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A COMPUTER PROGRAM FOR PLOTTING STRESS-STRAIN DATA FROM COMPRESSION, TENSION, AND TORSION TESTS OF MATERIALS

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16. Abstract

A computer program for plotting stress-strain curves obtained from compression and tension tests on rectangular (flat) specimens and circular-cross-section specimens (rods and tubes) and both stress-strain and torque-twist curves obtained from torsion tests on tubes is presented in detail. The program is written in FORTRAN IV lauguage for the Control Data 6000 series digital computer with the SCOPE 3.0 operating system and requires approximately 110000 octal locations of core storage. The program has the capability of plotting individual strain-gage outputs and/or the average output of several strain gages and the capability of computing the slope of a straight line which provides a least-squares fit to a specified section of the plotted curve. In addition, the program can compute the slope of the stress-strain curve at any point along the curve. The computer program input and output for three sample problems are presented.

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SUMMARY

A computer program for plotting stress-strain curves obtained from compression and tension tests on rectangular (flat) specimens and circular-cross-section specimens (rods and tubes) and both stress-strain and torque-twist curves obtained from torsion tests on tubes is presented in detail. The program has the capability of plotting individual strain-gage outputs and/or the average output of several strain gages and the capability of computing the slope of a straight line which provides a least-squares fit to a specified section of the plotted curve. In addition, the program can compute the slope of the stress-strain curve at any point along the curve. The program, its subroutines, and their variables are listed and defined. The computer input and output for three sample problems are presented in printed and plotted form to aid the user in setting up and utilizing the program.

The program is written in FORTRAN IV language for the Control Data 6000 series digital computer with the SCOPE 3.0 operating system and requires approximately 110000 octal locations of core storage. A typical problem with seven curves to be plotted, each curve containing approximately 200 data points, requires approximately 50 seconds of central processing time. Output from the program is stored on tape and then used by CalComp or Gerber plotters to construct curves. The input data may be stored on magnetic tape, a data cell, or punched cards.

INTRODUCTION

Reduction of test data to a presentable form, usually hand-drawn plots, can be a time-consuming task. This is especially true if a large number of data points are to be plotted or if the data must be combined in some manner or multiplied by scaling factors prior to plotting. A specific example is construction of the shear-stress—strain curve from strain-gage data obtained from a torsion test on a tubular specimen. Since there has been a continuing requirement at the Langley Research Center to make such data reductions, a computer program was developed to automate the task of constructing stress-strain plots for compression and tension tests on rectangular (flat) specimens and circular-cross-section specimens (rods and tubes) and stress-strain and torque-twist plots for torsion tests on tubular specimens. The program plots individual strain-gage outputs and/or the average output of several strain gages. The program also has the capability of computing the slope of a straight line which provides a least-squares fit to a specified section of the plotted curve and can compute the slope of the stress-strain curve at any point along the curve. The program is written in FORTRAN IV language for the Control Data 6000 series digital computer with the SCOPE 3.0 operating system. The input data may be stored on magnetic tape, a data cell, or punched cards. The equations have been programed so that either the International System of Units or the U.S. Customary Units may be used. Conversion factors relating the two systems are given in reference 1, and those pertinent to the present paper are presented in appendix A. This paper describes the program and presents sample problems to aid the user in setting up and utilizing the program.

SYMBOLS

ℓ	length, meters (inches)
P	load, newtons (pounds)
R	radius, meters (inches)
T	torque, newton-meters (inch-pounds)
t	thickness, meters (inches)
w	width, meters (inches)
δ	displacement, meters (inches)
ϵ	strain
θ	twist, radians (degrees)
σ	stress, pascals (pounds force per square inch)

τ shear stress, pascals (pounds force per square inch)

Abbreviations:

KSI kilopounds force per square inch

LVDT linear variable differential transformer

MPA megapascals

MICRO IN/IN micro inches per inch (see description of XMULT in appendix C)

MICRO M/M micro meters per meter (see description of XMULT in appendix C)

O.D. outer diameter, meters (inches)

PA pascals (newtons per square meter)

PSI pounds force per square inch

SG strain gage

PROBLEM DESCRIPTION

The task described herein is the development of a computer program to construct plots of stress-strain data from compression and tension tests and to construct plots of stress-strain and torque-twist data from torsion tests. At the beginning of the effort, the following criteria on program capability were selected:

(1) The program must be capable of reading load, strain, and displacement input data, which are arranged sequentially with respect to time and expressed in appropriate engineering units, from magnetic tape, a data cell, or punched cards.

(2) The program must be capable of plotting data in either the International System of Units or U.S. Customary Units. Data recorded in either system of units can only be plotted in the respective units.

(3) The program must be capable of constructing compression or tension stress-strain plots for either rectangular (flat) specimens or circular-cross-section specimens (rods and tubes) and constructing shear-stress—strain and torque-twist plots for thin-walled circular tubes.

(4) For compression or tension tests, the program must be capable of constructing plots of stress as a function of the output of individual strain gages and/or the average output of up to four specified strain gages (or other strain transducers).

(5) For torsion tests, the program must be capable of constructing plots of stress as a function of the output of individual strain gages, as a function of the average absolute output of the $\pm 45^{\circ}$ strain gages in a strain rosette, or as a function of the average absolute output of all $\pm 45^{\circ}$ strain gages in up to six strain rosettes. Also, the program must be capable of constructing torque-twist plots by utilizing the output of LVDT's or other transducers which measure displacements associated with the rotations at two locations along the length of a tubular specimen.

(6) The program must be capable of computing the slope of a straight line which provides a least-squares fit to a specified section of each averaged curve (stress-strain or torque-twist) and computing the tangent modulus (slope) at all points along the average stress-strain curve.

(7) The program must be capable of omitting from the calculations and plots any gages which the user specifies, and it must be capable of making more than one type of plot from one input of the same data set.

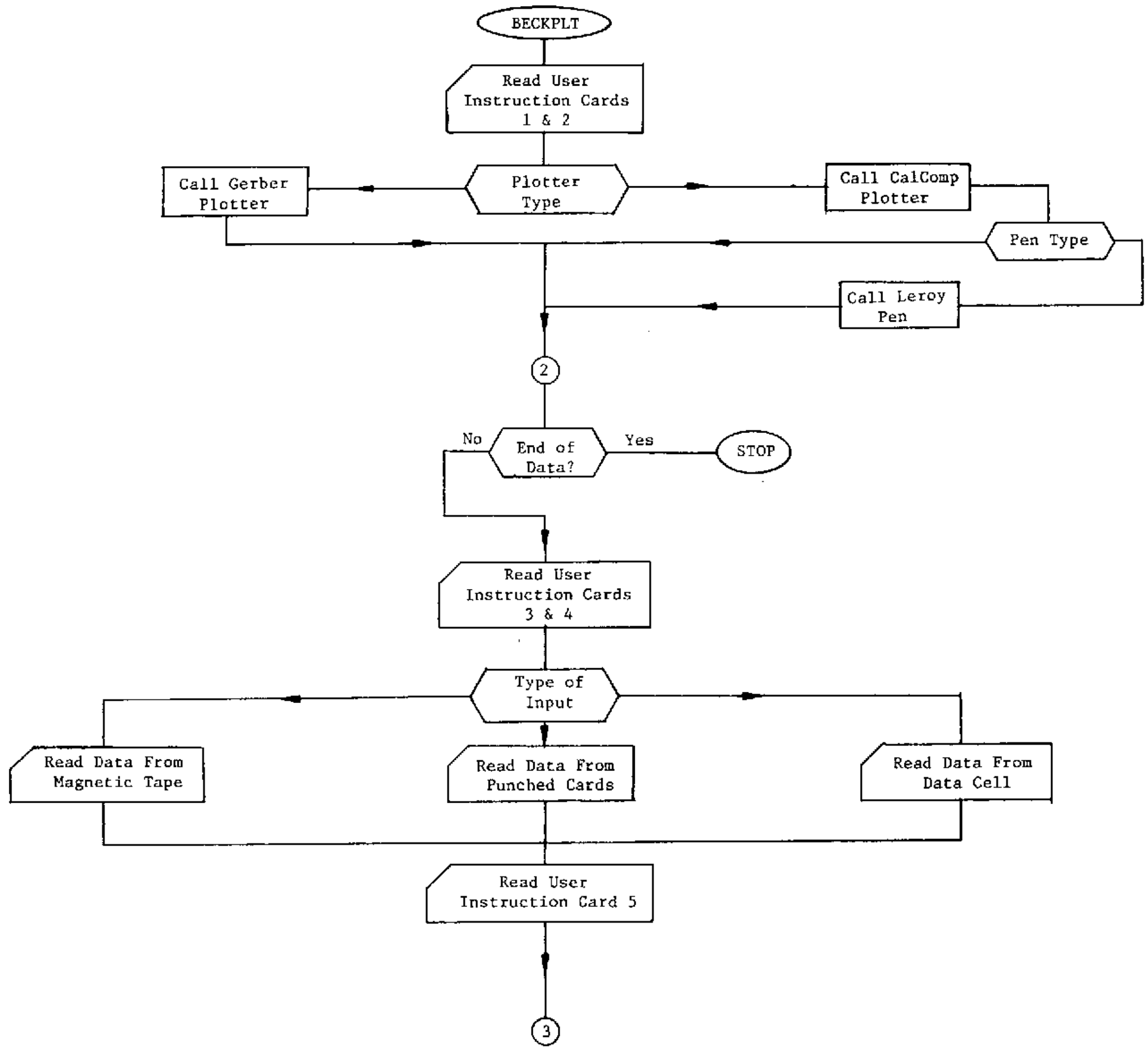
These criteria have been met and table I summarizes the plotting cases that have been programed. Ten cases have been programed and the table indicates specimen and test type, the quantities plotted on each axis, and whether moduli or slope calculations can be made for the case. Figure 1 shows sketches of specimen geometry for compression, tension, and torsion test specimens.

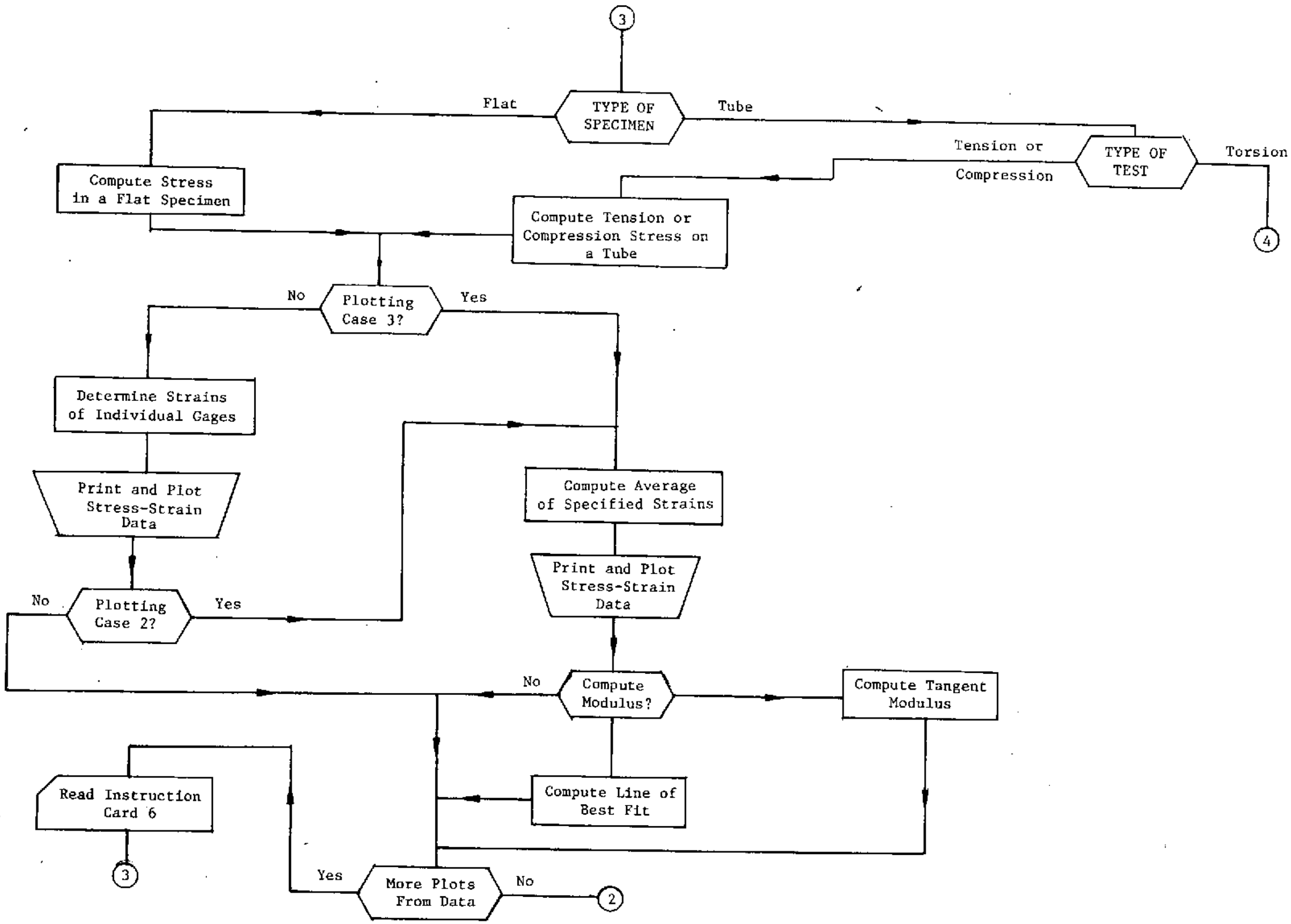
PROGRAM DESCRIPTION

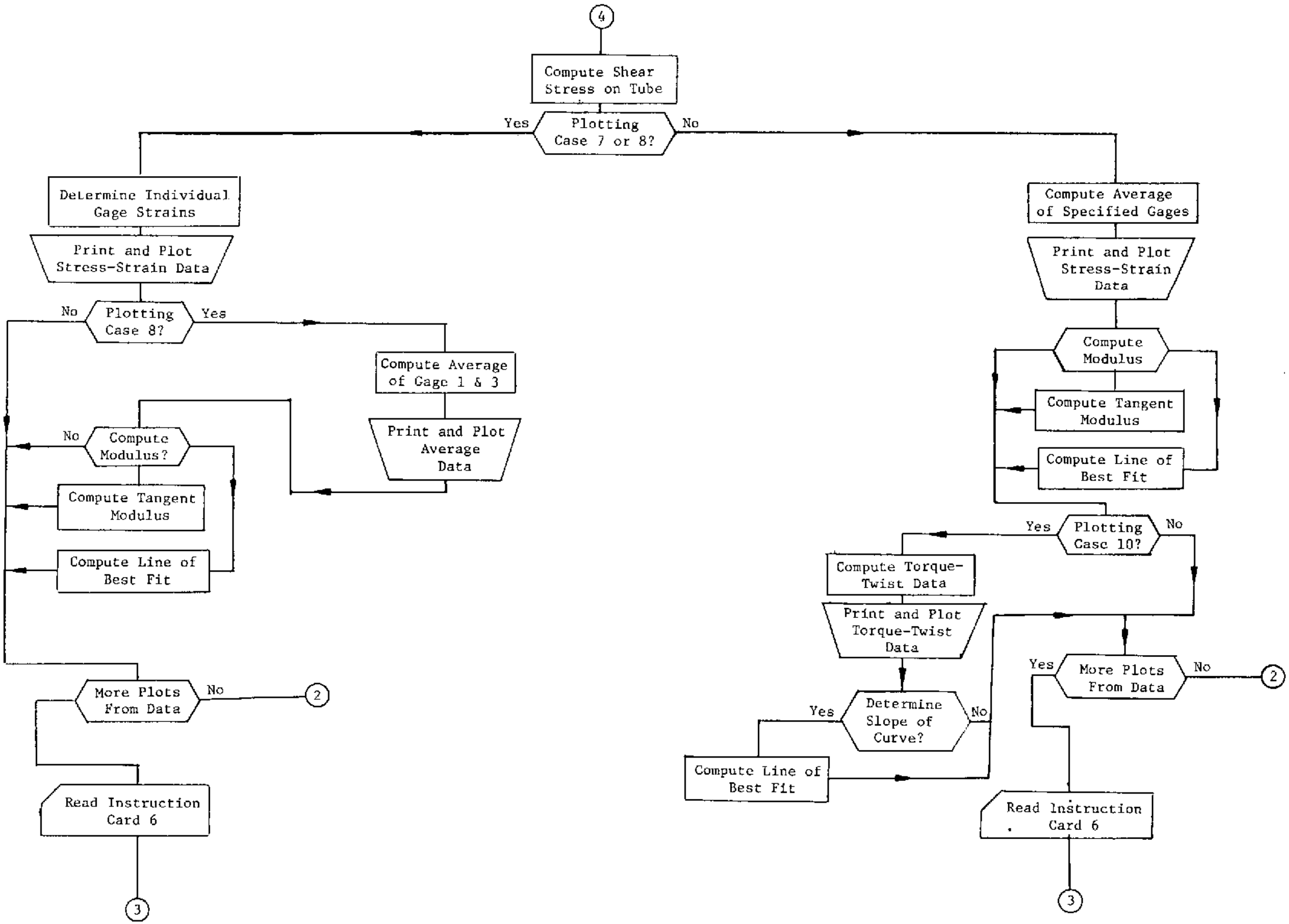
The computer program is written in FORTRAN IV language for the Control Data 6000 series digital computer with the SCOPE 3.0 operating system. With the present dimensions, the program requires approximately 110000 octal locations of core storage. A typical case with seven curves to be plotted, each curve containing approximately 200 data points, requires approximately 50 seconds of central processing time. During job execution, input data read from a data cell or magnetic tape are temporarily stored on a disk file (designated as tape 30 in the program listing). As currently written, the program is limited to a maximum of 20 data channels (18 if stored on a data cell) and 414 data frames per run, with 398 frames per run plotted. Dimension statements can be changed to allow for a larger number of channels and frames. A data channel is a listing that contains all data values derived from one output device (force transducer, strain gage, LVDT, etc.). A data frame is defined as all data values recorded at one value of time.

Thus, one data frame contains a data value for each output device. To use the program as it is currently written, the data must be identified by frame number and stored sequentially by frame number.

The main program, identified herein as BECKPLT, and its subprograms are identified and discussed. Except where noted, all subprograms were written for the task described herein. Appendixes B, C, and D give a source program listing, definitions of the FORTRAN variables, and the Langley Library subroutine MATINV and listing, respectively. A flow chart is shown on pages 6 to 8. The flow chart indicates that, first, instructions that indicate the title of the test, the type of plotter to be used (Gerber or CalComp), how the data are stored (magnetic tape, punched cards, or data cell), the specimen geometry (flat or tube), and test type (tension, compression, or torsion) are read from cards 1 and 2. For simplicity, the type of specimen is given in the program as flat or tube (includes both rods and tubes). The Gerber plot is a smooth continuous curve, whereas the CalComp plot is incremented in small steps. The CalComp plotter requires less time to develop a curve than a Gerber plotter, but the curve is of lower quality. Then the instructions that indicate the particular experiment being analyzed (referred to hereinafter as run), the number of data channels and frames to be plotted, and the curves to be plotted (refer to table I) are read from cards 3 and 4. The data are read from the designated storage device (tape, cards, or data cell) and then the specimen geometry is read from instruction card 5. Next, the load data are converted to stress values by multiplying by the appropriate constants which are a function of test type and specimen geometry. These stress values are stored in the Y-array. One subroutine is next selected to compute and store the strains in the X-array. Selection is based on the type of test and specimen. Possible choices of subroutines are: COMPIND (compression or tension test, individual gage plots), COMPAVG (compression or tension test, average plot), TORIND (torsion test, individual gage plots), and TORAVG (torsion test, average plot). At this point, the coordinates for the stress-strain curve are computed and stored on tape for subsequent use by the selected plotter. Several subroutines can now be requested in the program. Subroutine SLP can be called to calculate the slope of a straight line which provides a least-squares fit to a specified portion of the stress-strain curve. If requested by user instructions to compute the tangent modulus (slope) of the stress-strain curve as a function of stress, subroutine PROPLIM is called. Subroutine PROPLIM computes the coefficients of a second-degree polynomial that provides a least-squares fit to the stress-strain curve. Next, the slope of the stress-strain curve is approximated by the first derivative of the polynomial. The user is cautioned that meaningful tangent-moduli results will be produced only when the second-degree polynomial is a good approximation to the stress-strain curve. Preliminary attempts to compute the tangent moduli by piecewise fitting the data (5 to 15 points) with a second-degree


BECKPLT
Read User Instruction Cards 1 & 2
Call Gerber Plotter
Plotter Type
Call CalComp Plotter
Pen Type
Call Leroy Pen
2
No
End of Data?
Yes
STOP
Read User Instruction Cards 3 & 4
Type of Input
Read Data From Magnetic Tape
Read Data From Punched Cards
Read Data From Data Cell
Read User Instruction Card 5
3


3
TYPE OF SPECIMEN
Flat
Tube
Compute Stress in a Flat Specimen
TYPE OF TEST
Tension or Compression
Torsion
4
Compute Tension or Compression Stress on a Tube
Plotting Case 3?
No
Yes
Determine Strains of Individual Gages
Print and Plot Stress-Strain Data
Compute Average of Specified Strains
Print and Plot Stress-Strain Data
Plotting Case 2?
No
Yes
Compute Modulus?
No
Compute Tangent Modulus
Read Instruction Card 6
3
Compute Line of Best Fit
More Plots From Data
Yes
No
2


4
Compute Shear Stress on Tube
Plotting Case 7 or 8?
Yes
No
Determine Individual Gage Strains
Print and Plot Stress-Strain Data
Plotting Case 8?
No
Yes
Compute Average of Gage 1 & 3
Print and Plot Average Data
Compute Modulus?
No
Compute Tangent Modulus
Compute Line of Best Fit
More Plots From Data
No
2
Read Instruction Card 6
3
Compute Average of Specified Gages
Print and Plot Stress-Strain Data
Compute Modulus
Compute Tangent Modulus
Compute Line of Best Fit
Plotting Case 10?
Yes
No
Compute Torque-Twist Data
Print and Plot Torque-Twist Data
Determine Slope of Curve?
Yes
No
Compute Line of Best Fit
More Plots From Data
Yes
No
2
Read Instruction Card 6
3

polynomial generated plots (tangent moduli as a function of stress) of no practical value. Variation of the computed values of tangent moduli ranged up to 15 percent of the mean value, and the curves subsequently plotted had a sawtooth appearance.

More than one plot (case) can be developed from a data set (run) by utilizing instruction card 6. This card indicates the frames to be used and the type of additional plots to be generated. An example of how this feature of the program might be used is the construction of the average shear-stress—strain and torque-twist curves (case 10 in table I) after the program has constructed the individual stress-strain curves (case 7).

With one computer job submittal the stress-strain and/or torque-twist curves for each specimen of a group of specimens can be developed by repeating instruction cards 3 to 6 for each specimen.

The program just described was written primarily to develop data plots for the cases listed in table I. However, this program can be modified so that it can be used to construct data plots for other types of engineering tests. These modifications would include the subprograms that label axes and transform data. The location of the changes can be determined by following the flow chart just discussed.

PROGRAM USAGE

A typical program deck setup, with punched card input, is shown in figure 2. System control cards are utilized to position magnetic-tape or data-cell inputs for use by the source program. User instruction cards, described later in this section, are utilized for control of plots and computation of the slope of the curves. A detailed description of the output is also given in this section. In order to keep user instructions at a minimum, a pattern for identifying the strain gages and rosettes was selected. (Refer to appendix E.)

Input

Data format.- Input data for the program may be recorded on magnetic tape, a data cell, or punched cards by frame. Each frame includes the load and all strain-gage data recorded at a particular time. Frames are identified by integers which increase monotonically with increasing time from the start of the test. Load or torque values must be stored in the first data channel.

If a magnetic tape is used, test data for each frame must be stored on the tape in the following format which is currently used at Langley Research Center:

Word	Description	Type
1	Mode	Integer
2	2	Integer
3	3	Integer
4	Frame	Integer
5	5.0	Float
6	6.0	Float
7	7	Integer
8	8	Integer
9	9	Integer
10	10	Integer
11	11.0	Float
12	12.0	Float
13	13.0	Float
14	14.0	Float
15	15.0	Float
16	Load or torque	Float
17	Data channels	Float
↓	↓	↓
114		

Record length is 114 words. At the end of a run, a record is written with Mode = 8888. At the end of all data on a tape, a record is written with Mode = 9999. There is an EOF after this record. Mode = 2 for all other data frames.

When a data cell is used, input for each data frame must be in the following format:

Line	FORTRAN variable name	Description	Format
1	ITST, MRN, MD, IFRA	Test, run, mode, frame	3I12, 24X, I12
2	DTA(IFRA,1),DTA(IFRA,2), DTA(IFRA,3),DTA(IFRA,4), DTA(IFRA,5),DTA(IFRA,6)	Load or torque, first five data channels	6E12.4
3	DTA(IFRA,7),DTA(IFRA,8), DTA(IFRA,9),DTA(IFRA,10), DTA(IFRA,11),DTA(IFRA,12)	Next six data channels	6E12.4
4	DTA(IFRA,13),DTA(IFRA,14), DTA(IFRA,15),DTA(IFRA,16), DTA(IFRA,17),DTA(IFRA,18)	Next six data channels	6E12.4

(For a test with more than 18 channels stored on a data cell, the READ statements in subroutine RDCELL must be changed.)

Input data on punched cards must be in the following format for each data frame:

Card	FORTRAN variable name	Description	Format
1	IFRA, DTA(IFRA,1), DTA(IFRA,2),DTA(IFRA,3), DTA(IFRA,4),DTA(IFRA,5), DTA(IFRA,6),MD	Frame, load or torque, first five data channels, last card	I4, 6E12.4, I4
2	DTA(IFRA,7),DTA(IFRA,8), DTA(IFRA,9),DTA(IFRA,10), DTA(IFRA,11),DTA(IFRA,12), MD	Next six data channels, last card	6E12.4, I4

Repeat card 2 for all channels. For all data cards except the last card, MD = 2. On last card, MD = 8888 (end of data).

User instruction cards.- The following cards are supplied by the program user to control the graphic and printed output. Cards 1 to 3 have the same format for tension, compression, or torsion tests. However, the format for cards 4 to 6 is a function of test type as indicated herein.

User instruction cards 1 to 3 follow:

Card 1   Test title   (4A10)

Column

1 to 40   Title of test. Any characters in columns 1 to 40. This title is printed before all other output and is plotted in front of the graphs. (See section entitled "Sample Problems.")

Card 2   Plotting control   (9I4)

Column	FORTRAN variable	Value	
4	IPLT	1	Use Gerber plotter
		0	Use CalComp plotter

Column	FORTRAN variable	Value	
8	IPEN	1	Use Leroy pen (for CalComp plotter only)
		0	Use ballpoint pen (for CalComp plotter only)
		0	For Gerber
12	INPT	0	Input data on magnetic tape
		1	Input data on punched cards
		2	Input data on data cell
16	ISPEC	0	Flat specimen
		1	Tube specimen
20	ITEST	0	Tension or compression test
		1	Torsion test
21 to 24	IXSIZE		Length of X-axis for each plot (in inches). For tension or compression tests, IXSIZE = (IOMOVE) × (number of curves + 1). For torsion tests, IXSIZE = (IOMOVE) × (number of curves + 1) + (number of rosettes). The last term accounts for the extra space between plots for different rosettes
25 to 28	IYSIZE		Length of Y-axis in inches. If this field is blank or = 0, length of Y-axis defaults to 9 inches
29 to 32	IOMOVE		Distance between plots. If this field is blank or = 0, defaults to 2 inches
36	IUNITS	0	Input and output data expressed in U.S. Customary Units
		1	Input and output data expressed in SI Units

Card 3 Run title (4A10)

Column

1 to 40 Title of run. Any characters in colums 1 to 40. This title is printed before other output for this run and is plotted in the lower left-hand corner of the graph for this run. (See section entitled "Sample Problems.")

User instruction cards 4 to 6 for tension or compression tests follow:

Card 4 Run information (4I3,4I2,3I3,18I2,14X,I1)

Column	FORTRAN variable	Value	
2 to 3	JAC		Number of channels (=1 + number of strain channels)
4 to 6	NRL		First frame to be plotted
7 to 9	NRU		Last frame to be plotted
12	INDAVG		Type of plot (see table I)
		0	Case 1 or 4
		1	Case 2 or 5
		2	Case 3 or 6
13 to 20	IGAGES(1) IGAGES(2) IGAGES(3) IGAGES(4)		Channels to be averaged. See sample problem 2 for example of input data
23	MOD	0	Do not calculate slope
		1	Calculate slope
		2	Calculate tangent moduli
24 to 26	NRLSLP		First frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to first frame plotted

Column	FORTRAN variable	Value	
27 to 29	NRUSLP		Last frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to last frame plotted
30 to 65	NOPLT(1)		Strain gages to be omitted from plot
	NOPLT(2)		
	. . .		
	NOPLT(18)		
66 to 79			
80	MORE	0	No additional plots (cases) requested for this data set (card 6 must be omitted)
		1	Additional plots to be made for this run

If data are on punched cards, place data for this run after card 4.

<u>Card 5</u> Sectional data (4F12.0)

Column	FORTRAN variable	Value	
1 to 12	THICK		Thickness of flat specimen, wall thickness of tube or radius of rod (circular cross section)
13 to 24	WIDTH		Width of flat specimen; or outer diameter of tube specimen or rod
25 to 36	SCFAC	+1	Loads are positive
		-1	Loads are negative
			Loads are multiplied by this variable before calculating stresses

Column	FORTRAN variable	Value	
37 to 48	RMAXSN		Maximum strain value to be plotted

If additional plots were requested for this run, place the following card or cards after card 5.

Card 6 New set of run information (3I3,4I2,3I3,18I2,17X,I1)

Column	FORTRAN variable	Value	
1 to 3	NRL		First frame to be plotted
4 to 6	NRU		Last frame to be plotted
9	INDAVG		Case type (see table I)
		0	Case 1 or 4
		1	Case 2 or 5
		2	Case 3 or 6
10 to 17	IGAGES(1)		Channels to be averaged
	IGAGES(2)		
	IGAGES(3)		
	IGAGES(4)		
20	MOD	0	Do not calculate slope
		1	Calculate slope
		2	Calculate tangent moduli
21 to 23	NRLSLP		First frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to first frame plotted
24 to 26	NRUSLP		Last frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to last frame plotted

Column	FORTRAN variable	Value	
27 to 62	NOPLT(1)		Strain gages to be omitted from plot
	NOPLT(2)		
	.		
	.		
	.		
	NOPLT(18)		
63 to 79			
80	MORE	0	No additional plots (cases) requested for this data set (card 6 must be omitted)
		1	Additional plots requested for this run

User instruction cards 4 to 6 for a torsion test follow:

Card 4   Run information   (8I3,18I2,19X,I1)

Column	FORTRAN variable	Value	
2 to 3	JAC		Number of channels (= 1 + number of strain channels + number of deflection (δ) channels (see fig. 1))
4 to 6	NRL		First frame to be plotted
7 to 9	NRU		Last frame to be plotted
12	NROS		Number of rosettes
15	INDAVG		Case type (see table I)
		0	Case 7
		1	Case 9
		2	Case 10
		3	Case 8
18	MOD	0	Do not calculate slope
		1	Calculate slope
		2	Calculate tangent moduli

Column	FORTRAN variable	Value	
19 to 21	NRLSLP		First frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to first frame plotted
22 to 24	NRUSLP		Last frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to last frame plotted
25 to 60	NOPLT(1) NOPLT(2) . . . NOPLT(18)		Strain gages to be omitted from plotting and averaging
61 to 79			
80	MORE	0	No additional plots (cases) requested for this data set (omit card 6)
		1	Additional plots requested for this run

If input data are on punched cards, place data for this run after card 4.

<u>Card 5</u> Sectional data (6F12.4)

Column	FORTRAN variable	Value	
1 to 12	THICK		Thickness of tube
13 to 24	WIDTH		Outer diameter of tube
25 to 36	RLENGTH		Distance between arm stations (see fig. 1)
37 to 48	ALENGTH		Length of R (see fig. 1)

Column	FORTRAN variable	Value	
49 to 60	SCFAC	+1	Loads are positive
		-1	Loads are negative
			Loads are multiplied by this variable before calculating stresses
61 to 72	RMAXSN		Maximum strain value to be plotted

If additional plots were indicated for this run, place the following card or cards after card 5.

Card 6 New set of run information (7I3,18I2,22X,I1)

Column	FORTRAN variable	Value	
1 to 3	NRL		First frame to be plotted
4 to 6	NRU		Last frame to be plotted
9	NROS		Number of rosettes
12	INDAVG		Case type (see table I)
		0	Case 7
		1	Case 9
		2	Case 10
		3	Case 8
15	MOD	0	Do not calculate slope
		1	Calculate slope
		2	Calculate tangent moduli
16 to 18	NRLSLP		First frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to first frame plotted

Column	FORTRAN variable	Value	
19 to 21	NRUSLP		Last frame to be used in calculating slope. May be omitted if MOD ≠ 1. If MOD = 1 and this field is blank or 0, defaults to last frame plotted
22 to 57	NOPLT(1)		Strain gages to be omitted from plot
	NOPLT(2)		
	. . .		
	NOPLT(18)		
58 to 79			
80	MORE	0	No additional plots (cases) requested for this data set
		1	Additional plots requested for this run

Repeat card 6 for each plot after the first plot to be made for this run (until MORE = 0). Repeat cards 3 to 6 for each data set in a computer run.

Output

Printed.- Examples of printed and plotted output are presented in the discussion of sample problems. The test title supplied by the user is printed first, followed by the test and specimen type and the plotter. Next, the first run title supplied by the user is printed, followed by a list of data from the first three channels of every fifth or tenth frame (every tenth frame if the total number of frames is greater than 300). This data list is followed by the specimen thickness and width (for flat specimen) or outer diameter (for tube specimen). Next the coordinates of each stress-strain or torque-twist curve to be plotted are printed. These points are printed in pairs with the Y-value (stress or torque) first and the X-value (strain or twist) second. If tangent moduli are computed, they are listed next along with their associated stress-strain points. At the end of the printed output, the number of graphs plotted and the size of the axes are listed.

Plotted.- The test title is printed vertically on the plotting paper before the first plot is constructed. (See fig. 3.) The run title is printed in the lower left-hand corner of the graph, below the X-axis. In graphs with more than one plot, the X-axis is labeled with a drafting dimension: →|scale factor|←. In graphs with only one plot, both the X- and Y-axes are numbered at each tick mark. A grid of +'s is also drawn on the graph.

Above the graph, the gage number and the frames used for each plot are written. For plots where the gages to be averaged are specified by the user, the program prints AVG OF and lists these gages. For plots where the gages to be averaged are fixed (cases 9 and 10 in table I), it prints AVG PLOT.

If the tangent moduli have been calculated, they will be plotted as a function of stress on a 9- by 9-in. graph. On the X-axis will be STRESS in PSI or PA and on the Y-axis will be TANGENT MODULI in PSI or PA.

Diagnostics

This program contains a series of error diagnostics as follows:

Fatal errors –

(1) INVALID TEST NUMBER, ITEST = (test number specified). Neither tension, compression, or torsion test is indicated. (ITEST is not 0 or 1.)

(2) INVALID SPECIMEN NUMBER, ISPEC = (specimen number specified). Neither flat nor tube specimen is indicated. (ISPEC is not 0 or 1.)

(3) CANNOT HANDLE TORSION TEST ON FLAT SPECIMEN

(4) TOO MANY CHANNELS, JAC = (number of channels specified). The number of channels specified is greater than 20.

Nonfatal errors –

(1) LAST FRAME TO BE PLOTTED LESS THAN FIRST FRAME
FIRST FRAME = (first frame) LAST FRAME = (last frame)
WILL GO TO NEXT PLOT

This can be used to suppress plotting for a particular run, if desired.

(2) FIRST FRAME FOR SLOPE GREATER THAN LAST FRAME FOR SLOPE.
FIRST FRAME = (first frame for slope) LAST FRAME = (last frame for slope)
WILL NOT FIND SLOPE.

The program will print and plot the points for this run but will not calculate the slope of the line of best fit to any section of the curve.

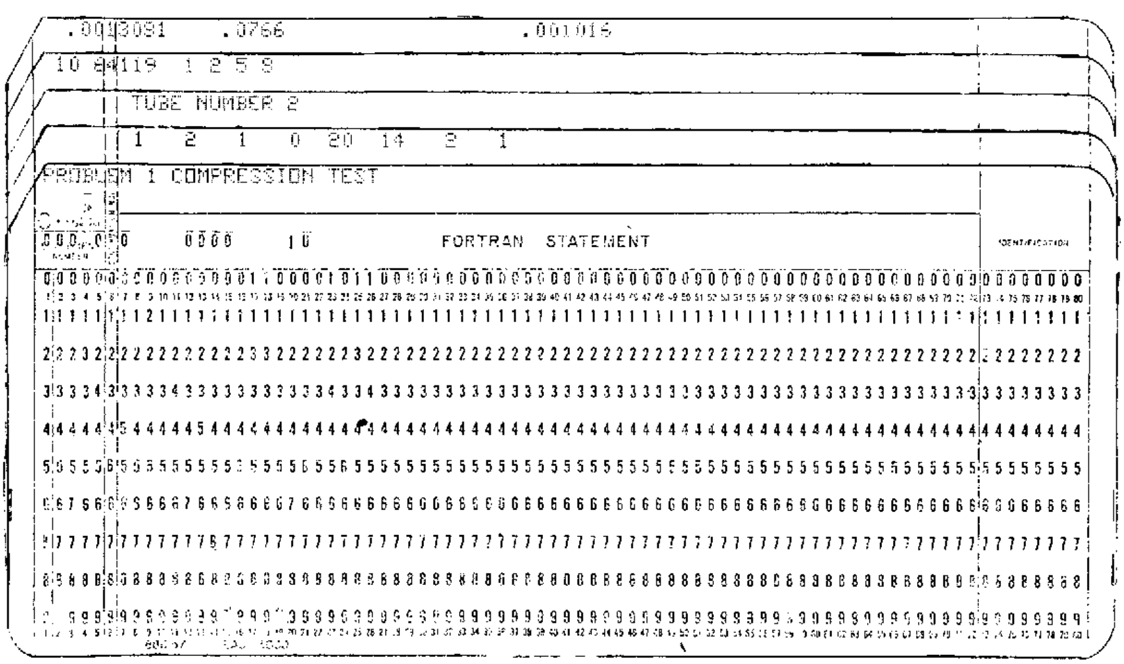
(3) FIRST FRAME FOR SLOPE INVALID.
FIRST FRAME = (first frame specified for slope)
WILL USE FIRST FRAME PLOTTED.

(4) LAST FRAME FOR SLOPE INVALID.
LAST FRAME = (last frame specified for slope)
WILL USE LAST FRAME PLOTTED.

SAMPLE PROBLEMS

Problem 1

This example illustrates the input, output, and typical stress-strain plots obtained from a compression test on a tube. The tube was instrumented with nine strain gages. The output of all nine gages as well as the average output of gages 2, 5, and 8 is plotted in figure 3. Input and output data are expressed in SI Units. The CalComp plotter with a Leroy pen was utilized to plot figure 3. A listing of the case instruction cards follows:



(Card 5)
(Card 4)
(Card 3)
(Card 2)
(Card 1)

The data set was obtained from a test on a graphite-epoxy tube.

The output listing for problem 1 follows:

```
PROBLEM 1 COMPRESSION TEST

COMPRESSION OR TENSION TEST  ON TUBE SPECIMEN
USING CALCOMP PLOTTER WITH LEROY PEN

        TUBE NUMBER 2
```

FRAME	LOAD	SG-1	SG-2
5	6.1760E+02	1.5341E-05	3.8352E-05
10	2.3267E+03	4.1697E-05	1.1005E-04
15	4.1988E+03	6.8367E-05	1.9093E-04
20	6.0299E+03	9.1712E-05	2.6597E-04
25	8.1100E+03	1.2006E-04	3.5351E-04
• • •			
155	1.5615E+04	2.2178E-04	6.7200E-04
160	1.7483E+04	2.4679E-04	7.5204E-04
165	1.9301E+04	2.7013E-04	8.3041E-04
170	2.1099E+04	2.9265E-04	9.0545E-04
175	2.2334E+04	3.0932E-04	9.5381E-04

```
THICKNESS =   1.3081E-03        OUTER DIAMETER =    7.6600E-02
```

STRESS-STRAIN POINTS FOR SG- 1   FRAMES 64 THROUGH 119

FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M
64	7.3814E+00	4.4199E+01	65	7.5446E+00	4.6690E+01	66	8.9380E+00	5.0859E+01	67	1.0018E+01	5.5027E+01
68	1.1173E+01	5.9362E+01	69	1.2428E+01	6.6700E+01	70	1.3784E+01	7.3370E+01	71	1.5064E+01	7.9206E+01
72	1.6231E+01	8.3375E+01	73	1.7287E+01	8.6710E+01	74	1.8303E+01	9.0879E+01	75	1.9383E+01	9.6715E+01
76	2.0725E+01	1.0338E+02	77	2.2220E+01	1.0839E+02	78	2.3688E+01	1.1339E+02	79	2.4881E+01	1.2006E+02
80	2.5961E+01	1.2173E+02	81	2.7041E+01	1.2673E+02	82	2.8083E+01	1.3006E+02	83	2.9149E+01	1.3590E+02
84	3.0215E+01	1.4257E+02	85	3.1359E+01	1.4591E+02	86	3.2513E+01	1.5007E+02	87	3.3794E+01	1.5508E+02
88	3.5087E+01	1.5841E+02	89	3.6354E+01	1.6425E+02	90	3.7598E+01	1.6925E+02	91	3.8840E+01	1.7342E+02
92	4.0046E+01	1.7509E+02	93	4.1301E+01	1.8342E+02	94	4.2506E+01	1.8843E+02	95	4.3749E+01	1.9176E+02
96	4.4941E+01	1.9843E+02	97	4.6147E+01	2.0343E+02	98	4.7389E+01	2.0844E+02	99	4.8582E+01	2.1344E+02
100	4.9774E+01	2.1928E+02	101	5.0904E+01	2.2423E+02	102	5.2034E+01	2.2845E+02	103	5.3177E+01	2.3428E+02
104	5.4294E+01	2.3762E+02	105	5.5390E+01	2.4179E+02	106	5.6641E+01	2.4596E+02	107	5.7984E+01	2.5346E+02
108	5.9252E+01	2.5763E+02	109	6.0570E+01	2.6246E+02	110	6.1864E+01	2.6847E+02	111	6.3169E+01	2.7597E+02
112	6.4424E+01	2.7764E+02	113	6.5713E+01	2.8181E+02	114	6.6973E+01	2.8848E+02	115	6.8228E+01	2.9348E+02
116	6.9496E+01	2.9681E+02	117	7.0501E+01	3.0098E+02	118	7.1555E+01	3.0432E+02	119	7.2145E+01	3.0932E+02

STRESS-STRAIN POINTS FOR SG- 2   FRAMES 64 THROUGH 119

FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M
64	7.3814E+00	1.0905E+02	65	7.5446E+00	1.1005E+02	66	8.9380E+00	1.2673E+02	67	1.0018E+01	1.4257E+02
68	1.1173E+01	1.5759E+02	69	1.2428E+01	1.7592E+02	70	1.3784E+01	1.9426E+02	71	1.5064E+01	2.1010E+02

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STRESS-STRAIN POINTS FOR SG- 4   FRAMES 64 THROUGH 119

FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M
64	7.3814E+00	1.6675E+01	65	7.5446E+00	1.8342E+01	66	8.9380E+00	2.1677E+01	67	1.0018E+01	2.6680E+01
68	1.1173E+01	3.3350E+01	69	1.2428E+01	3.9186E+01	70	1.3784E+01	4.5022E+01	71	1.5064E+01	5.0025E+01
72	1.6231E+01	5.4194E+01	73	1.7287E+01	5.9196E+01	74	1.8303E+01	6.4199E+01	75	1.9383E+01	6.8367E+01
76	2.0725E+01	7.5037E+01	77	2.2220E+01	8.0040E+01	78	2.3688E+01	8.6710E+01	79	2.4881E+01	9.2546E+01
80	2.5961E+01	9.6715E+01	81	2.7041E+01	1.0172E+02	82	2.8083E+01	1.0755E+02	83	2.9149E+01	1.1172E+02
84	3.0215E+01	1.1589E+02	85	3.1359E+01	1.2173E+02	86	3.2513E+01	1.2590E+02	87	3.3794E+01	1.3006E+02
88	3.5087E+01	1.3924E+02	89	3.6354E+01	1.4340E+02	90	3.7598E+01	1.4841E+02	91	3.8840E+01	1.5591E+02
92	4.0046E+01	1.6003E+02	93	4.1301E+01	1.6675E+02	94	4.2506E+01	1.7259E+02	95	4.3749E+01	1.7675E+02
96	4.4941E+01	1.8259E+02	97	4.6147E+01	1.8843E+02	98	4.7389E+01	1.9593E+02	99	4.8582E+01	2.0093E+02
100	4.9774E+01	2.0677E+02	101	5.0904E+01	2.1010E+02	102	5.2034E+01	2.1761E+02	103	5.3177E+01	2.2344E+02
104	5.4294E+01	2.2928E+02	105	5.5390E+01	2.3428E+02	106	5.6641E+01	2.3845E+02	107	5.7984E+01	2.4679E+02
108	5.9252E+01	2.5263E+02	109	6.0570E+01	2.5930E+02	110	6.1864E+01	2.6430E+02	111	6.3169E+01	2.7264E+02
112	6.4424E+01	2.7680E+02	113	6.5713E+01	2.8514E+02	114	6.6973E+01	2.9014E+02	115	6.8228E+01	2.9515E+02
116	6.9496E+01	3.0098E+02	117	7.0501E+01	3.0598E+02	118	7.1555E+01	3.1015E+02	119	7.2145E+01	3.1432E+02

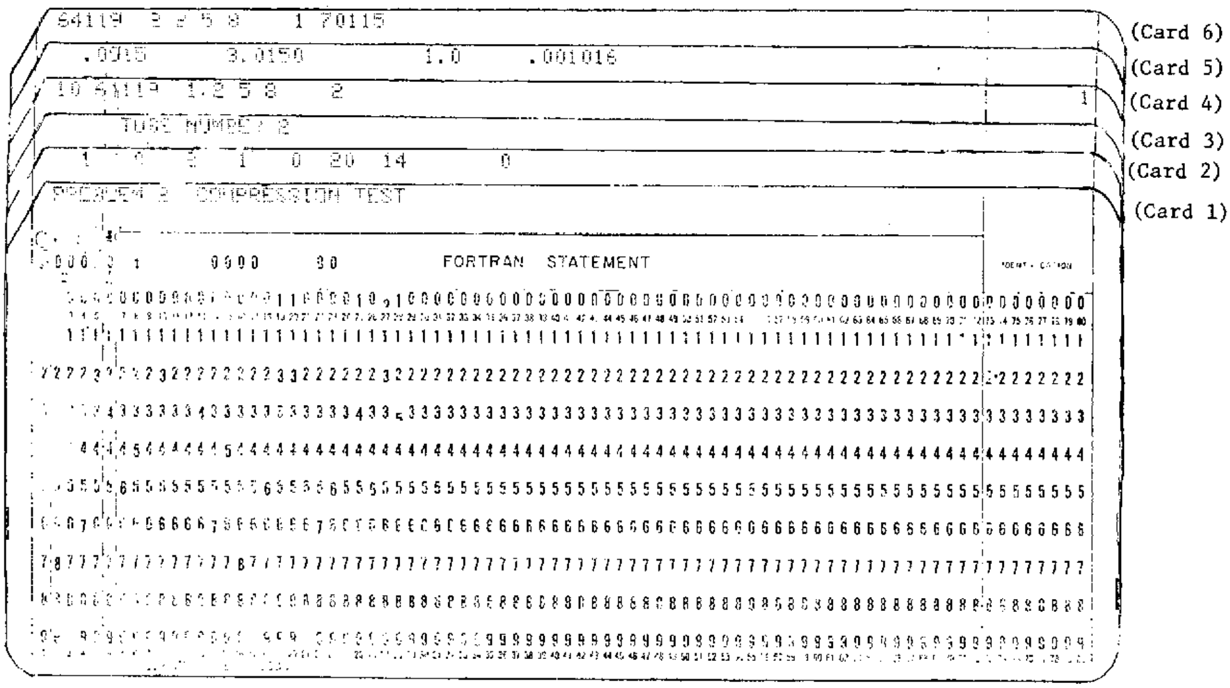
STRESS-STRAIN POINTS FOR AVG OF GAGES 2 5 8 -0   FRAMES 64 THROUGH 119

FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M	FRAME	STRESS MPA	STRAIN MICRO M/M
64	7.3814E+00	9.5159E+01	65	7.5446E+00	1.0116E+02	66	8.9380E+00	1.1867E+02	67	1.0018E+01	1.3534E+02
68	1.1173E+01	1.5963E+02	69	1.2428E+01	1.6925E+02	70	1.3784E+01	1.8759E+02	71	1.5064E+01	2.0399E+02
72	1.6231E+01	2.1903E+02	73	1.7287E+01	2.3373E+02	74	1.8303E+01	2.4790E+02	75	1.9383E+01	2.6096E+02
76	2.0725E+01	2.8070E+02	77	2.2220E+01	2.9959E+02	78	2.3688E+01	3.1905E+02	79	2.4881E+01	3.3461E+02
80	2.5961E+01	3.4926E+02	81	2.7041E+01	3.6295E+02	82	2.8083E+01	3.7769E+02	83	2.9149E+01	3.9103E+02
84	3.0215E+01	4.0657E+02	85	3.1359E+01	4.2243E+02	86	3.2513E+01	4.3827E+02	87	3.3794E+01	4.5550E+02
88	3.5087E+01	4.7301E+02	89	3.6354E+01	4.9025E+02	90	3.7598E+01	5.0664E+02	91	3.8840E+01	5.2387E+02
92	4.0046E+01	5.4927E+02	93	4.1301E+01	5.5750E+02	94	4.2506E+01	5.7362E+02	95	4.3749E+01	5.9030E+02
96	4.4941E+01	6.0697E+02	97	4.6147E+01	6.2365E+02	98	4.7389E+01	6.4060E+02	99	4.8582E+01	6.5644E+02
100	4.9774E+01	6.7367E+02	101	5.0904E+01	6.8951E+02	102	5.2034E+01	7.0480E+02	103	5.3177E+01	7.2092E+02
104	5.4294E+01	7.2176E+02	105	5.5390E+01	7.5176E+02	106	5.6641E+01	7.6900E+02	107	5.7984E+01	7.8817E+02
108	5.9252E+01	8.0624E+02	109	6.0570E+01	8.2346E+02	110	6.1864E+01	8.4098E+02	111	6.3169E+01	8.5959E+02
112	6.4424E+01	8.7794E+02	113	6.5713E+01	8.9517E+02	114	6.6973E+01	9.1268E+02	115	6.8228E+01	9.2991E+02
116	6.9496E+01	9.4596E+02	117	7.0501E+01	9.5937E+02	118	7.1555E+01	9.7578E+02	119	7.2145E+01	9.9131E+02

NUMBER OF PLOTS = 1
LENGTH OF X AXIS = 20 INCHES
LENGTH OF Y AXIS = 14 INCHES

Problem 2

This example illustrates the input and output data from a compression test on a graphite-epoxy tube. The data are expressed in U.S. Customary Units. This problem illustrates the option where more than one type of plot is obtained from a data set (run). First, the output of nine strain gages and the average of the output of gages 2, 5, and 8 are plotted in figure 4. The tangent modulus for the averaged curve (gages 2, 5, and 8) is plotted in figure 5 as a function of applied stress. The dashed curve in figure 5 is hand drawn and represents the slope of the straight line which provides the least-squares fit to the data. Figures 4 and 5 correspond to case 5 in table I. The additional output requested for this computer run is a separate plot of the average output of gages 2, 5, and 8 in figure 6. The slope of the stress-strain curve shown in figure 6 is 10.6×10^6, as indicated in the printout and by the dashed line in figure 5. A listing of the input data follows:



This data set was obtained from a test on a graphite-epoxy tube.

The output listing for problem 2 follows:

```
PROBLEM 2  COMPRESSION TEST

COMPRESSION OR TENSION TEST ON TUBE SPECIMEN
USING GERBER PLOTTER

     TUBE NUMBER 2
```

FRAME	LOAD	SG-1	SG-2
5	1.3885E+02	1.5841E-05	3.8352E-05
10	5.2308E+02	4.1687E-05	1.1005E-04
15	9.4398E+02	6.8367E-05	1.9093E-04
20	1.3579E+03	9.1712E-05	2.6597E-04

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FRAME	LOAD	SG-1	SG-2
75	1.3483E+03	9.6715E-05	2.6513E-04
80	1.8059E+03	1.2173E-04	3.4851E-04
85	2.1814E+03	1.4591E-04	4.2021E-04
90	2.6154E+03	1.6925E-04	4.9942E-04
95	3.0433E+03	1.9176E-04	5.8029E-04
100	3.4624E+03	2.1928E-04	6.6033E-04
105	3.8537E+03	2.4179E-04	7.3453E-04
110	4.3034E+03	2.6847E-04	8.2041E-04
115	4.7461E+03	2.9348E-04	9.0378E-04

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FRAME	LOAD	SG-1	SG-2
150	3.0695E+03	1.9676E-04	5.8863E-04
155	3.5105E+03	2.2178E-04	6.7200E-04
160	3.9305E+03	2.4679E-04	7.5204E-04
165	4.3392E+03	2.7013E-04	8.3041E-04
170	4.7435E+03	2.9265E-04	9.0545E-04
175	5.0212E+03	3.0932E-04	9.5381E-04

```
THICKNESS =    5.1500E-02        OUTER DIAMETER =    3.0150E+00
```

STRESS-STRAIN POINTS FOR SG- 1 FRAMES 64 THROUGH 119

FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN
64	1.0709E+00	4.4189E+01	65	1.0946E+00	4.6690E+01	66	1.2967E+00	5.0859E+01	67	1.4534E+00	5.5027E+01
68	1.6209E+00	5.8362E+01	69	1.8031E+00	6.6700E+01	70	1.9998E+00	7.3370E+01	71	2.1855E+00	7.9206E+01
72	2.3549E+00	8.3375E+01	73	2.5080E+00	8.6710E+01	74	2.6554E+00	9.0879E+01	75	2.8121E+00	9.6715E+01
76	3.0069E+00	1.0338E+02	77	3.2238E+00	1.0839E+02	78	3.4367E+00	1.1339E+02	79	3.6098E+00	1.2006E+02
80	3.7664E+00	1.2173E+02	81	3.9231E+00	1.2673E+02	82	4.0743E+00	1.3006E+02	83	4.2290E+00	1.3590E+02
84	4.3838E+00	1.4257E+02	85	4.5496E+00	1.4591E+02	86	4.7171E+00	1.5007E+02	87	4.9029E+00	1.5508E+02
88	5.0904E+00	1.5841E+02	89	5.2744E+00	1.6425E+02	90	5.4548E+00	1.6925E+02	91	5.6350E+00	1.7342E+02
92	5.8100E+00	1.7509E+02	93	5.9920E+00	1.8342E+02	94	6.1668E+00	1.8843E+02	95	6.3472E+00	1.9176E+02
96	6.5201E+00	1.9843E+02	97	6.6951E+00	2.0343E+02	98	6.8753E+00	2.0844E+02	99	7.0484E+00	2.1344E+02
100	7.2213E+00	2.1928E+02	101	7.3852E+00	2.2428E+02	102	7.5492E+00	2.2845E+02	103	7.7150E+00	2.3428E+02
104	7.8770E+00	2.3762E+02	105	8.0374E+00	2.4179E+02	106	8.2176E+00	2.4596E+02	107	8.4124E+00	2.5346E+02
108	8.5964E+00	2.5763E+02	109	8.7876E+00	2.6346E+02	110	8.9753E+00	2.6847E+02	111	9.1647E+00	2.7597E+02
112	9.3468E+00	2.7764E+02	113	9.5345E+00	2.8181E+02	114	9.7166E+00	2.8848E+02	115	9.8986E+00	2.9348E+02
116	1.0083E+01	2.9681E+02	117	1.0228E+01	3.0098E+02	118	1.0381E+01	3.0432E+02	119	1.0467E+01	3.0932E+02

STRESS-STRAIN POINTS FOR SG- 9 FRAMES 64 THROUGH 119

FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN
64	1.0709E+00	1.6675E+01	65	1.0946E+00	1.8342E+01	66	1.2967E+00	2.1677E+01	67	1.4534E+00	2.6680E+01
68	1.6209E+00	3.3350E+01	69	1.8031E+00	3.9186E+01	70	1.9998E+00	4.5022E+01	71	2.1855E+00	5.0025E+01
72	2.3549E+00	5.4194E+01	73	2.5080E+00	5.9196E+01	74	2.6554E+00	6.4199E+01	75	2.8121E+00	6.8367E+01
76	3.0069E+00	7.5037E+01	77	3.2238E+00	8.0040E+01	78	3.4367E+00	8.6710E+01	79	3.6098E+00	9.2546E+01
80	3.7664E+00	9.6715E+01	81	3.9231E+00	1.0172E+02	82	4.0743E+00	1.0755E+02	83	4.2290E+00	1.1172E+02
84	4.3838E+00	1.1589E+02	85	4.5496E+00	1.2173E+02	86	4.7171E+00	1.2590E+02	87	4.9029E+00	1.3006E+02
88	5.0904E+00	1.3924E+02	89	5.2744E+00	1.4340E+02	90	5.4548E+00	1.4841E+02	91	5.6350E+00	1.5591E+02
92	5.8100E+00	1.6008E+02	93	5.9920E+00	1.6675E+02	94	6.1668E+00	1.7259E+02	95	6.3472E+00	1.7675E+02
96	6.5201E+00	1.8259E+02	97	6.6951E+00	1.8843E+02	98	6.8753E+00	1.9593E+02	99	7.0484E+00	2.0093E+02

STRESS-STRAIN POINTS FOR AVG OF GAGES 2 5 8 -0 FRAMES 64 THROUGH 119

FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN
64	1.0709E+00	9.6159E+01	65	1.0946E+00	1.0116E+02	66	1.2967E+00	1.1667E+02	67	1.4534E+00	1.3534E+02
68	1.6209E+00	1.5063E+02	69	1.8031E+00	1.6925E+02	70	1.9998E+00	1.8759E+02	71	2.1855E+00	2.0399E+02
72	2.3549E+00	2.1900E+02	73	2.5080E+00	2.3373E+02	74	2.6554E+00	2.4790E+02	75	2.8121E+00	2.6096E+02
76	3.0069E+00	2.8070E+02	77	3.2238E+00	2.9959E+02	78	3.4367E+00	3.1905E+02	79	3.6098E+00	3.3461E+02
80	3.7664E+00	3.4906E+02	81	3.9231E+00	3.6296E+02	82	4.0743E+00	3.7769E+02	83	4.2290E+00	3.9103E+02
84	4.3838E+00	4.0687E+02	85	4.5496E+00	4.2243E+02	86	4.7171E+00	4.3827E+02	87	4.9029E+00	4.5550E+02
88	5.0904E+00	4.7301E+02	89	5.2744E+00	4.9025E+02	90	5.4548E+00	5.0664E+02	91	5.6350E+00	5.2387E+02
92	5.8100E+00	5.4027E+02	93	5.9920E+00	5.5750E+02	94	6.1668E+00	5.7362E+02	95	6.3472E+00	5.9030E+02
96	6.5201E+00	6.0697E+02	97	6.6951E+00	6.2365E+02	98	6.8753E+00	6.4060E+02	99	7.0484E+00	6.5644E+02
100	7.2213E+00	6.7367E+02	101	7.3852E+00	6.8951E+02	102	7.5492E+00	7.0480E+02	103	7.7150E+00	7.2092E+02
104	7.8770E+00	7.3676E+02	105	8.0374E+00	7.5176E+02	106	6.2176E+00	7.6900E+02	107	8.4124E+00	7.8817E+02
108	8.5964E+00	8.0624E+02	109	8.7876E+00	8.2346E+02	110	8.9753E+00	8.4098E+02	111	9.1647E+00	8.5959E+02
112	9.3468E+00	8.7794E+02	113	9.5345E+00	8.9517E+02	114	9.7166E+00	9.1268E+02	115	9.8986E+00	9.2991E+02
116	1.0083E+01	9.4686E+02	117	1.0228E+01	9.5937E+02	118	1.0381E+01	9.7578E+02	119	1.0467E+01	9.8131E+02

STRESS	STRAIN	TANGENT MODULUS
1.0709E+03	9.6159E-05	1.0870E+07
1.0946E+03	1.0116E-04	1.0867E+07
1.2967E+03	1.1867E-04	1.0858E+07
1.4534E+03	1.3534E-04	1.0848E+07
1.6209E+03	1.5063E-04	1.0840E+07
1.8031E+03	1.6925E-04	1.0830E+07
1.9998E+03	1.8759E-04	1.0820E+07
2.1855E+03	2.0399E-04	1.0811E+07
2.3549E+03	2.1900E-04	1.0803E+07

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9.7166E+03	9.1268E-04	1.0427E+07
9.8986E+03	9.2991E-04	1.0418E+07
1.0083E+04	9.4686E-04	1.0409E+07
1.0228E+04	9.5937E-04	1.0402E+07
1.0381E+04	9.7578E-04	1.0393E+07
1.0467E+04	9.8131E-04	1.0390E+07

STRESS-STRAIN POINTS FOR AVG OF GAGES 2 5 8 -0 FRAMES 64 THROUGH 119

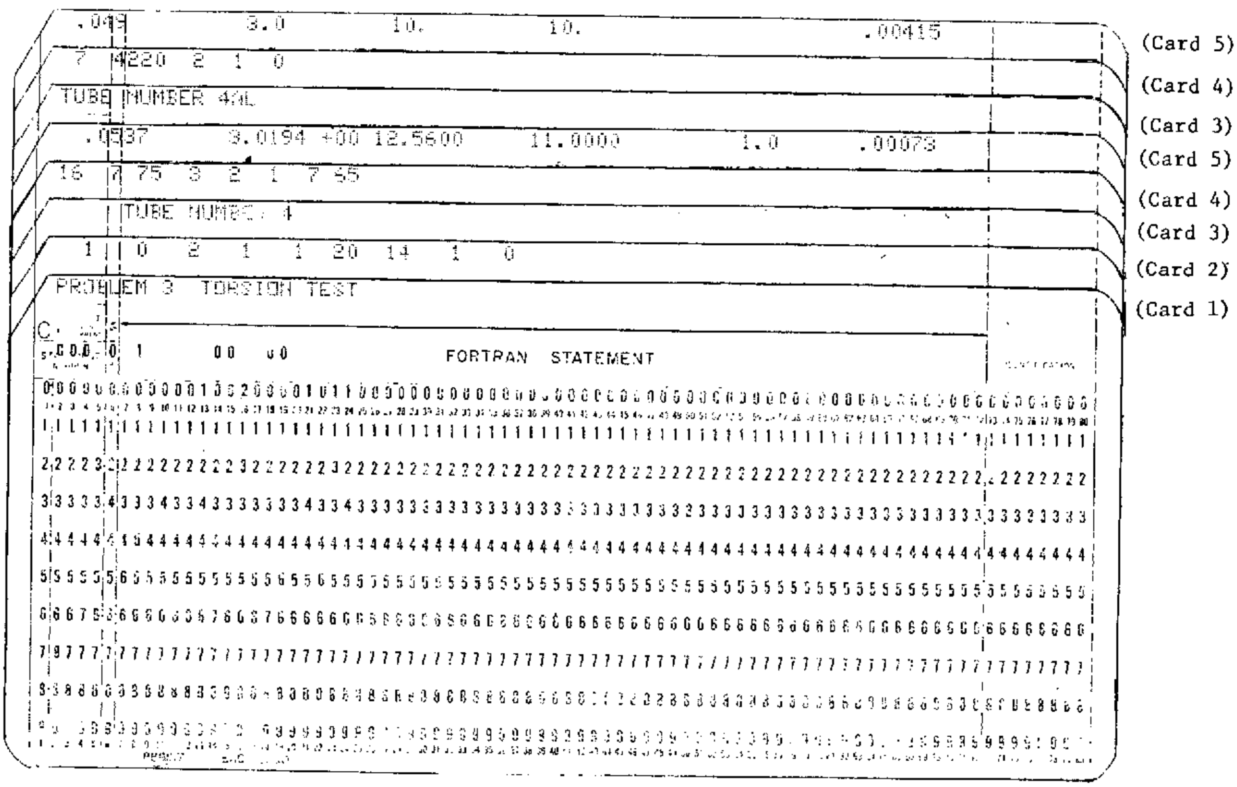
FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN
64	1.0709E+00	9.6159E+01	65	1.0946E+00	1.0116E+02	66	1.2967E+00	1.1867E+02	67	1.4534E+00	1.3534E+02
68	1.6209E+00	1.5063E+02	69	1.8031E+00	1.6925E+02	70	1.9998E+00	1.8759E+02	71	2.1855E+00	2.0399E+02
72	2.3549E+00	2.1900E+02	73	2.5080E+00	2.3373E+02	74	2.6554E+00	2.4790E+02	75	2.8121E+00	2.6096E+02
76	3.0069E+00	2.8070E+02	77	3.2238E+00	2.9959E+02	78	3.4367E+00	3.1905E+02	79	3.6098E+00	3.3461E+02
80	3.7664E+00	3.4906E+02	81	3.9231E+00	3.6296E+02	82	4.0743E+00	3.7769E+02	83	4.2290E+00	3.9103E+02
84	4.3838E+00	4.0687E+02	85	4.5496E+00	4.2243E+02	86	4.7171E+00	4.3827E+02	87	4.9029E+00	4.5550E+02
88	5.0904E+00	4.7301E+02	89	5.2744E+00	4.9025E+02	90	5.4548E+00	5.0664E+02	91	5.6350E+00	5.2387E+02
92	5.8100E+00	5.4027E+02	93	5.9920E+00	5.5750E+02	94	6.1668E+00	5.7362E+02	95	6.3472E+00	5.9030E+02
96	6.5201E+00	6.0697E+02	97	6.6951E+00	6.2365E+02	98	6.8753E+00	6.4060E+02	99	7.0484E+00	6.5644E+02
100	7.2213E+00	6.7367E+02	101	7.3852E+00	6.8951E+02	102	7.5492E+00	7.0480E+02	103	7.7150E+00	7.2092E+02
104	7.8770E+00	7.3676E+02	105	8.0374E+00	7.5176E+02	106	8.2176E+00	7.6900E+02	107	8.4124E+00	7.8817E+02
108	8.5964E+00	8.0624E+02	109	8.7876E+00	8.2346E+02	110	8.9753E+00	8.4098E+02	111	9.1647E+00	8.5959E+02
112	9.3468E+00	8.7794E+02	113	9.5345E+00	8.9517E+02	114	9.7166E+00	9.1268E+02	115	9.8986E+00	9.2991E+02
116	1.0083E+01	9.4686E+02	117	1.0228E+01	9.5937E+02	118	1.0381E+01	9.7578E+02	119	1.0467E+01	9.8131E+02

E = 1.06222E+07 FOR FRAMES 70 THROUGH 115

NUMBER OF PLOTS = 3
LENGTH OF X AXIS = 20 INCHES.
LENGTH OF Y AXIS = 14 INCHES.

Problem 3

This example illustrates the input, output, and plots obtained from the torsion test on two tubular specimens. The first tube was instrumented with three strain rosettes (each rosette contained three strain gages) and four LVDT's. A stress-strain curve based on the average absolute values from all ±45° oriented strain gages and a torque-twist curve based on the LVDT outputs are plotted in figures 7 and 8, respectively. The second tube (number 4AL) was instrumented with two strain rosettes. A curve based on the sum of the absolute values from the ±45° gages (case 9) is plotted in figure 9. The data are expressed in U.S. Customary Units. A listing of the input data follows:



The first data set was obtained from a test on a graphite-epoxy tube whereas the second data set was obtained from a test on an aluminum tube.

The output listing for problem 3 follows:

PROBLEM 3 TORSION TEST

TORSION TEST ON TUBE SPECIMEN
USING GERBER PLOTTER

TUBE NUMBER 4

FRAME	LOAD	SG-1	SG-2
5	6.2914E+01	1.4174E-05	-3.3350E-06
10	1.9128E+02	4.0020E-05	-8.3375E-06
15	3.7384E+02	7.6765E-05	-1.7509E-05
20	5.9548E+02	1.2089E-04	-3.0015E-05
25	8.3594E+02	1.6925E-04	-4.0854E-05
30	1.0898E+03	2.2094E-04	-5.3360E-05
•	•	•	•
160	2.1452E+03	4.3772E-04	-1.0589E-04
165	2.4476E+03	5.0192E-04	-1.1589E-04
170	2.7557E+03	5.6111E-04	-1.3340E-04
175	3.0723E+03	6.2781E-04	-1.4591E-04
180	3.3889E+03	6.9285E-04	-1.5841E-04
185	3.6257E+03	7.4037E-04	-1.7008E-04

THICKNESS = 5.3700E-02 OUTER DIAMETER = 3.0194E+00

AVG STRESS-STRAIN POINTS FOR FRAMES 7 THROUGH 75

FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN
7	1.3401E-01	4.6079E+01	8	1.7707E-01	5.7528E+01	9	2.1168E-01	6.9756E+01	10	2.5782E-01	8.3097E+01
11	2.9242E-01	9.6993E+01	12	3.4624E-01	1.1200E+02	13	3.9624E-01	1.2895E+02	14	4.5006E-01	1.4507E+02
15	5.0389E-01	1.6314E+02	16	5.5771E-01	1.8065E+02	17	6.1923E-01	1.9927E+02	18	6.8075E-01	2.1899E+02
19	7.4996E-01	2.3734E+02	20	7.9994E-01	2.5791E+02	21	8.6530E-01	2.7930E+02	22	9.3451E-01	2.9653E+02
23	9.9967E-01	3.1821E+02	24	1.0652E+00	3.3961E+02	25	1.1267E+00	3.6101E+02	26	1.1998E+00	3.8074E+02
27	1.2579E+00	4.0293E+02	28	1.3267E+00	4.2549E+02	29	1.3998E+00	4.4828E+02	30	1.4689E+00	4.6995E+02
31	1.5420E+00	4.9247E+02	32	1.6113E+00	5.1637E+02	33	1.6881E+00	5.3888E+02	34	1.7688E+00	5.6334E+02
35	1.8342E+00	5.8640E+02	36	1.9112E+00	6.1030E+02	37	1.9880E+00	6.3365E+02	38	2.0571E+00	6.5838E+02
39	2.1379E+00	6.8228E+02	40	2.2109E+00	7.0563E+02	41	2.2917E+00	7.3064E+02	42	2.3686E+00	7.5537E+02
43	2.4417E+00	7.8094E+02	44	2.5185E+00	8.0374E+02	45	2.5993E+00	8.2902E+02	46	2.6723E+00	8.5348E+02
47	2.7530E+00	8.7849E+02	48	2.8317E+00	9.0406E+02	49	2.9108E+00	9.2880E+02	50	2.9915E+00	9.5381E+02
51	3.0665E+00	9.7882E+02	52	3.1453E+00	1.0033E+03	53	3.2183E+00	1.0280E+03	54	3.3068E+00	1.0519E+03
55	3.3798E+00	1.0783E+03	56	3.4645E+00	1.1036E+03	57	3.5413E+00	1.1289E+03	58	3.6220E+00	1.1547E+03
59	3.7028E+00	1.1811E+03	60	3.7874E+00	1.2067E+03	61	3.8719E+00	1.2337E+03	62	3.9603E+00	1.2598E+03
63	4.0373E+00	1.2854E+03	64	4.1141E+00	1.3126E+03	65	4.1988E+00	1.3387E+03	66	4.2872E+00	1.3654E+03
67	4.3640E+00	1.3921E+03	68	4.4448E+00	1.4190E+03	69	4.5371E+00	1.4454E+03	70	4.6218E+00	1.4718E+03
71	4.6946E+00	1.4966E+03	72	4.7563E+00	1.5138E+03	73	4.8063E+00	1.5266E+03	74	4.8332E+00	1.5358E+03
75	4.8447E+00	1.5380E+03									

G = 3.14202E+06 FOR FRAMES 7 THROUGH 65

TORQUE TWIST POINTS, FRAMES 7 THROUGH 75

FRAME	TORQUE IN-LBS	TWIST DEG/IN	FRAME	TORQUE IN-LBS	TWIST DEG/IN	FRAME	TORQUE IN-LBS	TWIST DEG/IN	FRAME	TORQUE IN-LBS	TWIST DEG/IN
7	1.1426E+02	1.8359E-03	8	1.3137E+02	2.2133E-03	9	1.5705E+02	2.7207E-03	10	1.9128E+02	3.1796E-03
11	2.1695E+02	3.7222E-03	12	2.5698E+02	4.2360E-03	13	2.9397E+02	4.9076E-03	14	3.3390E+02	5.5009E-03
15	3.7384E+02	6.1870E-03	16	4.1377E+02	6.8387E-03	17	4.5941E+02	7.5224E-03	18	5.0505E+02	8.2823E-03
19	5.5640E+02	9.0248E-03	20	5.9348E+02	9.7439E-03	21	6.4197E+02	1.0504E-02	22	6.9332E+02	1.1232E-02
23	7.4181E+02	1.2004E-02	24	7.9030E+02	1.2838E-02	25	8.3594E+02	1.3638E-02	26	8.9014E+02	1.4434E-02
27	9.3293E+02	1.5273E-02	28	9.8427E+02	1.6096E-02	29	1.0385E+03	1.6933E-02	30	1.0898E+03	1.7798E-02
31	1.1440E+03	1.8662E-02	32	1.1954E+03	1.9578E-02	33	1.2524E+03	2.0439E-02	34	1.3123E+03	2.1313E-02
35	1.3608E+03	2.2230E-02	36	1.4179E+03	2.3131E-02	37	1.4749E+03	2.4032E-02	38	1.5262E+03	2.4916E-02
39	1.5861E+03	2.5786E-02	40	1.6403E+03	2.6716E-02	41	1.7002E+03	2.7644E-02	42	1.7573E+03	2.8571E-02
43	1.8115E+03	2.9503E-02	44	1.8685E+03	3.0431E-02	45	1.9284E+03	3.1431E-02	46	1.9826E+03	3.2293E-02
47	2.0425E+03	3.3272E-02	48	2.1053E+03	3.4215E-02	49	2.1595E+03	3.5209E-02	50	2.2194E+03	3.6123E-02
51	2.2765E+03	3.7095E-02	52	2.3335E+03	3.8051E-02	53	2.3877E+03	3.8972E-02	54	2.4533E+03	3.9959E-02
55	2.5075E+03	4.0894E-02	56	2.5703E+03	4.1865E-02	57	2.6273E+03	4.2874E-02	58	2.6872E+03	4.3872E-02
59	2.7471E+03	4.4844E-02	60	2.8099E+03	4.5808E-02	61	2.8726E+03	4.6864E-02	62	2.9382E+03	4.7872E-02
63	2.9953E+03	4.8869E-02	64	3.0523E+03	4.9906E-02	65	3.1151E+03	5.0901E-02	66	3.1807E+03	5.1950E-02
67	3.2377E+03	5.2999E-02	68	3.2976E+03	5.4082E-02	69	3.3661E+03	5.5117E-02	70	3.4289E+03	5.6141E-02
71	3.4831E+03	5.7070E-02	72	3.5287E+03	5.7798E-02	73	3.5658E+03	5.8355E-02	74	3.5858E+03	5.8708E-02
75	3.5943E+03	5.8776E-02									

SLOPE OF CURVE = 6.13878E+13 FOR FRAMES 7 THROUGH 65

TUBE NUMBER 4AL

FRAME	LOAD	SG-1	SG-2
10	3.5311E+02	-8.0043E-05	0.
20	1.1237E+03	-2.3075E-04	-1.0005E-05
30	1.9617E+03	-3.8769E-04	-1.7509E-05
40	2.9394E+03	-5.5945E-04	-2.5012E-05
50	3.8576E+03	-7.2287E-04	-3.0015E-05
60	4.8630E+03	-9.0795E-04	-3.5117E-05
70	5.3397E+03	-1.0522E-03	-4.8357E-05

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220	1.6928E+04	-3.3225E-03	1.7842E-04
230	1.6755E+04	-2.7672E-03	6.3532E-04
240	1.2676E+04	-1.1881E-03	3.1266E-04
250	1.1240E+04	-9.5631E-04	3.6685E-05

THICKNESS = 4.9030E-02 OUTER DIAMETER = 3.0000E+00

AVG STRESS-STRAIN POINTS FOR FRAMES 4 THROUGH 220

FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN	FRAME	STRESS KSI	STRAIN MICRO IN/IN
4	5.5392E-02	4.0853E+01	5	1.4110E-01	5.7528E+01	6	1.4110E-01	7.4203E+01	7	1.4110E-01	9.3797E+01
8	2.2682E-01	1.1547E+02	9	3.5539E-01	1.3924E+02	10	5.2681E-01	1.6633E+02	11	5.2681E-01	1.9301E+02
12	6.5539E-01	2.2219E+02	13	8.6966E-01	2.5179E+02	14	9.9823E-01	2.8138E+02	15	9.9823E-01	3.1265E+02
16	1.1697E+00	3.4142E+02	17	1.3411E+00	3.7560E+02	18	1.4268E+00	4.0895E+02	19	1.6839E+00	4.3855E+02
20	1.6839E+00	4.6815E+02	21	1.7697E+00	4.9691E+02	22	1.8982E+00	5.2568E+02	23	2.1554E+00	5.5736E+02
24	2.2840E+00	5.8988E+02	25	2.3268E+00	6.2156E+02	26	2.5410E+00	6.5157E+02	27	2.4982E+00	6.8451E+02
28	2.7125E+00	7.1619E+02	29	2.7982E+00	7.4870E+02	30	2.9267E+00	7.8497E+02	31	3.1839E+00	8.1832E+02
32	3.3553E+00	8.5043E+02	33	3.4839E+00	8.8586E+02	34	3.4411E+00	9.2004E+02	35	3.6125E+00	9.5339E+02
36	3.8696E+00	9.6799E+02	37	3.8696E+00	1.0222E+03	38	4.0838E+00	1.0568E+03	39	4.2124E+00	1.0914E+03
40	4.3839E+00	1.1256E+03	41	4.5553E+00	1.1602E+03	42	4.7267E+00	1.1952E+03	43	4.7695E+00	1.2314E+03
44	4.9839E+00	1.2635E+03	45	5.0267E+00	1.2990E+03	46	5.1553E+00	1.3332E+03	47	5.2410E+00	1.3694E+03
48	5.4982E+00	1.4065E+03	49	5.7124E+00	1.4390E+03	50	5.7552E+00	1.4762E+03	51	5.8410E+00	1.5116E+03
52	6.1410E+00	1.5470E+03	53	6.2267E+00	1.5825E+03	54	6.3981E+00	1.6183E+03	55	6.4839E+00	1.6542E+03
56	6.6553E+00	1.6892E+03	57	6.7839E+00	1.7246E+03	58	6.9124E+00	1.7600E+03	59	6.9982E+00	1.7967E+03
60	7.2552E+00	1.8301E+03	61	7.3410E+00	1.8672E+03	62	7.5124E+00	1.9018E+03	63	7.6838E+00	1.9381E+03
64	7.7695E+00	1.9739E+03	65	7.8553E+00	2.0102E+03	66	8.1123E+00	2.0460E+03	67	8.1981E+00	2.0831E+03
68	8.4553E+00	2.1200E+03	69	8.4553E+00	2.1556E+03	70	8.7124E+00	2.1931E+03	71	8.7982E+00	2.2290E+03
72	8.9266E+00	2.2640E+03	73	9.0980E+00	2.2994E+03	74	9.3124E+00	2.3353E+03	75	9.3981E+00	2.3716E+03
76	9.4834E+00	2.4071E+03	77	9.7837E+00	2.4458E+03	78	9.8695E+00	2.4829E+03	79	1.0041E+01	2.5192E+03
80	1.0170E+01	2.5546E+03	81	1.0384E+01	2.5921E+03	82	1.0470E+01	2.6275E+03	83	1.0684E+01	2.6621E+03
84	1.0855E+01	2.6993E+03	85	1.0941E+01	2.7351E+03	86	1.1027E+01	2.7726E+03	87	1.1284E+01	2.8101E+03

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188	2.3583E+01	6.6458E+03	189	2.3583E+01	6.6879E+03	190	2.3626E+01	6.7308E+03	191	2.3841E+01	6.7704E+03
192	2.3884E+01	6.8150E+03	193	2.3969E+01	6.8563E+03	194	2.3926E+01	6.8988E+03	195	2.3969E+01	6.9413E+03
196	2.4054E+01	6.9822E+03	197	2.4141E+01	7.0256E+03	198	2.4184E+01	7.0647E+03	199	2.4356E+01	7.1090E+03
200	2.4226E+01	7.1500E+03	201	2.4397E+01	7.1932E+03	202	2.4569E+01	7.2353E+03	203	2.4397E+01	7.2756E+03
204	2.4569E+01	7.3211E+03	205	2.4569E+01	7.3616E+03	206	2.4655E+01	7.4033E+03	207	2.4741E+01	7.4461E+03
208	2.4655E+01	7.4883E+03	209	2.4869E+01	7.5329E+03	210	2.4827E+01	7.5738E+03	211	2.4869E+01	7.6192E+03
212	2.4827E+01	7.6604E+03	213	2.4869E+01	7.7080E+03	214	2.4997E+01	7.7518E+03	215	2.4997E+01	7.7968E+03
216	2.4997E+01	7.8439E+03	217	2.5169E+01	7.8935E+03	218	2.5084E+01	7.9385E+03	219	2.5212E+01	7.9894E+03
220	2.5255E+01	8.0336E+03									

NUMBER OF PLOTS = 3
LENGTH OF X AXIS = 20 INCHES
LENGTH OF Y AXIS = 14 INCHES

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 18, 1974.

APPENDIX A

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures in 1960 (ref. 1). Conversion factors for the units used herein are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (a)	SI Unit (b)
Length	in.	0.0254	meters (m)
Load	lbf	4.448	newtons (N)
Modulus, stress	psi = lbf/in^2	6895	newtons per $meter^2$ (N/m^2)

[a]Multiply value given in U.S. Customary Units by conversion factor to obtain equivalent value in SI Units.

[b]Prefixes to indicate multiples of units are as follows:

Prefix	Multiple
micro (μ)	10^{-6}
kilo (k)	10^3
mega (M)	10^6
giga (G)	10^9
tera (T)	10^{12}

APPENDIX B

SOURCE PROGRAM LISTING

A listing of the Source Program BECKPLT is presented in this appendix. A description of the significant FORTRAN variables is given in appendix C. The matrix inversion subroutine MATINV used in this program is described in appendix D.

```
      PROGRAM BECKPLT(INPUT=201,OUTPUT=201,TAPE5=INPUT,TAPE30=201)
C
C   PROGRAM TO ASSIST IN THE REDUCTION OF BECKMAN DATA
C
      DIMENSION TITLE1(4),TITLE2(4),AC2(99),IGAGES(4),DTA(415,20),
     1X(400), Y(400), TEMPX(4), TEMPY(4)
      COMMON OMOVE,IPLOTS,NOPLT(18),XLN    ,YMULT,XMULT ,IUNITS
C
C     READ + PRINT TITLE.
      READ(5,1) (TITLE1(J),J=1,4)
    1 FORMAT(4A10)
      IF(EOF,5) 1000,2
    2 PRINT 3, (TITLE1(J),J =1,4)
    3 FORMAT(1H1 4A10 //)
C
C   READ PLOTTER, PEN, INPUT TYPE, SPECIMEN TYPE, TEST TYPE, PLOT INFO, UNITS
      READ(5,4) IPLT,IPEN,INPT,ISPEC,ITEST,IXSIZE,IYSIZE,IOMOVE,IUNITS
    4 FORMAT(9I4)
      IF(IYSIZE.EQ.0) IYSIZE=9
      IF(IOMOVE.EQ.0) IOMOVE=2
      IX=IXSIZE
      XLN = IXSIZE + 0.0
      YLN = IYSIZE + 0.0
      OMOVE=IOMOVE+0.0
      IF(ITEST.EQ.0 .AND. ISPEC.EQ.0) PRINT 41
   41 FORMAT(1H ,*COMPRESSION OR TENSION TEST ON FLAT SPECIMEN*)
      IF(ITEST.EQ.0 .AND. ISPEC.EQ.1) PRINT 42
   42 FORMAT(1H ,*COMPRESSION OR TENSION TEST ON TUBE SPECIMEN*)
      IF(ITEST.EQ.1 .AND. ISPEC.EQ.1) PRINT 43
   43 FORMAT(1H ,*TORSION TEST ON TUBE SPECIMEN*)
      IF(ITEST.NE.0 .AND. ITEST.NE.1) PRINT 44,ITEST
   44 FORMAT(1H ,*INVALID TEST NUMBER, ITEST = *,I4)
      IF(ITEST.NE.0 .AND. ITEST.NE.1) STOP
      IF(ISPEC.NE.0 .AND. ISPEC.NE.1) PRINT 45, ISPEC
   45 FORMAT(1H ,*INVALID SPECIMEN NUMBER, ISPEC = *,I4)
      IF(ISPEC.NE.0 .AND. ISPEC.NE.1) STOP
      IF(ITEST.EQ.1 .AND. ISPEC.EQ.0) PRINT 451
  451 FORMAT(1H ,*CANNOT HANDLE TORSION TEST ON FLAT SPECIMEN*)
      IF(ITEST.EQ.1 .AND. ISPEC.EQ.0) STOP
      IF(IPLT.EQ.0 .AND. IPEN.EQ.0) PRINT 46
   46 FORMAT(1H ,*USING CALCOMP PLOTTER WITH BALLPOINT PEN*///)
      IF(IPLT.EQ.0 .AND. IPEN.EQ.1) PRINT 47
   47 FORMAT(1H ,*USING CALCOMP PLOTTER WITH LEROY PEN*///)
      IF(IPLT.NE.0) PRINT 48
   48 FORMAT(1H ,*USING GERBER PLOTTER*///)
C
C   INITIALIZE PLOTTING ROUTINE.
      IF(IPLT .EQ. 0) CALL CALCOMP
      IF(IPLT.NE.0) CALL GERBER
      IF(IPLT .EQ. 0 .AND. IPEN .NE. 0) CALL LEROY
      KOUNT=0
```

```
C
C   PRINT TITLE ON GRAPH.
        CALL CALPLT(4.,1.2,-3)
        CALL NOTATE(-3.,0.,.25,TITLE1(1),90.,40)
C
C   READ + PRINT TITLE OF RUN.
    55 READ(5,1) (TITLE2(JJ), JJ =1,4)
        IF(EOF,5)1000,1100
  1100 PRINT 37, (TITLE2(JJ),JJ=1,4)
    37 FORMAT(1H ,4A10 ///)
        CALL NOTATE(0.,-1.1,.20,TITLE2(1),0.,40)
C
C   READ RUN INFO.
        IF(ITEST .EQ. 0) READ(5,6) JAC,NRL,NRU,INDAVG,IGAGES,MOD,NRLSLP,
       1NRUSLP,NOPLT,MORE
     6 FORMAT(4I3,4I2,3I3,18I2,14X,I1)
        IF(ITEST.EQ.1) READ(5,61) JAC,NRL,NRU,NROS,INDAVG,MOD,NRLSLP,
       1NRUSLP,NOPLT,MORE
    61 FORMAT(8I3,18I2,19X,I1)
        NP = NRU-NRL+1
        IF(JAC.GT.20) PRINT 75,JAC
    75 FORMAT(1H0,* TOO MANY CHANNELS, JAC = *,I4)
        IF(JAC.GT.20) GO TO 1000
C
C   READ IN DATA.
        IF(INPT .EQ. 0) CALL RDTAPE(JAC,NRL,NRU,MD,DTA)
        IF(INPT .EQ. 1) CALL RDCARD(JAC,NRL,NRU,MD,DTA)
        IF(INPT .EQ. 2) CALL RDCELL(JAC,NRL,NRU,MD,DTA)
        KNTRUN=0
C
C   READ IN SECTIONAL DATA.
        IF(ITEST .EQ. 0) READ(5,8) THICK,WIDTH,SCFAC,RMAXSN
   8    FORMAT(4F12.4)
        IF(ITEST .EQ. 1) READ(5,81) THICK,WIDTH,RLENGTH,ALENGTH,SCFAC,
       1RMAXSN
   81   FORMAT(6F12.4)
        IF(SCFAC.EQ.0) SCFAC=1.
    82 IF(NP.LT.1) PRINT 76, NRL,NRU
    76 FORMAT(1H0,* LAST FRAME TO BE PLOTTED LESS THAN FIRST FRAME*, /,
       1* FIRST FRAME = *,I3,6X,*LAST FRAME = *,I3, / , * WILL GO TO NEXT
       2PLOT*)
        IF(NP.LT.1) GO TO 50
C
C   USE TYPE OF SPECIMEN + SECTIONAL DATA TO COMPUTE STRESSES
C   AND STORE IN Y ARRAY.
        CALL LOADY(THICK,WIDTH,SCFAC,ISPEC,ITEST,NRL,NRU,Y,DTA,FAC,YMULT,
       1IUNITS,KNTRUN)
        IF(MOD.NE.1) GO TO 751
        IF(MOD.EQ.1 .AND. NRLSLP .EQ. 0) NRLSLP=NRL
        IF(MOD.EQ.1 .AND. NRUSLP.EQ.0) NRUSLP=NRU
        IF(NRLSLP.GT.NRUSLP) PRINT 613,NRLSLP,NRUSLP
   613 FORMAT(1H0,* FIRST FRAME FOR SLOPE GREATER THAN LAST FRAME FOR SLO
       1PE.*,/,* FIRST FRAME = *,I4,6X,* LAST FRAME = *,I4,/,* WILL NOT FI
       2ND SLOPE.*)
        IF(NRLSLP.GT.NRUSLP) MOD=0
        IF(MOD.EQ.0) GO TO 751
        IF(NRLSLP.LT.NRL .OR. NRLSLP.GT.NRU) PRINT 611,NRLSLP
   611 FORMAT(1H0,* FIRST FRAME FOR SLOPE INVALID.*, / , * FIRST FRAME =
       1*,I4, / , * WILL USE FIRST FRAME PLOTTED.*)
        IF(NRLSLP.LT.NRL .OR. NRLSLP.GT.NRU) NRLSLP=NRL
```

```
      IF(NRUSLP.LT.NRL .OR. NRUSLP.GT.NRU) PRINT 612,NRUSLP
  612 FORMAT(1HO,* LAST FRAME FOR SLOPE INVALID.*, / , * LAST FRAME = *,
     1I4,/* WILL USE LAST FRAME PLOTTED.*)
      IF(NRUSLP.LT.NRL .OR. NRUSLP.GT.NRU) NRUSLP=NRU
  751 CONTINUE
C
C  SET X + Y SCALES.
      XMULT=1.0
      IF(RMAXSN .LT. .1) XMULT=10.**6
      TEMPX(1)=0.
      TEMPX(2)=RMAXSN*XMULT
      IF(ISPEC.EQ.1 .AND. ITEST.EQ.1 .AND. INDAVG.NE.0) TEMPX(2)=2*TEMPX
     1(2)
      TEMPY(1)=0.
      TEMPY(2)=Y(NP)
      DO 761 I=1,NP
  761 IF(Y(I).GT.TEMPY(2)) TEMPY(2)=Y(I)
      IPLOTS=1
      IF(ITEST .EQ. 0 .AND. INDAVG .EQ. 0) IPLOTS=JAC-1
      IF(ITEST .EQ. 0 .AND. INDAVG .EQ. 1) IPLOTS=JAC
      IF(ISPEC .EQ. 1 .AND. ITEST .EQ. 1 .AND. INDAVG .EQ. 0) IPLOTS =
     13*NROS
      IF(ISPEC .EQ. 1 .AND. ITEST .EQ. 1 .AND. INDAVG .EQ. 3) IPLOTS =
     13*NROS+1
      IF(IX.EQ.0 .AND. ITEST.EQ.0) XLN=OMOVE*JAC
      IF(IX.EQ.0 .AND. ITEST.EQ.1) XLN=OMOVE*(3.*NRUS+1.)+NROS
      IXSIZE=XLN
      XXLN = XLN-OMOVE*(IPLOTS-1)
      IF(XXLN .LT. OMOVE) XXLN=OMOVE
      IF(ITEST.EQ.1 .AND. (INDAVG.EQ.0.OR.INDAVG.EQ.3))XXLN=OMOVE
      CALL ASCALE(TEMPX,XXLN,2,1,10.0)
      CALL ASCALE(TEMPY,YLN,2,1,10.0)
      X(NP+1)=0.
      X(NP+2)=TEMPX(4)
      XSC=TEMPX(4)
      Y(NP+1)=0.
      Y(NP+2)=TEMPY(4)
      YSC=TEMPY(4)
C
C  DRAW THE X+Y AXES.
      IF(IUNITS.NE.0) GO TO 695
      IF(ITEST .EQ. 0 .AND. YMULT .EQ. .001) CALL AXES(0.,0.,90.,YLN,0.,
     1YSC,1.,0.,10HSTRESS,KSI,.25,10)
      IF(ITEST .EQ. 0 .AND. YMULT .EQ. 1.) CALL AXES(0.,0.,90.,YLN,0.,
     1YSC,1.,0.,10HSTRESS,PSI,.25,10)
      IF(ITEST .EQ. 1 .AND. YMULT .EQ. .001) CALL AXES(0.,0.,90.,YLN,0.,
     1YSC,1.,0.,16HSHEAR STRESS,KSI,.25,16)
      IF(ITEST .EQ. 1 .AND. YMULT .EQ. 1.) CALL AXES(0.,0.,90.,YLN,0.,
     1YSC,1.,0.,16HSHEAR STRESS,PSI,.25,16)
      IF((INDAVG .NE.2) .AND. (ITEST .NE. 1 .OR. INDAVG .NE. 1))GO TO 68
      IF((ITEST.EQ.0 .OR. INDAVG.EQ.0 .OR. INDAVG.EQ.3) .AND. XMULT.EQ.1
     11) CALL AXES(0.,0.,0.,XLN,0.,XSC,1.0,0., 7HSTRAIN      ,.25,-12)
      IF((ITEST.EQ.1 .AND. (INDAVG.EQ.1.OR.INDAVG.EQ.2)) .AND. XMULT.EQ.
     11) CALL AXES(0.,0.,0.,XLN,0.,XSC,1.,0.,13HSHEAR STRAIN      ,.25,
     2-18)
      IF(XMULT .EQ. 1)GO TO 69
      CALL AXES(0.,0.,0.,XLN,0.,XSC,-1.,0.,1H ,.25,-1)
```

```
      IF(ITEST.EQ.0 .OR. (INDAVG.EQ.0.OR.INDAVG.EQ.3))CALL NOTATE(XLN/2.
     1,-.7,.25,18HSTRAIN,MICRO IN/IN,0.,18)
      IF(ITEST.EQ.1 .AND. (INDAVG.EQ.1 .OR. INDAVG.EQ.2)) CALL NOTATE(
     1XLN/2.,-.7,.25,24HSHEAR STRAIN,MICRO IN/IN,0.,24)
      GO TO 69
   68 CALL DASHLN(0.,0.,XLN,0.,XLN)
      PLACE=IXSIZE/4
      CALL DASHLN(PLACE ,-.6,PLACE ,0.,.6)
      CALL DASHLN(PLACE +1.,-.6,PLACE +1.,0.,.6)
      CALL PARROW(PLACE-.3,-.30,PLACE,-.30,1)
      CALL PARROW(PLACE+1.3,-.30,PLACE+1.,-.30,1)
      CALL NUMBER(PLACE+.2,-.37,.14,XSC/XMULT,0.,4)
      IF(ITEST .EQ. 0) CALL NOTATE(XLN/2.,-.8,.25, 7HSTRAIN      ,0.,12)
      IF(ITEST .EQ. 1) CALL NOTATE(XLN/2.,-.8,.25,13HSHEAR STRAIN      ,
     10.,18)
      GO TO 69
  695 IF(ITEST.EQ.0 .AND. YMULT.EQ.1.) CALL AXES(0.,0.,90.,YLN,0.,YSC,1.
     1,0., 9HSTRESS,PA,.25,9)
      IF(ITEST.EQ.0 .AND. YMULT.EQ. .001) CALL AXES(0.,0.,90.,YLN,0.,YSC
     1,1.,0.,10HSTRESS,KPA,.25,10)
      IF(ITEST.EQ.0 .AND. YMULT.EQ. 10.**(-6)) CALL AXES(0.,0.,90.,YLN,0
     1.,YSC,1.,0.,10HSTRESS,MPA,.25,10)
      IF(ITEST.EQ.0 .AND. YMULT.EQ. 10.**(-9)) CALL AXES(0.,0.,90.,YLN,0
     1.,YSC,1.,0.,10HSTRESS,GPA,.25,10)
      IF(ITEST.EQ.0 .AND. YMULT.EQ. 10.**(-12)) CALL AXES(0.,0.,90.,YLN,
     10.,YSC,1.,0.,10HSTRESS,TPA,.25,10)
      IF(ITEST.EQ.1 .AND. YMULT.EQ.1) CALL AXES(0.,0.,90.,YLN,0.,YSC,1.,
     10.,15HSHEAR STRESS,PA,.25,15)
      IF(ITEST.EQ.1 .AND. YMULT.EQ. .001) CALL AXES(0.,0.,90.,YLN,0.,YSC
     1,1.,0.,16HSHEAR STRESS,KPA,.25,16)
      IF(ITEST.EQ.1 .AND. YMULT.EQ. 10.**(-6)) CALL AXES(0.,0.,90.,YLN,0
     1.,YSC,1.,0.,16HSHEAR STRESS,MPA,.25,16)
      IF(ITEST.EQ.1 .AND. YMULT.EQ. 10.**(-9)) CALL AXES(0.,0.,90.,YLN,0
     1.,YSC,1.,0.,16HSHEAR STRESS,GPA,.25,16)
      IF(ITEST.EQ.1 .AND. YMULT.EQ. 10.**(-12)) CALL AXES(0.,0.,90.,YLN,
     10.,YSC,1.,0.,16HSHEAR STRESS,TPA,.25,16)
      IF((INDAVG.NE.2) .AND. (ITEST.NE.1 .OR. INDAVG.NE.1)) GO TO 685
      IF((ITEST.EQ.0 .OR. INDAVG.EQ.0 .OR. INDAVG.EQ.3) .AND. XMULT.EQ.1
     1) CALL AXES(0.,0.,0.,XLN,0.,XSC,1.0,0., 7HSTRAIN     ,.25,-10)
      IF((ITEST.EQ.1 .AND. (INDAVG.EQ.1.OR.INDAVG.EQ.2)) .AND. XMULT.EQ.
     11) CALL AXES(0.,0.,0.,XLN,C.,XSC,1.,0.,13HSHEAR STRAIN     ,.25,-16
     2)
      IF(XMULT.EQ.1)GO TO 69
      CALL AXES(0.,0.,0.,XLN,0.,XSC,-1.,0.,1H ,.25,-1)
      IF(ITEST.EQ.0 .OR. (INDAVG.EQ.0.OR.INDAVG.EQ.3))CALL NOTATE(XLN/2.
     1,-.7,.25,18HSTRAIN,MICRO  M/M ,0.,18)
      IF(ITEST.EQ.1 .AND. (INDAVG.EQ.1 .OR. INDAVG.EQ.2)) CALL NOTATE(
     1XLN/2.,-.7,.25,24HSHEAR STRAIN,MICRO  M/M ,0.,24)
      GO TO 69
  685 CALL DASHLN(0.,0.,XLN,0.,XLN)
      PLACE=IXSIZE/4
      CALL DASHLN(PLACE,-.6,PLACE,0.,.6)
      CALL DASHLN(PLACE+1.,-.6,PLACE+1.,0.,.6)
      CALL PARROW(PLACE-.3,-.3,PLACE,-.3,1)
      CALL PARROW(PLACE+1.3,-.3,PLACE+1.,-.3,1)
      CALL NUMBER(PLACE+.2,-.37,.14,XSC/XMULT,0.,4)
      IF(ITEST.EQ.0) CALL NOTATE(XLN/2.,-.8,.25, 7HSTRAIN     ,0.,10)
      IF(ITEST.EQ.1) CALL NOTATE(XLN/2.,-.8,.25,13HSHEAR STRAIN     ,0.,
     116)
   69 CALL DGRID(0.,0.,1.,1.,IXSIZE,IYSIZE,0.1)
      KOUNT=KOUNT+1
```

```
C
C  LOAD X ARRAY, PRINT, AND PLOT.
      IF(ITEST .EQ. 0 .AND. INDAVG .NE. 2)CALL COMPIND(IGAGES,MOD,NRLSLP
     1,NRUSLP,JAC,NRL,NRU,NP,X,Y,XMULT,INDAVG,IXSIZE,DTA,YLN,ISPEC,YMULT
     2,IUNITS)
      IF(ITEST .EQ. 0 .AND. INDAVG .EQ. 2)CALL COMPAVG(IGAGES,MOD,NRLSLP
     1,NRUSLP,JAC,NRL,NRU,NP,X,Y,XMULT,DTA,YLN,ISPEC,YMULT,IUNITS)
      IF(ISPEC .EQ. 1 .AND. ITEST .EQ. 1 .AND. (INDAVG .EQ. 0 .OR.
     1INDAVG .EQ. 3))CALL TORIND(IGAGES,MOD,NRLSLP,NRUSLP,JAC,NROS,NRL,
     2NRU,NP,X,Y,XMULT,INDAVG,IXSIZE,DTA,YLN,XSC,RMAXSN,YMULT,IUNITS)
      IF(ISPEC .EQ. 1 .AND. ITEST .EQ. 1 .AND. (INDAVG .EQ. 1 .OR.
     1INDAVG .EQ. 2))CALL TORAVG(IGAGES,MOD,NRLSLP,NRUSLP,JAC,NROS,NRL,
     2NRU,NP,X,Y,XMULT,INDAVG,IXSIZE,DTA,YLN,XSC,YSC,FAC,YMULT,ALENGTH,
     3RLENGTH,IUNITS)
      IF(ITEST.EQ.1 .AND. INDAVG.EQ.2) KOUNT=KOUNT+1
      IF(MOD.EQ.2) KOUNT=KOUNT+1
C
C  GO TO NEW GRAPH, NEW RUN.
   50 IF(MORE.EQ.0 .AND. MD.EQ.9999) GO TO 1000
      CALL CALPLT(XLN+6.,0.,-3)
      PRINT 1200
 1200 FORMAT(1H1)
      IF(MORE.EQ.0) GO TO 55
      KNTRUN=KNTRUN+1
      IF(ITEST.EQ.0) READ(5,700)NRL,NRU,INDAVG,IGAGES,MOD,NRLSLP,NRUSLP,
     1NOPLT,MORE
  700 FORMAT(3I3,4I2,3I3,18I2,17X,I1)
      IF(ITEST.EQ.1) READ(5,701) NRL,NRU,NROS,INDAVG,MOD,NRLSLP,NRUSLP,
     1NOPLT,MORE
  701 FORMAT(7I3,18I2,22X,I1)
      NP=NRU-NRL+1
      GO TO 82
1000  CALL CALPLT(0.,0.,999)
      PRINT 1025, KOUNT
 1025 FORMAT(/// 1H * NUMBER OF PLOTS = * I3)
      PRINT 1026, IXSIZE,IYSIZE
 1026 FORMAT(1H  *LENGTH OF X AXIS = * I4 * INCHES* /1H  *LENGTH OF Y AX
     1IS = * I4 * INCHES*)
      END
```

```
      SUBROUTINE RDTAPE(JAC,NRL,NRU,MD,DTA)
C
C  READS BECKMAN DATA FROM MAGNETIC TAPE IN FORMAT 2.
C
      DIMENSION AC2(99),DTA(415,20)
      PRINT 198
  198 FORMAT(1H0,*        FRAME     LOAD          SG-1          SG-2     *)
      N=2
      NP=NRU-NRL+1
  100 READ(30) MO,IFM,ISP,IFRA,TIM,TV,IFAC,ITST,MRN,MSN,DC6,DC7,DC8,DC9,
     1DC10,AC2
```

```
C
C  CHECK FOR END OF RUN.
      IF(MD .EQ. 8888 .OR. MD .EQ. 9999) GO TO 199
C
C  PRINT EVERY FIFTH OR TENTH FRAME.
      IF((NP .LE. 100 .AND. N/5*5 .EQ. N) .OR. (N/10*10 .EQ. N)) PRINT
     1101, IFRA,(AC2(K),K=1,3)
  101 FORMAT(1H0,I12,3E12.4)
C
C  STORE DATA IN ARRAY DTA.
      DO 103 J=1,JAC
  103 DTA(IFRA,J)=AC2(J)
      N=N+1
      GO TO 100
  199 RETURN
      END
```

```
      SUBROUTINE RDCELL(JAC,NRL,NRU,MD,DTA)
C
C READS DATA FROM DATA FILE ON DATA CELL--DATA ON TAPE30
C
      DIMENSION DTA(415,20)
      PRINT 198
  198 FORMAT(1H0,*        FRAME     LOAD          SG-1          SG-2     *)
      N=2
      NP=NRU-NRL+1
  400 READ(30,401) ITST,MRN,MD,IFRA,ISQ
  401 FORMAT(3I12,24X,I12,I8)
C  CHECK FOR END OF RUN.
      IF(MD .EQ. 8888 .OR. MD .EQ. 9999) GO TO 410
C  READ DATA INTO ARRAY DTA.
      DO 411 J=1,18,6
      JJ=J+5
  411 READ(30,402) (DTA(IFRA,K),K=J,JJ),ISQ
  402 FORMAT(6E12.4, I8)
C
C  PRINT EVERY FIFTH OR TENTH FRAME.
      IF((NP .LE. 100 .AND. N/5*5 .EQ. N) .OR. (N/10*10 .EQ. N)) PRINT
     1403, IFRA,(DTA(IFRA,K),K=1,3)
  403 FORMAT(1H0,I12,3E12.4)
      N=N+1
      GO TO 400
  410 RETURN
      END
```

APPENDIX B

```
      SUBROUTINE LOADY(THICK,WIDTH,SCFAC,ISPEC,ITEST,NRL,NRU,Y,DTA,FAC,
     1YMULT,IUNITS,KNTRUN)
C   COMPUTES STRESSES AND LOADS Y ARRAY FOR EACH SPEC + TEST TYPE.
C
      DIMENSION Y(400),DTA(415,20)
      IF(KNTRUN.NE.0) GO TO 19
      PI=3.14159
      IF(ISPEC .EQ. 0) FAC=THICK*WIDTH
      IF(ISPEC .EQ. 1 .AND. ITEST .EQ. 0) FAC=PI*(WIDTH-THICK)*THICK
      IF(ISPEC .EQ. 1 .AND. ITEST .EQ. 1) FAC=2*PI*(((WIDTH-THICK)/2)**2
     1)*THICK
      IF(ISPEC.EQ.0) PRINT 191, THICK,WIDTH
  191 FORMAT(1H0,* THICKNESS = *,E12.4,6X,* WIDTH = *,E12.4)
      IF(ISPEC.EQ.1) PRINT 192, THICK, WIDTH
  192 FORMAT(1H0,* THICKNESS = *,E12.4,6X,* OUTER DIAMETER = *,E12.4)
C   IF STRESSES TOO LARGE, DIVIDE BY 1000.
   19 YMULT=1.0
      RMAXLD=ABS(DTA(NRU,1))
      DO 196 I=NRL,NRU
  196 IF(ABS(DTA(I,1)).GT.RMAXLD) RMAXLD=ABS(DTA(I,1))
      RMAXSS=RMAXLD/FAC
      IF(RMAXSS .GT. 1000) YMULT=.001
      IF(IUNITS.EQ.0) GO TO 193
      IF(RMAXSS*.001 .GT. 1000) YMULT=10.**(-6)
      IF(RMAXSS*(10.**(-6)) .GT. 1000) YMULT=10.**(-9)
      IF(RMAXSS*(10.**(-9)) .GT. 1000) YMULT=10.**(-12)
C   PUT STRESSES IN Y ARRAY.
  193 DO 200 I=NRL,NRU
  200 Y(I-NRL+1)=(DTA(I,1)/FAC)*YMULT*SCFAC
      RETURN
      END
```

```
      FUNCTION POLYE1(X,M,C)
      DATA BIG/0377777777777777/
      DIMENSION C(M)
      IF(M-1)10,11,12
   12 N=M-1
      POLYE1=C(1)
      DO20I=1,N
   20 POLYE1=X*POLYE1+C(I+1)
      RETURN
   10 POLYE1=BIG
      RETURN
   11 POLYE1=C(1)
      RETURN
      END
```

```
      SUBROUTINE RDCARD(JAC,NRL,NRU,MD,DTA)
C
C  READS DATA FROM PUNCHED CARDS.
C
      DIMENSION DTA(415,20)
      PRINT 198
  198 FORMAT(1H0,*        FRAME    LOAD          SG-1          SG-2    *)
      N=2
      NP=NRU-NRL+1
  500 DO 511 J=1,JAC,6
      JJ=J+5
      IF(J.EQ.1) READ(5,501)IFRA,(DTA(IFRA,K),K=J,JJ),MD
  501 FORMAT(I4,6E12.4,I4)
      IF(J.NE.1) READ(5,502) (DTA(IFRA,K),K=J,JJ),MD
  502 FORMAT(6E12.4,I4)
  511 CONTINUE
C  CHECK FOR END OF RUN.
      IF(MD   .EQ. 8888 .OR. MD   .EQ. 9999) GO TO 510
C  PRINT EVERY FIFTH OR TENTH FRAME.
      IF((NP .LE. 100 .AND. N/5*5 .EQ. N) .OR. (N/10*10 .EQ. N)) PRINT
     1503, IFRA,(DTA(IFRA,K),K=1,3)
  503 FORMAT(I12,3E12.4)
      N=N+1
      GO TO 500
  510 RETURN
      END
```

```
      SUBROUTINE COMPIND(IGAGES,MOD,NRLSLP,NRUSLP,JAC,NRL,NRU,NP,X,Y,
     1XMULT,INDAVG,IXSIZE,DTA,YLN,ISPEC,YMULT,IUNITS)
C
C  LOADS X ARRAY FOR COMP TEST, INDIV GAGE PLOT, AND CALLS PRTPLT.
C
      DIMENSION IGAGES(4),X(400),Y(400),DTA(415,20)
      COMMON OMOVE,IPLOTS,NOPLT(18),XLN,AY,BX,IUTS
      DO 122 IGAG=2,JAC
      DO 124 K=1,18
  124 IF(IGAG-1.EQ.NOPLT(K)) GO TO 122
      DO 121 I=NRL,NRU
  121 X(I-NRL+1)=ABS(DTA(I,IGAG)*XMULT)
      CALL PRTPLT(ISPEC,0,INDAVG,IGAGES,IGAG,NRL,NRU,NP,X,Y,YLN)
      IF(IGAG .LT. JAC) CALL CALPLT(OMOVE,0.,-3)
  122 CONTINUE
      IF(INDAVG .EQ. 0) GO TO 123
      DO 125 K=1,18
      IF(JAC-1.EQ.NOPLT(K)) GO TO 126
  125 CONTINUE
      CALL CALPLT(OMOVE,0.,-3)
  126 CALL COMPAVG(IGAGES,MOD,NRLSLP,NRUSLP,JAC,NRL,NRU,NP,X,Y,XMULT,DTA
     1,YLN,ISPEC,YMULT,IUNITS)
  123 RETURN
      END
```

APPENDIX B

```
      SUBROUTINE COMPAVG(IGAGES,MOD,NRLSLP,NRUSLP,JAC,NRL,NRU,NP,X,Y,
     1XMULT,DTA,YLN,ISPEC,YMULT,IUNITS)
C
C  LOADS X ARRAY FOR COMP TEST, AVG PLOT, AND CALLS PRTPLT.
C  IF MOD=1, CALLS SLP.
C
      DIMENSION IGAGES(4),X(400),Y(400),DTA(415,20)
      COMMON OMOVE,IPLCTS,NOPLT(18),XLN,AY,BX,IUTS
C  FIND NUMBER OF GAGES TO BE AVERAGED.
      N=0
      DO 131 I=1,4
      IF(IGAGES(I) .NE. 0) N=N+1
  131 CONTINUE
C  FIND AVERAGES + PLOT.
      DO 132 I=1,NP
  132 X(I)=0
      DO 135 J=1,4
      IF(IGAGES(J) .EQ. 0) GO TO 135
      DO 134 I=NRL,NRU
      IGAGESJ=IGAGES(J)
  134 X(I-NRL+1)=X(I-NRL+1)+ABS(DTA(I,IGAGESJ+1)*XMULT/N)
  135 CONTINUE
      CALL PRTPLT(ISPEC,0,2,IGAGES,0,NRL,NRU,NP,X,Y,YLN)
C  IF MOD=1, FIND + PRINT SLOPE.
      IF(MOD .EQ. 0) GO TO 139
      IF(MOD.EQ.2) CALL PROPLIM(X,Y,NRL,NRU,NP,XMULT,YMULT,IUNITS)
      IF(MOD.EQ.2)GO TO 139
      DO 1531 I=NRLSLP,NRUSLP
      X(I-NRLSLP+1)=X(I-NRL+1)
 1531 Y(I-NRLSLP+1)=Y(I-NRL+1)
      NPSLP=NRUSLP-NRLSLP+1
      CALL SLP(X,Y,XBR,YBR,EX,NPSLP,XMULT,YMULT)
      PRINT 138,EX,NRLSLP,NRUSLP
  138 FORMAT(// 5X,* E = *,E12.5,4X,* FOR FRAMES*,I4,*  THROUGH*,I4 //)
  139 RETURN
      END
```

```
      SUBROUTINE TORIND(IGAGES,MOD,NRLSLP,NRUSLP,JAC,NRCS,NRL,NRU,NP,X,Y
     1,XMULT,INDAVG,IXSIZE,DTA,YLN,XSC,RMAXSN,YMULT,IUNITS)
C
C  LOADS X ARRAY FOR TUBE SPEC, TORSION TEST, INDIV GAGE PLOT, AND CALLS
C  PRTPLT.
C
      DIMENSION IGAGES(4),X(400),Y(400),DTA(415,20)
      COMMON OMOVE,IPLCTS,NOPLT(18),XLN,AY,BX,IUTS
      IGAG=3
  160 DO 166 K=1,18
  166 IF(IGAG-1.EQ.NOPLT(K)) GO TO 167
      DO 161 I=NRL,NRU
  161 X(I-NRL+1)=ABS(DTA(I,IGAG)*XMULT)
      CALL PRTPLT(1,1,INDAVG,IGAGES,IGAG,NRL,NRU,NP,X,Y,YLN)
      IF(IGAG/3*3 .EQ. IGAG) GO TO 162
```

```
      IGAG=IGAG+2
      IF(IGAG.GT.3*NROS+1) GO TO 164
      GO TO 163
  162 IGAG=IGAG-1
  163 CALL CALPLT(OMOVE,0.,-3)
      IF(IGAG.NE.3 .AND. IGAG/3*3.EQ.IGAG) CALL CALPLT(1.,0.,-3)
      GO TO 160
  167 IF(IGAG/3*3.EQ.IGAG) GO TO 168
      IGAG=IGAG+2
      IF(IGAG.GT.3*NROS+1) GO TO 164
      GO TO 160
  168 IGAG=IGAG-1
      GO TO 160
  164 IF(INDAVG .EQ. 0) GO TO 169
      DO 1641 K=1,18
      IF(3*NROS+1.EQ.NOPLT(K)) GO TO 1642
 1641 CONTINUE
      CALL CALPLT(OMOVE,0.,-3)
 1642 DO 165 I=NRL,NRU
  165 X(I-NRL+1)=(ABS(DTA(I,2))+ABS(DTA(I,4)))*XMULT
      CALL PRTPLT(1,1,INDAVG,IGAGES,-1,NRL,NRU,NP,X,Y,YLN)
C   IF MOD=1, FIND + PRINT SLOPE.
      IF(MOD .EQ. 0)GO TO 169
      IF(MOD.EQ.2) CALL PROPLIM(X,Y,NRL,NRU,NP,XMULT,YMULT,IUNITS)
      IF(MOD.EQ.2)GO TO 169
      DO 1531 I=NRLSLP,NRUSLP
      X(I-NRLSLP+1)=X(I-NRL+1)
 1531 Y(I-NRLSLP+1)=Y(I-NRL+1)
      NPSLP=NRUSLP-NRLSLP+1
      CALL SLP(X,Y,XBR,YBR,EX,NPSLP,XMULT,YMULT)
      PRINT 139,EX,NRLSLP,NRUSLP
  139 FORMAT(// 5X,* G = *,E12.5,4X,* FOR FRAMES*,I4,*  THROUGH*,I4 //)
  169 RETURN
      END
```

```
      SUBROUTINE TORAVG(IGAGES,MOD,NRLSLP,NRUSLP,JAC,NROS,NRL,NRU,NP,X,Y
     1,XMULT,INDAVG,IXSIZE,DTA,YLN,XSC,YSC,FAC,YMULT,ALENGTH,RLENGTH,
     2IUNITS)
C
C  LOADS X ARRAY FOR TUBE SPEC, TORSION TEST, AVG PLOT, AND CALLS
C  PRTPLT. IF MOD=1, CALLS SLP.
C
      DIMENSION IGAGES(4),X(400),Y(400),DTA(415,20),HOLDX(4),HOLDY(4)
      COMMON OMOVE,IPLOTS,NOPLT(18),XLN,AY,BX,IUTS
      DO 171 I=1,NP
  171 X(I)=0
      N=0
      DO 172 J=1,NROS
      DO 161 K=1,18
      IF(3*J-2.EQ.NOPLT(K).OR.3*J.EQ.NOPLT(K)) N=N+1
      IF(3*J-2.EQ.NOPLT(K).OR.3*J.EQ.NOPLT(K)) GO TO 172
  161 CONTINUE
```

```
      DO 163 I=NRL,NRU
  163 X(I-NRL+1)=X(I-NRL+1)+(ABS(DTA(I,3*J-1))+ABS(DTA(I,3*J+1)))*XMULT
  172 CONTINUE
      DO 162 I=NRL,NRU
  162 X(I-NRL+1)=X(I-NRL+1)/(NRCS-N)
      CALL PRTPLT(1,1,INDAVG,IGAGES,0,NRL,NRU,NP,X,Y,YLN)
C   IF MOD=1, FIND + PRINT SLOPE.
      IF(MOD .EQ. 0)GO TO 175
      IF(MOD.EQ.2) CALL PROPLIM(X,Y,NRL,NRU,NP,XMULT,YMULT,IUNITS)
      IF(MOD.EQ.2)GO TO 175
      DO 1531 I=NRLSLP,NRUSLP
      X(I-NRLSLP+1)=X(I-NRL+1)
 1531 Y(I-NRLSLP+1)=Y(I-NRL+1)
      NPSLP=NRUSLP-NRLSLP+1
      CALL SLP(X,Y,XBR,YBR,EX,NPSLP,XMULT,YMULT)
      PRINT 138,EX,NRLSLP,NRUSLP
  138 FORMAT(// 5X,* G = *,E12.5,4X,* FOR FRAMES*,I4,*  THROUGH*,I4 //)
C   IF INDAVG=1, PLOT TWIST CURVES.
  175 IF(INDAVG .NE. 2)GO TO 179
      PI=3.14159
      MIN=JAC-3
      MAX=MIN+3
C   MAKE NEW GRAPH.
      XLM=XLN
      IF(XLM.LT.9.) XLM=9.
      CALL CALPLT(XLM+6.,0.,-3)
      HOLDY(1)=0.
      HOLDY(2)=DTA(NRU,1)
      CALL ASCALE(HOLDY,YLN,2,1,10.0)
      YSC2=HOLDY(4)
      Y(NP+2)=YSC2
      HOLDX(1)=0.
      HOLDX(2)=      (ABS(DTA(NRU,MIN))+ABS(DTA(NRU,MIN+1))-ABS(DTA(NRU,
     1MIN+2))-ABS(DTA(NRU,MIN+3)))/(2*ALENGTH*RLENGTH)
      IF(IUNITS.EQ.0)  HOLDX(2) = HOLDX(2) *180./PI
      CALL ASCALE(HOLDX,XLN,2,1,10.0)
      XSC2=HOLDX(4)
      X(NP+2)=XSC2
      IF(IUNITS.EQ.0) CALL AXES(0.,0.,90.,YLN,0.,YSC2,-1.,0.,12HTORQUE,I
     1N-LB,.25,12)
      IF(IUNITS.EQ.1) CALL AXES(0.,0.,90.,YLN,0.,YSC2,-1.,0.,15HTORQUE,N
     1EWTON-M,.25,15)
      CALL AXES(0.,0.,0.,XLN,0.,XSC2,1.,0.,1H ,0.,-1)
      CALL NUMBER(-1.5/28.,-.25,.1875,0.,0.,-1)
      DO 1771 I=1,IXSIZE
      PLACE=I+0.
 1771 CALL NUMBER(PLACE-15./56.,-.25,.1875,XSC2*PLACE,0.,4)
      IF(IUNITS.EQ.0) CALL NCTATE(XLN/2.-1.3,-.75,.25,12HTWIST,DEG/IN,0.
     1,12)
      IF(IUNITS.EQ.1) CALL NCTATE(XLN/2.-1.3,-.75,.25,11HTWIST,RAD/M,0.,
     111)
      IYSIZE=YLN
      CALL DGRID(0.,0.,1.,1.,IXSIZE,IYSIZE,0.1)
C   LOAD X ARRAY.
      DO 176 I=NRL,NRU
      X(I-NRL+1) =      (ABS(DTA(I,MIN))+ABS(DTA(I,MIN+1))-ABS(DTA(I,MIN+
     12))-ABS(DTA(I,MIN+3)))/(2.*ALENGTH*RLENGTH)
      IF(IUNITS.EQ.0) X(I-NRL+1)= X(I-NRL+1) *180./PI
  176 CONTINUE
```

```
C   LOAD Y ARRAY.
        DO 177 I=NRL,NRU
  177 Y(I-NRL+1)=ABS(CTA(I,1))
C   PRINT + PLOT
        CALL PRTPLT(1,1,INDAVG,IGAGES,-2,NRL,NRU,NP,X,Y,YLN)
        IF(MOD.NE.1) GO TO 179
        DO 1532 I=NRLSLP,NRUSLP
        X(I-NRLSLP+1)=X(I-NRL+1)
 1532 Y(I-NRLSLP+1)=Y(I-NRL+1)
        NPSLP=NRUSLP-NRLSLP+1
        CALL SLP(X,Y,XBR,YBR,EX,NPSLP,XMULT,YMULT)
        PRINT 154,EX,NRLSLP,NRUSLP
  154 FORMAT(//5X*SLOPE OF CURVE = * E12.5,4X,*FOR FRAMES*
     1  I4 *  THROUGH*  I4 //)
  179 RETURN
        END
```

```
        SUBROUTINE PRTPLT(ISPEC,ITEST,INDAVG,IGAGES,IGAG,NRL,NRU,NP,X,Y,
     1YLN)
C
C   PRINTS + PLOTS POINTS FROM X,Y ARRAYS.
C
        DIMENSION IGAGES(4), X(400), Y(400)
        DIMENSION NOPLT2(18),IFRAM(400)
        COMMON OMOVE,IPLOTS,NOPLT(18),XLN,AY,BX,IUTS
        IXM = 1
        IYM = 1
        IFRAM(1)  = NRL
        DO 25 K = 2,NP
   25   IFRAM(K)  = IFRAM(K-1) + 1
        IF(BX.EQ.1) IXM = 1
        IF(BX.EQ.10**6) IXM = 2
        IF(IUTS.EQ.1) GO TO 20
C
C       U.S. CUSTOMARY UNITS
C
        IF(AY.EQ.1) IYM = 1
        IF(AY.EQ..001) IYM = 2
        GO TO 21
C
C       S I UNITS
C
   20   IF(AY.EQ.1) IYM = 1
        IF(AY.EQ..001) IYM = 2
        IF(AY.EQ.1.E-06) IYM = 3
        IF(AY.EQ.1.E-09) IYM = 4
        IF(AY.EQ.1.E-12)  IYM = 5
   21   CONTINUE
        RL=NRL+0.
        RU=NRU+0.
        IF(IGAG .LE. 0) GO TO 183
```

```
      JGAG=IGAG-1
      PRINT 181,JGAG,NRL,NRU
  181 FORMAT(1H1,* STRESS-STRAIN PCINTS FOR SG-*,I2,*   FRAMES *,I3,* TH
     1ROUGH *,I3)
      CALL NOTATE(1.,YLN+.35,.1,3HSG-,0.,3)
      GAG=IGAG-1.
      CALL NUMBER(1.+1.8/7.,YLN+.35,.1,GAG,0.,-1)
      GO TO 189
  183 IF(ITEST .NE. 0) GO TO 186
      PRINT 184, IGAGES,NRL,NRU
  184 FORMAT(1H1,*STRESS-STRAIN POINTS FOR AVG OF GAGES *,4I3,*  FRAMES
     1*,I3,* THROUGH *,I3)
      CALL NOTATE(1.,YLN+.35,.1,6HAVG OF,0.,6)
      N=0
      DO 1845 I=1,4
      IF(IGAGES(I) .EQ. 0) GC TO 1845
       UM=IGAGES(I)
      N=N+1
      CALL NUMBER(1.+3.6/7.+N*1.6/7.,YLN+.35,.1,UM,0.,-1)
 1845 CONTINUE
      GO TO 189
  186 IF(IGAG .NE. -2)GO TO 188
      PRINT 187, NRL,NRU
  187 FORMAT(1H1,* TORQUE TWIST PCINTS, FRAMES *,I3,* THROUGH *,I3)
      GO TO 189
  188 IF(IGAG.NE.0) GO TO 1882
      PRINT 1881, NRL,NRU
 1881 FORMAT(1H1,* AVG STRESS-STRAIN POINTS FOR FRAMES *,I3,* THROUGH *,
     1I3)
      K=1
      DO 10 N=1,18
      IF(NOPLT(N).EQ.0) GO TC 10
      NOPLT2(K)=NOPLT(N)
      K=K+1
   10 CONTINUE
      K=K-1
      IF(K.EQ.0) GO TO 15
      PRINT 11
   11 FORMAT(1H ,* GAGES OMITTED ARE *)
      PRINT 12, (NOPLT2(N),N=1,K)
   12 FORMAT(1H+,22X,18I3)
   15 CONTINUE
      CALL NOTATE(1.,YLN+.35,.1,8HAVG PLCT,0.,8)
      GO TO 189
 1882 PRINT 1883,NRL,NRU
 1883 FORMAT(1H1,* STRESS-STRAIN PCINTS FOR SUM OF GAGES 1 AND 3, FRAMES
     1 *,I3,* THROUGH *,I3)
      CALL NOTATE(1.,YLN+.35,.1,11HSG-1 + SG-3,0.,11)
  189 CONTINUE
      IF( IGAG.EQ.-2) GO TO 216
      PRINT 900
  900 FORMAT(1H0,1X, 4(28HFRAME     STRESS      STRAIN   ))
      IF(IUTS.EQ.1) GO TO 22
      GO TO (200,201) , IYM
  200 PRINT 901
  901 FORMAT(1H ,1X, 4(28H            PSI                ))
      GO TO 203
  201 PRINT 902
  902 FORMAT(1H ,1X, 4(28H            KSI                ))
  203 GO TO (204,205), IXM
```

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```
 204 PRINT 903
 903 FORMAT(1H+,1X, 4(28H                             IN/IN   ))
     GO TO 215
 205 PRINT 904
 904 FORMAT(1H+,1X, 4(28H                             MICRO   ))
     PRINT 905
 905 FORMAT(1H ,1X, 4(28H                             IN/IN   ))
     GO TO 215
  22 GO TO (206,207,208,209,210), IYM
 206 PRINT 906
 906 FORMAT(1H ,1X, 4(28H          PA                         ))
     GO TO 212
 207 PRINT 907
 907 FORMAT(1H ,1X, 4(28H         KPA                         ))
     GO TO 212
 208 PRINT 908
 908 FORMAT(1H ,1X, 4(28H         MPA                         ))
     GO TO 212
 209 PRINT 909
 909 FORMAT(1H ,1X, 4(28H         GPA                        .))
     GO TO 212
 210 PRINT 910
 910 FORMAT(1H ,1X, 4(28H         TPA                         ))
 212 GO TO (213,214),IXM
 213 PRINT 911
 911 FORMAT(1H+,1X, 4(28H                              M/M    ))
     GO TO 215
 214 PRINT 912
 912 FORMAT(1H+,1X, 4(28H                             MICRO   ))
     PRINT 913
 913 FORMAT(1H ,1X, 4(28H                              M/M    ))
     GO TO 215
 216 CONTINUE
C
C      TORQUE TWIST DATA
C
     PRINT 915
 915 FORMAT(1H0,1X, 4(28HFRAME     TORQUE       TWIST      ))
     IF(IUTS.EQ.1) GO TO 217
     PRINT 916
 916 FORMAT(1H ,1X  4(28H          IN-LBS      DEG/IN      ))
     GO TO 215
 217 PRINT 917
 917 FORMAT(1H ,1X, 4(28H          N-M         RAD/M       ))
 215 CONTINUE
     PRINT 191,((IFRAM(N),Y(N),X(N)),N =1,NP)
 191 FORMAT(1H ,1X, 4(I4,2E12.4))
     CALL NOTATE(1.,YLN+.2,.1,11HFR     -     ,0.,11)
     CALL NUMBER(1.+1.8/7.,YLN+.2,.1,RL,0.,-1)
     CALL NUMBER(1.+4.8/7.,YLN+.2,.1,RU,0.,-1)
     CALL LINPLT(X,Y,NP,1,0,0,1,0)
     RETURN
     END
```

APPENDIX B

```
      SUBROUTINE SLP(X,Y,XBR,YBR,SP,NU,XMULT,YMULT)
C
C     ROUTINE TO DETERMINE LINE OF BEST FIT
C      Y- YBR = SP*(X - XBR)
C
      DIMENSION X(400),Y(400)
      DO 20 I=1,NU
      X(I)=X(I)/XMULT
   20 Y(I)=Y(I)/YMULT
      XBR = X(1) /NU
      YBR = Y(1) /NU
      DO 10 JK =2, NU
      XBR = XBR + X(JK)/NU
      YBR = YBR + Y(JK)/NU
   10 CONTINUE
C
      AN = X(1)* Y(1)
      DO 11 JK = 2,NU
      AN = AN + X(JK)* Y(JK)
   11 CONTINUE
      AD = X(1)* X(1)
      DO 12 JK =2,NU
      AD = AD + X(JK)* X(JK)
   12 CONTINUE
      SP = (AN - NU* XBR* YBR ) / (AD - NU* XBR * XBR)
      RETURN
      END
```

```
      SUBROUTINE PROPLIM(X,Y,NRL,NRU,NP,XMULT,YMULT,IUNITS)
      DIMENSION X(400),Y(400),ETAN(400)
      DIMENSION YPS(400),YPTS(400,1),W(400),RESID(400,1),SUM(1),
     1  A(3,3),B(3,1),C(400,1)   ,XP(400)
      COMMON UMOVE,IPLOTS,NOPLT(18),XLN,AY,BX,IUTS
      DATAW/400*1.0/
      DO 10 I=1,NP
      X(I)=X(I)/XMULT
   10 Y(I)=Y(I)/YMULT
      DO 150 J =1,NP
      YPTS(J,1) = Y(J)
       XP(J) = X(J)
  150 CONTINUE
      CALLLSQPOL(XP,YPTS,W,RESID,NP,SUM,1,A,B,3,C,400,3)
      DO 151 J = 1,NP
  151 ETAN(J) = B(2,1) + 2.*B(3,1)*X(J)
      DO 152 KT = 1,NP
  152 YPS(KT) = B(1,1) + B(2,1)*X(KT) + B(3,1) *X(KT)*X(KT)
      PRINT 60
   60 FORMAT(1H1,*   STRESS              STRAIN        TANGENT MODULUS*)
      PRINT 70,((Y(I),        X(I),ETAN(I)),I =1,NP)
   70 FORMAT(1H ,3(E12.4,3X))
      CALL CALPLT(XLN+6.,0.,-3)
      CALL BSCALE(ETAN,9.,NP,1,0.,-1,0.)
```

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```
      CALL BSCALE(Y,9.,NP,1,0.,-1,0.)
      IF(IUNITS.EQ.0) CALL AXES(0.,0.,90.,9.,ETAN(NP+1),ETAN(NP+2),1.,0.
     1,19HTANGENT MODULUS,PSI,.25,19)
      IF(IUNITS.NE.0) CALL AXES(0.,0.,90.,9.,ETAN(NP+1),ETAN(NP+2),1.,0.
     1,18HTANGENT MODULUS,PA,.25,18)
      IF(IUNITS.EQ.0) CALL AXES(0.,0.,0.,9.,Y(NP+1),Y(NP+2),1.,0.,10HSTR
     1ESS,PSI,.25,-10)
      IF(IUNITS.NE.0) CALL AXES(0.,0.,0.,9.,Y(NP+1),Y(NP+2),1.,0.,9HSTRE
     1SS,PA,.25,-9)
      CALL DGRID(0.,0.,1.,1.,9,9,0.1)
      CALL LINPLT(Y,ETAN,NP,1,0,C,1,0)
      RETURN
      END
```

```
      SUBROUTINE LSQPOL(X,Y,W,RESID,N,SUM,L,A,B,M,C,NMAX,MMAX)
********* DOCUMENT DATE 08-01-68   SUBROUTINE REVISED 08-01-68 *********
C
      DIMENSION X(NMAX),Y(NMAX,L),RESID(NMAX,L),A(MMAX,MMAX),
     2B(MMAX,L),C(NMAX,M),SUM(L),W(NMAX)
C
   10 DO 20 I=1,N
   20 C(I,1)=1.0
   30 DO 50 J=2,M
   40 DO 50 I=1,N
   50 C(I,J)=C(I,J-1)*X(I)
   60 DO 100 I=1,M
   70 DO 100 J=1,M
   80 A(I,J)=0.0
   90 DO 100 K=1,N
  100 A(I,J)=A(I,J)+C(K,I)*C(K,J)*W(K)
  105 DO 150 J=1,L
  110 DO 150 I=1,M
  120 B(I,J)=0.0
  130 DO 150 K=1,N
  150 B(I,J)=B(I,J)+C(K,I)*Y(K,J)*W(K)
      CALL MATINV (A,M,B,L,DETERM,RESID, C,MMAX,ISCALE)
  180 DO 205 J=1,L
  185 SUM(J)=0.0
      KK=M
  192 DO 195 K=1,M
      C(K,1)=B(KK,J)
  195 KK=KK-1
  198 DO 205 I=1,N
      RESID(I,J)=POLYEI(X(I),M,C)-Y(I,J)
  205 SUM(J)=SUM(J)+RESID(I,J)**2*W(I)
  210 RETURN
      END
```

APPENDIX C

DESCRIPTION OF FORTRAN VARIABLES

The following list contains a description of the significant FORTRAN variables appearing in the program. The dimensions for each array are given by using the notation A(m,n). The variables which are input are not presented here since they are described in the section "Input."

FORTRAN variable	Description
AC2(99)	temporary storage for input data
B(3,1)	stores coefficients of the polynomial fitted to the data points
DTA(415,20)	stores input data for all channels
ETAN(400)	stores tangent moduli at each data point
EX	slope of the line of best fit to a specified section of the curve
FAC	number by which load is divided to get stress (refer to table I)
IPLOTS	number of curves to be plotted for this submission; determined by the computer from information given by the user
KNTRUN	number of plots that have been made for this submission
KOUNT	number of graphs that have been made. This is printed at the end of output.
NP	number of points to be plotted
NPSLP	number of points to be used in finding the slope of the line of best fit
PI	PI = 3.14159
RMAXSS	maximum stress to be plotted
X(400)	stores strain values to be plotted
XMULT	strains, read in units of in./in. are multiplied by XMULT; if the maximum strain is less than 0.1 in./in., XMULT = 10^6 and strains are changed to micro in./in.; otherwise, XMULT = 1. (When data are expressed in SI Units, strain is in m/m and micro m/m.)
XP(400)	temporary storage area used in computing the second-order polynomial which provides the least-squares fit to curve

FORTRAN variable	Description
XSC	units per inch on X-axis for stress-strain curves
XSC2	units per inch on X-axis for torque-twist curves
XXLN	distance over which strain values are scaled
Y(400)	stores stress values to be plotted
YMULT	stresses in psi are multiplied by YMULT; if the maximum stress is greater than 1000 psi, YMULT = 0.001 and stresses are changed to ksi; otherwise, YMULT = 1. (When data are expressed in SI Units, stress is in Pa and MPa.)
YPTS(400,1)	temporary storage area used in computing the second-order polynomial which provides the least-squares fit to curve
YSC	units per inch on Y-axis for stress-strain curves
YSC2	units per inch on Y-axis for torque-twist curves

APPENDIX D

LANGLEY LIBRARY SUBROUTINE MATINV

Language: FORTRAN

Purpose: MATINV solves the matrix equation $AX = B$, where A is a square coefficient matrix and B is a matrix of constant vectors. The solution to a set of simultaneous equations, the matrix inverse, and the determinant may be obtained.

Use: CALL MATINV(A,N,B,M,DETERM,IPIVOT,INDEX,NMAX,ISCALE)

A	A two-dimensional array of the coefficients. On return to the calling program, A^{-1} is stored in A
N	The order of A, $1 \leqq N \leqq NMAX$
B	A two-dimensional array of the constant vectors B. On return to the calling program, X is stored in B
M	The number of column vectors in B. The expression $M = 0$ signals that the subroutine is used solely for inversion; however, in the CALL statement an entry corresponding to B must still be present
DETERM	Gives the value of the determinant by the formula $DET(A) = \left(10^{100}\right)^{ISCALE}(DETERM)$
IPIVOT	A one-dimensional array of temporary storage used by the routine
INDEX	A two-dimensional array of temporary storage used by the routine
NMAX	The maximum order of A as stated in the DIMENSION statement of the calling program
ISCALE	A scale factor computed by the subroutine to keep the results of computation within the floating-point word size of the computer

Restrictions: Arrays A, B, IPIVOT, and INDEX have variable dimensions in the subroutine. The maximum size of these arrays must be specified in a DIMENSION statement of the calling program as A(NMAX,NMAX), B(NMAX,M), IPIVOT(NMAX), and INDEX(NMAX,2). The original matrices A and B are destroyed. They must be saved by the user if there is further need for them. The determinant is set to zero for a singular matrix.

Method: Jordan's method is used to reduce a matrix A to the identity matrix I through a succession of elementary transformations l_n, l_{n-1}, . . ., l_1. A = I. If these transformations are simultaneously applied to I and to a matrix B of constant vectors, the results are A^{-1} and X where $AX = B$. Each transformation is selected so that the largest element is used in the pivotal position. (See ref. (a).)

Accuracy: Total pivotal strategy is used to minimize the rounding errors; however, the accuracy of the final results depends upon how well-conditioned the original matrix is.

Reference: (a) Fox, L.: An Introduction to Numerical Linear Algebra. Oxford Univ. Press, 1965.

Storage: 542_8 locations.

APPENDIX D

A listing of subroutine MATINV is as follows:

```
      SUBROUTINE MATINV(A,N,B,M,DETERM,IPIVOT,INDEX,NMAX,ISCALE)
********* DOCUMENT DATE 08-01-68   SUBROUTINE REVISED 08-01-68 *********
C
C     MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C
      DIMENSION IPIVOT(N),A(NMAX,N),B(NMAX,M),INDEX(NMAX,2)
      EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)
C
C     INITIALIZATION
C
    5 ISCALE=0
    6 R1=10.0**100
    7 R2=1.0/R1
   10 DETERM=1.0
   15 DO 20 J=1,N
   20 IPIVOT(J)=0
   30 DO 550 I=1,N
C
C     SEARCH FOR PIVOT ELEMENT
C
   40 AMAX=0.0
   45 DO 105 J=1,N
   50 IF (IPIVOT(J)-1) 60, 105, 60
   60 DO 100 K=1,N
   70 IF (IPIVOT(K)-1) 80, 100, 740
   80 IF (ABS(AMAX)-ABS(A(J,K)))85,100,100
   85 IROW=J
   90 ICOLUM=K
   95 AMAX=A(J,K)
  100 CONTINUE
  105 CONTINUE
      IF (AMAX) 110,106,110
  106 DETERM=0.0
      ISCALE=0
      GO TO 740
  110 IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
C
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
  130 IF (IROW-ICOLUM) 140, 260, 140
  140 DETERM=-DETERM
  150 DO 200 L=1,N
  160 SWAP=A(IROW,L)
  170 A(IROW,L)=A(ICOLUM,L)
  200 A(ICOLUM,L)=SWAP
  205 IF(M) 260, 260, 210
  210 DO 250 L=1, M
  220 SWAP=B(IROW,L)
  230 B(IROW,L)=B(ICOLUM,L)
  250 B(ICOLUM,L)=SWAP
  260 INDEX(I,1)=IROW
  270 INDEX(I,2)=ICOLUM
  310 PIVOT=A(ICOLUM,ICOLUM)
      IF (PIVOT) 1000,106,1000
C
C     SCALE THE DETERMINANT
C
 1000 PIVOTI=PIVOT
 1005 IF(ABS(DETERM)-R1)1030,1010,1010
 1010 DETERM=DETERM/R1
      ISCALE=ISCALE+1
      IF(ABS(DETERM)-R1)1060,1020,1020
```

```
 1020 DETERM=DETERM/R1
      ISCALE=ISCALE+1
      GO TO 1060
 1030 IF(ABS(DETERM)-R2)1040,1040,1060
 1040 DETERM=DETERM*R1
      ISCALE=ISCALE-1
      IF(ABS(DETERM)-R2)1050,1050,1060
 1050 DETERM=DETERM*R1
      ISCALE=ISCALE-1
 1060 IF(ABS(PIVOTI)-R1)1090,1070,1070
 1070 PIVOTI=PIVOTI/R1
      ISCALE=ISCALE+1
      IF(ABS(PIVOTI)-R1)320,1080,1080
 1080 PIVOTI=PIVOTI/R1
      ISCALE=ISCALE+1
      GO TO 320
 1090 IF(ABS(PIVOTI)-R2)2000,2000,320
 2000 PIVOTI=PIVOTI*R1
      ISCALE=ISCALE-1
      IF(ABS(PIVOTI)-R2)2010,2010,320
 2010 PIVOTI=PIVOTI*R1
      ISCALE=ISCALE-1
  320 DETERM=DETERM*PIVOTI
C
C      DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
  330 A(ICOLUM,ICOLUM)=1.0
  340 DO 350 L=1,N
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT
  355 IF(M) 380, 380, 360
  360 DO 370 L=1,M
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT
C
C      REDUCE NON-PIVOT ROWS
C
  380 DO 550 L1=1,N
  390 IF(L1-ICOLUM) 400, 550, 400
  400 T=A(L1,ICOLUM)
  420 A(L1,ICOLUM)=0.0
  430 DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
  455 IF(M) 550, 550, 460
  460 DO 500 L=1,M
  500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
  550 CONTINUE
C
C      INTERCHANGE COLUMNS
C
  600 DO 710 I=1,N
  610 L=N+1-I
  620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
  630 JROW=INDEX(L,1)
  640 JCOLUM=INDEX(L,2)
  650 DO 705 K=1,N
  660 SWAP=A(K,JROW)
  670 A(K,JROW)=A(K,JCOLUM)
  700 A(K,JCOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
  740 RETURN
      END
```

APPENDIX E

STRAIN AND DISPLACEMENT TRANSDUCER LOCATIONS ON TORSION SPECIMEN

Most torsion tests on tubular specimens are conducted with one or more strain rosettes and four LVDT's or similar instruments for measuring rotation. In order to keep user instructions at a minimum, a pattern for identifying the strain gages and rosettes was selected. (See fig. 10.) Starting with the first strain rosette and continuing clockwise around the circumference of the cylinder, the strain transducers are numbered in monotonically increasing order. The first and last transducers in each rosette are oriented at -45° and $+45^{\circ}$, respectively, to the longitudinal axis of the specimen. As shown in figure 10, LVDT's number 1 and 2 measure displacements of radial arms at a station near the rotated end of the tube (δ_1 and δ_2) whereas LVDT's 3 and 4 measure displacements δ_3 and δ_4, respectively, near the fixed end of the tube. Utilization of a different pattern for identifying transducers will generally require changes in the program in order to generate accurate and usable plots.

REFERENCE

1. Anon.: Metric Practic Guide. E 380-72, Amer. Soc. Testing & Mater., June 1972.

TABLE I.- PROGRAM CAPABILITY

Case	Specimen	Test	Plot on Y-axis	Plot on X-axis	Compute slope	Compute tangent modulus
1	Flat	Compression or tension	$\sigma = \frac{P}{wt}$	$\epsilon_1, \epsilon_2, \ldots, \epsilon_{18}$	No	No
2	Flat	Compression or tension	$\sigma = \frac{P}{wt}$	$\epsilon_1, \epsilon_2, \ldots, \epsilon_{18}$ and average of strains from up to four gages	Yes, for averaged curve	Yes, for averaged curve
3	Flat	Compression or tension	$\sigma = \frac{P}{wt}$	Average of strains from up to four gages	Yes	Yes
4	Tube	Compression or tension	$\sigma = \frac{P}{\pi(O.D. - t)t}$	$\epsilon_1, \epsilon_2, \ldots, \epsilon_{18}$	No	No
5	Tube	Compression or tension	$\sigma = \frac{P}{\pi(O.D. - t)t}$	$\epsilon_1, \epsilon_2, \ldots, \epsilon_{18}$ and average of strains from up to four gages	Yes, for averaged curve	Yes, for averaged curve
6	Tube	Compression or tension	$\sigma = \frac{P}{\pi(O.D. - t)t}$	Average of strains from up to four gages	Yes	Yes
7	Tube	Torsion	$\tau = \frac{2T}{\pi(O.D. - t)^2 t}$	$\epsilon_1, \epsilon_2, \ldots, \epsilon_{18}$	No	No
8	Tube	Torsion	$\tau = \frac{2T}{\pi(O.D. - t)^2 t}$	$\epsilon_1, \epsilon_2, \ldots, \epsilon_{18}$ and sum of absolute values from $\pm 45^\circ$ gages in one rosette	Yes, for sum of absolute values from $\pm 45^\circ$ gages	Yes, for sum of absolute values from $\pm 45^\circ$ gages
9	Tube	Torsion	$\tau = \frac{2T}{\pi(O.D. - t)^2 t}$	Average of sum of absolute values from all $\pm 45^\circ$ gage	Yes	Yes
10	Tube	Torsion	$\tau = \frac{2T}{\pi(O.D. - t)^2 t}$ and T	Average of sum of absolute values from all $\pm 45^\circ$ gages and $\theta = \frac{180(\delta_1 + \delta_2 - \delta_3 - \delta_4)}{2\pi R \ell}$	Yes, for averaged strain curve and for torque-twist curve	Yes, for averaged stress-strain curve

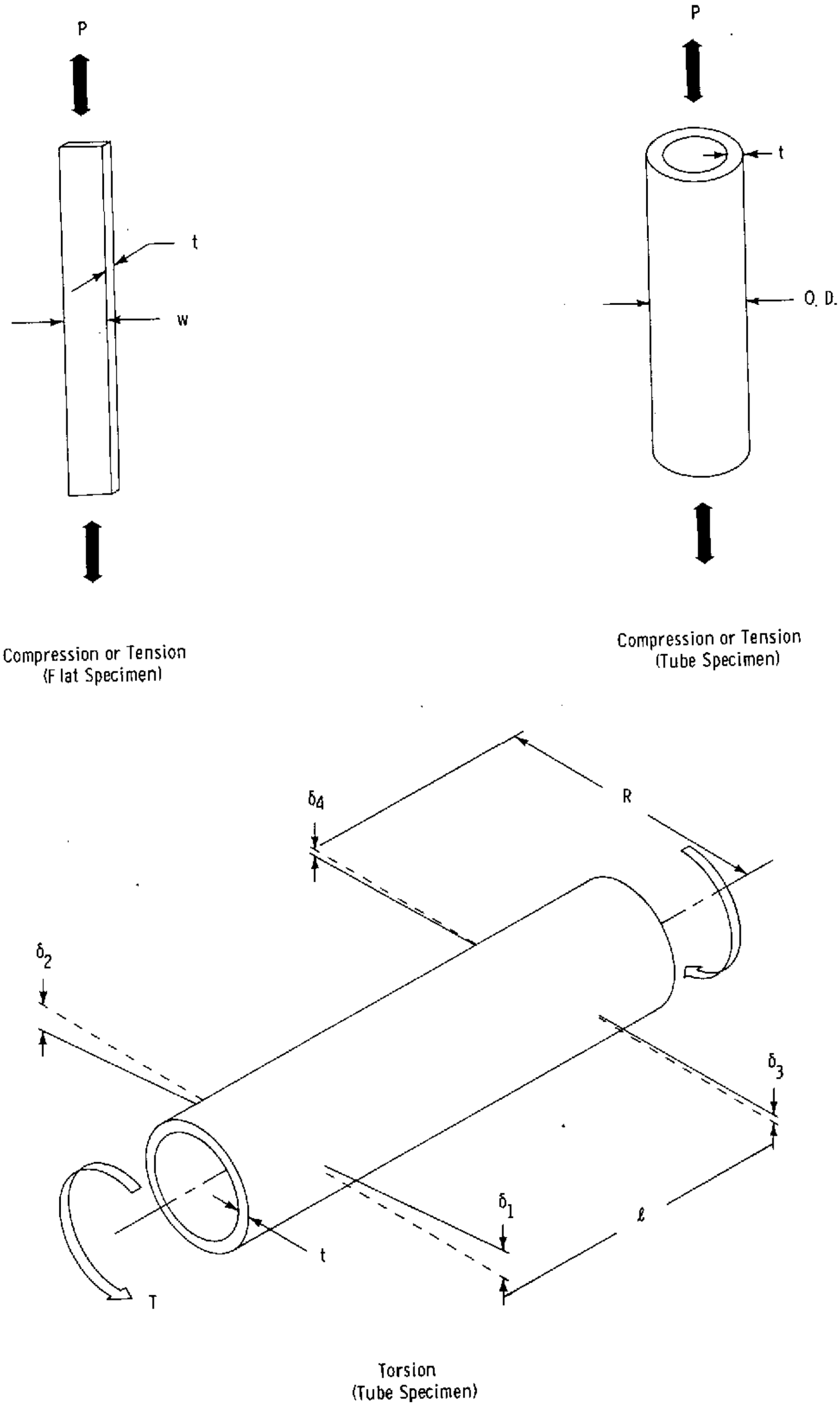


Figure 1.- Specimen geometry for compression, tension, and torsion tests.

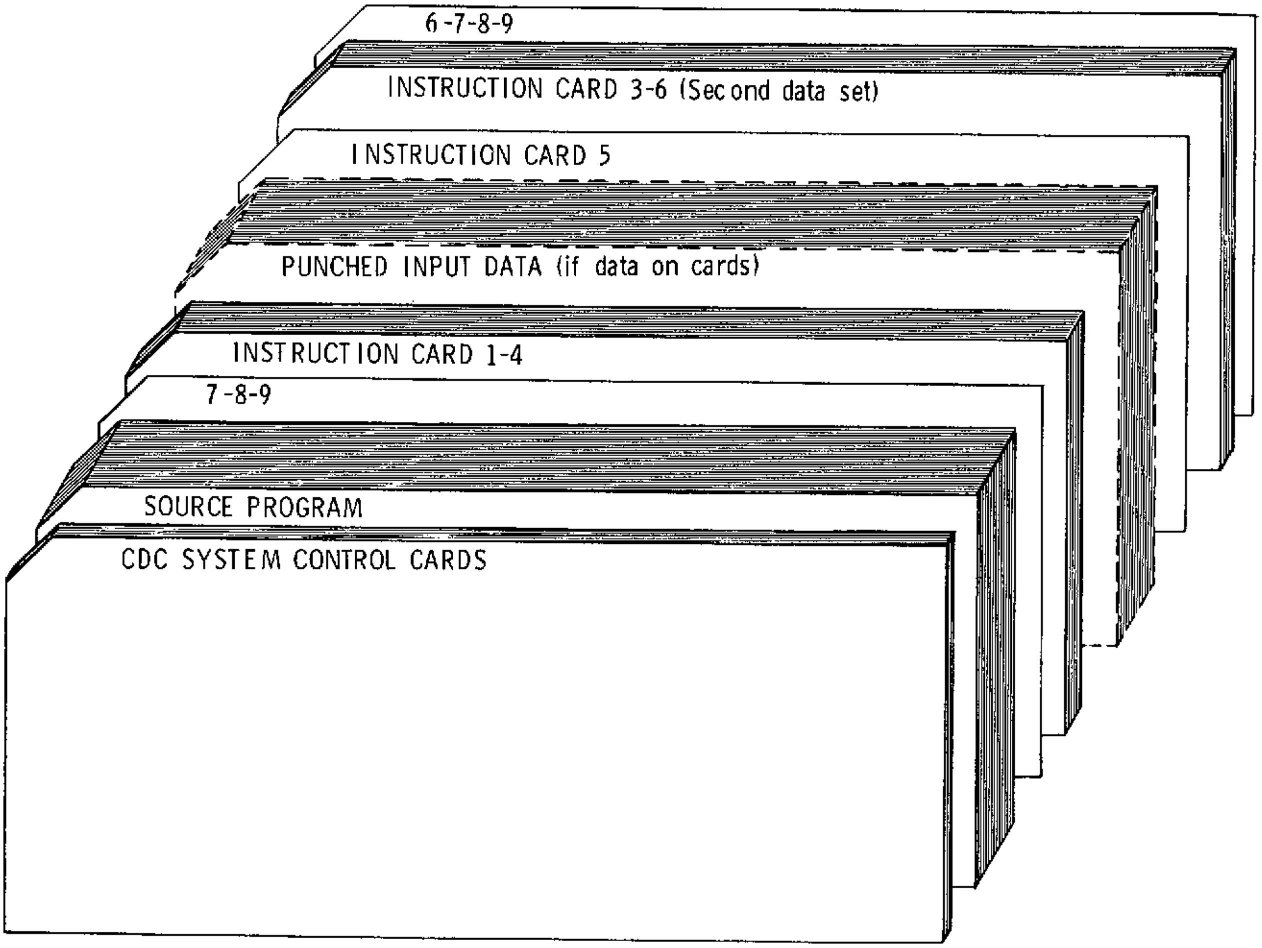


Figure 2.- Program BECKPLT deck setup.

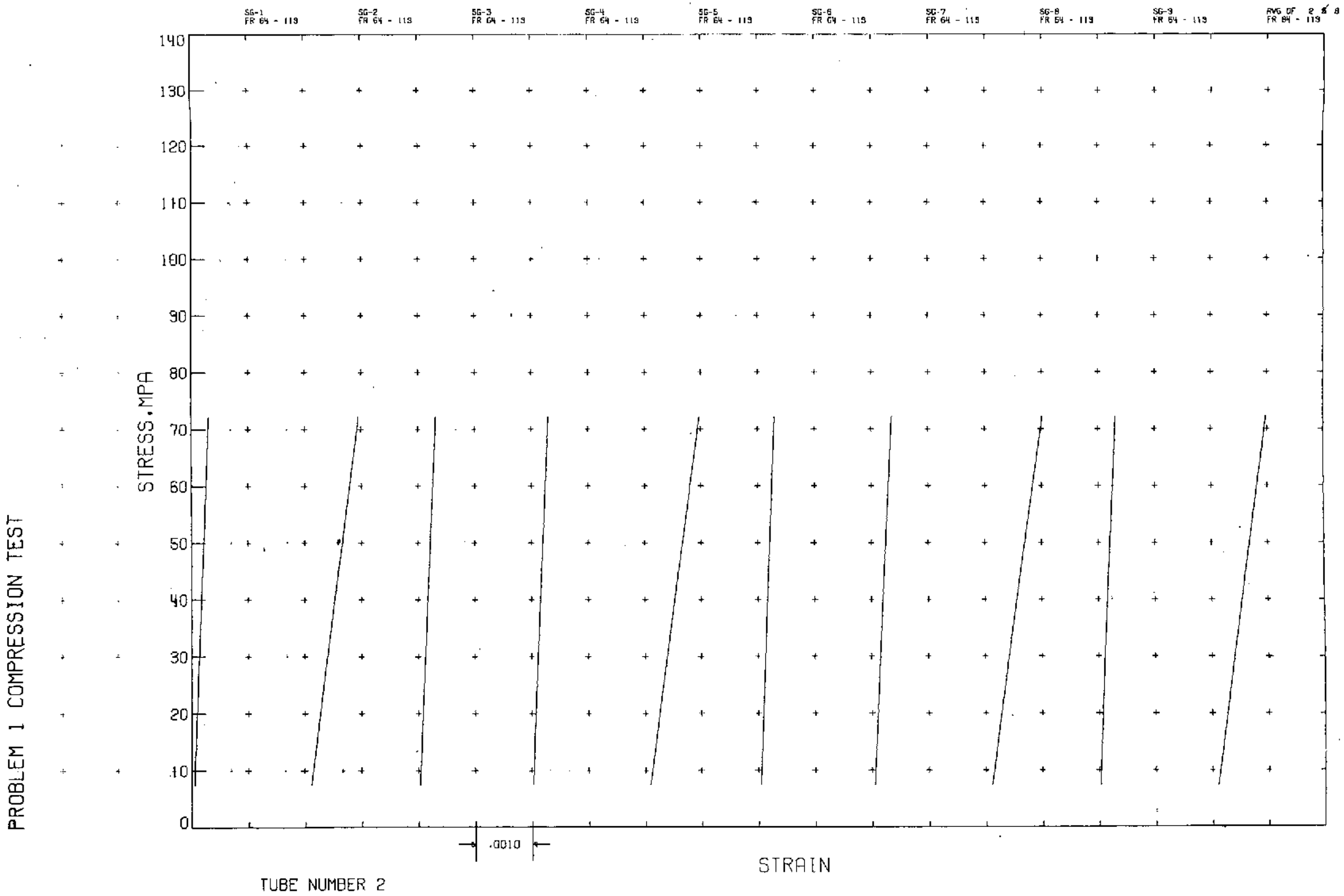


Figure 3.- Stress-strain plots developed from compression test on graphite-epoxy tube.

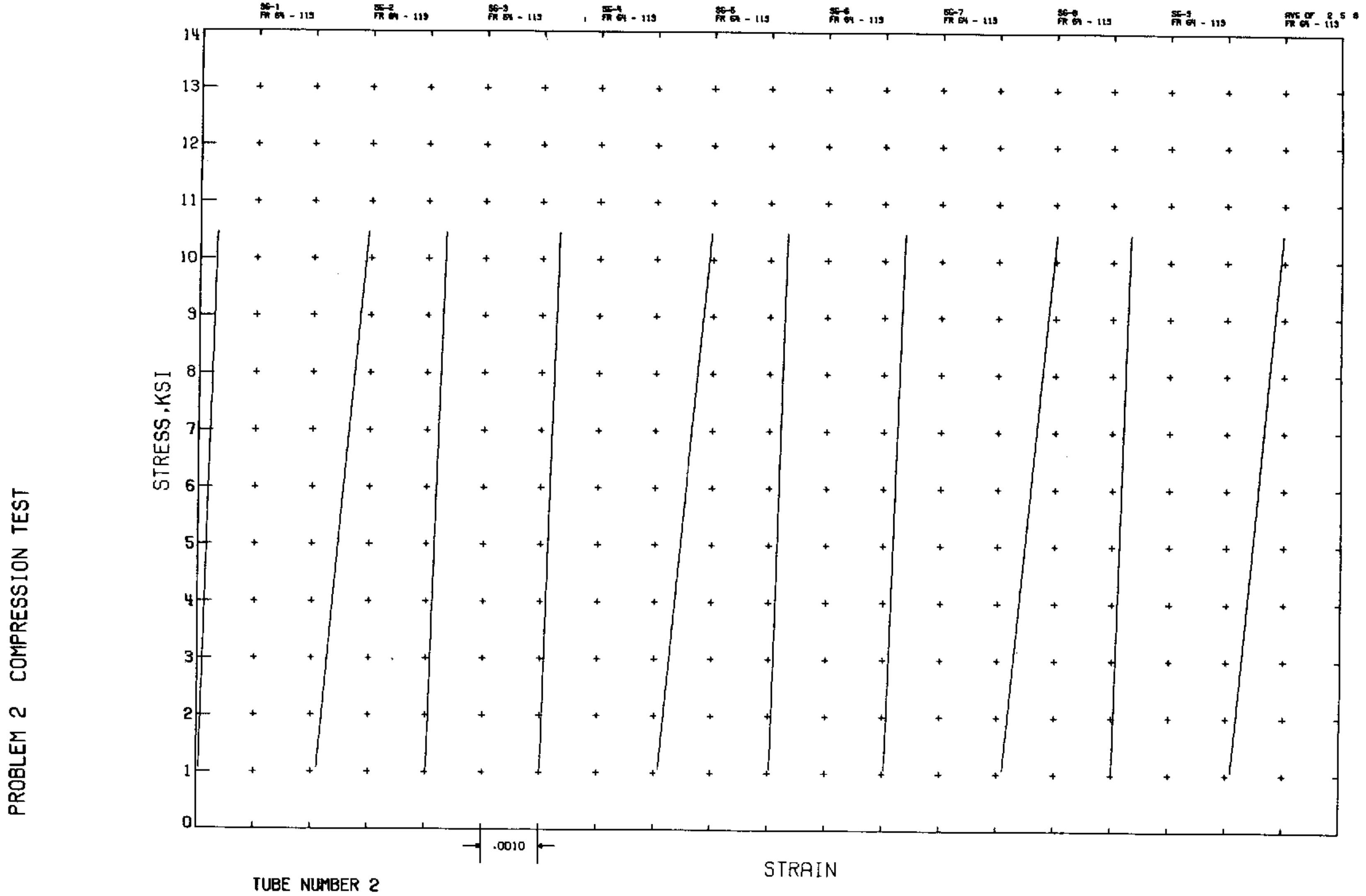


Figure 4.- Stress-strain plots developed from compression test on graphite-epoxy tube.

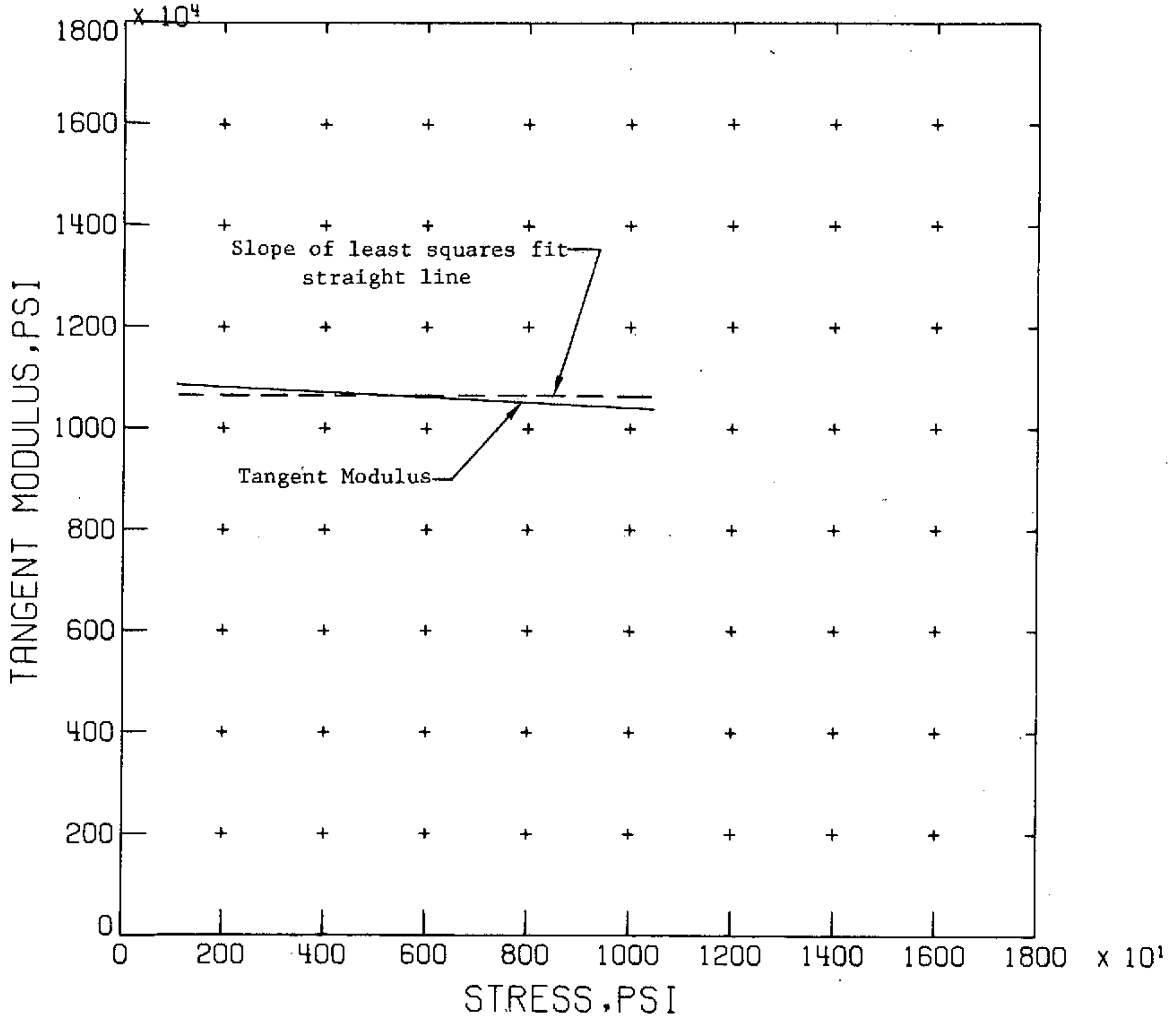


Figure 5.- Tangent-modulus—compressive-stress curve developed from compression test on graphite-epoxy tube.

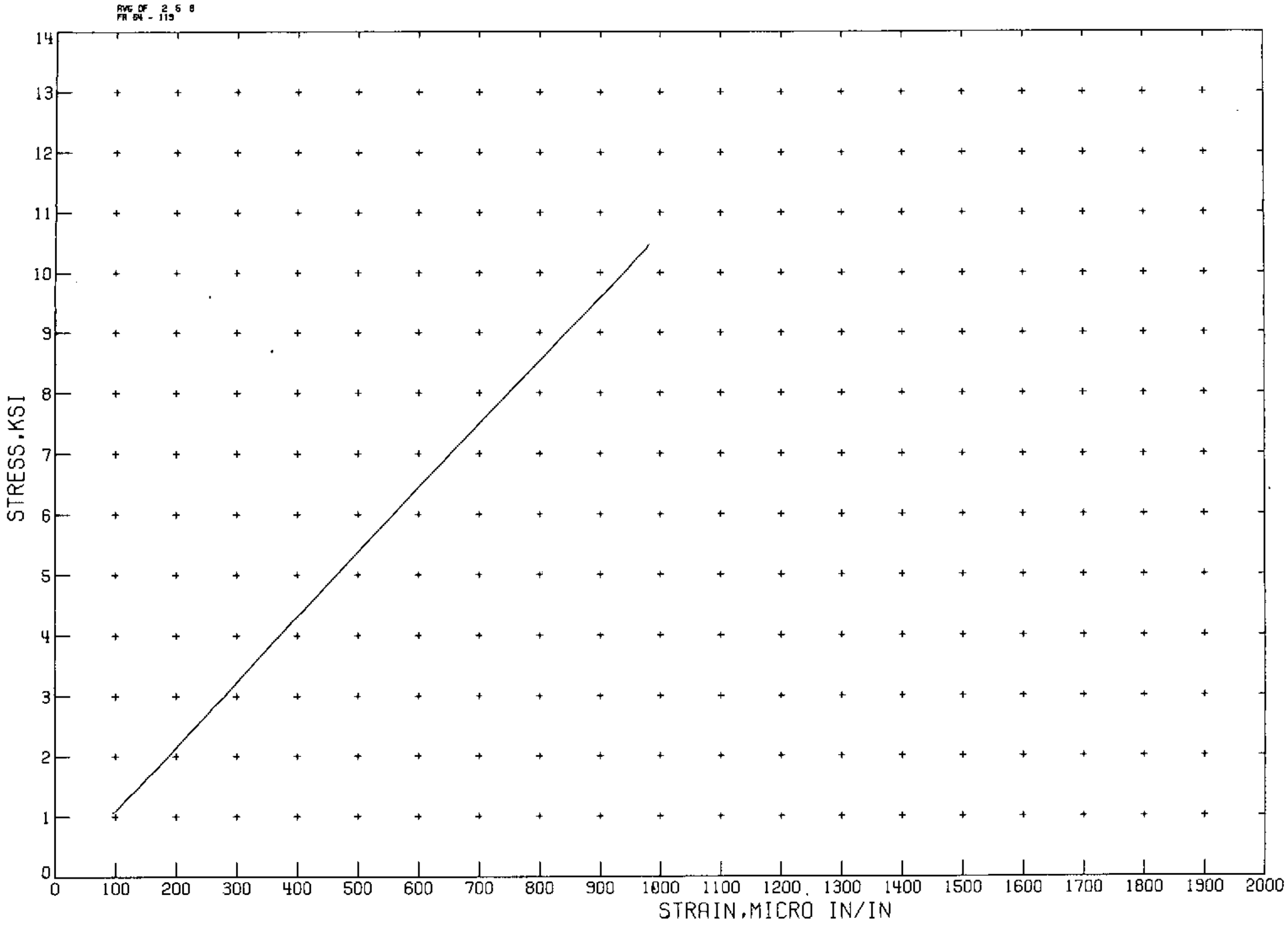


Figure 6.- Average stress-strain curve developed from compression test on graphite-epoxy tube.

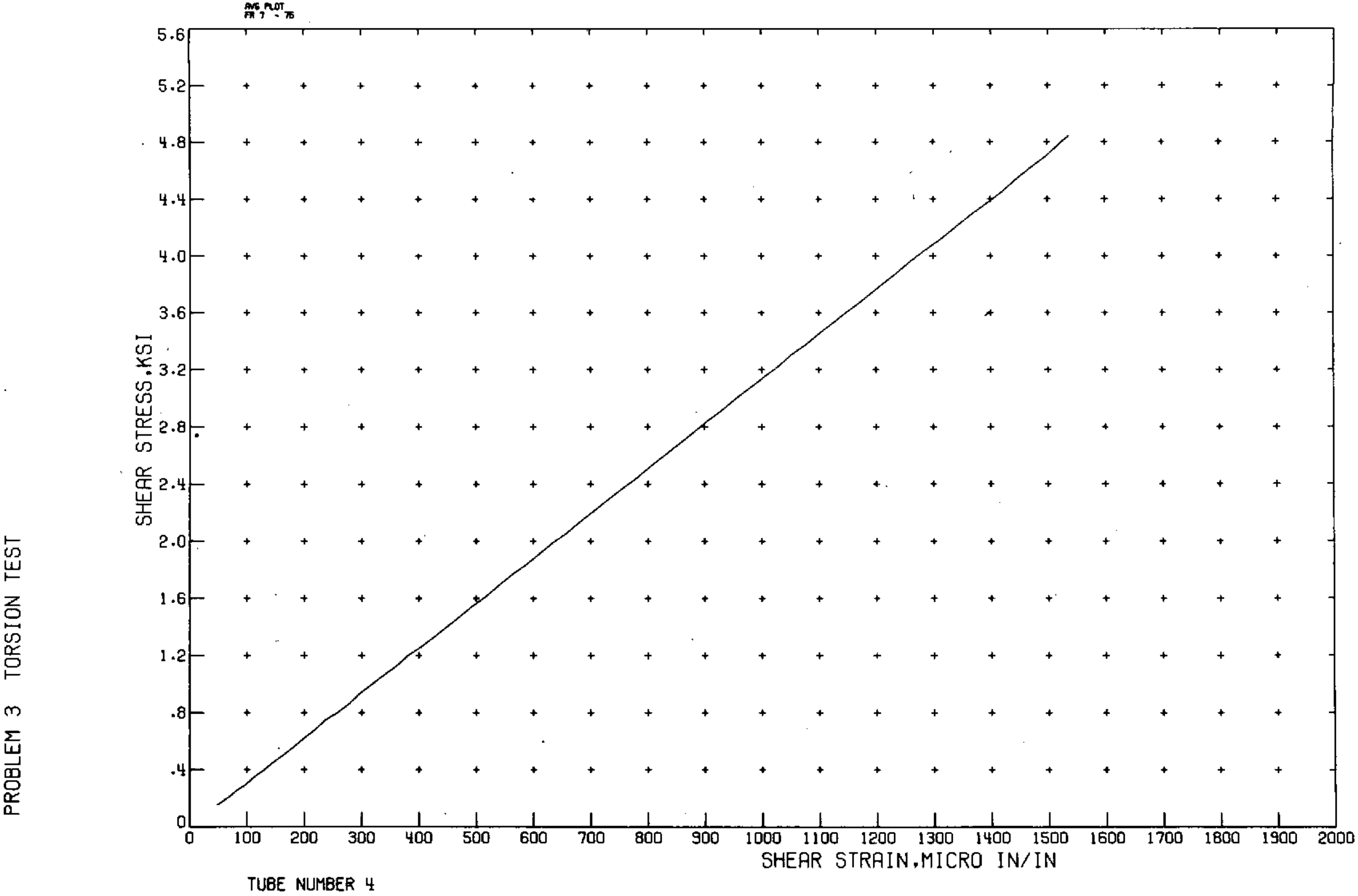


Figure 7.- Shear-stress—shear-strain curve developed from torsion test on a graphite-epoxy tube.

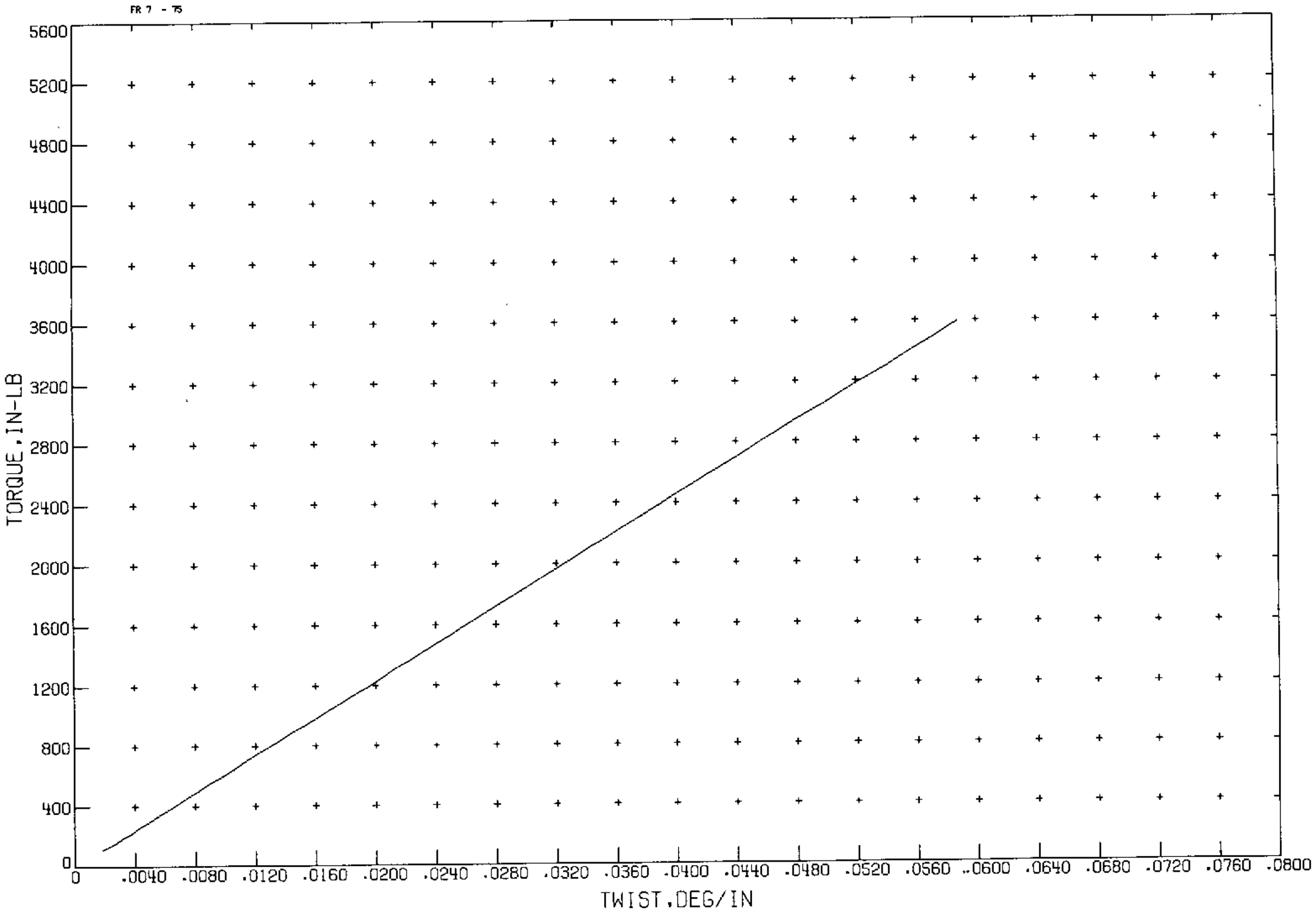


Figure 8.- Torque-twist curve for graphite-epoxy tube.

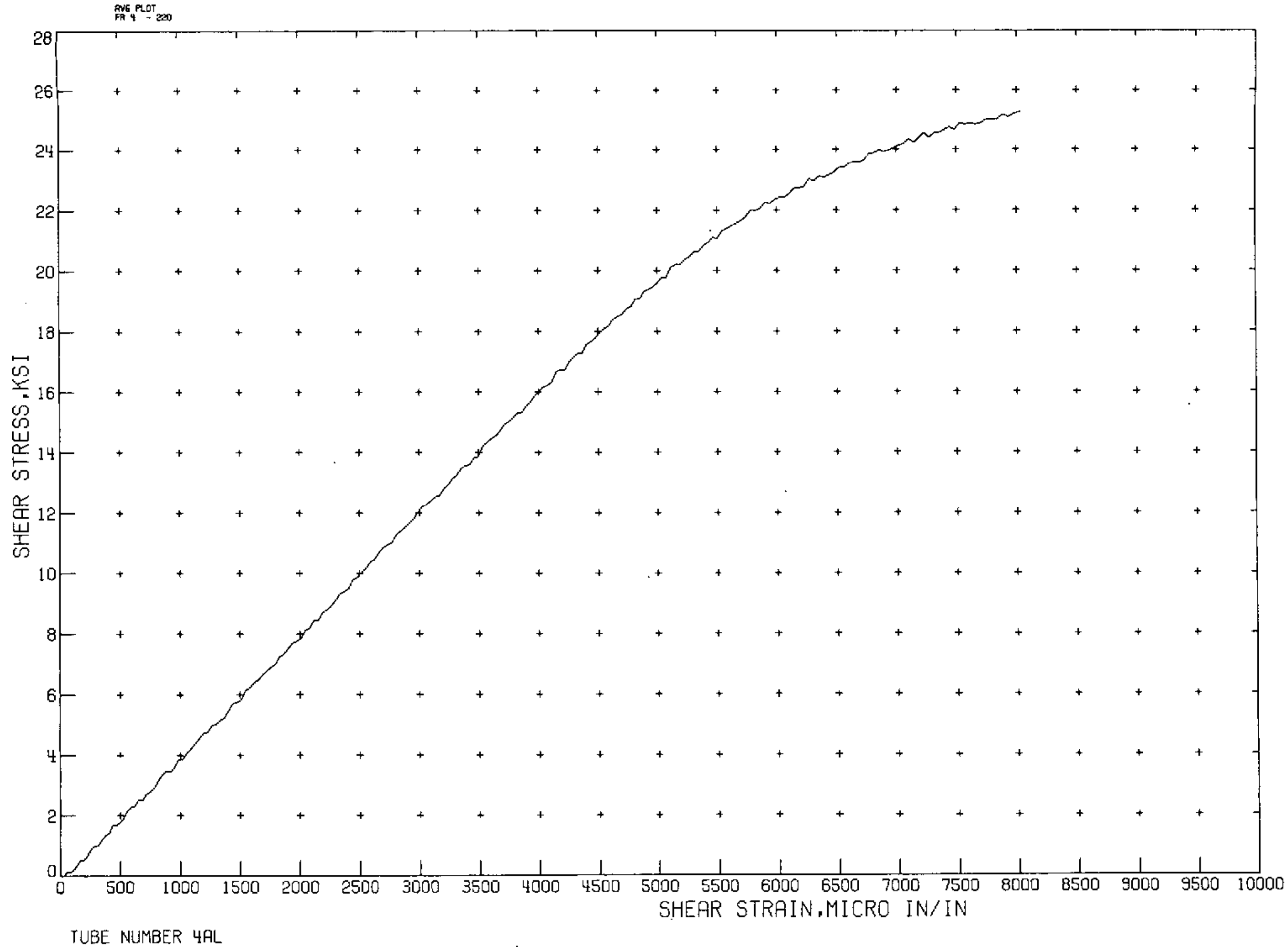
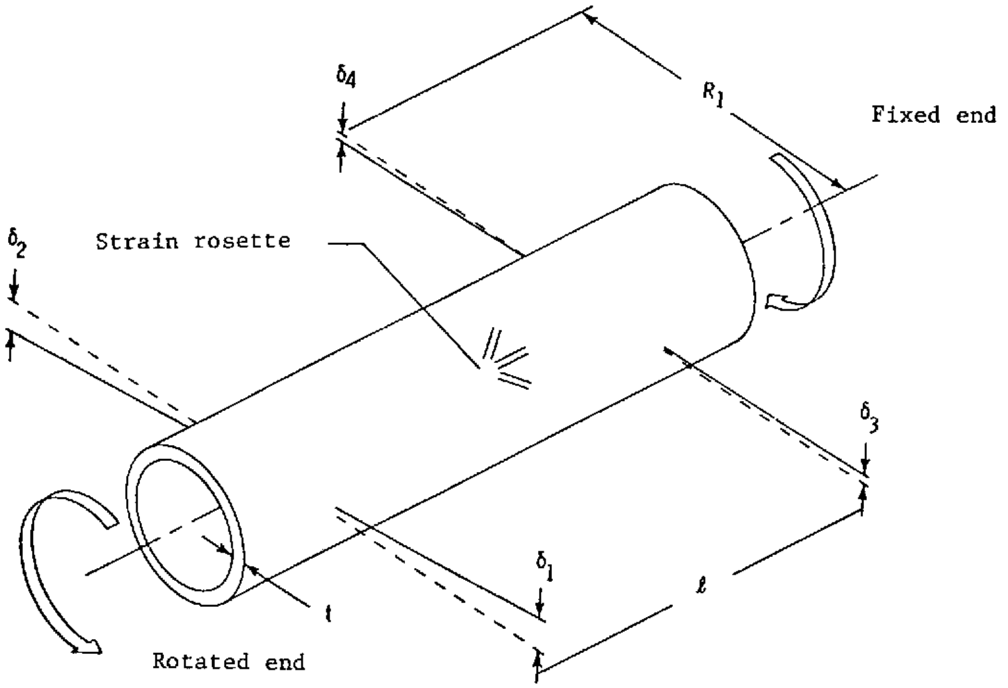
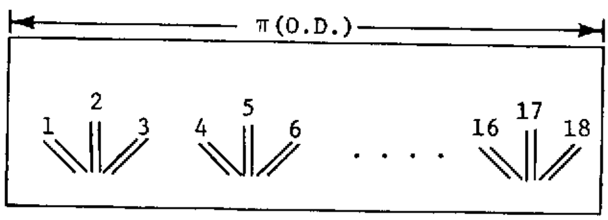


Figure 9.- Shear-stress—shear-strain curve developed from torsion test on aluminum tube.



Overview of torsion specimen



Circumferential strain gaged section of specimen

Figure 10.- Overview of torsion specimen and identification of strain-gage and LVDT numbering sequence.

NASA-Langley, 1974 L-9384