Fritz Laboratory Reports

Civil and Environmental Engineering

1970

Automatic plotting of residual stress diagrams, November 1970.

G. Beer

L. Tall

OFFICE

OF

RESEARCH

LEHIGH UNIVERSITY

Residual Stresses in Thick Welded Plates

AUTOMATIC PLOTTING OF RESIDUAL STRESS DIAGRAMS

by

G. Beer

L. Tall

Fritz Engineering Laboratory Report No. 337.26

Residual Stresses in Thick Welded Plates

AUTOMATIC PLOTTING OF RESIDUAL STRESS DIAGRAMS

by

G. Beer

L. Tall

This work has been carried out as part of an investigation sponsored jointly by the National Science Foundation and the Column Research Council.

Department of Civil Engineering

Fritz Engineering Laboratory
Lehigh University
Bethlehem, Pennsylvania

November, 1970

Fritz Engineering Laboratory Report No. 337.26

CONTENTS

		Page
	ABSTRACT	i
1.	INTRODUCTION	1
2.	DESCRIPTION OF PROGRAMS	3
	2.1 General Description	3
	2.2 Residual Stress Diagrams	4
	2.3 Isostress Diagrams	6
3.	SUMMARY	9
4.	ACKNOWLEDGEMENTS	10
5.	FIGURES	11
6.	APPENDIX 1: Data Card Setup	16
7.	APPENDIX 2: Flowcharts	25
8.	APPENDIX 3: Program Listings	29
9.	REFERENCES	45

ABSTRACT

This report describes how a digital computer can be used for the reduction of data obtained from residual stress measurements and how residual stress and isostress diagrams can be plotted automatically using a digital plotter.

The method for residual stress measurements used in this report is the relaxation method of "sectioning".

1. INTRODUCTION

The method of "sectioning" as described elsewhere(1) has been used for years for residual stress measurements in structural members. The "sectioning method" is based on the principle that internal stresses in a material are relieved by sectioning a specimen into many strips of small cross-section. The strain relieved is measured with an extensometer and the stress is found by applying Hooke's Law, assuming a completely elastic behavior.

The scope of the study described in this report was to develop a set of computer programs which perform the reduction of data obtained by residual stress measurements and to furnish the user with plotted residual stress and isostress diagrams of the residual stress distribution.

The programs are written in FORTRAN IV.

Residual stress diagrams are plotted using a California Computing Company (CALCOMP) plotter available at the Lehigh University Computing Center.

This is accomplished by calling subroutines, which drive the plotter. These subroutines are library subroutines of the Control Data Corporation (CDC) 6400 computer system. The programs as listed in the appendix can be run only on computer systems which have these plotter routines as library routines.

2. DESCRIPTION OF PROGRAMS

2.1 GENERAL INFORMATION

Three programs have been developed:

PLOTRS.....reduces the data obtained from measurements before and after sectioning or slicing and plots the results using an electronic plotter. (Several options of this program are described in detail in Appendix 1 of this report.)

RSANA......computes the two-dimensional residual stress-distribution from data reduced by PLOTRS, checks for equilibrium and provides the input for PLOTIS.

PLOTIS.....plots an isostress diagram of the two-dimensional residual stress-distribution.

The use of the program package is explained by the diagram in Fig. 1. The specimen is first sectioned. The program PLOTRS reduces the data obtained from measurements before and after sectioning and plots the one-dimensional residual stress distribution (the distribution of residual stress at the surfaces of the plate).

Next, a slicing procedure is performed. The program PLOTRS is used again for reducing the extensometer readings before and after slicing. Program RSANA uses the computed residual stresses from the sectioning and the slicing procedure to compute the two-dimensional residual stress distribution (that is, the distribution of residual stresses through the thickness and width of the plate).

Program PLOTIS is then used to plot the isostress diagrams of this distribution.

2.2 RESIDUAL STRESS DIAGRAMS

A sectioning procedure is performed in order to obtain a residual stress diagram. In the method, a mechanical entensometer is used to measure the distance between two gauge points.

The difference in readings before and after sectioning gives the relieved strain. To take into account the change in temperature during the measurement, the readings are compared with a reference bar after a set of readings has been taken.

To improve the accuracy of the measurements, three readings are taken at every gauge point. Readings of the extensometer are punched on cards and are the input for the program PLOTRS.

The analysis of these readings is performed by the computer program. Residual stresses are calculated as follows:

1) Compute average of a set of 3 readings for a strip i

$$\bar{A}_i = 1/3 \sum_{j=1}^{3} A_{ij} \qquad (1)$$

where A_{ij} are the initial readings of the extensometer (before sectioning).

The average value of initial readings ($\overline{REF\ A_i}$) on the reference bar, which are taken after a certain number of readings, is computed in the same manner.

In a similar way, average values of final readings (after sectioning) will be computed as $\overline{B}_i$ and ($\overline{REF}\ B_i$).

2) Compute residual stresses:

$$\sigma_{r_i} = \frac{E}{L} [(\overline{A}_i - \overline{REF}\ \overline{A}_i) - (\overline{B}_i - \overline{REF}\ \overline{B}_i)] \tag{2}$$

where

σ_{r_i} = residual stress in strip i,

E = modulus of elasticity,

L = gauge length (10")

After performing this analysis the results are printed out, together with the data. Subsequently, the result is checked if it exceeds a limit which is specified in the input (input variable MINY). As soon as one value of residual stress exceeds MINY, an error message is printed out and no plot is obtained. Otherwise the residual stress distribution is plotted. Figure 2 shows a sample output. The program PLOTRS has several options which also permit the application of this program to shapes. In this case, plots of the component plates (flanges and webs) are obtained in one run and then placed around the shape. Figure 2 shows part of a plot obtained for a box shape. In this case, the plot consists of 4 diagrams for both flanges and both webs.

The use of drumcard for exact format can make the data card preparation faster and more foolproof. The possibility of punching data automatically by means of linear transducers is being studied[2]. In this case the extensometer will be connected with the keypunch by an electronic device which transforms the readings and drives the keypunch. At this stage, no manual recording, computation or plotting will be needed.

2.3 ISOSTRESS DIAGRAMS

The specimen is cut further to obtain the variation of residual stress through the thickness. This procedure as described elsewhere in detail[3] is called "slicing".

From extensometer readings before and after slicing an additional strain-relief ($\epsilon_{slicing}$) is obtained by using the program PLOTRS. This strain must be superimposed upon the strains from the sectioning to obtain the total strain variation.

The residual stresses may be obtained from the relationship

$$\sigma_r = E\,(\epsilon_{sectioning} + \epsilon_{slicing}) \qquad (3)$$

The computer program RSANA performs this operation for all elements.* In addition an equilibrium check is made. A two-

---

* This program has been developed previously. The theory involved is described in detail in Reference 3 pp. 12, 13.

dimemsional residual stress distribution which is adjusted for equilibrium is printed and punched out.

In order to show the two-dimensional residual stress distribution in a plot, isostress diagrams have been used in some reports[3,4]. It is very tedious to prepare such a diagram by hand, since the points of the isostress lines (lines of equal stress) must be found graphically for every section along the width of the plate.

The computer program PLOTIS performs this operation and uses an electronic plotter to plot the isostress diagrams.

For the analysis the cross section of a plate is divided into many small strips as shown in Fig. 3.

The residual stress distribution along a strip is found by interpolating linearly. The residual stresses are assumed to be constant across the thickness of one strip.

A subroutine is used to search along these strips for points of equal stress interpolating linearly between two points of given residual stress.

The coordinates of these points are computed and plotted to scale using a special plotter symbol. Since these points come very close together, a line (of equal stress) can be seen. The beginning and end of these lines are annotated with the value of residual stress.

A sample output of a plotted isostress diagram as it is obtained by the electronic plotter is shown in Fig. 4. In this figure, half of the cross section of a flame-cut and center-welded 24" x 2" plate is shown.

Lines which lie close together on the flame-cut edge of the plate show a steep stress gradient, whereas the lines at the middle of the plate are far apart and indicate that the stress is nearly uniform through the thickness. The lines are annotated in ksi.

3. SUMMARY

The scope of the study presented here was to develop a set of computer programs which reduce data obtained from residual stress measurements. Three computer programs were developed which not only perform all necessary computations for the reduction of data but also furnish the user with automatic plots of the residual stress distribution. It is very tedious and time-consuming to obtain such residual stress distributions by hand. The isostress diagrams presented in some reports took up to 48 working hours to prepare.

The use of a high speed and accurate digital computer saves not only time but also money. To obtain an isostress diagram, such as the one in Fig. 4, the user pays about $3.00. For the diagram in Fig. 2, the cost will be about $1.00. These prices are based on the current rates at Lehigh University Computing Center, (1970).

4. ACKNOWLEDGEMENTS

This report presents a study carried out in connection with a research project "Residual Stresses in Thick Welded Plates", conducted at Fritz Engineering Laboratory, and the Department of Civil Engineering, Lehigh University, Bethlehem, Pennslyvania.

Lynn S. Beedle is the Director of Fritz Engineering Laboratory.

The investigation is being carried out under the sponsorship of the National Science Foundation and the Column Research Council.

The technical guidance of Task Group 1 of the Column Research Council under the chairmanship of John A. Gilligan is sincerely appreciated.

Thanks are due to Jacques Brozzetti, who commenced the study and assisted in its first stages. The computer program RSANA, which is used in this study, was developed by him.

The authors are indebted to Celal N. Kostem for his advice and help throughout this study.

Thanks also to the staff of the Lehigh University Computing Center for their assistance, John M. Gera for preparing the drawings and to Mrs. Jean Neiser for typing the manuscript.

5. FIGURES

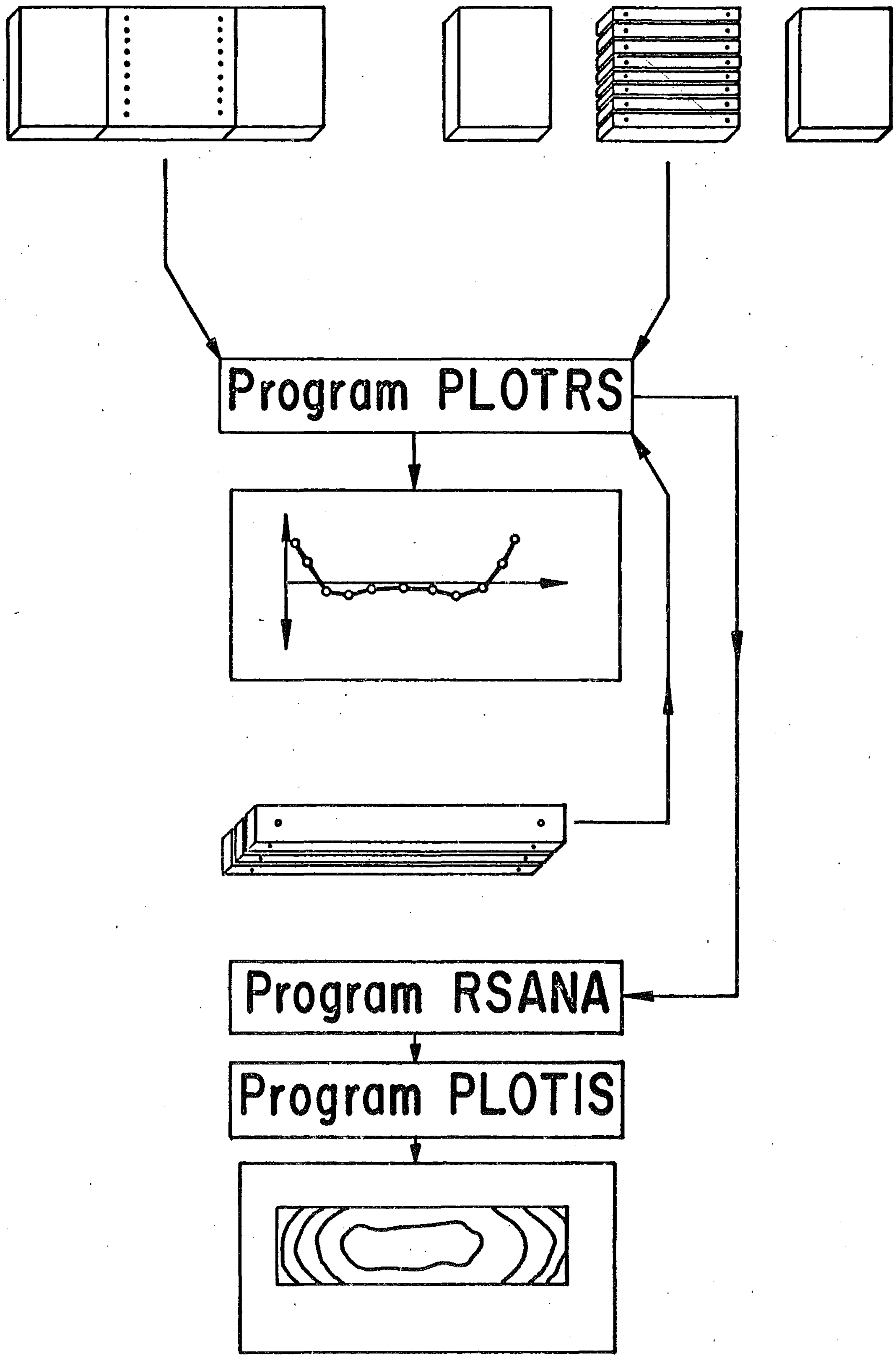


Fig. 1 Diagram of Program Package

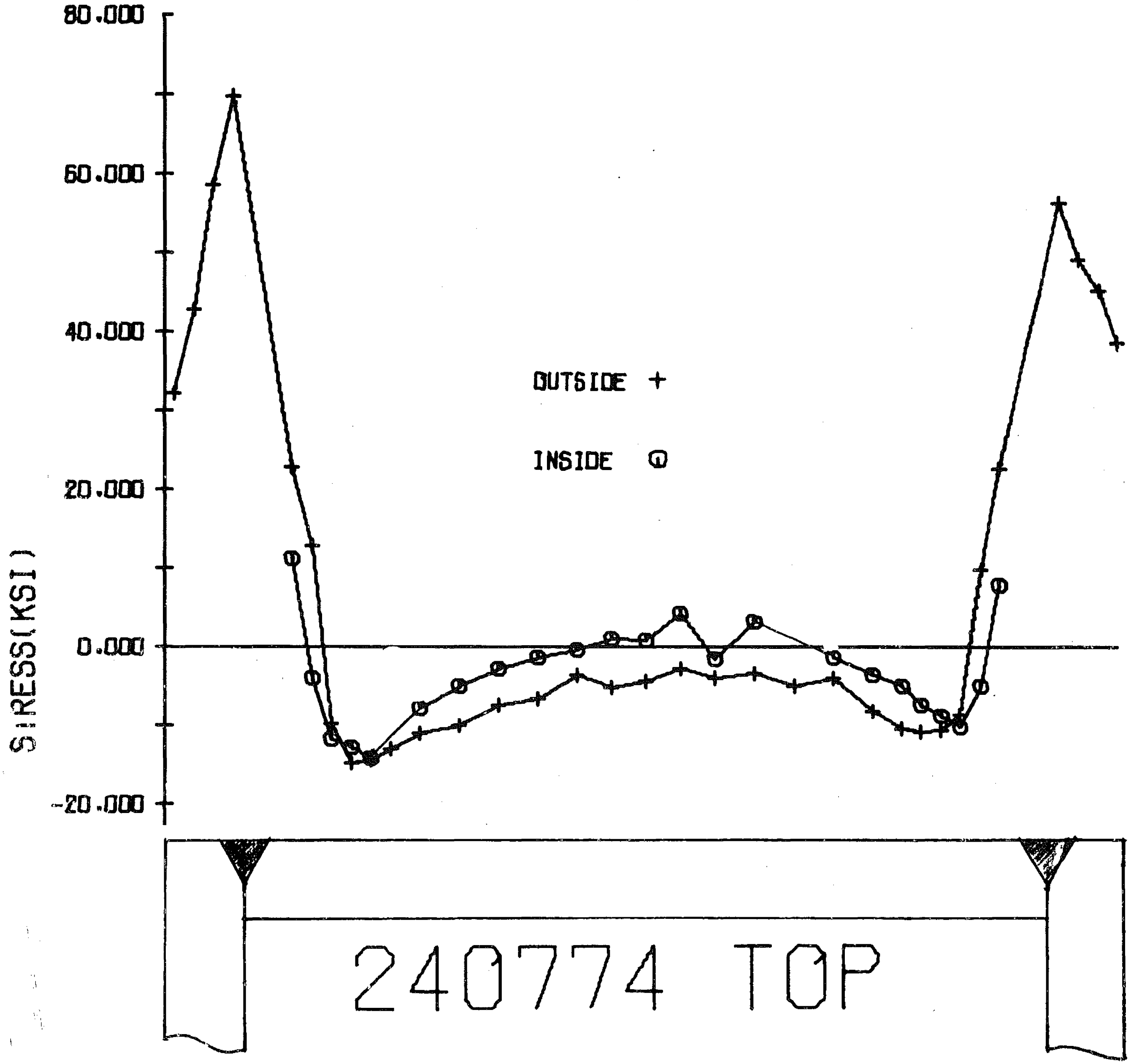


Fig. 2 Sample plotted output of "plotrs": residual stress distribution in the upper flange of a box shape 24□774

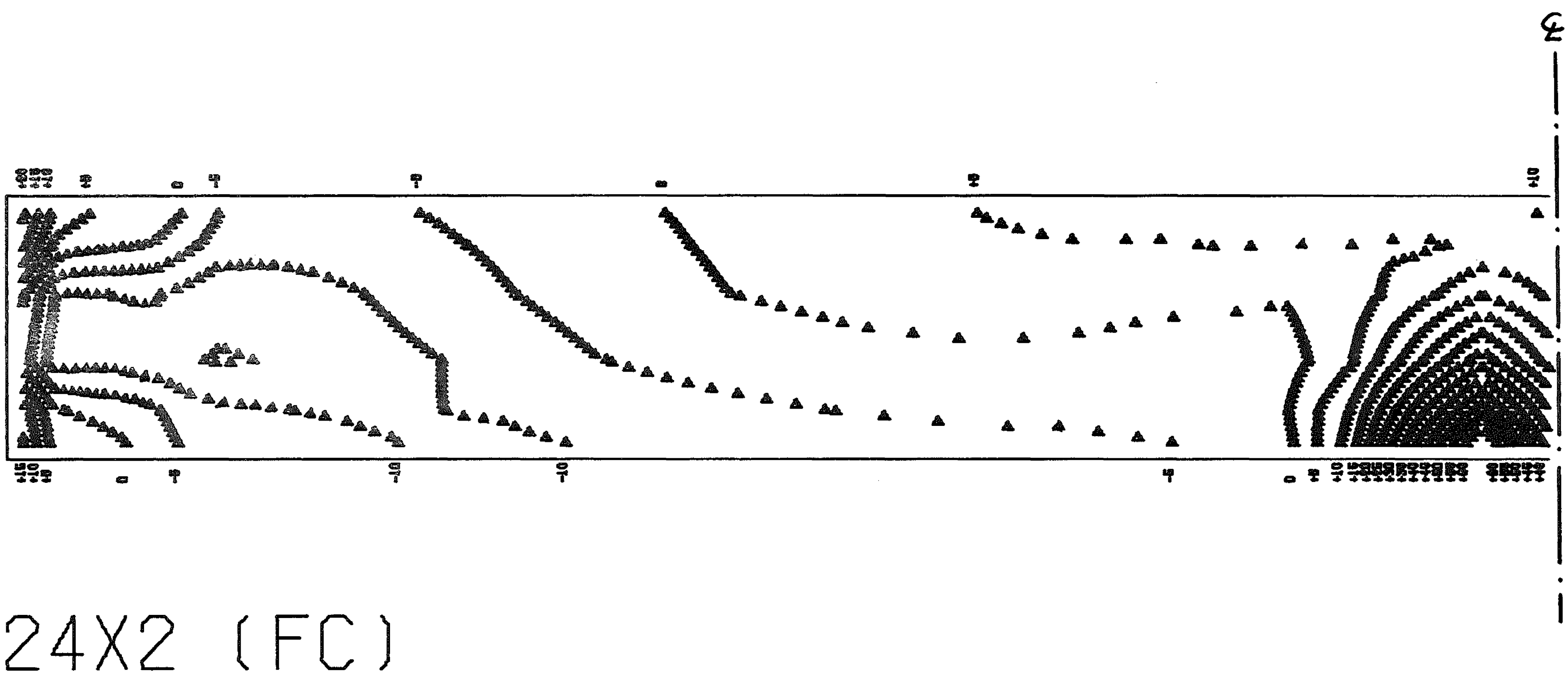


Fig. 4 Sample Plotted Output of "PLOTIS": Residual Stress Distribution in a Flame-Cut and Centerwelded 24"x2" Plate. (Only Half of the Plate is Shown).

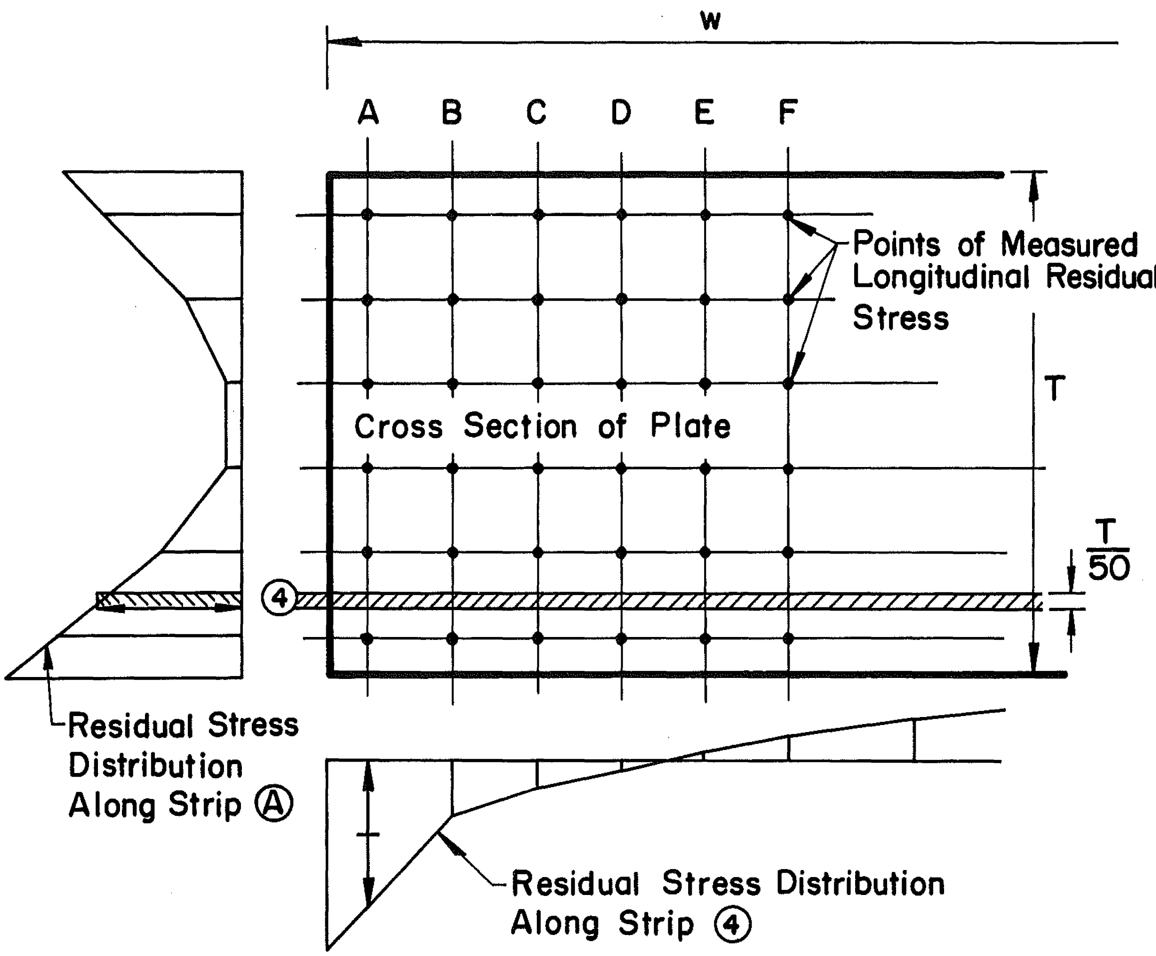


Fig. 3 Division of the Cross Section of a Plate into Small Strips. (Program PLOTIS).

APPENDIX 1: Data Card Input

1) <u>PROGRAM PLOTRS</u>

The program PLOTRS has several options to make it suitable for general use.

The options are:

1) Either a set of three readings or the average of these readings can be punched on each data card.
2) The computed residual stress distribution can be punched out.
3) The program can be run without obtaining a plot (the values and location of stresses will be printed out only).
4) A residual stress distribution can be given as input (no data reduction, only the plot).

In the data card setup the first ten cards contain information about the required scale of plot, choice of options, and geometry of the plate.

Then 4 sets of data follow:

1) initial reading - upper surface
2) final reading - upper surface
3) initial reading - lower surface
4) final reading - lower surface

Each set of data consists of the gauge readings in a format specified below.

At the end of each set, the readings on the reference bar follow in consecutive order.

For each set of data described above, the readings on the reference bar should be numbered starting with the number one.

For shapes, the residual stress diagrams of the component plates are ontained in one run.

The data setup is the same as for plates except:

The data giving information about scale of plot and choice of options are valid for all component plates. The data specifying the geometry vary for each component plate and must be specified before each four sets of data.

ONE MORE CARD

FORMAT (F10.2)
VARIABLE XMAXLG
CALL PLOTER
CALL LIMIT (XMAXLG)) PH 214

FORMAT OF DATA-CARDS

CARD NO.	FORMAT	VARIABLE	REMARKS
1	(2I2)	JSYM (I)	Numerical code of plotter symbols to be used in the plot for each surface of the plate [see plotter manual, otherwise use 3,1]
2	(3F10.0)	SCALEX	Scale factor of x-Axis (width of the plate): 1 inch in plot = SCALEX inches
		SCALEY	Scale factor of Y-Axis (stress axis): 1 inch in plot = SCALEY ksi
		MINY	Minimum (= maximum negative value) of residual stress (symmetrical stress axis)

CARD NO	FORMAT	VARIABLE	REMARKS
3	(L10)	AVARG	Logical variable is TRUE if the average of 3 readings is punched on data cards [the part of the program which computes the average of a set of readings will then be deleted]
4	(L10)	STRDAT	TRUE if the residual stress distribution is given as input (no data reduction, only plot)
5	(L10)	PNCH	TRUE if the computed residual stress distribution is to be punched out*
6	(L10)	NOPLT	TRUE if plot is to be deleted
7	(I2)	NPLT	NUMBER of plots to be plotted (for shapes: 1 plot for each component plate)
8	(A10)	TEXT1	Identification of plate for printed and plotted output.
9	(2I2)	N	Number of gauge points for one surface of the plate (also valid for the other surface)
		J	Number of readings on the reference bar for one surface of the plate (also valid for the other surface)

* The residual stress distribution will be punched out in Format F10.2

CARD NO.	FORMAT	VARIABLE	REMARKS
10	(80I1)	L(I)	String on integer numbers indicating the layout of gauge-holes (1=1/8", 2=2/8", etc.)*
11	(A10)	TEXT2	Identification to which surface of the plate the following data belong.

EXTENSOMETER READINGS

	(A3,3I5,I2)	IPOSA(I)	Number of identification of gauge point (if reference bar reading: punch REF).
		IA (I,K)	Set of 3 readings. Leave columns for 2. and 3. reading blank if average of these readings is input.
		LA(I)	Number of last reading on the reference bar which was taken before the gauge reading punched on this data card. (If reference bar reading: number of reading on the reference bar).

NOTE: IF A READING CAN NOT BE TAKEN, PUNCH IDENTIFICATION OF GAUGE HOLE AND LEAVE THE REST OF THE CARD BLANK.

---

* The first integer number indicates the distance of the first gauge point from the edge of the plate in 1/8". The following numbers indicate the distances between each gauge-point.

EXAMPLE: 123...means the first gauge-hole is 1/8" from the edge. The second gauge-hole is 2/8" from the first. The third gauge-hole is 3/8" from the second, and so on.

FORMAT OF A GIVEN RESIDUAL STRESS DISTRIBUTION

TO BE PLOTTED (NO DATA REDUCTION)

(A3,F10.0,I1)	IPOSA (I)	Identification of point.
	STRESS (I)	Residual stress at this point.
	LA(I)	Punch number one.

NOTE: IF POINT IS TO BE SKIPPED, PUNCH IDENTIFICATION AND LEAVE THE REST OF THE CARD BLANK.

2) PROGRAM RSANA

The input sequence and the format of the data cards are summarized below. For input of RSU, RSL and RSSL the punched output of program PLOTRS may be used

CARD NO	FORMAT	VARIABLE	REMARKS
1	(I2,X,I2)	K1	Number of gauge points across the width of the plate.
		IE	Number of gauge points across the thickness of the plate.
2	(A10)	TEXT1	Text for identification
3	(A10)	TEXT2	
4	(2F10.4)	B	Width of the plate in inches.
		T	Thickness of the plate
5	(12F5.2)	DY (J)	Dimension of finite area elements across width of the plate in inches (sectioning)
6	(6F8.8)	DX (J)	Dimension of finite area elements across thickness of the plate in inches (slicing)
7	(F10.2)	RSU (J)	Residual stress distribution after "sectioning" (upper surface)
8	(F10.2)	RSL (J)	Residual stress distribution after "sectioning" (lower surface)
9	(F10.2)	RSSL(I,J)	Residual stress distribution obtained from "slicing" the specimen. First variation (I) across the thickness of the plate. Input-sequence: ((RSSL(I,J), I=1,IE), J=1,K1)

3) PROGRAM PLOTIS

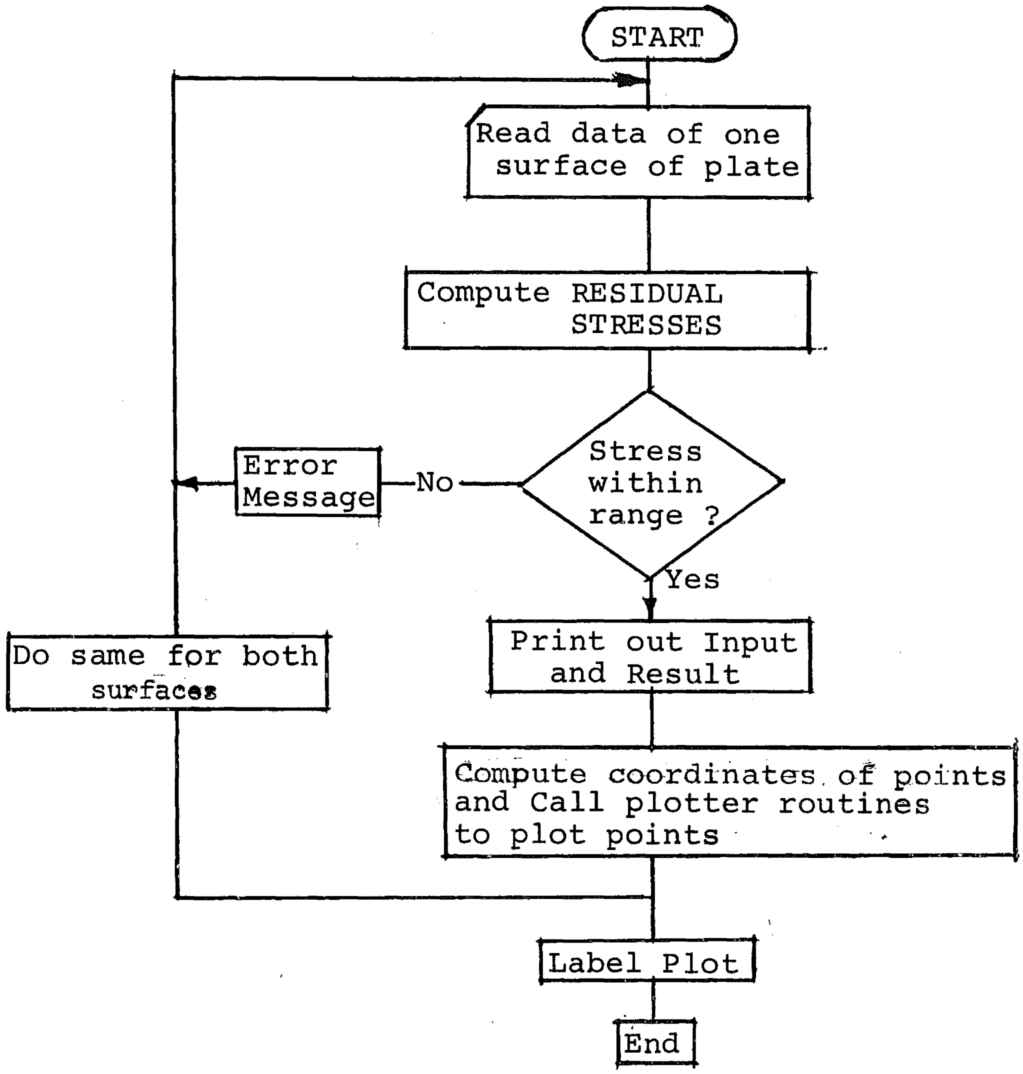
The format for the input data is specified below. For choice of the scale factors SCALEX and SCALEY the limitations of the plot area must be considered. The scale factors must be chosen so that the thickness of the plate does not exceed 7" in the plot and the width of the plate does not exceed 36" in the plot. For input of the two-dimensional residual stress distribution STR(I,K) the punched output obtained from program RSANA can be used.

FORMAT OF DATA CARDS

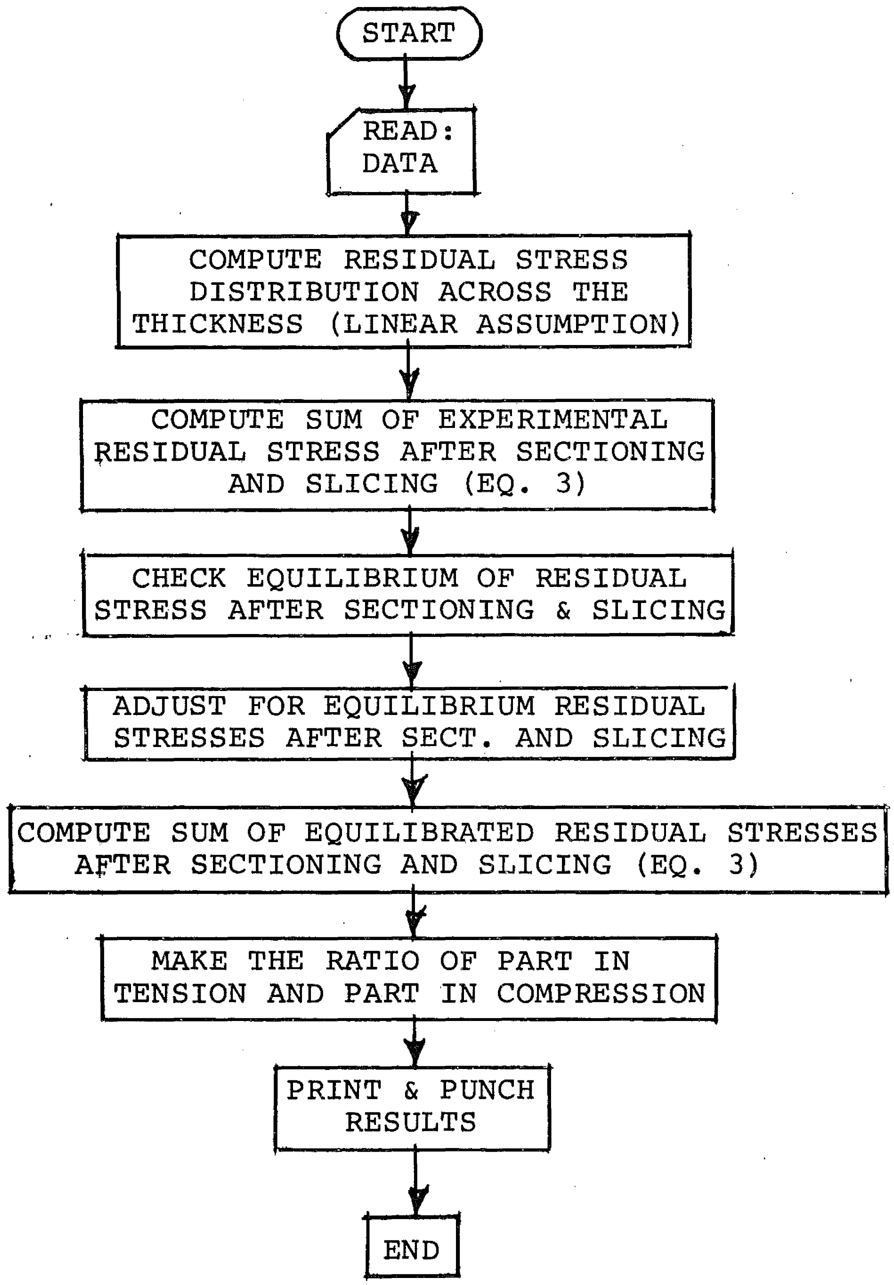
CARD NO.	FORMAT	VARIABLE	REMARKS
1	(A10)	TEXT1	Identification of plate (will appear on plot)
2	(2I2,3F6.2)	IEND	Number of gauge points through the thickness
		NN	Number of gauge points along width of plate
		B	Thickness of plate in inches
		SCALEX	Scale factor in X-direction (along plate-width)
		SCALEY	Scale factor in Y-direction (across thickness of plate)
3	(6F5.2)	W (I)	Lay-out of gauge points through the thickness in inches.
4	(2I2,F5.1)	NMAX	Minimum (=maximum negative value) of stress-level.

CARD NO.	FORMAT	VARIABLE	REMARKS
		PMAX	Maximum value of stress-level
		INTE	Interval in ksi NOTE: isostress lines will be drawn with an interval given by INTE starting with NMAX and terminating with PMAX.
5	(16A5)	TEXT(I)	Corresponding to the previous values indicate Text or number required to appear at both ends of each isostress line. This will allow to distinguish between the different isostress lines. Note that values must be provided for <u>all</u> isostress lines beginning with the one with minimum stress level.
6	(80I1)	JFORM(I)	Array containing the distances between the gauge-points in longitudinal direction (1=1/8", 2=2/8", etc.; Limit=9) (Same as for PLOTRS).
7	(F8.2)	STR(I,K)	Two-dimensional residual stress distribution. The first subscript (I) varies along the length, the second (K) through the thickness. Input sequence: ((STR(I,K), I=1, NN), K=1, IEND)

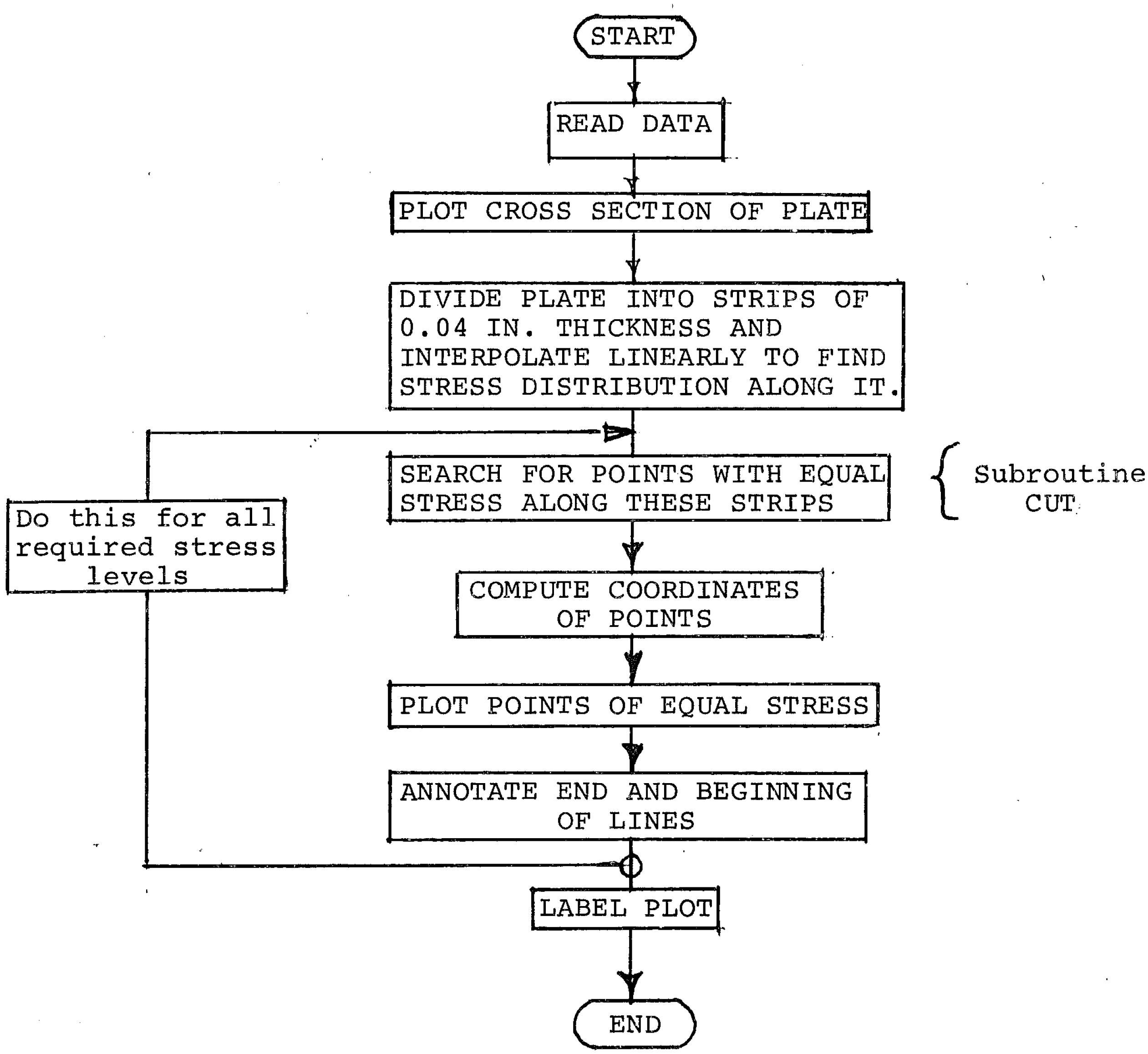
APPENDIX 2: FLOWCHARTS



Simplified Flowchart of Program "PLOTRS"



Simplified Flowchart for Program "RSANA"



Simplified Flowchart for Program "PLOTIS"

APPENDIX 3: Program Listings

```
      PROGRAM PLOTRS(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,PLOT,TAPE99=P
     1LOT,PUNCH)
C
C***********************************************************************
C
C     PLOTRS REDUCES DATA OBTAINED FROM RESIDUAL STRESS MEASSUREMENTS
C     AND FURNISHES THE USER WITH A PRINTED AND/OR PLOTTED AND/OR
C     PUNCHED OUTPUT OF THE RESIDUAL STRESS DISTRIBUTION.
C     DEVELOPED AT LEHIGH UNIVERSITY, FRITZ LABORATORY, JANUARY 1970
C     TESTED AT A CDC 6400 COMPUTER USING A CALCOMP PLOTTER.
C
C     NOTE.. THIS PROGRAM CAN ONLY BE USED AT ABOVE MENTIONED SYSTEMS
C     SINCE EACH PLOTTER HAS ITS OWN DRIVER ROUTINES.
C
C***********************************************************************
C
      DIMENSION IA(100,3), IB(100,3), IAVA(100), IAVB(100), IREFA(10), I
     1REFB(10), IPOSA(100), IPOSB(100), LA(100), LB(100), STRESS(100)
      DIMENSION X(100), L(100), STR(100), JSYM(2)
      INTEGER A
      INTEGER TEXT1,TEXT2
      REAL MINY
      LOGICAL AVARG,STRDAT,PNCH,NOPLT
C
C     FIRST GENERAL INFORMATION ABOUT GIVEN INPUT AND REQUIRED OUTPUT
C     IS READ IN
C
      READ (5,34) JSYM
      READ (5,38) SCALEX,SCALEY,MINY
      READ (5,40) AVARG
      READ (5,40) STRDAT
      READ (5,40) PNCH
      READ (5,40) NOPLT
      READ (5,34) NPLT
      NPLOT=0
C     START LOOP FOR EACH COMPONENT PLATE
    1 NPLOT=NPLOT+1
C
C     NEXT INFORMATION ABOUT NUMBER OF HOLES,GAGE-HOLE DISTRIBUTION ETC.
C     FOLLOW
C
      READ (5,33) TEXT1
      READ (5,34) N,J
      A=N+1
      READ (5,37) (L(I),I=1,A)
      LOOP=0
C     START LOOP FOR EACH SURFACE OF THE PLATE
    2 READ (5,33) TEXT2
      LOOP=LOOP+1
      IF (STRDAT) GO TO 8
      M=N+J
      IF (AVARG) GO TO 3
C
C     INPUT OF GAGE-READINGS - 3 READINGS
C
      READ (5,35) (IPOSA(I),(IA(I,K),K=1,3),LA(I),I=1,M)
      READ (5,35) (IPOSB(I),(IB(I,K),K=1,3),LB(I),I=1,M)
```

```
      GO TO 4
C
C     INPUT OF GAGE READINGS - AVERAGE OF 3 READINGS
C
    3 READ (5,39)  (IPOSA(I),IAVA(I),LA(I),I=1,M)
      READ (5,39)  (IPOSB(I),IAVB(I),LB(I),I=1,M)
      GO TO 6
C
C     COMPUTE AVERAGE
C
    4 DO 5 I=1,M
      IAVA(I)=(IA(I,1)+IA(I,2)+IA(I,3))/3
    5 IAVB(I)=(IB(I,1)+IB(I,2)+IB(I,3))/3
C
C     STORE READINGS OF LAST CARDS WHICH CONTAIN REFERENCE BAR READINGS
C     INTO ARRAY IREFA AND IREFB RESPECTIVELY
C
    6 DO 7 I=A,M
      K=I-N
      IREFA(K)=IAVA(I)
    7 IREFB(K)=IAVB(I)
C
C     WRITE LABELS
C
    8 WRITE (6,41)
      WRITE (6,42)
      WRITE (6,43) TEXT1
      WRITE (6,43) TEXT2
      IF (STRDAT) GO TO 15
      WRITE (6,41)
      WRITE (6,44)
C
C     WRITE INPUT DATA (INITIAL READINGS ) - IF POINT IS TO BE SKIPPED
C     WRITE POSITION AND A MESSAGE = CAN NOT BE MEASSURED
C
      DO 11 I=1,M
      IF (LA(I).EQ.0) GO TO 10
      IF (AVARG) GO TO 9
      WRITE (6,46) (IPOSA(I),(IA(I,K),K=1,3),LA(I),IAVA(I))
      GO TO 11
    9 WRITE (6,45) (IPOSA(I),LA(I),IAVA(I))
      GO TO 11
   10 WRITE (6,48) (IPOSA(I))
   11 CONTINUE
      WRITE (6,41)
      WRITE (6,47)
C
C     WRITE INPUT DATA (FINAL READINGS)
C
      DO 14 I=1,M
      IF (LB(I).EQ.0) GO TO 13
      IF (AVARG) GO TO 12
      WRITE (6,46) (IPOSB(I),(IB(I,K),K=1,3),LB(I),IAVB(I))
      GO TO 14
   12 WRITE (6,45) (IPOSB(I),LB(I),IAVB(I))
      GO TO 14
   13 WRITE (6,48) (IPOSB(I))
   14 CONTINUE
```

```
      GO TO 16
C
C     READ IN RESIDUAL STRESS DISTRIBUTION IF NO DATA-REDUCTION BUT
C     ONLY PLOT IS REQUIRED
C
   15 READ (5,36) (IPOSA(I),STRESS(I),LA(I),I=1,N)
   16 WRITE (6,41)
      WRITE (6,49)
C
C     COMPUTE RESIDUAL STRESS
C
      DO 19 I=1,N
      IF (STRDAT) LB(I)=LA(I)
      IF (LA(I).EQ.0.OR.LB(I).EQ.0) GO TO 18
      IF (STRDAT) GO TO 17
      LAR=LA(I)
      LBR=LB(I)
      IAVA(I)=IAVA(I)-IREFA(LAR)
      IAVB(I)=IAVB(I)-IREFB(LBR)
      IAVA(I)=IAVA(I)-IAVB(I)
      STRESS(I)=IAVA(I)*.03
C
C     WRITE RESIDUAL STRESS
C
      WRITE (6,50) (IPOSA(I),IAVA(I),STRESS(I))
      GO TO 19
   17 WRITE (6,51) (IPOSA(I),STRESS(I))
      GO TO 19
   18 WRITE (6,48) (IPOSA(I))
   19 CONTINUE
C
C     COMPUTE Y-VALUES OF POINTS FOR PLOTTER AND STORE IN ARRAY
C     IF STRESS CAN NOT BE MEASURED THE POINT IS NOT STORED IN THE ARRAY
C
      I=0
      IN=0
   20 I=I+1
      IN=IN+1
      IF (LA(I).EQ.0.OR.LB(I).EQ.0) GO TO 21
      STR(IN)=STRESS(I)
      GO TO 22
   21 IN=IN-1
   22 IF (I.LT.N) GO TO 20
C
C     CHECK FOR MAXIMUM
C
      DO 23 I=1,IN
      IF (ABS(STR(I)).GT.(-MINY)) GO TO 31
   23 CONTINUE
C
C     COMPUTE THE X-VALUES OF POINTS AND STORE IN ARRAY
C     IF POINT CAN NOT BE MEASURED SKIP IT AND GO TO NEXT POINT
C     NOTE THAT IN THIS CASE THE VALUE TO BE STORED IN X IS THE
C     SUMMATION OF ALL DISTANCES BETWEEN POINTS UP TO THIS PARTICULAR
C     POINT
C
      I=0
      IN=0
```

```
      XM=0.
      XN=0.
   24 I=I+1
      IN=IN+1
      IF (LA(I).EQ.0.OR.LB(I).EQ.0) GO TO 25
      XN=L(I)*0.125+XM+XN
      X(IN)=XN
      XM=0.
      GO TO 26
   25 XM=L(I)*0.125+XM
      IN=IN-1
   26 IF (I.LT.N) GO TO 24
C
C     WRITE COORDINATES OF POINTS
C
      WRITE (6,41)
      WRITE (6,52) (STR(I),X(I),I=1,IN)
C
C     PUNCH RESIDUAL STRESS DISTRIBUTION IF REQUIRED
C
      IF (PNCH) PUNCH 53, (STR(I),I=1,IN)
      IF (NOPLT) GO TO 30
C
C     STORE VALUES OF TIK1 AND DTICK INTO ARRAYS
C     (SEE PLOTTER MANUAL)
C
      X(IN+1)=0.0
      X(IN+2)=SCALEX
      STR(IN+1)=MINY
      STR(IN+2)=SCALEY
      ISYM=JSYM(LOOP)
      IF (LOOP.GT.1) GO TO 29
      IF (NPLOT.GT.1) GO TO 28
      A1=MINY/SCALEY
C     A2 IS THE LENGTH OF THE STRESS-AXIS
      A2=-2.*A1
C     THE FOLLOWING STATEMENTS CALL SUBROUTINES TO DRIVE THE PLOTTER
C     THESE SUBROUTINES ARE LIBRARY ROUTINES OF ABOVE MENTIONED SYSTEMS
C     REQUEST NUMBER OF PLOTS
      CALL PLTCNT (NPLT)
C     IDENTIFY PLOT
      CALL NAMPLT
C     MOVE TO NEW ORIGIN WITH PEN UP
      CALL PLOT (0.0,5.0,-3)
C     DRAW VERTICAL AXIS AND LABEL IT
   28 CALL AXIS1 (0.0,A1,11HSTRESS(KSI),11,A2,90.0,MINY,SCALEY,20.0)
C     PEN BACK TO ORIGIN
      CALL PLOT (0.0,0.0,3)
C     DRAW HORIZONTAL AXIS WITHOUT LABELING IT
C     XA IS THE LENGTH OF THE AXIS
      XA=(X(IN)+XM)/SCALEX
      CALL PLOT (XA,0.0,2)
C     PEN TO NEW ORIGIN
      CALL PLOT (0.0,A1,-3)
C     LABEL PLOT AND ASSIGN MEANING TO PLOTTER SYMBOL 1
      CALL SYMBOL (5.0,0.5,0.4,TEXT1,0.0,10)
      CALL SYMBOL (1.0,1.0,0.1,ISYM,0.0,-1)
      CALL SYMBOL (1.3,1.0,0.1,TEXT2,0.0,10)
```

```
C     DRAW CURVE AND MAKE SYMBOL AT EVERY POINT
   29 CALL LINE (X,STR,IN,1,1,ISYM)
   30 IF (LOOP.LT.2) GO TO 2
      IF (NOPLT) GO TO 90
C     ASSIGN MEANING OF PLOTTER SYMBOL 2
      CALL SYMBOL (1.0,1.5,0.1,ISYM,0.0,-1)
      CALL SYMBOL (1.3,1.5,0.1,TEXT2,0.0,10)
C     MOVE PEN OUT OF PLOT AREA AND ESTABLISH ORIGIN FOR NEXT PLOT
      CALL PLOT (10.0,-A1,-3)
C     GOTO NEXT COMPONENT PLATE ( ONLY FOR SHAPES )
      IF (NPLOT.LT.NPLT) GO TO 1
C     OTHERVISE TERMINATE PLOT
      CALL ENDPLT
      GO TO 32
C     PRINT OUT ERROR MESSAGES
C     NOTE.. JOB WILL BE ABORTED AFTER THIS MESSAGE IF PLOT IS REQUESTED
   31 WRITE (6,54)
      IF(.NOT.NOPLT) GOTO 100
      IF(LOOP.LT.2) GOTO 2
   90 IF (NPLOT.LT.NPLT) GO TO 1
      GOTO 32
  100 IF (LOOP.EQ.2) GOTO 110
      IF(NPLOT.GT.1) GOTO 120
  110 CALL PLOT(10.,.0,-3)
  120 CALL ENDPLT
      WRITE(6,55)
   32 CALL EXIT
C
   33 FORMAT (A10)
   34 FORMAT (2I2)
   35 FORMAT (A3,3I5,I2)
   36 FORMAT (A3,F10.0,I1)
   37 FORMAT (80I1)
   38 FORMAT (3F10.0)
   39 FORMAT (A3,I5,10X,I2)
   40 FORMAT (L10)
   41 FORMAT (1H1)
   42 FORMAT (8X,49(1H*)/8X,48HRESIDUAL STRESS EVALUATION OF EXPERIMENTA
     1L DATA*/8X,49(1H*)/)
   43 FORMAT (8X,12(1H*)/8X,1H*,A10,/8X,12(1H*)//)
   44 FORMAT (8X,15HINITIAL READING//8X,5H  POS,5X,2HA1,5X,2HA2,5X,2HA3,
     15X,3HREF,3X,7HAVERAGE//)
   45 FORMAT (10X,A3,27X,I1,6X,I4)
   46 FORMAT (10X,A3,4X,2(I4,3X),I4,5X,I1,6X,I4)
   47 FORMAT (///8X,16HAFTER SECTIONING//8X,5H  POS,5X,2HB1,5X,2HB2,5X,2
     1HB3,5X,3HREF,3X,7HAVERAGE//)
   48 FORMAT (10X,A3,4X,19HCAN NOT BE MEASURED)
   49 FORMAT (///8X,5H  POS,8X,6HSTRAIN,5X,6HSTRESS/)
   50 FORMAT (10X,A3,5X,I5,F13.2)
   51 FORMAT (10X,A3,10X,F13.2)
   52 FORMAT (15X,2F10.2)
   53 FORMAT (F10.2)
   54 FORMAT(/1H0,19H******ERROR IN DATA/1H0,36HSTRESSES PRINTED ABOVE E
     1XCEED MAXIMUM SPECIFIED IN INPUT)
   55 FORMAT(/1H0,20HJOB HAS BEEN ABORTED)
      END
```

```
      PROGRAM RSANA(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,PUNCH)
C
C***********************************************************************
C
C     THIS PROGRAM IS USED FOR ANLYSIS OF RESIDUAL STRESS MEASSUREMENTS
C     AFTER SECTIONING AND SLICING .
C
C     THE RESULT IS A TWODIMENSIONAL RESIDUAL STRESS DISTRIBUTION
C     ( VARIATION OF RESIDUAL STRESS THROUGH WIDTH AND THICKNESS OF A
C     PLATE ) WHICH IS CHECKED AND ADJUSTED FOR EQUILIBRIUM.
C     IN ADDITION THIS PROGRAM COMPUTES THE RATIO OF AREA UNDER NEGATIVE
C     RESIDUAL STRESS.
C
C     THIS PROGRAM IS VALID ONLY FOR PLATES.
C     THE RESIDUAL STRESS DISTRIBUTION OF ONLY HALF THE PLATE IS READ IN
C     THE OTHER HALF IS ASSUMED TO BE SYMMETRICAL.
C
C***********************************************************************
C
      DIMENSION DY(50), DX(10), Y(50), X(10), RSU(50), RSL(50), SRS(10,5
     10)
      DIMENSION RSSL(10,25), SSL(10,50), RS1(10,50), A(10,50), SSRS(10,5
     10)
      COMMON IO,N(50),K2,IE
      IN=5
      IO=6
C
C     READ NUMBER OF POINTS IN LONGITUDINAL DIRECTION - K1
C     READ NUMBER OF POINTS THROUGH THE THICKNESS - IE
C
      READ (IN,15) K1,IE
      K2=2*K1
      KK=K2+1
      WRITE (IO,18)
C
C     READ AND PRINT TEXT FOR IDENTIFICATION
C
      READ (IN,16) TEXT1
      READ (IN,16) TEXT2
      WRITE (IO,20)
      WRITE (IO,17) TEXT1
      WRITE (IO,17) TEXT2
C
C     READ IN WIDTH AND THICKNESS OF PLATE
C
      READ (IN,37) B,T
      AREA=B*T
C
C  READ DIMENSION OF ELEMENTS
C
      READ (IN,40) (DY(J),J=1,K2)
      READ (IN,38) (DX(I),I=1,IE)
C     COMPUTE AND PRINT X(I),Y(I) ( LAYOUT OF GAUGEHOLES )
      U=0.
      DO 1 J=1,K2
      Y(J)=U+DY(J)/2.
    1 U=U+DY(J)
```

```
      U=0.
      DO 2 I=1,IE
      X(I)=U+DX(I)/2.
    2 U=U+DX(I)
      WRITE (IO,19)
      WRITE (IO,34) (Y(J),J=1,K2)
      WRITE (IO,35) (X(I),I=1,IE)
      WRITE (IO,19)
C
C     READ IN RESIDUAL STRESS DISTRIBUTION AFTER SECTIONING
C     RSU - UPPER SIDE
C     RSL - LOWER SIDE
C
      READ (IN,39) (RSU(J),J=1,K2)
      READ (IN,39) (RSL(J),J=1,K2)
C
C     COMPUTE AND PRINT RESIDUAL STRESS DISTRIBUTION ACROSS THE
C     THICKNESS  ( LINEAR ASSUMPTION )
C
      DO 3 J=1,K2
      DO 3 I=1,IE
    3 SRS(I,J)=(RSL(J)-RSU(J))*X(I)/T+RSU(J)
      WRITE (IO,21)
      WRITE (IO,22)
      CALL OUT1 (SRS,K2)
C
C     READ IN RESIDUAL STRESS AFTER SLICING
C
      READ (IN,39) ((RSSL(I,J),I=1,IE),J=1,K1)
C
C     INITIALISATION OF RESIDUAL STRESSES AFTER SLICING IN THE RIGHT
C     PART OF THE PLATE
C
      DO 4 J=1,K1
      DO 4 I=1,IE
    4 SSL(I,J)=RSSL(I,J)
      DO 5 J=1,K1
      L=KK-J
      DO 5 I=1,IE
    5 SSL(I,L)=RSSL(I,J)
      WRITE (IO,18)
      WRITE (IO,23)
      CALL OUT (SSL,K2)
C
C     SUM OF EXPERIMENTAL RESIDUAL STRESS AFTER SECTIONING AND SLICING
C
      DO 6 J=1,K2
      DO 6 I=1,IE
    6 RS1(I,J)=SSL(I,J)+SRS(I,J)
      WRITE (IO,18)
      WRITE (IO,24)
      CALL OUT (RS1,K2)
C
C     COMPUTE AREA OF FINITE AREA ELEMENTS
C
      DO 7 J=1,K2
      DO 7 I=1,IE
    7 A(I,J)=DX(I)*DY(J)
```

```
C
C     CHECK EQUILIBRIUM OF RESIDUAL STRESSES AND PRINT OUT THE
C     OUT-OF-EQUILIBRIUM STRESS DUE TO SECTIONING AND SLICING
C
      RES1=0.
      DO 8 J=1,K2
      DO 8 I=1,IE
    8 RES1=RES1+A(I,J)*SRS(I,J)
      RES1=RES1/AREA
      WRITE (IO,18)
      WRITE (IO,25) RES1
      RES2=0.
      DO 9 J=1,K1
      DO 9 I=1,IE
    9 RES2=RES2+A(I,J)*RSSL(I,J)
      RES2=2.*RES2/AREA
      WRITE (IO,26) RES2
C
C     ADJUST RESIDUAL STRESSES DUE TO SECTIONING AND SLICING FOR
C     EQUILIBRIUM
C
      DO 10 J=1,K1
      L=KK-J
      DO 10 I=1,IE
      SSRS(I,J)=(SRS(I,J)+SRS(I,L))/2.
      SSRS(I,J)=SSRS(I,J)-RES1
   10 RSSL(I,J)=RSSL(I,J)-RES2
      WRITE (IO,18)
      WRITE (IO,27)
      WRITE (IO,28)
      CALL OUT (SSRS,K1)
      WRITE (IO,29)
      CALL OUT (RSSL,K1)
C
C     SUM OF ADJUSTED RESIDUAL STRESSES AFTER SECTIONING AND SLICING
C
      DO 11 J=1,K1
      DO 11 I=1,IE
   11 SSRS(I,J)=SSRS(I,J)+RSSL(I,J)
C
C     PRINT AND PUNCH ADJUSTED RESIDUAL STRESS DISTRIBUTION AFTER
C     SECTIONING AND SLICING
C
      WRITE (IO,18)
      WRITE (IO,30)
      WRITE (IO,31)
      CALL OUT (SSRS,K1)
      DO 12 I=1,IE
      DO 12 J=1,K1
   12 PUNCH 36, SSRS(I,J)
C
C     MAKE THE RATIO OF PART IN TENSION AND PART IN COMPRESSION
C
      SURF2=0.
      DO 14 J=1,K1
      DO 14 I=1,IE
      IF (SSRS(I,J)-0.) 13,13,14
   13 SURF2=SURF2+A(I,J)
```

```
   14 CONTTNUF
      RATIO=SURF2/AREA
      WRITE (IO,32)
      WRITE (IO,33) RATIO
      CALL EXIT
C
   15 FORMAT (I2,X,I2)
   16 FORMAT (A10)
   17 FORMAT (1H0,4X,A10)
   18 FORMAT (1H1)
   19 FORMAT (1H0)
   20 FORMAT (5X,32HRESIDUAL STRESS PATTERN ANALYSIS)
   21 FORMAT (5X,57HRESIDUAL STRESSES AFTER COMPLETE SECTIONING(EXPERIME
     1NTAL))
   22 FORMAT (5X,37HLINEAR VARIATION ACROSS THE THICKNESS/)
   23 FORMAT (5X,47HRESIDUAL STRESSES DUE TO SLICING (EXPERIMENTAL))
   24 FORMAT (5X,67HSUM OF EXPERIMENTAL RESIDUAL STRESSES DUE TO SECTION
     1ING AND SLICING/)
   25 FORMAT (5X,57HOUT OF EQUILIBRIUM FOR RESIDUAL STRESSES AFTER SECTI
     1ONING,F10.3,2X3HKSI/)
   26 FORMAT (5X,54HOUT OF EQUILIBRIUM FOR RESIDUAL STRESSES AFTER SLICI
     1NG,F10.3,2X,3HKSI)
   27 FORMAT (5X,40HEQUILIBRATE PATTERN OF RESIDUAL STRESSES)
   28 FORMAT (5X,60HFOR SYMETRICAL PATTERN OF RESIDUAL STRESSES AFTER SE
     1CTIONING)
   29 FORMAT (1H0,5X,57HFOR SYMETRICAL PATTERN OF RESIDUAL STRESSES AFTE
     1R SLICING)
   30 FORMAT (/5X,46HSUM OF SYMETRICAL PATTERN OF RESIDUAL STRESSES)
   31 FORMAT (5X,23HFOR EQUILIBRATE PATTERN)
   32 FORMAT (//5X,44HRATIO OF AREA UNDER NEGATIVE RESIDUAL STRESS)
   33 FORMAT (5X,1H=,F10.5)
   34 FORMAT (1H ,* Y(J)*,12F7.3)
   35 FORMAT (1H ,* X(J)*,12F7.3)
   36 FORMAT (6F8.2)
   37 FORMAT (2F10.4)
   38 FORMAT (6F8.3)
   39 FORMAT (F10.2)
   40 FORMAT (12F5.2)
      END
```

```
      SUBROUTINE OUT1 (RS,K)
C
C     THIS SUBROUTINE IS USED TO PRINT OUT A RESIDUAL STRESS
C     DISTRIBUTION IN A PLATE
C
      COMMON IO,N(50),K2,IE
      DIMENSION RS(10,50)
      DO 1 J=1,K2
    1 N(J)=J
      ENTRY OUT
      M=17
      L=1
    2 IF (K.LT.M) M=K
      WRITE (IO,4) (N(J),J=L,M)
      DO 3 I=1,IE
    3 WRITE (IO,5) (RS(I,J),J=L,M)
      IF (K.LE.M) RETURN
      L=L+17
      M=M+17
      GO TO 2
C
C
    4 FORMAT (1H0,17I7/)
    5 FORMAT (1H ,17F7.2)
      END
```

```
      PROGRAM PLOTIS(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,PLOT,
     1TAPE99=PLOT)
C
C*********************************************************************
C
C     PURPOSE OF THIS PROGRAM IS TO FIND POINTS OF EQUAL STRESS IN A TWO
C     DIMENSIONAL STRESS DISTRIBUTION.
C     THE COORDINATES OF THESE POINTS WILL BE COMPUTED AND PLOTTED TO
C     SCALE USING A DIGITAL PLOTTER.
C
C     DEVELOPED AT LEHIGH UNIVERSITY, FRITZ LABORATORY, JANUARY 1970
C     TESTED AT A CDC 6400 COMPUTER.
C     PLOTS WERE MADE USING A CALCOMP PLOTTER.
C
C     NOTE.. THIS PROGRAM CAN ONLY BE USED AT ABOVE MENTIONED SYSTEMS
C     SINCE EACH SYSTEM HAS ITS OWN PLOTTER ROUTINES.
C
C*********************************************************************
C
      COMMON Y,STRESS(100),NN,XA(10),X(100),MI,JFORM(100)
      DIMENSION W(10), STR(100,10), A(10), X1(100), Y1(100)
      INTEGER PMAX,TEXT1,TEXT(50)
      REAL INTE
      DELT=0.04
      READ (5,13) TEXT1
      READ (5,14) IEND,NN,B,SCALEX,SCALEY
      JEND=IEND-1
      READ (5,15) (W(I),I=1,IEND)
      READ (5,16) NMAX,PMAX,INTE
      NMAX=NMAX+1
      ME=NMAX+PMAX
      READ (5,17) (TEXT(I),I=1,ME)
      READ (5,18) (JFORM(I),I=1,NN)
      READ (5,19) ((STR(I,K),I=1,NN),K=1,IEND)
      WRITE (6,20)
      WRITE (6,21) ((STR(I,K),K=1,IEND),I=1,NN)
C     COMPUTE X-VALUES OF GAUGE POINTS
      AX=0
      DO 1 K=1,NN
      AX=AX+JFORM(K)*0.125
    1 X(K)=AX
C     LAYOUT OF GAUGE POINTS THROUGH THE THICKNESS
      AB=0
      DO 2 K=1,IEND
      AB=AB+W(K)
    2 A(K)=AB
      N=0
C
C     BEGIN WITH LOOP ( ALL STRESS LEVELS )
C
    3 N=N+1
      MM=N-NMAX
C     Y IS THE VALUE OF STRESSLEVEL
      Y=MM*INTE
      M=0
C     DIVIDE PLATE THICKNESS INTO STRIPS OF .04 INCHES AND INTERPOLATE
C     LINEARLY TO FIND STRESSDISTRIBUTION ALONG IT
```

```
      DO 7 MA=1,JEND
      MEND=W(MA+1)/DELT+1.
      DO 6 MF=1,MEND
      DO 4 I=1,NN
      STRESS(I)=STR(I,MA)-(MF-1)/W(MA+1)*DELT*(STR(I,MA)-STR(I,MA+1))
    4 CONTINUE
C     CALL SUBROUTINE TO SEARCH FOR POINTS OF EQUAL STRESS ALONG STRIP
      CALL CUT
      IF (MA.EQ.1.AND.MF.EQ.1) MI1=MI
C     COORDINATES OF POINTS ARE STORED INTO ARRAY X1(M) AND Y1(M)
      IF (MI.EQ.0) GO TO 6
      DO 5 K=1,MI
      M=M+1
      X1(M)=XA(K)
    5 Y1(M)=A(MA)+(MF-1)*DELT
    6 CONTINUE
    7 CONTINUE
      ITEXT=TEXT(N)
      IF (N.GT.1) GO TO 8
C     SCALE VALUES OF B AND AX
      B=B/SCALEY
      AX=AX/SCALEX
C
C     THE FOLLOWING STATEMENTS CALL SUBROUTINES TO DRIVE THE PLOTTER
C     THESE SUBROUTINES ARE LIBRARY ROUTINES OF ABOVE MENTIONED SYSTEMS
C
C     IDENTIFY PLOT
      CALL NAMPLT
C     DRAW BOUNDARIES OF PLATE
C     ORIGIN IS ESTABLISHED ON THE LOWER LEFT CORNER
      CALL PLOT (0.0,2.0,-3)
      CALL PLOT (0.0,B,2)
      CALL PLOT (AX,B,2)
      CALL PLOT (0.0,0.0,3)
      CALL PLOT (AX,0.0,2)
C     STORE SCALE-FACTORS INTO ARRAY ( SEE PLOTTER MANUAL )
    8 IF (M.EQ.0) GO TO 12
      X1(M+1)=0.0
      X1(M+2)=SCALEX
      Y1(M+1)=0.0
      Y1(M+2)=SCALEY
C     PLOT POINTS USING SPECIAL PLOTTER SYMBOL 2
      CALL LINE (X1,Y1,M,1,-1,2)
C
C     LABEL EACH LINE WITH VALUE IN KSI
C
C     LABEL BEGINNING OF LINES
      IF (MI1.EQ.0) GO TO 10
      NC=1
    9 Y11=Y1(NC)-0.3
      X11=X1(NC)
      CALL SYMBOL (X11,Y11,0.06,ITEXT,90.0,3)
      NC=NC+1
      IF (NC.LT.MI1) GO TO 9
C     LABEL END OF LINES
   10 IF (MI.EQ.0) GO TO 12
      NC=0
   11 Y11=Y1(M-NC)+0.2
```

```
      X11=X1(M-NC)
      CALL SYMBOL (X11,Y11,0.06,ITEXT,90.0,3)
      NC=NC+1
      IF (NC.LE.MI-1) GO TO 11
   12 IF (N.LT.MS) GO TO 3
C
C     END OF LOOP ( ALL STRESS LEVELS )
C
      CALL SYMBOL (0.0,-1.5,0.4,TEXT1,0.0,10)
C     MOVE PEN OUT OF PLOT AREA
      AX=AX+1.
      CALL PLOT (AX,0.0,-3)
      CALL ENDPLT
      CALL EXIT
C
   13 FORMAT (A10)
   14 FORMAT (2I2,3F6.2)
   15 FORMAT (6F5.2)
   16 FORMAT (2I2,F5.1)
   17 FORMAT (16A5)
   18 FORMAT (80I1)
   19 FORMAT (F8.2)
   20 FORMAT (1H1)
   21 FORMAT (1H0,20X,6F10.2)
      END
```

```
      SUBROUTINE CUT
C
C************************************************************************
C
C     CUT SEARCHES FOR POINTS OF EQUAL STRESS ALONG A SMALL STRIP,
C     INTERPOLATING LINEARLY BETWEEN TWO POINTS OF GIVEN STRESS.
C     THIS PROBLEM IS PRACTICALLY THE SAME AS TO FIND THE INTERSECTION
C     POINTS OF A LINE Y=CONST. WITH A POLYNOMIAL.
C     THE COORDINATES OF THE POINTS ARE STORED IN AN ARRAY CALLED XA
C
C************************************************************************
C
      COMMON Y,STRESS(100),NN,XA(10),X(100),MI,JFORM(100)
      DIMENSION IA(100)
      K=0
    1 K=K+1
      M=0
      IF (Y) 2,3,3
    2 M=-1
      GO TO 4
    3 M=1
    4 IF (M*STRESS(K)-M*Y) 6,5,7
    5 IA(K)=K
      GO TO 16
    6 IF (K.LT.NN) GO TO 15
      GO TO 17
    7 IF (K.EQ.1) GO TO 12
      IF (M*STRESS(K)-M*STRESS(K-1)) 10,8,8
    8 IF (M*STRESS(K-1)-M*Y) 9,10,10
    9 IA(K)=K-1
      IA(K-1)=K-1
      GO TO 11
   10 IA(K)=0
   11 IF (K.EQ.NN) GO TO 17
   12 IF (M*STRESS(K)-M*STRESS(K+1)) 15,13,13
   13 IF (M*STRESS(K+1)-M*Y) 14,15,15
   14 IA(K)=K
      GO TO 1
   15 IA(K)=0
   16 GO TO 1
   17 MI=0
      NNF=NN-1
      DO 24 MK=1,NNF
      II=IA(MK)
      IF (II.EQ.0) GO TO 24
      MI=MI+1
      IF (STRESS(II)) 18,19,19
   18 M=-1
      GO TO 20
   19 M=1
   20 IF (M*STRESS(II+1)-M*STRESS(II)) 22,23,21
   21 XA(MI)=X(II)+JFORM(II+1)*0.125*(Y-STRESS(II))/(STRESS(II+1)-
     1STRESS(II))
      GO TO 24
   22 XA(MI)=X(II)+JFORM(II+1)*0.125*(STRESS(II)-Y)/(STRESS(II)-
     1STRESS(II+1))
      GO TO 24
```

```
23 XA(MI)=X(II)
24 CONTINUE
   RETURN
   END
```

6. REFERENCES

1. Tebedge, N.
   MEASUREMENT OF RESIDUAL STRESS - A STUDY OF METHODS, M. S. Thesis, Lehigh University, 1969.

2. Brozzetti, J., and Tall, L.
   AUTOMATIC RECORDING OF THE WHITTEMORE STRAIN GAGE READINGS BY MEANS OF LINEAR TRANSDUCERS, Fritz Engineering Laboratory Report No. 337.25, Lehigh University, in preparation.

3. Alpsten, G. A., and Tall, L.
   RESIDUAL STRESSES IN HEAVY WELDED SHAPES, Welding Journal, Vol. 49, March 1970.

4. Brozzetti, J., Alpsten G. A., and Tall, L.
   RESIDUAL STRESSES IN A HEAVY ROLLED SHAPE 14WF730, Fritz Engineering Laboratory Report No. 337.10, February, 1970.