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LaRC DESIGN ANALYSIS REPORT

FOR

NATIONAL TRANSONIC FACILITY

FOR

304 STAINLESS STEEL TUNNEL SHELL

FINITE DIFFERENCE ANALYSIS OF CONE/CYLINDER JUNCTION

VOL. 1S

BY

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16. Abstract This report contains the results of extensive computer (finite element, finite difference and numerical integration), thermal, fatigue, and special analyses of critical portions of a large pressurized, cryogenic wind tunnel (National Transonic Facility). The computer models, loading and boundary conditions are described. Graphic capability was used to display model geometry, section properties, and stress results. A stress criteria is presented for evaluation of the results of the analyses. Thermal analyses were performed for major critical and typical areas. Fatigue analyses of the entire tunnel circuit is presented.

The major computer codes utilized are: SPAR - developed by Engineering Information Systems, Inc. under NASA Contracts NAS8-30536 and NAS1-13977; SALORS - developed by Langley Research Center and described in NASA TN D-7179; and SRA - developed by Structures Research Associates under NASA Contract NAS1-10091; "A General Transient Heat-Transfer Computer Program for Thermally Thick Walls" developed by Langley Research Center and described in NASA TM X-2058.

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NATIONAL TRANSONIC FACILITY

TUNNEL SHELL

NASA - LaRC

FINITE DIFFERENCE ANALYSIS

OF

CONE/CYLINDER JUNCTION

304 STAINLESS STEEL

SEPTEMBER 1976

VOLUME 1S

LaRC CALCULATIONS

FOR THE

NATIONAL TRANSONIC FACILITY

TUNNEL SHELL

DATE: SEPTEMBER, 1976

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This report is one volume of a Design Analysis Report prepared by LaRC on portions of the pressure shell for the National Transonic Facility. This report is to be used in conjunction with reports prepared under NASA Contract NAS1-13535(c) by the Ralph M. Parsons Company (Job Number 5409-3 dated September 1976) and Fluidyne Engineering Corporation (Job Number 1060 dated September 1976). The volumes prepared by LaRC are listed below:

1. Finite Difference Analysis of Cone/Cylinder Junction (304 S.S.) Vol. 1, NASA TM X-73957-1.

2. Finite Element Analysis of Corners #3 and #4 (304 S.S.), Vol. 2S, NASA TM X-73957-2.

3. Finite Element Analysis of Plenum Region Including Side Access Reinforcement, Side Access Door and Angle of Attack Penetration (304 S.S.), Vol. 3S, NASA TM X73957-3.

4. Thermal Analysis (304 S.S.) Vol. 4S, NASA TM X73957-4.

5. Finite Element and Numerical Integration Analyses of the Bulkhead Region (304 S.S.), Vol. 5S, NASA TM X73957-5.

6. Fatigue Analysis (304 S.S.), Vol. 6S, NASA TM X73957-6.

7. Special Studies (304 S.S.), Vol. 7S, NASA TM X73957-7.

NTF DESIGN CRITERIA
FOR 304 STAINLESS STEEL

GENERAL

THE DESIGN OF THE PRESSURE SHELL REFLECTED IN THIS REPORT SATISFIES THE DESIGN REQUIREMENTS OF THE ASME BOILER AND PRESSURE VESSEL CODE, SECTION VIII, DIVISION 1. SINCE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN, ADDITIONAL ANALYSES WERE PERFORMED IN AREAS HAVING COMPLEX CONFIGURATIONS SUCH AS THE CONE CYLINDER JUNCTIONS, THE GATE VALVE BULKHEADS, THE BULKHEAD-SHELL ATTACHMENTS, THE PLENUM ACCESS DOORS AND REINFORCEMENT AREAS, THE ELLIPTICAL CORNER SECTIONS, AND THE FIXED REGION (RING S8) OF THE TUNNEL. THE DIVISION 1 DESIGN CALCULATIONS, THE ADDITIONAL ANALYSES AND THE CRITERIA FOR EVALUATION OF THE RESULTS OF THE ADDITIONAL ANALYSES TO ENSURE COMPLIANCE WITH THE INTENT OF DIVISION 1 REQUIREMENTS ARE CONTAINED IN THE TEXT OF THIS REPORT. THE DESIGN ANALYSES AND ASSOCIATED CRITERIA CONSIDERED BOTH THE OPERATING AND HYDROSTATIC TEST CONDITIONS.

IN CONJUNCTION WITH THE DESIGN, A DETAILED FATIGUE ANALYSIS OF THE PRESSURE SHELL WAS ALSO PERFORMED UTILIZING THE METHODS OF THE ASME CODE, SECTION VIII, DIVISION 2.

MATERIAL

THE PRESSURE SHELL MATERIAL SHALL BE ASME, SA-240, GRADE 304 FOR PLATE AND SA-182, GRADE F304 FOR FORGINGS. THE MATERIAL PROPERTIES AT TEMPERATURES EQUAL TO OR BELOW 150°F ARE AS FOLLOWS:

(A) PLATE

YIELD = 30.0 KSI
ULTIMATE = 75.0 KSI

(B) WELDS (AUTOMATIC, SEMIAUTOMATIC, OR "STICK")

YIELD = 30.0 KSI
ULTIMATE = 75.0 KSI

OPERATING, DESIGN AND TEST CONDITIONS

THE OPERATING, DESIGN AND TEST CONDITIONS FOR THE TUNNEL PRESSURE SHELL AND ASSOCIATED SYSTEMS AND ELEMENTS ARE SUMMARIZED BELOW:

1. OPERATING MEDIUM

ANY MIXTURE OF AIR AND NITROGEN

2. DESIGN TEMPERATURE RANGE

MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT, EXCEPT IN THE REGION OF THE PLENUM BULKHEADS AND GATE VALVES INSIDE A 23-FOOT, 4-INCH DIAMETER, FOR WHICH THE TEMPERATURE RANGE IS MINUS 320 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT.

3. PRESSURE RANGE

	TUNNEL CONFIGURATION	OPERATING PRESSURE RANGE, PSIA	DESIGN PRESSURES PSID
A.	CONDITION I - PLENUM ISOLATION GATES OPEN AND TUNNEL OPERATING:		
	TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	PLENUM (PLENUM PRESSURE IS LIMITED TO .4 TO 1 TIMES THE REMAINDER OF THE TUNNEL CIRCUIT	3.3 to 130	A. 15 EXTERNAL B. 119 INTERNAL
	BULKHEAD		56 (EXTERNAL TO PLENUM)
B.	CONDITION II - PLENUM ISOLATION GATES OPEN AND TUNNEL SHUTDOWN:		
	ENTIRE TUNNEL CIRCUIT	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	BULKHEAD		0
C.	CONDITION III - PLENUM ISOLATION GATES AND ACCESS DOORS CLOSED:		
	TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL

PLENUM (PLENUM OPERATING PRESSURE CAN EXCEED THE PRESSURE IN THE REMAINDER OF THE TUNNEL CIRCUIT BY 24 PSI, BUT DOES NOT EXCEED THE 130 PSIA MAXIMUM OPERATING PRESSURE)	0 to 130	A. 15 EXTERNAL B. 119 INTERNAL
BULKHEAD		A. 25 (INTERNAL TO PLENUM) B. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *C. 115.7 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

D. CONDITION IV - PLENUM ISOLATION GATES CLOSED AND ACCESS DOORS OPEN:

TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
PLENUM	14.7	0
BULKHEAD		A. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *B. 115.7 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

4. HYDROSTATIC TEST DESIGN CONDITIONS

THE PRESSURE SHELL WAS DESIGNED FOR HYDROSTATIC TEST IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASME CODE, SECTION VIII, DIVISION 1. THE TEST PRESSURES SHALL BE AS FOLLOWS. PRESSURE SHELL TEMPERATURE SHALL BE EQUAL TO OR BELOW 100°F DURING HYDROSTATIC TESTS.

CONDITION (1) - MAXIMUM INTERNAL PRESSURE CONDITION FOR THE ENTIRE TUNNEL CIRCUIT

$$PH_1 = 1.5\ (119)\ \left(\frac{18.7}{18.2}\right) + \text{HYDROSTATIC HEAD}$$

$$= 183.4\ \text{PSI} + \text{HYDROSTATIC HEAD}$$

CONDITION (2) - MAXIMUM DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$PH_2 = 1.5\ \left(\frac{18.7}{18.2}\right)\ (119) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 + \text{HYDROSTATIC HEAD}$$

$$PH_2{}^* = 1.5\ (115.7)\ \left(\frac{18.7}{17.7}\right) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 + \text{HYDROSTATIC HEAD}$$

*TUNNEL OPERATION LIMITATIONS PRECLUDE PRESSURE DIFFERENTIALS ACROSS BULKHEADS IN EXCESS OF 115.7 PSI FOR BULKHEAD AND GATE TEMPERATURES IN EXCESS OF 150°F.

CONDITION (3) - MAXIMUM REVERSE DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$PH_3 = 1.5\ \left(\frac{18.7}{18.2}\right)\ (25) = 38.5\ \text{PSI}$$

THE PRESSURE SHELL EXCEPT FOR THE PLENUM SHALL BE PRESSURIZED TO 144.9 PSIG. THE PLENUM SHALL BE PRESSURIZED TO 183.4 PSIG.

PRESSURE SHELL STRESS EVALUATION CRITERIA

THIS CRITERIA ESTABLISHES THE BASIS FOR ANALYSIS AND DESIGN OF THE PRESSURE SHELL SO IT WILL MEET OR EXCEED ALL OF THE REQUIREMENTS OF SECTION VIII, DIVISION 1 OF THE ASME BOILER AND PRESSURE VESSEL CODE AND CAN BE STAMPED WITH A DIVISION 1 "U" STAMP.

1. SECTION VIII, DIVISION 1, DIRECT APPLICATION

(A) THE MAXIMUM ALLOWABLE STRESS (S)

$S = 18.2$ KSI (-320°F TO +150°F)

$S = 17.7$ KSI (-320°F TO +200°F)

(B) PRIMARY BENDING PLUS PRIMARY MEMBRANE STRESSES

THE LOCAL MEMBRANE STRESSES ARE NOT GENERALLY CONSIDERED IN SECTION VIII, DIVISION 1 DESIGNS. HOWEVER, FOR THE PURPOSE OF DESIGNING LOCAL REINFORCEMENT AT BRACKETS, RINGS OR PENETRATIONS NOT COVERED BY DESIGN BASED ON STRESS ANALYSIS, THE LOCAL SHELL MEMBRANE STRESS SHALL BE:

$$P_b + P_m \leq 1.5\ SE$$

NOTE: E IS JOINT EFFICIENCY

2. IN REGIONS OF THE PRESSURE SHELL WHERE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN (REF. U-2(g)), ADDITIONAL ANALYSES WERE PERFORMED UTILIZING THE GUIDELINES OF THE ASME CODE, SECTION VIII, DIVISION 2, APPENDIX 4, "DESIGN BASED ON STRESS ANALYSIS." THE BASIC STRESS CRITERIA FOR DIVISION 2 IS REPRESENTED IN FIGURE 4-130.1 AND RESTATED BELOW INDICATING ANY MODIFICATIONS OR EXCESS REQUIREMENTS APPLIED TO IT TO REMAIN WITHIN THE INTENT OF DIVISION 1 AND TO OBTAIN A DIVISION 1 STAMP.

A. GENERAL PRINCIPAL MEMBRANE STRESS

MAXIMUM ALLOWABLE STRESS

$S = 18.2$ KSI (-320°F TO +150°F)

$S = 17.7$ KSI (-320°F TO +200°F)

MAXIMUM ALLOWABLE STRESS INTENSITY

$S_m = 20.0$ KSI (-320°F TO +300°F)

B. PRIMARY GENERAL MEMBRANE STRESS INTENSITY

$$P_m \leq S_m$$

AND IN ORDER TO COMPLY WITH DIVISION 1, THE MAXIMUM PRINCIPAL MEMBRANE STRESS MUST BE:

$$P_m^* \leq S$$

NOTE: THE * IS USED TO DENOTE THAT MAXIMUM PRINCIPAL STRESSES ARE TO BE COMPUTED FOR THE GIVEN LOADING CONDITION. THE INTENT IS TO DETERMINE THE STRESSES WHICH REPRESENT THE HOOP STRESSES AND MERIDIONAL STRESSES WHICH ARE THE STRESSES USED IN DIVISION 1 COMPUTATIONS.

C. DESIGN LOADS, PRIMARY LOCAL MEMBRANE STRESS INTENSITY

$$P_L \leq 1.5\ S_m$$

NOTE: LOCAL MEMBRANE STRESS INTENSITY IS DEFINED IN ACCORDANCE WITH DIVISION 2, APPENDIX 4-112(i). THE TOTAL MERIDIONAL LENGTH IS CONSIDERED TO BE $1.0 \sqrt{RT}$.

D. DESIGN LOADS, PRIMARY LOCAL MEMBRANE PLUS PRIMARY BENDING STRESS INTENSITY

$$P_L + P_b \leq 1.5\ S_m$$

E. OPERATING LOADS, PRIMARY PLUS SECONDARY STRESS INTENSITY

$$P_L + P_b + Q \leq 3\ S_m$$

3. A FATIGUE ANALYSIS WAS CONDUCTED IN ACCORDANCE WITH SECTION VIII, DIVISION 2 WITHOUT MODIFICATION.

4. HYDROSTATIC TEST CONDITION DESIGN CONSIDERATIONS

A. PRESSURE SHELL

IN ACCORDANCE WITH DIVISION 1 OF THE ASME CODE, DESIGN ANALYSIS OF THE PRESSURE SHELL FOR THE HYDROSTATIC TEST CONDITION IS NOT REQUIRED. HOWEVER, IN ORDER TO PROVIDE A SATISFACTORY ENGINEERING DESIGN FOR THE PRESSURE SHELL SPECIAL EMPHASIS WAS GIVEN, AS PROMPTED BY NOTE (1) OF SECTION VIII, DIVISION 1 OF THE ASME CODE, TO FLANGES OF GASKETED JOINTS OR OTHER APPLICATIONS WHERE SLIGHT AMOUNTS OF DISTORTION CAN CAUSE LEAKAGE OR MALFUNCTION. EXAMPLES OF THESE AREAS ARE THE PLENUM, PLENUM ACCESS DOORS, PLENUM ACCESS DOOR REINFORCEMENT, THE BULKHEADS, AND BULKHEAD FLANGES.

B. SUPPORT RINGS

DESIGN OF THE PRESSURE SHELL SUPPORT RINGS, INCLUDING

THE CORNER RINGS, FOR THE HYDROSTATIC TEST CONDITION, COMPLIES WITH THE FOLLOWING:

(A) THE COMBINED VALUE OF THE SHELL CIRCUMFERENTIAL PRESSURE STRESS, S_1 AND SHELL

BENDING STRESS S_2, RESULTING FROM ACTION OF A

PORTION OF THE SHELL AS AN INNER FLANGE OF THE RING, SHALL NOT EXCEED 0.8 WELD YIELD STRESS:

$$S_1 + S_2 \leq 0.8 \text{ WELD YIELD STRESS,}$$

WHERE, FOR SUPPORT RINGS NOT ANALYZED BY FINITE ELEMENT TECHNIQUES,

$S_1 = P_H \left(\frac{R}{T}\right) + .6\ P_H$; P_H INCLUDES HYDROSTATIC HEAD CORRECTION, AND

S_2 = RING BENDING STRESS AT INNER FLANGE, BASED ON AN EFFECTIVE WIDTH OF THE PRESSURE SHELL ACTING AS AN INNER FLANGE OF THE RING OF 1.1 MULTIPLIED BY THE SQUARE ROOT OF D_0 T.

(B) THE BENDING STRESS, S_{2F} ON THE OUTSIDE FLANGE

SHALL NOT EXCEED .9 WELD YIELD STRESS. (IN THE COMPUTER ANALYSIS ALL LOADING CONDITIONS ARE LIMITED TO .9 S_Y ON THE OUTER FLANGE.)

(C) BRACKETS AND SUPPORT PAD WELDMENTS

THE DESIGN FOR ALL LOADING CONDITIONS INCLUDING THE HYDROSTATIC TEST CONDITION OF THOSE PORTIONS OF BRACKETS AND SUPPORT PAD WELDMENTS WHICH ARE ATTACHED TO THE PRESSURE SHELL BUT NOT ON THE SURFACE OF THE SHELL SHALL COMPLY WITH THE REQUIREMENTS OF THE AISC CODE, I.E. MAXIMUM STRESS IN TENSION EQUALS .6 S_Y, ETC.

Vol 15

Finite Difference Analyses of Cone / Cylinder Junctions

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PART 1

BY______________ DATE_________ SUBJECT____ SHEET NO.________OF______
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PART 2

Hydro Test Pressure

PART 3

EFFECT OF INSULATION TEE RINGS ON SHELL STRESSES

BY .... DATE .... SUBJECT NTF SHEET NO. 1 OF ......

CHKD. BY .... DATE .... Cone / Cylinder Junctions JOB NO. ....

304 S.S.

Part I

Reference Drawing No 944383 S & 944390 S

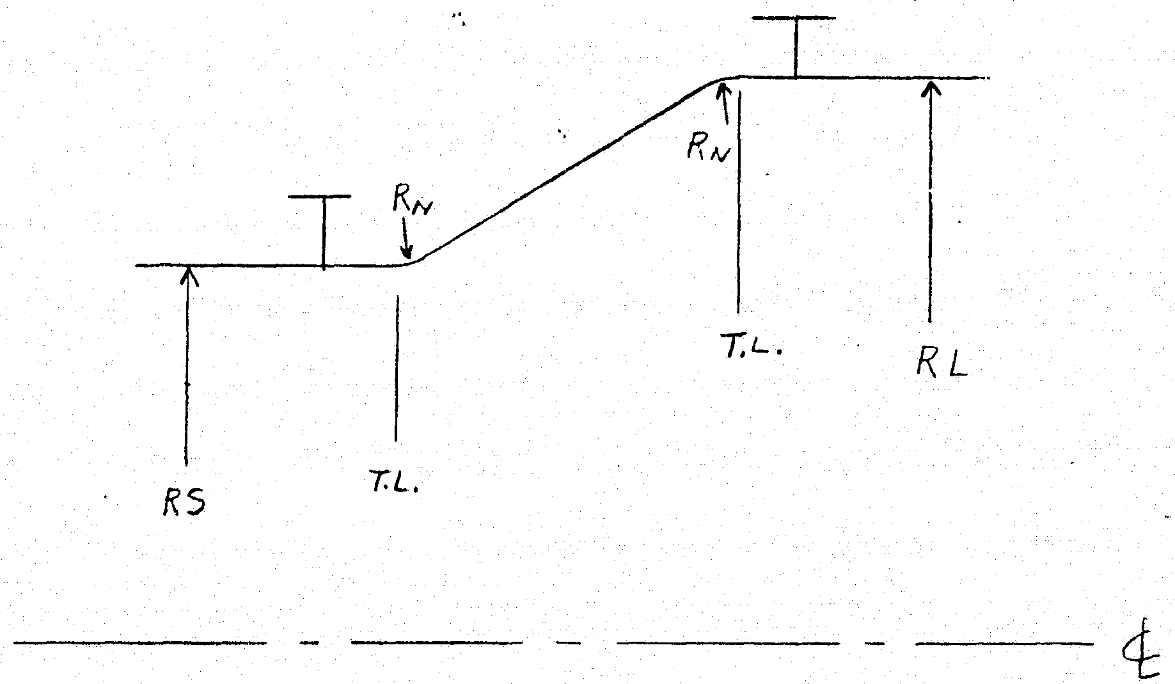
The cone / cylinder junctions were analized utilizing a shell of revolution computer code.

Computer Code

SALORS – Structural Analysis of Layered Orthotropic Ring-Stiffened Shell-of-Revolution – is a finite-difference code

Reference NASA TN D-7179

A typical cone / cylinder is shown below.



Loading

Internal pressure = 119 psig for Design condition

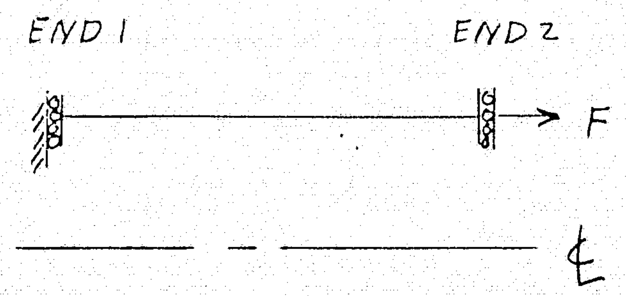
Internal pressure = 1.5(119) + water head for Hydro test condition

All pressure loadings remain normal to the deformed surface

Boundary Conditions

Symmetric B.C. were applied to each end of the model

End 1 was fixed in the axial direction. A boundary force of $\frac{1}{2} PR$ (lb/in of circ.) was applied to end 2



R1 to S2

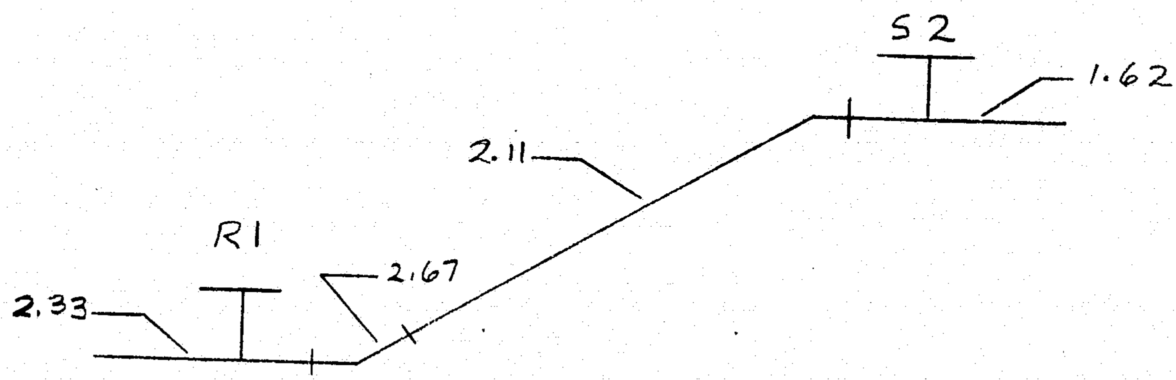


Fig 1 Computer plot of geometry

Fig 2 Average net-section hoop stress
P = 119 psi

Fig 3 Inside surface stress
longitudinal + hoop
P = 119 psi

Fig 4 Outside surface stress
longitudinal + hoop
P = 119 psi

Fig 5 Radial displacement
P = 119 psi

BY ______ DATE ______ SUBJECT ______ SHEET NO. 5A OF ______
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R1 to S2

Knuckle region at small dia cylinder

This model did not include the influence from corner #4 (elliptical ring R1). This region was considered in detail in the analyses of corner #4. See corner #4 (VOL 45) analyses of this region.

BY ______ DATE ______ SUBJECT ______ SHEET NO. 5B OF ______

CHKD. BY ______ DATE ______ JOB NO. ______

R. in S2.

Knuckle region at large dia cylinder

Membrane stress (intensity)

Primary local membrane stress intensity
(Fig 2, 3 & 4) P= 119 psi

$\sigma_1 = -14.5$ KSI

$\sigma_2 = \frac{28 + (-14.8)}{2} = 6.6$ KSI

$\sigma_3 = -\frac{.119}{2} = -.06$ KSI

$S_{12} = \sigma_1 - \sigma_2 = -14.5 - 6.6 = -21.1$ KSI

$S_{23} = 6.6 - (-.06) = 6.66$ KSI

$S_{31} = -.06 - (-14.5) = 14.44$ KSI

$P_L = |-21.1| = 21.1$ KSI

$P_L \leq 1.5 S_m$

$21.1 < 1.5(20) = 30$ O.K.

BY ________ DATE ________ SUBJECT ________________ SHEET NO. 6 OF ____
CHKD. BY ______ DATE ________ JOB NO. ________

Pi to S2

The meridional length at a stress intensity of 1.1 S_m (1.1 X 20 = 22 KSI) is 0. The peak stress intensity is less than 1.1 S_m

$$0 < \sqrt{RT}$$

∴ This stress intensity in this region is a local membrane stress intensity

General Membrane Stress Intensity

$$\sigma_1 = 18.0 \text{ KSI}$$

$$\sigma_2 = \frac{9+9}{2} = 9 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = 18.0 - 9 = 9.0 \text{ KSI}$$

$$S_{23} = 9 - (-.06) = 9.06 \text{ KSI}$$

$$S_{31} = -.06 - 18 = -18.06 \text{ KSI}$$

$$P_m = |-18.06| = 18.06 \text{ KSI}$$

BY ________ DATE ________ SUBJECT ________ SHEET NO. 7 OF ____

CHKD. BY ________ DATE ________ JOB NO. ________

R1 to S2

$P_m \le S_m$

$18.06 < 20$ KSI O.K

General principal membrane stress

$S = 18.0$ KSI

$S < 23.7$ KSI

$18.0 < 23.7$ KSI O.K.

The membrane stress (intensity) for the region meets the stress evaluation criteria.

BY ______ DATE ______ SUBJECT ______ SHEET NO. 8 OF ______
CHKD. BY ______ DATE ______ JOB NO. ______
R1 to S2

Primary Plus Secondary Stress

Inside Surface

$\sigma_1 = 28$ KSI

$\sigma_2 = -14.2$ KSI

$\sigma_3 = -\frac{.119}{2} = -.06$ KSI

$S_{12} = 28.0 - (-14.2) = 42.2$ KSI

$S_{21} = -14.2 - (-.06) = -14.14$ KSI

$S_{31} = -.06 - 28.0 = 28.06$ KSI

$S = |42.2| = 42.2$ KSI

$P_L + P_b + Q < 3S_m$

$42.2 < 3(20) = 60$ O.K.

Outside Surface

$\sigma_1 = -20.5$ KSI

$\sigma_2 = -13.8$ KSI

$\sigma_3 = 0$

$S_{12} = -20.5 - (-13.8) = -6.7$ KSI

$S_{23} = -13.8 - 0 = -13.8$ KSI

$S_{31} = 0 - 20.5 = -20.5$ KSI

$S = |-20.5| = 20.5$ KSI.

$P_L + P_b + Q \leq 3 S_m$

$20.5 < 3(20) = 60$ KSI O.K

The primary plus secondary stress intensity meets the stress evaluation criteria

BY ______ DATE ______ SUBJECT ______ SHEET NO. 10 OF ______

CHKD. BY ______ DATE ______ JOB NO. ______

S3 to R3

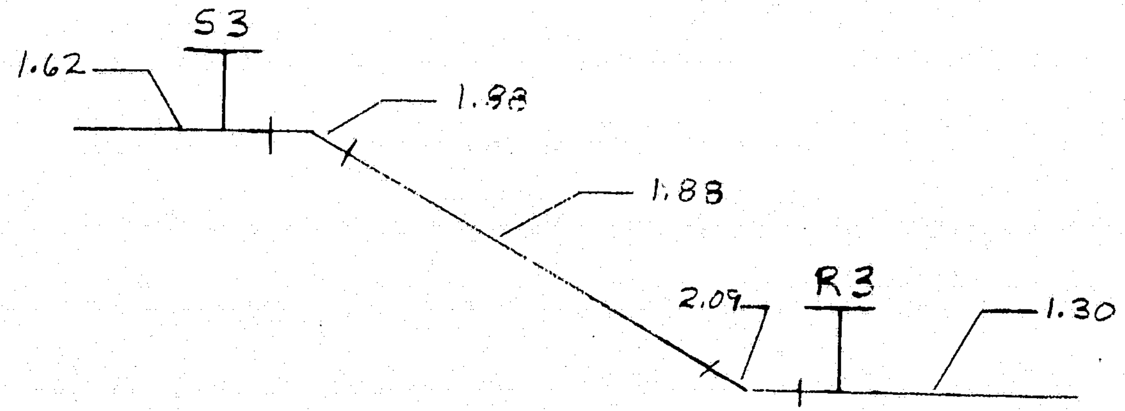


Fig 6 Computer Plot — Geometry

Fig 7 Average mid-section hoop stress
P=119 psi

Fig 8 Inside surface stress
longitudinal & hoop
P=119 psi

Fig 9 Outside surface stress
longitudinal & hoop
P=119 psi

Fig 10 Radial displacement
P=119 psi

BY ______ DATE ______ SUBJECT ______ SHEET NO. 11 OF ______
CHKD. BY ______ DATE ______ JOB NO. ______
B3 to R3

Knuckle region at the small dia cylinder

Membrane Stress (intensity)

Primary local membrane stress intensity
see Fig

$$\sigma_1 = 25 \text{ KSI}$$

$$\sigma_2 = \frac{20 + (-10)}{2} = 5 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = 25 - 5 = 20 \text{ KSI}$$

$$S_{23} = 5 - (-.06) = 5.06 \text{ KSI}$$

$$S_{31} = .06 - 25.0 = -25.06 \text{ KSI}$$

$$S = |-25.06| = 25.06 \text{ KSI}$$

$$P_L \le 1.5\ S_m$$

$$25.06 < 1.5(20) = 30 \text{ KSI}$$

O.K.

Since the stress intensity (25.06 KSI) is equal to (within reading accuracy of the stress plots) the stress (25.0 KSI), the meridional distance vs. stress intensity is taken from fig 7

The meridional distance at a stress intensity of 1.1 Sm (1.1 x 20 - 22 KSI) is 18.5"

$$18.5 < \sqrt{RT} = \sqrt{(1168.75)(2.09)} = 18.78'' \qquad \text{O.K.}$$

∴ The stress intensity in the region is a local membrane stress intensity

General Membrane Stress Intensity

$$\sigma_1 = 15.5 \text{ KSI}$$

$$\sigma_2 = \frac{20.0 + (-10)}{2} = 5 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

BY ______ DATE ______ SUBJECT ______ SHEET NO. 13 OF ______

CHKD. BY ______ DATE ______ JOB NO. ______

S3 to R3

$$S_{12} = 15.5 - 5 = 10.5 \text{ KSI}$$

$$S_{23} = 5 - .06 = 4.94 \text{ KSI}$$

$$S_{31} = -.06 - 15.5 = -15.56 \text{ KSI}$$

$$S = |-15.56| = 15.56 \text{ KSI}$$

$$P_m \leq S_m$$

$$15.56 < 20.0 \text{ KSI} \qquad \text{O.K.}$$

General principle membrane stress

$$\sigma = 15.5 \text{ KSI}$$

$$\sigma \leq S$$

$$15.5 < 23.7 \text{ KSI}$$

The membrane stress (intensity) meets the stress evaluation criteria.

BY ______ DATE ______ SUBJECT ______ SHEET NO. 14 OF ______
CHKD. BY ______ DATE ______ JOB NO. ______
S3 to R3

Primary Plus Secondary Stress Intensity

Inside Surface (Fig

$\sigma_1 = 20.3$ KSI

$\sigma_2 = -10.0$ KSI

$\sigma_3 = -.119$

$S_{12} = 20.3 - (-10.0) = 30.3$ KSI

$S_{23} = -10.0 - (-.119) = -9.881$ KSI

$S_{31} = -.119 - 20.3 = -20.419$ KSI

$S = |30.3| = 30.3$ KSI

$P_L + P_b + Q \leq 3S_m$

$30.3 < 3(20) = 60$ KSI O.K.

BY ______ DATE ______	SUBJECT ______	SHEET NO. 15 OF ______
CHKD. BY ______ DATE ______	______	JOB NO. ______
	S3 to R3	

Outside Surface

$\sigma_1 = 20.0$ KSI

$\sigma_2 = 29.0$ KSI

$\sigma_3 = 0$

$S_{12} = 20.0 - 29.0 = -9.0$ KSI

$S_{23} = 29.0 - 0 = 29.0$ KSI

$S_{31} = 0 - 20.0 = -20.0$ KSI

$S = 29.0$ KSI

$P_L + P_b + Q \leq 3 S_m$

$29.0 < 3(20) = 60$ KSI O.k.

$\therefore$ The primary plus secondary stress intensity meets the stress evaluation criteria.

BY ____ DATE ____ SUBJECT ____ SHEET NO. 16 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____

S3 to R3

Knuckle region at the large dia cylinder

Membrane stress (intensity)

Primary local membrane stress intensity

see Fig

$$\sigma_1 = -10.2 \text{ KSI}$$

$$\sigma_2 = \frac{-15 + 31.0}{2} = 8 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = -10.2 - 8.0 = -18.2 \text{ KSI}$$

$$S_{23} = 8 - (-.06) = 8.06 \text{ KSI}$$

$$S_{31} = -.06 - (-10.2) = 10.14 \text{ KSI}$$

$$S = |-18.2| = 18.2 \text{ KSI}$$

$$P_L \leq 1.5 \, S_m$$

$$18.2 < 1.5(20) = 30 \text{ KSI.} \qquad \text{O.K.}$$

Since the stress intensity is also < S_m (20 KSI), the stress intensity meets the stress evaluation criteria.

General Membrane Stress

$S = -10.2$ KSI (largest negative stress

or

$S = 17.0$ KSI positive stress on cone

$S \leq 18.2$ KSI

$17 < 18.2$ KSI O.K.

∴ The membrane stress (intensity) meets the stress evaluation criteria.

BY ____ DATE ____ SUBJECT ____ SHEET NO. 18 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____
S3 to R3

Primary Plus Secondary Stress Intensity

Inside Surface

$\sigma_1 = 31.0$ KSI

$\sigma_2 = -3.5$ KSI

$\sigma_3 = -.119$ KSI

$S_{12} = 31.0 - (-3.5) = 34.5$ KSI

$S_{23} = -3.5 - (-.119) = -3.381$ KSI

$S_{31} = -.119 - 31.0 = -31.119$ KSI

$S = |34.5| = 34.5$ KSI

$P_L + P_b + Q \leq 3S_m$

$34.5 < 3(20) = 60$ KSI O.K.

BY ______ DATE ______ SUBJECT ______ SHEET NO. 19 OF ______

CHKD. BY ______ DATE ______ JOB NO. ______

S3 to R3

Outside Surface

$\sigma_1 = -17.0$ KSI

$\sigma_2 = -15.0$ KSI

$\sigma_3 = 0$

$S_{12} = -17.0 - (-15.0) = -2.0$ KSI

$S_{23} = -15.0 - 0 = -15.0$ KSI

$S_{31} = 0 - (-17.0) = 17.0$ KSI

$S = |17.0| = 17.0$ KSI

$P_L + P_b + Q \leq 1.5\ S_m$

$17.0 < 1.5(20) = 30$ KSI O.K.

$\therefore$ The primary plus secondary stress intensity meets the stress evaluation criteria.

BY ______ DATE ______ SUBJECT ______ SHEET NO. 20 OF ______

CHKD. BY ______ DATE ______ JOB NO. ______

R6 to R9

R6 to R9

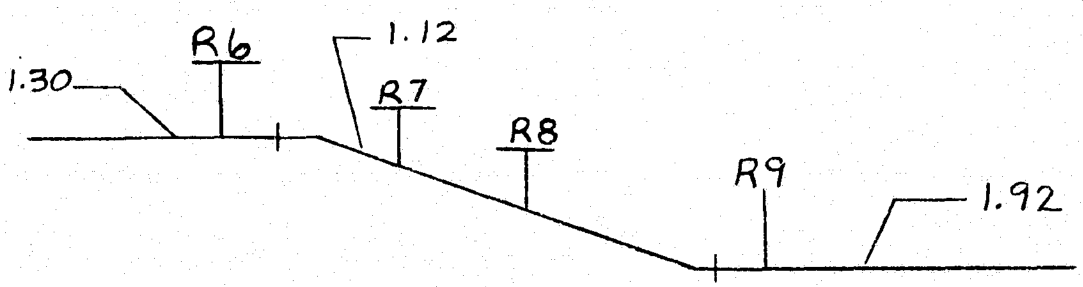


Fig 11 Computer plot of geometry

Fig 12 Average net-section hoop stress
P=119 psi

Fig 13 Inside surface stress
longitudinal & hoop
P=119 psi

Fig 14 Outside surface stress
longitudinal & hoop
P=119 psi

Fig 15 Radial displacement
P=119 psi

BY ____ DATE ____ SUBJECT ____ SHEET NO. 21 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____
R6 to R9

Junction region at the small dia cylinder

Membrane Stress (intensity)

Primary general membrane stress intensity

$$\sigma_1 = 14.0 \text{ KSI}$$

$$\sigma_2 = \frac{1+14}{2} = 7.5 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = 14.0 - 7.5 = 6.5 \text{ KSI}$$

$$S_{23} = 7.5 - (-.06) = 7.56 \text{ KSI}$$

$$S_{31} = -.06 - 14.0 = -14.06 \text{ KSI}$$

$$S = |-14.06| = 14.06 \text{ KSI}$$

BY ____ DATE ____ SUBJECT ____ SHEET NO. 22 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____
R6 to R9

This model did not consider the influence of corner #1.

The approximately influence for corner #1 can be determined by noting the influence of corner #4 on the cone/cylinder junction

From corner #4 analyses, the max. membrane stress was 24.10 KSI

From the salor analyses, the max membrane stress intensity was 20.8 KSI

% increase due to corner influence

$$\frac{24.10 - 20.8}{24.10} = 13.7\ \%$$

From corner # 4 analyses, the primary plus secondary stress intensity was

$S = 29.44$ KSI outside surface

$S = 29.46$ KSI inside surface

For SALOR analyses

Outside surface

$\sigma_1 = 24.0$ KSI

$\sigma_2 = 14.4$ KSI

$\sigma_3 = 0$

$S_{12} = 24.0 - 14.4 = 9.6$ KSI

$S_{23} = 14.2 - 0 = 14.2$ KSI

$S_{31} = 0 - 24.0 = -24.0$ KSI

$S = |-24.0| = 24.0$ KSI

BY________ DATE________ SUBJECT________ SHEET NO. 24 OF______
CHKD. BY______ DATE________ ________ JOB NO.______
R6 to R9

Inside surface

$\sigma_1 = 17.5$ KSI

$\sigma_2 = -7.0$ KSI

$\sigma_3 = -.\frac{119}{2} = -.06$ KSI

$S_{12} = 17.3 - (-7.0) = 24.3$ KSI

$S_{23} = -7.0 - (-.06) = -6.94$ KSI

$S_{31} = -.06 - 17.3 = 17.56$ KSI

$S = |24.3| = 24.3$ KSI

% increase due to corner influence
primary plus secondary stress intensity

outside surface

$$\frac{29.44 - 24.0}{29.44} = 18.4\%$$

Inside surface

$$\frac{29.46 - 24.3}{29.46} = 17.5\%$$

Increase membrane stress intensity at cone/cylinder junction near R 9 by 13.7 %

$$S = 1.137 \times 14.06 = 15.99 \text{ KSI}$$

$$P_m \leq S_m$$

$$15.99 < 20.0 \text{ KSI} \qquad \text{O.K.}$$

General Principal membrane stress

$$\sigma = 13.0$$

Increase by 13.7% due to corner influence

$$\sigma = 1.137 \times 13.0 = 14.78 \text{ KSI}$$

$$\sigma \leq 18.2 \text{ KSI}$$

$$14.78 < 18.2 \text{ KSI} \qquad \text{O.K.}$$

∴ The membrane stress (intensity) for this region meets the stress evaluation criteria.

Primary Plus Secondary Stress Intensity

Inside Surface

$\sigma_1 = 13.5$ KSI

$\sigma_2 = 1$ KSI

$\sigma_3 = -.119$ KSI

$S_{12} = 13.5 - 1 = 12.5$ KSI

$S_{23} = +1 - (-.12) = 1.12$ KSI

$S_{31} = -.12 - 13.5 = -13.65$ KSI

$S = |13.65| = 13.65$ KSI

Increase S by 17.5 % (see p.)

$S = 1.175\,(13.65) = 16.04$ KSI

$P_L + P_b + Q \leq 3\,S_m$

$16.04 < 3(20) = 60.0$ KSI

O.K.

Outside Surface

$\sigma_1 = 16.0$ KSI

$\sigma_2 = 14.0$ KSI

$\sigma_3 = 0$

$S_{12} = 16.0 - 14.0 = 2.0$ KSI

$S_{23} = 14.0 - 0 = 14.0$ KSI

$S_{31} = 0 - 16.0 = -16.0$ KSI

$S = |-16.0| = 16.0$ KSI

Increase S by 18.4% (see p.

$S = 1.184 \times 16.0 = 18.94$ KSI

$P_L + P_b + Q \leq 3S_m$

$18.94 < 3(20) = 60.0$ KSI

∴ The primary plus secondary stress intensity for this region meets the stress evaluation criteria.

Junction region at the large dia. cylinder

Membrane stress (intensity)

General membrane stress

$\sigma_1 = 8.0$ KSI

$\sigma_2 = \frac{-9+27}{2} = 9$ KSI

$\sigma_3 = -\frac{.119}{2} = -.06$ KSI

$S_{12} = 8.0 - 9 = -1$ KSI

$S_{23} = 9 - (-.06) = 9.06$ KSI

$S_{31} = -.06 - 8.0 = -8.06$ KSI

$S = |9.06| = 9.06$ KSI

$P_m \leq S_m$

$9.06 < 20.0$ KSI . O.K.

This region meets the criteria for general membrane stress intensity

BY ______ DATE ______	SUBJECT ______	SHEET NO. 29 OF ______
CHKD. BY ______ DATE ______		JOB NO. ______
	Rlp to P7	

General Membrane stress

$\sigma = 8.0$ at junction

or

$\sigma = 16.0$ on large cylinder

$\sigma \leq S$

$16 < 18.2$ KSI

The region meets the stress criteria for the general membrane stress.

BY ______ DATE ______	SUBJECT ______	SHEET NO. 30 OF ______
CHKD. BY ______ DATE ______		JOB NO. ______
	Pl6 to R9	

Primary Plus Secondary Stress Intensity

Inside Surface

$\sigma_1 = 27.6$ KSI

$\sigma_2 = 14.0$ KSI

$\sigma_3 = -.119 = -.12$ KSI

$S_{12} = 27.0 - 13.0 = 14.0$ KSI

$S_{23} = 14.0 - (-.12) = 14.12$ KSI

$S_{31} = -.12 - 27.0 = -27.12$ KSI

$S = |-27.12| = 27.12$ KSI

$P_L + P_b + Q \leq 3S_m$

$27.12 < 3(20) = 60.0$ KSI O.K.

BY ______ DATE ______ SUBJECT ______ SHEET NO. 31 OF ______
CHKD. BY ______ DATE ______ JOB NO. ______
R6 to R9

Outside Surface

$\sigma_1 = -9.0$ KSI

$\sigma_2 = 3.5$ KSI

$\sigma_3 = 0$

$S_{12} = -9.0 - 3.5 = 12.5$ KSI

$S_{23} = 3.5 - 0 = 3.5$ KSI

$S_{31} = 0 - (-9.0) = +9.0$ KSI

$S = |12.5| = 12.5$ KSI

$P_L + P_b + Q \leq 3 S_m$

$12.5 < 3(20) = 60$ KSI

The primary plus secondary stress intensity meets the stress evaluation criteria

The stresses in the region of R 7 to R 8 are approximately the same as the junction regions. Since the stresses in the junction meet the criteria by a large margin, a detail summary of the stresses at R 7 and R 8 is not given in this stress evaluation.

R10 to R12

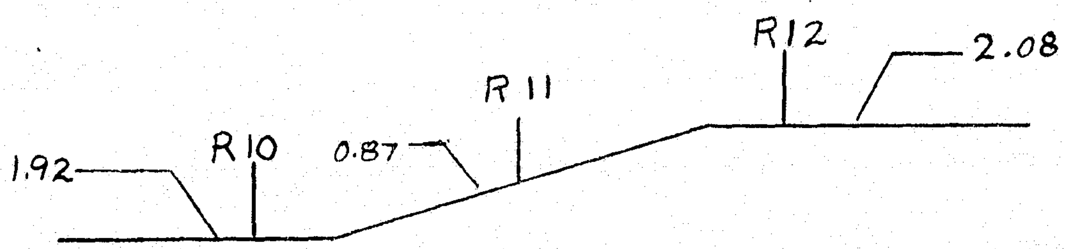


Fig 16 Computer plot of geometry

Fig 17 Average net-section hoop stress
P = 119 psi

Fig 18 Inside surface stress
longitudinal + hoop
P = 119 psi

Fig 19 Outside surface stress
longitudinal + hoop
P = 119 psi

Fig 20 Radial displacement
P = 119 psi

BY ____ DATE ____ SUBJECT ____ SHEET NO. 34 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____
R10 to R12

This model did not consider the influence from corner # 1 and corner # 2.

% increase due to corner influence for membrane
see p.

% increase 13.7 %

primary plus secondary stress intensity
(see p.

% increase

Outside surface 18.4 %

Inside surface 17.5 %

Junction region at the small dia cylinder

Membrane stress (intensity)

Primary local membrane stress intensity

$\sigma_1 = 17.0$ KSI

$\sigma_2 = \left[\frac{17.0 + 0}{2}\right] = 8.5$ KSI

$\sigma_3 = -\frac{.119}{2} = -.06$ KSI

$S_{12} = 17.0 - 8.5 = 8.5$ KSI

$S_{23} = 8.5 - (-.06) = 8.56$ KSI

$S_{31} = -.06 - 17.0 = -17.06$ KSI

$S = |-17.06| = 17.06$ KSI

$S = 1.137(17.06) = 19.39$

$P_m \leq S_m$

$19.39 < 20.0$ KSI O.K.

The general membrane stress intensity for this region meets the stress evaluation criteria

BY ______ DATE ______ SUBJECT ______ SHEET NO. 36 OF ______
CHKD. BY ______ DATE ______ JOB NO. ______
R10 to R12

General principal stress

$$\sigma = 1.137(16) = 18.19 \text{ KSI}$$

$$\sigma \leq S$$

$$18.19 < 18.2 \text{ KSI} \qquad \text{O.K.}$$

This region meets the criteria for membrane stress (intensity).

BY ______ DATE ______ SUBJECT ______ SHEET NO. 37 OF ______

CHKD. BY ______ DATE ______ JOB NO. ______

R10 to R12

Primary Plus Secondary Stress intensity

Inside Surface

$\sigma_1 = 16.5$ KSI

$\sigma_2 = 7.0$ KSI

$\sigma_3 = -.119$ KSI

$S_{12} = 16.5 - 7.0 = 9.5$ KSI

$S_{23} = 7.0 - (-.12) = 7.12$ KSI

$S_{31} = -.12 - 16.5 = -16.62$ KSI

$S = |-16.62| = 16.62$ KSI

Increase due to corner 17.5%

$S = 1.175(16.62) = 19.53$ KSI

$P_L + P_b + Q \leq 3S_m$

$19.53 < 3(20) = 60.0$ KSI

O.K.

Outside Surface

$\sigma_1 = 19.0$ KSI

$\sigma_2 = 12.0$ KSI

$\sigma_3 = 0$

$S_{12} = 19.0 - 12.0 = 7.0$ KSI

$S_{23} = 12.0 - 0 = 12.0$ KSI

$S_{31} = 0 - 19.0 = -19.0$ KSI

$S = |-19.0| = 19.0$ KSI

increase due to corner 18.4 %

$S = 1.184\,(19.0) = 22.50$ KSI

$P_L + P_b + Q \leq 3 S_m$

$22.50 < 3(20) = 60.0$ KSI

O.K.

The primary plus secondary stress intensity for this region meet the evaluation criteria.

Junction at the large dia cylinder

Membrane Stress (intensity)

$$\sigma_1 = 18.2 \text{ KSI}$$

$$\sigma_2 = \frac{12.2 + 6}{2} = 9.1 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = 18.2 - 9.1 = 9.1 \text{ KSI}$$

$$S_{23} = 9.1 - (-.06) = 9.06 \text{ KSI}$$

$$S_{31} = -.06 - 18.2 = -18.26 \text{ KSI}$$

$$S = |-18.26| = 18.26 \text{ KSI}$$

Assume the same % increase for this region as the small dia region (13.7 %)

$$\therefore \quad S = 1.137(18.26) = 20.76 \text{ KSI}$$

$$P_L \leq 1.5\, S_m$$

$$20.76 < 1.5(20) = 30.0 \text{ KSI} \quad \text{O.K.}$$

The stress intensity (20.76 KSI) < $1.1\, S_m$ ($1.1 \times 20 = 22.0$ KSI)

∴ The meridional length over which the stress intensity exist is 0

∴ This stress is a local membrane stress intensity

General Membrane Stress intensity

$$\sigma_1 = 18.0 \text{ KSI}$$

$$\sigma_2 = \frac{9+9}{2} = 9.0 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = 18.0 - 9.0 = 9.0 \text{ KSI}$$

$$S_{23} = 9.0 - (-.06) = 9.06 \text{ KSI}$$

$$S_{31} = -.06 - 18.06 = -18.06 \text{ KSI}$$

$$S = |-18.06| = 18.06 \text{ KSI}$$

BY ______ DATE ______	SUBJECT ______	SHEET NO. 41 OF ______
CHKD. BY ______ DATE ______	______	JOB NO. ______
	R10 to R12	

$$P_m \leq S_m$$

$18.06 < 20.0$ KSI   O.K

General membrane stress

$\sigma = 18.0$ KSI

$\sigma \leq S$

$18.0 < 18.2$ KSI   O.K.

∴ The membrane stress (intensity) meets the stress evaluation criteria.

Primary Plus Secondary Stress Intensity

Inside Surface

$\sigma_1 = 18.0$ KSI

$\sigma_2 = 11.0$ KSI

$\sigma_3 = -.119$ KSI

$S_{12} = 18.0 - 11.0 = 7.0$ KSI

$S_{23} = 11.0 - (-.12) = 11.12$ KSI

$S_{31} = -.12 - 18.0 = -18.12$ KSI

$S = |-18.12| = 18.12$ KSI

increase due to corner influence

$S = 1.175\,(18.12) = 21.29$ KSI

$P_L + P_b + Q \leq 3S_m$

$21.29 < 3(20) = 60$ KSI O.K.

BY ______ DATE ______	SUBJECT ______	SHEET NO. 43 OF ______
CHKD. BY ______ DATE ______	R10 to R12	JOB NO. ______

Outside Surface

$\sigma_1 = 18.0$ KSI

$\sigma_2 = 12.0$ KSI

$\sigma_3 = 0$

$S_{12} = 18.0 - 12.0 = 6.0$ KSI

$S_{23} = 12 - 0 = 12.0$ KSI

$S_{31} = 0 - 18.0 = -18.0$ KSI

$S = |-18.0| = 18.0$ KSI

increase due to corner

$S = 1.184\ (18.0) = 21.31$ KSI

$P_L + P_b + Q \leq 3 S_m$

$21.31 < 3(20) = 60$ KSI O.K.

The primary plus secondary stress intensity meets the criteria.

BY______ DATE______ SUBJECT______ SHEET NO. 44 OF______

CHKD. BY______ DATE______ JOB NO.______

R10 to R12

The analysis of this section includes a ring (R11) located on the cone section. This ring has subsequently been removed and ring R12 renumbered as R11. This analysis was not redone with this ring removed since the effects of it were negligible.

BY ____ DATE ____ SUBJECT ____ SHEET NO. 45 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____
R13A to S8

R13A to S8

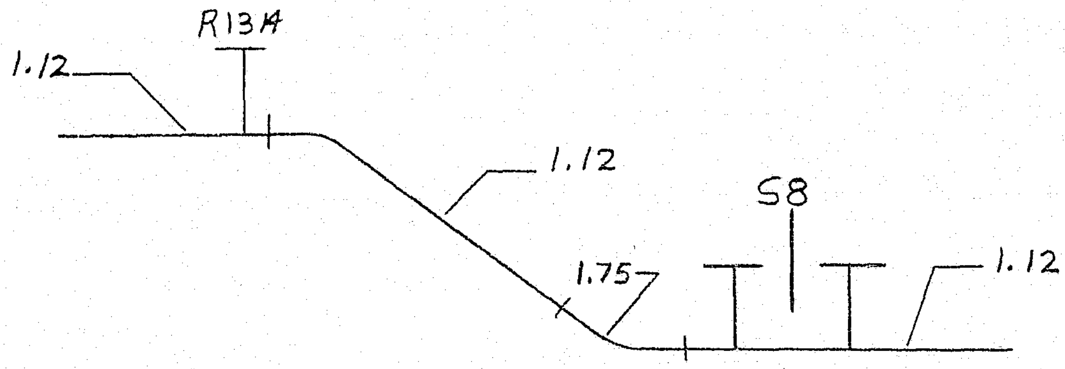


Fig 21 Computer plot of geometry

Fig 22 Average net-section hoop stress
$P = 119$ psi

Fig 23 Inside surface stress
longitudinal & hoop
$P = 119$ psi

Fig 24 Outside surface stress
longitudinal + hoop
$P = 119$ psi

Fig 25 Radial displacement
$P = 119$ psi

Knuckle region at the small dia cylinder

Membrane stress (intensity)

Primary local membrane stress intensity see Fig 22

$$\sigma_1 = 24.0 \text{ KSI}$$

$$\sigma_2 = \frac{-9.0 + 17.5}{2} = 4.25 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = 24.0 - 4.25 = 19.75 \text{ KSI}$$

$$S_{23} = 4.25 - (-.06) = 4.31 \text{ KSI}$$

$$S_{31} = -.06 - 24.0 = -24.06 \text{ KSI}$$

$$S = |-24.06| = 24.06 \text{ KSI}$$

$$P_L = 1.5\ S_m$$

$$24.06 < 1.5(20) = 30 \text{ KSI}$$

since the stress intensity (24.06 KSI) is equal to (within reading accuracy of the stress plots) the stress (24.0 KSI), the meridional distance vs. stress intensity is tak n from Fig

The meridional distance at a stress intensity of 1.1 Sm (1.1 x 20 = 22 KSI) is 13.5".

$$13.5'' < \sqrt{RT} = \sqrt{132(1.75)} = 15.20'' \quad \text{O.K.}$$

∴ The stress intensity in the region is a local membrane stress intensity.

General Membrane Stress Intensity

$$\sigma_1 = 12.3 \text{ KSI}$$

$$\sigma_2 = \frac{1.2 + 12.8}{2} = 7.0 \text{ KSI}$$

$$\sigma_3 = \frac{-.119}{2} = -.06 \text{ KSI}$$

$S_{12} = 12.3 - 7.0 = 5.3$ KSI

$S_{23} = 7.0 - (-.06) = 7.06$ KSI

$S_{31} = -.06 - 12.3 = -12.36$

$S = |-12.36| = 12.36$ KSI

$P_m \leq S_m$

$12.36 < 20.0$ KSI

General principle membrane stress

$\sigma = 12.3$

$\sigma \leq S$

$12.3 < 23.7$ KSI

The membrane stress (intensity) meets the stress evaluation criteria.

Primary Plus Secondary Stress Intensity

Inside surface (Fig

$\sigma_1 = 20.0$ KSI

$\sigma_2 = -9.0$ KSI

$\sigma_3 = -.119$ KSI

$S_{12} = 20.0 - (-9.0) = 29.0$ KSI

$S_{23} = -9.0 - (-.119) = -8.881$ KSI

$S_{31} = -.119 - 20.0 = -20.119$ KSI

$S = |29.0| = 29.0$ KSI

$P_L + P_b + Q \leq 3 S_m$

$29.0 < 3(20) = 60$ KSI o.k.

Outside surface

$$\sigma_1 = 27.5 \text{ KSI}$$
$$\sigma_2 = 17.5 \text{ KSI}$$
$$\sigma_3 = 0.$$

$$S_{12} = 27.5 - 17.5 = 10.0 \text{ KSI}$$
$$S_{23} = 17.5 - 0 = 17.5 \text{ KSI}$$
$$S_{31} = 0 - 27.5 = -27.5 \text{ KSI}$$

$$S = |-27.5| = 27.5 \text{ KSI}$$

$$P_L + P_b + Q \leq 3\, S_m$$
$$27.5 < 3(20) = 60 \text{ KSI}$$

∴ The primary plus secondary stress intensity meets the stress evaluation criteria.

Knuckle region at the large dia cylinder

Membrane stress (intensity)

Primary local membrane stress intensity. see Fig 22

$$\sigma_1 = -8.3 \text{ KSI}$$

$$\sigma_2 = \frac{32.6 + (-16.2)}{2} = 8.2 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = -8.3 - 8.2 = -16.5 \text{ KSI}$$

$$S_{23} = 8.2 - (-.06) = 8.06 \text{ KSI}$$

$$S_{31} = -.06 - (-8.3) = 8.24 \text{ KSI}$$

$$S = |-16.5| = 16.5 \text{ KSI}$$

$$P_L \leq 1.5\, S_m$$

$$16.5 < 1.5(20) = 30 \text{ KSI}$$

Since the stress intensity is also $< S_m$ (20 KSI), the stress intensity meets the stress evaluation criteria.

General Membrane Stress

$S = 17.0$ KSI (on cylinder

$S \leq 18.2$ KSI

$17.0 < 18.2$ KSI   O.K.

$\therefore$ The membrane stress (intensity) meets the stress evaluation criteria.

Primary Plus Secondary Stress Intensity

Inside Surface

$$\sigma_1 = 32.8 \text{ KSI}$$
$$\sigma_2 = -1.0 \text{ KSI}$$
$$\sigma_3 = -.119 \text{ KSI}$$

$$S_{12} = 32.8 - (-1.0) = 33.8 \text{ KSI}$$
$$S_{23} = -1.0 - (-.119) = -.881 \text{ KSI}$$
$$S_{31} = -.119 - 32.8 = -32.919 \text{ KSI}$$

$$S = |33.8| = 33.8 \text{ KSI}$$

$$P_L + P_b + Q \leq 3 S_m$$

$$33.8 < 3(20) = 60 \text{ KSI}$$

BY	DATE	SUBJECT	SHEET NO. 54 OF
CHKD. BY	DATE		JOB NO.
		RIBA to S8	

Outside surface

$$\sigma_1 = -16.5 \text{ KSI}$$

$$\sigma_2 = -15.8 \text{ KSI}$$

$$\sigma_3 = 0.$$

$$S_{12} = -16.5 - (-15.8) = 0.7 \text{ KSI}$$

$$S_{23} = -15.8 - 0 = -15.8 \text{ KSI}$$

$$S_{31} = 0 - (-16.5) = 16.5 \text{ KSI}$$

$$S = |16.5| = 16.5 \text{ KSI}$$

$$P_L + P_b + Q \leq 1.5 S_m$$

$$16.5 < 1.5(20) = 30 \text{ KSI}$$

S9 to R16

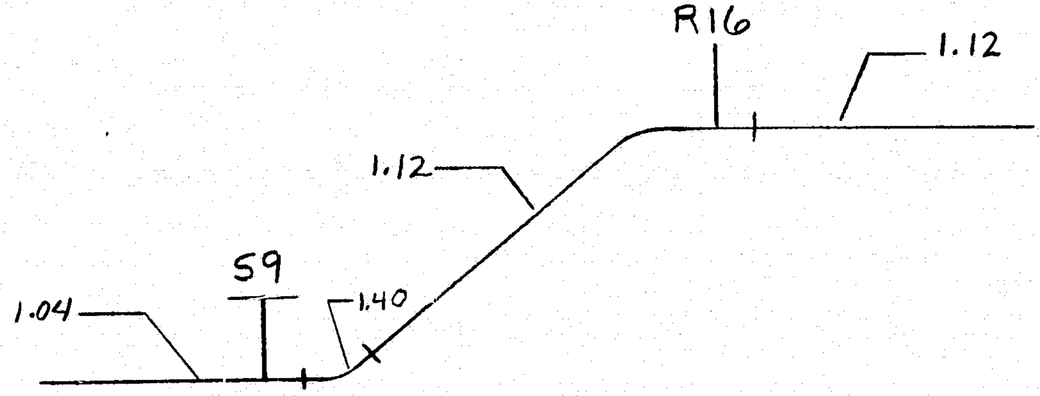


Fig 26 Computer plot of geometry

Fig 27 Average net-section hoop stress
P=119 psi

Fig 28 Inside surface stress
longitudinal + hoop
P=119 psi

Fig 29 Outside surface stress
longitudinal + hoop
P=119 psi

Fig 30 Radial displacement
P=119 psi

Knuckle region at the small dia cylinder

Membrane Stress (intensity)

Primary local membrane stress intensity
see Fig 27

$$\sigma_1 = 24.4 \text{ KSI}$$

$$\sigma_2 = \frac{18.0 + (-8.0)}{2} = 5.0 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = 24.4 - 5.0 = 19.4 \text{ KSI}$$

$$S_{23} = 5.0 - (-.06) = 5.06 \text{ KSI}$$

$$S_{31} = -.06 - 24.4 = -24.46$$

$$S = |-24.46| = 24.46 \text{ KSI}$$

$$P_L \leq 1.5\, S_m$$

$$24.46 < 1.5(20) = 30 \text{ KSI}$$

Since the stress intensity (24.46 KSI) is equal to (within reading accuracy of the stress plots) the stress (24.4 KSI), the meridional distance vs. stress intensity is taken from Fig 27.

The meridional distance at a stress intensity of $1.1 S_m$ ($1.1 \times 20 = 22$ KSI) is 12".

$$12'' < \sqrt{RT} = \sqrt{(110)(1.40)} = 12.5''$$

$\therefore$ the stress intensity in the region is a local membrane stress intensity.

General Membrane Stress Intensity

$$\sigma_1 = 15.0 \text{ KSI}$$

$$\sigma_2 = \frac{6.0 + 8.6}{2} = 7.3 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

BY............ DATE........ SUBJECT........................ SHEET NO. 58 OF......

CHKD. BY...... DATE........ JOB NO..........

S9 to R16

$$S_{12} = 15.0 - 7.3 = 7.7 \text{ KSI}$$

$$S_{23} = 7.3 - (-.06) = 7.36 \text{ KSI}$$

$$S_{31} = -.06 - 15.0 = -15.06 \text{ KSI}$$

$$S = |-15.06| = 15.06 \text{ KSI}$$

$$P_m \leq S_m$$

$$15.06 < 20.0 \text{ KSI}$$

General principal membrane stress

$$\sigma = 15.0 \text{ KSI}$$

$$\sigma \leq S$$

$$15.0 < 23.7 \text{ KSI}$$

The membrane stress (intensity) meets the stress evaluation criteria.

Primary plus Secondary Stress Intensity

Inside Surface (Fig 28)

$\sigma_1 = 20.5$ KSI

$\sigma_2 = -8.0$ KSI

$\sigma_3 = -.119$

$S_{12} = 20.5 - (-8.0) = 28.5$ KSI

$S_{23} = -8.0 - (-.119) = -7.881$ KSI

$S_{31} = -.119 - 20.5 = -20.619$ KSI

$S = |28.5| = 28.5$ KSI

$P_L + P_b + Q \leq 3\, S_m$

$28.5 < 3(20) = 60$ KSI   O.K.

Outside Surface

$\sigma_1 = 28.5$ KSI

$\sigma_2 = 18.0$ KSI

$\sigma_3 = 0.$

$S_{12} = 28.5 - 18.0 = 10.5$ KSI

$S_{23} = 18.0 - 0 = 18.0$ KSI

$S_{31} = 0 - 28.5 = -28.5$ KSI

$S = |-28.5| = 28.5$ KSI

$P_L + P_b + Q \leq 3 S_m$

$28.5 < 3(20) = 60$ KSI

∴ The primary plus secondary stress intensity meets the stress evaluation criteria.

Knuckle region at large dia cylinder

Membrane Stress (intensity)

Primary local membrane stress intensity. see Fig 27.

$$\sigma_1 = -9.1 \text{ KSI}$$

$$\sigma_2 = \frac{-16.0 + 32.2}{2} = 8.1 \text{ KSI}$$

$$\sigma_3 = -\frac{.119}{2} = -.06 \text{ KSI}$$

$$S_{12} = -9.1 - 8.1 = -17.2 \text{ KSI}$$

$$S_{23} = 8.1 - (-.06) = 8.16 \text{ KSI}$$

$$S_{31} = -.06 - (-9.1) = 9.04 \text{ KSI}$$

$$S = |-17.2| = 17.2 \text{ KSI}$$

$$P_L \leq 1.5\ S_m$$

$$17.2 < 1.5(20) = 30 \text{ KSI}$$

Since the stress intensity is also < Sm (20 KSI), the stress intensity meets the stress evaluation criteria.

General Membrane Stress

$S = -9.1$ KSI (largest negative stress)

or

$S = 17.0$ KSI (positive stress on cone)

$S \leq 18.2$ KSI

$17.0 < 18.2$ KSI o.k.

∴ The membrane stress (intensity) meets the stress evaluation criteria.

BY .... DATE .... SUBJECT .... SHEET NO. 63 OF ......
CHKD. BY ...... DATE .... JOB NO. ....
S9 TO R16

Primary Plus Secondary Stress Intensity

Inside Surface

$$\sigma_1 = 32.5 \text{ KSI}$$

$$\sigma_2 = -2.0 \text{ KSI}$$

$$\sigma_3 = -.119 \text{ KSI}$$

$$S_{12} = 32.5 - (-2.0) = 34.5 \text{ KSI}$$

$$S_{23} = -2.0 - (-.119) = -1.881 \text{ KSI}$$

$$S_{31} = -.119 - 32.5 = -32.619 \text{ KSI}$$

$$S = |34.5| = 34.5 \text{ KSI}$$

$$P_L + P_b + Q \leq 3 S_m$$

$$34.5 \checkmark < 3(20) = 60 \text{ KSI}$$

Outside surface

$$\sigma_1 = -16.0 \text{ KSI}$$

$$\sigma_2 = -15.8 \text{ KSI}$$

$$\sigma_3 = 0$$

$$S_{12} = -16.0 - (-15.8) = -0.2 \text{ KSI}$$

$$S_{23} = -15.8 - 0 = -15.8 \text{ KSI}$$

$$S_{31} = 0 - (-16.0) = 16.0 \text{ KSI}$$

$$S = |16.0| = 16.0 \text{ KSI}$$

$$P_L + P_b + Q \leq 1.5\, S_m$$

$$16.0 < 1.5(20) = 30 \text{ KSI}$$

∴ The primary plus secondary stress intensity meets the stress evaluation criteria.

S9 to R21

This region of the tunnel is a long shallow cone. The cone angle for the cone is shallower than the cone angle for the region between R6 + R9. Due to the fact shallow cone angles do not produce high stresses at the knuckles (Ref. Fig 11-14 and the evaluation of R6 to R9 cone p. 20 thru 32) the area was not analyzed by finite difference methods.

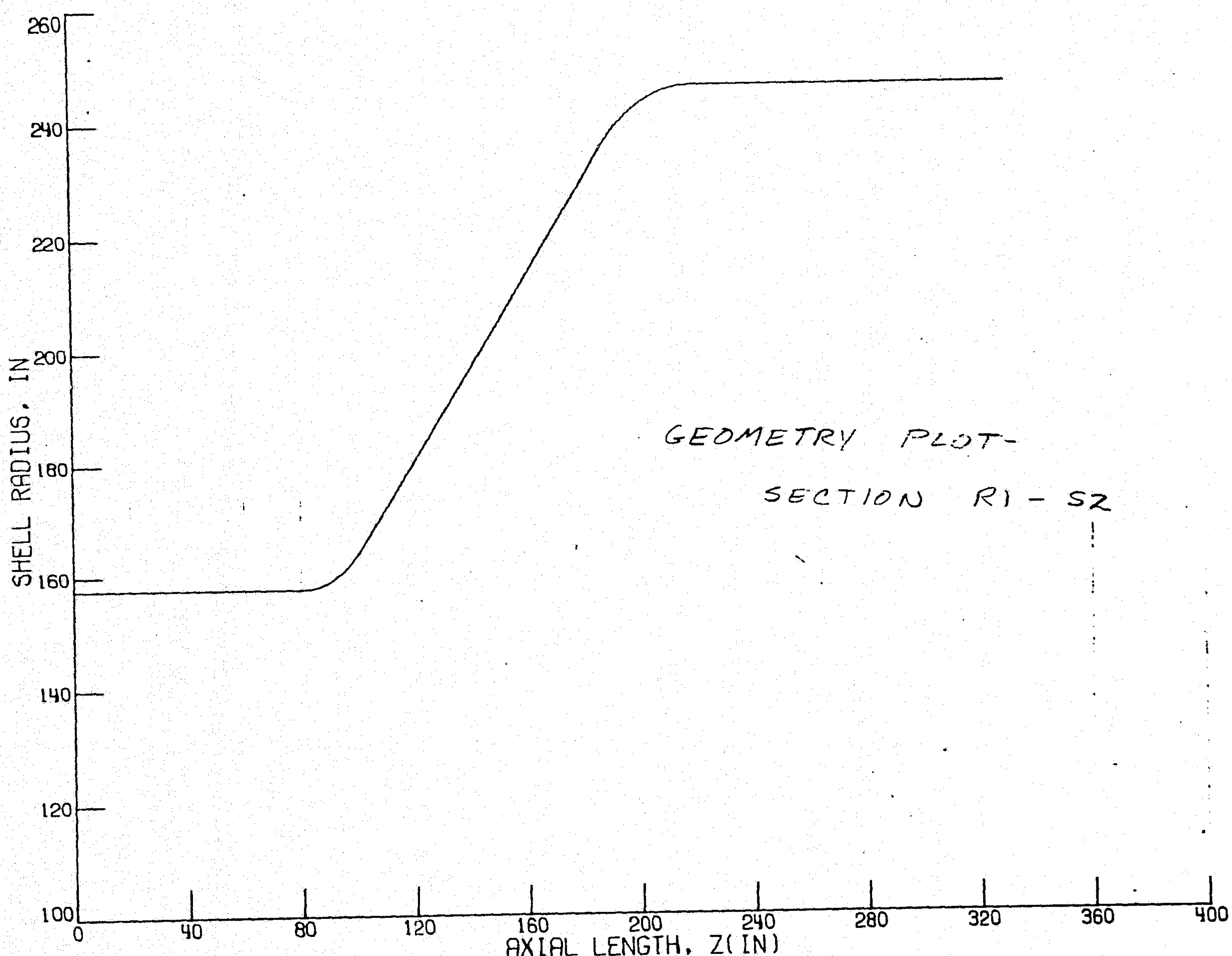
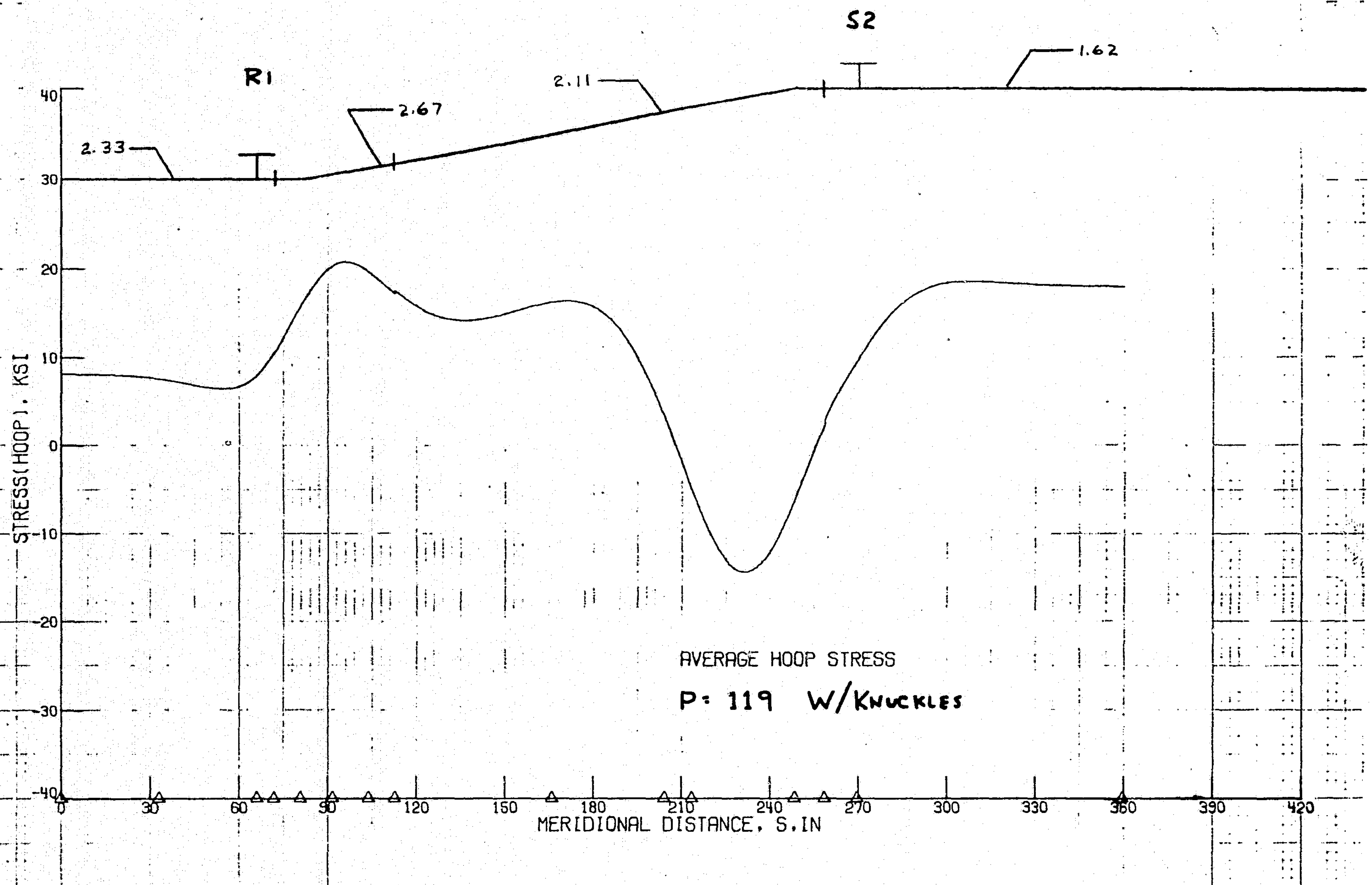
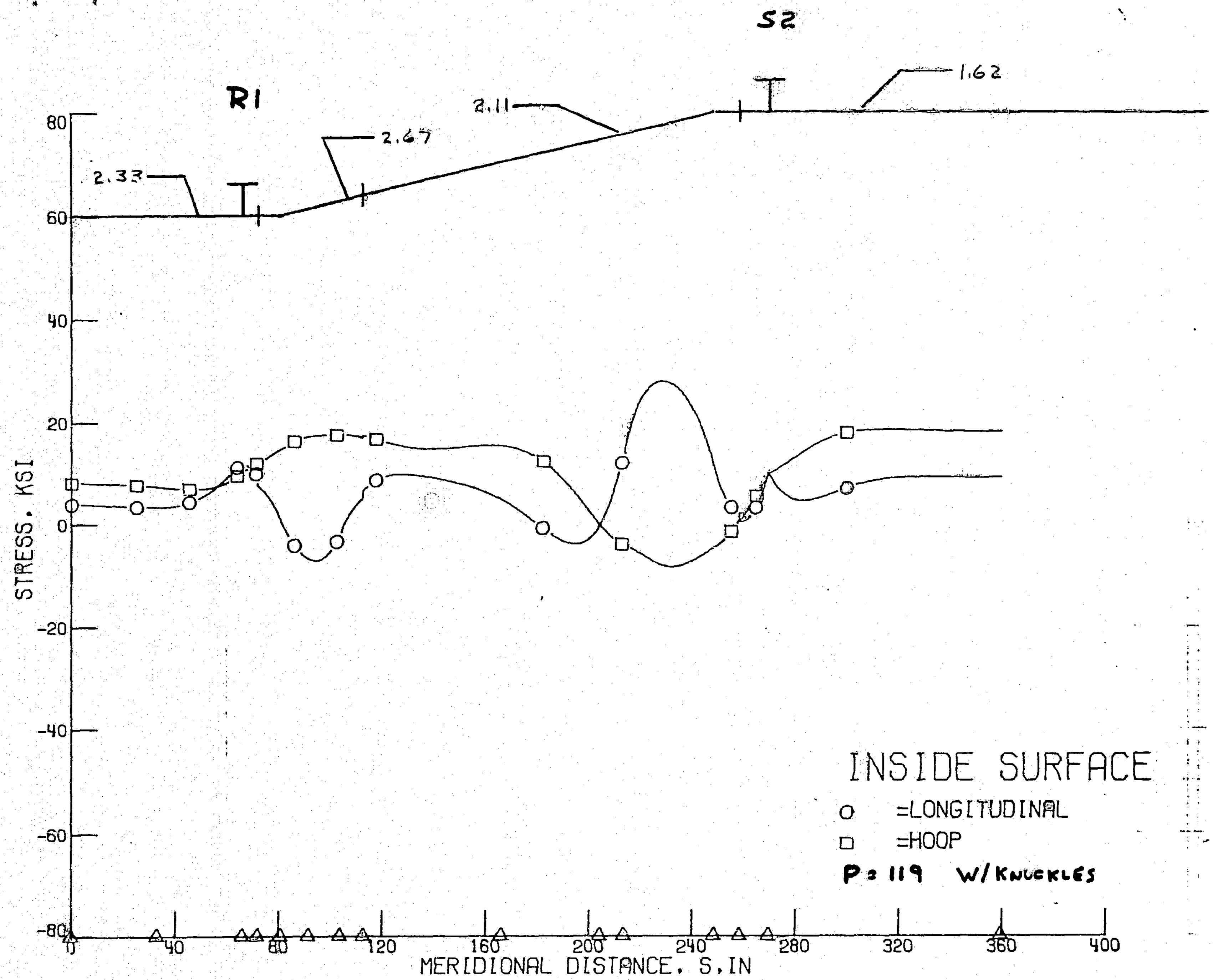

260
240
220
200
180
160
140
120
100
SHELL RADIUS, IN
0
40
80
120
160
200
240
280
320
360
400
AXIAL LENGTH, Z(IN)
GEOMETRY PLOT-
SECTION R1 - S2

FIGURE 1



S2
R1
1.62
2.11
2.67
2.33
40
30
20
10
0
-10
-20
-30
-40
STRESS(HOOP), KSI
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
MERIDIONAL DISTANCE, S.IN
AVERAGE HOOP STRESS
P= 119 W/KNUCKLES

FIGURE 2



S2
R1
1.62
2.11
2.67
2.33
80
60
40
20
0
-20
-40
-60
-80
STRESS, KSI
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S,IN
INSIDE SURFACE
=LONGITUDINAL
=HOOP
P = 119 W/KNUCKLES

FIGURE 3

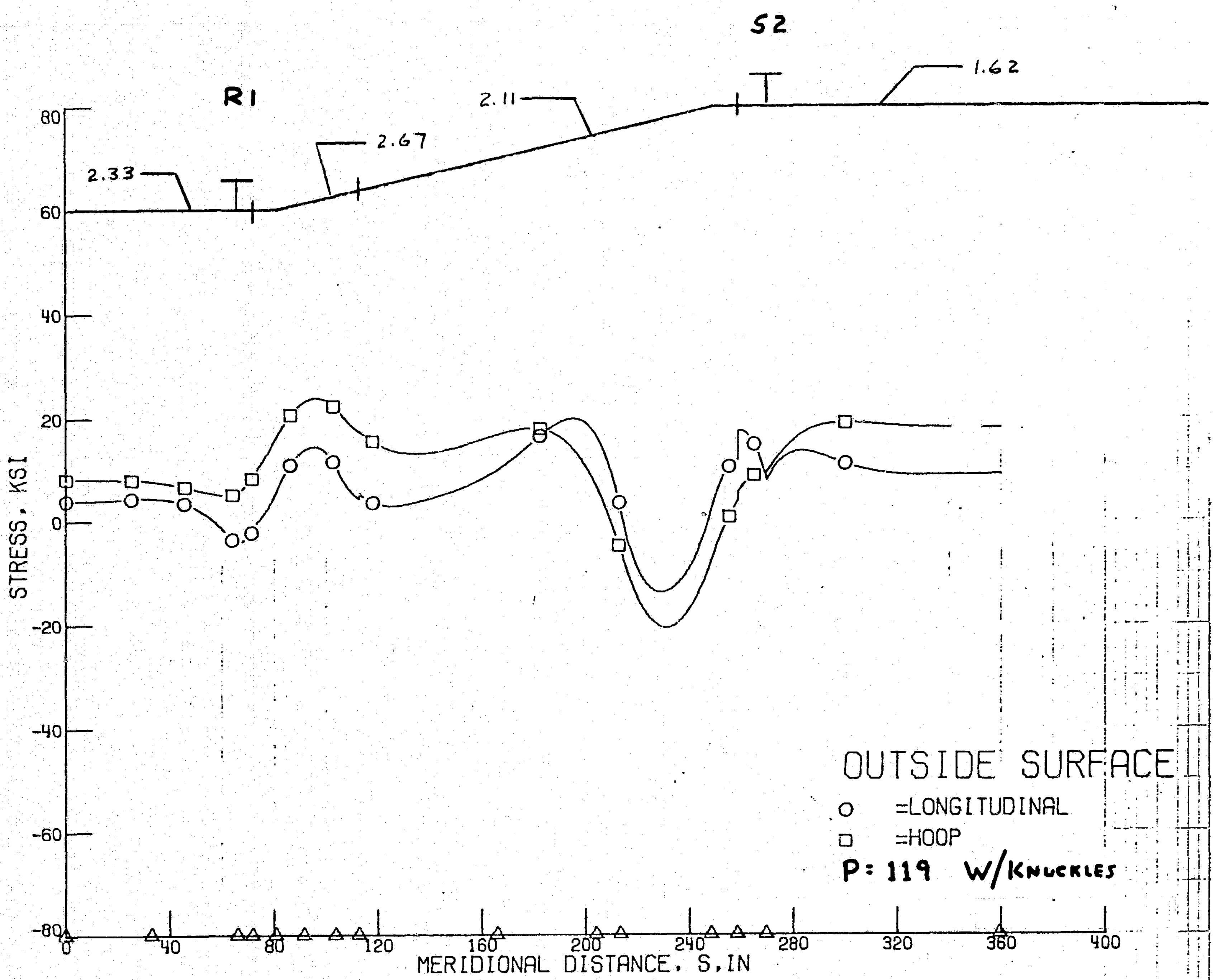
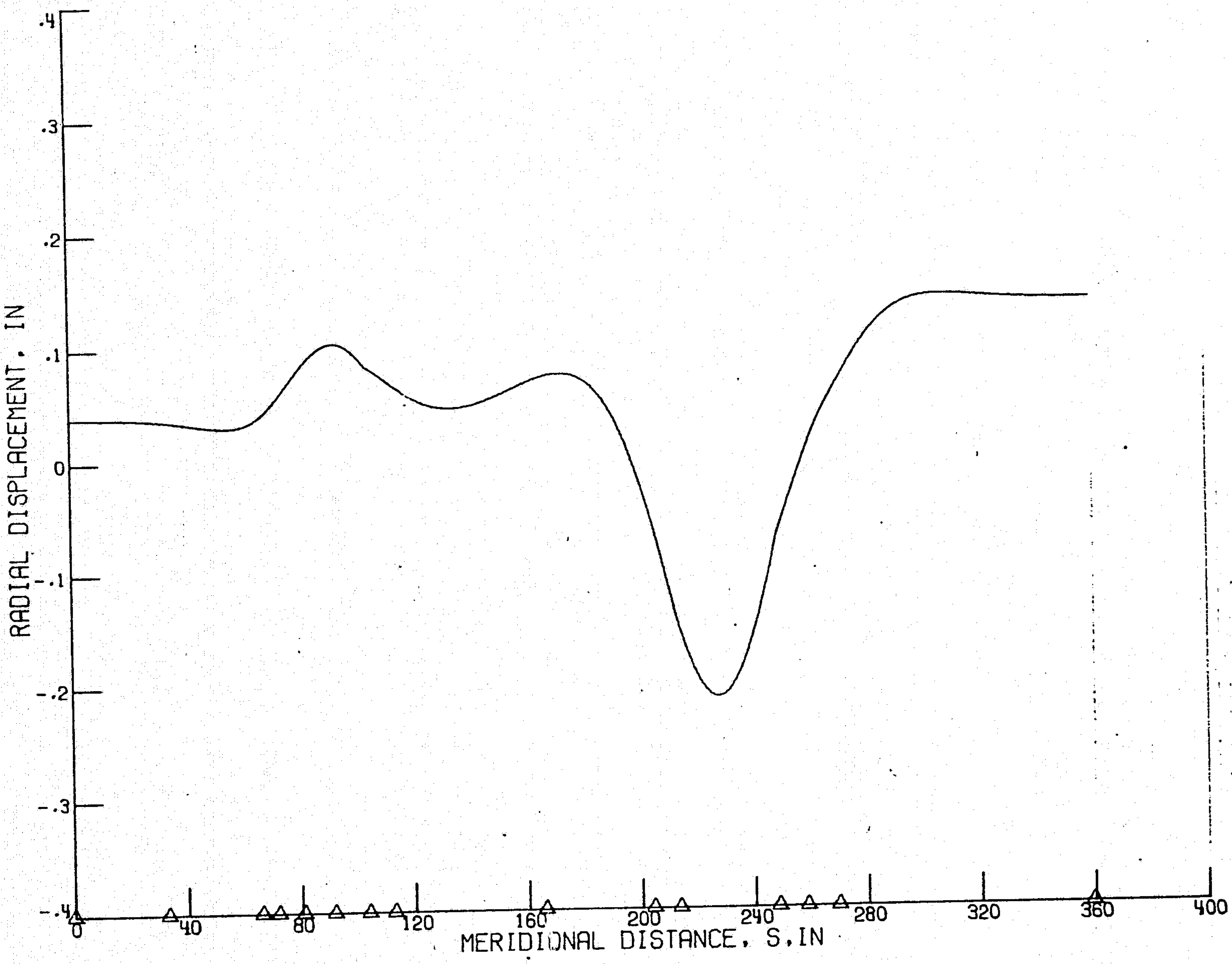
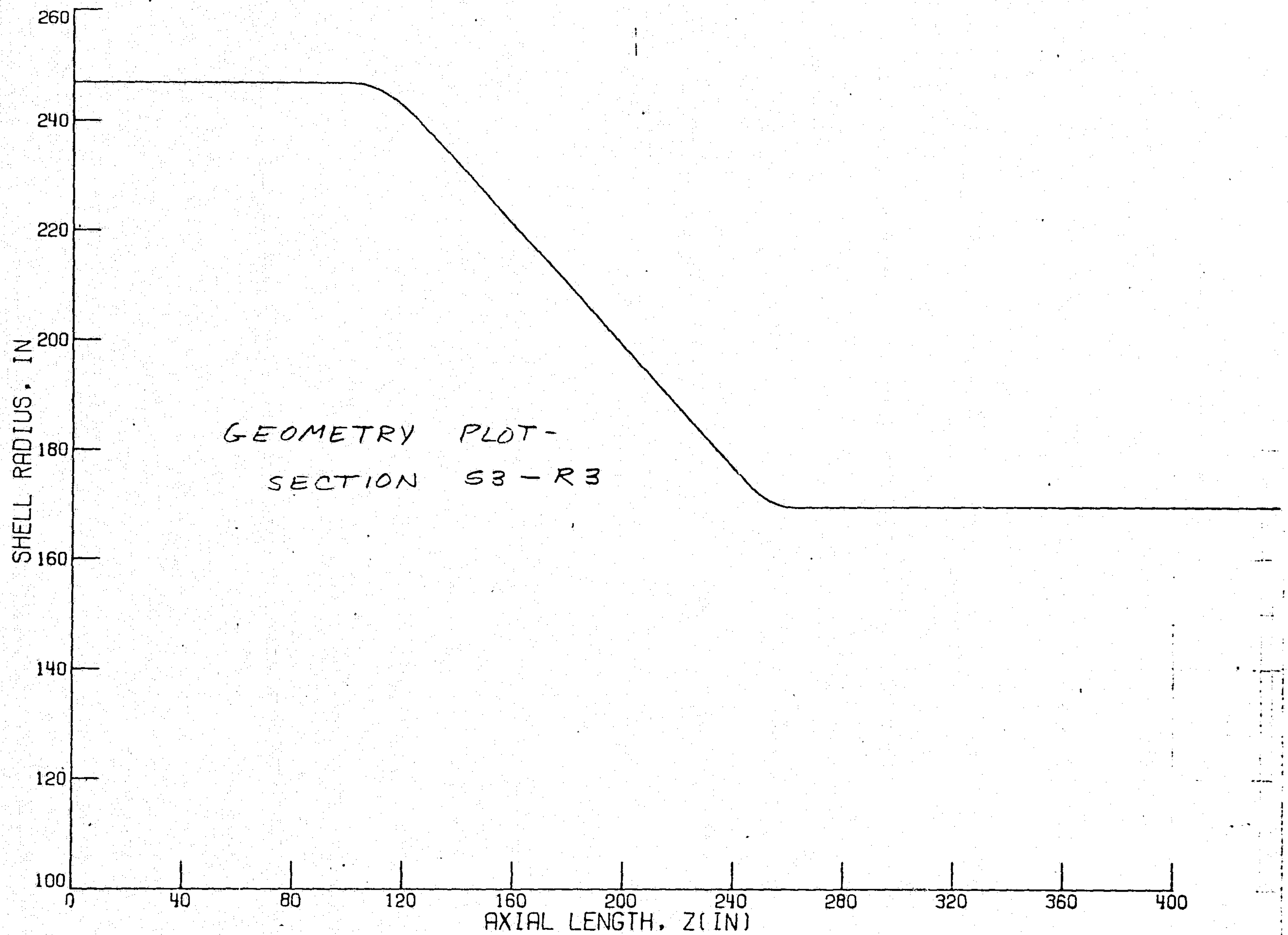

S2
R1
1.62
2.11
2.67
2.33
STRESS, KSI
MERIDIONAL DISTANCE, S,IN
OUTSIDE SURFACE
○ =LONGITUDINAL
□ =HOOP
P: 119 W/KNUCKLES

FIGURE 4



.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
RADIAL DISPLACEMENT, IN
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S,IN

FIGURE 5



260
240
220
200
180
160
140
120
100
SHELL RADIUS, IN
0
40
80
120
160
200
240
280
320
360
400
AXIAL LENGTH, Z(IN)
GEOMETRY PLOT -
SECTION S3 - R3

FIGURE 6

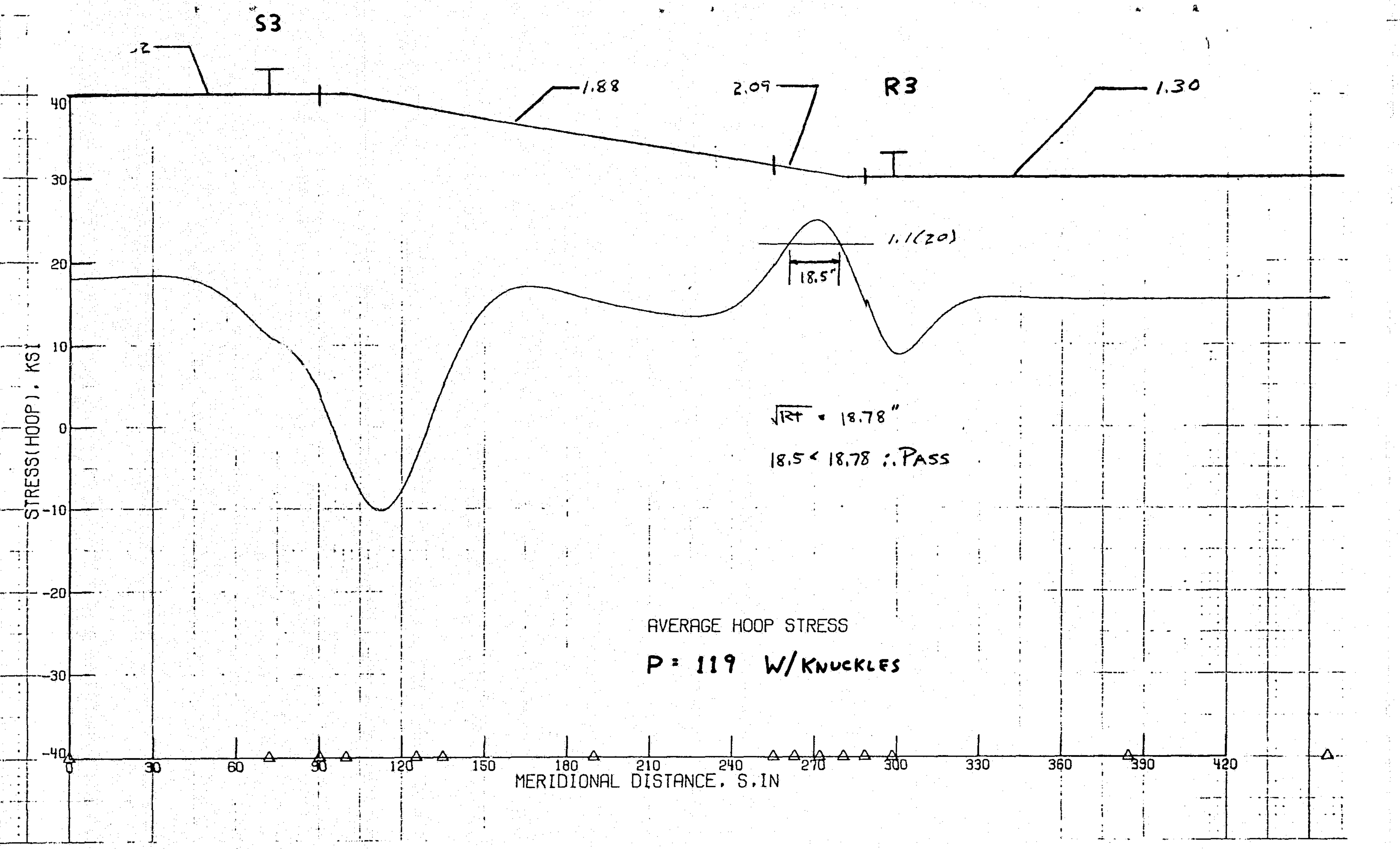

S3
R3
1.88
2.09
1.30
1.1(20)
18.5"
√Rt = 18.78"
18.5 < 18.78 ∴ PASS
AVERAGE HOOP STRESS
P = 119 W/KNUCKLES
STRESS(HOOP), KSI
MERIDIONAL DISTANCE, S,IN
40
30
20
10
0
-10
-20
-30
-40
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420

FIGURE 7

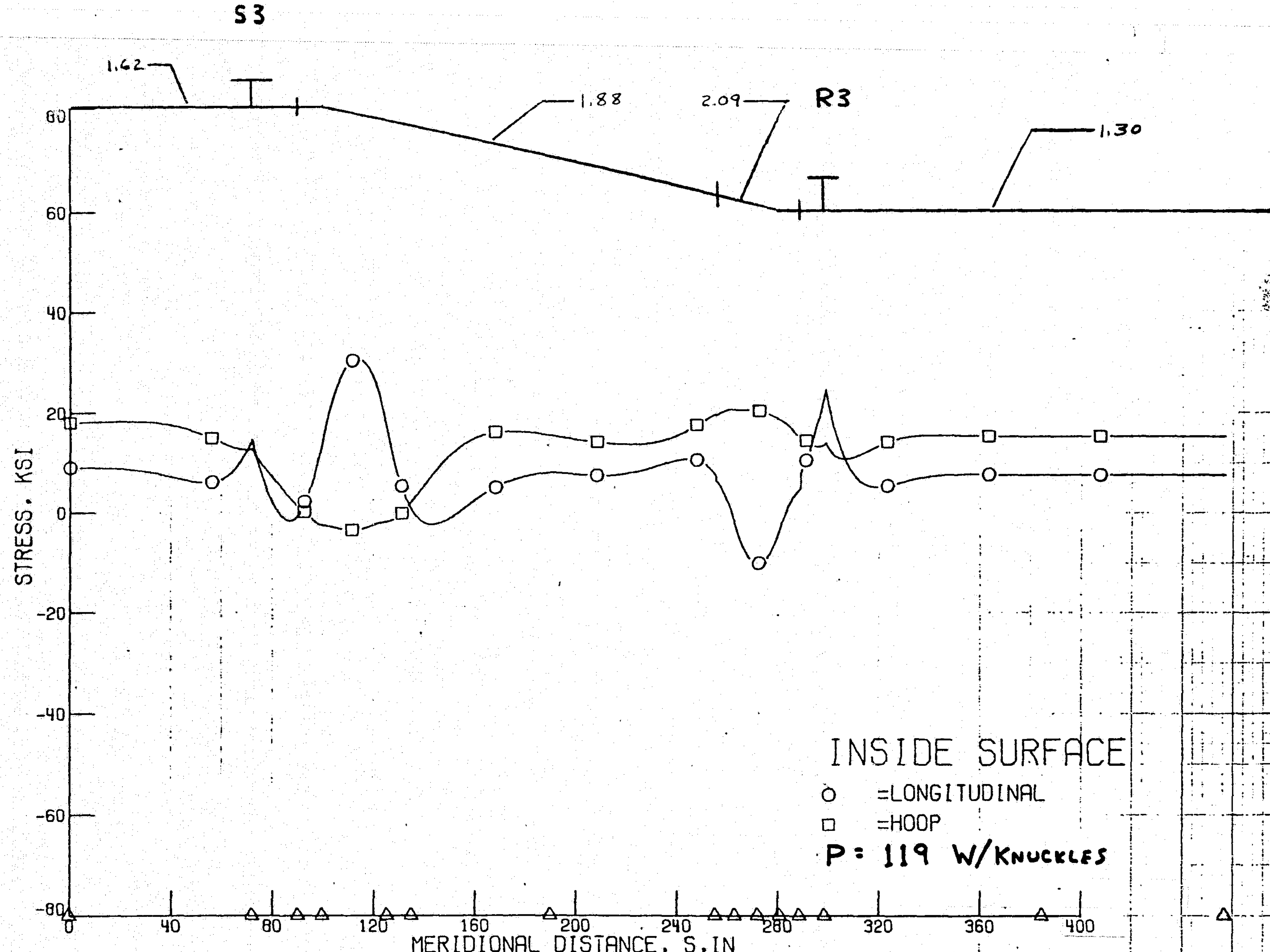

S3
R3
1.62
1.88
2.09
1.30
STRESS, KSI
80
60
40
20
0
-20
-40
-60
-80
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S,IN
INSIDE SURFACE
○ =LONGITUDINAL
□ =HOOP
P= 119 W/KNUCKLES

FIGURE 8

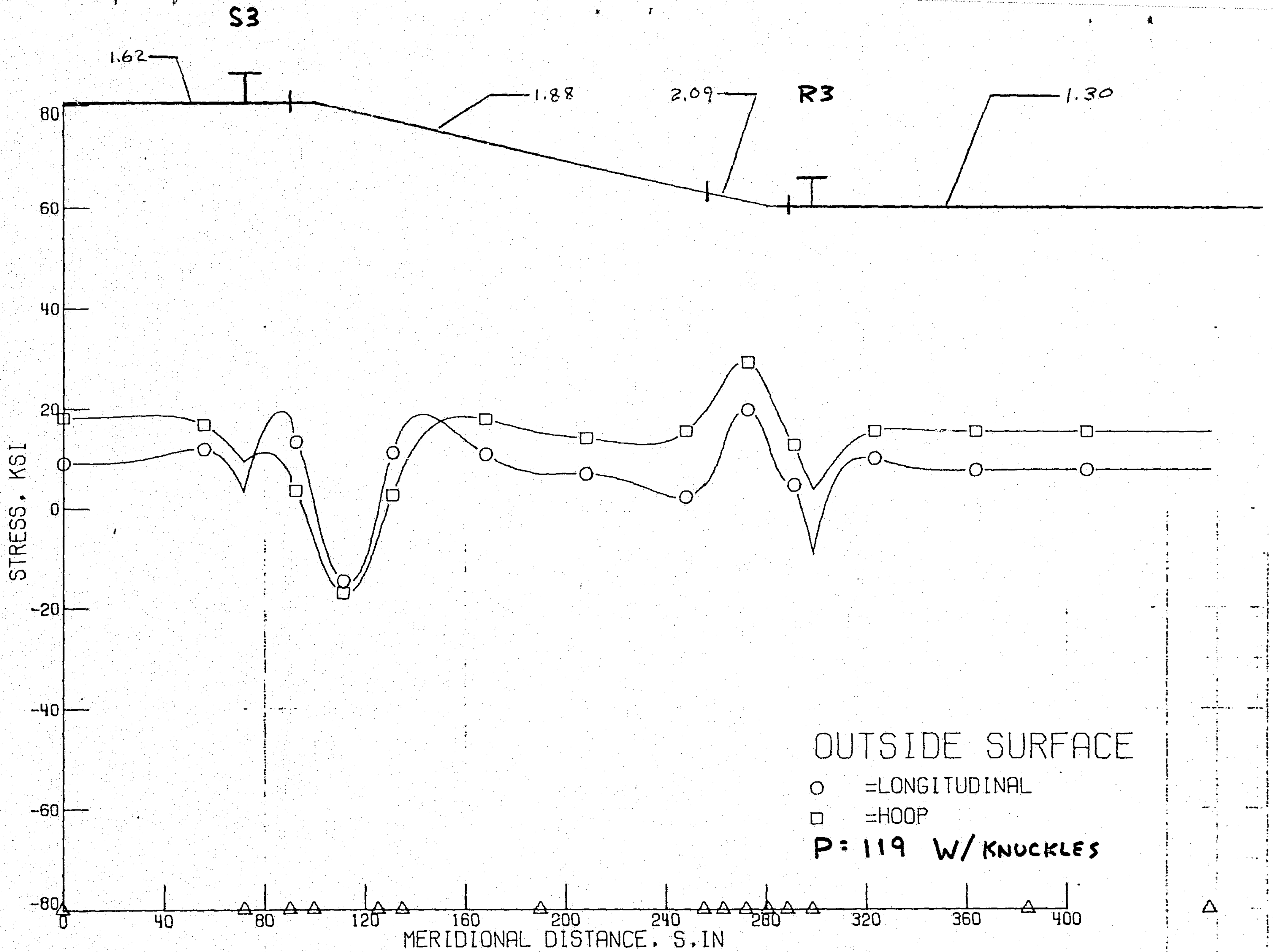

S3
R3
1.62
1.88
2.09
1.30
STRESS, KSI
80
60
40
20
0
-20
-40
-60
-80
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S,IN
OUTSIDE SURFACE
○ =LONGITUDINAL
□ =HOOP
P: 119 W/KNUCKLES

FIGURE 7

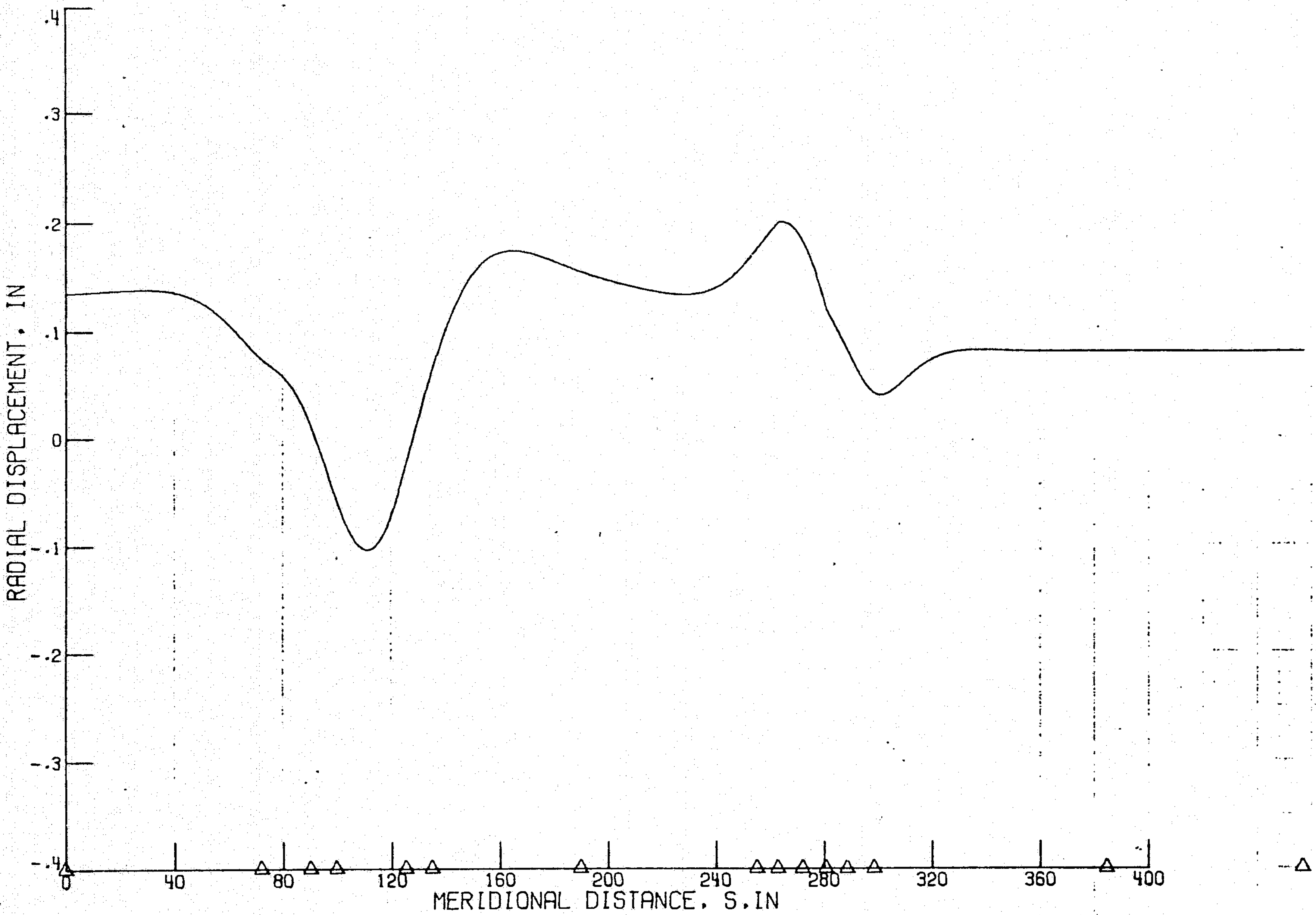

.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
RADIAL DISPLACEMENT, IN
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN

FIGURE 10

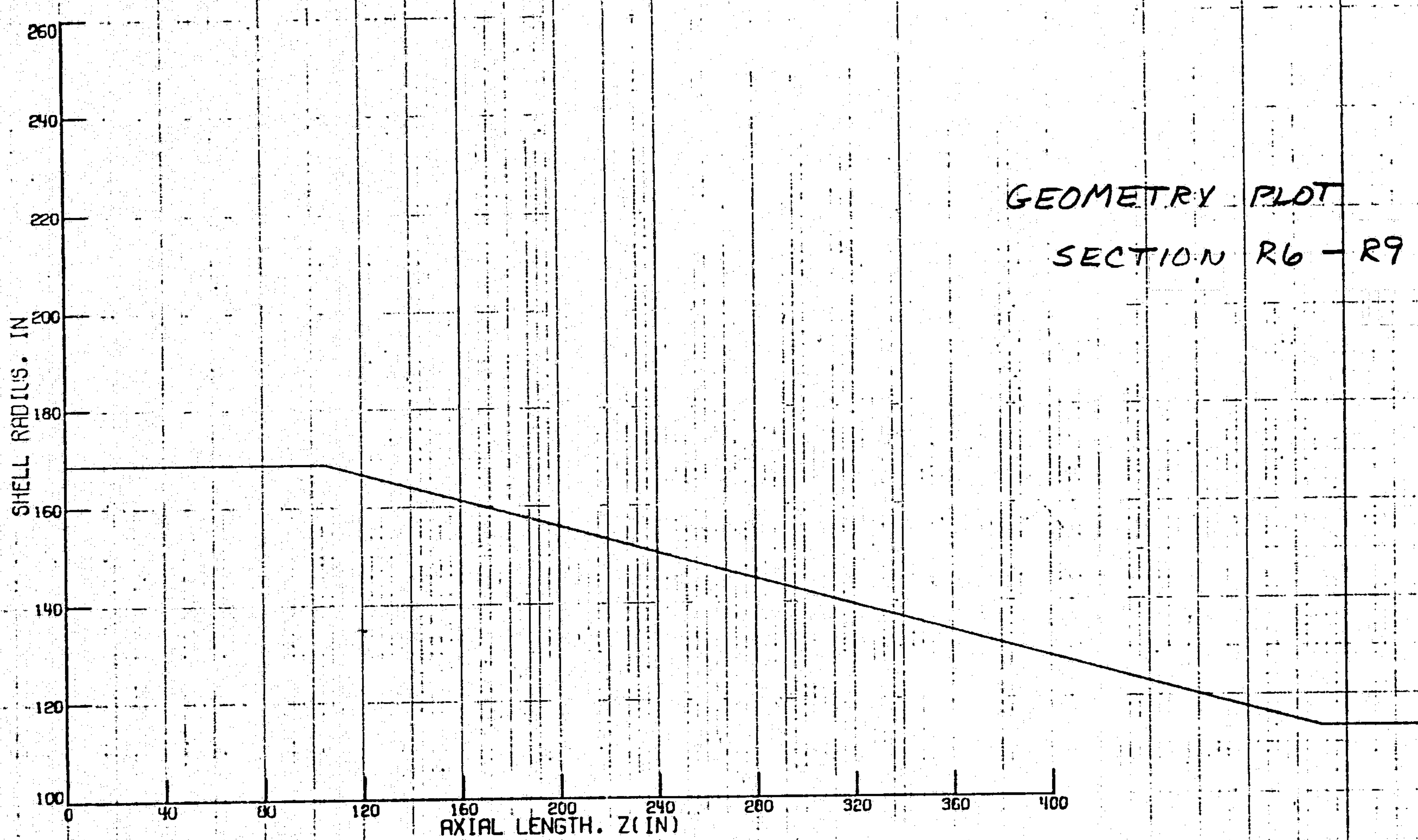
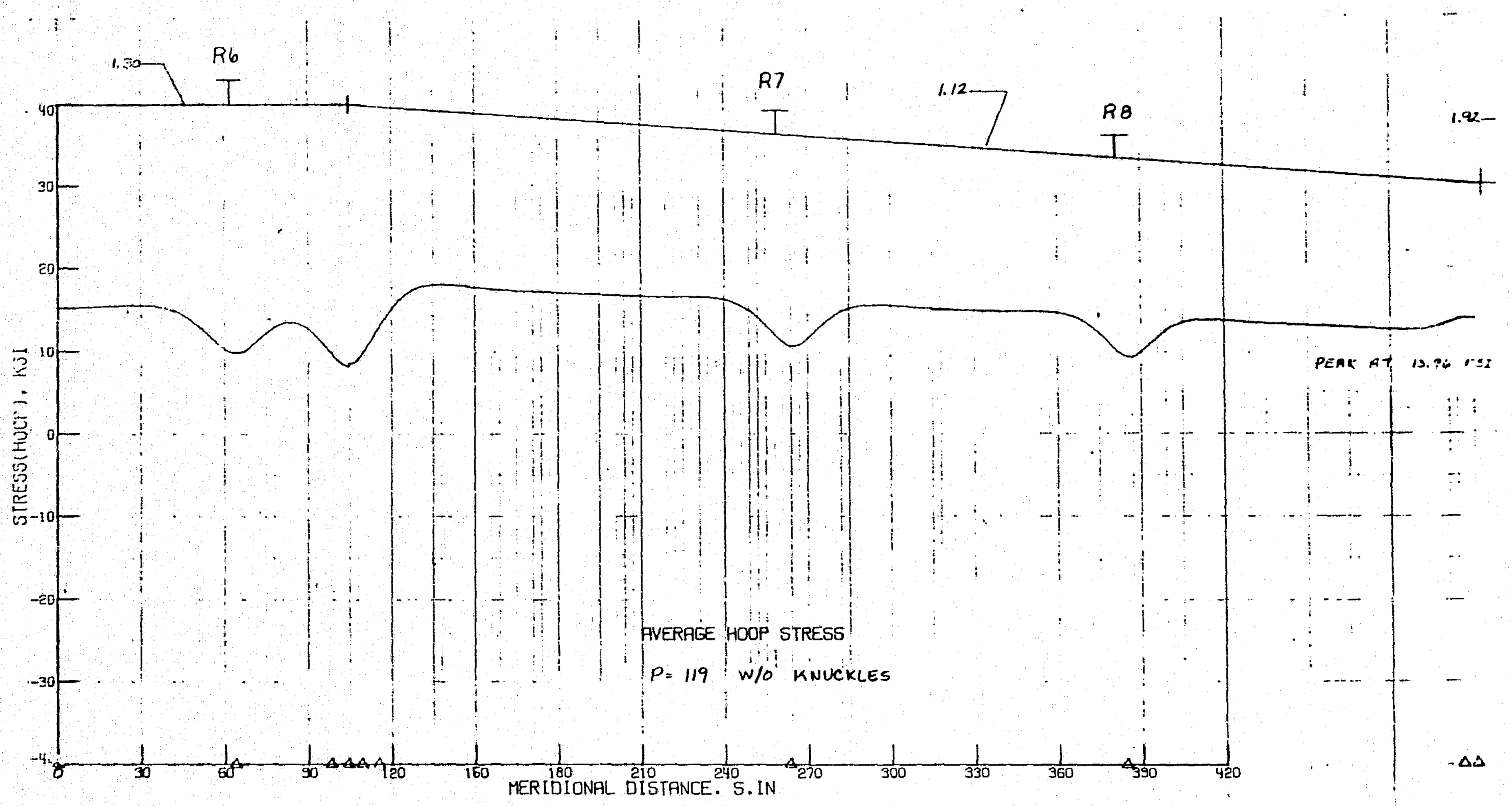
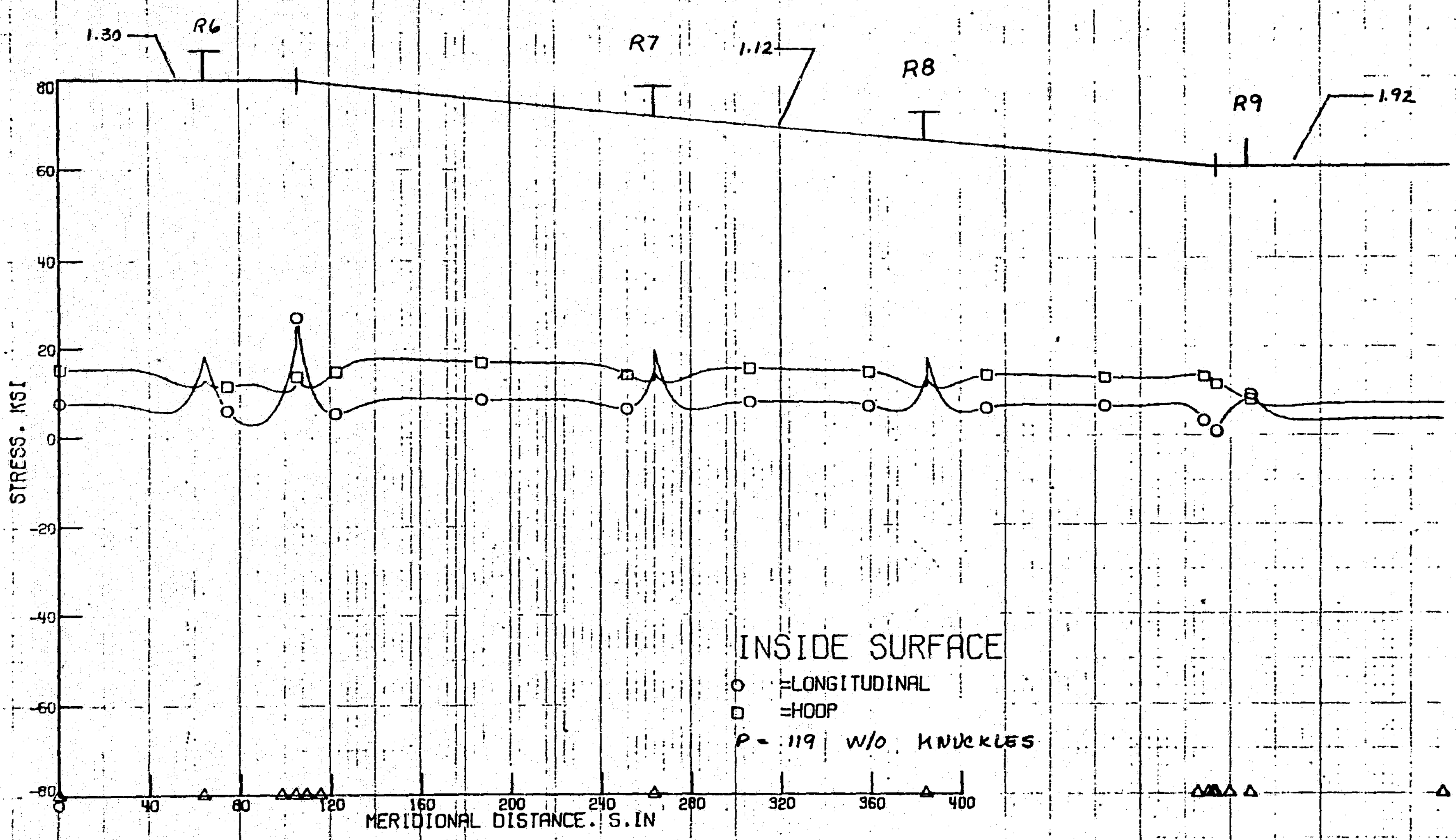

GEOMETRY PLOT
SECTION R6 - R9
SHELL RADIUS. IN
260
240
220
200
180
160
140
120
100
0
40
80
120
160
200
240
280
320
360
400
AXIAL LENGTH. Z(IN)

FIGURE 11

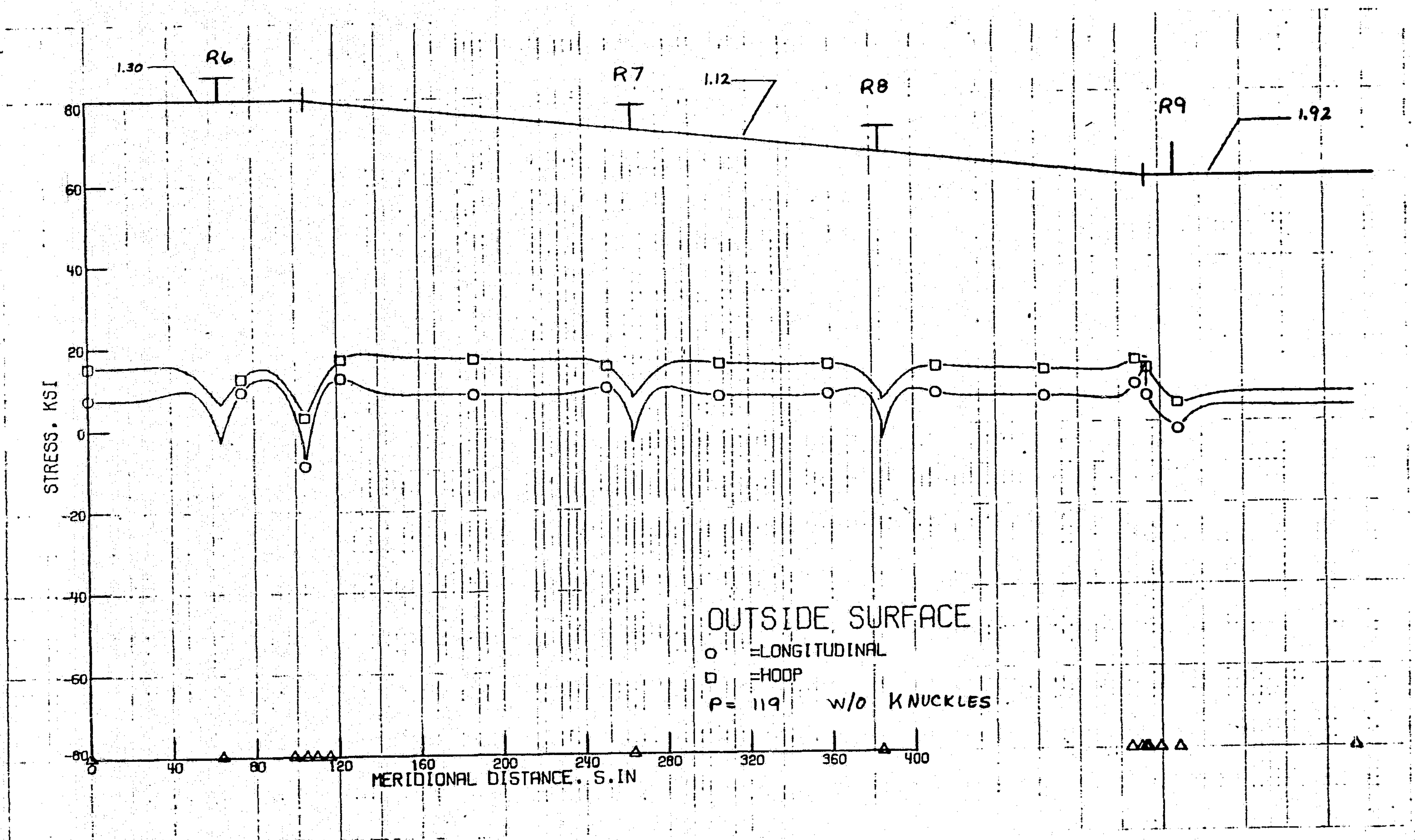


1.30
R6
R7
1.12
R8
1.92
40
30
20
10
0
-10
-20
-30
STRESS(HOOP), KSI
PEAK AT 13.96 KSI
AVERAGE HOOP STRESS
P= 119 W/O KNUCKLES
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
MERIDIONAL DISTANCE. S.IN



1.30
R6
R7
1.12
R8
R9
1.92
80
60
40
20
0
-20
-40
-60
-80
STRESS. KSI
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE. S.IN
INSIDE SURFACE
=LONGITUDINAL
=HOOP
P = 119 W/O KNUCKLES

FIGURE 13



R6
R7
R8
R9
1.30
1.12
1.92
80
60
40
20
0
-20
-40
-60
-80
STRESS, KSI
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN
OUTSIDE SURFACE
O =LONGITUDINAL
□ =HOOP
P= 119 w/o KNUCKLES

FIGURE 14

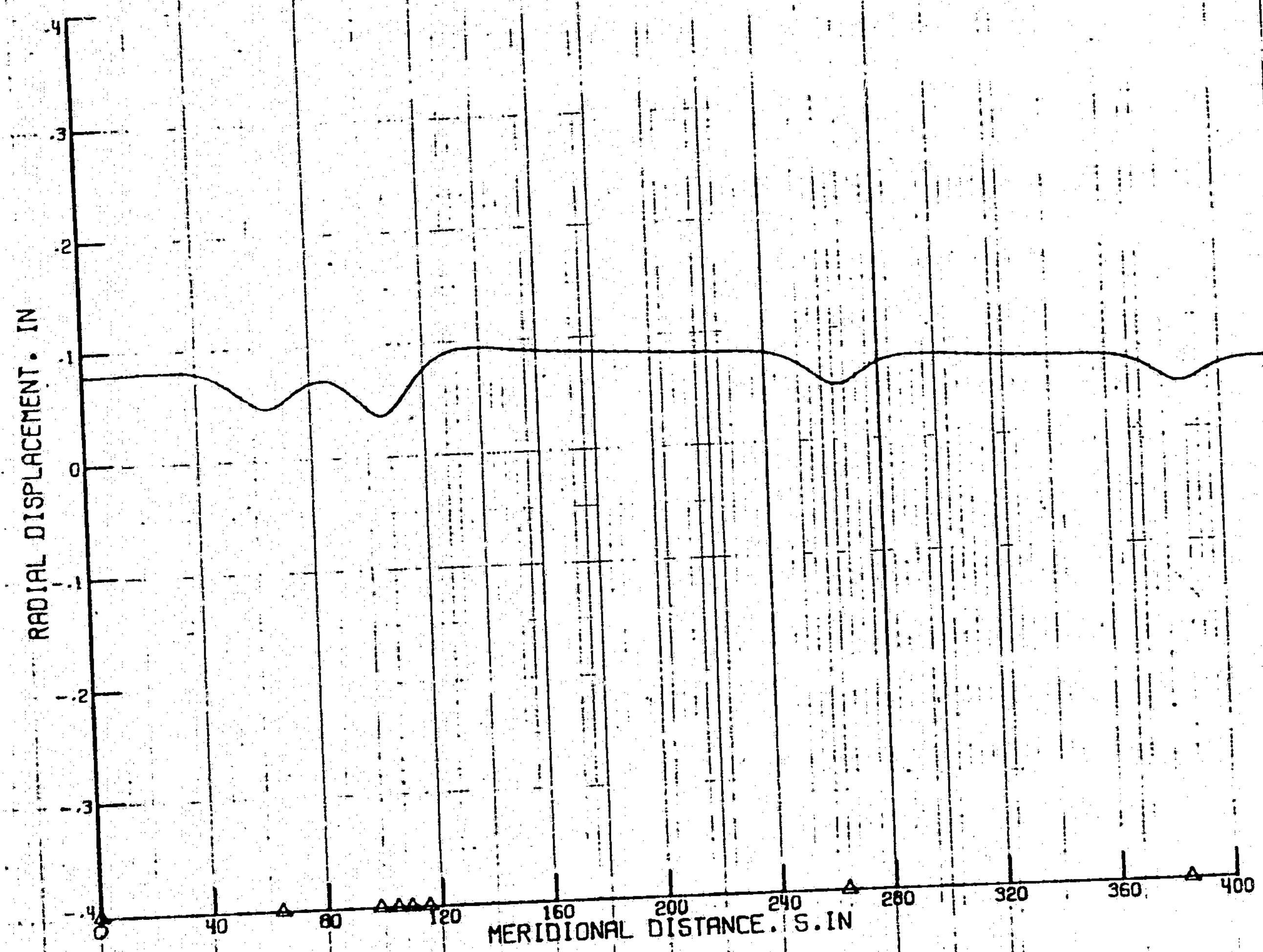

RADIAL DISPLACEMENT. IN
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE. S.IN

FIGURE 15

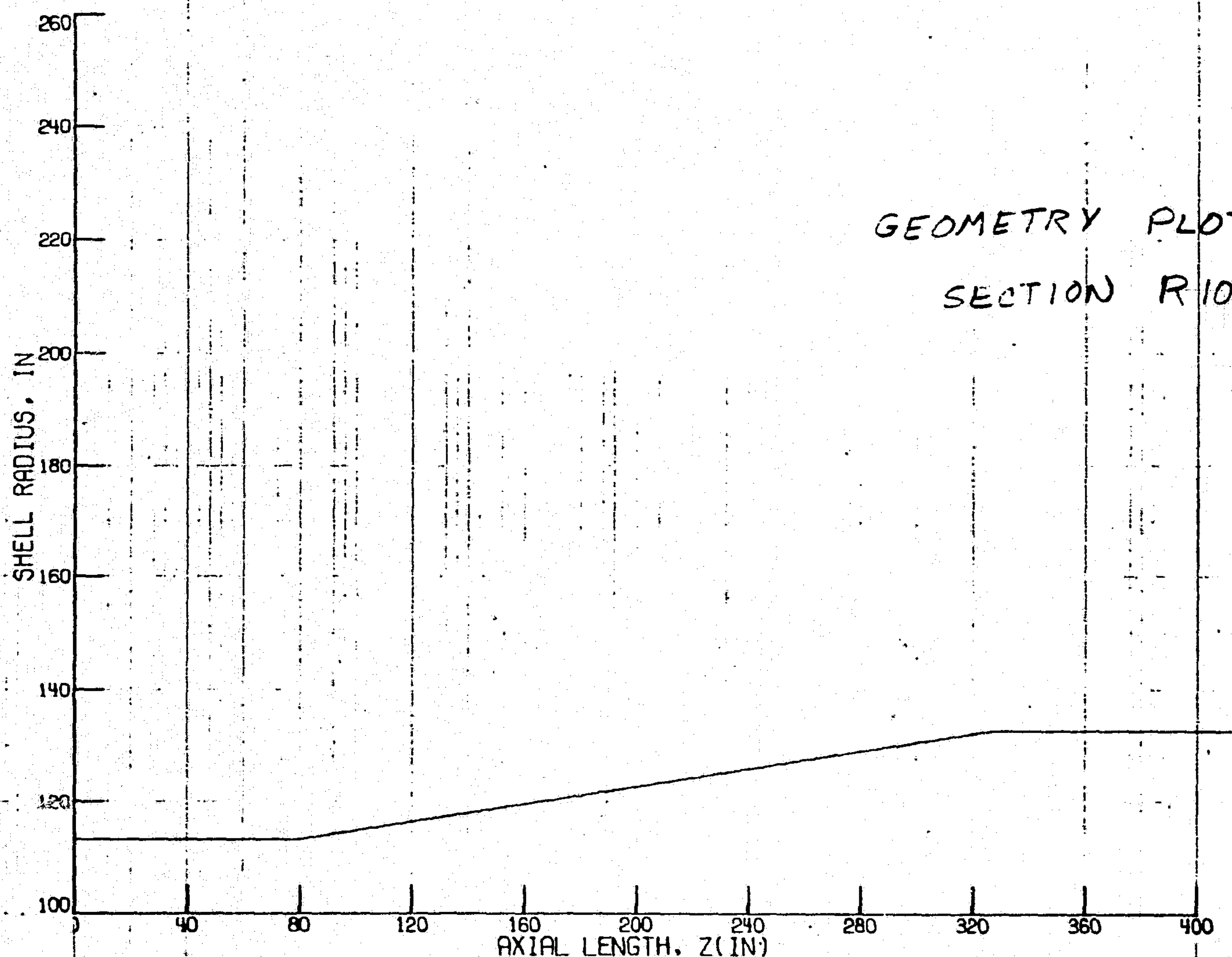
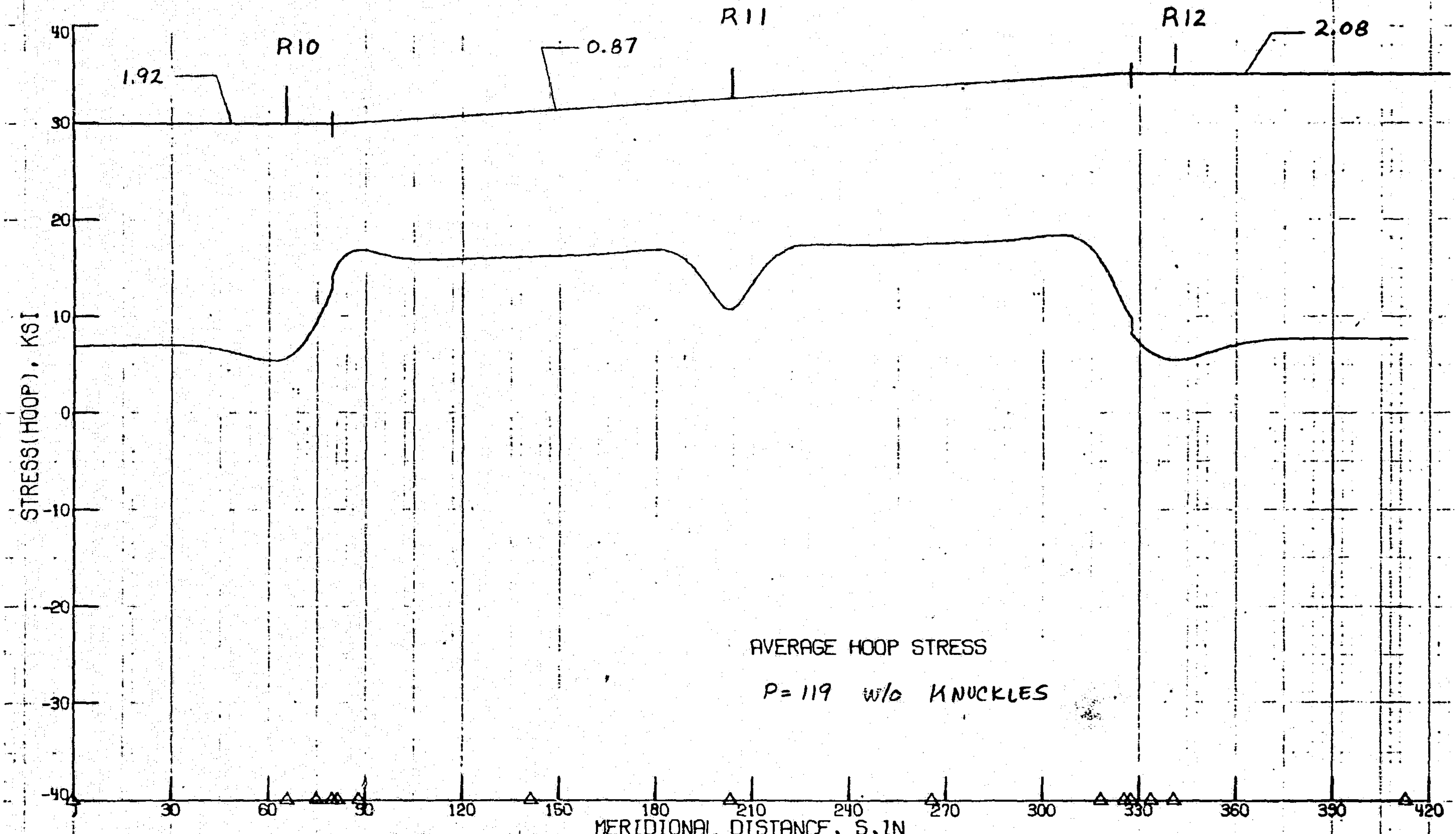
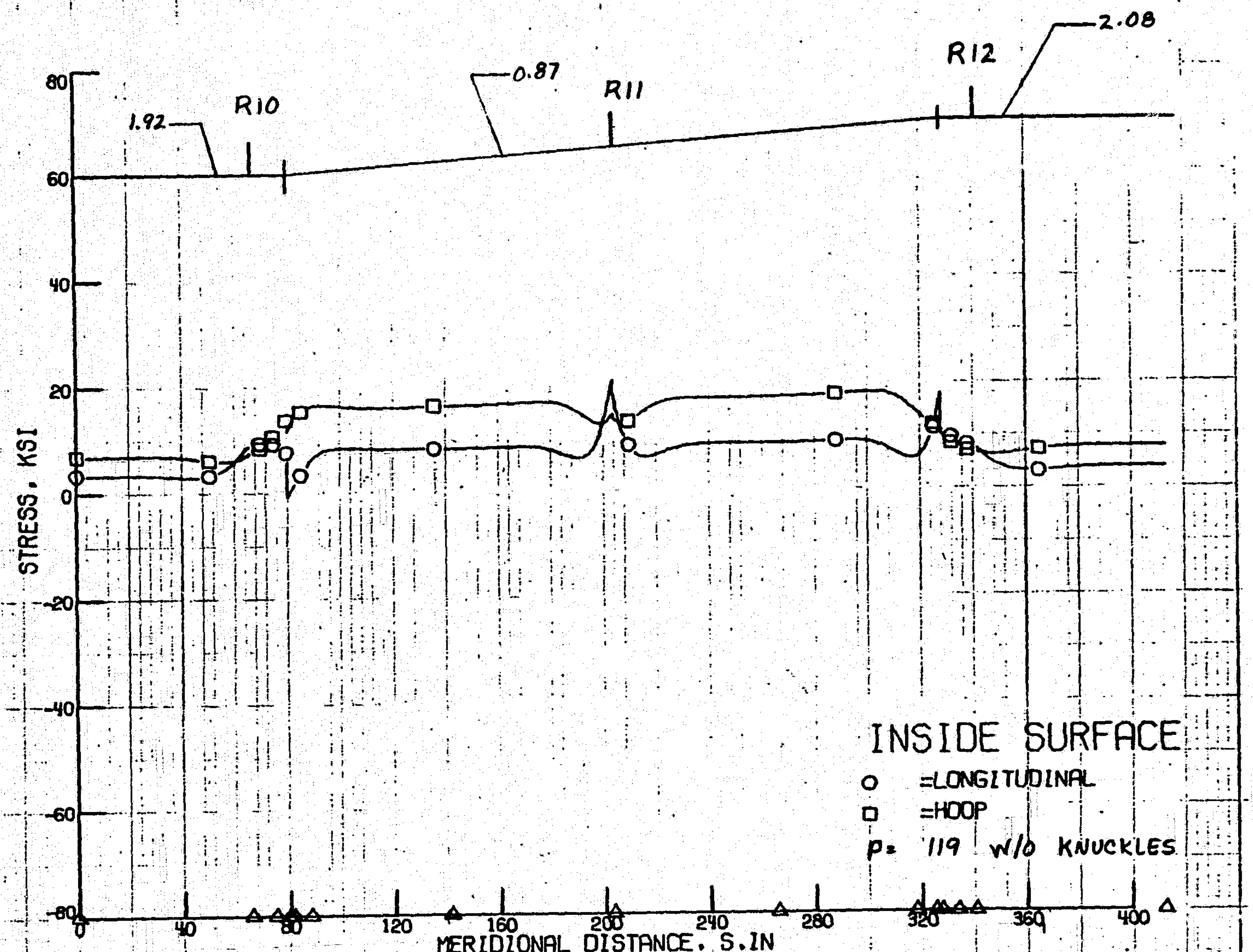

GEOMETRY PLOT
SECTION R10-R12
SHELL RADIUS, IN
260
240
220
200
180
160
140
120
100
0
40
80
120
160
200
240
280
320
360
400
AXIAL LENGTH, Z(IN)

FIGURE 16



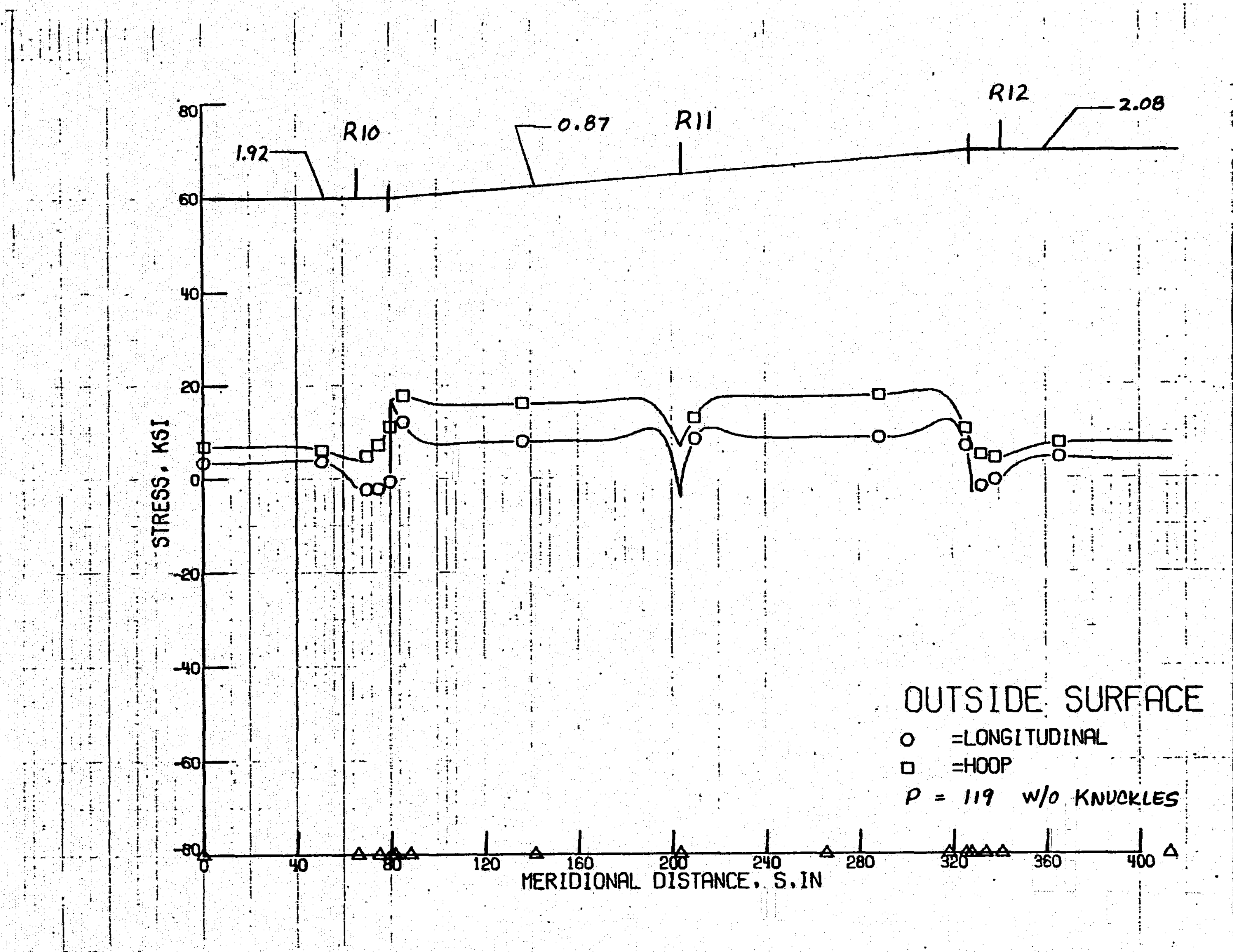
R10
R11
R12
1.92
0.87
2.08
STRESS(HOOP), KSI
MERIDIONAL DISTANCE, S,IN
AVERAGE HOOP STRESS
P= 119 w/o KNUCKLES

FIGURE 17



2.08
R12
0.87
R11
1.92
R10
80
60
40
20
0
-20
-40
-60
-80
STRESS, KSI
INSIDE SURFACE
○ =LONGITUDINAL
□ =HOOP
p= 119 W/O KNUCKLES
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN

FIGURE 18



R10
R11
R12
1.92
0.87
2.08
80
60
40
20
0
-20
-40
-60
-80
STRESS, KSI
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S,IN
OUTSIDE SURFACE
○ =LONGITUDINAL
□ =HOOP
P = 119 w/o KNUCKLES

FIGURE 19

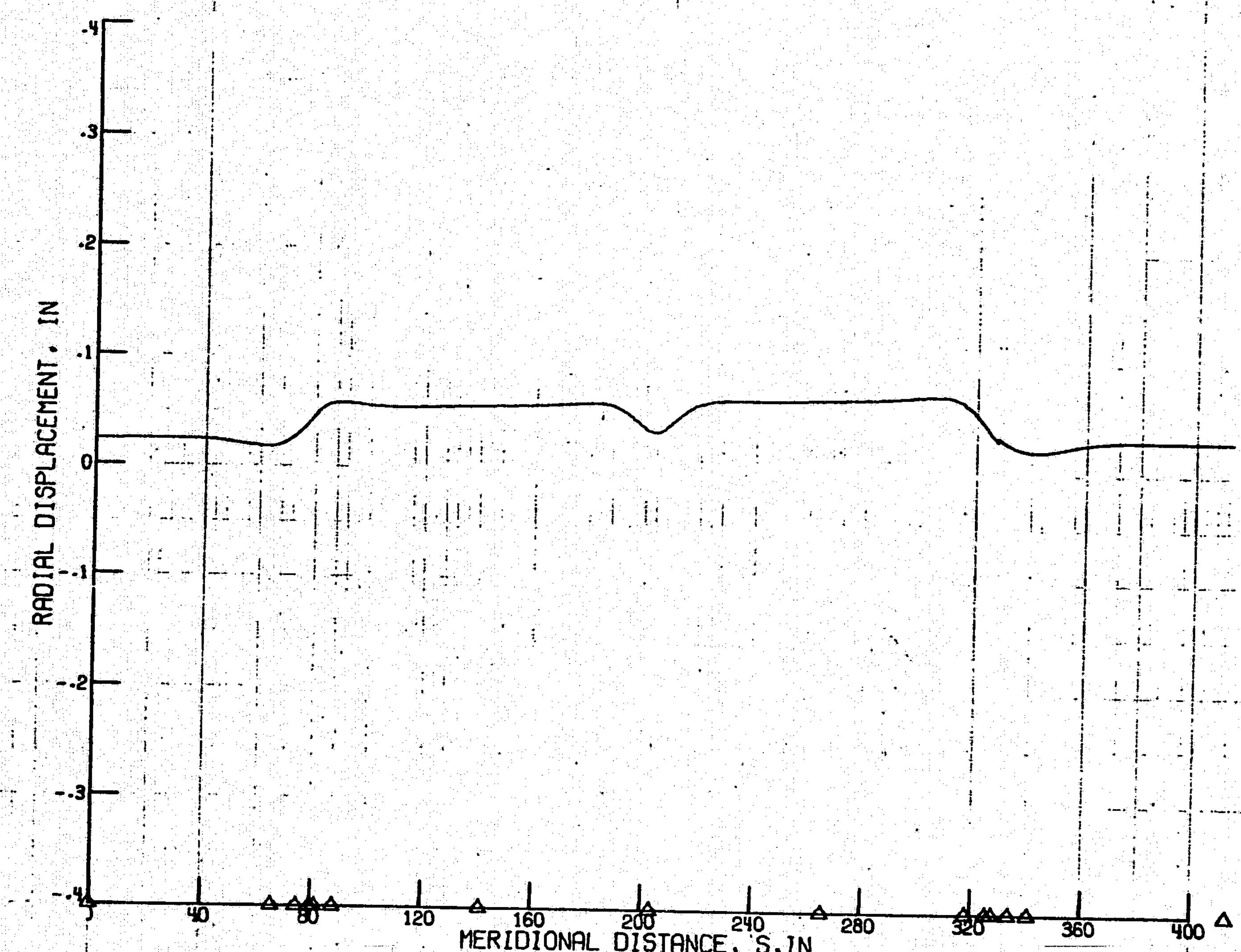
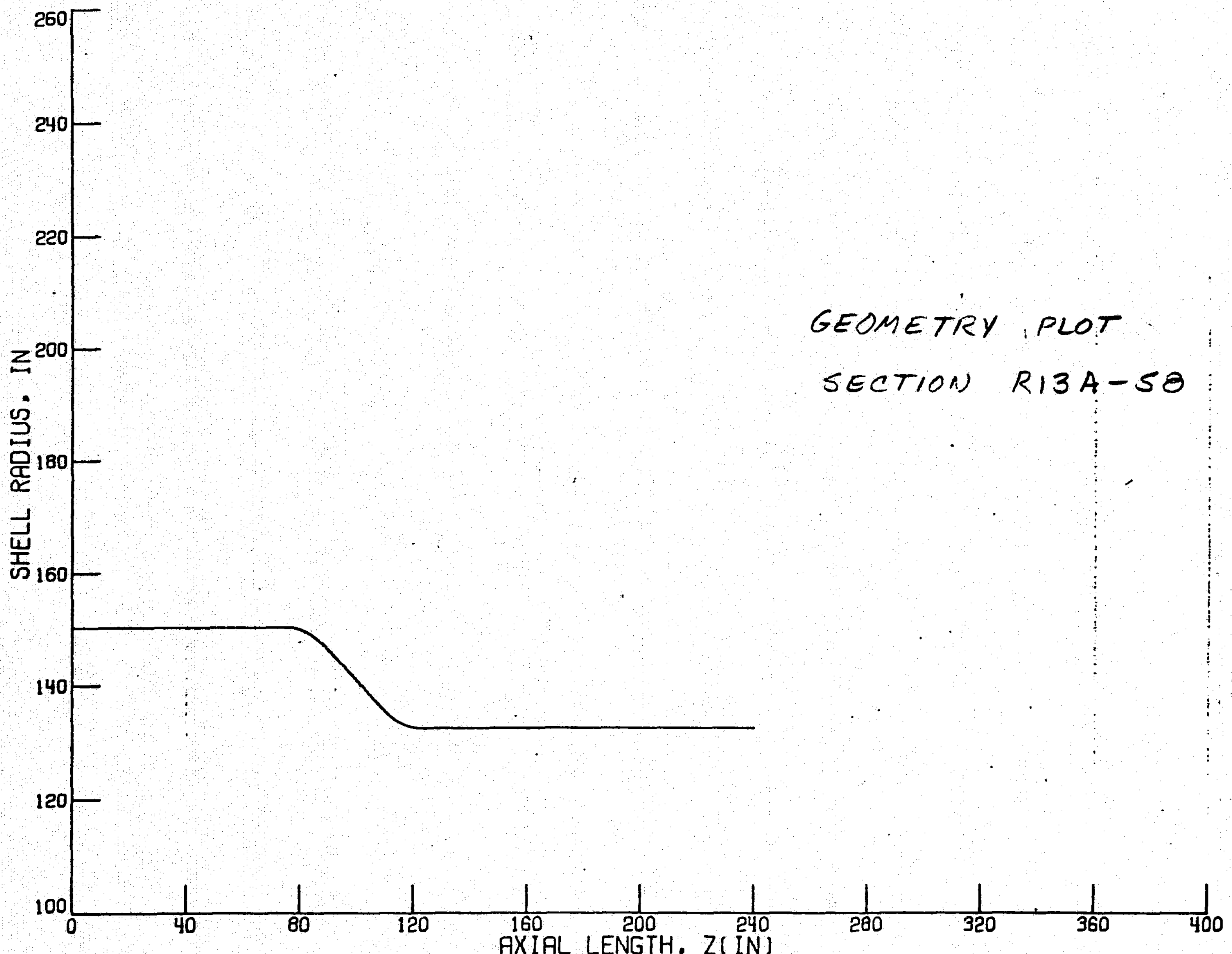

.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
RADIAL DISPLACEMENT, IN
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S,IN

FIGURE 20



SHELL RADIUS, IN
260
240
220
200
180
160
140
120
100
0
40
80
120
160
200
240
280
320
360
400
AXIAL LENGTH, Z(IN)
GEOMETRY PLOT
SECTION R13A-58

FIGURE 21

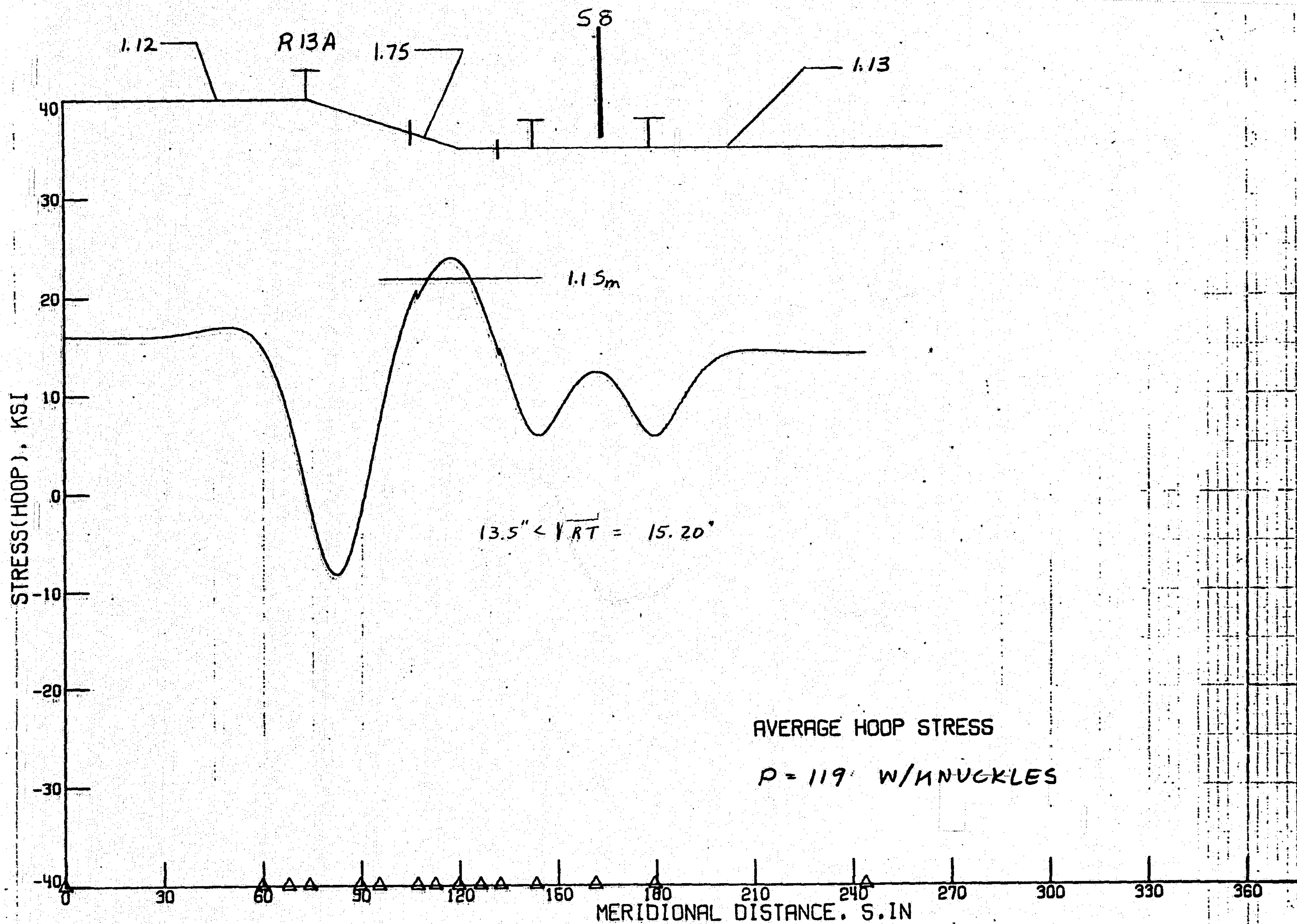
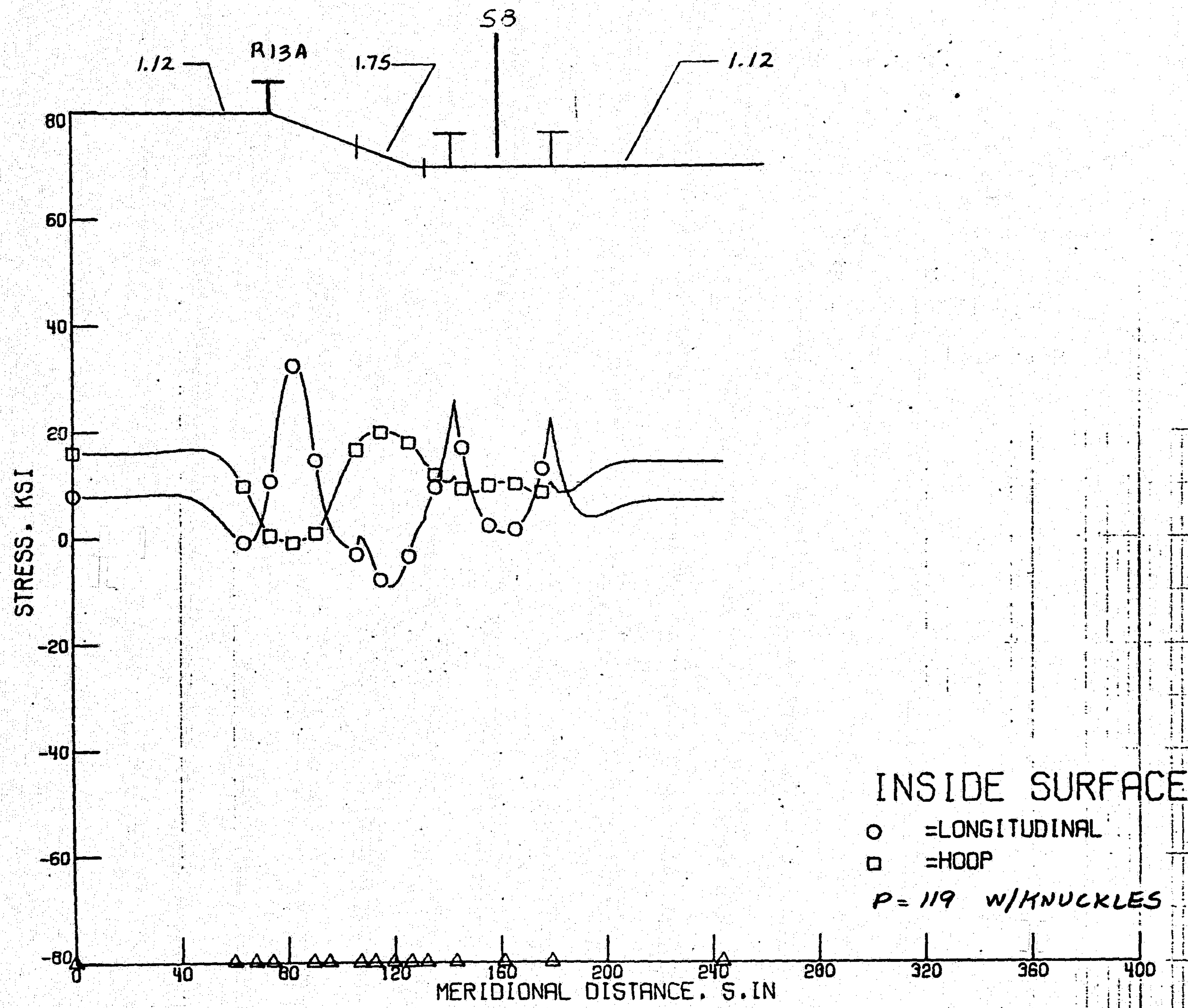
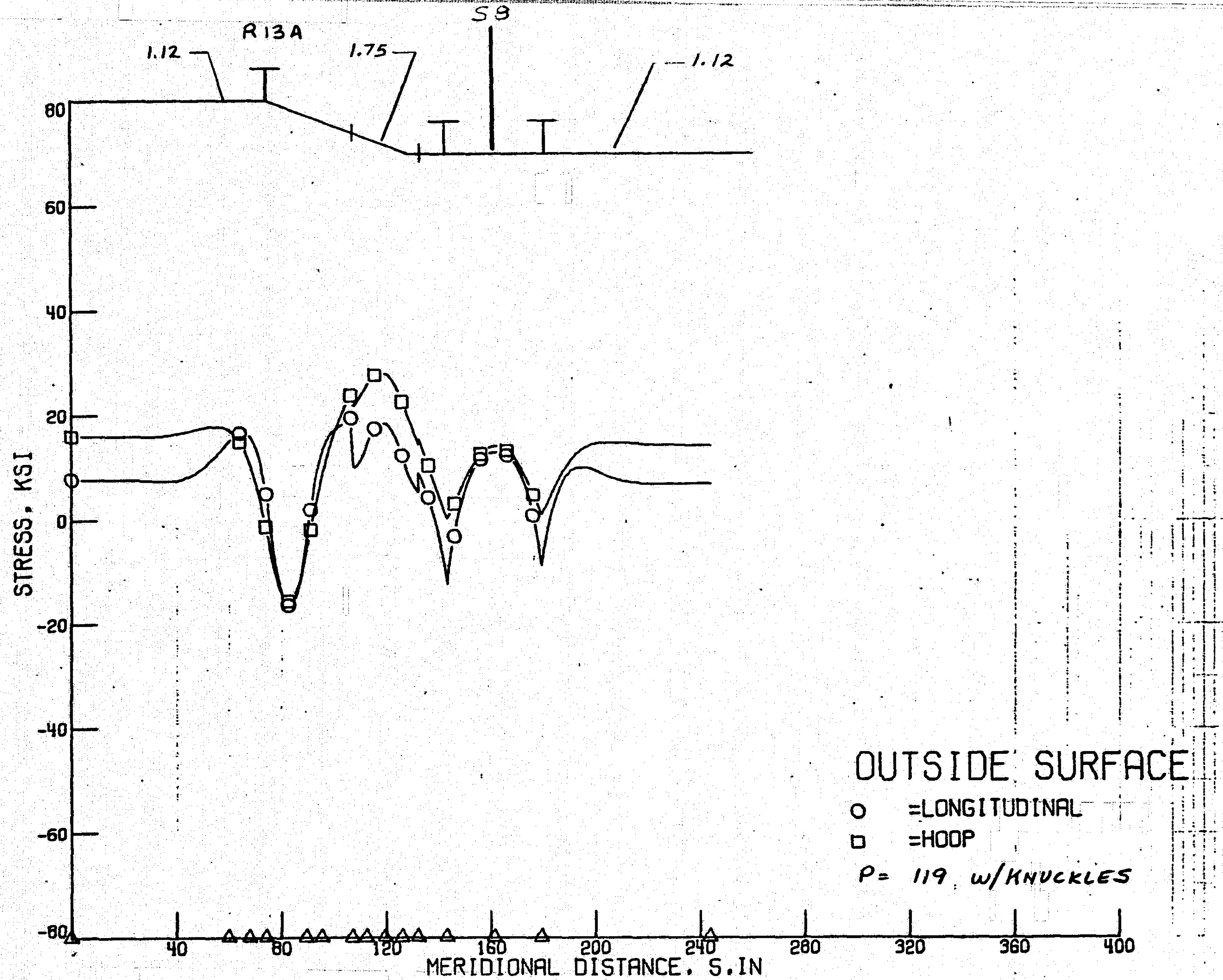

1.12
R13A
1.75
S8
1.13
1.1 Sm
13.5" < √RT = 15.20"
AVERAGE HOOP STRESS
P = 119 W/KNUCKLES
STRESS(HOOP), KSI
40
30
20
10
0
-10
-20
-30
-40
0
30
60
90
120
150
180
210
240
270
300
330
360
MERIDIONAL DISTANCE, S.IN

FIGURE 22



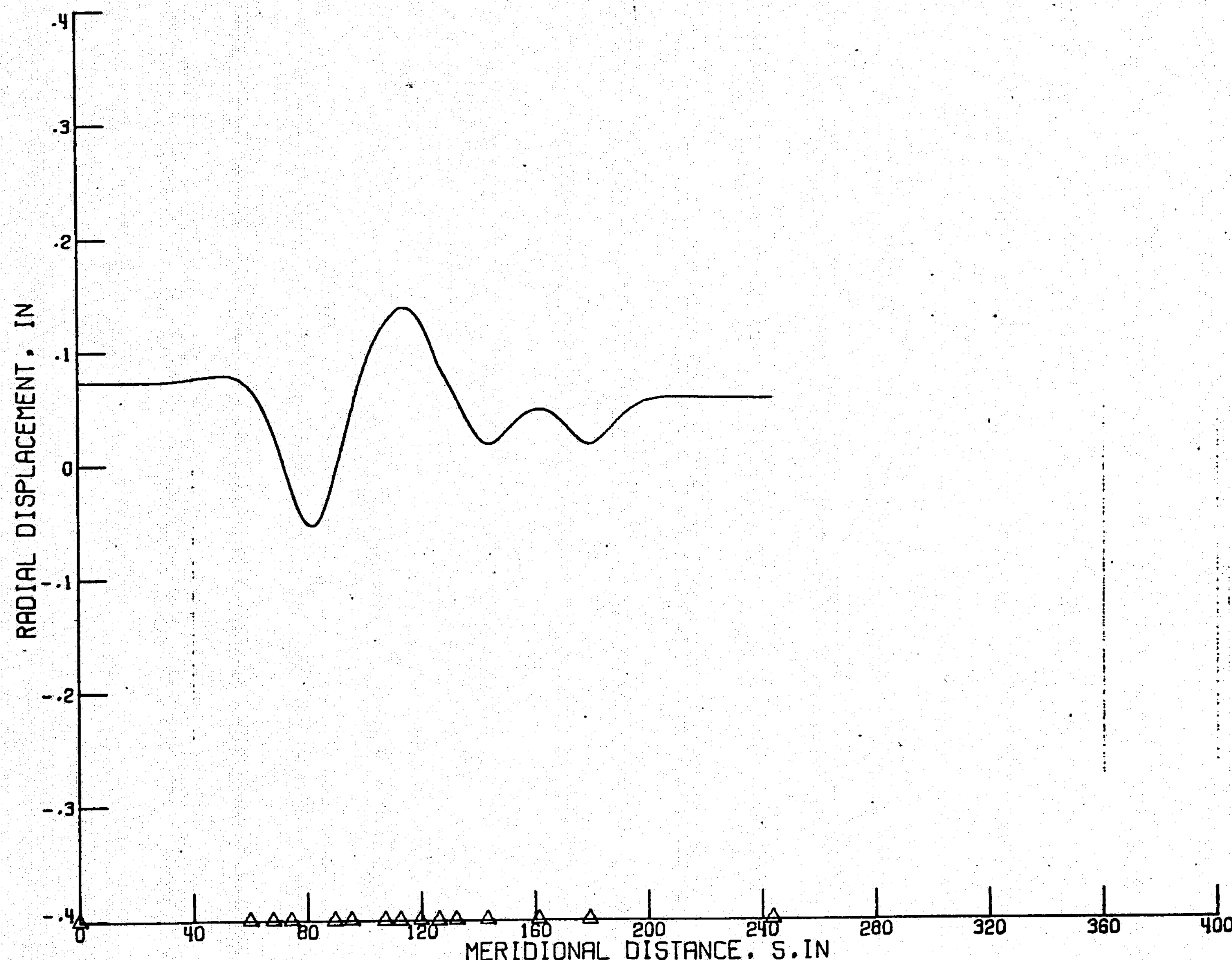
S8
1.12
R13A
1.75
1.12
STRESS, KSI
80
60
40
20
0
-20
-40
-60
-80
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN
INSIDE SURFACE
O =LONGITUDINAL
□ =HOOP
P= 119 W/KNUCKLES

FIGURE 23



S9
R13A
1.12
1.75
1.12
STRESS, KSI
80
60
40
20
0
-20
-40
-60
-80
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN
OUTSIDE SURFACE
○ =LONGITUDINAL
□ =HOOP
P= 119 w/KNUCKLES

FIGURE 24



RADIAL DISPLACEMENT, IN
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN

FIGURE 25

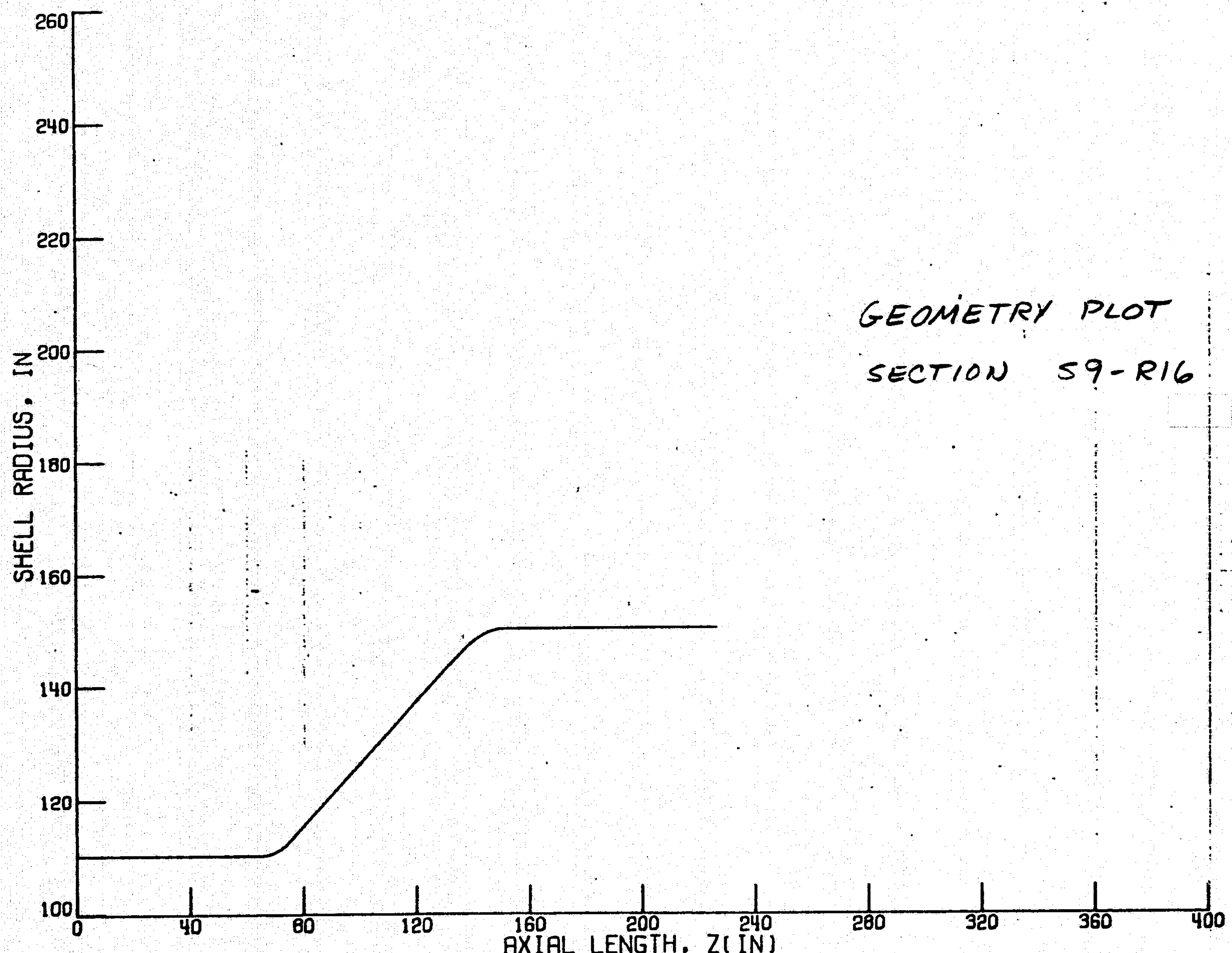

GEOMETRY PLOT
SECTION S9-R16
SHELL RADIUS, IN
260
240
220
200
180
160
140
120
100
0
40
80
120
160
200
240
280
320
360
400
AXIAL LENGTH, Z(IN)

FIGURE 26

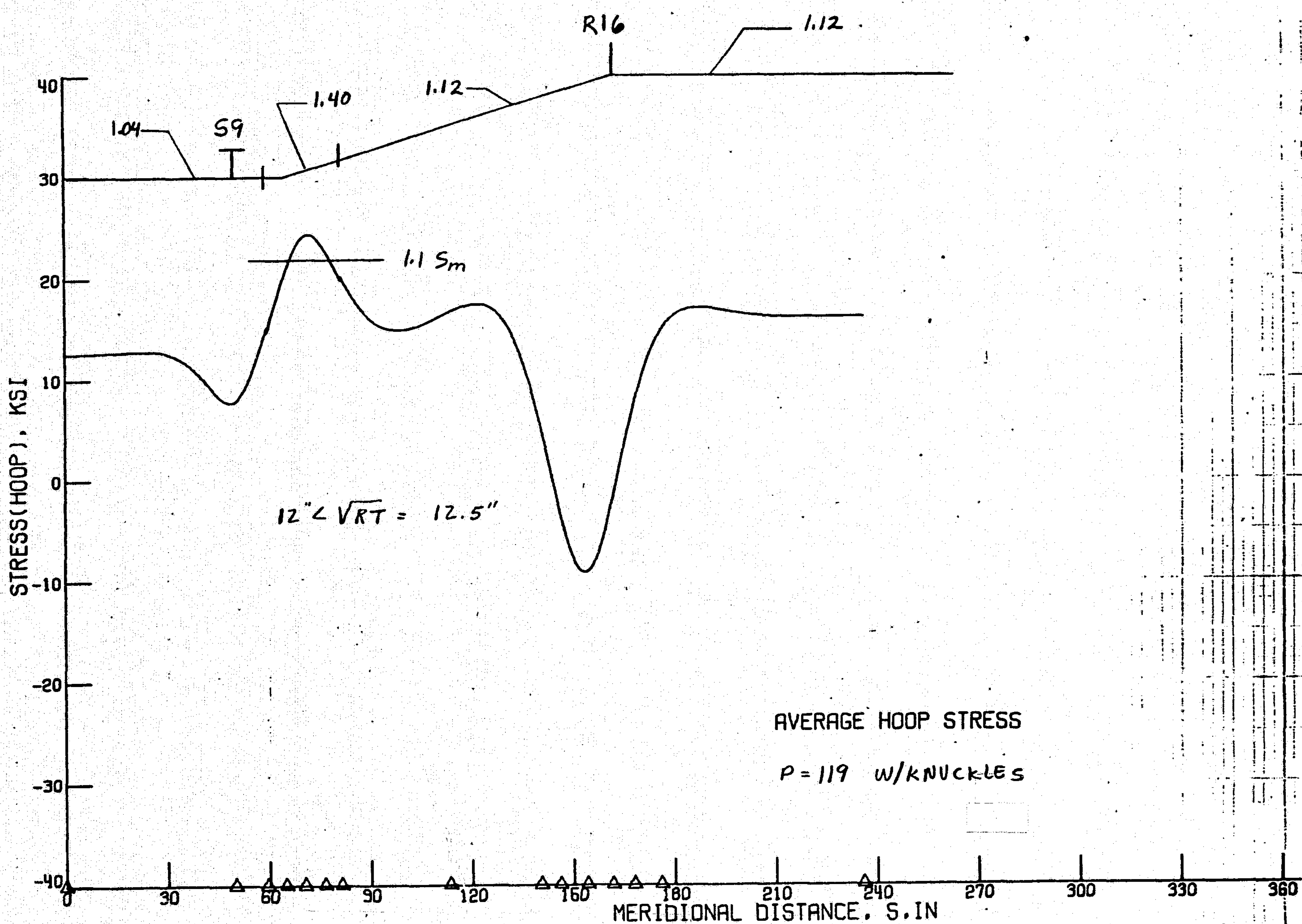

R16
1.12
1.12
1.40
1.04
S9
1.1 Sm
12" < √RT = 12.5"
AVERAGE HOOP STRESS
P = 119 W/KNUCKLES
STRESS(HOOP), KSI
40
30
20
10
0
-10
-20
-30
-40
0
30
60
90
120
150
180
210
240
270
300
330
360
MERIDIONAL DISTANCE, S.IN

FIGURE 27

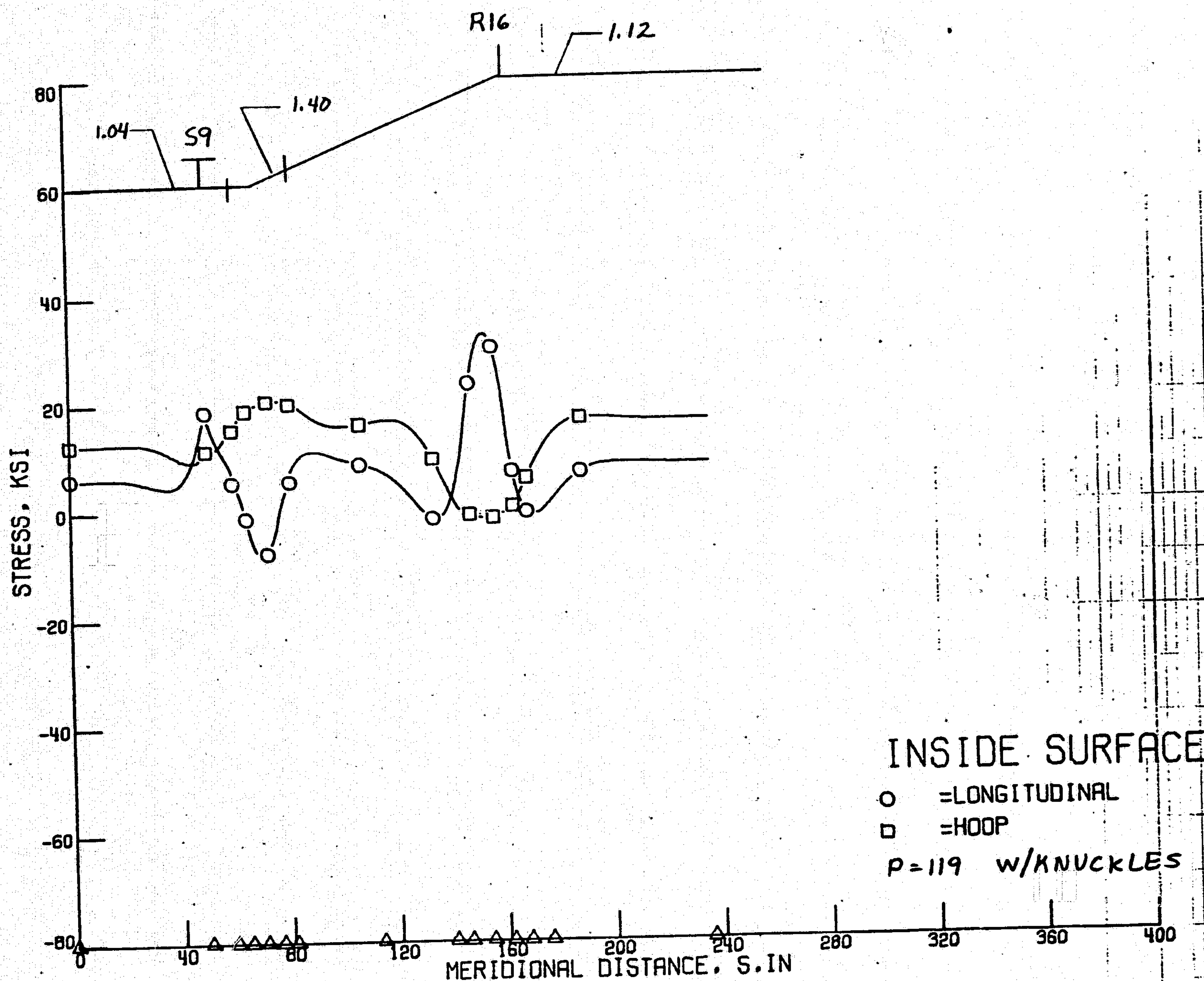
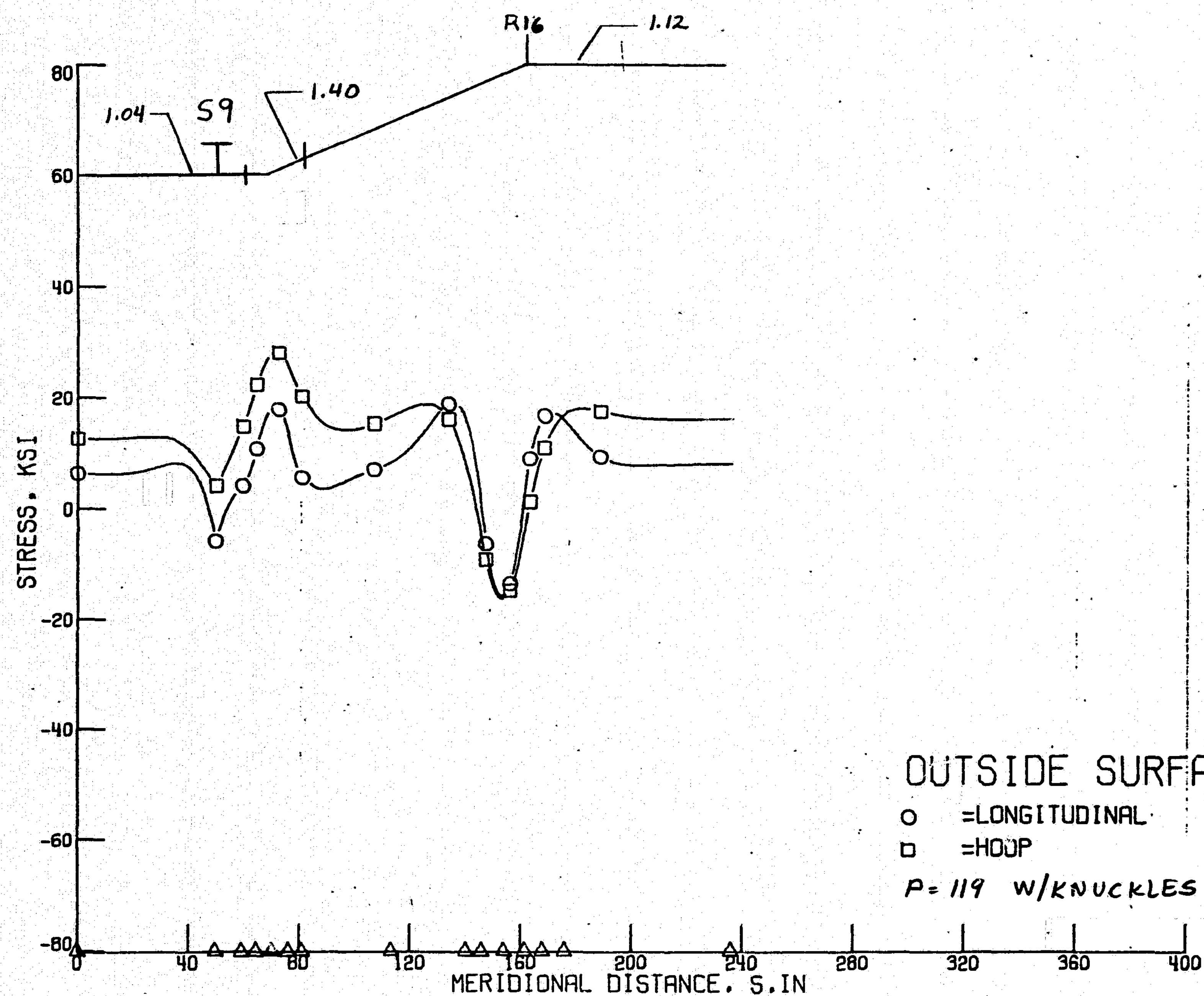

R16
1.12
1.04
S9
1.40
80
60
40
20
0
-20
-40
-60
-80
STRESS, KSI
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN
INSIDE SURFACE
=LONGITUDINAL
=HOOP
P=119 W/KNUCKLES

FIGURE 28



R16
1.12
1.04
S9
1.40
80
60
40
20
0
-20
-40
-60
-80
STRESS, KSI
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S.IN
OUTSIDE SURFACE
○ =LONGITUDINAL
□ =HOOP
P= 119 W/KNUCKLES

FIGURE 29

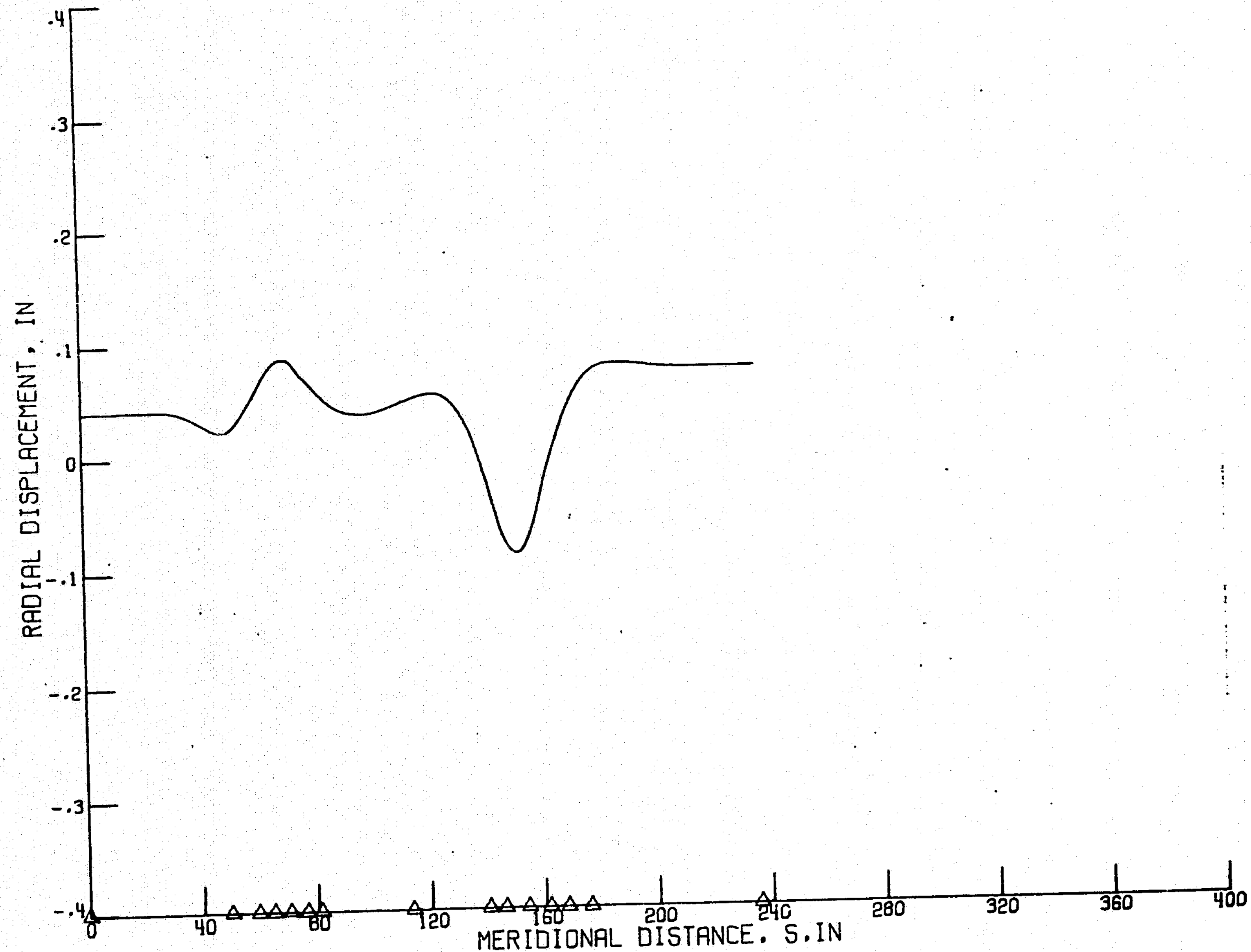

.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
RADIAL DISPLACEMENT, IN
0
40
80
120
160
200
240
280
320
360
400
MERIDIONAL DISTANCE, S,IN

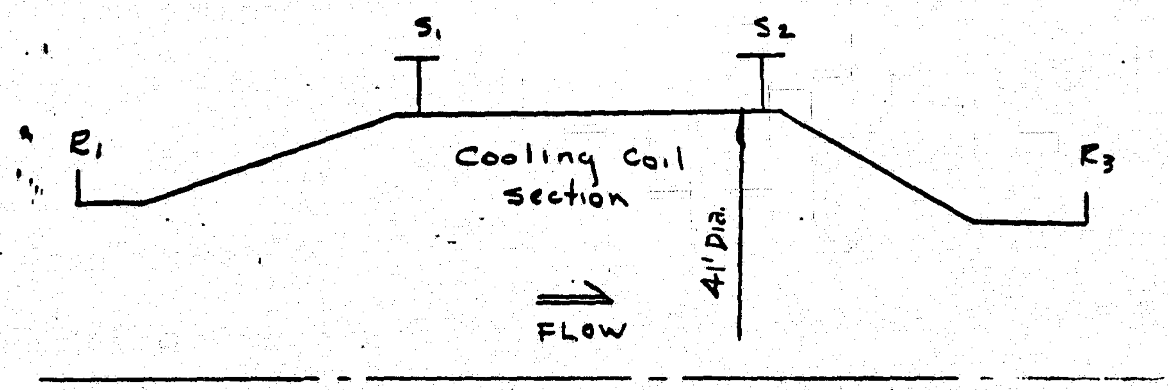
FIGURE 30

BY .... DATE .... SUBJECT NTF Pressure Shell SHEET NO. 1 OF ......
CHKD. BY .... DATE .... Stress Variation in shell JOB NO. ....
due to Hydro Conditions

304 S.S

Part 2

The following section of the tunnel was modeled using Nastran.



Note:

This is <u>not</u> a detailed analysis of this section of the Tunnel.

The following computer results and hand calculations are used only to verify stress scaling, due to Hydro test conditions

BY ____ DATE ____ SUBJECT ____ SHEET NO. 2 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____

Nastran (Nasa structural analysis) is a general purpose digital computer program for the analysis of large complex structures.

Nasa SP-222(01)

BY ____ DATE ____ SUBJECT ____ SHEET NO. 3 OF ____
CHKD. BY ____ DATE ____ JOB NO. ____

Nastran model description

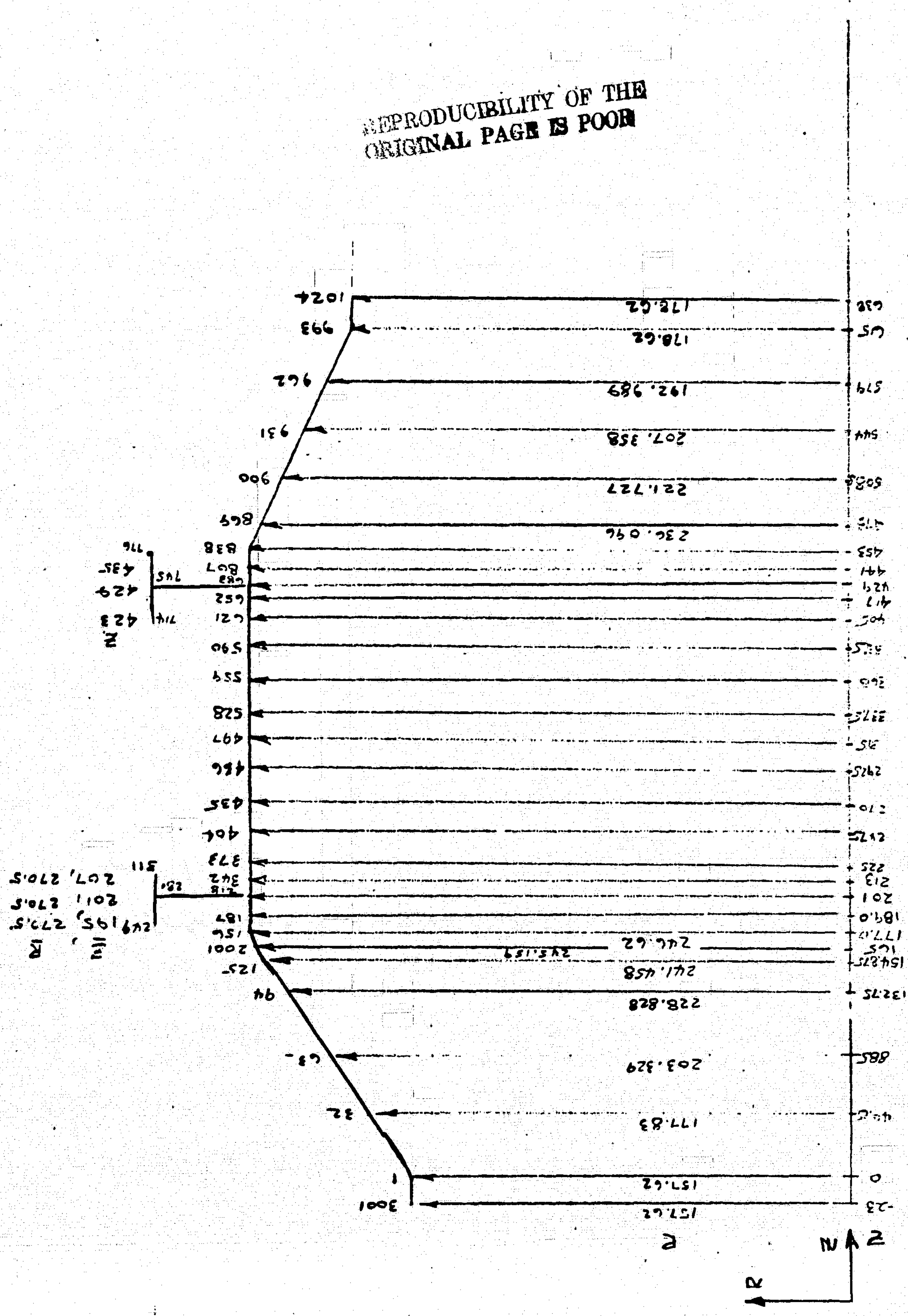
This section of the tunnel was modeled using homogenious quadrilaterial membrane and bending elements. except for R_1 & R_3 which were modeled using beam elements. Due to the need of modeling a varable pressure, a half model using 31 elements around the circumference was generated.

See figure 1 for a joint location sketch of this area

BY .... DATE .... SUBJECT .... SHEET NO. 4 OF ......

CHKD. BY .... DATE .... JOB NO. ....

NASTRAN COARSE MODEL



BY ________ DATE ________	SUBJECT ________	SHEET NO. 5 OF ____
CHKD. BY ________ DATE ________		JOB NO. ________

Constraints.

The R, Z plane was modeled as a plane of symmetry.

on the R_1 end of the model the Z displacement and rotations were removed.

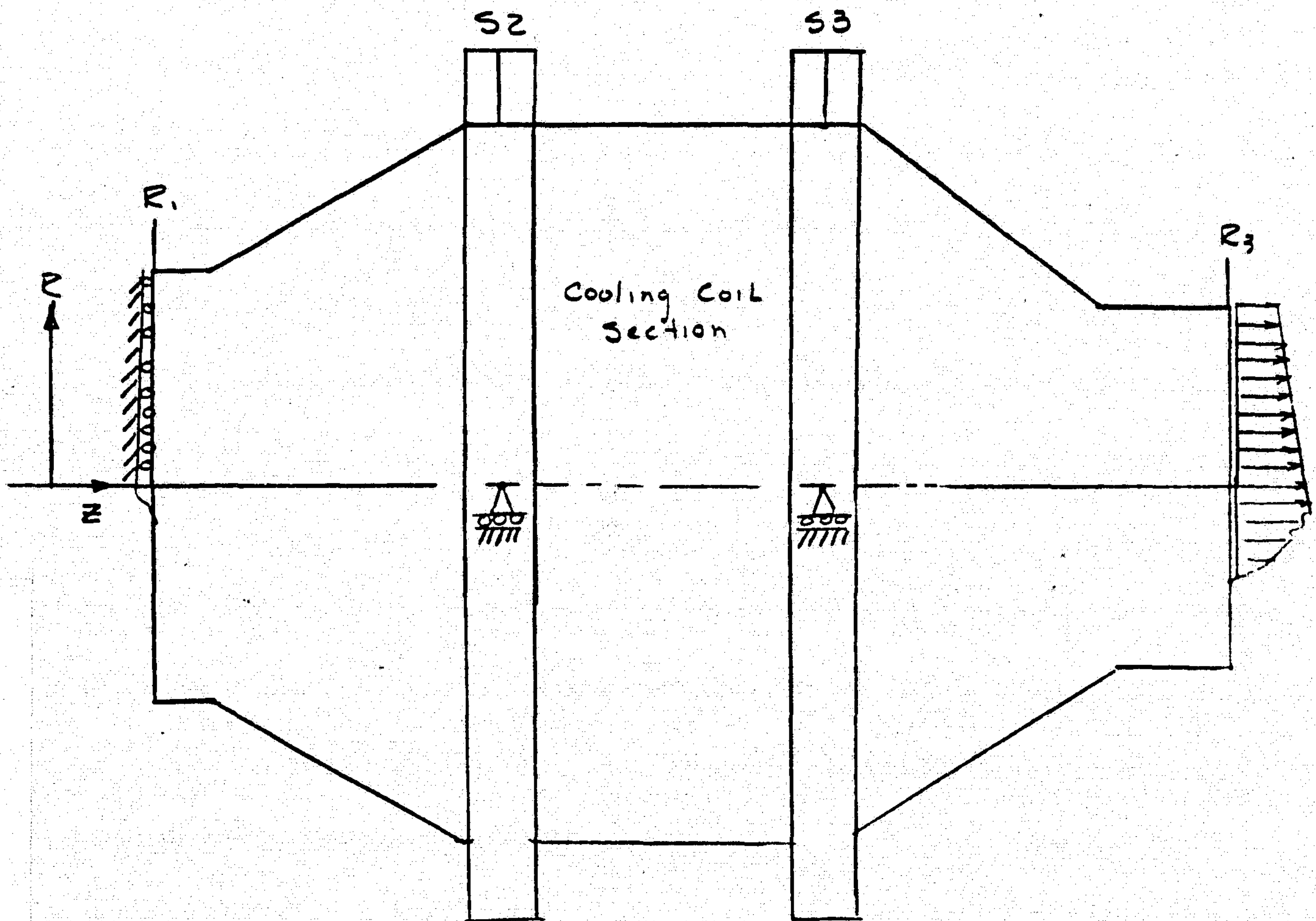
on the R_3 end of the model all rotions were removed.

The rotation normal to the shell elements was removed

nodes on the flange of the support tee S2 and S3 located at $\theta = 90$ were fixed in the vertical direction. (fig 2)

BY	DATE	SUBJECT	SHEET NO. 6 OF
CHKD. BY	DATE		JOB NO.

Boundary Conditions



BY ________ DATE ________	SUBJECT ________	SHEET NO. 7 OF ____
CHKD. BY ______ DATE ______		JOB NO. ________

Model geometry

as previously mentioned a half model with 31 elements around the circumference and 1117 nodes, was generated.

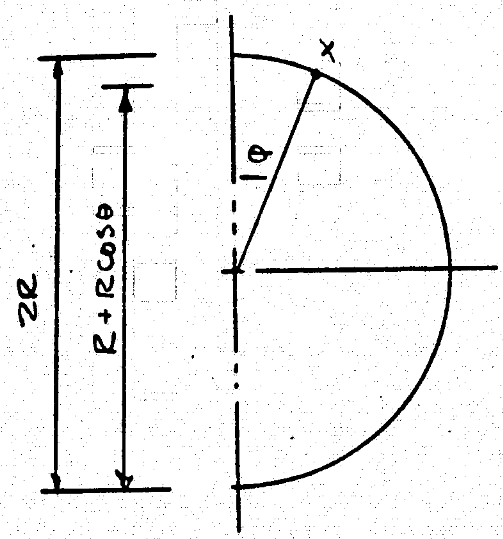
The model ran from ring location R1 To ring location R3.

all shell thickness were 1.24" except for the down stream shell part the second cone cylinder junction. This thickness was 1.00".

Material Constants
$E = 30 \times 10^6$ PSI
$\nu = 0.3$
$\rho = .283$ lbs/IN^3

Loading

a uniform element pressure of 119 psig was applied to all shell elements.
In addition to this uniform pressure, a variable pressure due to the water head was added on.



$\gamma = 62.4 \text{ lbs/ft}^3 = .0361 \frac{lb}{in^3}$

$P_{l_x} = \gamma\left[2R - (R + R\cos\theta)\right]$

$P_{l_x} = \gamma(R - R\cos\theta)$

$P_{TEST} = 1.5 \times P_{opp} = 1.5 \times 119 = 173.5$

The variable pressure at any point x around the circumference was defined by $P_{l_x} = \gamma(R - R\cos\theta) + P_{Test}$

Note: all pressures are in psi.

BY........ DATE........ SUBJECT........ SHEET NO. 9 OF......
CHKD. BY...... DATE........ JOB NO........

With 31 element around the circumference
The enclosure angle between elements
$180°/30$ spaces $= 6°$

Theta to the first element is $3°$.

Pressure at $\theta = 3°$

$P_a = 119 \times 1.5 + .0361(20.5 \times 12 - 20.5 \times 12 \times \cos(3))$
$= 178.55$ psi

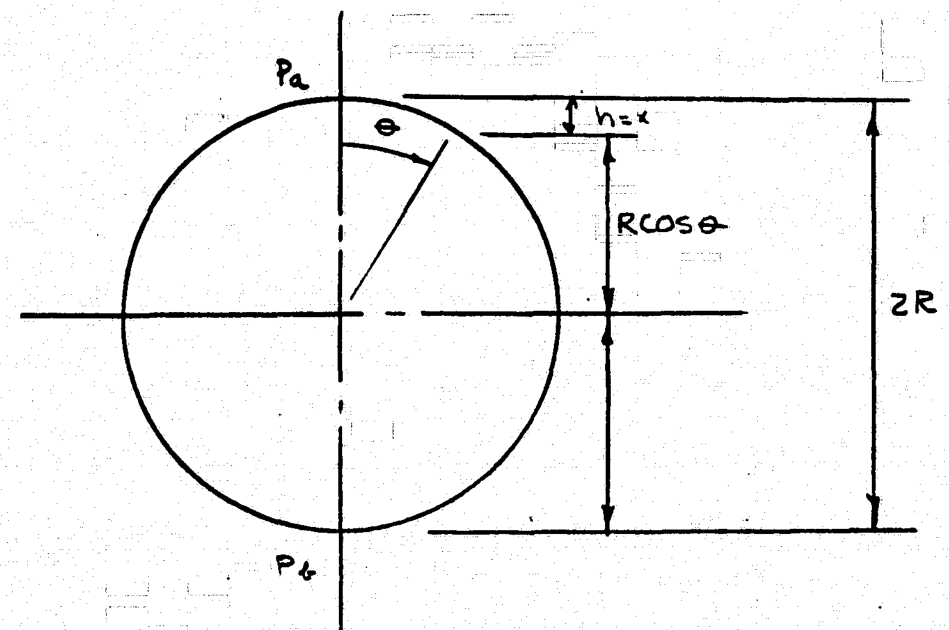
Pressure at $\theta = 180°$

$P_b = 119 \times 1.5 + .0361(20.5 \times 12 - 20.5 \times 12 \times \cos(180))$
$P_b = 196.23$ psi

Where $(119 \times 1.5) = 178.5$ psi is the Hydro test pressure.

$\gamma R(1 - \cos\theta)$ is the additional pressure at any point due to the water head.

a linear variable end force was applied to the R_3 end of the model given by



$$h = 2R - [R + R\cos\theta]$$
$$2R - R - R\cos\theta$$
$$R[2-1-\cos\theta]$$
$$R[1-\cos\theta]$$

$$P = \left(\frac{P_b - P_a}{2R}\right)x + P_a$$

$$P = \frac{\Delta P}{2R}\left[R(1-\cos\theta)\right] + P_a$$

$$\text{Pressure}\Big|_x = \frac{\Delta P}{2}\left[1-\cos\theta\right] + P_a .$$

Results

The primary purpose for this model was to verify that scaling of opperating stresses to hydo stresses wouldn't generate any incorrect stresses results.

also, note that this section of the tunnel has the highest and lowest elevation. There fore, The highest pressure due to the water head.

BY.............. DATE.......... SUBJECT.. SHEET NO. 12 OF......
CHKD. BY....... DATE.......... JOB NO.....................

Water weights - from computer run GT 78007

Node	Constraint Reaction lbs
264	-5.59934×10^4
295	-4.44728×10^5
362	-5.115345×10^4
729	-5.441023×10^4
760	-4.59041×10^5
791	-5.556915×10^4
3016	-4.098632×10^5
1039	-3.277161×10^5
TOTAL	1858475. lbs

Calculated

Weight of water in this section of the tunnel. 1851719.0 lbs.

Calculated	1851719.0	lbs
Model generated	1858475.0	lbs
Δ Water weight	-6756.0	lbs.
	.36 %	diff.

CHKD. BY........ DATE.........

opperating pressure   P=119.00

(TOP) Hydro pressure at element 2001 = .0483 + 178.5 = 178.55 psi
(bottom) Hydro pressure at element 2030 = 17.73 + 178.5 = 196.23 psi

Scale factor for top of tunnel:

$$\frac{178.55}{119} = 1.5004$$

Scale factor for bottom of tunnel:

$$\frac{196.23}{119} = 1.649$$

From Nastran run GT 78007 w/ P=119
(Peak stresses)

element	σ_{Hoop} KSI inside	σ_{Hoop} KSI outside	σ_{axial} KSI inside	σ_{axial} KSI outside	Location
2001	-4.43	-13.9	+27.59	-3.71	$\theta = 0°$
2030	-4.44	-13.9	+27.59	-3.71	$\theta = 180°$

Scaled stresses from above

element	σ_{Hoop} inside	σ_{Hoop} outside	σ_{axial} inside	σ_{axial} outside	Scale factor
2001	-6.647	-20.86	+41.396	-5.57	1.5
2030	-7.32	-22.92	+45.50	-6.12	1.649

Stresses from Hydro run P = 178.5 + H_2O head

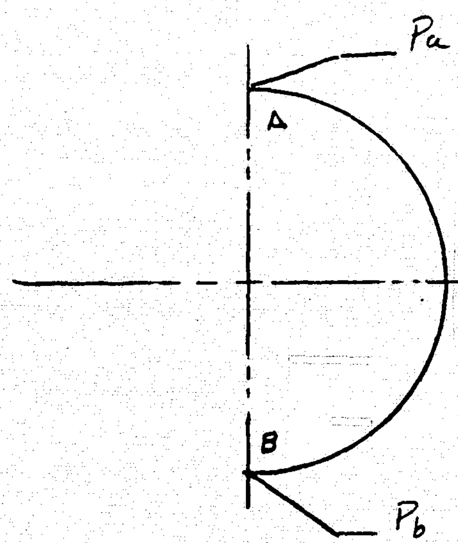
element	σ_{Hoop} KSI inside	σ_{Hoop} KSI outside	σ_{axial} KSI inside	σ_{axial} KSI outside	Location
2001	-7.14	-21.6	42.0	-5.71	$\theta = 0°$
2030	-7.15	-22.6	45.23	-6.03	$\theta = 180°$

As can be seen from the last two tables, scaling of opperating stresses does not generate any erroneous stresses.

To add additional verification to the above procedure some hand calculations to predict stresses in the region between support ring were made.

(element no. 529)

$P_a = 178.55$
$P_b = 196.23$



(element no. 557)

BY	DATE	SUBJECT	SHEET NO. 15 OF
CHKD. BY	DATE		JOB NO.

For Hydo conditions.

at point A. element No. 528

$R = 246.62$ $\theta = 0°$ $P_a = 178.55$ PSI

$\sigma_{Hoop} = (178.55 \times 246.62)/1.24 = 35511$ PSI

at point B element no. 557

$R = 246.62$ $\theta = 180°$ $P_b = 196.23$

$\sigma_{Hoop} = (196.23 \times 246.62)/1.24 = 39027.$ PSI

From Nastran run no. GT 78007 :

at element no. 528

σ_{Hoop} (inside) = 35503.9

σ_{Hoop} (outside) = 35405.8

$\sigma_{ave} = 35457$ PSI

at element no. 557

σ_{Hoop} (inside) = 38929

σ_{Hoop} (outside) = 39025

$\sigma_{ave} = 38977$ PSI

element	Hand Calculation	Computer results	θ	
528	35.5 KSI	35.5 KSI	0°	
557	39.0 KSI	39.0 KSI	180°	

BY	DATE	SUBJECT	SHEET NO. 16 OF
CHKD. BY	DATE		JOB NO.

In conclusion the following method was used in predicting hydro test stresses from opperating conditions.

Upper center line

$$P_{hydro} = 119 \times 1.5 + \gamma(41 \times 12/2 + D_L \times 12/2)$$

$\gamma = 0.0361$ lbs/in³

D_L = Local Diameter.

Lower center line

$$P_{hydro} = 119 \times 1.5 + \gamma(41 \times 12/2 + D_L \times 12/2 + 91.25)$$

There fore,

$$\sigma\text{'s}_{(HYDRO)} = \left\{\sigma\text{'s}\,(\text{opperating})\right\}\left\{\frac{P_{hydro}}{119.0}\right\}$$

BY.............. DATE.......... SUBJECT NTF PRESSURE SHELL SHEET NO. 1 OF......
CHKD. BY........ DATE.......... Effects of Insulation Rings JOB NO..................
on shell stresses

Part 3

304. S.S.

Assume a cylinder with no structural support ring and design in accordance with Div I of Code

$$t = \frac{PR}{SE - 0.6P}$$

$P = 119$ psig

$R = 120''$

$S = 25.0$ ksi

$E = 1$

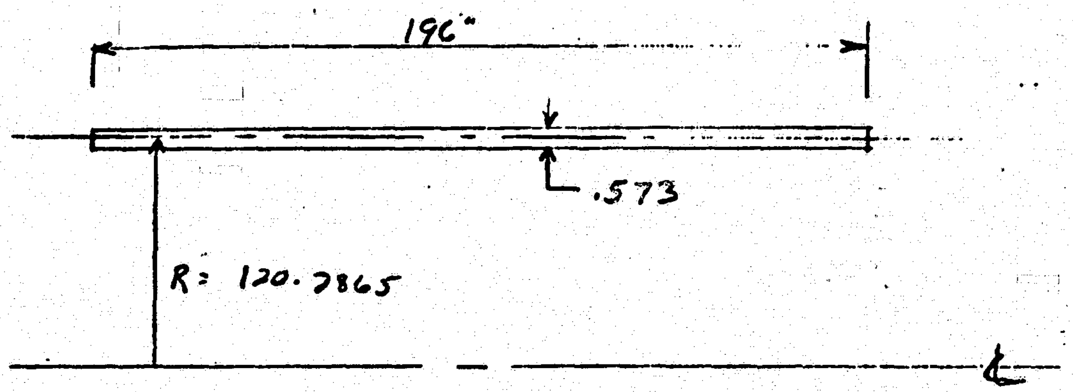
$$t = \frac{(119)(120)}{(25000)(1) - 0.6(119)}$$

$t = .573$ IN.

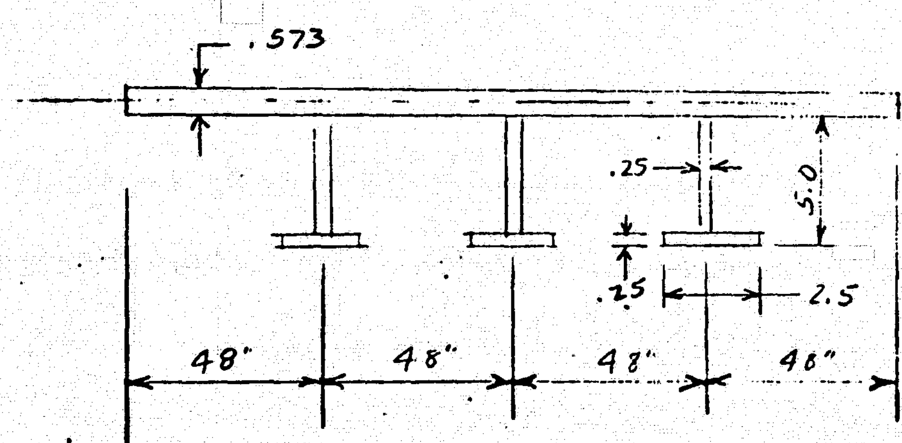
$$\sigma = \frac{Pr}{t} = \frac{(119)(120.286)}{.573} = 24,980 \text{ psi}$$

BY............ DATE........ SUBJECT NTF PRESSURE SHELL SHEET NO. 2 OF......
CHKD. BY...... DATE........ JOB NO.................

Cylinder with insulation rings MODEL 1



Cylinder with insulation rings Model 2

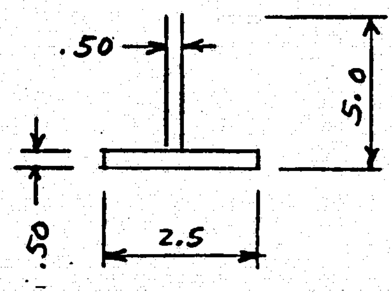


BY .... DATE .... SUBJECT .... SHEET NO. 3 OF ......

CHKD. BY .... DATE .... JOB NO. ....

Cylinder with insulation rings Model 3

Same as model 2 except ring as follows



Boundary Forces

$$F = \frac{(119)(120.2865)}{2}$$

$$F = 7157.05 \text{ lb/in}$$

BY............. DATE........ SUBJECT *NTF Pressure Shell* SHEET NO. *4* OF .....

CHKD. BY....... DATE........ JOB NO. ....

Ins. Rings

T-SECTION
PROPERTIES.
================

B=	2.500*
D=	5.000*
S=	0.250*
T=	0.250*
H=	4.875
AREA=	1.844
Y=	3.267
I X-X=	4.797
I Y-Y=	0.332

T-SECTION
PROPERTIES.
================

B=	2.500*
D=	5.000*
S=	0.500*
T=	0.500*
H=	4.750
AREA=	3.625
Y=	3.267
I X-X=	[illegible]
I Y-Y=	0.698

BY........ DATE........ SUBJECT NTF PRESSURE SHELL SHEET NO. 5 OF......

CHKD. BY........ DATE........ Effects of Insulation Rings JOB NO........

on Shell Stresses

Results: (From SALORS)

Cylinder with Insulation Rings # STUDY E

CASE 1 NO RINGS

(76/03/01. 14.00.05)

Hoop Stress = 25,003 psi

Long. Stress = 12,490 psi

rad disp. = .0882 IN.

Case 2 - With Insulation Rings t = .25

(76/03/01. 14.21.26)

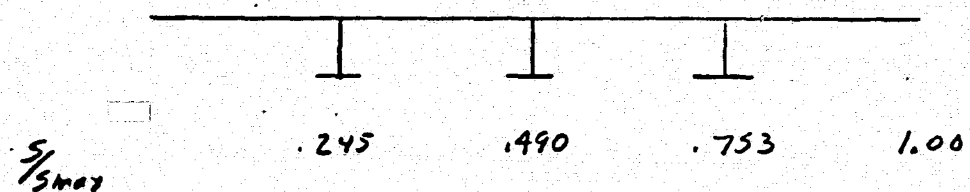
S/Smax 0 .245 .490 .735 1.00

S/Smax		Long. Stress (psi)	Hoop Stress (psi)	Rad. Defl. (IN)	Net Section Hoop
.490	INside	20,329.8	23,605.8	.0701	20647
	outside	4,601.9	18,287.5		
.611	I	12,360.6	25,261.1	.0894	25 295
	O	12,588.1	25,329.3		

BY .... DATE	SUBJECT NTF PRESSURE SHELL	SHEET NO. 6 OF ......
CHKD. BY ...... DATE	Effects of Insulation Rings	JOB NO. ....
	on Shell Stresses	

Case 3 With Insulation Rings $t = 0.50$

76/03/01 14.13.51



S/Smax		Long Stress (psi)	Hoop Stress (psi)	Rad. defl. (IN)	Net Section Hoop
.366	INSIDE	12277	25426		25482
	OUTSIDE	12650	25538		
.490	INSIDE	25,353	21725		17[illegible]4
	OUTSIDE	-4535	13983		
.611	INSIDE	12277	25426		25482
		12650	25538		

BY............DATE.......... SUBJECT NTF PRESSURE SHELL Effects of Insulation Rings on Shell Stresses SHEET NO. 7 OF......
CHKD. BY......DATE.......... JOB NO. ....

For 0.25 in thick Rings

$$\frac{25295 - 25003}{25295} = .011$$

∴ Insulation rings results in 1.1% net section stress in Hoop direction

---

For 0.50 in thick Rings

$$\frac{25482 - 25003}{25003} = 0.019$$

∴ Insulation results in 1.9% net section stress in Hoop direction

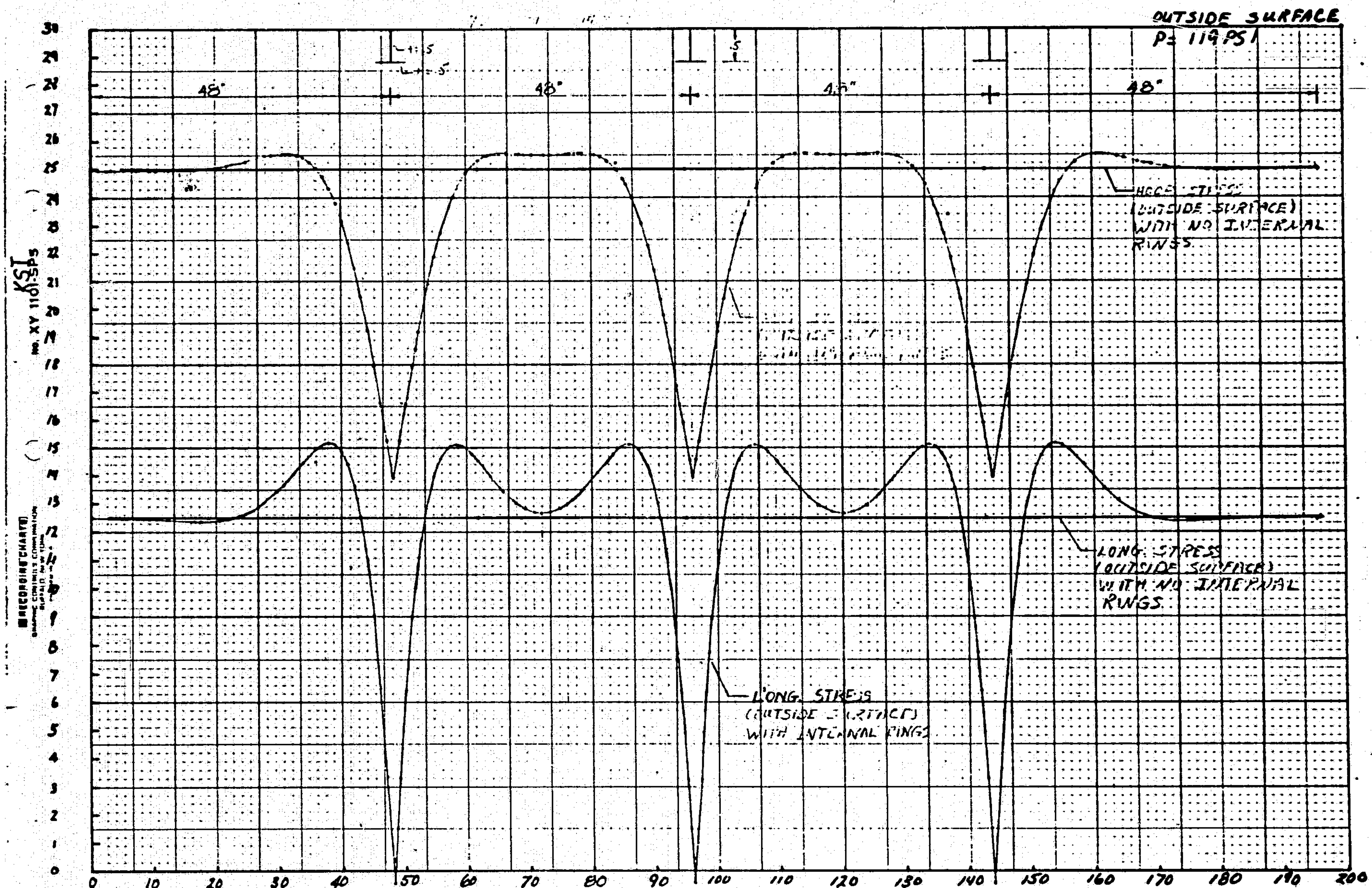
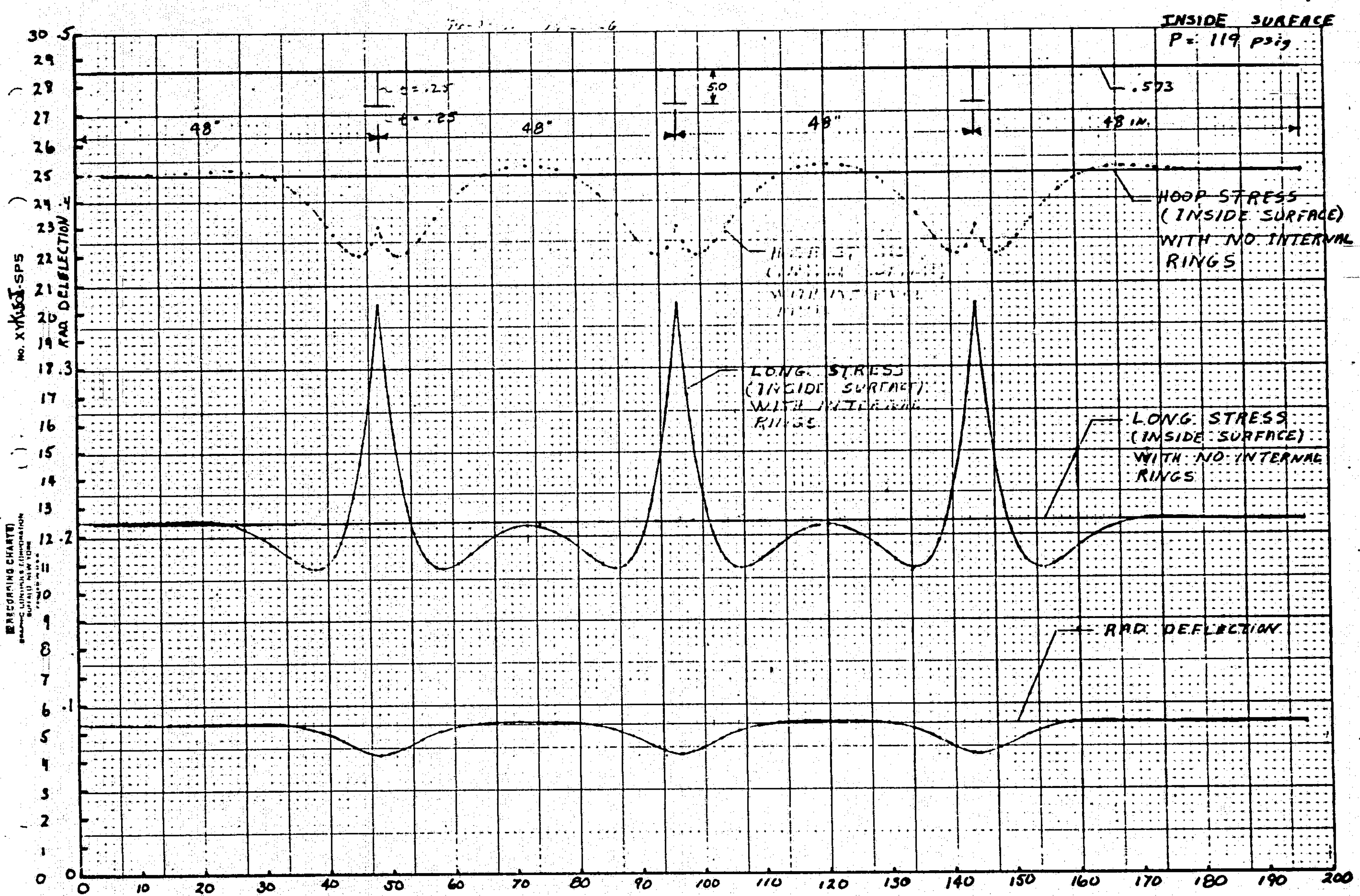
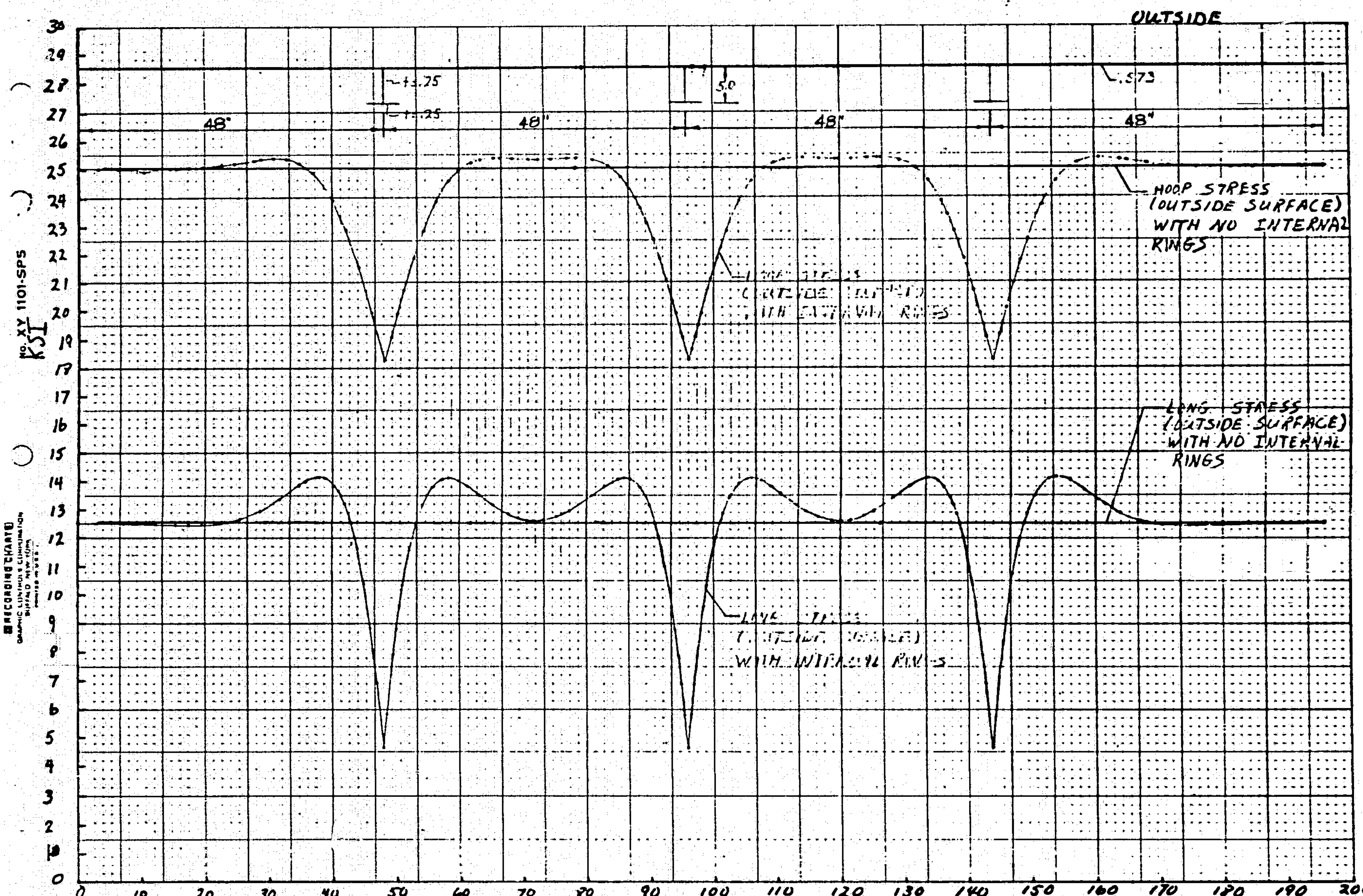

OUTSIDE SURFACE
P= 119 PSI
48"
48"
48"
KSI
LONG. STRESS (OUTSIDE SURFACE) WITH NO INTERNAL RINGS.
LONG. STRESS (OUTSIDE SURFACE) WITH INTERNAL RINGS
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

Fig. 1

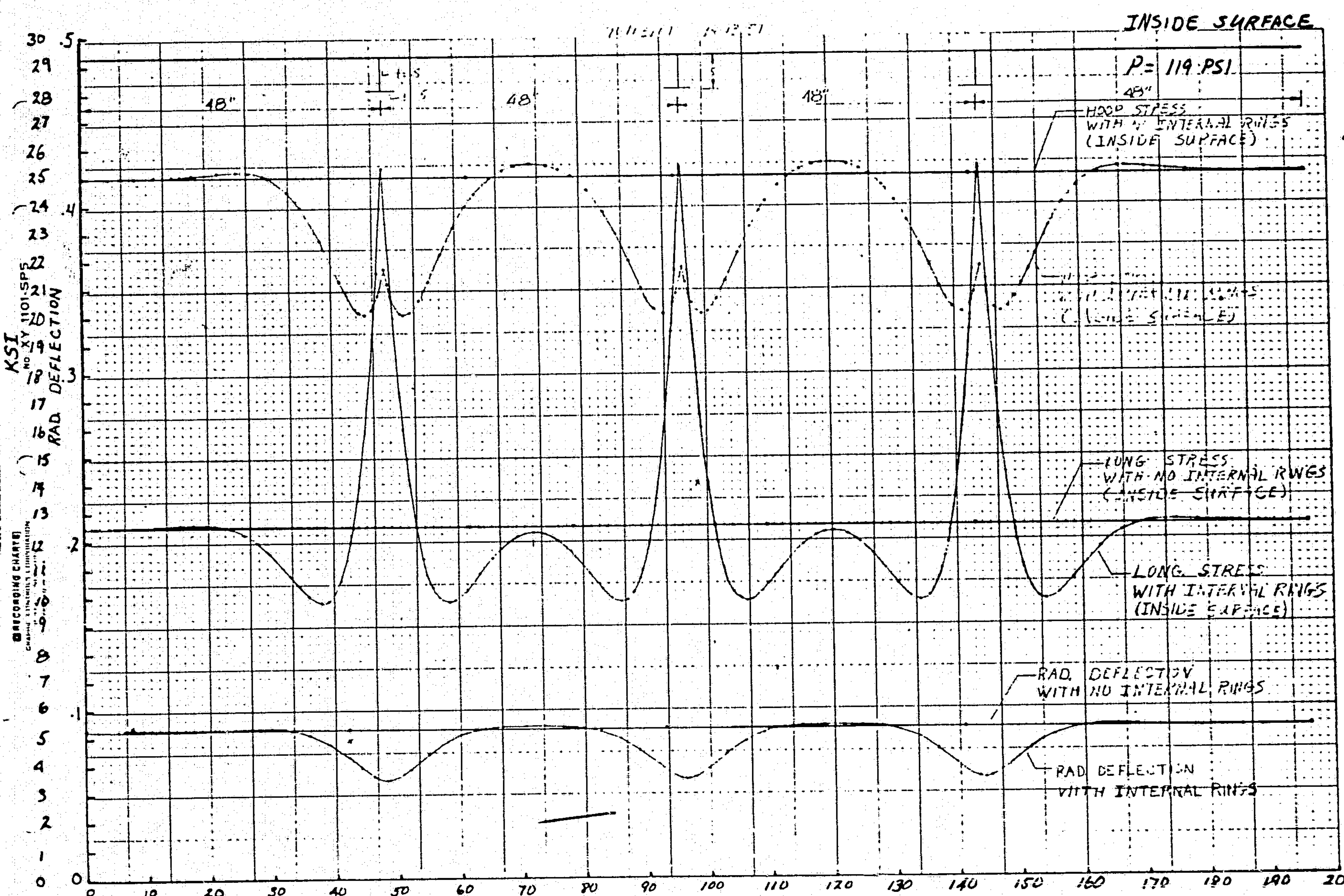


INSIDE SURFACE
P = 119 psig
.573
48"
48"
48"
48 IN.
5.0
HOOP STRESS (INSIDE SURFACE) WITH NO INTERNAL RINGS
LONG. STRESS (INSIDE SURFACE) WITH INTERNAL RINGS
LONG. STRESS (INSIDE SURFACE) WITH NO INTERNAL RINGS
RAD. DEFLECTION
KSI
RAD. DEFLECTION

Fig 2


OUTSIDE
1.75
1.25
.50
.573
48"
48"
48"
48"
HOOP STRESS (OUTSIDE SURFACE) WITH NO INTERNAL RINGS
LONG. STRESS (OUTSIDE SURFACE) WITH NO INTERNAL RINGS
WITH INTERNAL RINGS
KSI
No. XY 1101-SPS
RECORDING CHARTS
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

F, 3


INSIDE SURFACE
P= 119 PSI
48"
HOOP STRESS WITH NO INTERNAL RINGS (INSIDE SURFACE)
LONG. STRESS WITH NO INTERNAL RINGS (INSIDE SURFACE)
LONG. STRESS WITH INTERNAL RINGS (INSIDE SURFACE)
RAD. DEFLECTION WITH NO INTERNAL RINGS
RAD DEFLECTION WITH INTERNAL RINGS
KSI
RAD. DEFLECTION
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200