PROFILOMETRY OF STEAM GENERATOR TUBES

Consolidated Edison Company of New York, Inc.
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CONTENTS

APPENDICES

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1.0 OBJECTIVE

Con Edison programs developed to resolve the steam generator denting problem can be characterized broadly in two groups. One group of programs is aimed at alleviating the cause of denting by minimizing corrosion or by chemically removing the corrosion products in the tube/support plate annuli in the steam generator. The other group of programs is aimed at dealing with the effects of denting by developing a technique for continuing safe operation with the corroded steam generator.

The work described in this report falls into the latter category. A principal objective of this group of programs is to determine the strain in the steam generator tube wall because, as the strain increases, the susceptibility to stress corrosion cracking increases. It is believed that by tracking changes in tube strain, tubes becoming susceptible to cracking can be identified and preventively plugged. Further, by careful selection of tubes for plugging, it is believed that the service life of the steam generator can be extended, perhaps to the life of the plant.

2.0 CURRENT STEAM GENERATOR TUBE EXAMINATION PRACTICE

2.1 Dent Identification and Measurement

When the denting phenomenon was identified, an eddy current technique for non-destructive examination of steam generator tubes was developed to measure the degree of denting. This was coupled to the pre-existing eddy current technique for detection of defects in tubing. Interpretation of eddy current signals was based on comparison with signals from standards. Tubes of the same alloy and dimensions as those in the steam generator were deformed locally by rolling to develop a known reduced outer diameter for an axial length equal to the thickness of the support plate. (Figure 2-1). Although denting could be quantified, in-service tube leaks could not be anticipated.

2.2 Finite Element Analysis

As a result of the high frequency of in-service tube leaks at Virginia Electric Power Co.'s Surry Units 1 and 2, and at Florida Power & Light Co.'s Turkey Point Units 3 and 4, Westinghouse developed a preventive plugging program. This was based on a finite element analysis which assumed that the support plate tube holes were growing larger as a result of the expansive force of the voluminous corrosion product in the tube/support plate annuli. Quasi-material properties were developed to represent the matrix of support plate material with tube holes and flow holes. The points of support of the plates against the steam

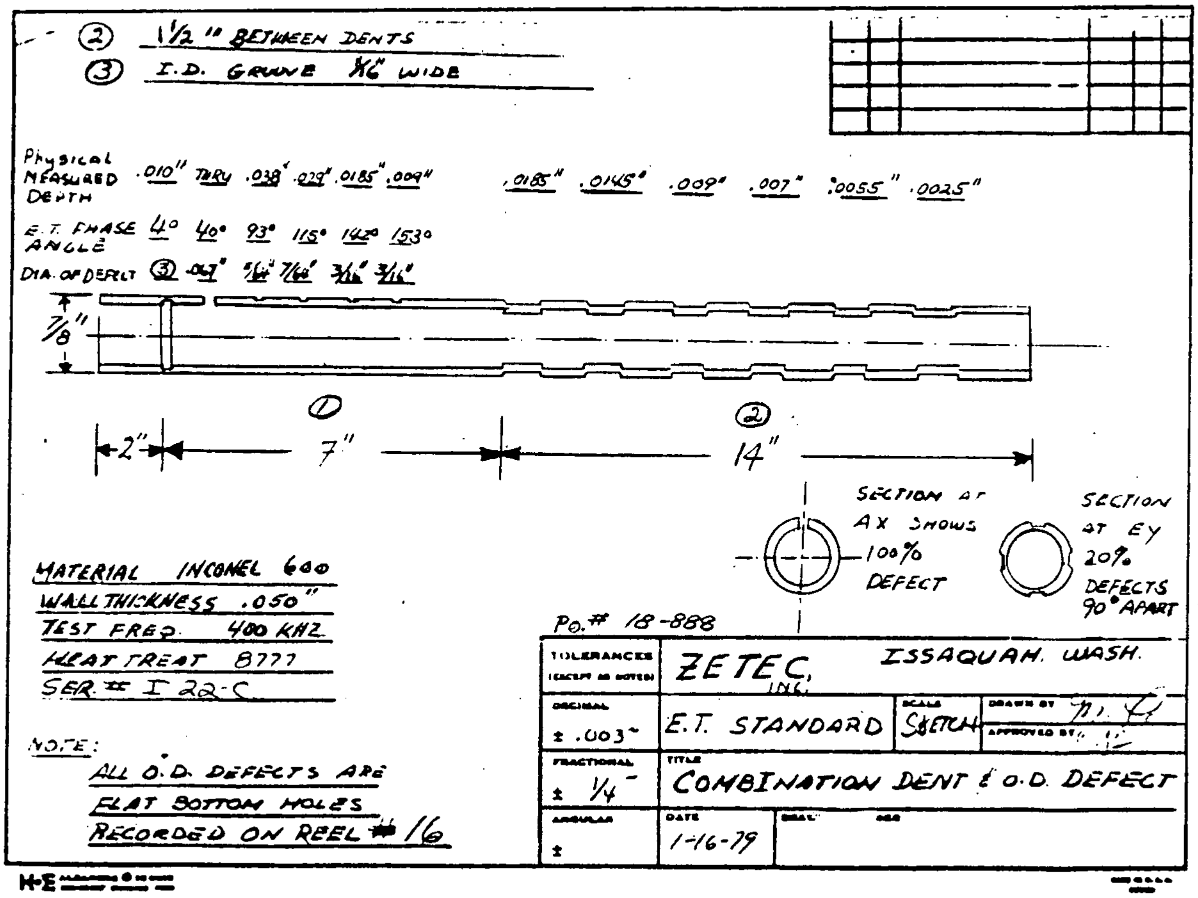


Figure 2-1 Calibration Standard for Eddy-current Dent and Defect Examination

generator wrapper were taken as the in-plane restraints, and a relationship was developed between support plate strain and tube strain. This led to a series of plate strain and tube strain contour maps which were used to identify those tubes believed to be susceptible to failure during the following service period.

The preventive plugging program was instituted at Surry and at Turkey Point, and resulted in plugging tubes in the first several rows in each steam generator. The program was successful in that the plants were able to resume operation for reasonable lengths of time without experiencing in-service tube leaks.

Some refinements in the assumptions used in the finite element analysis were made, and the analysis was repeated by Failure Analysis Associates as a contractor for Con Edison. Plate strain intensity and tube hoop-strain contour maps were developed (Figures 2-2, 2-3) but these were similar to the earlier Westinghouse maps.

2.3 Tube Gaging

As corrosion and denting progressed, it was found at many plants that in many instances the standard eddy current probe could not pass through the dented regions. Series of smaller diameter probes were selected so that examination of the more restricted tubes could be completed. At several plants, tubes which could not pass a 610 mil diameter probe were considered to be distorted severely enough to warrant preventive plugging. Further, the preventive plugging program described above was modified so that the analysis was used to identify tubes to be examined, and a

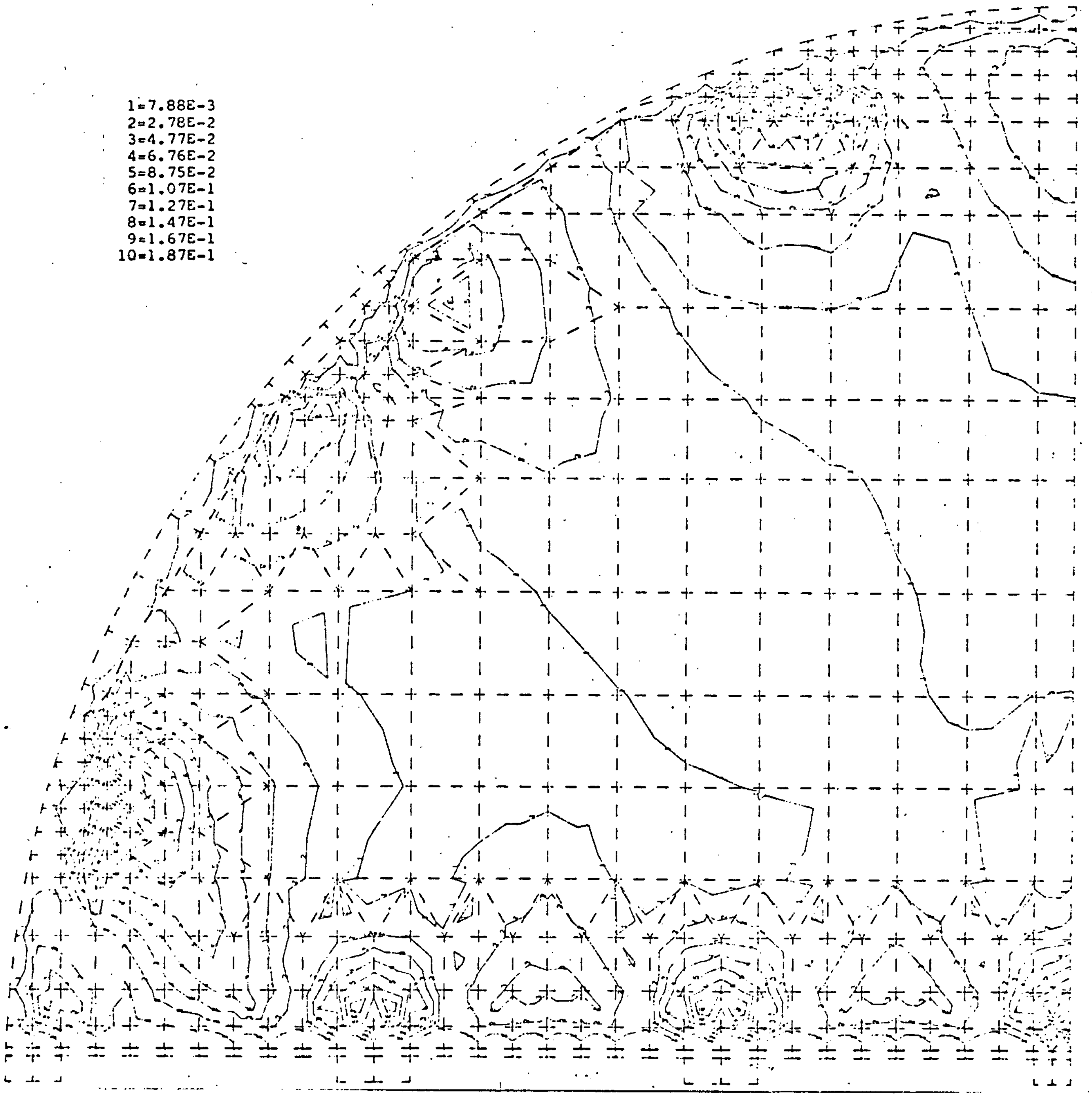


Figure 2-2 Steam Generator Plate Strain Intensity Contour Map at the Point where flow slots are closed 0.850".

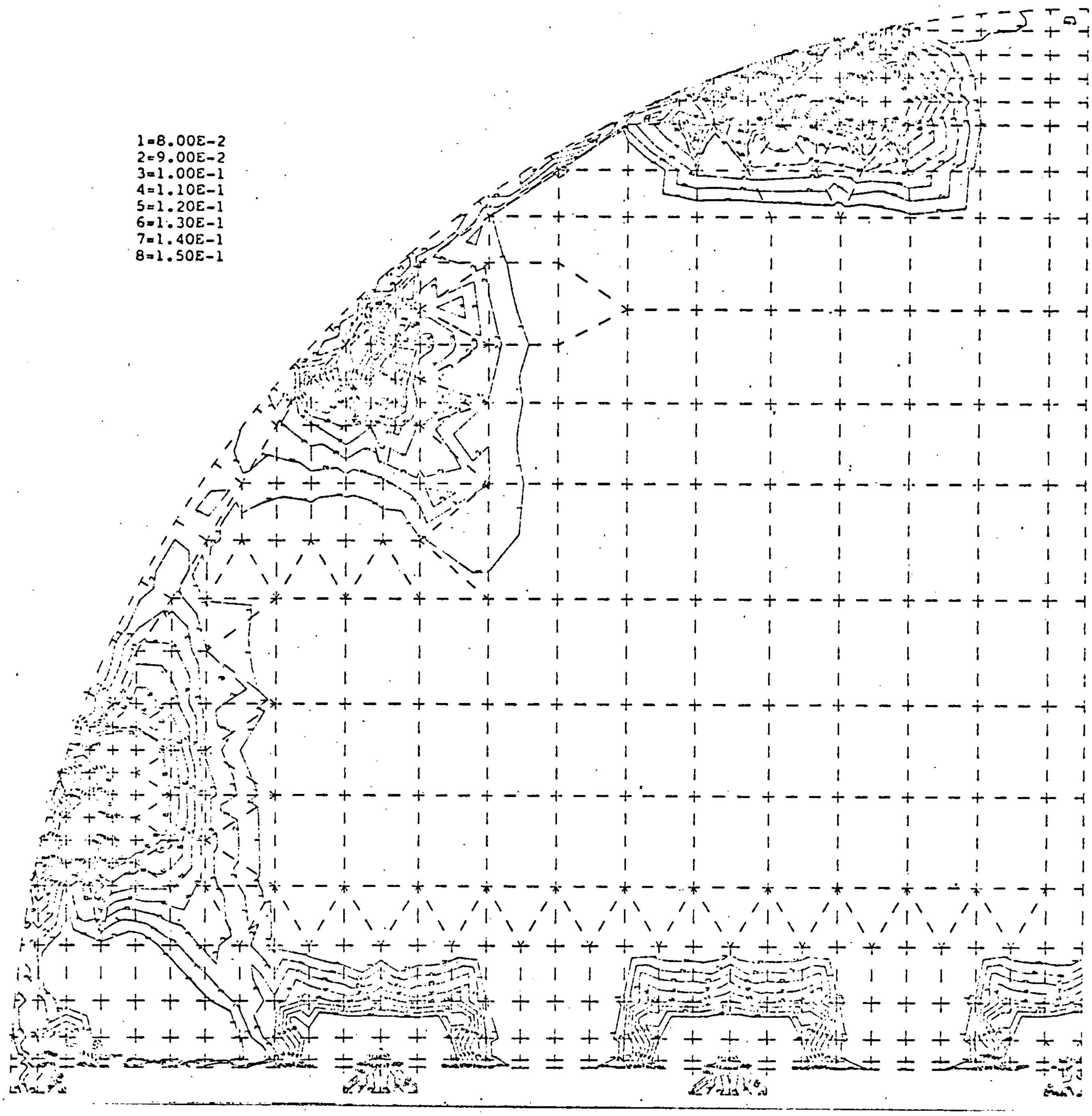


Figure 2-3 Steam Generator Tube Hoop Strain Contour Map at the Point where flow slots are closed 0.850".

decision on plugging was based on the diameter of the largest probe that could pass through the tube. Percentages of tubes plugged at Surry and Turkey Point reached close to 20%, and decisions were made to replace the steam generators at those plants. (Steam generators at Surry Unit 2 were replaced during the period from February 1979 to December 1979.)

2.4 Preventive Plugging Programs

The current preventive plugging program at Surry and Turkey Point utilizes the Westinghouse finite element analysis plus tube gaging. The analysis is used to identify tubes to be examined. These are eddy current examined for defects, and gaged for size. Tubes containing defects, tubes restricted to a 610 mil diameter probe and surrounding tubes are plugged preventively.

At other plants, the finite element analsyis is not used, and only those tubes containing defects and tubes restricted to some given diameter probe are plugged preventively. The limiting diameter ranges from 540 mils to 650 mils.

3.0 FIELD DATA

3.1 Indian Point 2 Support Plate Sample

In April 1978, as part of the chemical cleaning program, a sample of support plate consisting of 2 rows of 11 tubes each was removed from the lowest support plate in Steam Generator 23. (Figure 3-1). A location adjacent to a flow slot was decided upon because the finite element analysis predicted that this was a region of higher than average strain. Prior eddy current examination of the tubes in the sample had indicated that the tubes were free of defects, but were dented from two to five mils (radial). Only one of the tubes did not pass a standard 700 mil diameter probe, but did pass a 675 mil diameter probe. Mechnical measurements of the tubes after the sample was removed revealed that the tubes within the support plate holes were out-of-round by more than 0.050", and dents were not apparent. (Exact measurements are given in Table 3-1.) The flow holes were elongated, and several tube hole to flow hole ligaments were cracked.

3.2 Mechanical Tests

To improve understanding the behavior of the support plate, a number of mechanical tests were devised.

In one test, a 3/4" thick steel plate was machined to support plate dimensions containing a portion of a flow slot plus a 3 x 3 array of tube holes, as shown in Figure 3-2. The tube holes were mechanically expanded 0.050 to 0.090", causing the support plate segment to distort as shown. The flow slot edge distortion and the flow hole distortions are similar to conditions observed in the steam generators.

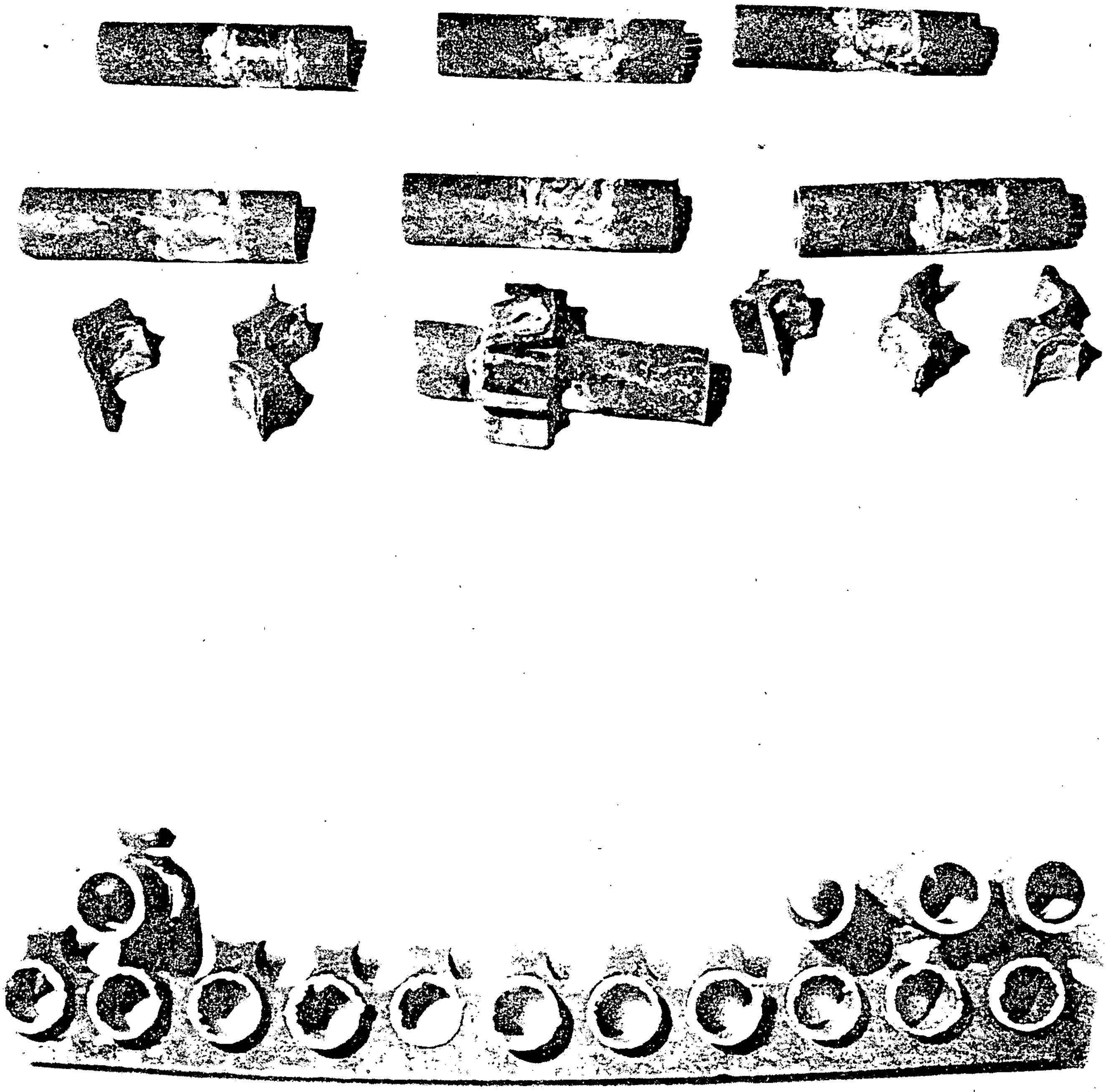


Figure 3-1 Support Plate Sample and Pieces as Removed from Steam Generator 23, April 1978.

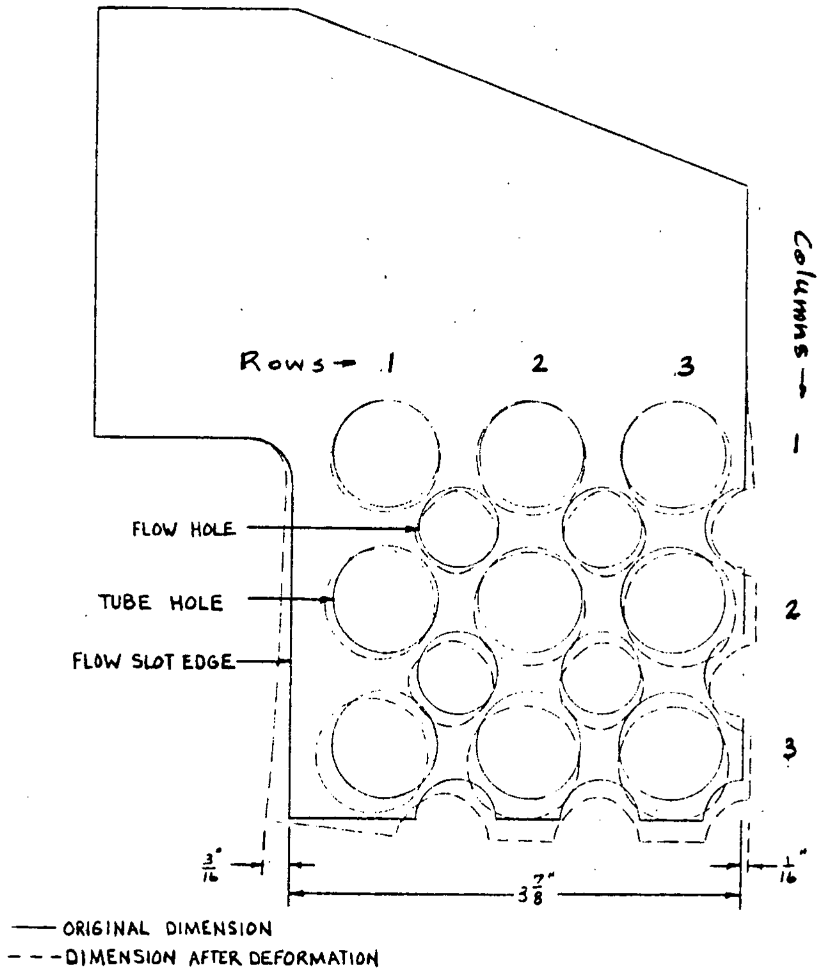
TABLE 3-1

Row 2 Tubes contained in Steam Generator Support Plate Sample

Tube No.	Eddy Current Dent, mils	Major I.D., mils	Minor I.D., mils
Row 2 Col. 3	5	807	708
Row 2 Col. 4	*	812	697
Row 2 Col. 5	2	806	710
Row 2 Col. 6	2	809	719
Row 2 Col. 7	2	797	728
Row 2 Col. 8	3	753	745
Row 2 Col. 9	2	765	740
Row 2 Col. 10	2	788	735
Row 2 Col. 11	2	768	764
Row 2 Col. 12	2	775	757
Ro2 2 Col. 13	2	772	765

Note: Nominal I.D. of tubes as supplied as 775 mils.

*Restricted to standard 700 mil probe



Tube Hole Dimensions After Deformation

Tube No.	R1C1	R1C2	R1C3	R2C1	R2C2	R2C3	R3C1	R3C2	R3C3
Major Diameter	0.972	0.958	0.993	0.990	0.990	0.992	0.990	0.991	0.982

Figure 3-2 Simulated Support Plate Segment, as Deformed Mechanically.

In another test, tensile test bars were machined as shown in Figure 3-3. Under tensile load, the bars elongated a small amount before breaking but the breaking load and the percentage elongation of the short ligament region which was stressed beyond yield was within the range normally expected of mild steel. In bending, the ligament is very "soft", and the tensile test bar can easily be bent by hand, with the deformation being limited to the narrow "waist" of the ligament.

These tests illustrate the shortcomings of an idealized "matrix" as used in the finite element analyses to describe the behavior of the support plate.

3.3 Tube Examination Data

In reviewing the history of tubes that were found to be restricted to the standard 700 mil diameter probe, it was found that there does not appear to be an orderly progression in tube deformation, as determined either by eddy current examination or by probe gaging.

At Indian Point, average and maximum dent sizes have not changed significantly since 1976. (Table 3-2). However, the numbers of tubes found obstructed by eddy current probes have steadily increased. (Table 3-3).

Of twelve tubes plugged preventively after the 1979 examination because the 610 mil diameter probe could not pass, only one was obstructed to a 640 mil diameter probe a year before. Others previously passed either the standard 700 mil diameter probe or a

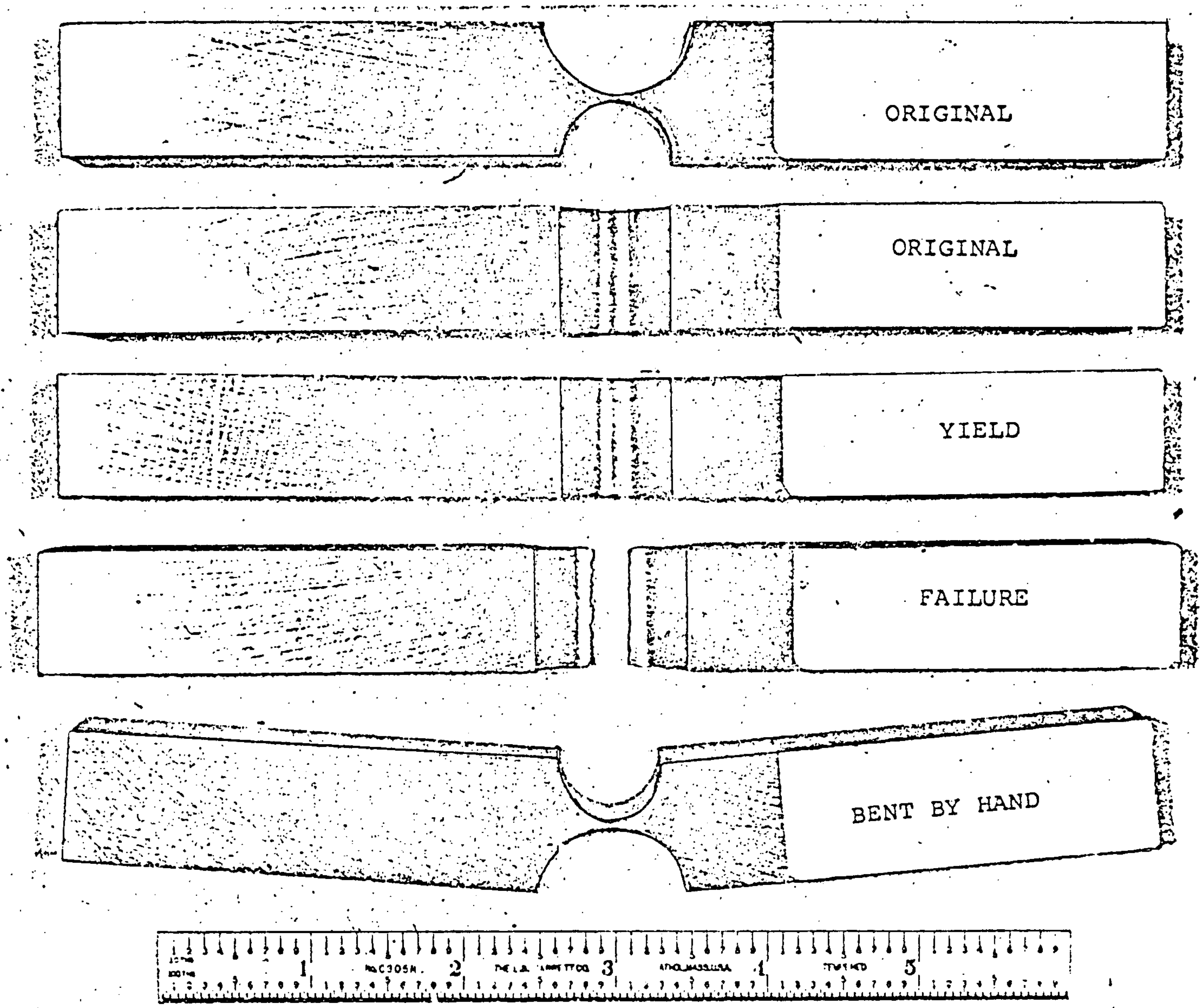


Figure 3-3 Test Bars Representing Steam Generator Support Plate Ligaments.

TABLE 3-2

INDIAN POINT UNIT 2

Dent Measurements
(mils)

S. G.	July 1979		March 1978		April 1977		1976	
	Avg	Max	Avg	Max	Avg	Max	Avg	Max
21	3.1	13		-	3.0	20	4.2	15
22	2.4	9		-	2.7	10	2.7	9
23	2.7	15	2.6	9			4.3	12
24	2.3	9	2.2	9			3.4	10

TABLE 3-3

INDIAN POINT UNIT 2

Tube Obstructed to 700 mil Dia. Probe

S. G.	1979	1978	1977	1976
21	27.7% (405)	-	0.02% (360)	0.01% (372)
22	19.0% (396)	-	0.01% (360)	0% (269)
23	26.0% (261)	10% (463)	-	0.02% (194)
24	26.4% (405)	14.8% (473)	-	0% (474)

Note: Percentages refer to sample examined, not to entire bundle. Numbers in parentheses are numbers of tubes examined.

675 mil diameter probe, giving no indication of possible future need for plugging. Similarly dents previously measured in these tubes were shallow, and the deepest ones (10 to 12 mils) appeared to be stable over a two year period. (Table 3-4)

Further, of 81 tubes continued in service after being found obstructed to the standard 700 mil diameter probe in the 1978 eddy current examination, 48 were unchanged in the 1979 examination, 10 were less severely restricted, and 23 were more severely restricted. (Tables 3-5 and 3-6)

3.4 Flow Slot Observations

For the past several years, the flow slots in the steam generator support plates have been observed to be deforming or "hourglassing". This hourglassing was taken to be, in some way, an integration or measure of all the in-plane distortion of the support plate due to the forces of the corrosion products.

However, in reviewing the history of flow slot hourglassing, it was found that there does not appear to be an orderly progression in deformation. Comparison of data taken at examination periods indicates that rates of change of individual flow slots are changing (Table 3-7). Furthermore, in any single support plate, there is a considerable variation in the degree of flow slot deformation. In Steam Generator 22, support plate 1, flow slots deformation ranges from 1/8" (3%) to 1 3/8" (50%) (Figure 3-4).

Finite element analyses of the effects of corrosion on support plate strain indicate that hourglassing of the flow slots is to be expected, but that the range of closures at any time is less than 10%.

TABLE 3-4

INDIAN POINT UNIT 2

HISTORY OF TUBES PLUGGED IN 1979

TUBE	PRIOR DENT MEASUREMENT	PRIOR PROBE PASSED
SG 21 R15C90	13 mil - 4/77	700 mil - 4/77
SG 22 R2C17	4 mil - 4/77	675 mil - 4/75
R2C20	4 mil - 4/77	700 mil - 4/77
R2C32	4 mil - 4/77	700 mil - 4/77
R2C33	4 mil - 4/77	700 mil - 4/77
R34C17	9 mil - 4/77	700 mil - 4/77
SG 23 R41C32	9 mil - 3/78	640 mil - 3/78
R41C36	12 mil - 3/78, 12 mil - 11/76	675 mil - 3/78
R42C37	10 mil - 3/78, 12 mil - 11/76	675 mil - 3/78
R43C38	4 mil - 3/78, 6 mil - 11/76	700 mil - 3/78
SG 24 R8C3	2 mil - 3/78	640 mil - 3/78
R35C18	9 mil - 3/78	610 mil - 3/78

TABLE 3-5

INDIAN POINT UNIT 2

Record of Restricted Tubes, S.G. 23

47 tubes were restricted to 700 mil probe in 1978

1978	1979
28 passed 675 mil probe	15 unchanged
	2 restricted to 675 mil probe
	1 removed
	10 no data
16 passed 640 mil probe	5 passed 675 mil probe
	6 unchanged
	5 no data
1 passed 610	no data

Two (2) did not pass 610 and were plugged in 1978

TABLE 3-6

INDIAN POINT UNIT 2

Record of Restricted Tubes S.G. 24

70 tubes were restricted to 700 mil probe in 1978

1978	1979
55 passed 675 mil probe	4 passed 700 mil probe
	21 unchanged
	14 restricted to 675 mil probe
	5 restricted to 640 mil probe
	11 no data
7 passed 640 mil probe	1 passed 675 mil probe
	4 unchanged
	2 restricted to 610 mil probe
2 passed 610 mil probe	unchanged

Six (6) did not pass 610 and were plugged in 1978

TABLE 3-7

INDIAN POINT UNIT 2

FLOW SLOT CLOSURE, STEAM GENERATOR 23*

Support Plate No. 1

Date	Slot M1	Slot M2	Slot M3	Slot N3	Slot N2	Slot N1
	Closure, inches (± 0.04)					
June '76	0	0.13	0.25	0.13	0.13	0
April '78	0.30	0.33	0.69	0.69	0.43	0.43
September '78	0.37	0.13	0.76	-	0.45	0.21
June '79	0.31	0.34	0.93	0.89	0.58	0.56

Support Plate No. 2

Date	Slot M1	Slot M2	Slot M3	Slot N3	Slot N2	Slot N1
April '78	0.55	0.54	0.95	0.95	0.71	0.61
September '78	0.80	0.62	0.90	-	-	0.33
June '79	0.91	0.86	1.03	1.11	0.75	0.65

Support Plate No. 3

Date	Slot M1	Slot M2	Slot M3	Slot N3	Slot N2	Slot N1
April '78	0.76	0.81	1.05**	0.95	0.99**	0.83
September '78	0.62	0.86	1.10**	0.94	0.90**	0.71
June '79	0.81	1.06	1.18**	0.92	1.23**	0.84

* Range of data as given for this steam generator is typical of other steam generators.

** Crack in ligament adjacent to flow slot.

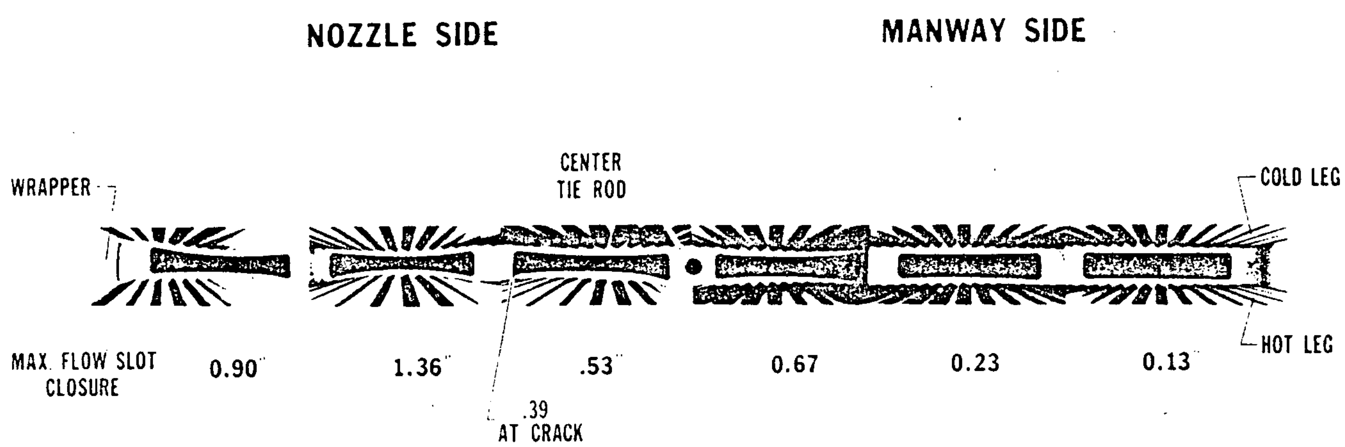


Figure 3-4 Composite of Photographs of Flow Slots, Steam Generator 22, Support Plate No. 1, July, 1979

4.0 PROFILOMETRY

4.1 Gaging Evaluation

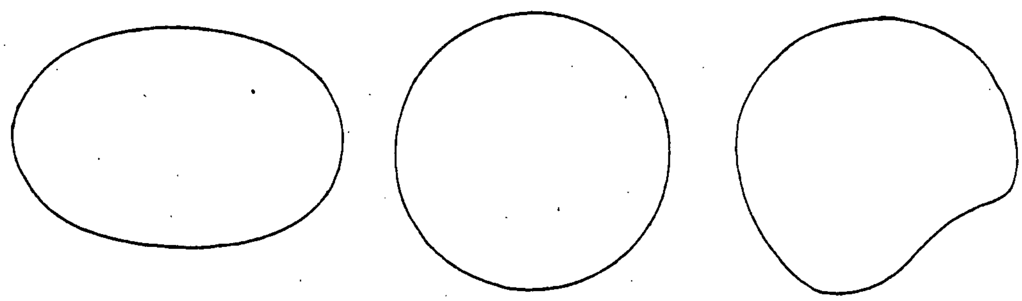
Analysis of the shapes of the tube stubs removed with the sample of support plate from the steam generator indicated that the maximum strain was of the order of 3% even though the tubes were significantly out-of-round, and a 700 mil diameter probe could not pass through one of the tubes.

Review of distorted tube shapes based on samples taken from many steam generators by several utilites clearly indicated that a decision to plug or not to plug a tube based on the minor diameter is not necessarily valid. For example, a tube may be ovalized to the point where its minor diameter is 610 mils, so that a 610 mil diameter probe would not pass and the strain would be only 3%; on the other hand, a tube may be distorted to a cardiod shape to the point where its minor diameter is 640 mils, so that a 610 mil diameter probe would pass easily, yet the strain would be as high as 20%. (Figure 4-1)

Therefore it was concluded that tube plugging criteria based on the diameter of a probe that could not pass through the tube would not provide assurance that in-service tube leaks would be prevented.

4.2 Profilometry Probe

In order to be able to determine the current condition of the steam generator tubes and to track changes in condition, the profilometry probe was developed with R&D funding.



OVAL 3% STRAIN
0.610 MINOR DIA.

INITIAL CONDITION, ZERO STRAIN
0.775 I.D.

IRREGULAR 20% STRAIN
0.648 MINOR DIA.

Figure 4-1 Comparison of Possible Tube Deformations

The probe consists of eight cantilevered fingers designed to ride against the inside wall of the tube. The fingers are centered at 45^{o} intervals around the probe. Each finger is strain gaged to monitor the deflection and thereby measure the radial distance from the center of the probe to the tube wall. The probe is also equipped with an eddy current coil to detect the presence of a tube support plate. The construction of the probe is shown in Figures 4-2, 4-3 and 4-4.

Appendices A and B describe tests conducted by B & W to evaluate the extent of wear on the profilometer fingers during use, and the possibility of scratching the inside wall of the steam generator tubes. With polished chrome plated fingers, it was found that wear was acceptable, and that the effect on the tube wall was only a burnishing of the oxide.

During a steam generator examination, the profilometry probe is fed into a selected tube via the Zetec manipulator and probe driver used for eddy current examination. The data developed is recorded on magnetic tape and on strip charts. The magnetic tape is subsequently used as input to the computerized data analysis program.

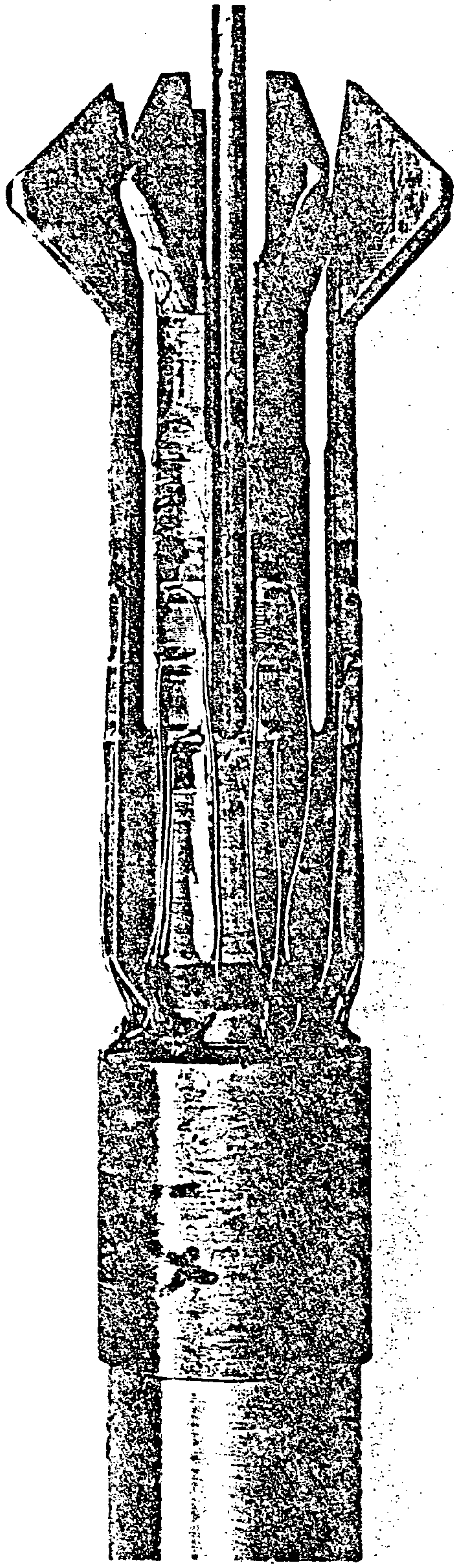


Figure 4-2 Profilometer Detail, Showing Strain Gages on Probe Fingers

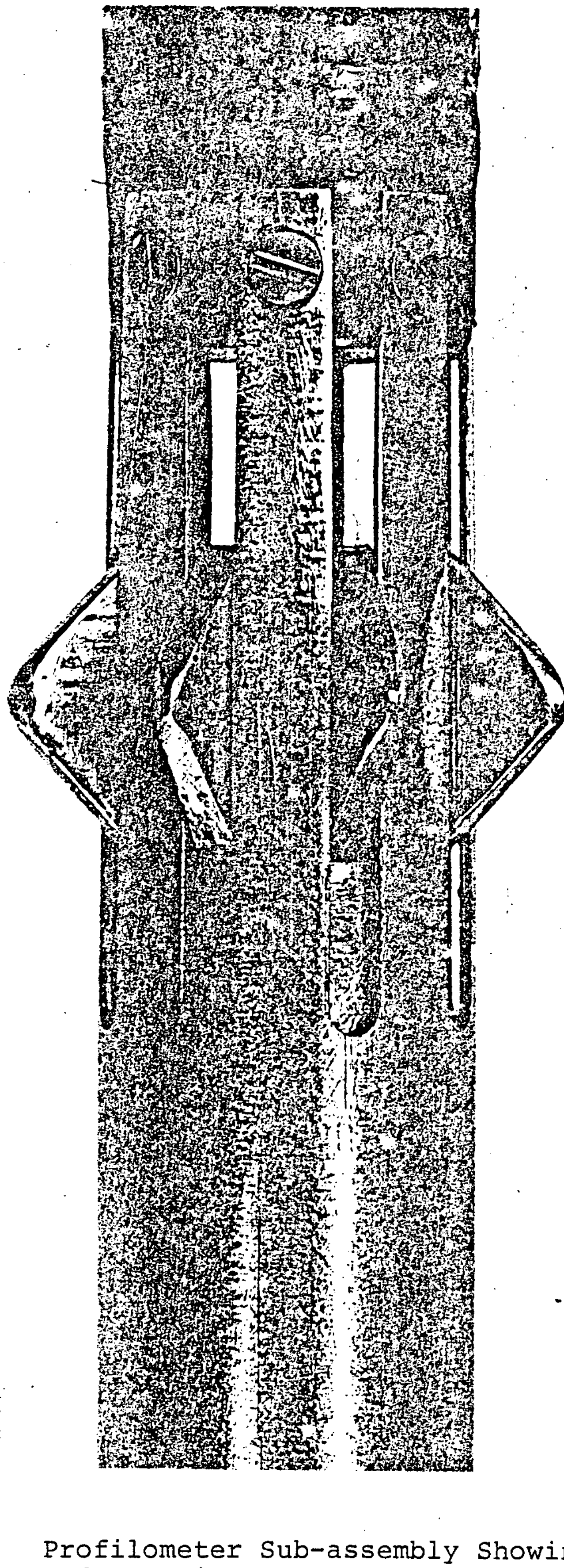


Figure 4-3 Profilometer Sub-assembly Showing Probe Fingers and Mounting Assembly

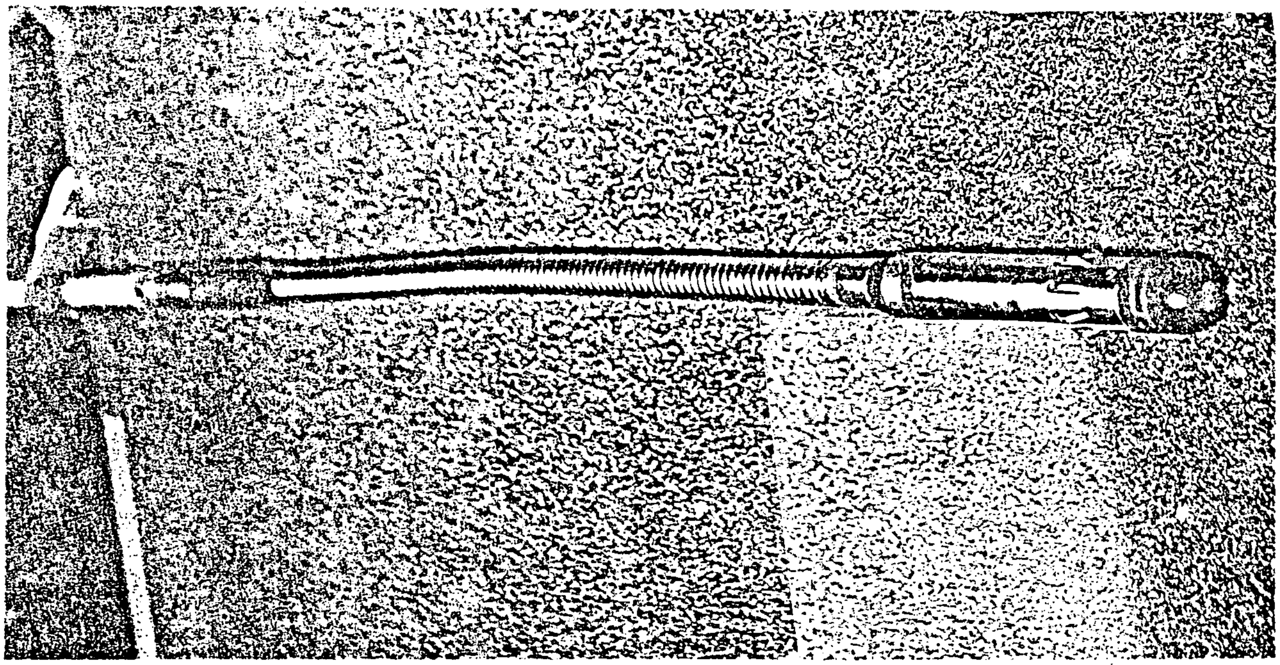


Figure 4-4   Profilometer Assembly

4.3 Tube Strain Computation

The B & W tube strain computer program is an interactive program written in Fortran and incorporated in conjunction with a Calcomp Plotter.

The tube strain due to denting is considered to be composed of a circumferential membrane component and a bending component. The effect of axial strain is neglected.

The membrane component is defined as the change in the circumference divided by the original circumference.

The bending component is the local change of length compared to the initial length and this can be related to the curvature of the curve at the specific location. The curvature of a curve at a point is defined as the instantaneous rate of change of the slope angle with respect to arc length.

We have defined the bending strain by

$$\frac{L_1 - L_o}{L_1}$$

and $L = R_o\ \theta_o,\ L_1 = R_1\ \theta_1$

where:
θ_o = angle of the arc of the original curve
θ_1 = " " " " " " deformed curve
R_o = radius of the arc of the original curve
R_1 = " " " " " " deformed curve
L_o = original arc length
L_1 = deformed arc length

we also assumed that the L_M measured along the center of the tube wall does not change during bending deformation. Thus,

$$L_M = \left(R_o + \frac{T}{2}\right)\theta_o = \left(R_1 + \frac{T}{2}\right)\theta_1$$

where: T = tube wall thickness

For the equation of a curve given in parametric form

$$x = f\ (t), \quad y = g\ (t)$$

the curvature K is given by

$$K = \frac{\frac{dx}{dt}\frac{d^2y}{dt^2} - \frac{dy}{dt}\frac{d^2x}{dt^2}}{\left[\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2\right]^{\frac{3}{2}}}$$

For the profilometry concept, the curve is best described in polar coordinates:

$$c = \left\{r\ (\theta)\ \cos\theta,\ r\ (\theta)\ \sin\theta\right\}$$

where $r(\theta)$ is a piecewise cubic polynomial.

Since $x = r(\theta)\ \cos\ (\theta)$, $y = r(\theta)\ \sin\theta$, $t = \theta$,

one obtains that the curvature is given by

$$K = \frac{2\left(\frac{dr}{d\theta}\right)^2 - r\left(\frac{d^2r}{d\theta^2} - r\right)}{\left[\left(\frac{dr}{d\theta}\right)^2 + r^2\right]^{\frac{3}{2}}}$$

Making use of the relations for L_M and the fact that $K_o = \frac{1}{R_o}$ and $K_1 = \frac{1}{R_1}$, the bending strain is related to the curvature by

$$\frac{L_1 - L_o}{L_o} = \frac{\frac{T}{2}\left(R_1 - R_o\right)}{R_o\left(R_1 + \frac{T}{2}\right)} = \frac{\frac{T}{2}\left(K_o \quad K_1\right)}{1 + \frac{T}{2}K_1}$$

The interior profile of the deformed tube is analytically defined using a periodic cubic spline on the basis of eight equally spaced radial measurements. The circumferential strains are then defined on the basis of this deformed interior profile. The membrane strain is estimated by comparing the arc length of the spline with the original inside circumference of the undeformed tube. The arc length of the spline is calculated using Gaussian quadrature. The bending strain is estimated by examining the radius of curvature of the spline curve at a set of equally spaced points to determine the location and magnitude of the largest bending strain.

Appendices C and D are B & W reports relative to the accuracy of the data analysis.

Copies of computer subroutines are shown in Appendices E and F. Typical computer calculations and Calcomp printout of the final deformed tube shape are shown in Figures 4-5 and 4-6. The plotter output consists of the following:

- Station and tube identification
- The graph of the estimated spline curve of the deformed tube with polar coordinate drawn for reference
- The eight input radii
- The values of the membrane strain and the maximum bending strain
- The maximum combined strain and its location

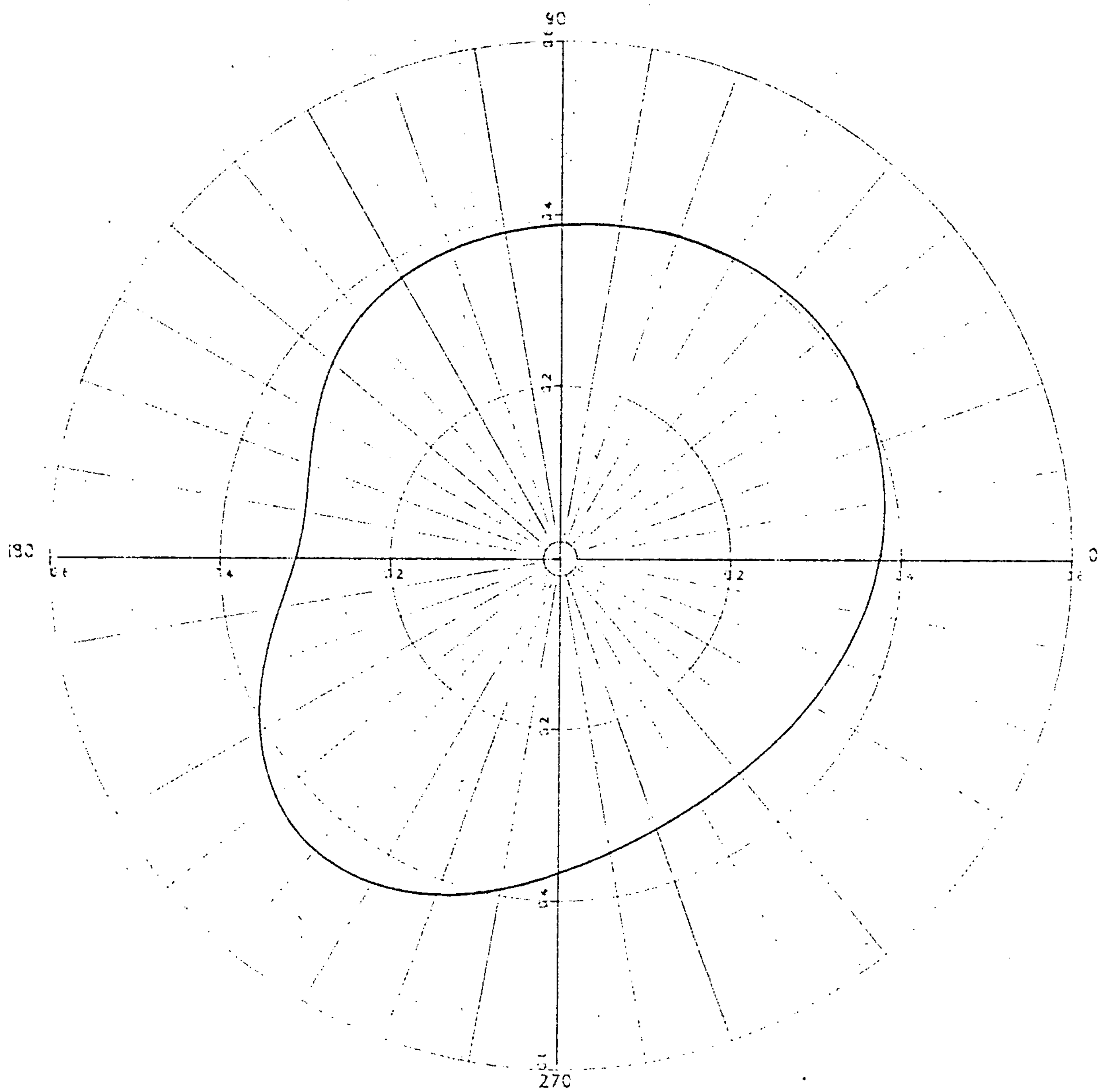
The current strain program is basically a one dimensional approach, neglecting the effect of the axial strain. Although the axial strain may not be as significant as the hoop strain in our case, for improved accuracy of the overall strain evaluation, a two dimensional approach to the tube strain calculation should be incorporated in any future program.

```
MESSAGE(S) COMPLETE.
*RDY-FOR*
-TUBES
 TUBE MEASUREMENTS FOR PLOT
 ENTER THE ROW LOCATION:
 ? 45
 ENTER THE COLUMN LOCATION:
 ? 40
 ENTER THE STEAM GENERATOR
 ? 24
 ENTER THE NOMINAL INSIDE RADIUS
 ? .3875
ENTER THE THICKNESS
 ? .050
ENTER THE EIGHT RADII IN COUNTER CLOCKWISE ORDER
 ? .375
 ? .407
 ? .387
 ? .359
 ? .310
 ? .443
 ? .369
 ? .331
 ANOTHER PLOT? (Y OR N)
 ? N
 STOP.


 STEAM GENERATOR: 24  ROW 45  COL. 40
 RADII:     .375   .407   .387   .359   .310   .443   .369   .331
 BENDING STRAIN =     .1551
 MEMBRANE STRAIN =   -.0110
 MAXIMUM COMBINED STRAIN =    -.1661
            OCCURS AT 178.0 DEGREES
 STOP.
DO YOU WANT ALL TUBES ON FILE TO BE PLOTTED?(Y OR N)
 ? N
ENTER TUBES TO BE PLOTTED
 BY STEAM GENERATOR,ROW,AND COLUMN
 IN A 3I2 FORMAT.  FOR EXAMPLE,
 240317 IS GENERATOR 24,ROW 3,COL.17
 AFTER YOU ENTER THE LAST TUBE,PUSH 'RETURN' TWICE
 ? 244540

COMMAND SYNTAX ERROR
 ?
   1 TUBES ENTERED
GEN. 24 ROW 45 COL 40 FOUND
 STOP.
```

Figure 4-5 Typical Computer Run

R 45 C 40
STEAM GEN. NO. 24 INDIAN POINT STATION

STEAM GENERATOR TUBE CROSS-SECTION



RADII	0.375	MEMBRANE STRAIN: −0.0110 IN./IN.
	0.407	
	0.387	BENDING STRAIN: ±0.1551 IN./IN.
	0.359	
	0.310	MAX. COMBINED STRAIN: −0.1661 IN./IN.
	0.443	OCCURS AT 178. DEGREES
	0.369	
	0.331	

Figure 4-6 Typical Calcomp Printout

4.4 Accuracy of Profilometer

The accuracy of the tube strain determination by profilometry as described above is dependent on the adequacy of the definition of the profile of the deformed tube and the computed strain-displacement relationship.

Inaccuracies in definition of the tube profile result from the use of the eight-fingered probe. Irregularities that lie between adjacent points of measurement will not be detected, as the computer program is such that it plots a "best-fit" profile based on the eight measurements by the probe.

In order to evaluate this source of error, five tube profiles were selected with maximum strains ranging from 3.5% to 32.9%. In each of these, the probe was rotated at 4.5° intervals, and radial measurements and strain computations were made at each interval. It was found that as the actual strain increases, the accuracy of the measured/computed strain decreases. The results are plotted in Figure 4-7. Based on this plot, measured/computed strain may be interpreted as listed in Table 4-1.

TABLE 4-1

Profilometry Accuracy

Measured/Computed Strain	Probable Range of Actual Strain
1%	1% - 3%
2%	2% - 4%
3%	3% - 6%
5%	5% - 8%
10%	9% - 16%
15%	14% - 30%

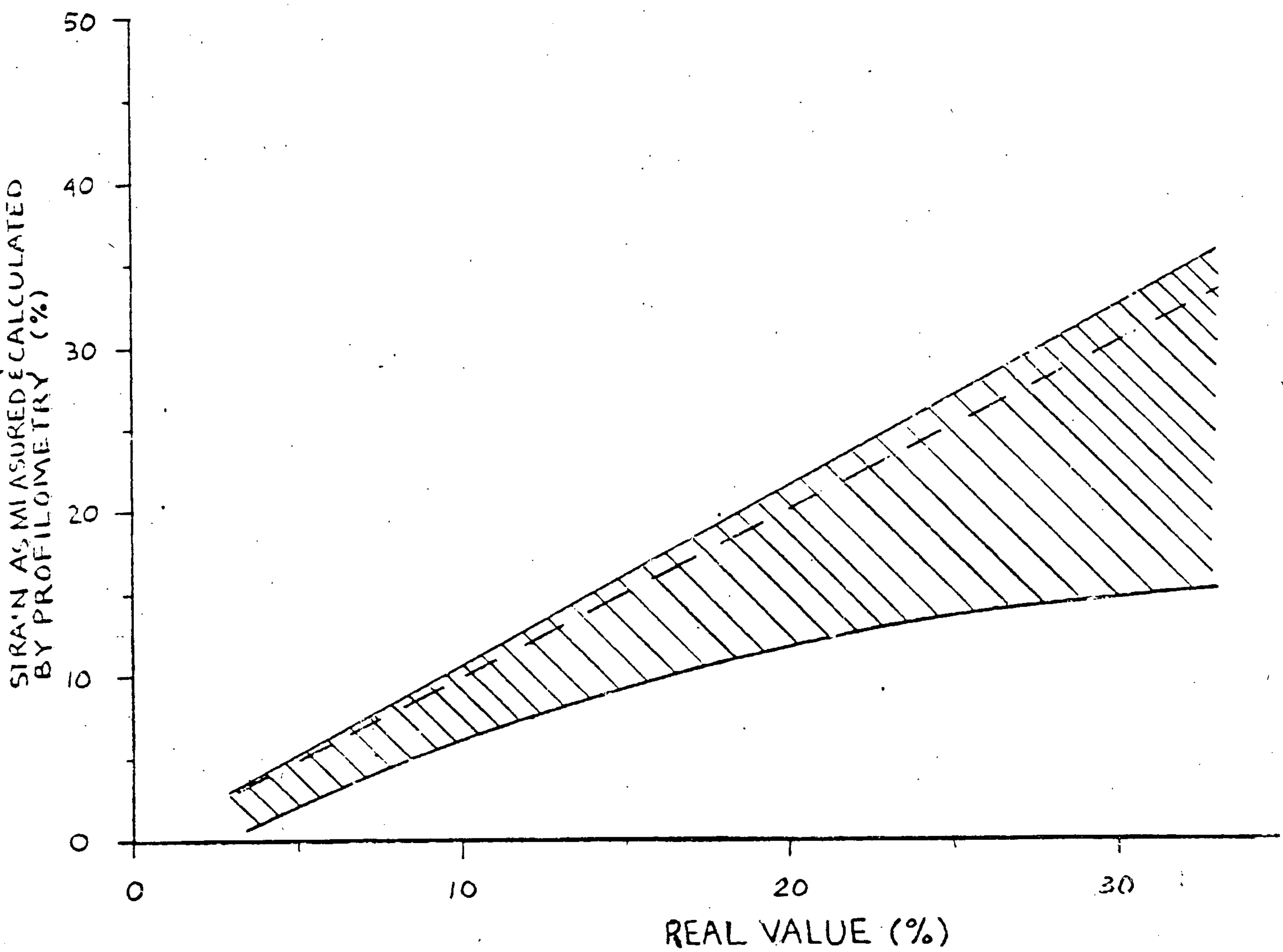


Figure 4-7 Comparison of Profilometry-Determined Strain and Real Values

5.0 INDIAN POINT PROFILOMETRY EXAMINATION

5.1 Scope of Examination

Approximately 150 tubes in one steam generator were selected for profilometry examination during the 1979 refueling. A preliminary selection was made on the basis of the analytical projections relative to plate strain. Further selection was made on the basis of strains reported in the course of the examination. The tubes examined are indicated in Figure 5-1.

5.2 Results of Examination

The results of the profilometry examination are listed in Table 5-1, and are printed out in the relative bundle locations in Figures 5-2 through 5-7.

At 674 intersections of the total of 705 tube/support plate intersections examined, the tube strain (as measured and calculated by profilometry) was 5% or less. Based on the curve in Figure 4-7 this indicates actual strain is probably less than 8%. Of the remaining 31 tube/support plate intersections only four exceeded 10% computed.

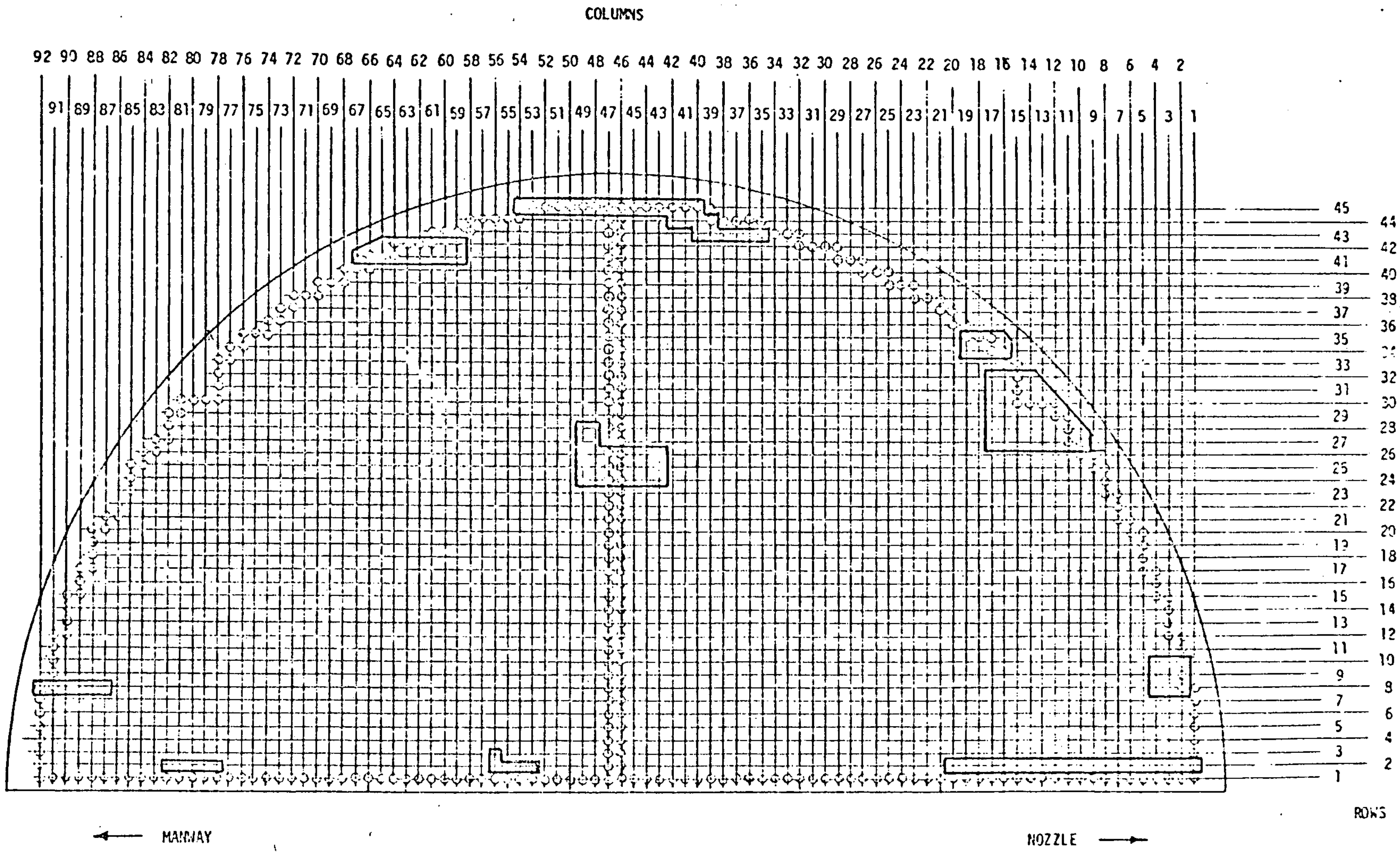


Figure 5-1 Location of Tubes Examined by Profilometry, July, 1979

TABLE 5-1

INDIAN POINT
STEAM GENERATOR #24
COMPUTED STRAIN, %

Tube No.		Support Plate No.					
Row	Col.	1	2	3	4	5	6
2	1	1.5	1.4	1.3	1.4		
	2	2.1	2.6	5.9	6.3	6.2	2.1
	3	2.1	2.9	2.6	3.9		
	4	1.0	1.8	3.0	3.1		
	5	1.1	1.6	2.8	3.3		
	6	1.7	1.5	2.6	2.6	3.7	
	7	1.6	1.6	2.9	2.7	3.3	2.4
	8	2.0	3.0	4.2	2.3	3.6	
	9	1.4	2.5	3.2	2.6	2.7	
	10	1.8	1.9	3.5	3.0	3.2	
	11	1.4	2.7	2.8	2.5		
	12	1.2	1.4	1.8	1.7		
	13	1.5	1.7	1.7	1.5		
	14	1.6	1.6	1.9	1.8		
	15	1.7	2.0	3.0	2.3		
	17	2.1	3.0	3.8	7.3	5.2	
	18	2.2	4.8	5.2	6.2	4.7	1.8
	19	2.0	2.6	2.8	3.0		
	20	2.5	3.4	2.7	2.5	3.4	
	53	1.7	2.5	5.3	4.3	4.3	

TABLE 5-1 (cont'd)

Tube No.		Support Plate No.					
Row	Col.	1	2	3	4	5	6
2	54	2.1	2.7	2.7	5.0	4.8	
	55	2.2	2.6	2.9	4.5	4.6	
	56	2.0	4.4	3.0	2.9	3.7	
	79	1.6	2.8	2.8	5.9		
	82	1.9	3.6	3.4	4.1		
	83	1.8	4.0	3.7	6.6		
3	31	1.8	2.3	2.0	1.7		
	56	2.3	4.0	3.1	3.6		
	90	1.3	1.2	1.3	1.2		
8	3	17.6	1.8	1.3	1.7	1.4	
	4	1.4	1.5	.8	2.7	2.0	
	5	1.8	1.4	1.5	1.2	1.8	
	87			2.8	1.9		
	88			1.8			
	89			2.5			
	90			6.0			
	91			2.2			
9	3	2.4	3.2	2.4	3.3	2.5	
	4	10.6	1.7	1.7	3.6	2.2	
	5	6.1	4.4	2.3	3.7		
10	3	1.6	3.9	2.5	3.1		
	4	2.7	2.4	1.5	2.1	4.1	

TABLE 5-1 (cont'd)

Tube No.		Support Plate No.					
Row	Col.	1	2	3	4	5	6
10	5	6.7	3.7	2.6	3.5	3.7	
13	88	1.8	6.9				
14	5	3.3	2.1	2.1	2.0	2.0	2.7
	89	1.4	9.4	5.2	4.4		
25*	43			2.2	2.2	2.1	
26	43	.9	1.4	1.3	1.9	1.5	
	49		1.3	1.4	1.2	1.2	
27	10	1.5	2.9	3.1	4.0	3.3	
	11	1.4	2.3	1.9	2.1	1.7	
	12	1.0	1.5	1.3	1.9	1.5	
	13	1.2	2.2	3.1	4.8	2.9	
	14	1.2	2.1	2.4	2.2	3.2	
	15	1.8	2.2	2.2	1.9	2.9	
	16	1.0	2.0	1.8	2.1	2.4	
	17	1.6	2.4	1.7	1.2	2.0	
28	13	1.0	2.1	2.3	2.1	4.0	
	14	1.2	2.3	2.1	2.0	2.3	
	15	1.1	2.3	2.0	2.3	2.6	1.9
	16	1.5	2.1	1.3	1.6	2.1	
	17	1.1	1.9	1.8	1.6	2.0	
29	11	1.4	3.3	5.2	5.8	6.8	
	12	1.3	2.7	3.2	2.0	4.9	
	13	1.5	2.3	2.0	1.7	2.7	

TABLE 5-1 (cont'd)

Tube No.		Support Plate No.					
Row	Col.	1	2	3	4	5	6
29	14	1.2	2.5	1.3	2.3	2.9	
	15	1.4	2.9	1.7	2.5	2.8	
	16	1.2	3.4	3.0	5.3	4.8	
	17	1.4	1.8	1.9	2.0	2.5	
30	12	1.3	1.8	1.8	2.5	2.9	
	13	1.0	2.2	2.2	2.7	3.7	
	16	1.5	3.1	1.7	1.1	3.6	5.9
	17	1.4	2.1	2.2	2.0	2.9	
31	15	1.6	2.3	2.0	2.5		
	16	1.3	2.6	2.1	2.7	2.9	
	17			2.2	1.9		
32	15			2.0	1.6		
	16			1.8	1.4	1.7	
	17			2.1	2.0	2.7	
34	16	1.2	3.7	4.1	4.7	7.5	
	19	1.5	2.4	3.7	2.8	4.0	
	18	1.7	3.8	2.4	4.3	5.1	
35	18	1.8	4.5	4.7	6.8	7.4	
	19	1.5	2.4	1.9	2.9	2.9	
41	59	2.5	4.4	2.3	3.0		
	60	1.1	9.8	3.7	2.7		
	61	.8	4.0	2.6	3.6		

TABLE 5-1 (cont'd)

Tube No.		Support Plate No.					
Row	Col.	1	2	3	4	5	6
41	62	1.4	7.7	2.7	3.8	3.1	
	63	2.0	3.8	2.4	3.6	3.2	
	64	.8	3.2	2.4	3.5	2.5	
	65	1.6	2.3	2.1	3.3	3.5	
	66	1.5	1.9	2.2	3.4	2.5	
42	60	1.1	1.2	3.5	3.8	2.8	
	61	1.0	6.8	2.3	3.3		
	62	1.4	7.6	2.5	4.0		
	63	1.1	3.7	1.7	3.7	2.7	
	64	2.0	2.6	2.0	3.5	2.9	
43	35	2.2	2.0	1.5	2.2	1.8	
	36	2.4	1.9	1.9	1.7	2.3	
	37	3.0	2.2	2.1	1.6	1.6	
	38	1.9	6.9	2.7	2.0	2.2	
	39	3.2	3.6	1.5	2.6	2.4	
	40	1.4	3.9	3.2	1.6	2.8	
44	39	1.6	1.6	2.7	2.4	4.2	
	40	2.5	2.6	2.3	2.2	3.1	
	41	2.6	3.8	4.7	2.9	2.9	2.4
	42	2.3	2.1	2.3	3.1	3.1	2.4
	53	3.4	14.8	3.7			
45	40	1.9	2.2	4.4	4.8	7.3	
	41	1.7	4.9	4.1	2.5	2.6	

TABLE 5-1 (cont'd)

Tube No.		Support Plate No.					
Row	Col.	1	2	3	4	5	6
45	42	1.6	4.8	2.6	6.7	3.4	
	43	3.5	3.9	4.1	6.7	5.2	
	44	2.2	4.1	4.5	6.1	4.6	
	45	1.6	3.4	1.9	3.9	3.7	
	46	2.7	2.5	1.8	2.8	2.6	
	47	1.2	2.0	2.6	4.1	3.4	
	48	1.9	1.5	2.1	2.3	3.2	
	49	1.4	1.6	1.7	3.0	3.1	
	50	1.6	1.4	2.4	1.5	4.4	
	51	1.5	2.4	2.9	3.9	3.7	
	52	1.6	3.0	2.7	2.7	5.1	
	53	2.0	3.6	4.0	6.3	3.7	
	54	4.0	3.0	7.8	1.9	4.2	

*Note: In addition to the tubes listed, tubes in rows 24 through 27, columns 43 to 49, support plates No. 1 through 5, were examined. Strains were not computed because visual reviews of strip-chart print-out indicated strains were less than 2%.

ROW

COL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
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Figure 5-2 Computer Printout of Results of Profilometry Measurements, Steam Generator 24, Support Plate 1 July, 1979

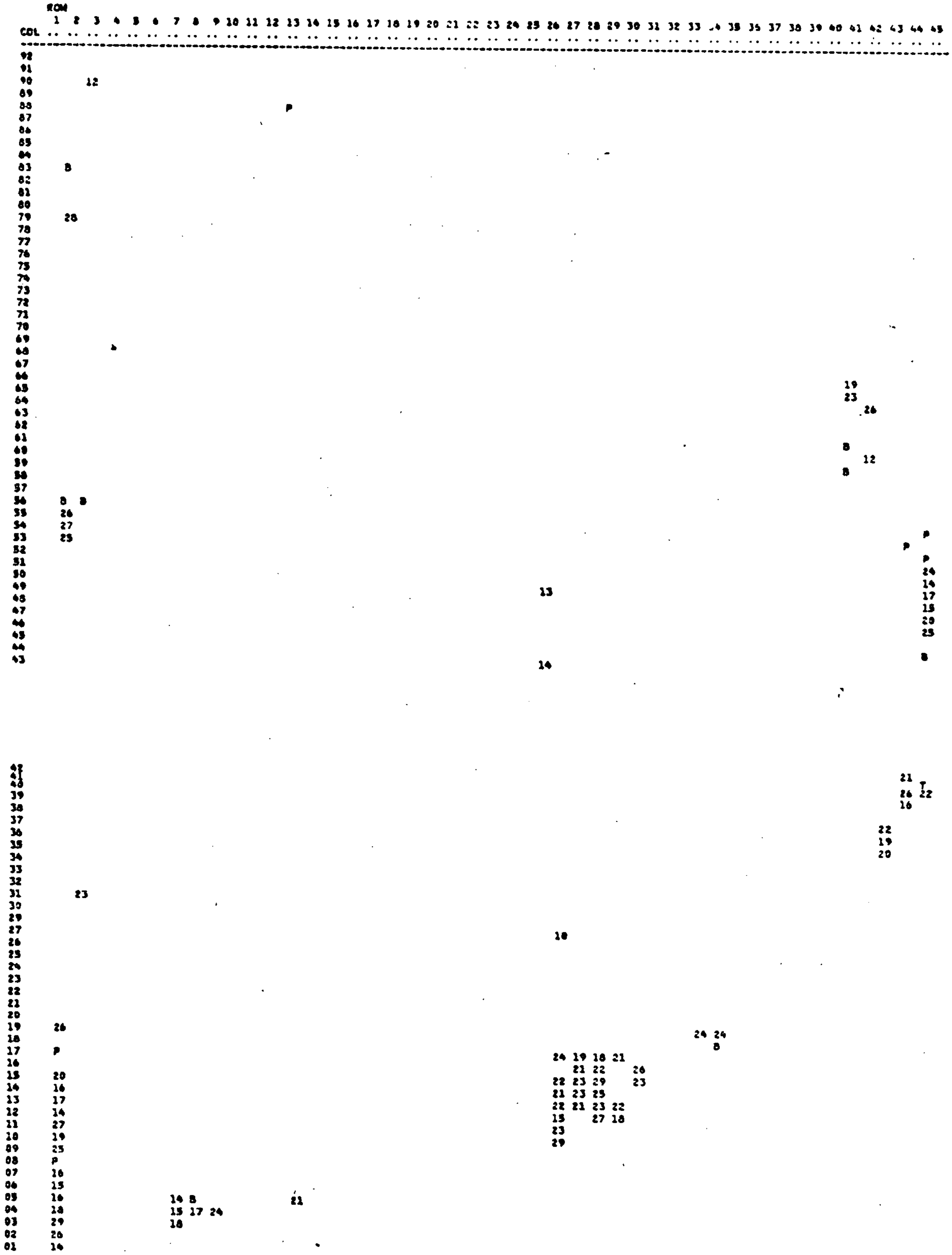


Figure 5-3 Computer Printout of Results of Profilometry Measurements Steam Generator 24, Support Plate 2 July, 1979

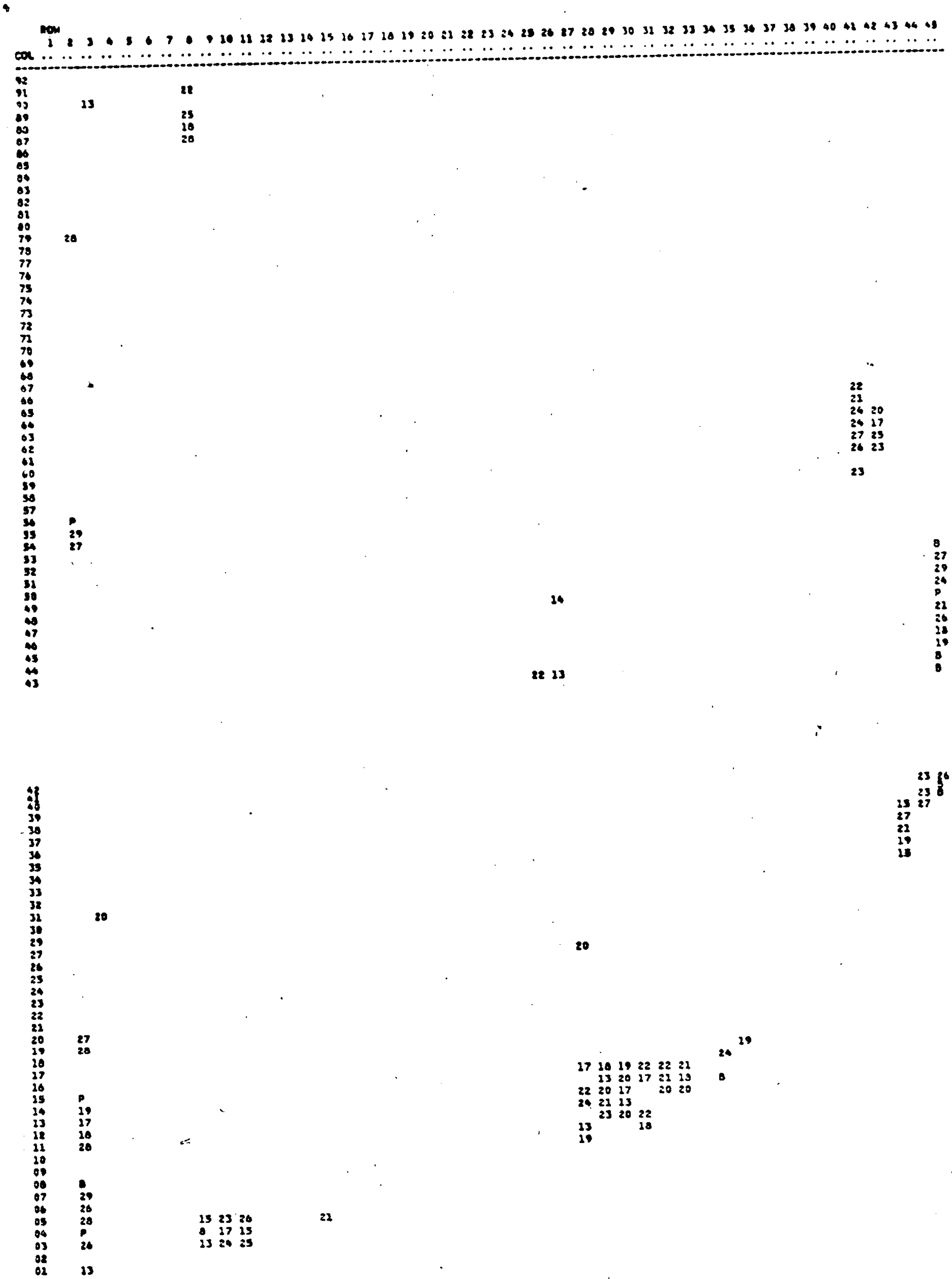


Figure 5-4 Computer Printout of Results of Profilometry Measurements, Steam Generator 24, Support Plate 3 July, 1979

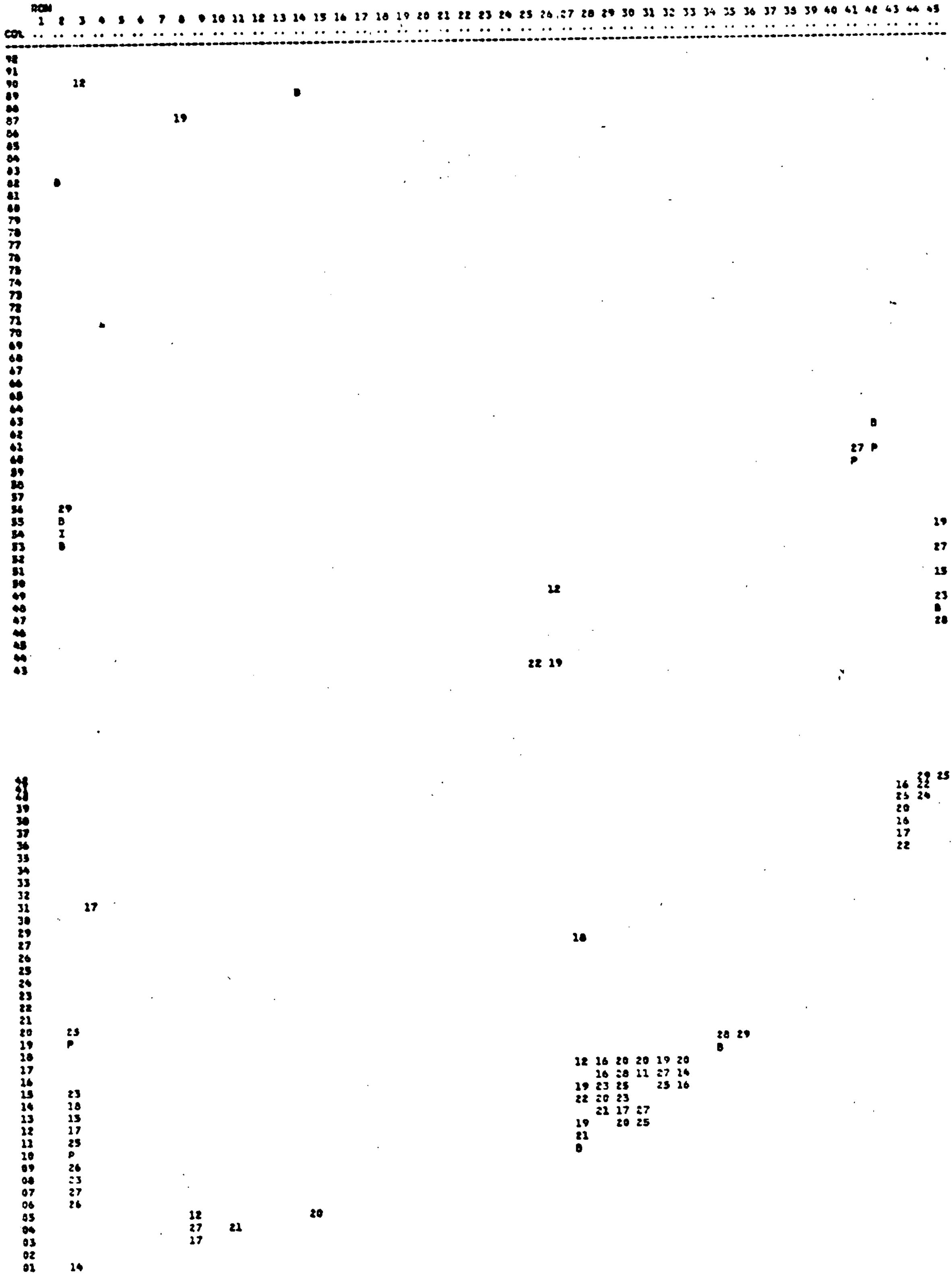


Figure 5-5 Computer Printout of Results of Profilometry Measurements, Steam Generator 24, Support Plate 4 July, 1979

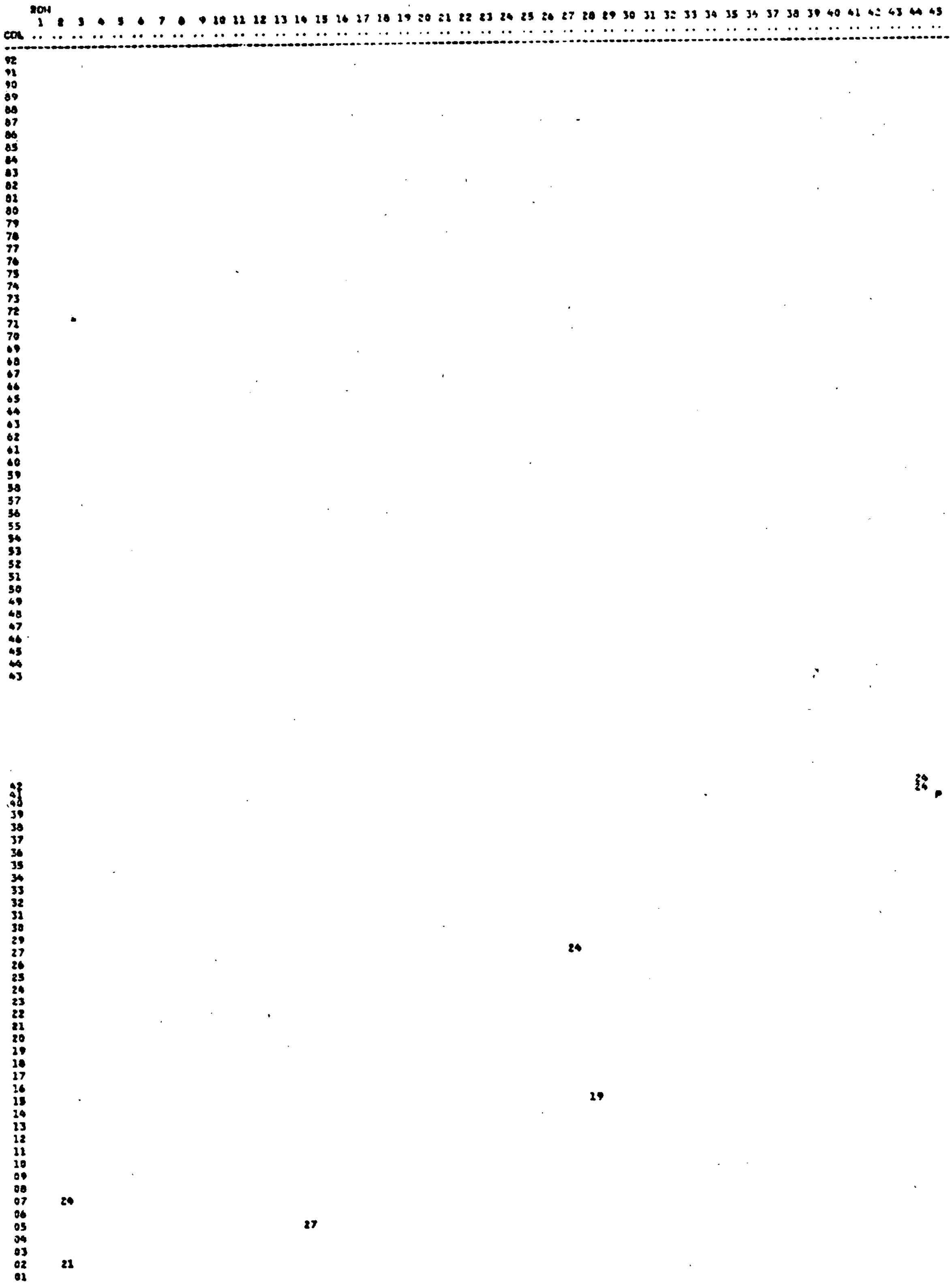


Figure 5-6 Computer Printout of Results of Profilometry Measurements, Steam Generator 24, Support Plate 5 July, 1979

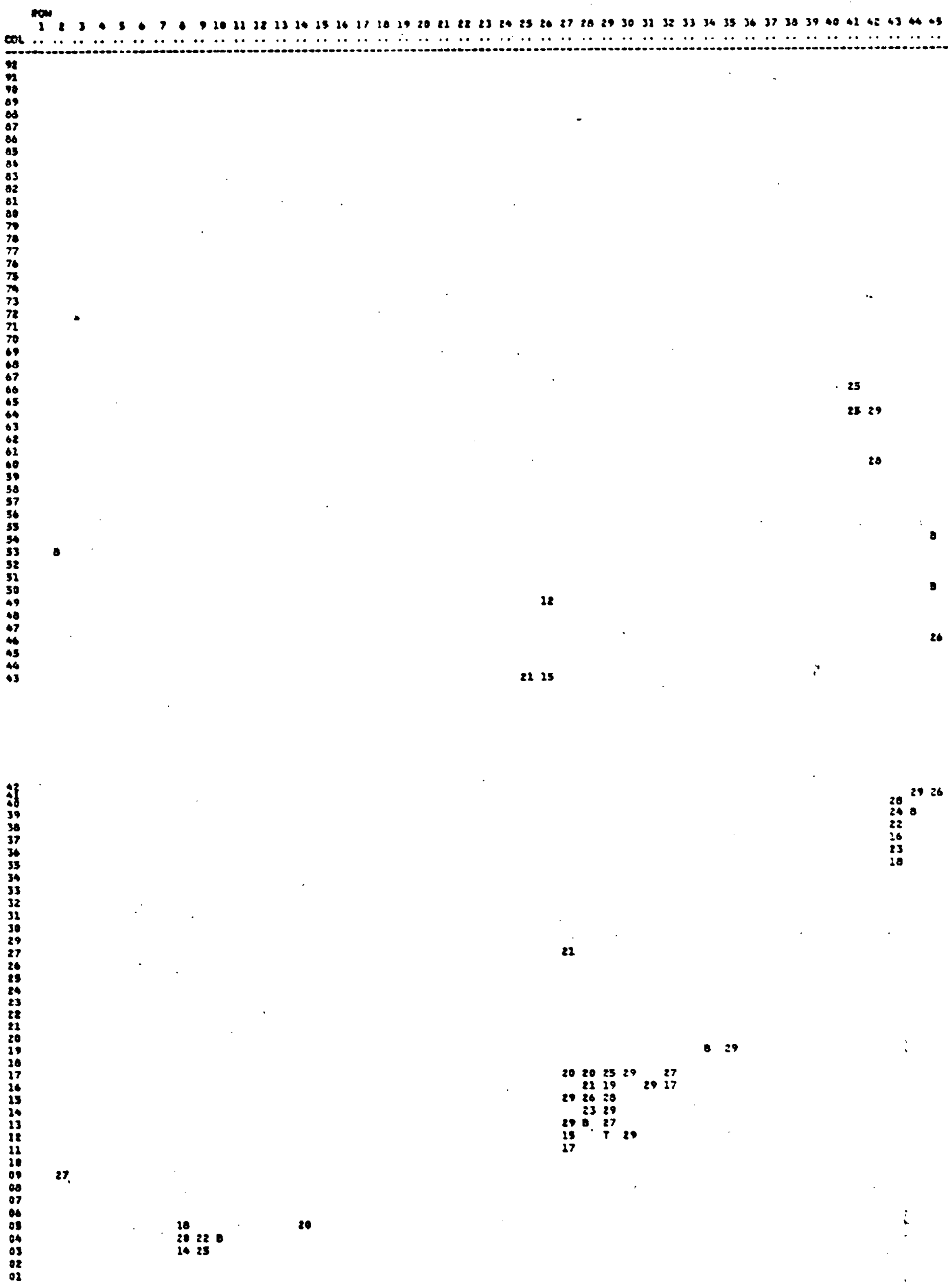


Figure 5-7 Computer Printout of Results of Profilometry Measurements, Steam Generator 24, Support Plate 6 July, 1979

5.3 Discussion of Results

Typical profiles of tubes with low strains are shown in Figure 5-8 and profiles of tubes with high strains are shown in Figure 5-9. For each of these, the dent size, as measured by eddy current is indicated. There appears to be no correlation between dent size and computed strain.

From the grouping of tubes which were restricted to the 700 mil diameter probe but passed the 640 mil diameter probe, typical profiles of tubes with low and with high strains are shown in Figures 5-10 and 5-11. Here again there appears to be no close correlation between probe size classification and computed strain.

The tube in row 8 column 3 was plugged preventively because the 610 mil diameter probe did not pass through the first support plate intersection. Tube strain at that intersection was computed to be 17.6%, and minor diameter was measured to be 610 mils. Profile of that tube is shown in Figure 5-12. Tube strains in this tube at the support plates above the first were all less than 2%.

Subsequent to the examination at Indian Point, Babcock & Wilcox personnel were able to modify the plotting routine so that the tube profile was rotated about its horizontal axis, and added similarly rotated profiles of the same tube at regular increments above and below the maximum strain profile. This produced a three-dimensional plot of the tube, (Figure 5-13) which shows

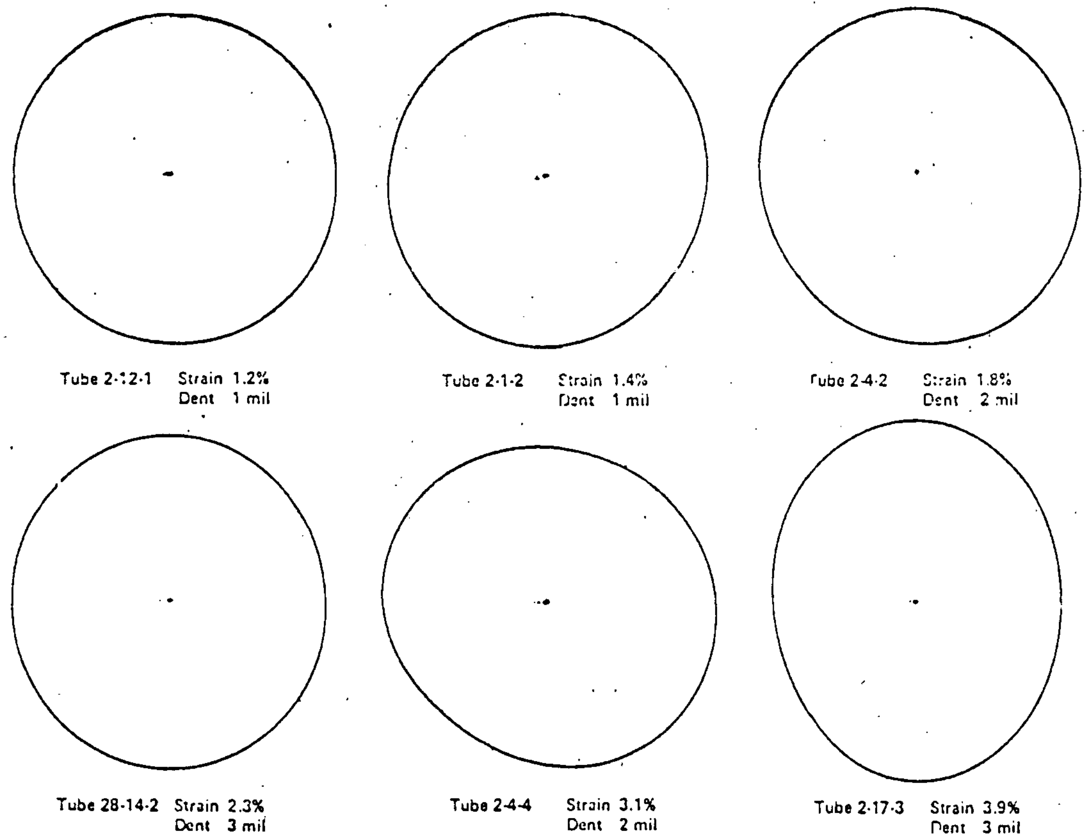


Figure 5-8 Representative "Low Strain" Profiles, with Corresponding Eddy-current Dent Measurements, Steam Generator 24, July 1979

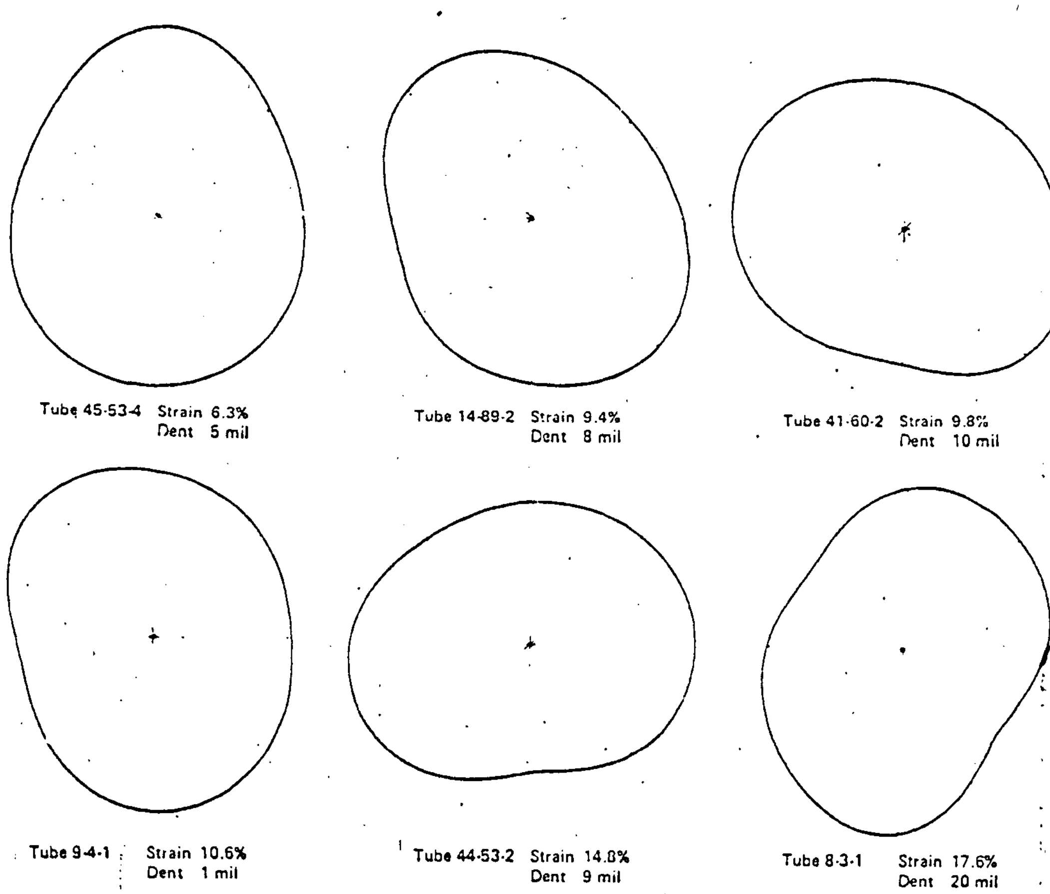


Figure 5-9 Representative "High Strain" Profiles, with Corresponding Eddy-current Dent Measurements, Steam Generator 24, July 1979

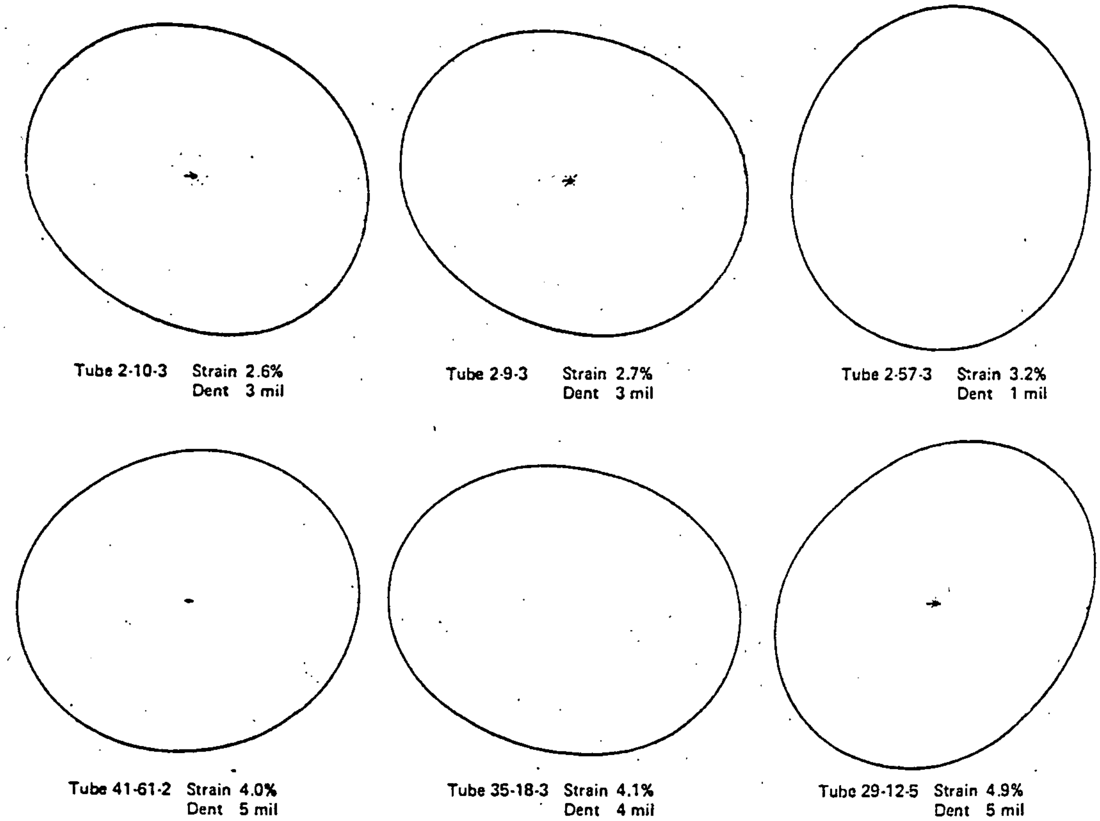


Figure 5-10 Representative "Low Strain" Profiles, with Corresponding Eddy-current Dent Measurements, Selected from tubes that passed 700 mil dia Probe, but were obstructed to 640 mil dia Probe, Steam Generator 24, July 1979

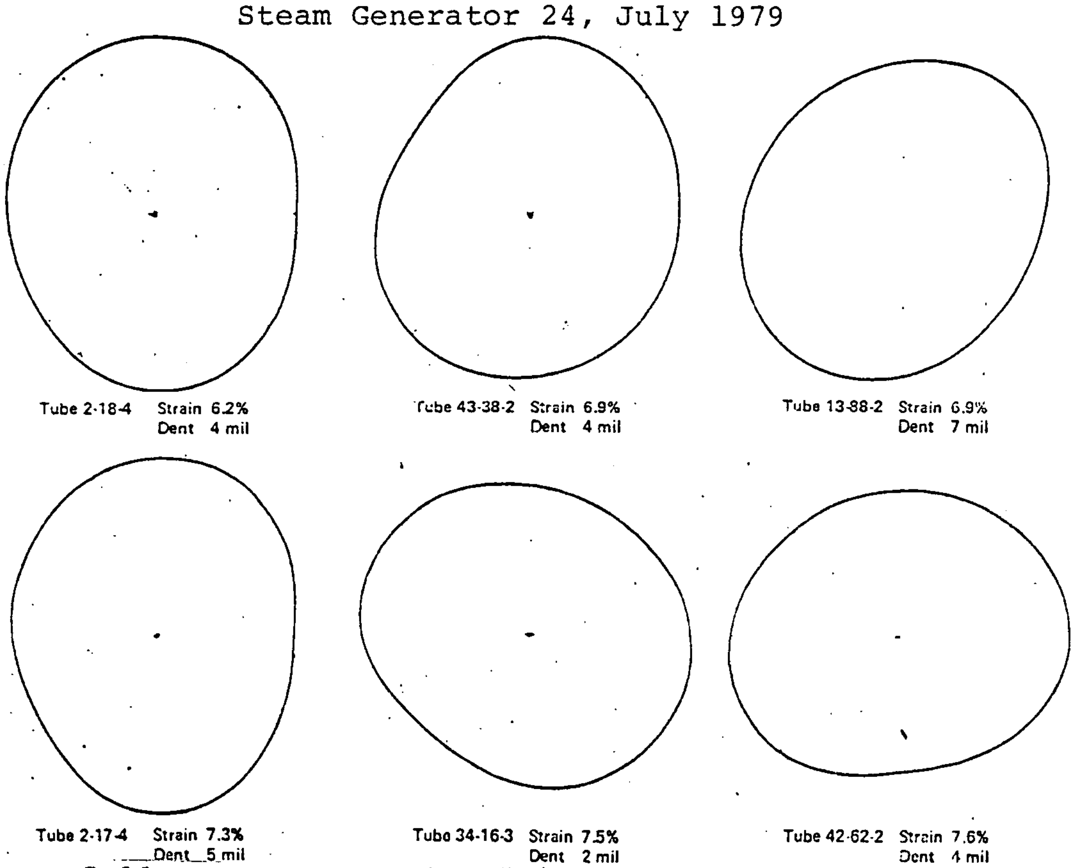


Figure 5-11 Representative "High Strain" Profiles with Corresponding Eddy-current Dent Measurements, Selected from tubes that passed 700 mil dia Probe, but were obstructed to 640 mil dia Probe, Steam Generator 24, July 1979

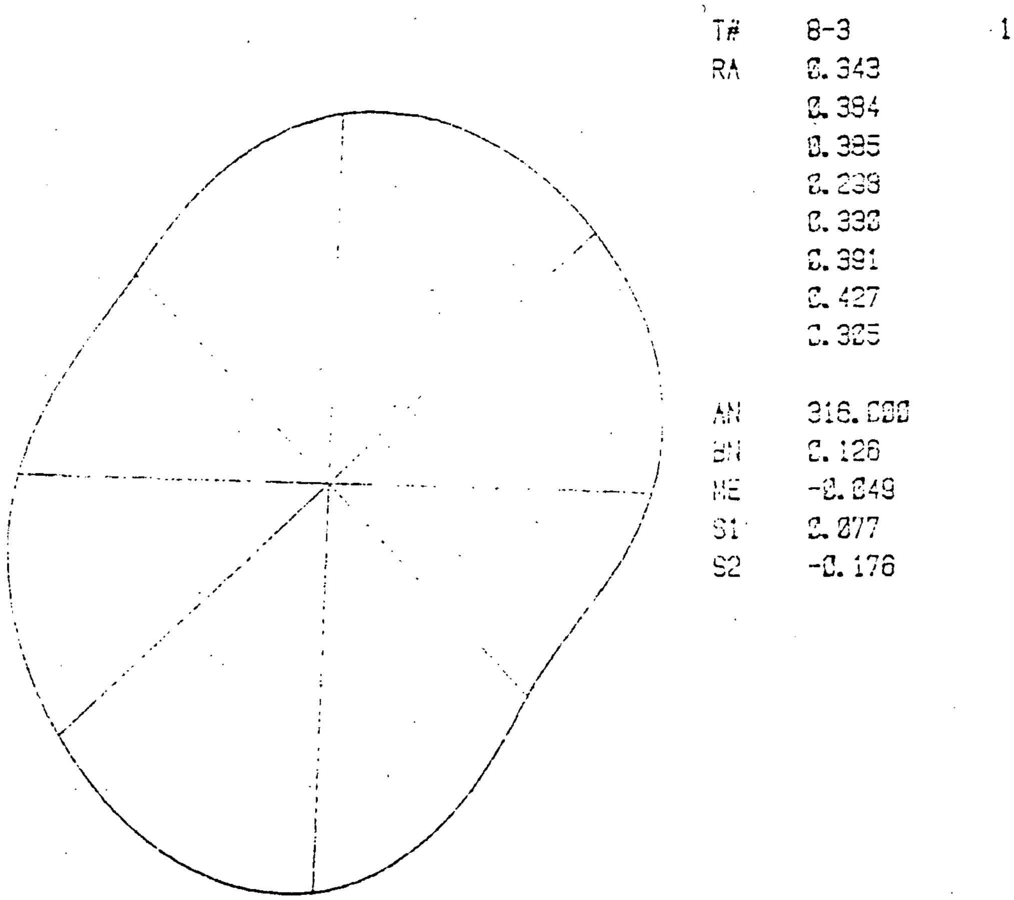


Figure 5-12 Calcomp Printout, Tube 8-3, Support Plate 1, Steam Generator 24, July 1979

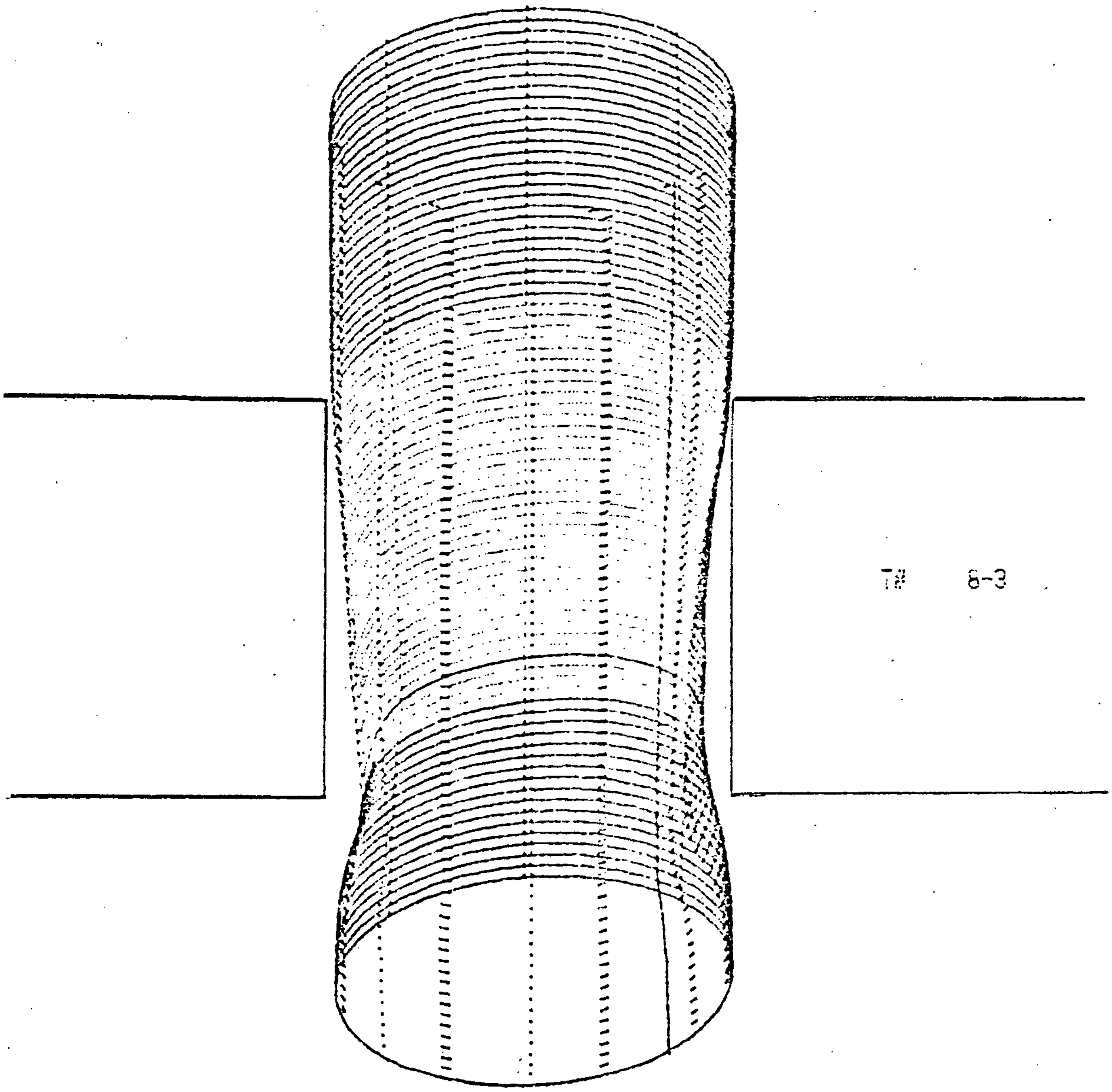


Figure 5-13 Three Dimensional Plot of Tube 8-3, Support Plate 1, Steam Generator 24, July 1979

the tube distortion very graphically. The relative size and location of the support plates is indicated by the rectangles on either side of the tube plot.

The tube in row 45 column 40 was found restricted to the 700 mil probe at the fifth support plate level, and to the 675 mil probe at the sixth support plate level. Minor diameters as measured by profilometry were 719 mils and 685 mils respectively. From this data it would appear that more than 19 mil clearance is necessary in order for a given probe to pass through a tube. The actual minor diameter of a tube is at least 20 mils larger than the smallest probe that passes therefore strain calculations based on probe dimensions should be adjusted accordingly. Tube strains at those intersections were computed (based on profilometry) to be 6.4% and 16.8% respectively, while tube strains in this tube at the lower support plates were found to be low. Profiles of this tube at each of the support plates are shown in Figure 5-14.

Close review of groups of tubes reveals some information about the support plate as well as the tubes. The design or as-fabricated condition of the support plate in the region of the tubes in rows 8, 9, 10 columns 1 through 5 is shown in Figure 5-15. Based on profilometry measurements, the major outer diameters of tubes row 8 column 3, row 9 column 4 and row 10 column 5 are 913 mils, 913 mils and 908 mils respectively. This diameter is larger than the drilled tube hole diameter of 903 mils. Furthermore, allowance has to be made for early deposits and corrosion products "grown" in the annuli, leading to the conclusion that the ligaments essentially parallel to these major

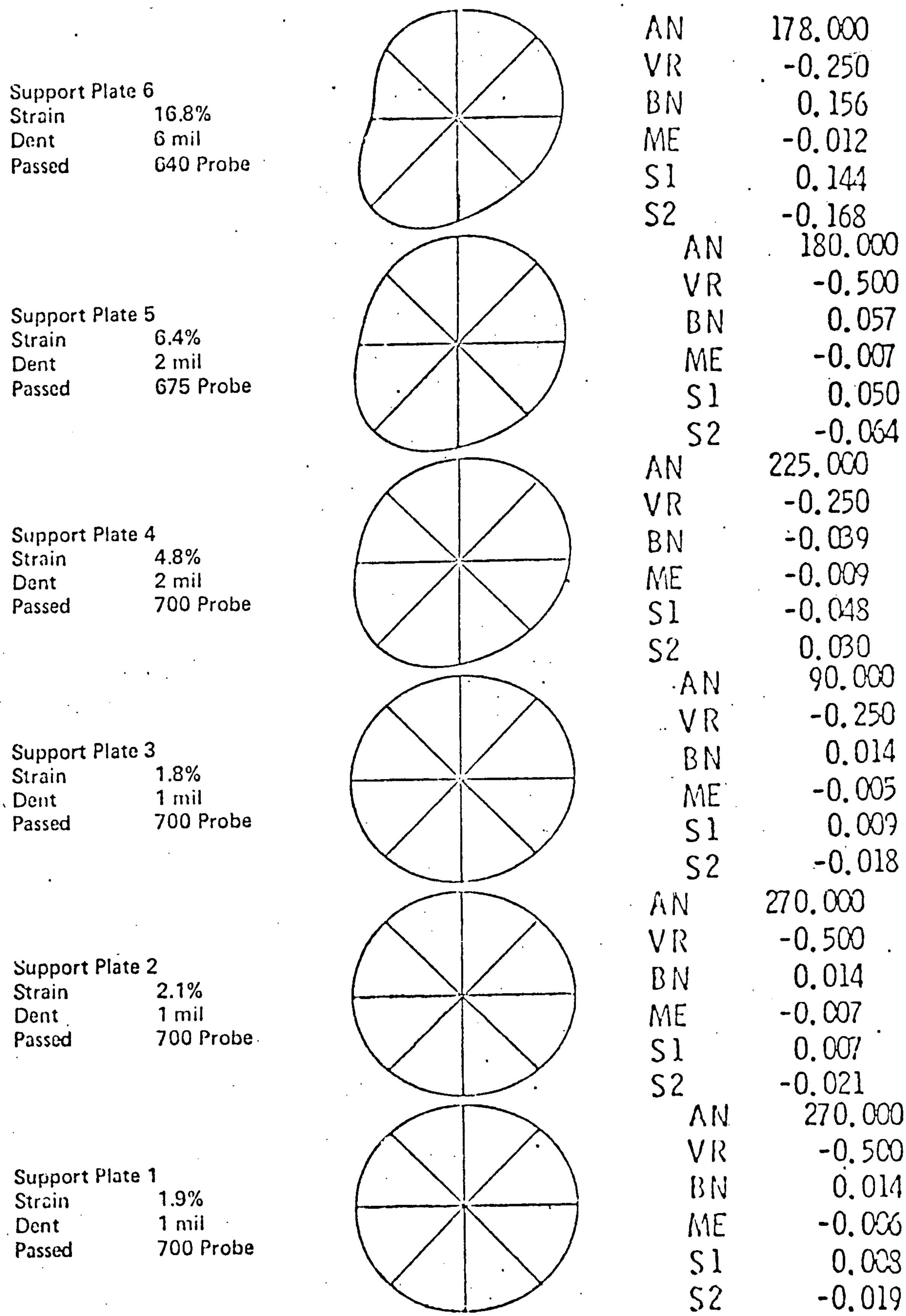


Figure 5-14 Composite of Calcomp Printouts of Profiles of Tube 45-40, Steam Generator 24, with Corresponding Eddy-current Dent, July 1979

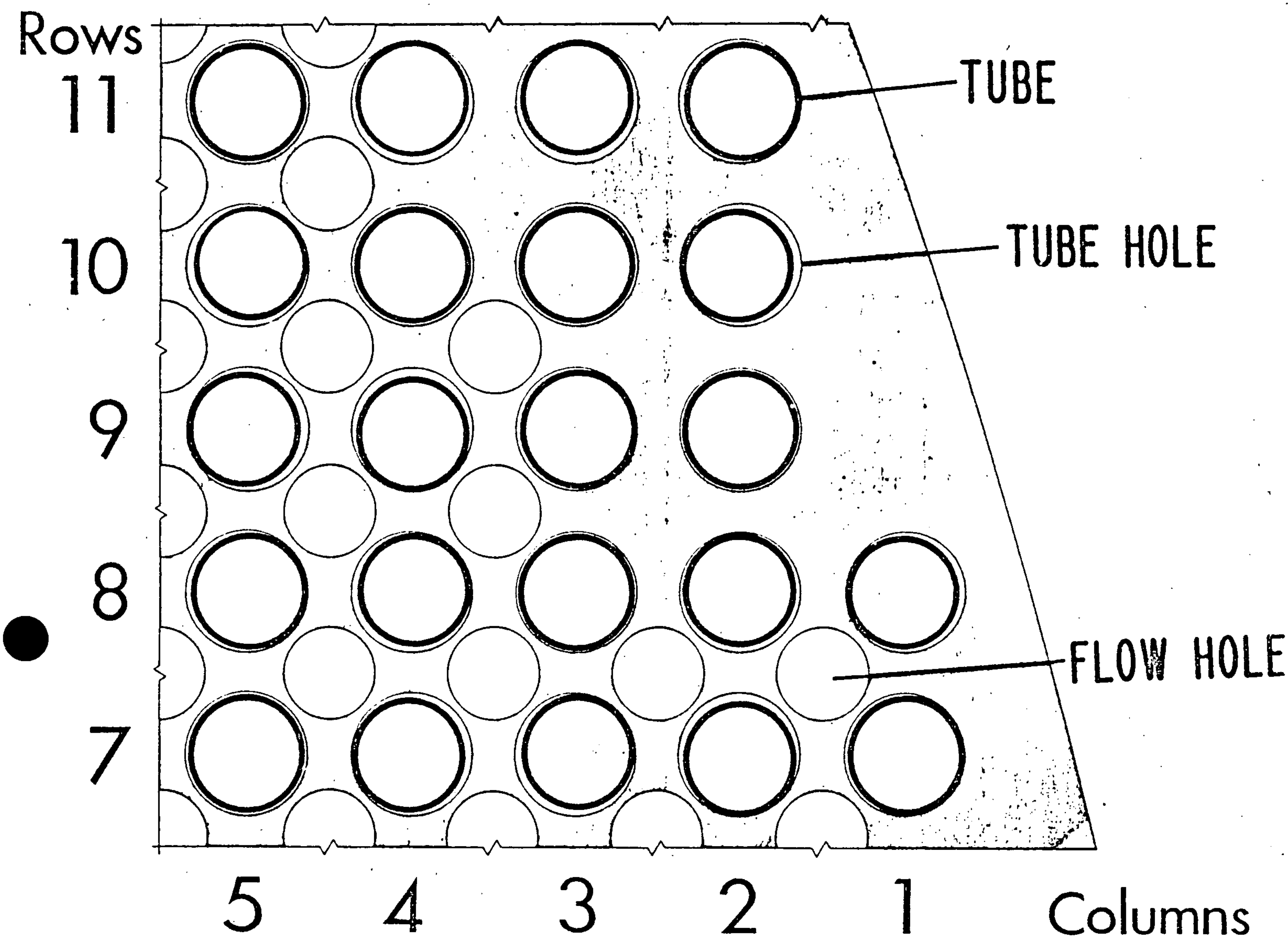


Figure 5-15 As Fabricated condition of support plate segment, Rows 7-11, Columns 1-5

axes must be elongated (as per the mechanical test sample described in Section 3-2). As corrosion proceeds, it is anticipated that the ligaments along this line of tubes will crack, as shown in Figure 5-16. It should be noted that strain or distortion in adjoining tubes is minimal, as listed in Table 5-2.

TABLE 5-2

Profilometer - Based Determinations of Strain and Diameter

Tube	Strain	Major Diameter
Row 8 Column 3	17.6%	0.825 inches
Row 8 Column 4	1.4%	0.787 inches
Row 8 Column 5	1.8%	0.792 inches
Row 9 Column 3	2.4%	0.772 inches
Row 9 Column 4	10.6%	0.823 inches
Row 9 Column 5	6.1%	0.817 inches
Row 10 Column 3	1.6%	0.782 inches
Row 10 Column 4	2.7%	0.797 inches
Row 10 Column 5	6.7%	0.818 inches

It may be that at least part of the mechanism for in-plane growth of support plates is that a slip line develops, and major displacement takes place along that line. Tubes along this slip line become severely distorted, while adjacent tubes merely are displaced along with the support plate, and suffer little or no distortion at all.

In the limited number of tubes sampled in the 1979 examination, this behavior pattern is evident only in this grouping of tubes. However, if this analysis is correct, it would appear that the tubes along these slip-lines are the ones that should be plugged preventively to prevent in-service leaks.

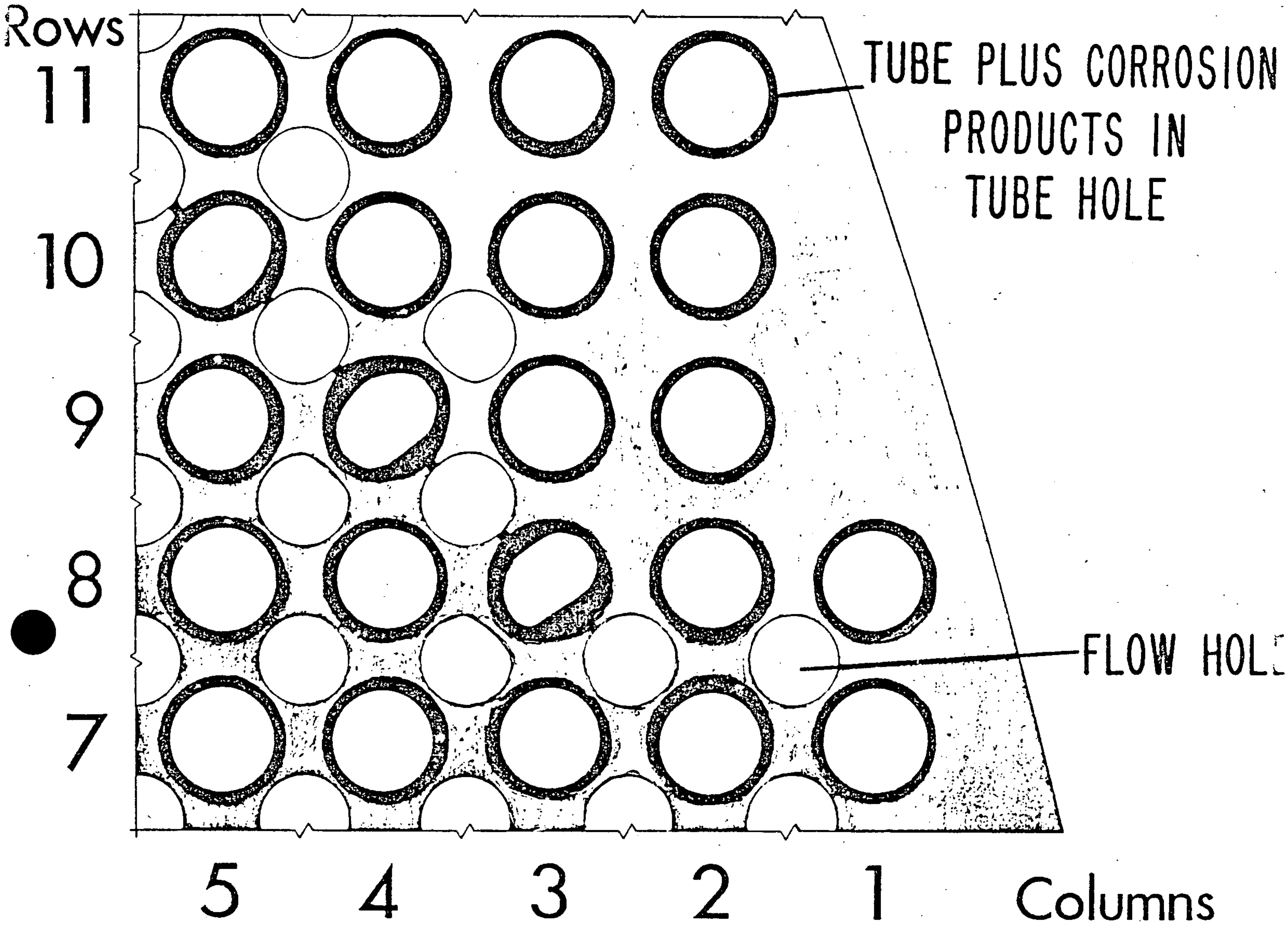


Figure 5-16 Suspected Condition of support plate segment, Rows 7-11, Columns 1-5 , Support Plate 1

6.0 CONCLUSIONS AND RECOMMENDATIONS

Within the limits of accuracy described, profiles of more than 150 steam generator tubes have been determined, and hoop strains have been computed for almost 700 tube/support plate intersections.

It appears that there is no correlation between tube shape and strain as determined in this program and the previous finite element analyses based predictions of support plate strain and tube strain, nor with eddy current dent measurements, nor with eddy current probe sizes. This lack of correlation explains why there did not appear to be an orderly progression in tube degradation. Eddy current examination for dents appears to be measuring changes in some sort of average tube inside diameter, and the probing simply measures the minimum tube diameter.

The objective of inservice examination of steam generator tubes is to identify tubes that may leak during the ensuing service period. These may be tubes that already contain defects which may propagate, or tubes that may become susceptible to stress corrosion cracking as a result of increase in strain.

It is recognized that eddy current techniques are effective in locating significant defects, and therefore, should be continued. However, it appears that dent measurements based on eddy current techniques are not a true measure of strain, and therefore, should be discontinued in favor of measurements by profilometry. Furthermore, preventive plugging of tubes should be based on profilometry measurement rather than probe size when appropriate criteria for plugging are established.

Therefore, it is tentatively planned that during the next scheduled refueling outage, examination of the steam generator tubing in one steam generator include the following:

1) Eddy current examination for defects.
2) Eddy current examination for dents. (Results to be used for comparison with results from profilometry.)
3) Profilometry examination for dents.

It appears that careful analysis of data derived from profilometry can provide significant information relative to the condition of the support plates. The scope of future examinations should be based on evaluation of results.

A total of ten probes were required to complete the examination described herein, and a significant amount of time was required during the examination to replace probes when they became defective. Consequently, for future examinations, modifications to improve probe life and reliability are necessary.

In order to significantly improve the accuracy of the profilometer it appears desirable to use a rotating device, which can define the complete profile of a tube rather than only measure eight (or any other finite number) pseudo - radii. Under contract to Con Edison, NUS Clearwater is working on the hardware development of a Con Edison concept of a rotating mechanical profilometer. This is scheduled to be ready in time for the 1980-81 refueling outage.

As a related activity, the EPRI Steam Generator Owners Group has retained Sigma Research Inc. to develop a rotating optical profilometer device. This is scheduled to be ready for field testing in 1982.

<u>APPENDIX A</u>

PROFILOMETER WEAR

BABCOCK & WILCOX

Babcock & Wilcox

Research and Development Division
Alliance Research Center Alliance,Ohio 44601

To	S. J. STUDER - ISI, COPLEY
From	S. E. REED - APPLIED MECHANICS, ARC
Cust.	CON ED INDIAN POINT-2
File No. or Ref.	
Subj.	PROBE WEAR
Date	JUNE 13, 1979

This letter to cover one customer and one subject only

Reference: 1. S. E. Reed to S. J. Studer, "Profilometer Wear", June 11, 1979.

In the referenced letter I described the wear on the profilometer feet of the probe used at the Indian Point-2 steam generator mockup, and recommended implementing hard chrome plating on the probe contact surfaces. This memo is to provide additional information about the hard chrome and an update on the status of the plating of the mockup probe.

According to "Modern Electroplating", hard chromium plating combines very great hardness, extremely good corrosion resistance, very low coefficient of friction, and non-galling characteristics. To attain these benefits, it is desirable for the base material to be quite hard, which ours is, and also quite smooth (also true in our application). Typically, hardnesses of Vickers 700 can be attained ($R_c \approx 60$) and coefficients of friction of less than 0.1.

The feet on the mockup probe were reground and the probe was coated with an acid-resistant compound to prevent damage to the parts of the probe which were not to be plated. A test sample with strain gages installed was immersed in an acid bath (comparable to the chroming solution) for about 3 hours to verify that the resist was adequate and that it could be removed without damaging the gages. The probe was then taken to the chroming vendor. Because the probe was assembled and instrumented, it was extremely difficult to clean off the surface oxidation. It was necessary to try to clean it with a Q-Tip and 280 grit silicon carbide paper. After this cleaning and a degreasing operation, the probe was plated. The feet were then finish ground and polished.

The diameters across the probe feet were then measured and are shown below:

W	0.909 inch
X	0.914 inch
Y	0.912 inch
Z	0.898 inch

cc: R. W. Curtis
C. T. Jones
P. E. Sensmeier PES
L. P. Williams - ISI, Copley A-1

The diameter of the probe after the mockup testing was 0.907 inch. It is estimated that at least 5 to 7 mils per foot (10 to 14 mils diametral) were removed by grinding to reshape the feet (more or less, depending on the initial condition). While the feet were not measured after grinding prior to plating, it is estimated that there is an average of 6 to 7 mils of chrome on the contact points.

The plating on the probe feet is shown in Figure 1. Good uniform coverage with a slightly greater buildup on the contact points was obtained on seven of the feet. On one foot, however, several patches were observed where the chrome did not plate to the copper surface. This is shown in Figure 2. After examining this surface, the vendor stated that he felt the lack of plating was due to surface contamination that was not removed by the mechanical cleaning. To avoid this on the 10 production probes, each probe head will have the surface oxide removed by abrasive blasting — either alumina or glass beads. The heads will then be bagged and taken to the vendor where they will be degreased and plated.

I do not believe that the defects in the plating on the mockup probe will adversely affect its performance in the testing planned at ARC. The planned cleaning sequence should prevent these defects from occurring on the production probes.

The mockup probe, however, is substantially undersize. It is estimated that the contact force will be reduced by 20 to 25 percent by this. This will affect both the life testing of the probe and the test to measure scratch depths produced by the probes in the tubes. For the scratch test, this problem has been circumvented. In addition to pushing the probe through a nominal (round) tube, it was also pushed through a tube which was ovalized by 100 mils (diametral). This will increase the contact force to 20 to 25 percent more than a full size probe in the nominal tube and will indicate whether contact force directly affects scratch depth.

It is unknown at this time how the contact force will affect the wear of the probe in the life test. It is also unknown how the difference in tube ID condition (as received versus oxidized) will affect the life test. In spite of these uncertainties, the life test should provide a good qualitative assessment of the probe life and identify any potential problems (other than wear) which could reduce probe life. It is thus planned to begin the life test using the Indian Point-2 mockup probe.

If you have any questions or need more information concerning this, please call me.

S E Reed

S. E. Reed

SER/skm

Attachments

FIGURE 1.
CHROME PLATING ON PROBE FEET

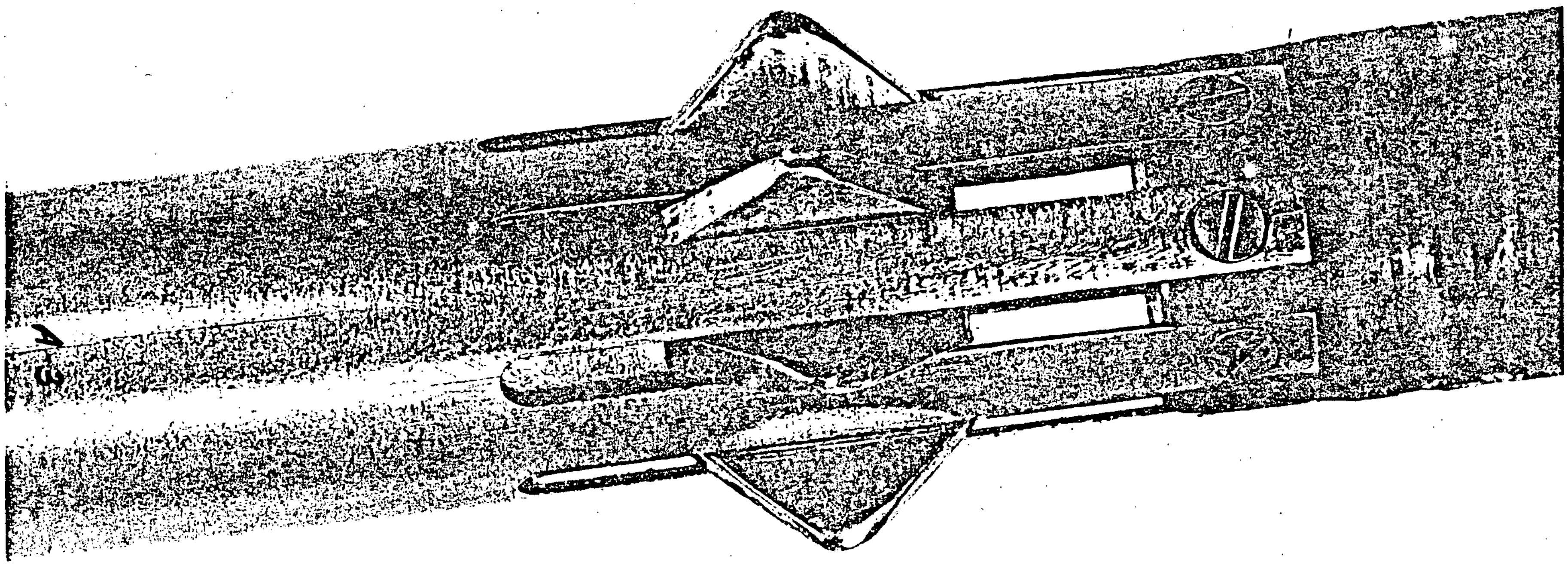
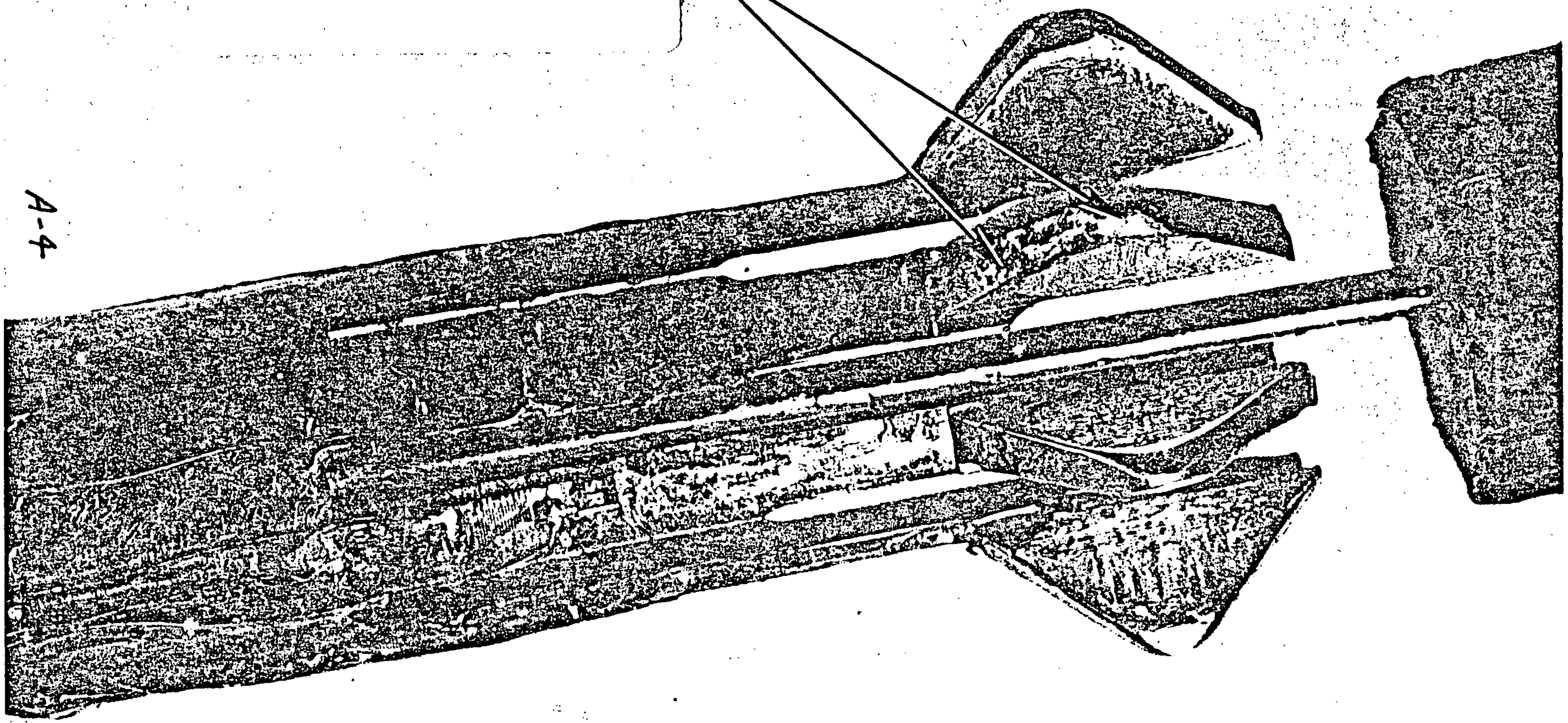


FIGURE 2. CHROMING DEFECTS



APPENDIX B

TUBE I.D. SCRATCHES

BABCOCK & WILCOX

Babcock & Wilcox

Research and Development Division
Alliance Research Center Alliance, Ohio 44601

To: S. J. STUDER - ISI, COPLEY

From: S. E. REED - APPLIED MECHANICS, ARC

RC-1 (rev. ...)

Cust.: CON ED - INDIAN POINT-2

File No. or Ref. 5470

Subj.: TUBE ID SCRATCHES

Date: JUNE 14, 1979

This letter to cover one customer and one subject only

A test was performed to determine the depth of scratches in Westinghouse steam generator tubing resulting from passing the radial profilometer through the tubing.

The tube that was tested was a spare short section of tube supplied to us by Consolidated Edison for the plastic strain test. The tube ID was in an as-received condition, not heavily oxidized. I believe that this should provide a worst case estimate of scratch depth, as the oxide in the generator tubes should afford some protection due to its hardness. An oval dent of approximately 100 mils (diametral) depth was produced in the center of the tube using the Consolidated Edison indenting tool. The diameters of the tube in both the round and oval sections were measured and are listed below.

Round Section			Oval Section		
OD	Wall	ID (calc)	OD	Wall	ID (calc)
0.872	0.0495	0.773	0.775	0.0495	0.676
0.871	0.0495	0.722	0.923	0.0495	0.824

The ID was calculated using the average wall thickness from all of the short tube sections supplied by Consolidated Edison.

The probe used for this test was the mockup probe with chrome plated feet. As discussed in my letter to you (S. E. Reed to S. J. Studer, "Probe Wear", June 13, 1979), this probe is substantially undersize because of the wear on the feet – about 42 mils (diametral) on the average. Because the dent size is about 100 mils, the net effect was about the same as passing a probe of nominal size through a dent of 58 mils (diametral).

The probe was passed through the tube and back once, then was rotated 10 to 15 mils and passed through the tube and back again. This was to insure that the minimum point of the oval section was actually hit by the probe feet. The probe was aligned such that the W-axis feet were passed

cc: R. W. Curtis
C. T. Jones
P. E. Sensmeier PES
L. P. Williams - ISI, Copley

through the minimum section. Visual inspection of the tube revealed the 16 marks on the tube wall from the probe passage.

Cross sections were then cut from the round and oval sections of the tube. The specimens were nickel plated for good edge definition and then were mounted in bakelite and polished.

The specimens were examined optically at 400 power. On the specimen from the round section no indications could be found other than normal surface roughness. This is shown in Figure 1. In the oval section a single scratch (depth about 0.0001 inch) was found, about halfway between the major and minor diameters of the tube. It is believed that this is one of several scratches which were observed in the tube, unrelated to the probe insertion.

A longitudinal section of the tube was then made of the tube. The area around the surface marks was inspected at 100x in a scanning electron microscope, and a stereo pair was made (see Figure 2). When viewed singly, the two parallel marks of the two insertions were visible. It could also be seen that the surface marks on adjacent areas were not obliterated by the marks, indicating that what was seen is a burnishing of the high points of the tube, leaving base material untouched. This was borne out when the pictures were viewed as a stereo pair. The surface roughness of the adjacent areas was clearly visible. No depth was observable at the marks, but the surface was somewhat smoother.

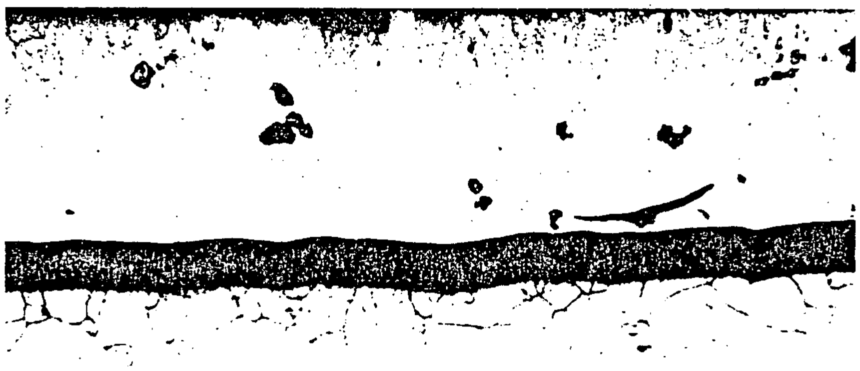
It is concluded from these tests that while the hard chrome plating is sufficiently hard to burnish the surface of tubes, no scratches of measurable depth will be produced by a nominal diameter probe in either a round tube or a dented tube with up to a 50 mil (diametral) dent. Because no significant difference was observed between the round tube and the dented tube tested, it is judged unlikely that significant scratching would occur, even in the minimum (0.580 diameter) tube.

S. Reed

S. E. Reed

SER/skm

Attachments



← Round Section

Oval Section →

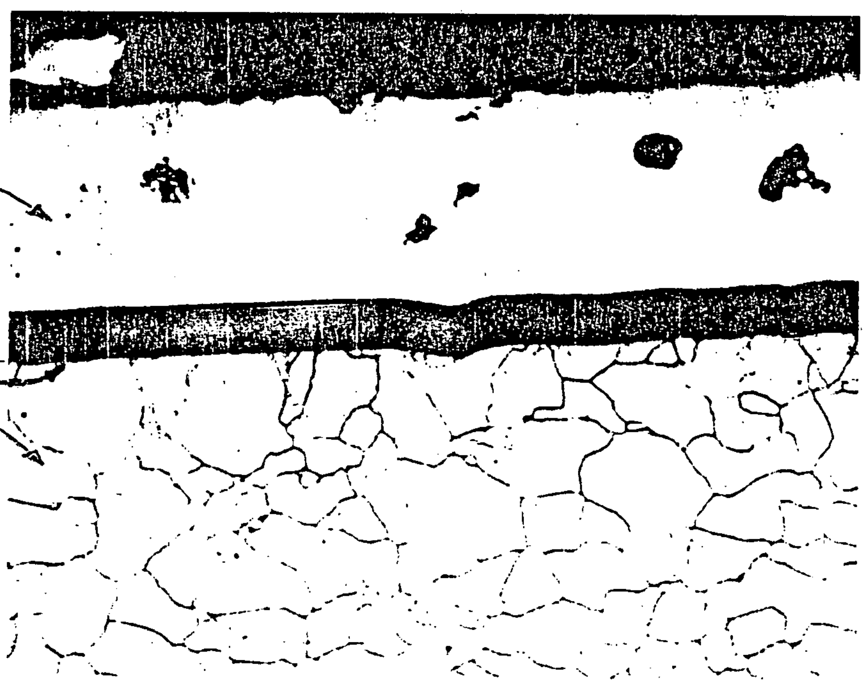


Figure 1 - Surface of Tube Cross Sections
Optical 400X

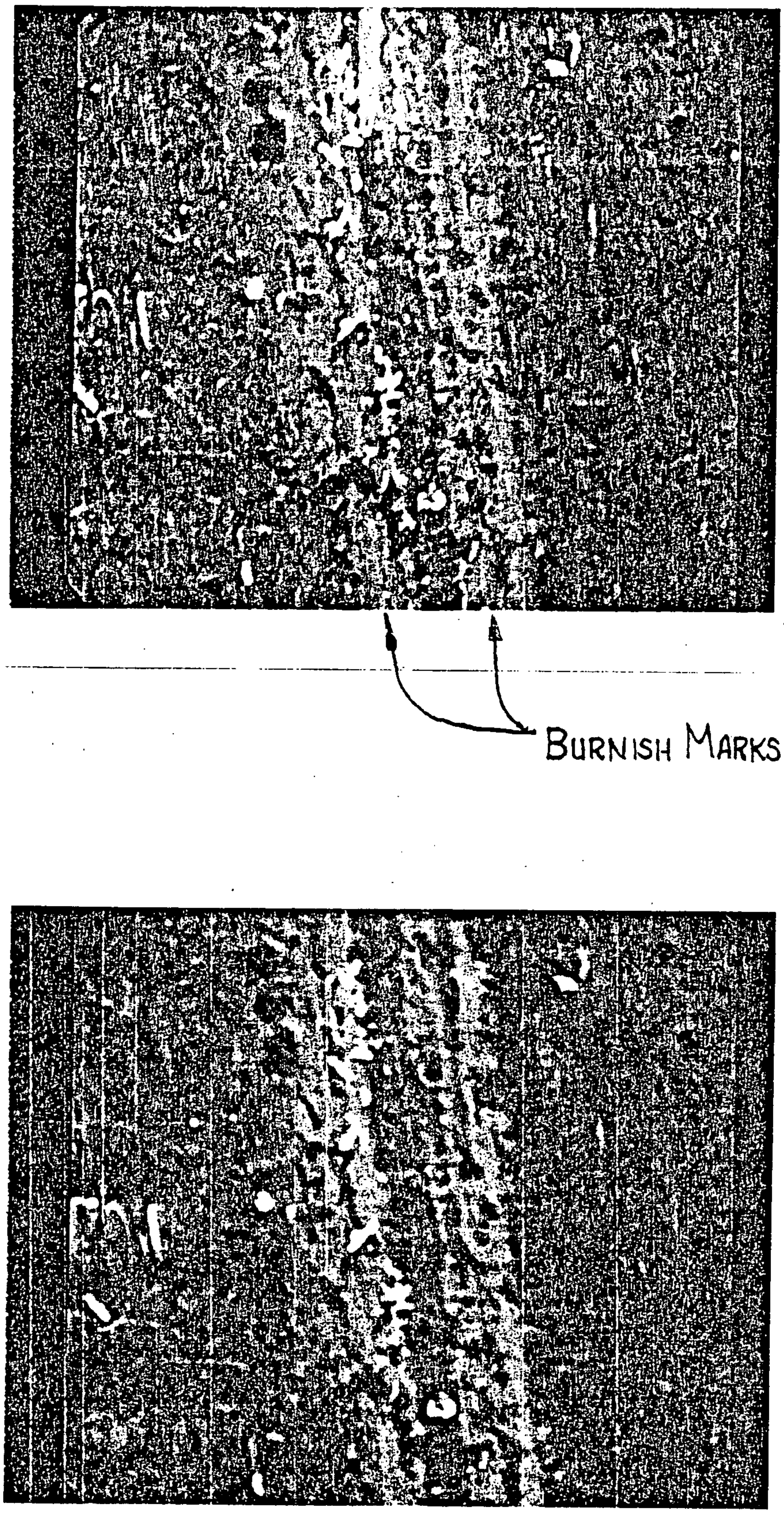


Figure 2 - Tube ID Surface Showing Burnish Marks
SEM 100x Stereo Pair

APPENDIX C

CONVERGENCE STUDY

BABCOCK & WILCOX

DRAFT
July 6, 1979

Babcock & Wilcox

Research and Development Division
Research Center   Alliance, Ohio 44601

To: S. J. STUDER - ISI, NPGD, LYNCHBURG

From: S. E. REED - APPLIED MECHANICS, ARC

Cust.: CONSOLIDATED EDISON

File No. or Ref.: LR:79:5470-04:03

Subj: CONVERGENCE STUDY

Date: JULY 6, 1979

This letter to cover one customer and one subject only

Reference: 1. S. E. Reed to S. J. Studer, "Plastic Strain Test:, June 13, 1979.

As described in reference 1, the strain calculation program written for Consolidated Edison was used to predict strains in the tubes which were dented in the laboratory. The strains predicted based on 100 points sampled on the outside of the tubes did not compare well with either the strains measured or with the strains predicted based on 8 points. The deformed tube shapes compared very well with the experimental data. Examination of the results indicated the possibility that the 100-point data overdefined the cubic spline, resulting in rapid changes of the derivatives and erratic behavior of the strain prediction.

To evaluate this, a study was performed to determine if there was a smaller number of points which could be used, which would maintain the excellent correlation of the deformed tube shapes while eliminating the erratic nature of the strain prediction. To accomplish this, the deformed tube data from reference 1 was used, as it was for the 100-point strain prediction. However, rather than using every point, the data was first sampled at every other point and later at every fourth point. This provided

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ISI, NPGD, Lynchburg
L. P. Williams

ARC
R. W. Curtis
J. Heminger
G. Musat
K. H. Schulze
P. E. Sensmeier
Library (3)
APM Files (5)

first 50 points, then 25 points to the curve fit routine to determine if the strain prediction could be stabilized without losing the shape definition and determine the values to which the strain prediction would converge.

Table 1 presents a comparison of the results of these computer runs to the results of the 100-point and 8-point runs previously performed. Plots of the predicted initial and deformed shapes for each of the tubes for 100-point, 50-point, 25-point, and 8-point runs are shown in Appendix A. The displacement and strain distribution plots for 100, 50, 25, and 8 points are shown in Appendix B.

TABLE 1. PREDICTED STRAIN COMPARISON
Predicted Maximum Strain (%) and Location (Degrees)

				8 Point	
	100 Point	50 Point	25 Point	Largest	Smallest
Tube 1	-6.73 356°	-4.32 201.6°	-3.42 201.6°	-1.15 205°	-0.26 225°
Tube 2	-22.48 21.6°	-8.12 353°	-6.12 176°	-5.90 180°	-2.08 200°
Tube 3	-29.53 187°	-15.34 187.2°	-12.9 187.2°	-4.09 185°	-1.03 205°
Tube 4	-35.28 184°	-13.45 7.2°	-8.39 187.2°	-3.96 5°	-0.84 345°
Tube 5	-12.08 187°	-3.59 180°	-2.89 201.6°	-1.81 200°	-0.69 45°
Tube 6	-16.83 184°	-10.51 187.2°	-8.80 187.2°	-5.35 195°	-2.53 220°

The data in Table 1 shows that for each tube, the maximum strain prediction decreases as the number of points decreases. Based on the strain distributions in Appendix B, much of this is due to a decrease in "noise" level in the strain calculation as the number of points is decreased. However, in order for the strain prediction to converge on a correct value, the number of data points must be minimized, while still maintaining a good definition of the deformed shape. Table 2 presents a summary of how well each of the pre- ctions does predicting the deformed shape. The 100-point shape was use as a reference.

TABLE 2. COMPARISON OF SHAPE PREDICTION

Tube No.	50 Point	25 Point	8 Point	Comments
1	G	F	P	8 pts missed maxima
2	E	E	G	
3	E	F	P	Local dent
4	G	G	P	Local dent
5	E	G	P	8 pts missed maxima
6	E	E	F	

E = excellent comparison, very small visible differences

G = good comparison; peak strains excellent, good agreement on overall shape (only minor differences)

F = fair comparison; some differences on peaks, fair agreement on overall shape (some major differences)

P = poor comparison, major differences in magnitudes or shapes.

In general, the 50-point fit had good or excellent agreement with the 100-point fit; the differences being in extremely local areas (1 point). The 25-point fit had excellent agreement on two tubes, good agreement on two tubes, and only fair agreement on the remaining two. The two that were fair were one with a very small dent (tube 1) and one with a small local dent (tube 3). The 8-point fit had good comparison for only one tube, and fair comparison on one. On two tubes, the 8-points missed the maxima and underpredicted the deformation. On the remaining two, the dents were localized and the 8-point fit broadened them considerably. For the two where the maxima were missed, the comparison would probably improve if the probe were rotated to hit them. For local dents improvement is unlikely by any method short of increasing the number of data points. If the dents are extremely localized, even 25 data points can provide only fair prediction of the dent shape.

It is concluded from this study that for simple deformation of the tubes that 8-point samples can adequately define the deformed shapes (and

DRAFT
July 6, 1979

thereby, strain), provided the samp points hit on or near the dent maxima. These shapes would be primarily ovalized. For more complex or localized dents, 8 points will tend to predict more gradually changing shapes and thus underpredict the strain levels by significant amounts. The optimum number of points for defining a deformed shape adequately appears to be a function of dent shape and size. Thus, either some assumptions or some prior knowledge of the basic deformed shape are necessary to determine how well any given number of samples will predict the tube shape and tube strain.

S. E. Reed

S. E. Reed

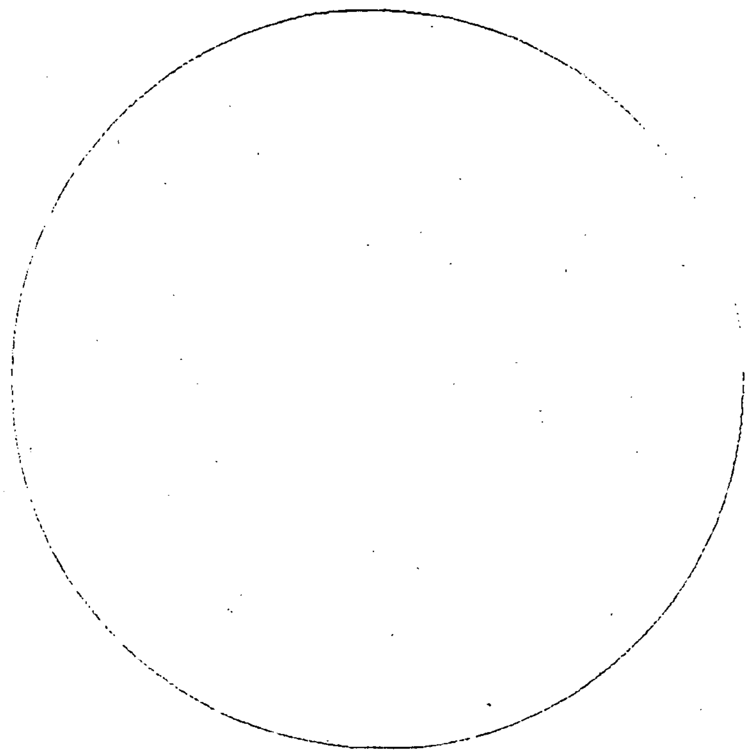
SER/skm
Attachments

APPENDIX A

INITIAL AND DEFORMED SHAPES, TUBES 1 - 6

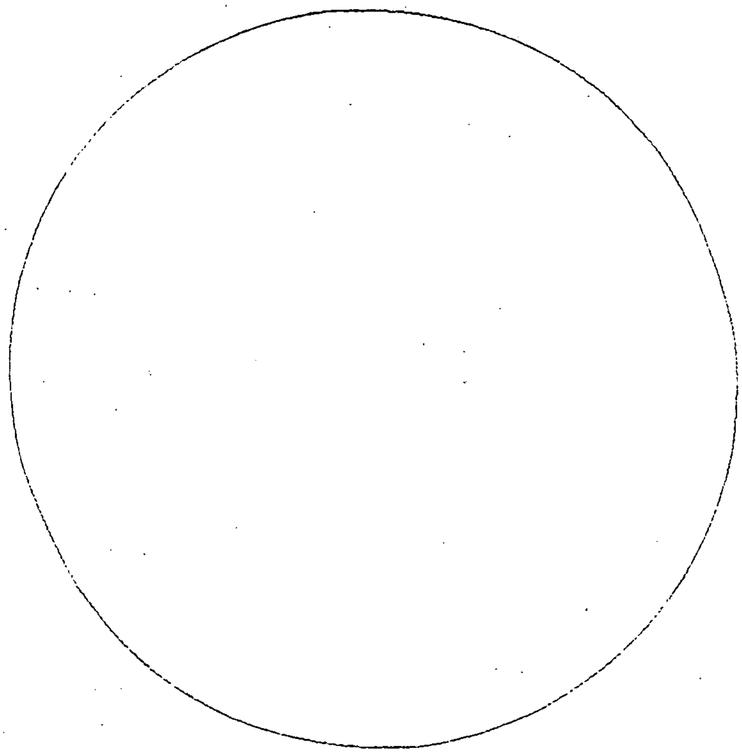
100 POINT, 50 POINT, 25 POINT, AND 8 POINT PREDICTIONS

PLASTIC STRAIN TEST
TUBE #1



INITIAL SHAPE

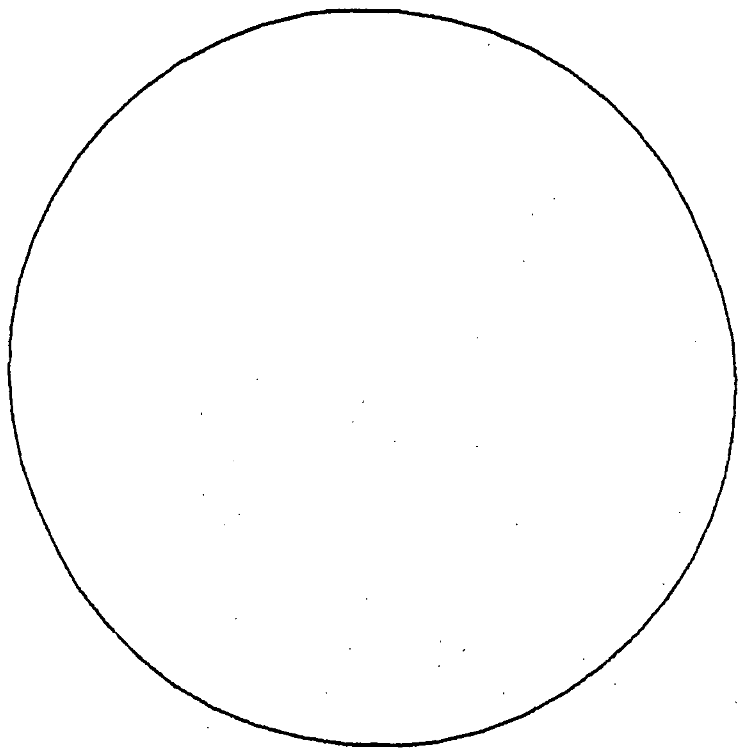
PLASTIC STRAIN TEST
TUBE #1



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #1

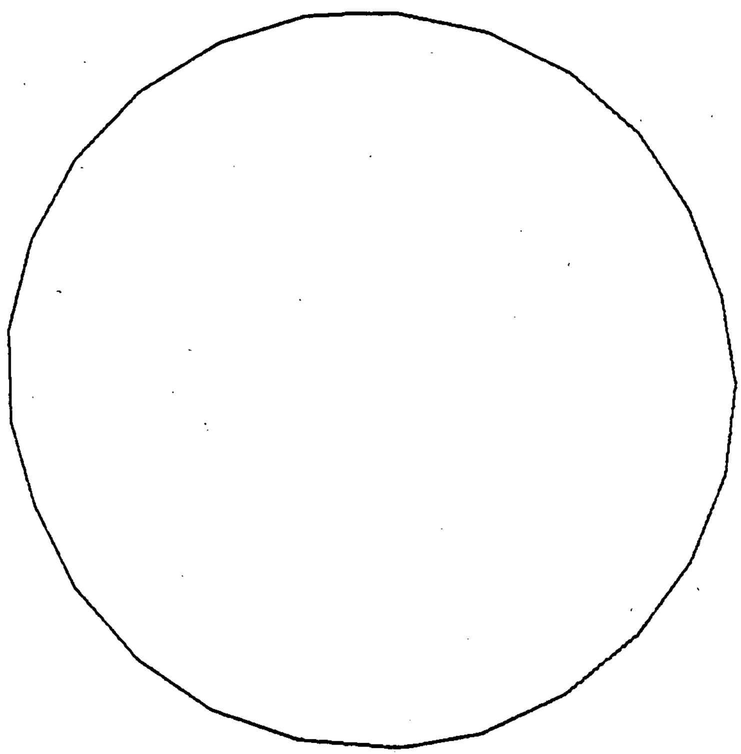
50 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #1

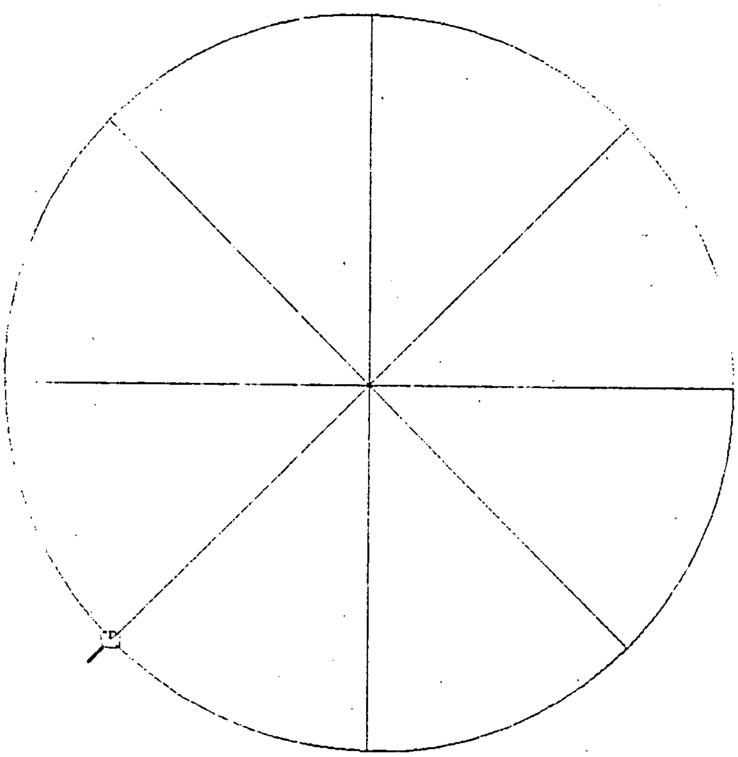
25 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #1

0 DEGREES ROTATION



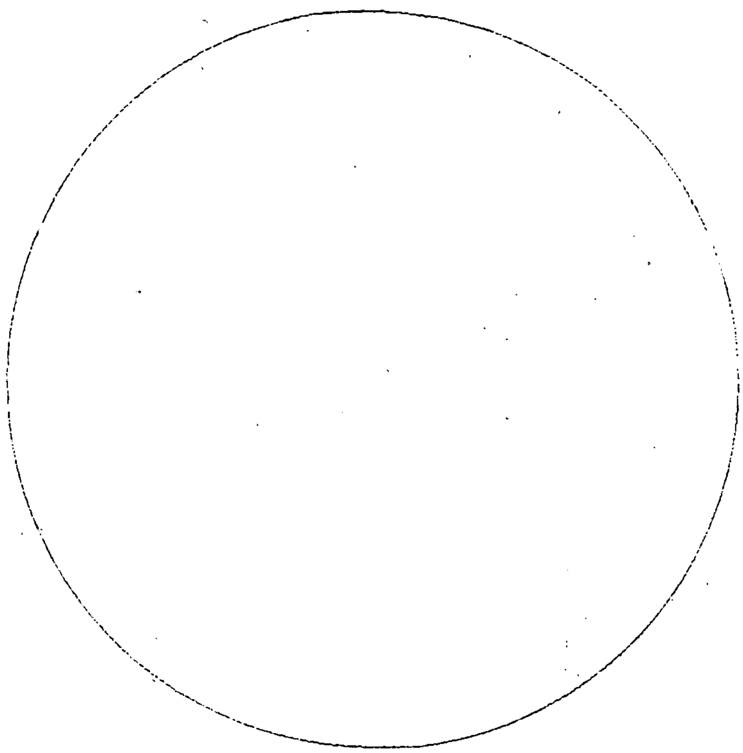
RADII

0.385
0.385
0.387
0.388
0.385
0.385
0.389
0.385

MEMBRANE STRAIN
-0.001

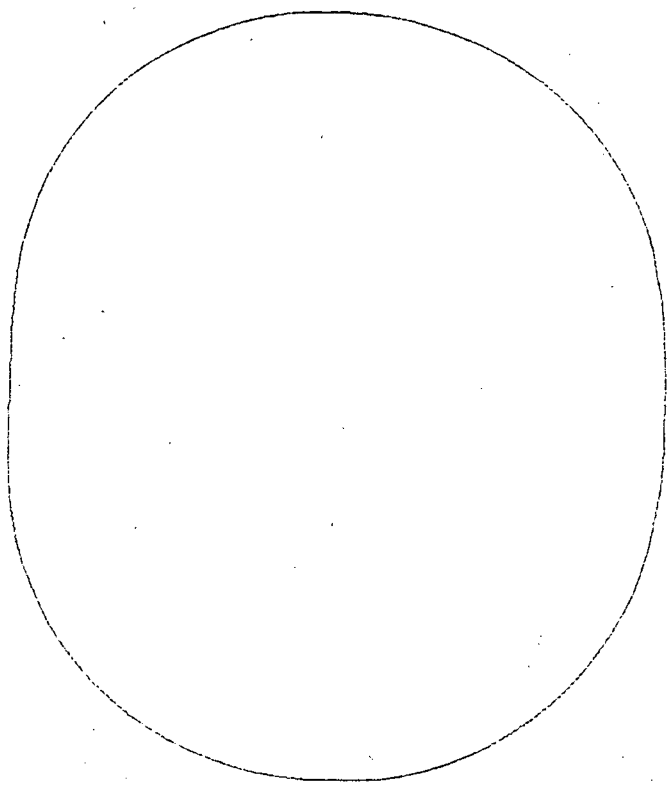
BENDING STRAIN
0.001

PLASTIC STRAIN TEST
TUBE #2



INITIAL SHAPE

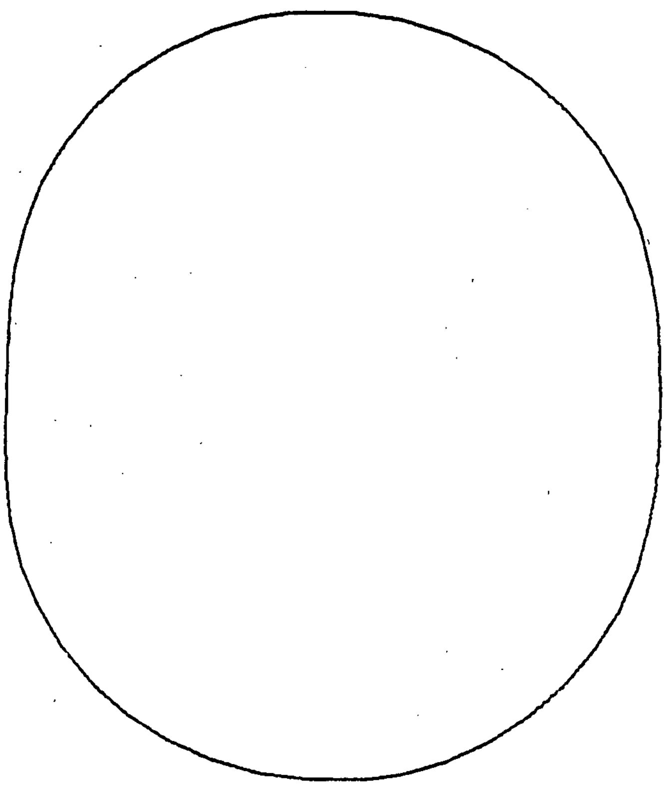
PLASTIC STRAIN TEST
TUBE #2



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #2

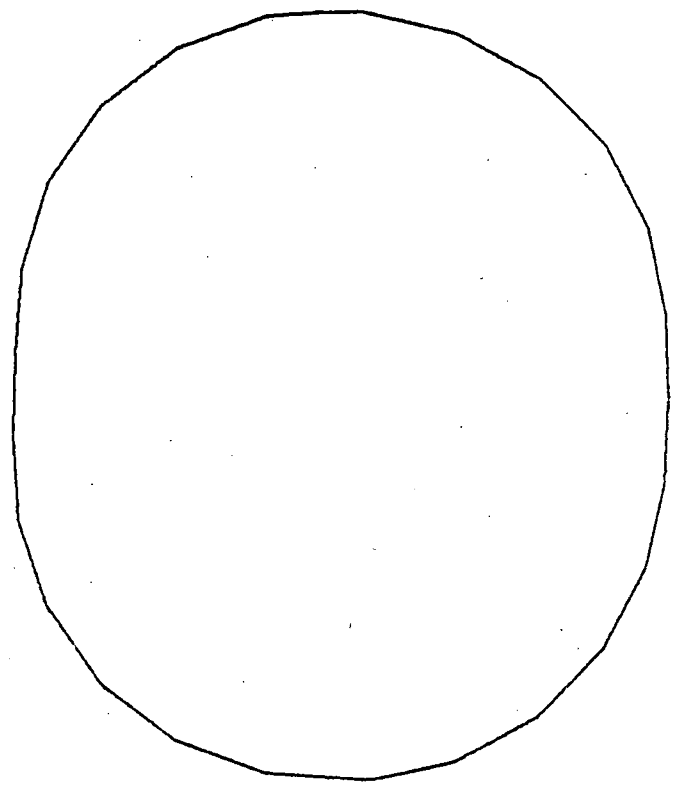
50 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #2

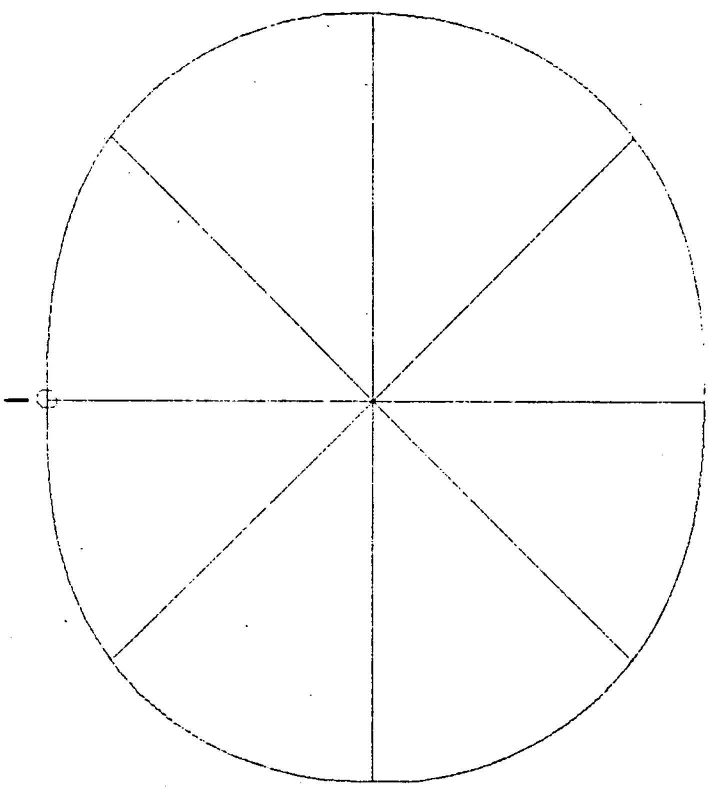
25 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #2

0 DEGREES ROTATION



RADII

0.350
0.390
0.405
0.389
0.343
0.391
0.405
0.337

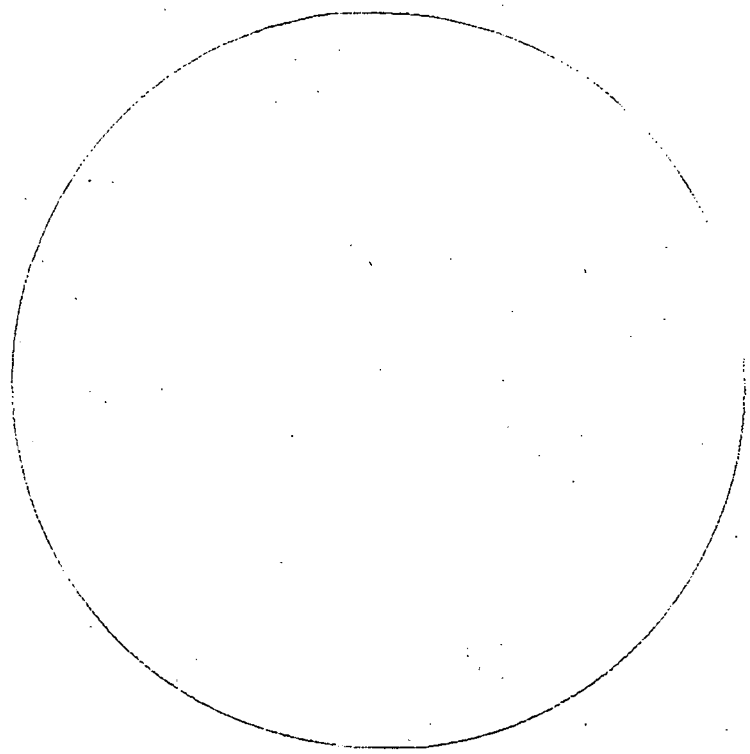
MEMBRANE STRAIN

-0.005

BENDING STRAIN

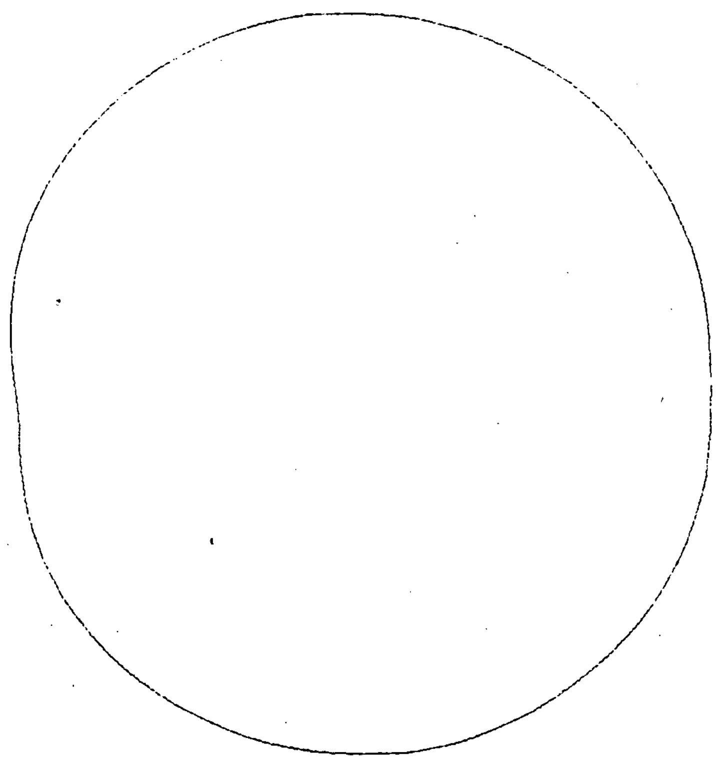
0.054

PLASTIC STRAIN TEST
TUBE #3



INITIAL SHAPE

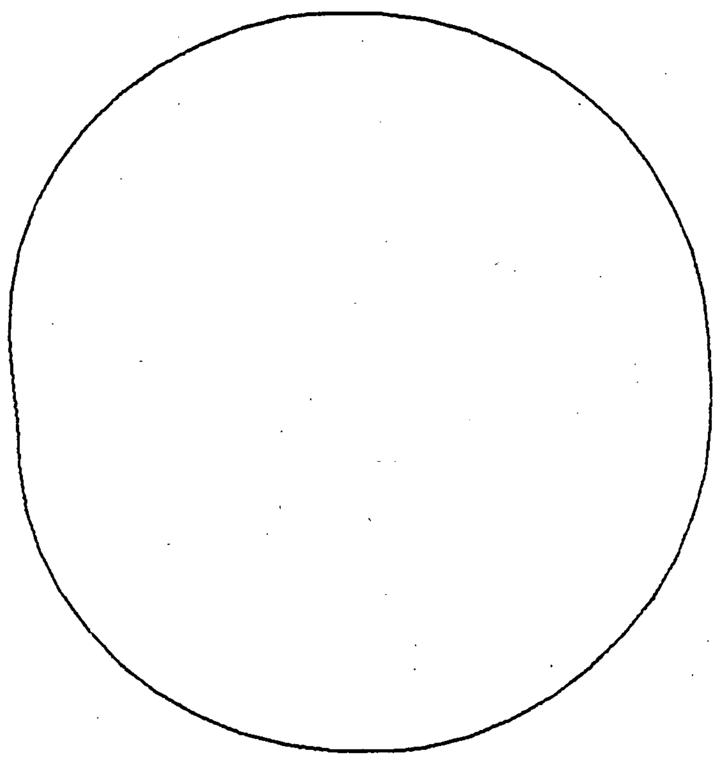
PLASTIC STRAIN TEST
TUBE #3



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #3

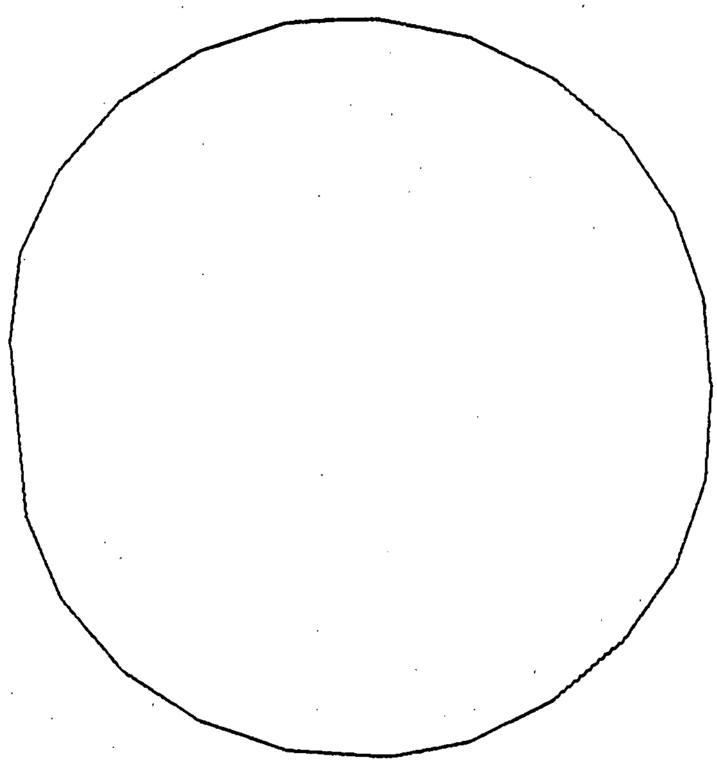
50 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #3

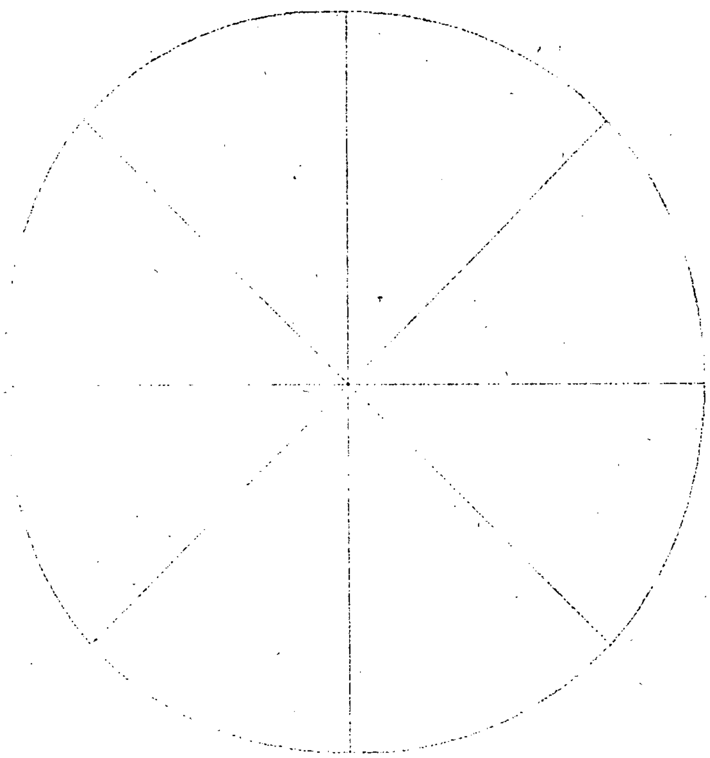
25 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #3

0 DEGREES ROTATION

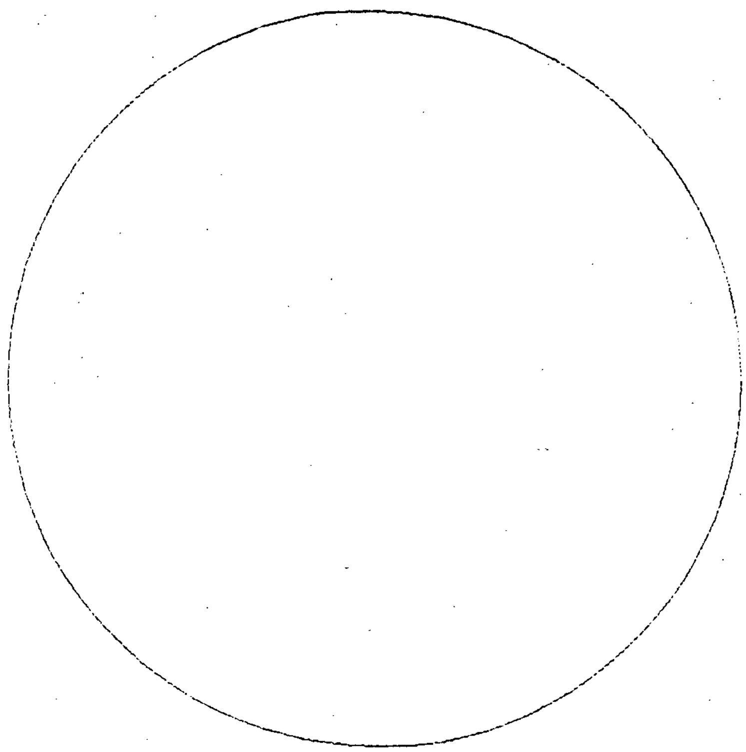


RADII

0.376
0.389
0.390
0.390
0.361
0.389
0.391
0.393

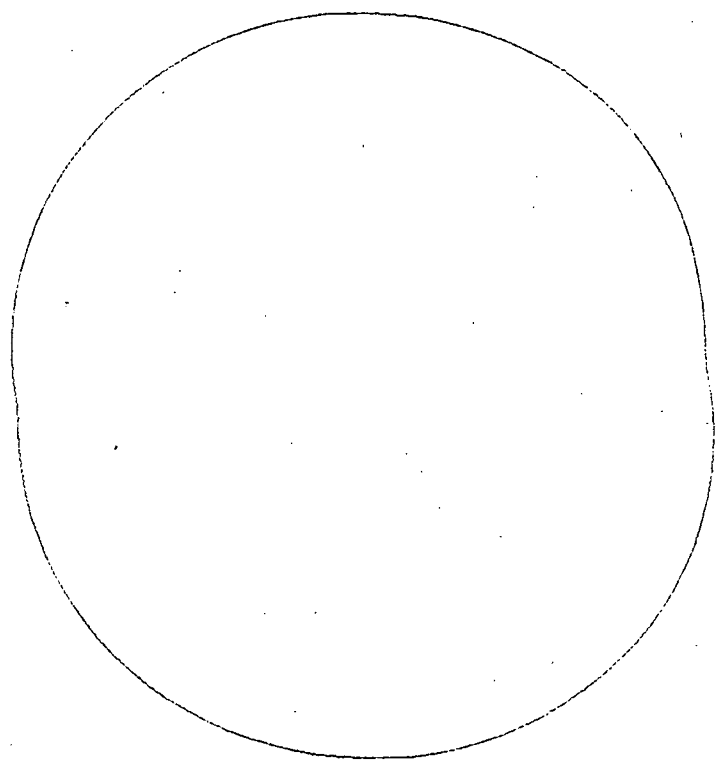
MEMBRANE STRAI
-0.006
BENDING STRAIN
0.032

PLASTIC STRAIN TEST
- TUBE #4



INITIAL SHAPE

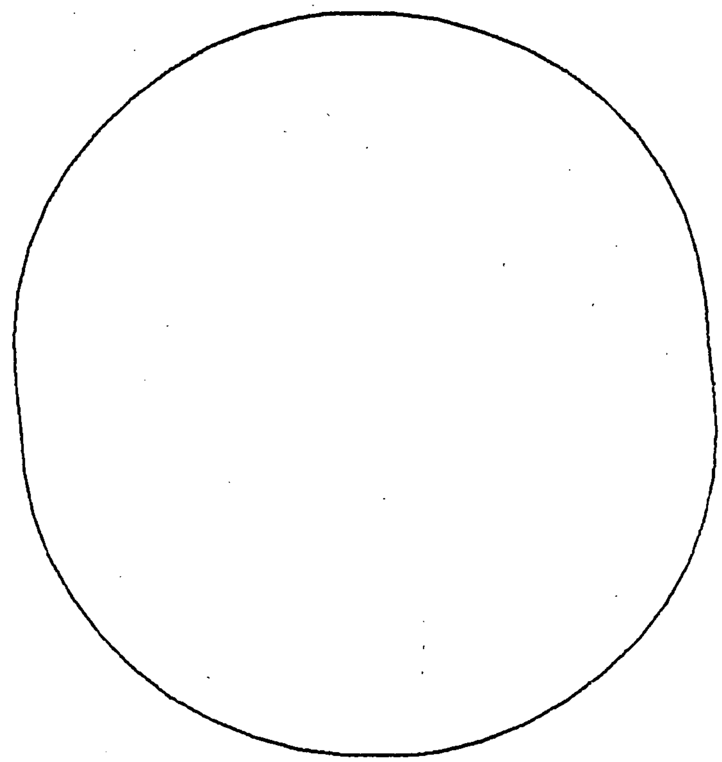
PLASTIC STRAIN TEST
- TUBE #4



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #4

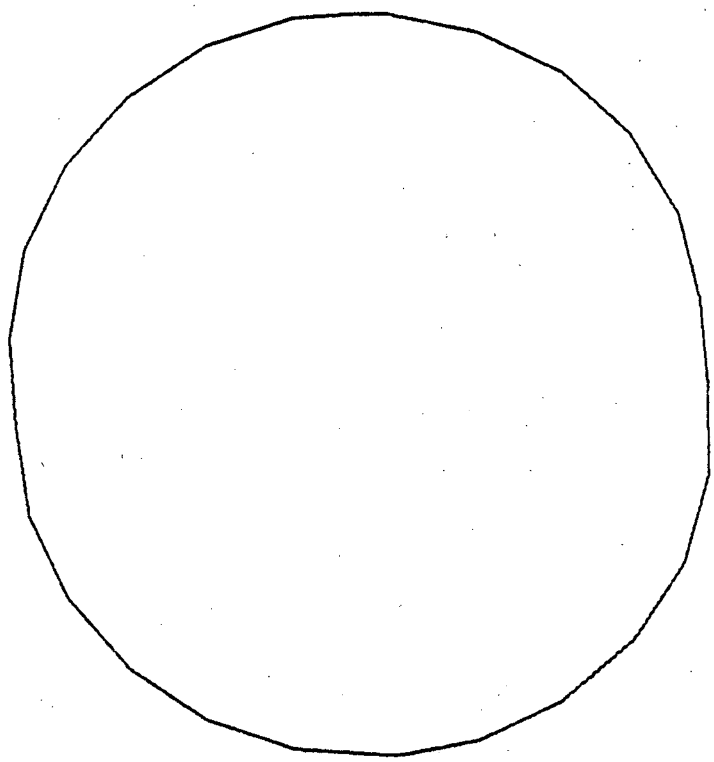
50 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #4

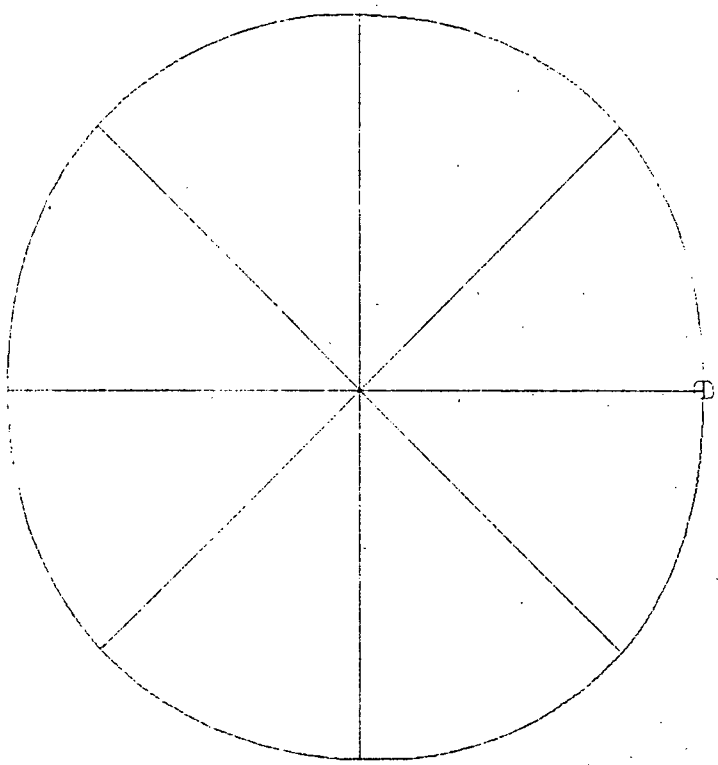
25 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #4

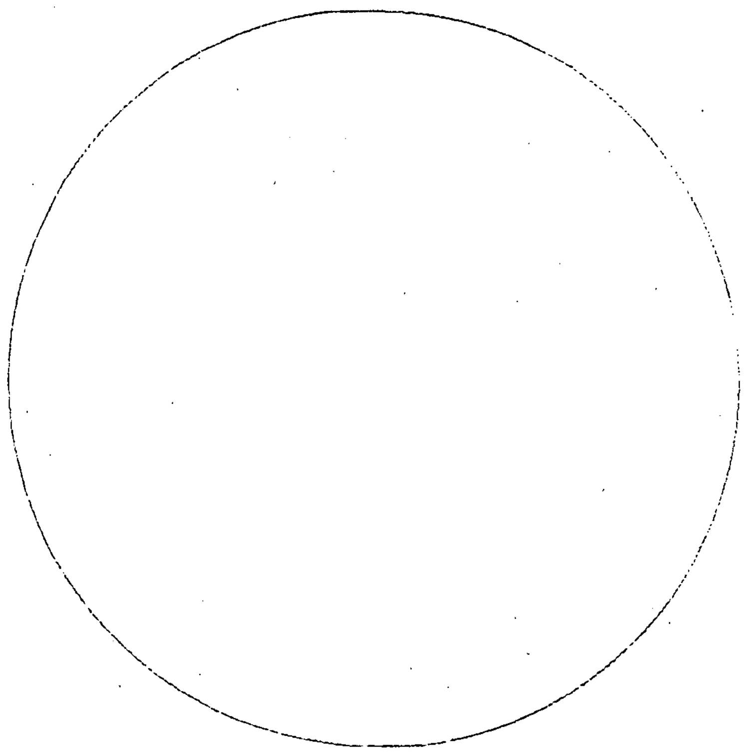
0 DEGREES ROTATION



RADII
0.363
0.389
0.393
0.390
0.372
0.389
0.392
0.391

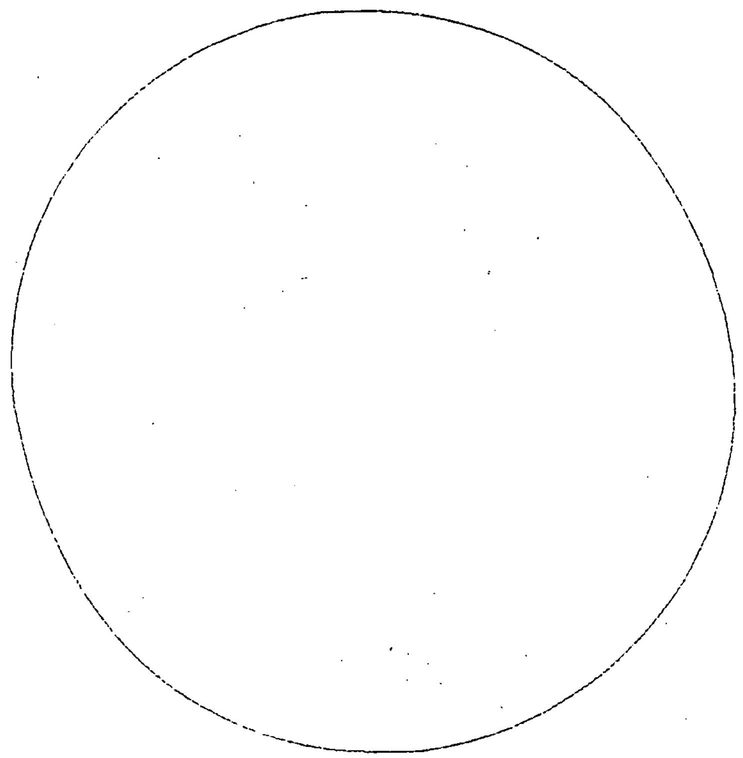
MEMBRANE STRAIN
-0.004
BENDING STRAIN
0.030

PLASTIC STRAIN TEST
- TUBE #5



INITIAL SHAPE

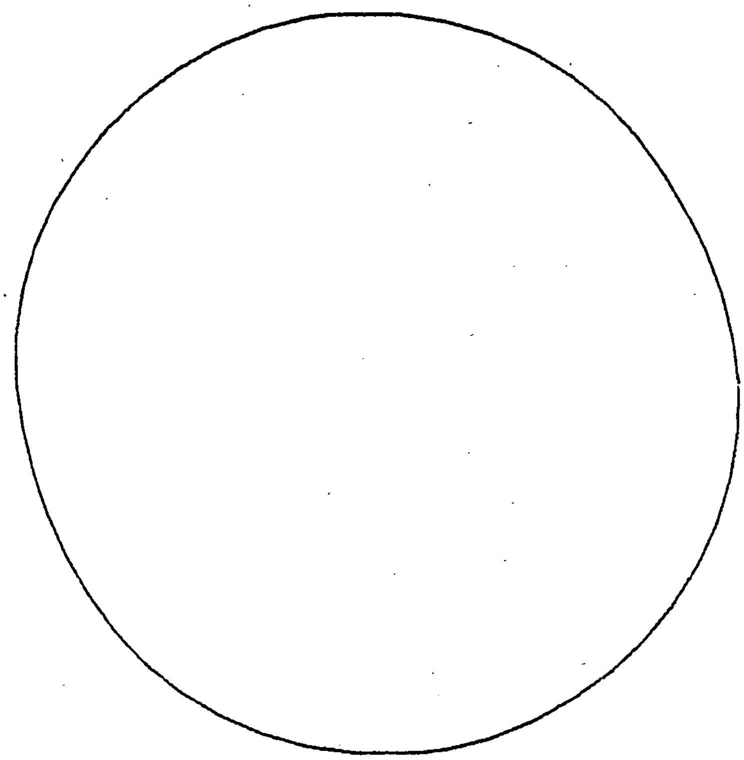
PLASTIC STRAIN TEST
- TUBE #5



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #5

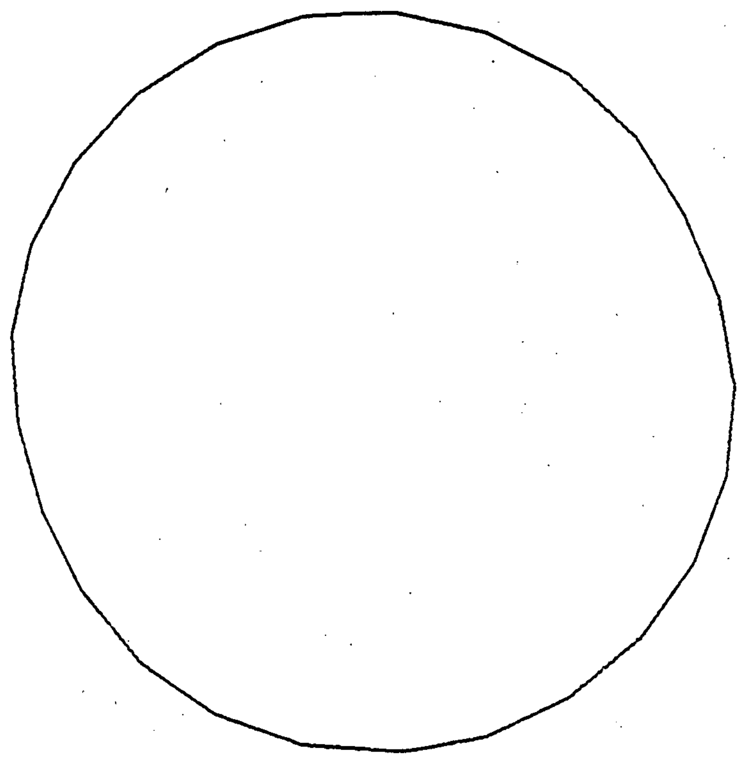
50 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #5

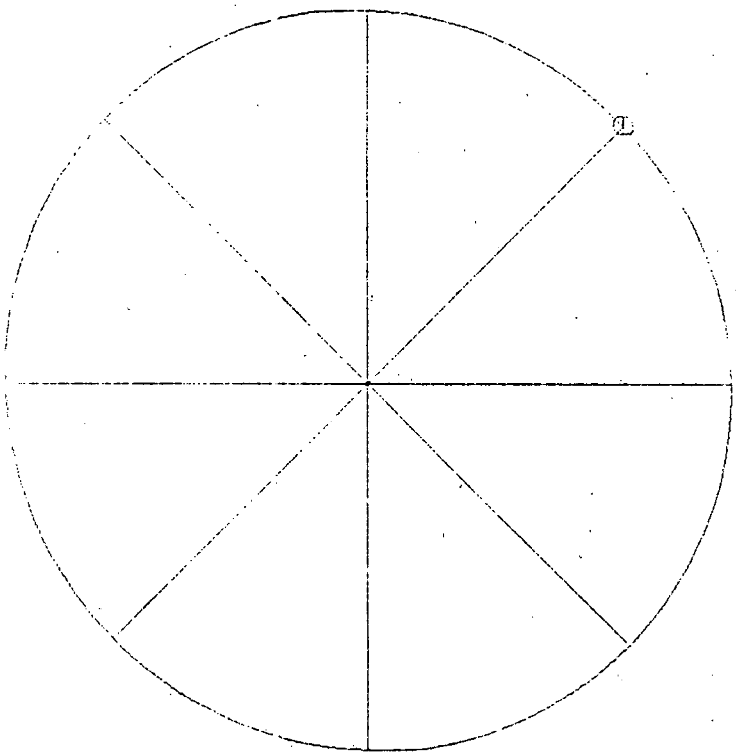
25 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #5

0 DEGREES ROTATION



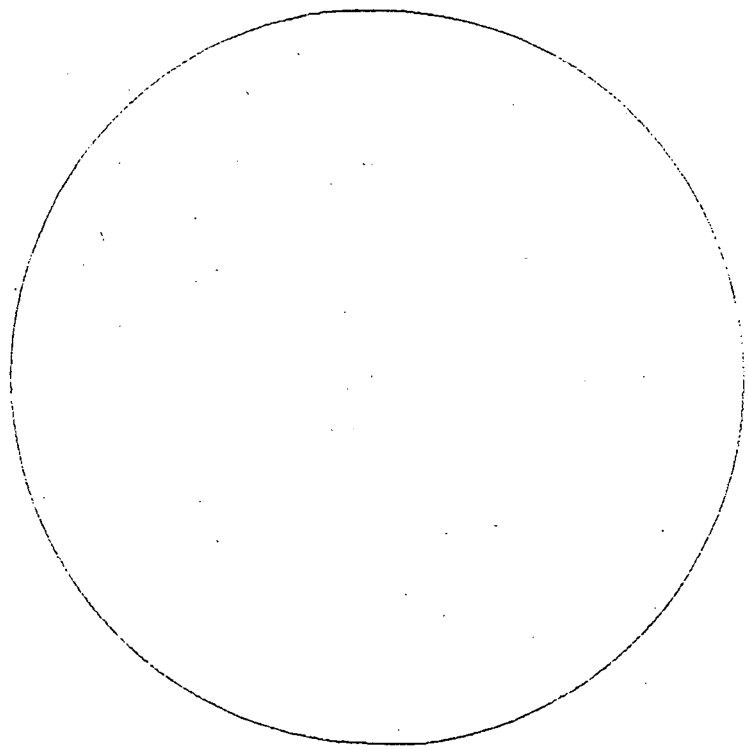
RADII

0.384
0.382
0.381
0.380
0.381
0.382
0.390
0.390

MEMBRANE STRAIN
-0.002

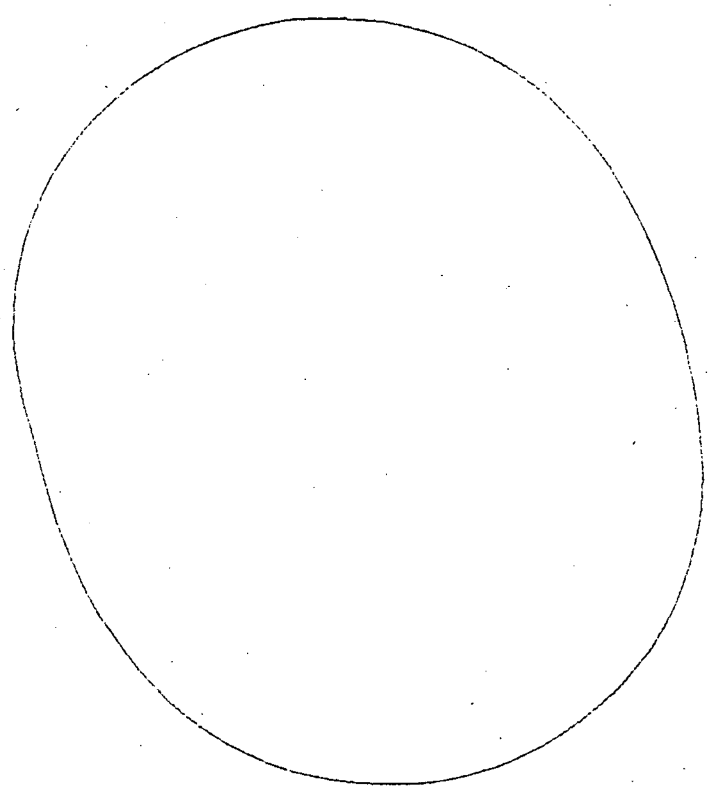
BENDING STRAIN
0.004

PLASTIC STRAIN TEST
TUBE #6



INITIAL SHAPE

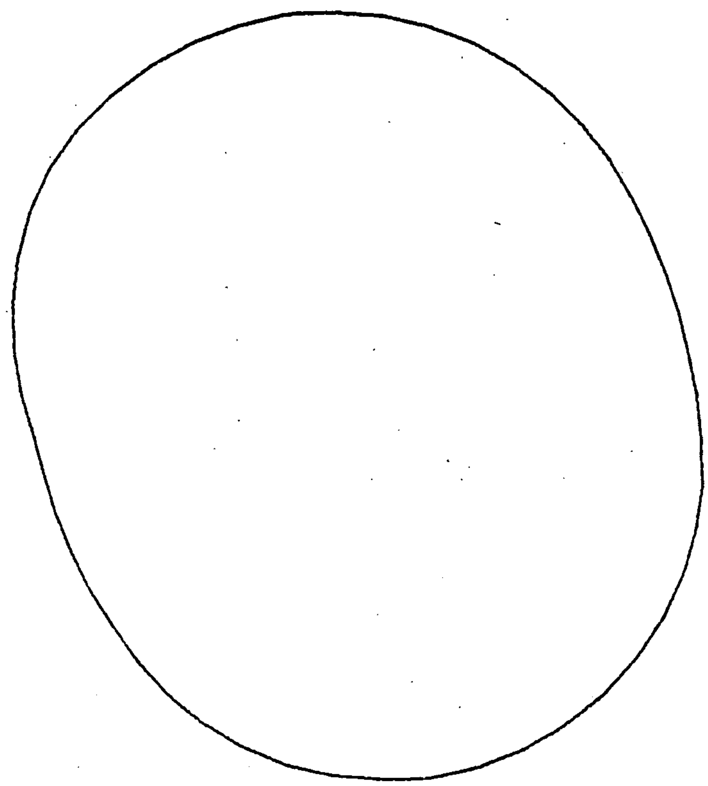
PLASTIC STRAIN TEST
TUBE #6



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #6

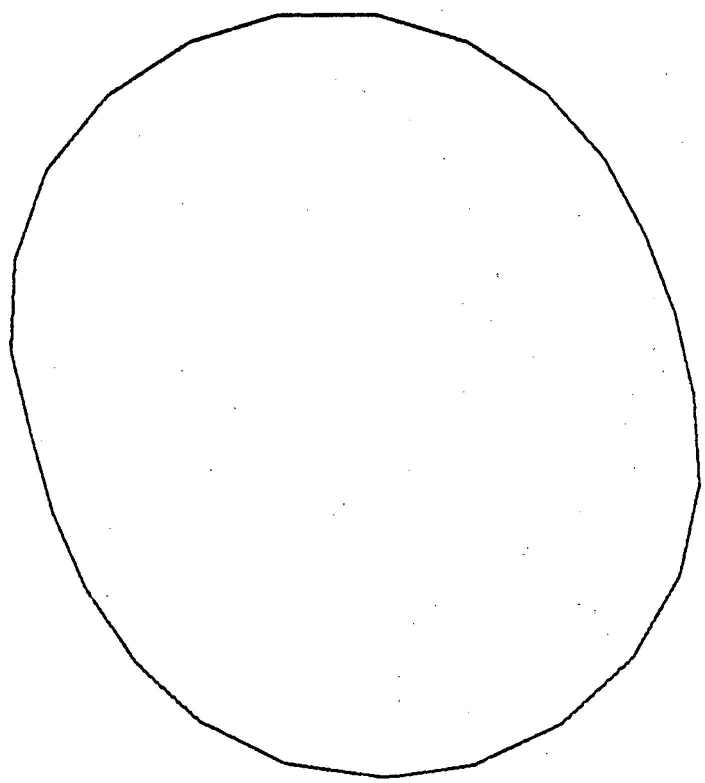
50 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #6

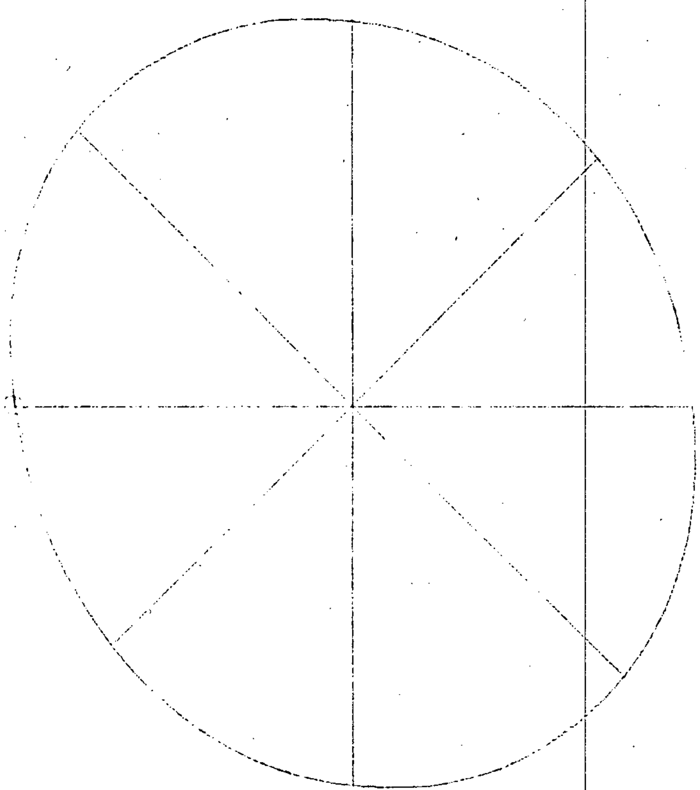
25 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #5

0 DEGREES ROTATION



RADII

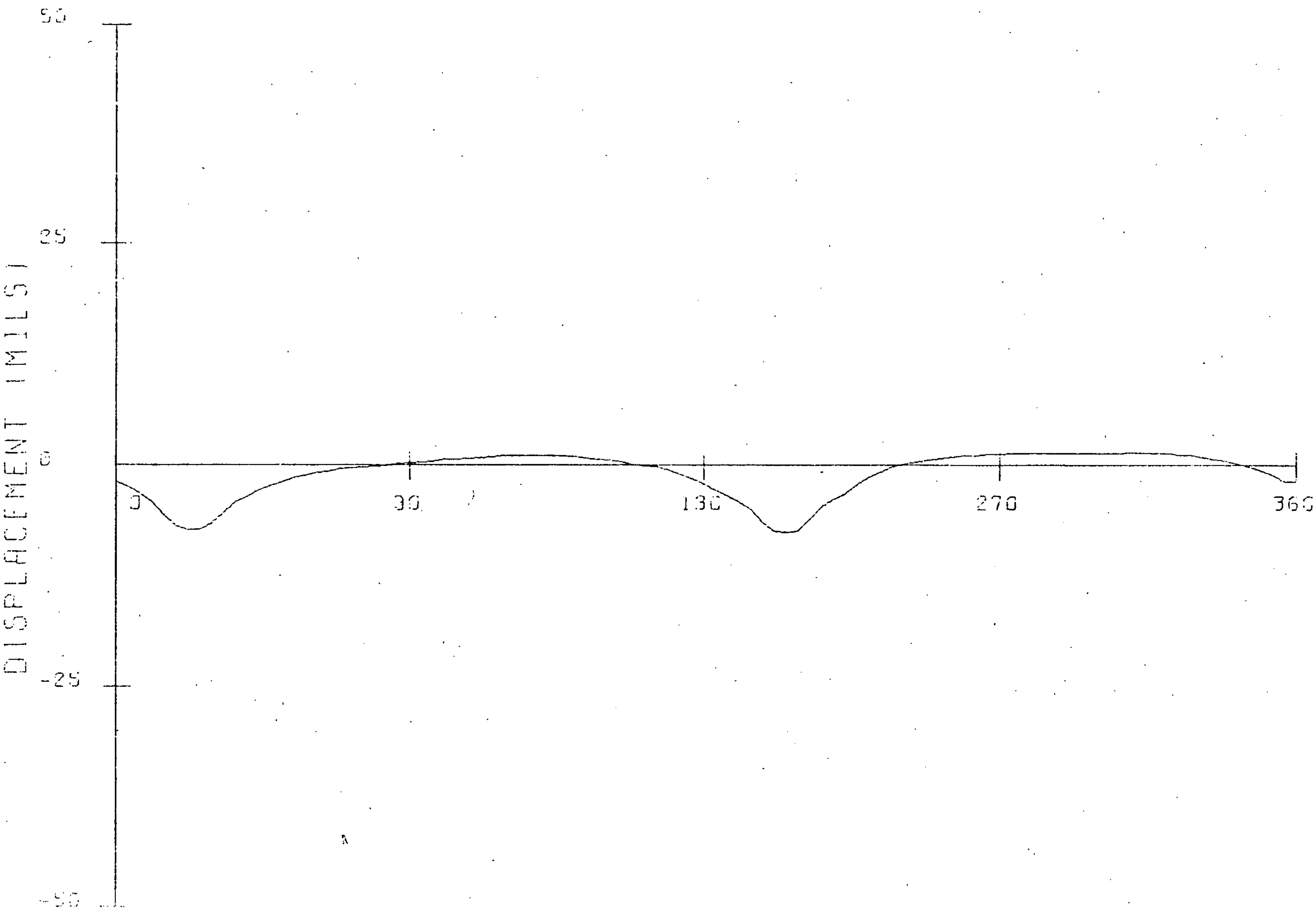
0.359
0.356
0.403
0.406
0.354
0.353
0.404
0.405

MEMBRANE STRAIN
-0.006
BENDING STRAIN
0.023

APPENDIX B

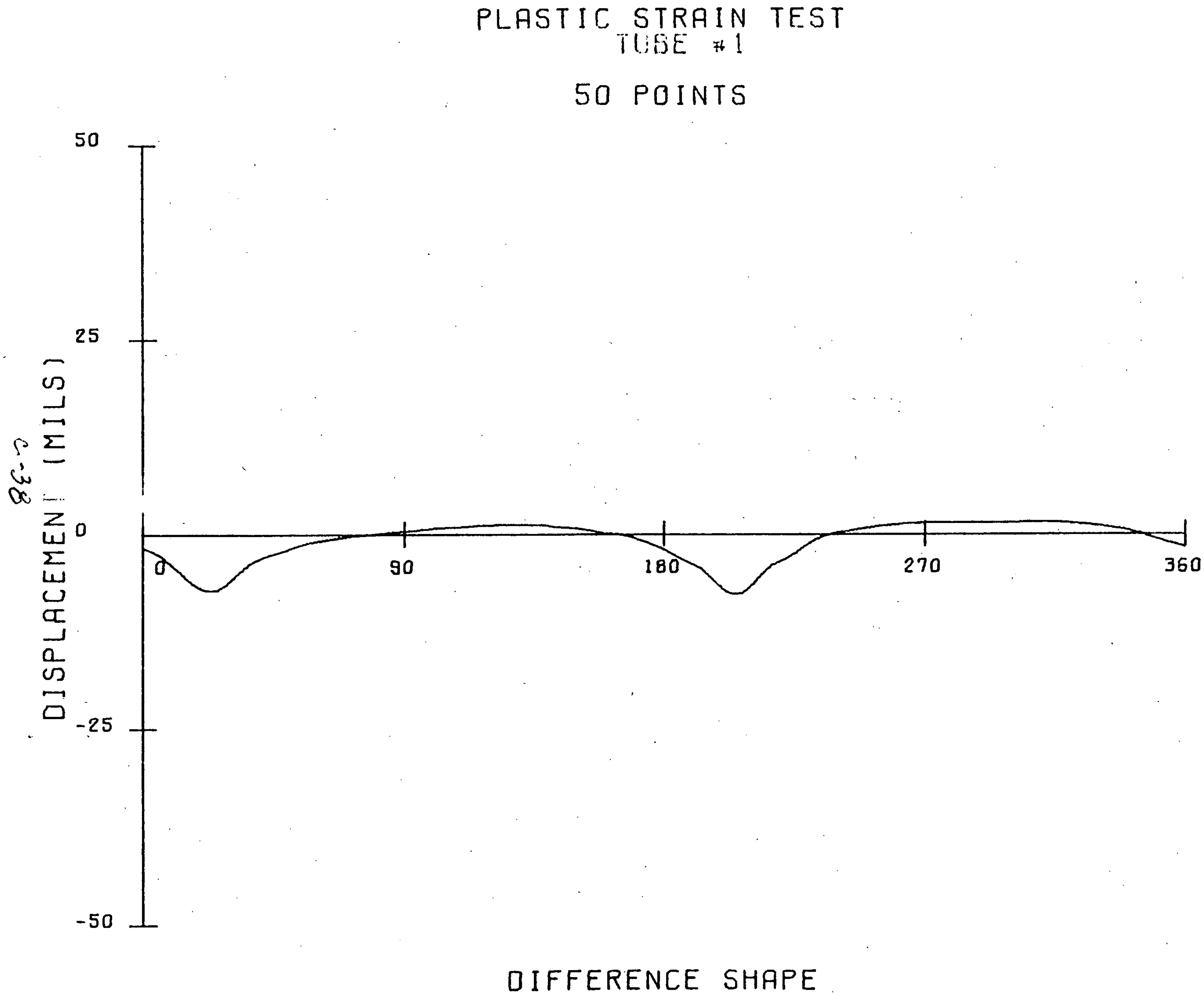
DISPLACEMENT DISTRIBUTIONS
STRAIN DISTRIBUTIONS

PLASTIC STRAIN TEST
TUBE #1



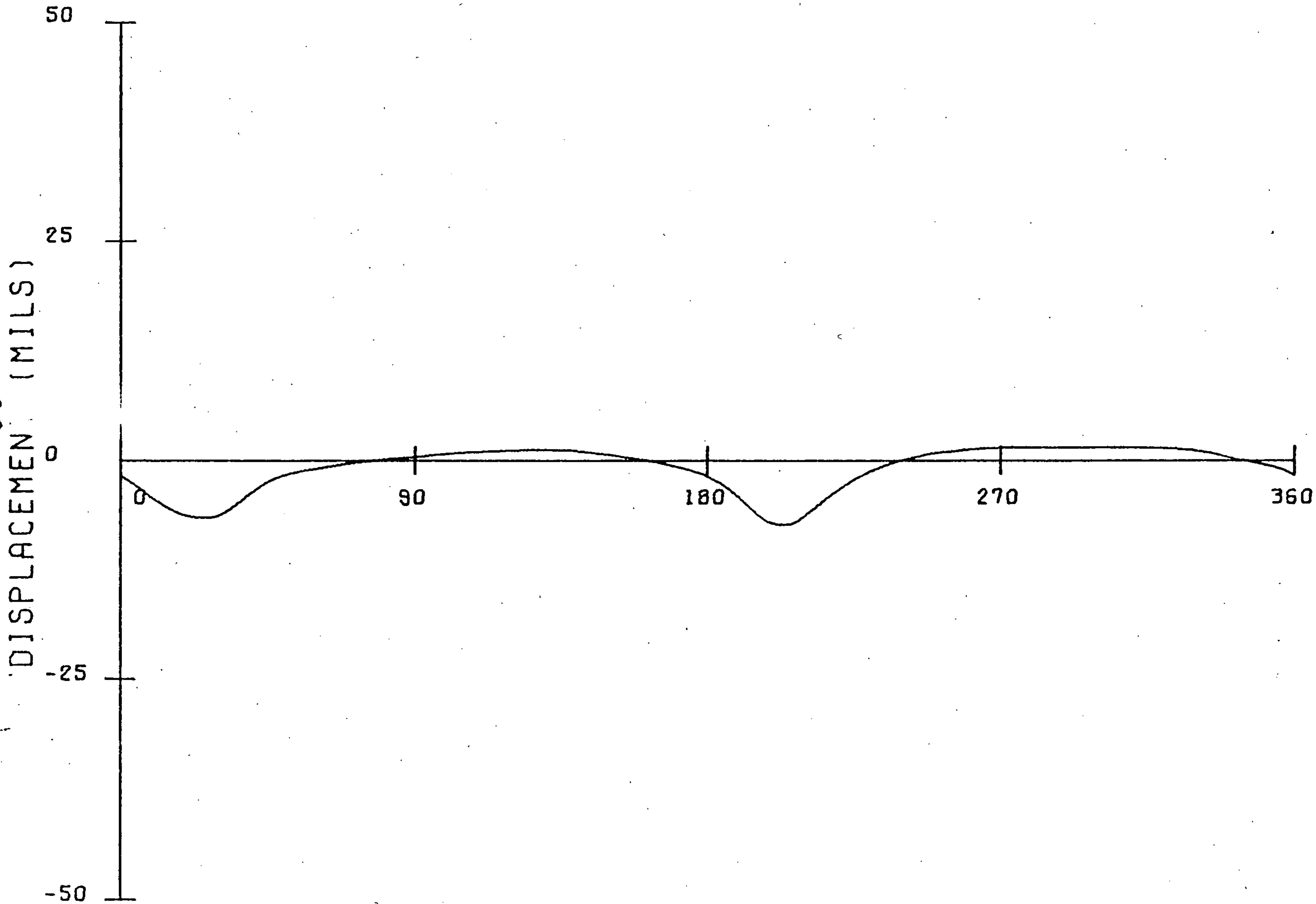
DIFFERENCE SHAPE

C-37


PLASTIC STRAIN TEST
TUBE #1
50 POINTS
50
25
0
-25
-50
DISPLACEMENT (MILS)
0
90
180
270
360
DIFFERENCE SHAPE
C-38

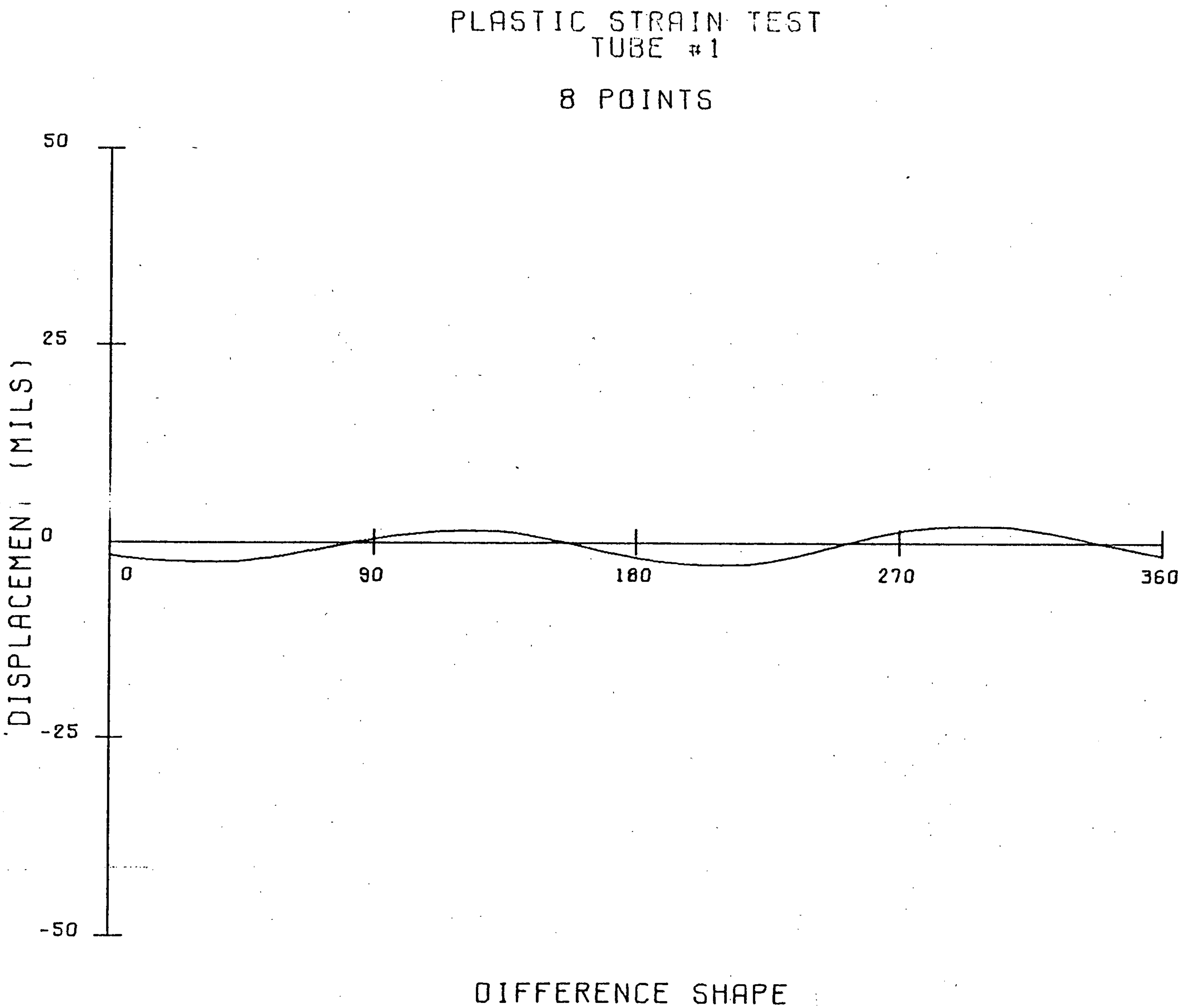
PLASTIC STRAIN TEST
TUBE #1

25 POINTS



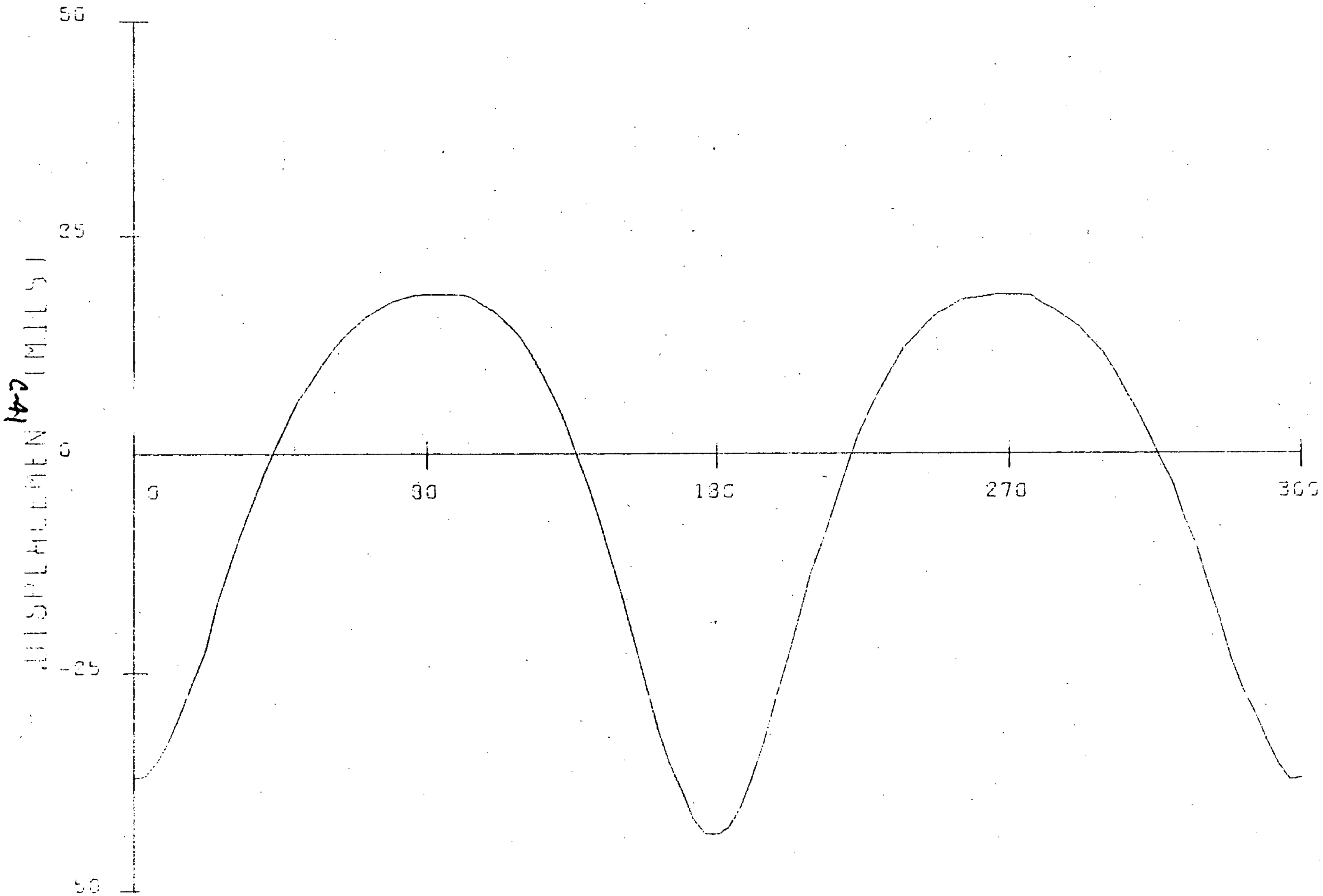
DIFFERENCE SHAPE

C-39


PLASTIC STRAIN TEST
TUBE #1
8 POINTS
50
25
0
-25
-50
DISPLACEMENT (MILS)
0
90
180
270
360
DIFFERENCE SHAPE

C-40

PLASTIC STRAIN TEST
TUBE #2

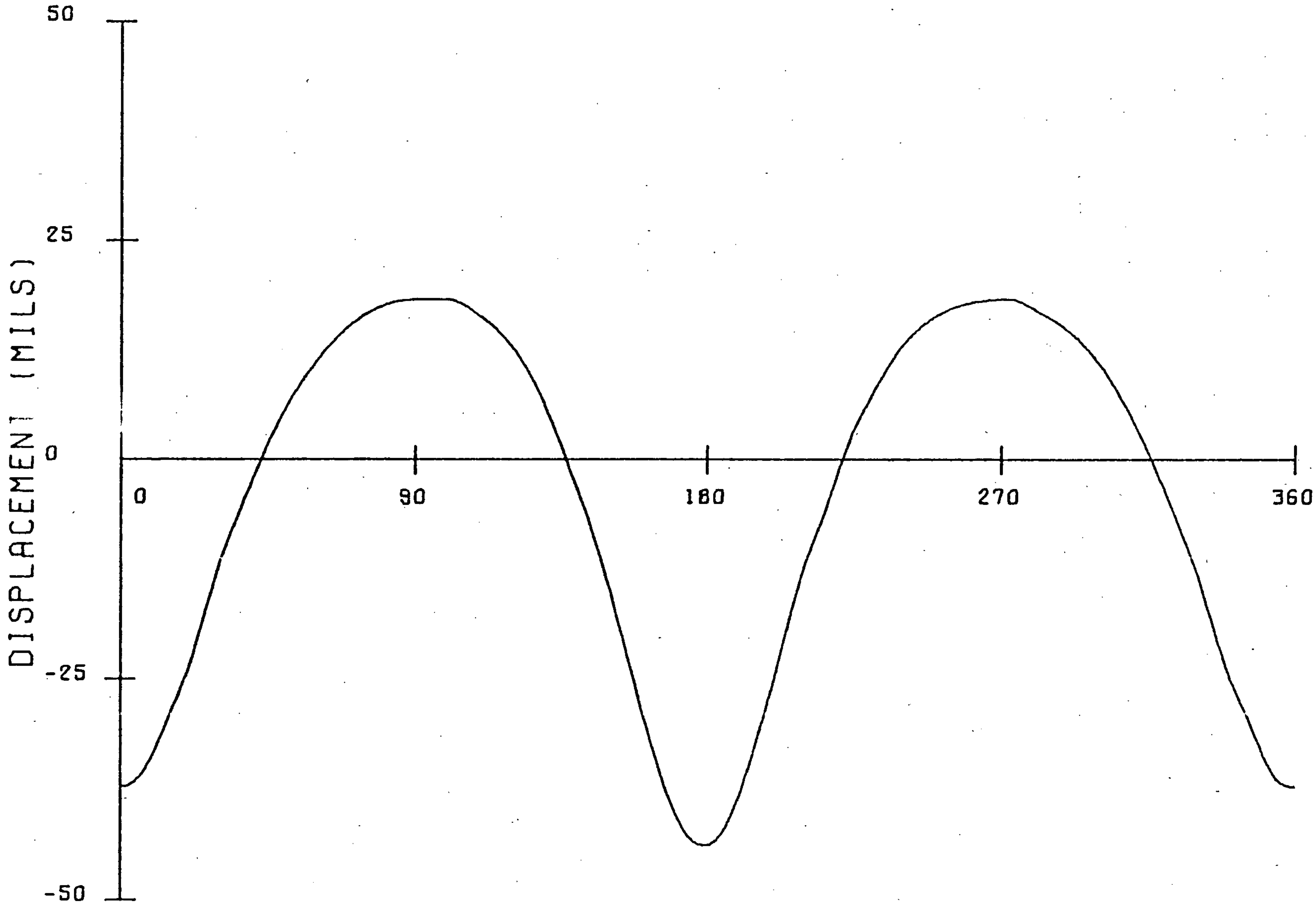


DIFFERENCE SHAPE

C-41

PLASTIC STRAIN TEST
TUBE #2

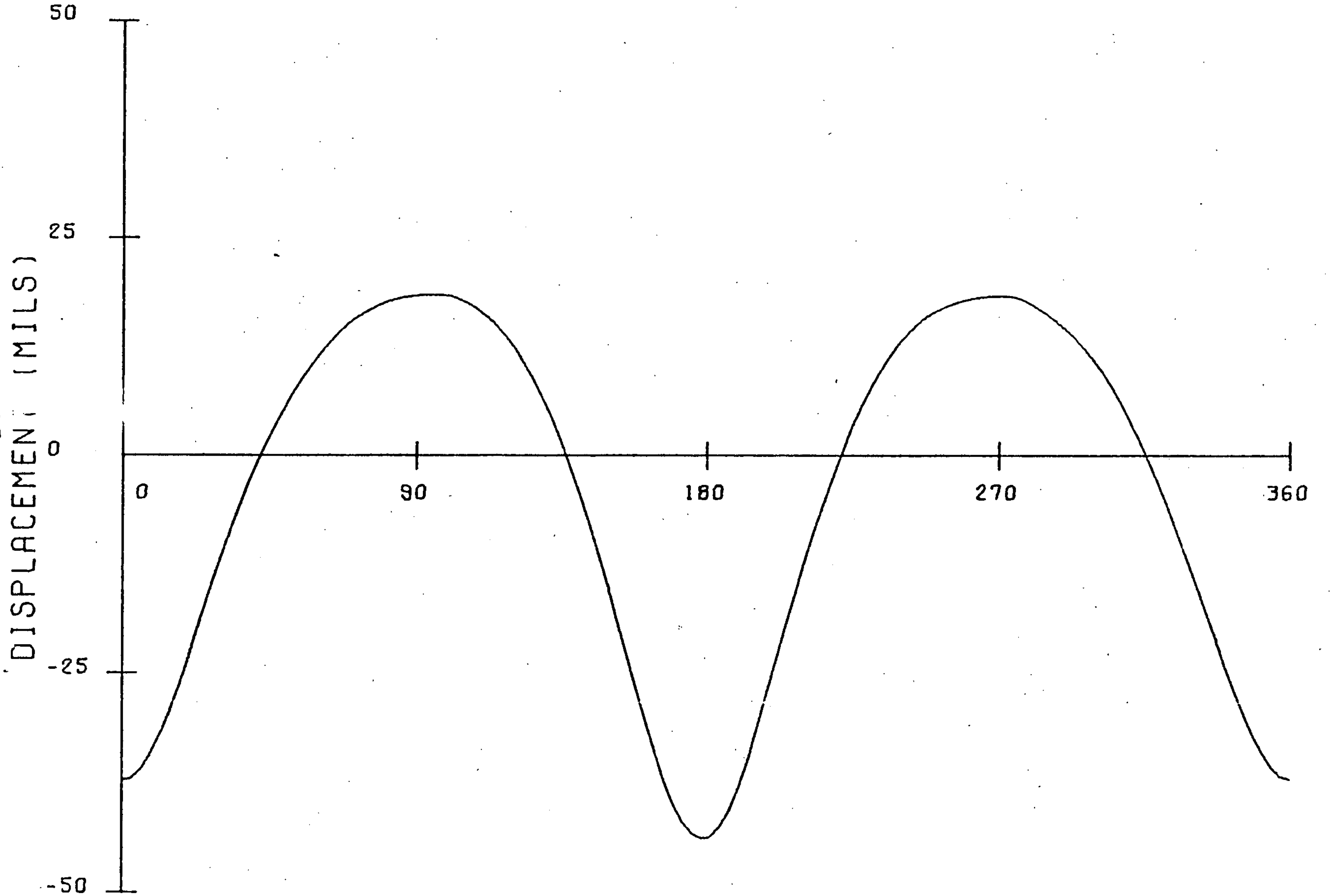
50 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #2

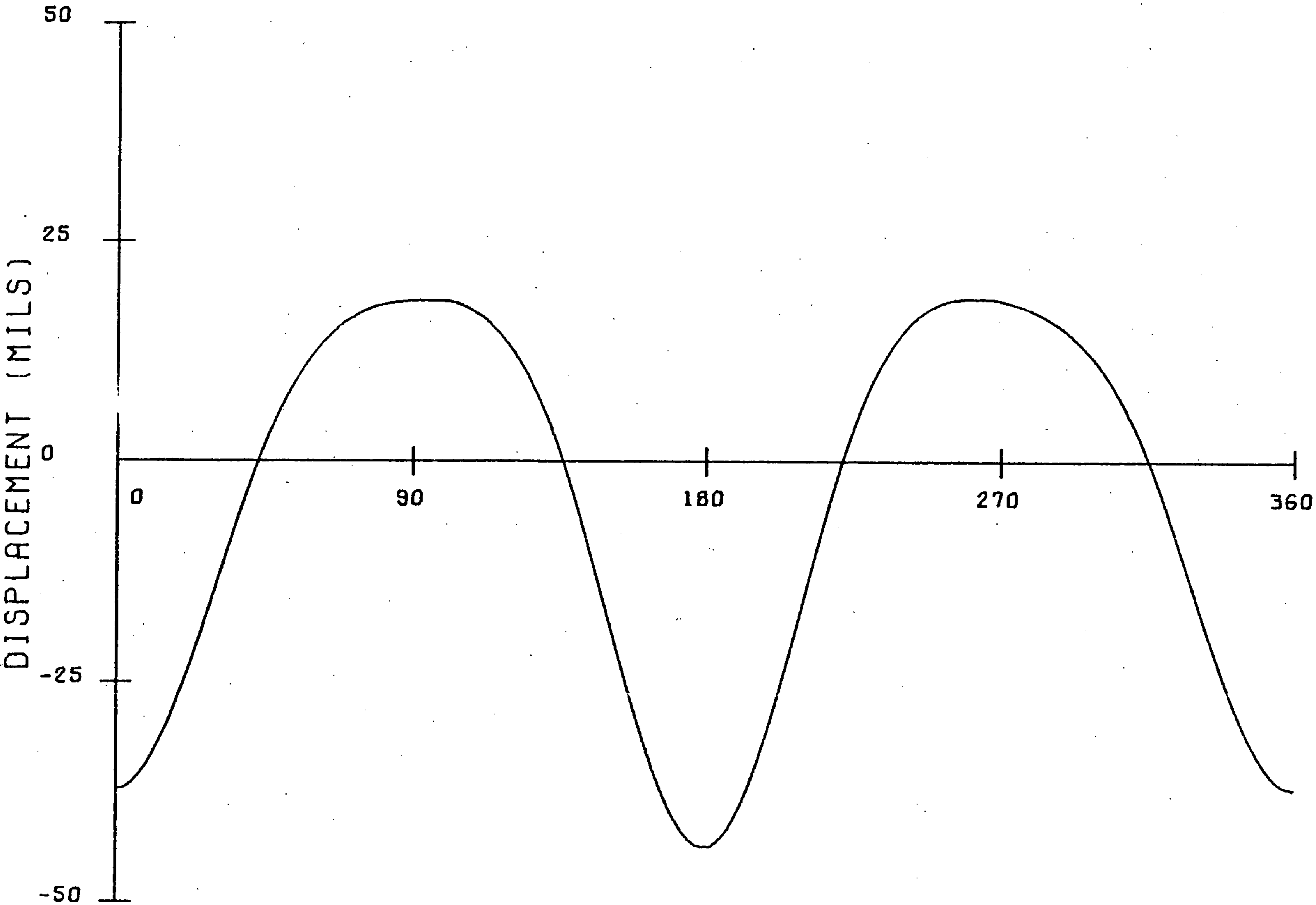
25 POINTS



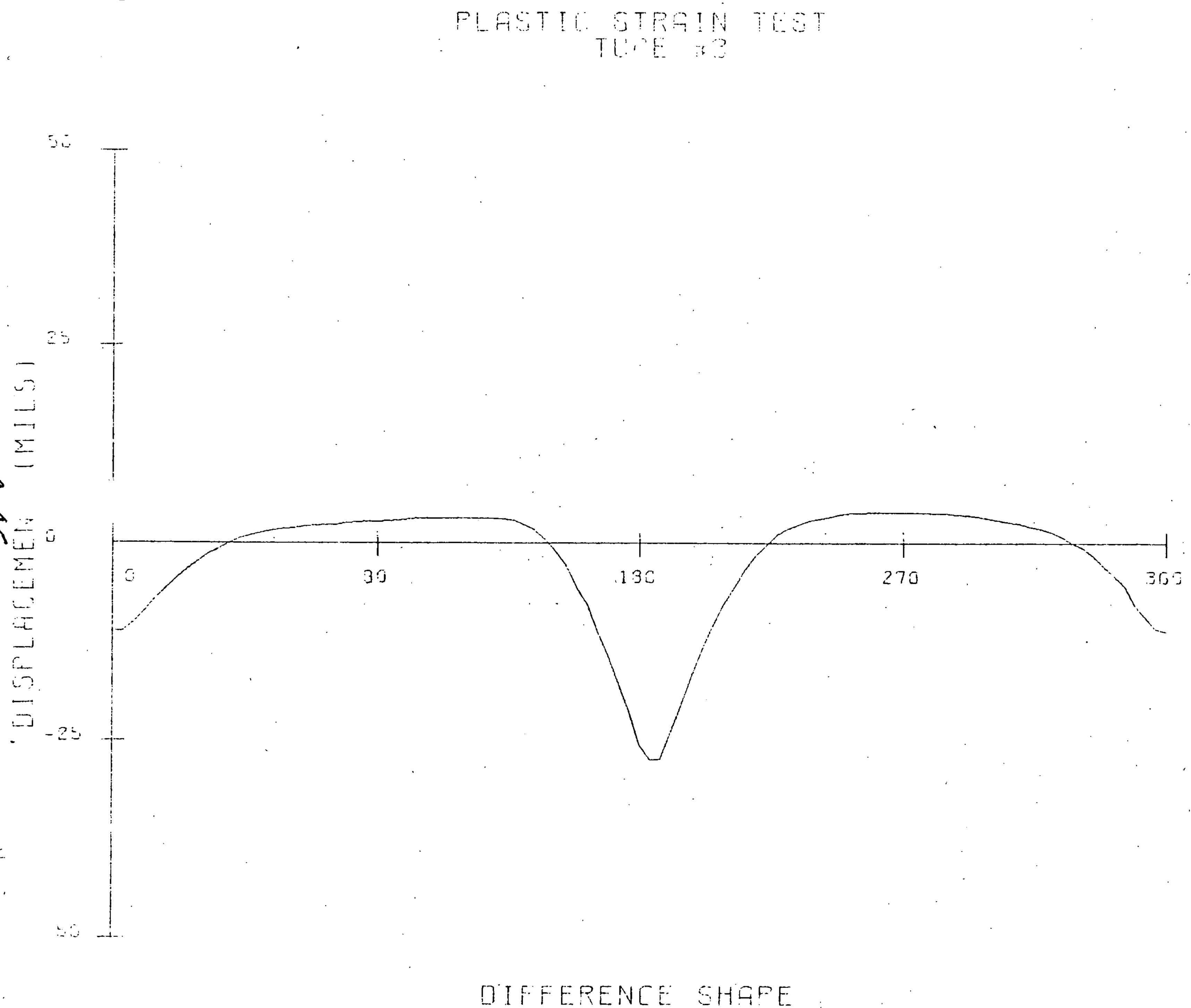
DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #2

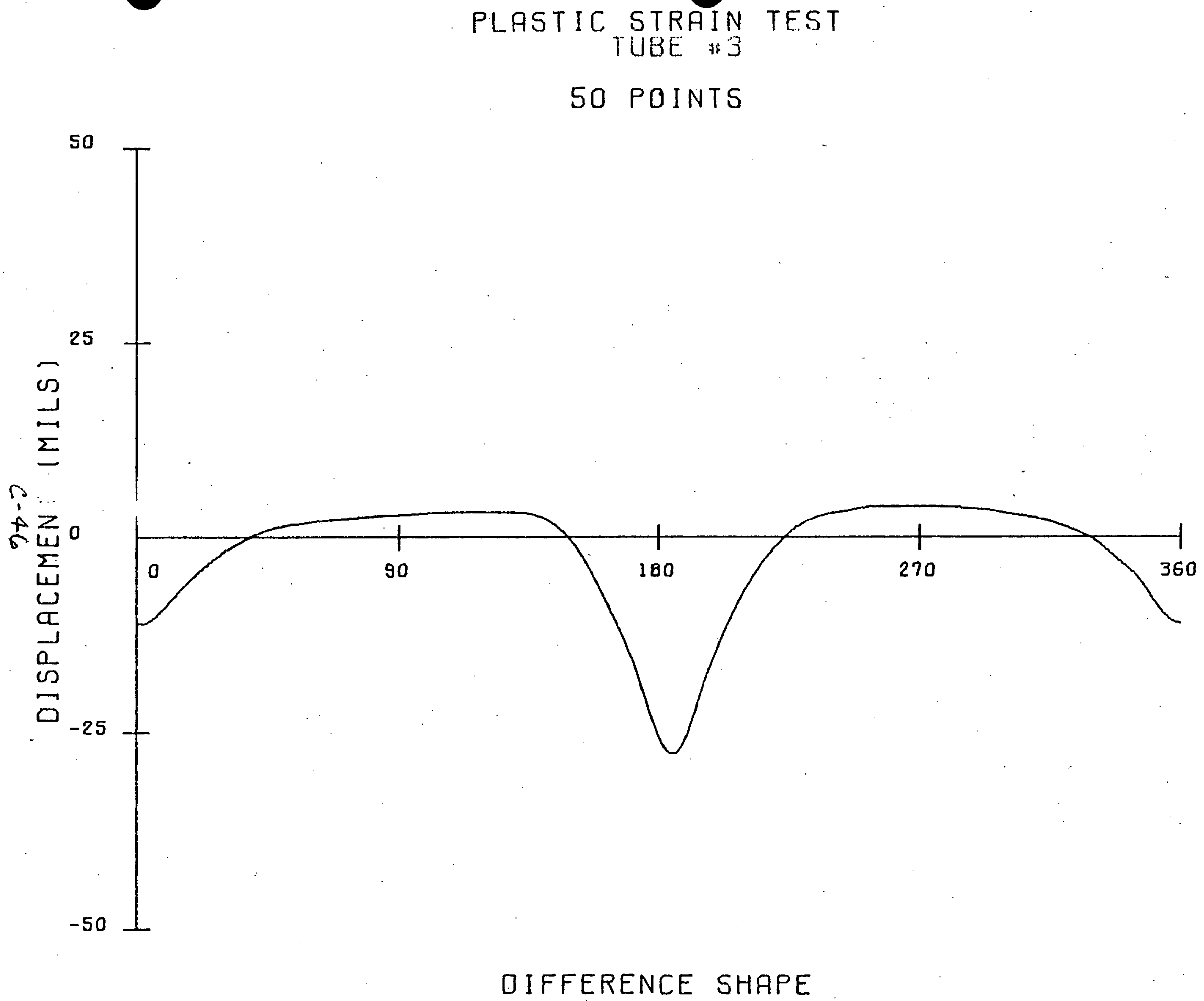
8 POINTS



DIFFERENCE SHAPE


PLASTIC STRAIN TEST
TUBE #3
50
25
0
-25
-50
DISPLACEMENT (MILS)
0
90
180
270
360
DIFFERENCE SHAPE

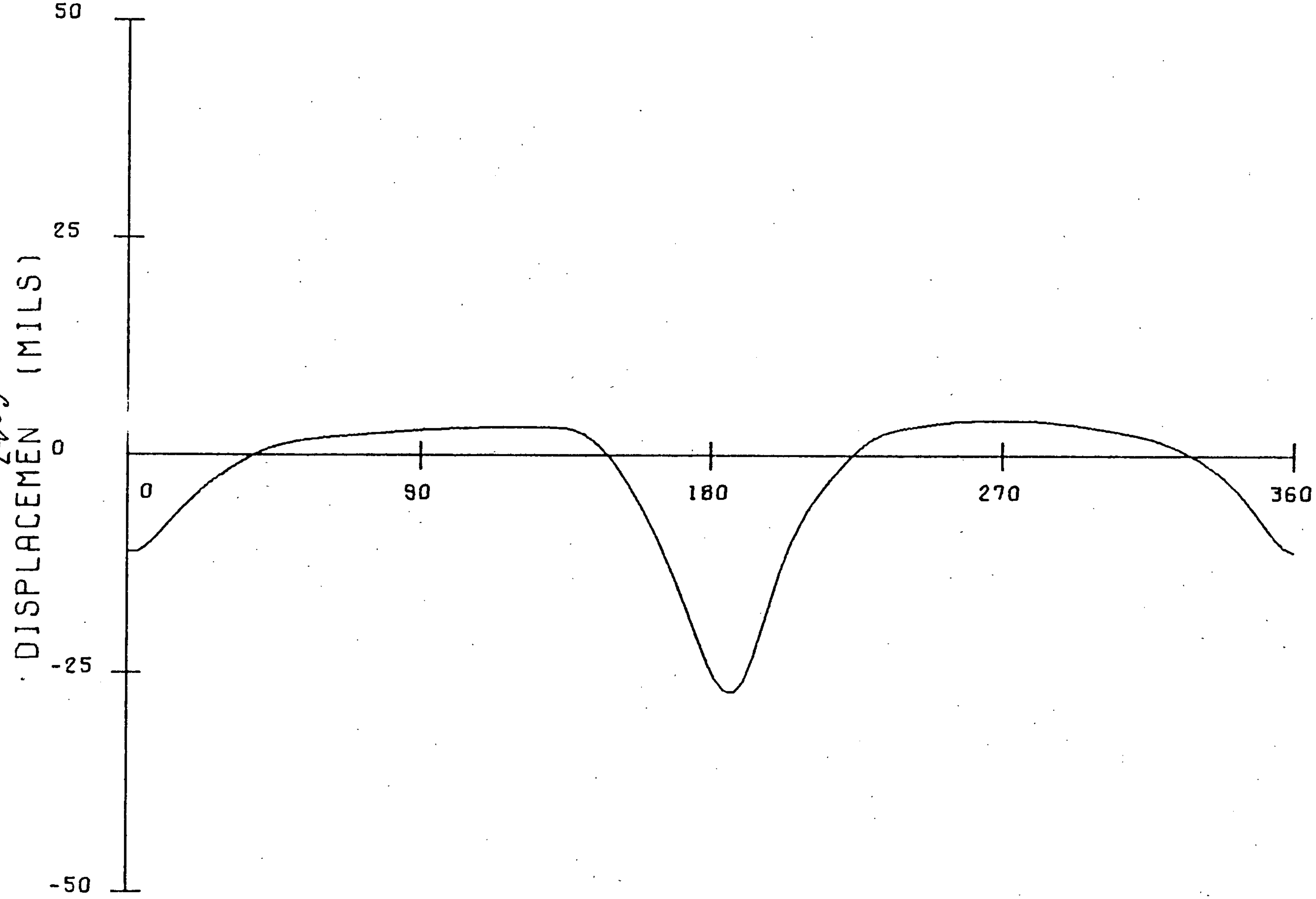
C-45



PLASTIC STRAIN TEST
TUBE #3
50 POINTS
50
25
0
-25
-50
DISPLACEMENT (MILS)
0
90
180
270
360
DIFFERENCE SHAPE
C-46

PLASTIC STRAIN TEST
TUBE #3

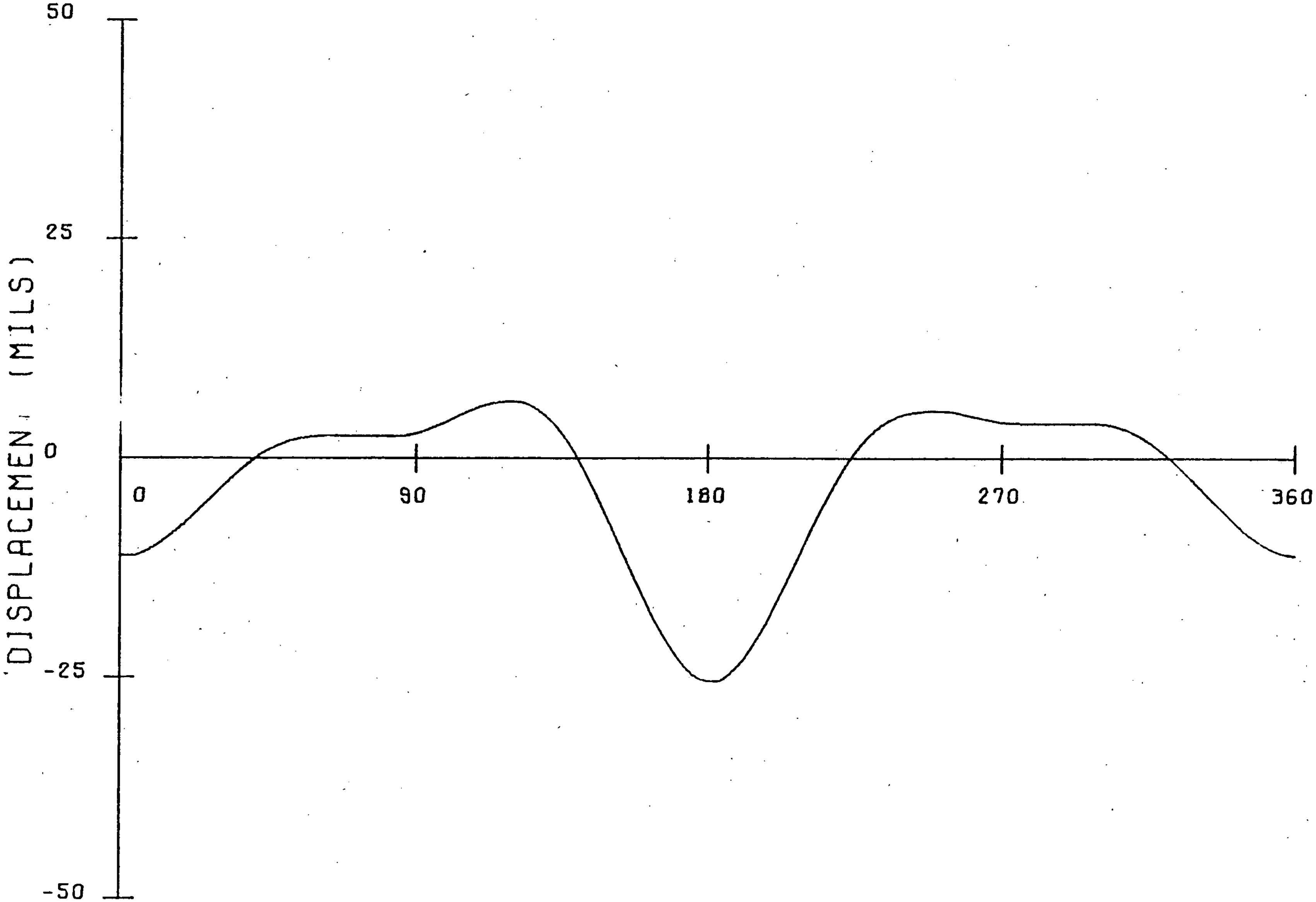
25 POINTS



DIFFERENCE SHAPE

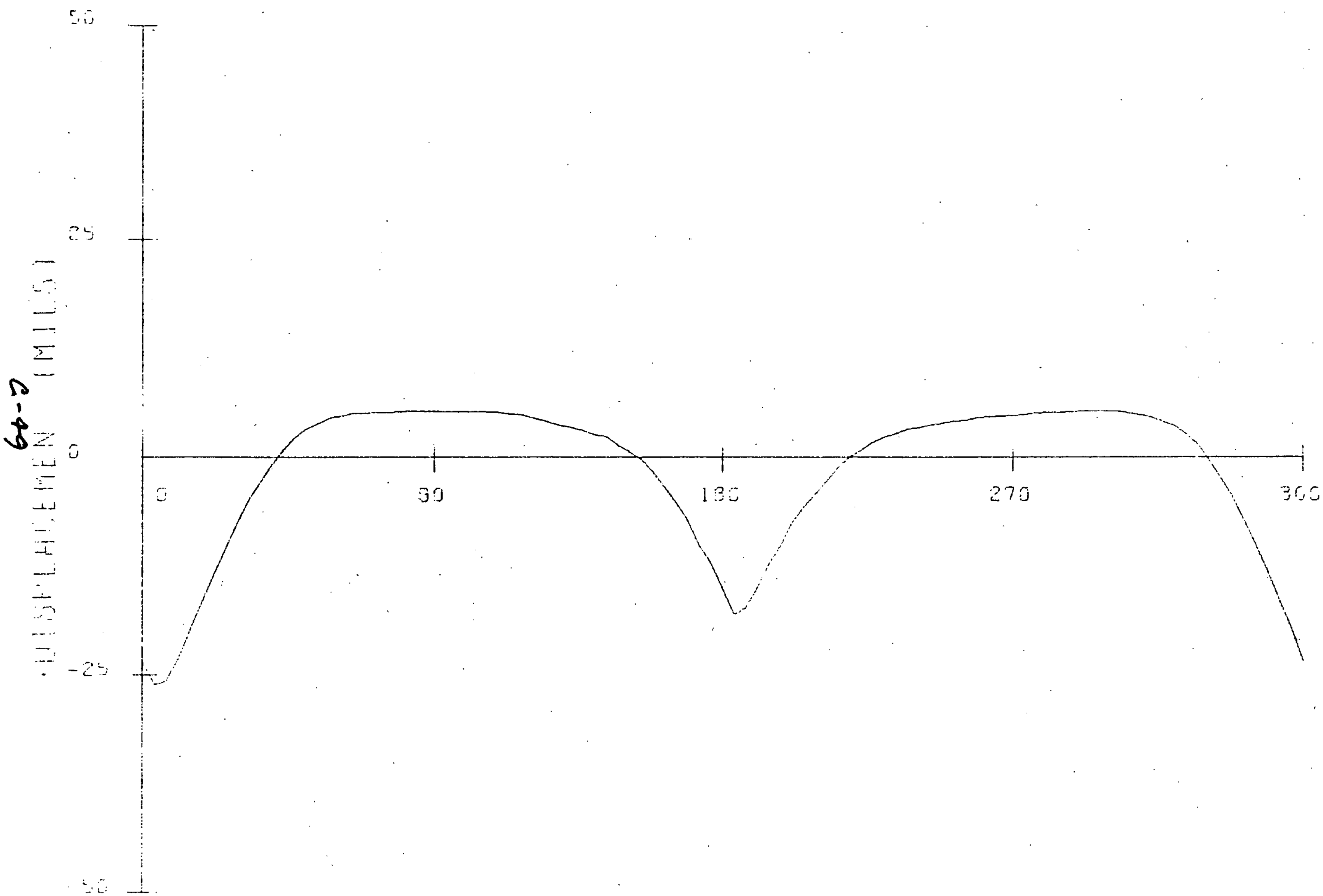
PLASTIC STRAIN TEST
TUBE #3

8 POINTS



DIFFERENCE SHAPE

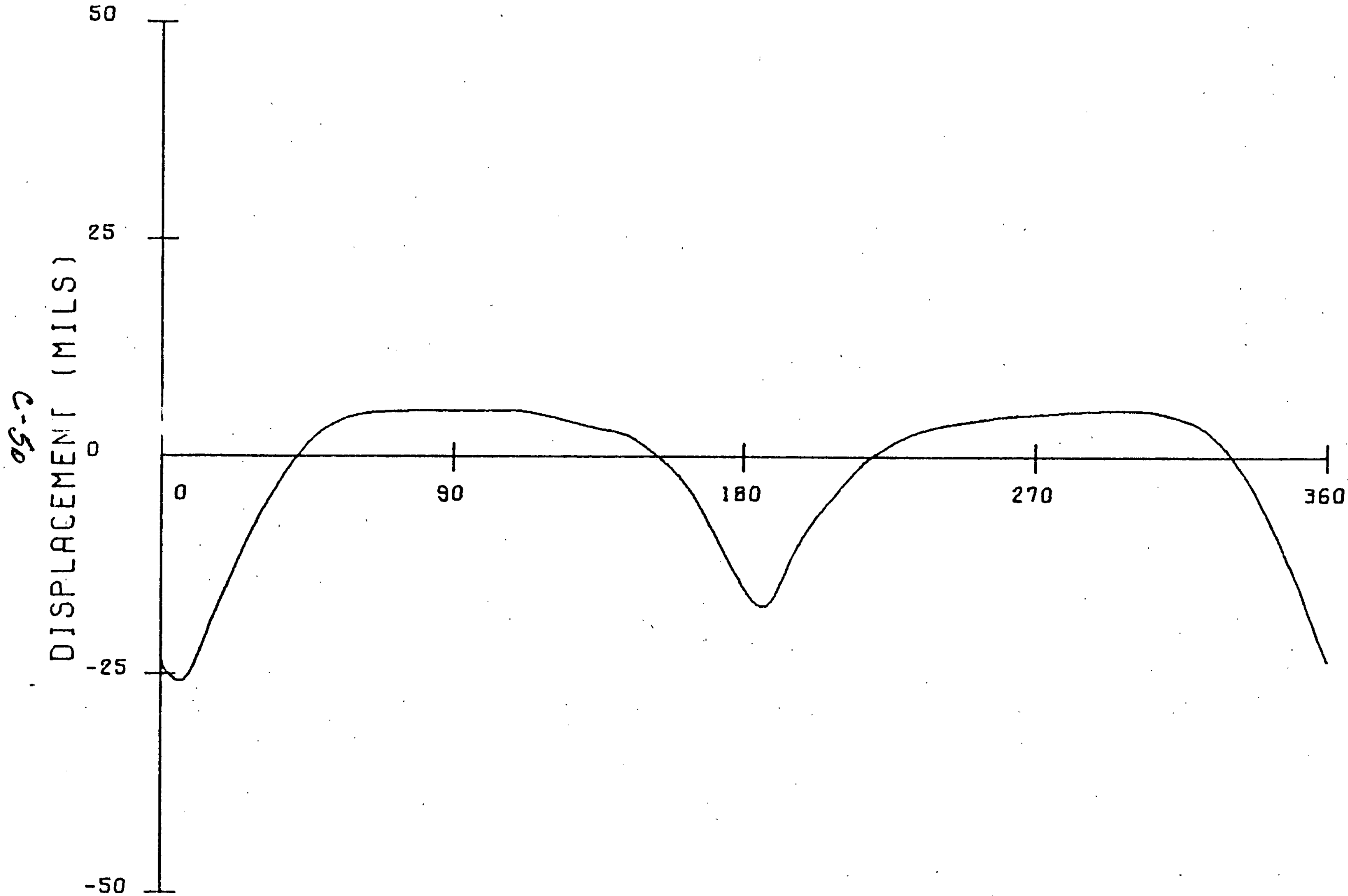
PLASTIC STRAIN TEST
- TUBE #1



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #4

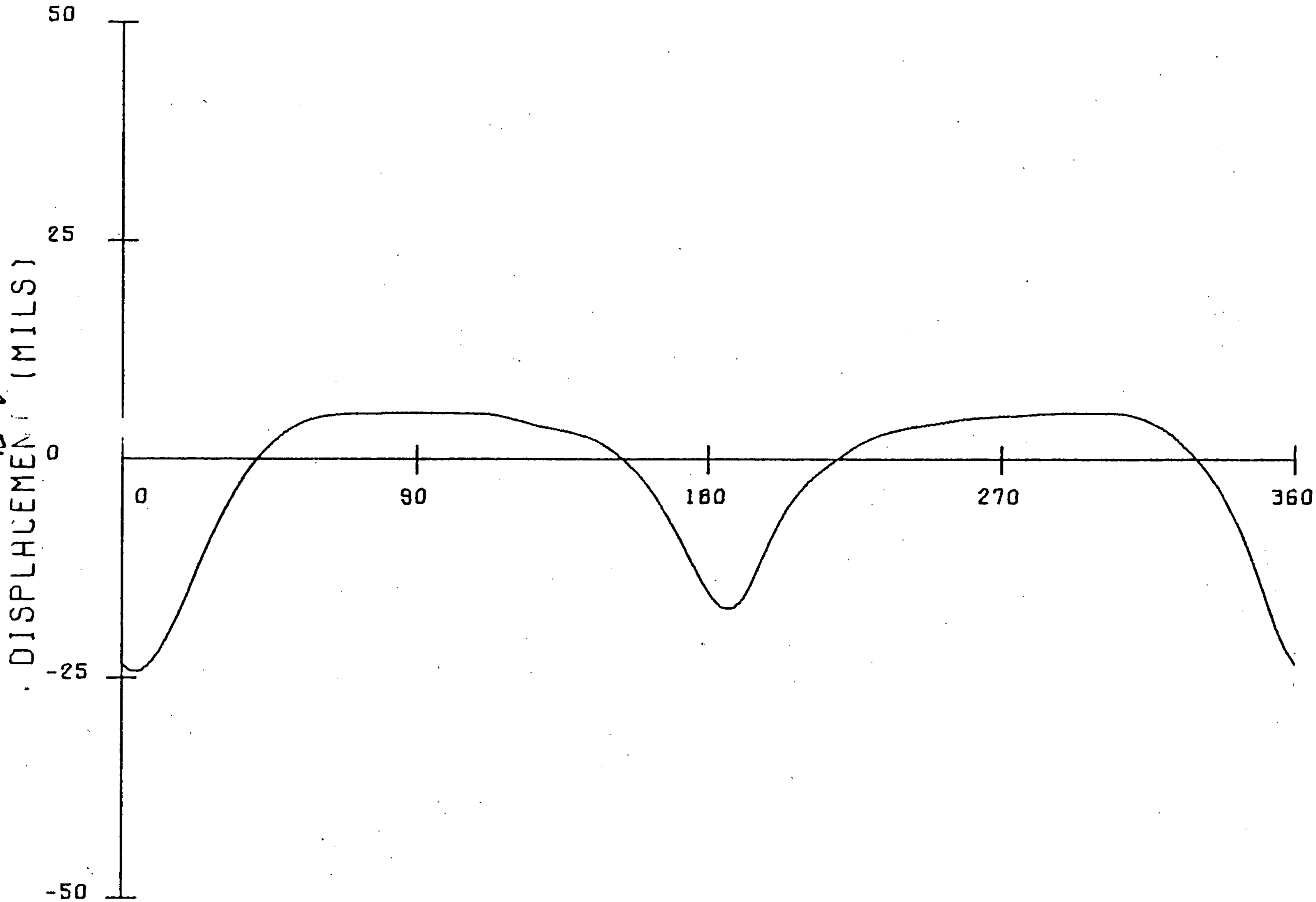
50 POINTS



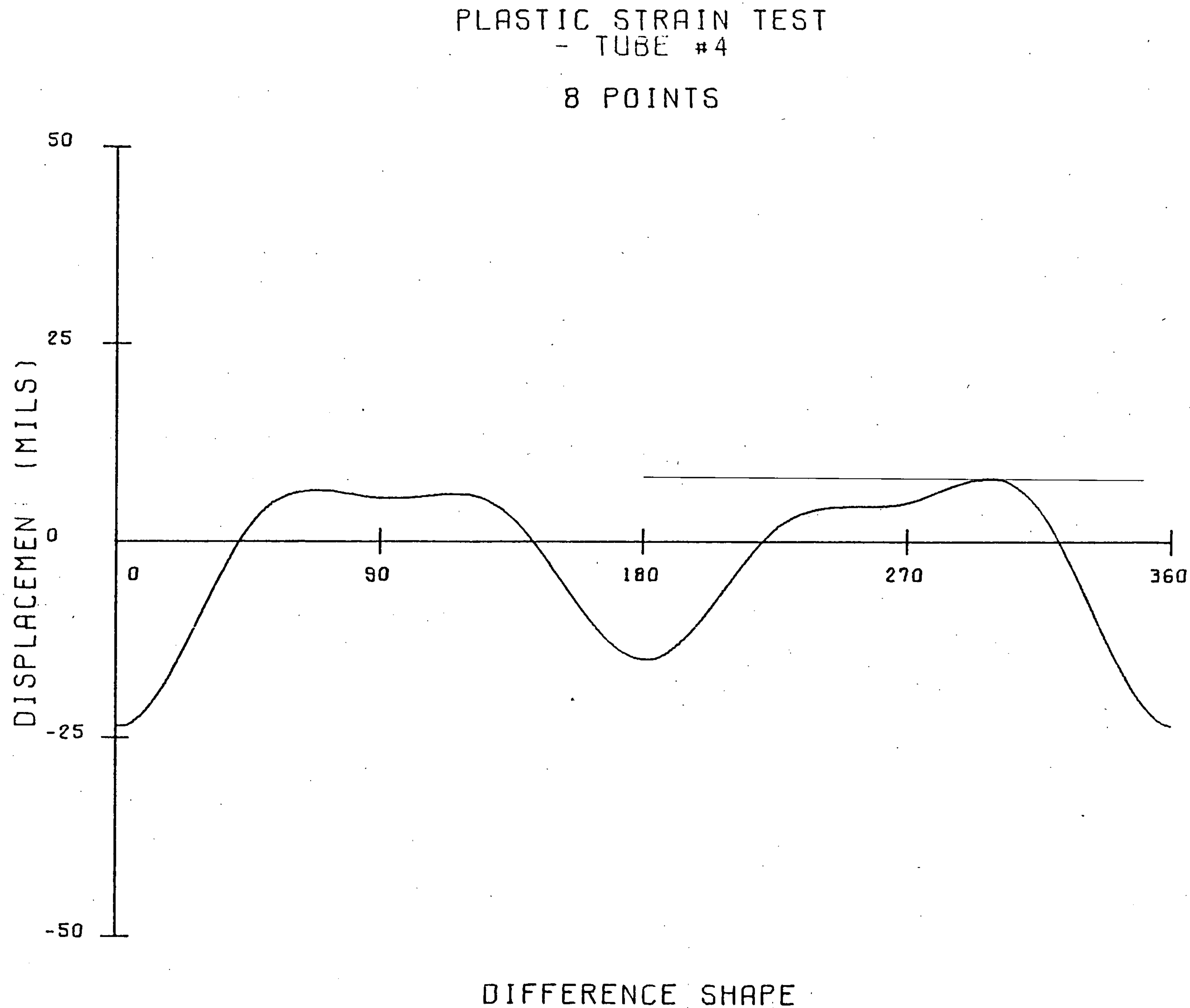
DIFFERENCE SHAPE

PLASTIC STRAIN TEST
- TUBE #4

25 POINTS

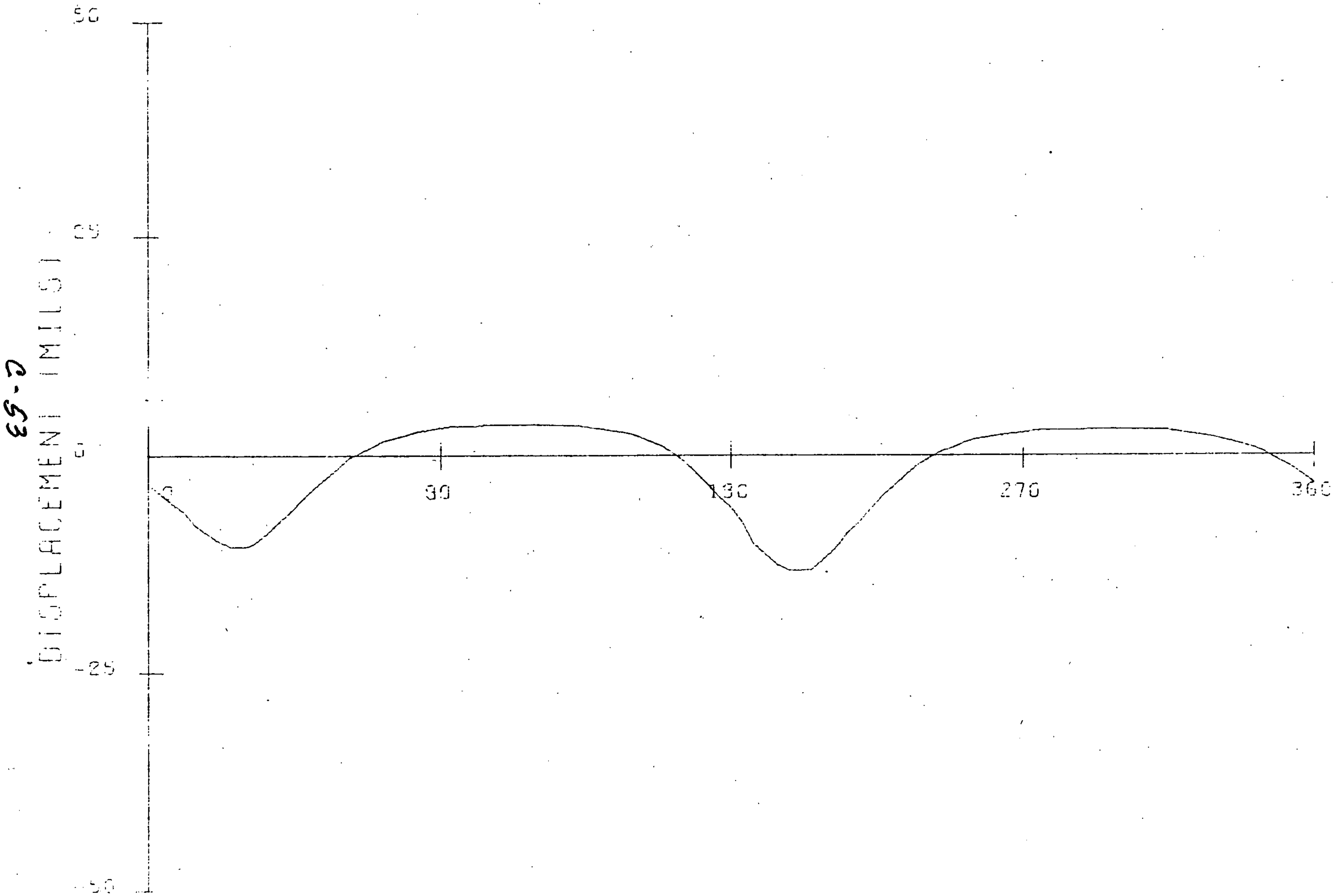


DIFFERENCE SHAPE

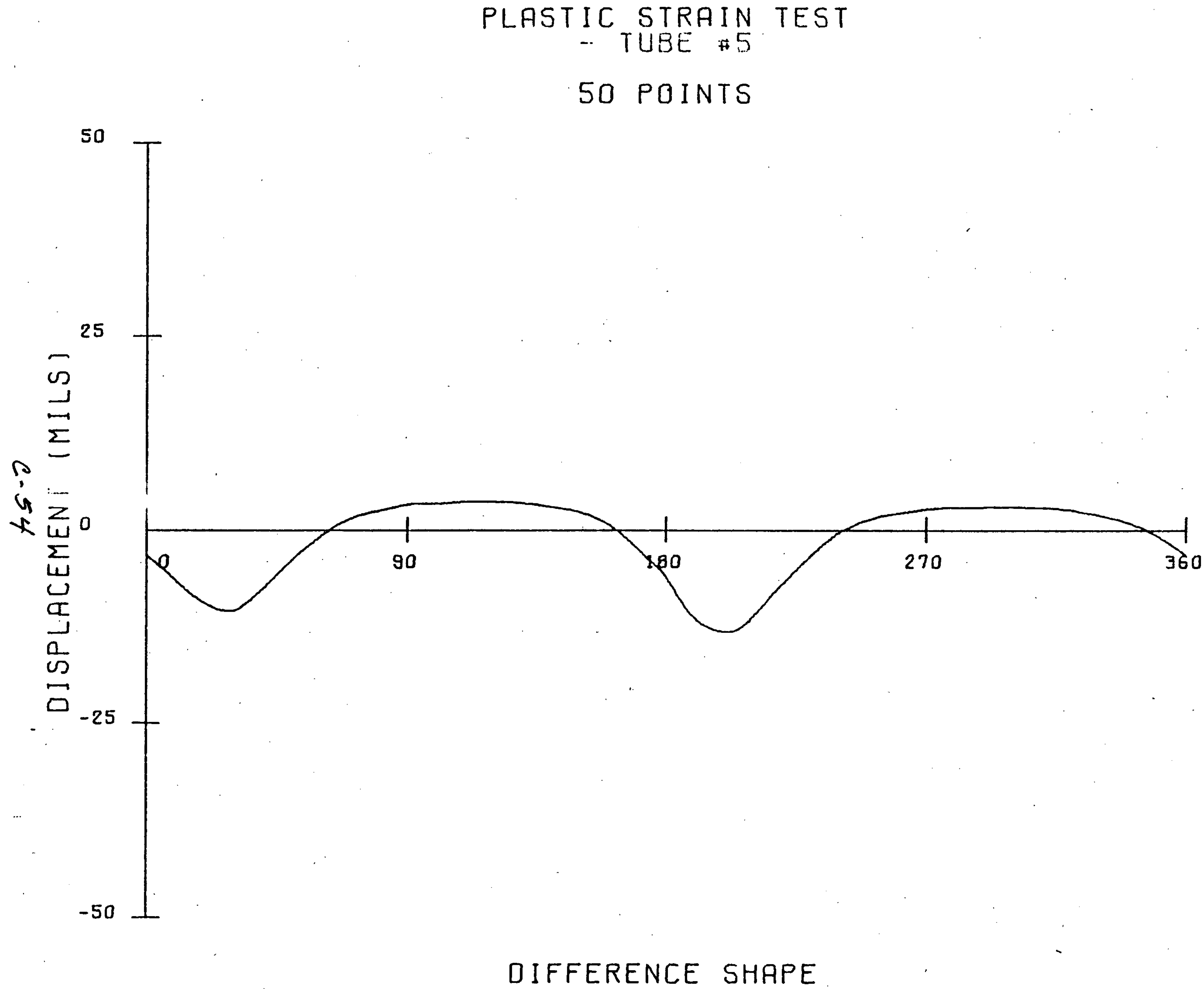

PLASTIC STRAIN TEST
- TUBE #4
8 POINTS
50
25
0
-25
-50
DISPLACEMEN (MILS)
0
90
180
270
360
DIFFERENCE SHAPE

C-52

PLASTIC STRAIN TEST
TUBE #5

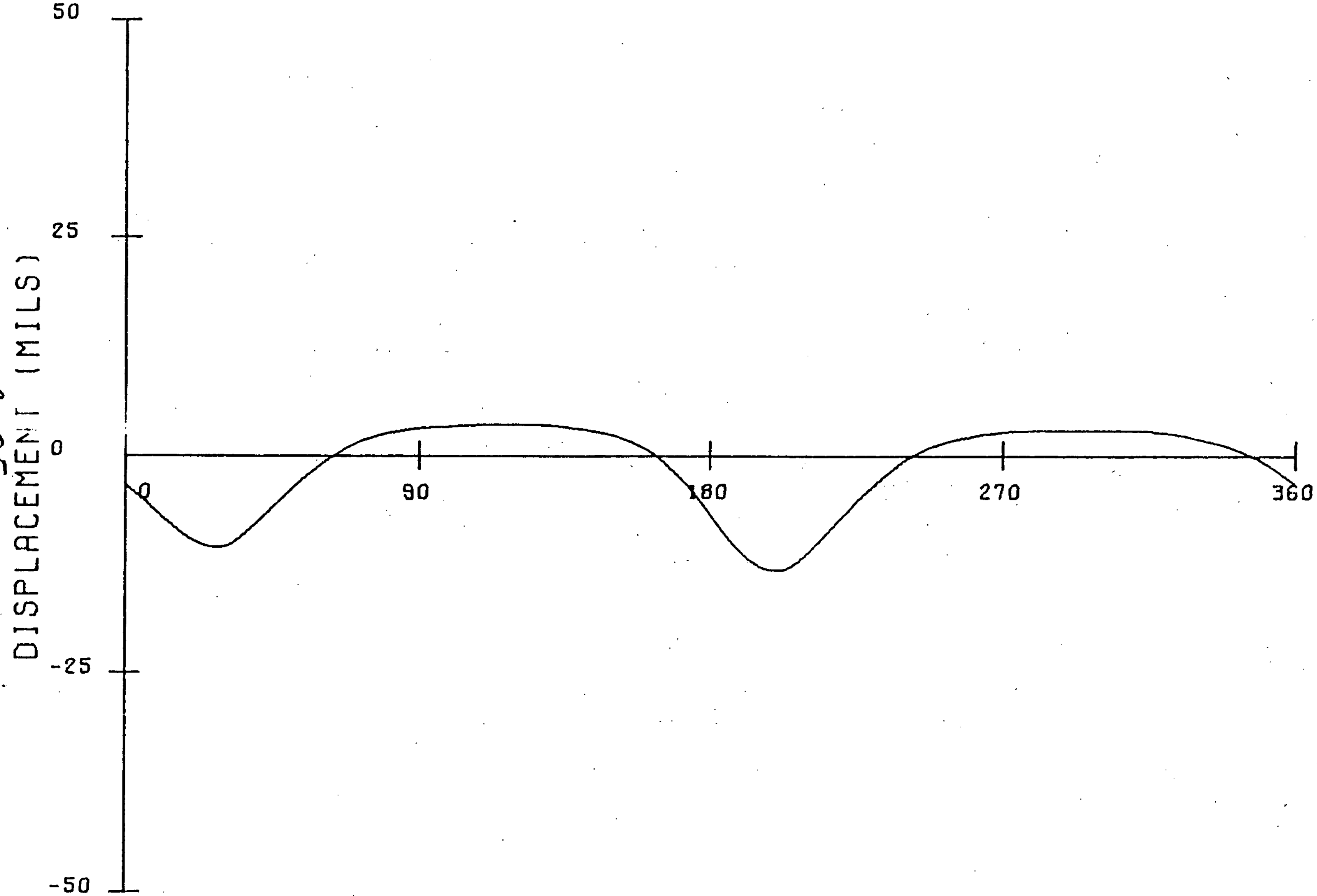


DIFFERENCE SHAPE


PLASTIC STRAIN TEST
- TUBE #5
50 POINTS
50
25
0
-25
-50
DISPLACEMENT (MILS)
0
90
180
270
360
DIFFERENCE SHAPE
C-54

PLASTIC STRAIN TEST
- TUBE #5

25 POINTS

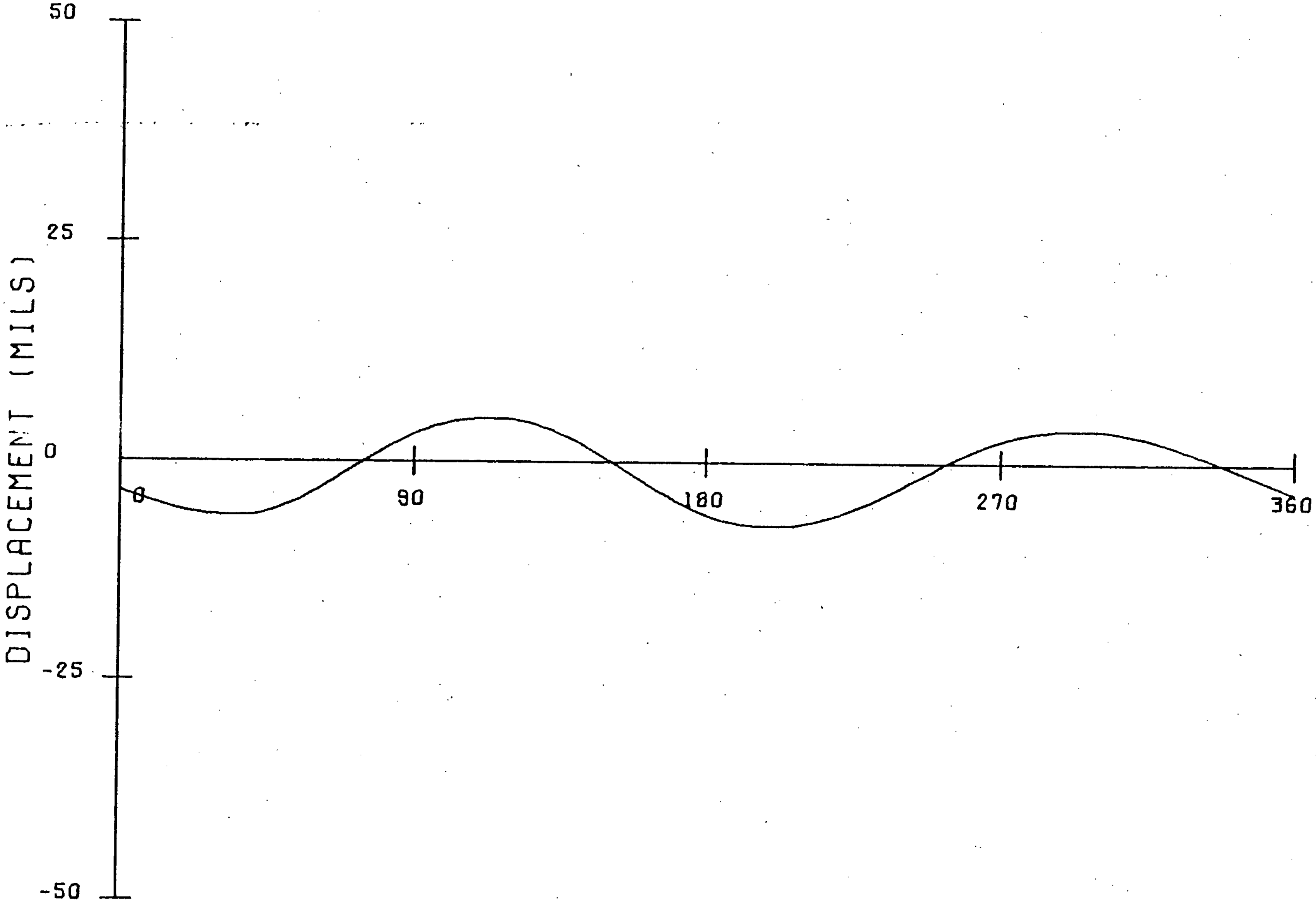


DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #5

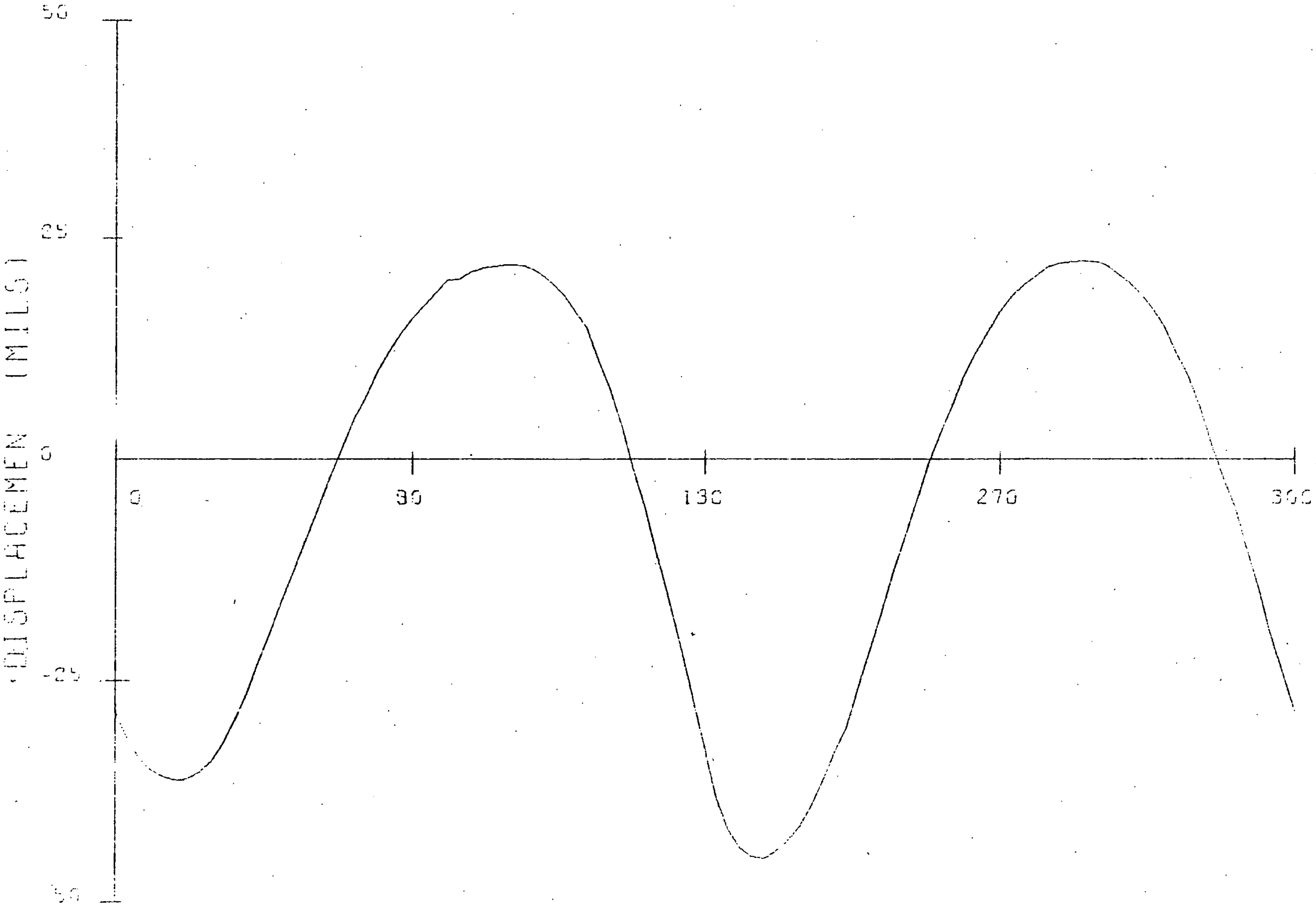
8 POINTS

C-56



DIFFERENCE SHAPE

PLASTIC STRAIN TEST



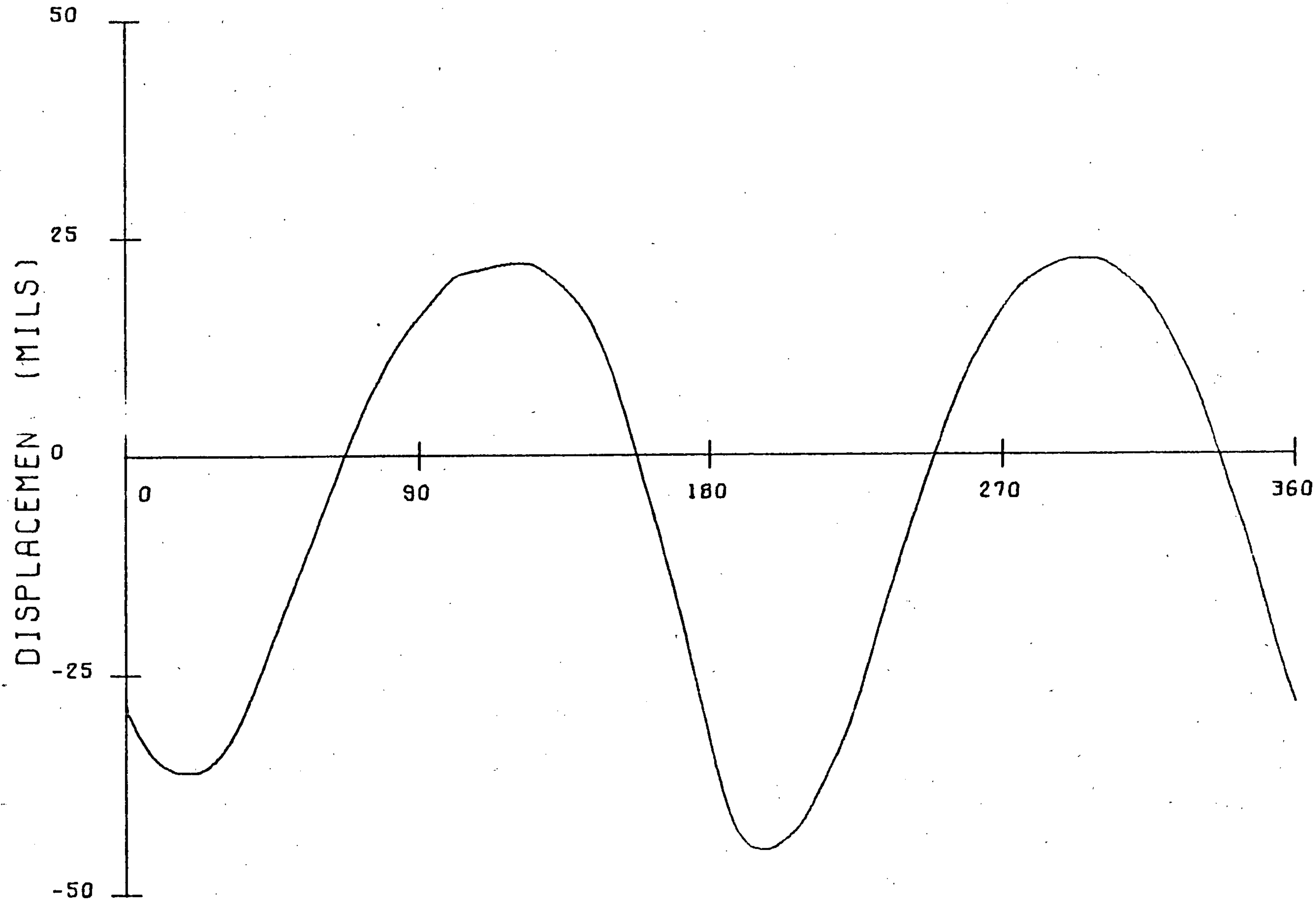
DIFFERENCE SHAPE

C-57

PLASTIC STRAIN TEST

TUBE #S

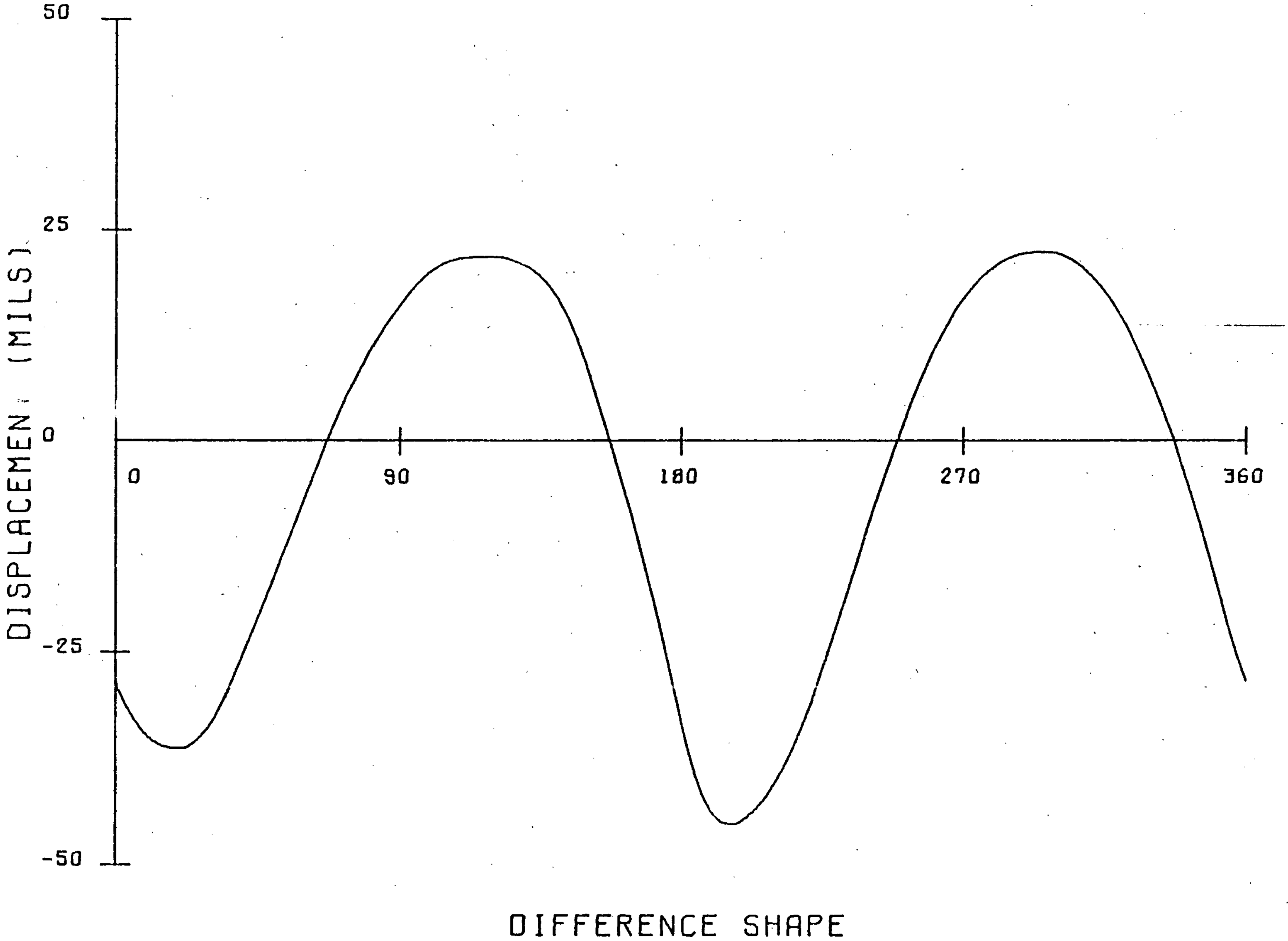
50 POINTS



DIFFERENCE SHAPE

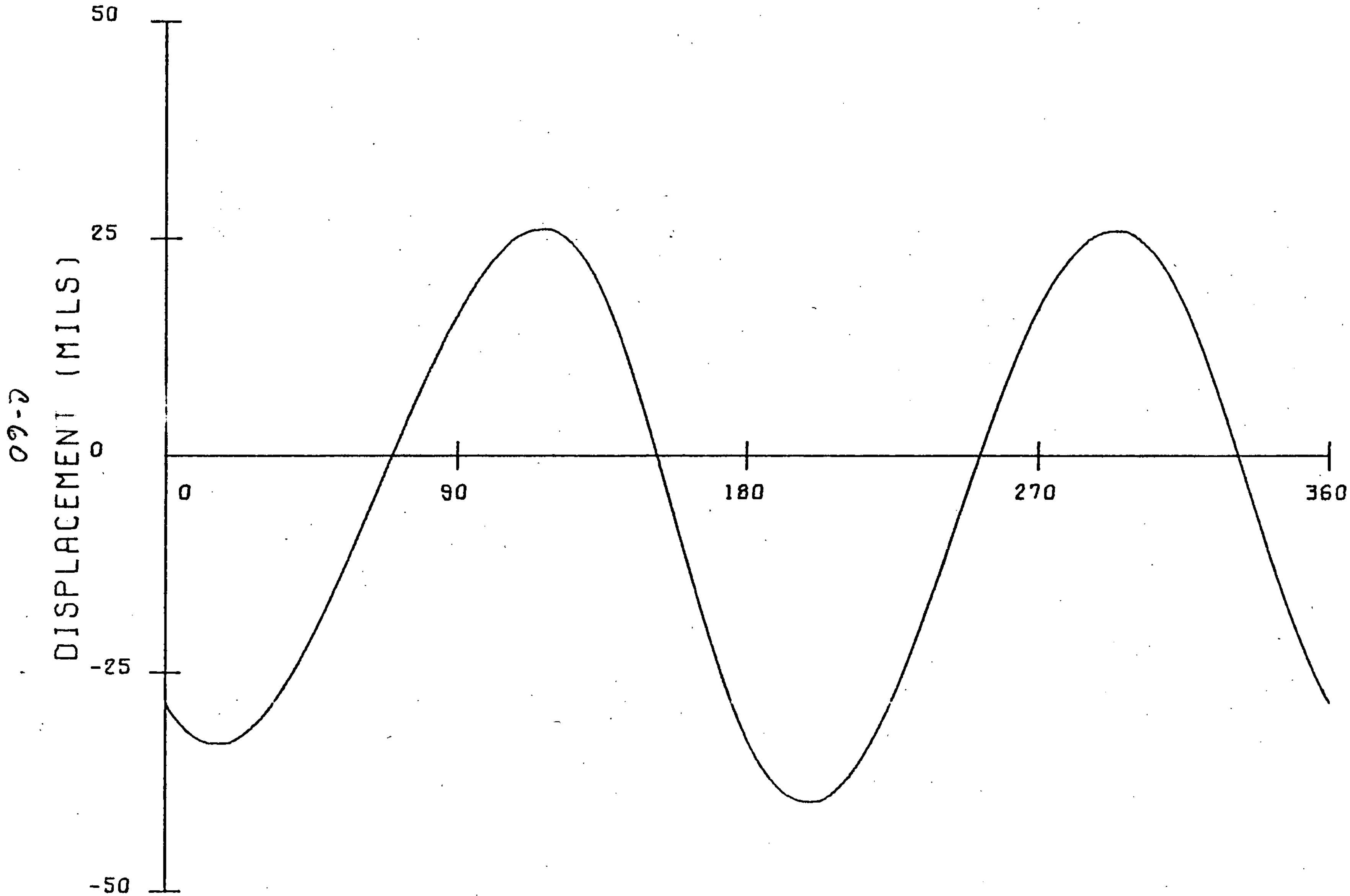
PLASTIC STRAIN TEST
TUBE #6

25 POINTS



PLASTIC STRAIN TEST
TUBE #6

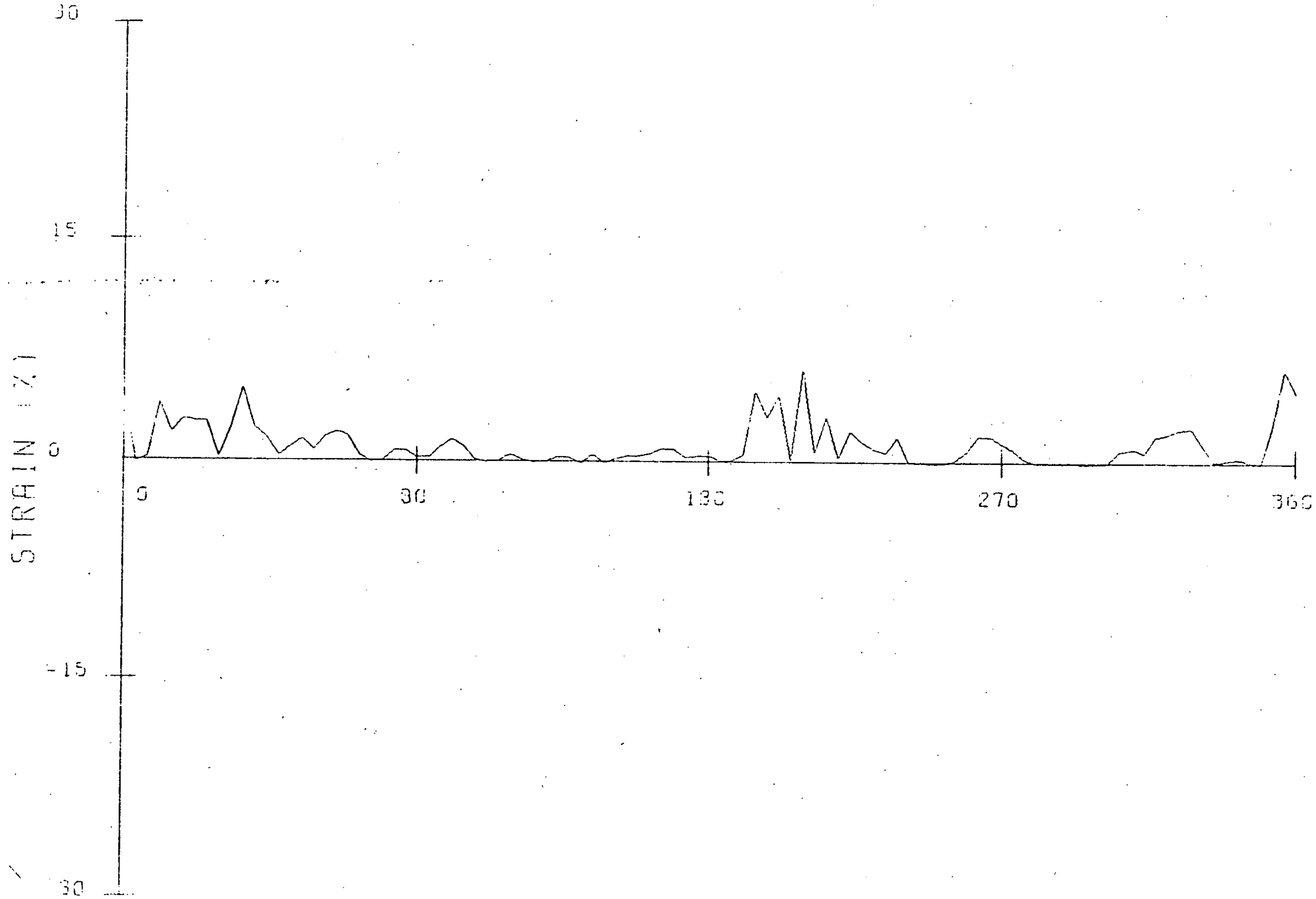
8 POINTS



DIFFERENCE SHAPE

PLASTIC STRAIN TEST
TUBE #[illegible]

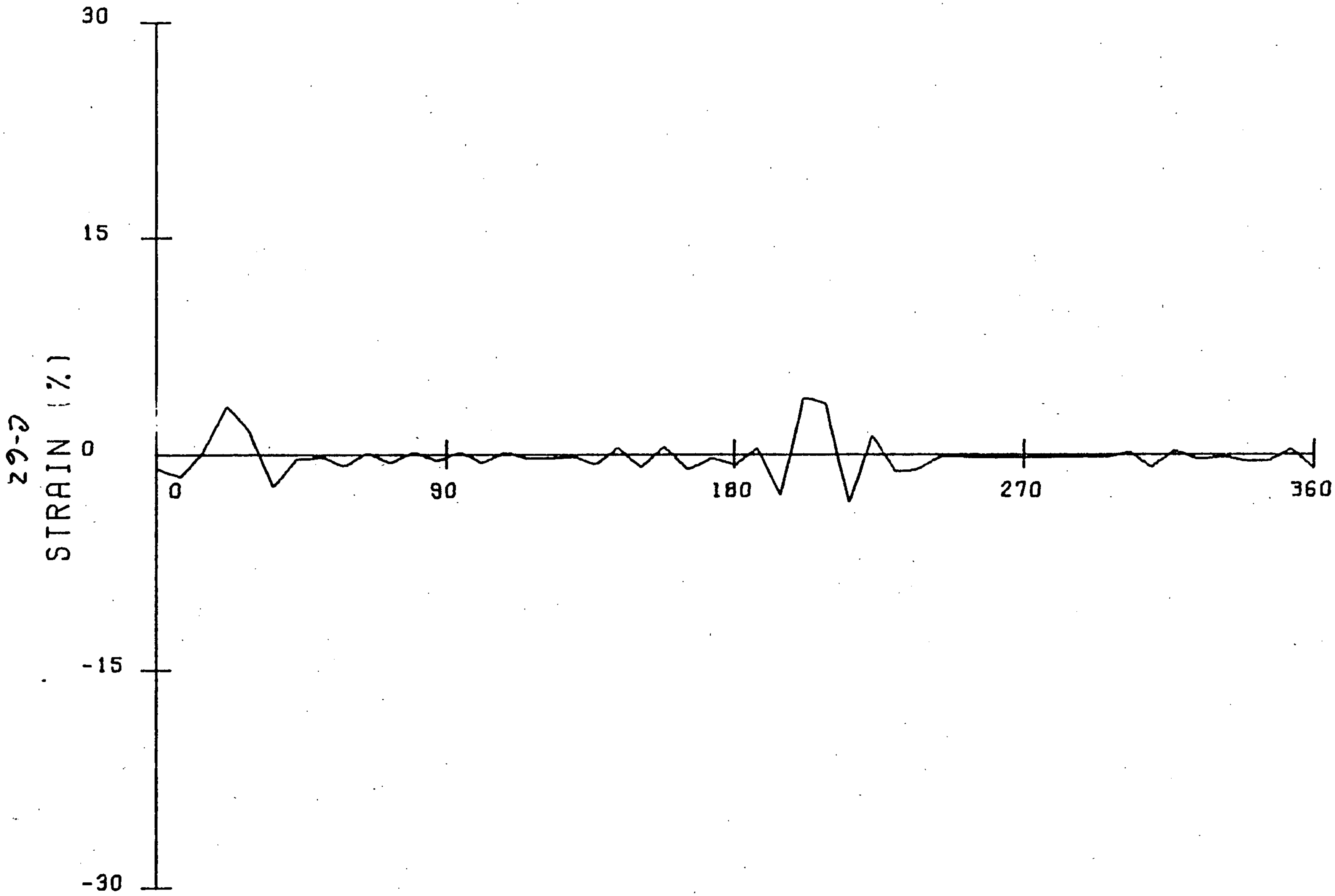
C-21



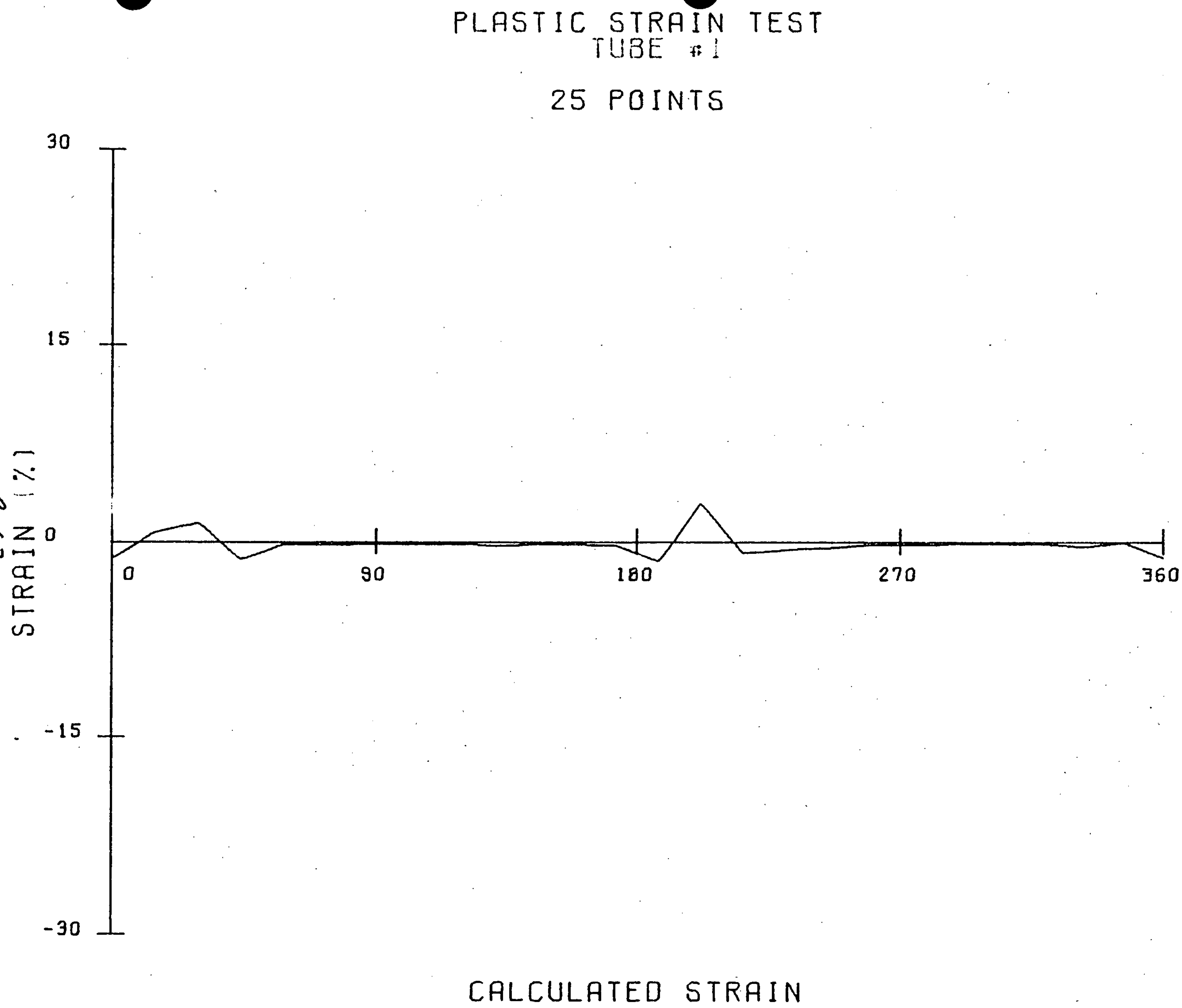
CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #1

50 POINTS

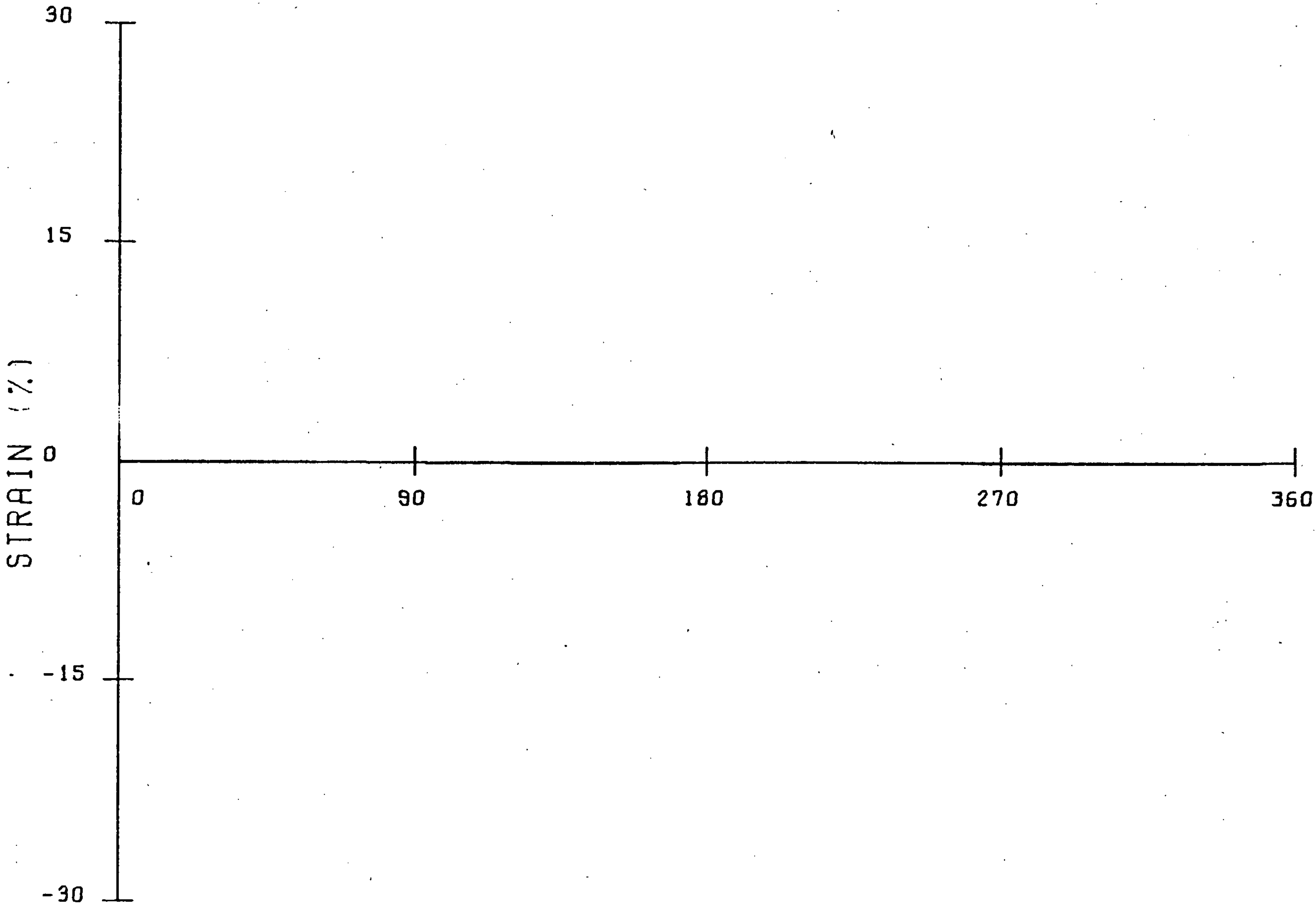


CALCULATED STRAIN


PLASTIC STRAIN TEST
TUBE #1
25 POINTS
30
15
0
-15
-30
STRAIN (%)
C-63
0
90
180
270
360
CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #1

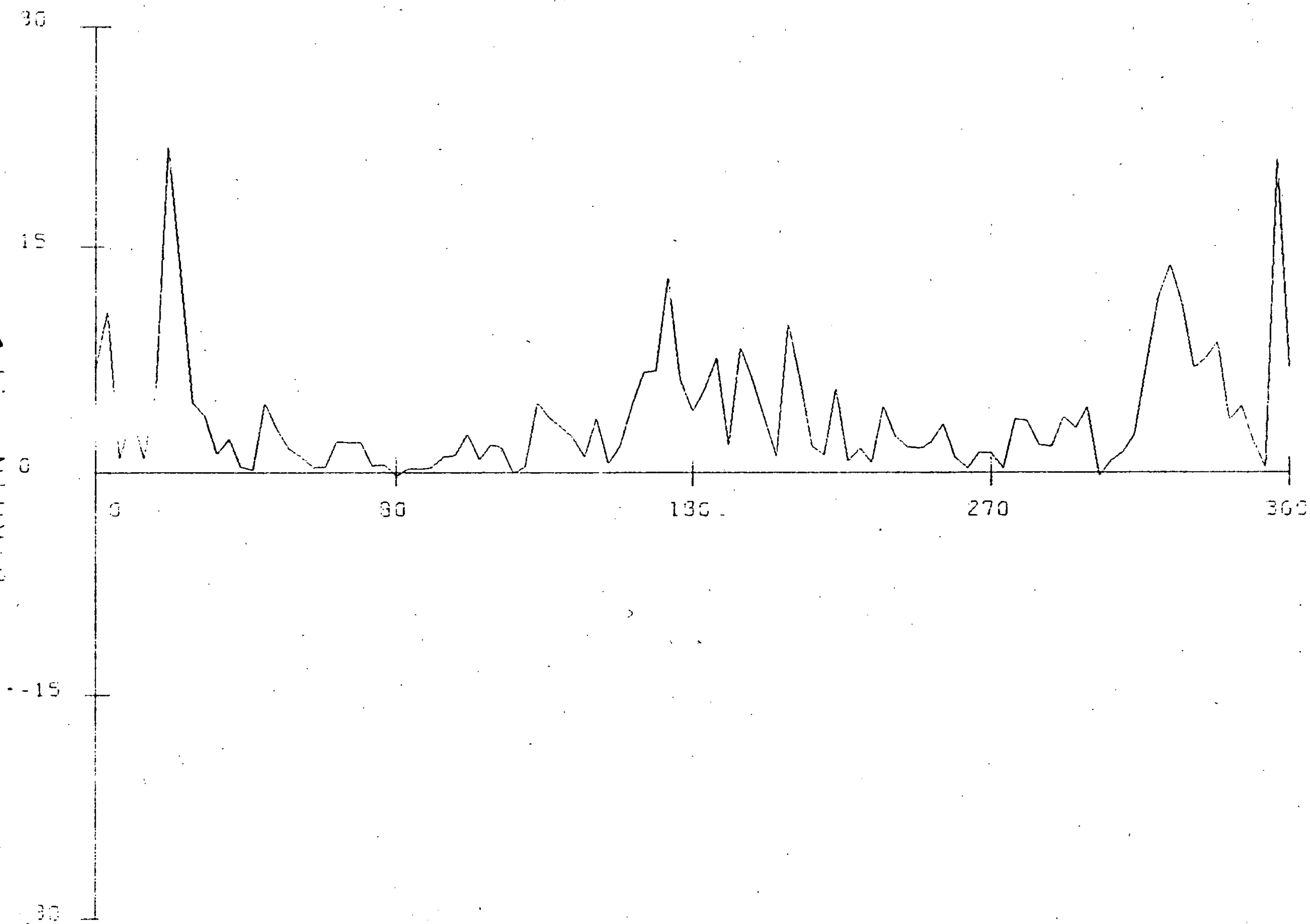
8 POINTS



CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #2

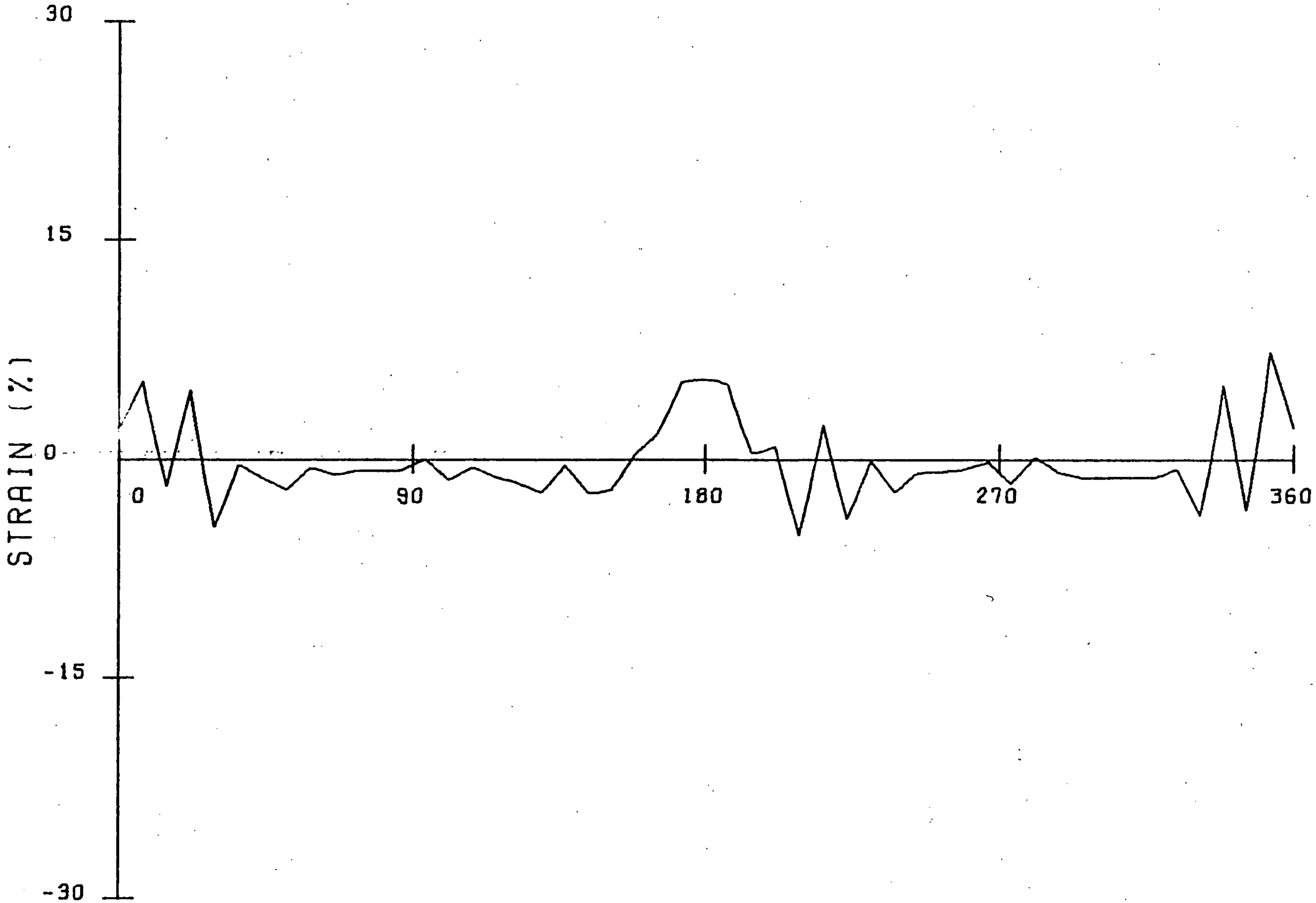
C-65



CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #2

50 POINTS

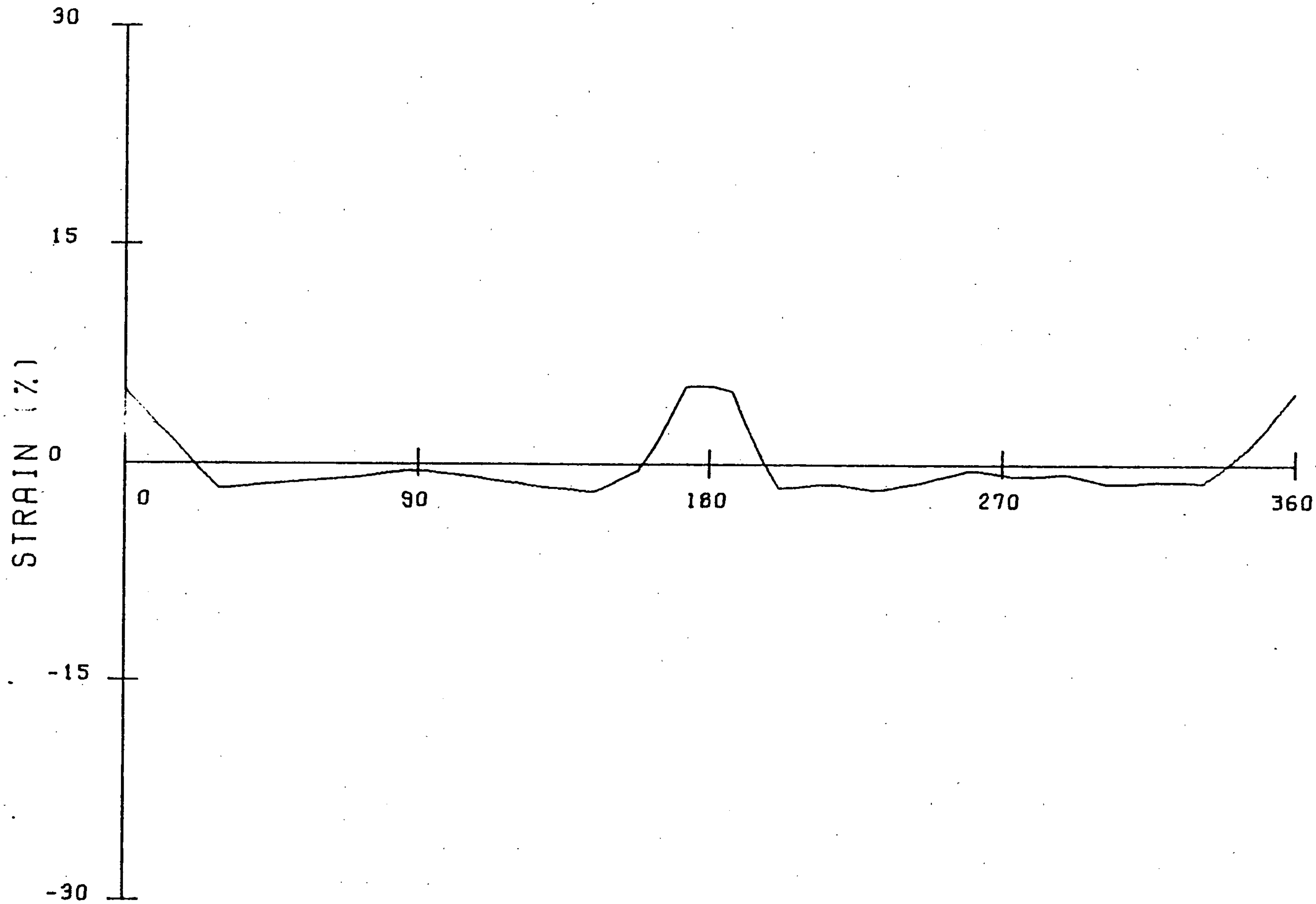


CALCULATED STRAIN

C-22

PLASTIC STRAIN TEST
TUBE #2

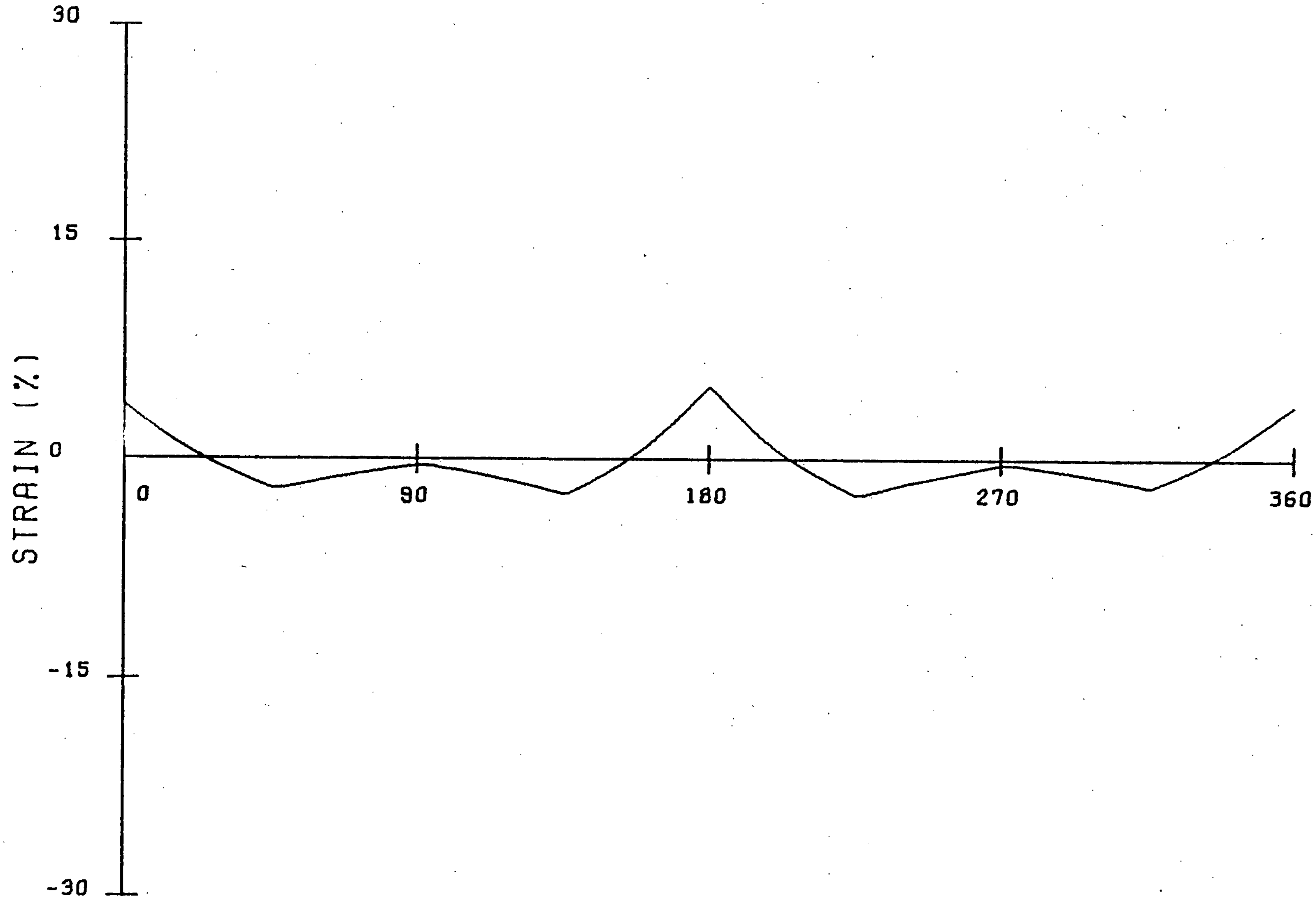
25 POINTS



CALCULATED STRAIN

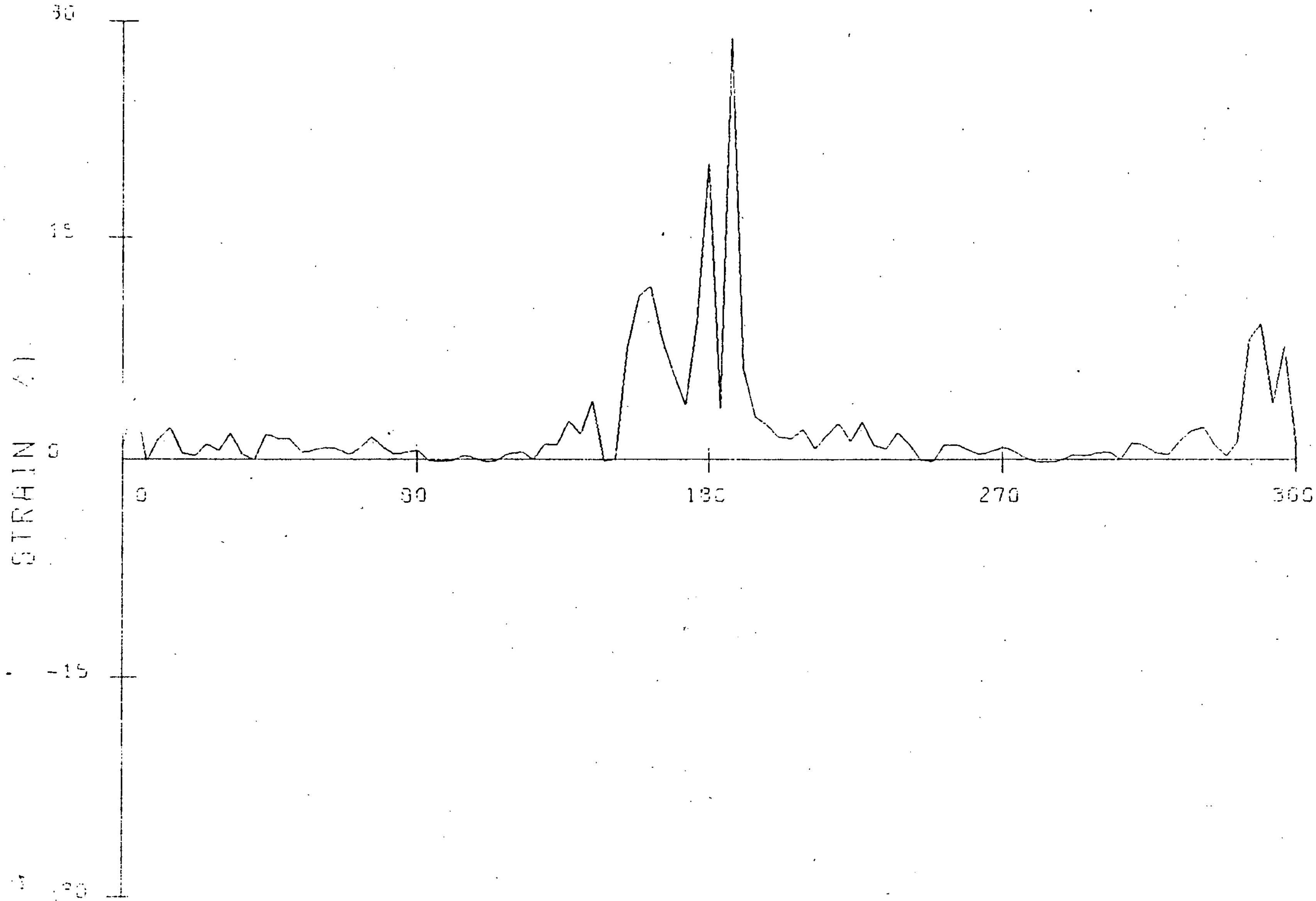
PLASTIC STRAIN TEST
TUBE #2

8 POINTS



CALCULATED STRAIN

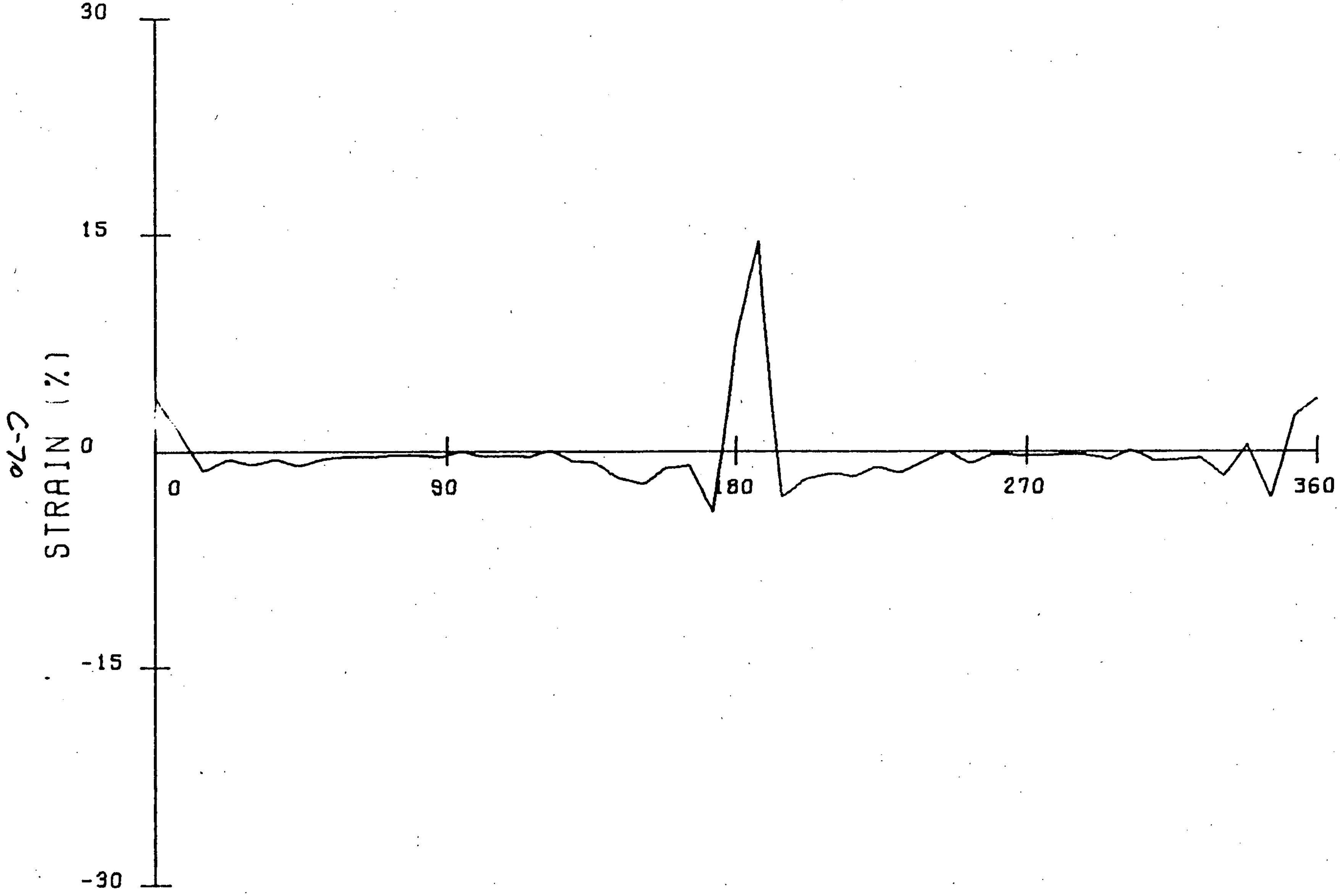
PLASTIC STRAIN TEST



CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #3

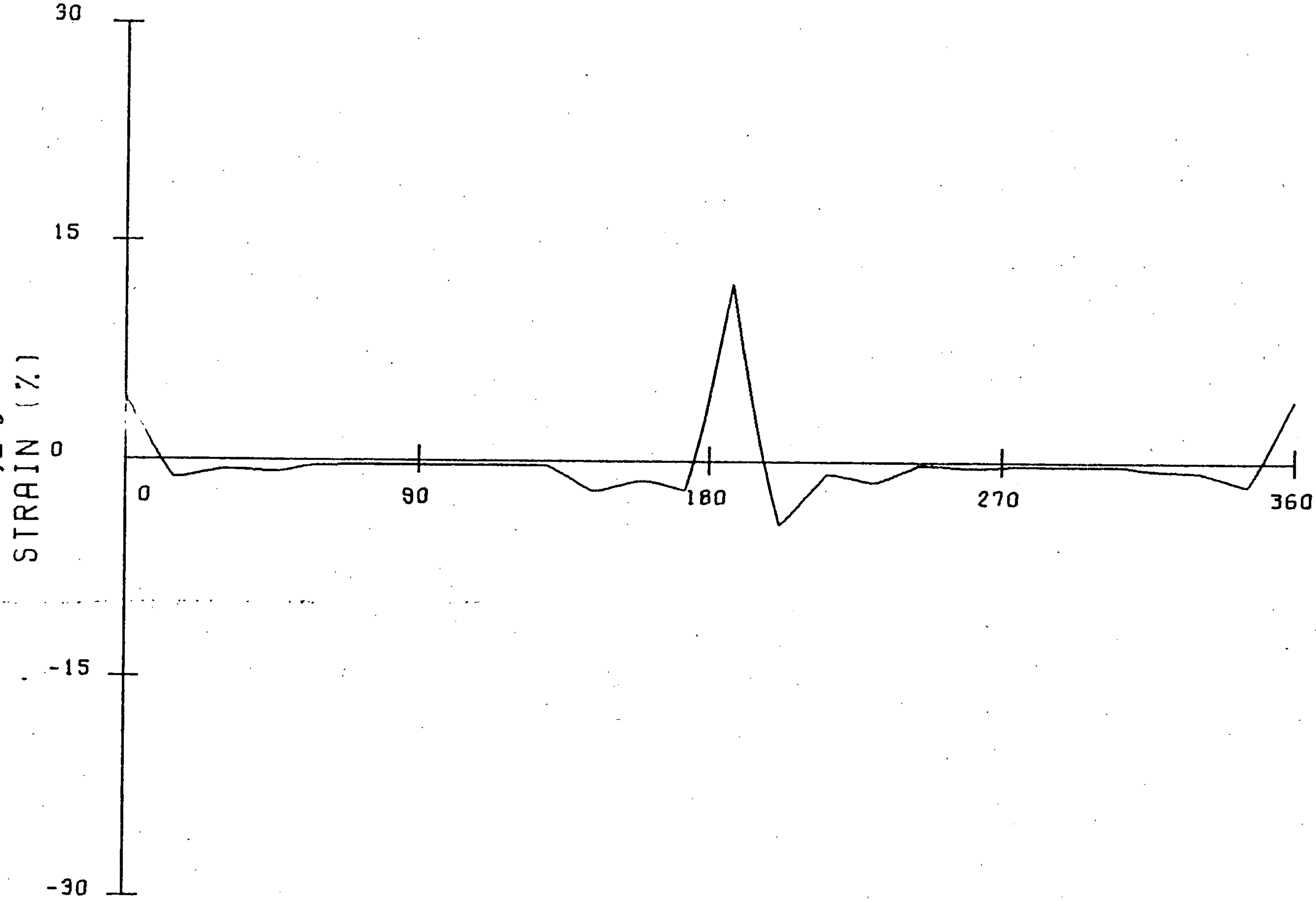
50 POINTS



CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #3

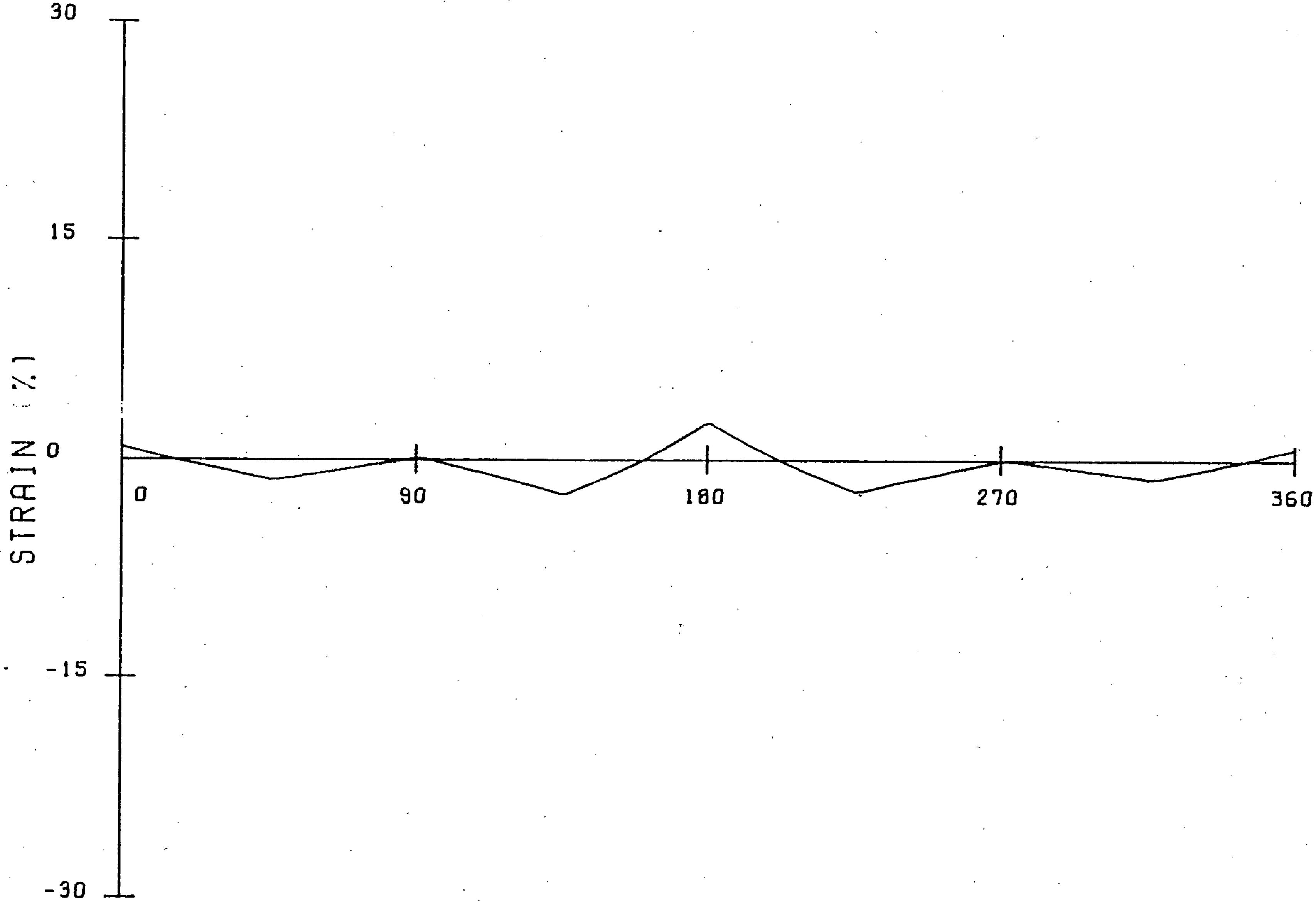
25 POINTS



CALCULATED STRAIN

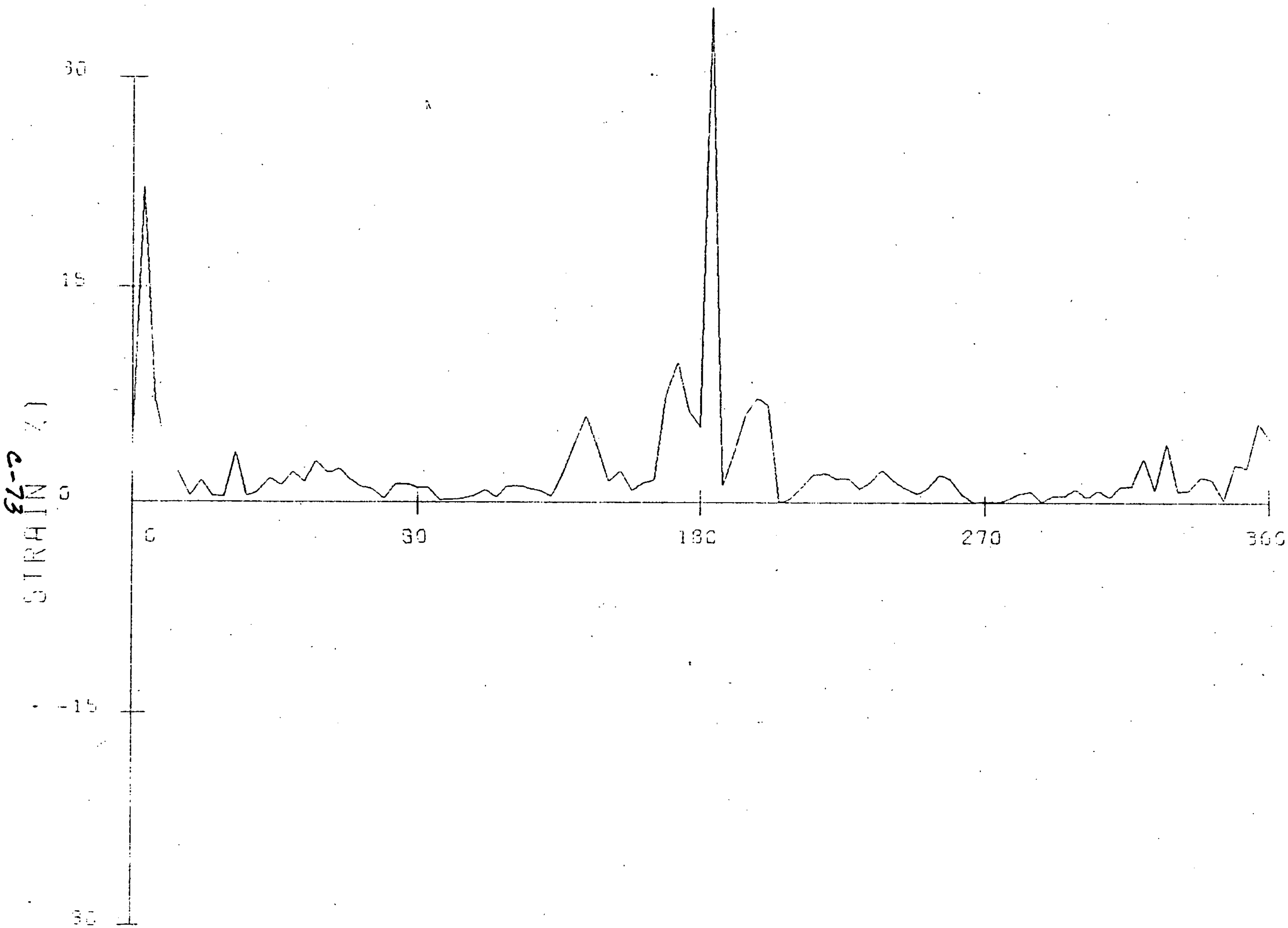
PLASTIC STRAIN TEST
TUBE #3

8 POINTS



CALCULATED STRAIN

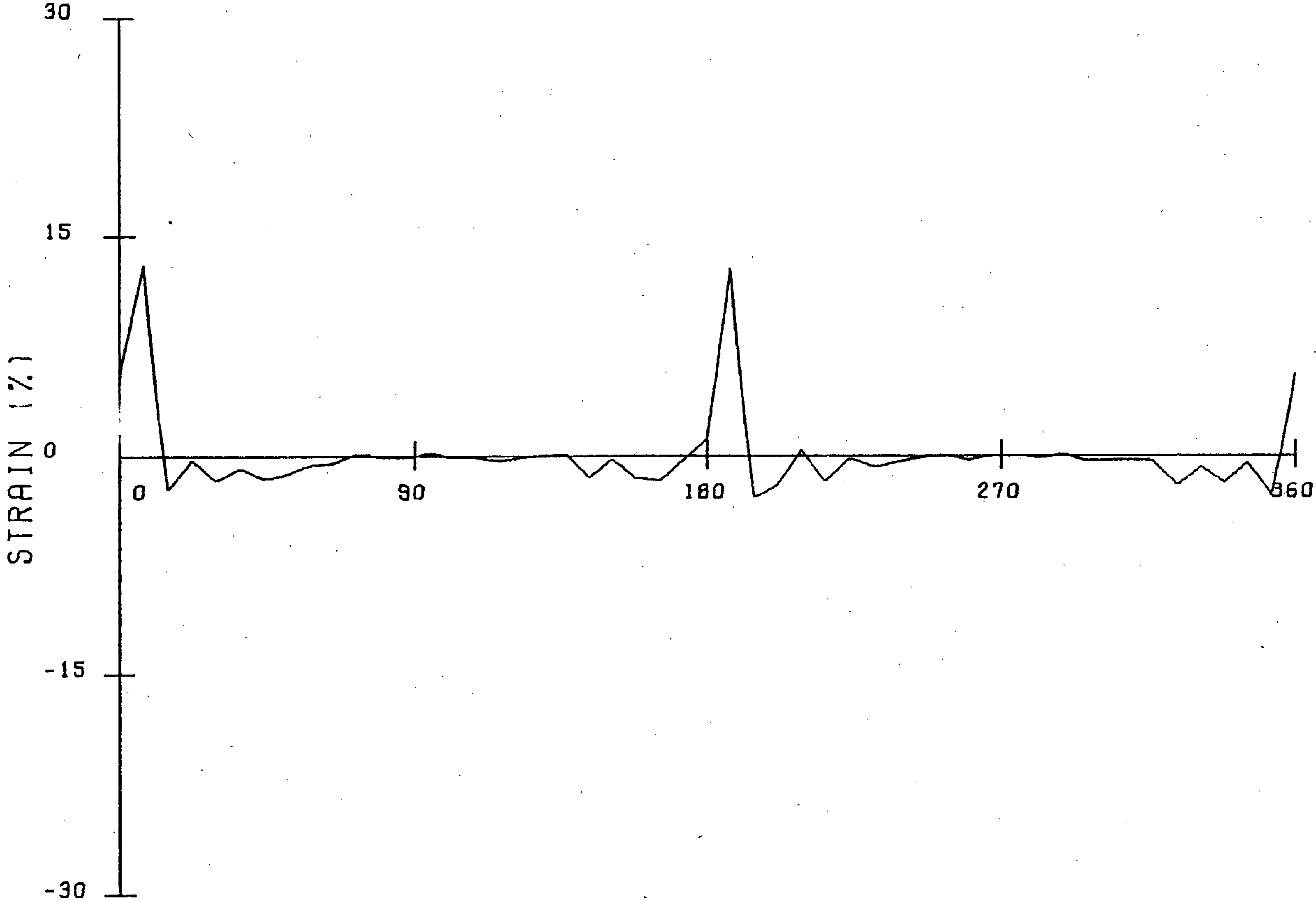
PLASTIC STRAIN TEST
- TUBE #4



CALCULATED STRAIN

PLASTIC STRAIN TEST
- TUBE #4

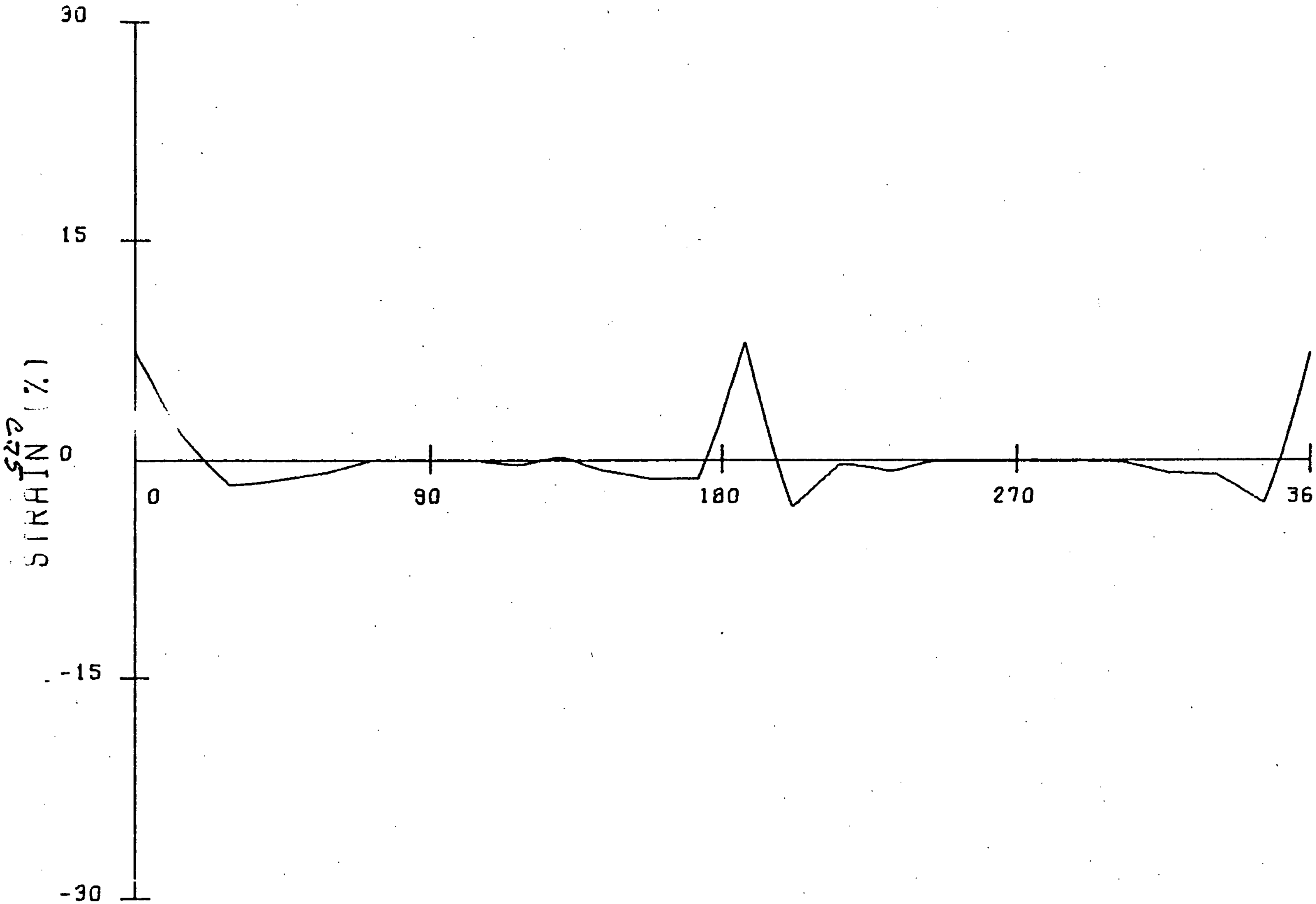
50 POINTS



CALCULATED STRAIN

PLASTIC STRAIN TEST
- TUBE #4

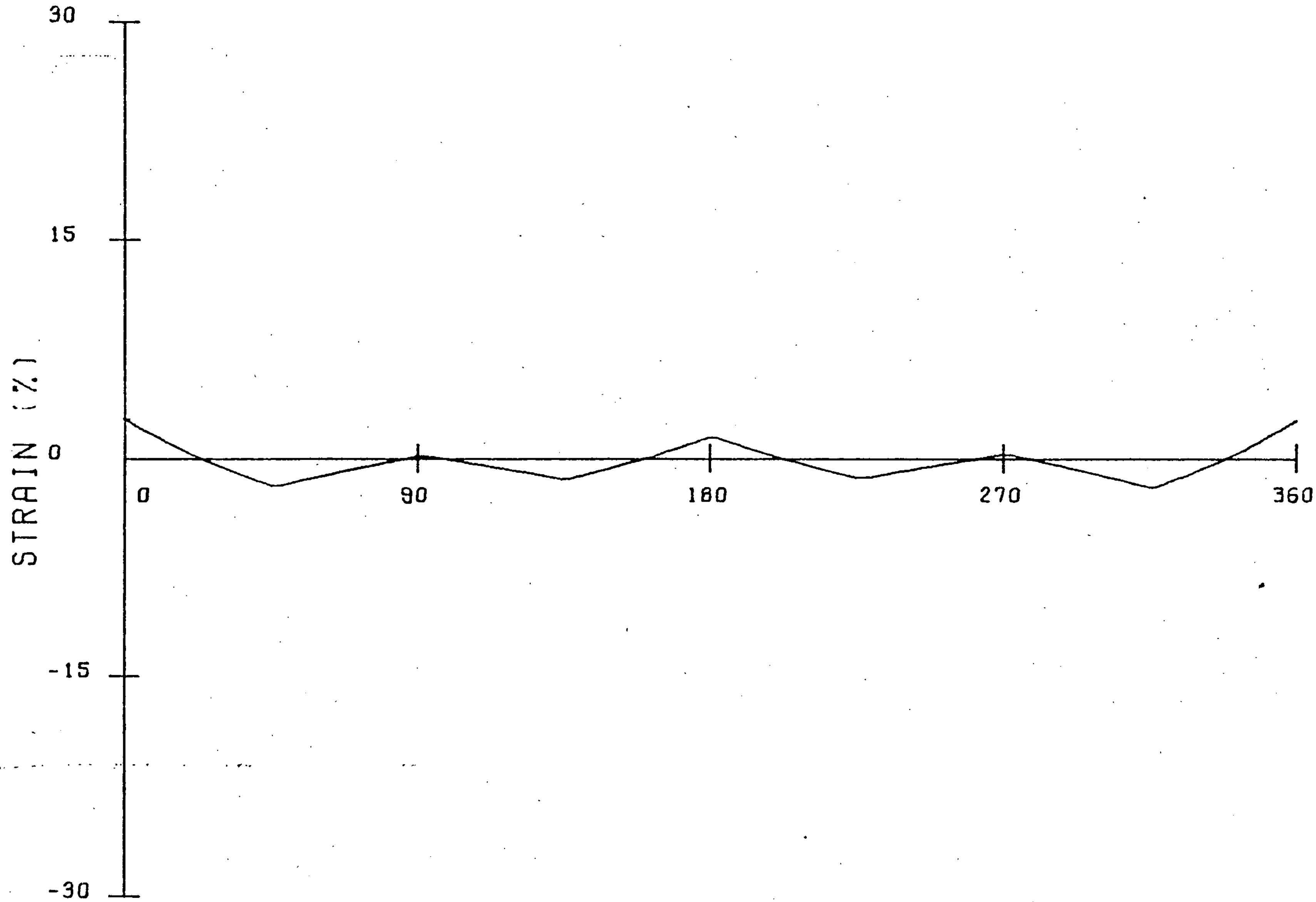
25 POINTS



CALCULATED STRAIN

PLASTIC STRAIN TEST
- TUBE #4

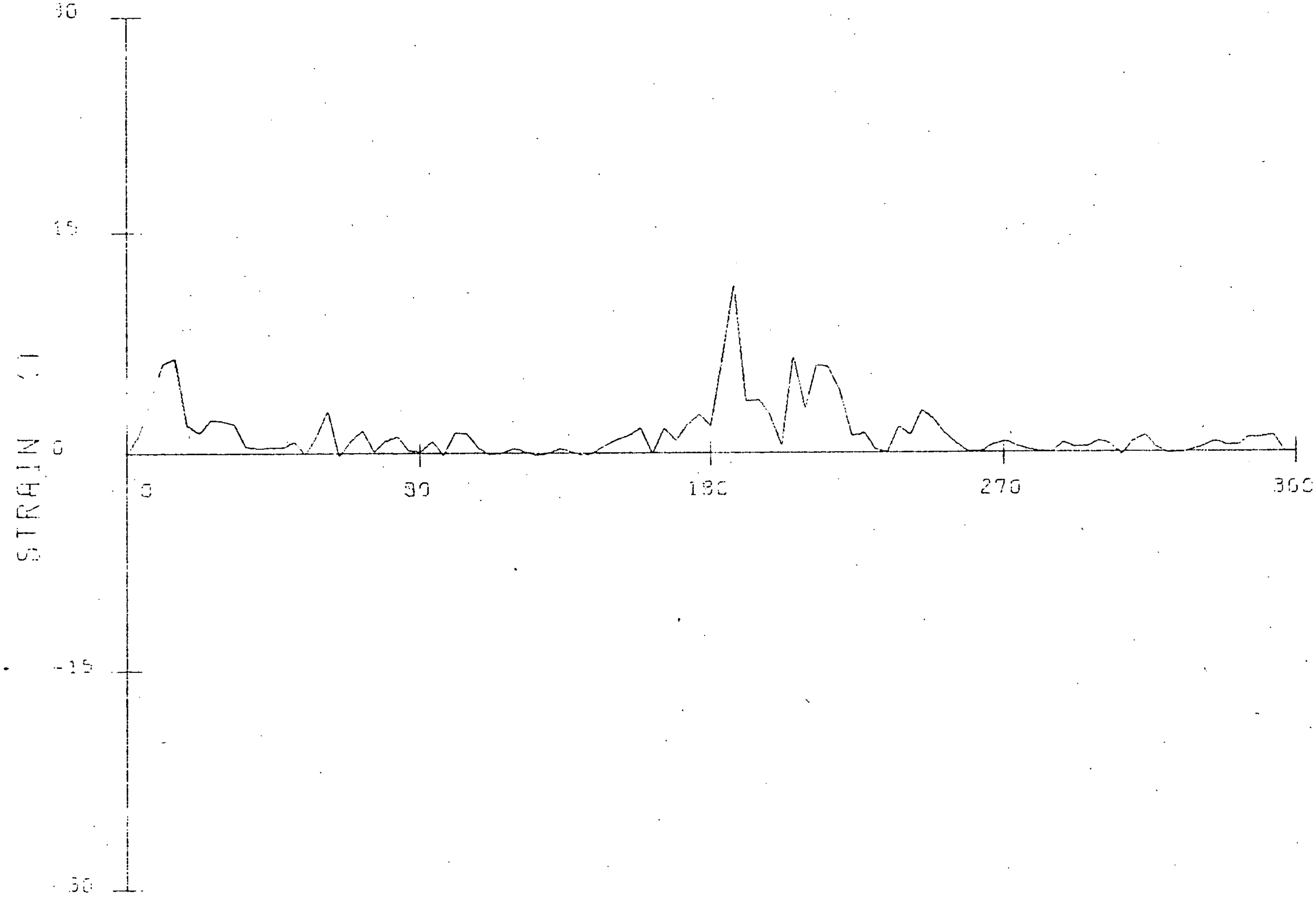
8 POINTS



CALCULATED STRAIN

C-76

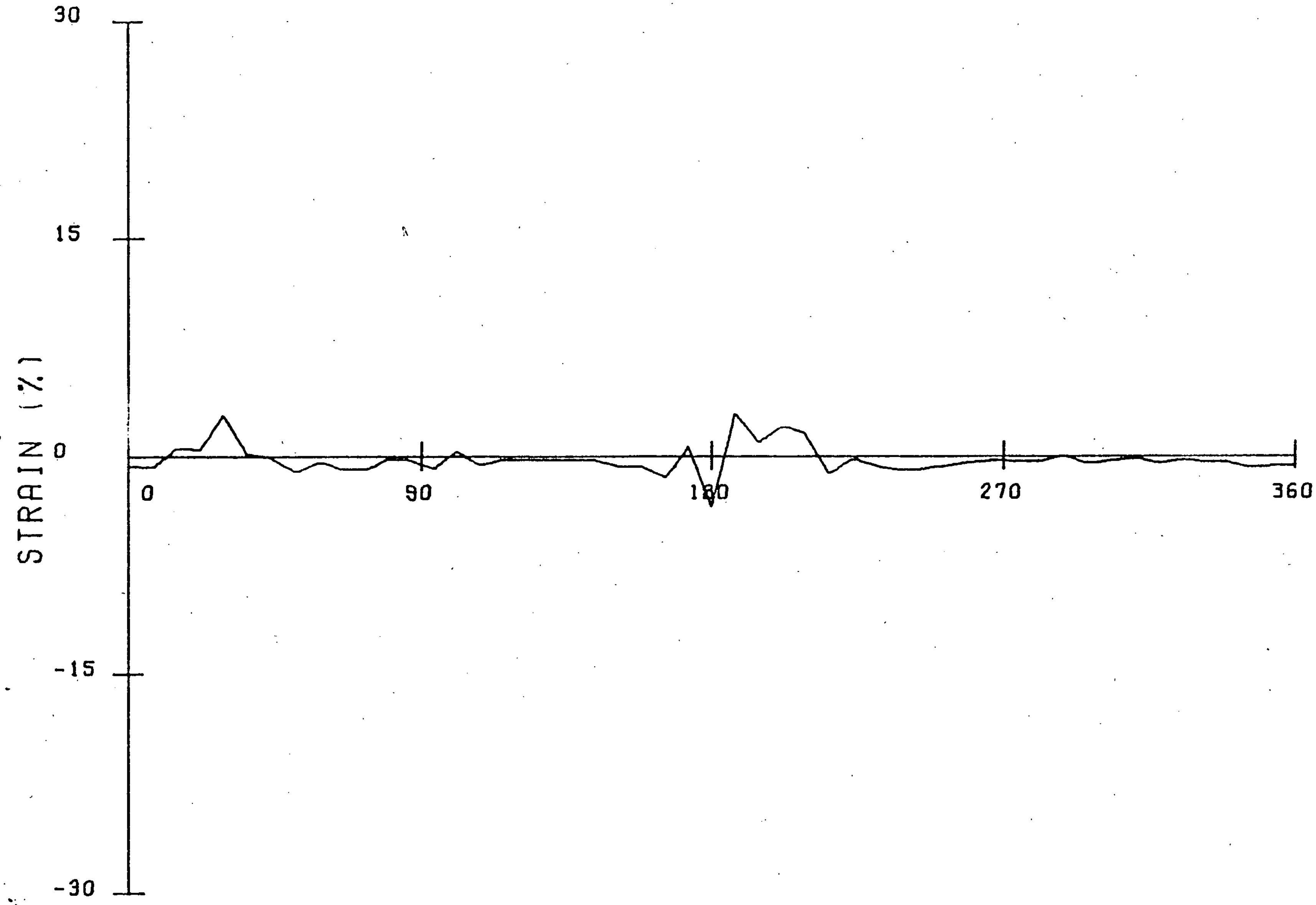
PLASTIC STRAIN TEST
- TUBE [illegible]



CALCULATED STRAIN

PLASTIC STRAIN TEST
- TUBE #5

50 POINTS

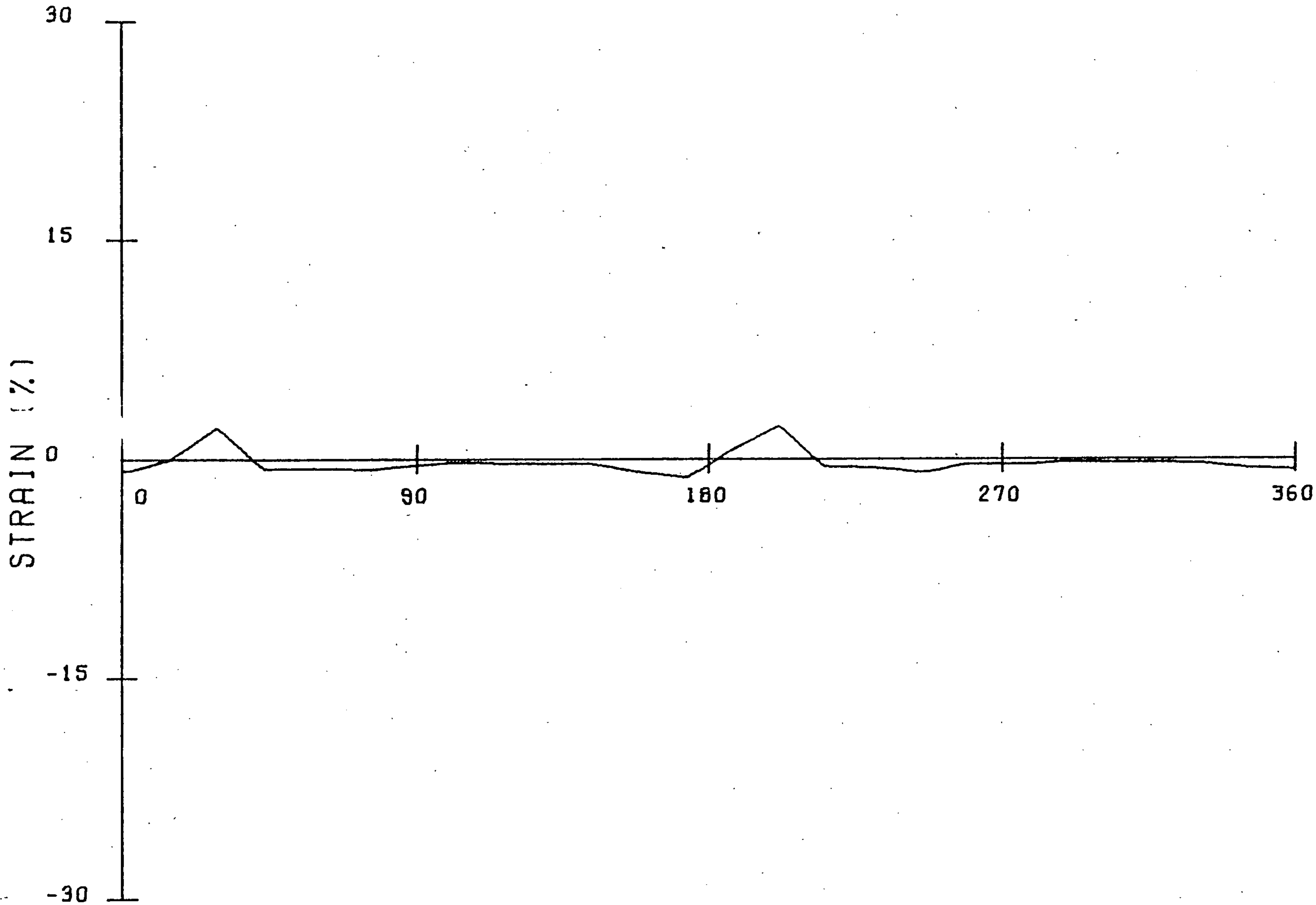


CALCULATED STRAIN

C-78

PLASTIC STRAIN TEST
- TUBE #5

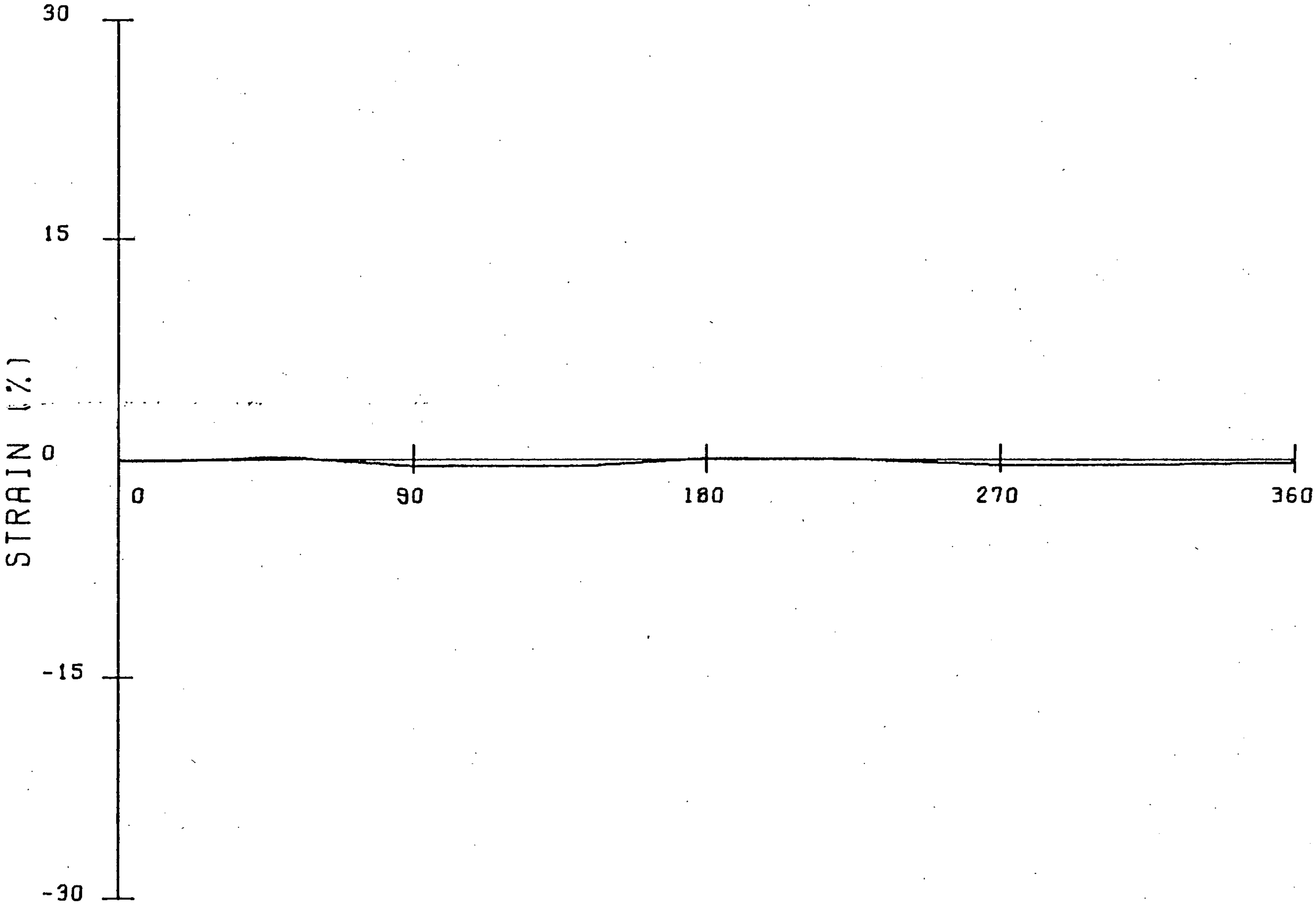
25 POINTS



CALCULATED STRAIN

PLASTIC STRAIN TEST
- TUBE #5

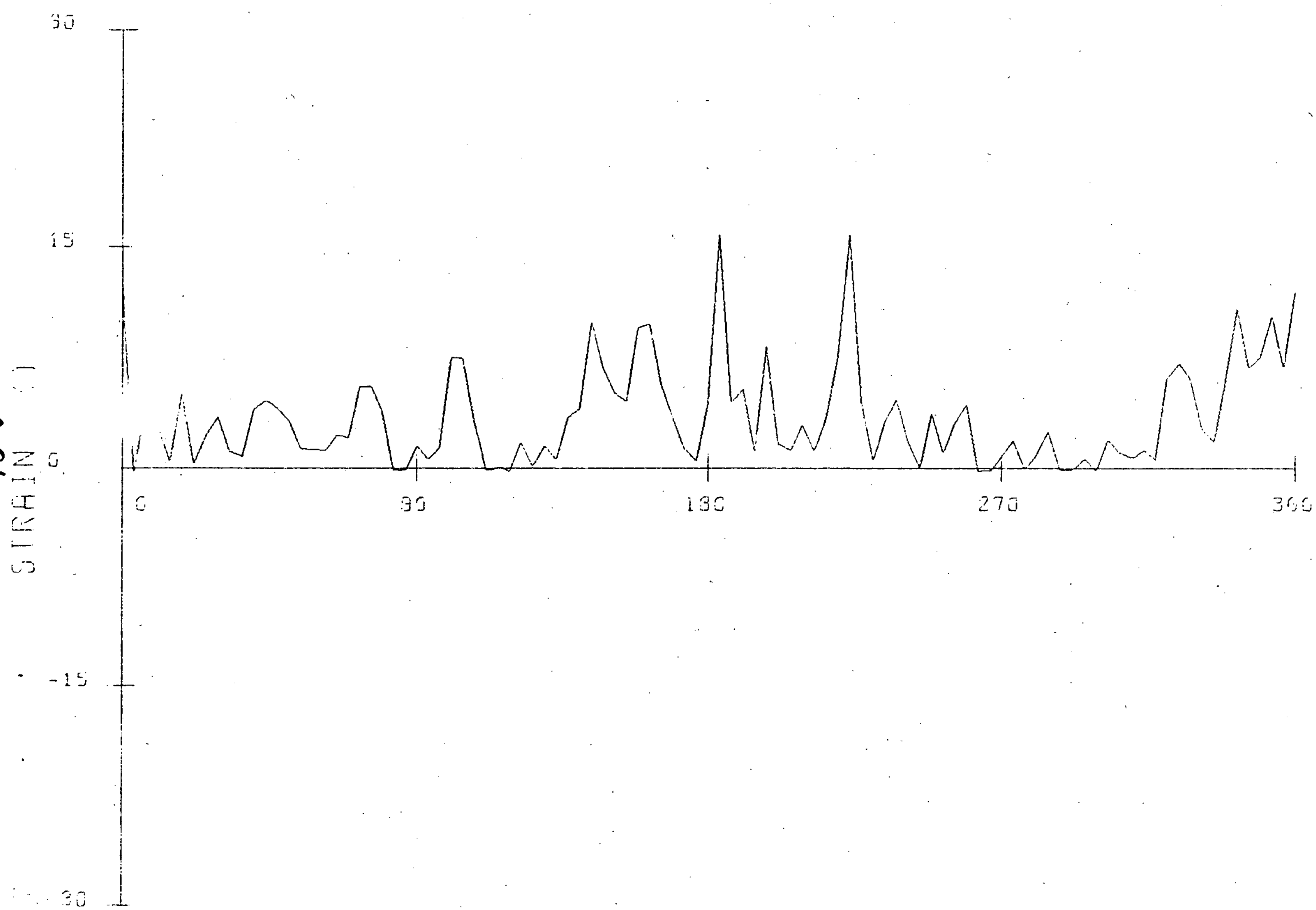
8 POINTS



CALCULATED STRAIN

C-80

PLASTIC STRAIN TEST
TUBE #C

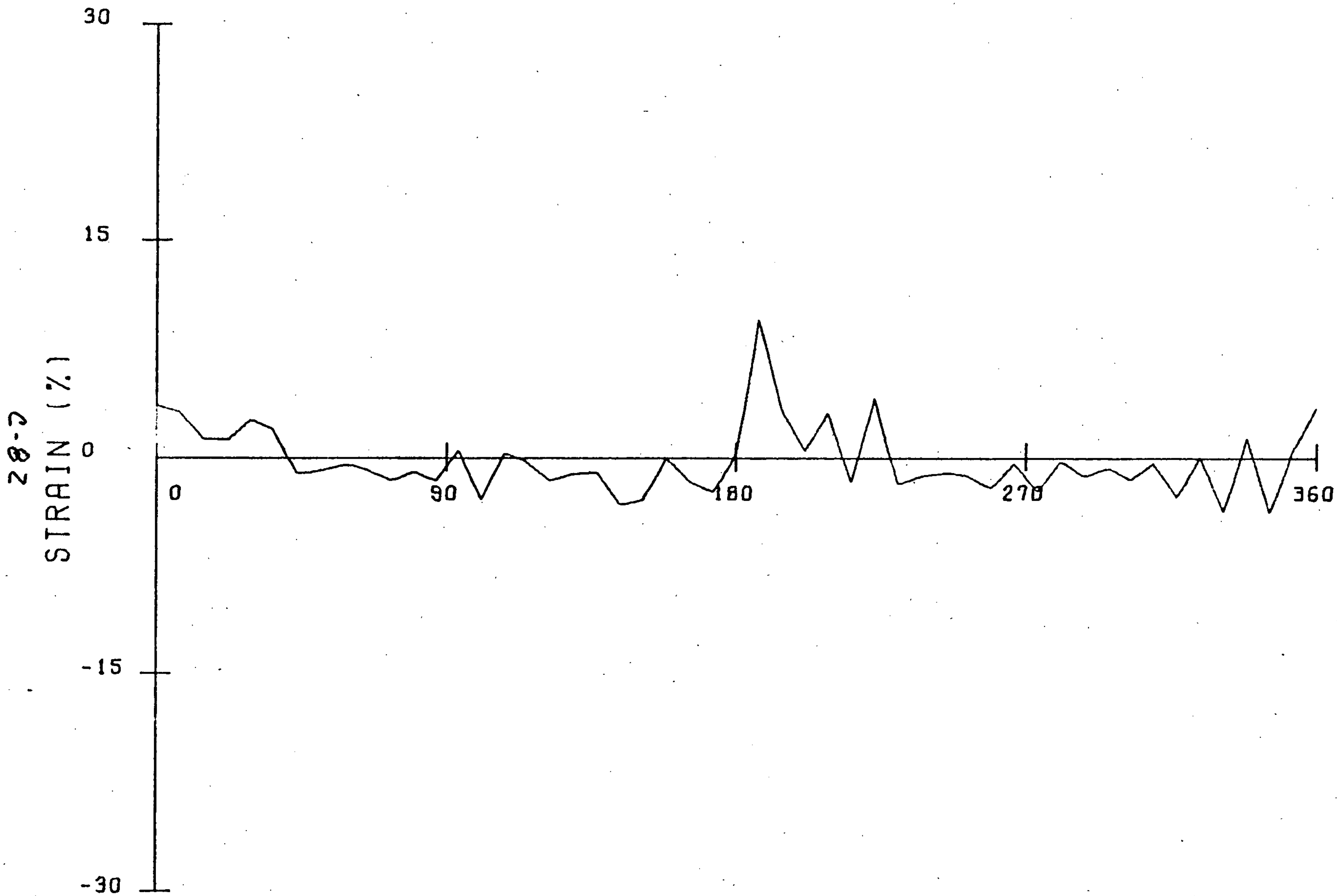


CALCULATED STRAIN

18-7

PLASTIC STRAIN TEST
TUBE #6

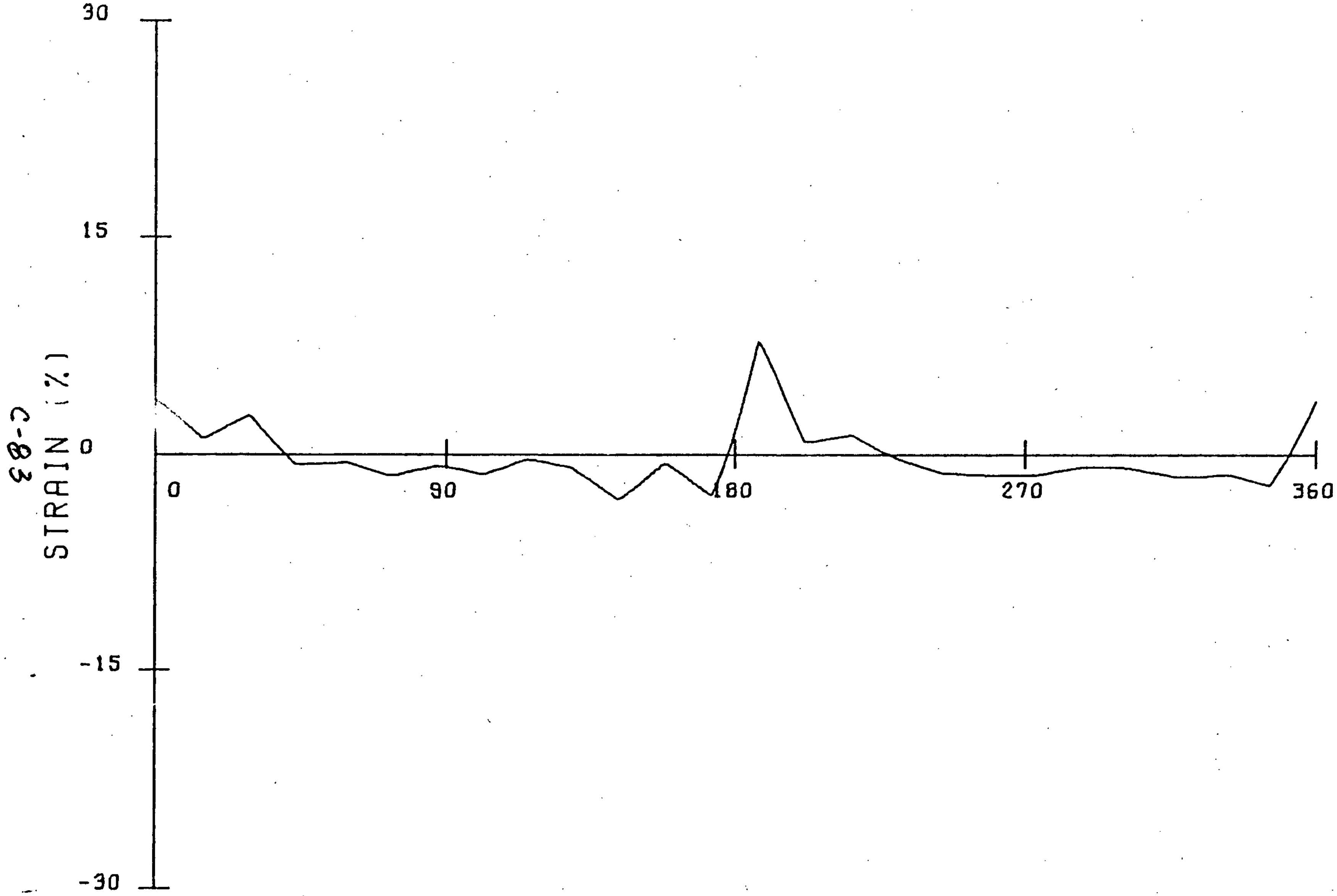
50 POINTS



CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #6

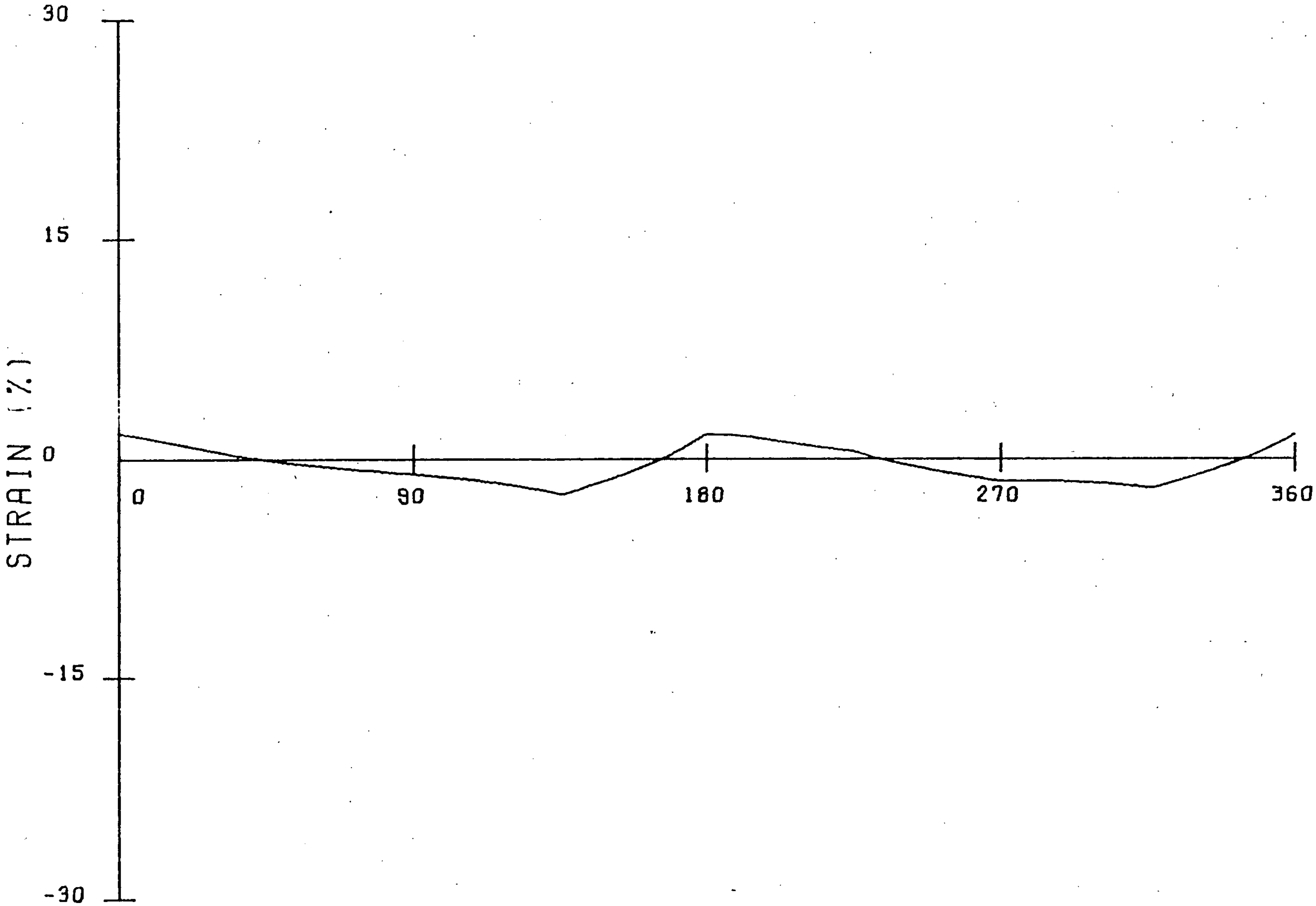
25 POINTS



CALCULATED STRAIN

PLASTIC STRAIN TEST
TUBE #6

8 POINTS



CALCULATED STRAIN

APPENDIX D

ELASTIC TEST CASE

BABCOCK & WILCOX

DRAFT
July 5, 1979

Babcock & Wilcox

Research and Development Division
Research Center Alliance, Ohio 44601

To: S. J. STUDER - ISI, NPGD, LYNCHBURG

From: S. E. REED - APPLIED MECHANICS, ARC

Cust.: CON ED INDIAN POINT 2

File No. or Ref.: LR:79:5470-04:02

Subj.: ELASTIC TEST CASE

Date: JULY 5, 1979

This letter to cover one customer and one subject only

A strain calculation algorithm is incorporated in the program which will be used to predict plastic strain in the tubes of Indian Point 2 steam generators based on profilometer data. A test case was performed to verify the ability to correctly predict strain from deflection data.

The test case chosen was that of a ring in diametral compression. This case was selected because of simplicity of analysis and because it is somewhat representative of the actual type of data anticipated. Finite element analysis was chosen for the baseline analysis.

Because of the symmetry of this case, only a quarter of the ring was modelled. Twenty-five shell elements were used, as shown in Figure 1, and 52 nodes. The ring was given an initial (centerline) radius of 0.4125 inch and a wall thickness of 0.050 inch; i.e., the nominal tube dimensions for the Indian Point steam generator tubing. At zero degrees (x-axis) the nodes were free in the x direction. The y and z translations and x and z rotations were constrained. At 90 degrees (y-axis) the nodes were free in the y direction, while x and z translation and y and z rotations were constrained. Two equal loads (P) were applied in the minus x direction, one at each node at zero degrees. These loads were selected to produce

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	G. Musat	APM Files (5)
	P. E. Sensmeier	

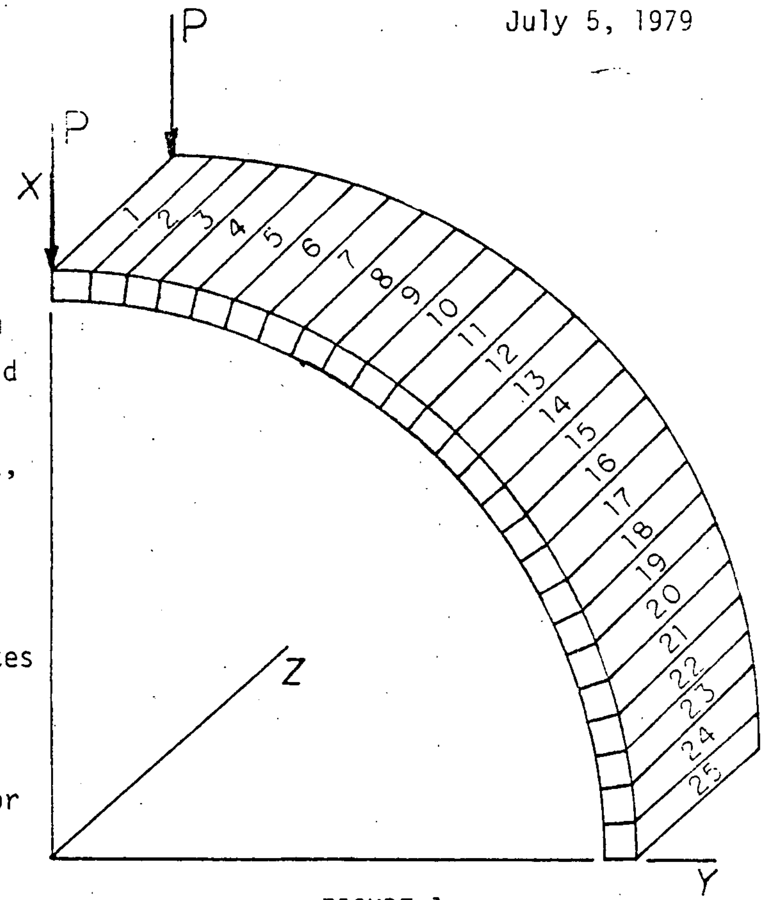


FIGURE 1.

deflections large enough to be measurable, but small enough that the structure would remain linear.

The finite element program output the nodal displacements and element strains. The original nodal coordinates were calculated, and added to the nodal displacements to produce the final nodal coordinates. These coordinates were converted to polar coordinates (an angle and a radius) and then fitted with the periodic cubic spline curve. The data points for input to the strain prediction program (100 points, 50 points, and 8 points) were then picked from this curve at equal angular increments (3.6 degrees, 7.2 degrees, and 45 degrees, respectively). The strain prediction program was then used to predict the strain from these deformed coordinates.

The maximum displacement found by the finite element model was -14.1 mils at the load point. Ninety degrees from the load point, the displacement was +12.8 mils. The largest strain predicted by the finite element model was -8393 microstrain, on the outside of the ring at 1.8 degrees. This was the closest element to the load application point. The printouts of nodal displacements and element strains are included in Appendix A.

The strain prediction program was used to predict the strain in the ring based on 100, 50, and 8 points. In addition to the printout of strain distribution and maximum strain location (found in Appendix A), plots were made of the deformed shape, the displacement distribution, and the strain distribution. These can be found in Appendix B. For the 8-point prediction, the eight sampled point were incremented at 5-degree intervals to determine the sensitivity of the strain prediction to the orientation of the sampled points.

Table 1 presents a comparison of results of the finite element model, the 100-point prediction, 50-point prediction, and 8-point prediction. The correlation of the 50-point and 8-point strain predictions with the finite element model were generally quite good at the locations of high strain.

TABLE 1. COMPARISON OF ELASTIC TEST CASE 1 RESULTS

Method	θ	ε_{Inside}	$\varepsilon_{Outside}$	Deviation Inside	Deviation Outside
Finite Element	1.8	-5281	4769	Ref.	Ref.
	88.2	8377	-8393	Ref.	Ref.
8 Points	2.25	-5868	6681	11.1	40.0
	87.75	9671	-8871	15.4	5.7
50 Points	1.44	-5376	6407	1.8	34.3
	87.84	9037	-8006	7.9	4.6
100 Points	3.6	-7287	8293	38.0	73.9
	86.4	14584	-13578	74.1	61.8

Maximum Strain Prediction

Method	ε_{Max}	Location
Finite Element	-8393	88.2°
8 Points	10346	90.0°
50 Points	9043	266.4°
100 Points	22613	68.4°

As has been observed before, the 50-point and especially the 100-point predictions showed significant levels of noise in the strain distribution. Because of this, the 8-point prediction did the best job of predicting the strain distribution as a whole. A comparison of the 8-point predicted strain distribution to the finite element predictions is shown in Figures 2 and 3.

FIGURE 2
ELASTIC TEST CASE
INSIDE SURFACE

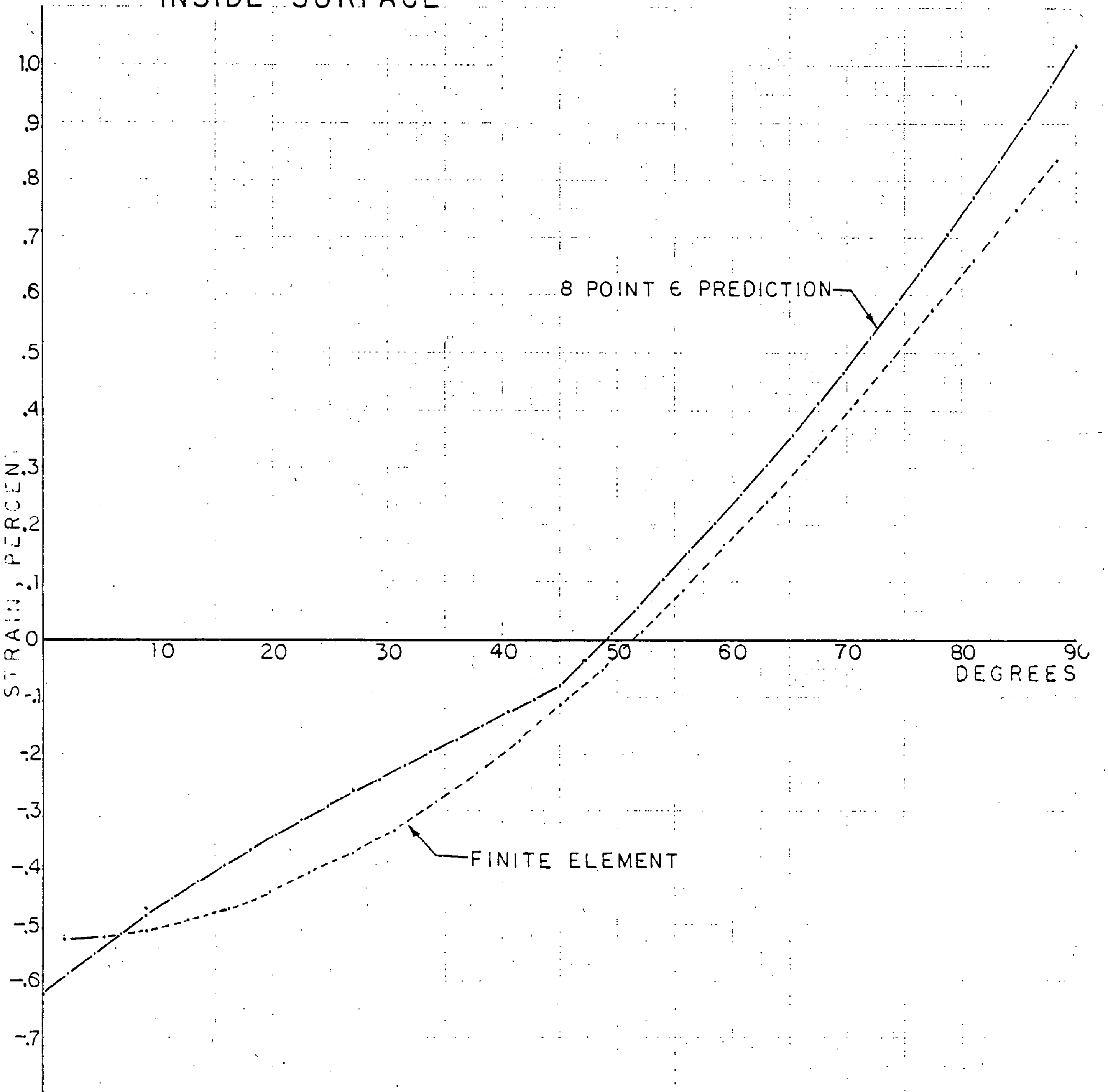
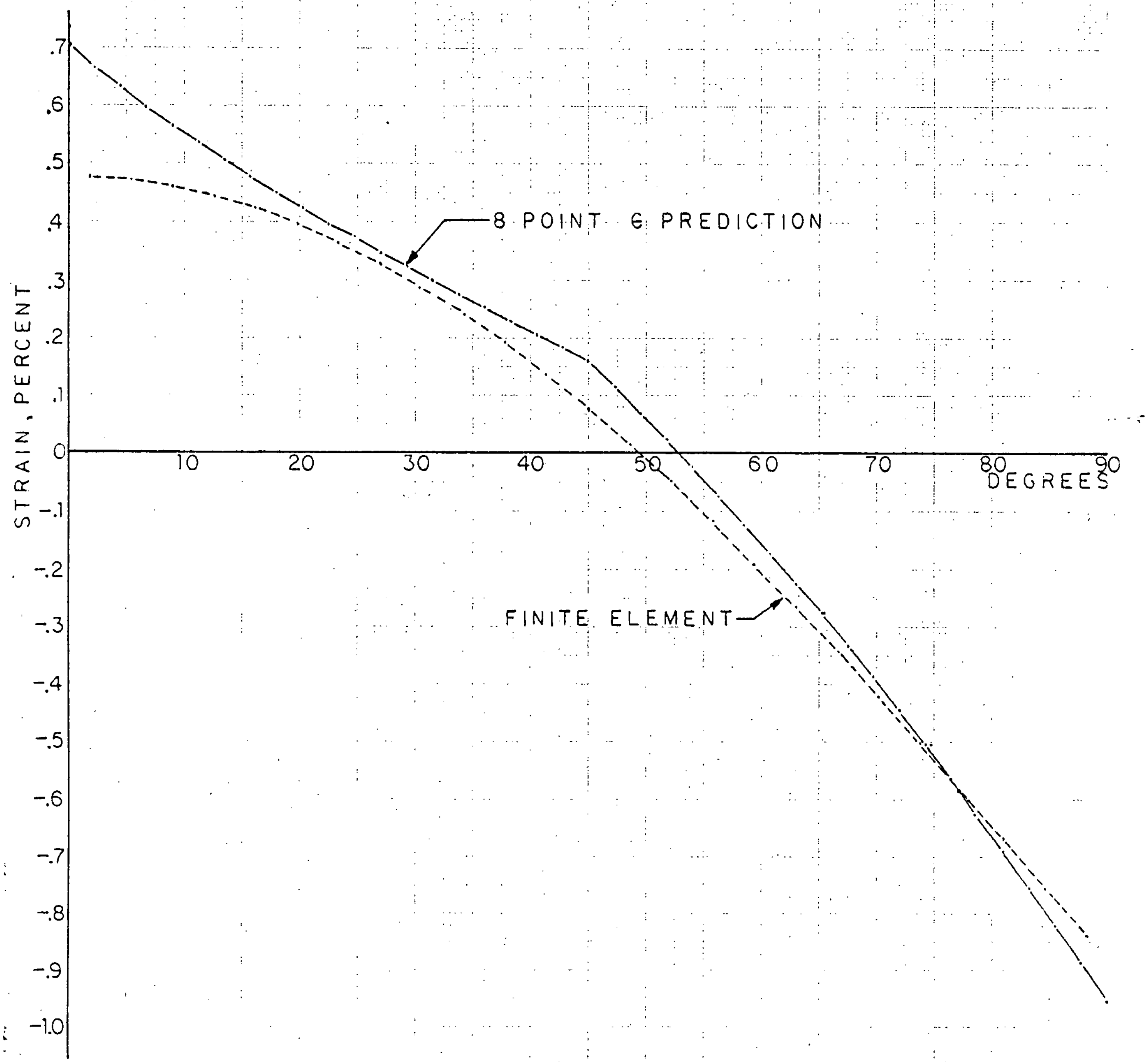


FIGURE 3

ELASTIC TEST CASE

OUTSIDE SURFACE



Rotation of the eight sample points at 5-degree intervals produced a comparatively small variation in the predicted strain, from 0.8 percent to 1.0 percent. This indicates that for this deformed shape, the 8-point prediction predicts just about the same shape regardless of the orientation of the points.

A review of the finite element results revealed that in addition to the displacements at the nodes, significant rotations also existed. Thus for this test case, the model was acting as a cylinder rather than a ring. Because of this, the displacements at the center of the elements where the strains are calculated are not the same as the nodal displacements used as input to the strain prediction program. To determine the significance of this on the correlation between the two methods, a second test case was run. The model was identical to that of the first case, but the boundary conditions were changed. In this case, only z-axis rotations were allowed at all nodes; x and y rotations were fixed. At the ends of the model, z rotations were also fixed.

As expected, this made the model somewhat more rigid. The maximum displacement at the load point was reduced to -12.8 mils and at 90 degrees to the load point, 11.7 mils. The maximum strain predicted was -7639 microstrain.

The input data for the strain prediction program was prepared as for case 1. For this case, only the 50-point and 8-point predictions were performed. The finite element results and strain prediction program results are in Appendix C. Table 2 summarizes the results of the two methods. Again, both the 50-point and 8-point strain predictions do an adequate job of predicting the maximum strain. As in case 1, the 8-point curve fit tends to overpredict the maximum strain, but (because of the noise on the 50-point strain distribution) does a better overall job of predicting the strain distribution.

TABLE 2. COMPARISON OF ELASTIC TEST CASE 2 RESULTS

Method	θ	ε_{Inside}	$\varepsilon_{Outside}$	Deviation, % Inside	Deviation, % Outside
Finite Element	1.8°	-4829	4317	Ref.	Ref.
	88.2°	7622	-7639	Ref.	Ref.
8 Points	2.25°	-5461	6115	13.1	41.6
	87.75°	8650	-7996	13.5	4.7
50 Points	1.44°	-5919	6763	22.6	56.8
	87.84°	8081	-7237	6.0	5.3

Maximum Strain Prediction

Method	ε_{Max}	Location
Finite Element	-7639	88.2°
8 Points	9235	270°
50 Points	8087	266°

A third test case was performed on the finite element model. This case used the same boundary conditions as case 2, but contained four times the number of elements to verify that the model of case 2 had converged. The results of this analysis indicated that the model of case 2 had, in fact, completely converged.

It is concluded from the analyses described that the strain calculation algorithm used in the strain prediction program provides reasonable accuracy for predicting strain from displacement data. It appears that the best overall prediction of strain results from the use of the least possible number of points which can still adequately define the deformed shape. For a shape such as used for the test cases, eight points provide adequate definition of the deformed shape.

S. E. Reed

SER/skm
Attachments

APPENDIX A

COMPUTER PRINTOUTS - ELASTIC TEST CASE 1
FINITE ELEMENT RESULTS
STRAIN PREDICTION PROGRAM RESULTS

FINITE ELEMENT

........NODE DISPLACEMENTS AND ROTATIONS

NODE	LOAD	X	Y	Z	XX	YY	ZZ
1	1	-1.413E-02	0.	0.	0.	5.03E-02	0.
2	1	-1.401E-02	3.442E-06	-1.651E-06	7.96E-02	5.28E-02	-8.69E-03
3	1	-1.368E-02	3.393E-05	-3.289E-06	7.64E-02	5.25E-02	-1.65E-02
4	1	-1.317E-02	1.140E-04	-4.899E-06	7.28E-02	5.19E-02	-2.33E-02
5	1	-1.250E-02	2.624E-04	-6.447E-06	6.99E-02	5.13E-02	-2.94E-02
6	1	-1.170E-02	4.925E-04	-7.950E-06	6.62E-02	5.02E-02	-3.45E-02
7	1	-1.075E-02	8.134E-04	-9.423E-06	6.37E-02	4.93E-02	-3.86E-02
8	1	-9.364E-03	1.229E-03	-1.078E-05	6.04E-02	4.78E-02	-4.22E-02
9	1	[illegible]	1.740E-03	-1.204E-05	5.72E-02	4.62E-02	-4.49E-02
10	1	-7.709E-03	2.343E-03	-1.319E-05	5.49E-02	4.48E-02	-4.67E-02
11	1	-6.781E-03	3.029E-03	-1.420E-05	5.17E-02	4.26E-02	-4.79E-02
12	1	-5.796E-03	3.789E-03	-1.507E-05	4.92E-02	4.07E-02	-4.81E-02
13	1	-4.804E-03	4.609E-03	-1.577E-05	4.68E-02	3.85E-02	-4.78E-02
14	1	-3.878E-03	5.472E-03	-1.630E-05	4.44E-02	3.61E-02	-4.69E-02
15	1	-3.109E-03	6.365E-03	-1.662E-05	4.22E-02	3.36E-02	-4.51E-02
16	1	-2.452E-03	7.264E-03	-1.676E-05	4.01E-02	3.09E-02	-4.29E-02
17	1	-1.878E-03	8.153E-03	-1.680E-05	3.75E-02	2.85E-02	-4.03E-02

18	1	-1.363E-03	[illegible]	[illegible]	3.66E-02	2.53E-02	-3.70E-02
19	1	-9.430E-04	9.828E-03	[illegible]	3.52E-02	2.24E-02	-3.30E-02
20	1	-6.150E-04	1.057E-02	-1.440E-05	3.39E-02	1.95E-02	-2.93E-02
21	1	-3.705E-04	1.123E-02	-1.317E-05	3.27E-02	1.62E-02	-2.49E-02
22	1	-2.007E-04	1.179E-02	-1.140E-05	3.18E-02	1.32E-02	-2.03E-02
23	1	-9.304E-05	1.224E-02	-9.265E-06	3.11E-02	9.85E-03	-1.54E-02
24	1	-3.441E-05	1.257E-02	-6.682E-06	3.06E-02	6.63E-03	-1.04E-02
25	1	[illegible]	1.277E-02	-3.609E-06	3.03E-02	3.32E-03	-5.21E-03
26	1	0.	1.283E-02	0.	3.02E-02	0.	0.
27	1	[illegible]	0.	0.	0.	-5.03E-02	0.
28	1	[illegible]	3.448E-06	1.681E-06	-7.96E-02	-5.28E-02	-8.47E-03
29	1	[illegible]	3.383E-05	3.289E-06	-7.64E-02	-5.25E-02	[illegible]
30	1	[illegible]	1.140E-04	4.999E-06	-7.28E-02	-5.19E-02	-2.74E-02
31	1	[illegible]	[illegible]	4.467E-06	-6.99E-02	-5.13E-02	-2.94E-02
32	1	-1.170E-02	[illegible]	[illegible]	-6.62E-02	-5.02E-02	[illegible]
33	1	[illegible]	8.134E-04	9.423E-06	-6.37E-02	-4.93E-02	[illegible]
34	1	-9.834E-03	1.229E-03	1.076E-05	-6.04E-02	-4.78E-02	-4.22E-02
35	1	-8.824E-03	1.740E-03	1.204E-05	-5.72E-02	-4.62E-02	[illegible]

36	1	-7.799E-03	2.343E-03	[illegible]	-5.49E-02	-4.48E-02	-4.57E-02
37	1	-6.781E-03	3.027E-03	1.409E-05	-5.17E-02	-4.26E-02	-4.78E-02
38	1	-5.795E-03	3.789E-03	1.507E-05	-4.92E-02	-4.07E-02	-4.81E-02
39	1	-4.358E-03	4.609E-03	1.577E-05	-4.68E-02	-3.85E-02	-4.75E-02
40	1	-3.987E-03	5.473E-03	1.630E-05	-4.44E-02	-3.61E-02	-4.68E-02
41	1	-3.194E-03	6.365E-03	1.662E-05	-4.22E-02	-3.36E-02	-4.51E-02
42	1	-2.409E-03	7.264E-03	1.672E-05	-4.01E-02	-3.09E-02	-4.29E-02
43	1	-1.873E-03	8.153E-03	1.658E-05	-3.85E-02	-2.85E-02	-4.02E-02
44	1	-1.365E-03	9.012E-03	1.618E-05	-3.66E-02	-2.53E-02	-3.70E-02
45	1	-9.456E-04	9.825E-03	1.548E-05	-3.52E-02	-2.24E-02	-3.33E-02
46	1	-6.100E-04	1.057E-02	1.446E-05	-3.39E-02	-1.95E-02	-2.93E-02
47	1	-3.708E-04	1.125E-02	1.313E-05	-3.27E-02	-1.62E-02	-2.49E-02
48	1	-2.037E-04	1.179E-02	1.140E-05	-3.18E-02	-1.32E-02	-2.03E-02
49	1	-9.094E-05	1.224E-02	9.265E-06	-3.11E-02	-9.85E-03	-1.54E-02
50	1	-3.441E-05	1.257E-02	6.680E-06	-3.06E-02	-6.63E-03	-1.04E-02
51	1	-8.766E-06	1.277E-02	3.609E-06	-3.03E-02	-3.32E-03	-5.21E-03
52	1	0.	1.283E-02	0.	-3.02E-02	0.	0.

SHELL ELEMENT STRESSES

	ELEMENT	LOAD	LONG SIG-X	CIRC. SIG-Y	SIG-XY
MEMBRANE	1	1	1.65	-8.53	-.00
BENDING			-2515.62	8385.41	-.00
+T/2 SIDE INSIDE			-2513.97	8376.87	-.00
-T/2 SIDE OUTSIDE			2517.27	-8393.94	-.00
MEMBRANE	2	1	4.94	-25.48	-.00
BENDING			-2255.06	7516.88	-.00
+T/2 SIDE			-2250.12	7491.41	-.00
-T/2 SIDE			2260.01	-7542.36	-.00
MEMBRANE	3	1	8.19	-42.29	-.00
BENDING			-1996.06	6653.52	-.00
+T/2 SIDE			-1987.87	6611.23	-.00
-T/2 SIDE			2004.25	-6695.82	-.00
MEMBRANE	4	1	11.37	-59.00	-.00
BENDING			-1739.63	5798.77	-.00
+T/2 SIDE			-1728.26	5739.76	-.00
-T/2 SIDE			1751.00	-5857.77	-.00
MEMBRANE	5	1	14.45	-75.40	-.00
BENDING			-1486.77	4955.90	-.00
+T/2 SIDE			-1472.32	4880.51	-.00
-T/2 SIDE			1501.22	-5031.30	-.00
MEMBRANE	6	1	17.40	-91.57	-.00
BENDING			-1238.47	4127.22	-.00
+T/2 SIDE			-1221.06	4035.65	-.00
-T/2 SIDE			1255.87	-4218.79	-.00
MEMBRANE	7	1	20.21	-107.24	-.00
BENDING			-995.70	3318.99	-.00
+T/2 SIDE			-975.49	3211.76	-.00
-T/2 SIDE			1015.91	-3426.23	-.00
MEMBRANE	8	1	23.09	-122.52	-.00
BENDING			-759.46	2531.52	-.00
+T/2 SIDE			-736.37	2409.00	-.00
-T/2 SIDE			782.28	-2654.04	-.00
MEMBRANE	9	1	25.23	-137.71	-.00

BENDING			-530.58	1742.72	-.00
+T/2 SIDE			-507.47	1651.61	-.00
-T/2 SIDE			557.90	-1906.23	-.00
MEMBRANE	10	1	27.59	-171.41	-.00
BENDING			-310.20	1934.02	-.00
+T/2 SIDE			-282.82	382.61	-.00
-T/2 SIDE			337.59	-1135.42	-.00
MEMBRANE	11	1	29.27	-164.95	-.00
BENDING			-98.98	329.94	-.00
+T/2 SIDE			-69.71	164.98	-.00
-T/2 SIDE			128.25	-494.89	-.00
MEMBRANE	12	1	30.84	-177.76	-.00
BENDING			102.15	-340.51	-.00
+T/2 SIDE			132.99	-518.26	-.00
-T/2 SIDE			-71.31	162.75	-.00
MEMBRANE	13	1	32.17	-190.70	-.00
BENDING			292.49	-974.96	-.00
+T/2 SIDE			324.66	-1134.77	-.00
-T/2 SIDE			-260.49	785.17	-.00
MEMBRANE	14	1	32.91	-201.06	-.00
BENDING			471.23	-1572.77	-.00
+T/2 SIDE			504.14	-1771.77	-.00
-T/2 SIDE			-437.32	1369.77	-.00
MEMBRANE	15	1	33.84	-211.37	-.00
BENDING			537.57	-2125.43	-.00
+T/2 SIDE			570.97	-2336.74	-.00
-T/2 SIDE			-504.29	1714.10	-.00
MEMBRANE	16	1	33.30	-220.75	-.00
BENDING			791.37	-2636.90	-.00
+T/2 SIDE			824.57	-2857.65	-.00
-T/2 SIDE			-757.77	2415.16	-.00
MEMBRANE	17	1	33.73	-229.12	-.00
BENDING			931.50	-3103.30	-.00
+T/2 SIDE			965.75	-3332.44	-.00
-T/2 SIDE			-898.24	2874.20	-.00
MEMBRANE	18	1	31.66	-235.53	-.00

BENDING			1056.79	-3522.64	-.00
+T/2 SIDE			1083.45	-3759.17	-.00
-T/2 SIDE			-1029.13	3264.11	-.00
MEMBRANE	19	1	29.96	-242.84	-.00
BENDING			1167.94	-3893.14	-.00
+T/2 SIDE			1197.90	-4135.98	-.00
-T/2 SIDE			-1137.98	3650.30	-.00
MEMBRANE	20	1	27.60	-248.00	-.00
BENDING			1264.07	-4213.58	-.00
+T/2 SIDE			1291.68	-4461.58	-.00
-T/2 SIDE			-1236.47	3965.57	.00
MEMBRANE	21	1	24.53	-252.05	-.00
BENDING			1344.76	-4482.54	-.00
+T/2 SIDE			1369.29	-4734.58	-.00
-T/2 SIDE			-1320.23	4230.49	.00
MEMBRANE	22	1	20.66	-254.86	-.00
BENDING			1409.68	-4698.92	-.00
+T/2 SIDE			1430.34	-4953.78	-.00
-T/2 SIDE			-1389.01	4444.06	.00
MEMBRANE	23	1	15.95	-255.45	-.00
BENDING			1458.59	-4861.96	-.00
+T/2 SIDE			1474.53	-5117.41	-.00
-T/2 SIDE			-1442.64	4606.51	.00
MEMBRANE	24	1	10.29	-256.76	-.00
BENDING			1491.30	-4971.01	-.00
+T/2 SIDE			1501.59	-5227.77	-.00
-T/2 SIDE			-1481.01	4714.25	.00
MEMBRANE	25	1	3.61	-255.76	-.00
BENDING			1507.72	-5025.73	-.00
+T/2 SIDE			1511.33	-5281.49	-.00
-T/2 SIDE			-1504.11	4769.97	-.00

Avg Memb = 168.75

LASTIC TEST CASE #1 8 POINTS

EGREES	BENDING	MEMBRANE	STRN1	STRN2
0.00	-6.634301E-03	4.000190E-04	-6.234282E-03	7.034320E-03
.25	-6.268086E-03	4.000190E-04	-5.868067E-03	6.668105E-03
.50	-5.918346E-03	4.000190E-04	-5.518327E-03	6.318365E-03
6.75	-5.583879E-03	4.000190E-04	-5.183860E-03	5.983898E-03
9.00	-5.263549E-03	4.000190E-04	-4.863530E-03	5.663568E-03
11.25	-4.956186E-03	4.000190E-04	-4.556167E-03	5.356205E-03
13.50	-4.660719E-03	4.000190E-04	-4.260700E-03	5.060738E-03
15.75	-4.376057E-03	4.000190E-04	-3.976038E-03	4.776075E-03
18.00	-4.101133E-03	4.000190E-04	-3.701114E-03	4.501152E-03
20.25	-3.834926E-03	4.000190E-04	-3.434907E-03	4.234945E-03
22.50	-3.576409E-03	4.000190E-04	-3.176390E-03	3.976428E-03
24.75	-3.324584E-03	4.000190E-04	-2.924565E-03	3.724603E-03
27.00	-3.078463E-03	4.000190E-04	-2.678444E-03	3.478481E-03
29.25	-2.837081E-03	4.000190E-04	-2.437062E-03	3.237099E-03
31.50	-2.599470E-03	4.000190E-04	-2.199451E-03	2.999488E-03
33.75	-2.364710E-03	4.000190E-04	-1.964692E-03	2.764729E-03
36.00	-2.131859E-03	4.000190E-04	-1.731840E-03	2.531878E-03
38.25	-1.900009E-03	4.000190E-04	-1.499990E-03	2.300028E-03
40.50	-1.668246E-03	4.000190E-04	-1.268227E-03	2.068265E-03
42.75	-1.435734E-03	4.000190E-04	-1.035715E-03	1.835753E-03
45.00	-1.201549E-03	4.000190E-04	-8.015301E-04	1.601568E-03
47.25	-7.529497E-04	4.000190E-04	-3.529307E-04	1.152969E-03
49.50	-2.976182E-04	4.000190E-04	1.024008E-04	6.976372E-04
51.75	1.657069E-04	4.000190E-04	5.657259E-04	2.343120E-04
54.00	6.381909E-04	4.000190E-04	1.038210E-03	-2.381719E-04
56.25	1.120982E-03	4.000190E-04	1.521001E-03	-7.209627E-04
58.50	1.615035E-03	4.000190E-04	2.015054E-03	-1.215016E-03
.75	2.121250E-03	4.000190E-04	2.521269E-03	-1.721231E-03
.00	2.640456E-03	4.000190E-04	3.040475E-03	-2.240437E-03
65.25	3.173239E-03	4.000190E-04	3.573258E-03	-2.773220E-03
67.50	3.720150E-03	4.000190E-04	4.120169E-03	-3.320131E-03
69.75	4.281516E-03	4.000190E-04	4.681535E-03	-3.881497E-03
72.00	4.857521E-03	4.000190E-04	5.257540E-03	-4.457502E-03
74.25	5.448140E-03	4.000190E-04	5.848159E-03	-5.048121E-03
76.50	6.053146E-03	4.000190E-04	6.453164E-03	-5.653127E-03
78.75	6.672157E-03	4.000190E-04	7.072176E-03	-6.272139E-03
81.00	7.304504E-03	4.000190E-04	7.704522E-03	-6.904485E-03
83.25	7.949347E-03	4.000190E-04	8.349366E-03	-7.549328E-03
85.50	8.605578E-03	4.000190E-04	9.005597E-03	-8.205559E-03
87.75	9.271880E-03	4.000190E-04	9.671899E-03	-8.871861E-03
90.00	9.946739E-03	4.000190E-04	1.034676E-02	-9.546720E-03
92.25	9.271880E-03	4.000190E-04	9.671899E-03	-8.871861E-03
94.50	8.605578E-03	4.000190E-04	9.005597E-03	-8.205559E-03
96.75	7.949347E-03	4.000190E-04	8.349366E-03	-7.549328E-03
99.00	7.304498E-03	4.000190E-04	7.704517E-03	-6.904479E-03
01.25	6.672157E-03	4.000190E-04	7.072176E-03	-6.272139E-03
03.50	6.053146E-03	4.000190E-04	6.453164E-03	-5.653127E-03
05.75	5.448134E-03	4.000190E-04	5.848153E-03	-5.048115E-03
08.00	4.857521E-03	4.000190E-04	5.257540E-03	-4.457502E-03
10.25	4.281516E-03	4.000190E-04	4.681535E-03	-3.881497E-03
12.50	3.720150E-03	4.000190E-04	4.120169E-03	-3.320131E-03
14.75	3.173239E-03	4.000190E-04	3.573258E-03	-2.773220E-03
17.00	2.640450E-03	4.000190E-04	3.040469E-03	-2.240431E-03
.25	2.121250E-03	4.000190E-04	2.521269E-03	-1.721231E-03
21.50	1.615029E-03	4.000190E-04	2.015048E-03	-1.215010E-03
23.75	1.120976E-03	4.000190E-04	1.520995E-03	-7.209571E-04
26.00	6.381909E-04	4.000190E-04	1.038210E-03	-2.381719E-04
28.25	1.657013E-04	4.000190E-04	5.657203E-04	2.343177E-04
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

7.25	.435739E-03	4.000190E-04	-1.035720E-03	35758E-03
9.50	-1.668252E-03	4.000190E-04	-1.268233E-03	2.068271E-03
41.75	-1.900014E-03	4.000190E-04	-1.499995E-03	2.300033E-03
44.00	-2.131864E-03	4.000190E-04	-1.731845E-03	2.531883E-03
6.25	-2.364716E-03	4.000190E-04	-1.964697E-03	2.764735E-03
48.50	-2.599475E-03	4.000190E-04	-2.199456E-03	2.999494E-03
75	-2.837081E-03	4.000190E-04	-2.437062E-03	3.237099E-03
00	-3.078463E-03	4.000190E-04	-2.678444E-03	3.478481E-03
55.25	-3.324584E-03	4.000190E-04	-2.924565E-03	3.724603E-03
57.50	-3.576409E-03	4.000190E-04	-3.176390E-03	3.976428E-03
59.75	-3.834937E-03	4.000190E-04	-3.434918E-03	4.234956E-03
62.00	-4.101133E-03	4.000190E-04	-3.701114E-03	4.501152E-03
64.25	-4.376068E-03	4.000190E-04	-3.976049E-03	4.776087E-03
66.50	-4.660719E-03	4.000190E-04	-4.260700E-03	5.060738E-03
68.75	-4.956186E-03	4.000190E-04	-4.556167E-03	5.356205E-03
71.00	-5.263544E-03	4.000190E-04	-4.863525E-03	5.663563E-03
73.25	-5.583873E-03	4.000190E-04	-5.183855E-03	5.983892E-03
75.50	-5.918340E-03	4.000190E-04	-5.518321E-03	6.318359E-03
77.75	-6.268075E-03	4.000190E-04	-5.868056E-03	6.668094E-03
80.00	-6.634290E-03	4.000190E-04	-6.234271E-03	7.034309E-03
82.25	-6.268075E-03	4.000190E-04	-5.868056E-03	6.668094E-03
84.50	-5.918340E-03	4.000190E-04	-5.518321E-03	6.318359E-03
86.75	-5.583873E-03	4.000190E-04	-5.183855E-03	5.983892E-03
89.00	-5.263544E-03	4.000190E-04	-4.863525E-03	5.663563E-03
91.25	-4.956186E-03	4.000190E-04	-4.556167E-03	5.356205E-03
93.50	-4.660719E-03	4.000190E-04	-4.260700E-03	5.060738E-03
95.75	-4.376062E-03	4.000190E-04	-3.976043E-03	4.776081E-03
8.00	-4.101135E-03	4.000190E-04	-3.701114E-03	4.501152E-03
00.25	-3.834926E-03	4.000190E-04	-3.434907E-03	4.234945E-03
2.50	-3.576409E-03	4.000190E-04	-3.176390E-03	3.976428E-03
04.75	-3.324584E-03	4.000190E-04	-2.924565E-03	3.724603E-03
07.00	-3.078463E-03	4.000190E-04	-2.678444E-03	3.478481E-03
25	-2.837081E-03	4.000190E-04	-2.437062E-03	3.237099E-03
50	-2.599475E-03	4.000190E-04	-2.199456E-03	2.999494E-03
13.75	-2.364716E-03	4.000190E-04	-1.964697E-03	2.764735E-03
16.00	-2.131864E-03	4.000190E-04	-1.731845E-03	2.531883E-03
18.25	-1.900014E-03	4.000190E-04	-1.499995E-03	2.300033E-03
20.50	-1.668252E-03	4.000190E-04	-1.268233E-03	2.068271E-03
22.75	-1.435739E-03	4.000190E-04	-1.035720E-03	1.835758E-03
25.00	-1.201555E-03	4.000190E-04	-8.015357E-04	1.601574E-03
27.25	-7.529497E-04	4.000190E-04	-3.529307E-04	1.152969E-03
29.50	-2.976182E-04	4.000190E-04	1.024008E-04	6.976372E-04
31.75	1.657013E-04	4.000190E-04	5.657203E-04	2.343177E-04
34.00	6.381909E-04	4.000190E-04	1.038210E-03	-2.381719E-04
36.25	1.120982E-03	4.000190E-04	1.521001E-03	-7.209627E-04
38.50	1.615029E-03	4.000190E-04	2.015048E-03	-1.215010E-03
40.75	2.121250E-03	4.000190E-04	2.521269E-03	-1.721231E-03
43.00	2.640456E-03	4.000190E-04	3.040475E-03	-2.240437E-03
45.25	3.173239E-03	4.000190E-04	3.573258E-03	-2.773220E-03
47.50	3.720150E-03	4.000190E-04	4.120169E-03	-3.320131E-03
49.75	4.281516E-03	4.000190E-04	4.681535E-03	-3.881497E-03
52.00	4.857521E-03	4.000190E-04	5.257540E-03	-4.457502E-03
54.25	5.448134E-03	4.000190E-04	5.848153E-03	-5.048115E-03
56.50	6.053146E-03	4.000190E-04	6.453164E-03	-5.653127E-03
58.75	6.672157E-03	4.000190E-04	7.072176E-03	-6.272139E-03
61.00	7.304498E-03	4.000190E-04	7.704517E-03	-6.904479E-03
63.25	7.949347E-03	4.000190E-04	8.349366E-03	-7.549328E-03
65.50	8.605578E-03	4.000190E-04	9.005597E-03	-8.205559E-03
75	9.271885E-03	4.000190E-04	9.671904E-03	-8.871866E-03
00	9.946739E-03	4.000190E-04	1.034676E-02	-9.546720E-03
72.25	9.271880E-03	4.000190E-04	9.671899E-03	-8.871861E-03
74.50	8.605571E-03	4.000190E-04	9.005590E-03	-8.205553E-03
76.75	7.949342E-03	4.000190E-04	8.349361E-03	-7.549323E-03
79.00	7.304498E-03	4.000190E-04	7.704517E-03	-6.904479E-03

[illegible].75	[illegible].445140E-0[illegible]	4.000190E-04	5.843159E-03	-[illegible]3121E-03
88.00	4.857521E-03	4.000190E-04	5.257540E-03	-4.457502E-03
90.25	4.281516E-03	4.000190E-04	4.681535E-03	-3.881497E-03
92.50	3.720156E-03	4.000190E-04	4.120175E-03	-3.320137E-03
94.75	3.173239E-03	4.000190E-04	3.573258E-03	-2.773220E-03
97.00	2.640456E-03	4.000190E-04	3.040475E-03	-2.240437E-03
[illegible].25	2.121250E-03	4.000190E-04	2.521269E-03	-1.721231E-03
[illegible].50	1.615041E-03	4.000190E-04	2.015060E-03	-1.215022E-03
03.75	1.120982E-03	4.000190E-04	1.521001E-03	-7.209627E-04
06.00	6.381909E-04	4.000190E-04	1.038210E-03	-2.381719E-04
08.25	1.657125E-04	4.000190E-04	5.657315E-04	2.343065E-04
10.50	-2.976182E-04	4.000190E-04	1.024008E-04	6.976372E-04
12.75	-7.529441E-04	4.000190E-04	-3.529251E-04	1.152963E-03
15.00	-1.201549E-03	4.000190E-04	-8.015301E-04	1.601568E-03
17.25	-1.435734E-03	4.000190E-04	-1.035715E-03	1.835753E-03
19.50	-1.668246E-03	4.000190E-04	-1.268227E-03	2.068265E-03
21.75	-1.900009E-03	4.000190E-04	-1.499990E-03	2.300028E-03
24.00	-2.131859E-03	4.000190E-04	-1.731840E-03	2.531878E-03
26.25	-2.364710E-03	4.000190E-04	-1.964692E-03	2.764729E-03
28.50	-2.599470E-03	4.000190E-04	-2.199451E-03	2.999488E-03
30.75	-2.837081E-03	4.000190E-04	-2.437062E-03	3.237099E-03
33.00	-3.078463E-03	4.000190E-04	-2.678444E-03	3.478481E-03
35.25	-3.324584E-03	4.000190E-04	-2.924565E-03	3.724603E-03
37.50	-3.576409E-03	4.000190E-04	-3.176390E-03	3.976428E-03
39.75	-3.834931E-03	4.000190E-04	-3.434912E-03	4.234950E-03
42.00	-4.101139E-03	4.000190E-04	-3.701120E-03	4.501157E-03
44.25	-4.376057E-03	4.000190E-04	-3.976038E-03	4.776075E-03
46.50	-4.660725E-03	4.000190E-04	-4.260706E-03	5.060744E-03
48.75	-4.956186E-03	4.000190E-04	-4.556167E-03	5.356205E-03
[illegible]1.00	-5.263549E-03	4.000190E-04	-4.863530E-03	5.663568E-03
[illegible]3.25	-5.583879E-03	4.000190E-04	-5.183860E-03	5.983898E-03
[illegible]5.50	-5.918346E-03	4.000190E-04	-5.518327E-03	6.318365E-03
[illegible].75	-6.268086E-03	4.000190E-04	-5.868067E-03	6.668105E-03

[illegible]CATION:

9.0000000E+01 DEGREES

ENDING STRAIN:

9.9467393E-03

EMBRANE STRAIN:

4.0001897E-04

TRAIN1:

1.0346758E-02

TRAIN2:

-9.5467204E-03

8 PTS

0° ROTATION

```
ELASTIC TEST           CASE #1
 0. DEGREES OF ROTATION
RADII:
              0.400
              0.388
              0.373
              0.388
              0.400
              0.388
              0.373
              0.388
LOCATION:
               9.0000000E+01 DEGREES
BENDING STRAIN:
               9.9501675E-03
MEMBPANE STRAIN:
               4.0285374E-04
STRAIN1:
               1.0353026E-02
STRAIN2:
              -9.5473090E-03

ELASTIC TEST           CASE #1
 5. DEGREES OF ROTATION
RADII:
              0.400
              0.385
              0.374
              0.390
              0.400
              0.385
              0.374
              0.390
LOCATION:
               9.0000000E+01 DEGREES
BENDING STRAIN:
               9.7740488E-03
MEMBRANE STRAIN:
               4.1255323E-04
STRAIN1:
               1.0186602E-02
STRAIN2:
              -9.3614953E-03

ELASTIC TEST           CASE #1
10. DEGREES OF ROTATION
RADII:
              0.400
              0.393
              0.374
              0.392
              0.400
              0.333
              0.374
              0.392
LOCATION:
               9.0000000E+01 DEGREES
BENDING STRAIN:
```

4.7965107E-04
STRAIN1:
9.4936043E-03
STRAIN2:
-8.5343421E-03

ELASTIC TEST CASE #1
15. DEGREES OF ROTATION
RADII:
0.399
0.381
0.375
0.394
0.399
0.381
0.375
0.394
LOCATION:
9.0000000E+01 DEGREES
BENDING STRAIN:
8.0012223E-03
MEMBRANE STRAIN:
4.8570233E-04
STRAIN1:
8.4869247E-03
STRAIN2:
-7.5155199E-03

ELASTIC TEST CASE #1
20. DEGREES OF ROTATION
RADII:
0.397
0.379
0.377
0.396
0.397
0.379
0.377
0.396
LOCATION:
9.0000000E+01 DEGREES
BENDING STRAIN:
6.7049639E-03
MEMBRANE STRAIN:
5.1664631E-04
STRAIN1:
7.2216154E-03
STRAIN2:
-6.1883228E-03

ELASTIC TEST CASE #1
25. DEGREES OF ROTATION
RADII:
0.396
0.377
0.379
0.397
0.396
0.377
0.379

BENDING STRAIN:
6.7049689E-03
MEMBRANE STRAIN:
5.1664631E-04
STRAIN1:
7.2216154E-03
STRAIN2:
-6.1883228E-03

ELASTIC TEST CASE #1
30. DEGREES OF ROTATION
RADII:
0.394
0.375
0.381
0.399
0.394
0.375
0.381
0.399
LOCATION:
4.5000000E+01 DEGREES
BENDING STRAIN:
8.0012158E-03
MEMBRANE STRAIN:
4.8580026E-04
STRAIN1:
8.4870160E-03
STRAIN2:
-7.5154155E-03

ELASTIC TEST CASE #1
35. DEGREES OF ROTATION
RADII:
0.392
0.374
0.383
0.400
0.392
0.374
0.383
0.400
LOCATION:
4.5000000E+01 DEGREES
BENDING STRAIN:
9.0139732E-03
MEMBRANE STRAIN:
4.7963107E-04
STRAIN1:
9.4936043E-03
STRAIN2:
-8.5343421E-03

ELASTIC TEST CASE #1
40. DEGREES OF ROTATION
RADII:
0.390
0.374
0.385
0.400

```
          1.400
LOCATION:
          2.2500000E+02 DEGREES
BENDING STRAIN:
          9.7740544E-03
MEMBRANE STRAIN:
          4.1265113E-04
STRAIN1:
          1.0186706E-02
STRAIN2:
         -9.3614031E-03
```

ELASTIC TEST CASE #1 50 POINTS

DEGREES	BENDING	MEMBRANE	STRN1	STRN2
[illegible].00	-6.489020E-03	5.154712E-04	-5.973549E-03	7.004491E-03
[illegible].44	-5.892175E-03	5.154712E-04	-5.376704E-03	6.407646E-03
2.88	-5.301022E-03	5.154712E-04	-4.785551E-03	5.816494E-03
4.32	-4.714768E-03	5.154712E-04	-4.199297E-03	5.230240E-03
5.76	-4.132633E-03	5.154712E-04	-3.617161E-03	4.648104E-03
7.20	-3.553890E-03	5.154712E-04	-3.038419E-03	4.069361E-03
8.64	-4.288987E-03	5.154712E-04	-3.773516E-03	4.804458E-03
10.08	-5.029163E-03	5.154712E-04	-4.513692E-03	5.544634E-03
11.52	-5.775286E-03	5.154712E-04	-5.259815E-03	6.290757E-03
12.96	-6.528243E-03	5.154712E-04	-6.012772E-03	7.043714E-03
14.40	-7.288918E-03	5.154712E-04	-6.773447E-03	7.804389E-03
15.84	-6.244308E-03	5.154712E-04	-5.728837E-03	6.759780E-03
17.28	-5.200707E-03	5.154712E-04	-4.685236E-03	5.716179E-03
18.72	-4.156505E-03	5.154712E-04	-3.641034E-03	4.671976E-03
20.16	-3.110148E-03	5.154712E-04	-2.594676E-03	3.625619E-03
21.60	-2.060161E-03	5.154712E-04	-1.544690E-03	2.575633E-03
23.04	-2.557642E-03	5.154712E-04	-2.042170E-03	3.073113E-03
24.48	-3.059807E-03	5.154712E-04	-2.544336E-03	3.575279E-03
25.92	-3.567083E-03	5.154712E-04	-3.051612E-03	4.082554E-03
27.36	-4.079924E-03	5.154712E-04	-3.564453E-03	4.595395E-03
28.80	-4.598779E-03	5.154712E-04	-4.083308E-03	5.114250E-03
30.24	-4.144233E-03	5.154712E-04	-3.628762E-03	4.659704E-03
31.68	-3.690206E-03	5.154712E-04	-3.174734E-03	4.205677E-03
33.12	-3.236026E-03	5.154712E-04	-2.720554E-03	3.751497E-03
34.56	-2.781053E-03	5.154712E-04	-2.265582E-03	3.296524E-03
36.00	-2.324644E-03	5.154712E-04	-1.809173E-03	2.840116E-03
[illegible].44	-1.957825E-03	5.154712E-04	-1.442354E-03	2.473296E-03
[illegible].88	-1.589245E-03	5.154712E-04	-1.073774E-03	2.104716E-03
40.32	-1.218404E-03	5.154712E-04	-7.029331E-04	1.733875E-03
41.76	-8.448733E-04	5.154712E-04	-3.294021E-04	1.360345E-03
43.20	-4.681649E-04	5.154712E-04	4.730633E-05	9.836361E-04
44.64	-7.329165E-04	5.154712E-04	-2.174453E-04	1.248388E-03
46.08	-9.996068E-04	5.154712E-04	-4.841356E-04	1.515078E-03
47.52	-1.268372E-03	5.154712E-04	-7.529010E-04	1.783843E-03
48.96	-1.579321E-03	5.154712E-04	-1.023849E-03	2.054792E-03
50.40	-1.812582E-03	5.154712E-04	-1.297111E-03	2.328054E-03
51.84	-5.705610E-04	5.154712E-04	-5.508983E-05	1.086032E-03
53.28	6.860272E-04	5.154712E-04	1.201498E-03	-1.705560E-04
54.72	1.958652E-03	5.154712E-04	2.474123E-03	-1.443181E-03
56.16	3.248550E-03	5.154712E-04	3.764022E-03	-2.733079E-03
57.60	4.556765E-03	5.154712E-04	5.072237E-03	-4.041294E-03
59.04	3.999581E-03	5.154712E-04	4.515052E-03	-3.484109E-03
60.48	3.440905E-03	5.154712E-04	3.956377E-03	-2.925434E-03
61.92	2.880750E-03	5.154712E-04	3.396221E-03	-2.365279E-03
63.36	2.319116E-03	5.154712E-04	2.834587E-03	-1.803645E-03
64.80	1.755970E-03	5.154712E-04	2.271441E-03	-1.240499E-03
66.24	2.236846E-03	5.154712E-04	2.752317E-03	-1.721374E-03
67.68	2.724292E-03	5.154712E-04	3.239763E-03	-2.208821E-03
69.12	3.218501E-03	5.154712E-04	3.733973E-03	-2.703030E-03
70.56	3.719624E-03	5.154712E-04	4.235095E-03	-3.204152E-03
72.00	4.227769E-03	5.154712E-04	4.743240E-03	-3.712297E-03
73.44	4.959382E-03	5.154712E-04	5.474853E-03	-4.443910E-03
[illegible].88	5.700131E-03	5.154712E-04	6.215602E-03	-5.184660E-03
[illegible].32	6.449959E-03	5.154712E-04	6.965430E-03	-5.934488E-03
77.76	7.209649E-03	5.154712E-04	7.724120E-03	-6.693178E-03
79.20	7.975909E-03	5.154712E-04	8.491380E-03	-7.460438E-03
80.64	8.079443E-03	5.154712E-04	8.594914E-03	-7.563972E-03
82.08	8.186431E-03	5.154712E-04	8.701902E-03	-7.670959E-03

[illegible].4	[illegible]	5.154712E-04	9.042508E-03	[illegible]
87.84	8.521524E-03	5.154712E-04	9.036995E-03	-[illegible].060535E-03
89.28	8.518756E-03	5.154712E-04	9.034228E-03	-8.003285E-03
90.72	8.518750E-03	5.154712E-04	9.034221E-03	-8.003279E-03
92.16	8.521507E-03	5.154712E-04	9.036978E-03	-8.006035E-03
93.60	8.527014E-03	5.154712E-04	9.042486E-03	-8.011543E-03
[illegible].04	8.410343E-03	5.154712E-04	8.925814E-03	-7.894872E-03
[illegible].48	8.296772E-03	5.154712E-04	8.812243E-03	-7.781301E-03
97.92	8.186460E-03	5.154712E-04	8.701931E-03	-7.670988E-03
99.36	8.079494E-03	5.154712E-04	8.594966E-03	-7.564023E-03
100.80	7.975976E-03	5.154712E-04	8.491447E-03	-7.460505E-03
102.24	7.208684E-03	5.154712E-04	7.724155E-03	-6.693212E-03
103.68	6.449954E-03	5.154712E-04	6.965425E-03	-5.934482E-03
105.12	5.700092E-03	5.154712E-04	6.215563E-03	-5.184621E-03
106.56	4.959308E-03	5.154712E-04	5.474779E-03	-4.443836E-03
108.00	4.227667E-03	5.154712E-04	4.743138E-03	-3.712196E-03
109.44	3.719550E-03	5.154712E-04	4.235021E-03	-3.204079E-03
110.88	3.218467E-03	5.154712E-04	3.733939E-03	-2.702996E-03
112.32	2.724297E-03	5.154712E-04	3.239768E-03	-2.208826E-03
113.76	2.236891E-03	5.154712E-04	2.752362E-03	-1.721419E-03
115.20	1.756037E-03	5.154712E-04	2.271509E-03	-1.240566E-03
116.64	2.319166E-03	5.154712E-04	2.834638E-03	-1.803695E-03
118.08	2.880755E-03	5.154712E-04	3.396227E-03	-2.365284E-03
119.52	3.440888E-03	5.154712E-04	3.956359E-03	-2.925416E-03
120.96	3.999535E-03	5.154712E-04	4.515007E-03	-3.484064E-03
122.40	4.556681E-03	5.154712E-04	5.072152E-03	-4.041209E-03
123.84	3.248511E-03	5.154712E-04	3.763982E-03	-2.733040E-03
125.28	1.958669E-03	5.154712E-04	2.474140E-03	-1.443197E-03
126.72	6.860889E-04	5.154712E-04	1.201560E-03	-1.706177E-04
128.16	-3.704603E-04	5.154712E-04	-5.498913E-05	1.085932E-03
129.60	-1.812449E-03	5.154712E-04	-1.296978E-03	2.327920E-03
131.04	-1.539231E-03	5.154712E-04	-1.023760E-03	2.054702E-03
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[illegible].92	-9.996236E-04	5.154712E-04	-4.841523E-04	1.515095E-03
135.36	-7.329724E-04	5.154712E-04	-2.175012E-04	1.248444E-03
136.80	-4.682656E-04	5.154712E-04	4.720566E-05	9.837368E-04
138.24	-8.449515E-04	5.154712E-04	-3.294803E-04	1.360423E-03
139.68	-1.218460E-03	5.154712E-04	-7.029891E-04	1.733931E-03
141.12	-1.589284E-03	5.154712E-04	-1.073813E-03	2.104755E-03
142.56	-1.957836E-03	5.154712E-04	-1.442365E-03	2.473307E-03
144.00	-2.324639E-03	5.154712E-04	-1.809168E-03	2.840110E-03
145.44	-2.781058E-03	5.154712E-04	-2.265587E-03	3.296530E-03
146.88	-3.236031E-03	5.154712E-04	-2.720560E-03	3.751502E-03
148.32	-3.690206E-03	5.154712E-04	-3.174734E-03	4.205677E-03
149.76	-4.144233E-03	5.154712E-04	-3.628762E-03	4.659704E-03
151.20	-4.598779E-03	5.154712E-04	-4.083308E-03	5.114250E-03
152.64	-4.079918E-03	5.154712E-04	-3.564447E-03	4.595390E-03
154.08	-3.567083E-03	5.154712E-04	-3.051612E-03	4.082554E-03
155.52	-3.059796E-03	5.154712E-04	-2.544325E-03	3.575268E-03
156.96	-2.557636E-03	5.154712E-04	-2.042165E-03	3.073107E-03
158.40	-2.060145E-03	5.154712E-04	-1.544673E-03	2.575616E-03
159.84	-3.110137E-03	5.154712E-04	-2.594665E-03	3.625608E-03
161.28	-4.156494E-03	5.154712E-04	-3.641023E-03	4.671965E-03
162.72	-5.200707E-03	5.154712E-04	-4.685236E-03	5.716179E-03
164.16	-6.244308E-03	5.154712E-04	-5.728837E-03	6.759780E-03
165.60	-7.288924E-03	5.154712E-04	-6.773453E-03	7.804395E-03
167.04	-6.528243E-03	5.154712E-04	-6.012772E-03	7.043714E-03
168.48	-5.775280E-03	5.154712E-04	-5.259809E-03	6.290752E-03
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172.80	-3.553868E-03	5.154712E-04	-3.038397E-03	4.069339E-03
174.24	-4.132627E-03	5.154712E-04	-3.617156E-03	4.648098E-03
175.68	-4.714774E-03	5.154712E-04	-4.199303E-03	5.230245E-03
177.12	-5.301050E-03	5.154712E-04	-4.785579E-03	5.816521E-03

181.44	-5.892202E-03	5.154712E-04	-5.376731E-03	6.407673E-03
182.88	-5.301044E-03	5.154712E-04	-4.785573E-03	5.816516E-03
184.32	-4.714774E-03	5.154712E-04	-4.199303E-03	5.230245E-03
185.76	-4.132627E-03	5.154712E-04	-3.617156E-03	4.648098E-03
187.20	-3.553868E-03	5.154712E-04	-3.038397E-03	4.069339E-03
188.64	-4.288970E-03	5.154712E-04	-3.773498E-03	4.804441E-03
190.08	-5.029151E-03	5.154712E-04	-4.513680E-03	5.544622E-03
191.52	-5.775280E-03	5.154712E-04	-5.259809E-03	6.290752E-03
192.96	-6.528249E-03	5.154712E-04	-6.012777E-03	7.043720E-03
194.40	-7.288929E-03	5.154712E-04	-6.773458E-03	7.804400E-03
195.84	-6.244308E-03	5.154712E-04	-5.728837E-03	6.759780E-03
197.28	-5.200702E-03	5.154712E-04	-4.685231E-03	5.716173E-03
198.72	-4.156483E-03	5.154712E-04	-3.641012E-03	4.671954E-03
200.16	-3.110114E-03	5.154712E-04	-2.594643E-03	3.625585E-03
201.60	-2.060111E-03	5.154712E-04	-1.544640E-03	2.575582E-03
203.04	-2.557625E-03	5.154712E-04	-2.042154E-03	3.073096E-03
204.48	-3.059824E-03	5.154712E-04	-2.544353E-03	3.575295E-03
205.92	-3.567133E-03	5.154712E-04	-3.051662E-03	4.082604E-03
207.36	-4.080002E-03	5.154712E-04	-3.564531E-03	4.595473E-03
208.80	-4.598890E-03	5.154712E-04	-4.083419E-03	5.114361E-03
210.24	-4.144311E-03	5.154712E-04	-3.628840E-03	4.659782E-03
211.68	-3.690239E-03	5.154712E-04	-3.174768E-03	4.205711E-03
213.12	-3.236020E-03	5.154712E-04	-2.720549E-03	3.751491E-03
214.56	-2.781003E-03	5.154712E-04	-2.265532E-03	3.296474E-03
216.00	-2.324561E-03	5.154712E-04	-1.809090E-03	2.840032E-03
217.44	-1.957752E-03	5.154712E-04	-1.442281E-03	2.473223E-03
218.88	-1.589195E-03	5.154712E-04	-1.073724E-03	2.104666E-03
220.32	-1.218371E-03	5.154712E-04	-7.028996E-04	1.733842E-03
221.76	-8.448677E-04	5.154712E-04	-3.293965E-04	1.360339E-03
223.20	-4.681649E-04	5.154712E-04	4.730633E-05	9.836361E-04
224.64	-7.329222E-04	5.154712E-04	-2.174510E-04	1.248393E-03
226.08	-9.996012E-04	5.154712E-04	-4.841300E-04	1.515072E-03
227.52	-1.268366E-03	5.154712E-04	-7.528953E-04	1.783838E-03
228.96	-1.539304E-03	5.154712E-04	-1.023833E-03	2.054775E-03
230.40	-1.812577E-03	5.154712E-04	-1.297106E-03	2.328048E-03
231.84	-5.705610E-04	5.154712E-04	-5.508983E-05	1.086032E-03
233.28	6.860215E-04	5.154712E-04	1.201493E-03	-1.705503E-04
234.72	1.958635E-03	5.154712E-04	2.474106E-03	-1.443164E-03
236.16	3.248511E-03	5.154712E-04	3.763982E-03	-2.733040E-03
237.60	4.556720E-03	5.154712E-04	5.072191E-03	-4.041249E-03
239.04	3.999558E-03	5.154712E-04	4.515029E-03	-3.484087E-03
240.48	3.440906E-03	5.154712E-04	3.956377E-03	-2.925434E-03
241.92	2.880767E-03	5.154712E-04	3.396238E-03	-2.365295E-03
243.36	2.319155E-03	5.154712E-04	2.834626E-03	-1.803684E-03
244.80	1.756015E-03	5.154712E-04	2.271486E-03	-1.240544E-03
246.24	2.236885E-03	5.154712E-04	2.752356E-03	-1.721414E-03
247.68	2.724297E-03	5.154712E-04	3.239768E-03	-2.208826E-03
249.12	3.218490E-03	5.154712E-04	3.733961E-03	-2.703019E-03
250.56	3.719578E-03	5.154712E-04	4.235049E-03	-3.204107E-03
252.00	4.227712E-03	5.154712E-04	4.743183E-03	-3.712241E-03
253.44	4.959336E-03	5.154712E-04	5.474807E-03	-4.443865E-03
254.88	5.700097E-03	5.154712E-04	6.215568E-03	-5.184626E-03
256.32	6.449937E-03	5.154712E-04	6.965408E-03	-5.934466E-03
257.76	7.208649E-03	5.154712E-04	7.724120E-03	-6.693178E-03
259.20	7.975914E-03	5.154712E-04	8.491385E-03	-7.460442E-03
260.64	8.079449E-03	5.154712E-04	8.594920E-03	-7.563978E-03
262.08	8.186437E-03	5.154712E-04	8.701908E-03	-7.670966E-03
263.52	8.296772E-03	5.154712E-04	8.812243E-03	-7.781301E-03
264.96	8.410360E-03	5.154712E-04	8.925831E-03	-7.894889E-03
266.40	8.527048E-03	5.154712E-04	9.042519E-03	-8.011577E-03
267.84	8.521541E-03	5.154712E-04	9.037012E-03	-8.006070E-03
269.28	8.518773E-03	5.154712E-04	9.034244E-03	-8.003302E-03
270.72	8.518773E-03	5.154712E-04	9.034244E-03	-8.003302E-03
272.16	8.521541E-03	5.154712E-04	9.037012E-03	-8.006070E-03

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279.36	8.079449E-03	5.154712E-04	8.594920E-03	-7.563978E-03
280.80	7.975914E-03	5.154712E-04	8.491385E-03	-7.460442E-03
282.24	7.208649E-03	5.154712E-04	7.724120E-03	-6.693178E-03
283.68	6.449942E-03	5.154712E-04	6.965414E-03	-5.934471E-03
12	5.700397E-03	5.154712E-04	6.215568E-03	-5.184626E-03
56	4.959336E-03	5.154712E-04	5.474807E-03	-4.443865E-03
288.00	4.227712E-03	5.154712E-04	4.743183E-03	-3.712241E-03
289.44	3.719578E-03	5.154712E-04	4.235049E-03	-3.204107E-03
290.88	3.218490E-03	5.154712E-04	3.733961E-03	-2.703019E-03
292.32	2.724297E-03	5.154712E-04	3.239768E-03	-2.208826E-03
293.76	2.236885E-03	5.154712E-04	2.752356E-03	-1.721414E-03
295.20	1.756015E-03	5.154712E-04	2.271486E-03	-1.240544E-03
296.64	2.319155E-03	5.154712E-04	2.834626E-03	-1.803684E-03
298.08	2.880767E-03	5.154712E-04	3.396238E-03	-2.365295E-03
299.52	3.440905E-03	5.154712E-04	3.956377E-03	-2.925434E-03
300.96	3.999558E-03	5.154712E-04	4.515029E-03	-3.484087E-03
302.40	4.556720E-03	5.154712E-04	5.072191E-03	-4.041249E-03
303.84	3.248511E-03	5.154712E-04	3.763982E-03	-2.733040E-03
305.28	1.958635E-03	5.154712E-04	2.474106E-03	-1.443164E-03
306.72	6.860215E-04	5.154712E-04	1.201493E-03	-1.705503E-04
308.16	-5.705610E-04	5.154712E-04	-5.508983E-05	1.086032E-03
309.60	-1.812588E-03	5.154712E-04	-1.297117E-03	2.328059E-03
311.04	-1.539369E-03	5.154712E-04	-1.023838E-03	2.054781E-03
312.48	-1.268361E-03	5.154712E-04	-7.528897E-04	1.783832E-03
313.92	-9.995844E-04	5.154712E-04	-4.841132E-04	1.515056E-03
315.36	-7.329098E-04	5.154712E-04	-2.174285E-04	1.248371E-03
316.80	-4.681369E-04	5.154712E-04	4.733432E-05	9.836081E-04
318.24	-8.448565E-04	5.154712E-04	-3.293853E-04	1.360328E-03
319.68	-1.218399E-03	5.154712E-04	-7.029275E-04	1.733870E-03
321.12	-1.589245E-03	5.154712E-04	-1.073774E-03	2.104716E-03
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325.44	-2.781086E-03	5.154712E-04	-2.265615E-03	3.296558E-03
326.88	-3.236042E-03	5.154712E-04	-2.720571E-03	3.751514E-03
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329.76	-4.144233E-03	5.154712E-04	-3.628762E-03	4.659704E-03
331.20	-4.598762E-03	5.154712E-04	-4.083291E-03	5.114233E-03
332.64	-4.079907E-03	5.154712E-04	-3.564436E-03	4.595378E-03
334.08	-3.567083E-03	5.154712E-04	-3.051612E-03	4.082554E-03
335.52	-3.059802E-03	5.154712E-04	-2.544331E-03	3.575273E-03
336.96	-2.557647E-03	5.154712E-04	-2.042176E-03	3.073118E-03
338.40	-2.060167E-03	5.154712E-04	-1.544696E-03	2.575638E-03
339.84	-3.110137E-03	5.154712E-04	-2.594665E-03	3.625608E-03
341.28	-4.156483E-03	5.154712E-04	-3.641012E-03	4.671954E-03
342.72	-5.200674E-03	5.154712E-04	-4.685203E-03	5.716145E-03
344.16	-6.244265E-03	5.154712E-04	-5.728793E-03	6.759736E-03
345.60	-7.288851E-03	5.154712E-04	-6.773380E-03	7.804322E-03
347.04	-6.528204E-03	5.154712E-04	-6.012733E-03	7.043676E-03
348.48	-5.775286E-03	5.154712E-04	-5.259815E-03	6.290757E-03
349.92	-5.029185E-03	5.154712E-04	-4.513714E-03	5.544656E-03
351.36	-4.289025E-03	5.154712E-04	-3.773554E-03	4.804496E-03
352.80	-3.553968E-03	5.154712E-04	-3.038497E-03	4.069440E-03
354.24	-4.132699E-03	5.154712E-04	-3.617228E-03	4.648170E-03
355.68	-4.714819E-03	5.154712E-04	-4.199347E-03	5.230290E-03
357.12	-5.301061E-03	5.154712E-04	-4.785590E-03	5.816532E-03
358.56	-5.892192E-03	5.154712E-04	-5.376720E-03	6.407663E-03

LOCATION:
2.6640002E+02 DEGREES
BENDING STRAIN:
8.5278479E-03
MEMBRANE STRAIN:
5.1547121E-04

50. PTS.

RAIL .

-0.0115767E-03

50 PTS.

100 PTS.

LASTIC TEST CASE #1

EGREES	BENDING	MEMBRANE	STRN1	STRN2
.0	-4.343795E-03	5.032307E-04	-3.840565E-03	4.847026E-03
.6	-7.790279E-03	5.032307E-04	-7.287048E-03	8.293509E-03
7.2	2.530246E-03	5.032307E-04	3.033477E-03	-2.027016E-03
10.8	-1.335049E-02	5.032307E-04	-1.284726E-02	1.385372E-02
14.4	-4.833939E-03	5.032307E-04	-4.330708E-03	5.337169E-03
18.0	-1.917017E-03	5.032307E-04	-1.413786E-03	2.420248E-03
21.6	-8.853030E-04	5.032307E-04	-3.820722E-04	1.388534E-03
25.2	-8.990064E-03	5.032307E-04	-8.486833E-03	9.493295E-03
28.8	-1.242321E-03	5.032307E-04	-7.390905E-04	1.745552E-03
32.4	-3.014425E-03	5.032307E-04	-2.511194E-03	3.517656E-03
36.0	-5.276912E-03	5.032307E-04	-4.773682E-03	5.780143E-03
39.6	4.081985E-03	5.032307E-04	4.585216E-03	-3.578755E-03
43.2	-9.508678E-03	5.032307E-04	-9.005447E-03	1.001191E-02
46.8	1.083831E-02	5.032307E-04	1.134154E-02	-1.033508E-02
50.4	-1.120823E-02	5.032307E-04	-1.070500E-02	1.171146E-02
54.0	7.442737E-03	5.032307E-04	7.945968E-03	-6.939507E-03
57.6	1.090169E-03	5.032307E-04	1.593400E-03	-5.869381E-04
61.2	6.251762E-03	5.032307E-04	6.754993E-03	-5.748531E-03
64.8	-9.110202E-03	5.032307E-04	-8.606971E-03	9.613433E-03
68.4	2.210990E-02	5.032307E-04	2.261313E-02	-2.160667E-02
72.0	-1.263188E-02	5.032307E-04	-1.212864E-02	1.313511E-02
75.6	1.853932E-02	5.032307E-04	1.904255E-02	-1.803609E-02
79.2	3.663715E-03	5.032307E-04	4.166945E-03	-3.160484E-03
82.8	5.034669E-03	5.032307E-04	5.537900E-03	-4.531438E-03
86.4	1.408174E-02	5.032307E-04	1.458497E-02	-1.357851E-02
90.0	2.387226E-03	5.032307E-04	2.890456E-03	-1.883995E-03
.6	1.408173E-02	5.032307E-04	1.458496E-02	-1.357850E-02
.2	5.034686E-03	5.032307E-04	5.537917E-03	-4.531455E-03
100.8	3.663658E-03	5.032307E-04	4.166889E-03	-3.160428E-03
104.4	1.853951E-02	5.032307E-04	1.904275E-02	-1.803628E-02
108.0	-1.263200E-02	5.032307E-04	-1.212877E-02	1.313523E-02
111.6	2.210968E-02	5.032307E-04	2.261291E-02	-2.160645E-02
115.2	-9.109765E-03	5.032307E-04	-8.606734E-03	9.613195E-03
118.8	6.251689E-03	5.032307E-04	6.754920E-03	-5.748458E-03
122.4	1.090219E-03	5.032307E-04	1.593450E-03	-5.869884E-04
126.0	7.442613E-03	5.032307E-04	7.945843E-03	-6.939382E-03
129.6	-1.120320E-02	5.032307E-04	-1.070497E-02	1.171143E-02
133.2	1.083872E-02	5.032307E-04	1.134195E-02	-1.033549E-02
136.8	-9.509090E-03	5.032307E-04	-9.005859E-03	1.001232E-02
140.4	4.082127E-03	5.032307E-04	4.585357E-03	-3.578896E-03
144.0	-5.277057E-03	5.032307E-04	-4.773826E-03	5.780288E-03
147.6	-3.014291E-03	5.032307E-04	-2.511060E-03	3.517522E-03
151.2	-1.242394E-03	5.032307E-04	-7.391630E-04	1.745624E-03
154.8	-8.990059E-03	5.032307E-04	-8.486828E-03	9.493290E-03
158.4	-8.852585E-04	5.032307E-04	-3.820276E-04	1.388489E-03
162.0	-1.917056E-03	5.032307E-04	-1.413825E-03	2.420287E-03
165.6	-4.833928E-03	5.032307E-04	-4.330697E-03	5.337159E-03
169.2	-1.335050E-02	5.032307E-04	-1.284727E-02	1.385373E-02
172.8	2.530330E-03	5.032307E-04	3.033561E-03	-2.027100E-03
176.4	-7.790378E-03	5.032307E-04	-7.287147E-03	8.293608E-03
180.0	-4.343773E-03	5.032307E-04	-3.840543E-03	4.847004E-03
183.6	-7.790279E-03	5.032307E-04	-7.287048E-03	8.293509E-03
.2	2.530240E-03	5.032307E-04	3.033471E-03	-2.027010E-03
.8	-1.335047E-02	5.032307E-04	-1.284724E-02	1.385370E-02
194.4	-4.833928E-03	5.032307E-04	-4.330697E-03	5.337159E-03
198.0	-1.917045E-03	5.032307E-04	-1.413814E-03	2.420275E-03
201.6	-3.852918E-04	5.032307E-04	-3.820611E-04	1.388323E-03
205.2	-8.989927E-03	5.032307E-04	-8.486697E-03	9.493158E-03

216.0	[illegible]	[illegible]	-4.773909E-03	[illegible]03702E-03
219.6	[illegible].062002E-03	5.032307E-04	4.585233E-03	-3.[illegible]78772E-03
223.2	-9.508541E-03	5.032307E-04	-9.005310E-03	1.001177E-02
226.8	1.063813E-02	5.032307E-04	1.134136E-02	-1.033490E-02
230.4	-1.120305E-02	5.032307E-04	-1.070482E-02	1.171128E-02
234.0	7.442572E-03	5.032307E-04	7.945803E-03	-6.939341E-03
[illegible].6	1.090230E-03	5.032307E-04	1.593461E-03	-5.869997E-04
[illegible].2	6.251683E-03	5.032307E-04	6.754913E-03	-5.748452E-03
244.8	-9.109948E-03	5.032307E-04	-8.606717E-03	9.613179E-03
248.4	2.210962E-02	5.032307E-04	2.261285E-02	-2.160639E-02
252.0	-1.263181E-02	5.032307E-04	-1.212858E-02	1.313504E-02
255.6	1.853930E-02	5.032307E-04	1.904253E-02	-1.803607E-02
259.2	3.663715E-03	5.032307E-04	4.166945E-03	-3.160484E-03
262.8	5.034669E-03	5.032307E-04	5.537900E-03	-4.531438E-03
266.4	1.408174E-02	5.032307E-04	1.458497E-02	-1.357851E-02
270.0	2.387310E-03	5.032307E-04	2.890541E-03	-1.884079E-03
273.6	1.408171E-02	5.032307E-04	1.458494E-02	-1.357848E-02
277.2	5.034681E-03	5.032307E-04	5.537912E-03	-4.531450E-03
280.8	3.663715E-03	5.032307E-04	4.166945E-03	-3.160484E-03
284.4	1.853930E-02	5.032307E-04	1.904253E-02	-1.803607E-02
288.0	-1.263181E-02	5.032307E-04	-1.212858E-02	1.313504E-02
291.6	2.210962E-02	5.032307E-04	2.261285E-02	-2.160639E-02
295.2	-9.109948E-03	5.032307E-04	-8.606717E-03	9.613179E-03
298.8	6.251683E-03	5.032307E-04	6.754913E-03	-5.748452E-03
302.4	1.090230E-03	5.032307E-04	1.593461E-03	-5.869997E-04
306.0	7.442572E-03	5.032307E-04	7.945803E-03	-6.939341E-03
309.6	-1.120305E-02	5.032307E-04	-1.070482E-02	1.171128E-02
313.2	1.063813E-02	5.032307E-04	1.134136E-02	-1.033490E-02
316.8	-9.508530E-03	5.032307E-04	-9.005299E-03	1.001176E-02
320.4	4.061974E-03	5.032307E-04	4.535205E-03	-3.578743E-03
324.0	-5.277016E-03	5.032307E-04	-4.773787E-03	5.780248E-03
327.6	-3.014302E-03	5.032307E-04	-2.511072E-03	3.517533E-03
[illegible].2	-1.242388E-03	5.032307E-04	-7.391574E-04	1.745619E-03
[illegible].8	-8.990059E-03	5.032307E-04	-8.486828E-03	9.493290E-03
338.4	-8.852304E-04	5.032307E-04	-3.819996E-04	1.388461E-03
342.0	-1.917162E-03	5.032307E-04	-1.413931E-03	2.420393E-03
345.6	-4.833539E-03	5.032307E-04	-4.330309E-03	5.336770E-03
349.2	-1.335096E-02	5.032307E-04	-1.284773E-02	1.385419E-02
352.8	2.530376E-03	5.032307E-04	3.033607E-03	-2.027145E-03
356.4	-7.790301E-03	5.032307E-04	-7.287070E-03	8.293532E-03

OCATION:
6.8399994E+01 DEGREES
ENDING STRAIN:
2.2109898E-02
EMBRANE STRAIN:
5.0323072E-04
TRAIN1:
2.2613129E-02
TRAIN2:
-2.1606667E-02

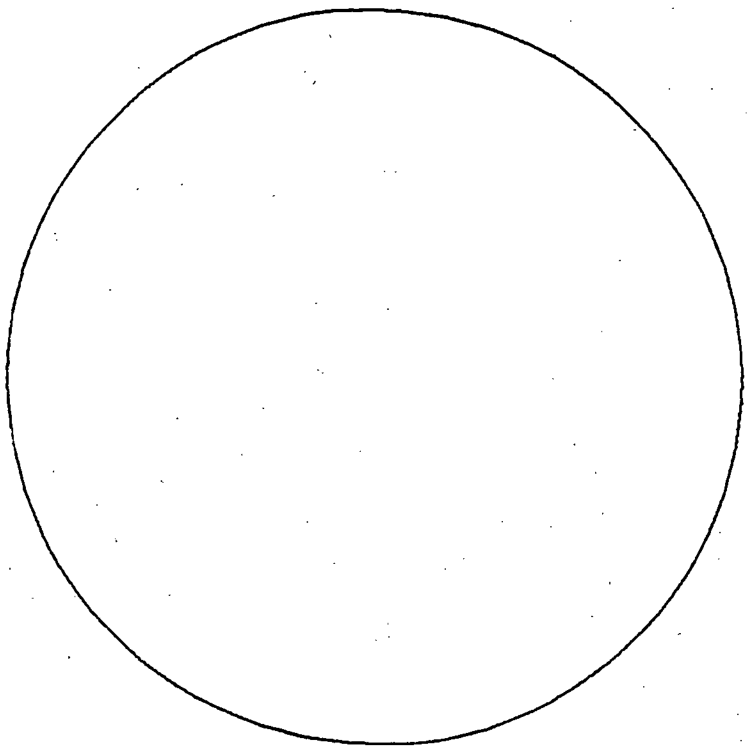
100 PTS.

APPENDIX B

STRAIN PREDICTION PROGRAM PLOTS
ELASTIC TEST CASE 1

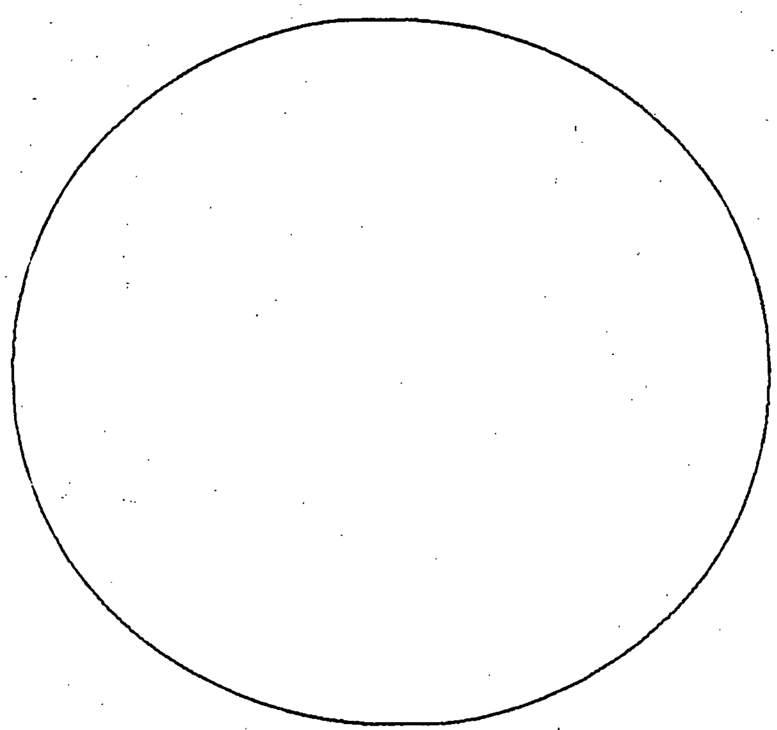
ELASTIC TEST
CASE #1

100 POINTS



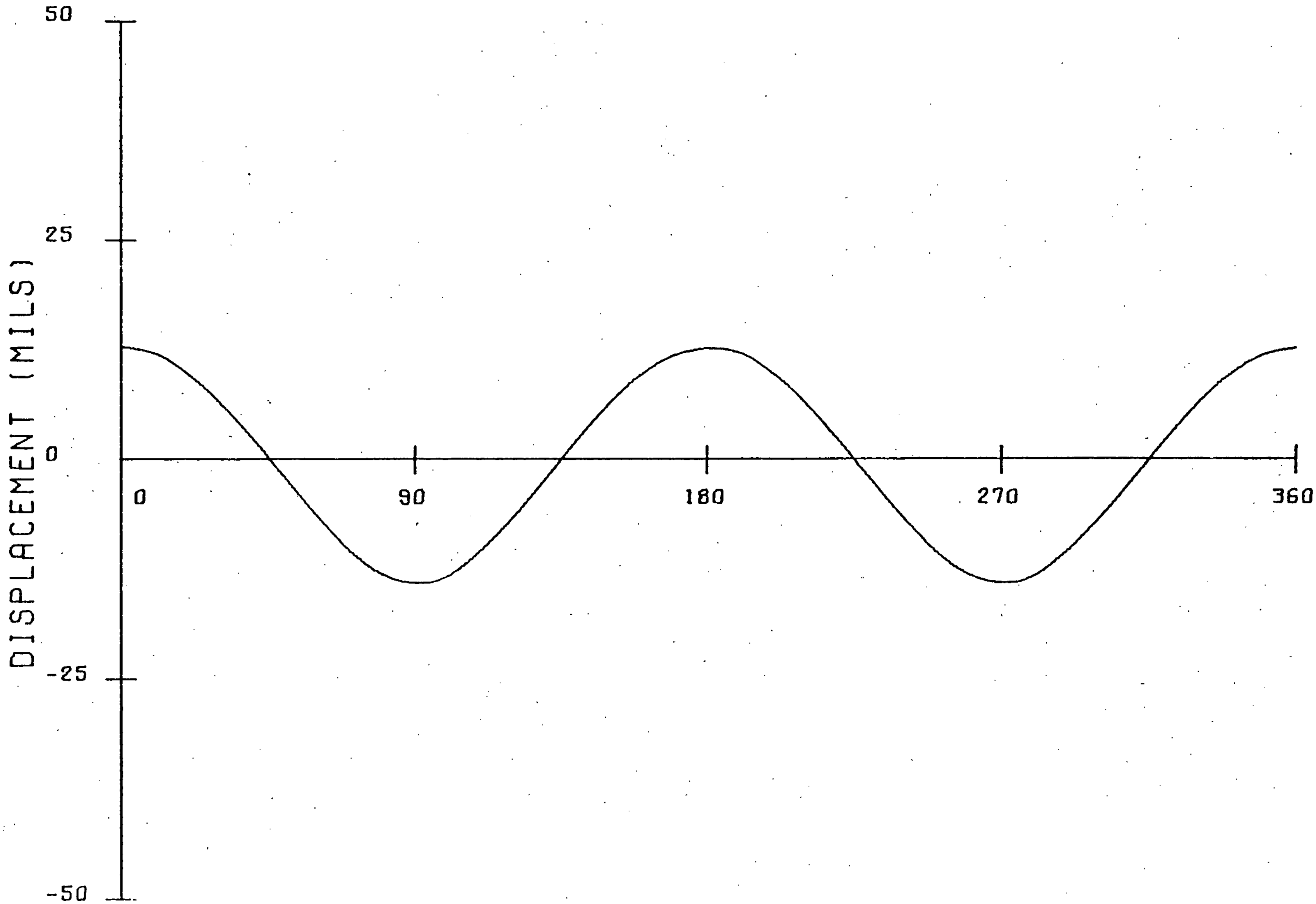
INITIAL SHAPE

ELASTIC TEST
CASE #1
100 POINTS



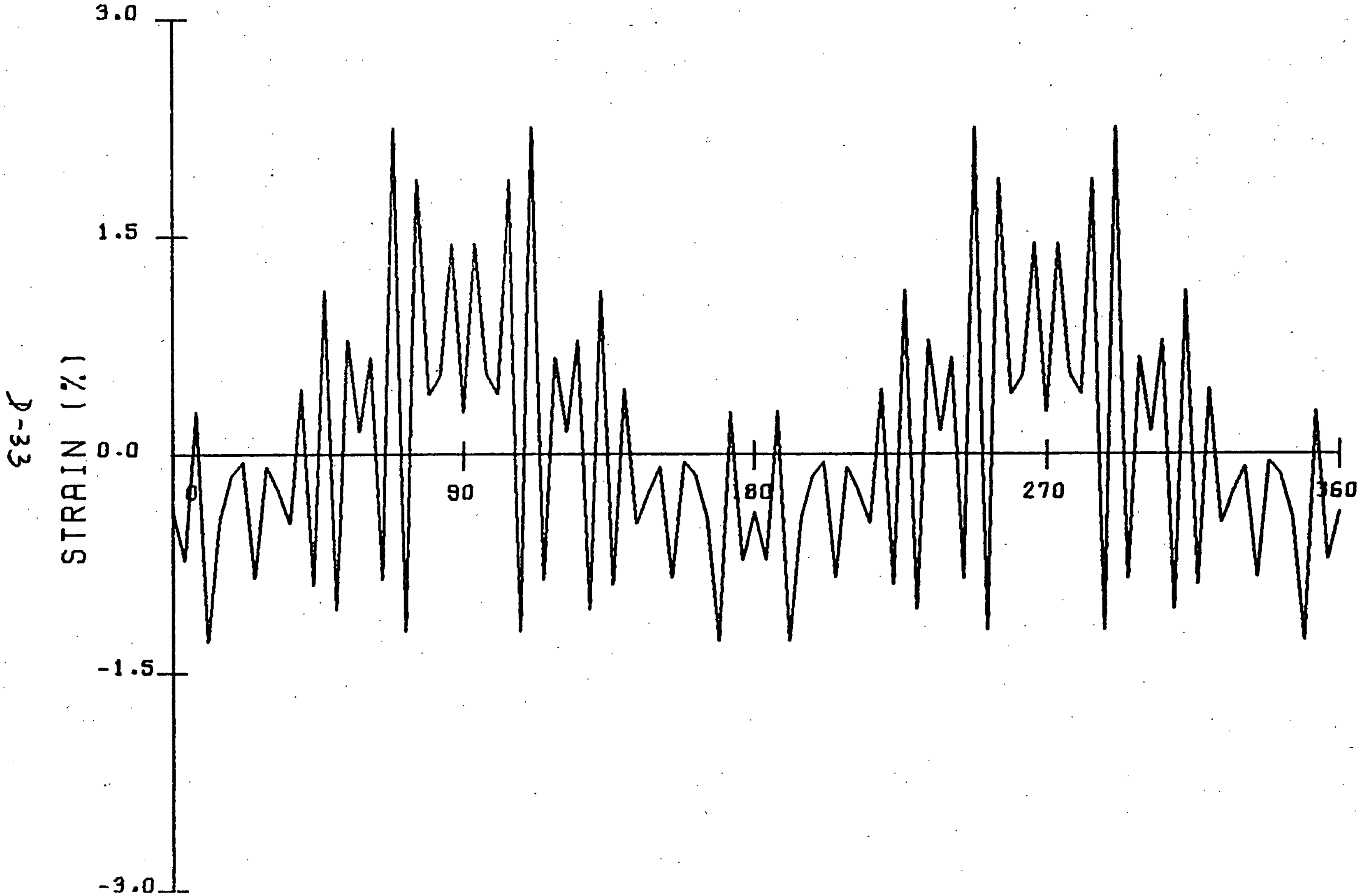
DIFFERENCE SHAPE

ELASTIC TEST
CASE #1
100 POINTS



DIFFERENCE SHAPE

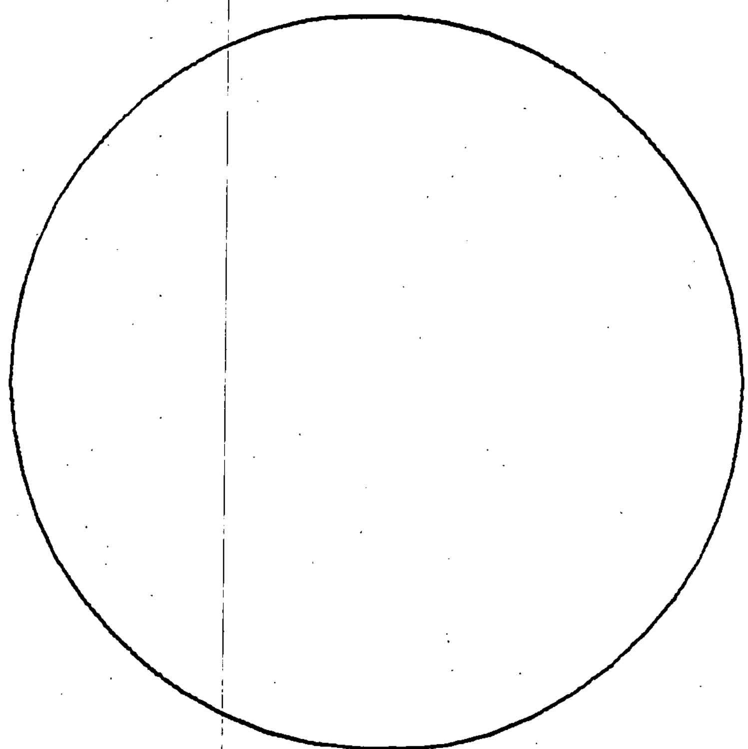
ELASTIC TEST
CASE #1



CALCULATED STRAIN

ELASTIC TEST
CASE #1

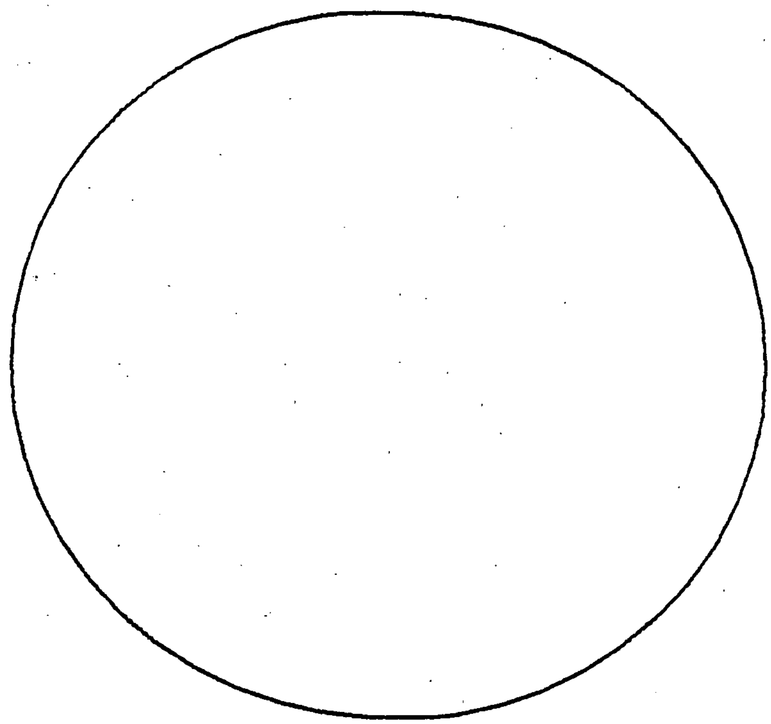
50 POINTS



INITIAL SHAPE

ELASTIC TEST
CASE #1

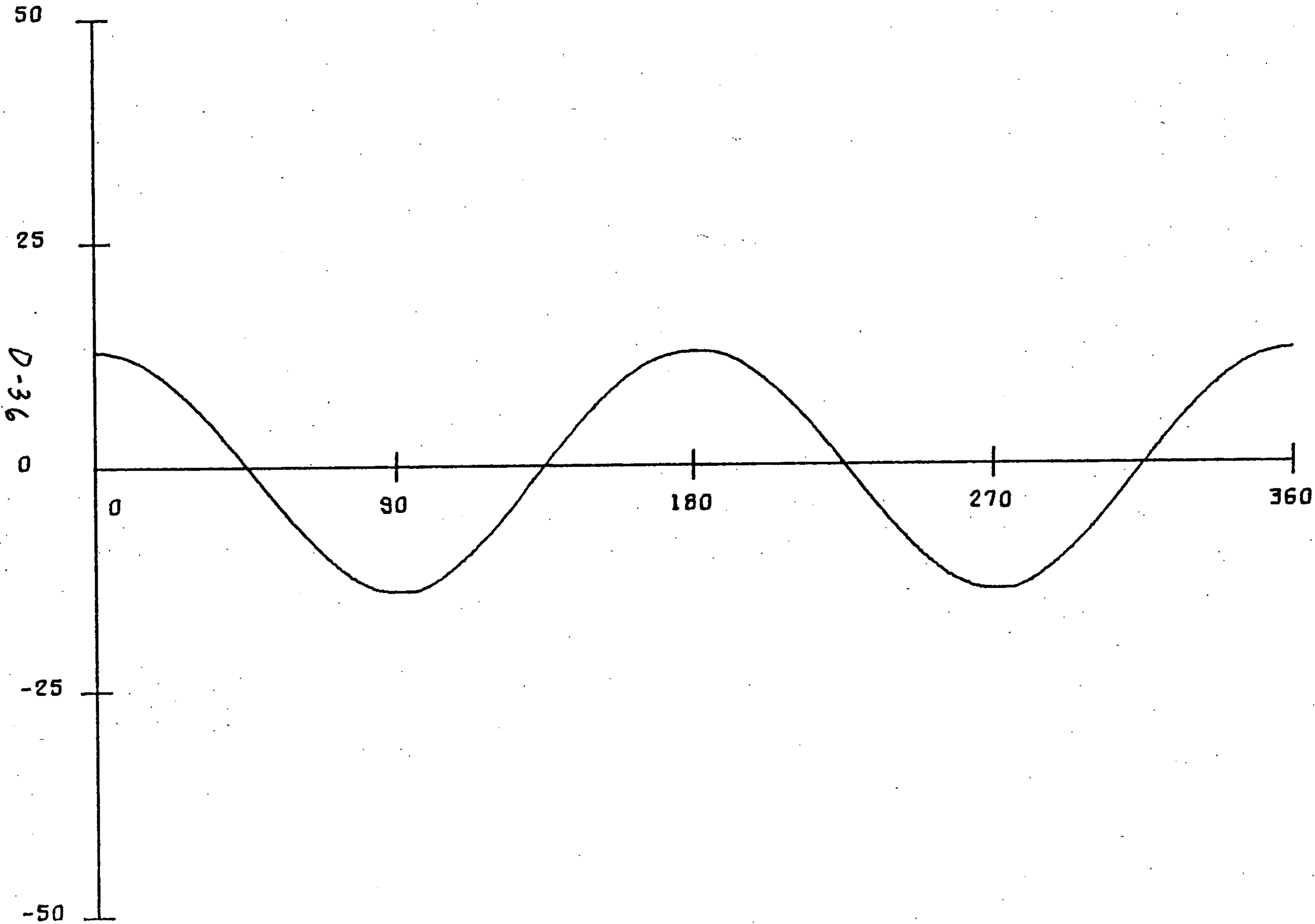
50 POINTS



DIFFERENCE SHAPE

ELASTIC TEST
CASE #1

50 POINTS

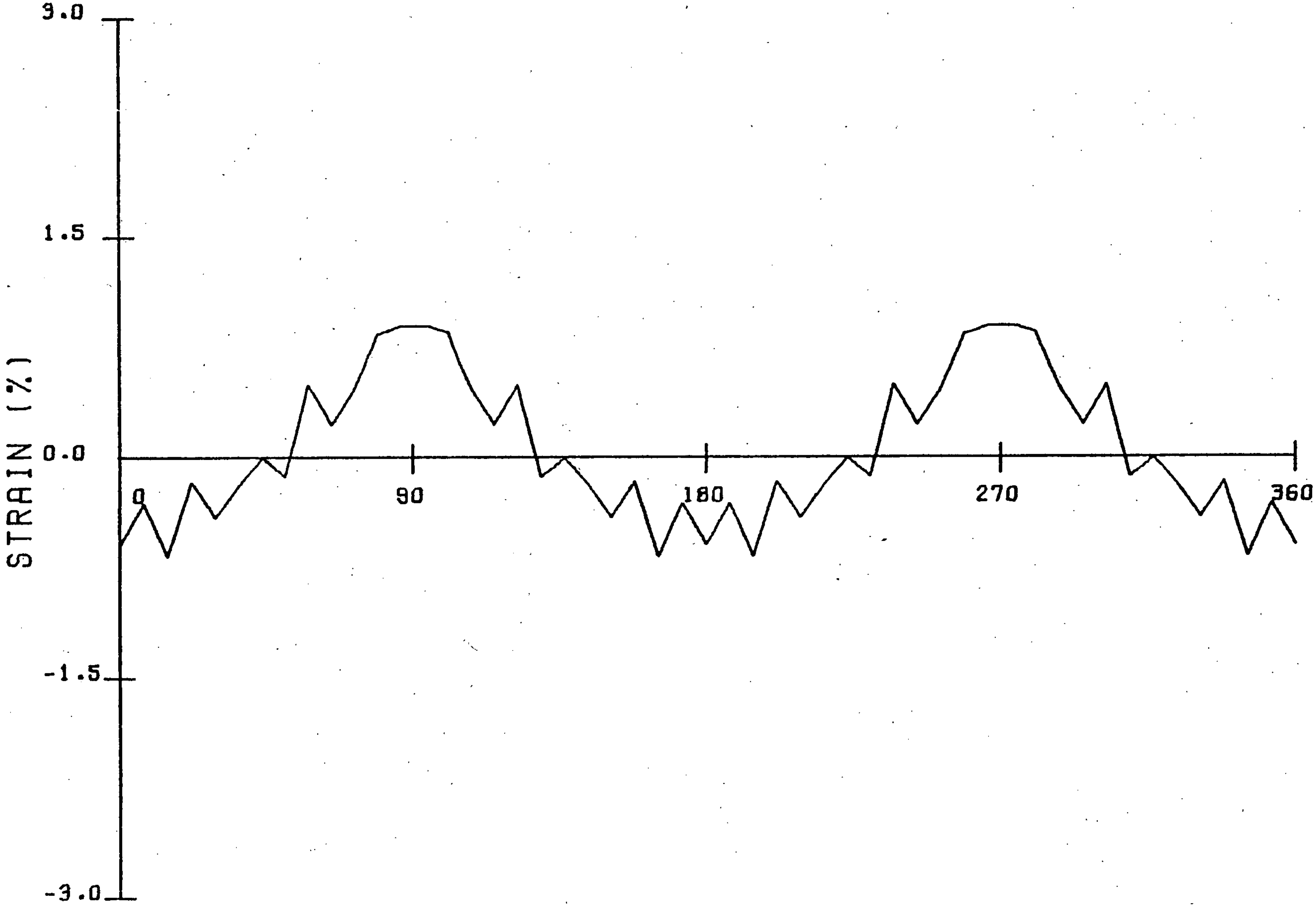


DIFFERENCE SHAPE

D-36

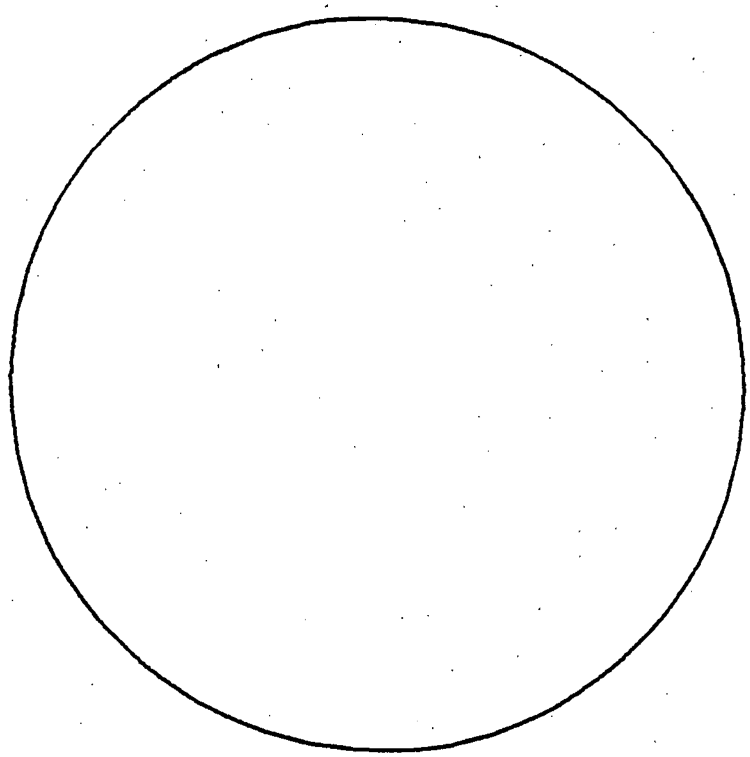
ELASTIC TEST
CASE #1

50 POINTS



CALCULATED STRAIN

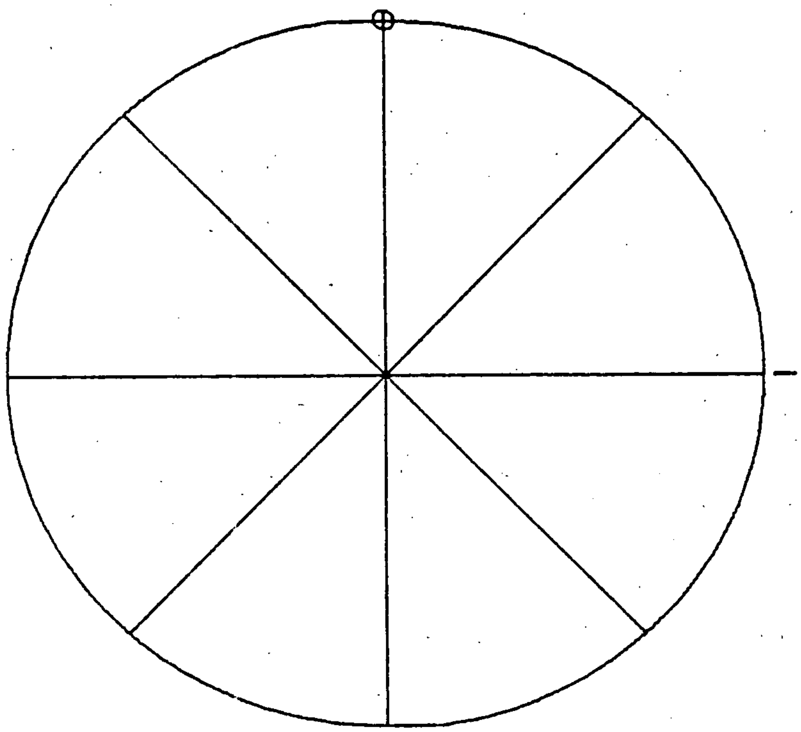
ELASTIC TEST
CASE #1



INITIAL SHAPE

ELASTIC TEST
CASE #1

0 DEGREES ROTATION

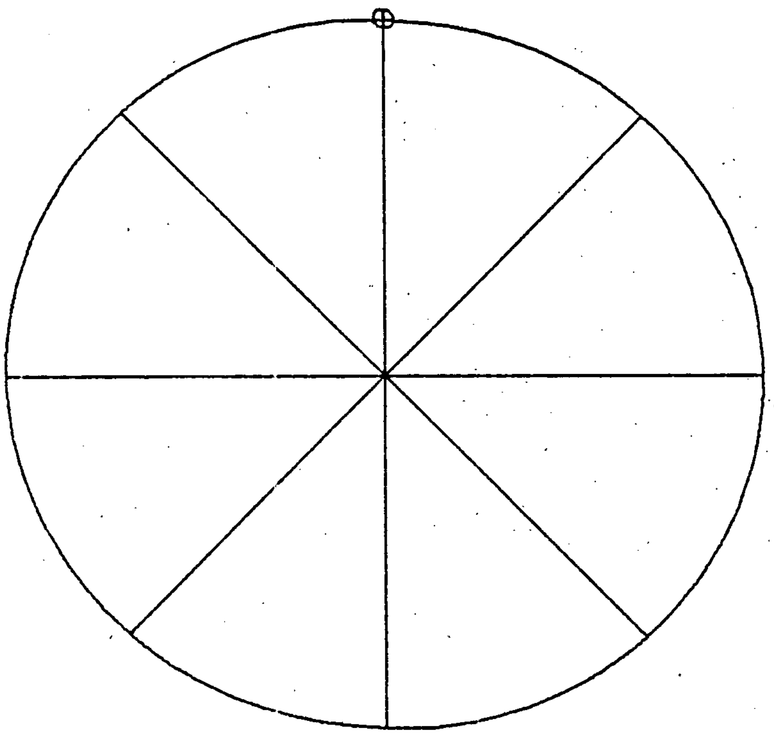


RADII
0.400
0.388
0.373
0.388
0.400
0.388
0.373
0.388

MEMBRANE STRAIN
0.000
BENDING STRAIN
0.010

ELASTIC TEST
CASE #1

5 DEGREES ROTATION

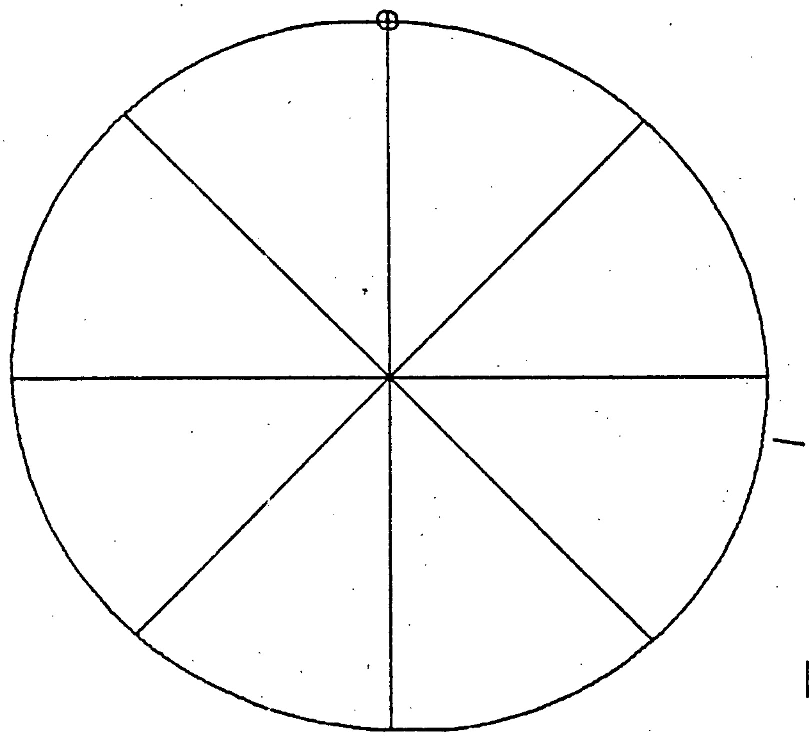


RADII
0.400
0.385
0.374
0.390
0.400
0.385
0.374
0.390

MEMBRANE STRAIN
0.000
BENDING STRAIN
0.010

ELASTIC TEST
CASE #1

10 DEGREES ROTATION

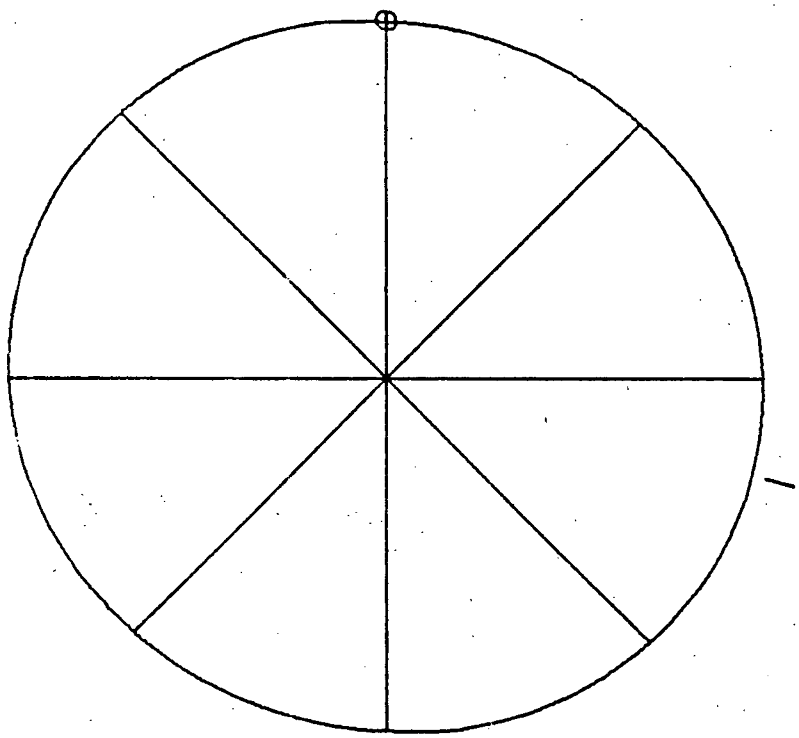


RADII
0.400
0.383
0.374
0.392
0.400
0.383
0.374
0.392

MEMBRANE STRAIN
0.000
BENDING STRAIN
0.009

ELASTIC TEST
CASE #1

15 DEGREES ROTATION

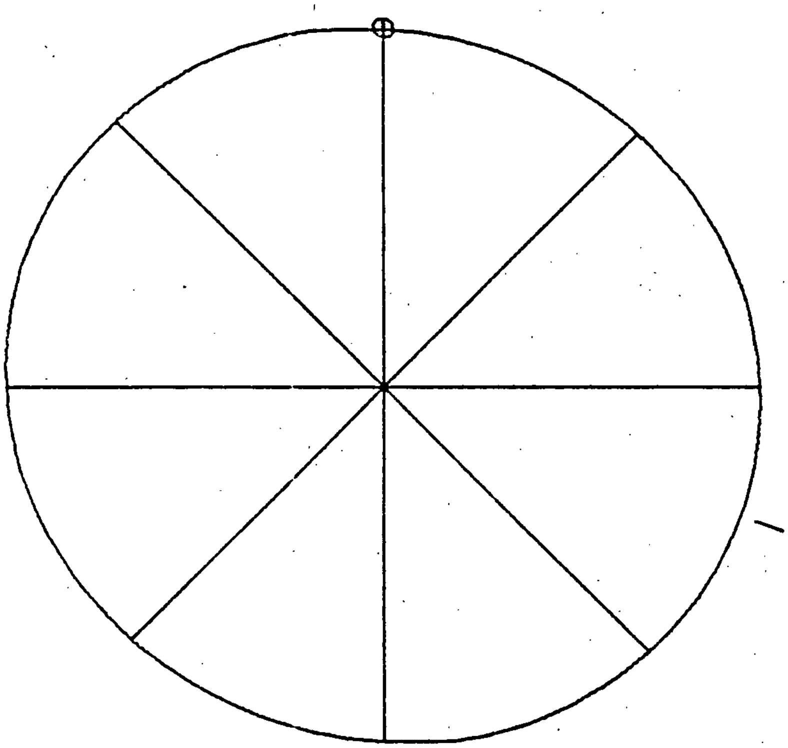


RADII
0.399
0.381
0.375
0.394
0.399
0.381
0.375
0.394

MEMBRANE STRAIN
0.000
BENDING STRAIN
0.008

ELASTIC TEST
CASE #1

20 DEGREES ROTATION

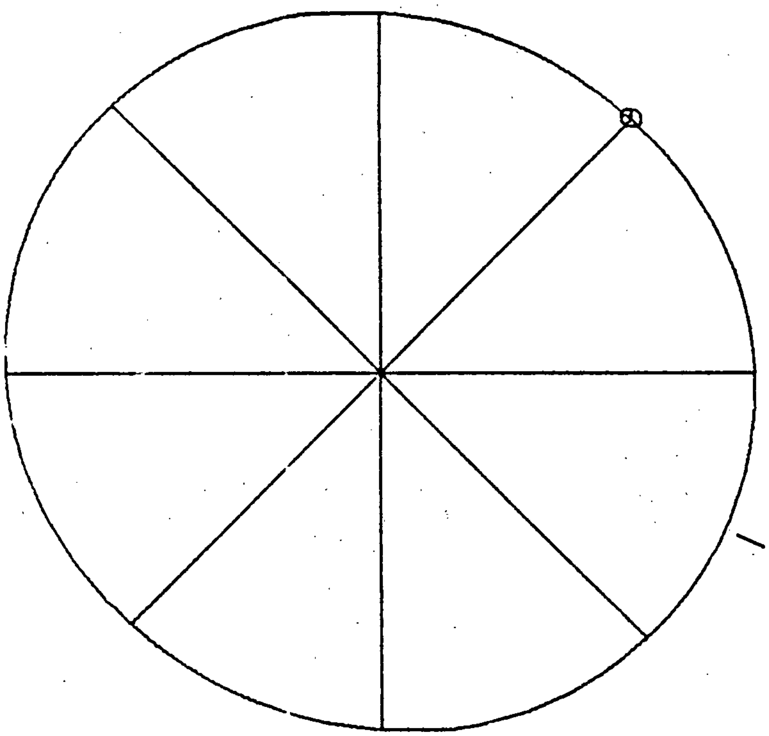


RADII
0.397
0.379
0.377
0.396
0.397
0.379
0.377
0.396

MEMBRANE STRAIN
0.001
BENDING STRAIN
0.007

ELASTIC TEST
CASE #1

25 DEGREES ROTATION



RADII

0.396
0.377
0.379
0.397
0.396
0.377
0.379
0.397

MEMBRANE STRAIN

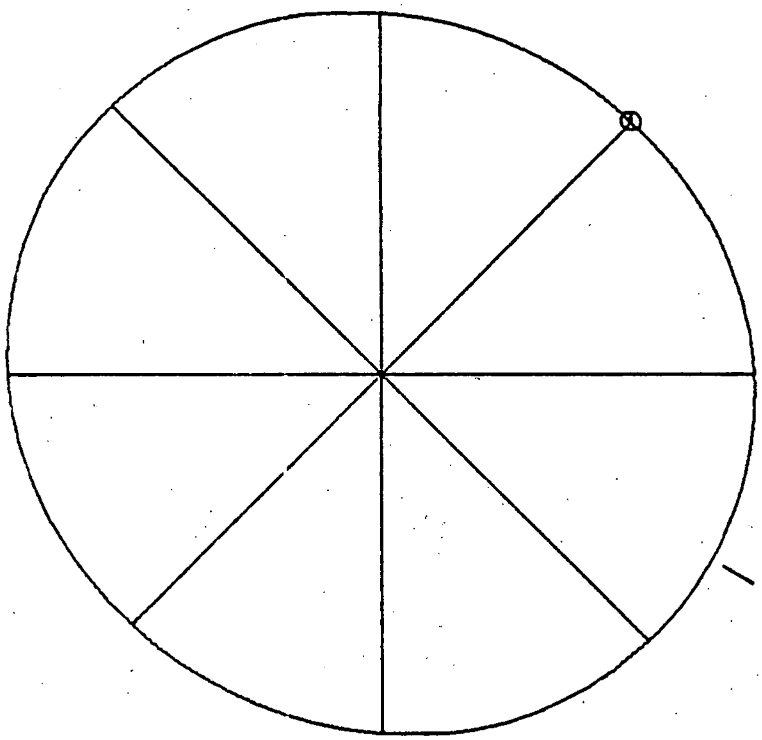
0.001

BENDING STRAIN

0.007

ELASTIC TEST
CASE #1

30 DEGREES ROTATION

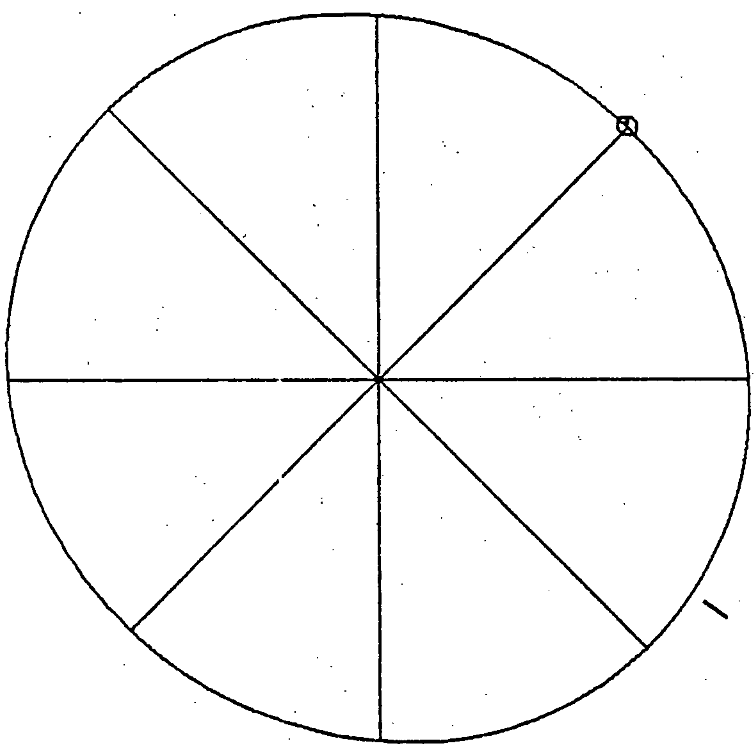


RADII
0.394
0.375
0.381
0.399
0.394
0.375
0.381
0.399

MEMBRANE STRAIN
0.000
BENDING STRAIN
0.008

ELASTIC TEST
CASE #1

35 DEGREES ROTATION

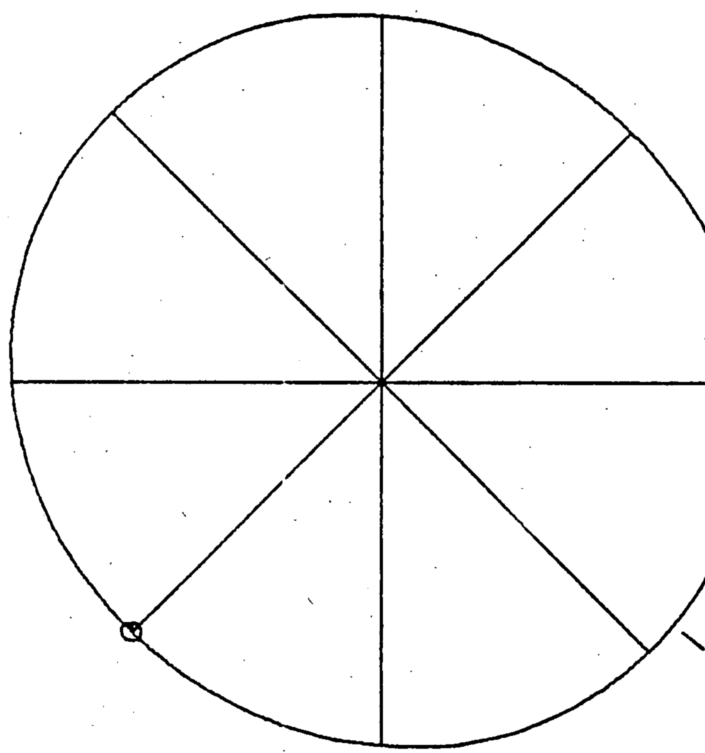


RADII
0.392
0.374
0.383
0.400
0.392
0.374
0.383
0.400

MEMBRANE STRAIN
0.000
BENDING STRAIN
0.009

ELASTIC TEST
CASE #1

40 DEGREES ROTATION

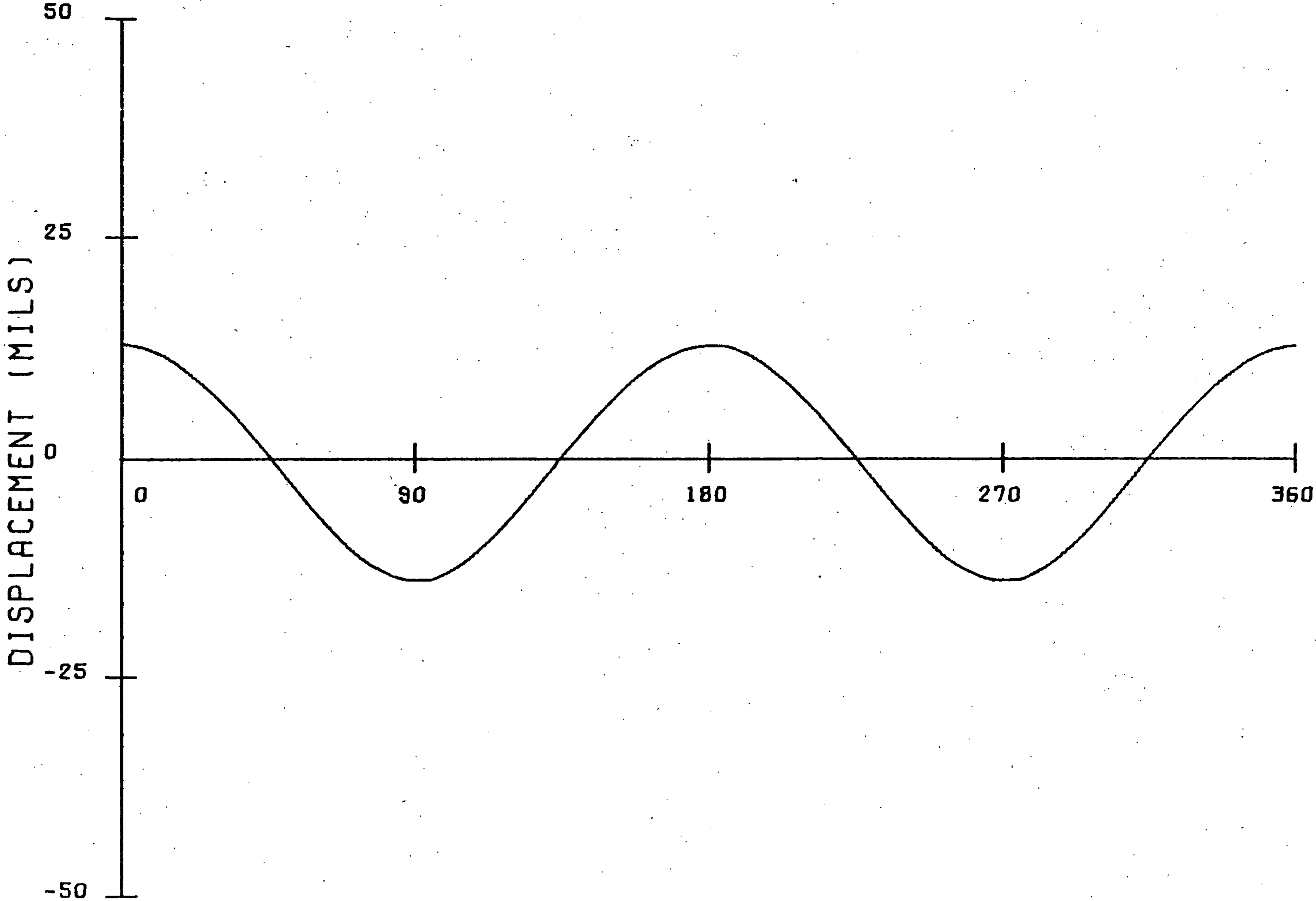


RADII
0.390
0.374
0.385
0.400
0.390
0.374
0.385
0.400

MEMBRANE STRAIN
0.000
BENDING STRAIN
0.010

ELASTIC TEST
CASE #1

8 POINTS

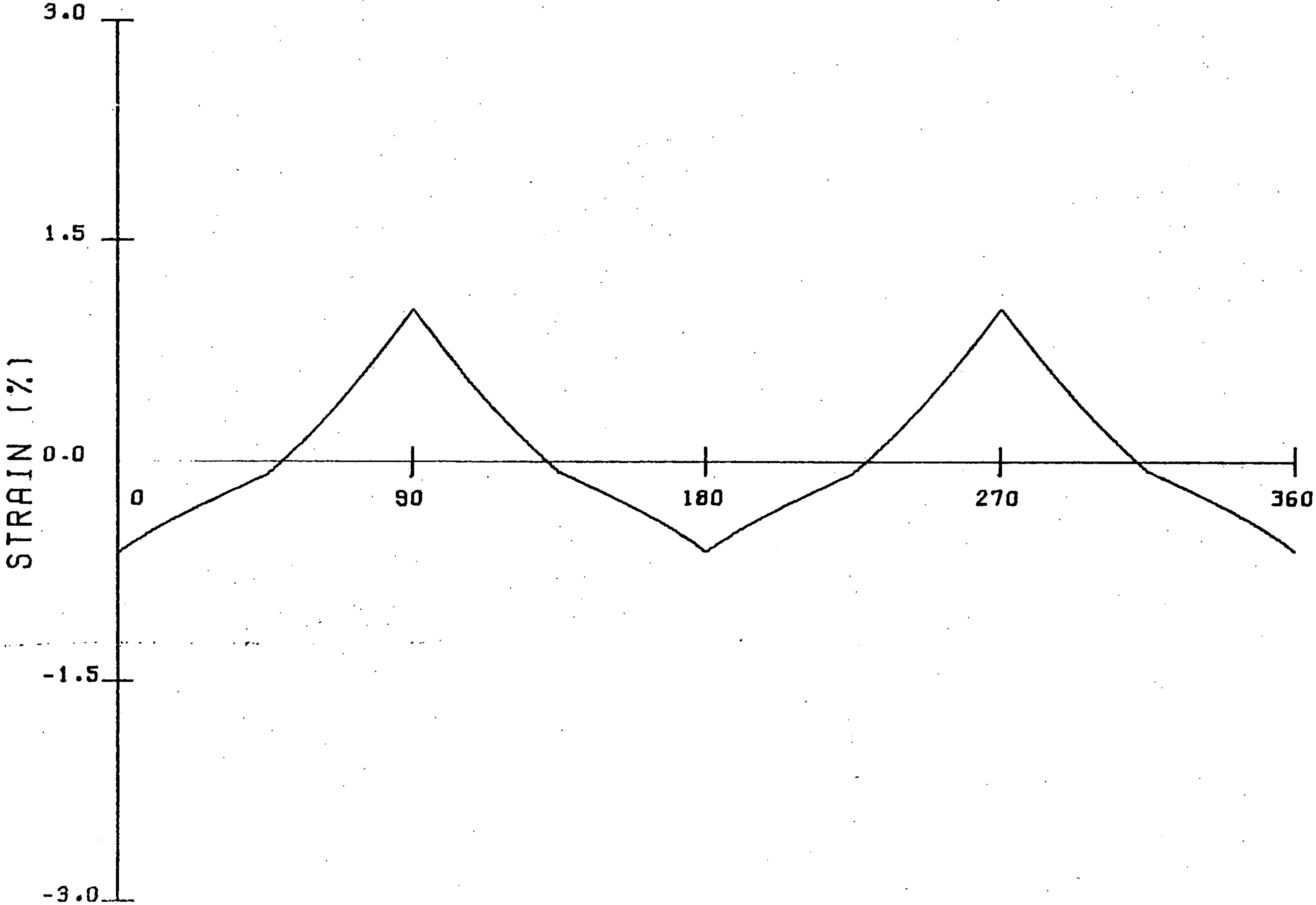


DIFFERENCE SHAPE

D-48

ELASTIC TEST
CASE #1

8 POINTS



CALCULATED STRAIN

APPENDIX C

COMPUTER PRINTOUTS - ELASTIC TEST CASE 2

FINITE ELEMENT RESULTS

STRAIN PREDICTION PROGRAM RESULTS

FINITE ELEMENT MODEL

.......NODE DISPLACEMENTS AND ROTATION

NODE	LOAD	X	Y	Z	XX	YY	ZZ
1	1	-1.284E-02	0.	0.	0.	0.	0.
2	1	-1.274E-02	3.050E-06	-1.651E-06	0.	0.	-7.91E-03
3	1	-1.244E-02	3.046E-05	-3.289E-06	0.	0.	-1.59E-02
4	1	-1.198E-02	1.031E-04	-4.899E-06	0.	0.	-2.13E-02
5	1	-1.137E-02	2.377E-04	-6.468E-06	0.	0.	-2.67E-02
6	1	-1.064E-02	4.465E-04	-7.981E-06	0.	0.	-3.14E-02
7	1	-9.826E-03	7.376E-04	-9.424E-06	0.	0.	-3.55E-02
8	1	-8.947E-03	1.115E-03	-1.078E-05	0.	0.	-3.84E-02
9	1	-8.029E-03	1.579E-03	-1.204E-05	0.	0.	-4.08E-02
10	1	-7.096E-03	2.127E-03	-1.319E-05	0.	0.	-4.23E-02
11	1	-6.172E-03	2.750E-03	-1.420E-05	0.	0.	-4.36E-02
12	1	-5.275E-03	3.441E-03	-1.507E-05	0.	0.	-4.38E-02
13	1	-4.423E-03	4.185E-03	-1.577E-05	0.	0.	-4.35E-02
14	1	-3.631E-03	4.971E-03	-1.630E-05	0.	0.	-4.25E-02
15	1	-2.910E-03	5.781E-03	-1.662E-05	0.	0.	-4.11E-02
16	1	-2.269E-03	6.598E-03	-1.672E-05	0.	0.	-3.91E-02
17	1	-1.712E-03	7.406E-03	-1.658E-05	0.	0.	-3.66E-02

18	1	-1.244E-03	3.187E-03	-1.[illegible]16E-05	0.	0.	-3.36E-02
19	1	-8.618E-04	8.923E-03	-1.548E-05	0.	0.	-3.03E-02
20	1	-5.626E-04	9.399E-03	-1.448E-05	0.	0.	-2.67E-02
21	1	-3.399E-04	1.020E-02	-1.313E-05	0.	0.	-2.27E-02
22	1	-1.849E-04	1.071E-02	-1.140E-05	0.	0.	-1.84E-02
23	1	-8.658E-05	1.112E-02	-9.265E-06	0.	0.	-1.40E-02
24	1	-3.246E-05	1.142E-02	-6.682E-06	0.	0.	-9.43E-03
25	1	-8.557E-06	1.160E-02	-3.609E-06	0.	0.	-4.74E-03
26	1	0.	1.166E-02	0.	0.	0.	0.
27	1	-1.284E-02	0.	0.	0.	0.	0.
28	1	-1.274E-02	3.050E-06	1.651E-06	0.	0.	-7.[illegible]1E-03
29	1	-1.244E-02	3.046E-05	3.289E-06	0.	0.	-1.59E-02
30	1	-1.176E-02	1.031E-04	4.899E-06	0.	0.	-2.13E-02
31	1	-1.137E-02	2.377E-04	6.468E-06	0.	0.	-2.67E-02
32	1	-1.064E-02	4.465E-04	7.981E-06	0.	0.	-3.14E-02
33	1	-9.826E-03	7.376E-04	9.424E-06	0.	0.	-3.53E-02
34	1	-8.947E-03	1.115E-03	1.078E-05	0.	0.	-3.34E-02
35	1	-8.029E-03	1.579E-03	1.204E-05	0.	0.	-4.03E-02

36	1	-7.096E-03	2.127E-03	1.[illegible]19E-05	0.	0.	-4.25E-02
37	1	-6.172E-03	2.750E-03	1.[illegible]0E-05	0.	0.	-4.35E-02
38	1	-5.275E-03	3.441E-03	1.507E-05	0.	0.	-4.38E-02
39	1	-4.423E-03	4.185E-03	1.577E-05	0.	0.	-4.35E-02
40	1	-3.631E-03	4.971E-03	1.630E-05	0.	0.	-4.25E-02
41	1	-2.910E-03	5.781E-03	1.662E-05	0.	0.	-4.11E-02
42	1	-2.259E-03	6.593E-03	1.672E-05	0.	0.	-3.91E-02
43	1	-1.718E-03	7.405E-03	1.658E-05	0.	0.	-3.66E-02
44	1	-1.244E-03	8.137E-03	1.618E-05	0.	0.	-3.38E-02
45	1	-8.618E-04	8.923E-03	1.548E-05	0.	0.	-3.03E-02
46	1	-5.623E-04	9.599E-03	1.448E-05	0.	0.	-2.67E-02
47	1	-3.399E-04	1.020E-02	1.313E-05	0.	0.	-2.27E-02
48	1	-1.849E-04	1.071E-02	1.140E-05	0.	0.	-1.84E-02
49	1	-8.658E-05	1.112E-02	9.265E-06	0.	0.	-1.40E-02
50	1	-3.246E-05	1.142E-02	6.6[illegible]2E-06	0.	0.	-9.43E-03
51	1	-8.557E-06	1.160E-02	3.609E-06	0.	0.	-4.[illegible]E-03
52	1	0.	1.166E-02	0.	0.	0.	0.

FINITE ELEMENT MODEL

SHELL ELEMENT STRESSES

	ELEMENT	LOAD	LONG. SIG-X	CIRC SIG-Y	SIG-XY
MEMBRANE	1	1	1.65	-8.51	.00
BENDING			.00	7630.81	-.00
+T/2 SIDE	INSIDE		1.65	7622.30	.00
-T/2 SIDE	OUTSIDE		1.65	-7639.32	.00
MEMBRANE	2	1	4.94	-25.45	.00
BENDING			.00	6840.46	-.00
+T/2 SIDE			4.94	6815.00	.00
-T/2 SIDE			4.94	-6865.91	.00
MEMBRANE	3	1	8.19	-42.31	.00
BENDING			.00	6054.76	.00
+T/2 SIDE			8.19	6012.45	.00
-T/2 SIDE			8.19	-6097.08	.00
MEMBRANE	4	1	11.37	-58.99	.00
BENDING			-.00	5276.83	.00
+T/2 SIDE			11.37	5217.84	.00
-T/2 SIDE			11.37	-5335.82	.00
MEMBRANE	5	1	14.45	-75.42	.00
BENDING			-.00	4509.75	.00
+T/2 SIDE			14.45	4434.34	.00
-T/2 SIDE			14.45	-4585.17	.00
MEMBRANE	6	1	17.40	-91.53	.00
BENDING			-.00	3756.56	.00
+T/2 SIDE			17.40	3665.03	.00
-T/2 SIDE			17.40	-3848.09	.00
MEMBRANE	7	1	20.21	-107.27	.00
BENDING			-.00	3020.20	.00
+T/2 SIDE			20.21	2912.93	.00
-T/2 SIDE			20.21	-3127.47	.00
MEMBRANE	8	1	22.62	-122.52	.00
BENDING			-.00	2303.60	.00
+T/2 SIDE			22.62	2181.07	.00
-T/2 SIDE			22.62	-2426.12	.00
MEMBRANE	9	1	25.23	-137.26	.00

BENDING			-.00	1609.60	.00
+T/2 SIDE			25.23	1472.34	.00
-T/2 SIDE			25.23	-1745.86	.00
MEMBRANE	10	1	27.39	-151.44	.00
BENDING			-.00	940.94	.00
+T/2 SIDE			27.39	789.50	.00
-T/2 SIDE			27.39	-1092.38	.00
MEMBRANE	11	1	29.27	-164.96	.00
BENDING			-.00	300.26	.00
+T/2 SIDE			29.27	135.30	.00
-T/2 SIDE			29.27	-465.22	.00
MEMBRANE	12	1	30.84	-177.75	.00
BENDING			-.00	-309.94	.00
+T/2 SIDE			30.84	-487.69	.00
-T/2 SIDE			30.84	132.20	.00
MEMBRANE	13	1	32.07	-189.79	.00
BENDING			.00	-887.26	.00
+T/2 SIDE			32.07	-1077.05	.00
-T/2 SIDE			32.07	697.47	.00
MEMBRANE	14	1	32.91	-201.01	.00
BENDING			.00	-1429.38	.00
+T/2 SIDE			32.91	-1630.39	.00
-T/2 SIDE			32.91	1228.37	.00
MEMBRANE	15	1	33.34	-211.33	.00
BENDING			.00	-1934.19	.00
+T/2 SIDE			33.34	-2145.51	.00
-T/2 SIDE			33.34	1722.86	.00
MEMBRANE	16	1	33.30	-220.73	.00
BENDING			.00	-2399.70	.00
+T/2 SIDE			33.30	-2620.43	.00
-T/2 SIDE			33.30	2178.98	.00
MEMBRANE	17	1	32.76	-229.15	.00
BENDING			.00	-2824.03	.00
+T/2 SIDE			32.76	-3053.18	.00
-T/2 SIDE			32.76	2594.88	.00
MEMBRANE	18	1	31.66	-235.53	.00

BENDING			.00	-3205.54	.00
+T/2 SIDE			31.66	-3442.07	.00
-T/2 SIDE			31.66	2969.02	.00
MEMBRANE	19	1	29.96	-242.83	.00
BENDING			.00	-3542.77	.00
+T/2 SIDE			29.96	-3785.60	.00
-T/2 SIDE			29.96	3299.94	.00
MEMBRANE	20	1	27.60	-248.02	.00
BENDING			.00	-3834.33	.00
+T/2 SIDE			27.60	-4082.35	.00
-T/2 SIDE			27.60	3586.31	.00
MEMBRANE	21	1	24.53	-252.04	.00
BENDING			.00	-4079.05	.00
+T/2 SIDE			24.53	-4331.09	.00
-T/2 SIDE			24.53	3827.01	.00
MEMBRANE	22	1	20.67	-254.84	.00
BENDING			-.00	-4276.00	.00
+T/2 SIDE			20.67	-4530.86	.00
-T/2 SIDE			20.67	4021.13	.00
MEMBRANE	23	1	15.95	-256.45	.00
BENDING			-.00	-4424.39	.00
+T/2 SIDE			15.95	-4680.84	.00
-T/2 SIDE			15.95	4167.95	.00
MEMBRANE	24	1	10.29	-255.76	.00
BENDING			-.00	-4523.63	.00
+T/2 SIDE			10.29	-4779.39	.00
-T/2 SIDE			10.29	4265.88	.00
MEMBRANE	25	1	3.61	-255.76	.00
BENDING			-.00	-4573.36	.00
+T/2 SIDE			3.61	-4829.12	.00
-T/2 SIDE			3.61	4317.60	.00

LASTIC TEST CASE #2 8 POINTS

EGREES	BENDING	MEMBRANE	STRN1	STRN2
0.00	-6.129556E-03	3.270657E-04	-5.802491E-03	6.456622E-03
.25	-5.788316E-03	3.270657E-04	-5.461250E-03	6.115381E-03
4.50	-5.462032E-03	3.270657E-04	-5.134967E-03	5.789098E-03
6.75	-5.149605E-03	3.270657E-04	-4.822539E-03	5.476670E-03
9.00	-4.849968E-03	3.270657E-04	-4.522903E-03	5.177034E-03
11.25	-4.562141E-03	3.270657E-04	-4.235076E-03	4.889207E-03
13.50	-4.285101E-03	3.270657E-04	-3.958036E-03	4.612167E-03
15.75	-4.017855E-03	3.270657E-04	-3.690789E-03	4.344921E-03
18.00	-3.759485E-03	3.270657E-04	-3.432419E-03	4.086551E-03
20.25	-3.509032E-03	3.270657E-04	-3.181966E-03	3.836098E-03
22.50	-3.265584E-03	3.270657E-04	-2.938518E-03	3.592650E-03
24.75	-3.028223E-03	3.270657E-04	-2.701157E-03	3.355289E-03
27.00	-2.796061E-03	3.270657E-04	-2.468996E-03	3.123127E-03
29.25	-2.568241E-03	3.270657E-04	-2.241176E-03	2.895307E-03
31.50	-2.343896E-03	3.270657E-04	-2.016830E-03	2.670962E-03
33.75	-2.122193E-03	3.270657E-04	-1.795127E-03	2.449259E-03
36.00	-1.902254E-03	3.270657E-04	-1.575188E-03	2.229320E-03
38.25	-1.683295E-03	3.270657E-04	-1.356229E-03	2.010361E-03
40.50	-1.464508E-03	3.270657E-04	-1.137443E-03	1.791574E-03
42.75	-1.245117E-03	3.270657E-04	-9.180516E-04	1.572183E-03
45.00	-1.024328E-03	3.270657E-04	-6.972622E-04	1.351394E-03
47.25	-6.198763E-04	3.270657E-04	-2.928106E-04	9.469420E-04
49.50	-2.098023E-04	3.270657E-04	1.172634E-04	5.368680E-04
51.75	2.068878E-04	3.270657E-04	5.339535E-04	1.201779E-04
54.00	6.312641E-04	3.270657E-04	9.583298E-04	-3.041984E-04
56.25	1.064283E-03	3.270657E-04	1.391349E-03	-7.372171E-04
8.50	1.506797E-03	3.270657E-04	1.833863E-03	-1.179731E-03
.75	1.959596E-03	3.270657E-04	2.286662E-03	-1.632531E-03
.00	2.423377E-03	3.270657E-04	2.750443E-03	-2.096312E-03
65.25	2.898710E-03	3.270657E-04	3.225776E-03	-2.571644E-03
67.50	3.386107E-03	3.270657E-04	3.713173E-03	-3.059041E-03
69.75	3.885879E-03	3.270657E-04	4.212945E-03	-3.558814E-03
72.00	4.398265E-03	3.270657E-04	4.725331E-03	-4.071199E-03
74.25	4.923320E-03	3.270657E-04	5.250385E-03	-4.596254E-03
76.50	5.460971E-03	3.270657E-04	5.788036E-03	-5.133905E-03
78.75	6.010989E-03	3.270657E-04	6.338055E-03	-5.683924E-03
81.00	6.572967E-03	3.270657E-04	6.900033E-03	-6.245902E-03
83.25	7.146302E-03	3.270657E-04	7.473368E-03	-6.819237E-03
85.50	7.730254E-03	3.270657E-04	8.057320E-03	-7.403188E-03
87.75	8.323915E-03	3.270657E-04	8.650981E-03	-7.996850E-03
90.00	8.926168E-03	3.270657E-04	9.253234E-03	-8.599102E-03
92.25	8.323915E-03	3.270657E-04	8.650981E-03	-7.996850E-03
94.50	7.730264E-03	3.270657E-04	8.057330E-03	-7.403199E-03
96.75	7.146302E-03	3.270657E-04	7.473368E-03	-6.819237E-03
99.00	6.572973E-03	3.270657E-04	6.900038E-03	-6.245907E-03
01.25	6.011001E-03	3.270657E-04	6.338066E-03	-5.683935E-03
03.50	5.460987E-03	3.270657E-04	5.788053E-03	-5.133922E-03
05.75	4.923332E-03	3.270657E-04	5.250398E-03	-4.596266E-03
08.00	4.398270E-03	3.270657E-04	4.725336E-03	-4.071204E-03
10.25	3.885896E-03	3.270657E-04	4.212962E-03	-3.558830E-03
12.50	3.386107E-03	3.270657E-04	3.713173E-03	-3.059041E-03
14.75	2.898738E-03	3.270657E-04	3.225804E-03	-2.571673E-03
17.00	2.423377E-03	3.270657E-04	2.750443E-03	-2.096312E-03
.25	1.959613E-03	3.270657E-04	2.286679E-03	-1.632548E-03
.50	1.506808E-03	3.270657E-04	1.833874E-03	-1.179743E-03
23.75	1.064294E-03	3.270657E-04	1.391360E-03	-7.372284E-04
26.00	6.312866E-04	3.270657E-04	9.583523E-04	-3.042209E-04
28.25	2.069159E-04	3.270657E-04	5.339815E-04	1.201499E-04

35.00	-1.024317E-03	3.270657E-04	-6.972511E-04	1.351382E-03
137.25	-1.245106E-03	3.270657E-04	-9.180494E-04	1.572172E-03
139.50	-1.464503E-03	3.270657E-04	-1.137437E-03	1.791568E-03
141.75	-1.683290E-03	3.270657E-04	-1.356224E-03	2.010355E-03
144.00	-1.902243E-03	3.270657E-04	-1.575177E-03	2.229309E-03
146.25	-2.122165E-03	3.270657E-04	-1.795099E-03	2.449231E-03
.50	-2.343896E-03	3.270657E-04	-2.016830E-03	2.670962E-03
.75	-2.568236E-03	3.270657E-04	-2.241170E-03	2.895302E-03
153.00	-2.796061E-03	3.270657E-04	-2.468996E-03	3.123127E-03
155.25	-3.028212E-03	3.270657E-04	-2.701146E-03	3.355278E-03
157.50	-3.265578E-03	3.270657E-04	-2.938513E-03	3.592644E-03
159.75	-3.509026E-03	3.270657E-04	-3.181961E-03	3.836092E-03
162.00	-3.759485E-03	3.270657E-04	-3.432419E-03	4.086551E-03
164.25	-4.017855E-03	3.270657E-04	-3.690789E-03	4.344921E-03
166.50	-4.285101E-03	3.270657E-04	-3.958036E-03	4.612167E-03
168.75	-4.562147E-03	3.270657E-04	-4.235081E-03	4.889213E-03
171.00	-4.849968E-03	3.270657E-04	-4.522903E-03	5.177034E-03
173.25	-5.149599E-03	3.270657E-04	-4.822534E-03	5.476665E-03
175.50	-5.462043E-03	3.270657E-04	-5.134978E-03	5.789109E-03
177.75	-5.788332E-03	3.270657E-04	-5.461267E-03	6.115398E-03
180.00	-6.129568E-03	3.270657E-04	-5.802502E-03	6.456633E-03
182.25	-5.788332E-03	3.270657E-04	-5.461267E-03	6.115398E-03
184.50	-5.462048E-03	3.270657E-04	-5.134983E-03	5.789114E-03
186.75	-5.149616E-03	3.270657E-04	-4.822550E-03	5.476682E-03
189.00	-4.849980E-03	3.270657E-04	-4.522914E-03	5.177045E-03
191.25	-4.562153E-03	3.270657E-04	-4.235087E-03	4.889218E-03
193.50	-4.285113E-03	3.270657E-04	-3.958047E-03	4.612179E-03
195.75	-4.017867E-03	3.270657E-04	-3.690801E-03	4.344932E-03
198.00	-3.759491E-03	3.270657E-04	-3.432425E-03	4.086556E-03
200.25	-3.509037E-03	3.270657E-04	-3.181972E-03	3.836103E-03
202.50	-3.265589E-03	3.270657E-04	-2.938524E-03	3.592655E-03
204.75	-3.028228E-03	3.270657E-04	-2.701163E-03	3.355294E-03
.00	-2.796072E-03	3.270657E-04	-2.469006E-03	3.123138E-03
.25	-2.568258E-03	3.270657E-04	-2.241193E-03	2.895324E-03
211.50	-2.343907E-03	3.270657E-04	-2.016841E-03	2.670973E-03
213.75	-2.122193E-03	3.270657E-04	-1.795127E-03	2.449259E-03
216.00	-1.902259E-03	3.270657E-04	-1.575194E-03	2.229325E-03
218.25	-1.683306E-03	3.270657E-04	-1.356241E-03	2.010372E-03
220.50	-1.464520E-03	3.270657E-04	-1.137454E-03	1.791585E-03
222.75	-1.245123E-03	3.270657E-04	-9.180573E-04	1.572189E-03
225.00	-1.024334E-03	3.270657E-04	-6.972678E-04	1.351399E-03
227.25	-6.198763E-04	3.270657E-04	-2.928106E-04	9.469420E-04
229.50	-2.098079E-04	3.270657E-04	1.172578E-04	5.368736E-04
231.75	2.068878E-04	3.270657E-04	5.339535E-04	1.201779E-04
234.00	6.312698E-04	3.270657E-04	9.583355E-04	-3.042041E-04
236.25	1.064283E-03	3.270657E-04	1.391349E-03	-7.372171E-04
238.50	1.506792E-03	3.270657E-04	1.833857E-03	-1.179726E-03
240.75	1.959602E-03	3.270657E-04	2.286668E-03	-1.632536E-03
243.00	2.423383E-03	3.270657E-04	2.750448E-03	-2.096317E-03
245.25	2.898727E-03	3.270657E-04	3.225793E-03	-2.571661E-03
247.50	3.386113E-03	3.270657E-04	3.713179E-03	-3.059047E-03
249.75	3.885890E-03	3.270657E-04	4.212956E-03	-3.558825E-03
252.00	4.398282E-03	3.270657E-04	4.725347E-03	-4.071216E-03
254.25	4.923326E-03	3.270657E-04	5.250392E-03	-4.596261E-03
256.50	5.460987E-03	3.270657E-04	5.788053E-03	-5.133922E-03
258.75	6.011006E-03	3.270657E-04	6.338072E-03	-5.683941E-03
261.00	6.572978E-03	3.270657E-04	6.900044E-03	-6.245913E-03
263.25	7.146314E-03	3.270657E-04	7.473380E-03	-6.819249E-03
.50	7.730275E-03	3.270657E-04	8.057341E-03	-7.403210E-03
.75	8.323933E-03	3.270657E-04	8.650999E-03	-7.996867E-03
270.00	8.926179E-03	3.270657E-04	9.253245E-03	-8.599114E-03
272.25	8.323933E-03	3.270657E-04	8.650999E-03	-7.996867E-03
274.50	7.730275E-03	3.270657E-04	8.057341E-03	-7.403210E-03
276.75	7.146314E-03	3.270657E-04	7.473380E-03	-6.819249E-03

3.50	[illegible].46[illegible]E-[illegible]	[illegible]657[illegible]04	5.788059E-03	-[illegible]3927E-03
5.75	4.923332E-03	3.270657[illegible]04	5.250398E-03	-[illegible]96266E-03
88.00	4.398282E-03	3.270657E-04	4.725347E-03	-4.071216E-03
90.25	3.885996E-03	3.270657E-04	4.212962E-03	-3.558830E-03
92.50	3.386107E-03	3.270657E-04	3.713173E-03	-3.059041E-03
94.75	2.898727E-03	3.270657E-04	3.225793E-03	-2.571661E-03
.00	2.423383E-03	3.270657E-04	2.750448E-03	-2.096317E-03
.25	1.959602E-03	3.270657E-04	2.286668E-03	-1.632536E-03
01.50	1.506792E-03	3.270657E-04	1.833857E-03	-1.179726E-03
03.75	1.064283E-03	3.270657E-04	1.391349E-03	-7.372171E-04
06.00	6.312698E-04	3.270657E-04	9.583355E-04	-3.042041E-04
08.25	2.068934E-04	3.270657E-04	5.339591E-04	1.201723E-04
10.50	-2.098079E-04	3.270657E-04	1.172578E-04	5.368736E-04
12.75	-6.198707E-04	3.270657E-04	-2.928050E-04	9.469364E-04
15.00	-1.024334E-03	3.270657E-04	-6.972678E-04	1.351399E-03
17.25	-1.245123E-03	3.270657E-04	-9.180573E-04	1.572189E-03
19.50	-1.464520E-03	3.270657E-04	-1.137454E-03	1.791585E-03
21.75	-1.683301E-03	3.270657E-04	-1.356235E-03	2.010367E-03
24.00	-1.902259E-03	3.270657E-04	-1.575194E-03	2.229325E-03
26.25	-2.122193E-03	3.270657E-04	-1.795127E-03	2.449259E-03
28.50	-2.343901E-03	3.270657E-04	-2.016836E-03	2.670967E-03
30.75	-2.568253E-03	3.270657E-04	-2.241187E-03	2.895318E-03
33.00	-2.796066E-03	3.270657E-04	-2.469001E-03	3.123132E-03
35.25	-3.028223E-03	3.270657E-04	-2.701157E-03	3.355289E-03
37.50	-3.265584E-03	3.270657E-04	-2.938518E-03	3.592650E-03
39.75	-3.509032E-03	3.270657E-04	-3.181966E-03	3.836098E-03
42.00	-3.759491E-03	3.270657E-04	-3.432425E-03	4.086556E-03
44.25	-4.017855E-03	3.270657E-04	-3.690789E-03	4.344921E-03
46.50	-4.285101E-03	3.270657E-04	-3.958036E-03	4.612167E-03
48.75	-4.562141E-03	3.270657E-04	-4.235076E-03	4.889207E-03
51.00	-4.849968E-03	3.270657E-04	-4.522903E-03	5.177034E-03
53.25	-5.149605E-03	3.270657E-04	-4.822539E-03	5.476670E-03
.50	-5.462032E-03	3.270657E-04	-5.134967E-03	5.789098E-03
.75	-5.788316E-03	3.270657E-04	-5.461250E-03	6.115381E-03

OCATION:
2.7000000E+02 DEGREES

NDING STRAIN:
8.9261793E-03

EMBRANE STRAIN:
3.2706570E-04

TRAIN1:
9.2532448E-03

TRAIN2:
-8.5991137E-03

8 POINTS

0° ROTATION

LASTIC TEST CASE #2 50 POINTS

EGREES	BENDING	MEMBRANE	STRN1	STRN2
[illegible].00	-7.319330E-03	4.221498E-04	-6.897180E-03	7.741480E-03
[illegible].44	-6.341834E-03	4.221498E-04	-5.919685E-03	6.763984E-03
2.88	-5.368976E-03	4.221498E-04	-4.946826E-03	5.791126E-03
4.32	-4.399440E-03	4.221498E-04	-3.977290E-03	4.821590E-03
5.76	-3.431988E-03	4.221498E-04	-3.009838E-03	3.854137E-03
7.20	-2.465400E-03	4.221498E-04	-2.043251E-03	2.887550E-03
8.64	-3.233849E-03	4.221498E-04	-2.811699E-03	3.655999E-03
10.08	-4.006180E-03	4.221498E-04	-3.584031E-03	4.428330E-03
11.52	-4.763261E-03	4.221498E-04	-4.341111E-03	5.185411E-03
12.96	-5.565892E-03	4.221498E-04	-5.143742E-03	5.988041E-03
14.40	-6.355009E-03	4.221498E-04	-5.932859E-03	6.777158E-03
15.84	-5.554485E-03	4.221498E-04	-5.132335E-03	5.976635E-03
17.28	-4.756046E-03	4.221498E-04	-4.333896E-03	5.178196E-03
18.72	-3.958542E-03	4.221498E-04	-3.536392E-03	4.380692E-03
20.16	-3.160847E-03	4.221498E-04	-2.738697E-03	3.582997E-03
21.60	-2.361888E-03	4.221498E-04	-1.939738E-03	2.784037E-03
23.04	-2.898024E-03	4.221498E-04	-2.475874E-03	3.320173E-03
24.48	-3.438945E-03	4.221498E-04	-3.016795E-03	3.861095E-03
25.92	-3.985090E-03	4.221498E-04	-3.562940E-03	4.407239E-03
27.36	-4.537006E-03	4.221498E-04	-4.114856E-03	4.959156E-03
28.80	-5.095194E-03	4.221498E-04	-4.673044E-03	5.517344E-03
30.24	-4.192602E-03	4.221498E-04	-3.770452E-03	4.614752E-03
31.68	-3.286997E-03	4.221498E-04	-2.864848E-03	3.709147E-03
33.12	-2.377063E-03	4.221498E-04	-1.954913E-03	2.799212E-03
34.56	-1.461547E-03	4.221498E-04	-1.039397E-03	1.883697E-03
36.00	-5.392342E-04	4.221498E-04	-1.170844E-04	9.613840E-04
[illegible].44	-7.477938E-04	4.221498E-04	-3.256440E-04	1.169944E-03
[illegible].88	-9.581241E-04	4.221498E-04	-5.359743E-04	1.380274E-03
40.32	-1.171291E-03	4.221498E-04	-7.491411E-04	1.593441E-03
41.76	-1.384446E-03	4.221498E-04	-9.622966E-04	1.806596E-03
43.20	-1.600658E-03	4.221498E-04	-1.178508E-03	2.022808E-03
44.64	-1.086462E-03	4.221498E-04	-6.643122E-04	1.508612E-03
46.08	-5.681829E-04	4.221498E-04	-1.460331E-04	9.903327E-04
47.52	-4.510876E-05	4.221498E-04	3.770409E-04	4.672586E-04
48.96	4.831327E-04	4.221498E-04	9.052825E-04	-6.098290E-05
50.40	1.017179E-03	4.221498E-04	1.439329E-03	-5.950292E-04
51.84	9.465723E-04	4.221498E-04	1.368722E-03	-5.244225E-04
53.28	8.767615E-04	4.221498E-04	1.298911E-03	-4.546117E-04
54.72	8.077840E-04	4.221498E-04	1.229934E-03	-3.856342E-04
56.16	7.396295E-04	4.221498E-04	1.161779E-03	-3.174797E-04
57.60	6.723142E-04	4.221498E-04	1.094464E-03	-2.501644E-04
59.04	1.104086E-03	4.221498E-04	1.526236E-03	-6.819362E-04
60.48	1.541223E-03	4.221498E-04	1.963373E-03	-1.119074E-03
61.92	1.983999E-03	4.221498E-04	2.406149E-03	-1.561849E-03
63.36	2.432497E-03	4.221498E-04	2.854647E-03	-2.010348E-03
64.80	2.887531E-03	4.221498E-04	3.309681E-03	-2.465381E-03
66.24	3.193823E-03	4.221498E-04	3.615973E-03	-2.771673E-03
67.68	3.505151E-03	4.221498E-04	3.927301E-03	-3.083001E-03
69.12	3.821615E-03	4.221498E-04	4.243765E-03	-3.399465E-03
70.56	4.143247E-03	4.221498E-04	4.565397E-03	-3.721097E-03
72.00	4.470102E-03	4.221498E-04	4.892252E-03	-4.047952E-03
73.44	4.915444E-03	4.221498E-04	5.337594E-03	-4.493294E-03
[illegible].88	5.366857E-03	4.221498E-04	5.789007E-03	-4.944707E-03
[illegible].32	5.824286E-03	4.221498E-04	6.246436E-03	-5.402136E-03
77.76	6.287472E-03	4.221498E-04	6.709622E-03	-5.865322E-03
79.20	6.756817E-03	4.221498E-04	7.178967E-03	-6.334667E-03
80.64	6.931238E-03	4.221498E-04	7.353388E-03	-6.509088E-03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

.48	[illegible]	4.221498E-04	8.087338E-03	[illegible]E-03
87.84	7.653521E-03	4.221498E-04	8.081861E-03	-[illegible]7591E-03
89.28	7.658774E-03	4.221498E-04	8.078923E-03	-7.234624E-03
90.72	7.656764E-03	4.221498E-04	8.076919E-03	-7.234619E-03
92.16	7.659640E-03	4.221498E-04	8.081789E-03	-7.237440E-03
.60	7.665416E-03	4.221498E-04	8.087566E-03	-7.243266E-03
.04	7.476658E-03	4.221498E-04	7.896808E-03	-7.054508E-03
.48	7.291294E-03	4.221498E-04	7.713444E-03	-6.869144E-03
97.92	7.109467E-03	4.221498E-04	7.531617E-03	-6.687317E-03
99.36	6.931277E-03	4.221498E-04	7.353427E-03	-6.509128E-03
00.80	6.756880E-03	4.221498E-04	7.179030E-03	-6.334730E-03
02.24	6.287701E-03	4.221498E-04	6.709851E-03	-5.865551E-03
03.68	5.824301E-03	4.221498E-04	6.246451E-03	-5.402151E-03
05.12	5.366823E-03	4.221498E-04	5.788973E-03	-4.944673E-03
06.56	4.915370E-03	4.221498E-04	5.337520E-03	-4.493220E-03
08.00	4.470012E-03	4.221498E-04	4.892162E-03	-4.047[illegible]E-03
09.44	4.143191E-03	4.221498E-04	4.565340E-03	-3.721041E-03
10.88	3.821587E-03	4.221498E-04	4.243737E-03	-3.399437E-03
12.32	3.505157E-03	4.221498E-04	3.927306E-03	-3.083007E-03
13.76	3.193857E-03	4.221498E-04	3.616006E-03	-2.771707E-03
15.20	2.887610E-03	4.221498E-04	3.309760E-03	-2.465[illegible]E-03
16.64	2.432748E-03	4.221498E-04	2.854898E-03	-2.010598E-03
18.08	1.984016E-03	4.221498E-04	2.406166E-03	-1.561866E-03
19.52	1.541201E-03	4.221498E-04	1.963351E-03	-1.119051E-03
20.96	1.104041E-03	4.221498E-04	1.526191E-03	-6.818913E-04
22.40	6.722414E-04	4.221498E-04	1.094391E-03	-[illegible]E-04
.84	7.396115E-04	4.221498E-04	1.161761E-03	-3.174517E-04
.28	8.077[illegible]E-04	4.221498E-04	1.229945E-03	-3.856465E-04
.72	8.568116E-04	4.221498E-04	1.278961E-03	-4.546619E-04
.16	9.416733E-04	4.221498E-04	1.363823E-03	-5.245[illegible]E-04
.60	1.017313E-03	4.221498E-04	1.439463E-03	-5.951637E-04
.04	[illegible]E-04	4.221498E-04	9.053673E-04	-6.106[illegible]E-05
.48	-4.5[illegible]767E-05	4.221498E-04	3.770691E-04	4.672[illegible]E-04
.92	-[illegible]E-04	4.221498E-04	-1.460[illegible]7E-04	9.[illegible]E-04
.34	-1.0[illegible]E-03	4.221498E-04	-6.643736E-04	1.508[illegible]E-03
.80	-1.600745E-03	4.221498E-04	-1.178595E-03	2.022[illegible]E-03
.24	-1.384[illegible]17E-03	4.221498E-04	-9.623677E-04	1.806[illegible]7E-03
.68	-1.1[illegible]E-03	4.221498E-04	-7.422[illegible]E-04	[illegible]E-04
41.12	-9.[illegible]E-04	4.221498E-04	-5.360079E-04	1.3[illegible]7E-03
.56	-7.47[illegible]E-04	4.221498E-04	-3.256573E-04	1.169757E-03
44.00	-5.39[illegible]E-04	4.221498E-04	-1.170751E-04	7.613747E-04
45.44	-1.461541E-03	4.221498E-04	-1.039391E-03	1.883691E-03
46.88	-2.377057E-03	4.221498E-04	-1.954908E-03	2.799207E-03
48.32	-3.2[illegible]E-03	4.221498E-04	-2.864648E-03	3.709[illegible]7E-03
49.76	-4.192[illegible]E-03	4.221498E-04	-3.770452E-03	4.614752E-03
51.20	-5.0[illegible]E-03	4.221498E-04	-4.673050E-03	5.517[illegible]E-03
52.64	-4.537006E-03	4.221498E-04	-4.114856E-03	4.959156E-03
54.08	-3.985069E-03	4.221498E-04	-3.562940E-03	4.407239E-03
55.52	-3.438734E-03	4.221498E-04	-3.016784E-03	3.861083E-03
56.96	-2.898024E-03	4.221498E-04	-2.475874E-03	3.320173E-03
58.40	-2.361871E-03	4.221498E-04	-1.939722E-03	2.784021E-03
59.84	-3.160832E-03	4.221498E-04	-2.738682E-03	3.582982E-03
61.28	-3.958531E-03	4.221498E-04	-3.536381E-03	4.380681E-03
62.72	-4.756041E-03	4.221498E-04	-4.333891E-03	5.178191E-03
64.16	-5.554485E-03	4.221498E-04	-5.132335E-03	5.976635E-03
65.60	-6.355013E-03	4.221498E-04	-5.932863E-03	6.777162E-03
67.04	-5.565592E-03	4.221498E-04	-5.143742E-03	5.988041E-03
68.48	-4.783256E-03	4.221498E-04	-4.361106E-03	5.205405E-03
69.92	-4.006170E-03	4.221498E-04	-3.584020E-03	4.428[illegible]E-03
71.36	-3.233332E-03	4.221498E-04	-2.811183E-03	3.655[illegible]E-03
72.80	-2.465379E-03	4.221498E-04	-2.043229E-03	2.887528E-03
74.24	-3.431[illegible]E-03	4.221498E-04	-3.009[illegible]35E-03	3.854[illegible]E-03
75.68	-4.399[illegible]E-03	4.221498E-04	-3.977302E-03	4.821401E-03

			[illegible]	[illegible]
.44	[illegible]	4.221498E-04	-5.719725E-03	[illegible]
2.88	-5.36[illegible]E-03	4.221498E-04	-4.946849E-03	5.7211[illegible]E-03
4.32	-4.509451E-03	4.221498E-04	-3.977792E-03	4.821901E-03
5.76	-3.4[illegible]E-03	4.221498E-04	-3.109833E-03	3.554132E-03
87.20	-2.468378E-03	4.221498E-04	-2.143729E-03	2.837526E-03
8.64	-3.233338E-03	4.221498E-04	-2.911663E-03	3.655982E-03
.08	-4.006180E-03	4.221498E-04	-3.584031E-03	4.428330E-03
1.52	-4.783256E-03	4.221498E-04	-4.361106E-03	5.205406E-03
92.96	-5.565597E-03	4.221498E-04	-5.143747E-03	5.988047E-03
94.40	-6.355015E-03	4.221498E-04	-5.932865E-03	6.777165E-03
95.84	-5.554490E-03	4.221498E-04	-5.132640E-03	5.976640E-03
97.28	-4.756041E-03	4.221498E-04	-4.333891E-03	5.178191E-03
98.72	-3.958520E-03	4.221498E-04	-3.536370E-03	4.380669E-03
00.16	-3.160815E-03	4.221498E-04	-2.738665E-03	3.582965E-03
01.60	-2.361844E-03	4.221498E-04	-1.939694E-03	2.783993E-03
03.04	-2.898019E-03	4.221498E-04	-2.475869E-03	3.320168E-03
04.48	-3.438956E-03	4.221498E-04	-3.016806E-03	3.861105E-03
05.92	-3.985133E-03	4.221498E-04	-3.562984E-03	4.407203E-03
07.36	-4.537073E-03	4.221498E-04	-4.114928E-03	4.959208E-03
08.80	-5.095299E-03	4.221498E-04	-4.673149E-03	5.517449E-03
10.24	-4.192674E-03	4.221498E-04	-3.770824E-03	4.614824E-03
11.68	-3.287025E-03	4.221498E-04	-2.864875E-03	3.709174E-03
13.12	-2.377587E-03	4.221498E-04	-1.954908E-03	2.799207E-03
14.56	-1.461491E-03	4.221498E-04	-1.039341E-03	1.883641E-03
16.00	-5.39[illegible]E-04	4.221498E-04	-1.170137E-04	9.613132E-04
17.44	-7.47[illegible]E-04	4.221498E-04	-3.255902E-04	1.169490E-03
18.88	-9.5807[illegible]E-04	4.221498E-04	-5.359295E-04	1.380229E-03
20.32	-1.170[illegible]E-03	4.221498E-04	-7.481132E-04	1.592413E-03
1.76	-1.384428E-03	4.221498E-04	-9.622783E-04	1.806578E-03
23.20	-1.60[illegible]E-03	4.221498E-04	-1.178805E-03	2.022[illegible]E-03
4.64	-1.0864[illegible]E-03	4.221498E-04	-6.643066E-04	1.508[illegible]E-03
.08	-5.681[illegible]E-04	4.221498E-04	-1.460031E-04	9.903[illegible]E-04
.52	-4.811707E-05	4.221498E-04	3.770321E-04	4.672674E-04
3.96	4.831[illegible]E-04	4.221498E-04	9.352950E-04	-6.993[illegible]E-05
0.40	1.017193E-03	4.221498E-04	1.439340E-03	-5.950404E-04
1.84	9.465723E-04	4.221498E-04	1.368722E-03	-5.244226E-04
3.28	8.767365E-04	4.221498E-04	1.298205E-03	-4.546057E-04
4.72	8.077670E-04	4.221498E-04	1.229917E-03	-3.856[illegible]E-04
6.16	7.396371E-04	4.221498E-04	1.161757E-03	-3.174673E-04
7.60	6.722408E-04	4.221498E-04	1.094430E-03	-2.501[illegible]E-04
39.04	1.104069E-03	4.221498E-04	1.526219E-03	-6.819[illegible]E-04
40.48	1.541223E-03	4.221498E-04	1.963373E-03	-1.119074E-03
1.92	1.984022E-03	4.221498E-04	2.406171E-03	-1.561872E-03
3.36	2.432737E-03	4.221498E-04	2.854386E-03	-2.012587E-03
4.80	2.887593E-03	4.221498E-04	3.309743E-03	-2.465443E-03
46.24	3.193851E-03	4.221498E-04	3.616001E-03	-2.771701E-03
47.68	3.505157E-03	4.221498E-04	3.927306E-03	-3.083007E-03
49.12	3.821604E-03	4.221498E-04	4.243754E-03	-3.399454E-03
50.56	4.143213E-03	4.221498E-04	4.565363E-03	-3.721063E-03
52.00	4.470051E-03	4.221498E-04	4.892201E-03	-4.047[illegible]E-03
53.44	4.915399E-03	4.221498E-04	5.337548E-03	-4.493249E-03
54.88	5.366829E-03	4.221498E-04	5.788979E-03	-4.944679E-03
56.32	5.824284E-03	4.221498E-04	6.246434E-03	-5.402134E-03
7.76	6.287672E-03	4.221498E-04	6.709822E-03	-5.865522E-03
9.20	6.756829E-03	4.221498E-04	7.178979E-03	-6.334679E-03
0.64	6.931249E-03	4.221498E-04	7.353399E-03	-6.509[illegible]E-03
2.08	7.109450E-03	4.221498E-04	7.531600E-03	-6.687300E-03
.52	7.291294E-03	4.221498E-04	7.713444E-03	-6.869144E-03
.96	7.476670E-03	4.221498E-04	7.898820E-03	-7.054[illegible]E-03
6.40	7.665451E-03	4.221498E-04	8.087601E-03	-7.243301E-03
7.84	7.659469E-03	4.221498E-04	8.081619E-03	-7.237319E-03
9.28	7.656797E-03	4.221498E-04	8.078947E-03	-7.234[illegible]E-03
70.72	7.656797E-03	4.221498E-04	8.078947E-03	-7.234[illegible]E-03

76.48	[illegible]	4.221498E-04	7.713444E-03	[illegible]
77.92	7.129459E-03	4.221498E-04	7.531600E-03	[illegible]
79.36	6.931249E-03	4.221498E-04	7.353399E-03	-6.609029E-03
80.80	6.736129E-03	4.221498E-04	7.175979E-03	-5.334679E-03
82.24	6.277672E-03	4.221498E-04	6.739822E-03	-5.355322E-03
83.68	5.824289E-03	4.221498E-04	6.246439E-03	-5.402139E-03
.12	5.366829E-03	4.221498E-04	5.788979E-03	-4.944679E-03
.56	4.915399E-03	4.221498E-04	5.337548E-03	-4.496269E-03
88.00	4.470951E-03	4.221498E-04	4.992201E-03	-4.047901E-03
89.44	4.143213E-03	4.221498E-04	4.555363E-03	-3.721063E-03
90.88	3.821604E-03	4.221498E-04	4.243754E-03	-3.399454E-03
92.32	3.505157E-03	4.221498E-04	3.927306E-03	-3.083007E-03
93.76	3.193851E-03	4.221498E-04	3.616001E-03	-2.771701E-03
95.20	2.887593E-03	4.221498E-04	3.309743E-03	-2.465443E-03
96.64	2.432737E-03	4.221498E-04	2.854836E-03	-2.010587E-03
.08	1.964022E-03	4.221498E-04	2.406171E-03	-1.561872E-03
99.52	1.541223E-03	4.221498E-04	1.963573E-03	-1.119074E-03
00.96	1.134069E-03	4.221498E-04	1.526219E-03	-6.819193E-04
02.40	6.722306E-04	4.221498E-04	1.094430E-03	[illegible]
03.84	7.396071E-04	4.221498E-04	1.161757E-03	-3.174573E-04
05.28	8.077616E-04	4.221498E-04	1.229911E-03	-3.936119E-04
06.72	8.767499E-04	4.221498E-04	1.298900E-03	-4.546001E-04
08.16	7.465723E-04	4.221498E-04	1.368722E-03	-5.244026E-04
09.60	1.017179E-03	4.221498E-04	1.439329E-03	[illegible]
11.04	4.831506E-04	4.221498E-04	9.053005E-04	-6.100122E-05
12.48	-4.511207E-05	4.221498E-04	3.770377E-04	4.672516E-04
13.92	-5.681306E-04	4.221498E-04	-1.459807E-04	9.928007E-04
.36	-1.076437E-03	4.221498E-04	-6.642097E-04	1.528[illegible]E-03
16.80	-1.600628E-03	4.221498E-04	-1.178478E-03	2.222776E-03
.24	-1.364428E-03	4.221498E-04	-9.622733E-04	1.806972E-03
.68	-1.170285E-03	4.221498E-04	-7.481356E-04	1.392458E-03
.12	-7.581296E-04	4.221498E-04	-5.359799E-04	1.[illegible]E-03
.56	-7.470126E-04	4.221498E-04	-3.256626E-04	1.149[illegible]E-03
.00	-5.392497E-04	4.221498E-04	-1.171200E-04	9.614[illegible]E-04
.44	-1.461563E-03	4.221498E-04	-1.039414E-03	1.8[illegible]E-03
26.88	-2.377080E-03	4.221498E-04	-1.954930E-03	2.799209E-03
.32	-3.286977E-03	4.221498E-04	-2.864848E-03	3.709147E-03
.76	-4.192502E-03	4.221498E-04	-3.770452E-03	4.614792E-03
.20	-5.093177E-03	4.221498E-04	-4.673027E-03	5.517[illegible]E-03
.64	-4.537000E-03	4.221498E-04	-4.114850E-03	4.959[illegible]E-03
34.08	-3.995089E-03	4.221498E-04	-3.562940E-03	4.407[illegible]E-03
35.52	-3.438939E-03	4.221498E-04	-3.016789E-03	3.861009E-03
36.96	-2.898038E-03	4.221498E-04	-2.475885E-03	3.320[illegible]E-03
.40	-2.361294E-03	4.221498E-04	-1.939744E-03	2.784[illegible]E-03
.84	-3.168388E-03	4.221498E-04	-2.738688E-03	3.582287E-03
1.28	-3.956314E-03	4.221498E-04	-3.536344E-03	4.330[illegible]E-03
2.72	-4.756015E-03	4.221498E-04	-4.333664E-03	5.170[illegible]E-03
44.16	-5.554440E-03	4.221498E-04	-5.132291E-03	5.976590E-03
45.60	-6.354248E-03	4.221498E-04	-5.932793E-03	5.777[illegible]E-03
7.04	-5.858358E-03	4.221498E-04	-5.143798E-03	[illegible]
.48	-4.787350E-03	4.221498E-04	-4.361100E-03	5.02[illegible]E-03
49.92	-4.086197E-03	4.221498E-04	-3.584047E-03	4.426347E-03
1.36	-3.237858E-03	4.221498E-04	-2.811778E-03	3.636[illegible]E-03
2.80	-2.460479E-03	4.221498E-04	-2.043329E-03	2.8[illegible]E-03
54.24	-3.432049E-03	4.221498E-04	-3.009900E-03	3.864199E-03
55.68	-4.329485E-03	4.221498E-04	-3.977330E-03	4.321[illegible]E-03
57.12	-5.389010E-03	4.221498E-04	-4.946260E-03	5.721[illegible]E-03
.56	-6.341851E-03	4.221498E-04	-5.919701E-03	6.76[illegible]E-03

TTION:
2.664000E+02 DEGREES
ENDING STRAIN:
7.665457E-03
MEMBRANE STRAIN:

50 PTS.

50 PTS

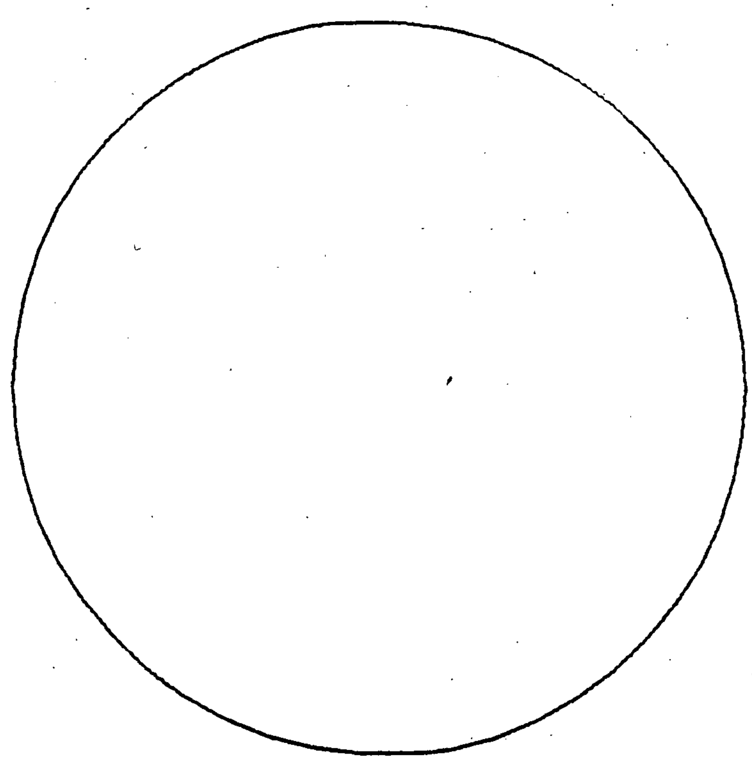
APPENDIX D

STRAIN PREDICTION PROGRAM PLOTS

ELASTIC TEST CASE 2

ELASTIC TEST
CASE #2

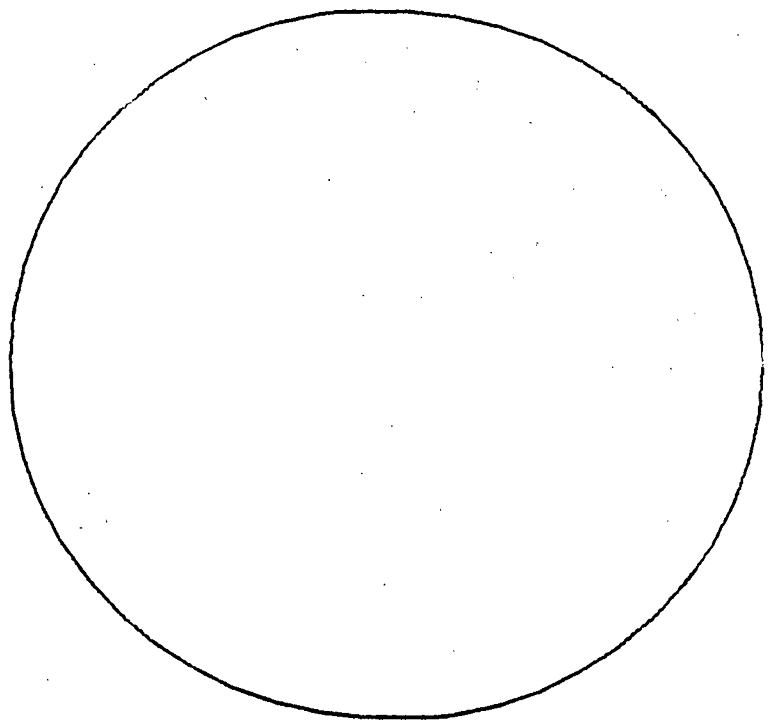
50 POINTS



INITIAL SHAPE

ELASTIC TEST
CASE #2

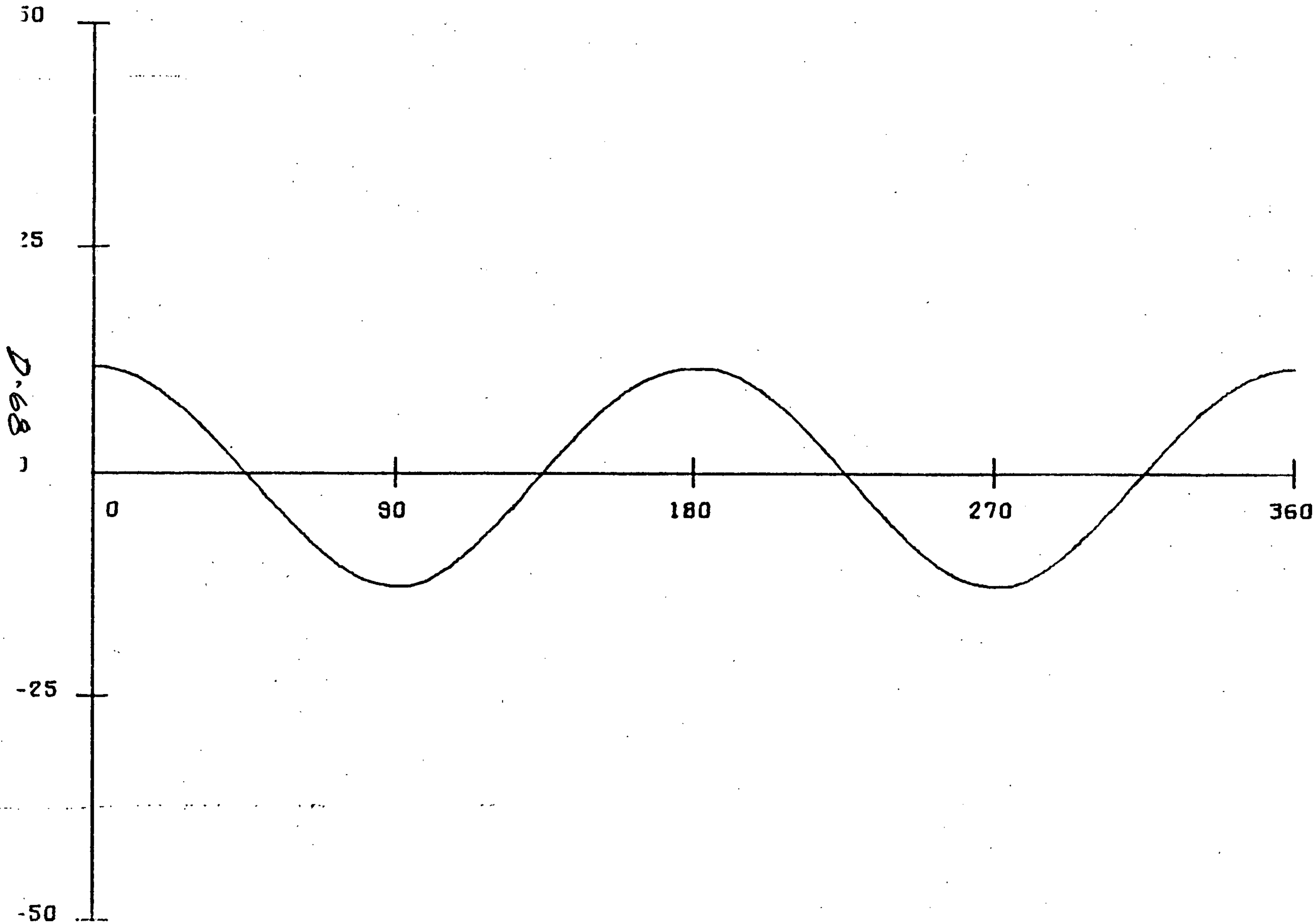
50 POINTS



DIFFERENCE SHAPE

ELASTIC TEST
CASE #2

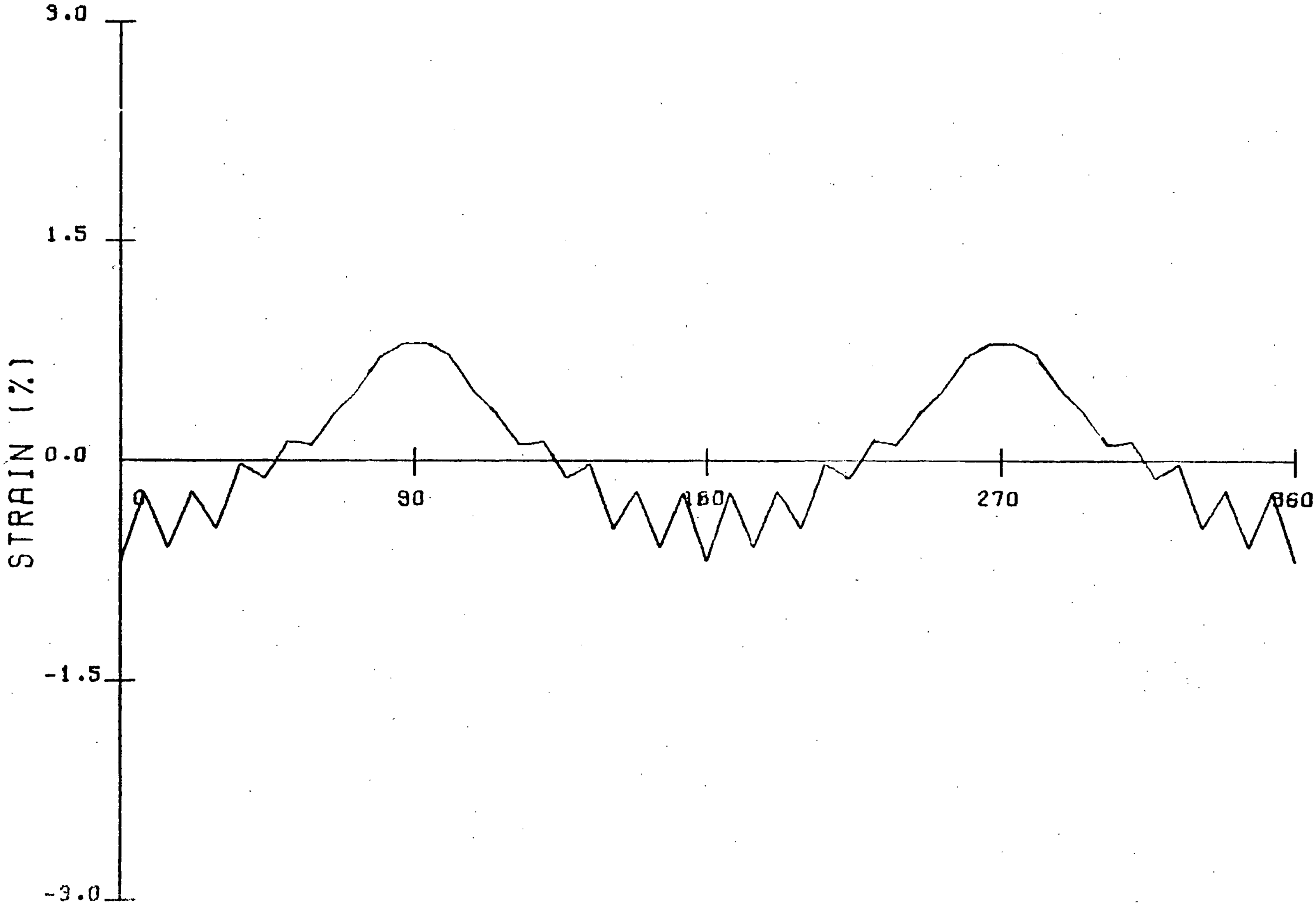
50 POINTS



DIFFERENCE SHAPE

ELASTIC TEST
CASE #2

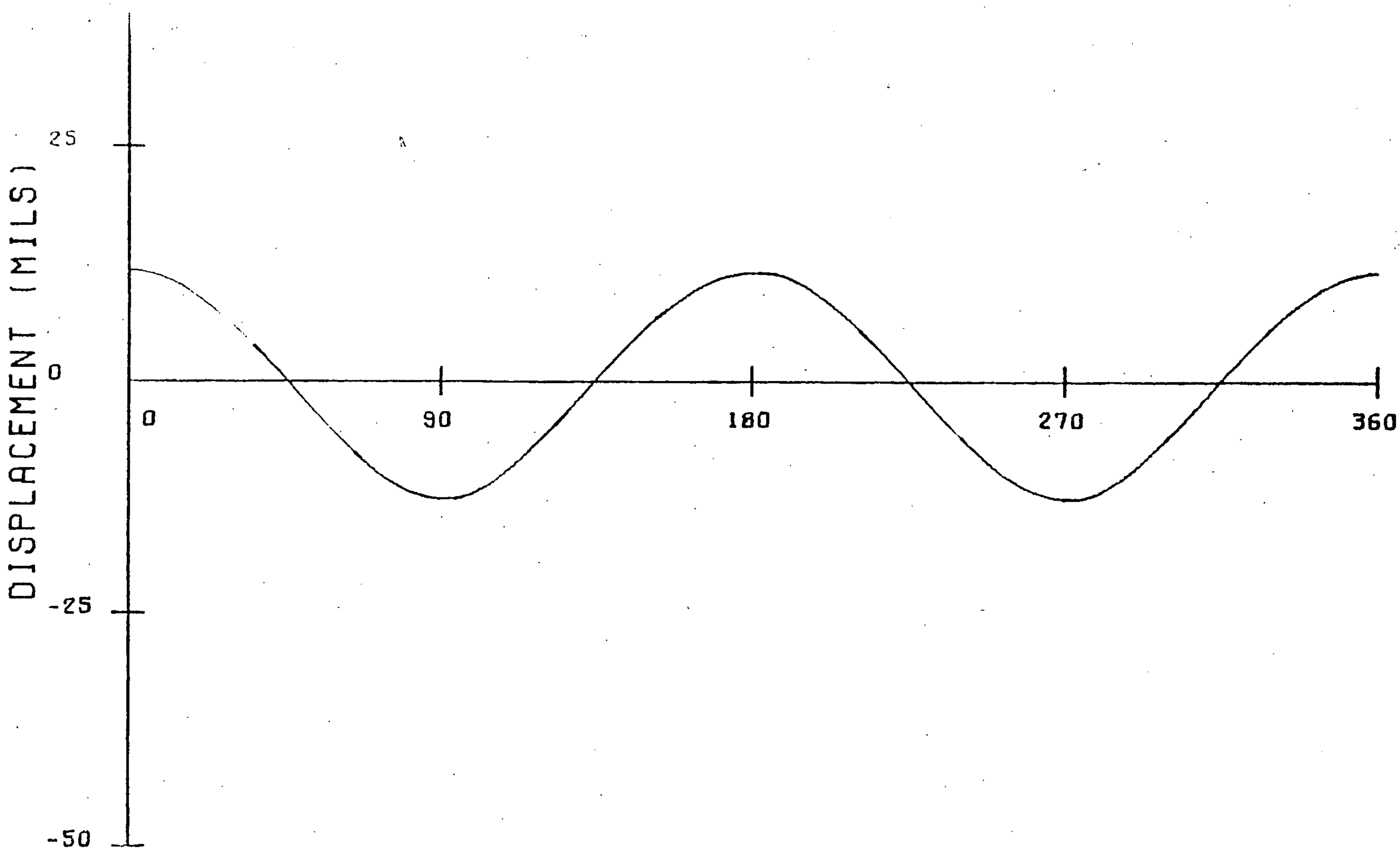
50 POINTS



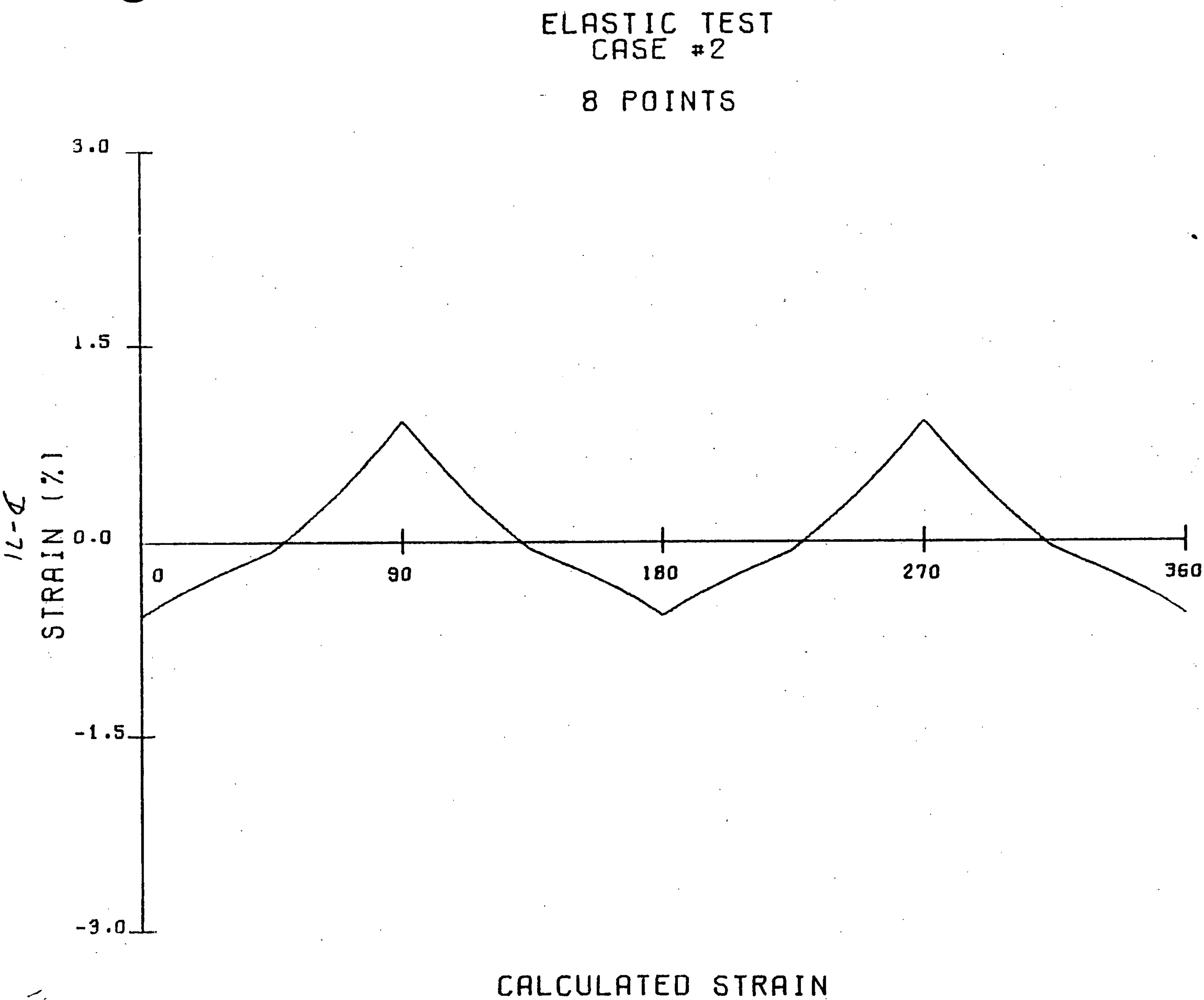
CALCULATED STRAIN

ELASTIC TEST
CASE #2

8 POINTS



DIFFERENCE SHAPE


ELASTIC TEST
CASE #2
8 POINTS
3.0
1.5
0.0
-1.5
-3.0
STRAIN (%)
0
90
180
270
360
CALCULATED STRAIN

IL-71

APPENDIX E

COMPUTER SUBROUTINES
FOR
STRAIN CALCULATIONS

BABCOCK & WILCOX

FIG. 1

```
      SUBROUTINE STNCAL(R,ANGLE,BNDSTN,MEMSTN,STRN1,STR    TMAX)
C     THIS SUBROUTINE APPROXIMATES THE INTERIOR CURVE OF A TUBE BY A
C     PERIODIC CUBIC SPLINE.  THE ARC LENGTH OF THE SPLINE IS CALCULATED
C     TOGETHER WITH ESTIMATES OF THE MEMBRANE AND BENDING STRAINS.
C          R - ARRAY OF RADII IN COUNTER-CLOCKWISE ORDER (INPUT).
C      ANGLE - DEGREES MEASURED FROM R(1) IN A COUNTER-CLOCKWISE DIRECTION
C              TO THE POINT OF MAXIMUM BENDING STRAIN (OUTPUT).
C     BNDSTN - BENDING STRAIN (OUTPUT).
C     MEMSTN - MEMBRANE STRAIN (REAL VARIABLE; OUTPUT).
C      STRN1 - MEMSTN+BNDSTN (OUTPUT).
C      STRN2 - MEMSTN-BNDSTN (OUTPUT).
C       TMAX - ANGLE IN RADIANS (OUTPUT).
      DIMENSION R(8),WKAREA(8,4)
      REAL KAPPAM
      COMMON A(8),CIRCUM,DEG,KAPPAM,MODE,PID4,RCIRCM,RDEG,RO,TC(4,8),
     .TCP(3,8),TCPP(2,8),TD2,THICK,TWOPI
      REAL KMAX,MEMSTN
      IF (MODE .EQ. 1) GO TO 20
         TWOPI=6.2831853
         PID4=TWOPI/8.
         DEG=PID4/45.
         RDEG=45./PID4
         CIRCUM=TWOPI*RO
         RCIRCM=1./CIRCUM
         TD2=.5*THICK
         DO 10 I=1,8
   10    A(I)=FLOAT(I-1)*PID4
         MODE=1
C     OBTAIN THE SPLINE COEFFICIENTS.
   20 CALL PCSI(A,R,8,TWOPI,TC,WKAREA(1,1),WKAREA(1,2),WKAREA(1,3),
     .WKAREA(1,4))
C     CALCULATE THE COEFFICIENTS FOR THE DERIVATIVES OF THE SPLINE.
      DO 30 I=1,8
         TCP(1,I)=3.*TC(1,I)
         TCP(2,I)=2.*TC(2,I)
         TCP(3,I)=TC(3,I)
         TCPP(1,I)=6.*TC(1,I)
   30    TCPP(2,I)=TCP(2,I)
C     CALCULATE THE ARCLENGTH.
      ARCLEN=0.
      DO 40 I=1,8
         CALL ROMBRG(I,SUMI)
   40    ARCLEN=ARCLEN+SUMI
C     CALCULATE THE MEMBRANE STRAIN.
      MEMSTN=(ARCLEN-CIRCUM)*RCIRCM
C     CALCULATE WHERE THE CURVATURE HAS CHANGED THE MOST.
      KAPPAM=TWOPI/ARCLEN
      CALL DELCUR(DCMAX,KMAX,TMAX)
C     CALCULATE THE BENDING STRAIN
      BNDSTN=TD2*DCMAX
C     CALCULATE THE ANGLE LOCATION OF THE MAXIMUM BENDING STRAIN.
      ANGLE=RDEG*TMAX
      STRN1=MEMSTN+BNDSTN
      STRN2=MEMSTN-BNDSTN
      RETURN
      END
```

APPENDIX F

COMPUTER SUBROUTINE
FOR
CALCULATING MAXIMUM BENDING STRAIN

FIG. 2

```
      SUBROUTINE DELCUR(DCMAX,KMAX,TMAX)
C     THIS SUBROUTINE MAXIMIZES (THE ABSOLUTE BENDING STRAIN)/(THICK/2).
C     FIRST WE CALCULATE THE CURVATURE AT TNEW, WHERE
C     TNEW IS THE RADIAN MEASURE FROM THE LAST KNOT (I. E., FROM
C     A(I)).  THIS USES THE FORMULATION OF THE RADIUS OF CURVATURE
C     WHERE THE CURVE IS PARAMETERIZED BY THETA.  SEE CALCULUS AND
C     ANALYTIC GEOMETRY BY GEORGE B. THOMAS, JR., THIRD EDITION, PP.
C     588-589.
C    DCMAX - (THE BENDING STRAIN)/(THICK/2) AT TMAX.
C     KMAX - THE CURVATURE AT TMAX.
C     TMAX - THE LOCATION IN RADIANS MEASURED COUNTER-CLOCKWISE FROM R(1)
C            OF THE MAXIMUM ABSOLUTE BENDING STRAIN.
      REAL KAPPAM
      COMMON A(8),CIRCUM,DEG,KAPPAM,MODE,PID4,RCIRCM,RDEG,RO,TC(4,8),
     .TCP(3,8),TCPP(2,8),TD2,THICK,TWOPI
      REAL KAPPA,KMAX
      DIMENSION DCTMP(8),TTMP(8)
      DO 10 I=1,8
         TTMP(I)=0.
         R=TC(4,I)
         DRDT=TCP(3,I)
         D2RDT2=TCPP(2,I)
         DRDT2=DRDT*DRDT
         P=2.*DRDT2+R*(R-D2RDT2)
         Q1=DRDT2+R*R
         Q=SQRT(Q1*Q1*Q1)
         KAPPA=P/Q
         DCTMP(I)=ABS((KAPPAM-KAPPA)/(1.+TD2*KAPPA))
         DO 10 J=1,44
            TNEW=FLOAT(J)*DEG
            R=((TC(1,I)*TNEW+TC(2,I))*TNEW+TC(3,I))*TNEW+TC(4,I)
            DRDT=(TCP(1,I)*TNEW+TCP(2,I))*TNEW+TCP(3,I)
            D2RDT2=TCPP(1,I)*TNEW+TCPP(2,I)
            DRDT2=DRDT*DRDT
            P=2.*DRDT2+R*(R-D2RDT2)
            Q1=DRDT2+R*R
            Q=SQRT(Q1*Q1*Q1)
            KAPPA=P/Q
            DCNEW=ABS((KAPPAM-KAPPA)/(1.+TD2*KAPPA))
            IF (DCNEW .LE. DCTMP(I)) GO TO 10
               TTMP(I)=TNEW
               DCTMP(I)=DCNEW
   10       CONTINUE
      DCMAX=DCTMP(1)
      INT=1
      TMAX=TTMP(1)
      DO 20 I=2,8
         IF (DCTMP(I) .LE. DCMAX) GO TO 20
            DCMAX=DCTMP(I)
            INT=I
            TMAX=A(I)+TTMP(I)
   20    CONTINUE
      T=TTMP(INT)
      R=((TC(1,INT)*T+TC(2,INT))*T+TC(3,INT))*T+TC(4,INT)
      DRDT=(TCP(1,INT)*T+TCP(2,INT))*T+TCP(3,INT)
      D2RDT2=TCPP(1,INT)*T+TCPP(2,INT)
      DRDT2=DRDT*DRDT
      P=2.*DRDT2+R*(R-D2RDT2)
      Q1=DRDT2+R*R
      Q=SQRT(Q1*Q1*Q1)
      KMAX=P/Q
      DCMAX=(KAPPAM-KMAX)/(1.+TD2*KMAX)
      RETURN
      END
```

F-1