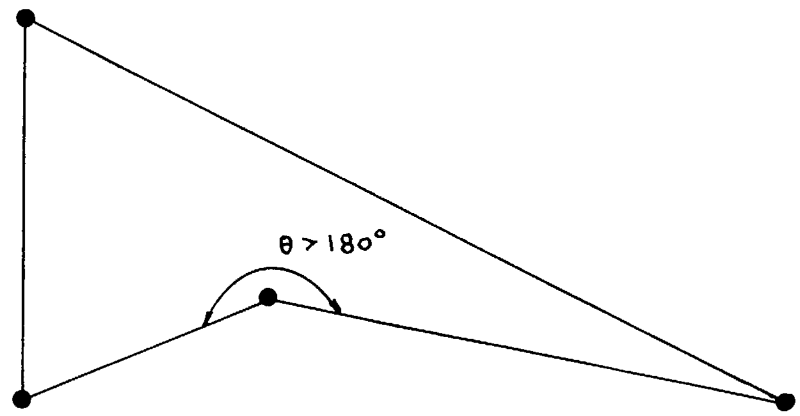


Figure 5a: Model zone with interior angle greater than 180^{o} is illegal.

● Corner specified points.

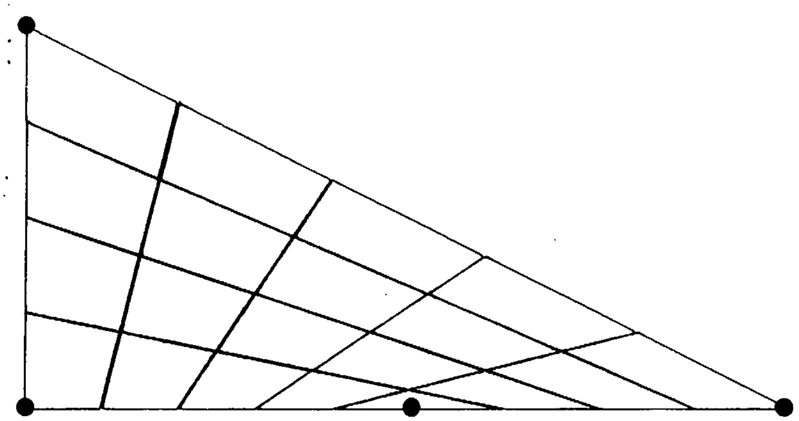


Figure 5b: Triangular model zone is legal.

and some ingenuity can pay large dividends here. The object is to minimize the number of zones subject to the following constraints.

A. Zones must be sufficiently small that an adequate representation of model curvilinear boundaries can be achieved.

B. Zones must be selected to achieve the mesh grading appropriate for the model without generating an overlarge number of nodal points and elements.

C. A given zone must be homogeneous with respect to material properties, although distinct zones can have identical properties.

D. If the 'cut' option is used then a given zone must be homogeneous as far as 'cut number' is concerned. (The MRC version of WILAX allows a progressive excavation sequence to be modelled without reinputting all the data for each excavation or 'subproblem' in WILAX terminology. The number of the subproblem in which a given element is eliminated is called the cut number of that element).

E. Any zone corner node interior to the model must be the corner node of exactly 4 zones.

F. Interior angles of zones must not be greater than 180 degrees. However as indicated in the last section triangular zones are possible.

G. To minimize the amount of hand modification to be performed later keep in mind the procedure used by MSHGEN in assigning boundary condition codes to nodal points (this is discussed later in section 2.3) and select the zone subdivision accordingly.

Figure 6b gives a possible zone subdivision of the demonstration model.

Step 3. ASSIGNING SPECIFIED POINTS

Each zone is identified and its connectivity with other zones established by specification of nodal numbers (the specified points). Numbering must be in a natural integer sequence (1 to NSPNP, where NSPNP is the total number of specified points). The 4 corner nodes of the model zones must always be specified. However when a zone side is a straight line and if no grading is required then the intermediate point is generated by the program and need not be specified. There is no restriction on what integer (1 to NSPNP) is associated with a given point. In specifying intermediate points for grading remember the restrictions on α given in the last section. Mesh grading with curvilinear zones is more difficult and the restriction on the intermediate points is less clear. Highly distorted curvilinear zones sometimes give trouble when grading is attempted. In this case it is probably better to use smaller zones. Figure 6c shows the specified points selected for the illustrative example.

Step 4. PRODUCTION OF KEY DIAGRAM

As described in the previous section with each model diagram zone we associate a key diagram zone in such a way that the assumed mapping maps the key zone to the model zone. A key diagram is made up of the associated key zones in such a way that model zone connectivity is maintained.

When this has been done it is very important that the key diagram have a sufficient number of zones added to it to form a complete rectangle. These key zones that are not associated with any model zone are called void zones. It is the completion of the key diagram to form a rectangle and the resulting regular structure that makes the programming relatively straightforward.

Figure 6d gives the key diagram for the example.

Step 5. SELECTION OF GLOBAL (EPS, ETA) KEY DIAGRAM REFERENCE SYSTEM AND NUMBERING OF ZONES

In general there are two possible right handed (EPS, ETA) co-ordinates reference systems that can be selected.

A. Take the origin at lower left hand corner of key diagram rectangle. EPS is then horizontal to the right and ETA vertical upward (Figure 6e)

B. Take the origin at upper left hand corner of key diagram. EPS is then vertically down and ETA horizontal to the right (Figure 6f).

Zones are always numbered in the manner shown in Figure 6e and 6f. Note that all zones including void zones are numbered.

Which alternative, A or B, is selected depends solely on which of the two possibilities gives the smaller maximum bandwidth (2 x node difference + 2) for the resulting finite element stiffness matrix.

MSHGEN always generates finite element nodal numbers in the EPS direction. So that once the number of subintervals into which each span is to be subdivided is selected there is no difficulty in calculating which of the two possibilities, A or B, is appropriate.

Figure 6h and 6i show the F.E. discretization, as well as resulting maximum bandwidth, for the key diagrams Figures 6e and 6f respectively, and a certain choice of subintervals. Thus 6e is the appropriate choice if bandwidth is to be minimized.

Step 6. TRANSFER OF ZONE NUMBERS

Transfer the nonvoid key zone numbers to the associated model zones of the model diagram (Figure 6g).

This completes the preliminary data preparation phase.

2.3 MSHGEN Boundary Condition Code Generation

WILAX demands that displacement constraints be assigned to all F.E. nodal points. This is done by specifying an appropriate integer value called the boundary condition code.

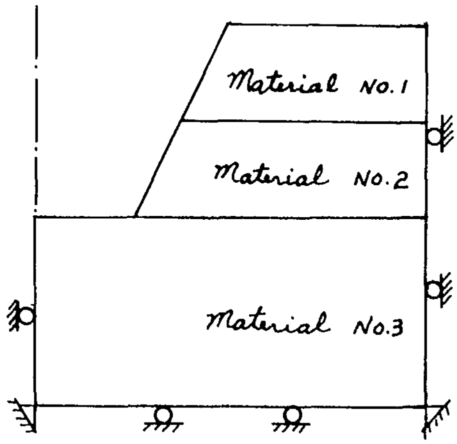
The following describes the procedure adopted in MSHGEN to select values for the generated F.E. condition codes. In MSHGEN the condition codes of all specified points are input and stored in an array called NCODSP. However, only the condition codes assigned to the corner specified points are used by MSHGEN.

The procedure is as follows:

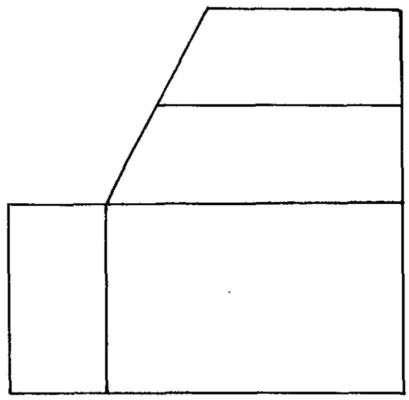
A. Corner zone specified points become F.E. nodal points. The condition codes of these points are unchanged.

B. On the boundary of a zone (possibly the interface between two zones) the condition code of intermedi-

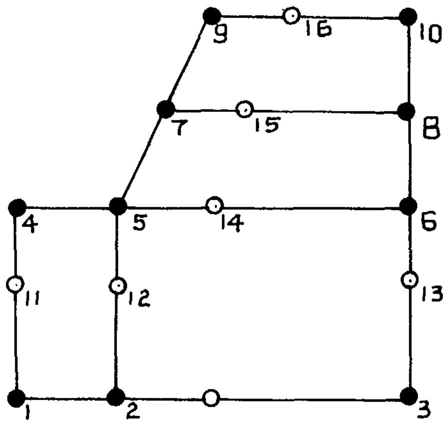
Figure 6



(a) Model-hypothetical slope with gravity loading



(b) Possible zone subdivision of model



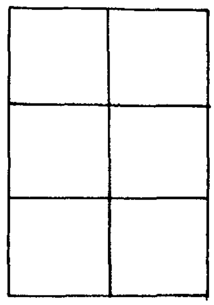
(c) Assigning specified points.

● Corner points

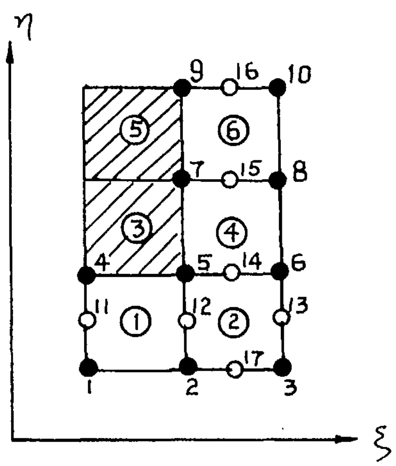
○ Intermediate points

▨ Void zone

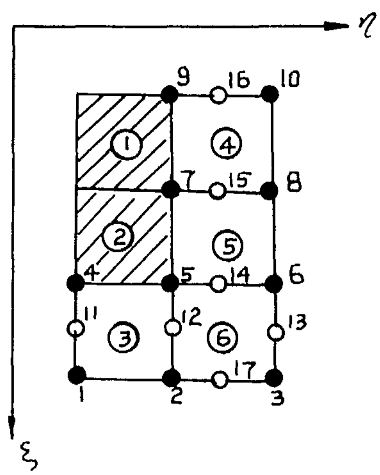
④ Zone number



(d) Associated key diagram.



(e) One possible choice of (EPS, ETA) with associated zone numbers.



(f) Second possible choice of (EPS, ETA) with associated zone numbers.

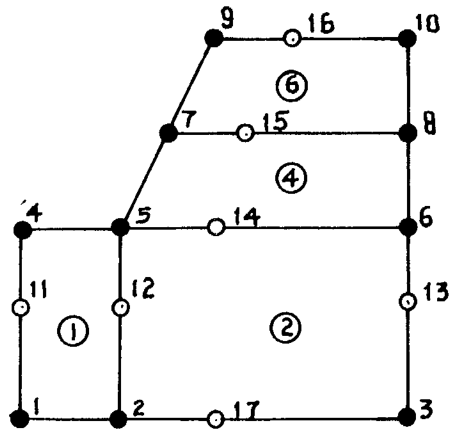


Figure 6g: Zone numbers tranfered to model diagram.

Number of nodal points = 317
Number of elements = 280
Max. bandwidth = 38

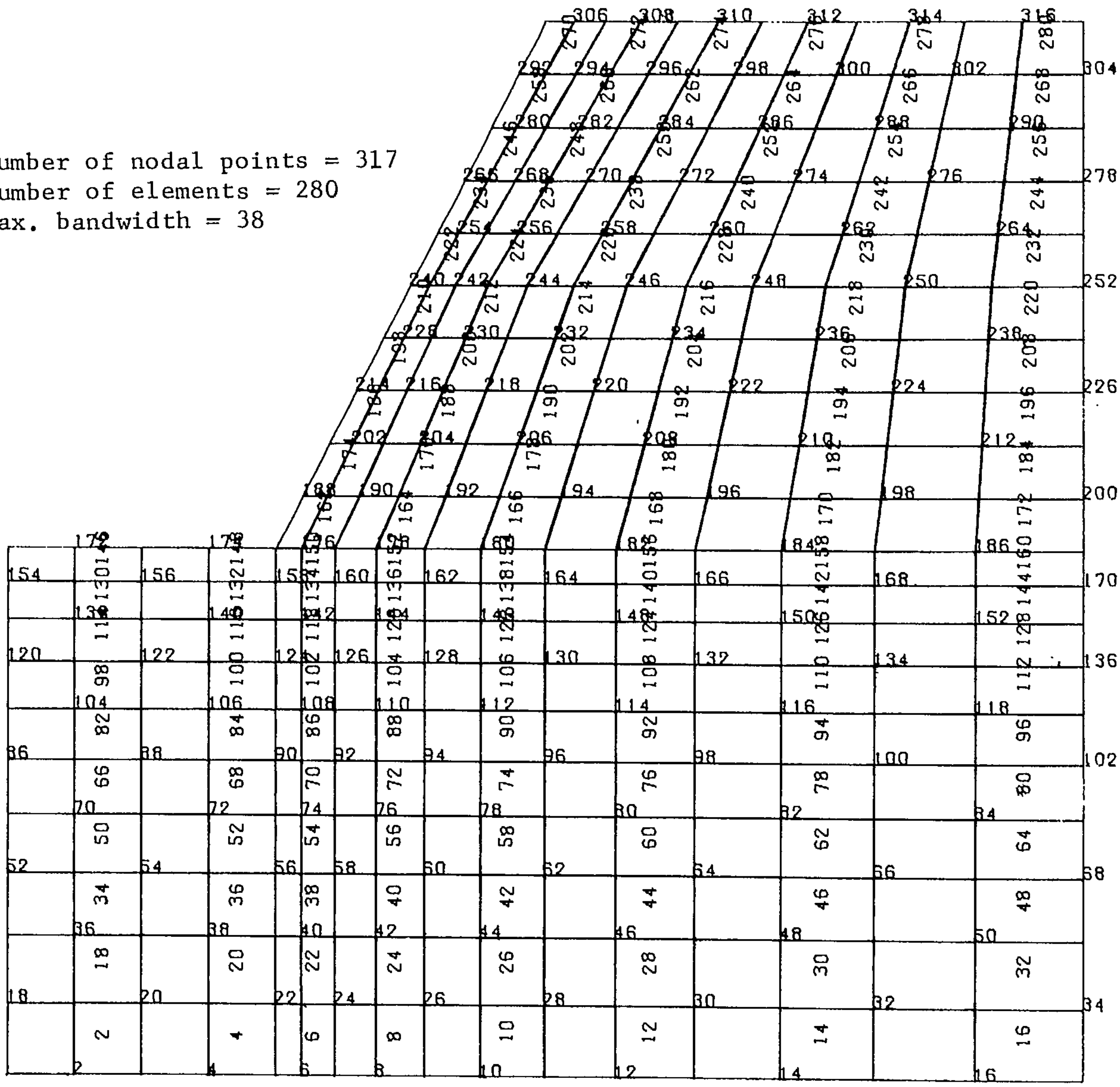


Figure 6h: F.E. discretization associated with Figure 6e. (Correspond to Key diagram 6e).

Number of nodal points = 317
Number of elements = 280
Max. bandwidth = 46

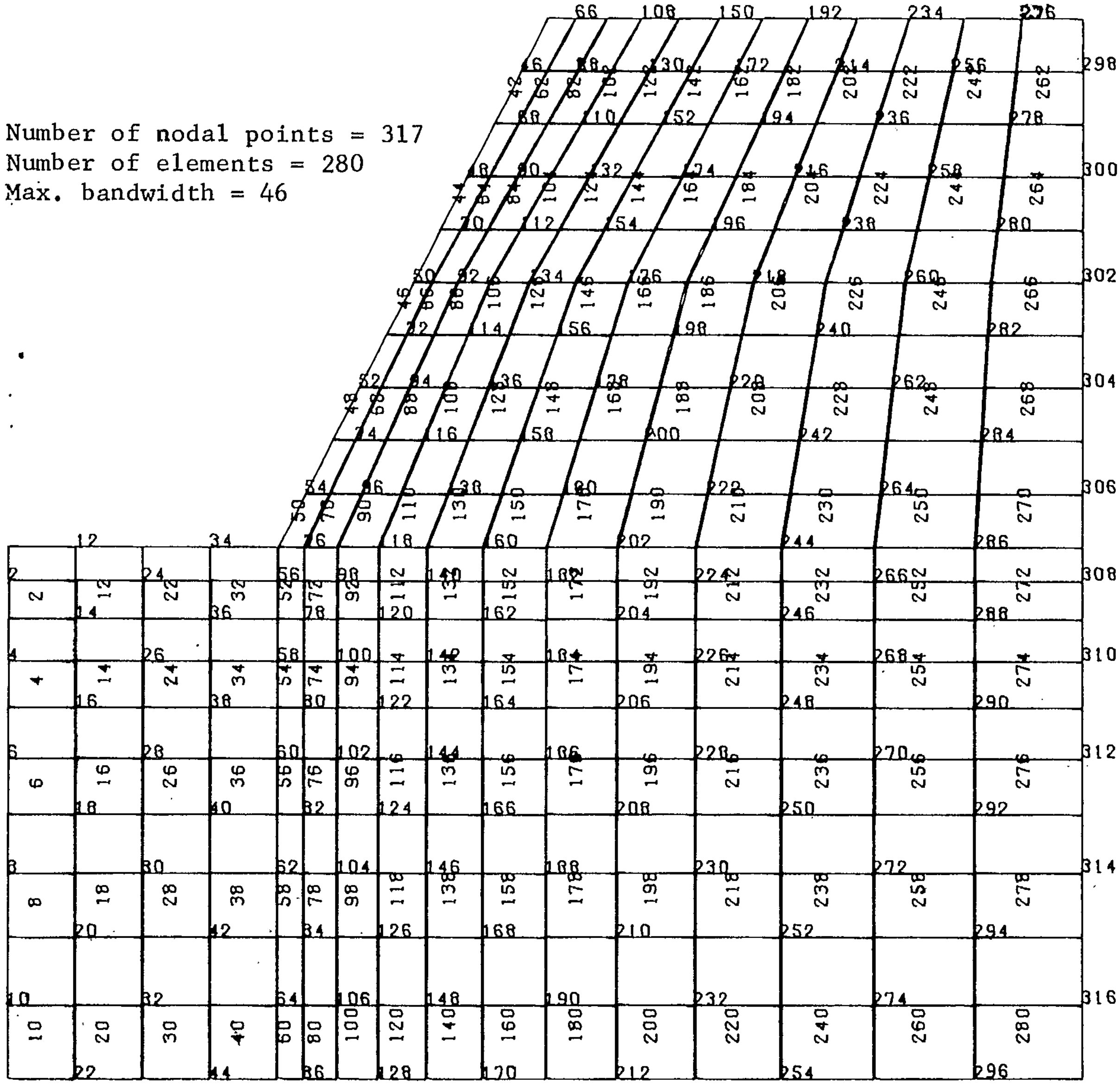


Figure 6i: F.E. discretization associated with Figure 6f.
(Correspond to Key diagram 6f).

ate generated F.E. nodal points is taken to be the minimum of the condition codes of the corner points of that zone (or those zones).

C. All generated F.E. nodal points in the interior of a zone are given a condition code of zero, i.e., treated as completely unconstrained.

The above choice of procedure although somewhat arbitrary has worked well for the class of problems encountered at MRC. If the above produces a WILAX nodal point condition code other than desired the user can follow one of the following procedures.

If there are many nodal points with incorrect condition codes it is probably best to either 1) rezone the model with the MSHGEN condition code generating procedure in mind or 2) modify MSHGEN to produce the correct F.E. code.

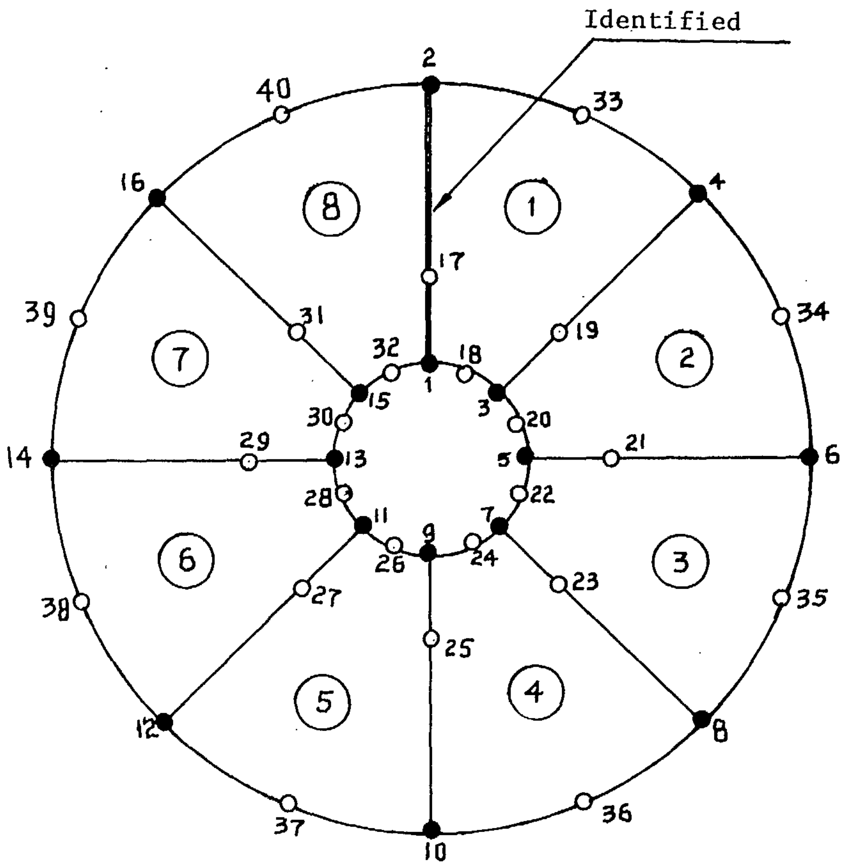
If however, only a few points need changing (the more usual case) then this is probably best done during the hand modification phase of the mesh development (discussed in section 5).

2.4 MSHGEN Identification Facility

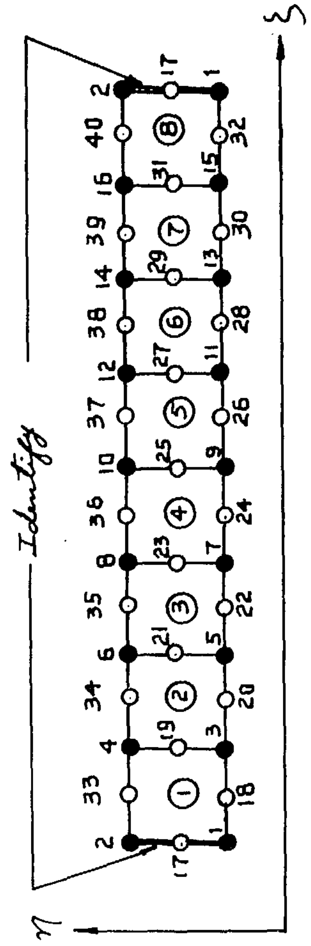
The identification capacity although built into MSHGEN has been little used at MRC on problems to date. The discussion given will be very brief and illustrated by only one example.

Using the procedure already introduced it would be difficult, if not impossible, to obtain a properly graded mesh for a multiply connected region (say a plate, with one or more openings). Figure 7 shows such an example. This problem can be alleviated by allowing the user to draw key zones in such a way that model zone connectivity is not necessarily maintained. Thus the same specified points would occur more than once in the key diagram as shown in the example (Figure 7).

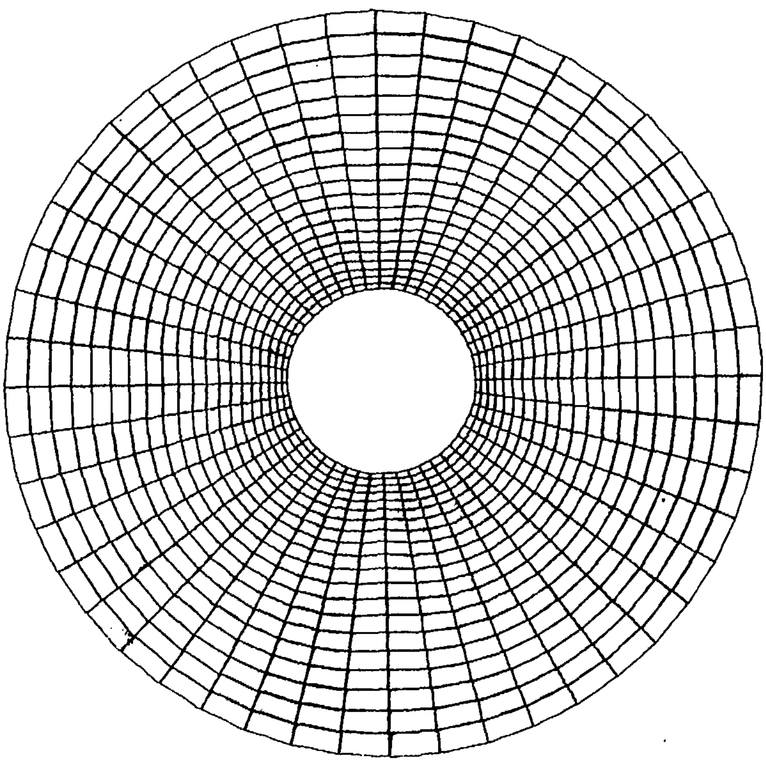
Note that the problem of minimizing bandwidth is now entirely different than for the simply connected no-identification procedure discussed previously. Thus changing the (EPS, ETA) global system in the example would increase the maximum bandwidth from 192 to 1976!



Model Diagram



Key Diagram



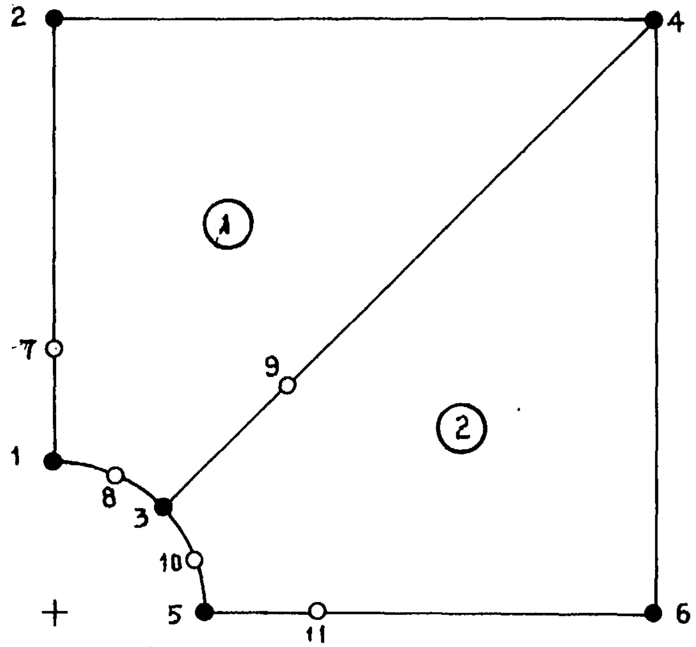
● Corner points

○ Intermediate points

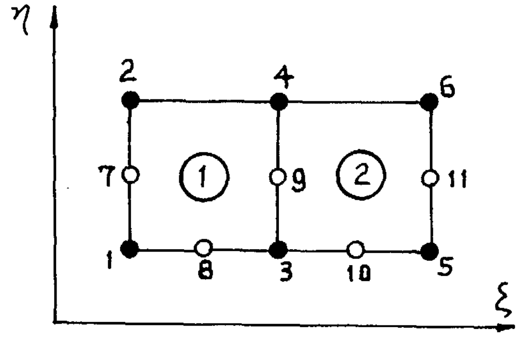
Max. zone number = 8
Non-void zone = 8
Number of nodal points = 1008
Number of elements = 960
Max. bandwidth = 192

Possible F.E. discretization

Figure 7: Use of identification facility.



Model diagram



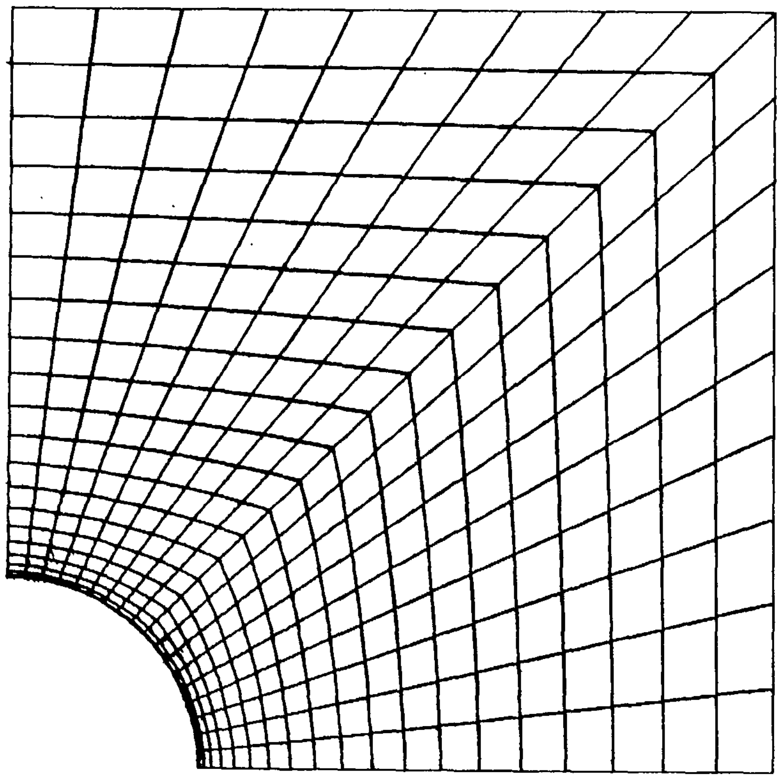
Key diagram

Legend:

● Corner points

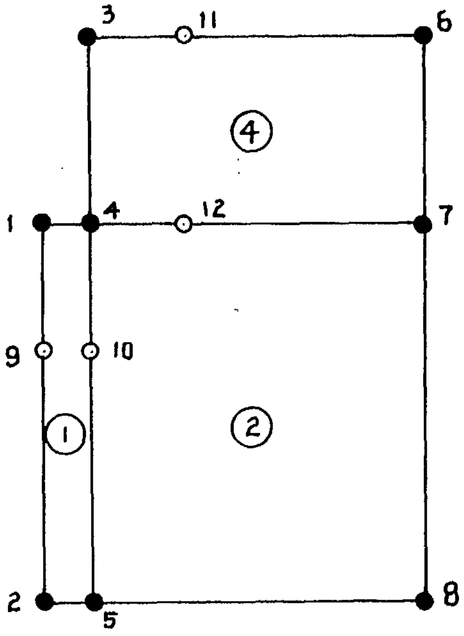
○ Intermediate points

Max. zone number = 2
Non-void zones = 2
Number of nodal points 399
Number of elements = 360
Max. bandwidth = 42

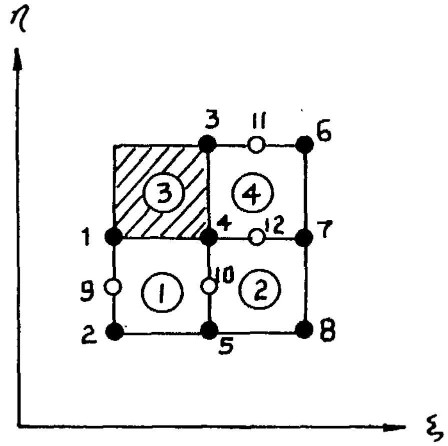


F.E. discretization

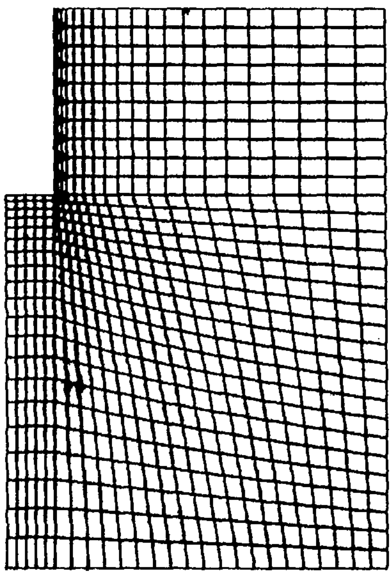
Figure 8: Plate with circular opening.



Zone diagram



Key diagram



F.E. Discretization

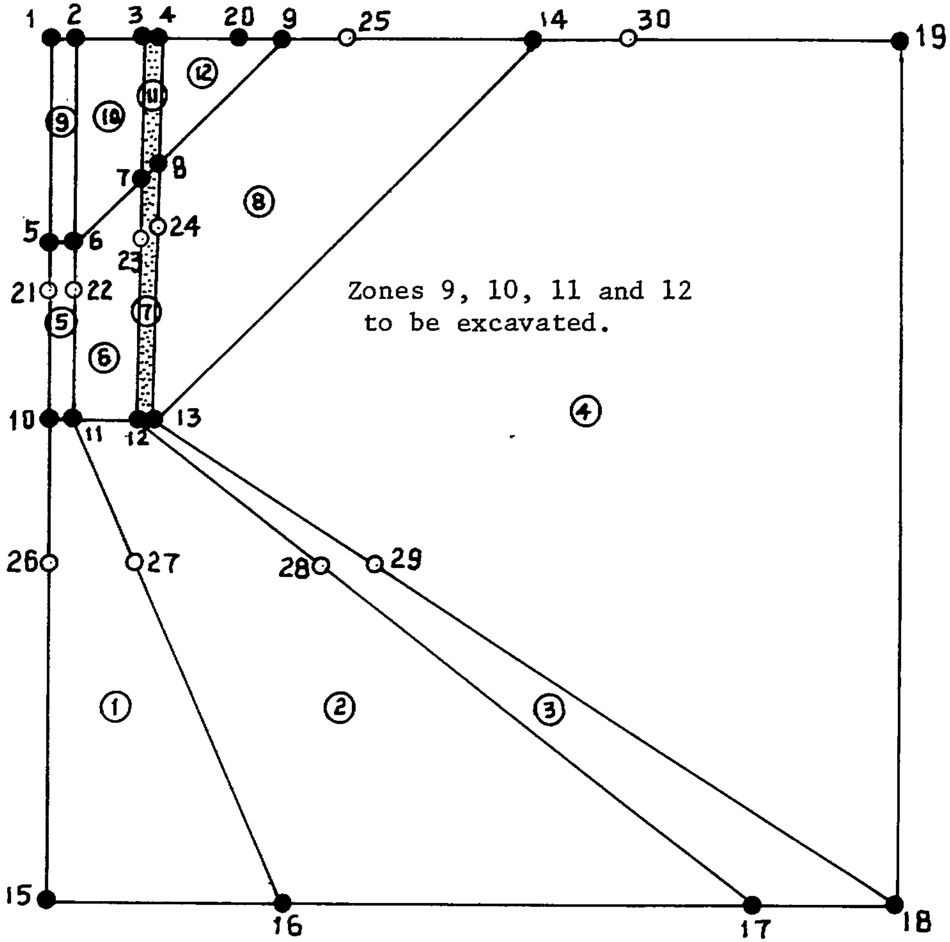
● Corner points

○ Intermediate points

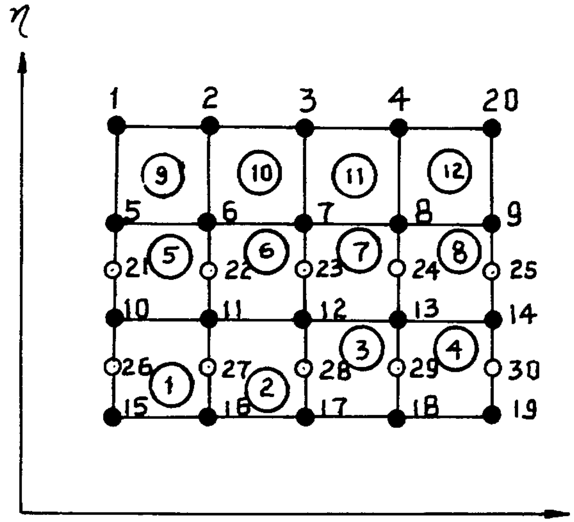
▨ Void zone

Max. zone number = 4
Non-void zones = 3
Number of nodal points = 756
Number of elements = 700
Max. bandwidth = 56

Figure 9: Cylinder with cylindrical opening.



Model zone diagram



Key zone diagram

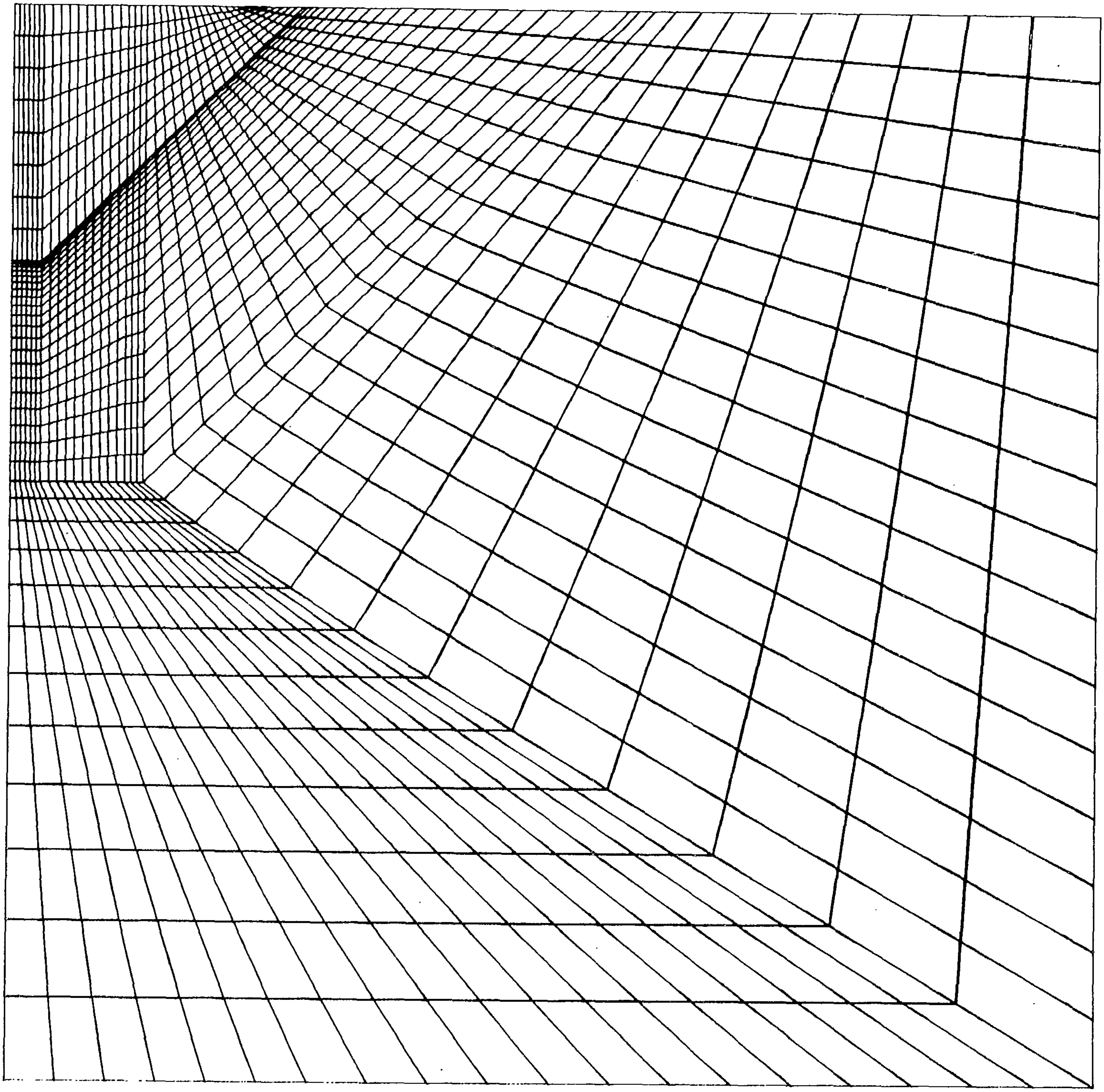
● Corner points

○ Intermediate points

Dyke material

Max. zone number = 12
Non-void zones = 12
Number of nodal points = 1476
Number of elements = 1400
Max. bandwidth = 76

Figure 10: Progressive excavation of a rock slope.



F.E. Discretization

Figure 10: (Continued)

2.5 Definition of Some Relevant Variables

Collected below are the definitions of the variables which need input values.

HDING	8-word array that holds heading or title of problem
NSPNP	Total number of specified nodal points
NVZONE	Total number of non-void zones
MXNP	Upper bound to number of F.E. nodal points generated. Used for storage allocation
MXEL	Upper bound to number of F.E. elements generated Used for storage allocation
NSPAN1	Total number of spans, making up key diagram rectangle, in the EPS direction
NSPAN2	Total number of spans, making up key diagram rectangle, in the ETA direction
MXCUT	The number of cuts (excavations) to be made. (The number of times elements have to be removed from input and problem resolved by WILAX)
NSIDNT	Identification indicator, "0" no identification, "1" identification required
NSBDV1	An array of length NSPAN1 which contains the number of subdivisions of each span in EPS direction
NSBDV2	An array of length NSPAN2 which contains the number of subdivions of each span in ETA direction
NCODSP	An array of length NSPNP which holds the boundary condition code of the specified corner points
XSP	An array of length NSPNP which contains the X-co-ordinates of all specified points
YSP	An array of length NSPNP which contains the Y-co-ordinates of all specified points
IZ	A matrix of dimension 8 by (NSPAN1*NSPAN2) This is the zone specification matrix. Rows corresponding to void zones are all zero. The row corresponding to a normal zone contains the specified nodal numbers that define the zone. The order in which these occur is very rigid. The local (EPS, ETA) system of all key zones is taken to be identical in direction as the global (EPS, ETA) system. Referring to Figure 1 then the specified node number must be in the order 1, 2, 3, 4, 5, 6, 7, 8. If any of the intermediate

	points are not given it is given the value 0
MATZ	An array of length NSPAN1*NSPAN2 This holds the material number of all zones. Void zones are given a MATZ value of zero by the program
NCUTZ	An array of length NSPAN1*NSPAN2 This holds the cut number of all zones. Zones that are not cuts are assigned a cut number of MXCUT+1 by the program

2.6 MSHGEN Input Cards

The definition of most of the variables used below can be found in subsection 2.5.

A. CARD #1 FORMAT 8A10

Contents

HDING

B. CARD #2 FORMAT 8I5

Contents

NSPNP, NVZONE, MXNP, MXEL, NSPAN1, NSPAN2, MXCUT, NSIDNT

C. CARD #3 FORMAT 16I5

Contents

NSPAN1 values of NSBDV1

(Note the implicit assumption on this card and the next that neither NSPAN1 or NSPAN2 exceeds 16)

D. CARD #4 FORMAT 16I5

Contents

NSPAN2 value of NSBDV2

E. Block of NSPNP cards - one for each specified point

These must be in natural order 1 to NSPNP

Card for specified point 'I'. FORMAT 2I5, 2E15.0

Contents

I NCODSP(I) XSP(I) YSP(I)

F. Block of NVZONE cards - one for each nonvoid zone

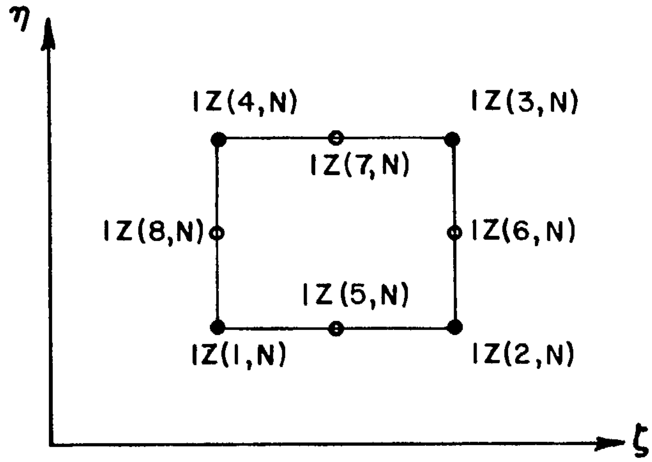
These cards can be in any order

Card for nonvoid zone 'N'. FORMAT 11I5

Contents

N IZ(1, N), IZ(2, N) .... IZ(8, N), MATZ(N), NCUTZ(N)

NOTE 1. IZ(1,N) to IZ(8,N) must be numbered counterclockwise in the local (EPS,ETA) system of all the Key zones



NOTE 2. Any of IZ(5, N) to IZ(8, N) can be blank signifying no intermediate specified points.

NOTE 3. If MATZ(N) is left blank it is assigned the material number 1 by default.

NOTE 4. If NCUTZ(N) is left blank it is assigned the cut number MXCUT + 1 by default.

The input cards for the illustrative example (Figure 6), previously discussed, are given in Figure 11.

2.7 <u>MSHGEN Output</u>

1) <u>Printer Output</u>

As well as reproducing the input data, MSHGEN also prints out the number of nodes and the number of elements generated, the maximum bandwidth found and the element in which this maximum bandwidth occurs.

2) <u>Output on fortran logical unit #1</u>

(a) Record #1 FORMAT (2I5)

Contents

NUMNP, NUMEL

(b) Block of 'NUMNP' records

FORMAT each record (2I5, 2E15.0)

Contents

Nodal number, boundary condition code, X & Y co-ordinates

```
A HYPOTHETICAL SLOPE
  17    4  320  320     2     3     0     0
   4   12
  10    5    5
   1    3              0.                0.
   2    2            100.                0.
   3    3            400.                0.
   4    1              0.              200.
   5                 100.              200.
   6    1            400.              200.
   7                 150.              300.
   8    1            400.              300.
   9                 200.              400.
  10    1            400.              400.
  11                   0.              120.
  12                 100.              120.
  13                 400.              120.
  14                 200.              200.
  15                 230.              300.
  16                 280.              400.
  17    2            200.                0.
   1    1    2    5     4     0    12     0    11     1
   2    2    3    6     5    17    13    14    12     1
   4    5    6    8     7    14     0    15     0     2
   6    7    8   10     9    15     0    16     0     3
```

Figure 11: Input to MSHGEN corresponding to problem given in Figure 6.

(c) Block of 'NUMEL' records

FORMAT each record (6I5)

Contents

Element number, 4 nodes describing element, material number

(d) MXCUT sets of excavation or cut data in the form and format demanded by WILAX.

NOTE: MSHGEN does not rewind file #1. Logical unit #1 will be used as input for the program WXCONV.

2.8 MSHGEN Storage Requirements

Sufficient storage must be allocated in the blank COMMON array ID for proper operation of MSHGEN.

The amount of blank COMMON storage 'MXDIM' should be greater than or equal to 3*NSPNP+10*NSPAN1*NSPAN2+4*MXNP+6*MXEL.

Two fortran cards must be changed in the main program of MSHGEN if storage requirements are to be changed

1) COMMON ID('MXDIM')

and 2) MXDIM = 'MXDIM'

MSHGEN performs a check to see if MXDIM as given in fortran statement #2 is sufficient. If storage allocation is insufficient MSHGEN aborts.

For the CDC 6400 the total storage requirements to load and execute MSHGEN are (in decimal)

8700 + MAX(MXDIM, 3400)

2.9 MSHGEN Program

A complete fortran listing (for CDC 6400) is given in Appendix B.

The fortran used is standard and no difficulties in converting to another computer are anticipated.

There are two restrictions in the current program that should be noted.

1) A maximum of 16 spans in either EPS or ETA direction. This restriction is easily removed.

2) In the identification subroutine IDENT it is necessary to check for 'identical' nodes. In the current program two nodes are called identical if both their X and Y co-ordinates differ by less than .00001. For certain scaling this could be too large or too small.

3. MSHPLT

3.1 General

The best way to check whether a generated finite element mesh is adequate is to plot the mesh and inspect it visually. MSHPLT (a slight modification of an old MRC program (3)) is a mesh plotting program especially designed to be used in conjunction with MSHGEN.

The plotting program features certain options which enhance its usefulness. These are:

1) A rectangular region can be specified and only elements inside this region are plotted. This allows magnification of given areas of a mesh.
2) A rectangular region can be specified and only elements outside this region are plotted. This lets the user exclude a very finely graded area.
3) All even nodal point numbers can be plotted.
4) All even element numbers can be plotted.
5) Nodal point numbers need not be plotted horizontally. This makes it easier to distinguish element numbers and nodal point numbers if both are plotted.

3.2 Definition of Some Relevant Variables

XFAC - Factor by which logical co-ordinates are multiplied to convert to inch co-ordinates.

NBOUND - If NBOUND = 0 the whole mesh is plotted.
- If NBOUND $\neq$ 0 then a rectangular region has to be specified and
- If NBOUND = 1 inside of rectangle is plotted or
- If NBOUND = 2 region outside of rectangle is plotted.

ELEOUT - Element number print indicator
ELEOUT = 0, No element number print.
ELEOUT = 1, Print even element numbers.

NPTOUT - Nodal number print indicator
NPTOUT = 0, No nodal number print.
NPTOUT = 1, Print even nodal numbers.

HT - Height of numbers if element numbers or/and nodal numbers are printed.

DIR - Angle in degrees with respect to X-axis. This defines the direction in which nodal point numbers are plotted.

ORGX - Logical X-co-ordinate of 'left side' of specified rectangle.

XORD - Logical X-co-ordinate of 'right side' of specified rectangle.

ORGY - Logical Y-co-ordinate of 'bottom' of specified rectangle.

YORD - Logical Y-co-ordinate of 'top' specified rectangle.

3.3 <u>MSHPLT Input</u>

1) INPUT CARD(S)

CARD 1 FORMAT (F10.0, 3I10, 2F10.0)

Contents:

XFAC, NBOUND, ELEOUT, NPTOUT, HT, DIR

Note: HT must be a multiple of .07. The default value of HT is .07

If NBOUND $\neq$ 0 there is a second card defining the specified rectangle

CARD 2 FORMAT (4F10.0)

ORGX, XORD, ORGY, YORD

The MSHPLT input data for the illustrative example (Figure 6) is shown in the examples given in the section on control cards..

2) INPUT FROM FORTRAN LOGICAL UNIT 1

The format needed is exactly that produced by MSHGEN on logical unit 1. There is a rewind of logical unit 1 prior to initiation of input in MSHPLT.

3.4 <u>MSHPLT Storage Requirements</u>

Default values currently in MSHPLT provides for a maximum number of nodal points (MXNP) of 500 and a maximum number of elements (MXEL) of 500. It is necessary that MXNP ≥ NUMNP and that MXEL ≥ NUMEL in any given problem. To change the amount of storage it is necessary to change the first line of the fortran blank COMMON statement.

COMMON R(MXNP), Z(MXNP), IX(MXEL, 5)

in the main program as well as in the subroutines PLOTR and XNODAL.

The following pertains only to a CDC 6000 series computer. Here the source deck of MSHPLT can be in UPDATE format. UPDATE is the CDC system program for creating and manipulating source libraries. By using the COMDECK feature of UPDATE it is only necessary to change the above COMMON statement once. The name of the COMDECK used at MRC is MSHDIM. The second statement, MSHDIM.2, must be changed if storage requirements are to be changed.

On the CDC 6400 the total storage requirement needed for loading and executing MSHPLT is (in decimal)

9400 + MAX(3400, 2*MXNP + 5*MXEL)

3.5 MSHPLT Program

A CDC 6400 fortran listing of MSHPLT is given in Appendix C.

4. WXCONV

4.1 General

MSHGEN produces only part of the input data required by WILAX, i.e., nodal point data, element data and cut data. Necessary WILAX information, for instance, the parameter control card, material properties cards, pressure cards and initial stress cards (the word card is used for card image), is missing. WXCONV takes this additional card information and merges it with the output of MSHGEN to produce an input file acceptable to WILAX. A listing of the current version of the WILAX program is given in Appendix F.

WXCONV does not modify the output of MSHGEN. WXCONV does not generate fully general WILAX input data. Such things, as temperature effects, concentrated nodal forces, nonzero specified nodal displacements and constraints in directions other than the X-Y directions, can not be introduced by WXCONV. At present such requirements would have to be affected during the hand modification phase of WILAX input preparation.

4.2 WXCONV Input

All input cards to WXCONV are in the exact format demanded by WILAX, i.e. in each case the whole card is transferred, with no checking or conversion, to the WXCONV output unit (fortran logical unit number 2). MSHGEN input on WXCONV is on fortran logical unit number 1.

Only the order of the cards will be listed below; for the necessary format consult the WILAX publication (1).

Input cards:

1. Title card.
2. Parameter card.
3. Block of cards describing material properties - two cards for each material number.
4. Block of cards giving boundary pressure condition if NUMPC $\neq$ 0.
5. Block of cards describing the initial stress if NRES $\neq$ 0

The section 6 on control cards gives the input WXCONV cards needed for the illustrative example (shown in Fig. 6).

4.3 WXCONV Storage Requirements

The only restrictions currently in WXCONV is that there be no more than 300 elements in any one cut and that the boundary of a cut be described by at most 100 nodal points. If either of these limits are exceeded then the fortran DIMENSION statement would have to be changed. NELCUT( ) is a list of the elements in a cut and NPCUT( ) is a list of the nodal points defining the boundary of the cut.

On the CDC 6400 with NELCUT(300) and NPCUT(100) the total storage requirement for loading and executing is less than 30000 octal words.

4.4 WXCONV Program

A CDC 6400 fortran listing WXCONV is given in Appendix D.

5. Hand Modification

The combination of MSHGEN and WXCONV will usually give a satisfactory mesh and complete WILAX input data (at least for the class of problems encountered at MRC). If this is not the case then hand modification will have to be carried out. If a system file manipulation and modification routine exists (e.g. UPDATE on the CDC 6000 series), then modification of data is probably best done using this routine.

Case 1:

The output of MSHGEN is incorrect or inadequate. The displacement constraint code at some nodal points could be wrong. The co-ordinates of some nodal points could be such as to give a poor representation of a boundary or possibly a poor element shape.

Case 2:

MSHGEN and WXCONV can generate input data that utilizes only part of WILAX's capabilities. Factors such as concentrated forces, temperature effects, constraints in other than global X and Y direction, etc. would have to be introduced using hand modification.

6. Control Cards for the CDC 6400

The control cards are very much machine dependent. However, in this section, some examples of the control cards needed for executing the programs previously described, on the CDC 6400 (Scope 3.4), are briefly discussed and given in Appendix E.

All programs associated with WILAX, including MSHGEN, MSHPLT and WXCONV reside on a multifile tape. The first file, with label L = WILAXSOURCE, contains the whole of WILAX, MSHGEN, MSHPLT and WXCONV, in UPDATE format. The second file, with label L = WILAXOBJECT, contains all the subprograms of WILAX in object form (with OPT = 1 compilation).

The first step in automatic WILAX data generation is to execute MSHGEN and use MSHPLT to check the resulting mesh by plotting it. This is continued until a satisfactory mesh is achieved. Appendix E-1 shows the control cards needed as well as the data required to execute the illustrative example.

The next step, after an adequate mesh has been generated, depends on whether or not hand modification is required. If not, the MSHGEN, WXCONV and WILAX can be executed in sequence to give WILAX output. Appendix E-2 shows a possible set of control cards and data to achieve this for the illustrative example. If hand modification is required then MSHGEN and WXCONV are executed and the output of WXCONV stored on a tape in UPDATE format.

7. References

1. Yu, Y.S. and Attar-Hassan, G.
"MRC User's Manual for a Computer Program of Finite Element Stress Analysis", Internal Rept. 72/87, Aug. 72

2. Zienkiewicz, O.C. and Phillips, D.V.,
"An Automatic Mesh Generation for Plane and Curved Surfaces by 'Isoparametric' Co-ordinates", Int. J. for Num. Meth. In Engineering Vol. 3, 519-528 (1971)

3. Thibault, M.
"Documentation of a Computer Program of a Mesh Generator For Finite Element Analysis", Internal Rept. Mr 70/73 - ID, Aug. 70

APPENDIX A

Quadratic Interpolating Functions

Given below are the quadratic interpolating functions used in the mapping from a key diagram zone to a model zone. Note that for typing convenience (EPS, ETA) is used for (ξ, η) in much of the report.

The order of the interpolating functions correspond to the key zone numbering in Figure 1.

$$N1 = -.25(1 - \xi)\ (1 - \eta)\ (\xi + \eta + 1)$$

$$N2 = -.25(1 + \xi)\ (1 - \eta)\ (-\xi + \eta + 1)$$

$$N3 = -.25(1 + \xi)\ (1 + \eta)\ (-\xi - \eta + 1)$$

$$N4 = -.25(1 - \xi)\ (1 + \eta)\ (\xi - \eta + 1)$$

$$N5 = .5(1 + \xi)\ (1 - \xi)\ (1 - \eta)$$

$$N6 = .5(1 + \xi)\ (1 + \eta)\ (1 - \eta)$$

$$N7 = .5(1 + \xi)\ (1 - \xi)\ (1 + \eta)$$

$$N8 = .5(1 - \xi)\ (1 + \eta)\ (1 - \eta)$$

APPENDIX B

FORTRAN LISTING OF MSHGEN

```
      PROGRAM MSHGEN(INPUT,OUTPUT,TAPE1)
C
C     THIS PROGRAM GENERATES FINITE ELEMENT MESH DATA FOR WILAX .
C
      COMMON/CNTL/NSPNP,NVZONE,MXNP,MXEL,NSPAN1,NSPAN2,NSIDNT,MXZONE,
     1 MXCUT,HDING(8)
C
C     THE DIMENSION OF ID MUST BE SET EQUAL TO MXDIM
C      MXDIM IS GREATER THAN OR EQUAL TO
C      3*NSPNP+10*NSPAN1*NSPAN2+4*MXNP+6*MXEL
C        NSPNP-NO. OF SPECIFIED POINTS
C        NSPAN1-NO. OF SPANS IN EPS DIRECTION
C        NSPAN2-NO. OF SPANS IN THE ETA DIRECTION
C        MXNP-UPPER BOUND TO NUMBER OF FINITE ELEMENT NODAL POINTS
C        MXEL- UPPER BOUND TO NUMBER OF FINITE ELEMENT ELEMENTS
C
      COMMON ID(3000)
      MXDIM=3000
      REWIND 1
C     READ CONTROL CARD
      READ 100,HDING,NSPNP,NVZONE,MXNP,MXEL,NSPAN1,NSPAN2,MXCUT,NSIDNT
  100 FORMAT(8A10/8I5)
      PRINT 200,HDING,NSPNP,NVZONE,MXNP,MXEL,NSPAN1,NSPAN2,MXCUT,NSIDNT
  200 FORMAT(1H1,8A10/
     1 41H0NUMBER OF SPECIFIED POINTS---------------,I5/
     2 41H0NUMBER OF NON-VOID ZONES-----------------,I5/
     3 41H0MAX. NUMBER OF GENERATED NODAL POINTS---,I5/
     4 41H0MAX. NUMBER OF GENERATED ELEMENTS-------,I5/
     5 41H0NUMBER OF SPANS IN EPS DIRECTION--------,I5/
     6 41H0NUMBER OF SPANS IN ETA DIRECTION--------,I5/
     7 41H0NUMBER OF CUTS--------------------------,I5/
     8 41H0IDENTIFICATION,1=YES,0=NO---------------,I5)
      MXZONE=NSPAN1*NSPAN2
C     ALLOCATION OF COMMON STORAGE
      I1=1
      I2=I1+NSPNP
      I3=I2+NSPNP
      I4=I3+NSPNP
      I5=I4+8*MXZONE
      I6=I5+MXZONE
      I7=I6+MXZONE
      I8=I7+NSPAN1
      I9=I8+NSPAN2
      I10=I9+MXNP
      I11=I10+MXNP
      I12=I11+MXNP
      I13=I12+MXNP
      I14=I13+5*MXEL
      I15=I14+MXEL-1
      PRINT 300,I15,MXDIM
  300 FORMAT(// " MINIMUM VALUE ALLOWABLE FOR MXDIM=",I5/
     1 " VALUE OF MXDIM ASSIGNED=",I5)
      IF(I15.GT.MXDIM) CALL ABORT
      CALL INPUT(ID(I1),ID(I2),ID(I3),ID(I4),ID(I5),ID(I6),ID(I7),
     1 ID(I8))
      CALL CONTRL(ID(I1),ID(I2),ID(I3),ID(I4),ID(I5),ID(I6),
     1 ID(I7),ID(I8),ID(I9),ID(I10),ID(I11),ID(I12),ID(I13),ID(I14))
```

```
               REWIND 1                                              MSHGEN      59
               STOP                                                  MSHGEN      60
    60         END                                                   MSHGEN      61
```

```
      SUBROUTINE INPUT(XSP,YSP,NCODSP,IZ,MATZ,NCUTZ,NSBDV1,NSBDV2)        MSHGEN  62
C                                                                         MSHGEN  63
C     INPUT ROUTINE FOR MSHGEN                                            MSHGEN  64
C                                                                         MSHGEN  65
      COMMON/CNTL/NSPNP,NVZONE,MXNP,MXEL,NSPAN1,NSPAN2,NSIDNT,MXZONE,     MSHGEN  66
     1 MXCUT,HDING(8)                                                     MSHGEN  67
      DIMENSION XSP(1),YSP(1),NCODSP(1),IZ(8,1),MATZ(1),                  MSHGEN  68
     1 NCUTZ(1),NSBDV1(1),NSBDV2(1)                                       MSHGEN  69
C                                                                         MSHGEN  70
C     READ NUMBER OF SUBDIVISONS OF EACH SPAN                             MSHGEN  71
C     IN EPS DIRECTION                                                    MSHGEN  72
      READ 100,(NSBDV1(I),I=1,NSPAN1)                                     MSHGEN  73
  100 FORMAT(16I5)                                                        MSHGEN  74
C     IN ETA DIRECTION                                                    MSHGEN  75
      READ 100,(NSBDV2(I),I=1,NSPAN2)                                     MSHGEN  76
      PRINT 200,(NSBDV1(I),I=1,NSPAN1)                                    MSHGEN  77
  200 FORMAT("1 SPAN SUBDIVISIONS IN EPS DIRECTION"/(1H ,16I5))           MSHGEN  78
      PRINT 300,(NSBDV2(I),I=1,NSPAN2)                                    MSHGEN  79
  300 FORMAT("0 SPAN SUBDIVISIONS IN ETA DIRECTION"/(1H ,16I5))           MSHGEN  80
C                                                                         MSHGEN  81
C     READ IN COORDINATES OF SPECIFIED POINTS WITH ASSOCIATED CONSTRAINT  MSHGEN  82
      PRINT 400                                                           MSHGEN  83
  400 FORMAT(1H1,50X,"S P E C I F I E D    P O I N T S"/1H0,              MSHGEN  84
     1"POINT NO.",17X,"CONSTRAINT NO.",18X,"X-COORDINATE",18X,            MSHGEN  85
     2 "Y-COORDINATE")                                                    MSHGEN  86
      DO 10 I=1,NSPNP                                                     MSHGEN  87
      READ 500,N,NCODSP(I),XSP(I),YSP(I)                                  MSHGEN  88
  500 FORMAT(2I5,2E15.0)                                                  MSHGEN  89
      PRINT 600,N,NCODSP(I),XSP(I),YSP(I)                                 MSHGEN  90
  600 FORMAT(I10,10X,I10,10X,E20.6,10X,E20.6)                             MSHGEN  91
      IF(I.NE.N)GO TO 20                                                  MSHGEN  92
   10 CONTINUE                                                            MSHGEN  93
      GO TO 30                                                            MSHGEN  94
   20 PRINT 700                                                           MSHGEN  95
  700 FORMAT(" CARDS GIVING COORDINATES OF SPECIFIED POINTS NOT "         MSHGEN  96
     1 "IN ORDER")                                                        MSHGEN  97
      STOP                                                                MSHGEN  98
   30 CONTINUE                                                            MSHGEN  99
C     INPUT ZONE SPECIFICATIONS                                           MSHGEN 100
C     INITIALIZE MATERIAL NUMBER TO ZERO                                  MSHGEN 101
      DO 40 I=1,MXZONE                                                    MSHGEN 102
      MATZ(I)=0                                                           MSHGEN 103
      NCUTZ(I)=0                                                          MSHGEN 104
   40 CONTINUE                                                            MSHGEN 105
      PRINT 800                                                           MSHGEN 106
  800 FORMAT(1H1,45X,"Z O N E    S P E C I F I C A T I O N",/1H0,2X,      MSHGEN 107
     1"ZONE NO.", 7X,"NP1",7X,"NP2",7X,"NP3",7X,"NP4",7X,"NP5",7X,"NP6",  MSHGEN 108
     2 7X,"NP7",7X,"NP8",2X,"MAT. NO.",3X,"CUT NO.")                      MSHGEN 109
      DO 50 J=1,NVZONE                                                    MSHGEN 110
      READ 900,N,(IZ(I,N),I=1,8),MATZ(N),NCUTZ(N)                         MSHGEN 111
  900 FORMAT(11I5)                                                        MSHGEN 112
      IF(MATZ(N).EQ.0)MATZ(N)=1                                           MSHGEN 113
      IF(NCUTZ(N).EQ.0)NCUTZ(N)=MXCUT+1                                   MSHGEN 114
      PRINT 1000,N,(IZ(I,N),I=1,8),MATZ(N),NCUTZ(N)                       MSHGEN 115
 1000 FORMAT(1H ,11I10)                                                   MSHGEN 116
   50 CONTINUE                                                            MSHGEN 117
C                                                                         MSHGEN 118
```

```
      RETURN                                            MSHGEN   119
      END                                               MSHGEN   120
```

```
      SUBROUTINE CONTRL(XSP,YSP,NCODSP,IZ,MATZ,NCUTZ,NSBDV1,NSBDV2,     MSHGEN 121
     1 X,Y,NCODE,NPCUT,IX,NELCUT)                                       MSHGEN 122
C     CONTROL ROUTINE FOR MSHGEN                                        MSHGEN 123
C                                                                       MSHGEN 124
      COMMON/CNTL/NSPNP,NVZONE,MXNP,MXEL,NSPAN1,NSPAN2,NSIDNT,          MSHGEN 125
     1 MXZONE,MXCUT,HDING(8)                                            MSHGEN 126
      COMMON/ZROW/NUMNP,NUMEL,NPOLD,NDIV1,ICNTNP,ICNTEL,MATZZ,          MSHGEN 127
     1 NCUTEL,NPC1,NCD(3),NCT(3),ETA,XZ(8),YZ(8)                        MSHGEN 128
      DIMENSION XSP(1),YSP(1),NCODSP(1),IZ(8,1),MATZ(1),                MSHGEN 129
     1 NCUTZ(1),NSBDV1(1),NSBDV2(1),X(1),Y(1),NCODE(1),NPCUT(1),        MSHGEN 130
     2 IX(5,1),NELCUT(1),NCDZ(4),NCTZ(4)                                MSHGEN 131
C                                                                       MSHGEN 132
C     INITIALIZATION                                                    MSHGEN 133
      NUMEL=0                                                           MSHGEN 134
      NUMNP=0                                                           MSHGEN 135
      NZ1=1-NSPAN1                                                      MSHGEN 136
      NSP2=0                                                            MSHGEN 137
C     FIRST ROW IS A ZONE INTERFACE                                     MSHGEN 138
      GO TO 110                                                         MSHGEN 139
C                                                                       MSHGEN 140
C     MAIN CONTROL LOOP FOLLOWS                                         MSHGEN 141
C                                                                       MSHGEN 142
   10 NSP2=NSP2+1                                                       MSHGEN 143
      IF(NSP2.GT.NSPAN2)GO TO 200                                       MSHGEN 144
      NZ1=NZ1+NSPAN1                                                    MSHGEN 145
      ICNTEL=0                                                          MSHGEN 146
      ICNTNP=0                                                          MSHGEN 147
      NDIV2=NSBDV2(NSP2)                                                MSHGEN 148
      IF(NDIV2.LE.1)GO TO 100                                           MSHGEN 149
C                                                                       MSHGEN 150
C     PROCESS ROW ABOVE INTERFACE. NEW ROW ASSUMED TO BE NON-INTERFACE  MSHGEN 151
      ETAINC=2./NDIV2                                                   MSHGEN 152
      ETA=-1.+ETAINC                                                    MSHGEN 153
C     SAVE CURRENT NUMNP AND NUMEL                                      MSHGEN 154
      NUMNPO=NUMNP                                                      MSHGEN 155
      NUMELO=NUMEL                                                      MSHGEN 156
      NZ=NZ1-1                                                          MSHGEN 157
      DO 40 I=1,NSPAN1                                                  MSHGEN 158
      NZ=NZ+1                                                           MSHGEN 159
      NDIV1=NSBDV1(I)                                                   MSHGEN 160
      MATZZ=MATZ(NZ)                                                    MSHGEN 161
      IF(MATZZ.EQ.0)GO TO 30                                            MSHGEN 162
      NCUTEL=NCUTZ(NZ)                                                  MSHGEN 163
      CALL CORDZN(0,NZ,IZ,IX,XSP,YSP,X,Y,XZ,YZ)                         MSHGEN 164
      NPOLD=IZ(1,NZ)                                                    MSHGEN 165
      IF(ICNTEL.EQ.0)NPOLD=NPOLD-1                                      MSHGEN 166
      DO 20 J=1,4                                                       MSHGEN 167
      LJ=IZ(J,NZ)                                                       MSHGEN 168
      IF(J.LE.2)GO TO 15                                                MSHGEN 169
      NCDZ(J)=NCODSP(LJ)                                                MSHGEN 170
      GO TO 20                                                          MSHGEN 171
   15 NCDZ(J)=NCODE(LJ)                                                 MSHGEN 172
   20 CONTINUE                                                          MSHGEN 173
      NCD(1)=MIN0(NCDZ(1),NCDZ(4))                                      MSHGEN 174
      NCD(2)=0                                                          MSHGEN 175
      NCD(3)=MIN0(NCDZ(2),NCDZ(3))                                      MSHGEN 176
      IF(I.EQ.1)GO TO 22                                                MSHGEN 177
```

```
      IF(MATZ(NZ-1).LE.0)GO TO 22
      NCD(1)=0
   22 IF(I.EQ.NSPAN1)GO TO 24
      IF(MATZ(NZ+1).LE.0)GO TO 24
      NCD(3)=0
   24 CONTINUE
      NCT(1)=0
      NCT(2)=MXCUT+1
      NCT(3)=0
      IF((I.GT.1).AND.(NCUTZ(NZ).NE.NCUTZ(NZ-1)))
     1 NCT(1)=MIN0(NCUTZ(NZ),NCUTZ(NZ-1))
      IF((I.LT.NSPAN1).AND.(NCUTZ(NZ).NE.NCUTZ(NZ+1)))
     1 NCT(3)=MIN0(NCUTZ(NZ),NCUTZ(NZ+1))
      CALL ZRWEXY(X,Y,NCODE,NPCUT,IX,NELCUT)
      ICNTNP=1
      ICNTEL=1
      GO TO 40
   30 ICNTEL=0
      ICNTNP=0
   40 CONTINUE
      INTERF=0
      NELINC=NUMEL-NUMELO
      NNPINC=NUMNP-NUMNPO
      NRL=NDIV2-2
      NPO=NUMNPO+1
      NPOLD=NUMNPO
      IF(NRL.LE.0)GO TO 110
C
C     INSERT INTERMEDIATE NODAL POINTS AND ELEMENTS IN CURRENT ETA SPAN
C
      ICNTNP=0
      NZ=NZ1-1
      NELO=NUMELO
      DO 90 I=1,NSPAN1
      NZ=NZ+1
      MATZZ=MATZ(NZ)
      IF(MATZZ.EQ.0)GO TO 80
      NCUTEL=NCUTZ(NZ)
      NDIV1=NSBDV1(I)
      EPSINC=2./NDIV1
      CALL CORDZN(0,NZ,IZ,IX,XSP,YSP,X,Y,XZ,YZ)
      EPS=-1.
      IF(ICNTNP.NE.0)GO TO 60
      ICNTNP=1
      ETAN=ETA
      NP=NPO
      DO 50 J=1,NRL
      NP=NP+NNPINC
      ETAN=ETAN+ETAINC
      CALL LOC(XZ,YZ,EPS,ETAN,X(NP),Y(NP))
      NCODE(NP)=NCODE(NPO)
      NPCUT(NP)=0
   50 CONTINUE
   60 DO 70 K=1,NDIV1
      NPO=NPO+1
      NELO=NELO+1
      EPS=EPS+EPSINC
```

```
      NP=NPO                                                            MSHGEN 235
      NEL=NELO                                                          MSHGEN 236
      ETAN=ETA                                                          MSHGEN 237
      DO 70 L=1,NRL                                                     MSHGEN 238
      NEL=NEL+NELINC                                                    MSHGEN 239
      NPS=NP                                                            MSHGEN 240
      NP=NP+NNPINC                                                      MSHGEN 241
      ETAN=ETAN+ETAINC                                                  MSHGEN 242
      CALL LOC(XZ,YZ,EPS,ETAN,X(NP),Y(NP))                              MSHGEN 243
      NCODE(NP)=NCODE(NPO)                                              MSHGEN 244
      NPCUT(NP)=NPCUT(NPO)                                              MSHGEN 245
      IX(1,NEL)=NPS-1                                                   MSHGEN 246
      IX(2,NEL)=NPS                                                     MSHGEN 247
      IX(3,NEL)=NP                                                      MSHGEN 248
      IX(4,NEL)=NP-1                                                    MSHGEN 249
      IX(5,NEL)=MATZZ                                                   MSHGEN 250
      NELCUT(NEL)=NCUTEL                                                MSHGEN 251
   70 CONTINUE                                                          MSHGEN 252
      GO TO 90                                                          MSHGEN 253
   80 IF(ICNTNP.EQ.0)GO TO 90                                           MSHGEN 254
      ICNTNP=0                                                          MSHGEN 255
      NPO=NPO+1                                                         MSHGEN 256
   90 CONTINUE                                                          MSHGEN 257
      NUMEL=NUMEL+NELINC*NRL                                            MSHGEN 258
      NUMNP=NUMNP+NNPINC*NRL                                            MSHGEN 259
      NPOLD=NUMNP-NNPINC                                                MSHGEN 260
      GO TO 110                                                         MSHGEN 261
C                                                                       MSHGEN 262
C     GENERATE INTERFACE NODAL POINTS AND ELEMENTS WITH ROW BELOW       MSHGEN 263
C     ROW BELOW IS INTERFACE IF INTERF=1,NON-INTERFACE IF INTERF=0      MSHGEN 264
C                                                                       MSHGEN 265
  100 INTERF=1                                                          MSHGEN 266
  110 ICNTNP=0                                                          MSHGEN 267
      ICNTEL=0                                                          MSHGEN 268
      NZO=NZ1-1                                                         MSHGEN 269
      NZN=NZO+NSPAN1                                                    MSHGEN 270
      DO 190 I=1,NSPAN1                                                 MSHGEN 271
      NZO=NZO+1                                                         MSHGEN 272
      NZN=NZN+1                                                         MSHGEN 273
      IS1=0                                                             MSHGEN 274
      IS2=0                                                             MSHGEN 275
      IF(NZO.LE.0)IS1=1                                                 MSHGEN 276
      IF(NZN.GT.MXZONE)IS2=1                                            MSHGEN 277
      DO 115 J=1,4                                                      MSHGEN 278
      NCTZ(J)=0                                                         MSHGEN 279
  115 CONTINUE                                                          MSHGEN 280
      NDIV1=NSBDV1(I)                                                   MSHGEN 281
      IF(IS1.NE.0)GO TO 120                                             MSHGEN 282
      MATZZ=MATZ(NZO)                                                   MSHGEN 283
      IF(MATZZ.NE.0)GO TO 140                                           MSHGEN 284
  120 IF(IS2.NE.0)GO TO 180                                             MSHGEN 285
      IF(MATZ(NZN).LE.0)GO TO 180                                       MSHGEN 286
C     GENERATE NODES ONLY                                               MSHGEN 287
      CALL CORDZN(1,NZN,IZ,IX,XSP,YSP,X,Y,XZ,YZ)                        MSHGEN 288
      DO 130 J=1,2                                                      MSHGEN 289
      LJ=IZ(J,NZN)                                                      MSHGEN 290
      NCDZ(J)=NCODSP(LJ)                                                MSHGEN 291
```

```
  130 CONTINUE
      NCD(1)=NCDZ(1)
      NCD(3)=NCDZ(2)
      NCD(2)=MIN0(NCD(1),NCD(3))
      NCTZ(3)=NCUTZ(NZN)
      IF(I.EQ.1)GO TO 132
      NCTZ(1)=NCUTZ(NZN-1)
      IF(IS1.EQ.0)NCTZ(2)=NCUTZ(NZO-1)
  132 NCT(1)=-MAX0(NCTZ(1),NCTZ(2),NCTZ(3),NCTZ(4))
      NCT(2)=0
      IF(I.EQ.NSPAN1)GO TO 134
      NCTZ(1)=NCUTZ(NZN+1)
      IF(IS1.EQ.0)NCTZ(4)=NCUTZ(NZO+1)
  134 NCT(3)=-MAX0(NCTZ(1),NCTZ(2),NCTZ(3),NCTZ(4))
      ETA=-1.
      CALL ZROWXY(X,Y,NCODE,NPCUT)
      ICNTEL=0
      ICNTNP=1
      GO TO 170
C     GENERATE BOTH NODES AND ELEMENTS
  140 CALL CORDZN(0,NZO,IZ,IX,XSP,YSP,X,Y,XZ,YZ)
      ETA=1.
      DO 150 J=3,4
      LJ=IZ(J,NZO)
      NCDZ(J)=NCODSP(LJ)
  150 CONTINUE
      NCD(1)=NCDZ(4)
      NCD(3)=NCDZ(3)
      NCD(2)=MIN0(NCD(1),NCD(3))
      IF(IS2.NE.0)GO TO 155
      IF(MATZ(NZN).LE.0)GO TO 155
      NCD(2)=0
  155 CONTINUE
      IF(IS2.NE.0)GO TO 152
      NCTZ(3)=NCUTZ(NZN)
      IF(I.GT.1)NCTZ(1)=NCUTZ(NZN-1)
  152 IF(IS1.NE.0)GO TO 154
      NCTZ(4)=NCUTZ(NZO)
      IF(I.GT.1)NCTZ(2)=NCUTZ(NZO-1)
  154 NCT(1)=-MAX0(NCTZ(1),NCTZ(2),NCTZ(3),NCTZ(4))
      NCT(2)=MIN0(NCTZ(3),NCTZ(4))
      IF(NCTZ(3).EQ.NCTZ(4))NCT(2)=MXCUT+1
      NCTZ(1)=0
      NCTZ(2)=0
      IF(I.EQ.NSPAN1)GO TO 156
      IF(IS2.EQ.0)NCTZ(1)=NCUTZ(NZN+1)
      IF(IS1.EQ.0)NCTZ(2)=NCUTZ(NZO+1)
  156 NCT(3)=-MAX0(NCTZ(1),NCTZ(2),NCTZ(3),NCTZ(4))
      NCUTEL=NCUTZ(NZO)
      IF(INTERF.EQ.0)GO TO 160
      NPOLD=IZ(1,NZO)
      IF(ICNTEL.LE.0)NPOLD=NPOLD-1
  160 CALL ZRWEXY(X,Y,NCODE,NPCUT,IX,NELCUT)
      ICNTEL=1
      ICNTNP=1
      IZ(3,NZO)=NUMNP
      IZ(4,NZO)=NPC1
```

```
      IF(NZN.GT.MXZONE)GO TO 190
      IF(MATZ(NZN).EQ.0)GO TO 190
  170 IZ(1,NZN)=NPC1
      IZ(2,NZN)=NUMNP
      GO TO 190
  180 ICNTEL=0
      ICNTNP=0
  190 CONTINUE
      GO TO 10
C
  200 NUMNPA=NUMNP
      IF(NSIDNT.EQ.0)GO TO 210
C     IDENTIFICATION OF ZONE SIDES
      CALL IDENT(NUMEL,NUMNP,NUMNPA,X,Y,NCODE,NPCUT,IX)
C
C     FIND BANDWIDTH
  210 CONTINUE
      NPDIF=0
      DO 220 I=1,NUMEL
      DO 220 J=1,3
      I1=IX(J,I)
      K1=J+1
      DO 220 K=K1,4
      NPD=IABS(I1-IX(K,I))
      IF(NPD.LE.NPDIF)GO TO 220
      NPDIF=NPD
      N=I
  220 CONTINUE
      MBAND=2*NPDIF+2
      PRINT 1000,NUMNPA,NUMEL,MBAND,N
 1000 FORMAT("1NUMBER OF NODAL POINTS--------",I5/
     1         "0NUMBER OF ELEMENTS------------",I5/
     2         "0MAXIMUM BANDWIDTH-------------",I5/
     3         "0MXBAND OCCURS FIRST IN ELEMENT",I5)
C     OUTPUT NODAL POINT DATA IF NSIDNT=0
      IF(NSIDNT.NE.0)GO TO 230
      WRITE(1,1200)NUMNPA,NUMEL
      DO 225 I=1,NUMNPA
      WRITE(1,1100) I,NCODE(I),X(I),Y(I)
  225 CONTINUE
 1100 FORMAT(2I5,2E15.5)
  230 CONTINUE
C
C     OUTPUT ELEMENT DATA
      DO 235 I=1,NUMEL
      WRITE(1,1200) I,(IX(J,I),J=1,5)
  235 CONTINUE
 1200 FORMAT(6I5)
C
C     OUTPUT CUT DATA
      IF(MXCUT.EQ.0)GO TO 280
      DO 270 I=1,MXCUT
      NPC=0
      NELC=0
      DO 250 J=1,NUMNP
      IF(NPCUT(J).EQ.I)GO TO 240
      IF(NPCUT(J).GE.(-I))GO TO 250
```

```
  240 NPC=NPC+1
      NCODE(NPC)=J
  250 CONTINUE
      DO 260 J=1,NUMEL
      IF(NELCUT(J).NE.I)GO TO 260
      NELC=NELC+1
      IX(1,NELC)=J
  260 CONTINUE
      WRITE(1,1300)I,NPC,NELC
 1300 FORMAT(3I5)
      WRITE(1,1400)(NCODE(J),J=1,NPC)
 1400 FORMAT(15I5)
      WRITE(1,1400)(IX(1,J),J=1,NELC)
  270 CONTINUE
  280 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CORDZN(IONZ,NZ,IZ,IX,XSP,YSP,X,Y,XZ,YZ)                MSHGEN   423
C                                                                       MSHGEN   424
C     ROUTINE FINDS THE COORDINATES OF THE EIGHT NODES DEFINING A ZONE  MSHGEN   425
C                                                                       MSHGEN   426
      DIMENSION IZ(8,1),IX(5,1),XSP(1),YSP(1),X(1),Y(1),XZ(1),YZ(1),    MSHGEN   427
     1 NPER(4)                                                          MSHGEN   428
C     ARGUMENTS                                                         MSHGEN   429
C       IN                                                              MSHGEN   430
C       IONZ- WHEN THE INTERFACE BETWEEN TWO ZONES IS GENERATED THE     MSHGEN   431
C               ZONE CORNER NODES ARE REPLACED BY THE FINITE ELEMENT    MSHGEN   432
C               NODAL NUMBERS.IONZ INDICATES TO CORDZN IF THIS HAS      MSHGEN   433
C               OCCURED TO THE CURRENT ZONE NZ.(EQUAL ZERO IF CHANGE    MSHGEN   434
C               HAS OCCURED,NONZERO OTHERWISE)                          MSHGEN   435
C       NZ-   CURRENT ZONE NUMBER                                       MSHGEN   436
C       IZ-   THE 8-VECTOR DEFINED BY THE NZ COLUMN OF IZ DEFINES       MSHGEN   437
C               ZONE NZ                                                 MSHGEN   438
C       IX-   THE 5-VECTOR DEFINED BY THE NUMEL COLUMN OF IX DEFINES    MSHGEN   439
C               THE NUMEL FINITE ELEMENT                                MSHGEN   440
C       XSP,YSP- X AND Y COORDINATES OF SPECIFIED POINTS                MSHGEN   441
C       X,Y      X AND Y COORDINATES OF FINITE ELEMENT NODAL POINTS     MSHGEN   442
C      OUT                                                              MSHGEN   443
C       XZ,YZ    X AND Y COORDINATES OF SPECIFIED NODES DEFINING NZ     MSHGEN   444
      DATA NPER/2,3,4,1/                                                MSHGEN   445
C                                                                       MSHGEN   446
      IF(IONZ.EQ.0)GO TO 20                                             MSHGEN   447
      DO 10 I=1,4                                                       MSHGEN   448
      N=IZ(I,NZ)                                                        MSHGEN   449
      XZ(I)=XSP(N)                                                      MSHGEN   450
      YZ(I)=YSP(N)                                                      MSHGEN   451
   10 CONTINUE                                                          MSHGEN   452
      GO TO 30                                                          MSHGEN   453
   20 N=IZ(1,NZ)                                                        MSHGEN   454
      XZ(1)=X(N)                                                        MSHGEN   455
      YZ(1)=Y(N)                                                        MSHGEN   456
      N=IZ(2,NZ)                                                        MSHGEN   457
      XZ(2)=X(N)                                                        MSHGEN   458
      YZ(2)=Y(N)                                                        MSHGEN   459
      N=IZ(3,NZ)                                                        MSHGEN   460
      XZ(3)=XSP(N)                                                      MSHGEN   461
      YZ(3)=YSP(N)                                                      MSHGEN   462
      N=IZ(4,NZ)                                                        MSHGEN   463
      XZ(4)=XSP(N)                                                      MSHGEN   464
      YZ(4)=YSP(N)                                                      MSHGEN   465
   30 K=4                                                               MSHGEN   466
      DO 50 I=1,4                                                       MSHGEN   467
      K=K+1                                                             MSHGEN   468
      N=IZ(K,NZ)                                                        MSHGEN   469
C     IF SPECIFIED NODAL NUMBER = 0 GENERATE MID-POINT COORDINATES      MSHGEN   470
      IF(N.EQ.0)GO TO 40                                                MSHGEN   471
      XZ(K)=XSP(N)                                                      MSHGEN   472
      YZ(K)=YSP(N)                                                      MSHGEN   473
      GO TO 50                                                          MSHGEN   474
   40 J=NPER(I)                                                         MSHGEN   475
      XZ(K)=.5*(XZ(I)+XZ(J))                                            MSHGEN   476
      YZ(K)=.5*(YZ(I)+YZ(J))                                            MSHGEN   477
   50 CONTINUE                                                          MSHGEN   478
      RETURN                                                            MSHGEN   479
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      END                                                         MSHGEN     480
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      SUBROUTINE ZROWXY(X,Y,NCODE,NPCUT)                                MSHGEN  481
C                                                                       MSHGEN  482
C     ROUTINE GENERATES A ROW OF NODAL POINTS ACCROSS A ZONE            MSHGEN  483
C                                                                       MSHGEN  484
C     DESCRIPTION OF IMPORTANT PARAMETERS                               MSHGEN  485
C     INPUT                                                             MSHGEN  486
C       NDIV1-NUMBER OF SUBDIVISIONS IN EPS DIRECTION                   MSHGEN  487
C       ICNTNP- INDICATOR OF CONTINUITY OF NODAL POINTS                 MSHGEN  488
C         =0,CONTINUOUS NONZERO,NONCONTINUOUS                           MSHGEN  489
C         HAS NODE AT EPS=-1 BEEN PREVIOUSLY GENERATED(=0)OR NOT        MSHGEN  490
C       NCT( )- GIVES NPCUT NUMBER TO BE ASSIGNED TO NODAL POINTS       MSHGEN  491
C         NCT(1),CUT NUMBER OF NODE EPS=-1                              MSHGEN  492
C         NCT(2),CUT NUMBER OF NODE EPS=+1                              MSHGEN  493
C         NCT(3),CUT NUMBER OF INTERMEDIATE NODES                       MSHGEN  494
C       NCD( )- GIVES CODE NUMBER(NCODE)TO BE ASSIGNED TO NODAL POINTS  MSHGEN  495
C         NCD(1),NCD(2)AND NCD(3) ARE DEFINED ANALGOUSLY TO NCT         MSHGEN  496
C       ETA- CURRENT ETA VALUE                                          MSHGEN  497
C       XZ,YZ- COORDINATES OF NODES DEFINING CURRENT ZONE               MSHGEN  498
C     OUTPUT                                                            MSHGEN  499
C       NUMNP- NUMBER OF NODAL POINTS IS UPDATED                        MSHGEN  500
C       X,Y - COORDINATES OF NODAL POINT ARE INSERTED IN X(NUMNP) AND   MSHGEN  501
C             Y(NUMNP)                                                  MSHGEN  502
C       NCODE - CODE NUMBER IS STORED IN NCODE(NUMNP)                   MSHGEN  503
C       NPCUT - CUT NUMBER IS STORED IN NPCUT(NUMNP)                    MSHGEN  504
C       NPC1  - STORES NUMNP AT EPS=-1 FOR FUTURE USE                   MSHGEN  505
C                                                                       MSHGEN  506
      COMMON/ZROW/NUMNP,NUMEL,NPOLD,NDIV1,ICNTNP,ICNTEL,MATZZ,          MSHGEN  507
     1 NCUTEL,NPC1,NCD(3),NCT(3),ETA,XZ(8),YZ(8)                        MSHGEN  508
      DIMENSION X(1),Y(1),NCODE(1),NPCUT(1)                             MSHGEN  509
C                                                                       MSHGEN  510
      EPS=-1.                                                           MSHGEN  511
      IF(ICNTNP.NE.0)GO TO 10                                           MSHGEN  512
C     GENERATE NODE AT EPS=-1 IF ICNTNP .NE. 0                          MSHGEN  513
      NUMNP=NUMNP+1                                                     MSHGEN  514
      CALL LOC(XZ,YZ,EPS,ETA,X(NUMNP),Y(NUMNP))                         MSHGEN  515
      NCODE(NUMNP)=NCD(1)                                               MSHGEN  516
      NPCUT(NUMNP)=NCT(1)                                               MSHGEN  517
C                                                                       MSHGEN  518
   10 NPC1=NUMNP                                                        MSHGEN  519
      IF(NDIV1.LE.1)GO TO 30                                            MSHGEN  520
      EPSINC=2./NDIV1                                                   MSHGEN  521
      NZ=NDIV1-1                                                        MSHGEN  522
      NC=NCD(2)                                                         MSHGEN  523
      NT=NCT(2)                                                         MSHGEN  524
C     GENERATE INTERMEDIATE NODES IF NDIV1 .GT. 1                       MSHGEN  525
      DO 20 N=1,NZ                                                      MSHGEN  526
      NUMNP=NUMNP+1                                                     MSHGEN  527
      EPS=EPS+EPSINC                                                    MSHGEN  528
      CALL LOC(XZ,YZ,EPS,ETA,X(NUMNP),Y(NUMNP))                         MSHGEN  529
      NCODE(NUMNP)=NC                                                   MSHGEN  530
      NPCUT(NUMNP)=NT                                                   MSHGEN  531
   20 CONTINUE                                                          MSHGEN  532
C                                                                       MSHGEN  533
C     GENERATE FINAL NODE AT EPS=+1                                     MSHGEN  534
   30 NUMNP=NUMNP+1                                                     MSHGEN  535
      EPS=1.                                                            MSHGEN  536
      CALL LOC(XZ,YZ,EPS,ETA,X(NUMNP),Y(NUMNP))                         MSHGEN  537
```

```
                    NCODE(NUMNP)=NCD(3)                                     MSHGEN    538
                    NPCUT(NUMNP)=NCT(3)                                     MSHGEN    539
   60          C                                                            MSHGEN    540
                    RETURN                                                  MSHGEN    541
                    END                                                     MSHGEN    542
```

```
      SUBROUTINE ZRWEXY(X,Y,NCODE,NPCUT,IX,NELCUT)                      MSHGEN   543
C                                                                       MSHGEN   544
      COMMON/ZROW/NUMNP,NUMEL,NPOLD,NDIV1,ICNTNP,ICNTEL,MATZZ,          MSHGEN   545
     1 NCUTEL,NPC1,NCD(3),NCT(3),ETA,XZ(8),YZ(8)                        MSHGEN   546
      DIMENSION X(1),Y(1),NCODE(1),NPCUT(1),IX(5,1),NELCUT(1)           MSHGEN   547
C                                                                       MSHGEN   548
C     ROUTINE GENERATES A ROW OF NODAL POINTS AS WELL AS                MSHGEN   549
C     ELEMENTS WITH ROW BELOW                                           MSHGEN   550
C                                                                       MSHGEN   551
C     DESCRIPTION OF IMPORTANT PARAMETERS                               MSHGEN   552
C     INPUT                                                             MSHGEN   553
C       NDIV1,ICNTNP,NCT,NCD,ETA,XZ,YZ ARE AS DEFINED IN ZROWXY         MSHGEN   554
C       ICNTEL-INDICATOR CONTINUITY OF ELEMENTS                         MSHGEN   555
C         =0,CONTINUOUS NONZERO,NONCONTINUOUS.                          MSHGEN   556
C         ON A BOUNDARY ICNTEL WILL BE NONZERO                          MSHGEN   557
C       MATZZ-THE MATERIAL NUMBER ASSOCIATED WITH THE CURRENT ZONE      MSHGEN   558
C       NCUTEL-THE CUT NUMBER OF THE CURRENT ZONE                       MSHGEN   559
C     OUTPUT                                                            MSHGEN   560
C       NUMNP,X,Y,NCODE,NPCUT AND NPC1 ARE DEFINED AS IN ZROWXY         MSHGEN   561
C       NUMEL-THE NUMBER OF ELEMENTS IS UPDATED AS THEY ARE             MSHGEN   562
C           GENERATED                                                   MSHGEN   563
C       NPOLD-KEEPS TRACK OF NODAL NUMBERS OF ROW BELOW.THESE ARE       MSHGEN   564
C           NEEDED FOR ELEMENT GENERATION.ON ENTRY TO THIS ROUTINE       MSHGEN   565
C           NPOLD CONTAINS F.E. NODAL NUMBER OF EPS=-1 NODE OF ROW      MSHGEN   566
C           BELOW IF ICNTEL=0,OTHERWISE IT IS ONE LESS                  MSHGEN   567
C       IX( )-DEFINES F.E. ELEMENTS WITH MATERIAL NUMBER                MSHGEN   568
C       NELCUT()-CONTAINS THE CUT NUMBERS OF ALL ELEMENTS GENERATED     MSHGEN   569
C                                                                       MSHGEN   570
      EPS=-1.                                                           MSHGEN   571
C     GENERATE FIRST NODE IF NECESSARY                                  MSHGEN   572
      IF(ICNTNP.NE.0)GO TO 10                                           MSHGEN   573
      NUMNP=NUMNP+1                                                     MSHGEN   574
      CALL LOC(XZ,YZ,EPS,ETA,X(NUMNP),Y(NUMNP))                         MSHGEN   575
      NCODE(NUMNP)=NCD(1)                                               MSHGEN   576
      NPCUT(NUMNP)=NCT(1)                                               MSHGEN   577
C                                                                       MSHGEN   578
   10 IX(4,NUMEL+1)=NUMNP                                               MSHGEN   579
      NPC1=NUMNP                                                        MSHGEN   580
      IF(ICNTEL.NE.0)GO TO 20                                           MSHGEN   581
      NPOLD=NPOLD+1                                                     MSHGEN   582
   20 IX(1,NUMEL+1)=NPOLD                                               MSHGEN   583
      IF(NDIV1.LE.1)GO TO 40                                            MSHGEN   584
      EPSINC=2./NDIV1                                                   MSHGEN   585
      NZ=NDIV1-1                                                        MSHGEN   586
      NC=NCD(2)                                                         MSHGEN   587
      NT=NCT(2)                                                         MSHGEN   588
C     GENERATE INTERMEDIATE NODES AND ALL ELEMENTS EXCEPT THE LAST      MSHGEN   589
      DO 30 N=1,NZ                                                      MSHGEN   590
      NUMEL=NUMEL+1                                                     MSHGEN   591
      NUMNP=NUMNP+1                                                     MSHGEN   592
      NPOLD=NPOLD+1                                                     MSHGEN   593
      IX(2,NUMEL)=NPOLD                                                 MSHGEN   594
      IX(3,NUMEL)=NUMNP                                                 MSHGEN   595
      IX(5,NUMEL)=MATZZ                                                 MSHGEN   596
      NELCUT(NUMEL)=NCUTEL                                              MSHGEN   597
      EPS=EPS+EPSINC                                                    MSHGEN   598
      CALL LOC(XZ,YZ,EPS,ETA,X(NUMNP),Y(NUMNP))                         MSHGEN   599
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          NCODE(NUMNP)=NC                                        MSHGEN    600
          NPCUT(NUMNP)=NT                                        MSHGEN    601
          IX(4,NUMEL+1)=NUMNP                                    MSHGEN    602
          IX(1,NUMEL+1)=NPOLD                                    MSHGEN    603
       30 CONTINUE                                               MSHGEN    604
C                                                                MSHGEN    605
C         GENERATE FINAL NODE AND FINAL ELEMENT                  MSHGEN    606
       40 NUMEL=NUMEL+1                                          MSHGEN    607
          NUMNP=NUMNP+1                                          MSHGEN    608
          NPOLD=NPOLD+1                                          MSHGEN    609
          EPS=1.                                                 MSHGEN    610
          CALL LOC(XZ,YZ,EPS,ETA,X(NUMNP),Y(NUMNP))              MSHGEN    611
          IX(2,NUMEL)=NPOLD                                      MSHGEN    612
          IX(3,NUMEL)=NUMNP                                      MSHGEN    613
          IX(5,NUMEL)=MATZZ                                      MSHGEN    614
          NELCUT(NUMEL)=NCUTEL                                   MSHGEN    615
          NCODE(NUMNP)=NCD(3)                                    MSHGEN    616
          NPCUT(NUMNP)=NCT(3)                                    MSHGEN    617
C                                                                MSHGEN    618
          RETURN                                                 MSHGEN    619
          END                                                    MSHGEN    620
```

```
      SUBROUTINE LOC(VX,VY,EPS,ETA,X,Y)                                  MSHGEN   621
C     THIS SUBROUTINE CALCULATES (X,Y) COORDINATES CORRESPONDING TO      MSHGEN   622
C     LOCAL CORDINATES (EPS,ETA) USING QUADRATIC INTERPOLATION FUNCTIONS MSHGEN   623
      DIMENSION VX(8),VY(8),RN(8)                                        MSHGEN   624
      EPSP=1.+EPS                                                        MSHGEN   625
      EPSM=1.-EPS                                                        MSHGEN   626
      ETAP=1.+ETA                                                        MSHGEN   627
      ETAM=1.-ETA                                                        MSHGEN   628
      RN(1)=-.25*EPSM*ETAM*(EPS+ETAP)                                    MSHGEN   629
      RN(2)=-.25*EPSP*ETAM*(-EPS+ETAP)                                   MSHGEN   630
      RN(3)=-.25*EPSP*ETAP*(-EPS+ETAM)                                   MSHGEN   631
      RN(4)=-.25*EPSM*ETAP*(EPS+ETAM)                                    MSHGEN   632
      RN(5)=.5*ETAM*EPSP*EPSM                                            MSHGEN   633
      RN(6)=.5*EPSP*ETAP*ETAM                                            MSHGEN   634
      RN(7)=.5*ETAP*EPSP*EPSM                                            MSHGEN   635
      RN(8)=.5*EPSM*ETAP*ETAM                                            MSHGEN   636
      X=0.0                                                              MSHGEN   637
      Y=0.                                                               MSHGEN   638
      DO 10 I=1,8                                                        MSHGEN   639
      X=X+RN(I)*VX(I)                                                    MSHGEN   640
      Y=Y+RN(I)*VY(I)                                                    MSHGEN   641
   10 CONTINUE                                                           MSHGEN   642
      RETURN                                                             MSHGEN   643
      END                                                                MSHGEN   644
```

```
      SUBROUTINE IDENT(NUMEL,NUMNP,NUMNPA,X,Y,NCODE,NPCUT,IX)         MSHGEN  645
C     ROUTINE PERFORMS IDENTIFICATION OF NODAL POINTS FOR GENMSH       MSHGEN  646
      DIMENSION X(1),Y(1),NCODE(1),NPCUT(1),IX(5,1)                    MSHGEN  647
C                                                                      MSHGEN  648
C     LOCATE IDENTIFIED NODAL POINTS                                   MSHGEN  649
      NUMNPA=NUMNP                                                     MSHGEN  650
      NPF=NUMNP-1                                                      MSHGEN  651
      DO 20 NP=1,NPF                                                   MSHGEN  652
      IF(NCODE(NP).LT.0)GO TO 20                                       MSHGEN  653
      XC=X(NP)                                                         MSHGEN  654
      YC=Y(NP)                                                         MSHGEN  655
      NP1=NP+1                                                         MSHGEN  656
      DO 10 I=NP1,NUMNP                                                MSHGEN  657
      IF(ABS(YC-Y(I)).GT.1.E-5)GO TO 10                                MSHGEN  658
      IF(ABS(XC-X(I)).GT.1.E-5)GO TO 10                                MSHGEN  659
      NUMNPA=NUMNPA-1                                                  MSHGEN  660
      NCODE(I)=-NP                                                     MSHGEN  661
   10 CONTINUE                                                         MSHGEN  662
   20 CONTINUE                                                         MSHGEN  663
C     OUTPUT NODAL POINT DATA                                          MSHGEN  664
      WRITE(1,100)NUMNPA,NUMEL                                         MSHGEN  665
      NPA=0                                                            MSHGEN  666
      DO 40 NP=1,NUMNP                                                 MSHGEN  667
      NC=NCODE(NP)                                                     MSHGEN  668
      IF(NC.LT.0)GO TO 30                                              MSHGEN  669
      NPA=NPA+1                                                        MSHGEN  670
      WRITE(1,100)NPA,NC,X(NP),Y(NP)                                   MSHGEN  671
  100 FORMAT(2I5,2E15.5)                                               MSHGEN  672
      NCODE(NP)=NPA                                                    MSHGEN  673
      NPCUT(NPA)=NPCUT(NP)                                             MSHGEN  674
      GO TO 40                                                         MSHGEN  675
   30 NC=-NC                                                           MSHGEN  676
      NCODE(NP)=NCODE(NC)                                              MSHGEN  677
   40 CONTINUE                                                         MSHGEN  678
C     REDEFINE ELEMENTS                                                MSHGEN  679
      DO 50 NEL=1,NUMEL                                                MSHGEN  680
      DO 50 I=1,4                                                      MSHGEN  681
      NP=IX(I,NEL)                                                     MSHGEN  682
      IX(I,NEL)=NCODE(NP)                                              MSHGEN  683
   50 CONTINUE                                                         MSHGEN  684
      RETURN                                                           MSHGEN  685
      END                                                              MSHGEN  686
```

APPENDIX C

FORTRAN LISTING OF MSHPLT

```
      PROGRAM MSHPLT(INPUT,OUTPUT,TAPE1,TAPE3=OUTPUT)                   MSHPLT       2
C                                                                       MSHPLT       3
C     THIS ROUTINE PLOTS THE RESULTS OF THE MESH GENERATOR "MSHGEN"     MSHPLT       4
C     CALCOMP SOFTWARE IS USED                                          MSHPLT       5
C                                                                       MSHPLT       6
C                                                                       MSHPLT       7
C                                                                       MSHPLT       8
C   ******************************************************************** MSHPLT       9
C                                                                       MSHPLT      10
C                                                                       MSHPLT      11
C   SAMPLE PLOT                                                         MSHPLT      12
C                                                                       MSHPLT      13
C                                                                       MSHPLT      14
C                                                                       MSHPLT      15
C                                                                       MSHPLT      16
C   -----------*******************************************************  MSHPLT      17
C    1         *                  *********************              *  MSHPLT      18
C    1         *                  *********************              *  MSHPLT      19
C    1         *                  *********************              *  MSHPLT      20
C    1         *                  *********************              *  MSHPLT      21
C    1         *                  *********************              *  MSHPLT      22
C    1         *                  *********************              *  MSHPLT      23
C    1         *                  *********************              *  MSHPLT      24
C    1         *                  *********************              *  MSHPLT      25
C    1   ------*------------------*********************              *  MSHPLT      26
C    1   1     *                  1                   1              *  MSHPLT      27
C    1   1     *                  1                   1              *  MSHPLT      28
C   Y    1     *                  1                   1              *  MSHPLT      29
C   O    1     *                  1                   1              *  MSHPLT      30
C   R    1     *                  1                   1              *  MSHPLT      31
C   D    1     *                  1                   1              *  MSHPLT      32
C    1   1     *                  1                   1              *  MSHPLT      33
C    1  O      *                  1                   1              *  MSHPLT      34
C    1  R      *                  1                   1              *  MSHPLT      35
C    1  G      *                  1                   1              *  MSHPLT      36
C    1  Y      *                  1                   1              *  MSHPLT      37
C    1   1     *                  1                   1              *  MSHPLT      38
C    1   1     *                  1                   1              *  MSHPLT      39
C    1   1     *                  1                   1              *  MSHPLT      40
C    1   1     *                  1                   1              *  MSHPLT      41
C    1   1     *                  1                   1              *  MSHPLT      42
C    1   1     *                  1                   1              *  MSHPLT      43
C   -----------*******************************************************  MSHPLT      44
C              1                  1                   1                 MSHPLT      45
C              1-------ORGX-------1                   1                 MSHPLT      46
C              1                                      1                 MSHPLT      47
C              1-----------------XORD-----------------1                 MSHPLT      48
C                                                                       MSHPLT      49
C                                                                       MSHPLT      50
C                                                                       MSHPLT      51
C                                                                       MSHPLT      52
C*********************************************************************** MSHPLT      53
C                                                                       MSHPLT      54
C                                                                       MSHPLT      55
C                                                                       MSHPLT      56
C*********************************************************************** MSHPLT      57
C     VARIABLE NAMES AND DEFINITIONS                                    MSHPLT      58
```

```
C                                                                       MSHPLT  59
C     ICR,ICP,IPR.....LOGICAL UNIT NUMBERS - READ, PUNCH, PRINT         MSHPLT  60
C     ORGY............DISTANCE ALONG THE Y AXIS TO THE BOTTOM OF THE    MSHPLT  61
C                     REGION TO BE PLOTTED                              MSHPLT  62
C     YORD............DISTANCE ALONG THE Y AXIS TO THE TOP OF THE       MSHPLT  63
C                     SECTION TO BE PLOTTED                             MSHPLT  64
C     ORGX............DISTANCE ALONG THE X AXIS TO THE LEFT HAND        MSHPLT  65
C                     BOUNDARY OF THE SECTION TO BE PLOTTED             MSHPLT  66
C     XORD............DISTANCE ALONG THE X AXIS TO THE RIGHT HAND       MSHPLT  67
C                     BOUNDARY OF THE SECTION TO BE PLOTTED             MSHPLT  68
C     NBOUND..........CODE FOR PLOTTING INSIDE OR OUTSIDE THE SECTION   MSHPLT  69
C                     NBOUND = 0 .PLOT ALL DATA                         MSHPLT  70
C                            = 1  PLOT INSIDE REGION SPECIFIED          MSHPLT  71
C                            = 2  PLOT OUTSIDE REGION SPECIFIED         MSHPLT  72
C     ELEOUT..........CODE FOR PRINTING OUT THE EVEN ELEMENT NUMBERS    MSHPLT  73
C                     ELEOUT = 0   DONT PRINT ELEMENT NUMBERS           MSHPLT  74
C                            = 1   PRINT OUT ELEMENT NUMBERS            MSHPLT  75
C     NPTOUT..........CODE FOR PRINTING EVEN NODAL POINT NUMBERS        MSHPLT  76
C                     SAME CODING AS ELEOUT                             MSHPLT  77
C     XFAC............SCALING FACTOR  MULTIPLY ALL DIMENSIONS BY XFAC   MSHPLT  78
C                     IF XFAC = 0.5   PLOT WILL BE HALF SIZE            MSHPLT  79
C     HT..............HEIGHT IN INCHES OF ELEMENT AND NODAL POINT       MSHPLT  80
C                     NUMBERS THAT ARE TO BE PRINTED                    MSHPLT  81
C                     SUGGEST HT = 0.07                                 MSHPLT  82
C     DIR.............COUNTER CLOCKWISE ANGLE (DEGREES) FROM POSITIVE   MSHPLT  83
C                     X AXIS FOR PRINTING THE NODAL POINT NUMBERS       MSHPLT  84
C                     FOR LEFT TO RIGHT PRINTING  DIR = 0.              MSHPLT  85
C     NUMNP...........TOTAL NUMBER OF NODAL POINTS IN MESH              MSHPLT  86
C     NUMEL...........TOTAL NUMBER OF ELEMENTS IN MESH                  MSHPLT  87
C     N...............A NODAL POINT NUMBER                              MSHPLT  88
C     X AND Y.........ITS X AND Y CO-ORDINATES                          MSHPLT  89
C     L...............INTERMEDIATE STORAGE OF LAST NODAL POINT READ IN  MSHPLT  90
C     R(N), Z(N)......ARRAY CONTAINING THE X AND Y CO-ORDINATES OF ALL  MSHPLT  91
C                     THE NODAL POINTS                                  MSHPLT  92
C     M...............AN ELEMENT NUMBER                                 MSHPLT  93
C     I,J,K,L ........NODAL POINT NUMBERS OF THE FOUR CORNERS OF AN     MSHPLT  94
C                     ELEMENT.  IF ELEMENT IS TRIANGULAR, K = L         MSHPLT  95
C     NELE............NUMBER OF SIDES OF AN ELEMENT  =3 OR 4            MSHPLT  96
C     AREA............AREA OF AN ELEMENT, USED FOR TESTING IF ELEMENT   MSHPLT  97
C                     PARAMETERS ARE NUMBERED CORRECTLY                 MSHPLT  98
C     IX(NUMEL,5).....ARRAY CONTAINING ELEMENT PARAMETERS               MSHPLT  99
C                     SUBSCRIPTS 1 TO 4 CONTAIN CORNER POINTS           MSHPLT 100
C                     SUBSCRIPT 5 IS THE ELEMENT MATERIAL NUMBER        MSHPLT 101
C     DX(5), DY(5)....ARRAYS CONTAINING THE X AND Y CO-ORDINATES OF     MSHPLT 102
C                     THE CORNERS OF AN ELEMENT                         MSHPLT 103
C                                                                       MSHPLT 104
C*********************************************************************** MSHPLT 105
C                                                                       MSHPLT 106
      INTEGER ELEOUT                                                    MSHPLT 107
C     THE COMMON CARD MUST BE OF THE FORM                               MSHPLT 108
C     COMMON R(MXNP),Z(MXNP),IX(MXEL,5)                                 MSHPLT 109
C      WITH MXNP AND MXEL REPLACED BY APPROPRIATE VALUES. MXNP AND MXEL MSHPLT 110
C      ARE UPPER BOUNDS TO NUMNP AND NUMEL RESPECTIVELY.DEFAULT VALUES  MSHPLT 111
C      ARE MXNP=MXEL=500. THIS COMMON CARD IF MODIFIED MUST ALSO BE     MSHPLT 112
C      REPLACED IN SUBROUTINES PLOTR AND XNODAL. ON THE CDC 6400 THIS   MSHPLT 113
C      IS PERFORMED BY USING COMDECK MSHDIM                             MSHPLT 114
      COMMON R(500),Z(500),IX(500,5)                                    MSHDIM   2
```

```
         1 ,DX(5),DY(5),NUMNP,NUMEL,XFAC,HT,DIR,
         2 ORGX,XORD,ORGY,YORD,NBOUND,ELEOUT,NPTOUT
          DIMENSION DATA(1024)
          DATA ICR/1/,ICP/2/,IPR/3/
          CALL PLOTS(DATA,1024)
C
C
          REWIND ICR
C
C*********************************************************************
C         READ IN THE INPUT PARAMETERS AND PRINT THEM
C*********************************************************************
          READ(ICR,300)NUMNP,NUMEL
      300 FORMAT(2I5)
          READ 100 ,XFAC,NBOUND,ELEOUT,NPTOUT,HT,DIR
      100 FORMAT(F10.0,3I10,2F10.0)
          IF(XFAC.EQ.0.0)XFAC=1.
          IF(HT.EQ.0.0) HT=0.07
C         IF NBOUND NOT EQUAL ZERO READ IN COORDINATES OF SPECIFIED
C            RECTANGLE.THESE ARE IN LOGICAL UNITS NOT INCHES
          IF(NBOUND.EQ.0) GO TO 125
          READ 150,ORGX,XORD,ORGY,YORD
      150 FORMAT(4F10.0)
      125 PRINT 175,XFAC,NBOUND,ELEOUT,NPTOUT,HT,DIR,NUMNP,NUMEL
      175 FORMAT(1H1,10X,"MSHPLT CONTROL CARD"/
         1 21H0XFAC--------------- ,G12.5/
         2 21H NBOUND------------- ,I10/
         3 21H ELEOUT------------- ,I10/
         4 21H NPTOUT------------- ,I10/
         5 21H HT----------------- ,G12.5/
         6 21H DIR---------------- ,G12.5/
         7 21H NUMNP-------------- ,I10/
         8 21H NUMEL-------------- ,I10)
          IF(NBOUND.EQ.0) GO TO 275
          IF(NBOUND.EQ.1)PRINT 200
      200 FORMAT(// 10X,"INSIDE OF SPECIFIED REGION IS PLOTTED")
          IF(NBOUND.EQ.2)PRINT 225
      225 FORMAT(// 10X,"OUTSIDE OF SPECIFIED REGION IS PLOTTED")
          PRINT 250,ORGX,XORD,ORGY,YORD
      250 FORMAT(1H0,10X,"SPECIFIED REGION"/
         1 21H ORGX--------------- ,G12.5/
         2 21H XORD--------------- ,G12.5/
         3 21H ORGY--------------- ,G12.5/
         4 21H YORD--------------- ,G12.5)
      275 CONTINUE
C*********************************************************************
C         INPUT NODAL POINTS
C*********************************************************************
          DO 401 I=1,NUMNP
          READ(ICR,400) R(I),Z(I)
      400 FORMAT(10X,2E15.6)
      401 CONTINUE
          DO 450 LL=1,NUMNP
          R(LL)=R(LL)*XFAC
          Z(LL)=Z(LL)*XFAC
      450 CONTINUE
C*********************************************************************
```

```
      IF(NBOUND .EQ. 0) GO TO 475                                       MSHPLT 173
      XORD=XORD*XFAC                                                    MSHPLT 174
      YORD=YORD*XFAC                                                    MSHPLT 175
      ORGY=ORGY*XFAC                                                    MSHPLT 176
      ORGX=ORGX*XFAC                                                    MSHPLT 177
  475 CONTINUE                                                          MSHPLT 178
C*********************************************************************** MSHPLT 179
C     INPUT ELEMENT DATA                                                MSHPLT 180
C*********************************************************************** MSHPLT 181
      DO 501 I=1,NUMEL                                                  MSHPLT 182
      READ(ICR,500) (IX(I,J),J=1,5)                                     MSHPLT 183
  500 FORMAT(5X,5I5)                                                    MSHPLT 184
  501 CONTINUE                                                          MSHPLT 185
C                                                                       MSHPLT 186
      CALL PLOTR                                                        MSHPLT 187
C                                                                       MSHPLT 188
      STOP                                                              MSHPLT 189
      END                                                               MSHPLT 190
```

```
      SUBROUTINE PLOTR                                                  MSHPLT  191
      INTEGER ELEOUT                                                    MSHPLT  192
      COMMON R(500),Z(500),IX(500,5)                                    MSHDIM    2
     1 ,DX(5),DY(5),NUMNP,NUMEL,XFAC,HT,DIR,                            MSHPLT  194
     2 ORGX,XORD,ORGY,YORD,NBOUND,ELEOUT,NPTOUT                         MSHPLT  195
      DATA IPR/3/                                                       MSHPLT  196
C    ****************************************************************** MSHPLT  197
C     THIS SUBROUTINE PLOTS A NUMBER OF DIFFERENT SECTIONS OF A MESH.   MSHPLT  198
C     IF THE BOTTOM PART OF THE SECTION TO BE PLOTTED IS NOT ON THE X-AX MSHPLT  199
C     THE WHOLE SECTION IS BROUGHT DOWN TO THE X-AXIS.                  MSHPLT  200
C     INITIALIZE PLOT                                                   MSHPLT  201
C    ****************************************************************** MSHPLT  202
      RM=0.                                                             MSHPLT  203
      DO 30 M=1,NUMEL                                                   MSHPLT  204
      RM=RM+1.                                                          MSHPLT  205
      I=IX(M,1)                                                         MSHPLT  206
      J=IX(M,2)                                                         MSHPLT  207
      K=IX(M,3)                                                         MSHPLT  208
      L=IX(M,4)                                                         MSHPLT  209
C********************************************************************** MSHPLT  210
C     TEST ELEMENT TO SEE IF IT IS A TRIANGLE OR QUADRILATERAL          MSHPLT  211
C********************************************************************** MSHPLT  212
      IF(K-L)500,600,500                                                MSHPLT  213
C********************************************************************** MSHPLT  214
C     THE ELEMENT IS A TRIANGLE IF K = L                                MSHPLT  215
C********************************************************************** MSHPLT  216
  600 NELE=4                                                            MSHPLT  217
      DX(1)=R(I)                                                        MSHPLT  218
      DY(1)=Z(I)                                                        MSHPLT  219
      DX(2)=R(J)                                                        MSHPLT  220
      DY(2)=Z(J)                                                        MSHPLT  221
      DX(3)=R(K)                                                        MSHPLT  222
      DY(3)=Z(K)                                                        MSHPLT  223
      DX(4)=DX(1)                                                       MSHPLT  224
      DY(4)=DY(1)                                                       MSHPLT  225
C********************************************************************** MSHPLT  226
C     IF AREA IS 0 OR NEGATIVE,PRINT ERROR MESSAGE                      MSHPLT  227
C********************************************************************** MSHPLT  228
      AREA=((DX(2)-DX(1))*(DY(3)-DY(1))-(DX(3)-DX(1))*(DY(2)-DY(1)))*0.5 MSHPLT  229
      IF(AREA.GT.0.) GO TO 275                                          MSHPLT  230
      WRITE(IPR,270) M                                                  MSHPLT  231
  270 FORMAT(1X," AREA OF TRIANGLE",I5," IS NONPOSITIVE")               MSHPLT  232
      GO TO 275                                                         MSHPLT  233
C********************************************************************** MSHPLT  234
C     THE ELEMENT IS A QUADRILATERAL                                    MSHPLT  235
C********************************************************************** MSHPLT  236
  500 NELE=5                                                            MSHPLT  237
      DX(1)=R(I)                                                        MSHPLT  238
      DY(1)=Z(I)                                                        MSHPLT  239
      DX(2)=R(J)                                                        MSHPLT  240
      DY(2)=Z(J)                                                        MSHPLT  241
      DX(3)=R(K)                                                        MSHPLT  242
      DY(3)=Z(K)                                                        MSHPLT  243
      DX(4)=R(L)                                                        MSHPLT  244
      DY(4)=Z(L)                                                        MSHPLT  245
      DX(5)=DX(1)                                                       MSHPLT  246
      DY(5)=DY(1)                                                       MSHPLT  247
```

```
      C******************************************************************* MSHPLT   248
      C     IF AREA IS 0 OR NEGATIVE,PRINT ERROR MESSAGE                    MSHPLT   249
      C******************************************************************* MSHPLT   250
            AREA=((DX(2)-DX(1))*(DY(3)-DY(1))-(DX(3)-DX(1))*(DY(2)-DY(1)))*0.5 MSHPLT   251
           1+((DX(3)-DX(1))*(DY(4)-DY(1))-(DX(4)-DX(1))*(DY(3)-DY(1)))*0.5    MSHPLT   252
            IF(AREA.GT.0.) GO TO 275                                         MSHPLT   253
            WRITE(IPR,271) M                                                 MSHPLT   254
        271 FORMAT(1X,"AREA OF QUADRILATERAL",I5," IS NONPOSITIVE")          MSHPLT   255
      C******************************************************************* MSHPLT   256
      C     CHECK THE BOUNDS OF THE SECTION TO BE PLOTTED                   MSHPLT   257
      C******************************************************************* MSHPLT   258
        275 IF(NBOUND.EQ.0)GO TO 700                                         MSHPLT   259
            IF(NBOUND.NE.1)GO TO 310                                         MSHPLT   260
            DO 300 N=1,NELE                                                  MSHPLT   261
            IF(DY(N).LE.YORD.AND.DY(N).GE.ORGY.AND.DX(N).GE.ORGX.AND.DX(N).LE. MSHPLT   262
           1XORD) GO TO 6                                                    MSHPLT   263
            GO TO 30                                                         MSHPLT   264
          6 DY(N)=DY(N)-ORGY                                                 MSHPLT   265
        300 CONTINUE                                                         MSHPLT   266
            GO TO 700                                                        MSHPLT   267
        310 DO 320 N=1,NELE                                                  MSHPLT   268
            IF(DY(N).GT.ORGY.AND.DY(N).LT.YORD.AND.DX(N).GT.ORGX.AND.DX(N).LT. MSHPLT   269
           1XORD) GO TO 30                                                   MSHPLT   270
        320 CONTINUE                                                         MSHPLT   271
      C                                                                     MSHPLT   272
      C------------------------------------------------------------------- MSHPLT   273
      C                                                                     MSHPLT   274
        700 IF(K-L) 350,400,350                                              MSHPLT   275
      C******************************************************************* MSHPLT   276
      C     PLOT OUT THE TRIANGULAR ELEMENT                                 MSHPLT   277
      C******************************************************************* MSHPLT   278
        400 CALL PLOT(DX(1),DY(1),3)                                         MSHPLT   279
            DO 25 LL=2,4                                                     MSHPLT   280
         25 CALL PLOT(DX(LL),DY(LL),2)                                       MSHPLT   281
      C******************************************************************* MSHPLT   282
      C     TEST TO SEE IF ELEMENT NUMBERS ARE TO BE PRINTED                MSHPLT   283
      C******************************************************************* MSHPLT   284
            IF(ELEOUT.EQ.0)GO TO 30                                          MSHPLT   285
            IF(2*(M/2)-M) 30,26,26                                           MSHPLT   286
         26 CALL ELE(DX,DY,RM,K,L,HT)                                        MSHPLT   287
            GO TO 30                                                         MSHPLT   288
      C******************************************************************* MSHPLT   289
      C     PLOT OUT THE QUADRILATERAL ELEMENT                              MSHPLT   290
      C******************************************************************* MSHPLT   291
        350 CALL PLOT(DX(1),DY(1),3)                                         MSHPLT   292
            DO 250 KK=2,5                                                    MSHPLT   293
        250 CALL PLOT(DX(KK),DY(KK),2)                                       MSHPLT   294
      C******************************************************************* MSHPLT   295
      C     TEST TO SEE IF THE ELEMENT NUMBER IS TO BE PRINTED              MSHPLT   296
      C******************************************************************* MSHPLT   297
            IF(ELEOUT.EQ.0) GO TO 30                                         MSHPLT   298
            IF(2*(M/2)-M) 30,260,260                                         MSHPLT   299
        260 CALL ELE(DX,DY,RM,K,L,HT)                                        MSHPLT   300
       30   CONTINUE                                                         MSHPLT   301
      C******************************************************************* MSHPLT   302
      C     TEST TO SEE IF NODAL POINT NUMBERS ARE TO BE PRINTED            MSHPLT   303
      C******************************************************************* MSHPLT   304
```

```
      IF(NPTOUT.EQ.0) GO TO 31
      CALL XNODAL
   31 CALL PLOT(0.,0.,999)
      RETURN
      END
```

```
      SUBROUTINE XNODAL                                                 MSHPLT   310
      COMMON R(500),Z(500),IX(500,5)                                    MSHDIM     2
     1 ,DX(5),DY(5),NUMNP,NUMEL,XFAC,HT,DIR,                            MSHPLT   312
     2 ORGX,XORD,ORGY,YORD,NBOUND,ELEOUT,NPTOUT                         MSHPLT   313
C     ****************************************************************** MSHPLT   314
C     THIS SUBROUTINE PLOTS ALL EVEN-NUMBERED NODAL POINTS OF THE SECTIO MSHPLT   315
C     TO BE PLOTTED.                                                    MSHPLT   316
C     ****************************************************************** MSHPLT   317
      RI=0.                                                             MSHPLT   318
      DO 150 I=1,NUMNP                                                  MSHPLT   319
      RI=RI+1.                                                          MSHPLT   320
      IF(2*(I/2)-I) 150,10,10                                           MSHPLT   321
   10 X=R(I)                                                            MSHPLT   322
      Y=Z(I)                                                            MSHPLT   323
C********************************************************************** MSHPLT   324
C     CHECK IF THE NODAL POINT LIES WITHIN THE BOUNDS SPECIFIED         MSHPLT   325
C********************************************************************** MSHPLT   326
      IF(NBOUND.EQ.0)GO TO 100                                          MSHPLT   327
      IF(NBOUND.NE.1)GO TO 90                                           MSHPLT   328
   43 IF(Y.LE.YORD.AND.Y.GE.ORGY.AND.X.GE.ORGX.AND.X.LE.XORD) GO TO 80  MSHPLT   329
      GO TO 150                                                         MSHPLT   330
   80 Y=Y-ORGY                                                          MSHPLT   331
      GO TO 100                                                         MSHPLT   332
C                                                                       MSHPLT   333
   90 IF(Y.GE.ORGY.AND.Y.LE.YORD .AND. X.GE.ORGX.AND.X.LE.XORD)GO TO 150 MSHPLT   334
  100 CALL NUMBER(X,Y,HT,RI,DIR,-1)                                     MSHPLT   335
  150 CONTINUE                                                          MSHPLT   336
      RETURN                                                            MSHPLT   337
      END                                                               MSHPLT   338
```

```
      SUBROUTINE ELE(DX,DY,RM,K,L,HT)                                   MSHPLT   339
      DIMENSION DX(5),DY(5)                                             MSHPLT   340
C                                                                       MSHPLT   341
      IF(K-L) 40,30,40                                                  MSHPLT   342
   30 X=1./3.*(DX(1)+DX(2)+DX(3))                                       MSHPLT   343
      Y=1./3.*(DY(1)+DY(2)+DY(3))                                       MSHPLT   344
      GO TO 100                                                         MSHPLT   345
C                                                                       MSHPLT   346
   40 X=1./4.*(DX(1)+DX(2)+DX(3)+DX(4))                                 MSHPLT   347
      Y=1./4.*(DY(1)+DY(2)+DY(3)+DY(4))                                 MSHPLT   348
C                                                                       MSHPLT   349
  100 CALL NUMBER(X,Y,HT,RM,90.,-1)                                     MSHPLT   350
      RETURN                                                            MSHPLT   351
      END                                                               MSHPLT   352
```

APPENDIX D

FORTRAN LISTING OF WXCONV

```
      PROGRAM WXCONV(INPUT,OUTPUT,TAPE1,TAPE2,TAPE5=INPUT)
C     WXCONV COMBINES MSHGEN GENERATED FINITE ELEMENT DATA ON TAPE1
C          WITH CARD INPUT DATA TO PRODUCE AN INPUT FILE FOR WILAX
C          ON TAPE2
C     ALL WXCONV OUTPUT IS ON TAPE2
      DIMENSION A(8),B(3),NPCUT(100),NELCUT(300)
      DATA B/3*0.0/
      REWIND 1
C     CARD READ AND OUTPUT TITLE CARD
      READ 100,A
      WRITE(2,100) A
  100 FORMAT(8A10)
C     CARD READ AND OUTPUT WILAX CONTROL CARD
C          SEE WILAX FOR DEFINITION OF VARIABLES
      READ 200,   NUMNP,NUMEL,NUMMAT,NUMPC,ACELZ,ANGFQ,Q,SCALE,MAXPD,NP,
     1NPP,NEND,NCD,NCUT,NRES
      WRITE(2,200)NUMNP,NUMEL,NUMMAT,NUMPC,ACELZ,ANGFQ,Q,SCALE,MAXPD,NP,
     1NPP,NEND,NCD,NCUT,NRES
  200 FORMAT(4I5,F10.2,3F5.2,7I5)
C     CARD READ AND OUTPUT MATERIAL INFORMATION-2 CARDS FOR EACH
C          MATERIAL IN FORMAT USED IN WILAX
      DO 10 I=1,NUMMAT
      READ 100,A
      WRITE(2,100) A
      READ 100,A
      WRITE(2,100) A
   10 CONTINUE
C     TAPE1 READ NUMNP AND NUMEL
      READ(1,300) NUMNP,NUMEL
  300 FORMAT(2I5)
C     TAPE1 READ AND OUTPUT NODAL POINT DATA
      DO 20 I=1,NUMNP
      READ(1,400) N,NCODE,X,Y
  400 FORMAT(2I5,2E15.5)
      CODE=NCODE
      WRITE(2,500) N,CODE,X,Y,B
  500 FORMAT(I5,F5.0,2F15.3,3F10.3)
   20 CONTINUE
C     TAPE1 READ AND OUTPUT ELEMENT DATA
      DO 30 I=1,NUMEL
      READ(1,600) B
      WRITE(2,600) B
  600 FORMAT(3A10)
   30 CONTINUE
      IF(NUMPC .EQ. 0) GO TO 50
C     CARD READ AND OUTPUT PRESSURE CARDS IN WILAX FORMAT
      DO 40 I=1,NUMPC
      READ 100,A
      WRITE(2,100) A
   40 CONTINUE
   50 CONTINUE
      IF(NRES .EQ. 0) GO TO 70
C     CARD READ AND OUTPUT INITIAL STRESS
   60 READ 100,A
      IF(EOF(5).NE. 0) GO TO 70
      WRITE(2,100) A
      GO TO 60
```

```
   70 CONTINUE
      IF(NCUT .EQ. 0) GO TO 90
C     TAPE1 READ AND OUTPUT "CUT" DATA
      DO 80 I=1,NCUT
      READ(1,700) NCUTN,NCUTNP,NCUTEL
  700 FORMAT(3I5)
      WRITE(2,700) NCUTN,NCUTNP,NCUTEL
      READ(1,800) (NPCUT(J),J=1,NCUTNP)
      WRITE(2,800) (NPCUT(J),J=1,NCUTNP)
  800 FORMAT(15I5)
      READ(1,800) (NELCUT(J),J=1,NCUTEL)
      WRITE(2,800) (NELCUT(J),J=1,NCUTEL)
   80 CONTINUE
   90 CONTINUE
      REWIND 2
      STOP
      END
```

APPENDIX E

CONTROL CARDS

E-1

```
*****************************************************
   CONTROL CARDS TO GENERATE MESH USING MSHGEN
     PRODUCE WILAX INPUT FILE USING WXCONV
     AND EXECUTE WILAX
*****************************************************

H1234,CM......,T...,P0,MT2,IO.....       INPUT TAPE ER4520
ACCOUNT,12345.
REQUEST,WILAX,MF,E.                 ER4520
LABEL,OLDPL,R,L=WILAXSOURCE,M=WILAX,P=1.
UPDATE(L=A1,C=MSHGENS)
UPDATE(L=A1,C=WXCONVS)
UPDATE(L=A1,C=WILAXS)
FTN(I=MSHGENS,B=MSHGENO,L=0,OPT=1)
FTN(I=WXCONVS,B=WXCONVO,L=0,OPT=1)
FTN(I=WILAXS,B=WILAXO,L=0,OPT=1)
LDSET(OMIT=ABORT)
MSHGENO(,,GENOUT)
REWIND,GENOUT.
WXCONVO(,,GENOUT,WILIN)
LABEL,OBJECT,R,L=WILAXOBJECT,M=WILAX,P=2.
EDITLIB.
LABEL,TAPE7,W,L=WILAXOUT,T=30.
FILE(TAPE40,BT=C,RT=S)
FILE(TAPE41,BT=C,RT=S)
FILE(TAPE42,BT=C,RT=S)
FILE(TAPE43,BT=C,RT=S)
LDSET(LIB=WILOBJ,OMIT=ABORT,FILES=TAPE41/TAPE42/TAPE42/TAPE43)
WILAXO(WILIN)
7/8/9
*C MSHGEN
*IDENT MODGEN
*D MSHGEN.18,MSHGEN.19
      COMMON ID('MXDIM')
      MXDIM='MXDIM'
7/8/9
*C WXCONV
7/8/9
*C WILAX
*IDENT MODWIL
*D WILAX.26,WILAX.27
     6 ID('MXDIM')
      MXDIM='MXDIM'
7/8/9
******INPUT DATA TO MSHGEN IS INSERTED HERE
7/8/9
******INPUT DATA TO WXCONV IS INSERTED HERE
7/8/9
SEQTORAN(OBJECT,WILOBJ)
ENDRUN.
7/8/9
6/7/8/9
```

E-2

```
*******************************************
  CONTROL CARDS TO GENERATE AND PLOT MESH
*******************************************

H1234,CM.....,T...,P2,MT2.    ER4520
ACCOUNT,12345.
ATTACH,PLTSUB,PLOTLIB,MR=1.
REQUEST,PLOTER.
REQUEST,WILAX,MF,E.           ER4520
LABEL,OLDPL,R,L=WILAXSOURCE,M=WILAX,P=1.
UPDATE(L=A1,C=MSHGENS)
UPDATE(L=A1,C=MSHPLTS)
FTN(I=MSHGENS,B=MSHGENO,L=0,OPT=1)
FTN(I=MSHPLTS,B=MSHPLTO,L=0,OPT=1)
LDSET(OMIT=ABORT)
MSHGENO(,,GENOUT)
REWIND,GENOUT.
LDSET(LIB=PLTSUB)
MSHPLTO(,,GENOUT)   "JOHN DOE,CORKSTOWN RD."
UNLOAD,PLOTER.
EXIT.  DO NOT PLOT TAPE
7/8/9
*C MSHGEN
*IDENT MODGEN
*D MSHGEN.18,MSHGEN.19
      COMMON ID("MXDIM")
      MXDIM="MXDIM"
7/8/9
*C MSHPLT
*IDENT MODPLT
*D MSHDIM.2
      COMMON R("MXNP"),Z("MXNP"),IX("MXEL",5)
7/8/9
*****INPUT DATA TO MSHGEN IS INSERTED HERE
7/8/9
*****INPUT DATA TO MSHPLT IS INSERTED HERE
7/8/9
6/7/8/9
```

```
*********************************************
          INPUT DATA FOR WXCONV
*********************************************


********** EXAMPLE - A HYPOTHETICAL SLOPE ************************************
  317  280    3    0         1.    0.    0.  12.    24    1   -1    1    1    0    0
    1    1      .0955
               3.0E+6         .33    3.0E+6        .33
    2    1      .0955
               2.0E+6         .25    2.0E+6        .25
    3    1      .0955
               4.0E+6         .30    4.0E+6        .30



*********************************************
          INPUT DATA FOR MSHPLT
*********************************************

      .015          0          1          1
```

APPENDIX F

FORTRAN LISTING OF WILAX

```
      PROGRAM WILAX(INPUT,OUTPUT,TAPE41,TAPE42,TAPE40,TAPE43,          WILAX   2
     1 TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)                                  WILAX   3
C*********************************************************************** WILAX   4
C     1.   THIS PROGRAM IS CAPABLE OF HANDLING STRESS ANALYSIS FOR       WILAX   5
C               ARBITRARY AXISYMMETRIC SOLIDS WITH AXISYMMETRIC LOADING. WILAX   6
C     2.   PLANE STRESS AND PLANE STRAIN ARE OPTIONAL.                   WILAX   7
C     4.   BI-LINEAR MATERIAL PROPERTIES AND THERMAL STRESSES  CAN ALSO  WILAX   8
C               BE CONSIDERED,HOWEVER,THIS OPTION WAS NOT FULLY TESTED.  WILAX   9
C     5.   ONE OR SEVERAL PROGRESSIVE CUTS OR EXCAVATIONS CAN BE MADE.   WILAX  10
C*********************************************************************** WILAX  11
C NOTE.....SEVERAL MODIFICATIONS WERE MADE ON JUNE 12/1973.              WILAX  12
C     A.   SUBROUTINES READ AND WRITE WERE ADDED SO THAT USERS HAVE TO   WILAX  13
C          MAKE ONLY MINOR CHANGE WHEN RUNNING THIS PROGRAM ON MACHINES  WILAX  14
C          OTHER THAN CDC 6400.                                          WILAX  15
C     B.   A VARIABLE "SCALE" IS ADDED. IT IS A SCALING FACTOR FOR THE   WILAX  16
C          INPUT COORDINATES R AND Z. THE DEFAULT VALUE IS 1.0           WILAX  17
C                                                                        WILAX  18
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,           WILAX  19
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD,             WILAX  20
     2 MAXPD1,NEL,ACELZ,ANGFQ,TEMP,Q,U,HED(20),LM(4),RO(12),XXNN(12),    WILAX  21
     3 ANGLE(4),SIG(10),GH(4),RRR(5),ZZZ(5),S(10,10),P(10),TT(4),DD(3,3) WILAX  22
     4 ,HH(6,10),E(8,8,12),RR(4),ZZ(4),C(4,4),H(6,10),TP(6),XI(10),EE(7) WILAX  23
     5 ,F(6,10),D(6,6),SCALE,                                            WILAX  24
C                                                                        WILAX  25
     6 ID(1000)                                                          WILAX  26
      MXDIM=1000                                                         WILAX  27
C*********************************************************************** WILAX  28
C     6.   THIS MAIN PROGRAM IS DESIGNED TO ALLOCATE THE MEMORIES OF     WILAX  29
C               VARIABLES.                                               WILAX  30
C     7.   THE USER MUST CALCULATE THE MAX. DIMENSION,MXDIM,WHICH        WILAX  31
C               DEPENDS ON THE SIZE OF PROBLEM TO BE EXECUTED.           WILAX  32
C     8.   DIMENSION OF ID MUST EQUAL TO OR GREATER THAN MXDIM.          WILAX  33
C               MXDIM IS CALCULATED FROM THE FOLLOWING FORMULA.          WILAX  34
C               MXDIM = 3*NUMPC + 6*NUMNP + 10*NUMEL + 2*MXBAND +        WILAX  35
C                       2*MXBAND**2                                      WILAX  36
C               WHERE MXBAND = 2*( MAXIMUN NODAL POINT DIFFERENCE + 1 )  WILAX  37
C     9.   LOGICAL UNITS 40,41,42,43 ARE SCRACHING TAPES OR DISCS, TAPE  WILAX  38
C               7 IS USED FOR OUTPUT.                                    WILAX  39
C*********************************************************************** WILAX  40
      NTAPC=41                                                           WILAX  41
      NTAPD=42                                                           WILAX  42
      NTAPB=40                                                           WILAX  43
      NTAPE=43                                                           WILAX  44
C*********************************************************************** WILAX  45
C     10.  ICR, IPR ARE THE LOGICAL UNIT NUMBERS FOR READER AND LINE     WILAX  46
C               PRINTER.                                                 WILAX  47
C     11.  ICP CAN BE THE LOGICAL UNIT NUMBER FOR CARD PUNCH OR          WILAX  48
C               OUTPUT TAPE DEPENDS ON USERS REQUIREMENTS.               WILAX  49
C*********************************************************************** WILAX  50
      ICR=5                                                              WILAX  51
      ICP=7                                                              WILAX  52
      IPR=6                                                              WILAX  53
C*********************************************************************** WILAX  54
C     12.  READ AND PRINT OF CONTROL INFORMATION                         WILAX  55
C*********************************************************************** WILAX  56
C     13.  HED IS THE HEADING OR PROBLEM IDENTIFICATION TO BE PRINTED.   WILAX  57
C     14.  NUMNP = MAXIMUM NUMBER OF NODAL POINTS.                       WILAX  58
```

```
      C     15.  NUMEL = MAXIMUM NUMBER OF ELEMENTS.                           WILAX  59
      C     16.  NUMMAT = MAXIMUM NUMBER OF MATERIALS.                         WILAX  60
      C     17.  NUMPC =MAXIMUM NUMBER OF PRESSURE CARDS.                      WILAX  61
      C     17.  ACELZ = AXIAL ACCELERATION.                                   WILAX  62
      C     18.  ANGFQ = ANGULAR VELOCITY.                                     WILAX  63
      C     19.  Q = REFERENCE TEMPERATURE.                                    WILAX  64
      C     20.  MAXPD = MAXIMUM NODAL POINT DIFFERENCE IN ANY ELEMENT.        WILAX  65
      C     21.  NP = NUMBER OF APPROXIMATIONS, FOR AN ELASTIC ANALYSIS NP IS  WILAX  66
      C             ALWAYS EQUAL TO 1.                                         WILAX  67
      C     22.  NPP IS A CODING FOR THE TYPE OF ANALYSIS,                     WILAX  68
      CC            NPP =0 SPECIFIES AXISYMMETRIC CASE,                        WILAX  69
      C                 =1 SPECIFIES PLANE STRESS OPTION,                      WILAX  70
      C                 =-1 SPECIFIES PLANE STRAIN OPTION.                     WILAX  71
      C     23.  NEND IS A CODING FOR NUMBER OF PROBLEMS TO BE SOLVED,         WILAX  72
      C             NEND = 1 INDICATES ONLY ONE PROBLEM TO SOLVE,              WILAX  73
      C                  = 0 INDICATES MORE THAN ONE PROBLEM TO SOLVE.         WILAX  74
      C     24.  NCD IS A CODING FOR OUTPUT FOR PLOTTING PURPOSE,              WILAX  75
      C             NCD = 1 MAY HAVE OUTPUT FROM CARDS OR ON TAPE DEPENDING    WILAX  76
      C                   ON THE UNIT ICP, USUALLY THERE IS NO OUTPUT FOR THE  WILAX  77
      C                   FIRST SUB-PROBLEM.                                   WILAX  78
      C             NCD = 0 SPECIES NO OUTPUT EITHER FROM CARDS OR ON TAPE     WILAX  79
      C     25.  NCUT = NUMBER OF CUTS OR EXCAVATIONS, NCUT = 0 SPECIFIES      WILAX  80
      C                 NO EXCAVATION.                                         WILAX  81
      C     26.  NRES IS A CODING FOR INITIAL RESIDUAL STRESSES,               WILAX  82
      C             NRES = 0 NO RESIDUAL STRESSES TO BE READ IN,               WILAX  83
      C                  = 1 RESIDUAL STRESSES WILL BE READ IN.                WILAX  84
      C     27.  SCALE IS A SCALING FACTOR FOR THE COORDINATES R AND Z. THE    WILAX  85
      C             DEFAULT IS 1.0                                             WILAX  86
      C*********************************************************************** WILAX  87
          1 READ(ICR,1000) HED,NUMNP,NUMEL,NUMMAT,NUMPC,ACELZ,ANGFQ,Q,SCALE,   WILAX  88
           1 MAXPD,NP,NPP,NEND,NCD,NCUT,NRES                                   WILAX  89
       1000 FORMAT(20A4/4I5,F10.2,3F5.0,7I5)                                   WILAX  90
            IF(SCALE .EQ. 0.) SCALE=1.0                                        WILAX  91
            WRITE(IPR,2000) HED,NUMNP,NUMEL,NUMMAT,NUMPC,ACELZ,ANGFQ,MAXPD,Q,  WILAX  92
           1 NP,NCUT,NRES,SCALE                                                WILAX  93
       2000 FORMAT(1H1 20A4/                                                   WILAX  94
           1 30H0 NUMBER OF NODAL POINTS------ I4 /                            WILAX  95
           2 30H0 NUMBER OF ELEMENTS---------- I4 /                            WILAX  96
           3 30H0 NUMBER OF DIFF. MATERIALS--- I3 /                            WILAX  97
           4 30H0 NUMBER OF PRESSURE CARDS---- I3 /                            WILAX  98
           5 30H0 AXIAL ACCELERATION---------- E12.4/                          WILAX  99
           6 30H0 ANGULAR VELOCITY------------ E12.4/                          WILAX 100
           * 30H0 MAXIMUM NODES DIFFERENCE---- I3/                             WILAX 101
           7 30H0 REFERENCE TEMPERATURE------- E12.4/                          WILAX 102
           8 30H0 NUMBER OF APPROXIMATIONS---- I3/                             WILAX 103
           9 30H0 NUMBER OF CUTS-------------- I3 /                            WILAX 104
           * 30H0 INITIAL RESIDUAL STRESSES--- I3/                             WILAX 105
           * 30H0 COORDINATE-MULTIPLY FACTOR-- E12.4 )                         WILAX 106
      C                                                                        WILAX 107
      C     27.  THE DEFINITIONS OF MAXPD1,MXBAND AND MXBAN2 ARE SELF-         WILAX 108
      C                 EXPLANATORY.                                           WILAX 109
            MAXPD1=MAXPD+1                                                     WILAX 110
            MXBAND=2*MAXPD1                                                    WILAX 111
            MXBAN2=2*MXBAND                                                    WILAX 112
      C*********************************************************************** WILAX 113
      C     MEMORY ALLOCATION.                                                 WILAX 114
      C*********************************************************************** WILAX 115
```

```
      N1=1                                                              WILAX   116
      N2=N1+NUMPC                                                       WILAX   117
      N3=N2+NUMPC                                                       WILAX   118
      N4=N3+NUMPC                                                       WILAX   119
      N5=N4+NUMNP                                                       WILAX   120
      N6=N5+NUMNP                                                       WILAX   121
      N7=N6+NUMNP                                                       WILAX   122
      N8=N7+NUMNP                                                       WILAX   123
      N9=N8+NUMNP                                                       WILAX   124
      N10=N9+NUMNP                                                      WILAX   125
      N11=N10+4*NUMEL                                                   WILAX   126
      N12=N11+5*NUMEL                                                   WILAX   127
      M1=N12+NUMEL                                                      WILAX   128
      M2=M1+MXBAN2                                                      WILAX   129
      M3=M2+MXBAN2*MXBAND-1                                             WILAX   130
C*********************************************************************** WILAX   131
C     28.  TEST WHETHER DIMENSION REQUIRED EXCEEDS DIMENSION ASSIGNED,  WILAX   132
C               IF M3 IS GREATER THAN MXDIM, PROGRAM TERMINATES.        WILAX   133
C*********************************************************************** WILAX   134
      IF(M3.GT.MXDIM) GO TO 290                                         WILAX   135
      IF(NPP .NE. 2) GO TO 50                                           WILAX   136
      WRITE(IPR,2005)                                                   WILAX   137
 2005 FORMAT(1H0,"PLANE STRAIN STRUCTURE WITH ORTHOTROPIC MATERIAL")    WILAX   138
      GO TO 56                                                          WILAX   139
   50 IF(NPP) 55,56,54                                                  WILAX   140
   54 WRITE(IPR,2008)                                                   WILAX   141
 2008 FORMAT (23H0PLANE STRESS STRUCTURE )                              WILAX   142
      GO TO 56                                                          WILAX   143
   55 WRITE(IPR,2012)                                                   WILAX   144
 2012 FORMAT(23H0PLANE STRAIN STRUCTURE )                               WILAX   145
C*********************************************************************** WILAX   146
C     29.  IF NEND EQUALS 0,GO BACK TO SOLVE ANOTHER PROGRAM.           WILAX   147
C*********************************************************************** WILAX   148
   56 CALL LAYOUT(ID(N1),ID(N2),ID(N3),ID(N4),ID(N5),ID(N6),ID(N7),     WILAX   149
     1 ID(N8),ID(N9),ID(N10),ID(N11),ID(N12),ID(M1),ID(M2),             WILAX   150
     2 NUMEL)                                                           WILAX   151
      IF(NEND.EQ.0) GO TO 1                                             WILAX   152
  290 PRINT 1500,MXDIM,M3                                               WILAX   153
 1500 FORMAT(21H0 DIMENSION ASSIGNED=I6/18H DIMENSION NEEDED=I6)        WILAX   154
      STOP                                                              WILAX   155
      END                                                               WILAX   156
```

```
      SUBROUTINE LAYOUT(IBC,JBC,PR,UR,UZ,R,Z,CODE,T,RESID,IX,EPS,B,A,
     1 NUMEL)
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD,
     2 MAXPD1,NEL,ACELZ,ANGFQ,TEMP,Q,U,HED(20),LM(4),RO(12),XXNN(12),
     3 ANGLE(4),SIG(10),GH(4),RRR(5),ZZZ(5),S(10,10),P(10),TT(4),DD(3,3)
     4 ,HH(6,10),E(8,8,12),RR(4),ZZ(4),C(4,4),H(6,10),TP(6),XI(10),EE(7)
     5 ,F(6,10),D(6,6),SCALE
      DIMENSION IBC(1),JBC(1),PR(1),UR(1),UZ(1),R(1),Z(1),CODE(1),T(1),
     1 RESID(NUMEL,4),IX(NUMEL,5),EPS(1),B(1),A(1,1),ANG(12),
     2 NPCUT(100),NELCUT(100)
C*********************************************************************
C     1    SUBROUTINE LAYOUT HAS THE FOLLOWING FUNCTIONS,
C               A. READ AND PRINT INPUT DATA SUCH AS MATERIAL PROPERTIES,
C                  COORDINATES OF NODAL POINTS AND ELEMENTS PARAMETERS,ETC
C               B. GENERATES THOSE OMITTED NODAL POINTS AND ELEMENTS,
C               C. CHECKS FOR DATA ERRORS,
C               D. DETERMINES MAXIMUM BANDWIDTH,
C               E. CONTROLS OUTPUT REQUIREMENTS.
C*********************************************************************
      ICR=5
      ICP=7
      IPR=6
C*********************************************************************
C     2.   MTYPE = MATERIAL IDENTIFICATION NUMBER, A TOTAL OF 12
C                  DIFFERENT MATERIALS CAN BE ALLOWED.
C     3.   NUMTC = NUMBER OF TEMPERATURE CARDS FOR WHICH MATERIAL
C                  PROPERTIES ARE GIVEN, 8 MAXIMUN.
C     3.   RO(MTYPE) = MASS DENSITY OF MATERIAL, IF SET ACELZ = 1,
C                  THEN THE UNIT WEIGHT OF THE MATERIAL CAN BE USED.
C     4.   XXNN(MTYPE)=MODULUS RATIO,INPUT FOR BI-LINEAR MATERIAL ONLY.
C*********************************************************************
      DO 59 M=1,NUMMAT
      READ(ICR,1001) MTYPE,NUMTC,RO(MTYPE),XXNN(MTYPE)
 1001 FORMAT(2I5,3F10.0)
      WRITE(IPR,2011) MTYPE,NUMTC,RO(MTYPE),XXNN(MTYPE)
 2011 FORMAT(1H0,"MATERIAL NUMBER=",I3,2X,"NUMBER OF TEMPERATURE CARDS="
     1,I3,2X,"MASS DENSITY =",E12.4,"MODULUS RATIO =",E12.4)
C*********************************************************************
C     5.   E(I,J,MTYPE) ARE THE MATERIAL PARAMETERS FOR EACH TEMPERATURE
C               I, WHERE J = 1 FOR TEMPERATURE
C                          = 2 FOR MODULUS OF ELASTICITY, E(R),AND E(Z)
C                          = 3 FOR POISSONS RATIO MU(RZ)
C                          = 4 FOR MODULUS OF ELASTICITY, E(T)
C                          = 5 FOR POISSONS RATION MU(TR) AND MU(TZ)
C                          = 6 FOR COEFF. OF THERMAL EXPANSION ALPHA(R)
C                            AND ALPHA(Z)
C                          = 7 FOR COEFF. OF THERMAL EXPANSION ALPHA(T)
C                          = 8 FOR YIELD STRESS.
C*********************************************************************
      READ(ICR,1005) ((E(I,J,MTYPE),J=1,8),I=1,NUMTC)
 1005 FORMAT (8F10.0)
      WRITE(IPR,2010)((E(I,J,MTYPE),J=1,8),I=1,NUMTC)
 2010 FORMAT  (14H0 TEMPERATURE 10X 5HE(RZ) 9X 6HNU(RZ) 11X 4HE(T)
     1 10X 5HNU(T) 6X 9HALPHA(RZ) 7X 8HALPHA(T) 15H   YIELD STRESS /
     2 (F15.2,7E15.5))
C*********************************************************************
```

```
      C     6.   A MAXIMUM OF 8 TEMPERATURE CARDS FOR ONE MATERIAL CAN BE       LAYOUT  59
      C             PROVIDED,IF MATERIAL PROPERTIES ARE THE SAME AT 8           LAYOUT  60
      C             DIFFERENT TEMPERATURE RANGES,THEN ONLY PROPERTIES AT ONE    LAYOUT  61
      C             TEMPERATURE NEED BE SUPPLIED.                               LAYOUT  62
      C*********************************************************************** LAYOUT  63
            DO 58 I= NUMTC,8                                                    LAYOUT  64
            DO 58 J=1,8                                                         LAYOUT  65
         58 E(I,J,MTYPE)=E(NUMTC,J,MTYPE)                                       LAYOUT  66
         59 CONTINUE                                                            LAYOUT  67
      C                                                                         LAYOUT  68
      C*********************************************************************** LAYOUT  69
      C     7.   ********** READ AND PRINT NODAL POINT DATA **********           LAYOUT  70
      C          N = NODAL POINT NUMBER                                         LAYOUT  71
      C          CODE IS A NUMBER WHICH INDICATES IF DISPLACEMENTS OR FORCES    LAYOUT  72
      C             ARE TO BE SPECIFIED, IF                                     LAYOUT  73
      C             CODE = 0 UR IS THE SPECIFIED R-LOAD AND                     LAYOUT  74
      C                      UZ IS THE SPECIFIED Z-LOAD.                        LAYOUT  75
      C                  = 1 UR IS THE SPECIFIED R-DISPLACEMENT AND             LAYOUT  76
      C                      UZ IS THE SPECIFIED Z-LOAD.                        LAYOUT  77
      C                  = 2 UR IS THE SPECIFIED R-LOAD AND                     LAYOUT  78
      C                      UZ IS THE SPECIFIED Z-DISPLACEMENT.                LAYOUT  79
      C                  = 3 UR IS THE SPECIFIED R-DISPLACEMENT AND             LAYOUT  80
      C                      UZ IS THE SPECIFIED Z-DISPLACEMENT.                LAYOUT  81
      C          R,Z = COORDINATES IN THE RADIAL AND AXIAL DIRECTIONS           LAYOUT  82
      C          UR,UZ = RADIAL DISPLACEMENT OR LOAD AND AXIAL DISPLACEMENT     LAYOUT  83
      C                  OR LOAD.                                               LAYOUT  84
      C          T = TEMPERATURE                                                LAYOUT  85
      C*********************************************************************** LAYOUT  86
            WRITE(IPR,2004)                                                     LAYOUT  87
       2004 FORMAT (108H1NODAL POINT         TYPE  R-ORDINATE  Z-ORDINATE  R LO LAYOUT  88
           1AD OR DISPLACEMENT  Z LOAD OR DISPLACEMENT TEMPERATURE )            LAYOUT  89
            L=0                                                                 LAYOUT  90
         60 READ(ICR,1002) N,CODE(N),R(N),Z(N),UR(N),UZ(N),T(N)                 LAYOUT  91
            IF(SCALE .EQ.1.0) GO TO 6                                           LAYOUT  92
            R(N)=R(N)*SCALE                                                     LAYOUT  93
            Z(N)=Z(N)*SCALE                                                     LAYOUT  94
       1002 FORMAT(I5,F5.0,2F15.3,3F10.3)                                       LAYOUT  95
      C*********************************************************************** LAYOUT  96
      C     8.   IF CODE IS OTHER THAN 0,1,2 OR 3,IT IS INTERPRETED AS THE      LAYOUT  97
      C             MAGNITUDE OF AN ANGLE IN DEGREES,AND IT MUST ALWAYS BE      LAYOUT  98
      C             INPUT AS A NEGATIVE ANGLE. THEN A SKEW BOUNDARY IS          LAYOUT  99
      C             CONSIDERED, EG,UR IS THE SPECIFIED LOAD  AND UZ IS THE      LAYOUT 100
      C             SPECIFIED DISPLACEMENT IN S AND N DIRECTION RESPECTIVELY.   LAYOUT 101
      C*********************************************************************** LAYOUT 102
          6 IF(CODE(N))7,8,8                                                    LAYOUT 103
          7 CODE(N)=CODE(N)/57.3                                                LAYOUT 104
          8 CONTINUE                                                            LAYOUT 105
            NL=L+1                                                              LAYOUT 106
            ZX=N-L                                                              LAYOUT 107
            IF(L)4817,4817,4816                                                 LAYOUT 108
      C*********************************************************************** LAYOUT 109
      C     9.   AUTOMATIC GENERATION OF OMITTED NODES AND THEIR COORDINATES    LAYOUT 110
      C             AND TEMPERATURE IF ANY.                                     LAYOUT 111
      C*********************************************************************** LAYOUT 112
       4817 DR=R(N)/ZX                                                          LAYOUT 113
            DZ=Z(N)/ZX                                                          LAYOUT 114
            DT=T(N)/ZX                                                          LAYOUT 115
```

```
                  GO TO 70                                                 LAYOUT   116
            4816  CONTINUE                                                 LAYOUT   117
                  DR=(R(N)-R(L))/ZX                                        LAYOUT   118
                  DZ=(Z(N)-Z(L))/ZX                                        LAYOUT   119
                  DT=(T(N)-T(L))/ZX                                        LAYOUT   120
              70  L=L+1                                                    LAYOUT   121
                  IF(N-L) 100,90,80                                        LAYOUT   122
              80  CODE(L)=0.0                                              LAYOUT   123
                  R(L)=R(L-1)+DR                                           LAYOUT   124
                  Z(L)=Z(L-1)+DZ                                           LAYOUT   125
                  UR(L)=0.0                                                LAYOUT   126
                  UZ(L)=0.0                                                LAYOUT   127
                  T(L)=T(L-1)+DT                                           LAYOUT   128
                  GO TO 70                                                 LAYOUT   129
              90  WRITE(IPR,2002)(K,CODE(K),R(K),Z(K),UR(K),UZ(K),T(K),K=NL,N)  LAYOUT   130
            2002  FORMAT(I12,F12.2,2F12.3,2E24.7,F10.2)                    LAYOUT   131
                  IF(NUMNP-N) 100,110,60                                   LAYOUT   132
             100  WRITE(IPR,2009) N                                        LAYOUT   133
            2009  FORMAT (26H0NODAL POINT CARD ERROR N= I5)                LAYOUT   134
                  CALL EXIT                                                LAYOUT   135
             110  CONTINUE                                                 LAYOUT   136
           C******************************************************************* LAYOUT   137
           C      10.  READ AND PRINT ELAMENT DATA AND AUTOMATICALLY GENERATE THOSE  LAYOUT   138
           C              OMITTED ELEMENTS EXECPT TRIANGULAR ELEMENTS,         LAYOUT   139
           C              M IS ELEMENT NUMBER AND IX(M,1) TO IX(M,4) ARE THE I,J,K,  LAYOUT   140
           C              LTH NODES RESPECTIVELY, K AND L MUST BE EQUAL IF IT IS A  LAYOUT   141
           C              TRIANGULAR ELEMENT,IX(M,5) IS MATERIAL IDENTIFICATION.  LAYOUT   142
           C******************************************************************* LAYOUT   143
                  WRITE(IPR,2001)                                          LAYOUT   144
            2001  FORMAT (49H1ELEMENT NO.      I      J      K      L    MATERIAL  )  LAYOUT   145
                  N=0                                                      LAYOUT   146
             130  READ(ICR,1003) M,(IX(M,I),I=1,5)                         LAYOUT   147
            1003  FORMAT (6I5)                                             LAYOUT   148
             140  N=N+1                                                    LAYOUT   149
                  IF (M-N) 170,170,150                                     LAYOUT   150
             150  IX(N,1)=IX(N-1,1)+1                                      LAYOUT   151
                  IX(N,2)=IX(N-1,2)+1                                      LAYOUT   152
                  IX(N,3)=IX(N-1,3)+1                                      LAYOUT   153
                  IX(N,4)=IX(N-1,4)+1                                      LAYOUT   154
                  IX(N,5)=IX(N-1,5)                                        LAYOUT   155
             170  WRITE(IPR,2003) N,(IX(N,I),I=1,5)                        LAYOUT   156
            2003  FORMAT (1I13,4I6,1I12)                                   LAYOUT   157
                  IF (M-N) 180,180,140                                     LAYOUT   158
             180  IF (NUMEL-N) 190,190,130                                 LAYOUT   159
             190  CONTINUE                                                 LAYOUT   160
           C******************************************************************* LAYOUT   161
           C      11.  READ AND PRINT BOUNDARY PRESSURE CONDITIONS.        LAYOUT   162
           C              ONE CARD FOR EACH BOUNDARY ELEMENT WHICH IS SUBJECTED TO  LAYOUT   163
           C              A NORMAL PRESSURE MUST BE SUPPLIED,COMPRESSION POSITIVE.  LAYOUT   164
           C******************************************************************* LAYOUT   165
                  IF (NUMPC) 290,310,290                                   LAYOUT   166
             290  WRITE(IPR,2005)                                          LAYOUT   167
            2005  FORMAT (29H0PRESSURE BOUNDARY CONDITIONS/ 24H      I      J    PRESS  LAYOUT   168
                 1URE )                                                    LAYOUT   169
                  DO 300 L=1,NUMPC                                         LAYOUT   170
                  READ(ICR,1004) IBC(L),JBC(L),PR(L)                       LAYOUT   171
            1004  FORMAT (2I5,F10.0)                                       LAYOUT   172
```

```
  300 WRITE(IPR,2007) IBC(L),JBC(L),PR(L)                              LAYOUT
 2007 FORMAT (2I6,F12.3)                                               LAYOUT
  310 CONTINUE                                                         LAYOUT
C********************************************************************* LAYOUT
C      12.  DETERMINE MAXIMUM BANDWIDTH IN ANY ONE  ELEMENT            LAYOUT
C********************************************************************* LAYOUT
      J=0                                                              LAYOUT
      DO 340 N=1,NUMEL                                                 LAYOUT
      DO 340 I=1,4                                                     LAYOUT
      DO 325 L=1,4                                                     LAYOUT
C********************************************************************* LAYOUT
C      13.  DETERMINE MAXIMUM NODAL POINTS DIFFERENCE IN ANY ONE ELEMENT. LAYOUT
C********************************************************************* LAYOUT
      KK=IABS(IX(N,I)-IX(N,L))                                         LAYOUT
      IF (KK-J) 325,325,320                                            LAYOUT
  320 J=KK                                                             LAYOUT
  325 CONTINUE                                                         LAYOUT
  340 CONTINUE                                                         LAYOUT
      MBAND=2*J+2                                                      LAYOUT
      NUMBLK=(2*NUMNP)/MBAND+1                                         LAYOUT
      IF((NUMBLK-(NUMBLK/2)*2) .NE. 0) NUMBLK=NUMBLK+1                 LAYOUT
      IF(NUMBLK .GT. MBAND) MBAND=NUMBLK                               LAYOUT
      WRITE(IPR,341) MBAND                                             LAYOUT
  341 FORMAT(8H  MBAND=I4)                                             LAYOUT
C*****MXBAN2 IS REDEFINED,I.E. IT IS NO MORE TWICE THE BANDWIDTH       LAYOUT
      MXBAN2=MBAND                                                     LAYOUT
      IF(MBAND .LE.MXBAND) GO TO 315                                   LAYOUT
      PRINT 3018, MXBAND                                               LAYOUT
 3018 FORMAT(" MAXIMUN BANDWIDTH =",I5,"  TOO SMALL")                  LAYOUT
      STOP                                                             LAYOUT
  315 CONTINUE                                                         LAYOUT
C********************************************************************* LAYOUT
C      14.  READ AND GENERATE INITIAL RESIDUAL STRESSES IF ANY,STRESSES LAYOUT
C               ARE INPUT AS POSITIVE FOR COMPRESSION,                 LAYOUT
C               RESID(N,1) =RADIAL OR R STRESS,                        LAYOUT
C               RESID(N,2) = AXIAL OR Z STRESS,                        LAYOUT
C               RESID(N,3) = TANGENTIAL OR T STRESS,                   LAYOUT
C               RESID(N,4) = SHEAR OR RZ STRESS.                       LAYOUT
C********************************************************************* LAYOUT
      DO 32 N=1,NUMEL                                                  LAYOUT
      DO 32 I=1,4                                                      LAYOUT
   32 RESID(N,I)=0.0                                                   LAYOUT
      IF(NRES.EQ.0) GO TO 45                                           LAYOUT
      L = 1                                                            LAYOUT
   47 READ 1007, N,(RESID(N,I),I=1,4)                                  LAYOUT
      RESID(N,1)=-RESID(N,1)                                           LAYOUT
      RESID(N,2)=-RESID(N,2)                                           LAYOUT
      RESID(N,3)=-RESID(N,3)                                           LAYOUT
      IF(N-L) 40,41,42                                                 LAYOUT
 1007 FORMAT(I5,4E15.4)                                                LAYOUT
   42 DO 46 I=1,4                                                      LAYOUT
   46 RESID(L,I)=RESID(L-1,I)                                          LAYOUT
   41 IF ( L .EQ. NUMEL)  GO TO 45                                     LAYOUT
      L = L + 1                                                        LAYOUT
      IF (N - L)  47, 41, 42                                           LAYOUT
   40 PRINT 1008,N                                                     LAYOUT
 1008 FORMAT(" RESIDUAL STRESS INPUT ERROR, N="I4)                     LAYOUT
```

```
      GO TO 47
   45 IF(NRES.EQ.2) NRES=0
      NNC=NCUT
      IF(NRES.EQ.0) NNC=NCUT+1
      NCARD=0
C
C     15.  BIG LOOP FOR EACH CUT OR FXCAVATION.
C
      DO 600 NC=1,NNC
      IF(NCD.EQ.0)GO TO 49
C*********************************************************************
C     16.  NCARD IS A CONTROL FOR OUTPUT EITHER ON CARDS OR ON TAPE FOR
C               PLOTTING PURPOSE, IT ALSO DEPENDS ON NCD AND NCUT.
C*********************************************************************
      IF(NRES.EQ.0.AND.NC.EQ.2) NCARD=1
      IF(NRES.NE.0.AND.NC.EQ.1) NCARD=1
      IF(NRES.EQ.0.AND.NCUT.EQ.0) NCARD=1
   49 CONTINUE
      IF(NC.EQ.1.AND.NRES.EQ.0) GO TO 450
C*********************************************************************
C     17.  ********** READ AND PRINT OF EXCAVATION DATA IF ANY *********
C          NCUTN = CUT NUMBER,EG,FIRST CUT OR 2ND CUT,
C          NCUTNP= TOTAL NUMBER OF NODAL POINTS WHICH DEFINE THE CUT,
C          NCUTEL= TOTAL NUMBER OF ELEMENTS IN THE CUT,
C          NPCUT = ARRAY USED TO STORE NODAL POINTS WHICH DEFINE THE CUT
C          NELCUT= ARRAY USED TO STORE ELEMENTS IN THE CUT.
C*********************************************************************
      READ 3006,NCUTN,NCUTNP,NCUTEL
 3006 FORMAT(3I5)
      PRINT 3008,NCUTN,NCUTNP,NCUTEL
 3008 FORMAT(1H1,40X,10HCUT NUMBER ,I3/1H0,10X,35HNUMBER OF NODAL POINTS
     1 DEFINING CUT ,I4, 5X,25HNUMBER OF ELEMENTS IN CUT ,I4)
      READ 3010,(NPCUT(I),I=1,NCUTNP)
 3010 FORMAT(15I5)
      READ 3010,(NELCUT(I),I=1,NCUTEL)
      PRINT 3012,(NPCUT(I),I=1,NCUTNP)
 3012 FORMAT(1H0,10X,25HNODAL POINTS DEFINING CUT //(21X,15I5))
      PRINT 3014,(NELCUT(I),I=1,NCUTEL)
 3014 FORMAT(1H0,10X,15HELEMENTS IN CUT //(21X,15I5))
C*********************************************************************
C     18.  SET MATERIAL PROPERTIES CLOSE TO NULL FOR THOSE ELEMENTS IN
C               THE CUT,AND MODIFY THE BOUNDARY CONSTRAINTS FOR THE
C               NODES IN THE CUT EXCEPT THOSE DEFINING THE CUT.
C*********************************************************************
      DO 425 I=1,NCUTEL
      NEL=NELCUT(I)
      IX(NEL,5)=NUMMAT
      DO 390 J=1,4
  390 RESID(NEL,J)=0.0
      DO 425 J=1,4
      NPT=IX(NEL,J)
      DO 400 K=1,NCUTNP
      IF(NPT.EQ.NPCUT(K)) GO TO 425
  400 CONTINUE
      CODE(NPT)=3.
      UR(NPT)=0.0
      UZ(NPT)=0.0
```

```
  425 CONTINUE
  450 CONTINUE
C***********************************************************************
C      19.  SOLVE NON-LINEAR STRUCTURE BY SUCCESSIVE APPROXIMATIONS,
C                IF ALL ELEMENTS ARE ELASTIC,THEN NO ITERATION REQUIRED.
C                EG, NP ALWAYS EQUALS TO 1 FOR ELASTIC ANALYSIS.
C***********************************************************************
      DO 350   N=1,NUMEL
  350 EPS(N)=0.0
      DO 500 NNN=1,NP
C***********************************************************************
C      20.  FORM STIFFNESS MATRIX.
C***********************************************************************
      CALL STIFF(IBC,JBC,PR,UR,UZ,R,Z,CODE,RESID,IX,B,A,EPS,T,ANG,
     1 NUMEL,MXBAN2)
C***********************************************************************
C      21.  SOLVE FOR DISPLACEMENTS.
C***********************************************************************
      CALL BANSOL(B,A,MXBAN2)
C***********************************************************************
C     PRINT NODAL POINT AND ITS DISPLACEMENT IN R AND Z DIRECTIONS
C***********************************************************************
      WRITE(IPR,2006) (N,B(2*N-1),B(2*N),N=1,NUMNP)
 2006 FORMAT (12H1N.P. NUMBER 18X 2HUR 18X 2HUZ / (1I12,2E20.7))
      IF(NCARD.EQ.0)GO TO 499
C***********************************************************************
C      22.  OUTPUT DISPLACEMENTS EITHER ON CARDS OR ON TAPE FOR PLOTTING.
C***********************************************************************
      WRITE(ICP,3016)(N,R(N),Z(N),B(2*N-1),B(2*N),N=1,NUMNP)
 3016 FORMAT(I5,2E15.6,5X,2F20.6)
      ENDFILE ICP
  499 CONTINUE
C***********************************************************************
C      23.  COMPUTE STRESSES.
C***********************************************************************
  501 CALL STRESS(IX,EPS,RESID,B,A,R,Z,CODE,T,ANG,NUMEL,MXBAN2)
C
  500 CONTINUE
  600 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE STIFF(IBC,JBC,PR,UR,UZ,R,Z,CODE,RESID,IX,B,A,EPS,T,ANG, STIFF   2
     1 NUMEL,MXBAN2)                                                      STIFF   3
C******************************************************************* STIFF   4
C     SUBROUTINE STIFF FORMS OVERALL STIFFNESS MATRIX OF THE STRUCTURE  STIFF   5
C******************************************************************* STIFF   6
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,           STIFF   7
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD,             STIFF   8
     2 MAXPD1,NEL,ACELZ,ANGFQ,TEMP,Q,U,HED(20),LM(4),RO(12),XXNN(12),   STIFF   9
     3 ANGLE(4),SIG(10),GH(4),RRR(5),ZZZ(5),S(10,10),P(10),TT(4),DD(3,3) STIFF  10
     4 ,HH(6,10),E(8,8,12),RR(4),ZZ(4),C(4,4),H(6,10),TP(6),XI(10),EE(7) STIFF  11
     5 ,F(6,10),D(6,6)                                                   STIFF  12
      DIMENSION IBC(1),JBC(1),PR(1),UR(1),UZ(1),R(1),Z(1),CODE(1),       STIFF  13
     1 RESID(NUMEL,4),IX(NUMEL,5),B(1),A(MXBAN2,1),EPS(1),T(1),ANG(12)   STIFF  14
      ICR=5                                                               STIFF  15
      ICP=7                                                               STIFF  16
      IPR=6                                                               STIFF  17
C******************************************************************* STIFF  18
C     INITIALIZATION                                                    STIFF  19
C******************************************************************* STIFF  20
      NTAPB=40                                                            STIFF  21
      REWIND NTAPB                                                        STIFF  22
      REWIND NTAPC                                                        STIFF  23
      ND=MBAND                                                            STIFF  24
      NB=MBAND/2                                                          STIFF  25
      ND2=2*ND                                                            STIFF  26
      STOP=0.0                                                            STIFF  27
      NUMBLK=0                                                            STIFF  28
      NCO=(ND-1)*MXBAN2+MBAND                                             STIFF  29
C                                                                         STIFF  30
      DO 50 N=1,ND2                                                       STIFF  31
      B(N)=0.0                                                            STIFF  32
      DO 50 M=1,ND                                                        STIFF  33
   50 A(M,N)=0.0                                                          STIFF  34
C******************************************************************* STIFF  35
C     FORM STIFFNESS MATRIX IN BLOCKS                                   STIFF  36
C     NUMBLK IS NUMBER OF THE BLOCK OF THE STIFFNESS MATRIX             STIFF  37
C     NH IS LAST ELEMENT OF NEXT BLOCK                                  STIFF  38
C     NM IS LAST ELEMENT OF BLOCK IN QUESTION                           STIFF  39
C     NL IS FIRST ELEMENT OF BLOCK IN QUESTION                          STIFF  40
C     KSHIFT IS THE AMOUNT  THE DIAGONAL OF THE STIFFNESS MATRIX SHOULD STIFF  41
C     BE SHIFTED FOR STORAGE IN THE FIRST COLUMN                        STIFF  42
C******************************************************************* STIFF  43
   60 NUMBLK=NUMBLK+1                                                     STIFF  44
      NH=NB*(NUMBLK+1)                                                    STIFF  45
      NM=NH-NB                                                            STIFF  46
      NL=NM-NB+1                                                          STIFF  47
      KSHIFT=2*NL-2                                                       STIFF  48
C                                                                         STIFF  49
      DO 210 N=1,NUMEL                                                    STIFF  50
C******************************************************************* STIFF  51
C     TESTING IF THE STIFFNESS MATRIX OF THE ELEMENT HAS ALREADY BEEN   STIFF  52
C     INTRODUCED.                                                       STIFF  53
C******************************************************************* STIFF  54
C                                                                         STIFF  55
      IF (IX(N,5)) 210,210,65                                             STIFF  56
   65 DO 80 I=1,4                                                         STIFF  57
C******************************************************************* STIFF  58
```

```
C     TESTING IF THE ELEMENT CONTAINING THE NODAL POINT IS STORED IN
C     THE BLOCK BEING FORMED
C*********************************************************************
      IF (IX(N,I)-NL) 80,70,70
   70 IF (IX(N,I)-NM) 90,90,80
   80 CONTINUE
      GO TO 210
C*********************************************************************
C     CALCULATE QUADRILATERAL ELEMENT STIFFNESS MATRIX
C*********************************************************************
   90 DO 85 I=1,4
   85 SIG(I)=RESID(N,I)
      CALL QUAD(N,VOL,T,IX,EPS,R,Z,CODE,ANG,NUMEL)
      IF(VOL) 142,142,144
  142 WRITE(IPR,2003) N
 2003 FORMAT (26HONEGATIVE AREA ELEMENT NO. I4)
C*********************************************************************
C     STOP= CODE USED TO CHECK FOR DATA ERRORS.
C*********************************************************************
      STOP=1.0
  144 IF(IX(N,3)-IX(N,4)) 145,165,145
C*********************************************************************
C     REDUCE QUADRILATERAL STIFFNESS  MATRIX TO 8*8 BY GAUSSIAN
C     ELIMINATION.
C     S = STIFFNESS MATRIX FOR ONE FINITE ELEMENT.
C     P MATRIX OF FORCES ON ONE FINITE ELEMENT
C*********************************************************************
  145 DO 150 II=1,9
      CC=S(II,10)/S(10,10)
      P(II)=P(II)-CC*P(10)
      DO 150 JJ=1,9
  150 S(II,JJ)=S(II,JJ)-CC*S(10,JJ)
C
      DO 160 II=1,8
      CC=S(II,9)/S(9,9)
      P(II)=P(II)-CC*P(9)
      DO 160 JJ=1,8
  160 S(II,JJ)=S(II,JJ)-CC*S(9,JJ)
C*********************************************************************
C            ADD ELEMENT STIFFNESS TO TOTAL STIFFNESS
C*********************************************************************
  165 DO 166 I=1,4
  166 LM(I)=2*IX(N,I)-2
C
      DO 200 I=1,4
      DO 200 K=1,2
      II=LM(I)+K-KSHIFT
      KK=2*I-2+K
      B(II)=B(II)+P(KK)
      DO 200 J=1,4
      DO 200 L=1,2
      JJ=LM(J)+L-II+1-KSHIFT
      LL=2*J-2+L
      IF(JJ) 200,200,175
C*********************************************************************
C     TEST IF BAND WIDTH EXCEEDS ALLOWABLE
C*********************************************************************
```

```
  175 IF(ND-JJ) 180,195,195
  180 WRITE(IPR,2004) N
 2004 FORMAT (29H0BAND WIDTH EXCEEDS ALLOWABLE I4)
      STOP=1.0
      GO TO 210
  195 A(JJ,II)=A(JJ,II)+S(KK,LL)
  200 CONTINUE
  210 CONTINUE
C
C*******************************************************************
C     ADD CONCENTRATED FORCES WITHIN BLOCK
C*******************************************************************
      DO 250 N=NL,NM
      K=2*N-KSHIFT
      B(K)=B(K)+UZ(N)
  250 B(K-1)=B(K-1)+UR(N)
C*******************************************************************
C     BOUNDARY CONDITIONS
C
C       1. PRESSURE B.C.
C     CONVERT PRESSURE FORCES TO POINT FORCES WITHIN BLOCK
C*******************************************************************
      IF (NUMPC) 260,310,260
  260 DO 300 L=1,NUMPC
      I=IBC(L)
      J=JBC(L)
      PP=PR(L)/6.
      DZ=(Z(I)-Z(J))*PP
      DR=(R(J)-R(I))*PP
      RX=2.0*R(I)+R(J)
      ZX=R(I)+2.0*R(J)
      IF (NPP) 262,264,262
  262 RX=3.0
      ZX=3.0
  264 II=2*I-KSHIFT
      JJ=2*J-KSHIFT
      IF (II) 280,280,265
  265 IF (II-ND) 270,270,280
  270 SINA=0.0
      COSA=1.0
C*******************************************************************
C     CODE(I) NEGATIVE MEANS MAGNITUDE OF AN ANGLE IN RADIANS
C*******************************************************************
      IF (CODE(I)) 271,272,272
  271 SINA=SIN(CODE(I))
      COSA=COS(CODE(I))
C*******************************************************************
C     CHANGE TO R DIRECTION
C*******************************************************************
  272 B(II-1)=B(II-1)+RX*(COSA*DZ+SINA*DR)
      B(II)=B(II)-RX*(SINA*DZ-COSA*DR)
  230 IF (JJ) 300,300,285
  235 IF (JJ-ND) 290,290,300
C*******************************************************************
C     CHANGE TO Z DIRECTION
C*******************************************************************
  290 SINA=0.0
```

```
      COSA=1.0
      IF (CODE(J)) 291,292,292
  291 SINA=SIN(CODE(J))
      COSA=COS(CODE(J))
  292 B(JJ-1)=B(JJ-1)+ZX*(COSA*DZ+SINA*DR)
      B(JJ)=B(JJ)-ZX*(SINA*DZ-COSA*DR)
  300 CONTINUE
C*****************************************************************
C     2.CONSIDER DISPLACEMENT B.C. WITHIN BLOCK
C     CODE=0  SPECIFIED R LOAD AND/OR Z LOAD
C     CODE=1  SPECIFIED R DISPLACEMENT AND/OR Z LOAD
C     CODE=2  SPECIFIED R LOAD AND/OR Z DISPLACEMENT
C     CODE=3  SPECIFIED R DISPLACEMENT AND Z DISPLACEMENT
C*****************************************************************
  310 DO 400 M=NL,NH
      IF (M-NUMNP) 315,315,400
  315 U=UR(M)
      N=2*M-1-KSHIFT
      IF (CODE(M)) 390,400,316
  316 IF (CODE(M)-1.) 317,370,317
  317 IF (CODE(M)-2.) 318,390,318
  318 IF (CODE(M)-3.) 390,380,390
  370 CALL MODIFY(A,B,ND2,N,U,MXBAN2)
      GO TO 400
  380 CALL MODIFY(A,B,ND2,N,U,MXBAN2)
  390 U=UZ(M)
      N=N+1
      CALL MODIFY(A,B,ND2,N,U,MXBAN2)
  400 CONTINUE
C*****************************************************************
C     WRITE BLOCK OF EQUATIONS ON TAPE AND SHIFT UP LOWER BLOCK
C*****************************************************************
C
      CALL WRITE(NTAPC,A,NCO)
      CALL WRITE(NTAPB,B,ND)
C
      DO 420 N=1,ND
      K=N+ND
      B(N)=B(K)
      B(K)=0.0
      DO 420 M=1,ND
      A(M,N)=A(M,K)
  420 A(M,K)=0.0
C*****************************************************************
C     CHECK FOR LAST BLOCK.
C*****************************************************************
      IF (NM-NUMNP) 60,480,480
  480 CONTINUE
C*****************************************************************
C     CHECK FOR DATA ERROR.
C     STOP = 0.0, NO DATA ERROR
C     STOP = 1.0, DATA ERRORS EXIST AND PROGRAM IS TERMINATED.
C*****************************************************************
      IF(STOP) 490,500,490
  490 CALL EXIT
  500 RETURN
C
```

```
      END                                                              STIFF     230
```

```
      SUBROUTINE QUAD(N,VOL,T,IX,EPS,R,Z,CODE,ANG,NUMEL)                QUAD   2
C     ***************************************************************** QUAD   3
C     FORM 10*10 QUADRILATERAL STIFFNESS MATRIX FOR N TH ELEMENT, FIND  QUAD   4
C     CENTROID OF QUADRILATERAL, DIVIDE IT INTO 4 TRIANGLES.            QUAD   5
C****************************************************************** QUAD   6
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,          QUAD   7
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD,            QUAD   8
     2 MAXPD1,NEL,ACELZ,ANGFQ,TEMP,Q,U,HED(20),LM(4),RO(12),XXNN(12),   QUAD   9
     3 ANGLE(4),SIG(10),GH(4),RRR(5),ZZZ(5),S(10,10),P(10),TT(4),DD(3,3) QUAD  10
     4 ,HH(6,10),E(8,8,12),RR(4),ZZ(4),C(4,4),H(6,10),TP(6),XI(10),EE(7) QUAD  11
     5 ,F(6,10),D(6,6)                                                  QUAD  12
      DIMENSION T(1),IX(NUMEL,5),EPS(1),R(1),Z(1),CODE(1)               QUAD  13
C                                                                       QUAD  14
   90 I=IX(N,1)                                                         QUAD  15
      J=IX(N,2)                                                         QUAD  16
      K=IX(N,3)                                                         QUAD  17
      L=IX(N,4)                                                         QUAD  18
      MTYPE=IX(N,5)                                                     QUAD  19
      NTYPE=IX(N,5)                                                     QUAD  20
C****************************************************************** QUAD  21
C     SET IX(N,5) NEGATIVE TO SHOW THAT STIFFNESS MATRIX HAS BEEN FORMED QUAD  22
C     FOR THE ELEMENT WHEN RETURN TO STIFF.                             QUAD  23
C****************************************************************** QUAD  24
      IX(N,5)=-IX(N,5)                                                  QUAD  25
      NEL=N                                                             QUAD  26
C****************************************************************** QUAD  27
C     CORRECT MATERIAL PROPERTIES DUE TO TEMPERATURE                    QUAD  28
C     EE(1)=MODULUS OF ELASTICITY IN R DIRECTION,EE(2)=POISSON RATIO(RZ) QUAD  29
C     EE(3)=MODULUS OF ELASTICITY IN Z DIRECTION,EE(4)=POISSON RATIO(TR) QUAD  30
C     EE(5)=THERMAL COEFFICIENT(R)  EE(6)=THERMAL COEFFICIENT(T)        QUAD  31
C     EE(7)=YIELD STRESS, Q IS REFERENCE TEMPERATURE                    QUAD  32
C****************************************************************** QUAD  33
      TEMP=(T(I)+T(J)+T(K)+T(L))/4.0                                    QUAD  34
C****************************************************************** QUAD  35
C     DETERMINE THE TEMPERATURE INTERVALS IN WHICH TEMP LIES.           QUAD  36
C****************************************************************** QUAD  37
      DO 103 M=2,8                                                      QUAD  38
      IF (E(M,1,MTYPE)-TEMP) 103,104,104                                QUAD  39
  103 CONTINUE                                                          QUAD  40
  104 RATIO=0.0                                                         QUAD  41
      DEN=E(M,1,MTYPE)-E(M-1,1,MTYPE)                                   QUAD  42
      IF (DEN) 70,71,70                                                 QUAD  43
   70 RATIO=(TEMP-E(M-1,1,MTYPE))/DEN                                   QUAD  44
   71 DO 105 KK=1,7                                                     QUAD  45
  105 EE(KK)=E(M-1,KK+1,MTYPE)+RATIO*(E(M,KK+1,MTYPE)-E(M-1,KK+1,MTYPE)) QUAD  46
      TEMP=TEMP-Q                                                       QUAD  47
C****************************************************************** QUAD  48
C     CHANGE PROPERTIES DUE TO BI-LINEAR BEHAVIOUR                      QUAD  49
C     EPSR  STRAIN AT YIELD POINT                                       QUAD  50
C     EPS  PLASTIC STRAIN OR EFFECTIVE STRAIN FOR MODULUS OF ELASTICITY QUAD  51
C     OF LAST TRIAL                                                     QUAD  52
C****************************************************************** QUAD  53
      EPSR=EE(7)/EE(1)                                                  QUAD  54
      IF(EPSR-EPS(N))106,108,108                                        QUAD  55
  106 RATIO=(EE(7)/(EPS(N)*EE(1)))*(1.0-XXNN(MTYPE))+XXNN(MTYPE)        QUAD  56
      EE(1)=EE(1)*RATIO                                                 QUAD  57
      EE(3)=EE(3)*RATIO                                                 QUAD  58
```

```
  108 CONTINUE
C*****************************************************************
C              FORM STRESS-STRAIN RELATIONSHIP
C*****************************************************************
      IF(NPP)85,86,84
C*****************************************************************
C     PLANE STRESS OPTION
C*****************************************************************
   84 XX=EE(1)/EE(3)
      COMM=EE(1)/(XX-EE(2)**2)
      C(1,1)=COMM*XX
      C(1,2)=COMM*EE(2)
      C(1,3)=0.0
      C(2,1)=C(1,2)
      C(2,2)=COMM
      C(2,3)=0.0
      C(3,1)=0.0
      C(3,2)=0.0
      C(3,3)=0.0
      C(4,4)=.5*EE(1)/(XX+EE(2))
      GO TO 88
C*****************************************************************
C     PLANE STRAIN OPTION
C*****************************************************************
   85 XX=EE(1)/EE(3)
      COMM=EE(3)/((1.+EE(2))*(1.-EE(2)-2.*XX*EE(4)**2))
      C(1,1)=COMM*XX*(1.-XX*EE(4)**2)
      C(1,2)=COMM*XX*EE(4)*(1.+EE(2))
      C(1,3)=0.
      C(2,1)=C(1,2)
      C(2,2)=COMM*(1.-EE(2)**2)
      C(2,3)=0.
      C(3,1)=0.
      C(3,2)=0.
      C(3,3)=0.
      C(4,4)=0.5*EE(3)/(1.+EE(4))
      GO TO 88
C*****************************************************************
C     AXISYMMETRIC OPTION
C*****************************************************************
   86 C(1,1)=1.0/EE(1)
      C(1,2)=-EE(2)/EE(1)
      C(1,3)=-EE(4)/EE(3)
      C(2,1)=C(1,2)
      C(2,2)=C(1,1)
      C(2,3)=C(1,3)
      C(3,1)=C(1,3)
      C(3,2)=C(2,3)
      C(3,3)=1.0/EE(3)
      CALL SYMINV(C,3)
      C(4,4)=EE(1)/(2.0+2.0*EE(2))
C*****************************************************************
C     CALCULATE STRESS DUE TO TEMPERATURE
C*****************************************************************
   88 DO 110 M=1,3
  110 TT(M)=((C(M,1)+C(M,2))*EE(5)+C(M,3)*EE(6))*TEMP
C*****************************************************************
```

```
      C     INITIALIZATION
      C***********************************************************************
            RRR(5)=(R(I)+R(J)+R(K)+R(L))/4.0
            ZZZ(5)=(Z(I)+Z(J)+Z(K)+Z(L))/4.0
            DO 94 M=1,4
            MM=IX(N,M)
      C***********************************************************************
      C     TO PREVENT DIVIDING BY ZERO AND SET CODE=0 IN AXISYMMETRIC CASE TO
      C     CODE = 1
      C***********************************************************************
            IF(NPP.NE.0)GO TO 93
            IF(R(MM)) 93,91,93
         91 R(MM)=.0001*RRR(5)
            IF(CODE(MM)) 93,92,93
         92 CODE(MM)=1.0
         93 RRR(M)=R(MM)
         94 ZZZ(M)=Z(MM)
      C
            DO 100 II=1,10
            P(II)=0.0
            DO 95 JJ=1,6
         95 HH(JJ,II)=0.0
            DO 100 JJ=1,10
        100 S(II,JJ)=0.0
            DO 119 II=1,4
            JJ=IX(N,II)
        119 ANGLE(II)=CODE(JJ)
      C
            IF (K-L) 125,120,125
      C***********************************************************************
      C     FORM STIFFNESS MATRIX FOR TRIANGULAR ELEMENT
      C     VOL = AREA OR VOLUME OF ELEMENT
      C     RRR(5) AND ZZZ(5) IS CENTROID OF TRIANGULAR ELEMENT.
      C***********************************************************************
        120 CALL TRISTF(1,2,3)
            RRR(5)=(RRR(1)+RRR(2)+RRR(3))/3.0
            ZZZ(5)=(ZZZ(1)+ZZZ(2)+ZZZ(3))/3.0
            VOL=XI(1)
            GO TO 130
      C***********************************************************************
      C          FORM QUADRILATERAL STIFFNESS MATRIX
      C***********************************************************************
        125 VOL=0.0
            CALL TRISTF(4,1,5)
            VOL=VOL+XI(1)
            CALL TRISTF(1,2,5)
            VOL=VOL+XI(1)
            CALL TRISTF(2,3,5)
            VOL=VOL+XI(1)
            CALL TRISTF(3,4,5)
            VOL=VOL+XI(1)
      C
      C***********************************************************************
      C     DIVIDE HH BY 4,DUE TO CALL TRISTF 4 TIMES
      C***********************************************************************
            DO 140 II=1,6
            DO 140 JJ=1,10
```

```
          140 HH(II,JJ)=HH(II,JJ)/4.0                       QUAD     173
      C                                                     QUAD     174
          130 RETURN                                        QUAD     175
      C                                                     QUAD     176
              END                                           QUAD     177
```

```
      SUBROUTINE TRISTF(II,JJ,KK)                                       TRISTF   2
C*********************************************************************** TRISTF   3
C     TO FORM 6*6 STIFFNESS MATRIX FOR TRIANGULAR ELEMENT               TRISTF   4
C*********************************************************************** TRISTF   5
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,          TRISTF   6
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD,            TRISTF   7
     2 MAXPD1,NEL,ACELZ,ANGFQ,TEMP,Q,U,HED(20),LM(4),RO(12),XXNN(12),   TRISTF   8
     3 ANGLE(4),SIG(10),GH(4),RRR(5),ZZZ(5),S(10,10),P(10),TT(4),DD(3,3) TRISTF   9
     4 ,HH(6,10),E(8,8,12),RR(4),ZZ(4),C(4,4),H(6,10),TP(6),XI(10),EE(7) TRISTF  10
     5 ,F(6,10),D(6,6)                                                  TRISTF  11
C*********************************************************************** TRISTF  12
C       1. INITIALIZATION                                               TRISTF  13
C*********************************************************************** TRISTF  14
      LM(1)=II                                                          TRISTF  15
      LM(2)=JJ                                                          TRISTF  16
      LM(3)=KK                                                          TRISTF  17
C                                                                       TRISTF  18
      RR(1)=RRR(II)                                                     TRISTF  19
      RR(2)=RRR(JJ)                                                     TRISTF  20
      RR(3)=RRR(KK)                                                     TRISTF  21
      RR(4)=RRR(II)                                                     TRISTF  22
      ZZ(1)=ZZZ(II)                                                     TRISTF  23
      ZZ(2)=ZZZ(JJ)                                                     TRISTF  24
      ZZ(3)=ZZZ(KK)                                                     TRISTF  25
      ZZ(4)=ZZZ(II)                                                     TRISTF  26
C                                                                       TRISTF  27
   85 DO 100 I=1,6                                                      TRISTF  28
      DO 90 J=1,10                                                      TRISTF  29
      F(I,J)=0.0                                                        TRISTF  30
   90 H(I,J)=0.0                                                        TRISTF  31
      DO 100 J=1,6                                                      TRISTF  32
  100 D(I,J)=0.0                                                        TRISTF  33
C*********************************************************************** TRISTF  34
C       3. FORM INTEGRAL(G)T*(C)*(G)                                    TRISTF  35
C*********************************************************************** TRISTF  36
      CALL INTER                                                        TRISTF  37
C                                                                       TRISTF  38
      D(2,6)=XI(1)*(C(1,2)+C(2,3))                                      TRISTF  39
      D(3,5)=XI(1)*C(4,4)                                               TRISTF  40
      D(5,5)=XI(1)*C(4,4)                                               TRISTF  41
      D(6,6)=XI(1)*C(2,2)                                               TRISTF  42
      IF (NPP) 104,106,104                                              TRISTF  43
  104 D(2,2)=XI(1)*C(1,1)                                               TRISTF  44
      D(3,3)=XI(1)*C(4,4)                                               TRISTF  45
      GO TO 108                                                         TRISTF  46
  106 D(1,1)=XI(3)*C(3,3)                                               TRISTF  47
      D(1,2)=XI(2)*(C(1,3)+C(3,3))                                      TRISTF  48
      D(1,3)=XI(5)*C(3,3)                                               TRISTF  49
      D(1,6)=XI(2)*C(2,3)                                               TRISTF  50
      D(2,2)=XI(1)*(C(1,1)+2.0*C(1,3)+C(3,3))                           TRISTF  51
      D(2,3)=XI(4)*(C(1,3)+C(3,3))                                      TRISTF  52
      D(3,3)=XI(6)*C(3,3)+XI(1)*C(4,4)                                  TRISTF  53
      D(3,6)=XI(4)*C(2,3)                                               TRISTF  54
C*********************************************************************** TRISTF  55
C     TRANSPOSE(G)T*(C)*(G) MATRIX                                      TRISTF  56
C*********************************************************************** TRISTF  57
  108 DO 110 I=1,6                                                      TRISTF  58
```

```
      DO 110 J=I,6
  110 D(J,I)=D(I,J)
C***********************************************************************
C      4. FORM  COEFFICIENT-DISPLACEMENT TRANSFORMATION MATRIX
C***********************************************************************
      COMM=RR(2)*(ZZ(3)-ZZ(1))+RR(1)*(ZZ(2)-ZZ(3))+RR(3)*(ZZ(1)-ZZ(2))
      DD(1,1)=(RR(2)*ZZ(3)-RR(3)*ZZ(2))/COMM
      DD(1,2)=(RR(3)*ZZ(1)-RR(1)*ZZ(3))/COMM
      DD(1,3)=(RR(1)*ZZ(2)-RR(2)*ZZ(1))/COMM
      DD(2,1)=(ZZ(2)-ZZ(3))/COMM
      DD(2,2)=(ZZ(3)-ZZ(1))/COMM
      DD(2,3)=(ZZ(1)-ZZ(2))/COMM
      DD(3,1)=(RR(3)-RR(2))/COMM
      DD(3,2)=(RR(1)-RR(3))/COMM
      DD(3,3)=(RR(2)-RR(1))/COMM
C***********************************************************************
C     TRANSPOSE COEFFICIENT- DISPLACEMENT TRANSFORMATION MATRIX
C***********************************************************************
      DO 120 I=1,3
      J=2*LM(I)-1
      H(1,J)=DD(1,I)
      H(2,J)=DD(2,I)
      H(3,J)=DD(3,I)
      H(4,J+1)=DD(1,I)
      H(5,J+1)=DD(2,I)
  120 H(6,J+1)=DD(3,I)
C***********************************************************************
C     ROTATE UNKNOWNS IF REQUIRED
C***********************************************************************
      DO 125 J=1,2
      I=LM(J)
      IF (ANGLE(I)) 122,125,125
  122 SINA=SIN(ANGLE(I))
      COSA=COS(ANGLE(I))
      IJ=2*I
      DO 124 K=1,6
      TEM=H(K,IJ-1)
      H(K,IJ-1)=TEM*COSA+H(K,IJ)*SINA
  124 H(K,IJ)= -TEM*SINA+H(K,IJ)*COSA
  125 CONTINUE
C***********************************************************************
C       5. FORM ELEMENT STIFFNESS MATRIX (H)T*(D)*(H)
C***********************************************************************
      DO 130 J=1,10
      DO 130 K=1,6
      IF (H(K,J)) 128,130,128
  128 DO 129 I=1,6
  129 F(I,J)=F(I,J)+D(I,K)*H(K,J)
  130 CONTINUE
C
      DO 140 I=1,10
      DO 140 K=1,6
      IF (H(K,I)) 138,140,138
  138 DO 139 J=1,10
  139 S(I,J)=S(I,J)+H(K,I)*F(K,J)
  140 CONTINUE
C***********************************************************************
```

```
C     FORM BODY FORCE MATRIX
C*********************************************************************
      IF (NPP) 145,150,145
  145 TT(3)=0.0
  150 COMM=RO(MTYPE)*ANGFQ**2
      TP(1)=COMM*XI(7) + XI(2)*TT(3)
      TP(2)=COMM*XI(9) + XI(1)*(TT(1)+TT(3))
      TP(3)=COMM*XI(10)+ XI(4)*TT(3)
      COMM=-RO(MTYPE)*ACELZ
      TP(4)=COMM*XI(1)
      TP(5)=COMM*XI(7)
      TP(6)=COMM*XI(8)  +XI(1)*TT(2)
C
      DO 160 I=1,10
      DO 160 K=1,6
  160 P(I)=P(I)+H(K,I)*TP(K)
C
C*********************************************************************
C     NP = 1  LINEAR MATERIAL, RESIDUAL STRESSES CAN BE CONSIDERED.
C     NP NOT=1 BI-LINEAR MATERIAL, NO RESIDUAL STRESSES ARE CONSIDERED
C*********************************************************************
      IF(NP.NE.1) GO TO 400
C*********************************************************************
C     SUBTRACT RESIDUAL STRESS VECTOR
C*********************************************************************
      DO 200 I=1,10
      GH(1)=H(2,I)*XI(1)
      GH(2)=H(6,I)*XI(1)
      GH(3)=H(1,I)*XI(2) + GH(1) + H(3,I)*XI(4)
      GH(4)=(H(3,I) + H(5,I))*XI(1)
      DO 200 J=1,4
  200 P(I)=P(I)-SIG(J)*GH(J)
C
  400 DO 410 I=1,6
      DO 410 J=1,10
  410 HH(I,J)=HH(I,J)+H(I,J)
C
      RETURN
C
      END
```

```
      SUBROUTINE STRESS(IX,EPS,RESID,B,A,R,Z,CODE,T,ANG,NUMEL,MXBAN2)    STRESS   2
C*********************************************************************** STRESS   3
C     SUBROUTINE STRESS CALCULATES STRESSES AT CENTRIOD OF EACH ELEMENT  STRESS   4
C*********************************************************************** STRESS   5
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,           STRESS   6
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD,             STRESS   7
     2 MAXPD1,NEL,ACELZ,ANGFQ,TEMP,Q,U,HED(20),LM(4),RO(12),XXNN(12),    STRESS   8
     3 ANGLE(4),SIG(10),GH(4),RRR(5),ZZZ(5),S(10,10),P(10),TT(4),DD(3,3) STRESS   9
     4 ,HH(6,10),E(8,8,12),RR(4),ZZ(4),C(4,4),H(6,10),TP(6),XI(10),EE(7) STRESS  10
     5 ,F(6,10),D(6,6)                                                   STRESS  11
      DIMENSION IX(NUMEL,5),EPS(1),RESID(NUMEL,4),B(1),A(MXBAN2,1),R(1)  STRESS  12
     1 ,Z(1),CODE(1),T(1),ANG(12)                                        STRESS  13
      ICR=5                                                              STRESS  14
      ICP=7                                                              STRESS  15
      IPR=6                                                              STRESS  16
      MPRINT=0                                                           STRESS  17
C*********************************************************************** STRESS  18
C     INITIALIZATION FOR ELEMENT STRESSES                                STRESS  19
C*********************************************************************** STRESS  20
      DO 100 I=1,10                                                      STRESS  21
  100 SIG(I)=0.                                                          STRESS  22
C                                                                        STRESS  23
C     BIG LOOP FOR EACH ELEMENT                                          STRESS  24
C                                                                        STRESS  25
      DO 300 M=1,NUMEL                                                   STRESS  26
C                                                                        STRESS  27
C*********************************************************************** STRESS  28
C     SET MTYPE POSITIVE, WHICH WAS SET NEGATIVE TO DENOTE ELEMENT       STRESS  29
C     STIFFNESS MATRIX HAS BEEN FORMED FOR THAT ELEMENT.                 STRESS  30
C*********************************************************************** STRESS  31
      N=M                                                                STRESS  32
      IX(N,5)=IABS(IX(N,5))                                              STRESS  33
      MTYPE=IX(N,5)                                                      STRESS  34
C                                                                        STRESS  35
      CALL QUAD(N,VOL,T,IX,EPS,R,Z,CODE,ANG,NUMEL)                       STRESS  36
      IX(N,5)=MTYPE                                                      STRESS  37
C*********************************************************************** STRESS  38
C     B IS DISPLACEMENT                                                  STRESS  39
C*********************************************************************** STRESS  40
      DO 120 I=1,4                                                       STRESS  41
      II=2*I                                                             STRESS  42
      JJ=2*IX(N,I)                                                       STRESS  43
      P(II-1)=B(JJ-1)                                                    STRESS  44
  120 P(II)=B(JJ)                                                        STRESS  45
C*********************************************************************** STRESS  46
C     SOLVE FOR RR(1) AND RR(2), FORCES AT CENTROID.                     STRESS  47
C*********************************************************************** STRESS  48
      DO 150 I=1,2                                                       STRESS  49
      RR(I)=P(I+8)                                                       STRESS  50
      DO 150 K=1,8                                                       STRESS  51
  150 RR(I)=RR(I)-S(I+8,K)*P(K)                                          STRESS  52
C*********************************************************************** STRESS  53
C     SOLVE FOR DISPLACEMENT AT CENTROID BY KRAMERS RULE                 STRESS  54
C*********************************************************************** STRESS  55
      COMM=S(9,9)*S(10,10)-S(9,10)*S(10,9)                               STRESS  56
      IF (COMM) 155,160,155                                              STRESS  57
  155 P(9)=(S(10,10)*RR(1)-S(9,10)*RR(2))/COMM                           STRESS  58
```

```
      P(10)=(-S(10,9)*RR(1)+S(9,9)*RR(2))/COMM
C***********************************************************************
C     SOLVE FOR CONSTANT COEFFICIENTS
C***********************************************************************
  160 DO 170 I=1,6
      TP(I)=0.0
      DO 170 K=1,10
  170 TP(I)=TP(I)+HH(I,K)*P(K)
C
C
      RR(1)=TP(2)
      RR(2)=TP(6)
      RR(3)=(TP(1)+TP(2)*RRR(5)+TP(3)*ZZZ(5))/RRR(5)
      RR(4)=TP(3)+TP(5)
C***********************************************************************
C***********************************************************************
C     SOLVE FOR STRESSES IN R,Z,T DIRECTIONS
C***********************************************************************
      IF(NP.NE.1) GO TO 179
C***********************************************************************
C     STRESSES FOR LINEAR MATERIAL
C***********************************************************************
  176 DO 180 I=1,3
      SIG(I)=-TT(I)  + RESID(N,I)
      DO 180 K=1,3
  180 SIG(I)=SIG(I)+C(I,K)*RR(K)
      SIG(4)=RESID(N,4)  + C(4,4)*RR(4)
      DO 185 I=1,4
  185 RESID(N,I)=SIG(I)
      GO TO 25
C***********************************************************************
C     STRESSES FOR BI-LINEAR MATERIAL
C***********************************************************************
  179 DO 181 I=1,3
      SIG(I)=-TT(I)
      DO 181 K=1,3
  181 SIG(I)=SIG(I)+C(I,K)*RR(K)
      SIG(4)=C(4,4)*RR(4)
   25 IF (NPP) 251,252,251
C***********************************************************************
C     SOLVE FOR PRINCIPAL STRAINS
C***********************************************************************
  251 RR(3)=-(SIG(1)+SIG(2))*EE(2)/EE(1)
  252 CC=(RR(1)+RR(2))/2.0
      CR=SQRT( ((RR(2)-RR(1))/2.0)**2 + (RR(4)/2.0)**2 )
      RR(1)=CC+CR
      RR(2)=CC-CR
C***********************************************************************
C     FIND PLASTIC STRAIN
C***********************************************************************
      EPS(N)=SQRT((RR(1)-RR(2))**2+(RR(1)-RR(3))**2+(RR(2)-RR(3))**2)
     1*0.707/(1.0+EE(2))
C
C***********************************************************************
C     OUTPUT STRESSES
C     CALCULATE PRINCIPAL STRESSES
C***********************************************************************
```

```
               CC=(SIG(1)+SIG(2))/2.0                                  STRESS    116
               BB=(SIG(1)-SIG(2))/2.                                   STRESS    117
               CR=SQRT(BB**2+SIG(4)**2)                                STRESS    118
               SIG(5)=CC+CR                                            STRESS    119
               SIG(6)=CC-CR                                            STRESS    120
               IF(ABS(BB) .GT. .1E-10) GO TO 255                       STRESS    121
               SIG(7)=0.0                                              STRESS    122
               GO TO 256                                               STRESS    123
           255 SIG(7)=28.648*ATAN2(-SIG(4),-BB)                        STRESS    124
           256 CONTINUE                                                STRESS    125
         C******************************************************************** STRESS    126
         C     STRESSES PARALLEL TO LINE I-J                           STRESS    127
         C     SIG(8), SIG(9) AND SIG(10) ARE RESPECTIVELY THE TANGENTIAL, STRESS    128
         C     NORMAL AND SHEARING STRESSES ON A PLANE PARALLEL TO IJ. STRESS    129
         C******************************************************************** STRESS    130
               I=IX(N,1)                                               STRESS    131
               J=IX(N,2)                                               STRESS    132
               ANGL=2.*ATAN2(Z(J)-Z(I),R(J)-R(I))                      STRESS    133
               COS2A=COS(ANGL)                                         STRESS    134
               SIN2A=SIN(ANGL)                                         STRESS    135
               CX=.5*(SIG(1)-SIG(2))                                   STRESS    136
               SIG(8)=CX*COS2A+SIG(4)*SIN2A+CC                         STRESS    137
               SIG(9)=2.*CC-SIG(8)                                     STRESS    138
               SIG(10)=-CX*SIN2A+SIG(4)*COS2A                          STRESS    139
         C******************************************************************** STRESS    140
         C     MPRINT IS CONTROL TO PRINT HEADING FOR STRESSES         STRESS    141
         C******************************************************************** STRESS    142
           104 IF (MPRINT) 110,105,110                                 STRESS    143
           105 WRITE(IPR,2000)                                         STRESS    144
               MPRINT=50                                               STRESS    145
           110 MPRINT=MPRINT-1                                         STRESS    146
         C                                                             STRESS    147
         C******************************************************************** STRESS    148
         C     REVERSE THE SIGNS OF STRESSES SO THAT COMPRESSIONS ARE POSITIVE STRESS    149
         C          AND TENSIONS NEGATIVE,SHEARING STRESSES ARE NOT CHANGED.  STRESS    150
         C******************************************************************** STRESS    151
               DO 10 I=1,9                                             STRESS    152
            10 SIG(I)=-SIG(I)                                          STRESS    153
               SIG(4)=-SIG(4)                                          STRESS    154
               SIG(7)=-SIG(7)                                          STRESS    155
         C******************************************************************** STRESS    156
         C     STRESSES OF ELEMENTS IN CUT SHOULD BE ZERO              STRESS    157
         C******************************************************************** STRESS    158
               DO 5 I=1,10                                             STRESS    159
             5 IF(ABS(SIG(I)) .LT. .1E-10) SIG(I)=0.                   STRESS    160
         C                                                             STRESS    161
           305 WRITE(IPR,2001) N,RRR(5),ZZZ(5),(SIG(I),I=1,10)         STRESS    162
         C******************************************************************** STRESS    163
         C     OUTPUT STRESSES EITHER ON CARDS OR ON TAPE FOR PLOTTING IF DESIRED STRESS    164
         C******************************************************************** STRESS    165
               IF(NCARD)301,300,301                                    STRESS    166
           301 SIGG=SIG(7)                                             STRESS    167
          3053 WRITE(ICP,2002)N,RRR(5),ZZZ(5),SIG(1),SIG(2),SIG(4),SIG(6),SIG(5), STRESS    168
              1SIGG                                                    STRESS    169
          2002 FORMAT(I5,7F10.2,F5.1)                                  STRESS    170
         C                                                             STRESS    171
               IF(N.EQ. NUMEL) ENDFILE ICP                             STRESS    172
```

```
        300 CONTINUE                                                      STRESS   173
      C*******************************************************************STRESS   174
      C     PRINT OUT NUMBER OF APPROXIMATIONS                            STRESS   175
      C*******************************************************************STRESS   176
            WRITE(IPR,131) NP                                             STRESS   177
        131 FORMAT(1H0,"NUMBER OF APPROXIMATIONS =",I5/////,              STRESS   178
           1" -THE COORDINATES AND STRESSES ARE IN INCHES AND LB/SQ.IN. OR IN STRESS   179
           2 CM. AND KG/SQ.CM. DEPENDS ON YOUR INPUT UNITS.",//,          STRESS   180
           3" -THE ANGLES ARE IN DEGREES.")                               STRESS   181
      C                                                                   STRESS   182
        320 RETURN                                                        STRESS   183
      C                                                                   STRESS   184
       2000 FORMAT (7H1EL.NO.  7X 1HR  7X 1HZ 4X 8HR-STRESS 4X 8HZ-STRESS 4X  STRESS   185
           1 8HT-STRESS 3X 9HRZ-STRESS 2X 10HMIN-STRESS 2X 10HMAX-STRESS  STRESS   186
           2 37H  ANGLE IJ-TSTRES IJ-NSTRES  IJ-SHEAR)                    STRESS   187
       2001 FORMAT(I5,2F10.2,3E11.4,2X,3E11.4,1X,F6.1,1X,3E10.4)          STRESS   188
      C                                                                   STRESS   189
            END                                                           STRESS   190
```

```
      SUBROUTINE SYMINV(A,NMAX)
C*********************************************************************
C     TO INVERT MATRIX  NMAX IS SIZE OF MATRIX TO BE INVERTED
C*********************************************************************
      DIMENSION A(4,4)
C
      DO 200 N=1,NMAX
C
      D=A(N,N)
      DO 100 J=1,NMAX
  100 A(N,J)=-A(N,J)/D
C
      DO 150 I=1,NMAX
      IF(N-I) 110,150,110
  110 DO 140 J=1,NMAX
      IF(N-J) 120,140,120
  120 A(I,J)=A(I,J)+A(I,N)*A(N,J)
  140 CONTINUE
  150 A(I,N)=A(I,N)/D
C
      A(N,N)=1.0/D
C
  200 CONTINUE
C
      RETURN
C
      END
```

```
      SUBROUTINE INTER                                                  INTER    2
C*********************************************************************** INTER    3
C     NUMERICAL INTEGRATION OVER TRIANGULAR ELEMENT                     INTER    4
C*********************************************************************** INTER    5
C                                                                       INTER    6
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,          INTER    7
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD,            INTER    8
     2 MAXPD1,NEL,ACELZ,ANGFQ,TEMP,Q,U,HED(20),LM(4),RO(12),XXNN(12),   INTER    9
     3 ANGLE(4),SIG(10),GH(4),RRR(5),ZZZ(5),S(10,10),P(10),TT(4),DD(3,3) INTER   10
     4 ,HH(6,10),E(8,8,12),RR(4),ZZ(4),C(4,4),H(6,10),TP(6),XI(10),EE(7) INTER   11
     5 ,F(6,10),D(6,6)                                                  INTER   12
      DIMENSION XM(6),R(6),Z(6),XX(6)                                   INTER   13
C*********************************************************************** INTER   14
C     SET INTEGRATION FACTOR                                            INTER   15
C*********************************************************************** INTER   16
      XX(1) = 1.0                                                       INTER   17
      XX(2) = 1.0                                                       INTER   18
      XX(3) = 1.0                                                       INTER   19
      XX(4) = 3.0                                                       INTER   20
      XX(5) = 3.0                                                       INTER   21
      XX(6) = 3.0                                                       INTER   22
C*********************************************************************** INTER   23
C     FIND AREA OF TRIANGULAR ELEMENT                                   INTER   24
      COMM=RR(2)*(ZZ(3)-ZZ(1))+RR(1)*(ZZ(2)-ZZ(3))+RR(3)*(ZZ(1)-ZZ(2))  INTER   25
      COMM=COMM/24.0                                                    INTER   26
C*********************************************************************** INTER   27
      DO 20 I=1,10                                                      INTER   28
   20 XI(I)=0.0                                                         INTER   29
      IF(NPP) 200,30,200                                                INTER   30
   30 CONTINUE                                                          INTER   31
      R(1)=RR(1)                                                        INTER   32
      R(2)=RR(2)                                                        INTER   33
      R(3)=RR(3)                                                        INTER   34
      R(4)=(R(1)+R(2))/2.                                               INTER   35
      R(5)=(R(2)+R(3))/2.                                               INTER   36
      R(6)=(R(3)+R(1))/2.                                               INTER   37
C                                                                       INTER   38
      Z(1)=ZZ(1)                                                        INTER   39
      Z(2)=ZZ(2)                                                        INTER   40
      Z(3)=ZZ(3)                                                        INTER   41
      Z(4)=(Z(1)+Z(2))/2.                                               INTER   42
      Z(5)=(Z(2)+Z(3))/2.                                               INTER   43
      Z(6)=(Z(3)+Z(1))/2.                                               INTER   44
C                                                                       INTER   45
      DO 35 I=1,6                                                       INTER   46
   35 XM(I)=XX(I)*R(I)                                                  INTER   47
C*********************************************************************** INTER   48
C     DETERMINE XI                                                      INTER   49
C*********************************************************************** INTER   50
C                                                                       INTER   51
      DO 100 I=1,6                                                      INTER   52
      XI(1)=XI(1)+XM(I)                                                 INTER   53
      XI(2)=XI(2)+XM(I)/R(I)                                            INTER   54
      XI(3)=XI(3)+XM(I)/(R(I)**2)                                       INTER   55
      XI(4)=XI(4)+XM(I)*Z(I)/R(I)                                       INTER   56
      XI(5)=XI(5)+XM(I)*Z(I)/(R(I)**2)                                  INTER   57
      XI(6)=XI(6)+XM(I)*Z(I)**2/(R(I)**2)                               INTER   58
```

```
                XI(7)=XI(7)+XM(I)*R(I)                                 INTER    59
                XI(8)=XI(8)+XM(I)*Z(I)                                 INTER    60
                XI(9)=XI(9)+XM(I)*R(I)**2                              INTER    61
                XI(10)=XI(10)+XM(I)*R(I)*Z(I)                          INTER    62
            100 CONTINUE                                               INTER    63
          C                                                            INTER    64
                DO 150 I=1,10                                          INTER    65
            150 XI(I)=XI(I)*COMM                                       INTER    66
          C                                                            INTER    67
                RETURN                                                 INTER    68
            200 XI(1)=12.*COMM                                         INTER    69
                XI(7)=4.*COMM*(RR(1)+RR(2)+RR(3))                      INTER    70
                XI(8)=4.*COMM*(ZZ(1)+ZZ(2)+ZZ(3))                      INTER    71
                RETURN                                                 INTER    72
          C                                                            INTER    73
                END                                                    INTER    74
```

```
      SUBROUTINE MODIFY(A,B,NEQ,N,U,MXBAN2)
C***********************************************************************
C     MODIFY STIFFNESS MATRIX A AND LOAD MATRIX B FOR SPECIFIED
C     DISPLACEMENTS AND BOUNDARY CONDITIONS.
C***********************************************************************
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD
      DIMENSION B(1),A(MXBAN2,1)
C
      DO 250 M=2,MBAND
      K=N-M+1
      IF(K) 235,235,230
C***********************************************************************
C     IN THE 2 BLOCKS SOLVING, SUBTRACT FORCE DUE TO SPECIFIED
C     DISPLACEMENT AND SET ALL STIFFNESS TERMS CORRESPONDING TO THIS
C     DISPLACEMENT ZERO.
C***********************************************************************
  230 B(K)=B(K)-A(M,K)*U
      A(M,K)=0.0
  235 K=N+M-1
      IF(NEQ-K) 250,240,240
  240 B(K)=B(K)-A(M,N)*U
      A(M,N)=0.0
  250 CONTINUE
C***********************************************************************
C     SET STIFFNESS TERM ON MAIN DIAGONAL,CORRESPONDING TO THIS
C     DISPLACEMENT TO 1 AND SET DISPLACEMENT AT POINT CONSIDERED
C     TO ITS SPECIFIED DISPLACEMENT.
C***********************************************************************
      A(1,N)=1.0
      B(N)=U
      RETURN
C
      END
C
```

```
      SUBROUTINE BANSOL(B,A,MXBAN2)
      COMMON NUMNP,NUMMAT,NUMPC,NCARD,MTYPE,NP,NPP,NEND,NTAPC,
     1 NTAPD,NCD,NCUT,NRES,MBAND,MXBAND,NUMBLK,NUMAPP,MAXPD
      DIMENSION B(1),A(MXBAN2,1)
      EQUIVALENCE(MM,MBAND)
C
      NTAPB=40
      NTAPE=43
      REWIND NTAPB
      REWIND NTAPE
      REWIND NTAPC
      REWIND NTAPD
      NN=MBAND
      NL=NN+1
      NH=NN+NN
      NB=0
      NCI=(NH-NL)*MXBAN2+MM
      NCO=(NN-1)*MXBAN2+MM-1
      NCB=(NH-NL)+1
      GO TO 150
C*******************************************************************
C     REDUCE EQUATIONS BY BLOCKS
C     1. SHIFT BLOCK OF EQUATIONS
C*******************************************************************
  100 NB=NB+1
      DO 125 N=1,NN
      NM=NN+N
      B(N)=B(NM)
      B(NM)=0.0
      DO 125 M=1,MM
      A(M,N)=A(M,NM)
  125 A(M,NM)=0.0
C*******************************************************************
C     2. READ NEXT BLOCK OF EQUATIONS INTO CORE
C*******************************************************************
      IF (NUMBLK-NB) 150,200,150
  150 CALL READ(NTAPC,A(1,NL),NCI)
      CALL READ(NTAPB,B(NL),NCB)
      IF (NB) 200,100,200
C*******************************************************************
C     3. REDUCE BLOCK OF EQUATIONS
C*******************************************************************
  200 DO 300 N=1,NN
      IF (A(1,N)) 225,300,225
  225 B(N)=B(N)/A(1,N)
      DO 275 L=2,MM
      IF(A(L,N)) 230,275,230
  230 C=A(L,N)/A(1,N)
      I=N+L-1
      J=0
      DO 250 K=L,MM
      J=J+1
  250 A(J,I)=A(J,I)-C*A(K,N)
      B(I)=B(I)-A(L,N)*B(N)
      A(L,N)=C
  275 CONTINUE
  300 CONTINUE
```

```
C*******************************************************************
C      4. WRITE BLOCK OF REDUCED EQUATIONS ON TAPES(DISCS) NTAPD,NTAPE
C*******************************************************************
       IF (NUMBLK-NB) 375,400,375
   375 CALL WRITE(NTAPD,A(2,1),NCO)
       CALL WRITE(NTAPE,B,NN)
       GO TO 100
C*******************************************************************
C      BACK-SUBSTITUTION
C*******************************************************************
   400 DO 450 M=1,NN
       N=NN+1-M
       DO 425 K=2,MM
       L=N+K-1
   425 B(N)=B(N)-A(K,N)*B(L)
       NM=N+NN
       B(NM)=B(N)
   450 A(NB,NM)=B(N)
       NB=NB-1
       IF (NB) 475,500,475
C*******************************************************************
C      BACKSPACE CAUSES THE SPECIFIED TAPE OR DRUM TO BE POSITIONED
C      AT THE BEGINNING OF THE LOGICAL RECORD LAST WRITTEN OR READ
C*******************************************************************
   475 BACKSPACE NTAPD
       BACKSPACE NTAPE
       CALL READ(NTAPD,A(2,1),NCO)
       CALL READ(NTAPE,B,NN)
       BACKSPACE NTAPD
       BACKSPACE NTAPE
       GO TO 400
C*******************************************************************
C      ORDER UNKNOWNS IN B ARRAY
C*******************************************************************
   500 K=0
       DO 600 NB=1,NUMBLK
       DO 600 N=1,NN
       NM=N+NN
       K=K+1
   600 B(K)=A(NB,NM)
C
       RETURN
C
       END
```

```
      SUBROUTINE WRITE (LUN,A,N)                                        IO      2
C     ******************************************************************IO      3
      DIMENSION A(N)                                                    IO      4
      WRITE(LUN)A                                                       IO      5
      RETURN                                                            IO      6
      END                                                               IO      7
```

```
      SUBROUTINE READ (LUN,A,N)
C     ******************************************************************
      DIMENSION A(N)
      READ(LUN) A
    5 RETURN
      END
```

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