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Bethesda, Md. 20084

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FINITE ELEMENT ANALYSIS OF PIPE ELBOWS

by

Melvyn S. Marcus and Gordon C. Everstine

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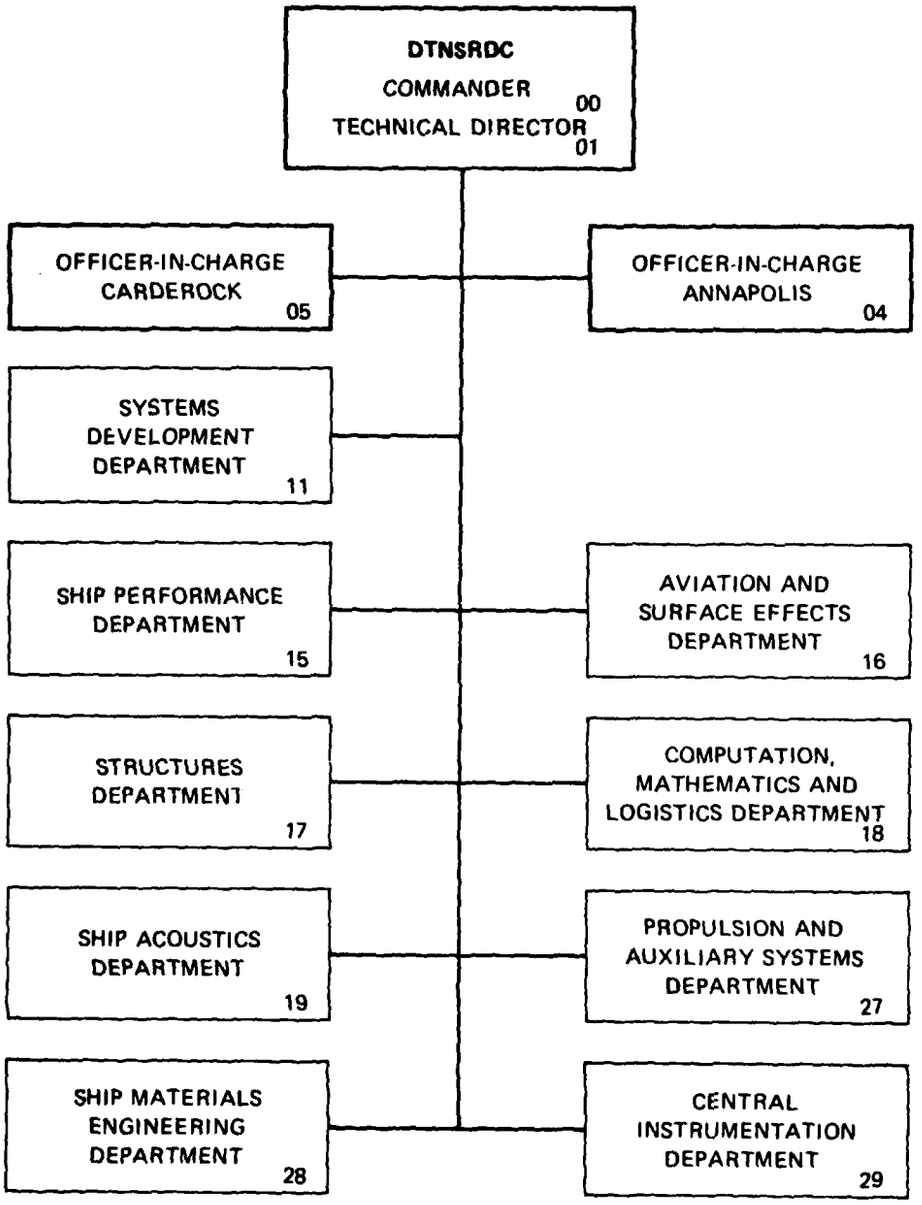

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NASTRAN analyses were performed with three different finite element models on a 90-degree pipe elbow to determine principal stresses due to internal pressure, inplane bending, out-of-plane bending, and torsion moment loadings. Comparison with stresses experimentally obtained under the four loading conditions demonstrates the adequacy of a finite element model with ideal geometry assumptions and an economical mesh spacing. Implementation of the NASTRAN modeling is described in detail. Deck set-ups for a sequence of

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computer runs to automatically generate NASTRAN input data, execute NASTRAN, and postprocess NASTRAN output are included. A sample NASTRAN data input file is also listed.

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	iv
LIST OF TABLES	iv
ABSTRACT	1
BACKGROUND	1
STATEMENT OF THE PROBLEM	2
THE NASTRAN MODELS	4
THE DATA GENERATOR	7
SOLUTION SEQUENCE	11
FLEXIBILITY FACTORS	13
RESULTS AND DISCUSSION	14
ACKNOWLEDGMENTS	24
REFERENCES	25
APPENDIX A - LISTING OF DECK TO CREATE UPDATE PROGRAM LIBRARY, COMPILE SOURCE CODE, AND CATALOG EXECUTABLE CODE FOR ELBOW DATA GENERATOR	27
APPENDIX B - LISTING OF DECK TO EXECUTE ELBOW DATA GENERATOR AND CREATE NASTRAN INPUT DATA FILE FOR MESH A	35
APPENDIX C - LISTING OF DECK TO EXECUTE NASTRAN AND SAVE STRESSES AT MIDDLE OF ELBOW	39
APPENDIX D - LISTING OF DECK TO SMOOTH PRINCIPAL STRESSES AND CREATE SOLUTION FILE IN PLOTQUICK FORMAT	41
APPENDIX E - LISTING OF NASTRAN INPUT DATA FILE FOR MESH A	45

LIST OF FIGURES

	Page
1 - Geometry and Coordinate Systems of Pipe Elbow ME-1.....	3
2 - Finite Element Model of Elbow (Mesh A).....	8
3 - Comparison of Polygonal and Smoothed Plots of Major Principal Stress at Middle of Elbow Due to Inplane Moment Load (Mesh A).....	12
4 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Pressure Load.....	16
5 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Pressure Load.....	17
6 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Inplane Moment Load.....	18
7 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Inplane Moment Load.....	19
8 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Out-of-Plane Moment Load.....	20
9 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Out-of-Plane Moment Load.....	21
10 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Torsion Moment Load.....	22
11 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Torsion Moment Load.....	23

LIST OF TABLES

1 - Measured Values of Wall Thickness for ME-1.....	1
2 - Measured Values of Outside Diameter for ME-1.....	6

LIST OF TABLES (Continued)

Page

3 - Summary of Finite Element Analyses..... 9

4 - Flexibility Factors for Mesh A..... 15

ABSTRACT

NASTRAN analyses were performed with three different finite element models on a 90-degree pipe elbow to determine principal stresses due to internal pressure, inplane bending, out-of-plane bending, and torsion moment loadings. Comparison with stresses experimentally obtained under the four loading conditions demonstrates the adequacy of a finite element model with ideal geometry assumptions and an economical mesh spacing. Implementation of the NASTRAN modeling is described in detail. Deck set-ups for a sequence of computer runs to automatically generate NASTRAN input data, execute NASTRAN, and postprocess NASTRAN output are included. A sample NASTRAN data input file is also listed.

BACKGROUND

The objective of one of DTNSRDC's programs is to reduce the size and weight of sea-water piping systems sufficiently to achieve the design goals. This objective can be accomplished in several ways: (1) by using higher strength materials, (2) by improving fabrication techniques, (3) by better designs, and (4) by less conservative structural acceptance criteria and stress factors. The third and fourth alternatives require the application of more refined structural analysis methods such as the finite element method (FEM). With the FEM, the analyst can gain a more accurate understanding of general end point motions, which influence piping system designs, as well as of motions and stresses in the piping systems themselves.

The design of piping systems depends on a knowledge of the stresses and deflections of the pipes due to the anticipated service loads. In general, these loads may be either static or dynamic. The static category includes pressure, moment, and thermal loads; the dynamic includes shock loadings. For any of these loads, the most critical locations are usually in components such as elbows and tees. It is well known, for example, that a curved pipe does not respond to bending loads in the way predicted by elementary beam theory, which is usually adequate for straight pipes.

This report describes finite element analyses of piping elbows subjected to both pressure and moment loads. The NASTRAN finite element structural analysis computer program was used. Stresses and flexibility factors were computed, and the stresses were compared to experiment. The two main purposes of the work were:

(1) to determine modeling conditions (including mesh size and ideal geometry assumptions) for which a NASTRAN finite element analysis of the pipe elbow would yield results in good agreement with experiment, and

(2) to provide deck set-ups for NASTRAN data generation and solution implementation which could be used to automate a computerized parameter study of pipe elbows.

Such a study, for example, could yield basic information on the structural behavior of elbows. Also, given the increased accuracy and reliability attainable with finite element models, compared to the less precise traditional methods, the studies could be conducted in accordance with less conservative design rules similar to those of the ASME Section III nuclear pressure vessel code.

STATEMENT OF THE PROBLEM

The structure to be analyzed is the 10-inch, schedule 40, 90-degree carbon steel pipe elbow referred to as ME-1 by the Reactor Division of the Oak Ridge National Laboratory.[1*] This elbow, one of four machined at Oak Ridge to test the effects of thinning and ovalling, was machined so as to simulate as far as possible an elbow with ideal (uniform) geometry. Details on the geometry of ME-1 are shown in Figure 1. Oak Ridge also

*A complete listing of references is given on page 25.

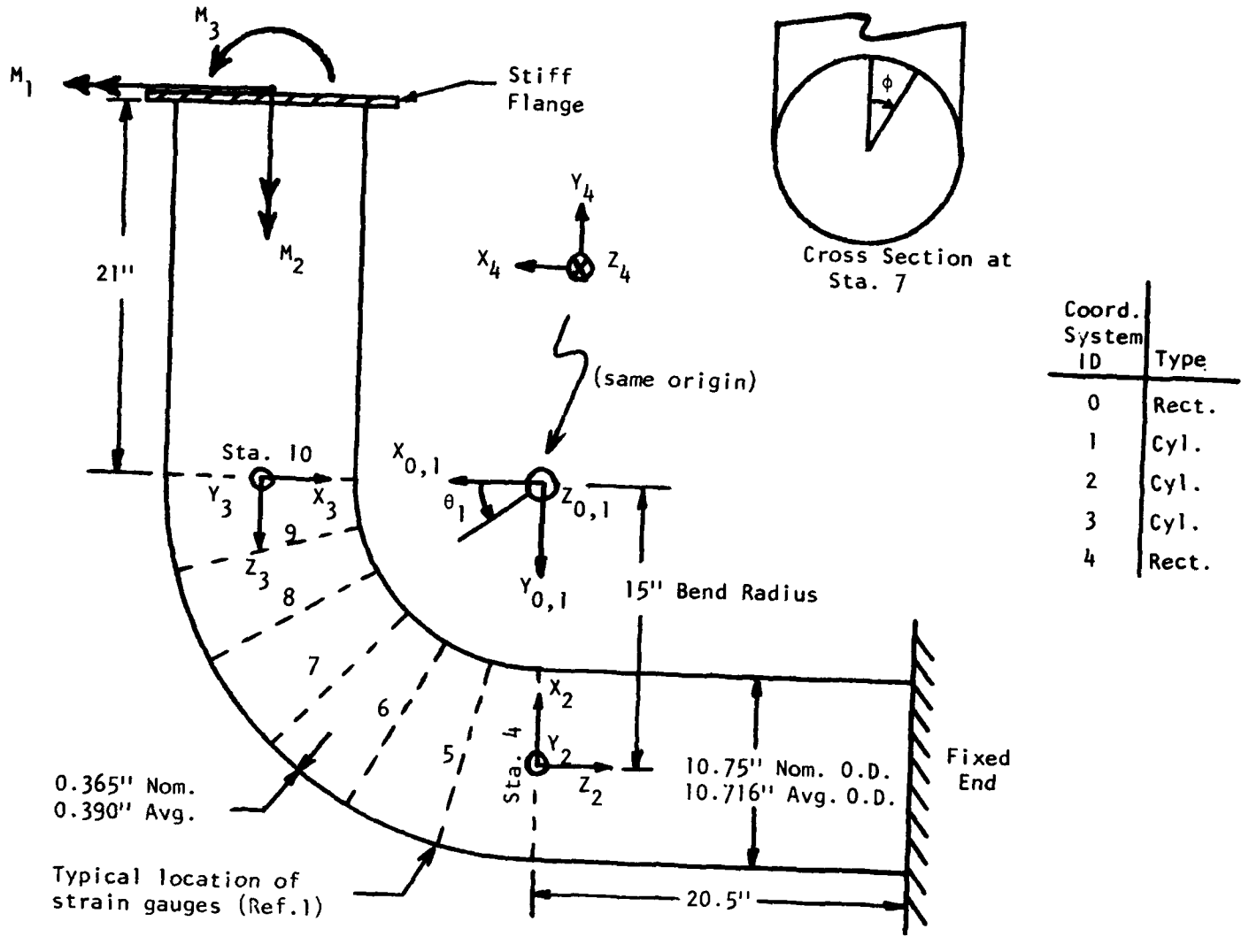

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Figure 1 - Geometry and Coordinate Systems of Pipe Elbow ME-1

made measurements of the actual wall thickness and elbow diameter for the test model; these measurements are listed in Tables 1 and 2, respectively. All values in each table were averaged to obtain the average wall thickness and outside diameter values of 0.390 inch and 10.716 inches, respectively. Thus the average value of mean radius (to middle of wall) is 5.163 inches.

This elbow structure was subjected to four different loadings:

(1) internal pressure of 75.53 psi

(2) in-plane moment of 32,660 in-lb (M_3 = -32660 in Figure 1)

(3) out-of-plane moment of 32,660 in-lb (M_1 = 32660 in Figure 1)

(4) torsional moment of 32,660 in-lb (M_2 = 32660 in Figure 1)

These loads were also used for the analysis.

The material properties of carbon steel are $E = 2.9 \times 10^7$ psi (Young's modulus) and $\nu = 0.3$ (Poisson's ratio).

THE NASTRAN MODELS

Three analyses were performed:

Mesh A -- a uniformly spaced mesh of finite elements (Figure 2) for an ideal (uniform geometry) elbow having the same thickness and diameter throughout; the values used for the wall thickness and middle radius were the mean values computed from Tables 1 and 2: 0.390 inch and 5.163 inches, respectively.

Mesh B -- similar to Mesh A except that the number of elements in each direction was increased by 50%.

Mesh C -- a uniformly spaced mesh of finite elements for the actual elbow ME-1 as measured and tabulated in Tables 1 and 2; the mesh spacing was the same as for Mesh A, the coarser of the two idealized models.

For the ideal models (Meshes A and B), the structure is symmetric with respect to the plane $Z_0 = 0$ in Figure 1, so that only one-half of the structure need be modeled. Although the actual geometry used for Mesh C does not exhibit the same symmetry, such symmetry was assumed here also, and only half the structure was modeled. This assumption is equivalent to assuming that the nonsymmetry in the thickness variation on the unmodeled side ($Z_0 < 0$) has little effect on the solution on the modeled side

TABLE 1 - MEASURED VALUES OF WALL THICKNESS FOR ME-1

ϕ (degrees)	Wall Thickness (in inches) at St. 4	St. 5	St. 6	St. 7	St. 8	St. 9	St. 10
0	0.395	0.389	0.404	0.402	0.384	0.388	0.381
22.5	0.394	0.392	0.401	0.399	0.384	0.393	0.391
45.0	0.394	0.389	0.406	0.401	0.381	0.378	0.398
67.5	0.398	0.398	0.396	0.398	0.385	0.376	0.401
90.0	0.396	0.397	0.398	0.404	0.386	0.392	0.392
112.5	0.394	0.383	0.386	0.393	0.381	0.379	0.385
135.0	0.395	0.375	0.382	0.393	0.384	0.378	0.381
157.5	0.394	0.380	0.382	0.393	0.379	0.384	0.380
180.0	0.390	0.389	0.388	0.383	0.386	0.386	0.380
202.5	0.396	0.391	0.388	0.389	0.389	0.391	0.387
225.0	0.395	0.380	0.382	0.386	0.402	0.392	0.397
247.5	0.394	0.366	0.372	0.374	0.389	0.383	0.387
270.0	0.396	0.381	0.406	0.401	0.391	0.406	0.401
292.5	0.390	0.383	0.393	0.390	0.390	0.394	0.394
315.0	0.390	0.384	0.394	0.383	0.391	0.389	0.394
337.5	0.391	0.382	0.399	0.408	0.395	0.388	0.390

Average thickness = 0.390 in.

TABLE 2 - MEASURED VALUES OF OUTSIDE DIAMETER FOR ME-1

ϕ (degrees)	Outside Diameter (in inches) at St. 4	St. 5	St. 6	St. 7	St. 8	St. 9	St. 10
0	10.765	10.729	10.730	10.705	10.735	10.750	10.787
22.5	10.765	10.735	10.720	10.725	10.710	10.741	10.797
45.0	10.738	10.700	10.690	10.717	10.685	10.705	10.759
67.5	10.738	10.677	10.671	10.690	10.664	10.677	10.700
90.0	10.700	10.680	10.672	10.680	10.660	10.690	10.681
112.5	10.713	10.680	10.675	10.695	10.694	10.716	10.732
135.0	10.735	10.695	10.685	10.707	10.715	10.728	10.762
157.5	10.758	10.703	10.713	10.740	10.737	10.745	10.807

Average O.D. = 10.716 in.

($Z_0 \geq 0$). Since a deliberate attempt was made to machine the ME-1 model to minimize thickness variations, this is probably a reasonable assumption.

For all three meshes, the elbow and its adjoining straight sections were modeled with flat plate finite elements (the NASTRAN element QUAD2) which have both membrane and bending stiffness. As indicated in Figure 1, one end was completely fixed, and the other end (where loads are applied) was connected to a stiff flange (which was assumed to be rigid in the finite element model).

The bulk of the NASTRAN data deck for each model was generated by a computer program called PIPELB, described briefly in the next section.

The finite element (QUAD2) used in these models yields stresses at element centroids. Hence, to facilitate comparison with experiment at the middle of the elbow ($\theta = 45°$), an odd number of elements was used in the longitudinal direction.

Figure 2 shows the Mesh A finite element model. This plot was generated using the Structural Analysis via Generalized Interactive Graphics (STAGING) system.[2]

The characteristics of the three meshes are summarized in Table 3. In all three cases, the element aspect ratios within the elbow were selected so as not to deviate significantly from unity, which is the optimum aspect ratio for the QUAD2 finite element.

THE DATA GENERATOR

The computer program PIPELB was written to generate NASTRAN data for THETA-degree elbows of ideal or non-ideal geometry adjoined on both sides by straight sections of arbitrary length. In addition to the GRID cards, which locate the finite element mesh points, the program also generates the plating (NASTRAN data card CQUAD2), pressure loading (PLOAD2), symmetry and other constraints (SPC), and flags for congruent elements (CNGRNT). As added conveniences, PIPELB will automatically generate the set of element identification numbers (ID's) for the mid-THETA elements which constitute the solution set for stresses; flexible spokes (CBAR) radiating from the centers of both elbow end-circles which facilitate the

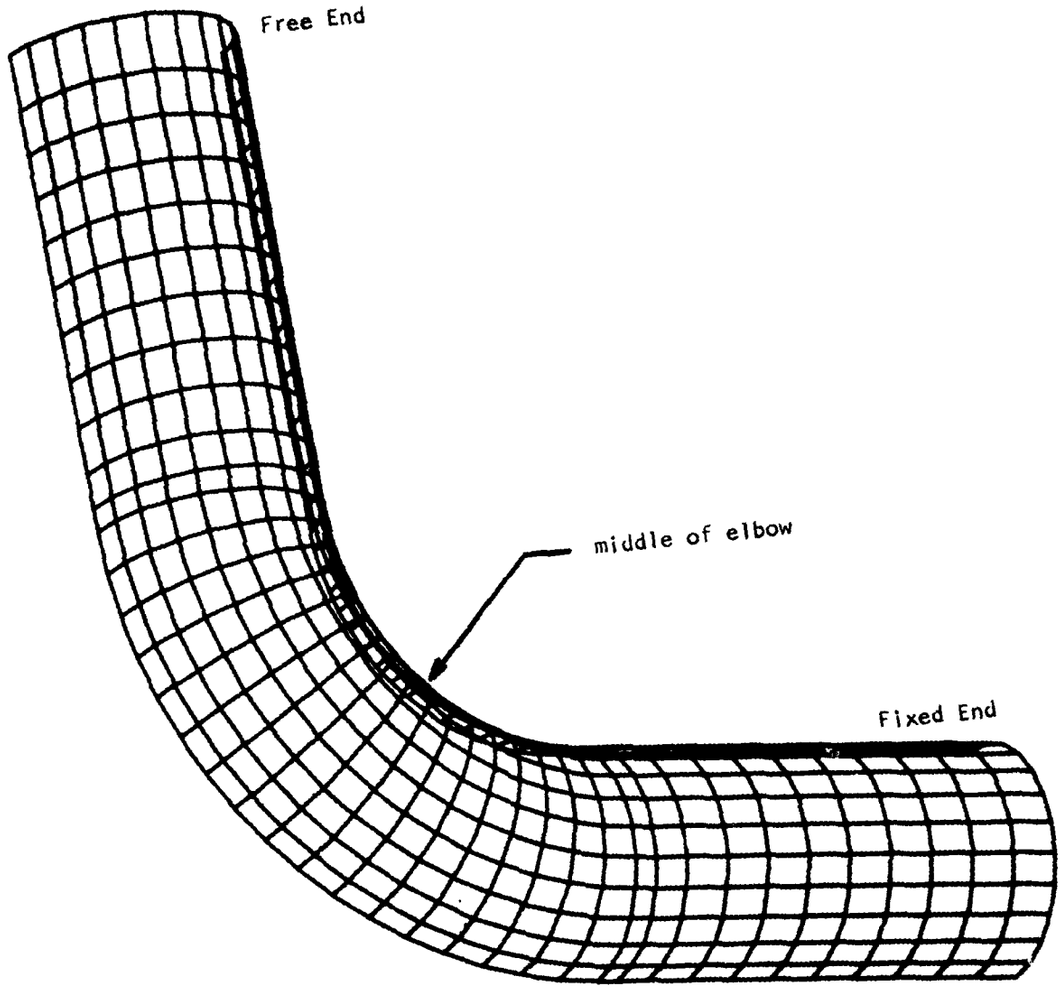


Figure 2 - Finite Element Model of Elbow (Mesh A)

TABLE 3 - SUMMARY OF FINITE ELEMENT ANALYSES

Structure Being Analyzed: Pipe Elbow ME-1 (See Figure 1)

Modeling and Computational Parameters	Mesh A	Mesh B	Mesh C
Ideal or actual geometry	ideal	ideal	actual
Mean radius of pipe	5.163 in.	5.163 in.	see Tables 1,2
Thickness of pipe	0.390 in.	0.390 in.	see Table 1
No. of elements in circumferential direction	12	18	12
No. of elements longitudinally spanning 90° elbow	17	27	17
No. of elements longitudinally spanning 21.0" straight section	11	16	11
No. of elements longitudinally spanning 20.5" straight section	11	16	11
Total number of elements	468	1062	468
Number of grid points	520	1140	520
Number of degrees of freedom	2745	6273	2745
Average matrix wavefront	79	116	79
NASTRAN CP time (CDC 6400)	949 sec.	2850 sec.	1339 sec.

computation of flexibility factors; a rigid element (CRIGD1) at the free (loaded) end of the pipe; and the end cap longitudinal load (FORCE) due to unit internal pressure.

The data generator defines grid locations within the elbow section in terms of a local cylindrical coordinate system (ID number 1 in Figure 1) defined by

$$\begin{aligned} R &= RBEND - RPIPE \cdot \cos \phi \\ T &= \theta_1 \\ Z &= RPIPE \cdot \sin \phi \end{aligned} \tag{1}$$

where RBEND is the elbow bend radius measured to the pipe centerline, RPIPE is the mean pipe radius, ϕ is the angle spanning the pipe half-circumference, and θ_1 is the angle spanning the elbow arc of THETA degrees. (Other coordinate systems used in the NASTRAN data deck are defined in Figure 1.) The grid marking system defines the grid ID's as

$$\text{GRID ID} = 1000 \cdot (500 + \text{ITH}) + \text{IPH} \tag{2}$$

where ITH and IPH are θ_1 and ϕ, respectively, rounded to the nearest integer. The element ID assigned to each quadrilateral is equal to the GRID ID that would be assigned for a node located at the element centroid.

For example, for Mesh A, the elbow was modeled with 17 elements covering the 90° elbow arc longitudinally (i.e., a spacing of 5.294°) and 12 elements covering 180° (i.e., a spacing of 15°) in the circumferential direction. Thus, for this mesh, point 51100 is at the intrados (the inside edge), 511090 is at the top, and 511180 is at the extrados (the outside edge) of the elbow, with all three points at θ_1 = 10.588°.

The shell was modeled with plate elements (NASTRAN data card CQUAD2). Symmetry constraints were applied with SPC's at ϕ = 0° and ϕ = 180°. An internal pressure loading was specified using a PLOAD2 card for each plate element, and the resultant longitudinal load at the closed free end (due to the pressure) was specified with a FORCE card. The inplane bending, out-of-plane bending, and torsion moment loads were applied at the rigid flange at the free end using MOMENT cards. All grid points at the fixed end were constrained in all six degrees of freedom.

Appendix A provides a listing of the card deck needed to create an UPDATE program library, compile source code, and catalog executable code for the data generator PIPELB.

Appendix B gives a listing of a typical card deck needed to execute the data generator and create a data file suitable for input to NASTRAN. The specific example used in Appendix B is for Mesh A. The result of executing this step is the NASTRAN data deck, which is listed in Appendix E. Various sections of this data deck have been labeled with comment cards, which have a $ in card column number one.

For Mesh C, which uses the measured geometry as listed in Tables 1 and 2, the data generator interpolates to obtain pipe thicknesses at element centroids and to obtain pipe radii at the grid points. This interpolation is performed within the generator in subroutine FIND. For Mesh C, each element has a unique thickness and hence a unique property card (PQUAD2).

SOLUTION SEQUENCE

The general computational approach is to perform the following steps:

Step 1: Compile the elbow data generator, and catalog an executable form of the program. See Appendix A.

Step 2: For the desired mesh, execute the generator, and create and store the NASTRAN data deck. See Appendix B.

Step 3: Using the data deck created in Step 2, execute NASTRAN and save (on a permanent file) the stresses at the desired location ($\theta_1 = 45°$). See Appendix C for a listing of control cards to accomplish this.

Step 4: Smooth the stress curves in preparation for plotting, storing the results. Figure 3 shows a typical plot of the type desired, where various stresses at the section $\theta_1 = 45°$ are plotted as a function of ϕ, the circumferential coordinate. As can be seen in Figure 3, the smoothing merely provides a more attractive display of the results. The smoothing in Figure 3 was obtained by using the B-spline[3] application subprogram CRVFIT.[4,5] See Appendix D for a listing of the deck to read the NASTRAN principal stresses and perform the smoothing.

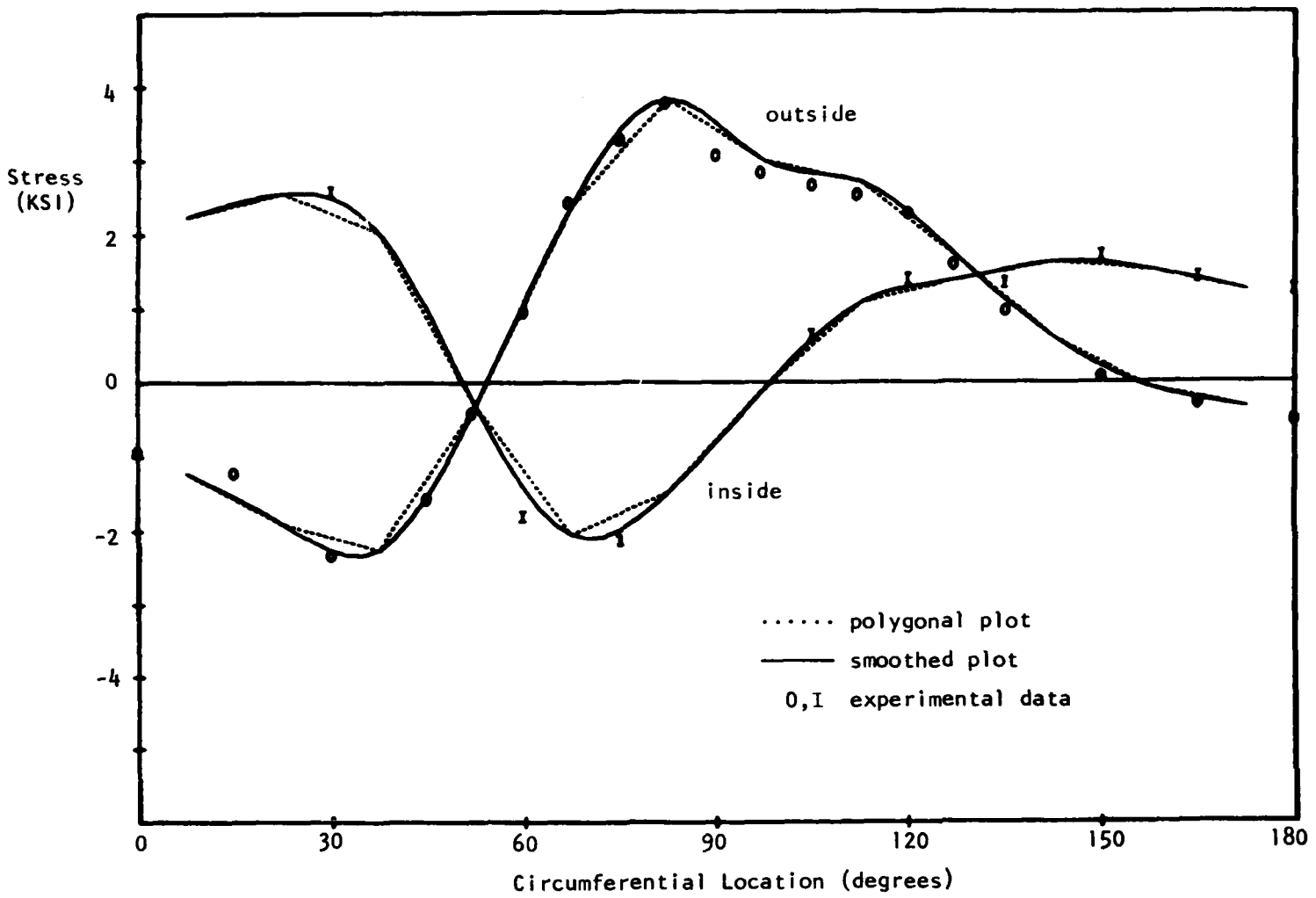


Figure 3 - Comparison of Polygonal and Smoothed Plots of Major Principal Stress at Middle of Elbow Due to Inplane Moment Load (Mesh A)

Step 5: Plot the smoothed results using the informally documented interactive computer graphics package PLOT QUICK developed by Mr. Melvin E. Haas of DTNSRDC (Code 1843).

FLEXIBILITY FACTORS

The finite element models also allow for the convenient determination of flexibility factors, which are of vital interest to piping systems designers. To avoid confusion, the term "flexibility factor," as used in this report, will be defined precisely. The flexibility factor k of a piping component is defined as the ratio of a relative rotation of that component to a nominal rotation:

$$k = \frac{\theta_{ab}}{\theta nom} \tag{3}$$

where

θ_{ab} = rotation of end "a" of the piping component relative to end "b" of that component due to a moment loading M, and in the direction of M.

θ_{nom} = nominal rotation of an equal length of straight pipe due to the moment M.

For elbows, the nominal rotation is computed using simple beam theory, in which case one obtains

$$\theta_{nom} = \frac{ML}{EI} \tag{4}$$

for inplane and out-of-plane moments, and

$$\theta_{nom} = \frac{ML}{GJ} \tag{5}$$

for torsional moments, where

M = applied moment load

L = arc length of elbow

E = Young's modulus of material

G = shear modulus of material

I = moment of inertia of cross-section

J = torsional constant of cross-section (equal to the polar moment

of inertia for circular cross-sections)

For 90° elbows, $L = \pi R/2$, where R is the bend radius.

The determination of the relative rotation θ_{ab} from the finite element model is complicated by the fact that plane cross-sections do not remain plane after deformation, so that each point on the surface of the shell has a different rotation. However, an "average" rotation for a cross-section may be obtained by connecting very flexible beam spokes from each shell grid point to a new grid point located at the center of the circular cross-section. The rotation of this center point may be used as the average rotation for the cross-section. For Mesh A, the center point at Station 4 in Figure 1 is labeled 590500 (end "a") and at Station 10, 500500 (end "b").

Table 4 shows the details of the flexibility factor calculations for the three moment loads for Mesh A.

RESULTS AND DISCUSSION

Principal stresses were computed by NASTRAN at the middle of the elbow ($\theta_1 = 45°$) and compared to experimental results obtained at the Oak Ridge National Laboratory.[1] These stresses were computed for four separate loading conditions:

1) internal pressure of 75.53 psi
2) inplane bending moment of 32,660 in-lb
3) out-of-plane bending moment of 32,660 in-lb
4) torsional moment of 32,660 in-lb

Figures 4-11 compare the smoothed NASTRAN stress curves as computed using Meshes A, B, and C with the experimental data points. The major and minor principal stress results are presented on alternating figures for each of the four loading conditions. Note that placing more strain gauges on the outer surface than on the inner surface of the pipe wall resulted in a greater number of experimental data points there. Also, for selected experiments, some gauge results were missing.

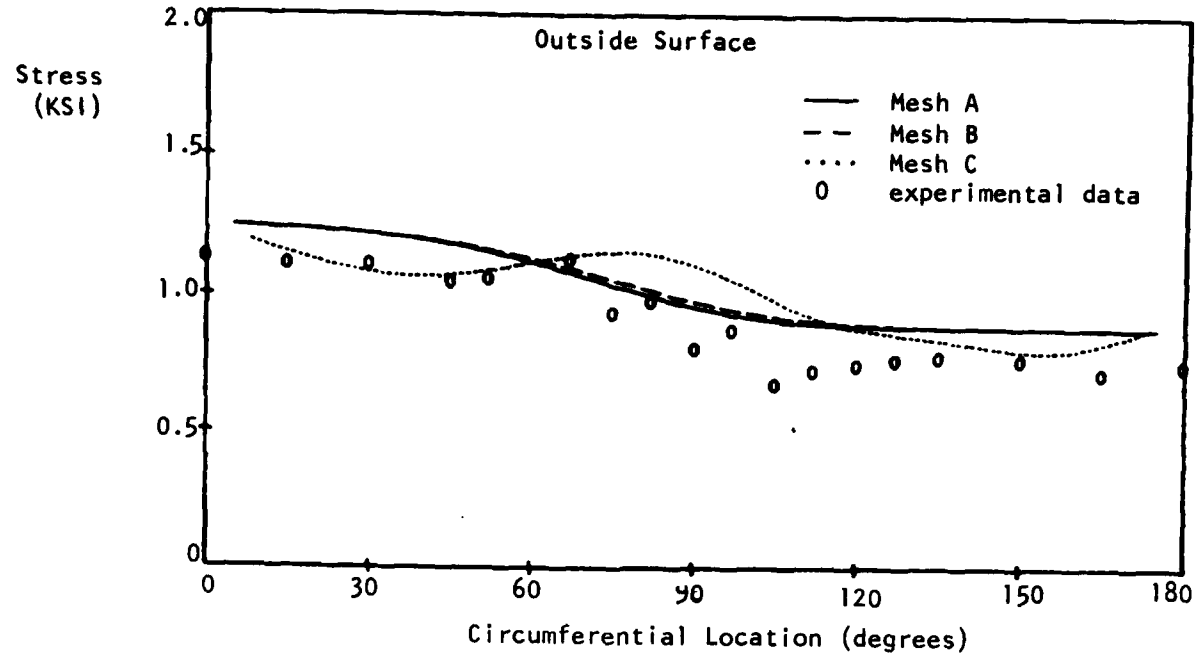
The following conclusions may be drawn from Figures 4-11:

1. The NASTRAN results using Meshes A and B (both ideal geometry) are in good overall agreement with the experimental results. Although

TABLE 4 - FLEXIBILITY FACTORS FOR MESH A

Moment Load	θ_a (rad)	θ_b	$\theta_{ab} = \theta_b - \theta_a$	θ_{nom}	k
Inplane	1.32×10^{-4}	11.08×10^{-4}	9.76×10^{-4}	1.57×10^{-4}	6.2
Out-of-plane	1.78×10^{-4}	7.19×10^{-4}	5.41×10^{-4}	1.57×10^{-4}	3.4
Torsion	1.32×10^{-4}	6.79×10^{-4}	5.47×10^{-4}	2.04×10^{-4}	2.7

$$\text{flexibility factor} = k = \frac{\theta_{ab}}{\theta_{nom}}$$



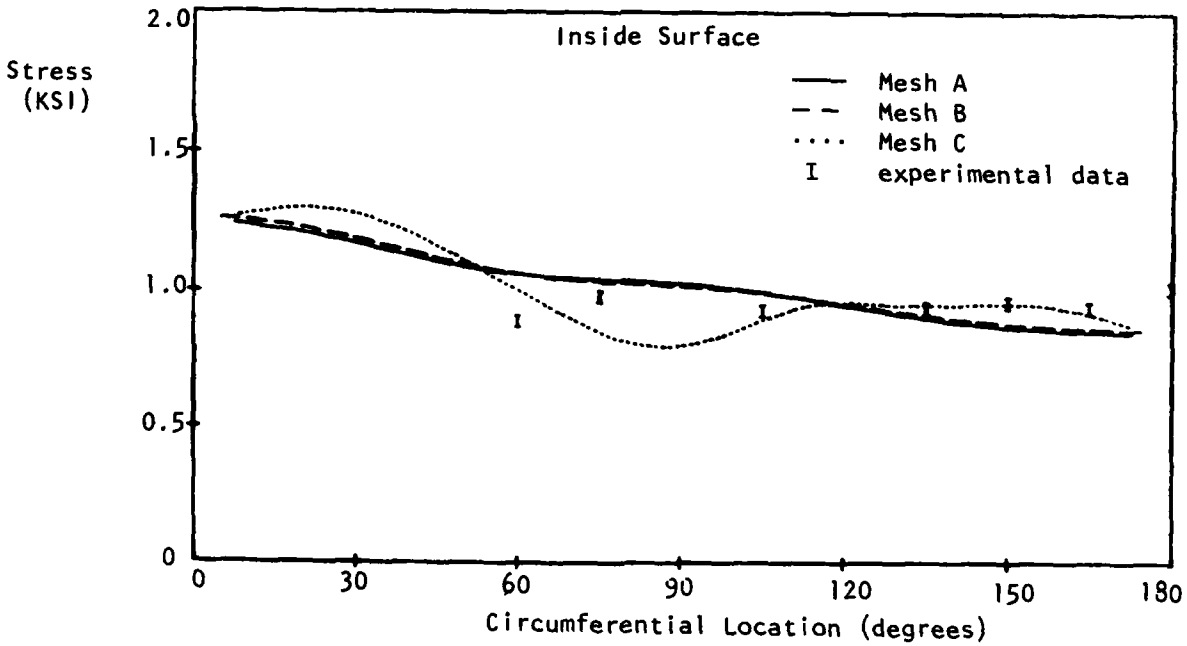
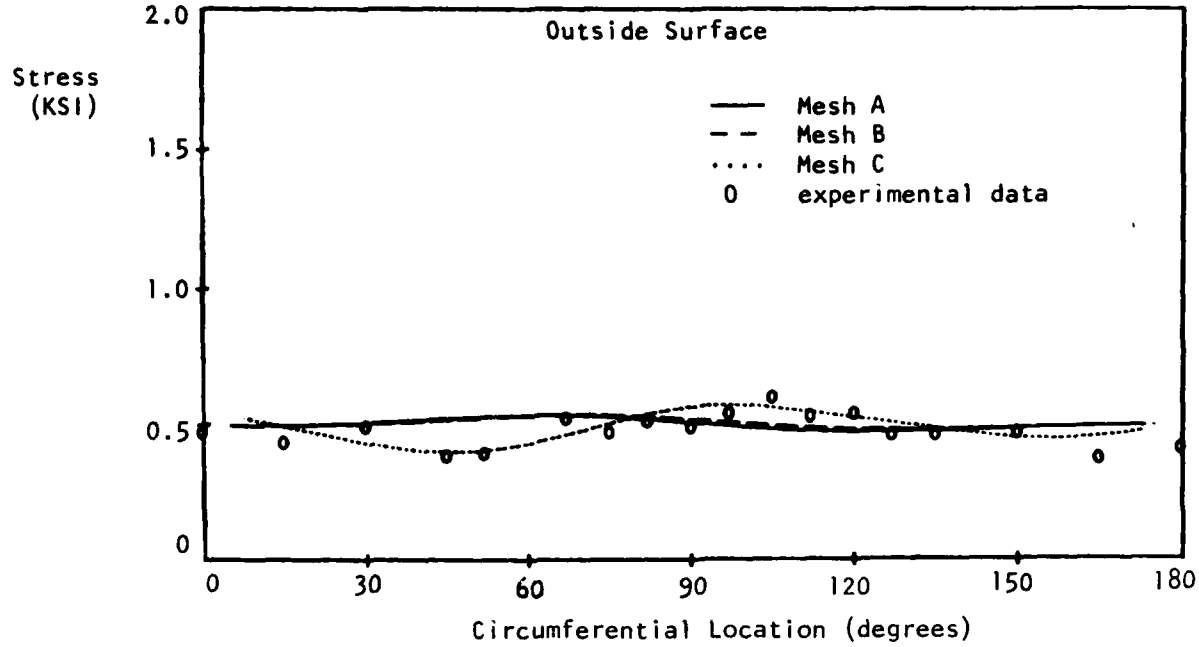


Figure 4 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Pressure Load



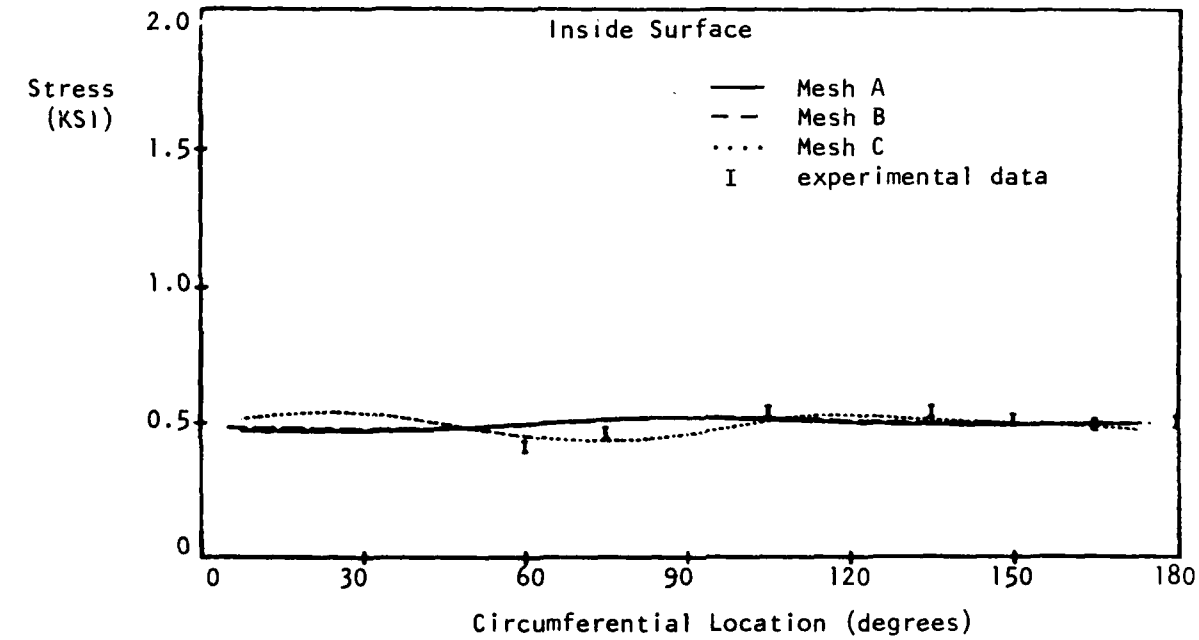


Figure 5 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Pressure Load

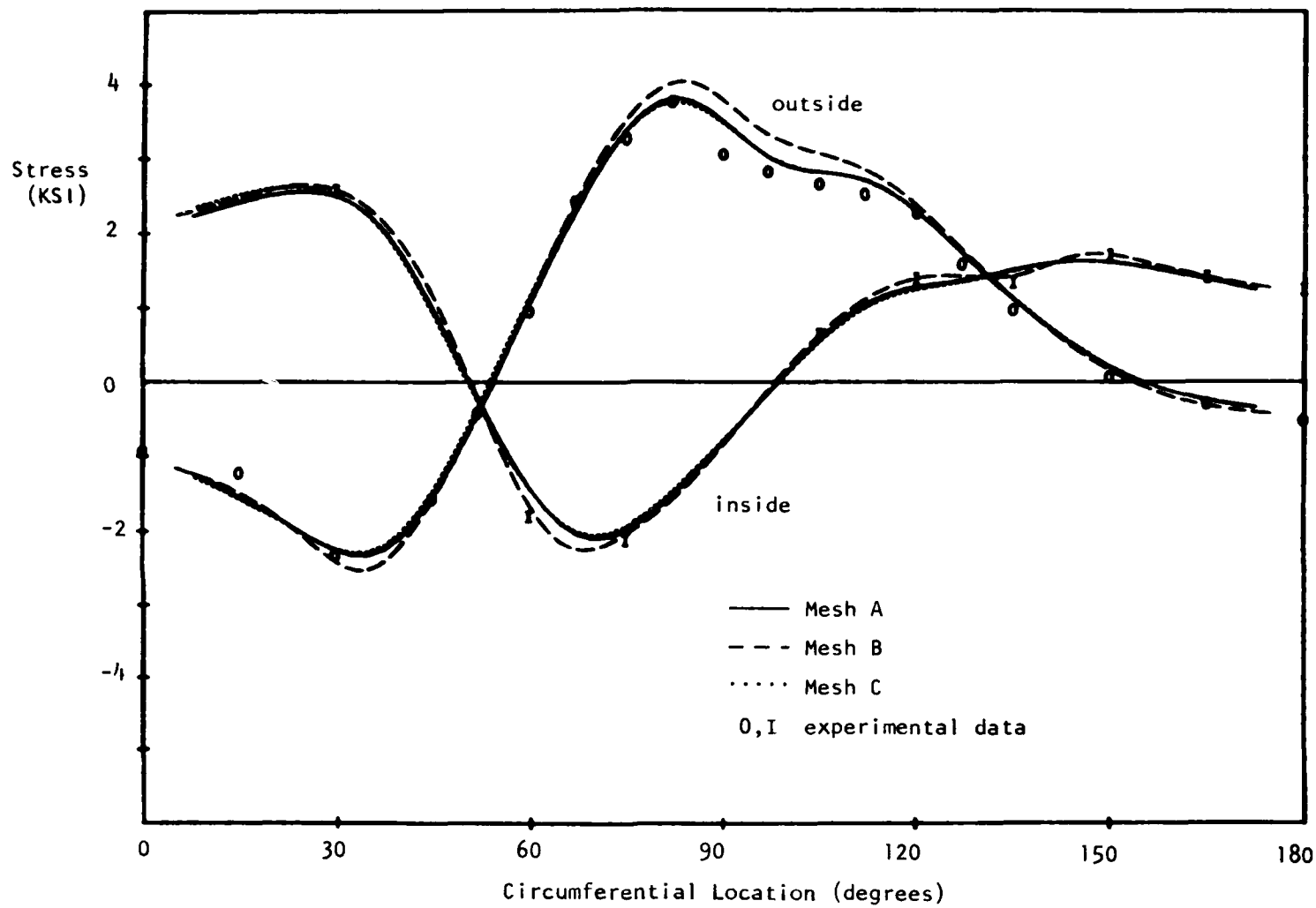


Figure 6 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Inplane Moment Load

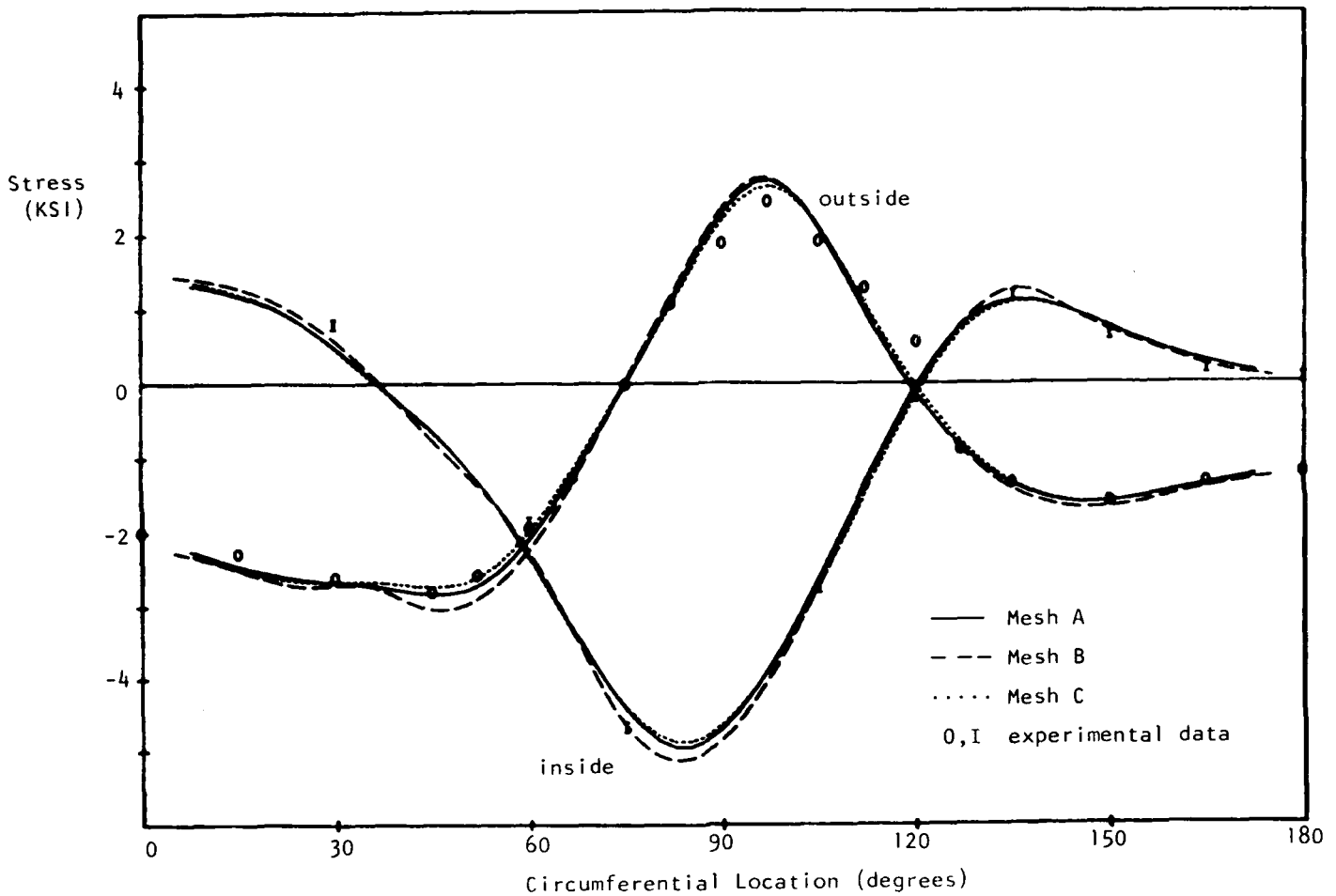


Figure 7 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Inplane Moment Load

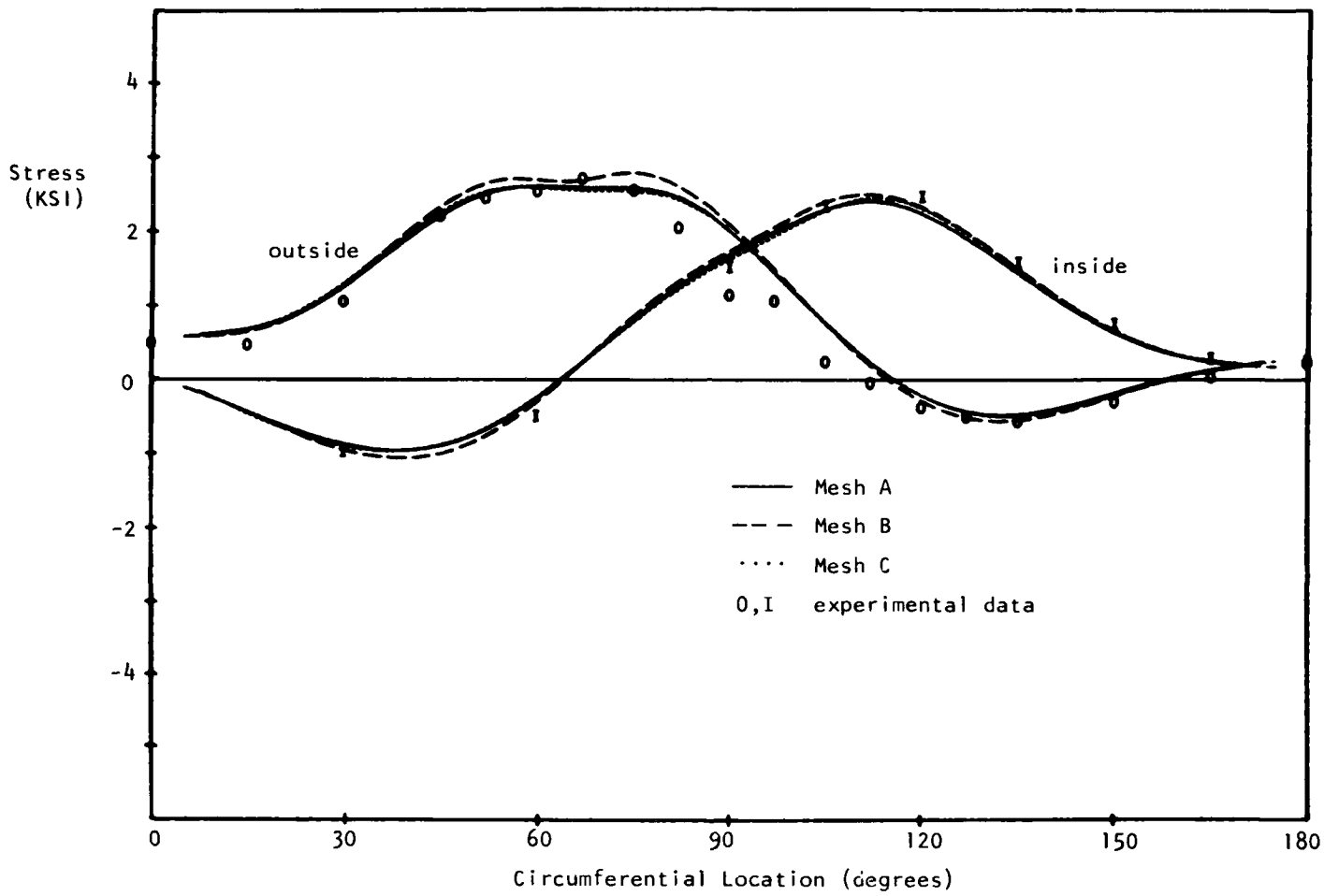


Figure 8 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Out-of-Plane Moment Load

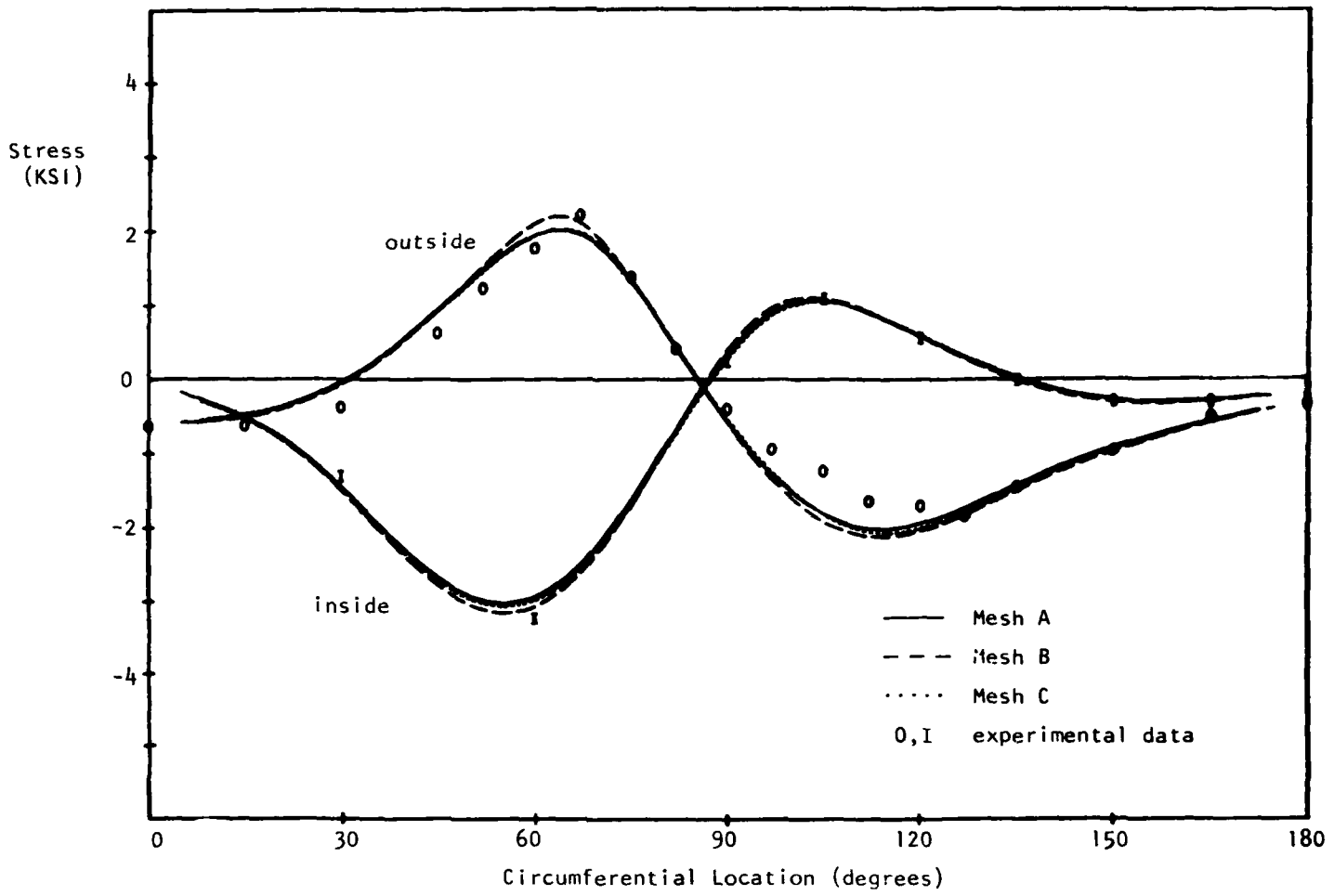


Figure 9 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Out-of-Plane Moment Load

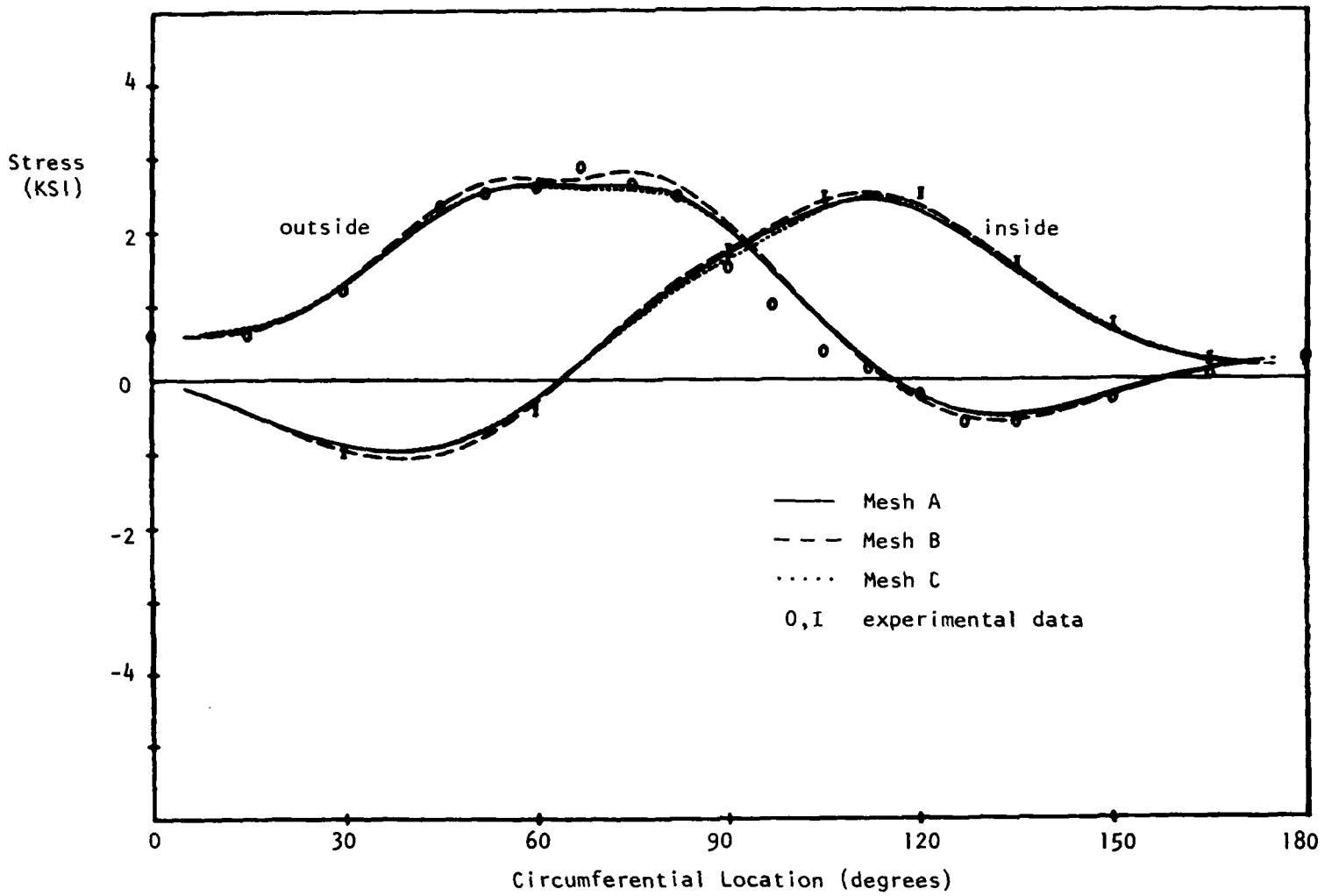


Figure 10 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Major Principal Stress, Torsion Moment Load

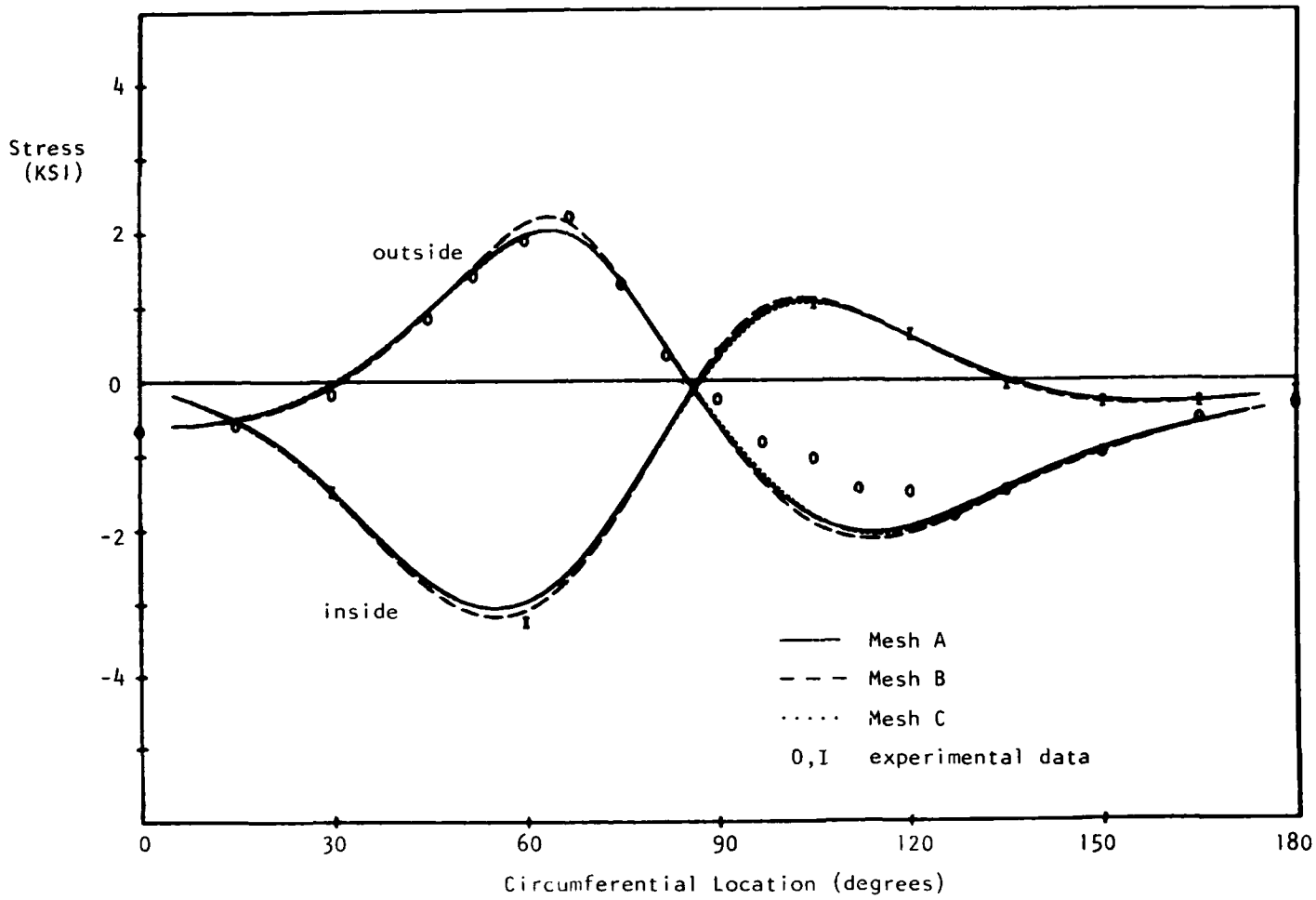


Figure 11 - Comparison of Computed and Experimental Stresses at Middle of Elbow - Minor Principal Stress, Torsion Moment Load

the coarser model (Mesh A) is non-conservative in that it underestimates (in absolute value) the stresses, its prediction of peak principal stresses is nevertheless excellent.

2. The Mesh C (actual geometry) results indicate that, except for internal pressure loading, the small variations in geometry shown in Tables 2 and 3 play an insignificant role in the stress computations. (The Oak Ridge researchers found in their more extensive experiments[1] that ovality in the pipe cross-section had a major influence on stresses only for pressure loading.)

3. When a large series of computer runs (e.g., a parameter study of pipe elbows) is contemplated, the gain in accuracy achieved with Mesh B (which has a fifty percent finer mesh spacing than Mesh A) would probably not be cost-effective. (The CDC 6400 computer charge at DTNSRDC was $292 for Mesh B compared to $99 for Mesh A.)

ACKNOWLEDGMENTS

The authors acknowledge with pleasure the fruitful discussions held with Mr. L. Kaldor and Dr. Y.P. Lu, both of the Engineering Analysis Branch (Code 2744), DTNSRDC.

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3. McKee, James M., "B-Spline Functions As a Solution to Some Knotty Geometric Modeling Problems," Proceedings of the Symposium on Computer Methods in Engineering, University of Southern California (Aug 1977).

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APPENDIX A

Listing of Deck to Create UPDATE Program Library, Compile Source Code, and Catalog Executable Code for Elbow Data Generator

```
(JOB CARD)
(CHARGE CARD)
REQUEST,NEWPL,*PF.
UPDATE,F,C,N.
CATALOG,NEWPL,PFNAME1,ID=XXXX.
REQUEST,LGO,*PF.
FTN,OPT=1,R=3,PL=5000000,I=COMPILE.
CATALOG,LGO,PFNAME2,ID=XXXX.
7/8/9 EOR   **** SOURCE DECK FOR DATA GENERATOR FOLLOWS ****
*DECK ELB
      PROGRAM PIPELB(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8,TAPE9,
     - TAPE10,TAPE11,TAPE12,TAPE13,TAPE14,TAPE15,TAPE16,TAPE17,TAPE18,
     - TAPE19,TAPE20,TAPE21,TAPE22,TAPE23,TAPE24,TAPE25,TAPE26,TAPE27)
C
C     DATA GENERATOR FOR NASTRAN STRESS  ANALYSIS OF A PIPE HAVING
C         THETA DEGREE ELBOW AND STRAIGHT SECTIONS
C     INPUT GENERATION INCLUDES FINITE ELEMENT PLATING (CQUAD2,GRID),
C        CONGRUENCY (CNGRNT) AND PRESSURE LOADING (PLOAD2) FOR ELEMENTS,
C        AND GRID POINT CONSTRAINTS (SPC)
C
C     MEL MARCUS,DTNSRDC 1843,JAN 1979
C
      DIMENSION IDUM(8),ICNGR(35,24)
      INTEGER ASET(24)
      COMMON/A/THETA,NPH1,DPH,RPIPS,PIDS,LOADID,PLOAD
      COMMON/B/NX,NY,TABX(9),TABY(7),TABF(9,7,2)
      INTEGER          EID,PIDS,PID,SID,G(4)
      INTEGER CPC,CDC
      DATA PI/3.141592654/
C
    1 FORMAT (1H1)
    3 FORMAT (10F8.3)
    4 FORMAT (24I3)
    8 FORMAT (8A10)
    9 FORMAT (8HCBAR    ,4I8,3F8.1,I8)
   10 FORMAT (8HCNGRNT  ,2I8)
   11 FORMAT (8HCQUAD2  ,6I8)
   12 FORMAT (8HGRID    ,2I8,F8.4,F8.3,F8.4,2I8)
   15 FORMAT (8HPLOAD2  ,I8,F8.3,I8)
   16 FORMAT (8HPQUAD2  ,2I8,F8.3)
   17 FORMAT (8HSPC     ,3I8)
   26 FORMAT (8HSET 1 = ,8(I6,2H, )/(8X, 8(I6,2H, )))
   27 FORMAT (8X,I6)
   28 FORMAT (8HFORCE   ,3I8,F8.4,3F8.0)
C
C
C
C     PRESENTED BELOW ARE THE 4 READ ITEMS WHICH OCCUR IN PIPELB
C     ALSO INDICATED  ARE THE 4 READ ITEMS WHICH FOLLOW
C           IN 2 CALLS TO SUBROUTINE STRATE
C
C
C     PHI=PORTION OF PIPE CIRCUMFERENCE MODELED, DEGREES
C     THETA=PORTION OF ELBOW ARC MODELED ,DEGREES
C
      PHI=180.
      READ  (5,3) THETA
      WRITE (6,3) THETA
C
C     NPHI=NUMBER OF ELEMENTS IN PHI DIRECTION
C     NTHETA=NUMBER OF ELEMENTS IN THETA DIRECTION (COORD SYSTEM CPC)
C
      READ  (5,4) NPHI,NTHETA
```

```
      WRITE (6,4) NPHI,NTHETA
C
C     RBEND=BEND RADIUS MEASURED TO PIPE CENTERLINE
C     RPIPS,PIDS=NOMINAL VALUES OF PIPE RADIUS ,THICKNESS (PROPERTY ID)
C
      PIDS=200
      READ  (5,3) RBEND,RPIPS
      WRITE (6,3) RBEND,RPIPS
C
C     THIS ITEM CONTAINS A SINGLE READ (BLANK CARD)
C           OR MULTIPLE (3+NF*NY) READS
C     DEPENDING ON WHETHER NF=0 (IDEAL ELBOW)
C                OR NF=2 (VARIABLE RADIUS AND THICKNESS)
C
C     NX,NY=NUMBERS OF PHI,THETA-DIRECTION VALUES (TABX,TABY)
C             AT WHICH TABULATED VALUES OF
C     RADIUS  AND THICKNNESS (NF=2) ARE SPECIFIED FOR ELBOW
C
C     IF NF=0, THEN NOMINAL VALUES OF OF PIPE RADIUS
C             AND THICKNESS ARE USED THROUGHOUT
C     OTHERWISE, VARIABLE RADIUS AND THICKNESS VALUES ARE COMPUTED
C         FOR THETA-DIR VALUES BETWEEN TABY(1) AND TABY(NY) DEGREES
C             WITH NOMINAL VALUES USED ELSEWHERE
C
      READ  (5,4) NX,NY,NF
      WRITE (6,4) NX,NY,NF
      IF (NF.EQ.0) GO TO 45
      READ  (5,3) (TABX(I),I=1,NX)
      WRITE (6,3) (TABX(I),I=1,NX)
      READ  (5,3) (TABY(I),I=1,NY)
      WRITE (6,3) (TABY(I),I=1,NY)
      DO 40 K=1,NF
      DO 40 J=1,NY
      READ  (5,3) (TABF(I,J,K),I=1,NX)
      WRITE (6,3) (TABF(I,J,K),I=1,NX)
   40 CONTINUE
   45 CONTINUE
C
C     THE 2 ITEMS READ NEXT ARE TRIGGERED BY "CALL STRATE(1)"
C     THE ITEMS TO BE READ ARE DESCRIBED ATOP SUBROUTINE STRATE
C
C     THE LAST 2 ITEMS READ ARE TRIGGERED BY "CALL STRATE(2)"
C     THE ITEMS TO BE READ ARE DESCRIBED ATOP SUBROUTINE STRATE
C
C
C
      CPC=1
      CDC=1
      MID=45
      LOADID=21
      PLOAD=-1.
C
      DPH=PHI/NPHI
      DTH=THETA/NTHETA
      NPH1=NPHI+1
      NTH1=NTHETA+1
      IHTH=NTH1/2
C
C     END CAP LOAD DUE TO UNIT INTERNAL PRESSURE - 27
C
      CAPLD=.5*NPHI*RPIPS*RPIPS*SIN(DPH *PI/180.)
      WRITE (27,28) LOADID,200500,3,CAPLD,0.,0.,-1.
C
```

```
C
C     GENERATE FE PLATING FOR STRAIGHT SECTION  (TOP)
C     CHECK SUBROUTINE STRATE FOR INPUT TO BE READ IN
      CALL STRATE (1)
C
C
C     GENERATE FE PLATING FOR ELBOW
C
C
      TH=0.
      IBASE=500000
C
C
      DO 200 I=1,NTH1
      PID=PIDS
      RPIPE=RPIPS
      ITH=TH+.5
      INEXT=TH+DTH+.5
      IMOVE=1000*(INEXT-ITH)
      PH=0.
      ID=IBASE
C
C     DEFINE MYTHICAL CENTER POINTS ALONG ELBOW
C
      NBARS=0
      IDCEN=ID+500
C
C
      DO 150 J=1,NPH1
C
C     SPOKES (CBAR - 9) CONVERGE TO MYTHICAL CENTERS AT ELBOW ENDS
C
      IF (I.NE.1.AND.I.NE.NTH1) GO TO 50
      NBARS=NBARS+1
      IDBAR=IDCEN+NBARS
      IF (J.EQ.1.OR .J.EQ.NPH1) GO TO 52
      WRITE (9,9)IDBAR,PIDS+2,ID,IDCEN,0.,1.,0.,1
      GO TO 50
   52 WRITE (9,9)IDBAR,PIDS+1,ID,IDCEN,0.,1.,0.,1
   50 CONTINUE
C
      IPH=PH+.5
      INEXT=PH+DPH+.5
      JMOVE=INEXT-IPH
C
C     POSSIBLY INTERPOLATE FOR PIPE RADIUS
C
      IF (NF.EQ.0) GO TO 60
      IF (TH.GT.TABY(NY)) GO TO 62
      CALL FIND (PH,TH,1,THICK)
      CALL FIND (PH,TH,2,OD)
      RPIPE=.5*(OD-THICK)
      IREG=NTH1
      GO TO 64
   60 IREG=1
      GO TO 64
   62 IREG=I
   64 IREG1=IREG+1
C
C
C     GRID FOR ELBOW - 13
C
C
```

```
C     ELBOW MODELED IN CYLINDRICAL R,T,Z COORD SYSTEM CPC
C           IN WHICH T IS PORTION OF THETA
C
      ANG=PH+PI/180.
      R=RBEND-RPIPE*COS(ANG)
      Z=RPIPE*SIN(ANG)
      WRITE (13,12) ID,CPC,R,TH,Z,CDC
      IF (J.EQ. NPH1) GO TO  20
      IF (I.EQ. NTH1) GO TO  115
C
      ICEN=TH+.5*DTH+.5
      JCEN=PH+.5*DPH+.5
      EID=1000*ICEN+JCEN+500000
      IF (I.EQ.IHTH) ASET(J)=EID
C
C     ASSIGNING   CONGRUENCY
C
      ICNGR(I,J)=EID
C
C     POSSIBLY INTERPOLATE FOR PIPE THICKNESS
C     IF SO , GENERATE PROPERTY CARD - 16
C
      IF (NY.EQ.0) GO TO 80
      IF (IH.GT.TABY(NY)) GO TO 80
      PID=EID
      PC=PH+.5*DPH
      TC=TH+.5*DTH
      CALL FIND (PC,TC,1,THICK)
      WRITE (16,16) PID,MID,THICK
   80 CONTINUE
C
C     CQUAD2 FOR ELBOW - 11
C
      G(1)=ID
      G(2)=G(1)+IMOVE
      G(3)=G(2)+JMOVE
      G(4)=G(3)-IMOVE
      WRITE (11,11) EID,PID,(G(L),L=1,4)
C
C     PLOAD2 FOR QUADS - 15
C
      WRITE (15,15) LOADID,PLOAD,EID
  115 IF (J.NE.1) GO TO 100
C
C     SPC FOR ELBOW - 18,21
C           SYM B.C. AT PHI=0,180 - 18
C     ANTI- SYM B.C. AT PHI=0,180 - 21
C
   20 SID=71
      L=345
      WRITE (18,17) SID,ID,L
      SID=72
      L=126
      WRITE (21,17) SID,ID,L
C
  100 ID=ID+JMOVE
      PH=PH+DPH
C
C
  150 CONTINUE
C
C
      IBASE=IBASE+IMOVE
```

```
      TH =TH +DTH
  200 CONTINUE
C
C
C     CNGRNT (THETA DIRECTION ONLY) FOR ELBOW - 10
C
      IF (IREG .GE.NTHETA) GO TO 210
      DO 205 J=1,NPHI
      DO 205 I=IREG1,NTHETA
  205 WRITE (10,10) ICNGR(IREG,J),ICNGR(I,J)
  210 CONTINUE
C
C     SOLUTION SET FOR CASE CONTROL - 26
C
      WRITE (26,26) (ASET(J),J=1,NPHI)
      WRITE (26,27) 999999
C
C
C     GENERATE FE PLATING FOR STRAIGHT SECTION (BOTTOM)
C     CHECK SUBROUTINE STRATE FOR INPUT TO BE READ IN
      CALL STRATE (2)
C
C
C
      WRITE (6,1)
      DO 1000 I=9,27
      REWIND I
  910 READ (I,8) (IDUM(K),K=1,8)
      IF (EOF(I).NE.0) GO TO 920
      WRITE(8,8) (IDUM(K),K=1,8)
      GO TO 910
  920 REWIND I
 1000 CONTINUE
      REWIND 8
C
C
      STOP
      END
      SUBROUTINE STRATE (IFLAG)
C
C     GENERATE FE PLATING FOR STRAIGHT SECTION
C     IFLAG=1,2 INDICATES PORTION ABOVE,BELOW ELBOW
C
      DIMENSION       ZS(25),IZDZCH(6),KOUNT( 5),IJCNGR(5,500)
      COMMON/A/THETA,NPH1,DPH,RPIPS,PIDS,LOAD1D,PLOAD
      INTEGER CPS,CDS,EID,PIDS,PID,SID,G(4)
C
    2 FORMAT (I8,9F8.2/(10F8.2))
    4 FORMAT (24I3)
   10 FORMAT (8HCNGRNT  ,2I8)
   11 FORMAT (8HCQUAD2  ,6I8)
   12 FORMAT (8HGRID    ,2I8,F8.4,F8.3,F8.4,2I8)
   15 FORMAT (8HPLOAD2  ,I8,F8.3,I8)
   17 FORMAT (8HSPC     ,3I8)
   25 FORMAT (8HCRIGD1  ,3I8)
C
C
C     STRAIGHT SECTION MODELED IN CYLINDRICAL R,T,Z COORD SYSTEM CPS
C            IN WHICH Z IS DISTANCE ALONG STRAIGHT EDGE
C             ( Z=0 AT POINTS OF CURVATURE/TANGENCY )
C
C
C
```

```
C     NZS1=NUMBER OF GRID POINTS IN Z DIRECTION
C     ZS(I)=Z-COORDS OF THE NZS1 PTS IN COORD SYSTEM CPS
C
C     FOR IFLAG=1, VALUES BEGIN AT Z=-L1 AND END AT Z=0
C     FOR IFLAG=2, VALUES BEGIN AT Z=0 AND END AT Z=L2
C           WHERE L1,L2 ARE PIPE LENGTHS ABOVE,BELOW ELBOW
C
      READ  (5,2) NZS1,(ZS(I),I=1,NZS1)
      WRITE (6,2) NZS1,(ZS(I),I=1,NZS1)
C
C     NDZCHS=NUMBER OF CHANGES IN DZ=ZS(I+1)-ZS(I)
C     IZDZCH(K)=VALUES OF I ,I=1 TO NZS1, AT WHICH DZ CHANGES
C        (CONVENTION IS TO SPECIFY I=1 AS A CHANGE)
C
      READ  (5,4) NDZCHS,(IZDZCH(K),K=1,NDZCHS)
      WRITE (6,4) NDZCHS,(IZDZCH(K),K=1,NDZCHS)
C
C
C
C     SET UP CONGRUENCY SETS
C
      IBOOM=0
      NSETS=  NDZCHS
      DO 650 I=1,NSETS
  650 KOUNT(I)=0
C
C
      IF (IFLAG.EQ.2) GO TO 20
      CPS=3
      CDS=3
      NTPGRD=12
      NTPSYM=17
      NTPAS=20
      ILIM=NZS1-1
      IBASE=(500-10*ILIM)*1000
      IRIGID=IBASE
      GO TO 30
   20 CPS=2
      CDS=2
      NTPGRD=14
      NTPSYM=19
      NTPAS=22
      ILIM=NZS1
      IBASE=(500+THETA)*1000
   30 RPIPE=RPIPS
      PID=PIDS
C
C
      DO 400 I=1,ILIM
      IMOVE=10000
      PH=0.
      ID=IBASE
C
C
      DO 350 J=1,NPH1
      IPH=PH+.5
      INEXT=PH+DPH+.5
      JMOVE=INEXT-IPH
C
C     RIGID ELEMENTS AT FREE END - 25
C
      IF (I.NE.1.OR.IFLAG.NE.1) GO TO 27
      WRITE (25,25) J+1,200500,IRIGID
```

```
      IRIGID=IRIGID+JMOVE
   27 CONTINUE
C
C
C     GRID FOR STRAIGHT SECTION - NTPGRD
C
      IF (IFLAG.EQ.2.AND.I.EQ.1) GO TO 202
      NT=NTPGRD
      WRITE (NT,12) ID,CPS,RPIPE,PH,?S(I),CDS
  202 IF (J.EQ. NPH1) GO TO 220
      IF (IFLAG.EQ.2.AND.I.EQ.ILIM) GO TO 215
C
      EID=ID
      IF (IFLAG.EQ.1.AND.I.EQ.ILIM) GO TO 204
      IF (IFLAG.EQ.2.AND.I.EQ.1)    GO TO 204
C
C     TESTING FOR AND ASSIGNING CONGRUENCY
C
      IBOOM=IBOOM+1
      IZDZCH(NDZCHS+1)=NZS1
      DO 700 K=1,NDZCHS
      NSET=0
      IZ1=IZDZCH(K   )-1
      IZ2=IZDZCH(K+1)-1
      IF (I.GT.IZ1.AND.I.LE.IZ2) NSET=K
      IF (NSET.EQ.0) GO TO 700
      IF (IBOOM.EQ.1) NSET1=NSET
      NSETS=NSET
      KOUNT(NSET)=KOUNT(NSET)+1
      KNT=KOUNT(NSET)
      IJCNGR(NSET,KNT) =EID
  700 CONTINUE
C
C     CQUAD2 FOR STRAIGHT SECTION - 11
C
  204 G(1)=ID
      G(2)=G(1)+IMOVE
      G(3)=G(2)+JMOVE
      G(4)=G(3)-IMOVE
      WRITE (11,11) EID,PID,(G(L),L=1,4)
C
C     PLOAD2 FOR QUADS - 15
C
      WRITE (15,15) LOADID,PLOAD,EID
      IF (IFLAG.EQ.1.AND.I.EQ.1) GO TO 300
  215 IF (J.EQ.1) GO TO 220
      IF (IFLAG.EQ.2.AND.I.EQ.ILIM) GO TO 225
      GO TO 300
C
C     SPC FOR STRAIGHT SECTION - NTPSYM,NTPAS,23,24
C           SYM B.C. AT PHI=0,180 - NTPSYM
C     ANTI- SYM B.C. AT PHI=0,180 - NTPAS
C     ELIM ZERO DOF  AT PHI=0,180 - 23
C     CONSTRAIN FIXED END         - 24
C
  220 IF (I.EQ.1) GO TO 300
      SID=71
      L=246
      NT=NTPSYM
      WRITE (NT,17) SID,ID,L
      SID=72
      L=135
      NT=NTPAS
```

```
      WRITE (NT,17) SID,ID,L
      SID=80
      L=4
      WRITE (23,17) SID,ID,L
      IF (IFLAG.EQ.2.AND.I.EQ.ILIM) GO TO 225
      GO TO 300
  225 SID=85
      L=123456
      WRITE (24,17) SID,ID,L
C
  300 ID=ID+JMOVE
      PH=PH+DPH
C
C
C
  350 CONTINUE
      IBASE=IBASE+IMOVE
C
C
  400 CONTINUE
C
C
C     CNGRNT (BOTH DIRECTIONS) FOR STRAIGHT SECTION - 10
C
      DO 405 K=NSET1,NSETS
      KNT=KOUNT(K)
      DO 405 L=2,KNT
  405 WRITE (10,10) IJCNGR(K,1),IJCNGR(K,L)
C
C
      RETURN
      END
      SUBROUTINE FIND (X,Y,K,FXY)
C
C     INTERPOLATE FOR FUNCTIONAL VALUES WHICH ARE
C     TABULATED FOR BOTH X AND Y TABULATED VALUES
C
C     K INDICATES FUNCTION BEING CONSIDERED
C
      DIMENSION FX(7)
      COMMON/B/NX,NY,TABX(9),TABY(7),TABF(9,7,2)
C
      DO 10 J=2,NY
      IF (TABY(J).GT.Y) GO TO 15
   10 CONTINUE
      J2=NY
      GO TO 20
   15 J2=J
   20 J1=J2-1
C
      DO 30 I=2,NX
      IF (TABX(I).GT.X) GO TO 35
   30 CONTINUE
      I2=NX
      GO TO 40
   35 I2=I
   40 I1=I2-1
C
      XRAT=(X-TABX(I1))/(TABX(I2)-TABX(I1))
      DO 50 J=J1,J2
   50 FX(J)=TABF(I1,J,K)+XRAT*(TABF(I2,J,K)-TABF(I1,J,K))
C
      YRAT=(Y-TABY(J1))/(TABY(J2)-TABY(J1))
      FXY=FX(J1)+YRAT*(FX(J2)-FX(J1))
C
      RETURN
      END
6/7/8/9 EOF
```

APPENDIX B

Listing of Deck to Execute Elbow Data Generator and Create NASTRAN Input Data File for Mesh A

```
(JOB CARD)
(CHARGE CARD)
ATTACH,PIPELB,PFNAME2,ID=XXXX.
PIPELB.
REQUEST,NEWPL,*PF.
UPDATE,F,C,N,D.
CATALOG,NEWPL,PFNAME3,ID=XXXX.
COPYSBF,COMPILE.
7/8/9 EOR    **** INPUT DATA (MESH A) FOR DATA GENERATOR FOLLOWS ****
90.
 12 17
15.0    5.163
(BLANK CARD)
      12 -21.    -18.5    -16.5    -14.5    -12.5    -10.5    -8.5    -6.5    -4.5
-2.5    -1.      0.
  4  1  2 10 11
      12 0.      1.       2.5      4.5      6.5      8.5      10.5    12.5    14.5
16.5    18.5     20.5
  3  1  2  3
7/8/9 EOR    **** INPUT DECK TO UPDATE FOLLOWS ****
*DECK DATA
NASTRAN CONFIG=6,FILES=(PLT2,NPTP,OPTP,INPT)
ID PIPE,ELBOW
APP DISP
SOL 1,0
TIME 25
$SEQUENCE YES
$GRID=525
$CONFIG=6
CEND
TITLE =STRESS ANALYSIS OF ELBOW ME-1  (ORNL-TM-4834)
MAXLINES=500000
*READ TAPE26
DISP=ALL
STRESS(PRINT,PUNCH)=1
SPCFORCE=ALL
$
$        SUBCASES HAVING SAME B.C. ARE GROUPED TOGETHER
$           TO AVOID UNNECESSARY MATRIX DECOMPOSITIONS
$
SUBCASE 1
   SUBTITLE=UNIT PRESSURE LOAD
   LABEL=SYM B.C.
   LOAD=21
   SPC=91
   OLOAD=ALL
   STRESS=1
SUBCASE 2
   SUBTITLE=UNIT IN-PLANE (Z) MOMENT
   LABEL=SYM B.C.
   LOAD=22
   SPC=91
   OLOAD=ALL
   STRESS=1
SUBCASE 3
   SUBTITLE=UNIT OUT-OF-PLANE (X) MOMENT
   LABEL=ANTI-SYM B.C.
   LOAD=23
   SPC=92
   OLOAD=ALL
   STRESS=1
SUBCASE 4
   SUBTITLE=UNIT TORSIONAL (Y) MOMENT
```

```
   LABEL=ANTI-SYM B.C.
   LOAD=24
   SPC=92
   OLOAD=ALL
   STRESS=1
SUBCOM 21
   SUBTITLE=PRESSURE LOAD OF 75.53 PSI
   SUBSEQ=75.53,0.,0.,0.
SUBCOM 22
   SUBTITLE=IN-PLANE MOMENT OF 32660 IN-LB
   SUBSEQ=0.,-32660.,0.,0.
SUBCOM 23
   SUBTITLE=OUT-OF-PLANE MOMENT OF 32660 IN-LB
   SUBSEQ=0.,0.,32660.,0.
SUBCOM 24
   SUBTITLE=   TORSIONAL MOMENT OF 32660 IN-LB
   SUBSEQ=0.,0.,0.,32660.
$
$
$       STRUCTURE     ...PIPE (RPIPE=5.163) CONSISTS OF
$                          90 DEGREE ELBOW (RBEND=15.0)
$                          ADJOINED BY STRAIGHT SECTIONS
$
$       SYMMETRY      ...IMPOSED AT PIPE HALF-CIRCUM (PHI=0,180)
$
$       COORD SYSTEMS...(ELBOW) R=RBEND-RPIPE*COS(PHI)
$                               T=THETA, (THETA=0,90 AT P.C.,P.T.)
$                               Z=RPIPE*SIN(PHI)
$
$       COORD SYSTEMS...(STRAIGHT SEC) R=RPIPE
$                                      T=PHI
$                                (TOP) Z=-DISTANCE FROM P.C.
$                             (BOTTOM) Z=DISTANCE FROM P.T.
$
$       NODAL VALUES ...(ELBOW)        ID=1000*(500+ITH)+IPH
$                               WHERE ITH ARE ROUNDED NODAL VALUES OF THETA
$                                     IPH ARE ROUNDED NODAL VALUES OF PHI
$
$                       (STRAIGHT SEC)
$                                (TOP) ID=1000*(500-10*(J-I))+IPH
$                                                   I=0,1,2,...,J-1
$                             (BOTTOM) ID=1000*(590+10*I)+IPH
$                                                 I=1,2,...,K
$                       WHERE J IS NO. OF Z-INTERVALS SUBDIVIDING TOP SEC
$                             K IS NO. OF Z-INTERVALS SUBDIVIDING BOT SEC
$
$
$
BEGIN BULK
$
$       SPOKES AT ELBOW ENDS CONVERGE TO MYTHICAL CENTER POINTS
$
*READ TAPE9
$
$       ELEMENT CONGRUENCY...(ELBOW)        THETA DIRECTION ONLY
$                            (STRAIGHT SEC) BOTH DIRECTIONS
$
*READ TAPE10
$
$                   ELBOW DEFINED IN COORD SYSTEM 1
$       STRAIGHT BOTTOM  DEFINED IN COORD SYSTEM 2
$       STRAIGHT TOP     DEFINED IN COORD SYSTEM 3
$       ORNL CARTESIAN SYSTEM IS NO. 4
```

```
$
CORD2C  1       0       0.      0.      0.      0.      0.      1.      +COR1
+COR1   1.      0.      0.
CORD2C  2       0       0.      15.     0.      -1.     15.     0.      +COR2
+COR2   0.      14.     0.
CORD2C  3       0       15.     0.      0.      15.     1.      0.      +COR3
+COR3   14.     0.      0.
CORD2R  4       0       0.      0.      0.      0.      0.      -1.     +COR4
+COR4   1.      0.      0.
$
$       FINITE ELEMENT PLATING
$
*READ TAPE11
$
$       RIGID CONNECTION FOR FREE  (LOADED) END OF PIPE
$
CRIGD1  1       200500  100500
*READ TAPE25
$
$       END CAP LOAD DUE TO UNIT INTERNAL PRESSURE
$
*READ TAPE27
$
$       GRID POINTS
$
$       MYTHICAL CENTER POINT 1 UNIT BEYOND FREE END OF PIPE
$
GRID    100500  0       15.0    -22.0   0.      4
$
$       MYTHICAL CENTER POINT AT FREE END OF PIPE
$
GRID    200500  0       15.0    -21.0   0.      4
$
$       STRAIGHT SECTION ABOVE THETA=0
$
*READ TAPE12
$
$       MYTHICAL CENTER POINT AT THETA=0 END OF ELBOW
$             (EQUIV TO ORIGIN OF COORD SYS 3)
$
GRID    500500  0       15.0    0.      0.      4
$
$       ELBOW POINTS
$
*READ TAPE13
$
$       MYTHICAL CENTER POINT AT THETA=90 END OF ELBOW
$             (EQUIV TO ORIGIN OF COORD SYS 2)
GRID    590500  0       0.      15.     0.      4
$
$       STRAIGHT SECTION BELOW THETA=90
$
*READ TAPE14
$
MAT1    45      2.9+7           0.3     7.324-4                         STEEL
$
$       BENDING MOMENTS APPLIED AT FREE END
$
MOMENT  22      200500  0       0.50    0.      0.      1.
MOMENT  23      200500  0       0.50    1.      0.      0.
MOMENT  24      200500  0       0.50    0.      1.      0.
$
PBAR    201     45      1.0-8   1.0-9   1.0-9   2.0-9
```

```
PBAR    202     45      2.0-6   2.0-9   2.0-9   4.0-9
$
$       INTERNAL PRESSURE LOADING FOR PIPE
$
*READ TAPE15
$
PQUAD2  200     45      0.390
$
$       SPC...(SID=71)       SYM B.C. AT MIDPLANE CUTTING PIPE CIRCUM
$
SPC     71      200500  345
*READ TAPE17
SPC     71      500500  345
*READ TAPE18
SPC     71      590500  345
*READ TAPE19
$
$             (SID=72)  ANTI-SYM B.C. AT MIDPLANE CUTTING PIPE CIRCUM
$
SPC     72      200500  126
*READ TAPE20
SPC     72      500500  126
*READ TAPE21
SPC     72      590500  126
*READ TAPE22
$
$       ELIMINATION OF ZERO STIFFNESS DOF
$
*READ TAPE23
$
$       CONSTRAIN FIXED END
$
*READ TAPE24
$
SPCADD  91      71      80      85
SPCADD  92      72      80      85
ENDDATA
6/7/8/9 EOF
```

APPENDIX C

Listing of Deck to Execute NASTRAN and Save Stresses at Middle of Elbow

```
(JOB CARD)
(CHARGE CARD)
LIMIT,13000.
MAP,OFF,
ATTACH,OLDPL,PFNAME3,ID=XXXX.
UPDATE,F,C=DATA,N,D.
ATTACH,NASTRAN.
REQUEST,PUN,*PF.
RFL,160000.
BEGIN,NASTRAN,NASTRAN,,DATA,,PUN.
CATALOG,PUN,PFNAME4,ID=XXXX.
7/8/9 EOR   **** UPDATE CORRECTIONS (IF ANY) FOLLOW ****
6/7/8/9 EOF
```

APPENDIX D

Listing of Deck to Smooth Principal Stresses and Create Solution File in PLOT QUICK Format

```
(JOB CARD)
(CHARGE CARD)
ATTACH,TAPE9,PFNAME4,ID=XXXX.
REQUEST,TAPE10,*PF.
ATTACH,PROD,461PRODUCTS,ID=CSYS.
ATTACH,BSPLNLB,ID=CAMK.
LIBRARY,PROD,BSPLNLB.
LOADLDR.
FTN.
LOADLDR.
LGO.
CATALOG,TAPE10,PFNAME5,ID=XXXX.
7/8/9 EOR    **** SOURCE DECK FOLLOWS *****
      PROGRAM PREPLT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE9,TAPE10)
C
C
C
C     THIS PROGRAM READS (TAPE9) NASTRAN-GENERATED ELBOW STRESS OUTPUT,
C     SELECTS FROM IT A SOLUTION SUBSET,
C     SMOOTHS THIS SOLUTION SET,
C     AND THEN SCALES + SAVES THE ORIGINAL AND SMOOTHED SOLUTION SETS,
C     EACH IN A PLOTQUICK (INTERACTIVE PLOTTING) FORMAT ON TAPE10
C
C
C     CARD INPUT CONSISTS OF NPTS,THE NO. OF ELMTS IN CIRCUMFER DIREC,
C     FOLLOWED BY A SHORT AND LONG NAME, TITS AND TITL, RESPECTIVELY,
C     FOR EACH OF THE 34 CURVES WHICH GIVE,
C     IN AN ALTERNATING (UNSMOOTHED AND SMOOTHED) PATTERN,
C      THE CIRCUMFERENTIAL COORDINATES, FOLLOWED BY A CONSECUTIVE STRING
C     OF MAJOR-OUTER,MINOR-OUTER,MAJOR-INNER,MINOR-INNER STRESS VALUES
C     FOR EACH OF THE 4 DIFFERENT LOADING CONDITIONS
C
C     MEL MARCUS, DTNSRDC 1843, FEB 1979
C
C
C
      DIMENSION Z(19),TITS(1),TITL(8)
      DIMENSION GPVAL(16),X(18),   NSEEK(4),C1(2,18),C2(2,103),Y(4,4,18)
      COMMON WORK(3000)
C
    1 FORMAT(1H1)
    2 FORMAT(13F6.2)
    3 FORMAT(12G11.4)
    4 FORMAT(8A10)
    5 FORMAT(1X,8A10)
    7 FORMAT(26I3)
    8 FORMAT(I10,8X,3E18.6/(18X,3E18.6,8X))
    9 FORMAT(2I3,E16.8)
C
      NLOADS=4
      NSKIP=7
      NVALUS=16
      NS=4
      NSEEK(1)=6
      NSEEK(2)=7
      NSEEK(3)=14
      NSEEK(4)=15
C
      READ  (5,9) NPTS
      WRITE (6,9) NPTS
      DANG=180./NPTS
      N1=6+(NPTS-1)+1
C
```

```
C
C
      WRITE (6,1)
      DO  20 K=1,NLOADS
      WRITE (6,9) K
C
      DO 10 I=1,NSKIP
   10 READ (9,4) TITS(1)
C
      DO 20 I=1,NPTS
      READ (9,8)  ID,(GPVAL(M),M=1,NVALUS)
      WRITE (6,8) ID,(GPVAL(M),M=1,NVALUS)
      X(I)=(I-.5)*DANG
C
      DO 20 J=1,NS
      N=NSEEK(J)
   20 Y(K,J,I)=GPVAL(N)
C
C
C
      SCFAC=.001
C
      WRITE (6,1)
      KOUNT=0
      DO 100 K=1,NLOADS
      DO 100 J=1,NS
C
      DO 30 I=1,NPTS
      C1(1,I)=X(I)
   30 C1(2,I)=Y(K,J,I)
C
      CALL CRVFIT(C1,2,NPTS,1,1.0,3,0,1.E-6,N1,0,WORK,3000,C2,RMS,IFAIL)
C
      IF (K.NE.1.OR.J.NE.1) GO TO 40
      KOUNT=KOUNT+1
      WRITE (6,7) KOUNT
      READ  (5,4) TITS(1)
      WRITE (6,5) TITS(1)
      WRITE (10)  TITS(1)
      READ  (5,4) (TITL(I),I=1,8)
      WRITE (6,5) (TITL(I),I=1,8)
      WRITE (10)  (TITL(I),I=1,8)
      WRITE (6,3) (C1(1,I),I=1,NPTS)
      WRITE (10)  (C1(1,I),I=1,NPTS)
      KOUNT=KOUNT+1
      WRITE (6,7) KOUNT
      READ  (5,4) TITS(1)
      WRITE (6,5) TITS(1)
      WRITE (10)  TITS(1)
      READ  (5,4) (TITL(I),I=1,8)
      WRITE (6,5) (TITL(I),I=1,8)
      WRITE (10)  (TITL(I),I=1,8)
      WRITE (6,3) (C2(1,I),I=1,N1)
      WRITE (10)  (C2(1,I),I=1,N1)
   40 CONTINUE
C
      KOUNT=KOUNT+1
      WRITE (6,7) KOUNT
      READ  (5,4) TITS(1)
      WRITE (6,5) TITS(1)
      WRITE (10)  TITS(1)
      READ  (5,4) (TITL(I),I=1,8)
      WRITE (6,5) (TITL(I),I=1,8)
```

```
      WRITE (10)  (TITL(I),I=1,8)
      WRITE (6,3) (C1(2,I)*SCFAC,I=1,NPTS)
      WRITE (10)  (C1(2,I)*SCFAC,I=1,NPTS)
      KOUNT=KOUNT+1
      WRITE (6,9) KOUNT,IFAIL,RMS
      READ  (5,4) TITS(1)
      WRITE (6,5) TITS(1)
      WRITE (10)  TITS(1)
      READ  (5,4) (TITL(I),I=1,8)
      WRITE (6,5) (TITL(I),I=1,8)
      WRITE (10)  (TITL(I),I=1,8)
      WRITE (6,3) (C2(2,I)*SCFAC,I=1,N1)
      WRITE (10)  (C2(2,I)*SCFAC,I=1,N1)
C
  100 CONTINUE
C
C
C
      END
7/8/9 EOR   **** INPUT DATA (MESH A) FOLLOWS *****
 12
PHI-U
PIPE CIRCUMFERENCE (DEGREES)
PHI
PIPE CIRCUMFERENCE (DEGREES)
PRES-UOMJR
NASTRAN MAJOR STRESS AT OUTER STATION 7 DUE TO PRESSURE LOAD
PRES-NOMJR
NASTRAN MAJOR STRESS AT OUTER STATION 7 DUE TO PRESSURE LOAD
********** SHORT AND LONG NAMES FOR 30 MORE CURVES FOLLOW ************
6/7/8/9 EOF
```

APPENDIX E

Listing of NASTRAN Input Data File for Mesh A

```
NASTRAN CONFIG=6,FILES=(PLT2,NPTP,OPTP,INPT)                          DATA    2
ID PIPE,ELBOW                                                         DATA    3
APP DISP                                                              DATA    4
SOL 1,0                                                               DATA    5
TIME 25                                                               DATA    6
$SEQUENCE YES                                                         DATA    7
$GRID=525                                                             DATA    8
$CONFIG=6                                                             DATA    9
CEND                                                                  DATA   10
TITLE =STRESS ANALYSIS OF ELBOW ME-1  (ORNL-TM-4834)                  DATA   11
MAXLINES=500000                                                       DATA   12
SET 1 = 545008, 545023, 545038, 545053, 545068, 545083, 545098, 545113,  DATA   13
        545128, 545143, 545158, 545173,                               DATA   14
        999999                                                        DATA   15
DISP=ALL                                                              DATA   16
STRESS(PRINT,PUNCH)=1                                                 DATA   17
SPCFORCE=ALL                                                          DATA   18
$                                                                     DATA   19
$       SUBCASES HAVING SAME B.C. ARE GROUPED TOGETHER                DATA   20
$          TO AVOID UNNECESSARY MATRIX DECOMPOSITIONS                 DATA   21
$                                                                     DATA   22
SUBCASE 1                                                             DATA   23
   SUBTITLE=UNIT PRESSURE LOAD                                        DATA   24
   LABEL=SYM B.C.                                                     DATA   25
   LOAD=21                                                            DATA   26
   SPC=91                                                             DATA   27
   OLOAD=ALL                                                          DATA   28
   STRESS=1                                                           DATA   29
SUBCASE 2                                                             DATA   30
   SUBTITLE=UNIT IN-PLANE (Z) MOMENT                                  DATA   31
   LABEL=SYM B.C.                                                     DATA   32
   LOAD=22                                                            DATA   33
   SPC=91                                                             DATA   34
   OLOAD=ALL                                                          DATA   35
   STRESS=1                                                           DATA   36
SUBCASE 3                                                             DATA   37
   SUBTITLE=UNIT OUT-OF-PLANE (X) MOMENT                              DATA   38
   LABEL=ANTI-SYM B.C.                                                DATA   39
   LOAD=23                                                            DATA   40
   SPC=92                                                             DATA   41
   OLOAD=ALL                                                          DATA   42
   STRESS=1                                                           DATA   43
SUBCASE 4                                                             DATA   44
   SUBTITLE=UNIT TORSIONAL (Y) MOMENT                                 DATA   45
   LABEL=ANTI-SYM B.C.                                                DATA   46
   LOAD=24                                                            DATA   47
   SPC=92                                                             DATA   48
   OLOAD=ALL                                                          DATA   49
   STRESS=1                                                           DATA   50
SUBCOM 21                                                             DATA   51
   SUBTITLE=PRESSURE LOAD OF 75.53 PSI                                DATA   52
   SUBSEQ=75.53,0.,0.,0.                                              DATA   53
SUBCOM 22                                                             DATA   54
```

```
   SUBTITLE=IN-PLANE MOMENT OF 32660 IN-LB                                DATA    55
   SUBSEQ=0.,-32660.,0.,0.                                                DATA    56
SUBCOM 23                                                                 DATA    57
   SUBTITLE=OUT-OF-PLANE MOMENT OF 32660 IN-LB                            DATA    58
   SUBSEQ=0.,0.,32660.,0.                                                 DATA    59
SUBCOM 24                                                                 DATA    60
   SUBTITLE=   TORSIONAL MOMENT OF 32660 IN-LB                            DATA    61
   SUBSEQ=0.,0.,0.,32660.                                                 DATA    62
$                                                                         DATA    63
$                                                                         DATA    64
$       STRUCTURE     ...PIPE (RPIPE=5.163) CONSISTS OF                   DATA    65
$                        90 DEGREE ELBOW (RBEND=15.0)                     DATA    66
$                        ADJOINED BY STRAIGHT SECTIONS                    DATA    67
$                                                                         DATA    68
$       SYMMETRY      ...IMPOSED AT PIPE HALF-CIRCUM (PHI=0,180)          DATA    69
$                                                                         DATA    70
$       COORD SYSTEMS...(ELBOW) R=RBEND-RPIPE*COS(PHI)                    DATA    71
$                               T=THETA, (THETA=0,90 AT P.C.,P.T.)        DATA    72
$                               Z=RPIPE*SIN(PHI)                          DATA    73
$                                                                         DATA    74
$       COORD SYSTEMS...(STRAIGHT SEC) R=RPIPE                            DATA    75
$                                      T=PHI                              DATA    76
$                                (TOP) Z=-DISTANCE FROM P.C.              DATA    77
$                             (BOTTOM) Z=DISTANCE FROM P.T.               DATA    78
$                                                                         DATA    79
$       NODAL VALUES ...(ELBOW)          ID=1000*(500+ITH)+IPH            DATA    80
$                               WHERE ITH ARE ROUNDED NODAL VALUES OF THETA DATA  81
$                                     IPH ARE ROUNDED NODAL VALUES OF PHI DATA    82
$                                                                         DATA    83
$                       (STRAIGHT SEC)                                    DATA    84
$                                (TOP) ID=1000*(500-10*(J-I))+IPH         DATA    85
$                                                     I=0,1,2,...,J-1     DATA    86
$                             (BOTTOM) ID=1000*(590+10*I)+IPH             DATA    87
$                                                  I=1,2,...,K            DATA    88
$                       WHERE J IS NO. OF Z-INTERVALS SUBDIVIDING TOP SEC DATA    89
$                             K IS NO. OF Z-INTERVALS SUBDIVIDING BOT SEC DATA    90
$                                                                         DATA    91
$                                                                         DATA    92
$                                                                         DATA    93
BEGIN BULK                                                                DATA    94
$                                                                         DATA    95
$       SPOKES AT ELBOW ENDS CONVERGE TO MYTHICAL CENTER POINTS           DATA    96
$                                                                         DATA    97
CBAR     500501    201  500000  500500    0.0     1.0     0.0       1    DATA    98
CBAR     500502    202  500015  500500    0.0     1.0     0.0       1    DATA    99
CBAR     500503    202  500030  500500    0.0     1.0     0.0       1    DATA   100
CBAR     500504    202  500045  500500    0.0     1.0     0.0       1    DATA   101
CBAR     500505    202  500060  500500    0.0     1.0     0.0       1    DATA   102
CBAR     500506    202  500075  500500    0.0     1.0     0.0       1    DATA   103
CBAR     500507    202  500090  500500    0.0     1.0     0.0       1    DATA   104
CBAR     500508    202  500105  500500    0.0     1.0     0.0       1    DATA   105
CBAR     500509    202  500120  500500    0.0     1.0     0.0       1    DATA   106
CBAR     500510    202  500135  500500    0.0     1.0     0.0       1    DATA   107
CBAR     500511    202  500150  500500    0.0     1.0     0.0       1    DATA   108
```

```
CBAR     500512    202  500165  500500    0.0     1.0     0.0       1        DATA   109
CBAR     500513    201  500180  500500    0.0     1.0     0.0       1        DATA   110
CBAR     590501    201  590000  590500    0.0     1.0     0.0       1        DATA   111
CBAR     590502    202  590015  590500    0.0     1.0     0.0       1        DATA   112
CBAR     590503    202  590030  590500    0.0     1.0     0.0       1        DATA   113
CBAR     590504    202  590045  590500    0.0     1.0     0.0       1        DATA   114
CBAR     590505    202  590060  590500    0.0     1.0     0.0       1        DATA   115
CBAR     590506    202  590075  590500    0.0     1.0     0.0       1        DATA   116
CBAR     590507    202  590090  590500    0.0     1.0     0.0       1        DATA   117
CBAR     590508    202  590105  590500    0.0     1.0     0.0       1        DATA   118
CBAR     590509    202  590120  590500    0.0     1.0     0.0       1        DATA   119
CBAR     590510    202  590135  590500    0.0     1.0     0.0       1        DATA   120
CBAR     590511    202  590150  590500    0.0     1.0     0.0       1        DATA   121
CBAR     590512    202  590165  590500    0.0     1.0     0.0       1        DATA   122
CBAR     590513    201  590180  590500    0.0     1.0     0.0       1        DATA   123
$                                                                             DATA   124
$       ELEMENT CONGRUENCY...(ELBOW)        THETA DIRECTION ONLY              DATA   125
$                            (STRAIGHT SEC) BOTH DIRECTIONS                   DATA   126
$                                                                             DATA   127
CNGRNT   390000  390015                                                       DATA   128
CNGRNT   390000  390030                                                       DATA   129
CNGRNT   390000  390045                                                       DATA   130
CNGRNT   390000  390060                                                       DATA   131
CNGRNT   390000  390075                                                       DATA   132
CNGRNT   390000  390090                                                       DATA   133
CNGRNT   390000  390105                                                       DATA   134
CNGRNT   390000  390120                                                       DATA   135
CNGRNT   390000  390135                                                       DATA   136
CNGRNT   390000  390150                                                       DATA   137
CNGRNT   390000  390165                                                       DATA   138
CNGRNT   400000  400015                                                       DATA   139
CNGRNT   400000  400030                                                       DATA   140
CNGRNT   400000  400045                                                       DATA   141
CNGRNT   400000  400060                                                       DATA   142
CNGRNT   400000  400075                                                       DATA   143
CNGRNT   400000  400090                                                       DATA   144
CNGRNT   400000  400105                                                       DATA   145
CNGRNT   400000  400120                                                       DATA   146
CNGRNT   400000  400135                                                       DATA   147
CNGRNT   400000  400150                                                       DATA   148
CNGRNT   400000  400165                                                       DATA   149
CNGRNT   400000  410000                                                       DATA   150
CNGRNT   400000  410015                                                       DATA   151
CNGRNT   400000  410030                                                       DATA   152
CNGRNT   400000  410045                                                       DATA   153
CNGRNT   400000  410060                                                       DATA   154
CNGRNT   400000  410075                                                       DATA   155
CNGRNT   400000  410090                                                       DATA   156
CNGRNT   400000  410105                                                       DATA   157
CNGRNT   400000  410120                                                       DATA   158
CNGRNT   400000  410135                                                       DATA   159
CNGRNT   400000  410150                                                       DATA   160
CNGRNT   400000  410165                                                       DATA   161
CNGRNT   400000  420000                                                       DATA   162
```

```
CNGRNT    400000    420015                                    DATA    163
CNGRNT    400000    420030                                    DATA    164
CNGRNT    400000    420045                                    DATA    165
CNGRNT    400000    420060                                    DATA    166
CNGRNT    400000    420075                                    DATA    167
CNGRNT    400000    420090                                    DATA    168
CNGRNT    400000    420105                                    DATA    169
CNGRNT    400000    420120                                    DATA    170
CNGRNT    400000    420135                                    DATA    171
CNGRNT    400000    420150                                    DATA    172
CNGRNT    400000    420165                                    DATA    173
CNGRNT    400000    430000                                    DATA    174
CNGRNT    400000    430015                                    DATA    175
CNGRNT    400000    430030                                    DATA    176
CNGRNT    400000    430045                                    DATA    177
CNGRNT    400000    430060                                    DATA    178
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$                                                                         DATA   555
$                 ELBOW DEFINED IN COORD SYSTEM 1                         DATA   556
$       STRAIGHT BOTTOM  DEFINED IN COORD SYSTEM 2                        DATA   557
$       STRAIGHT TOP     DEFINED IN COORD SYSTEM 3                        DATA   558
$       ORNL CARTESIAN SYSTEM IS NO. 4                                    DATA   559
$                                                                         DATA   560
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+COR1   1.      0.      0.                                                DATA   562
CORD2C  2       0       0.      15.     0.      -1.     15.     0.      +COR2  DATA   563
+COR2   0.      14.     0.                                                DATA   564
CORD2C  3       0       15.     0.      0.      15.     1.      0.      +COR3  DATA   565
+COR3   14.     0.      0.                                                DATA   566
CORD2R  4       0       0.      0.      0.      0.      0.      -1.     +COR4  DATA   567
+COR4   1.      0.      0.                                                DATA   568
$                                                                         DATA   569
$       FINITE ELEMENT PLATING                                            DATA   570
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CQUAD2   587158   200   585150   590150   590165   585165                    DATA   906
CQUAD2   587173   200   585165   590165   590180   585180                    DATA   907
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CQUAD2	600045	200	600045	610045	610060	600060	DATA	923
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CQUAD2	600105	200	600105	610105	610120	600120	DATA	927
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CQUAD2	640060	200	640060	650060	650075	640075	DATA	972

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CQUAD2    690150     200  690150  700150  700165  690165                    DATA  1038
CQUAD2    690165     200  690165  700165  700180  690180                    DATA  1039
$                                                                            DATA  1040
$       RIGID CONNECTION FOR FREE  (LOADED) END OF PIPE                      DATA  1041
$                                                                            DATA  1042
CRIGD1  1        200500  100500                                              DATA  1043
CRIGD1         2  200500  390000                                              DATA  1044
CRIGD1         3  200500  390015                                              DATA  1045
CRIGD1         4  200500  390030                                              DATA  1046
CRIGD1         5  200500  390045                                              DATA  1047
CRIGD1         6  200500  390060                                              DATA  1048
CRIGD1         7  200500  390075                                              DATA  1049
CRIGD1         8  200500  390090                                              DATA  1050
CRIGD1         9  200500  390105                                              DATA  1051
CRIGD1        10  200500  390120                                              DATA  1052
CRIGD1        11  200500  390135                                              DATA  1053
CRIGD1        12  200500  390150                                              DATA  1054
CRIGD1        13  200500  390165                                              DATA  1055
CRIGD1        14  200500  390180                                              DATA  1056
$                                                                            DATA  1057
$       END CAP LOAD DUE TO UNIT INTERNAL PRESSURE                           DATA  1058
$                                                                            DATA  1059
FORCE         21  200500       3 41.3954      0.      0.     -1.             DATA  1060
$                                                                            DATA  1061
$       GRID POINTS                                                          DATA  1062
$                                                                            DATA  1063
$       MYTHICAL CENTER POINT 1 UNIT BEYOND FREE END OF PIPE                 DATA  1064
$                                                                            DATA  1065
GRID    100500  0        15.0    -22.0   0.      4                           DATA  1066
$                                                                            DATA  1067
$       MYTHICAL CENTER POINT AT FREE END OF PIPE                            DATA  1068
$                                                                            DATA  1069
GRID    200500  0        15.0    -21.0   0.      4                           DATA  1070
$                                                                            DATA  1071
$       STRAIGHT SECTION ABOVE THETA=0                                       DATA  1072
$                                                                            DATA  1073
GRID      390000       3  5.1630   0.000-21.0000       3                    DATA  1074
GRID      390015       3  5.1630  15.000-21.0000       3                    DATA  1075
GRID      390030       3  5.1630  30.000-21.0000       3                    DATA  1076
GRID      390045       3  5.1630  45.000-21.0000       3                    DATA  1077
GRID      390060       3  5.1630  60.000-21.0000       3                    DATA  1078
GRID      390075       3  5.1630  75.000-21.0000       3                    DATA  1079
GRID      390090       3  5.1630  90.000-21.0000       3                    DATA  1080
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GRID	390105	3	5.1630	105.000-21.0000	3	DATA	1081
GRID	390120	3	5.1630	120.000-21.0000	3	DATA	1082
GRID	390135	3	5.1630	135.000-21.0000	3	DATA	1083
GRID	390150	3	5.1630	150.000-21.0000	3	DATA	1084
GRID	390165	3	5.1630	165.000-21.0000	3	DATA	1085
GRID	390180	3	5.1630	180.000-21.0000	3	DATA	1086
GRID	400000	3	5.1630	0.000-18.5000	3	DATA	1087
GRID	400015	3	5.1630	15.000-18.5000	3	DATA	1088
GRID	400030	3	5.1630	30.000-18.5000	3	DATA	1089
GRID	400045	3	5.1630	45.000-18.5000	3	DATA	1090
GRID	400060	3	5.1630	60.000-18.5000	3	DATA	1091
GRID	400075	3	5.1630	75.000-18.5000	3	DATA	1092
GRID	400090	3	5.1630	90.000-18.5000	3	DATA	1093
GRID	400105	3	5.1630	105.000-18.5000	3	DATA	1094
GRID	400120	3	5.1630	120.000-18.5000	3	DATA	1095
GRID	400135	3	5.1630	135.000-18.5000	3	DATA	1096
GRID	400150	3	5.1630	150.000-18.5000	3	DATA	1097
GRID	400165	3	5.1630	165.000-18.5000	3	DATA	1098
GRID	400180	3	5.1630	180.000-18.5000	3	DATA	1099
GRID	410000	3	5.1630	0.000-16.5000	3	DATA	1100
GRID	410015	3	5.1630	15.000-16.5000	3	DATA	1101
GRID	410030	3	5.1630	30.000-16.5000	3	DATA	1102
GRID	410045	3	5.1630	45.000-16.5000	3	DATA	1103
GRID	410060	3	5.1630	60.000-16.5000	3	DATA	1104
GRID	410075	3	5.1630	75.000-16.5000	3	DATA	1105
GRID	410090	3	5.1630	90.000-16.5000	3	DATA	1106
GRID	410105	3	5.1630	105.000-16.5000	3	DATA	1107
GRID	410120	3	5.1630	120.000-16.5000	3	DATA	1108
GRID	410135	3	5.1630	135.000-16.5000	3	DATA	1109
GRID	410150	3	5.1630	150.000-16.5000	3	DATA	1110
GRID	410165	3	5.1630	165.000-16.5000	3	DATA	1111
GRID	410180	3	5.1630	180.000-16.5000	3	DATA	1112
GRID	420000	3	5.1630	0.000-14.5000	3	DATA	1113
GRID	420015	3	5.1630	15.000-14.5000	3	DATA	1114
GRID	420030	3	5.1630	30.000-14.5000	3	DATA	1115
GRID	420045	3	5.1630	45.000-14.5000	3	DATA	1116
GRID	420060	3	5.1630	60.000-14.5000	3	DATA	1117
GRID	420075	3	5.1630	75.000-14.5000	3	DATA	1118
GRID	420090	3	5.1630	90.000-14.5000	3	DATA	1119
GRID	420105	3	5.1630	105.000-14.5000	3	DATA	1120
GRID	420120	3	5.1630	120.000-14.5000	3	DATA	1121
GRID	420135	3	5.1630	135.000-14.5000	3	DATA	1122
GRID	420150	3	5.1630	150.000-14.5000	3	DATA	1123
GRID	420165	3	5.1630	165.000-14.5000	3	DATA	1124
GRID	420180	3	5.1630	180.000-14.5000	3	DATA	1125
GRID	430000	3	5.1630	0.000-12.5000	3	DATA	1126
GRID	430015	3	5.1630	15.000-12.5000	3	DATA	1127
GRID	430030	3	5.1630	30.000-12.5000	3	DATA	1128
GRID	430045	3	5.1630	45.000-12.5000	3	DATA	1129
GRID	430060	3	5.1630	60.000-12.5000	3	DATA	1130
GRID	430075	3	5.1630	75.000-12.5000	3	DATA	1131
GRID	430090	3	5.1630	90.000-12.5000	3	DATA	1132
GRID	430105	3	5.1630	105.000-12.5000	3	DATA	1133
GRID	430120	3	5.1630	120.000-12.5000	3	DATA	1134

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GRID     430150     3  5.1630 150.000-12.5000     3                    DATA  1136
GRID     430165     3  5.1630 165.000-12.5000     3                    DATA  1137
GRID     430180     3  5.1630 180.000-12.5000     3                    DATA  1138
GRID     440000     3  5.1630   0.000-10.5000     3                    DATA  1139
GRID     440015     3  5.1630  15.000-10.5000     3                    DATA  1140
GRID     440030     3  5.1630  30.000-10.5000     3                    DATA  1141
GRID     440045     3  5.1630  45.000-10.5000     3                    DATA  1142
GRID     440060     3  5.1630  60.000-10.5000     3                    DATA  1143
GRID     440075     3  5.1630  75.000-10.5000     3                    DATA  1144
GRID     440090     3  5.1630  90.000-10.5000     3                    DATA  1145
GRID     440105     3  5.1630 105.000-10.5000     3                    DATA  1146
GRID     440120     3  5.1630 120.000-10.5000     3                    DATA  1147
GRID     440135     3  5.1630 135.000-10.5000     3                    DATA  1148
GRID     440150     3  5.1630 150.000-10.5000     3                    DATA  1149
GRID     440165     3  5.1630 165.000-10.5000     3                    DATA  1150
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GRID     450015     3  5.1630  15.000 -8.5000     3                    DATA  1153
GRID     450030     3  5.1630  30.000 -8.5000     3                    DATA  1154
GRID     450045     3  5.1630  45.000 -8.5000     3                    DATA  1155
GRID     450060     3  5.1630  60.000 -8.5000     3                    DATA  1156
GRID     450075     3  5.1630  75.000 -8.5000     3                    DATA  1157
GRID     450090     3  5.1630  90.000 -8.5000     3                    DATA  1158
GRID     450105     3  5.1630 105.000 -8.5000     3                    DATA  1159
GRID     450120     3  5.1630 120.000 -8.5000     3                    DATA  1160
GRID     450135     3  5.1630 135.000 -8.5000     3                    DATA  1161
GRID     450150     3  5.1630 150.000 -8.5000     3                    DATA  1162
GRID     450165     3  5.1630 165.000 -8.5000     3                    DATA  1163
GRID     450180     3  5.1630 180.000 -8.5000     3                    DATA  1164
GRID     460000     3  5.1630   0.000 -6.5000     3                    DATA  1165
GRID     460015     3  5.1630  15.000 -6.5000     3                    DATA  1166
GRID     460030     3  5.1630  30.000 -6.5000     3                    DATA  1167
GRID     460045     3  5.1630  45.000 -6.5000     3                    DATA  1168
GRID     460060     3  5.1630  60.000 -6.5000     3                    DATA  1169
GRID     460075     3  5.1630  75.000 -6.5000     3                    DATA  1170
GRID     460090     3  5.1630  90.000 -6.5000     3                    DATA  1171
GRID     460105     3  5.1630 105.000 -6.5000     3                    DATA  1172
GRID     460120     3  5.1630 120.000 -6.5000     3                    DATA  1173
GRID     460135     3  5.1630 135.000 -6.5000     3                    DATA  1174
GRID     460150     3  5.1630 150.000 -6.5000     3                    DATA  1175
GRID     460165     3  5.1630 165.000 -6.5000     3                    DATA  1176
GRID     460180     3  5.1630 180.000 -6.5000     3                    DATA  1177
GRID     470000     3  5.1630   0.000 -4.5000     3                    DATA  1178
GRID     470015     3  5.1630  15.000 -4.5000     3                    DATA  1179
GRID     470030     3  5.1630  30.000 -4.5000     3                    DATA  1180
GRID     470045     3  5.1630  45.000 -4.5000     3                    DATA  1181
GRID     470060     3  5.1630  60.000 -4.5000     3                    DATA  1182
GRID     470075     3  5.1630  75.000 -4.5000     3                    DATA  1183
GRID     470090     3  5.1630  90.000 -4.5000     3                    DATA  1184
GRID     470105     3  5.1630 105.000 -4.5000     3                    DATA  1185
GRID     470120     3  5.1630 120.000 -4.5000     3                    DATA  1186
GRID     470135     3  5.1630 135.000 -4.5000     3                    DATA  1187
GRID     470150     3  5.1630 150.000 -4.5000     3                    DATA  1188
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GRID      470165        3  5.1630 165.000 -4.5000        3                    DATA  1189
GRID      470180        3  5.1630 180.000 -4.5000        3                    DATA  1190
GRID      480000        3  5.1630   0.000 -2.5000        3                    DATA  1191
GRID      480015        3  5.1630  15.000 -2.5000        3                    DATA  1192
GRID      480030        3  5.1630  30.000 -2.5000        3                    DATA  1193
GRID      480045        3  5.1630  45.000 -2.5000        3                    DATA  1194
GRID      480060        3  5.1630  60.000 -2.5000        3                    DATA  1195
GRID      480075        3  5.1630  75.000 -2.5000        3                    DATA  1196
GRID      480090        3  5.1630  90.000 -2.5000        3                    DATA  1197
GRID      480105        3  5.1630 105.000 -2.5000        3                    DATA  1198
GRID      480120        3  5.1630 120.000 -2.5000        3                    DATA  1199
GRID      480135        3  5.1630 135.000 -2.5000        3                    DATA  1200
GRID      480150        3  5.1630 150.000 -2.5000        3                    DATA  1201
GRID      480165        3  5.1630 165.000 -2.5000        3                    DATA  1202
GRID      480180        3  5.1630 180.000 -2.5000        3                    DATA  1203
GRID      490000        3  5.1630   0.000 -1.0000        3                    DATA  1204
GRID      490015        3  5.1630  15.000 -1.0000        3                    DATA  1205
GRID      490030        3  5.1630  30.000 -1.0000        3                    DATA  1206
GRID      490045        3  5.1630  45.000 -1.0000        3                    DATA  1207
GRID      490060        3  5.1630  60.000 -1.0000        3                    DATA  1208
GRID      490075        3  5.1630  75.000 -1.0000        3                    DATA  1209
GRID      490090        3  5.1630  90.000 -1.0000        3                    DATA  1210
GRID      490105        3  5.1630 105.000 -1.0000        3                    DATA  1211
GRID      490120        3  5.1630 120.000 -1.0000        3                    DATA  1212
GRID      490135        3  5.1630 135.000 -1.0000        3                    DATA  1213
GRID      490150        3  5.1630 150.000 -1.0000        3                    DATA  1214
GRID      490165        3  5.1630 165.000 -1.0000        3                    DATA  1215
GRID      490180        3  5.1630 180.000 -1.0000        3                    DATA  1216
$                                                                              DATA  1217
$       MYTHICAL CENTER POINT AT THETA=0 END OF ELBOW                          DATA  1218
$             (EQUIV TO ORIGIN OF COORD SYS 3)                                 DATA  1219
$                                                                              DATA  1220
GRID    500500  0       15.0    0.      0.      4                              DATA  1221
$                                                                              DATA  1222
$       ELBOW POINTS                                                           DATA  1223
$                                                                              DATA  1224
GRID      500000        1  9.8370   0.000  0.0000        1                    DATA  1225
GRID      500015        1 10.0129   0.000  1.3363        1                    DATA  1226
GRID      500030        1 10.5287   0.000  2.5815        1                    DATA  1227
GRID      500045        1 11.3492   0.000  3.6508        1                    DATA  1228
GRID      500060        1 12.4185   0.000  4.4713        1                    DATA  1229
GRID      500075        1 13.6637   0.000  4.9871        1                    DATA  1230
GRID      500090        1 15.0000   0.000  5.1630        1                    DATA  1231
GRID      500105        1 16.3363   0.000  4.9871        1                    DATA  1232
GRID      500120        1 17.5815   0.000  4.4713        1                    DATA  1233
GRID      500135        1 18.6508   0.000  3.6508        1                    DATA  1234
GRID      500150        1 19.4713   0.000  2.5815        1                    DATA  1235
GRID      500165        1 19.9871   0.000  1.3363        1                    DATA  1236
GRID      500180        1 20.1630   0.000  -.0000        1                    DATA  1237
GRID      505000        1  9.8370   5.294  0.0000        1                    DATA  1238
GRID      505015        1 10.0129   5.294  1.3363        1                    DATA  1239
GRID      505030        1 10.5287   5.294  2.5815        1                    DATA  1240
GRID      505045        1 11.3492   5.294  3.6508        1                    DATA  1241
GRID      505060        1 12.4185   5.294  4.4713        1                    DATA  1242
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GRID	505075	1	13.6637	5.294	4.9871	1	DATA	1243
GRID	505090	1	15.0000	5.294	5.1630	1	DATA	1244
GRID	505105	1	16.3363	5.294	4.9871	1	DATA	1245
GRID	505120	1	17.5815	5.294	4.4713	1	DATA	1246
GRID	505135	1	18.6508	5.294	3.6508	1	DATA	1247
GRID	505150	1	19.4713	5.294	2.5815	1	DATA	1248
GRID	505165	1	19.9871	5.294	1.3363	1	DATA	1249
GRID	505180	1	20.1630	5.294	-.0000	1	DATA	1250
GRID	511000	1	9.8370	10.588	0.0000	1	DATA	1251
GRID	511015	1	10.0129	10.588	1.3363	1	DATA	1252
GRID	511030	1	10.5287	10.588	2.5815	1	DATA	1253
GRID	511045	1	11.3492	10.588	3.6508	1	DATA	1254
GRID	511060	1	12.4185	10.588	4.4713	1	DATA	1255
GRID	511075	1	13.6637	10.588	4.9871	1	DATA	1256
GRID	511090	1	15.0000	10.588	5.1630	1	DATA	1257
GRID	511105	1	16.3363	10.588	4.9871	1	DATA	1258
GRID	511120	1	17.5815	10.588	4.4713	1	DATA	1259
GRID	511135	1	18.6508	10.588	3.6508	1	DATA	1260
GRID	511150	1	19.4713	10.588	2.5815	1	DATA	1261
GRID	511165	1	19.9871	10.588	1.3363	1	DATA	1262
GRID	511180	1	20.1630	10.588	-.0000	1	DATA	1263
GRID	516000	1	9.8370	15.882	0.0000	1	DATA	1264
GRID	516015	1	10.0129	15.882	1.3363	1	DATA	1265
GRID	516030	1	10.5287	15.882	2.5815	1	DATA	1266
GRID	516045	1	11.3492	15.882	3.6508	1	DATA	1267
GRID	516060	1	12.4185	15.882	4.4713	1	DATA	1268
GRID	516075	1	13.6637	15.882	4.9871	1	DATA	1269
GRID	516090	1	15.0000	15.882	5.1630	1	DATA	1270
GRID	516105	1	16.3363	15.882	4.9871	1	DATA	1271
GRID	516120	1	17.5815	15.882	4.4713	1	DATA	1272
GRID	516135	1	18.6508	15.882	3.6508	1	DATA	1273
GRID	516150	1	19.4713	15.882	2.5815	1	DATA	1274
GRID	516165	1	19.9871	15.882	1.3363	1	DATA	1275
GRID	516180	1	20.1630	15.882	-.0000	1	DATA	1276
GRID	521000	1	9.8370	21.176	0.0000	1	DATA	1277
GRID	521015	1	10.0129	21.176	1.3363	1	DATA	1278
GRID	521030	1	10.5287	21.176	2.5815	1	DATA	1279
GRID	521045	1	11.3492	21.176	3.6508	1	DATA	1280
GRID	521060	1	12.4185	21.176	4.4713	1	DATA	1281
GRID	521075	1	13.6637	21.176	4.9871	1	DATA	1282
GRID	521090	1	15.0000	21.176	5.1630	1	DATA	1283
GRID	521105	1	16.3363	21.176	4.9871	1	DATA	1284
GRID	521120	1	17.5815	21.176	4.4713	1	DATA	1285
GRID	521135	1	18.6508	21.176	3.6508	1	DATA	1286
GRID	521150	1	19.4713	21.176	2.5815	1	DATA	1287
GRID	521165	1	19.9871	21.176	1.3363	1	DATA	1288
GRID	521180	1	20.1630	21.176	-.0000	1	DATA	1289
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GRID	526015	1	10.0129	26.471	1.3363	1	DATA	1291
GRID	526030	1	10.5287	26.471	2.5815	1	DATA	1292
GRID	526045	1	11.3492	26.471	3.6508	1	DATA	1293
GRID	526060	1	12.4185	26.471	4.4713	1	DATA	1294
GRID	526075	1	13.6637	26.471	4.9871	1	DATA	1295
GRID	526090	1	15.0000	26.471	5.1630	1	DATA	1296

GRID	526105	1	16.3363	26.471	4.9871	1	DATA	1297
GRID	526120	1	17.5815	26.471	4.4713	1	DATA	1298
GRID	526135	1	18.6508	26.471	3.6508	1	DATA	1299
GRID	526150	1	19.4713	26.471	2.5815	1	DATA	1300
GRID	526165	1	19.9871	26.471	1.3363	1	DATA	1301
GRID	526180	1	20.1630	26.471	-.0000	1	DATA	1302
GRID	532000	1	9.8370	31.765	0.0000	1	DATA	1303
GRID	532015	1	10.0129	31.765	1.3363	1	DATA	1304
GRID	532030	1	10.5287	31.765	2.5815	1	DATA	1305
GRID	532045	1	11.3492	31.765	3.6508	1	DATA	1306
GRID	532060	1	12.4185	31.765	4.4713	1	DATA	1307
GRID	532075	1	13.6637	31.765	4.9871	1	DATA	1308
GRID	532090	1	15.0000	31.765	5.1630	1	DATA	1309
GRID	532105	1	16.3363	31.765	4.9871	1	DATA	1310
GRID	532120	1	17.5815	31.765	4.4713	1	DATA	1311
GRID	532135	1	18.6508	31.765	3.6508	1	DATA	1312
GRID	532150	1	19.4713	31.765	2.5815	1	DATA	1313
GRID	532165	1	19.9871	31.765	1.3363	1	DATA	1314
GRID	532180	1	20.1630	31.765	-.0000	1	DATA	1315
GRID	537000	1	9.8370	37.059	0.0000	1	DATA	1316
GRID	537015	1	10.0129	37.059	1.3363	1	DATA	1317
GRID	537030	1	10.5287	37.059	2.5815	1	DATA	1318
GRID	537045	1	11.3492	37.059	3.6508	1	DATA	1319
GRID	537060	1	12.4185	37.059	4.4713	1	DATA	1320
GRID	537075	1	13.6637	37.059	4.9871	1	DATA	1321
GRID	537090	1	15.0000	37.059	5.1630	1	DATA	1322
GRID	537105	1	16.3363	37.059	4.9871	1	DATA	1323
GRID	537120	1	17.5815	37.059	4.4713	1	DATA	1324
GRID	537135	1	18.6508	37.059	3.6508	1	DATA	1325
GRID	537150	1	19.4713	37.059	2.5815	1	DATA	1326
GRID	537165	1	19.9871	37.059	1.3363	1	DATA	1327
GRID	537180	1	20.1630	37.059	-.0000	1	DATA	1328
GRID	542000	1	9.8370	42.353	0.0000	1	DATA	1329
GRID	542015	1	10.0129	42.353	1.3363	1	DATA	1330
GRID	542030	1	10.5287	42.353	2.5815	1	DATA	1331
GRID	542045	1	11.3492	42.353	3.6508	1	DATA	1332
GRID	542060	1	12.4185	42.353	4.4713	1	DATA	1333
GRID	542075	1	13.6637	42.353	4.9871	1	DATA	1334
GRID	542090	1	15.0000	42.353	5.1630	1	DATA	1335
GRID	542105	1	16.3363	42.353	4.9871	1	DATA	1336
GRID	542120	1	17.5815	42.353	4.4713	1	DATA	1337
GRID	542135	1	18.6508	42.353	3.6508	1	DATA	1338
GRID	542150	1	19.4713	42.353	2.5815	1	DATA	1339
GRID	542165	1	19.9871	42.353	1.3363	1	DATA	1340
GRID	542180	1	20.1630	42.353	-.0000	1	DATA	1341
GRID	548000	1	9.8370	47.647	0.0000	1	DATA	1342
GRID	548015	1	10.0129	47.647	1.3363	1	DATA	1343
GRID	548030	1	10.5287	47.647	2.5815	1	DATA	1344
GRID	548045	1	11.3492	47.647	3.6508	1	DATA	1345
GRID	548060	1	12.4185	47.647	4.4713	1	DATA	1346
GRID	548075	1	13.6637	47.647	4.9871	1	DATA	1347
GRID	548090	1	15.0000	47.647	5.1630	1	DATA	1348
GRID	548105	1	16.3363	47.647	4.9871	1	DATA	1349
GRID	548120	1	17.5815	47.647	4.4713	1	DATA	1350

GRID	548135	1	18.6508	47.647	3.6508	1	DATA	1351
GRID	548150	1	19.4713	47.647	2.5815	1	DATA	1352
GRID	548165	1	19.9871	47.647	1.3363	1	DATA	1353
GRID	548180	1	20.1630	47.647	-.0000	1	DATA	1354
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GRID	553015	1	10.0129	52.941	1.3363	1	DATA	1356
GRID	553030	1	10.5287	52.941	2.5815	1	DATA	1357
GRID	553045	1	11.3492	52.941	3.6508	1	DATA	1358
GRID	553060	1	12.4185	52.941	4.4713	1	DATA	1359
GRID	553075	1	13.6637	52.941	4.9871	1	DATA	1360
GRID	553090	1	15.0000	52.941	5.1630	1	DATA	1361
GRID	553105	1	16.3363	52.941	4.9871	1	DATA	1362
GRID	553120	1	17.5815	52.941	4.4713	1	DATA	1363
GRID	553135	1	18.6508	52.941	3.6508	1	DATA	1364
GRID	553150	1	19.4713	52.941	2.5815	1	DATA	1365
GRID	553165	1	19.9871	52.941	1.3363	1	DATA	1366
GRID	553180	1	20.1630	52.941	-.0000	1	DATA	1367
GRID	558000	1	9.8370	58.235	0.0000	1	DATA	1368
GRID	558015	1	10.0129	58.235	1.3363	1	DATA	1369
GRID	558030	1	10.5287	58.235	2.5815	1	DATA	1370
GRID	558045	1	11.3492	58.235	3.6508	1	DATA	1371
GRID	558060	1	12.4185	58.235	4.4713	1	DATA	1372
GRID	558075	1	13.6637	58.235	4.9871	1	DATA	1373
GRID	558090	1	15.0000	58.235	5.1630	1	DATA	1374
GRID	558105	1	16.3363	58.235	4.9871	1	DATA	1375
GRID	558120	1	17.5815	58.235	4.4713	1	DATA	1376
GRID	558135	1	18.6508	58.235	3.6508	1	DATA	1377
GRID	558150	1	19.4713	58.235	2.5815	1	DATA	1378
GRID	558165	1	19.9871	58.235	1.3363	1	DATA	1379
GRID	558180	1	20.1630	58.235	-.0000	1	DATA	1380
GRID	564000	1	9.8370	63.529	0.0000	1	DATA	1381
GRID	564015	1	10.0129	63.529	1.3363	1	DATA	1382
GRID	564030	1	10.5287	63.529	2.5815	1	DATA	1383
GRID	564045	1	11.3492	63.529	3.6508	1	DATA	1384
GRID	564060	1	12.4185	63.529	4.4713	1	DATA	1385
GRID	564075	1	13.6637	63.529	4.9871	1	DATA	1386
GRID	564090	1	15.0000	63.529	5.1630	1	DATA	1387
GRID	564105	1	16.3363	63.529	4.9871	1	DATA	1388
GRID	564120	1	17.5815	63.529	4.4713	1	DATA	1389
GRID	564135	1	18.6508	63.529	3.6508	1	DATA	1390
GRID	564150	1	19.4713	63.529	2.5815	1	DATA	1391
GRID	564165	1	19.9871	63.529	1.3363	1	DATA	1392
GRID	564180	1	20.1630	63.529	-.0000	1	DATA	1393
GRID	569000	1	9.8370	68.824	0.0000	1	DATA	1394
GRID	569015	1	10.0129	68.824	1.3363	1	DATA	1395
GRID	569030	1	10.5287	68.824	2.5815	1	DATA	1396
GRID	569045	1	11.3492	68.824	3.6508	1	DATA	1397
GRID	569060	1	12.4185	68.824	4.4713	1	DATA	1398
GRID	569075	1	13.6637	68.824	4.9871	1	DATA	1399
GRID	569090	1	15.0000	68.824	5.1630	1	DATA	1400
GRID	569105	1	16.3363	68.824	4.9871	1	DATA	1401
GRID	569120	1	17.5815	68.824	4.4713	1	DATA	1402
GRID	569135	1	18.6508	68.824	3.6508	1	DATA	1403
GRID	569150	1	19.4713	68.824	2.5815	1	DATA	1404

GRID	569165	1	19.9871	68.824	1.3363	1	DATA	1405
GRID	569180	1	20.1630	68.824	-.0000	1	DATA	1406
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GRID	574015	1	10.0129	74.118	1.3363	1	DATA	1408
GRID	574030	1	10.5287	74.118	2.5815	1	DATA	1409
GRID	574045	1	11.3492	74.118	3.6508	1	DATA	1410
GRID	574060	1	12.4185	74.118	4.4713	1	DATA	1411
GRID	574075	1	13.6637	74.118	4.9871	1	DATA	1412
GRID	574090	1	15.0000	74.118	5.1630	1	DATA	1413
GRID	574105	1	16.3363	74.118	4.9871	1	DATA	1414
GRID	574120	1	17.5815	74.118	4.4713	1	DATA	1415
GRID	574135	1	18.6508	74.118	3.6508	1	DATA	1416
GRID	574150	1	19.4713	74.118	2.5815	1	DATA	1417
GRID	574165	1	19.9871	74.118	1.3363	1	DATA	1418
GRID	574180	1	20.1630	74.118	-.0000	1	DATA	1419
GRID	579000	1	9.8370	79.412	0.0000	1	DATA	1420
GRID	579015	1	10.0129	79.412	1.3363	1	DATA	1421
GRID	579030	1	10.5287	79.412	2.5815	1	DATA	1422
GRID	579045	1	11.3492	79.412	3.6508	1	DATA	1423
GRID	579060	1	12.4185	79.412	4.4713	1	DATA	1424
GRID	579075	1	13.6637	79.412	4.9871	1	DATA	1425
GRID	579090	1	15.0000	79.412	5.1630	1	DATA	1426
GRID	579105	1	16.3363	79.412	4.9871	1	DATA	1427
GRID	579120	1	17.5815	79.412	4.4713	1	DATA	1428
GRID	579135	1	18.6508	79.412	3.6508	1	DATA	1429
GRID	579150	1	19.4713	79.412	2.5815	1	DATA	1430
GRID	579165	1	19.9871	79.412	1.3363	1	DATA	1431
GRID	579180	1	20.1630	79.412	-.0000	1	DATA	1432
GRID	585000	1	9.8370	84.706	0.0000	1	DATA	1433
GRID	585015	1	10.0129	84.706	1.3363	1	DATA	1434
GRID	585030	1	10.5287	84.706	2.5815	1	DATA	1435
GRID	585045	1	11.3492	84.706	3.6508	1	DATA	1436
GRID	585060	1	12.4185	84.706	4.4713	1	DATA	1437
GRID	585075	1	13.6637	84.706	4.9871	1	DATA	1438
GRID	585090	1	15.0000	84.706	5.1630	1	DATA	1439
GRID	585105	1	16.3363	84.706	4.9871	1	DATA	1440
GRID	585120	1	17.5815	84.706	4.4713	1	DATA	1441
GRID	585135	1	18.6508	84.706	3.6508	1	DATA	1442
GRID	585150	1	19.4713	84.706	2.5815	1	DATA	1443
GRID	585165	1	19.9871	84.706	1.3363	1	DATA	1444
GRID	585180	1	20.1630	84.706	-.0000	1	DATA	1445
GRID	590000	1	9.8370	90.000	0.0000	1	DATA	1446
GRID	590015	1	10.0129	90.000	1.3363	1	DATA	1447
GRID	590030	1	10.5287	90.000	2.5815	1	DATA	1448
GRID	590045	1	11.3492	90.000	3.6508	1	DATA	1449
GRID	590060	1	12.4185	90.000	4.4713	1	DATA	1450
GRID	590075	1	13.6637	90.000	4.9871	1	DATA	1451
GRID	590090	1	15.0000	90.000	5.1630	1	DATA	1452
GRID	590105	1	16.3363	90.000	4.9871	1	DATA	1453
GRID	590120	1	17.5815	90.000	4.4713	1	DATA	1454
GRID	590135	1	18.6508	90.000	3.6508	1	DATA	1455
GRID	590150	1	19.4713	90.000	2.5815	1	DATA	1456
GRID	590165	1	19.9871	90.000	1.3363	1	DATA	1457
GRID	590180	1	20.1630	90.000	-.0000	1	DATA	1458

```
$                                                                       DATA  1459
$       MYTHICAL CENTER POINT AT THETA=90 END OF ELBOW                  DATA  1460
$             (EQUIV TO ORIGIN OF COORD SYS 2)                          DATA  1461
GRID    590500  0       0.      15.     0.      4                       DATA  1462
$                                                                       DATA  1463
$       STRAIGHT SECTION BELOW THETA=90                                 DATA  1464
$                                                                       DATA  1465
GRID      600000        2  5.1630   0.000  1.0000        2             DATA  1466
GRID      600015        2  5.1630  15.000  1.0000        2             DATA  1467
GRID      600030        2  5.1630  30.000  1.0000        2             DATA  1468
GRID      600045        2  5.1630  45.000  1.0000        2             DATA  1469
GRID      600060        2  5.1630  60.000  1.0000        2             DATA  1470
GRID      600075        2  5.1630  75.000  1.0000        2             DATA  1471
GRID      600090        2  5.1630  90.000  1.0000        2             DATA  1472
GRID      600105        2  5.1630 105.000  1.0000        2             DATA  1473
GRID      600120        2  5.1630 120.000  1.0000        2             DATA  1474
GRID      600135        2  5.1630 135.000  1.0000        2             DATA  1475
GRID      600150        2  5.1630 150.000  1.0000        2             DATA  1476
GRID      600165        2  5.1630 165.000  1.0000        2             DATA  1477
GRID      600180        2  5.1630 180.000  1.0000        2             DATA  1478
GRID      610000        2  5.1630   0.000  2.5000        2             DATA  1479
GRID      610015        2  5.1630  15.000  2.5000        2             DATA  1480
GRID      610030        2  5.1630  30.000  2.5000        2             DATA  1481
GRID      610045        2  5.1630  45.000  2.5000        2             DATA  1482
GRID      610060        2  5.1630  60.000  2.5000        2             DATA  1483
GRID      610075        2  5.1630  75.000  2.5000        2             DATA  1484
GRID      610090        2  5.1630  90.000  2.5000        2             DATA  1485
GRID      610105        2  5.1630 105.000  2.5000        2             DATA  1486
GRID      610120        2  5.1630 120.000  2.5000        2             DATA  1487
GRID      610135        2  5.1630 135.000  2.5000        2             DATA  1488
GRID      610150        2  5.1630 150.000  2.5000        2             DATA  1489
GRID      610165        2  5.1630 165.000  2.5000        2             DATA  1490
GRID      610180        2  5.1630 180.000  2.5000        2             DATA  1491
GRID      620000        2  5.1630   0.000  4.5000        2             DATA  1492
GRID      620015        2  5.1630  15.000  4.5000        2             DATA  1493
GRID      620030        2  5.1630  30.000  4.5000        2             DATA  1494
GRID      620045        2  5.1630  45.000  4.5000        2             DATA  1495
GRID      620060        2  5.1630  60.000  4.5000        2             DATA  1496
GRID      620075        2  5.1630  75.000  4.5000        2             DATA  1497
GRID      620090        2  5.1630  90.000  4.5000        2             DATA  1498
GRID      620105        2  5.1630 105.000  4.5000        2             DATA  1499
GRID      620120        2  5.1630 120.000  4.5000        2             DATA  1500
GRID      620135        2  5.1630 135.000  4.5000        2             DATA  1501
GRID      620150        2  5.1630 150.000  4.5000        2             DATA  1502
GRID      620165        2  5.1630 165.000  4.5000        2             DATA  1503
GRID      620180        2  5.1630 180.000  4.5000        2             DATA  1504
GRID      630000        2  5.1630   0.000  6.5000        2             DATA  1505
GRID      630015        2  5.1630  15.000  6.5000        2             DATA  1506
GRID      630030        2  5.1630  30.000  6.5000        2             DATA  1507
GRID      630045        2  5.1630  45.000  6.5000        2             DATA  1508
GRID      630060        2  5.1630  60.000  6.5000        2             DATA  1509
GRID      630075        2  5.1630  75.000  6.5000        2             DATA  1510
GRID      630090        2  5.1630  90.000  6.5000        2             DATA  1511
GRID      630105        2  5.1630 105.000  6.5000        2             DATA  1512
```

GRID	630120	2	5.1630	120.000	6.5000	2	DATA	1513
GRID	630135	2	5.1630	135.000	6.5000	2	DATA	1514
GRID	630150	2	5.1630	150.000	6.5000	2	DATA	1515
GRID	630165	2	5.1630	165.000	6.5000	2	DATA	1516
GRID	630180	2	5.1630	180.000	6.5000	2	DATA	1517
GRID	640000	2	5.1630	0.000	8.5000	2	DATA	1518
GRID	640015	2	5.1630	15.000	8.5000	2	DATA	1519
GRID	640030	2	5.1630	30.000	8.5000	2	DATA	1520
GRID	640045	2	5.1630	45.000	8.5000	2	DATA	1521
GRID	640060	2	5.1630	60.000	8.5000	2	DATA	1522
GRID	640075	2	5.1630	75.000	8.5000	2	DATA	1523
GRID	640090	2	5.1630	90.000	8.5000	2	DATA	1524
GRID	640105	2	5.1630	105.000	8.5000	2	DATA	1525
GRID	640120	2	5.1630	120.000	8.5000	2	DATA	1526
GRID	640135	2	5.1630	135.000	8.5000	2	DATA	1527
GRID	640150	2	5.1630	150.000	8.5000	2	DATA	1528
GRID	640165	2	5.1630	165.000	8.5000	2	DATA	1529
GRID	640180	2	5.1630	180.000	8.5000	2	DATA	1530
GRID	650000	2	5.1630	0.000	10.5000	2	DATA	1531
GRID	650015	2	5.1630	15.000	10.5000	2	DATA	1532
GRID	650030	2	5.1630	30.000	10.5000	2	DATA	1533
GRID	650045	2	5.1630	45.000	10.5000	2	DATA	1534
GRID	650060	2	5.1630	60.000	10.5000	2	DATA	1535
GRID	650075	2	5.1630	75.000	10.5000	2	DATA	1536
GRID	650090	2	5.1630	90.000	10.5000	2	DATA	1537
GRID	650105	2	5.1630	105.000	10.5000	2	DATA	1538
GRID	650120	2	5.1630	120.000	10.5000	2	DATA	1539
GRID	650135	2	5.1630	135.000	10.5000	2	DATA	1540
GRID	650150	2	5.1630	150.000	10.5000	2	DATA	1541
GRID	650165	2	5.1630	165.000	10.5000	2	DATA	1542
GRID	650180	2	5.1630	180.000	10.5000	2	DATA	1543
GRID	660000	2	5.1630	0.000	12.5000	2	DATA	1544
GRID	660015	2	5.1630	15.000	12.5000	2	DATA	1545
GRID	660030	2	5.1630	30.000	12.5000	2	DATA	1546
GRID	660045	2	5.1630	45.000	12.5000	2	DATA	1547
GRID	660060	2	5.1630	60.000	12.5000	2	DATA	1548
GRID	660075	2	5.1630	75.000	12.5000	2	DATA	1549
GRID	660090	2	5.1630	90.000	12.5000	2	DATA	1550
GRID	660105	2	5.1630	105.000	12.5000	2	DATA	1551
GRID	660120	2	5.1630	120.000	12.5000	2	DATA	1552
GRID	660135	2	5.1630	135.000	12.5000	2	DATA	1553
GRID	660150	2	5.1630	150.000	12.5000	2	DATA	1554
GRID	660165	2	5.1630	165.000	12.5000	2	DATA	1555
GRID	660180	2	5.1630	180.000	12.5000	2	DATA	1556
GRID	670000	2	5.1630	0.000	14.5000	2	DATA	1557
GRID	670015	2	5.1630	15.000	14.5000	2	DATA	1558
GRID	670030	2	5.1630	30.000	14.5000	2	DATA	1559
GRID	670045	2	5.1630	45.000	14.5000	2	DATA	1560
GRID	670060	2	5.1630	60.000	14.5000	2	DATA	1561
GRID	670075	2	5.1630	75.000	14.5000	2	DATA	1562
GRID	670090	2	5.1630	90.000	14.5000	2	DATA	1563
GRID	670105	2	5.1630	105.000	14.5000	2	DATA	1564
GRID	670120	2	5.1630	120.000	14.5000	2	DATA	1565
GRID	670135	2	5.1630	135.000	14.5000	2	DATA	1566

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GRID     670150       2  5.1630 150.000 14.5000       2                          DATA  1567
GRID     670165       2  5.1630 165.000 14.5000       2                          DATA  1568
GRID     670180       2  5.1630 180.000 14.5000       2                          DATA  1569
GRID     680000       2  5.1630   0.000 16.5000       2                          DATA  1570
GRID     680015       2  5.1630  15.000 16.5000       2                          DATA  1571
GRID     680030       2  5.1630  30.000 16.5000       2                          DATA  1572
GRID     680045       2  5.1630  45.000 16.5000       2                          DATA  1573
GRID     680060       2  5.1630  60.000 16.5000       2                          DATA  1574
GRID     680075       2  5.1630  75.000 16.5000       2                          DATA  1575
GRID     680090       2  5.1630  90.000 16.5000       2                          DATA  1576
GRID     680105       2  5.1630 105.000 16.5000       2                          DATA  1577
GRID     680120       2  5.1630 120.000 16.5000       2                          DATA  1578
GRID     680135       2  5.1630 135.000 16.5000       2                          DATA  1579
GRID     680150       2  5.1630 150.000 16.5000       2                          DATA  1580
GRID     680165       2  5.1630 165.000 16.5000       2                          DATA  1581
GRID     680180       2  5.1630 180.000 16.5000       2                          DATA  1582
GRID     690000       2  5.1630   0.000 18.5000       2                          DATA  1583
GRID     690015       2  5.1630  15.000 18.5000       2                          DATA  1584
GRID     690030       2  5.1630  30.000 18.5000       2                          DATA  1585
GRID     690045       2  5.1630  45.000 18.5000       2                          DATA  1586
GRID     690060       2  5.1630  60.000 18.5000       2                          DATA  1587
GRID     690075       2  5.1630  75.000 18.5000       2                          DATA  1588
GRID     690090       2  5.1630  90.000 18.5000       2                          DATA  1589
GRID     690105       2  5.1630 105.000 18.5000       2                          DATA  1590
GRID     690120       2  5.1630 120.000 18.5000       2                          DATA  1591
GRID     690135       2  5.1630 135.000 18.5000       2                          DATA  1592
GRID     690150       2  5.1630 150.000 18.5000       2                          DATA  1593
GRID     690165       2  5.1630 165.000 18.5000       2                          DATA  1594
GRID     690180       2  5.1630 180.000 18.5000       2                          DATA  1595
GRID     700000       2  5.1630   0.000 20.5000       2                          DATA  1596
GRID     700015       2  5.1630  15.000 20.5000       2                          DATA  1597
GRID     700030       2  5.1630  30.000 20.5000       2                          DATA  1598
GRID     700045       2  5.1630  45.000 20.5000       2                          DATA  1599
GRID     700060       2  5.1630  60.000 20.5000       2                          DATA  1600
GRID     700075       2  5.1630  75.000 20.5000       2                          DATA  1601
GRID     700090       2  5.1630  90.000 20.5000       2                          DATA  1602
GRID     700105       2  5.1630 105.000 20.5000       2                          DATA  1603
GRID     700120       2  5.1630 120.000 20.5000       2                          DATA  1604
GRID     700135       2  5.1630 135.000 20.5000       2                          DATA  1605
GRID     700150       2  5.1630 150.000 20.5000       2                          DATA  1606
GRID     700165       2  5.1630 165.000 20.5000       2                          DATA  1607
GRID     700180       2  5.1630 180.000 20.5000       2                          DATA  1608
$                                                                                 DATA  1609
MAT1     45       2.9+7            0.3      7.324-4                     STEEL    DATA  1610
$                                                                                 DATA  1611
$        BENDING MOMENTS APPLIED AT FREE END                                      DATA  1612
$                                                                                 DATA  1613
MOMENT   22       200500   0       0.50     0.       0.       1.                  DATA  1614
MOMENT   23       200500   0       0.50     1.       0.       0.                  DATA  1615
MOMENT   24       200500   0       0.50     0.       1.       0.                  DATA  1616
$                                                                                 DATA  1617
PBAR     201      45       1.0-6   1.0-9    1.0-9    2.0-9                       DATA  1618
PBAR     202      45       2.0-6   2.0-9    2.0-9    4.0-9                       DATA  1619
$                                                                                 DATA  1620
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$       INTERNAL PRESSURE LOADING FOR PIPE                                DATA  1621
$                                                                         DATA  1622
PLOAD2        21  -1.000  390000                                          DATA  1623
PLOAD2        21  -1.000  390015                                          DATA  1624
PLOAD2        21  -1.000  390030                                          DATA  1625
PLOAD2        21  -1.000  390045                                          DATA  1626
PLOAD2        21  -1.000  390060                                          DATA  1627
PLOAD2        21  -1.000  390075                                          DATA  1628
PLOAD2        21  -1.000  390090                                          DATA  1629
PLOAD2        21  -1.000  390105                                          DATA  1630
PLOAD2        21  -1.000  390120                                          DATA  1631
PLOAD2        21  -1.000  390135                                          DATA  1632
PLOAD2        21  -1.000  390150                                          DATA  1633
PLOAD2        21  -1.000  390165                                          DATA  1634
PLOAD2        21  -1.000  400000                                          DATA  1635
PLOAD2        21  -1.000  400015                                          DATA  1636
PLOAD2        21  -1.000  400030                                          DATA  1637
PLOAD2        21  -1.000  400045                                          DATA  1638
PLOAD2        21  -1.000  400060                                          DATA  1639
PLOAD2        21  -1.000  400075                                          DATA  1640
PLOAD2        21  -1.000  400090                                          DATA  1641
PLOAD2        21  -1.000  400105                                          DATA  1642
PLOAD2        21  -1.000  400120                                          DATA  1643
PLOAD2        21  -1.000  400135                                          DATA  1644
PLOAD2        21  -1.000  400150                                          DATA  1645
PLOAD2        21  -1.000  400165                                          DATA  1646
PLOAD2        21  -1.000  410000                                          DATA  1647
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PLOAD2        21  -1.000  410030                                          DATA  1649
PLOAD2        21  -1.000  410045                                          DATA  1650
PLOAD2        21  -1.000  410060                                          DATA  1651
PLOAD2        21  -1.000  410075                                          DATA  1652
PLOAD2        21  -1.000  410090                                          DATA  1653
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PLOAD2        21  -1.000  420000                                          DATA  1659
PLOAD2        21  -1.000  420015                                          DATA  1660
PLOAD2        21  -1.000  420030                                          DATA  1661
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PLOAD2        21  -1.000  420075                                          DATA  1664
PLOAD2        21  -1.000  420090                                          DATA  1665
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PLOAD2        21  -1.000  420120                                          DATA  1667
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PLOAD2        21  -1.000  430030                                          DATA  1673
PLOAD2        21  -1.000  430045                                          DATA  1674
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PLOAD2      21  -1.000  430060                                  DATA  1675
PLOAD2      21  -1.000  430075                                  DATA  1676
PLOAD2      21  -1.000  430090                                  DATA  1677
PLOAD2      21  -1.000  430105                                  DATA  1678
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PLOAD2      21  -1.000  440060                                  DATA  1687
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PLOAD2      21  -1.000  440090                                  DATA  1689
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PLOAD2      21  -1.000  450060                                  DATA  1699
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PLOAD2      21  -1.000  470090                                  DATA  1725
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PLOAD2      21  -1.000  470120                                  DATA  1727
PLOAD2      21  -1.000  470135                                  DATA  1728
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PLOAD2      21  -1.000  490120                                  DATA  1751
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PLOAD2      21  -1.000  503023                                  DATA  1756
PLOAD2      21  -1.000  503038                                  DATA  1757
PLOAD2      21  -1.000  503053                                  DATA  1758
PLOAD2      21  -1.000  503068                                  DATA  1759
PLOAD2      21  -1.000  503083                                  DATA  1760
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PLOAD2      21  -1.000  503143                                  DATA  1764
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PLOAD2      21  -1.000  508083                                  DATA  1772
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SPC             71  400180      246                                         DATA  2098
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SPC          71  640180     246                                          DATA  2164
SPC          71  650000     246                                          DATA  2165
SPC          71  650180     246                                          DATA  2166
SPC          71  660000     246                                          DATA  2167
SPC          71  660180     246                                          DATA  2168
SPC          71  670000     246                                          DATA  2169
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SPC          71  680000     246                                          DATA  2171
SPC          71  680180     246                                          DATA  2172
SPC          71  690000     246                                          DATA  2173
SPC          71  690180     246                                          DATA  2174
SPC          71  700000     246                                          DATA  2175
SPC          71  700180     246                                          DATA  2176
$                                                                        DATA  2177
$            (SID=72)  ANTI-SYM B.C. AT MIDPLANE CUTTING PIPE CIRCUM     DATA  2178
$                                                                        DATA  2179
SPC     72     200500  126                                               DATA  2180
SPC          72  400000     135                                          DATA  2181
SPC          72  400180     135                                          DATA  2182
SPC          72  410000     135                                          DATA  2183
SPC          72  410180     135                                          DATA  2184
SPC          72  420000     135                                          DATA  2185
SPC          72  420180     135                                          DATA  2186
SPC          72  430000     135                                          DATA  2187
SPC          72  430180     135                                          DATA  2188
SPC          72  440000     135                                          DATA  2189
SPC          72  440180     135                                          DATA  2190
SPC          72  450000     135                                          DATA  2191
SPC          72  450180     135                                          DATA  2192
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SPC          72  470000     135                                          DATA  2195
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SPC          72  521000     126                                          DATA  2210
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SPC          72  526180     126                                          DATA  2213
SPC          72  532000     126                                          DATA  2214
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SPC          72  537180     126                                    DATA  2217
SPC          72  542000     126                                    DATA  2218
SPC          72  542180     126                                    DATA  2219
SPC          72  548000     126                                    DATA  2220
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SPC          72  553000     126                                    DATA  2222
SPC          72  553180     126                                    DATA  2223
SPC          72  558000     126                                    DATA  2224
SPC          72  558180     126                                    DATA  2225
SPC          72  564000     126                                    DATA  2226
SPC          72  564180     126                                    DATA  2227
SPC          72  569000     126                                    DATA  2228
SPC          72  569180     126                                    DATA  2229
SPC          72  574000     126                                    DATA  2230
SPC          72  574180     126                                    DATA  2231
SPC          72  579000     126                                    DATA  2232
SPC          72  579180     126                                    DATA  2233
SPC          72  585000     126                                    DATA  2234
SPC          72  585180     126                                    DATA  2235
SPC          72  590000     126                                    DATA  2236
SPC          72  590180     126                                    DATA  2237
SPC     72       590500  126                                        DATA  2238
SPC          72  600000     135                                    DATA  2239
SPC          72  600180     135                                    DATA  2240
SPC          72  610000     135                                    DATA  2241
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SPC          72  640180     135                                    DATA  2248
SPC          72  650000     135                                    DATA  2249
SPC          72  650180     135                                    DATA  2250
SPC          72  660000     135                                    DATA  2251
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SPC          72  670000     135                                    DATA  2253
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SPC          72  680180     135                                    DATA  2256
SPC          72  690000     135                                    DATA  2257
SPC          72  690180     135                                    DATA  2258
SPC          72  700000     135                                    DATA  2259
SPC          72  700180     135                                    DATA  2260
$                                                                   DATA  2261
$       ELIMINATION OF ZERO STIFFNESS DOF                           DATA  2262
$                                                                   DATA  2263
SPC          80  400000       4                                    DATA  2264
SPC          80  400180       4                                    DATA  2265
SPC          80  410000       4                                    DATA  2266
SPC          80  410180       4                                    DATA  2267
SPC          80  420000       4                                    DATA  2268
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SPC          80  430000      4                                    DATA  2270
SPC          80  430180      4                                    DATA  2271
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SPC          80  480180      4                                    DATA  2281
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SPC          80  490180      4                                    DATA  2283
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SPC          80  620000      4                                    DATA  2288
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SPC          80  630000      4                                    DATA  2290
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SPC          80  700000      4                                    DATA  2304
SPC          80  700180      4                                    DATA  2305
$                                                                 DATA  2306
$       CONSTRAIN FIXED END                                       DATA  2307
$                                                                 DATA  2308
SPC          85  700000  123456                                   DATA  2309
SPC          85  700015  123456                                   DATA  2310
SPC          85  700030  123456                                   DATA  2311
SPC          85  700045  123456                                   DATA  2312
SPC          85  700060  123456                                   DATA  2313
SPC          85  700075  123456                                   DATA  2314
SPC          85  700090  123456                                   DATA  2315
SPC          85  700105  123456                                   DATA  2316
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SPC          85  700135  123456                                   DATA  2318
SPC          85  700150  123456                                   DATA  2319
SPC          85  700165  123456                                   DATA  2320
SPC          85  700180  123456                                   DATA  2321
$                                                                 DATA  2322
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SPCADD  91      71      80      85                      DATA  2323
SPCADD  92      72      80      85                      DATA  2324
ENDDATA                                                 DATA  2325
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