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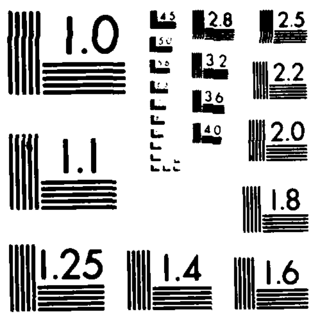
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AFWAL-TR-82-3098, Part III

(This report supersedes AFWAL-TR-80-3151, dated January 1981)

2

MAGNA (Materially and Geometrically Nonlinear Analysis)
Part III - Postprocessor Manual

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This technical report has been reviewed and is approved for publication.

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The computer program contained in this technical report is theoretical and in no way affects any Air Force owned software programs.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Three computer graphics programs, designed to present the results of finite element structural analysis in a readily assimilated form, are described. The first, GPLOT, performs plotting of original and/or deformed mesh geometries. A second program, CPLOT, produces contour or relief maps of displacement, strain, or stress results. These two programs are command-driven and offer a wide variety of display options. The third program,

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XYPLOT, generates variable-versus-variable plots with user-defined labeling, symbols, titling, and plot size. The graphics programs are operational with Tektronix and Hewlett-Packard display devices, on CDC and VAX machines.

FOREWORD

This report describes the finite element solution program MAGNA, developed at the University of Dayton Research Institute, Dayton, Ohio. Development of the program was performed between January, 1978 and December, 1982, by the Analytical Mechanics Group (Dr. F. K. Bogner, Leader) within the Aerospace Mechanics Division (D. H. Whitford, Supervisor) of the Research Institute.

This work effort was accomplished under Project 2402, "Vehicle Equipment Technology," Task 240203, "Aerospace Vehicle Recovery and Escape Subsystems," Work Unit 24020332, "Computer Aided Design of Bird-Resistant Transparencies for USAF Aircraft."

The present report provides final documentation of the developments performed on Air Force Contract F33615-80-C-3403 between March, 1980 and December, 1982 for the Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. The project manager for this effort was Dr. Fred K. Bogner, and the Principal Investigator was Dr. Robert A. Brockman. Technical direction and support was provided by Mr. Robert E. McCarty (AFWAL/FIER) as the Air Force Project Engineer. The work described herein represents a continuation of previous developments performed in-house at the University of Dayton Research Institute, and on Air Force Contract F33615-76-C-3103.

The author wishes to express his appreciation for the contributions of several individuals and organizations whose efforts, support, and suggestions have resulted in significant improvements to the MAGNA program. Continuing support and many useful discussions have been provided by Dr. Fred K. Bogner; numerous improvements to both the program and its documentation have been suggested by Mr. Robert E. McCarty. The analytical development performed by Dr. H. C. Rhee and Dr. Mohan L. Soni, and the computer graphics support provided by Messrs. T. S. Bruner, C. S. King, M. P. Bouchard, M. J. Hecht, Ms. M. A. Dominic, and Ms. M. E. Wright are also gratefully acknowledged.

Mr. Thomas W. Held performed the conversion of MAGNA to the VAX 11/780. Computer resources and assistance in adapting the program to the CRAY-1 computer were provided by United Information Services; special thanks are due to Mr. Kent Griffith of UIS, who developed the necessary direct access file utilities. Finally, the efforts of Mrs. Kathy Reineke in typing the manuscript of this manual are deeply appreciated.

This report (Parts I, II, III, and IV) supersedes AFWAL-TR-80-3152, AD99454 dated January 1981; AFWAL-TR-80-3151, AD A0099530 dated January 1981; AFWAL-TR-81-3180, AD A117544 dated February 1982; and AFWAL-TR-81-3181, AD A116541 dated February 1982.

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SUMMARY

This report describes three computer graphics postprocessors intended for use in reducing and interpreting results generated by finite element structural analysis programs. Programs GPLOT and CPLOT are interactive mesh plotters which are capable of displaying model geometry and deformed shapes, as well as contour and relief maps of stresses, strains and displacements. Both GPLOT and CPLOT operate in an easy-to-learn command-driven mode, permitting great flexibility in exercising the numerous plotting options. The variable-versus-variable plotting program XYPLOT can be used in a stand-alone mode, with data entered at the keyboard, or in conjunction with the utility programs WRTFIL and WTFILA, which perform data reduction of finite element analysis results. Additional utility programs are provided for editing files containing either analysis results or plotting data. All of the postprocessing programs can be executed using stored control language procedures. Together, the postprocessing programs described here provide a substantial capability for reducing, interpreting and presenting the results of complex structural analyses.

SECTION 1
INTRODUCTION

Finite element methods of structural analysis have matured to the point where extremely complex simulations may be performed at reasonable cost and high accuracy. However, the great detail which is possible in the finite element solution presents a serious problem when the numerical results must be interpreted by the engineer, since important trends and critical locations are difficult to identify in the mass of computed results.

Graphical presentation of analysis data permits the analyst to assimilate important results in a relatively short time. Thus, a wider range of design concepts or details can be studied, each one being evaluated with an increased level of confidence.

1.1 OVERVIEW

This report describes three interactive computer graphics processors designed for use in connection with finite element structural analysis software [1]. These programs provide for the presentation of analysis data in three basic forms:

- plots of model geometry and deformations;
- plots of displacement, strain and stress results in the form of contour or surface relief maps; and
- plots of one variable versus another ("x-y" plots).

The FORTRAN codes which accomplish these tasks are GPLOT (geometry plotting), CPLOT (contour/relief plotting) and XYPLOT (x-y plotting). All of the programs operate in an interactive mode, are based upon a common set of plotting utilities, and accept similar forms of analysis data as input.

All three of the graphics programs described herein have been written to interface directly with the analysis data files created by a single finite element analysis program, MAGNA [2,3] (Materially And Geometrically Nonlinear Ananlysis). The data output by MAGNA is described in the Appendix. It should be noted that other analysis programs may be interfaced with the postprocessing programs rather easily, either by writing the needed results files directly or by means of special-purpose translator programs. XYPLOT can also be executed as a stand-alone program, using manual data input.

The remainder of this Section summarizes the hardware requirements for using GPLOT, CPLOT and XYPLOT, and describes the plotting software libraries needed to support them. The three programs are described in detail in Sections 2, 3 and 4, respectively. Section 5 discusses additional utility programs which are useful in combining data files containing analysis results and/or plotting data.

1.2 HARDWARE REQUIREMENTS

The GPLOT, CPLOT and XYPLOT programs are operational on the following computers:

- CDC (6000 series, and CYBER 74, 175 and 750); and
- DEC (VAX 11/780 under VAX/VMS).

All three programs are written for compatibility with Tektronix series 4010 graphic display terminals, and with the Hewlett-Packard HP-7221A four-color pen plotter. The Tektronix versions have been executed successfully on a number of other devices which offer a Tektronix emulation option.

1.3 GRAPHICS SUPPORT SOFTWARE

GPLOT, CPLOT and XYPLOT require two graphics library packages for each type of output device. One of these is a device driver (PLOT10 Terminal Control System [5] for Tektronix terminals, PLOT21 [6] for the HP-7221A). The other library is the three-dimensional vector graphics library PLOT3D [7].

CPLOT contains additional output options not supported by the other two programs. The DISSPLA [8] device-independent plotting library can be used to create neutral "metafile" output, which can then be directed to any plotting device supported by the DISSPLA postprocessors. In this case, the DISSPLA library assumes the role of the "device driver." A special-purpose version of the PLOT3D library is available for use with DISSPLA.

SECTION 2
STRUCTURAL GEOMETRY PLOTTING

The geometry plotting postprocessor program GPLOT is an interactive code which produces undeformed and/or deformed line drawings of a finite element model. GPLOT contains numerous viewing options such as clipping, zooming, node/element labeling, "exploded" views, and choice of orthogonal or perspective projections. The program is command-driven, so that the user may select options, set parameters or review all plot information at any stage of a plotting session.

GPLOT can accept as input either the 'MPOST' postprocessor file generated by MAGNA (see the Appendix) or the standard MAGNA input data file. Therefore, GPLOT can also be used to generate simple geometry plots of a model prior to performing a finite element analysis. The description of GPLOT which follows applies to either plotting mode (pre- or post-analysis).

2.1 PROGRAM OPERATION

GPLOT is executed through stored control language procedures which automatically access the disc files needed for execution. To run GPLOT, it is necessary for the user to define the data file to be used and to initiate the proper control procedure.

On CDC computers, the following sequence of commands is used:

```
ATTACH,TAPE5,postprocessorfile.
ATTACH,P,PLOTPROC,ID=BROCKMAN,SN=AFFDL,MR=1.
BEGIN,GPLOT,P.
```

The above commands cause the Tektronix version of GPLOT to be executed; with the HP-7221A pen plotter, the BEGIN command must be modified slightly to

```
BEGIN,GPLOT,P,HP.
```

On the VAX 11/780 computer, only the RUN command is needed to execute GPLOT:

```
RUN [*****]GPLOT
```

The program will request the name of a disk file to be used as input in this case. Note that the directory name (written as [*****] above) will be installation-dependent.

When GPLOT begins execution, several prompts are issued to determine the type of file input, the terminal type, and other information:

```
ENTER INPUT FILE NAME ........:    (VAX only)
ENTER CHARACTERS PER SECOND ..:
TEKTRONIX OR HP PLOTTER ......:
TEKTRONIX TERMINAL TYPES -         (Tektronix only)
  0, 4006-1
  1, 4010 / 4012 / 4013
  2, 4014 / 4015
  3, 4014 / 4015 (ENH.GR.MOD.)
ENTER TERMINAL TYPE (0,1,2,3) :
MODEL INPUT FILE TYPES -
  1, INPUT DATA FILE
  2, POSTPROCESSOR (MPOST) FILE
ENTER FILE TYPE (1,2) ........:
ENTER THE MODEL NUMBER
(=1 IF ONLY ONE ON FILE)......:
```

Note that more than one set of data may be stored on a single file, and that any data set may be accessed by giving its sequence number on the file. The normal response to this last prompt is "1".

Once the initial input is complete, GPLOT enters a "command mode" with the flow of control governed by the user. Execution in the command mode is described in Subsection 2.2.

2.2 SUMMARY OF COMMANDS

Following the initial prompted input, GPLOT enters a command mode of execution. Commands may be entered in any sequence, as many times as necessary, to set options and plotting parameters which control the final appearance of a plot. Only a command to "DRAW" will actually result in the generation of a plot.

Whenever GPLOT is waiting to accept a new command, the prompt symbol "*" is displayed. A description of the available commands can be obtained by typing "HELP", and the status of all options and parameters can be displayed by typing "SUMMary". Some of the commands will cause GPLOT to request additional data needed to process the command.

Table 2.1 summarizes the commands recognized by GPLOT, in alphabetical order. In every case, only the first four letters of the command are required. A more detailed description of the individual commands follows.

AXES

The AXES command selects or deselects the axis plot option. When the axis option is selected, Cartesian axes are drawn, with the length of each axis being 10% greater than the maximum nodal coordinate in that direction. The default is no axis plotting.

CLIP

CLIP can be used to inhibit plotting of portions of the model close to the viewer position (see the EYE command). The user is asked to define a "clip factor", defined as CLPFAC = C/P, where C is the distance from the viewer to the clipping plane, and P is the distance from the viewer to the site position (usually the centroid). Points between the viewer and the clipping plane are not plotted. Parameters C and P are shown in Figure 2.1. The default value of CLPFAC is 0.01. An example of a plot using a larger value of CLPFAC is shown in Figure 2.2.

TABLE 2.1

GPLOT COMMAND SUMMARY

COMMAND	DESCRIPTION
AXES	Select axis plotting and labeling
CLIP	Specify clipping plane position
CUBE	Define minimum, maximum coordinates for plotting
DEFAult	Reset all plotting parameters to default values
DEFOrm	Select deformed geometry for plotting
DRAW	Plot the model using current options and parameters
ELEMents	Define specific elements to be plotted
EYE	Specify viewing position
HELP	Request listing of valid commands
LABEl	Select labeling of elements and/or nodes
NEW	Access data for a different model on the input file
PROJection	Select orthogonal or perspective view

TABLE 2.1 (concluded)

GPLOT COMMAND SUMMARY

COMMAND	DESCRIPTION
REFLect	Specify a plane of symmetry
ROTAte	Prescribe 3-D rotations of model
SCALe	Switch plot scaling on or off
SHRInk	Select "exploded" view
SITE	Adjust site position for plot centering
STOP	Terminate execution
SUMMary	Display current parameter values
TIME	Display CPU time elapsed since sign-on
TRANslate	Prescribe 3-D translations of model
VERTical	Define vertical axis direction on plot
ZOOM	Define area for close-up viewing

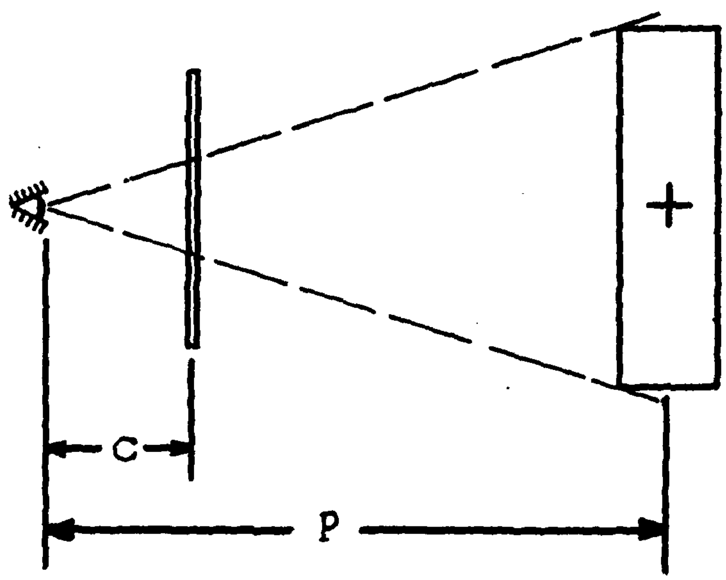


Figure 2.1 Geometric Parameters for the CLIP Command.

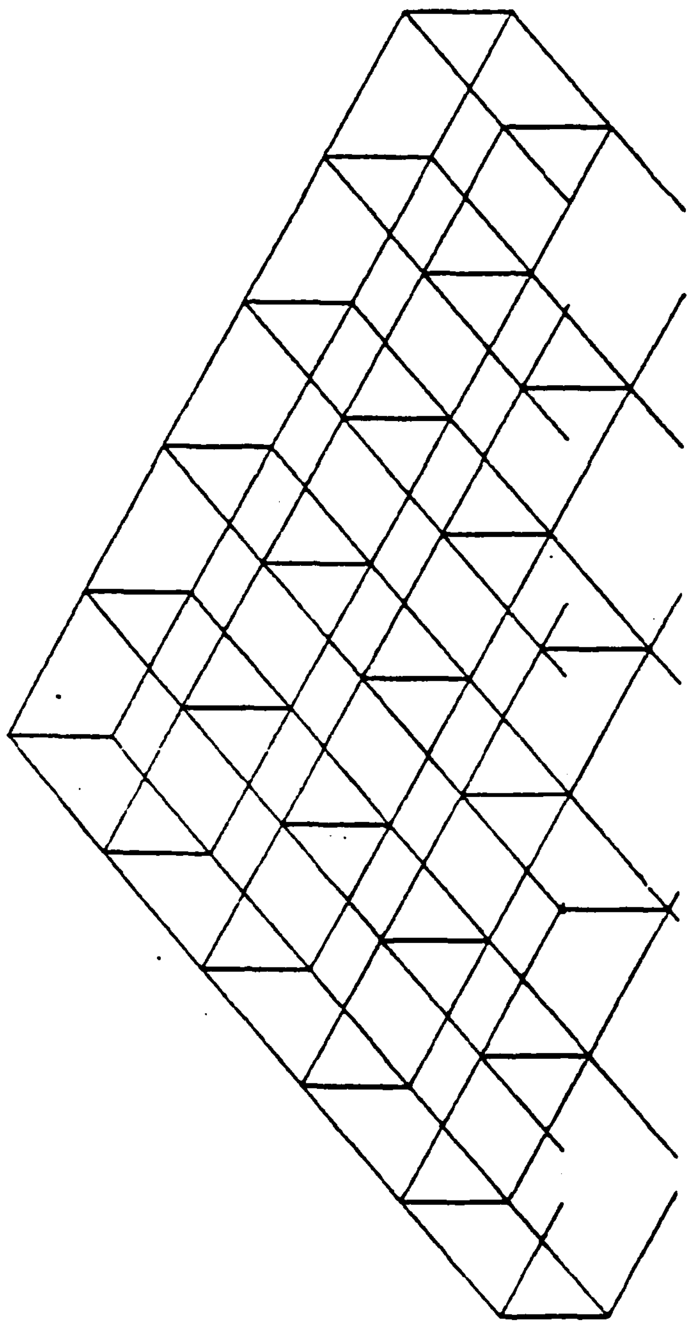


Figure 2.2 Example of CLIP Command.

CUBE

CUBE allows the user to override the automatic scaling done by GPLOT, and to isolate the portion of the model contained within a rectangular region defined by limiting values of X, Y and Z. CUBE is most useful when a number of different views of a small portion of the model are needed; otherwise, the function performed by CUBE is accomplished more easily using ZOOM. If the region defined using CUBE is far from the centroid of the entire model, the SITE command can be used to re-center the plot on the page. Figure 2.3 illustrates the effect of CUBE.

DEFAult

When the DEFAULT command is entered, all plotting options and parameters are reset to their original (default) values. Default values are determined both from internally-defined values and from data on the input file.

DEFOrm

DEFORM selects the type of geometry to be plotted: deformed, undeformed, or both. When deformed geometry is selected, the increment, mode or load case number must be input, together with a scale factor for the displacements (1=actual size, 2=twice actual size, etc.). When both undeformed and deformed views are drawn on the same plot, the original geometry appears in dashed lines and the displaced shape in solid lines (Figure 2.4). If the data file is a MAGNA input file, only undeformed geometry may be plotted. The default DEFORM option is to plot only the undeformed geometry.

DRAW

The DRAW command causes a plot of the model to be generated, using the current geometric and plotting parameters. When the plot is complete, a command to "GO" will resume execution; this pause permits hard copies to be made without extraneous printing appearing on the screen. Note that DRAW may be entered as the first command, since default values are assigned to all of the necessary parameters; this strategy is often useful in "getting oriented" with a complicated model.

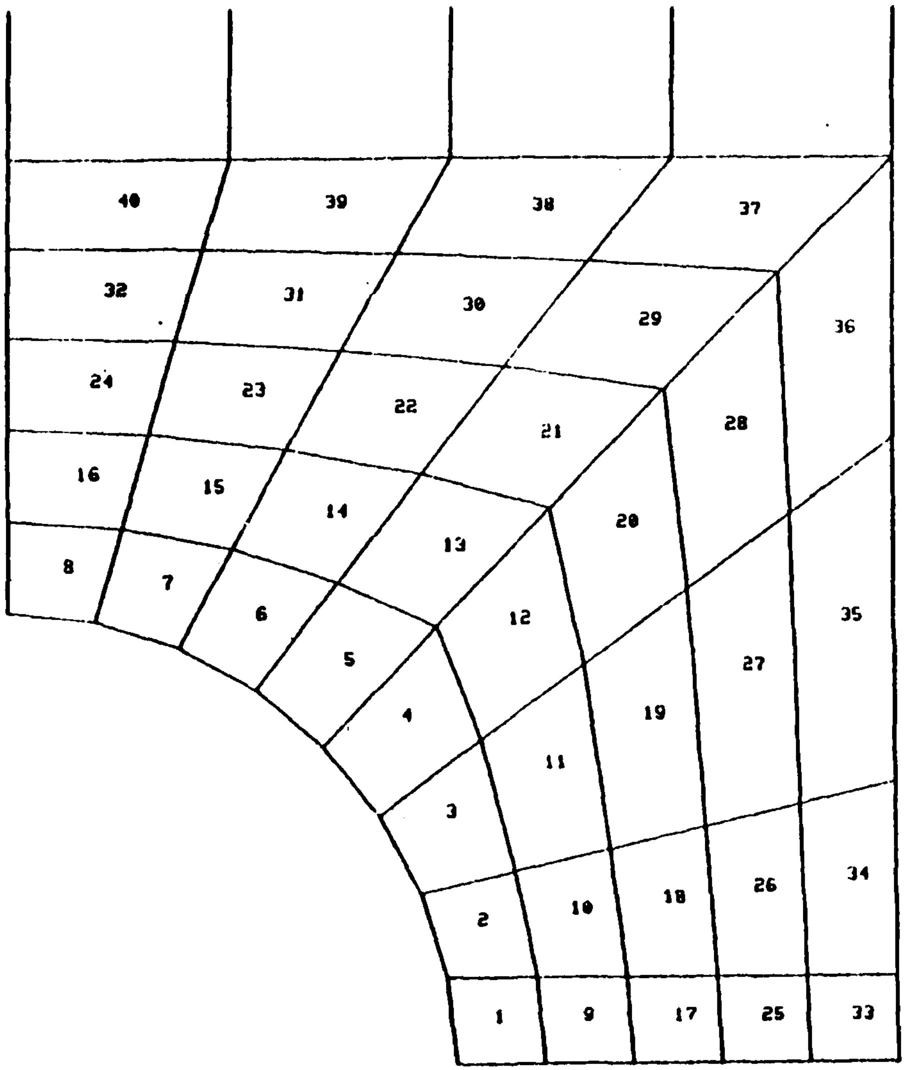


Figure 2.3 Effect of the CUBE Command.

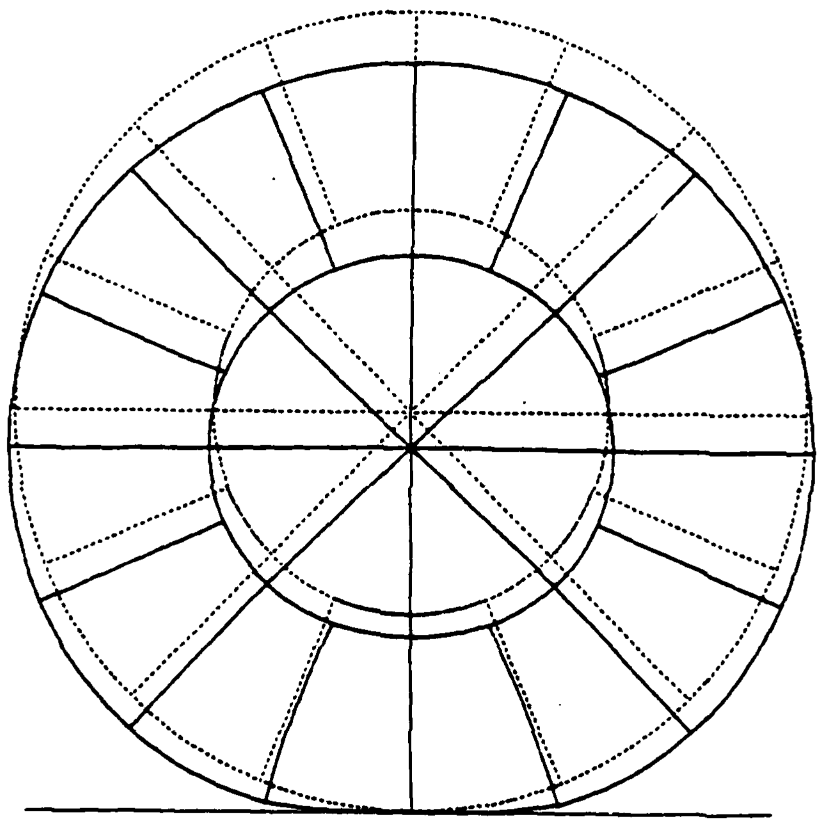


Figure 2.4 Plot with Deformed Geometry Superimposed on Original Model.

ELEMents

A group of finite elements can be selected for plotting using the ELEMENTS command. The elements are arranged in groups called "element types"; the element types recognized by GPLOT are summarized in Table 2.2. For each distinct element type, the particular elements to be plotted can be specified by any of three methods:

Method 1: Select random elements, by entering the number of elements, followed by the element numbers. A maximum of 60 elements can be selected in this fashion. For example, entering 3, 1, 4, 20 selects three elements (elements 1, 4 and 20) for plotting.

Method 2: Specify starting and ending element numbers, and an increment (e.g., elements 10 through 50 by an increment of 5). From one to three ranges may be given for each element type.

Method 3: Specify plotting for all elements of a given element type.

The default ELEMENTS option is to plot all elements in the model.

EYE

The EYE command defines the viewer position in space, and therefore the orientation of the plot. The EYE position may be placed anywhere in space. Note that an EYE position very close to (or within) the model may cause unintended clipping (see the CLIP command). Also, a viewing position very close to the model may cause excessive distortion in perspective plots (see the PROJECTION command). The effect of different EYE positions is shown in Figure 2.5. The default EYE position is X = 100, Y = 100, Z = 100.

HELP

Entering the HELP command produces a listing of all GPLOT commands, accompanied by a brief description of each command.

TABLE 2.2

FINITE ELEMENT TYPES CONSIDERED IN GPLOT

Element Type	Description	Number of Nodes
1	3-D Solid	8-27
2	3-D Solid	8
3	2-D Plane Stress, Plane Strain or Shear Panel Element	4
4	Bar (Truss)	2
5	Thin Shell	8
6	3-D Solid	20
7	3-D Solid	8-20
8	3-D Solid/Thick Shell	16
9	2-D Plane Stress	4-9
10	2-D Axisymmetric	4-9
11	3-D Layered Shell	16
12	3-D Curved Beam	2-3

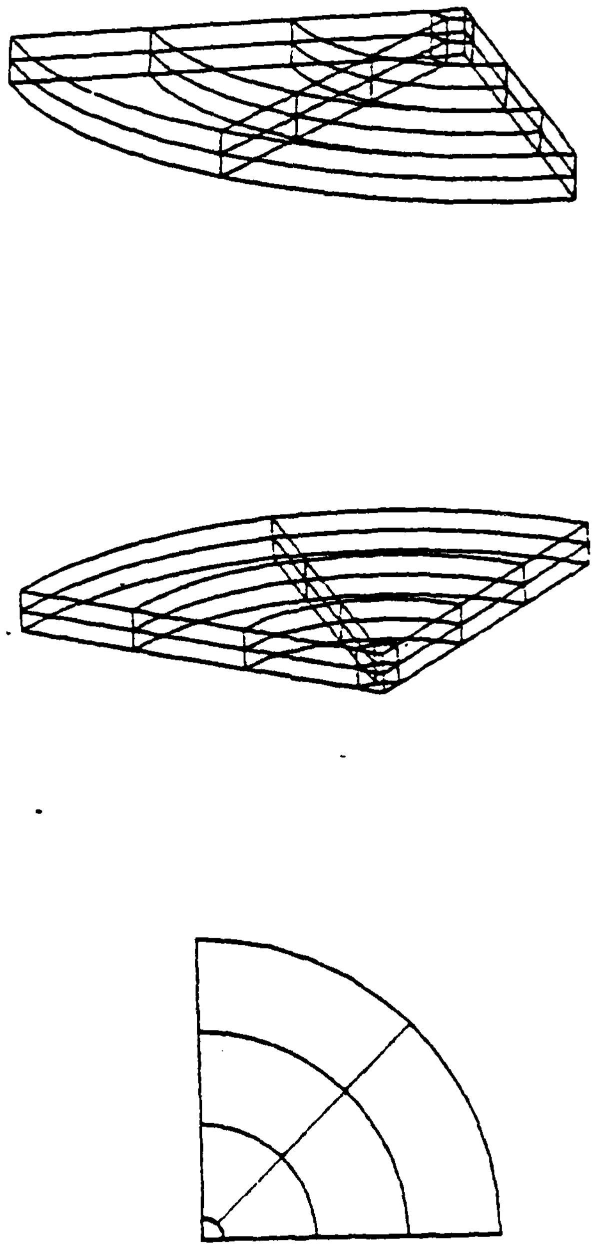


Figure 2.5 Effect of the EYE Command.

LABEl

LABEL is used to select or deselect labeling of node points and/or elements. Element labeling may be selected by element types. If nodes are to be labeled, a surface number may be defined for each element type, on which labeling is to occur. This device is useful in making plots of solid elements more readable. If desired, all surfaces (i.e., all nodes) may be labeled. The numbering of element surfaces for three-dimensional elements is shown in Figure 2.6. The default condition is no node or element labeling.

NEW

When more than one set of data is stored on a single file, the NEW command can be used to select a different set of data at any time during the session. Data sets are referred to by the order in which they appear on the input file.

PROJection

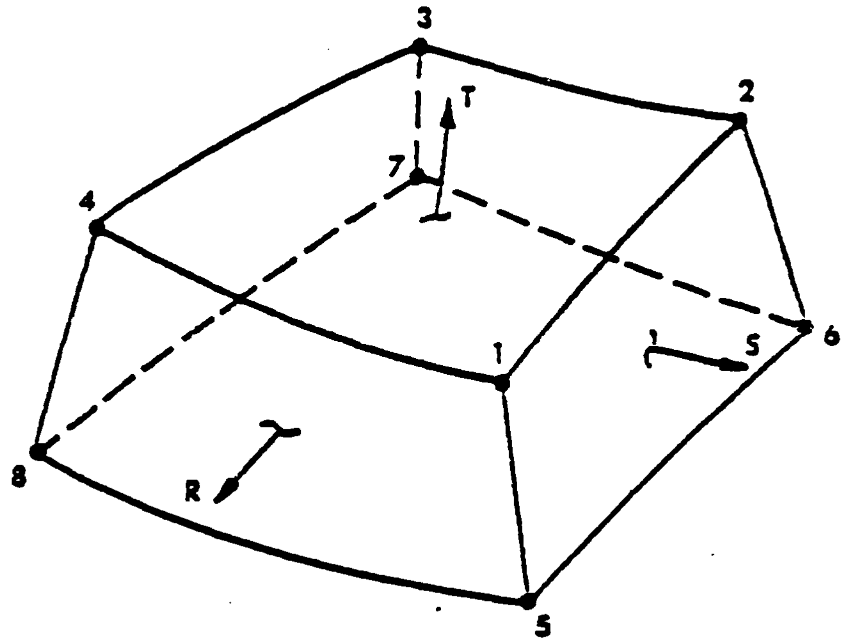
PROJECTION allows the selection of orthogonal (axonometric) or perspective views of the model. The difference between these two options is illustrated in Figure 2.7. The default projection type is orthogonal.

REFLect

The REFLECT command permits a symmetric model to be reflected about the Y-Z, X-Z or X-Y global coordinate planes. All parts of the plot are reflected, including undeformed and deformed geometry and labels. The default is no reflection.

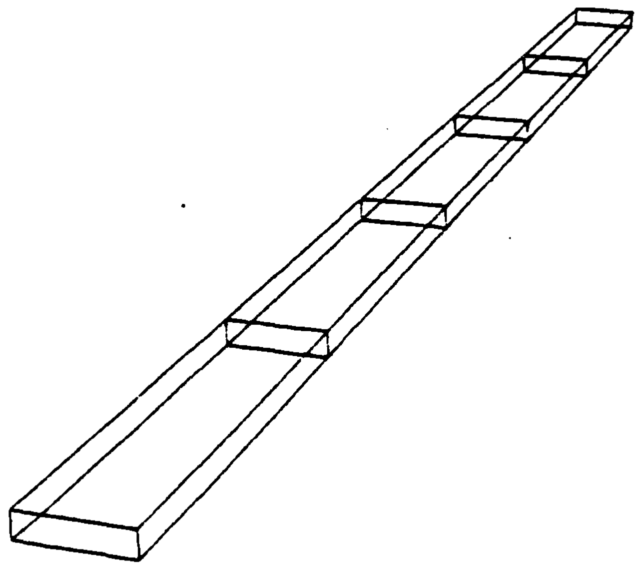
ROTAte

ROTATE may be used to rotate the model in space, while keeping the viewer position fixed. Rotations are specified in degrees, with positive rotations determined by the right-hand rule (i.e., a positive rotation, when viewed along the axis of rotation looking toward the origin, appears counterclockwise). The default is no rotation.

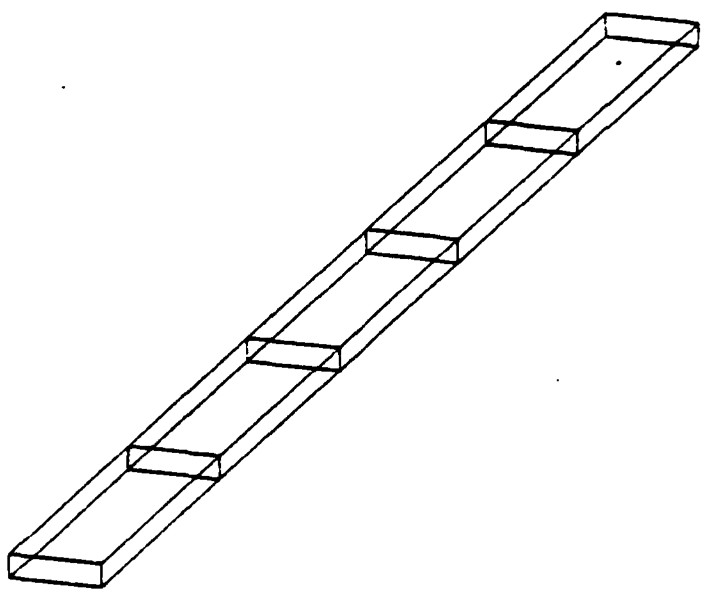


SURFACE	LOCATION	CORNER NODES
1	R = -1	2 - 3 - 7 - 6
2	S = -1	3 - 4 - 8 - 7
3	T = -1	5 - 6 - 7 - 8
4	R = +1	1 - 4 - 8 - 5
5	S = +1	1 - 5 - 6 - 2
6	T = +1	1 - 2 - 3 - 4

Figure 2.6 Solid Element Surfaces for Node Point Labeling.



PERSPECTIVE



ORTHOGONAL

Figure 2.7 Orthogonal and Perspective Projection of a Rectangular Bar.

SCALe

GPLOT automatically scales all final plots to be correctly proportioned while filling the available plotting surface. In some instances, it may be advantageous to scale the model independently in the horizontal and vertical directions (as when node labels are to be plotted on a very long, slender model). The SCALE directive permits the automatic scaling to be switched on and off as required. The default is proper scaling.

SHRInk

The SHRINK option reduces elements in size by a specified proportion, giving the effect of an "exploded" view of the model. An example appears in Figure 2.8. When SHRINK is selected, a "shrink factor" between 0 and 1 must be given; a shrink factor of 0 corresponds to no shrinkage (normal plot), while a factor of 1 would collapse all elements to their centroids. A shrink factor of about 0.1 generally works well. The default is no element shrinking (factor=0).

SITE

The SITE command allows the specification of a point which will be located (approximately) at the center of the screen in the final plot. SITE is usually used with the CUBE command, to restore proper centering of the plot on the screen. The default SITE position is the geometric center of the model.

STOP

Entering STOP causes GPLOT to terminate execution, and to return all temporary data files created during the session.

SUMMary

The SUMMARY command produces a listing of all current plot options and geometric parameters.

TIME

Entering TIME produces a message giving the total C.P.U. time elapsed since signing onto the system.

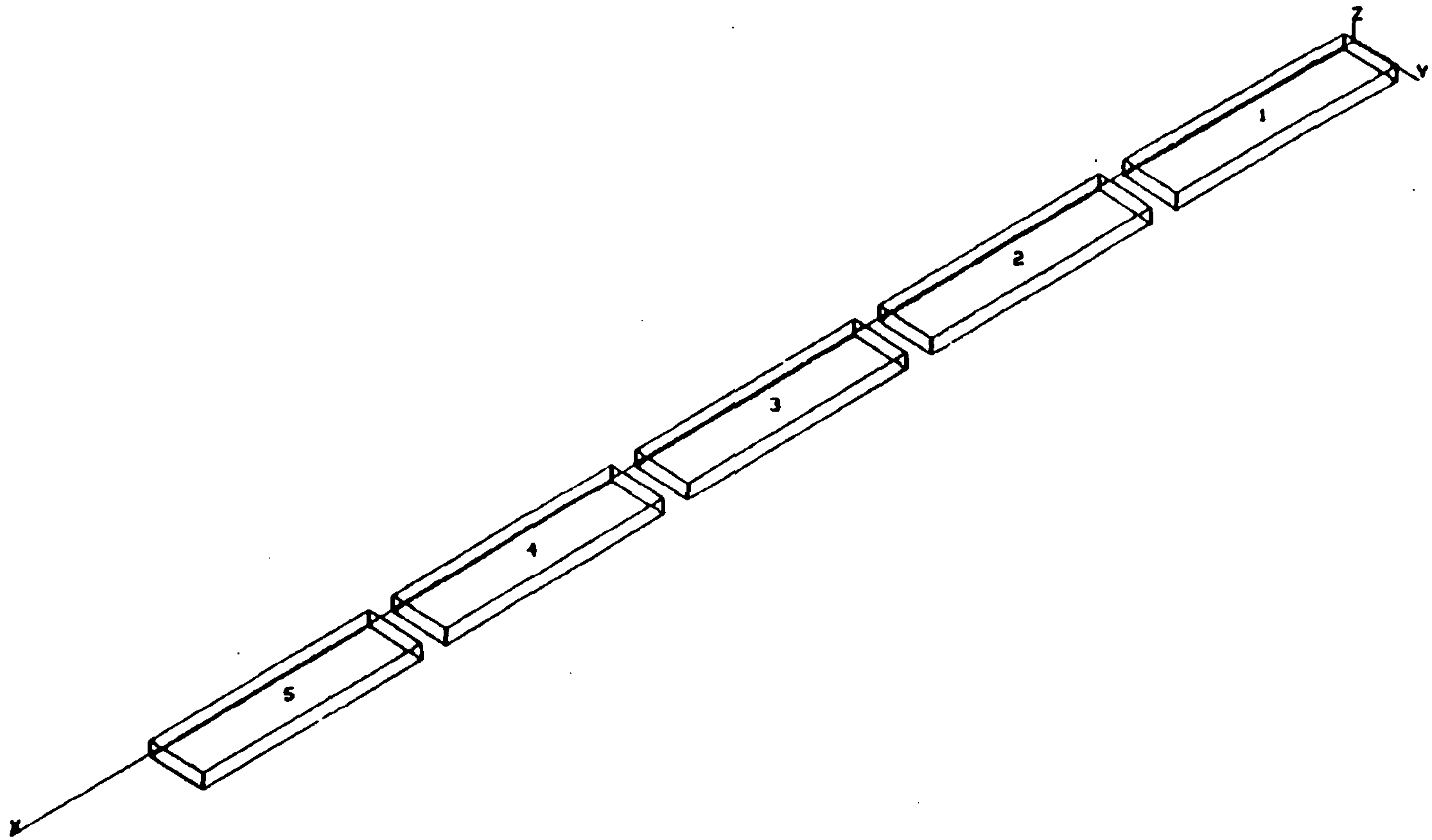


Figure 2.8 Exploded View Obtained with the SHRINK Option.

TRANslate

TRANSLATE can be used to modify the position of the model, without changing its orientation. In most cases, TRANSLATE is used in conjunction with the AXES command, to position the model closer to (or further from) the plotted axes. The default is no translation.

VERTical

The VERTICAL command permits the definition of the global coordinate direction to be oriented vertically in the final plot. Any of the axes X, Y or Z may be selected. The default vertical direction is Z.

ZOOM

With ZOOM, the user may identify a portion of the model which is to be expanded to fill the entire screen. The model should be plotted in the desired orientation before requesting a ZOOM. The "ZOOM area" is defined by cursor input locating the lower-left and upper-right corners of the area to be expanded. Note that ZOOMing may be performed more than once, to obtain plots of successively smaller portions of the model. The default condition is no ZOOMing.

2.3 SAMPLE INTERACTIVE SESSION

To illustrate the operation of GPLOT and to demonstrate the effect of certain commands, a sample terminal session with GPLOT is reproduced in this Subsection. The session is rather short, since it is not intended to demonstrate all possible options in the program. Experience has shown that the most effective means of learning the program is simply to run it, trying each option and making generous use of the HELP and SUMMARY commands.

```
COMMAND- ATTACH,P,PLOTPROC,ID=BROCKMAN,MR=1.
 AT CY= 000 SN=AFFDL
COMMAND- ATTACH,TAPE5,MAGNADATA,CY=1.

COMMAND- BEGIN,GPLOT,P.

 ****************************************
 BEGIN GPLOT - PRE/POST ANALYSIS GEOMETRY
               PLOTTER FOR MAGNA PROGRAM.
 ****************************************

  ENTER THE CHARACTERS PER SECOND ..............! 120
  TEKTRONIX OR HP PLOTTER(T,H) .................! T
  TEKTRONIX TERMINAL TYPES ---
   0, 4006-1
   1, 4010 / 4012 / 4013
   2, 4014 / 4015
   3, 4014 / 4015 (ENH.GR.MOD.)
  ENTER TERMINAL TYPE ( 0, 1, 2, 3 )............! 3
  MODEL INPUT FILE TYPES:
  1 - INPUT DATA FILE
  2 - POSTPROCESSOR (MPOST) FILE
  ENTER FILE TYPE(1,2) .........................! 1


  ENTER THE MODEL NUMBER
  ( = 1 IF ONLY ONE MODEL ON FILE ) ...........! 1
*HELP
 COMMAND        DESCRIPTION
 *******        ***********
  AXES           AXES DRAW AND LABEL
  CLIP           CLIP PLANE POSITION
  CUBE           SET MINIMA AND MAXIMA
  DEFAULT        SET DEFAULT VALUES
  DEFORM         DEFORMED MODEL REPRESENTATION
  DRAW           DRAW MODEL
  ELEMENTS       PLOTS ALL OR SELECTED ELEMENTS
  EYE            EYE POSITION
  HELP           LIST ALL COMMANDS
  LABELS         LABELS ELEMENTS AND/OR NODES
  NEW            NEW STRUCTURE
  PROJECTION     PROJECTION TYPE
  REFLECT        REFLECT A PLANE
  ROTATE         ROTATE MODEL ABOUT AXES
  SCALE          SCALE PLOT
  SHRINK         SHRINK ELEMENTS
  STOP           END PROGRAM
  SUMMARY        LIST ALL PARAMETER VALUES
  TIME           PRINT CPU TIME SINCE START OF SESSION
  TRANSLATE      TRANSLATE MODEL FROM ORIGIN
  VERTICAL       VERTICAL AXIS
  ZOOM           ZOOM ON THE MODEL
  SITE           SITE POSITION
```

```
*SUMM
  LABEL AXES. . . . . . .NO
  LABEL ELEMENTS. . . . .NO
  LABEL NODES . . . . . .NO
  SCALE PLOT. . . . . . .YES
  PLOT ALL ELEMENTS . . .YES
  ZOOM OPTION . . . . . .NO
  AXIS VERTICAL . . . . .Z-AXIS
  PLANE REFLECTED . . . .NONE
  PROJECTION TYPE . . . .PERSPECTIVE
  CLIP PLANE FACTOR . . .     .0100
  PLOT OPTION . . . . . .UNDEFORMED
  SHRINK FACTOR . . . . .    0.0000
  EYE POSITION:
      X-EYE=       100.0000
      Y-EYE=       100.0000
      Z-EYE=       100.0000
  SITE POSITION:
      XSITE=         0.0000
      YSITE=         0.0000
      ZSITE=         0.0000
  ORIGIN TRANSLATION:
     X=        0.0000
     Y=        0.0000
     Z=        0.0000
  ROTATION:
     X-ANGLE=        0.0000
     Y-ANGLE=        0.0000
     Z-ANGLE=        0.0000
  CUBE MINIMA AND MAXIMA:
     MINIMUM X      0.            MAXIMUM X    2.00000E+01
     MINIMUM Y      0.            MAXIMUM Y    6.00000E-01
     MINIMUM Z      0.            MAXIMUM Z    1.00000E+00
  STRUCTURE NUMBER. . . .   1
  UNDEFORMED MINIMA AND MAXIMA:
     MINIMUM X      0.            MAXIMUM X    2.00000E+01
     MINIMUM Y      0.            MAXIMUM Y    6.00000E-01
     MINIMUM Z      0.            MAXIMUM Z    1.00000E+00
*DRAW
```

Figure 2.9 Typical teractive Session Using GPLOT.

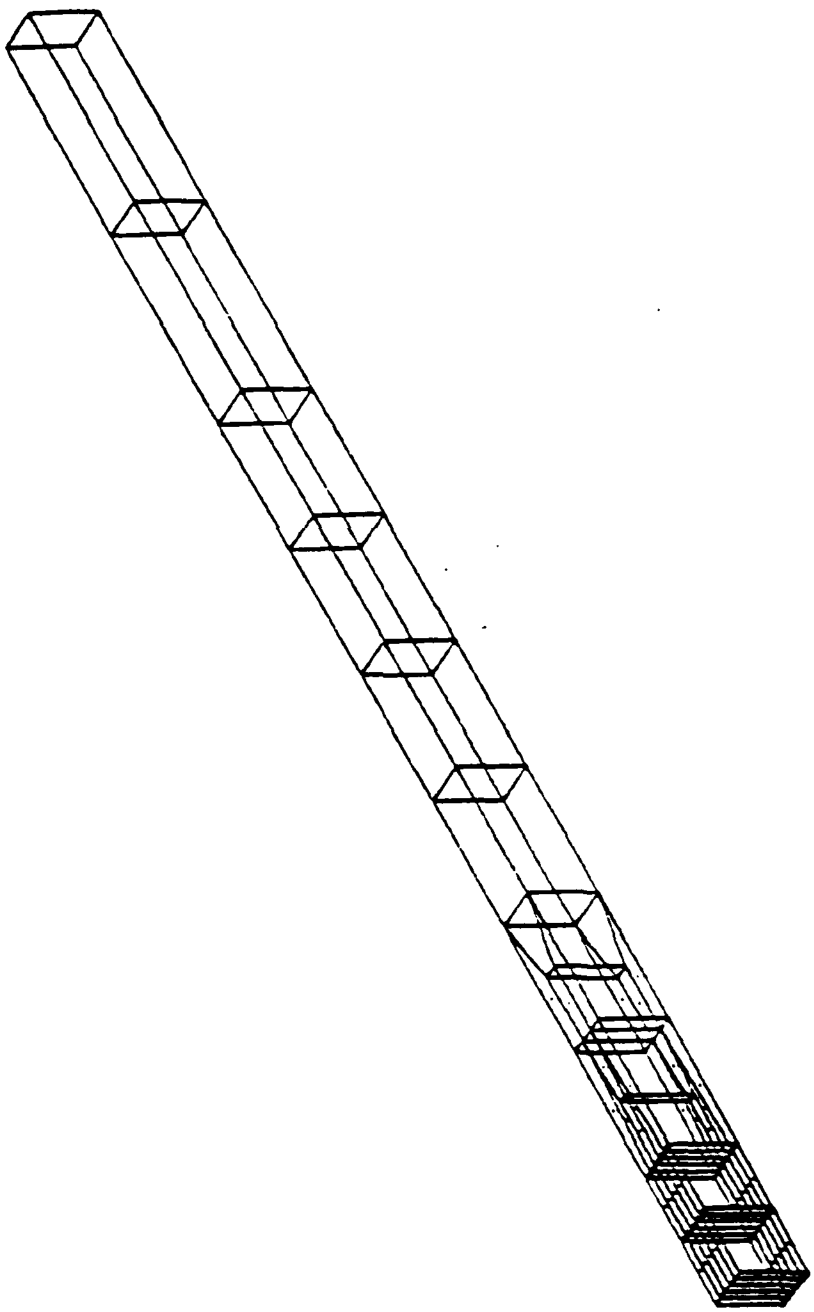


Figure 2.9 (continued)

```
$AXES
  PLOT AND LABEL THE AXES?(Y,N) ...............! Y
$EYE
  ENTER THE EYE POSITION,
  XEYE, YEYE, ZEYE ...........................! 100,40,20
$VERT
  WHICH AXIS IS VERTICAL?
  ENTER 1 FOR X, 2 FOR Y, OR 3 FOR Z .........! 2
$PROJ
  ENTER THE PROJECTION TYPE,
  PERSPECTIVE OR ORTHOGONAL(P,O) ..............! P
$DRAW
```

Figure 2.9 (continued)

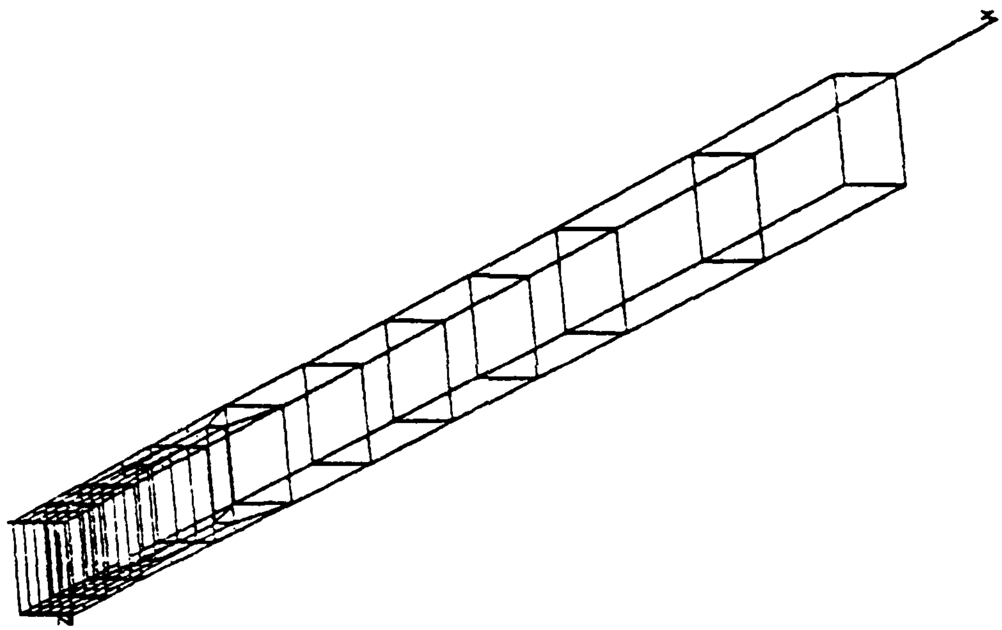


Figure 2.9 (continued)

```
@ZOOM
  DO YOU WANT THE ZOOM OPTION?(Y/N) ..........: Y
  DO YOU WISH TO HAVE THE ZOOM AREA SCALED? ...: Y
  DIGITIZE THE LOWER LEFT CORNER
  AND THE UPPER RIGHT CORNER OF THE
  ZOOM AREA
  (PRESS ANY KEY, THEN C/R, TO ACTIVATE CURSOR)

 @DRAW
```

Figure 2.9 ' tinued)

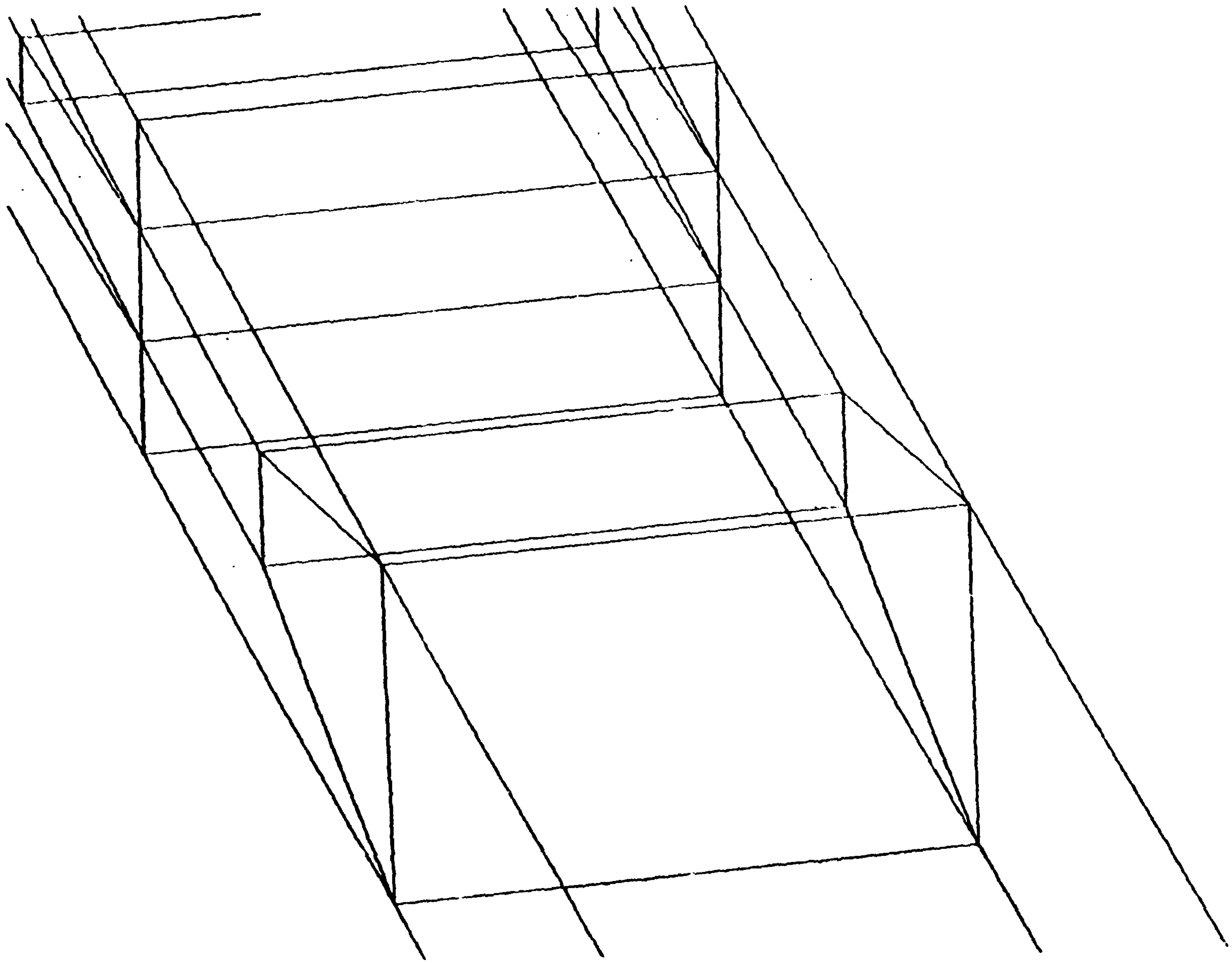


Figure 2.9 (continued)

```
*LABE
  LABEL THE ELEMENTS?(Y,N) .....................! N
  LABEL THE NODES?(Y,N) ........................! Y
  LABEL ALL THE SURFACES?(Y,N) .................! Y
*DRAW
```

Figure 2.9 (continued)

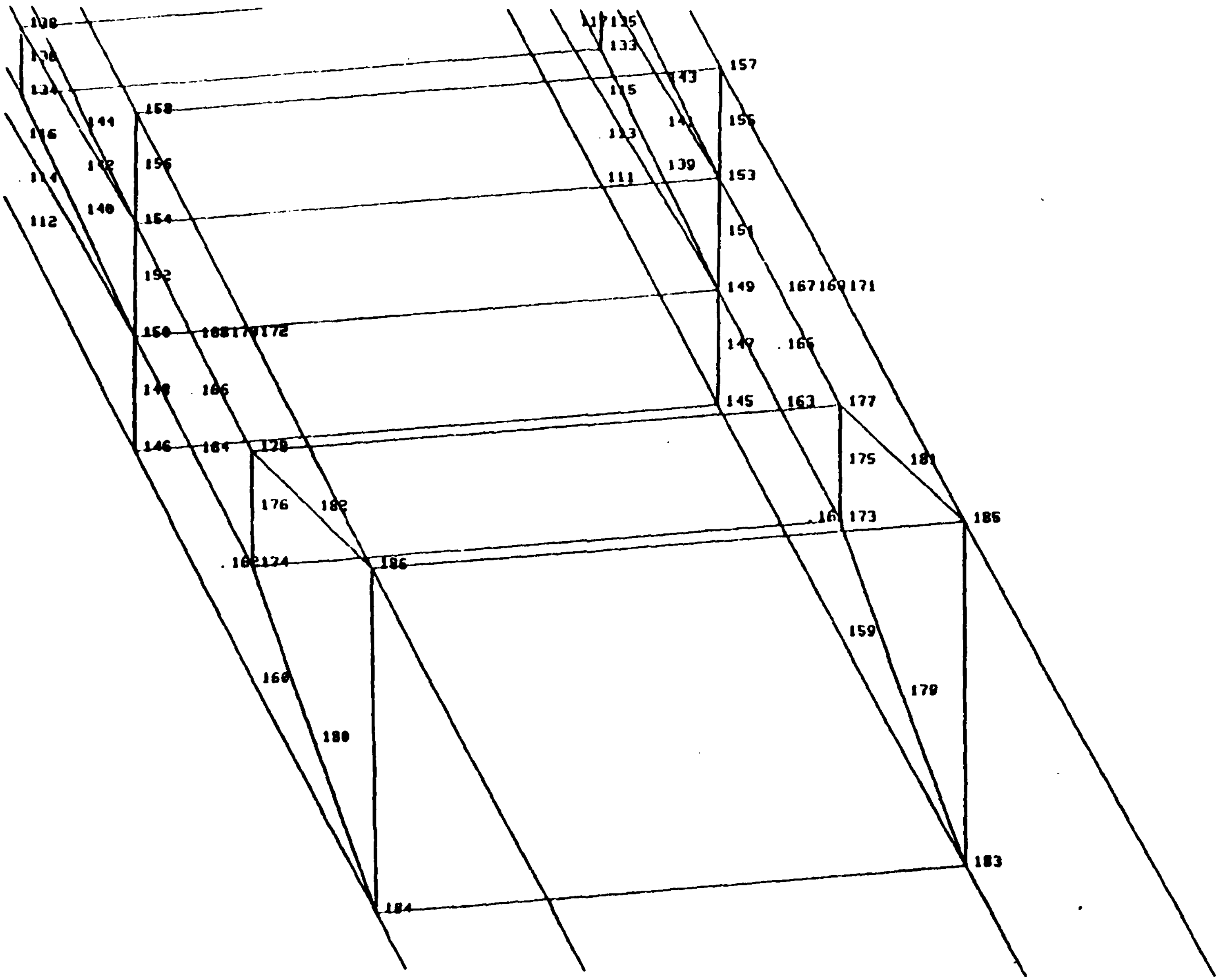


Figure 2.9 (continued)

```
$STOP

046600 MAXIMUM EXECUTION FL.
 2.150 CP SECONDS EXECUTION TIME.
COMMAND-
```

Figure 2.9 (cluded)

SECTION 3
CONTOUR AND RELIEF PLOTTING

CPLOT is an interactive program designed for the display of stress, strain and displacement results from finite element structural analyses. CPLOT is capable of preparing two types of plots:

- contour plots (Figure 3.1), tracing the paths on a surface along which the quantity of interest is constant; and
- relief plots (Figure 3.2), displaying function values projected above a surface by an amount proportional to their magnitude.

In contrast to the commonly used "box methods" of contour plotting [9,10], CPLOT uses a contouring technique which is computationally efficient and better-suited for finite element work [11]. On any surface of a finite element, a function can be interpolated as a function of the natural or "parametric" surface coordinates (r,s), which vary from -1 to +1 within an element [1]. Since the relation defining a contour of a function f(r,s) is

$$df = \frac{\partial f}{\partial r}\, dr + \frac{\partial f}{\partial s}\, ds = 0 \tag{3.1}$$

the relationship between surface coordinates r and s along any contour line can be found by integrating one of the equations

$$\frac{ds}{dr} = - \frac{\partial f/\partial r}{\partial f/\partial s} \tag{3.2}$$

or

$$\frac{dr}{ds} = - \frac{\partial f/\partial s}{\partial f/\partial r} \tag{3.3}$$

Equation (3.2) or (3.3) is integrated over each element using a Runge-Kutta method to trace individual contours. This approach is reliable and relatively fast, so that contour plots can be generated interactively.

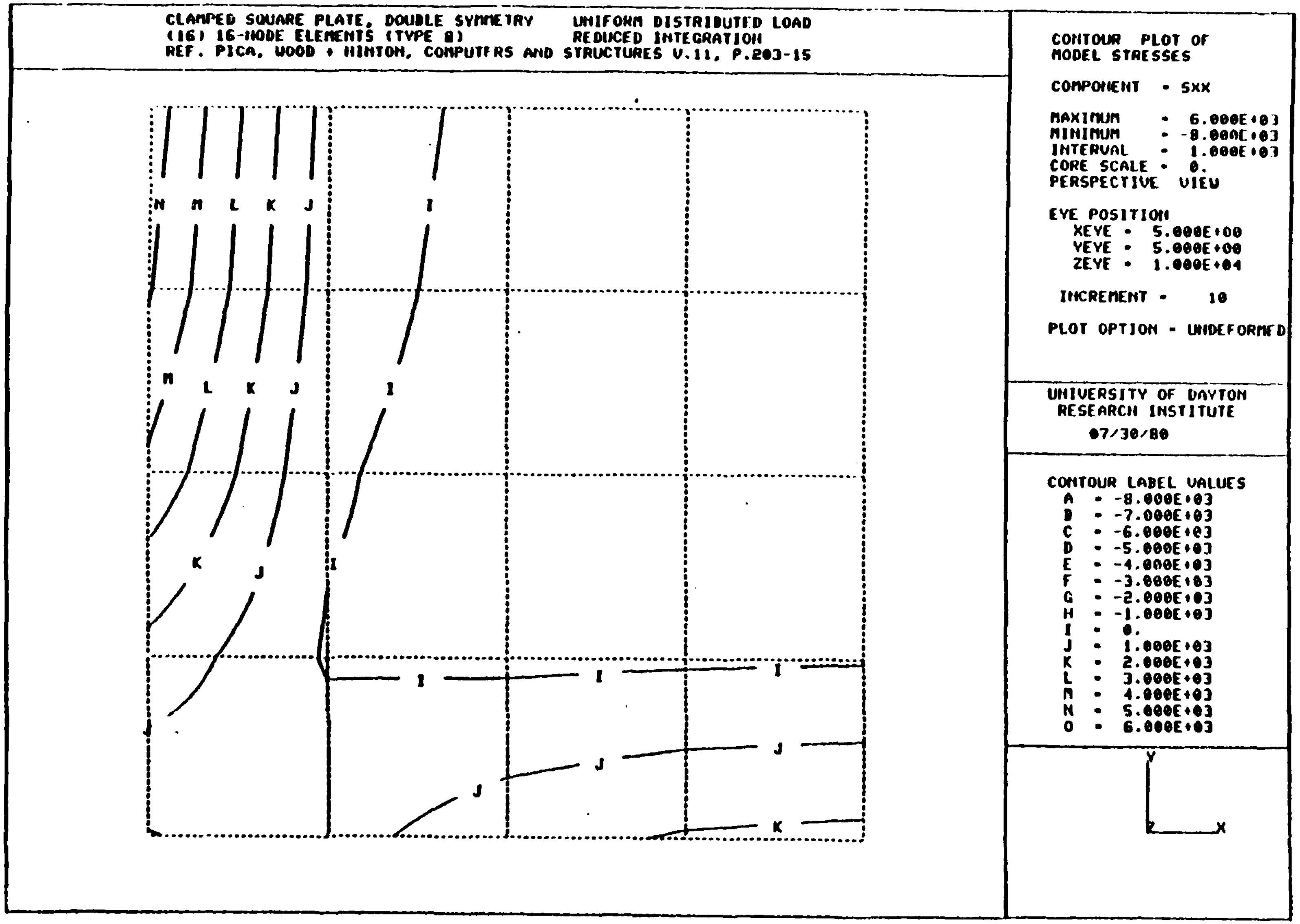


Figure 3.1 Typ 1 Contour Plot.

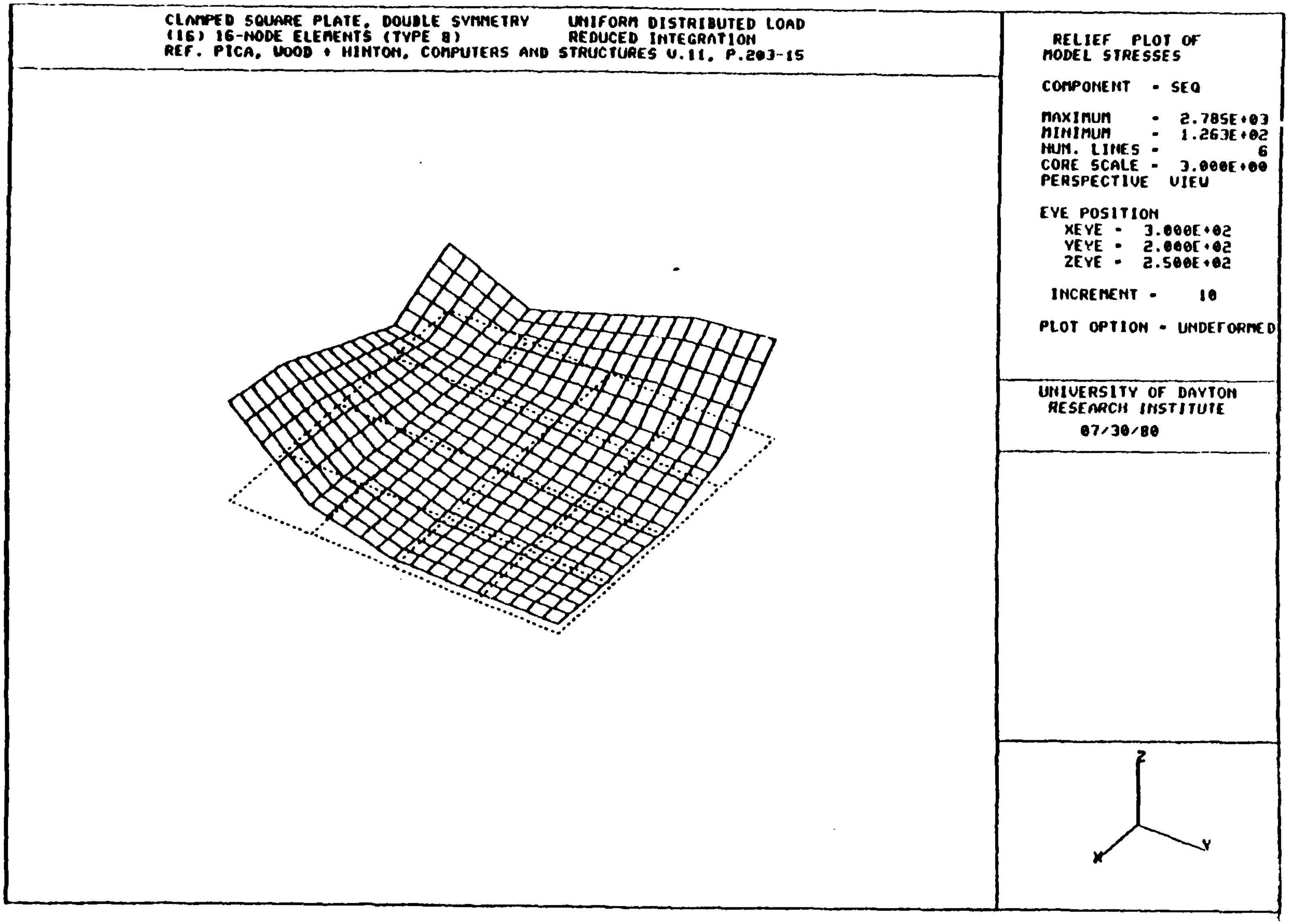


Figure 3.2 Typical Relief Plot.

In the case of relief plotting, function (displacement, strain or stress) values are projected along the element surface normal direction,

$$\hat{n} = \frac{(\partial\vec{R}/\partial r) \times (\partial\vec{R}/\partial s)}{|(\partial\vec{R}/\partial r) \times (\partial\vec{R}/\partial s)|} \tag{3.4}$$

where $\vec{R}$ describes the spatial position of a point on the surface.

CPLOT offers most of the geometry plotting options available in GPLOT (CLIP, LABEL, REFLECT, SHRINK, ZOOM, etc.). In addition, CPLOT permits contour and relief maps to be plotted separately or together, allows automatic or manual selection of contour levels, and can produce labeled or unlabeled contour curves. Plots may be outlined, titled and subtitled, with summaries of axis orientations, plot options and contour values listed.

The types of data which can be displayed using CPLOT include

- displacement components in global directions,
- displacement magnitude,
- displacement normal to a surface,
- strain components in global or user-defined directions,
- stress components in global or user-defined directions, and
- von Mises effective stress.

Data is supplied to CPLOT from the 'APOST' postprocessor file generated by the MAGNA postprocessor STRAVG [2], which performs local stress/strain averaging of finite element results. The APOST file formats are summarized in the Appendix and in Reference [2]. CPLOT is capable of accepting function data which is not continuous between adjacent finite elements, so that strains and stresses in the vicinity of material interfaces are displayed correctly.

Optionally, CPLOT can be used to generate output in a device-independent format using the DISSPLA [8] graphics package. This facility is useful for generating high-quality output (from any DISSPLA-supported device) and for off-line plotting of longer sequences of plot frames.

CPLOT is a command-driven program. Its operation is similar to that of GPLOT, in that options and parameters may be specified and reviewed as needed before actually doing a plot. The next few subsections describe operating procedures, control commands and plotting parameters for CPLOT in some detail.

3.1 PROGRAM OPERATION

CPLOT is executed under the control of command language procedures which automatically access the proper files, and return them when the session is complete. The plotting data to be used in CPLOT must be in the form of an 'APOST' results file (see the Appendix), and is always assumed to reside on FORTRAN logical unit 99.

On most CDC computers, the necessary commands for executing CPLOT are:

```
ATTACH,TAPE99,apostfilename.
ATTACH,P,PLOTPROC,ID=BROCKMAN,SN=AFFDL,MR=1.
BEGIN,CPLOT2,P.
```

The default version of the program uses the Tektronix 4010 series graphic display (or emulator); for plotting on the HP-7221A pen plotter, the BEGIN command is modified to read

```
BEGIN,CPLOT2,P,HP.
```

The DISSPLA output option is normally used in batch (background) mode, due to the size of the DISSPLA library. A typical batch control stream would have the form:

```
myid,Txxx,IOxxx,CM150000,STANY. account,name,address.
    :    :    :
ATTACH,TAPE99,apostfilename.
ATTACH,P,PLOTPROC,ID=BROCKMAN,SN=AFFDL,MR=1.
REQUEST,PLFILE,*PF.
BEGIN,CPLOT,P,DS.
CATALOG,PLFILE,plotfilename.
    :    :    :
    :    :    :
7/8/9   (end-of-record)
```

```
        :
        :
  ( CPLOT commands and input )
        :
        :
7/8/9   (end-of-record)
6/7/8/9 (end-of-file)
```

On the VAX 11/780 computer, CPLOT can be executed using the single command

```
RUN [*****]CPLOT
```

where [*****] is the directory name (installation-dependent) on which CPLOT is stored. In this case, the program will issue an input prompt requesting the file name of the APOST file to be used for plotting. Only the Tektronix terminal version of CPLOT is available on the VAX at present.

When execution begins, CPLOT requests a number of initial data items (such as the transmission rate and terminal type), similar to GPLOT. After this preliminary input phase, CPLOT enters the command mode, in which the sequence of events is controlled by the user. The various control commands and options which are available in the command mode are the subject of the following two subsections. The DISSPLA option, which is usually used in batch mode, is discussed separately in subsection 3.4.

3.2 SUMMARY OF CONTROL COMMANDS

CPLOT control commands are used to request some immediate action by the program. Any of these commands, as well as the option commands described in subsection 3.3, may be entered whenever CPLOT is in the command mode. In the command mode, a prompt symbol "?" is always displayed when new input is expected. A complete summary of both types of commands can be listed during a session simply by typing "HELP".

Control commands recognized by CPLOT are listed in Table 3.1 in alphabetical order. In each case, only four letters are needed as input (these are capitalized in the Table). More detailed descriptions of each control command are given below.

DRAW

The DRAW command causes CPLOT to generate a contour and/or relief plot of the model using all current plotting parameters. At the completion of the plot, the cursor crosshairs appear on the screen; typing any character will cause CPLOT to return to the command mode. This pause permits hard copies to be made without extraneous printing appearing on the screen. Note that DRAW may be entered as the first command, since default values are assigned to all of the necessary parameters.

EXIT

EXIT terminates execution of CPLOT, and causes all temporary data files created during the session to be deleted.

HELP

The HELP command produces a listing of all CPLOT control commands and options, accompanied by a brief description of each command.

TABLE 3.1

CPLOT CONTROL COMMAND SUMMARY

COMMAND	DESCRIPTION
DRAW	Plot using current data and options
EXIT	Terminate execution
HELP	Display valid commands and options
MultipleDRAW	Plot similar data for a series of increments
NewDATA	Select new set of data from current model
NewINCrement	Select new solution increment for plotting
RESEt	Reset all parameters to default values
SUMMary	Display current parameter values
TIME	Display CPU time elapsed since sign-on

MDRAw

MDRA (Multiple DRAw) causes a series of increments to be plotted one after the other, with the same plotting parameters and options used for each plot. This command is normally used in connection with the DISSPLA metafile option, to produce a series of frames for later off-line plotting. Care should be taken in defining plot scaling and contouring values when using MDRA, since maximum and minimum values of displacements, strains, and stresses may vary considerably from one increment to another.

NDAT

The NDAT (New DATa) command is used to select a different set of analysis data for plotting. The possible data types are displacment components, normal displacements, displacement magnitudes, strain/stress components, and von Mises effective stress. The increment number is assumed unchanged. Note that it is advisable to follow an NDAT command with the CORE option command (Subsection 3.3), to reset contouring values for the new set of data.

NINC

NINC (New INCrement) selects a new increment (or mode, or loading condition) from which results are to be retrieved. The data type (e.g., displacement, stress) is assumed unchanged. Note that it is advisable to follow an NINC command with the CORE option command (Subsection 3.3), to reset contouring values for the new set of data.

RESE

This command restores the default values of all plotting options described in Subsection 3.3. Note that a listing of all default values can be obtained by typing HELP, and current values can be listing by typing SUMMary.

SUMM

The SUMM (SUMMary) command requests a listing of all current option and parameter settings.

TIME

Entering TIME produces a message giving the total C.P.U. time elapsed since signing onto the system.

3.3 SUMMARY OF PLOTTING OPTION COMMANDS

CPLOT plotting option commands are used to select plotting features, and to specify parameters which affect the content and appearance of a final plot. Option commands may be entered in any order and any number of times, whenever CPLOT is in command mode. In command mode, the prompt symbol "?" is displayed when the program is waiting for input. A complete summary of all possible commands can be obtained by typing "HELP".

Valid CPLOT option commands are listed in alphabetical order in Table 3.2. Only the first four letters of a command are required. A more detailed description of the individual commands is given below.

CLIP

CLIP can be used to inhibit plotting of portions of the model close to the viewer position (see the EYE command). The user is asked to define a "clip factor", defined as CLPFAC = C/P, where C is the distance from the viewer to the clipping plane, and P is the distance from the viewer to the site position (usually the centroid). Points between the viewer and the clipping plane are not plotted. Parameters C and P are shown in Figure 2.1. The default value of CLPFAC is 0.01.

CORE

The CORE (COntour-RElief) command allows the selection of the type of plot (contour, relief, or both) to be performed, and the definition of parameters governing the number, type and location of contour or relief lines. The following parameters may be defined through the CORE command:

- plot type (contour/relief)
- number of contour lines or relief lines
- contouring values
- contour label switch (label/no-label)

TABLE 3.2

CPLOT PLOTTING OPTION COMMAND SUMMARY

COMMAND	DESCRIPTION
ELEM	Select specific elements to be plotted
CLIP	Specify clipping plane position
CONL	Select contour labeling
CORE	Define contour or relief plotting parameters
CUBE	Modify coordinate limits
DEFOrm	Select deformed geometry for plotting
ENTE	Specify plotting of entire element
EXPLode	Select exploded view option
EYEP	Specify eye (viewing) position
TITLe	Request title block and outline on final plot
LAXS	Draw and label coordinate axes
LABEl	Select element labeling
NODE	Select node labeling
ORIN	Define alternate axis system for stresses

TABLE 3.2 (concluded)

CPLOT PLOTTING OPTION COMMAND SUMMARY

COMMAND	DESCRIPTION
MOVIe	Retain plotting limits for multiple-frame plots
PROJection	Select orthogonal or perspective view
REFLect	Specify a plane of reflection
SITE	Define site position to modify plot centering
STEP	Modify step size for contour line integration
SUBTitle	Specify subtitle to appear on plot
SURFace	Specify element surface number and layer number (for layered shell elements) for plotting
VERTical	Define vertical axis direction
ZOOM	Define area for close-up viewing

- label placement parameters
- relief scale
- relief "displacement"

For contour plots, contouring values may be specified in the form (start, end, increment); when an increment of zero is input, the contour values are selected automatically by CPLOT. Note that the time required to generate a contour plot is strongly dependent upon the number of contour lines requested. Contours can be labeled optionally, and normally this labeling is done within each element of sufficient size. Label density can be controlled by means of the label position parameter, which is normally set to zero. Entering a value close to -1 will cause labeling in nearly all elements, while values close to 1 will cause labels to be placed only along longer contour lines.

For relief plots, the number of relief lines drawn per element in each direction may be specified, but must be at least two (that is, relief lines only above actual element edges). The "relief scale" is specified in the same length units used for the geometry of the model, to define the distance by which function values are to be projected above the model surface. The "relief displacement" defines a constant offset from the surface for the entire relief plot, for easier viewing. Note that relief "scale" and "displacement" can also be specified for contour plots, to project contour lines above the model surface (normally these are both set to zero for contour plots).

Contour and relief plots may be drawn over either undeformed or deformed geometry (see the DEFOrm command). For relief plots, it should also be noted that the initial plot scaling may be overly conservative, generating a rather small image on the plot surface; when this problem occurs, the ZOOM command can be used to increase the image size.

Several effects which can be produced by modifying the CORE parameters are shown in Figures 3.3 through 3.7.

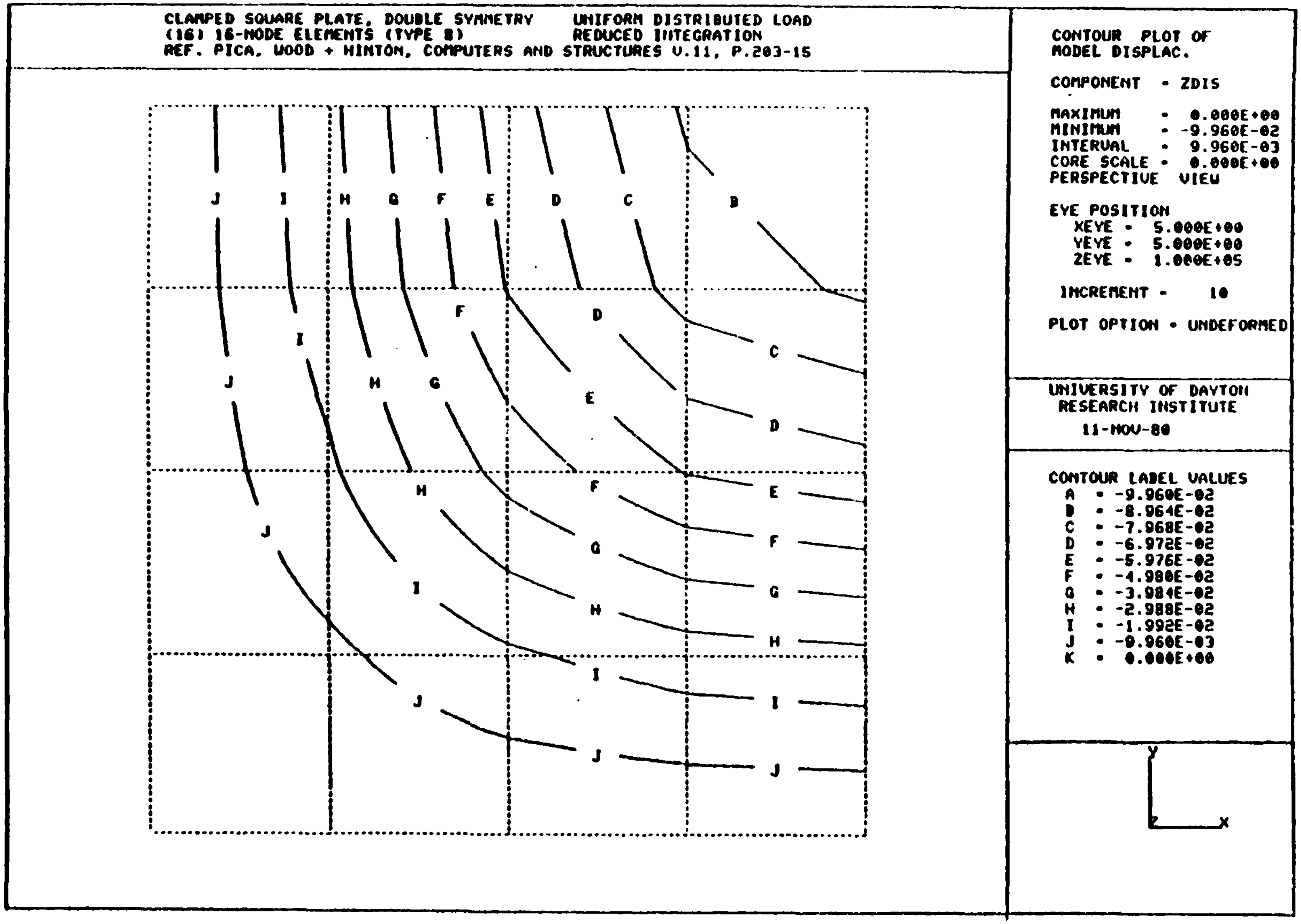


Figure 3.3 Effect of COR' arameters (Sample No. 1).

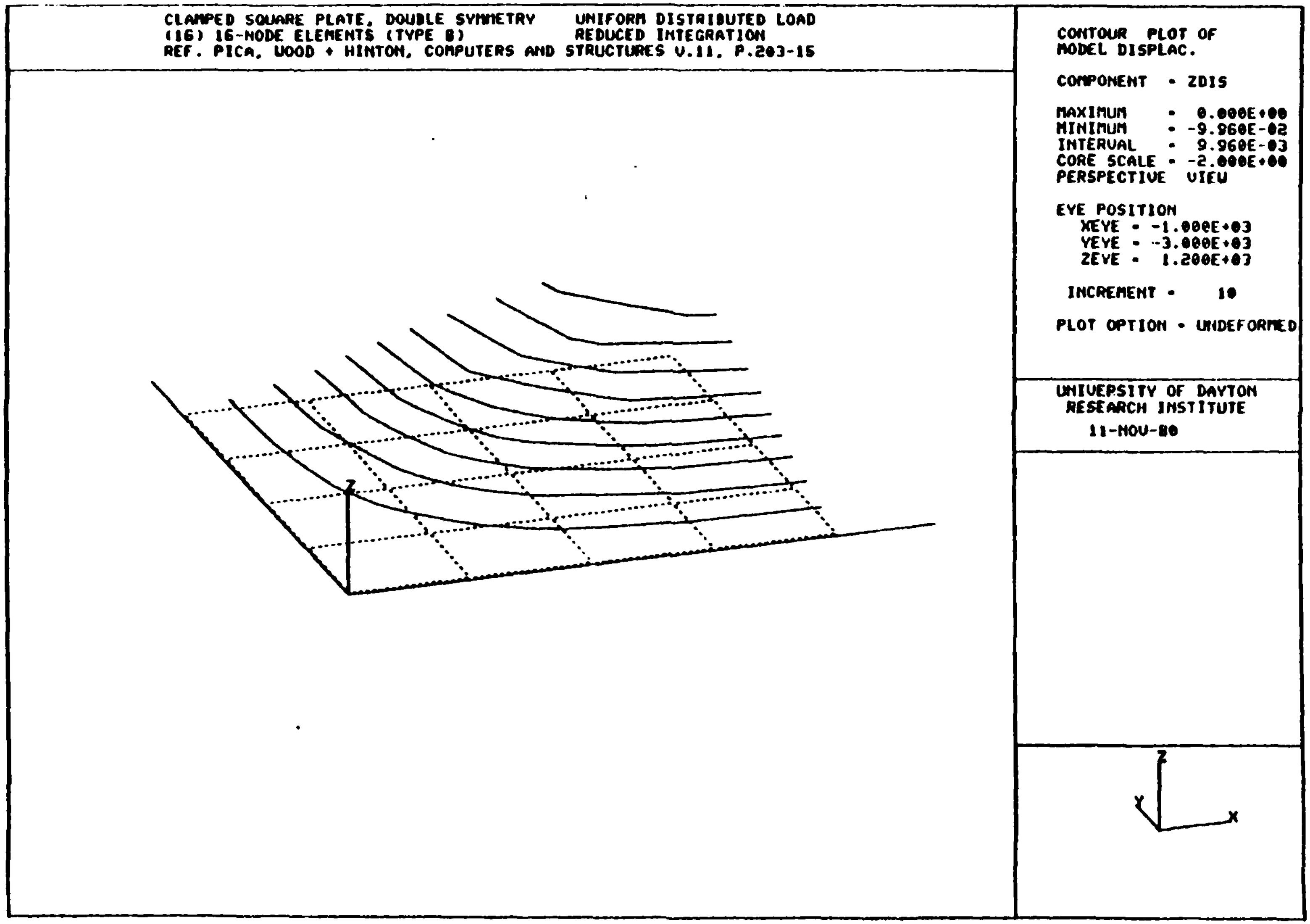


Figure 3.4 Effect of CORE Parameters (Sample No. 2).

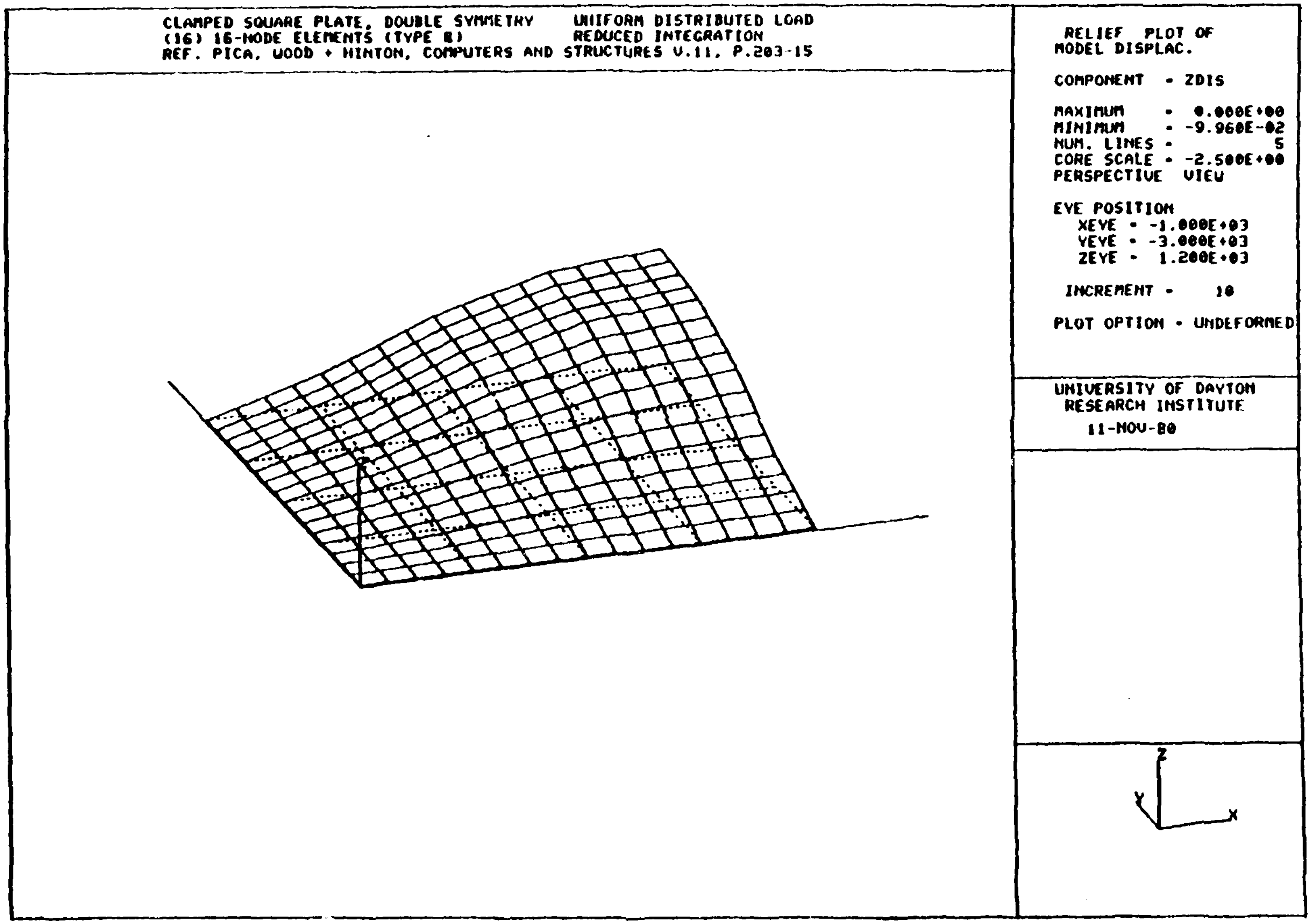


Figure 3.5 Effect of COR rameters (Sample No. 3).

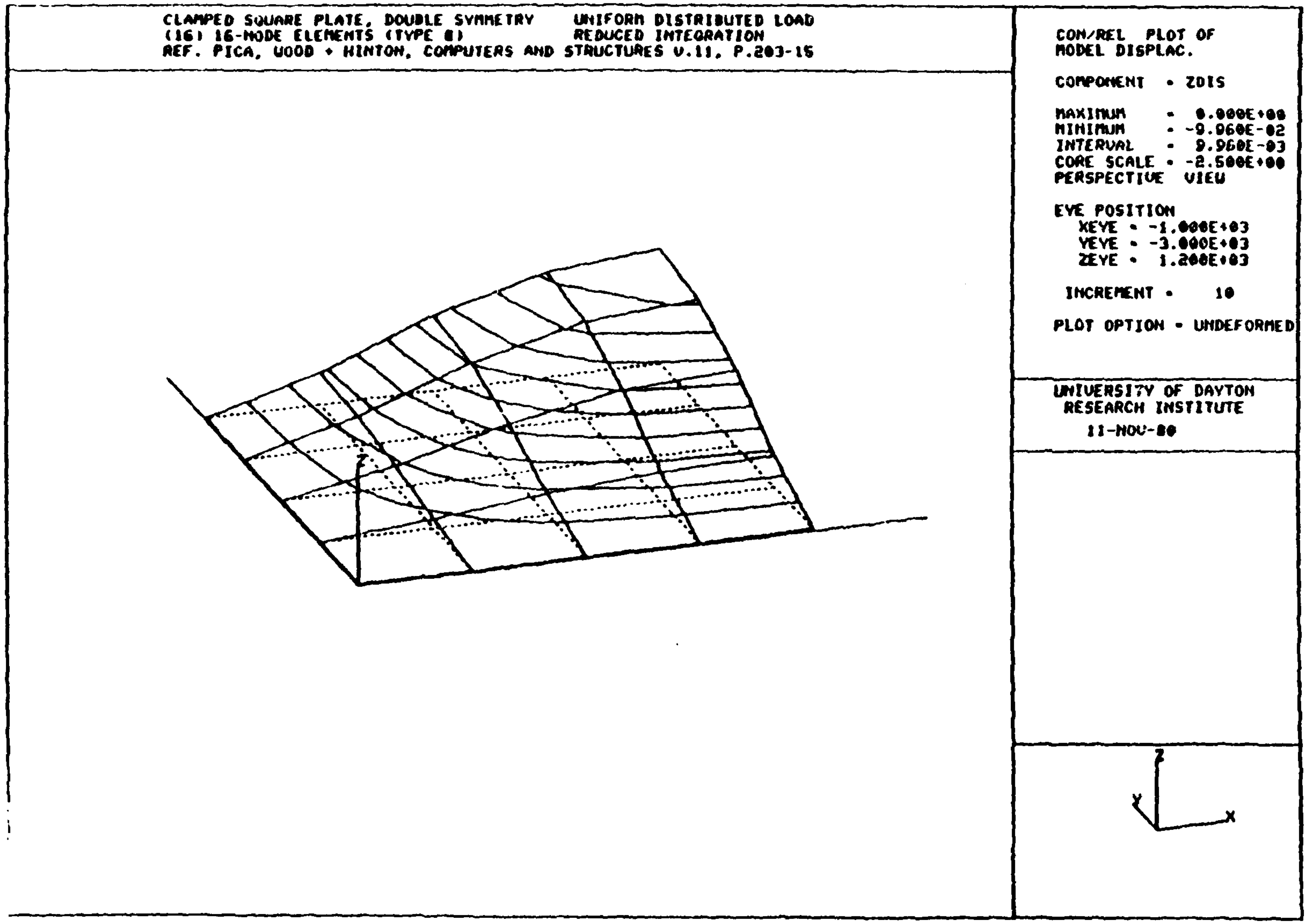


Figure 3.6 Effect of CORE Parameters (Sample No. 4).

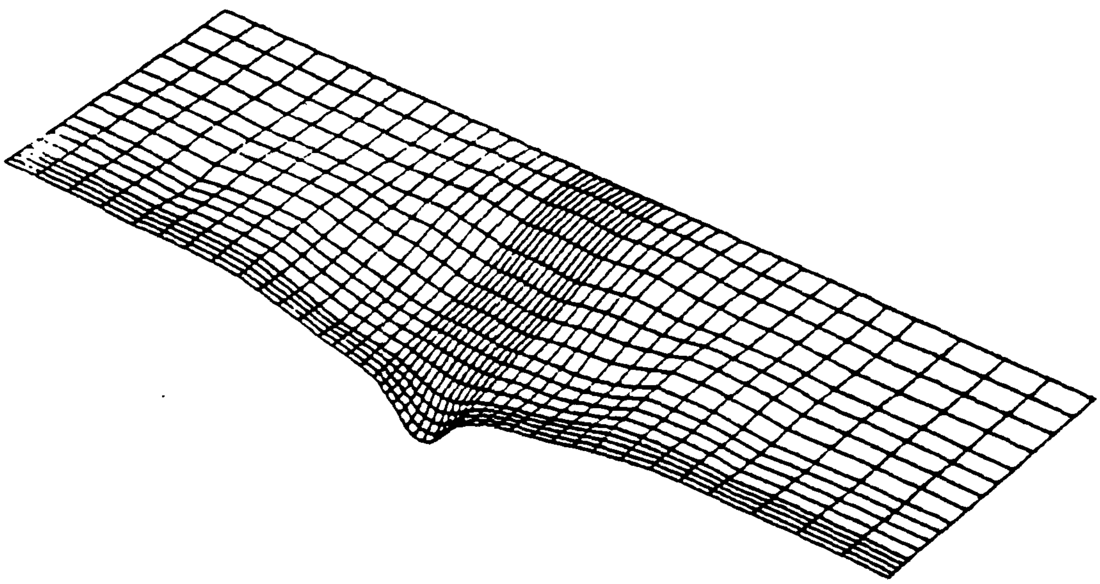


Figure 3.7 Relief Plot Option used to Refine a Plot of Deformed Geometry.

CUBE

CUBE allows the user to override the automatic scaling done by CPLOT, and to isolate the portion of the model contained within a rectangular region defined by limiting values of X, Y and Z. CUBE is most useful when a number of different views of a small portion of the model are needed; otherwise, the function performed by CUBE is accomplished more easily using ZOOM. If the region defined using CUBE is far from the centroid of the entire model, the SITE command can be used to re-center the plot on the page.

DEFOrm

DEFORM selects the type of geometry to be plotted: deformed, undeformed, or both. The displacement values used are those for the currently selected increment (a different increment can be selected using the NINC control command), and may be scaled by a constant multiplier for visibility. When the geometry type is changed, the current contour/relief plotting parameters remain unchanged, and contour or relief lines will be superimposed on the type of geometry last selected.

ELEMents

A group of finite elements can be selected for plotting using the ELEMENTS command. The elements are arranged in groups called "element types"; the element types recognized by CPLOT are the same as those recognized by GPLOT, and are summarized in Table 3.3. For each distinct element type, lists of elements may be selected for plotting by any of three methods: (1) a list of random elements; (2) a range (or ranges) of elements, each defined by a starting number, an ending number, and an increment; and (3) selection of all elements of a given type.

ENTIre

The ENTIRE command selects plotting of entire finite elements, rather than plotting surfaces only (see the SURFACE command). The effect of the ENTIRE option is shown in Figure 3.8. This command has no effect on two-dimensional finite elements.

TABLE 3.3

FINITE ELEMENT TYPES CONSIDERED IN CPLOT

Element Type	Description	Number of Nodes
1	3-D Solid	8-27
2	3-D Solid	8
3	2-D Plane Stress, Plane Strain or Shear Panel Element	4
4	Bar (Truss)	2
5	Thin Shell	8
6	3-D Solid	20
7	3-D Solid	8-20
8	3-D Solid/Thick Shell	16
9	2-D Plane Stress	4-9
10	2-D Axisymmetric	4-9
11	3-D Layered Shell	16

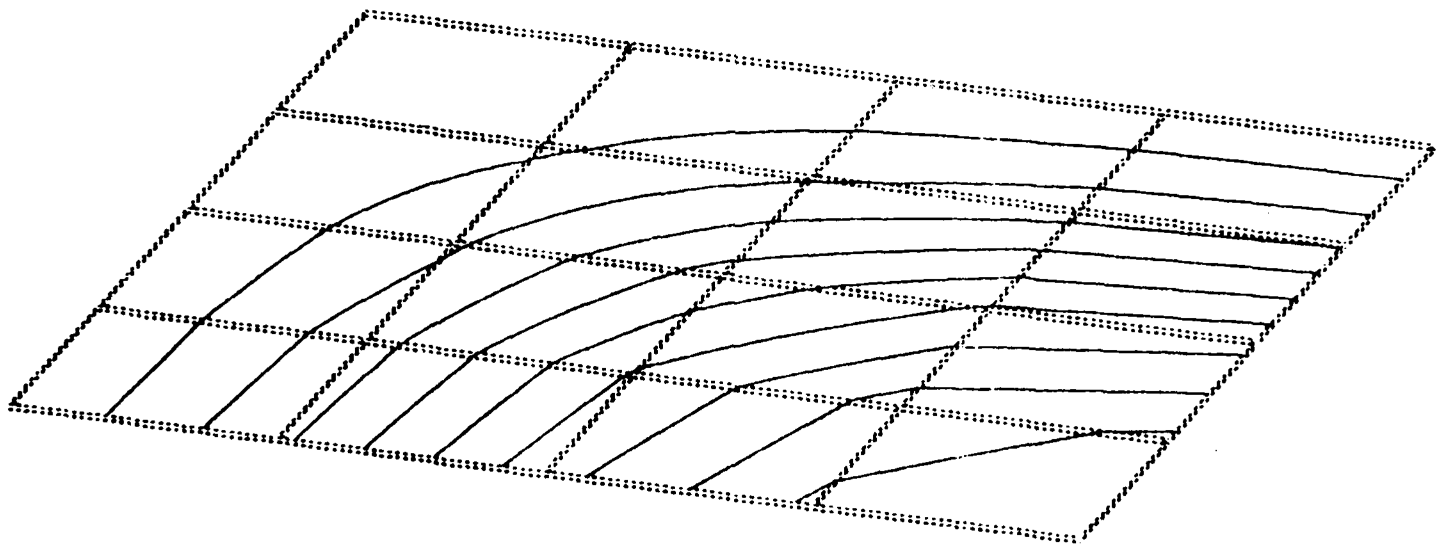


Figure 3.8 Effect of the ENTE Option.

EXPLode

EXPLODE permits the generation of "exploded geometry" plots, in which individual elements are reduced in size by a uniform proportion controlled by the user. EXPLODE is identical to the GPLOT "shrink" function; the amount of "shrinking" is controlled by a "shrink factor" between 0 and 1. A factor of about 0.1 generally works well.

EYE

The EYE command allows a new viewer position ("EYE position") to be defined. The viewer position may be anywhere in space, although a position very close to (or inside) the model may cause inadvertant clipping (see the CLIP command) and/or excessive distortion in perspective plots (see the PROJECTION command). The default EYE position is X = 100., Y = 100., Z = 100..

LABEl

LABEL is used to select or deselect labeling of elements. The default condition is no element labeling.

LAXS

The LAXS (Label AXeS) command selects or deselects the axis plotting option in CPLOT. If axis labeling is selected, Cartesian axes are drawn, with the length of each axis being 10% greater than the maximum nodal coordinate in that direction. The default condition is no axis plotting.

MOVIe

MOVIE can be used to generate a series of plots with identical geometric scaling. When the MOVIE option is selected, the maximum and minimum coordinate values defined via the CUBE command are retained for all subsequent plots, or until MOVIE is deselected. No re-scaling of the plot is done to account for increases or decreases in maximum function values (in the case of relief plots), or for changes in displacement values (for deformed geometry plotting). This option is useful whenever a series of plot frames must be superimposed, or used in sequence for "animated" displays. Note that at least one plot must be performed prior to selecting the MOVIE option, to define the plot scaling to be retained.

NODEs

The NODES command selects or deselects labeling of the nodes on a contour or relief plot. When this labeling option is active, only those nodes actually appearing on the final plot (i.e., those on the current plotting surface, see the SURFACE command) will be labeled. The default condition is no labeling.

ORIEnt

ORIENT can be used to define alternative orientations and/or coordinate systems for the display of stress or strain results. By default, stresses and strains are normally referred to the global system of Cartesian (X,Y,Z) axes. Using ORIENT, it is possible to define rectangular, cylindrical or spherical systems, with origins located arbitrarily in space. All plotted stress and strain data will be transformed to this auxiliary coordinate system prior to contour or relief plotting. The default ORIENT option refers all stresses and strains to the global Cartesian system of coordinates.

PROJection

PROJECTION allows the selection of orthogonal (axonometric) or three-point perspective views of the model. The default projection type is perspective.

REFLect

The REFLECT option permits a symmetric model to be drawn reflected about the X-Y, X-Z, or Y-Z coordinate plane. All parts of the plot are reflected, including original and deformed geometry, contours, relief lines, and node or element labels. The default condition is no reflection.

SITE

The SITE command allows the specification of a point which will be located (approximately) at the center of the screen in the final plot. SITE is usually used with the CUBE command, to restore proper centering of the plot on the screen. The default SITE position is the geometric center of the model.

STEP

STEP is used to modify the step size used in integrating contour lines over the surfaces of individual elements. The step size is defined in the parametric (natural) coordinates of a finite element, in which the distance across an element in any direction is equal to 2 units. The default step size of 0.05 is normally sufficient. STEP may be useful for increasing contour resolution in pathological situations, as when contour lines intersect. STEP can also be used to increase the step size for drawing contours quickly at low resolution. The suggested range of STEP sizes is 0.01 - 0.2, with the default size of 0.05 being adequate for most purposes.

SUBTitle

SUBTITLE, when used with the TITLE option, provides for printing of a user-defined subtitle within the title block of a contour or relief plot. SUBTITLE text is printed below the plotting area, beginning near the left edge of the title block. The default is no SUBTITLE.

SURFace

The SURFACE command defines the element surface number on which function values are to be displayed in contour or relief form. Plotting SURFACEs may be defined separately for each element type; surface numbering follows the same conventions as node numbering, as shown in Figure 2.6. Note also that only the plotting surface of an element will appear on the plot, unless the ENTIRE option is selected. The default SURFACE number for all finite element types is 6. For Element Type 11 (layered shell, see Table 3.3), the SURFACE command also allows specification of the layer number in which stress or strain data is to be plotted. Layers are numbered from bottom to top; the default layer number is 1 (bottom layer).

TITLe

The TITLE option causes a title block to be drawn around a finished plot, containing problem identification, date, plot type and parameters, a sketch of axis orientations, and option subtitling (see the SUBTITLE command). The overall plot size is reduced slightly to fit within the TITLE block, but all scaling functions (CUBE, CLIP, SITE, ZOOM, etc.) will be otherwise unaffected. The default option is no TITLE block.

VERTical

VERTICAL is used to select the axis direction which will be oriented in the vertical screen direction on the plot. Any of the global coordinate directions (X,Y,Z) may be selected. The default vertical axis direction is Z.

ZOOM

With ZOOM, the user may identify a portion of the model which is to be expanded to fill the entire screen. The model should be plotted in the desired orientation before requesting a ZOOM. The "ZOOM area" is defined by cursor input locating the lower-left and upper-right corners of the area to be expanded. Note that ZOOMing may be performed more than once, to obtain plots of successively smaller portions of the model. The default condition is no ZOOMing.

3.4 DISSPLA POSTPROCESSING

The CPLOT postprocessor may be used in conjunction with the DISSPLA [8] graphics package to create a device-independent plot file for later use. This option must be exercised in batch mode only, with CPLOT input parameters being supplied in the same order as for interactive execution. The resulting plot file, which can contain multiple plot frames, can be plotted on any device supported by the DISSPLA post-processor package.

Use of the DISSPLA output facility is illustrated in the batch job stream listed below. In the example, several viewing options are selected prior to plotting; then, the Multiple DRaw command is used to generate a sequence of 60 plot frames.

```
JOB,T600,IO2000,CM200000,PE1.
COMMENT.***********************************
COMMENT.**  INTERCOM BATCH JOB - NO DECK  **
COMMENT.***********************************
ATTACH,TAPE99,apostfilename.
ATTACH,P,PLOTPROC,ID=BROCKMAN,SN=AFFDL,MR=1.
BEGIN,CPLOT,P,DS.
REQUEST,TAPE,PE,RING,VSN=L____.
REWIND,PLFILE.
COPYBF,PLFILE,TAPE.
*EOR
   0                              <set baud rate to zero>
   0                              <terminal type>
MOVIE                             <retain plotting scale>
Y
Y
1 60 1
```

```
DEFORM                              <select deformed geometry>
2
Y
1.0
VERTICAL                            <vertical direction=y>
2
EYEP                                <set view angle>
Y
0 0 10000
CORE                                <set contouring parameters>
1
0 0 1
N
0
ENTE                                <plot entire elements>
Y
CUBE                                <clip view area>
Y
-130. 130. -50. 120. 0. 1.
Y
MDRAW                               <plot multiple frames>
Y
1 60 1
EXIT                                <stop program>
*EOR
*EOF
```

Notice that, in batch execution of CPLOT, input parameters are precisely the same as for interactive execution; therefore, it is possible to test a sequence of plotting commands interactively before a larger background job is entered. All input is entered in free format, with the exception of alphanumeric data (command names and yes/no responses), which must begin in column one. Any of the normal CPLOT options may be exercised with the DISSPLA output feature, with the exception of options generating alphanumeric output (such as CONL, LABEL, LELE, NODE, etc.).

3.5 SAMPLE INTERACTIVE SESSION

A typical terminal session using CPLOT is reproduced on the following pages, to illustrate the operation of the program and the effect of certain commands. As with GPLOT, once the mode of operation is understood the inexperienced user can best become familiar with CPLOT by actually executing the available options, making frequent use of the HELP and SUMMARY commands.

```
COMMAND- ATTACH,P,PLOTPROC,ID=BROCKMAN,MR=1.
 AT CY= 000 SN=AFFDL
COMMAND- ATTACH,TAPE00,MAGNAPOST,ID=BROCKMAN
 AT CY= 001 SN=AFFDL
COMMAND- BEGIN,CPLOT2,P.

 ****************************************

 BEGIN CPLOT  (CONTOUR / RELIEF PLOTTING)

 ****************************************

ENTER CHARACTERS PER SECOND------120

TEKTRONIX TERMINAL TYPES ---
 0, 4006-1
 1, 4010 / 4012 / 4013
 2, 4014 / 4015 / 4062
 3, 4014 / 4015 (ENH.GR.MOD.)
 4, 4114

ENTER TERMINAL TYPE (0,1,2,3,4): 4


 ENTER COMMANDS
  ?VERT
  WHICH AXIS VERTICAL(1=X,2=Y,3=Z) .......: 2
  ?EYE
  XEYE   100.0000YEYE   100.0000ZEYE   100.0000
         CHANGE THESE VALUES? (Y,N).............: Y
  ENTER THE EYE POSITION
         XEYE,YEYE,ZEYE .....................: 0 0 10000
  ?TITL
  OUTLINE AND LABEL THE PLOT? (Y,N)......: Y
  ?CORE
  OPTION 1:  CONTOUR ONLY
  OPTION 2:  RELIEF ONLY
  OPTION 3:  BOTH
  ENTER THE PLOT OPTION (1,2,3)..................: 1
  MINIMUM VALUE ---: 3.300000E-01    MAXIMUM VALUE---:,6.260000E+00
  ENTER THE CONTOUR VALUES (MIN, MAX, INCR)......: 0 6.5 .5
  LABEL CONTOURS? (Y,N)...........................: Y
  ENTER CONTOUR LABEL DISTANCE (-1. - 1.) 0.-CENTER..: 0
  DO YOU WANT TO SEE THE CURRENT LABEL VALUES?N
  ENTER THE RELIEF (AND/OR)CONTOUR SCALE.........: 0
  ?DRAW
```

Figure 3.9   Typical Interactive Session with CPLOT.

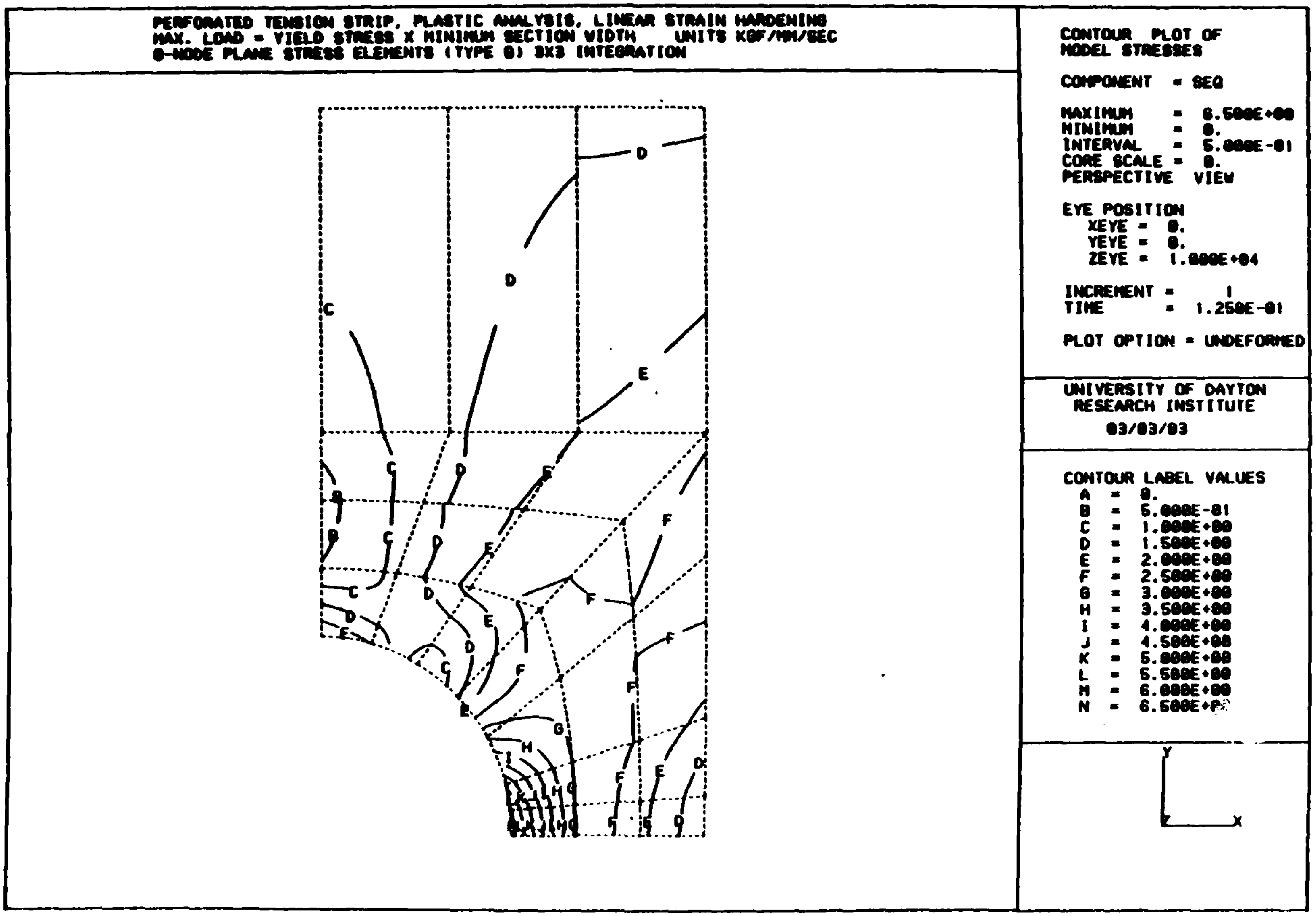


Figure 3.9 (continued)

```
?EXIT

     STOP
     052500 MAXIMUM EXECUTION FL.
      2.587 CP SECONDS EXECUTION TIME.
COMMAND-
```

Figure 3.9 (concluded).

SECTION 4
VARIABLE-VERSUS-VARIABLE PLOTTING

XYPLOT is an interactive program designed for producing two-dimensional plots of one variable versus another. Used in a stand-alone mode, XYPLOT can be used to draw finished plots of any type of data, which are entered manually at the computer terminal. Alternatively, the utility programs WRTFIL and WTFILA can be used to collect analysis data (displacements, strains, stresses, etc.) from postprocessor files (see the Appendix) in a form suitable for input to XYPLOT.

Although XYPLOT operates on both the Tektronix graphics terminal and the Hewlett-Packard 7221A four-color pen plotter, the full capabilities of the program can best be utilized with the H-P pen plotter. In this mode, an enhanced set of options is available, including adjustable plot size and labeling format, plotting in more than one color, and plotting directly on transparency materials for use on overhead projectors.

4.1 PROGRAM OPERATION

XYPLOT is executed on CDC machines under control of command language procedures which automatically access the required disk files, and return scratch data files at the end of a session. Three possible modes of operation exist:

Option 1: Results are stored on an 'MPOST' postprocessing file. Program WRTFIL is used to collect data for plotting, and XYPLOT is executed immediately afterward.

Option 2: Results are stored on an 'APOST' postprocessing file. Program WTFILA is used to collect data for plotting, and XYPLOT is executed immediately afterward.

Option 3: Plotting data is to be entered directly from the terminal keyboard. In this case, XYPLOT will be executed as a stand-alone program.

Typical control statements for each option are as follows:

Option 1:
```
ATTACH,TAPE99,mpostfilename.
ATTACH,P,PLOTPROC,ID=BROCKMAN,SN=AFFDL,MR=1.
BEGIN,WRTFIL,P.
```

Option 2:
```
ATTACH,APOST,apostfilename.
ATTACH,P,PLOTPROC,ID=BROCKMAN,SN=AFFDL,MR=1.
BEGIN,WTFILA,P.
```

Option 3:
```
ATTACH,P,PLOTPROC,ID=BROCKMAN,SN=AFFDL,MR=1.
BEGIN,XYPLOT,P.
```

When WRTFIL or WTFILA is executed before XYPLOT, the BEGIN command will control the execution of both programs, one after the other. The BEGIN statement as written above accesses the default (Tektronix) version of XYPLOT. To access the HP-7221A version, the BEGIN statement must contain the additional key word "HP"; for example,

```
BEGIN,WTFILA,P,HP.
```

On the VAX 11/780 computer, each program can be executed using the RUN command:

```
$ RUN WRTFIL
$ RUN WTFILA
$ RUN XYPLOT
```

4.2 SUMMARY OF DATA AND OPTIONS

In WRTFIL, WTFILA, and XYPLOT, data are entered in a question and answer mode, with the input sequences largely controlled by the program. The following paragraphs summarize the types of data and options available in each of the three computer programs.

4.2.1 Summary of Input for WRTFIL

WRTFIL requests three types of input:

1. Flags indicating whether displacements or stress-strain results are to be retrieved;
2. Data defining which displacement, stress or strain values are to be plotted; and
3. Selection of option to add the point (0,0) as the initial point on each curve.

When displacement values are to be plotted, WRTFIL will request the node and component (direction) numbers defining each displacement to be plotted; for example, the displacement parallel to the Y-axis at node 37 is identified by "37,2". For each node and direction requested (up to the maximum of ten), values are retieved for each increment stored on the postprocessor file. The dependent variable for displacement plotting is always the time (or loading parameter) value.

Stress or strain data are selected in WRTFIL by specifying an element type, an element number, and a stress-strain code. Table 4.1 lists the element types which are recognized by WRTFIL. Stress-strain codes are summarized in Table 4.2, and also are listed during execution of the program. In all instances, the stress-strain values output by WRTFIL are average values over the selected elements; note that nodal stresses may be retrieved by

TABLE 4.1

FINITE ELEMENT TYPES RECOGNIZED BY WRTFIL

Element Type	Description	Number of Nodes
1	3-D Solid	8-27
2	3-D Solid	8
3	2-D Plane Stress, Plane Strain or Shear Panel Element	4
4	Bar (Truss)	2
5	Thin Shell	8
6	3-D Solid	20
7	3-D Solid	8-20
8	3/D Solid/Thick Shell	16
9	2-D Plane Stress	4-9

TABLE 4.2

STRESS/STRAIN CODES FOR WRTFIL

Code	Quantity	Component
1	Strain	ε_x
2	Strain	ε_y
3	Strain	ε_z
4	Strain	γ_{yz}
5	Strain	γ_{xz}
6	Strain	γ_{xy}
7	Stress	σ_x
8	Stress	σ_y
9	Stress	σ_z
10	Stress	τ_{yz}
11	Stress	τ_{xz}
12	Stress	τ_{xy}
13	von Mises Stress	σ_e

using WTFILA (Paragraph 4.2.2).

WRTFIL will, at the direction of the user, add an "initial condition" (the point 0,0) as the first point of each data set, since the initial values are not contained on the postprocessor file. This option can be selected for some or all of the generated data curves.

4.2.2 Summary of Input for WTFILA

WTFILA performs a similar function to WRTFIL. With WTFILA, however, only nodal data are retrieved, and the number of options is much greater. Once a node has been selected, any of the following data may be assembled for plotting, one against the other:

- increment number;
- time (or loading parameter) value;
- X, Y, or Z displacement components;
- displacement magnitude;
- any component of strain;

- X, Y, or Z unit extensions;
- any component of stress; or
- von Mises effective stress.

When a node is connected to elements of two different types or materials, all elements to which the node is connected are listed, and one of these is selected for the collection of data.

Element types recognized by WTFILA are the same as for WRTFIL (Table 4.1). The "initial condition" option, which adds the point (0,0) as the first point on a curve, is also available.

4.2.3 Summary of Input for XYPLOT

Initially, XYPLOT requests input concerning the mode of execution; the plotting device must be either a Hewlett-Packard pen plotter or a Tektronics graphic display terminal. Plotting data may be read from a plot data file, or entered manually at the keyboard. If the file input option is selected, either WRTFIL or WTFILA should have been executed prior to entering XYPLOT.

When data is entered manually, each (X,Y) point is input in sequence; input is terminated by entering the point (999,999). For example:

```
ENTER THE X-Y POINTS FOR THIS SET;
ENTER 999,999 AFTER THE LAST PAIR . . .
      0., 0.
      1., 1.
      2., 4.
      3., 9.
      4., 16.
      999,999
```

Up to ten curves, each containing a maximum of 400 data points, may be entered. If the file input option is selected, this section of the input is skipped. For each set of data, scale

factors may be specified to normalize the values or to convert from one system of units to another. If conversion factors are used, the scaled data are displayed as conversion takes place.

Once all of the data has been defined, those curves which are actually to be drawn can be selected, as follows:

```
DO YOU WISH TO INPUT MORE DATA.......... N
HOW MANY CURVES DO YOU WISH TO PLOT..... 3
WHICH SETS OF DATA DO YOU WISH TO PLOT.. 1,2,4
```

Based on the data selected for plotting, maximum and minimum data limits are computed, and may be modified as necessary. On Tektronix graphic terminals, the plot will be scaled to (nearly) fill the screen. On the HP-7221A plotter, overall plot size can be modified also:

```
LIKE THE DEFAULT PLOT SIZE (250mm X 150mm) . . :  N
ENTER THE NEW PLOT SIZE VALUES
X-VALUES MUST BE BETWEEN 400 AND 4000
Y-VALUES MUST BE BETWEEN 250 AND 2650
AS AN APPROXIMATION USE LENGTH DESIRED
 (IN mm) MULTIPLIED BY 10.
ENTER XMIN, XMAX, YMIN, YMAX . . . . . . . . . . :
      1000, 2500, 1000, 2000
```

The above plot size fits nicely on an 8-1/2 by 11 inch (216 by 279 mm) page.

The interval size for axis labeling is computed automatically, but may be modified by the user. For Tektronix plots, only one number is needed for each of the two axes to define tic mark locations and values. With the Hewlett-Packard version, FORTRAN format specifications can also be input for the labels on each axis, to control the number of decimal places and the location of label values.

Axis titles can be composed of any alphanumeric values, including parentheses and punctuation symbols. The alphanumeric labels for each axis are limited to a maximum of forty characters.

Available options for curve drawing include the following:

- solid line, dashed line or no line;
- symbols at each point, or no symbols; and
- pen number (HP plotter only).

Each of these options may be selected independently for each curve to be plotted. Optional symbols which can be selected for marking data points are summarized in Tables 4.3 and 4.4.

Upon completion of the input sequence, the finished plot will appear on the screen. For the HP plotter, elements of the plot are drawn step-by-step as the plotting parameters are prescribed. At the end of a plot, execution is suspended so that hard copies may be made; execution can be resumed by typing "GO", followed by a carriage return. At this time, additional plots can be made with the same or different data, or new data sets may be entered to begin a completely new plot.

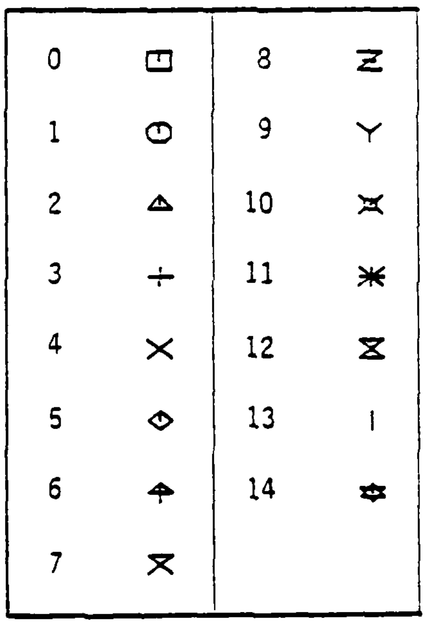
TABLE 4.3

SYMBOL OPTIONS (Tektronix 4010 Terminals)

Symbol Number	Description
0	No Symbol
1	Circle
2	Drawn "X"
3	Triangle
4	Square
5	Star
6	Diamond
7	Vertical Bar
8	Cross
9	Up Arrow Below Point
10	Down Arrow Below Point
11	Reversed Triangle

TABLE 4.4

SYMBOL OPTIONS (Hewlett-Packard Pen Plotter)



4.3 EXAMPLES

In this Subsection, several examples are reproduced to illustrate the capabilities of XYPLOT. Most of the labeling and titling options are demonstrated in the sample plots. Some other options, such as plot size adjustment and multi-pen plots, cannot be shown adequately in this report.

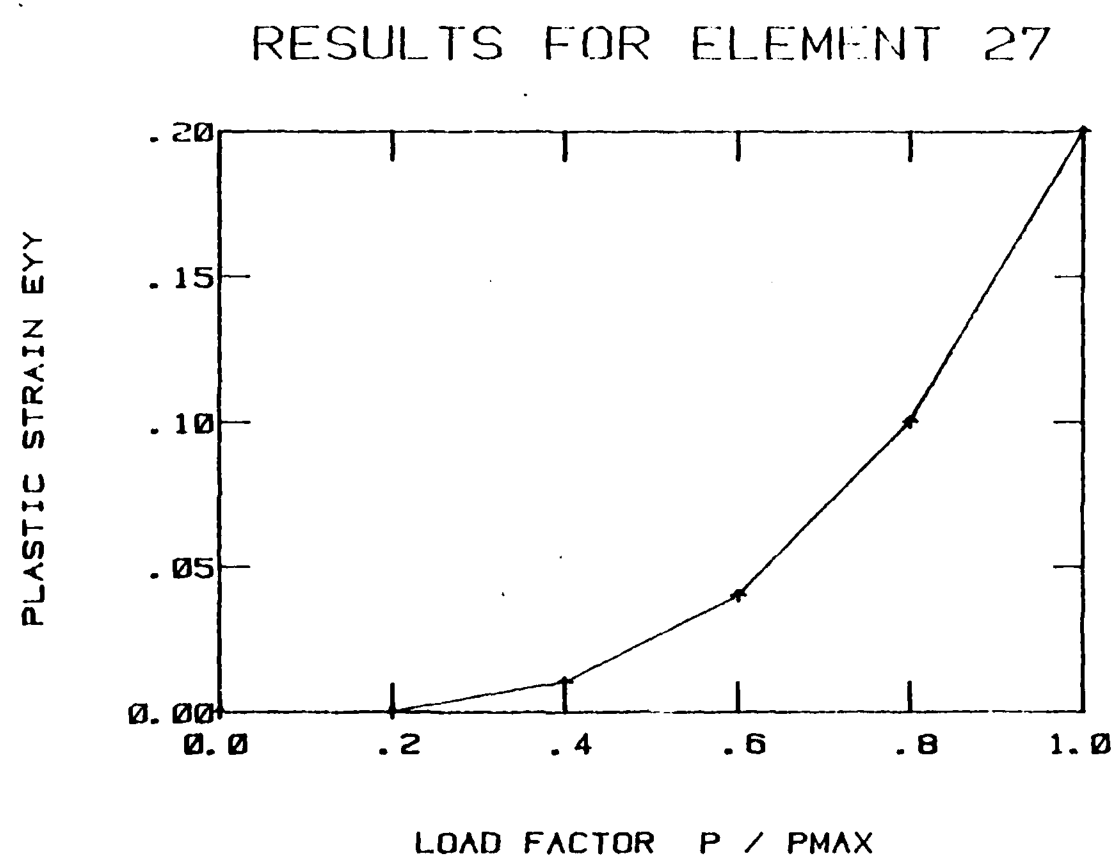


Figure 4.1 X-Y Plot (Sample No. 1).

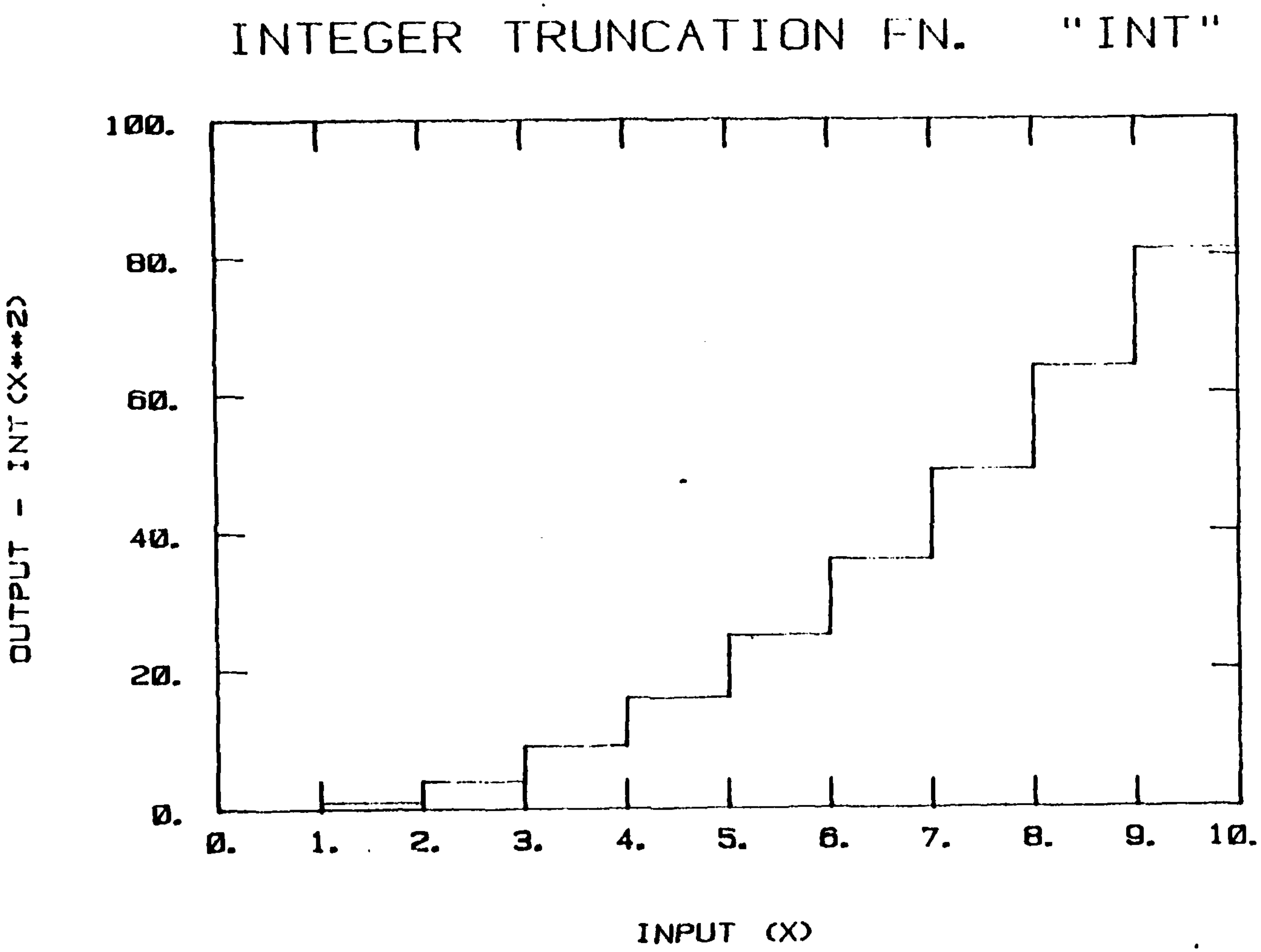


Figure ´.2 X-Y Plot (Sample No. 2).

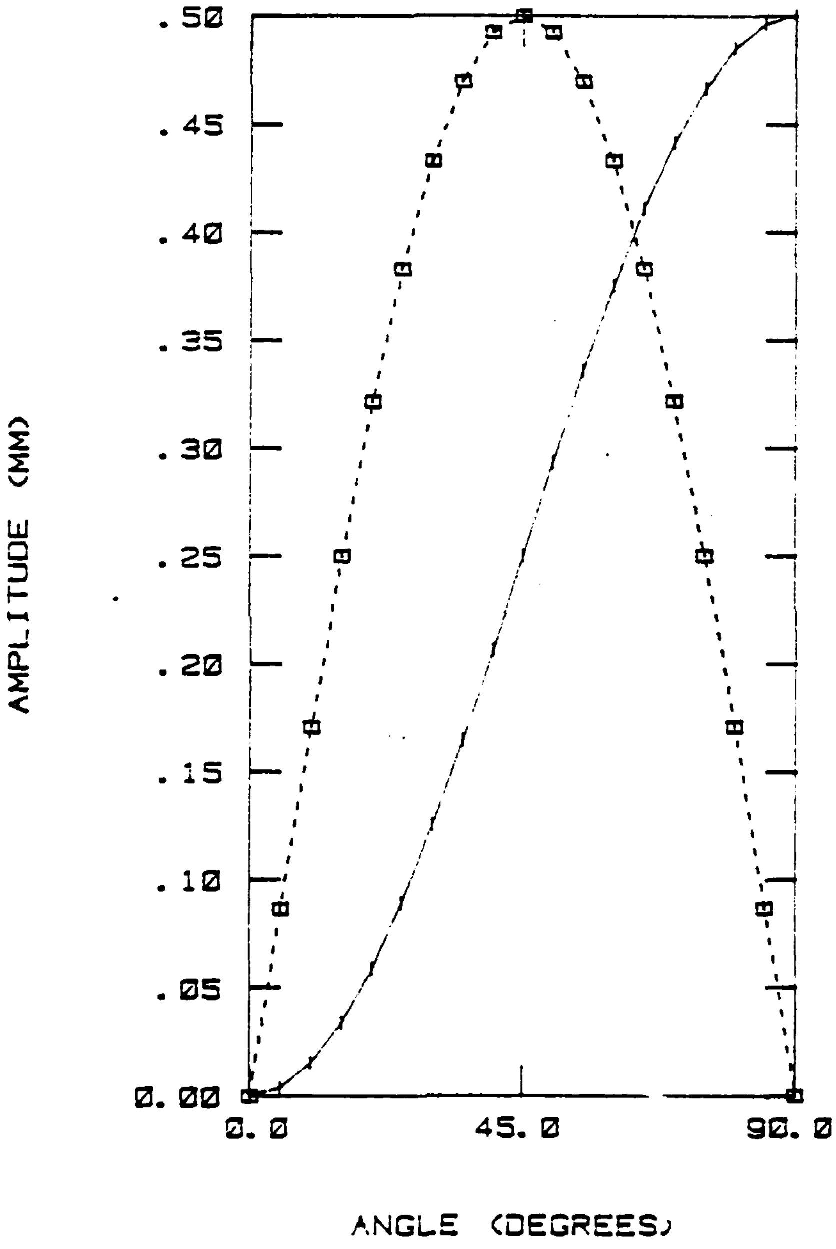


Figure 4.3 X-Y Plot (Sample No. 3.)

SECTION 5
FILE MANAGEMENT UTILITIES

Occasionally, it may be necessary to perform a finite element solution in a number of parts, each of which produces a separate file of analysis results. Subsections 5.1 and 5.2 describe two simple utility programs which can be used to merge these results into a single file, which can then be read by WRTFIL or WTFILA. In other situations, it may be advantageous to process each of the results files separately using WRTFIL or WTFILA, and to save the resulting X-Y plotting files. Subsection 5.3 describes a utility program which will accept a number of such files as input, and generate a single X-Y plotting file as output.

5.1 MERGING 'MPOST' FILES

MPOST postprocessing files may be combined using the utility program MPOSTMERGE. Input to MPOSTMERGE consists of (a) the number of MPOST files to be merged, and (b) the files themselves. Up to ten files may be merged at once. The procedure for executing the MPOSTMERGE utility is as follows:

```
ATTACH,MPOST1,mpostfilename1.
ATTACH,MPOST2,mpostfilename2.
  :       :        :      :
  :       :        :      :
ATTACH,MPOST10,mpostfilename10.
ATTACH,MERGLGO,MPOSTMERGE,ID=BROCKMAN,SN=AFFDL,MR=1.
REQUEST,MERMPO,*PF.
MERGLGO.
CATALOG,MERMPO,mergedfilename.
```

MPOSTMERGE will prompt for input of the number of files to be merged; no other input is necessary. If MPOSTMERGE is to be run in batch (background) mode, the number of files is entered on a single record following the first end-of-record, as

```
JOBID,T200,IO400,CM60000,STANY. account,name,phone
ATTACH,MPOST1,mpostfilename1.
ATTACH,MPOST2,mpostfilename2.
ATTACH,MPOST3,mpostfilename3.
ATTACH,MERGLGO,MPOSTMERGE,ID=BROCKMAN,SN=AFFDL,MR=1.
REQUEST,MERMPO,*PF.
MERGLGO.
CATALOG,MERMPO,COMPLETEMPOSTFILE,RP=900.
7/8/9   (end of record)
3       (number of files)
6/7/8/9 (end of file)
```

Note that the batch mode of execution may be preferable if many relatively large files are to be combined.

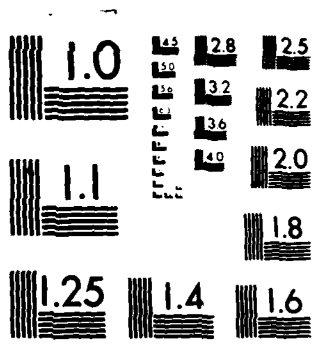
5.2 MERGING 'APOST' FILES

APOST postprocessing files may be combined using the utility program APOSTMERGE. Operation of APOSTMERGE is the same as for MPOSTMERGE (Subsection 5.1), with the exception of program and data file names. Up to ten APOST files may be merged at once. The procedure for executing APOSTMERGE is as follows:

```
ATTACH,APOST1,apostfilename1.
ATTACH,APOST2,apostfilename2.
  :       :       :       :
  :       :       :       :
ATTACH,APOST10,apostfilename10.
ATTACH,MERGLGO,APOSTMERGE,ID=BROCKMAN,SN=AFFDL,MR=1.
REQUEST,MAPOST,*PF.
MERGLGO.
CATALOG,MAPOST,mergedfilename.
```

AD-A129 222 MAGNA (MATERIALLY AND GEOMETRICALLY NONLINEAR ANALYSIS) 2/2
PART III POSTPROC..(U) DAYTON UNIV OH RESEARCH INST
R A BROCKMAN ET AL. DEC 82 UDR-TR-82-113
UNCLASSIFIED AFWAL-TR-82-3098-PT-3 F33615-80-C-3403 F/G 9/2 NL

END
DATE FILMED
7 83
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

5.3 *MERGING X-Y PLOT FILES*

X-Y plotting data files are output from programs WRTFIL and WTFILA in the form of formatted, sequential files, with the file name 'XYSCR0'. The details of the file format may be found in Reference [2], Chapter 11. A number of these X-Y plotting files may be merged using the utility program XYPMERGE. A maximum of five data files can be combined in a single pass through the program.

Input supplied to XYPMERGE consists of the number of data files to be combined, and the files themselves. Each file must contain a similar number of data sets, although the number of data points in each set may be different.

The size of the X-Y plotting files is usually much smaller than the original ('MPOST' or 'APOST') postprocessing files, and therefore XYPMERGE is usually executed interactively. The procedure for running XYPMERGE is as follows:

```
ATTACH,XYDAT1,datafile1.
ATTACH,XYDAT2,datafile2.
ATTACH,XYDAT3,datafile3.  (optional)
ATTACH,XYDAT4,datafile4.  (optional)
ATTACH,XYDAT5,datafile5.  (optional)
ATTACH,MERGLGO,XYPMERGE,ID=BROCKMAN,SN=AFFDL,MR=1.
REQUEST,XYMERGE,*PF.
MERGLGO.
CATALOG,XYMERGE,mergedfilename.
```

The program will prompt for input of the number of data files to be combined, and no other input is required.

APPENDIX

(MAGNA Postprocessor File Formats)

The three graphics programs described in this report accept analysis results in the form output by the MAGNA [2,3] finite element program. The MAGNA postprocessor files are of two types. Raw analysis results are contained on the 'MPOST' postprocessor file, which is used as input to GPLOT and WRTFIL. Additional results, including continuous stress and strain data, are written on the 'APOST' postprocessor file. Both of these files are formatted files, with a maximum of 132 characters per record. Results for different nodes, elements and analysis time steps are delimited by keywords indicating the type of data and some relevant sizing parameters.

Detailed information concerning the file formats, results output locations and reference axes can be found in Chapters 5 and 10 of Reference [2]. For easy reference, the description of the contents of both types of postprocessing files are repeated in this Appendix, Tables A-1 through A-3.

TABLE A-1

HEADER RECORDS FOR POSTPROCESSOR FILE MPOST

Item		Data Type	Format
COOR	Keyword for Nodal Coordinates Data	A	A4,11X
I1	Number of Node Points	I	I5
CONN	Keyword for Element Connectivity Data	A	A4,1X
I1	Element Type	I	I5
I2	Maximum Number of Nodes per Element	I	I5
I3	Number of Elements of this Type	I	I5
ENDD	Keyword for End of Data	A	A4
DISP	Keyword for Nodal Displacement Data	A	A4,1X
I1	Increment or Load Case Number	I	I5
I2	Number of Nodes	I	I5
R1	Time (or Load Parameter) Value	R	E15.8
ELSS	Keyword for Element Stress/Strain Data	A	A4,1X
I1	Number of Element Types Used	I	I5
I1	Increment or Load Case Number	I	I5
R1	Time (or Load Parameter) Value	R	E15.8
ETYP	Element Type Header for Stress/Strain Data	A	A4,1X
I1	Element Type	I	I5
I2	Element Dimensionality	I	I5
I3	Interpolation Type Code	I	I5
I4	Number of Elements of this Type	I	I5
ELEM	Element Header for Stress/Strain Data	A	A4,1X
I1	Element Number	I	I5
I2	Maximum Number of Nodes per Element	I	I5
I3	Number of Numerical Integration Points	I	I5
ENDP	End-of-Problem Trailer	A	A4

TABLE A-2

DATA RECORDS FOR POSTPROCESSOR FILE MPOST

DATA TYPE	DATA DESCRIPTION	FORMAT
COOR Header	(1)	A4,11X,I5
Coordinates	1. Node Number 2. Coordinates X,Y,Z (one record per node point)	I5,5X,3E10.3
CONN Header (2)	(1)	A4,1X,3I5
Connectivity (2)	1. Element Number 2. Connected Nodes (one record per element)	28I4
ENDD Trailer	(1)	A4
DISP Header (3)	(1)	A4,1X,2I5,E15.8
Displacements (3)	1. Node Number 2. Displacement Components (one record per node point)	I5,5X,3E10.3
ELSS Header (3)	(1)	A4,1X,2I5,E15.8
ETYP Header (4)	(1)	A4,1X,4I5
ELEM Header (5)	(1)	A4,1X,3I5
Element Strain and Stress (6)	1. Strain Components (6) 2. Stress Components (6) 3. Equivalent Stress	13E10.3
ENDP Trailer	(1)	A4

Notes:

(1) See Table A.1 for header and trailer record descriptions
(2) Repeated for each element type used
(3) Repeated for each solution time step or loading case
(4) Repeated for each element type at each time step or loading case
(5) Repeated for each element at each time step or loading case
(6) Repeated for each integration point at each time step or loading case

TABLE A-3

MAGNA POSTPROCESSOR FILE 'APOST' - GENERAL DESCRIPTION AND FORMAT

Record	Columns	Format	Description
1	1-80	20A4	Problem Title (Line 1 of 3)
2	1-80	20A4	Problem Title (Line 2 of 3)
3	1-80	20A4	Problem Title (Line 3 of 3)
4	1-4	A4	'INCS' - Increment List Header
	5	1X	(Blank)
	6-10	15	Number of Solution Increments, Modes or Loading Conditions to appear on file
5	1-100	20I5	List of Increments in ascending order. (Additional records are used as needed)
6	1-10	10I1	Flags for Element Types Appearing in the Model.
7	1-4	A4	'LIMC' - Coordinate Limits Header
	5	1X	(Blank)
	6-20	E15.8	X - Maximum Value
	21-35	E15.8	Y - Maximum Value
	36-50	E15.8	Z - Maximum Value
	51-65	E15.8	X - Minimum Value
	66-80	E15.8	Y - Minimum Value
	81-95	E15.8	Z - Minimum Value

<<<<< Records 8-17 (described on the next page) each >>>>>
<<<<< include data computed at each increment of the >>>>>
<<<<< finite element solution. Each of these records >>>>>
<<<<< is repeated (in the same order) for each solu- >>>>>
<<<<< tion increment, mode shape or loading case >>>>>
<<<<< listed in Record 5. >>>>>

TABLE A-3 (Continued)

Record	Columns	Format	Description
8	1-4	A4	'INCT' - Increment Header.
	5	1X	(Blank)
	6-10	I5	Increment Number
	11-15	I5	Total Number of Elements
	16-30	E15.8	Time Value at this Increment
9	1-4	A4	'LIMC' - Displacement Limits Header
	5	1X	(Blank)
	6-20	E15.8	X - Maximum Displacement
	21-35	E15.8	Y - Maximum Displacement
	36-50	E15.8	Z - Maximum Displacement
	51-65	E15.8	X - Minimum Displacement
	66-80	E15.8	Y - Minimum Displacement
	81-05	E15.8	Z - Minimum Displacement
10	1-4	A4	'ELMT' - Element Header
	5	1X	(Blank)
	6-10	15	Part Number (A 'part' is any distinct combination of element type and material property code; elements appearing in the file are sorted by parts).
	11-15	I5	Global Element Sequence Number (numbers are secondary sort key)
	16-20	I5	Element Type (as defined in MAGNA)
	21-25	I5	Element Sequence Number (within type)
	26-30	I5	Material Property Code
	31-35	I5	Maximum Number of Nodes
	36-40	I5	Length of Coordinate Records (3*Nodes)
11	1-108	27I4	List of Connected Nodes (up to 27)
12	1-120	10E12.5	(Xcoor(i),i=1,maxnodes), (Ycoor(i),i=1,maxnodes), (Zcoor(i),i=1,maxnodes). Nodal coordinates are written up to 10 entries per line, over as many lines as needed (up to 9, for 27-node elements).
13	1-120	10E12.5	(Xdisp(i),i=1,maxnodes), (Ydisp(i),i=1,maxnodes), (Zdisp(i),i=1,maxnodes).

TABLE A-3 (Continued)

Record	Columns	Format	Description
14	1-10	E10.3	XX - Strain at Local Node #1
	11-20	E10.3	YY - Strain at Local Node #1
	21-30	E10.3	ZZ - Strain at Local Node #1
	31-40	E10.3	YZ - Strain at Local Node #1
	41-50	E10.3	XZ - Strain at Local Node #1
	51-60	E10.3	XY - Strain at Local Node #1
	61-70	E10.3	XX - Stress at Local Node #1
	71-80	E10.3	YY - Stress at Local Node #1
	81-90	E10.3	ZZ - Stress at Local Node #1
	91-100	E10.3	YZ - Stress at Local Node #1
	101-110	E10.3	XZ - Stress at Local Node #1
	111-120	E10.3	XY - Stress at Local Node #1
	121-130	E10.3	Von Mises Stress for Node #1

<<<<< Record 14 is repeated for each node point >>>>>
<<<<< connected to the element. Omitted points >>>>>
<<<<< in variable-node elements assigned zeros. >>>>>

Record	Columns	Format	Description
15	1-4	A4	'LIMS' - Stress/Strain Limits Header
16	1-10	E10.3	Maximum XX - Strain for this Increment
	11-20	E10.3	Maximum YY - Strain for this Increment
	21-30	E10.3	Maximum ZZ - Strain for this Increment
	31-40	E10.3	Maximum YZ - Strain for this Increment
	41-50	E10.3	Maximum XZ - Strain for this Increment
	51-60	E10.3	Maximum XY - Strain for this Increment
	61-70	E10.3	Maximum XX - Stress for this Increment
	71-80	E10.3	Maximum YY - Stress for this Increment
	81-90	E10.3	Maximum ZZ - Stress for this Increment
	91-100	E10.3	Maximum YZ - Stress for this Increment
	101-110	E10.3	Maximum XZ - Stress for this Increment
	111-120	E10.3	Maximum XY - Stress for this Increment
	121-130	E10.3	Maximum von Mises Stress for Increment
17	1-10	E10.3	Minimum XX - Strain for this Increment
	11-20	E10.3	Minimum YY - Strain for this Increment
	21-30	E10.3	Minimum ZZ - Strain for this Increment
	31-40	E10.3	Minimum YZ - Strain for this Increment
	41-50	E10.3	Minimum XZ - Strain for this Increment
	51-60	E10.3	Minimum XY - Strain for this Increment
	61-70	E10.3	Minimum XX - Stress for this Increment
	71-80	E10.3	Minimum YY - Stress for this Increment
	81-90	E10.3	Minimum ZZ - Stress for this Increment
	91-100	E10.3	Minimum YZ - Stress for this Increment
	101-110	E10.3	Minimum XZ - Stress for this Increment
	111-120	E10.3	Minimum XY - Stress for this Increment
	121-130	E10.3	Minimum von Mises Stress for Increment

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