USER'S GUIDE: SPAR 11 STRUCTURAL ANALYSIS FINITE ELEMENT PROGRAM (INCLUDING GRAPHICS), FOR USE ON A DEC-2050 COMPUTER SYSTEM

REPORT NO. R-489

TRACK TRAIN DYNAMICS
MATHEMATICAL MODEL

TRACK TRAIN DYNAMICS
AAR

IATIONAL GOVERNMENT-INDUSTRY RESEARCH PROGRAM ON TRACK-TRAIN DYNAMICS

Association of American Railroads

Research and Test Department

USER'S GUIDE: SPAR 11 STRUCTURAL ANALYSIS FINITE ELEMENT PROGRAM (INCLUDING GRAPHICS), FOR USE ON A DEC-2050 COMPUTER SYSTEM

REPORT NO. R-489

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AAR Technical Center

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13. ABSTRACT

SPAR 11 is a version of Level 11 of the SPAR program, as modified and enhanced for the Association of American Railroads. The enhancements are in the area of interactive use and graphics on the DEC-2050 computer. This user's guide does not replace the SPAR Program Manual, but has instead the following two functions: first, to help the beginner to get acquainted with the SPAR system, and second, to document the use of the enhanced graphics and interactive capabilities.

14. SUBJECT TERMS

AUS Processor
ELD Processor
Interactive Graphics
PLOT 12 Program
TAB Processor

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BACKGROUND INFORMATION

ON THE

TRACK-TRAIN DYNAMICS PROGRAM

The Track-Train Dynamics Program encompasses studies of the dynamic interaction of a train consist with track as affected by operating practices, terrain, and climatic conditions.

Trains cannot move without these dynamic interactions. Such interactions, however, frequently manifest themselves in ways climaxing in undesirable and costly results. While often differing and sometimes necessarily so, previous efforts to reasonably control these dynamic interactions have been reflected in the operating practices of each railroad and in the design and maintenance specifications for track and equipment.

Although the matter of track-train dynamics is by no means a new phenomenon, the increase in train lengths, car sizes, and loadings has emphasized the need to reduce wherever possible excessive dynamic train action. This, in turn, requires a greater effort to achieve more control over the stability of the train as speeds have increased and railroad operations become more systematized.

The Track-Train Dynamics Program is representative of many new programs in which the railroad industry is pooling its resources for joint study and action.

A major planning effort on track-train dynamics was initiated in July 1971 by the Southern Pacific Transportation Company under contract to the AAR and carried out with AAR staff support. Completed in early 1972, this plan clearly indicated that no individual railroad had both the resources and the incentive to undertake the entire program. Therefore, AAR was authorized by its Board to proceed with the Track-Train Dynamics Program.

In the same general period, the FRA signaled its interest in vehicle dynamics by development of plans for a major test facility. The design of a track loop for train dynamic testing and the support of related research programs were also pursued by FRA.

In organizing the effort, it was recognized that a substantial body of information and competence on this program resided in the railroad supply industry and that significant technical and financial resources were available in government.

Through the Railroad Progress Institute, the supply industry coordinated its support for this program and has made available men, equipment, data from earlier proprietary studies, and monetary contributions.

Through the FRA, contractor personnel and direct financial resources have been made available.

Through the Transport Canada Research and Development Centre (TDC), the Canadian Government has made a major commitment to work on this problem and to coordinate that work with the United States' effort.

Through the Office de Recherces et D'Essais, the research arm of the Union Internationale des Chemins de Fer, the basis for a full exchange of information with European groups active in this field has been arranged.

The Track-Train Dynamics Program is managed by the Research and Test Department of the Association of American Railroads under the direction of an industry-government steering committee. Railroad members are designated by elected members of the AAR's Operation-Transportation General Committee, supply industry members by the Railway Progress Institute, U. S. Government members by the Federal Railroad Administration, and Canadian Government members by the Transport Development Centre. Appropriate task forces and advisory groups are established by the Steering Committee on an ad hoc basis as necessary to pursue and resolve elements of the program.

The staff of the program comprises AAR employees, personnel contributed on a full- or part-time basis by railroads or members of the supply industry, and personnel under contract to the Federal Railroad Administration or the Transportation Development Agency.

The program plan as presented in 1972 comprises:

1) Phase I -- 1972-1974

   Analysis of an interim action regarding the present dynamic aspects of track, equipment, and operations to reduce excessive train action.

2) Phase II -- 1974-1977

   Development of improved track and equipment specifications and operating practices to increase dynamic stability.

3) Phase III -- 1977-1982

   Application of more advanced scientific principles to railroad track, equipment, and operations to improve dynamic stability.

Phase I officially ended in December of 1974. The major technical elements of Phase I included:

a) The establishment of the dynamic characteristics of track and equipment.

b) The development and validation of mathematical models to permit the rapid analysis of the effects on dynamic stability of modifications in design, maintenance, and use of equipment and track structures.

c) The development of interim guidelines for train handling, makeup, track structures, and engineer training to reduce excessive train action.

The major techncical elements of Phase II include:

a) The adaptation of Phase I analytical models to allow for conducting parameter investigations in the area of track, trucks, draft gear and cushion units, and vehicle behavior.

b) The development of fatigue analysis guidelines.

c) The development of a comprehensive program for identifying the loads to which track, vehicles, and vehicle components are subjected.

Reports on all elements of Phase I and Phase II activities have been essentially completed and are available through the AAR. A list of the Track Train Dynamics publications is available upon request.

The Phase III program, now actively underway, includes:

a) The development of performance guidelines for the design, development, and fabrication of a dynamically stable bulk commodity car.

b) The application of high-speed, data processing systems as on-board aid to train operations.

c) The demonstration of advanced coupling, suspension, braking, and draft systems to enable thorough evaluation of potential benefits.

d) The development methods for measuring and monitoring the physical strength of track structures.

EXECUTIVE SUMMARY

SPAR 11 is one version of Level 11 of the SPAR Program, as modified and enhanced for the Association of American Railroads. The first program enhancement is in the area of improved interactive use, since SPAR 11 now solicits major portions of the input from the user. It also has additional instructions that the user can obtain by entering question marks. The second enhancement is in the area of graphics. The user may display the finite element model and subject it to a series of translations and/or rotations, and, if desired, can "zoom in" on sections of the model, defined by a viewing model. Deformed models representing displacement and vibrational mode shapes can also be displayed. Stress components for two-dimensional problems may be displayed as stress contours.

This User's Guide does not replace the SPAR Program Manual, but has instead the following two functions: first, to help the beginner to get acquainted with the SPAR system, and second, to document the use of the enhanced graphics and interactive capabilities.

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1.0 INTRODUCTION

1.1 What is SPAR?

Spar is a package of programs (herein called processsors) that may be used to perform a finite element analysis of a structure. It has been developed by W. D. Whetstone, originally at Lockheed Corporation. Several versions of SPAR are in use and the package is distributed by a government agency - COSMIC. Mr. Whetstone has a more advanced and proprietary version of SPAR called EAL (for Engineering Analysis Language), which is marketed by his own company - Engineering Information System, Inc. (EISI) of San Jose, California. SPAR may be used for static analysis, calculations of vibrational frequencies and modes, transient structural response, buckling analysis, etc. SPAR is versatile, efficient and flexible and is, therefore, useful for solving complex engineering problems, as well as being a teaching aid in finite element courses.

The present guide is specific to the SPAR 11 version of SPAR, which is in use by the Association of American Railroad's Technical Center on a DEC-2050 computer system.

1.2 How to Use This Guide

Like most computer programs which are used by more than one or two people, SPAR has a user's manual. Like most user manuals, the SPAR Manual is useful only to a person who already knows how to use the program. This guide is intended to help you get started. It is not intended to replace the regular manual. It assumes that you already have that manual as a source for detailed information on the input formats.

This guide gives you some general rules concerning the input for SPAR, followed by step by step instructions on how to prepare the data. Only the simplest options are explained. For others, you are referred to the SPAR User's Manual. Before you start preparing your data for SPAR with the help of this guide, have the following items handy:

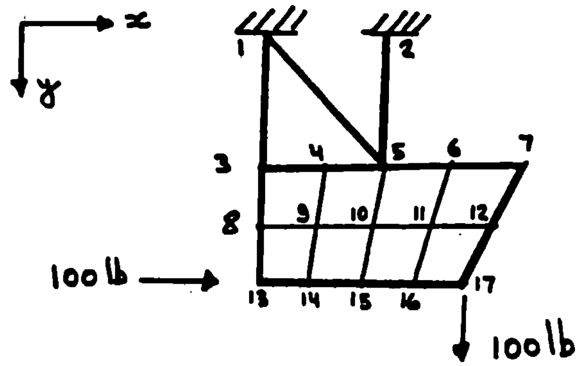
1. A drawing or sketch of your finite element model, and
2. The regular SPAR User's Manual.

1.3 General Input Rules

Because SPAR is composed of several processors, the input to SPAR consists of cards calling on these different processors, followed by data for the processors. Because of the difference between computer systems, on the cards calling the various processors, special characters appearing in the input may be different. This guide is written in the DEC-2050 computer notation.

An example with a typical SPAR input is given in Figure 1.1. Before you continue, open the SPAR Manual and read Pages 2.3-1 through 2.3-3. The following points cause beginners a lot of grief:

1. Exponents are not denoted by E as in FORTRAN.




```
@RUN  MPTAB
* START 17  3 4 5 6$    ONLY THE X,Y TRANSLATIONS ARE FREE
* TEXT
*' STEEL PLATE SUSPENDED ON ALUMINUM RODS
* JOINT LOCATIONS
* 1   0. 0. 0.
* 2   4. 0. 0.
* 3   0. 4. 0.    8. 4. 0.   5 1 3$     USE AUTOMATIC MESH GENERATIONS FOR
* 5   0. 6. 0.    7. 6. 0.$             JOINTS 3-17.
* CONSTRAINT 1
* ZERO 1 2  $   CONSTRAIN DEGREES OF FREEDOM 1 AND 2 (X AND Y TRANSLATIONS)
* 1 2       $   AT JOINTS 1 THROUGH 2
* MATERIAL CONSTANTS
* 1   1.+7   .3   2.59-4$   ALUMINUM,  E=10MILLION PSI
* 2   3.+7   .3   7.40-4$   STEEL,  E=30MILLION PSI
*BC   $ROD ELEMENT (E23) SECTION PROPERTIES
* 1 .1: 2 .2$   CROSS SECTIONAL AREAS OF 0.1 AND 0.2 RESPECTIVELY
*SA   $SHELL SECTION PROPERTIES
* 1 .2$   THICKNESS IS 0.2
* STOP
@RUN  MPELD
E23
* 1 3: 1 5
* NSECT=2: 2 5$   THE THIRD ELEMENT HAS A DIFFERENT CROSS-SECTIONAL AREA.
* E41
* NMAT=2$   THE FOLLOWING ELEMENTS ARE MADE OF STEEL
* 3 4 9 8 1 4 2$   AUTOMATIC ELEMENT GENERATION
* STOP
@RUN  MPAUS
* SYSVEC:   APPLIED FORCES 1
* I=1: J=13: 100.
* I=2: J=17: 100.
* STOP
@RUN  MPTOPO
* STOP$   DEFINE CONNECTIVITY MATRICES
@RUN  MPE
* STOP$   DEFINE ELEMENT GEMETRICAL AND MASS PROPERTIES
@RUN  MPEKS
* STOP$   CALCULATE ELEMENT STIFFNESS AND STRESS MATRICES
@RUN  MPK
* STOP$   ASSEMBLE GLOBAL STIFFNESS MATRIX
@RUN  MPINV
* STOP$   FACTOR STIFFNESS MATRIX
@RUN  MPSSOL
* STOP$   SOLVE FOR DISPLACEMENTS
@RUN  MPVPRT
* PRINT APPLIED FORCES
* PRINT STATIC DISPLACEMENTS
* STOP
@RUN  MPGSF
* STOP$   GENERATE STRESSES
@RUN  MPPSF
* STOP$   PRINT OUT STRESSESS
@RUN  MPDCU
* TOC 1$  PRINT TABLE OF CONTENTS OF DATA BASE
* STOP
```

Figure 1.1 Sample SPAR Input.

Do not write 1.E4, but 1.+4; not 1.E-4 but 1.-4.

2. Do not use more than 7 digits in the mantissa of a number.

3. Do not use both a comma and a space to separate numbers. SPAR interprets 4 , 5 as 4 0 5.

4. Input data that could be non-integer must have a decimal point. For example, even if the thickness of an element happens to be 2 inches, remember to input it as 2. or 2.0.

5. Each processor is invoked by a record of the type @RUN MPXXX, where XXX is the processor name. The data for the processor is terminated by a STOP card.

1.4 Structural Definition Processor: TAB

The first processor of SPAR is used to define the structure and the finite element joints. Figure 1.1 shows an example of a two dimensional structure and the SPAR input for it. The first input card is always the START card. This card specifies the number of joints and the degrees-of-freedom which are zero for all joints. In the example of Figure 1.1, we have 17 joints. The degrees-of-freedom corresponding to translation in the z direction and all three rotations are zero. Rotational degrees of freedom are used only when bending elements are present.

The data for processor TAB consists of descriptive sub-processor headings (such as JOINT LOCATIONS) and data

following these headings. There is some degree of flexibility in the order of the sub-processor input. Here, we recommend the fixed order used by the interactive version of SPAR. Table 1.1 gives the recommended sequence of the TAB sub-processors. The following is a description of the simplest options of input that are available for some of the sub-processors.

1.4.1 Text

Type a heading for your output, starting with an apostrophe in Column 1.

1.4.2 Joint Locations

Type in the joint number, followed by the x,y,z coordinates. For automatic joint generation, see the SPAR Reference Manual, Page 3.1.5-1.

1.4.3 Constraint n

For most problems, you have only one set of boundary conditions, so type CONSTRAINT 1. This heading is followed by groups of cards specifying which displacement components are zero at which joints. For example,

ZERO 1 2 3: 4 6

specifies that the three translations are zero at Joints 4,5,6. Another example is,

ZERO 4 : 5 : 8 : ZERO 1 3 : 6

specifies that rotation about the x axis is zero at Joints 5 and 8 and the x,z translations are zero at Joint 6.

Table 1.1

Recommended Sequence of TAB Sub-processors

	Name	Comments
1.	(TEXT)*	A descriptive heading,
2.	(ALTERNATIVE REFERENCE FRAMES)	needed if you use more than one coordinate system.
3.	JOINT LOCATIONS	
4.	(JOINT REFERENCE FRAMES)	Assigns coordinate systems to joints.
5.	CONSTRAINT DEFINITION n	Defines boundary conditions
6.	MATERIAL CONSTANTS	
7.	(BEAM ORIENTATION)	
8.	(BEAM RIGID LINKS)	
9.	Section properties, one or more of the following:	
	a. BA	General beam section
	b. BB	Beam defined by its user - input stiffness matrix
	c. BC	Axial element (rod)
	d. DB	Plane beam
	e. SA	Plate section
	f. SB	Shear web section
10.	(DISTRIBUTED WEIGHT)	Additional to element weight
11.	(RIGID MASSES)	

*Sub-processors in parentheses are necessary for some problems, but not for others.

1.4.4 Material Constants

The material cards are given in the following format:

$$k \; E \; \nu \; \rho$$

where E, ν and ρ are Young's modulus, Poisson's ratio and the density, respectively, for material k. You will be better off specifying mass density rather than weight density. Otherwise, you will need additional commands in subsequent processors to convert weights to masses. For example, if E is in psi, give ρ in lb - sec^2/in^4.

1.4.5 Section Properties

BC

For axial (rod) elements, the input format is k a, where: a is the cross-sectional area of the k-th rod section.

SA

For isotropic plate elements, the input format is k t, where: t is the thickness of the k-th plate section.

1.5 Element Definition Processor: ELD

This processor is used to generate the elements and associate them with material and section entries. Table 1.2 contains a list of some of the elements available in SPAR. The general format is an element name, followed by the node numbers of the elements and references to material and section properties. For example, the sequence:

Table 1.2

Partial List of SPAR Processors

E21 - GENERAL THREE DIMENSIONAL BEAM ELEMENT

E23 - ROD ELEMENT (NO BENDING)

E24 - A PLANE BEAM ELEMENT

E31 - TRIANGULAR MEMBRANE ELEMENT (NO BENDING)

E41 - QUADRILATERAL MEMBRANE ELEMENT (NO BENDING)

E33 - TRIANGULAR PLATE ELEMENT

E43 - QUADRILATERAL PLATE ELEMENT

E41: 1 3 4 5 : NMAT=3: 2 4 5 6

defines two quadrilateral membrane elements, both of section properties, SA, number 1 (default). The first element is made of material number 1; the second of material number 3.

In another example, the sequence:

E23: 2 5 : E32 : 3 4 7 : NSECT=3: 4 8 10 : 4 9 10

defines one rod element and three triangular bending elements. All elements are made of material number 1 (default). The cross-sectional area of the rod element is defined by section property, BC, number 1 (default). The thickness of the first plate element is defined by section property, SA, number 1 (default), and the thickness of the other two plate elements by section property, SA, number 3.

Automatic mesh generation, available in SPAR, is important as a labor saving device; see the SPAR Reference Manual.

1.6 Load Generation Processor: AUS

In this guide, we discuss only one type of load input, specifying the force components at the joints via processor AUS. The imput sequence is best explained by a couple of examples.

Example 1. The sequence:

SYSVEC: APPLIED FORCES 1

I=2: J=4 10: 420.

specifies a force of 420 in the y direction, acting at Joints

4 through 10 (each).

Example 2. The sequence:

```
SYSVEC: APPLIED FORCES 1
I=1 2 3: J=7 8: 17. 27. 37: 18. 28. 38
I=5: J=2 10 2: 6. 4.
```

specifies the x,y,z components of the force, acting at Joint 7 to be 17. 27. and 37., respectively; the x,y,z force components at Joint 8 are 18., 28., and 38., respectively. Finally, moments about the y axis of magnitudes 6., 4., 4., 4. act at Joints 2, 4, 6, 8 and 10, respectively.

1.7 Other Processors

To execute different types of analyses, several SPAR processors are called in sequence, with minimal amount of input. Table 1.3 gives the recommended sequences for a static analysis and for a natural frequency calculation.

Table 1.3

Recommended Sequence of Processors, Following the TAB, ELD and AUS Inputs

a. Static Analysis

```
@RUN  MPTOPO
* STOP$   DEFINE CONNECTIVITY MATRICES
@RUN  MPE
* STOP$   DEFINE ELEMENT GEMETRICAL AND MASS PROPERTIES
@RUN  MPEKS
* STOP$   CALCULATE ELEMENT STIFFNESS AND STRESS MATRICES
@RUN  MPK
* STOP$   ASSEMBLE GLOBAL STIFFNESS MATRIX
@RUN  MPINV
* STOP$   FACTOR STIFFNESS MATRIX
@RUN  MPSSOL
* STOP$   SOLVE FOR DISPLACEMENTS
@RUN  MPVPRT
* PRINT APPLIED FORCES
* PRINT STATIC DISPLACEMENTS
* STOP
@RUN  MPGSF
* STOP$   GENERATE STRESSES
@RUN  MPPSF
* STOP$   PRINT OUT STRESSESS
@RUN  MPDCU
* TOC 1$  PRINT TABLE OF CONTENTS OF DATA BASE
* STOP
```

b. Calculation of the First n Natural Frequencies

```
@RUN  MPTOPO
* STOP$   DEFINE CONNECTIVITY MATRICES
@RUN  MPE
* STOP$   DEFINE ELEMENT GEMETRICAL AND MASS PROPERTIES
@RUN  MPEKS
* STOP$   CALCULATE ELEMENT STIFFNESS AND STRESS MATRICES
@RUN  MPK
* STOP$   ASSEMBLE GLOBAL STIFFNESS MATRIX
@RUN  MPINV
* STOP$   FACTOR STIFFNESS MATRIX
@RUN  MPEIG
* RESET INIT=2n$   Put in an actual number for 2n
* PRINT 0 0 0 0 1
* STOP
@RUN  MPDCU
* TOC 1$   PRINT TABLE OF CONTENTS OF DATA BASE
* STOP
```

2.0 USING SPAR INTERACTIVELY

2.1 SPAR 11 Interactive Facilities

SPAR 11 may be used in the batch mode by creating, through the editor, an input file and then submitting it for execution. However, it is also possible to use SPAR 11 interactively, typing the input in line-by-line. This mode is effective for detecting errors in the input deck. SPAR 11 provides two facilities for helping the interactive user. First, instructions on the required input are available to the user by typing a question mark. Second, for each processor which is used interactively, an echo file of the user input is created, so as to be available for later batch runs. The echo file may also be used in the interactive mode, by having SPAR 11 read part of the input from it and then switching (when a SWITCH card is encountered) to input from the user's console.*

The bulk of the data for static and dynamic structural analysis is entered through the SPAR processors TAB, ELD and AUS. These are, therefore, the only processors with detailed interactive messages. For the other processors, the only interactive displays are of the reset controls.

---

*Note that when the echo file is used, problems may occur if the colon (:) is used for multiple records on one line. It is recommended not to use the colon, and instead have each record on a separate line.

2.1.1 Commands

There are three commands that are used with the interactive SPAR processor:

1. ? n — The question mark is a request for information. The number that follows it is optional. If n is omitted, the next information segment will be displayed. Otherwise, SPAR displays the n-th in the present sequence. A large value of n will elicit the last segment.

2. SHUT UP — This command turns off the information messages, until the user requests more information by typing a question mark.

3. SWITCH — This command is used when part of the data is already available on a data file, and SPAR is executed, with the input being read from that file. With the SWITCH command at the end of the data file, SPAR will solicit additional data through the console.

2.1.2 TAB Processor

This processor is used to process different input segments describing the geometry, element properties, boundary conditions, etc. There is a great degree of flexibility in the order that the different data items may be input; however, the interactive messages solicit the data in a fixed order that is designed for maximum simplicity for a novice user. Each data item (such as joint location, material properties, etc.) has several informational messages that may be displayed by repeated use of a question mark. The last segment contains instructions to the user as to which data item should be typed next.

2.1.3 ELD Processor

The ELD processor is used to generate the elements and identify the properties, such as thicknesses and materials associated with each element. The messages given by SPAR contain information on the types of elements available, and on the automatic mesh generators which are most commonly used.

2.1.4 AUS Processor

Processor AUS is used for a large number of different functions. The interactive messages that may be elicited by typing a question mark pertain only to the definition of static loads.

2.1.5 Other Processors

The only information that may be solicited from SPAR for other processors is the list of RESET options and their default values.

2.2 Examples of Interactive Use

2.2.1 Use of the Echo File

The following example is composed of three parts: (a) an initial interactive run; (b) editing the echo file; (c) run restarted from echo file. Table 2.1 shows the user input and interactive messages for Part (a). Note that the SPAR output does not appear here, but goes to the line printer (LPT). The run is aborted by typing a STOP card.

The next step is to edit the echo file to

Table 2.1

Example of Initial Interactive Run (User Input Is Underlined)

```
@DEF 5:TTY:
@DEF 6:LPT:
@RUN MPTAB

THE FIRST INPUT RECORD FOR PROCESSOR TAB IS THE START RECORD. IT HAS THE
FOLLOWING FORMAT:

START  JT  I1 I2 I3...

WHERE JT IS THE NUMBER OF JOINTS AND I1,I2, ETC. ARE DEGREES OF FREEDOM
 WHICH ARE RESTRAINED FOR ALL THE JOINTS.  FOR EXAMPLE, FOR A PLANE STRESS
PROBLEM WITH 87 JOINTS THE START RECORD MAY BE

START 87  3 4 5 6

NOW, PLEASE TYPE THE START RECORD
?START 17  3 4 5 6

PLEASE TYPE IN THE WORD TEXT
?SHUTUP

?TEXT

?' STEEL PLATE SUSPENDED ON ALUMINUM RODS

?Z

NEXT TYPE   ALTR   IF YOU PLAN TO USE MORE THAN ONE COORDINATE SYSTEM,
OTHERWISE  JLOC  OR JOINT LOCATIONS
?JLOC

TO INPUT THE COORDINATES OF A SINGLE JOINT TYPE  K  X Y Z
WHERE X,Y,Z ARE THE COORDINATES OF THE K-TH JOINT
?1 0. 0. 0.

?2 4. 0. 0.

?STOP

END OF EXECUTION
CPU TIME: 1.75  ELAPSED TIME: 2:55.91
```

replace the STOP card by a SWITCH. This is shown in Table 2.2.

Finally, the run is resumed as shown in Table 2.3. The data in the echo file is used and then the program switched to input from the console.

Table 2.2

Editing the Echo File

```
ED ECHO.DAT
Edit: ECHO.DAT.8
*P
00100    START 17  3 4 5 6

00200    SHUTUP

00300    TEXT

00400    ' STEEL PLATE SUSPENDED ON ALUMINUM RODS

00500    JLOC

00600    1 0. 0. 0.

00700    2 4. 0. 0.

00800    STOP

*R800
00800    SWITCH
```

Table 2.3

Continuation Run, Using an Old Echo File (User Input Is Underlined)

```
@COPY (FROM) ECHO.DAT.9 (TO) FOR05.DAT
 ECHO.DAT.9 => FOR05.DAT.7 [OK]
@DEF 5:DSK:
@RUN (PROGRAM) MPTAB.EXE.3

THE FIRST INPUT RECORD FOR PROCESSOR TAB IS THE START RECORD. IT HAS THE
FOLLOWING FORMAT:

START  JT  I1 I2 I3...

WHERE JT IS THE NUMBER OF JOINTS AND I1,I2, ETC. ARE DEGREES OF FREEDOM
 WHICH ARE RESTRAINED FOR ALL THE JOINTS.  FOR EXAMPLE, FOR A PLANE STRESS
PROBLEM WITH 87 JOINTS THE START RECORD MAY BE

START 87  3 4 5 6

NOW, PLEASE TYPE THE START RECORD
?
PLEASE TYPE IN THE WORD TEXT
?
?
?
?
?
?
?
INPUT DEVICE SWITCHED TO TTY.
YOU MAY NOW ENTER DATA FROM YOUR TTY.
?? 3

TO GENERATE A TWO DIMENSIONAL GRID OF JOINTS USE  THE FOLLOWING FORMAT:

K  XA YA ZB   XB YB ZB  NI IJUMP NJ
JJUMP   XC YC ZC   XD YD ZD

THE ABOVE TWO RECORDS DESCRIBE A QUADRILATERAL REGION WITH VERTICES A,B,C,D.
THERE ARE NI JOINTS ALONG THE EDGE AB, THE FIRST IS JOINT K FOLLOWED
BY  K+IJUMP,K+2*IJUMP, ETC.  THERE ARE NJ JOINTS ALONG THE LINE AC
K,K+JJUMP,K+2*JJUMP, ETC.
?3   0. 4. 0.   8. 4. 0.   5 1 3

?5   0. 6. 0.   7. 6. 0.

?STOP

END OF EXECUTION
CPU TIME: 2.22  ELAPSED TIME: 2:37.34
```

3.0 SPAR 11 GRAPHICS

3.1 What is Available in SPAR 11 Graphics?

The SPAR 11 graphic processors are intended for use in model checking and for presenting complex output in an easily perceived form. There are three basic formats of the graphics output which are available to the user:

(a) a labeled nodes plot
(b) a transformed element plot
(c) a stress contour plot

The first two are available through processor PLOT12 and the last through processor SCON1.

The labeled node plot is used primarily for model checking. The element plot is the most versatile graphics output form, and may be used both for checking the model and for displaying a deformed shape of the structure. Because of its usefulness, the element plot has many options that permit the user to rotate, window and zoom in on parts of the model. The stress contour plot is a very powerful form of stress output, but its usefulness is limited to two dimensional problems.

3.2 How to Run the PLOT12 Graphics Processor

Like most other SPAR processors, PLOT12 has several RESET controls that constitute the first set of input to the processor. A list of the RESET controls for PLOT12 and their functions is given in Table 3.1. After the user is done with the RESET input, he needs to hit the carriage return, and the program then queries him whether his terminal has cursor control. Figure 3.1 shows the initial

Table 3.1

RESET Controls for the PLOT12 Processor

NAME	DEFAULT VALUE	FUNCTION
INLIB	1	Library containing nodal and element data.
IXPL	0	If IXPL=1, the size of each element is multiplied by DMAG, while the location of its centroid remains the same. This permits distinguishing individual elements better in the element plot.
DMAG	0.8	
MING	1	Only elements belonging to group numbers between MING and MAXG are drawn
MAXG	1000	
KSXY	0	If KSXY=1, the structure is reflected in the X-Y plane and both sides are displayed.
KSXZ	0	If KSXZ=1, the structure is reflected in the X-Z plane and both sides are displayed.
KSYZ	0	If KSYZ=1, the structure is reflected in the Y-Z plane and both sides are displayed.
NPLT	0	NPLT=0 for an element plot NPLT=1 for a nodal plot

```
@DEF 5:TTY:
@DEF 6:TTY:
@RUN PLOT12

ENTER RESETS(IE. NODE PLOT): RESET NPLT=1
OTHER RESET OPTIONS: INLIB IXPLODE MING MAXG
KSXY KSXZ KSYZ DMAG MOD6
RESET     NPLT=  1

NPLT=          1

DATA SPACE=     80000
IF YOU HAVE CONTROL OVER GRAPHICS CURSER
THEN ANSWER "YES". OTHERWISE ANSWER "NO".
?
YES

ENTER TERMINAL I/O SPEED IN CHAR/SEC.
?
960
```

Figure 3.1 Initial Dialog with the PLOT12 Processor.

dialog of the program with a user on a TEKTRONIX-4010 terminal operating at 9600 baud. The user inputs a single RESET control NPLT, choosing a nodal plot. PLOT12 then displays three regions (terminal screen areas) of the four that are available for graphics output and a menu of available options, as shown in Figure 3.2.

3.3 Working with a Nodal or Element Plot

The options available to the user with an element* plot are displayed in the menu in Figure 3.2. The use of these options is explained with the aid of an element plot of a railroad car bolster. Figure 3.3 contains the user-program dialog and the resulting graphics display. The dialog is explained in some detail in the following sections.

3.3.1 Display Model in Region 1.

This operation was accomplished by typing D in response to the flashing asterik on the top line. The model is displayed in the default region, Region 1.

3.3.2 Defining a Window

Next, a W was typed to request a window. The program responded by instructing the user to move the cursor first to the lower left corner and then to the upper right corner of the desired window. Once the cursor is in the right place the user hits the space

*All the options available with an element plot are also available with a nodal plot.

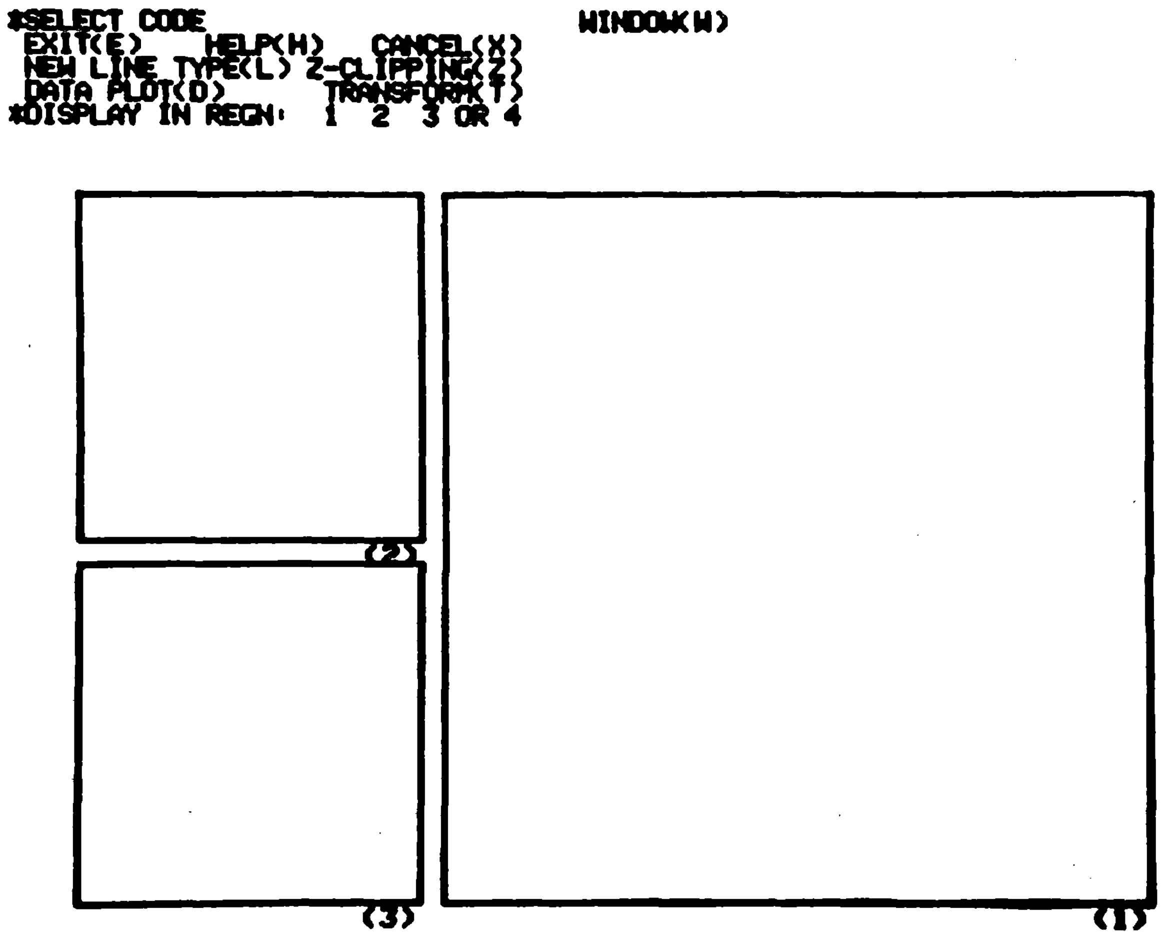


Figure 3.2 Initial Screen and Element or Nodal Plot Options.

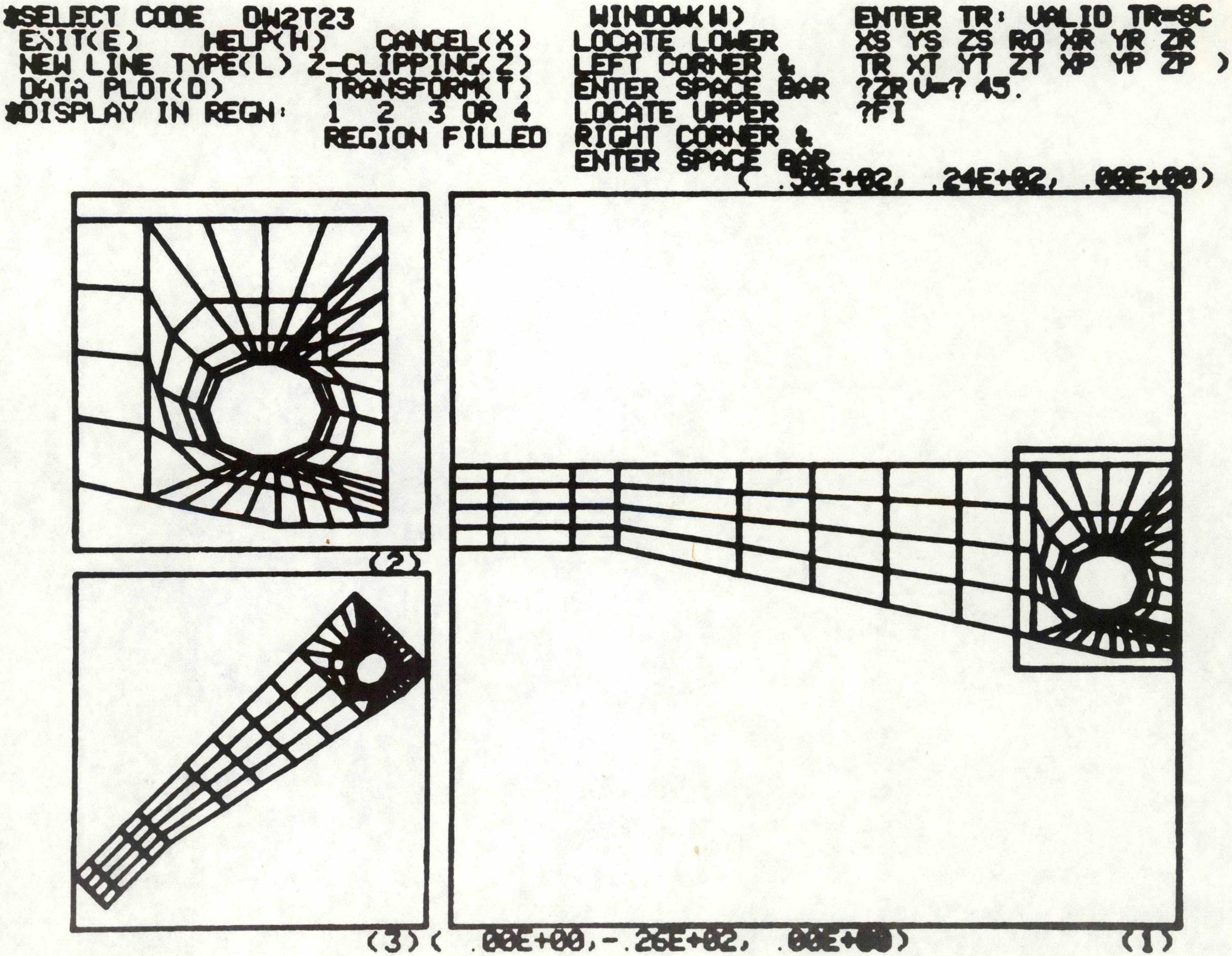


Figure 3.3 Example of PLOT12 Dialog.

bar to indicate this to the program. If a console without cursor control is used, the program requests numerical values for the coordinates of the center of the window and its dimensions. After defining the window, the user selected Region 2 for display, in response to a flashing asterisk in front of the 'DISPLAY IN REGION' heading.

3.3.3 Rotation

Next, a T was typed by the user to indicate a transformation. The program responded by issuing a menu of possible transformations. Table 3.2 contains a list of these possible transformations and their meaning. The user selected a rotation about the z-axis (perpendicular outward from screen), and specified a direction of 45 degrees (ccw) in response to a program query. He then indicated all transformations were complete (FI) and that the rotated model should be displayed in Region 2. The program indicated that Region 2 was already filled, so that the user then selected Region 3. Note that the transformation is permanent and that further operations are performed on the new state.

3.3.4 Zooming

Next the user typed 1 (not shown in the Figure) and SPAR 11 cleared the screen and displayed the model in Region 1, as shown in Figure 3.4. The user then windowed as before. This time, however, the

Table 3.2

Transformations Available in PLOT12

NAME	REQUIRED INPUT	FUNCTION
SC	3 scaling factors	combination of XS,YS and ZS
XS	1 scaling factor	scale x coordinates of structure
YS	1 scaling factor	scale y coordinates of structure
ZS	1 scaling factor	scale z coordinates of structure
RO	3 angles (degrees)	combined XR,YR,ZR
XR	1 angle (degrees)	rotate structure about x axis (CCWT)
YR	1 angle (degrees)	rotate structure about y axis
ZR	1 angle (degrees)	rotate structure about z axis
TR	3 lengths	combined XT,YT,ZT
XT	1 length	translate structure in x direction
YT	1 length	translate structure in Y direction
ZT	1 length	translate structure in Z direction
XP	1 length	perspective view from x=XP
YP	1 length	perspective view from y=YP
ZP	1 length	perspective view from z=ZP
FI	none	indicates that all transformations have been supplied

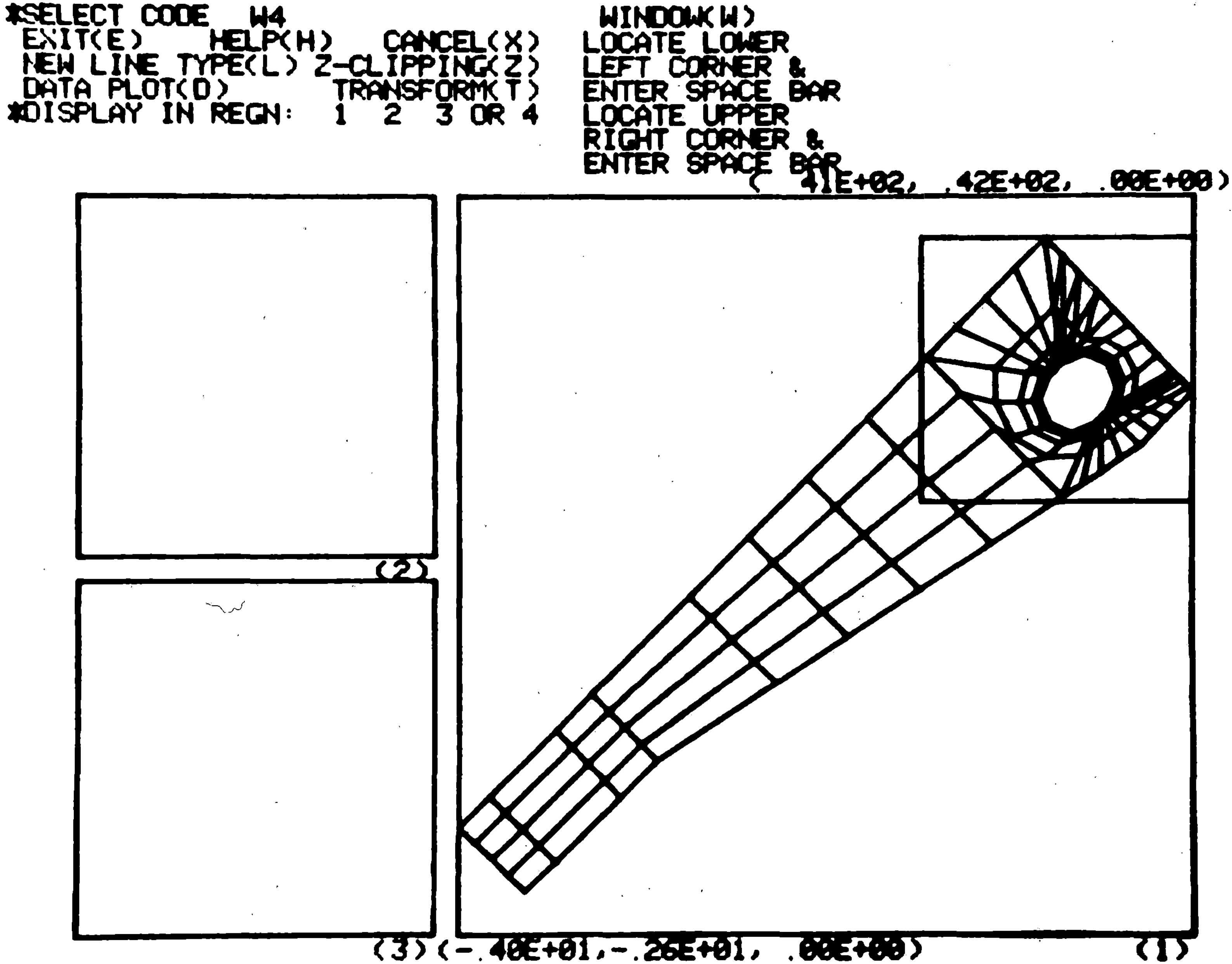


Figure 3.4 Example of Transformation with PLOT12.

window was displayed in Region 4, which is the entire screen; see Figure 3.5.

3.3.5 Z-Clipping, Line Type, Help and Exit.

These commands are not illustrated in the example. Z-clipping (Z) permits deletion of nodal points (and the edges which connect to them) in front of and behind Z-planes with user-defined locations. These feature provides a clearer view of elements in the interior of a structure. Line type (L) permits selection of short or long dash lines (in place of solid lines) for plotting the mesh. Help (H) displays a message introducing the plotting system. Exit (E) causes a normal exit from plotting.

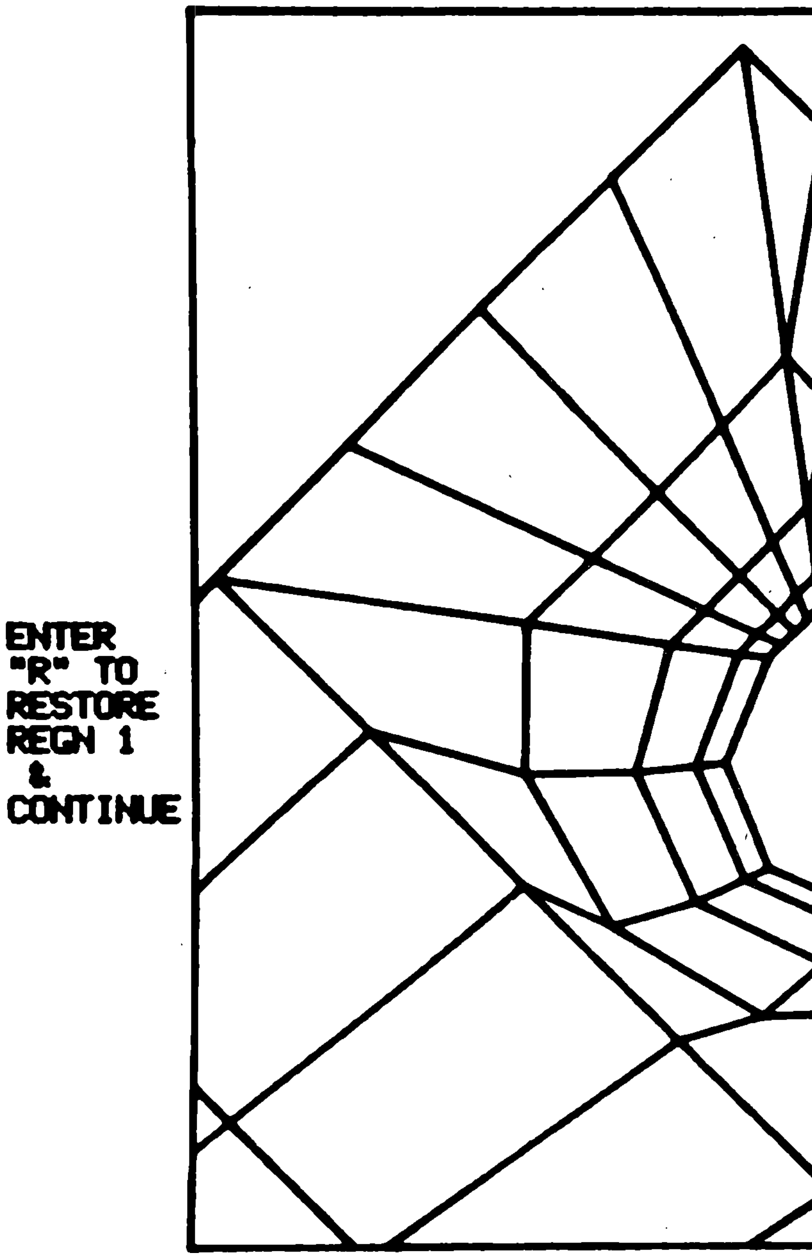
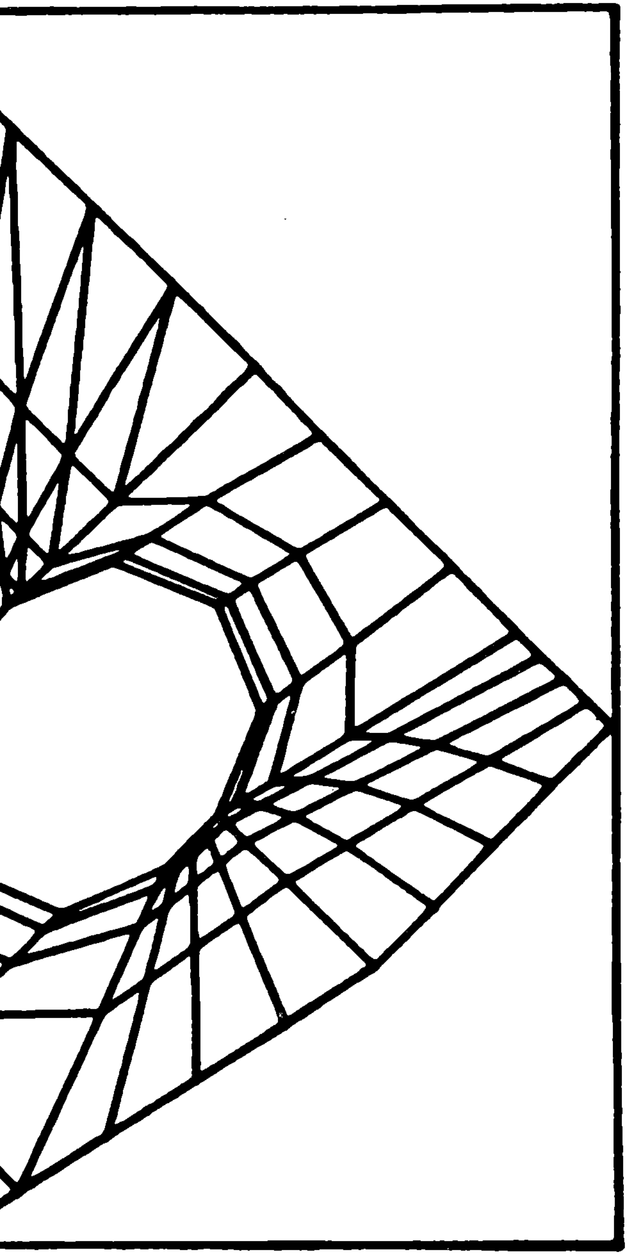


Figure 3.5 Example of Use of Region 4.



(4)

3.4 Generating Stress Contours

Stress contours are generated by the graphics processor SCON1. This processor reads the stress data at the centroids of the elements from the SPAR data base and uses spline interpolation to calculate them at additional points. This spline interpolation is costly, both in terms of required core and CPU. Figure 3.6 shows the beginning dialog between the user and SCON1. The program starts by requesting a title and subtitle (up to 60 characters each). In the example of Figure 3.6, the title is PLATE and the subtitle was left blank. The title and subtitle are later displayed with the stress contours. The program then requests the reset controls and terminal speed. Table 3.3 contains the list of reset controls, their meaning and their defaults. In the example documented by Figure 3.6, the user selected the display of maximum shear stress (KSTR=6) and seven contours. The generated stress contours are shown in Figure 3.7. After the stress contours are drawn, the program queries the user whether he wants to continue and get another plot. Upon a request to continue, the follow-up dialog is shown in Figure 3.8. The user wanted to increase the number of contours to 8 and keep the same type (maximum shear stress), so he typed a C, and, in response to queries, specified 8 contours and stress component 6. The resulting plot is shown in Figure 3.9.

```
@DEFINE (LOGICAL NAME) 5:TTY:
@DEFINE (LOGICAL NAME) 6:TTY:
@RUN (PROGRAM) SCON1.EXE.1

ENTER TITLE

?PLATE

?

ENTER RESETS (I.E. FOR MAX. PRINCIPAL STRESS)

RESET KSTR=4

OTHER RESET OPTIONS: INLIB, MING, MAXG, KGRNP,

NS, ISET, ICASE, ISRF, IGRD, NSA, RX1, RX2, RY1, RY2, JLAY,  NCON
RESET KSTR=6,NS=7

KSTR=        6
NS  =        7

DATA SPACE=     90000
ENTER TERMINAL SPEED IN CHAR/SEC
?120
```

Figure 3.6   Initial Dialog with Program SCON1.

Table 3.3

RESET Controls for SCON1

Name	Default Value	Meaning
INVIB	1	Data source library for data sets STRS EIJ ISET ICASE, JLOC BTAB 5 2, and CASE TITL INSET.
MING	1	Smallest element group number to be displayed
MAXG	1,000	Largest element group number to be displayed.
NS	5	Number of equally spaced stress values to be displayed.
KSTR	6	Type of stress to be displayed.

KSTR	TYPE
1	Normal stress in X direction (σ_x)
2	Normal stress in Y direction (σ_y)
3	Shear stress in X plane in Y direction (τ_{xy})
4	Max. principal stress (σ_1)
5	Min. principal stress (σ_2)
6	Max. shear stress (τ_{max})

Name	Default Value	Meaning
INSET	1	Load set.
ICASE	1	Load case
ISRF	1	*Surface location.

ISRF	Location
1	Mid surface (C)
2	Upper surface (A)
3	Lower surface (B)

Name	Default Value	Meaning
IGRD	0	Node plot. If other than 0, nodal points will be plotted.

*ISRF is used only for bending or bending + membrane elements. (Refer to 4-3-A)

Table 3.3 (Continued)

Name	Default Value	Meaning
NSA	0	Additional number of specific stress values to be displayed. If other than 0, computer prompts for the NSA stress values. (Total number of stress contours to be displayed is NS+NSA).
RX1	180.	Min. X screen coordinates of Region 1 for plotting contours.
RX2	820.	Max. X screen coordinates of Region 1 for plotting contours.
RY1	60.	Min. Y screen coordinates of Region 1 for plotting contours.
ON	1	Constraint case.

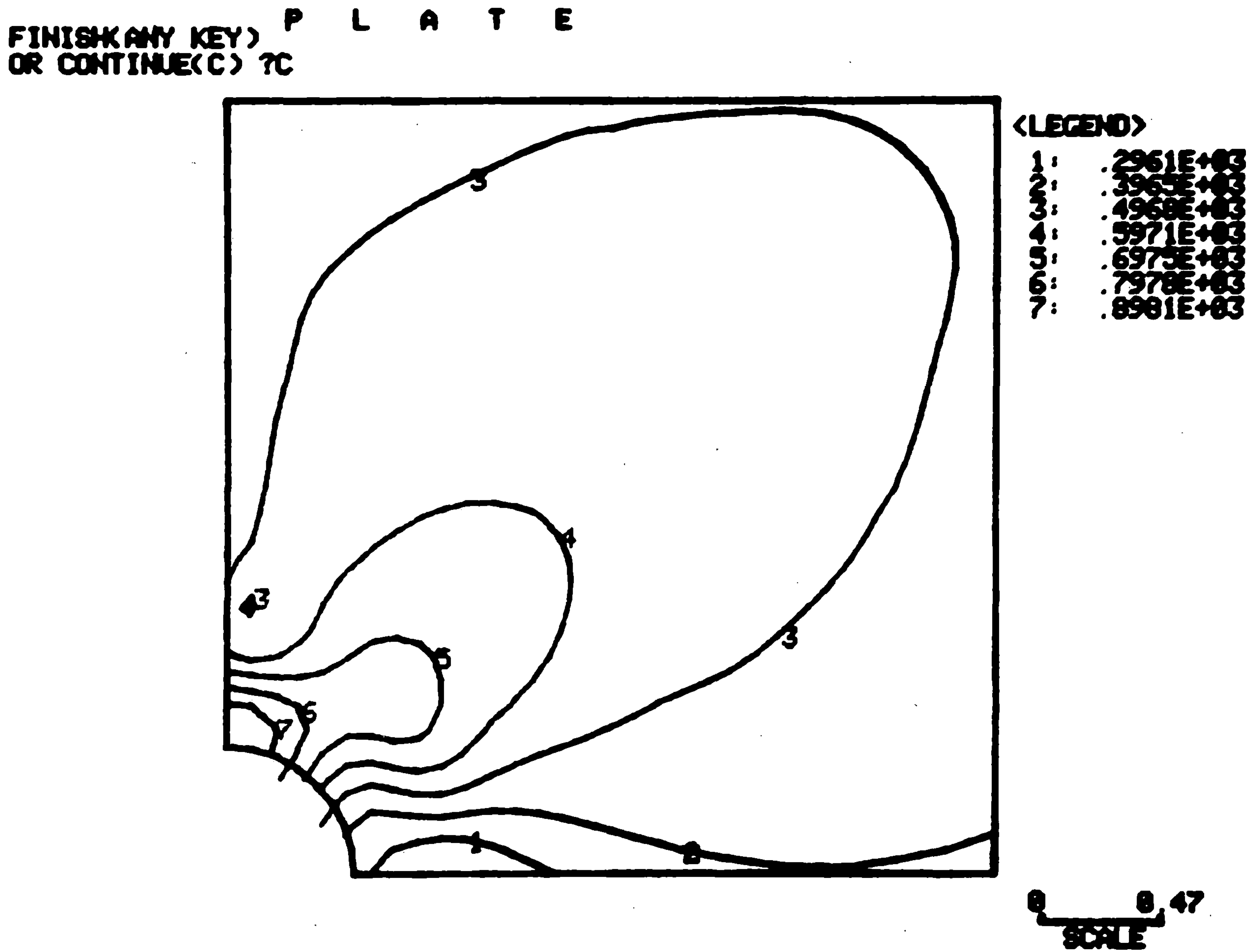


Figure 3.7 Maximum Shear Stress Contours for Plate Example.

```
 0C- CHANGE STRESS VALUES(C)
 0 - CHANGE TYPE OF STRESS (T)

  SPECIFY STRESS VALUES(NS,NSA,(SVAL(I),I=1,NSA))
?8 0 0.
```

Figure 3.8 Follow-up Dialog for Program SCON1.

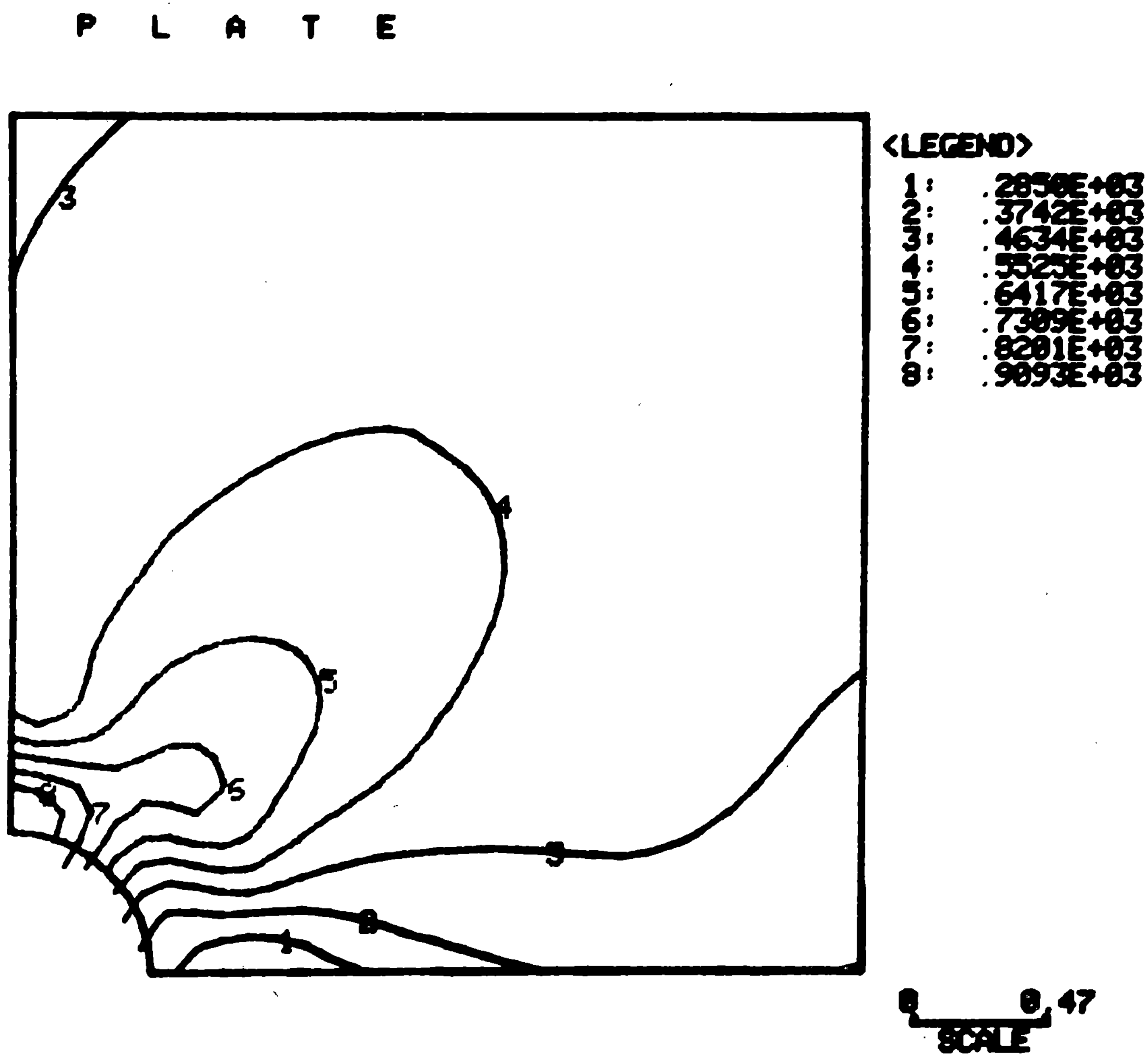


Figure 3.9 Plate Stress Contours with an Additional Contour.

4.0 APPENDIX: HOW TO DRAW THE DEFORMED STRUCTURE

4.1 Basic Approach

The plot processor reads the coordinates of the structure from the SPAR data base, where they are stored as a data set, called "JLOC BTAB 2 5." If we want to generate a plot of the deformed structure, we need to generate a data set by that name containing the deformed coordinates. For this purpose, we need to add the displacements to the original coordinates. Occasionally, when the displacements are very small, we may want to exaggerate the deformation by adding a multiple of the displacements to the original cordinates.

4.2 How the Coordinates and Displacements are Stored

The coordinates are stored as a matrix with 3 rows (corresponding to the x,y,z coordinates). Thus, the order of coordinates in "JLOC BTAB 2 5" is x_1, y_1, z_1, x_2, y_2, z_2, . . . The displacements are stored in a data set called "STAT DISP set con" where set and con are the load set number and constraint set number used to generate the displacements. The data set may contain several blocks corresponding to the load cases within the given load set. Each block is a matrix, with each row corresponding to a displacement component. For example, if the structure is a planar frame in the x,z plane, the displacement components are stored as u_{x1}, u_{z1}, θ_{y1}, u_{x2}, u_{z2}, θ_{y2} . . .

4.3 How to Add the Displacements to the Coordinates

There are two steps in the process of addition. First, the relevant displacement components have to be extracted from the data set "STAT DISP," and transferred to another data set that has the same dimensions as the coordinate data set "JLOC BTAB." This is done with the aid of the TRANSFER statements of processor AUS, described in the SPAR User's Manual, Page 5.1.3.1 -8. The following set of examples may obviate the need to consult the manual for most applications. In all of them, the transformed displacement vector is stored in a data set called "TRNS DISP 0 0."

(1) Plane stress in x,y plane; a single displacement vector in data base

```
DEFINE AA=1 STAT DISP
TABLE (NI=3, NJ=njoints*):  TRNS DISP 0 0
TRANSFER (SOURCE=AA, ILIM=2, JLIM=njoints,* DSKIP=1)
```

(2) Planar frame in x,y plane; operating on displacement vector associated with Case 2 of Load Set 3 and Boundary Condition Set 4

```
DEFINE AA=1 STAT DISP 3 4 2
TABLE (NI=3, NJ=njoints*):  TRNS DISP 0 0
TRANSFER (SOURCE=AA, ILIM=2, JLIM=njoints,* SSKIP=1,
          DSKIP=1)
```

(3) Three dimensional solid (all 6 degrees-of-freedom active); a single displacement vector in data base

---

*Put in the actual number of joints

```
DEFINE AA=1 STAT DISP
TABLE (NI=3, NJ=njoints*):  TRNS DISP 0 0
TRANSFER (SOURCE=AA, ILIM=3, JLIM=njoints,* SSKIP=3)
```

The second step in the addition process uses the AUS function SUM. If, for example, we wish to amplify the displacements by a factor of 1.79, the sequence of operations following the generation of "TRNS DISP" is:

```
DEFINE TD=1 TRNS DISP 0 0
DEFINE JL=1 JLOC BTAB 2 5
JLOC BTAB 2 5=SUM (JL, 1.79, TD)
```

---

*Put in the actual number of joints

User's Guide: Spar 11, Structural Analysis Finite Element Program (Including Graphics), for Use on a DEC-2050 Computer System, RT Haftka, RC Dix, N Shah, 1981, 26 Biblio 06 Train Control & Comm