VIEWGRAPHS ACCOMPANYING

PRESENTATION BY J. MEYER, NRC

JUNE 17, 1980

WASH-1400 ASSUMPTIONS ON CONTAINMENT OVERPRESSURIZATION FAILURES

- ASSUMED FAILURE PRESSURE - 100 PSIA ± 15 PSI

- FAILURE MODE - EXTENSIVE CRACKING OF REINFORCED CONCRETE, FOLLOWED BY TEARING OF LINER

- FAILURE EXPECTED AT TOP OF CONTAINMENT

- DEPRESSURIZATION IS RAPID COMPARED TO THE HALF-LIVES OF ISOTOPES BEING CONSIDERED

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PRIMARY CONTAINMENT ULTIMATE CAPACITY OF ZION NUCLEAR POWER PLANT

A STUDY PREPARED FOR

COMMONWEALTH EDISON COMPANY

CHICAGO, ILLINOIS

JUNE 16, 1980

SARGENT & LUNDY ENGINEERS

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- CONTAINMENT DESCRIPTION
- OBJECTIVES OF STUDY
- CONTAINMENT SHELL BEHAVIOR UNDER LOAD
- ANALYSIS
- MATERIAL PROPERTIES
- RESULTS
- CONCLUSIONS

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OBJECTIVES

1. Ultimate Pressure Capacity.
2. Effect of High Temperatures
3. Identify Failure Mode(s)
4. Possible Remedies If Meaningful
5. Effect of Rate of Pressure / Temperature Rise

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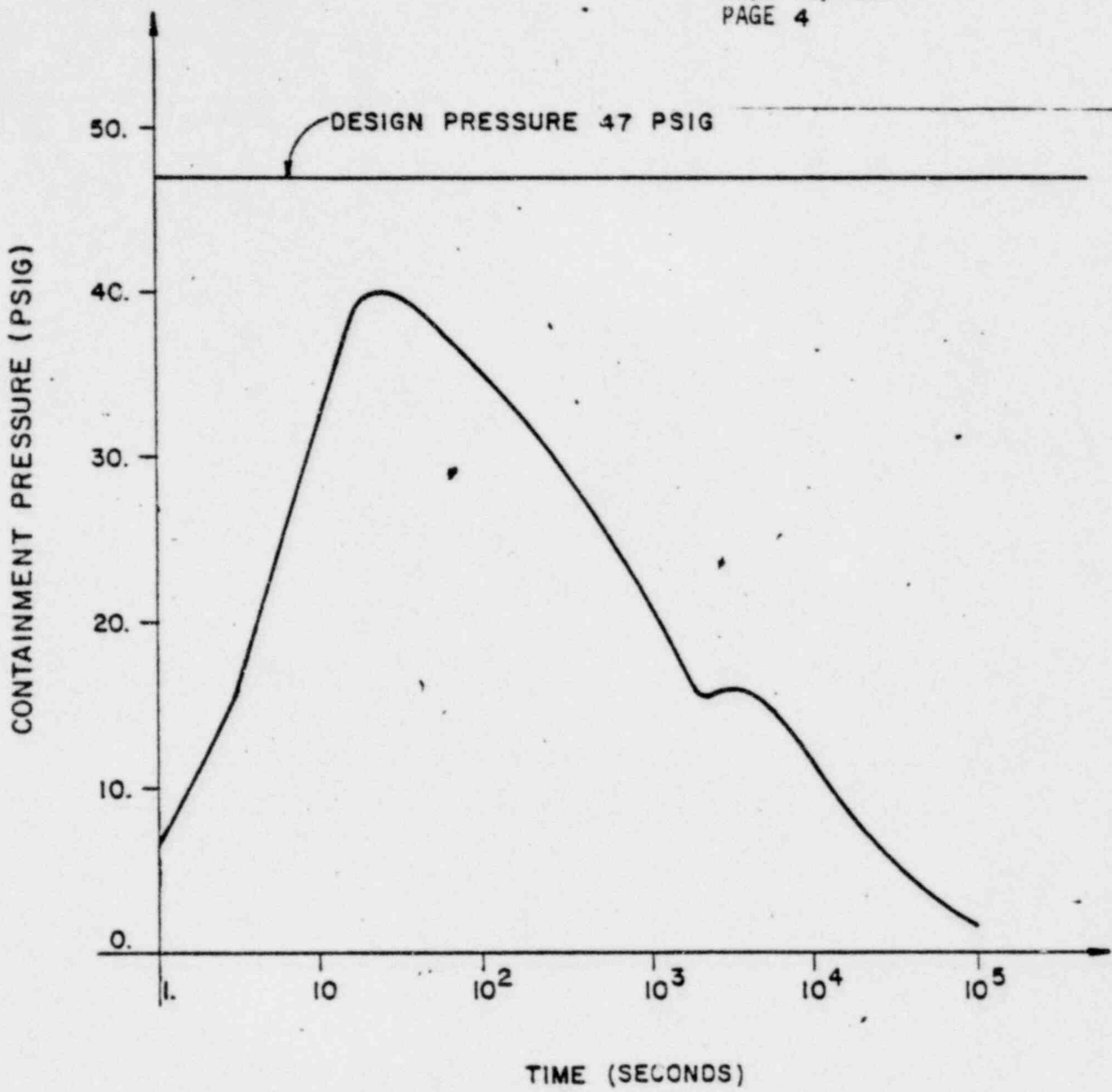

CONTAINMENT PRESSURE RESPONSE TO LOCA

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	NO.	LOAD COMBINATION
WORKING STRESS	1	$D + F + 1.15\,P_a$
	2	$D + F + T_a$
	3	$D + F + P_a + T_a$
	4	$D + F + P_a + T_a + E$
YIELD LIMIT	5	$D + F + 1.5\,P_a + T_a$
	6	$D + F + 1.25\,P_a + T_a + 1.25\,E$
	7	$D + F + P_a + T_a + E'$

D = DEAD LOAD

F = POST-TENSIONING LOAD

P_a = LOCA PRESSURE LOAD

T_a = LOCA TEMPERATURE LOAD

E = SEISMIC (OBE) LOAD

E' = SEISMIC (SSE) LOAD

CONTAINMENT ORIGINAL DESIGN LOAD COMBINATIONS

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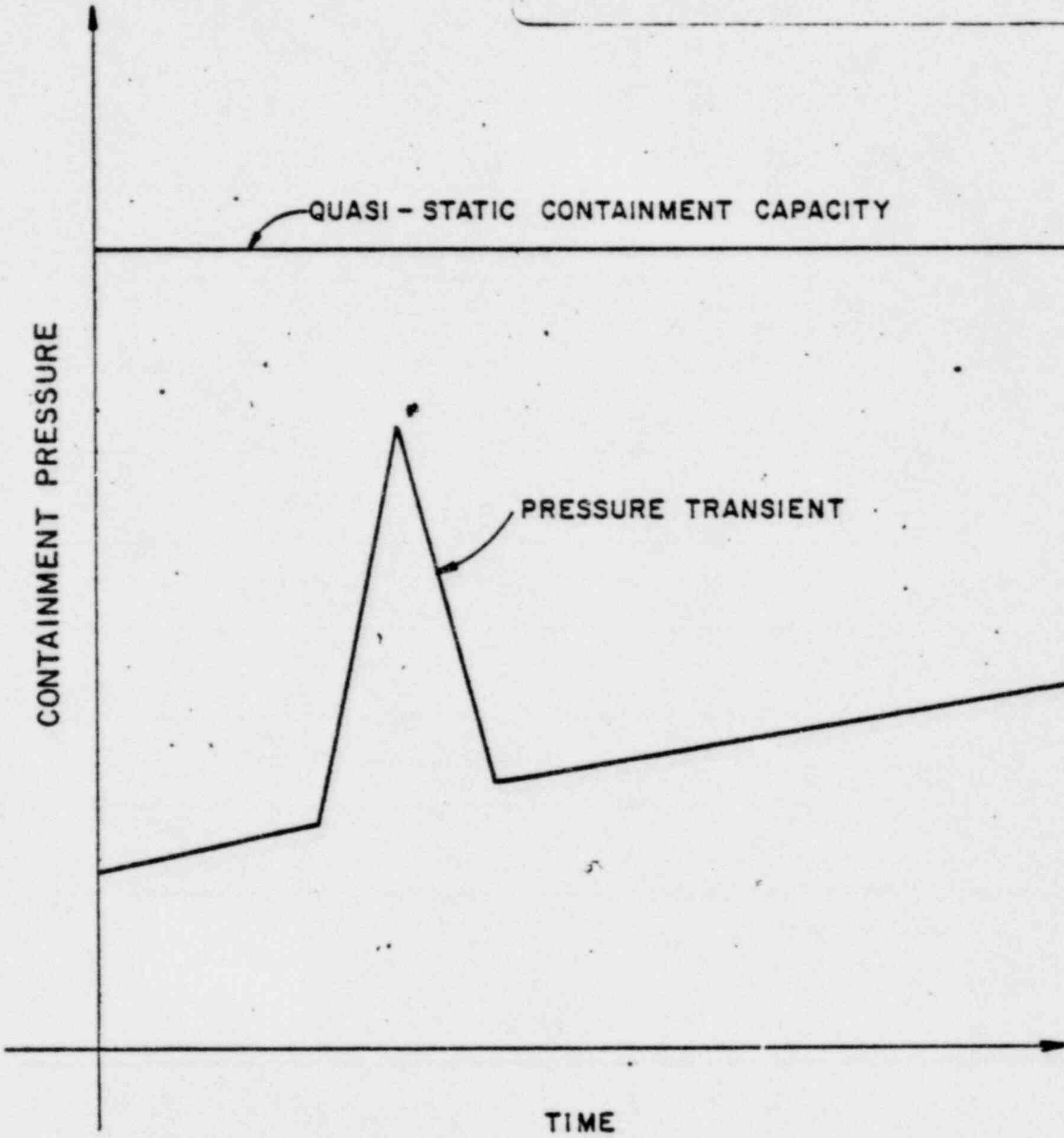

CLASS 9 ACCIDENT CONTAINMENT PRESSURE TRANSIENTS

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CLASS 9 ACCIDENT TEMPERATURE EFFECTS

- SELF-LIMITING LOADS : NO EFFECT ON ULTIMATE STRUCTURAL STRENGTH.
- LINER MATERIAL INTACT :
  LEAK-TIGHTNESS NOT JEOPORDIZED
- DETERMINE PRESSURE CAPACITY WITH AND WITHOUT LINER.
- LINER STRAINS.
- CONCRETE MATERIAL INTACT.

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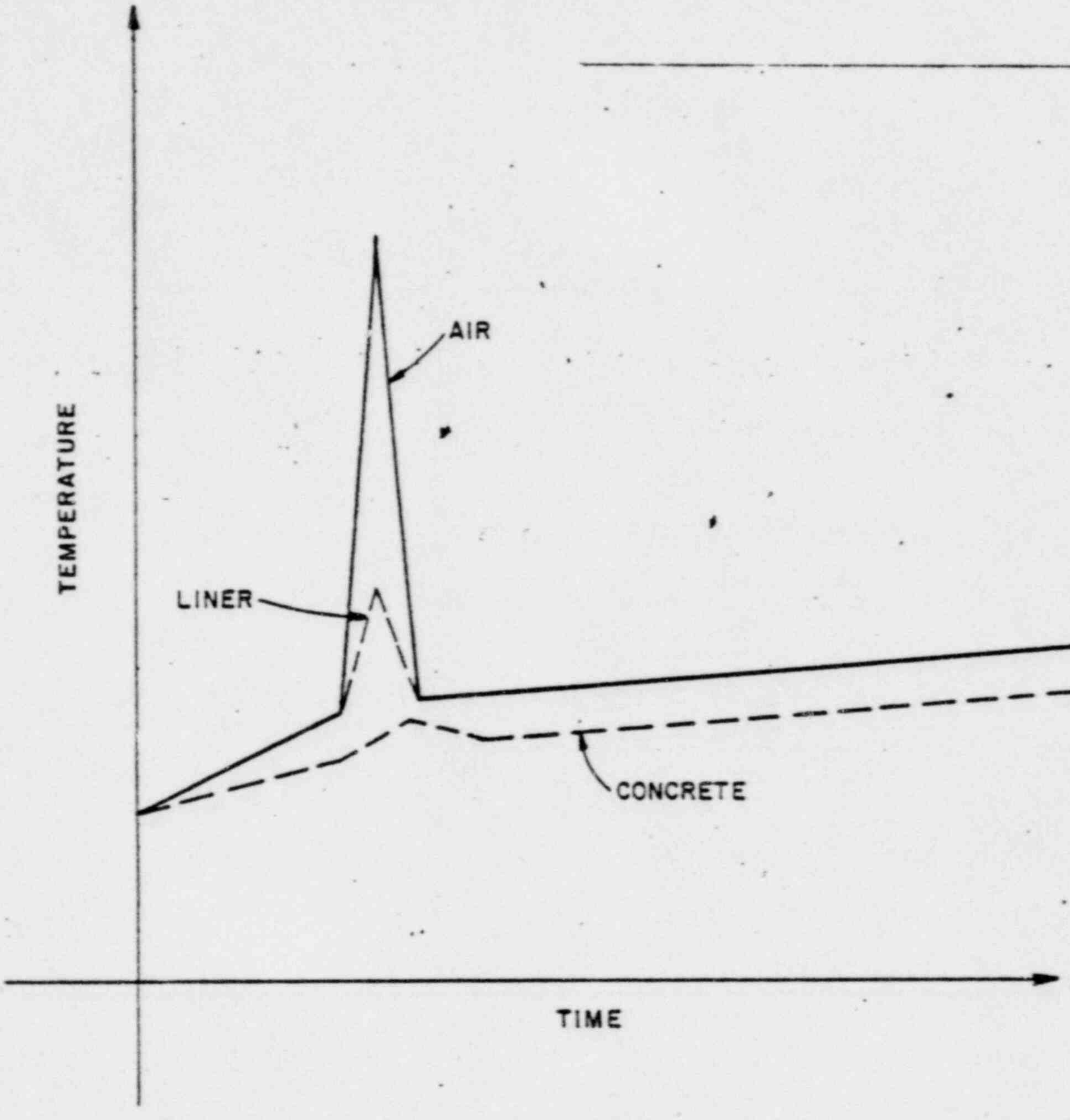

CLASS 9 ACCIDENT CONTAINMENT THERMAL TRANSIENTS

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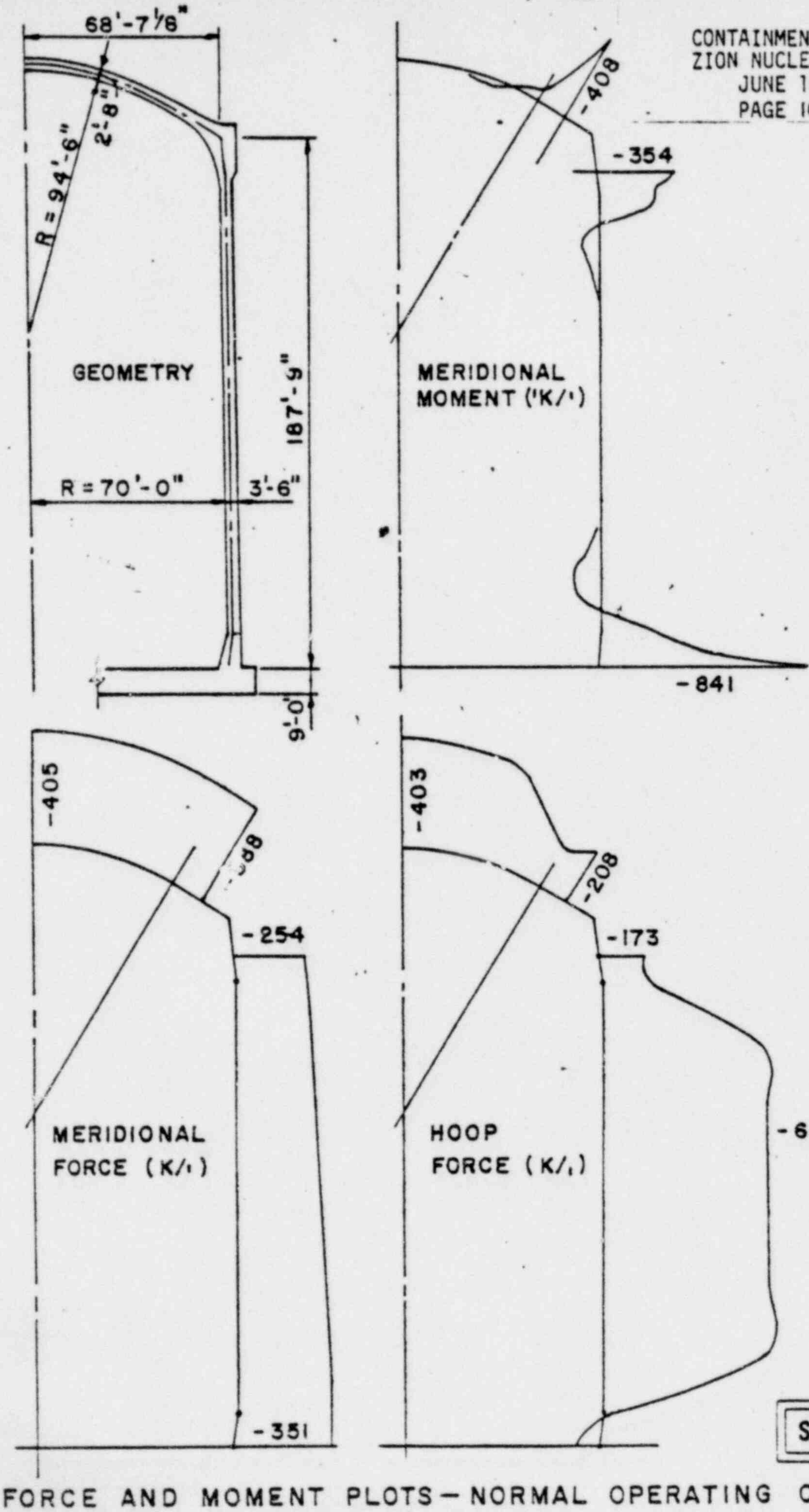

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FORCE AND MOMENT PLOTS — NORMAL OPERATING CONDITIONS

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POTENTIAL FAILURE MODES

- TENDON YIELDING: HOOP, VERTICAL, DOME.
- SHEAR FAILURE: DISCONTINUITIES.
- LINER FRACTURE: STRAINS.
- REINFORCING BARS: STRAINS.
- PENETRATIONS: EQUIPMENT HATCH.
- SOIL FAILURE.

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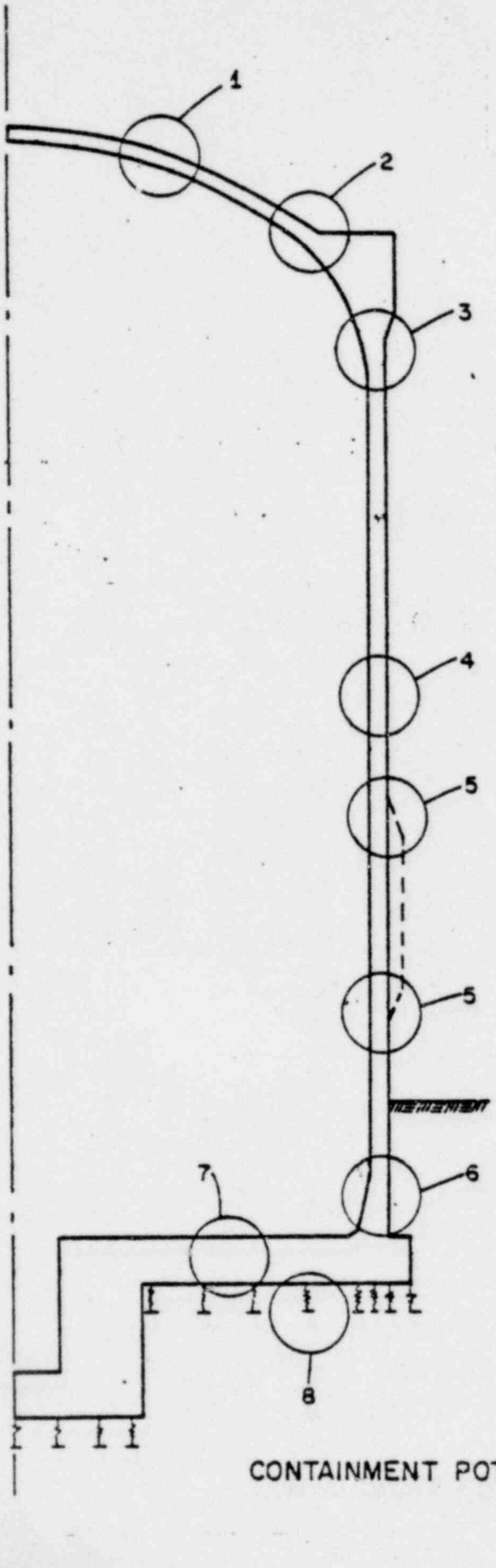

1 - DOME TENDONS

2 - DOME DISCONTINUITY (MOMENTS, SHEARS)

3 - CYLINDER DISCONTINUITY (MOMENTS, SHEARS)

4 - HOOP TENDONS, LINER, VERTICAL TENDONS

5 - EQUIPMENT HATCH FAILURE

6 - CYLINDER RESTRAINT (MOMENTS, SHEARS)

7 - BASE MAT REINFORCING AND SHEAR TIES

8 - SOIL PRESSURE

CONTAINMENT POTENTIAL MODES OF FAILURE

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FAILURE CRITERIA

- TENDON YIELDING: (μ)
- SHEAR FAILURE: $(\mu - \sigma)$
- LINER MEMBRANE STRAIN: $15\ \varepsilon_y\ (\mu) \leq 1/4\ \varepsilon_u (\mu - \sigma)$
- LINER FIBER STRAIN: $\frac{1}{2}\ \varepsilon_u\ (\mu - \sigma)$
- SOIL FAILURE: F_u
- REINFORCEMENT STRAIN: $10\ \varepsilon_y\ (\mu) \leq 1/4\ \varepsilon_u (\mu - \sigma)$

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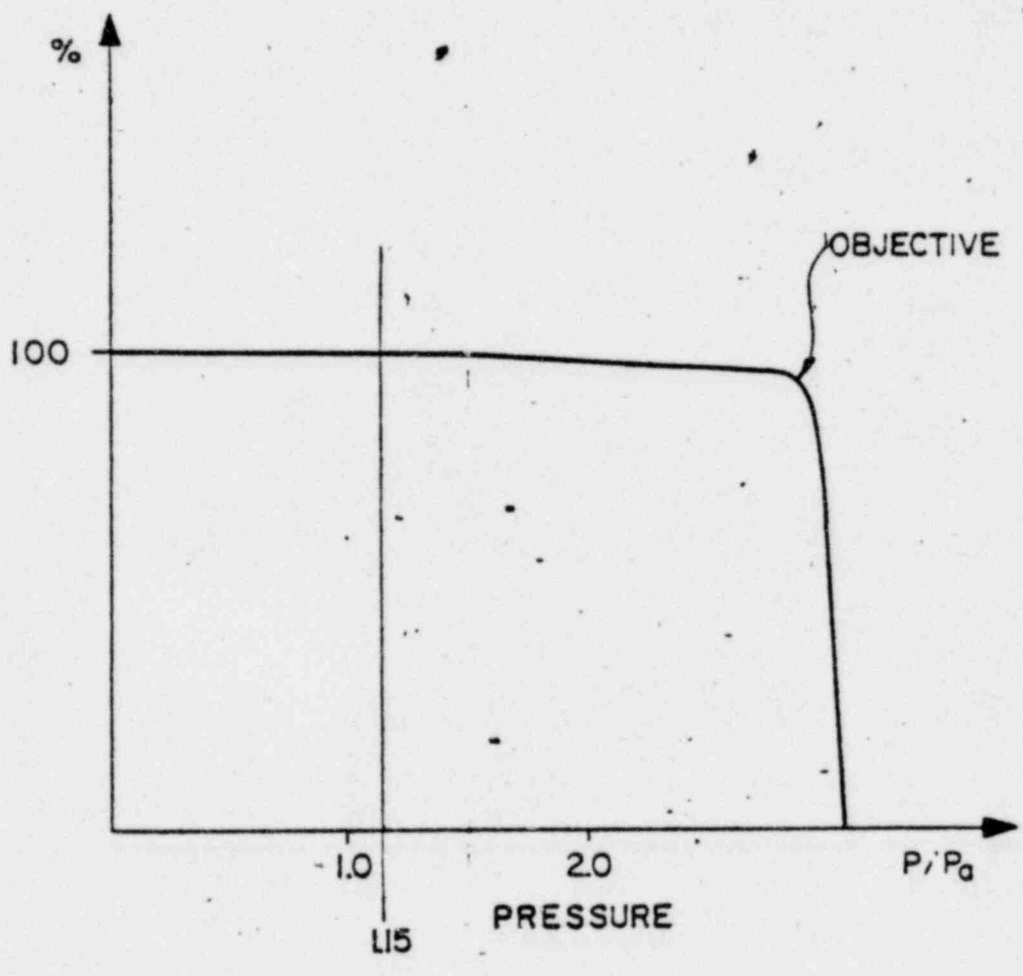
CONFIDENCE LEVEL: QUALITATIVE



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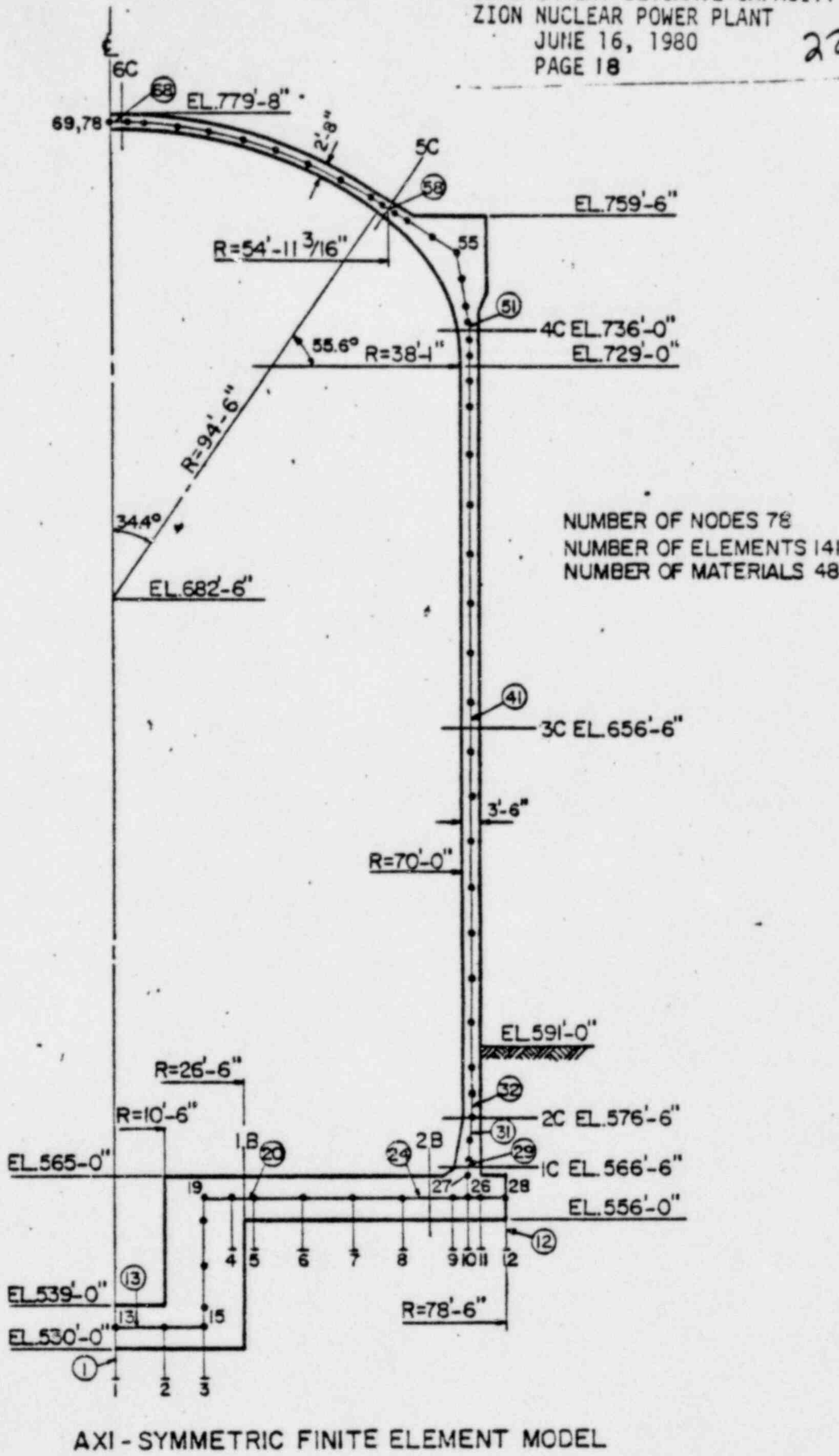
ANALYSIS

- COMPUTER ANALYSIS
  - TENDON YIELDING : HOOP, VERTICAL, DOME.
  - SHEAR FAILURE : DISCONTINUITIES
  - LINER : MEMBRANE STRAINS
  - REINFORCING BARS : STRAINS
  - SOIL FAILURE

- HAND CALCULATIONS
  - TENDON YIELDING : HOOP, VERTICAL, DOME
  - LINER : FLEXURAL STRAINS - BUCKLING
  - PENETRATIONS : EQUIPMENT HATCH

FINITE ELEMENT ANALYSIS

- THIN SHELL OF REVOLUTION
- MATERIAL NON-LINEARITY : CONCRETE CRACKING AND STEEL YIELDING
- LAYERED ELEMENTS : CONCRETE AND REBARS
- POST-TENSIONING TENDONS : TRI-LINEAR
- SOIL : ONE-WAY SPRINGS
- COMBINED LOADS :
  - DEAD LOAD
  - POST-TENSIONING (PERMANENT) LOADS
  - PRESSURE LOADS : 2.0, 2.2, 2.4, 2.6, 2.8 x Pa



AXI - SYMMETRIC FINITE ELEMENT MODEL

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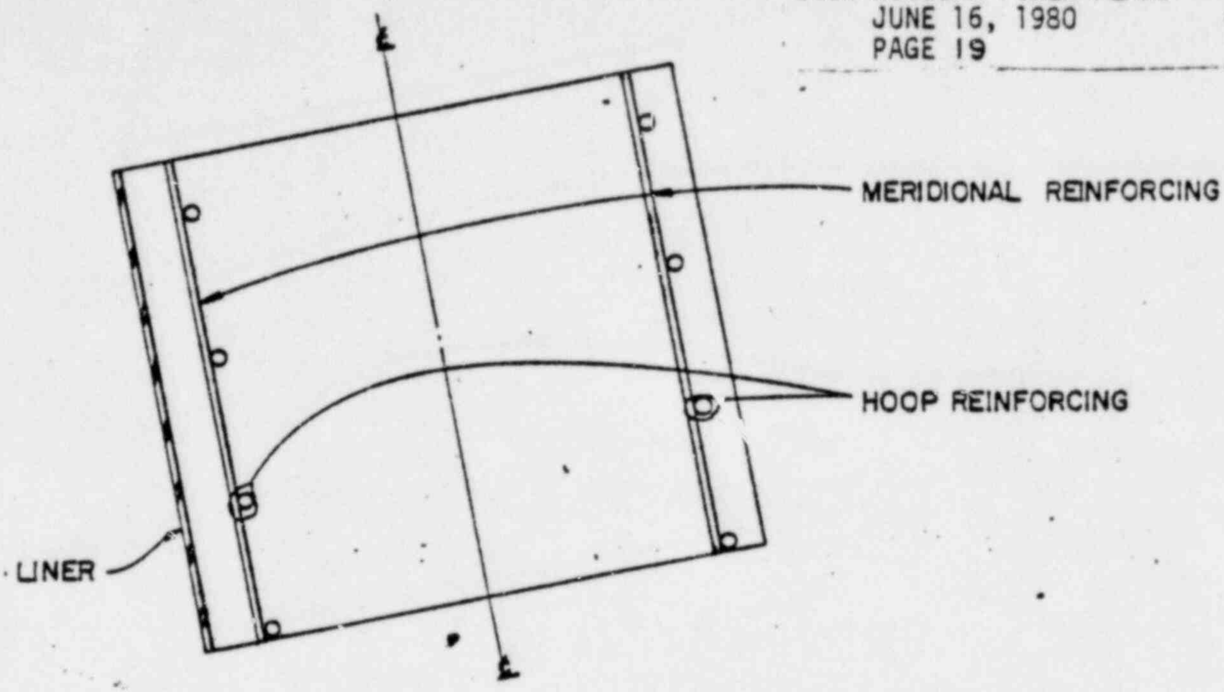
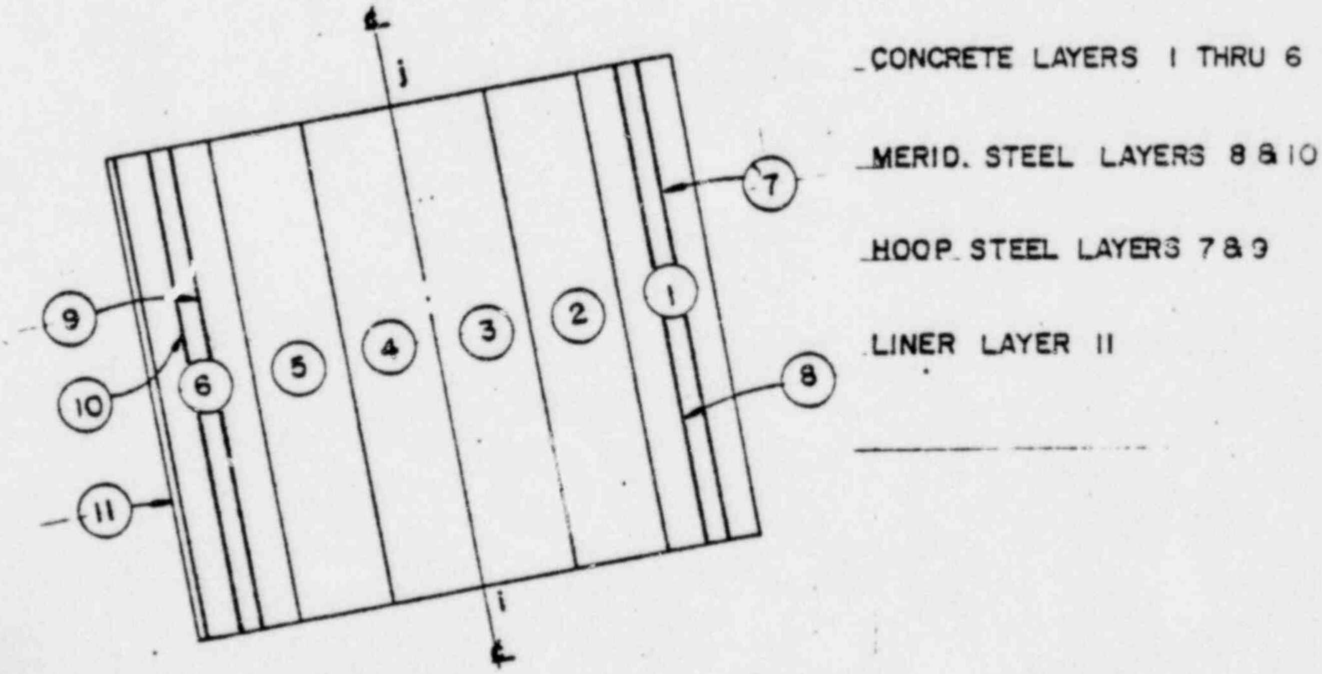


REINFORCED CONCRETE SHELL ELEMENT



LAYERED ELEMENT FOR NONLINEAR FINITE ELEMENT ANALYSIS

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ASTM A-421 TYPE BA

PROPERTY	SPECIFIED VALUE	NO. OF SAMPLES	ACTUAL VALUE	
			AVERAGE VALUE	STANDARD DEVIATION
YIELD STRENGTH AT 1% ELONG	204 KSI MIN.	735	222.5 KSI	7.42 KSI
TENSILE STRENGTH	240 KSI MIN.	APPROX. 1120	VERIFY MINIMUM VALUE	
ELONGATION IN 8	4% MIN.	1298	5.07%	.49%
MODULUS OF ELASTICITY		144	28.9×10^3 KSI	0.1×10^3 KSI

POST-TENSIONING WIRE MATERIAL PROPERTIES
(UNIT 2)

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ASTM A-615 GRADE 60

PROPERTY	SPECIFIED VALUE	NO.OF SAMPLES	ACTUAL VALUE	
			AVERAGE VALUE	STANDARD DEVIATION
YIELD STRENGTH	60 KSI (MIN)	3,500	67.2KSI	5.5KSI
TENSILE SRENGTH	90 KSI (MIN)		VERIFY MINIMUM VALUES	
ELONGATION IN 8"	7%	645	14.7%	3.5%

REINFORCING STEEL MATERIAL PROPERTIES

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ASTM A-442 GRADE 60

PROPERTY	SPECIFIED VALUE	NO. OF SAMPLES	ACTUAL VALUE	
			AVERAGE VALUE	STANDARD DEVIATION
YIELD STRENGTH	32 KSI MIN.	74	48.43 KSI	2.32 KSI
TENSILE STRENGTH	60 KSI MIN.		VERIFY MINIMUM VALUE	
ELONGATION IN 8"	20% MIN.	73	26.2%	1.9%

STEEL LINER MATERIAL PROPERTIES

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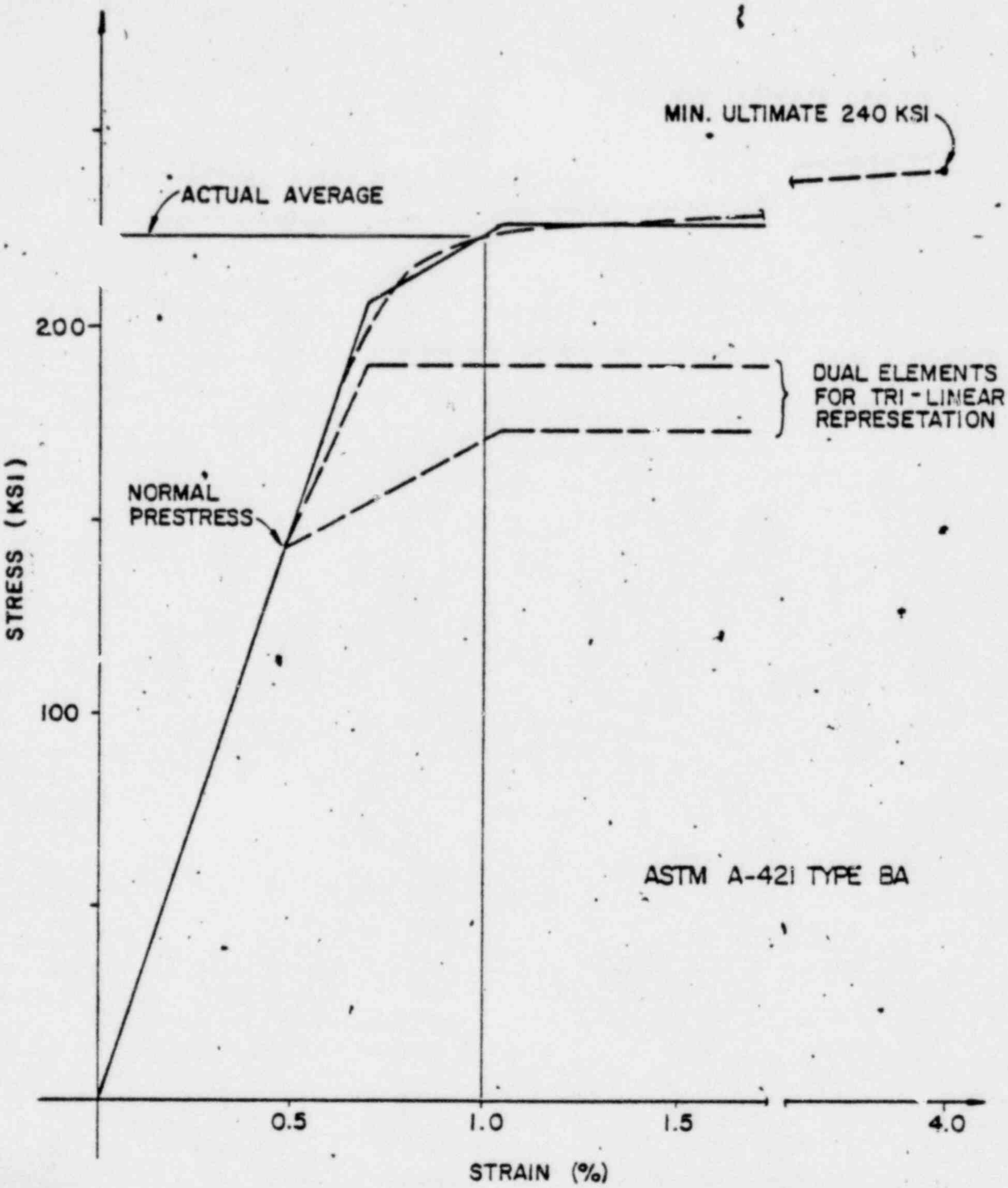
			ACTUAL VALUE	
LOCATION	SPECIFIED VALUE	No. OF SAMPLES	AVERAGE VALUE	STANDARD DEVIATION
BASEMAT	5,000 PSI	76	5,948 PSI	570 PSI
CONTAINMENT	5,500 PSI	404	6,663 PSI	617 PSI

90 DAY CONCRETE COMPRESSIVE STRENGTH



TENDON IDEALIZED STRESS - STRAIN CURVE

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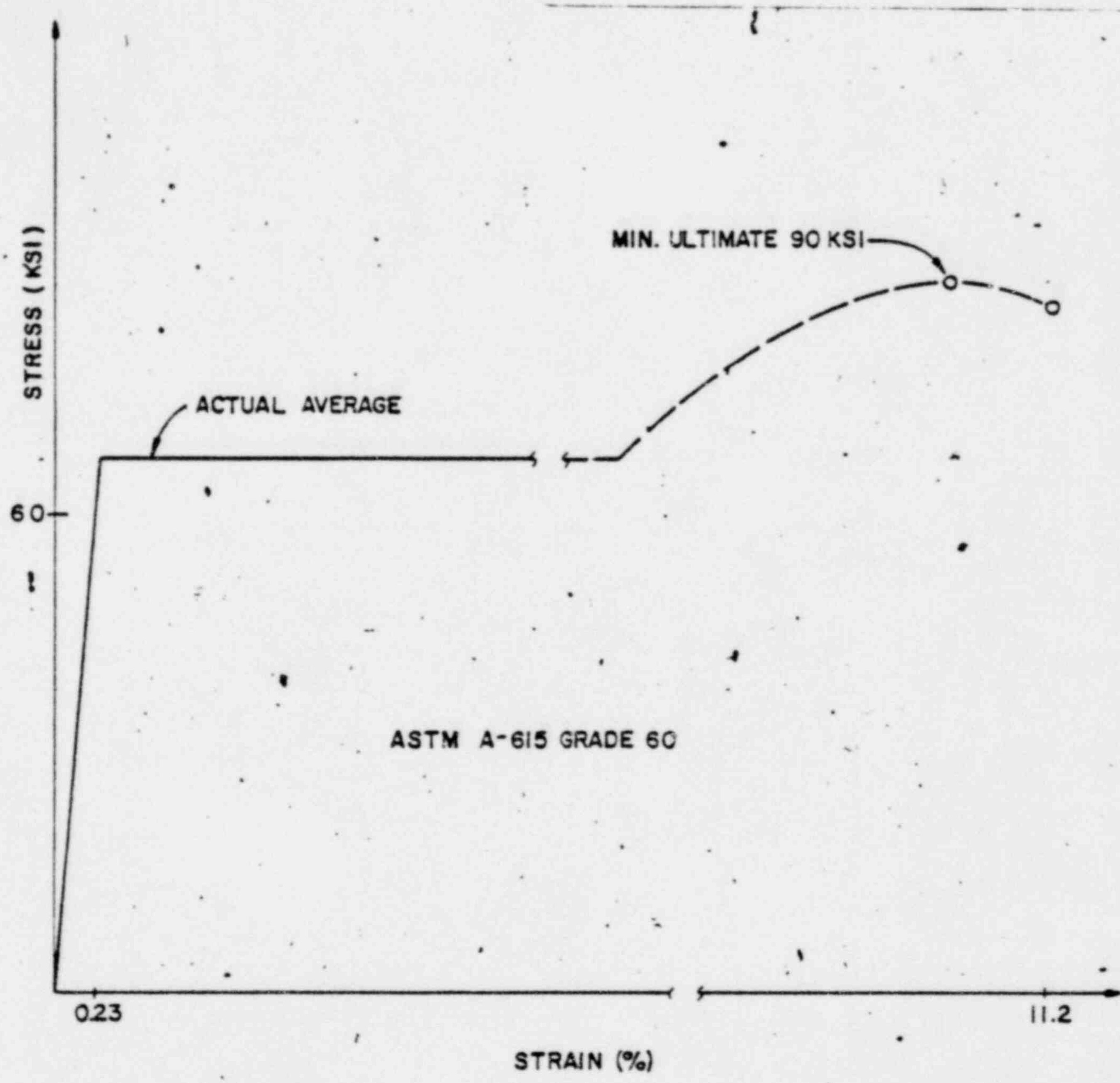
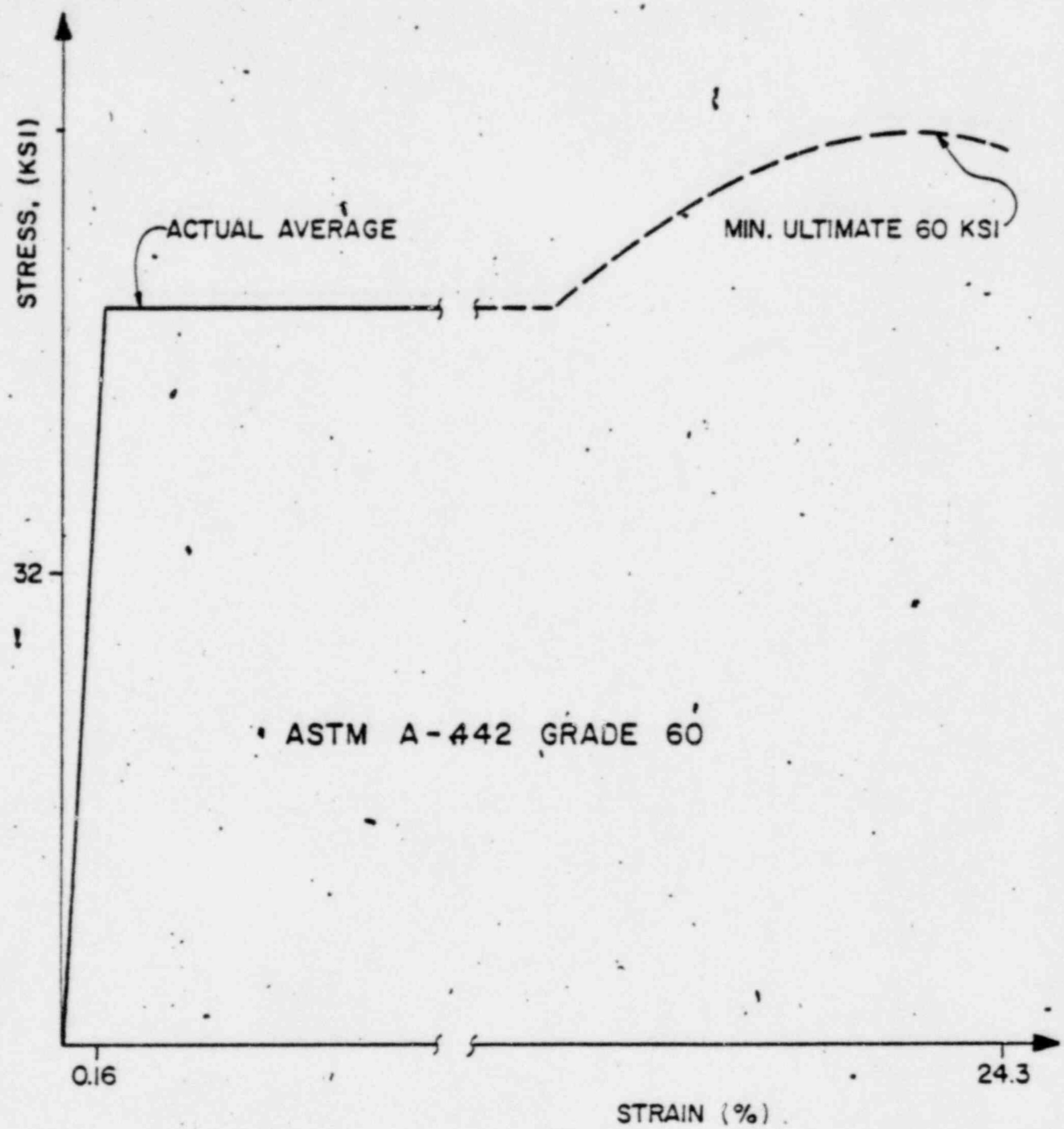
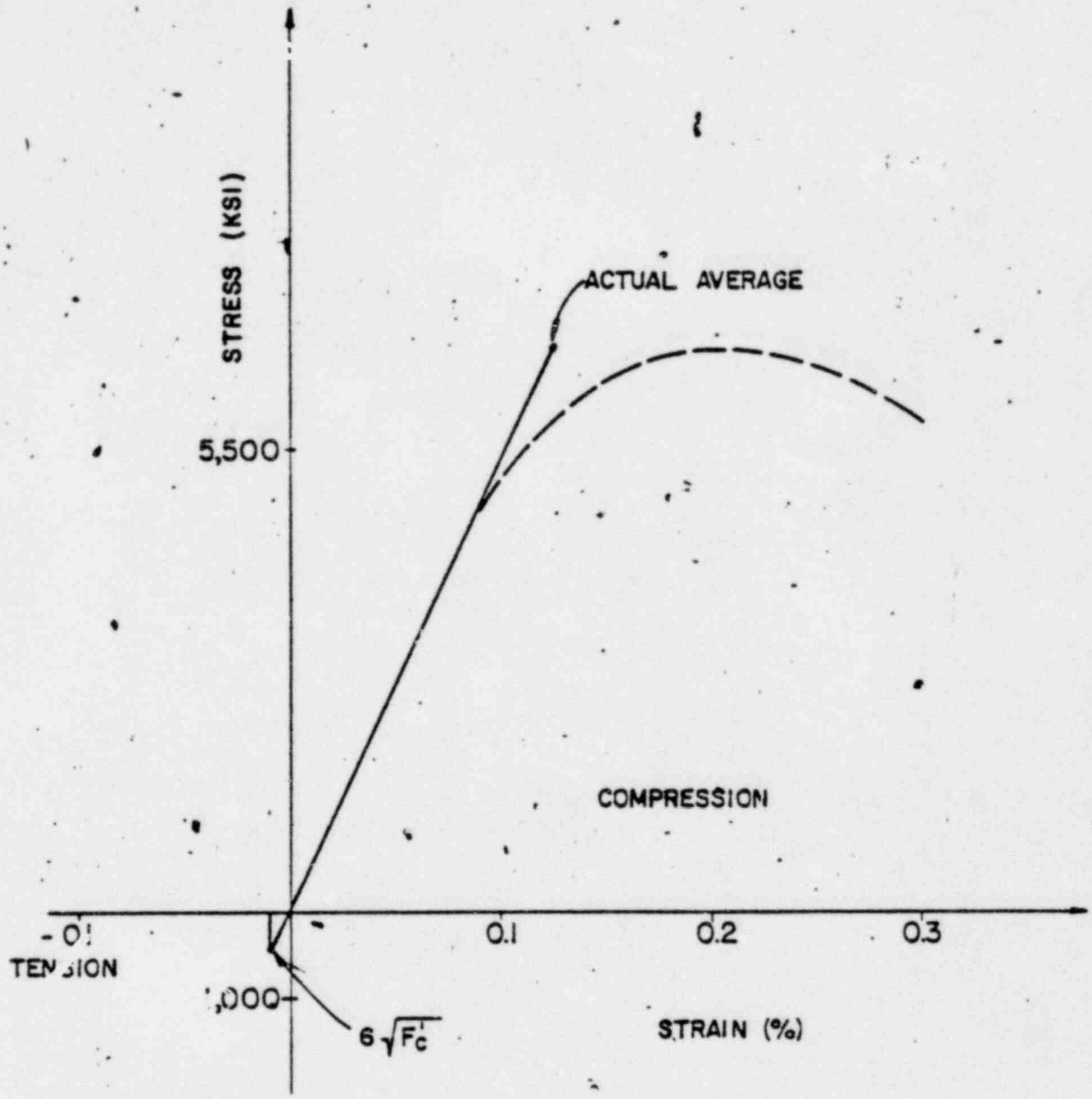


REINFORCEMENT IDEALIZED STRESS-STRAIN CURVE



LINER IDEALIZED STRESS - STRAIN CURVE



CONTAINMENT CONCRETE IDEALIZED STRESS - STRAIN CURVE

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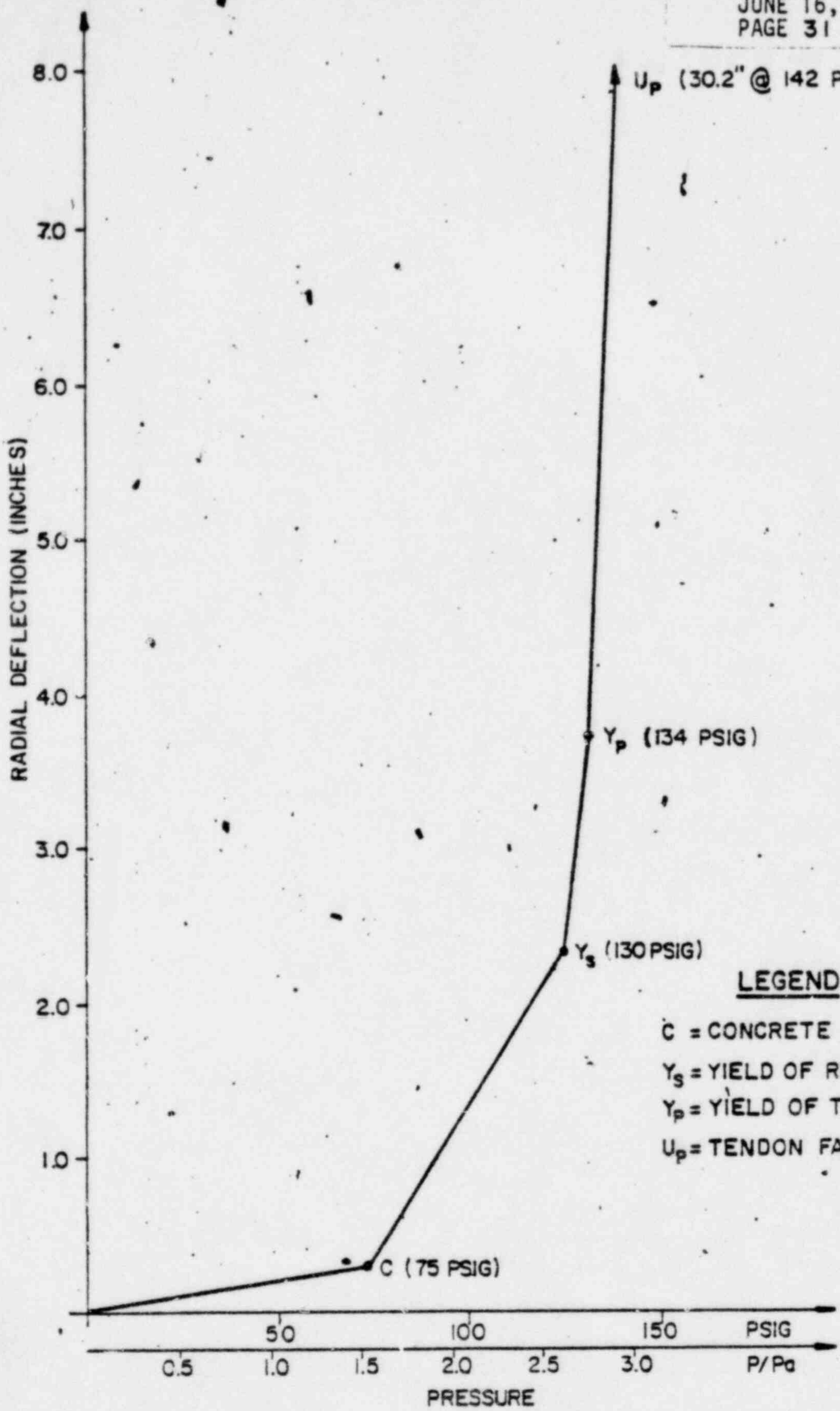
DIRECTION	LINER	CONC. CRACK	REBAR YIELD	TENDON YIELD	TENDON FAIL
HOOP	WITHOUT	75.4 (1.605)	116.2 (2.47)	120.0 (2.55)	128.0 (2.72)
HOOP	WITH	75.4 (1.605)	130.6 (2.778)	134.4 (2.86)	142.4 (3.03)
MERIDIONAL	WITHOUT	83.8 (1.78)	121.9 (2.59)	130.0 (2.765)	137.5 (2.925)
MERIDIONAL	WITH	83.8 (1.78)	150.7 (3.21)	158.8 (3.38)	166.3 (3.54)
DOME	WITHOUT	81.6 (1.73)	119.9 (2.55)	131.5 (2.80)	140.6 (2.99)
DOME	WITH	83.24 (1.77)	141.24 (3.00)	152.84 (3.252)	161.97 (3.446)

( ) = P/P_a P_a = 47 PSIG

PRESSURE AT VARIOUS RESPONSE STAGES (PSIG)

HAND CALCULATIONS: EQUILIBRIUM REQUIREMENTS



RADIAL DEFLECTION OF CONTAINMENT-HAND CALCULATIONS

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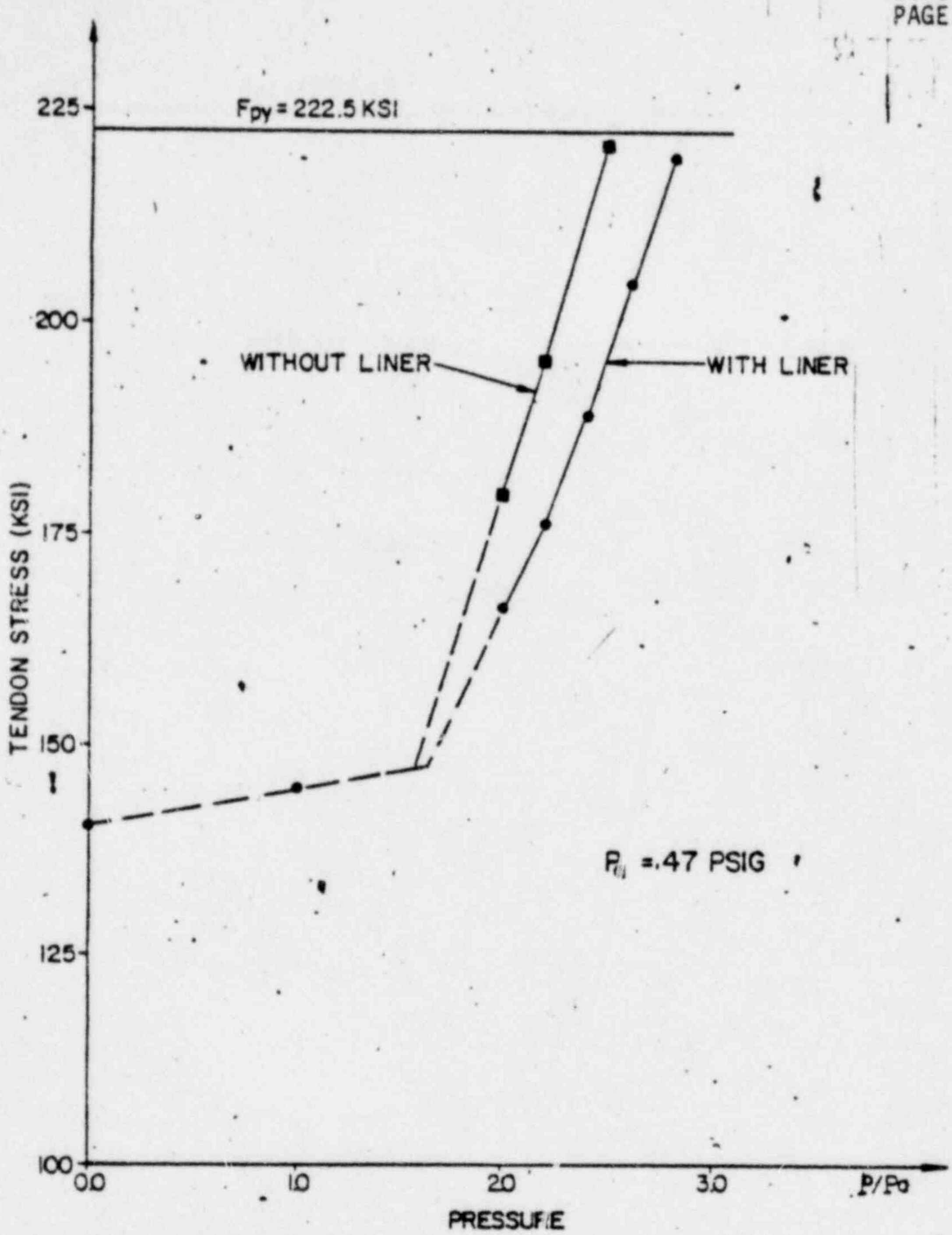

HOOP TENDON STRESSES vs. PRESSURE

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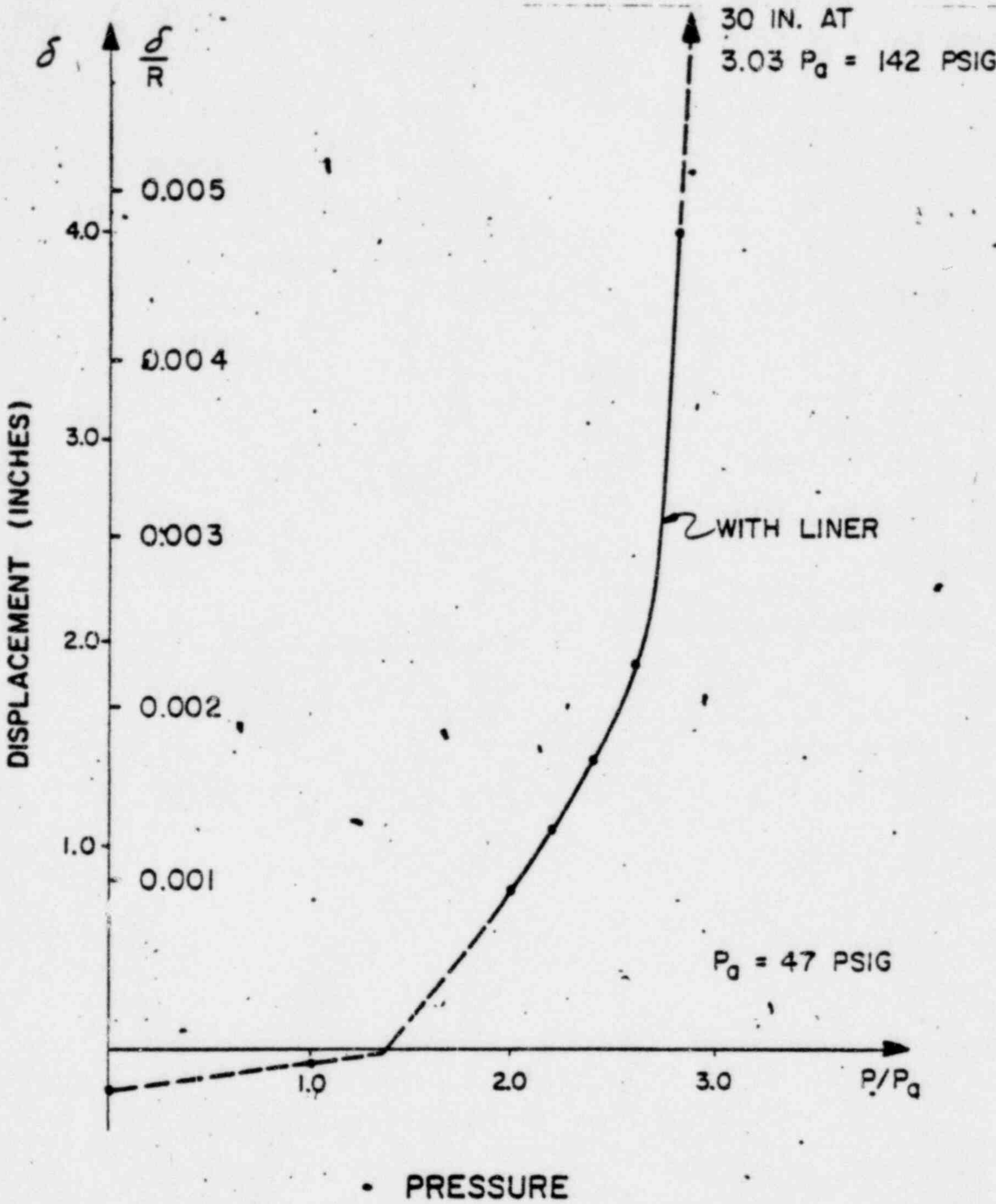

RADIAL DISPLACEMENT OF CYLINDER VS PRESSURE

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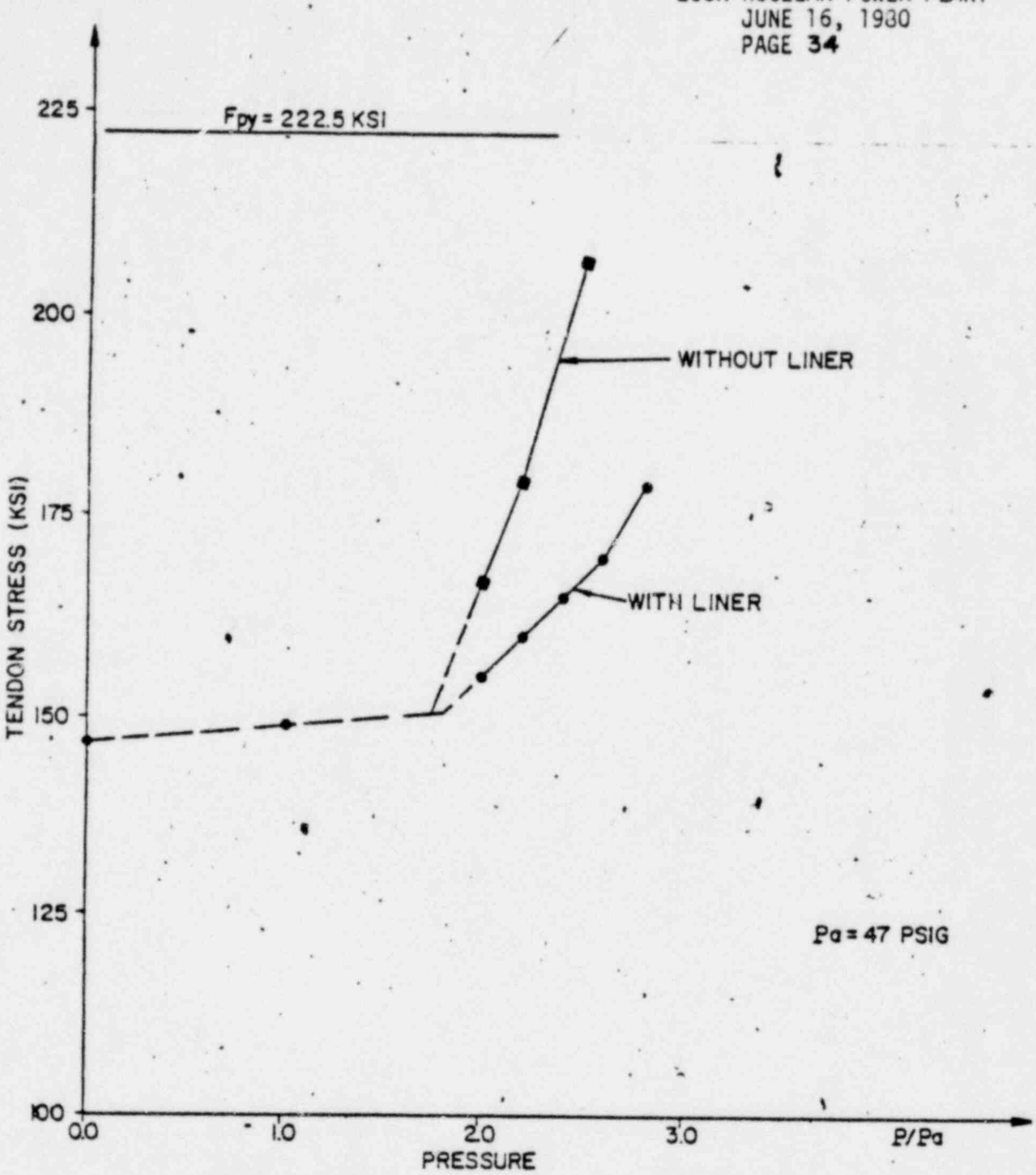

VERTICAL TENDON STRESSES VS. PRESSURE

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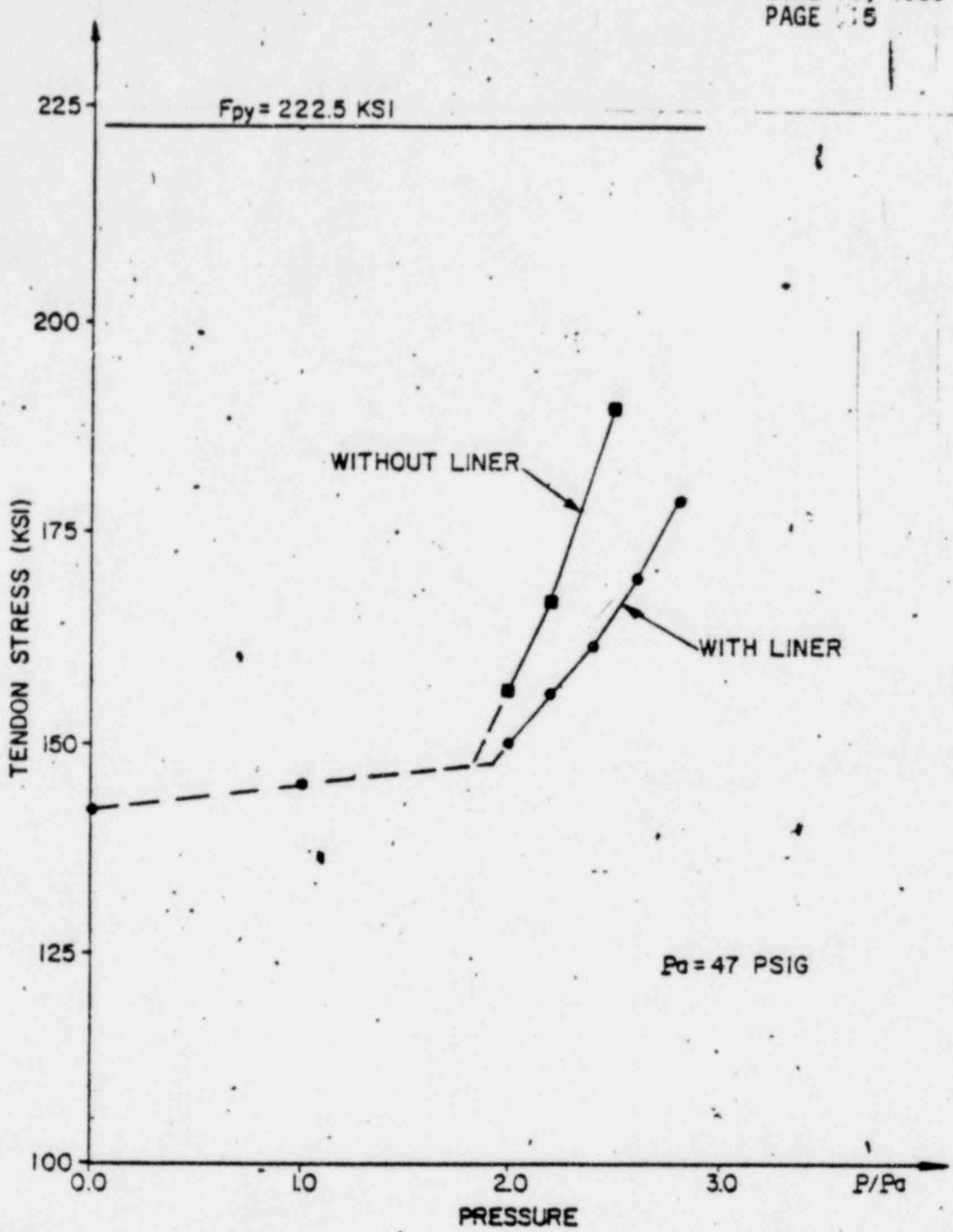

DOME TENDON STRESSES vs. PRESSURE

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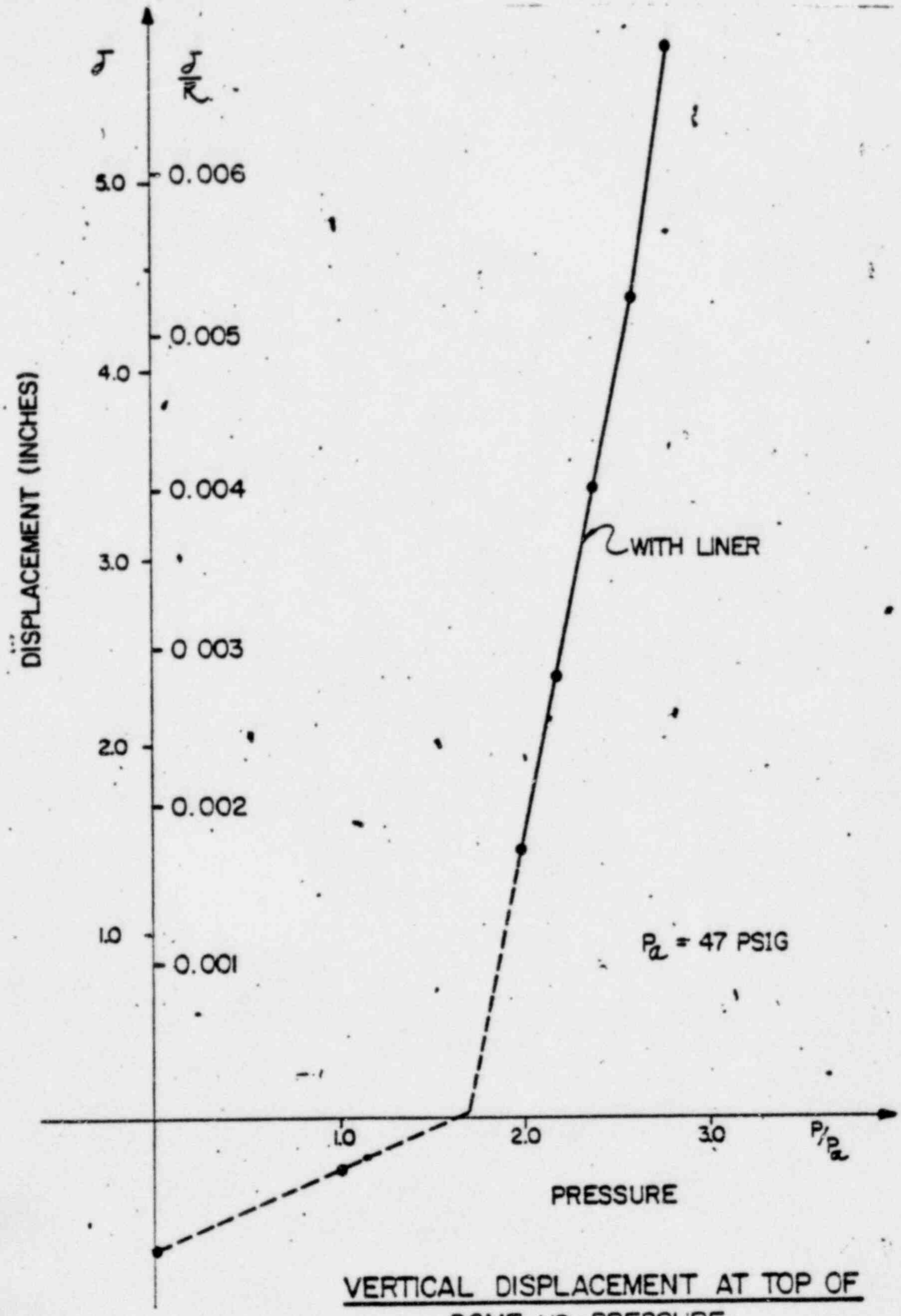

VERTICAL DISPLACEMENT AT TOP OF DOME VS. PRESSURE

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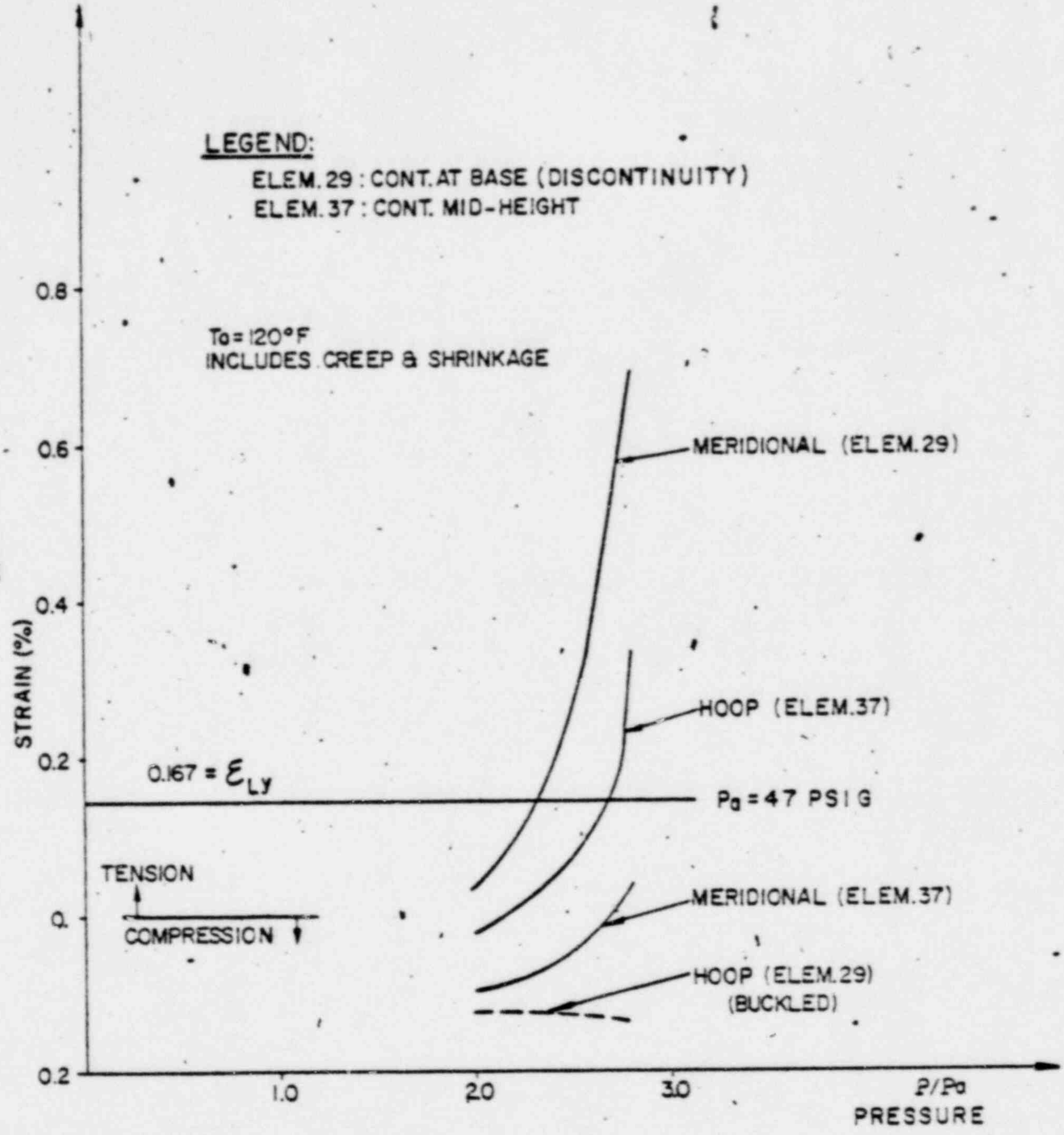

STEEL LINER MEMBRANE STRAINS VS. PRESSURE

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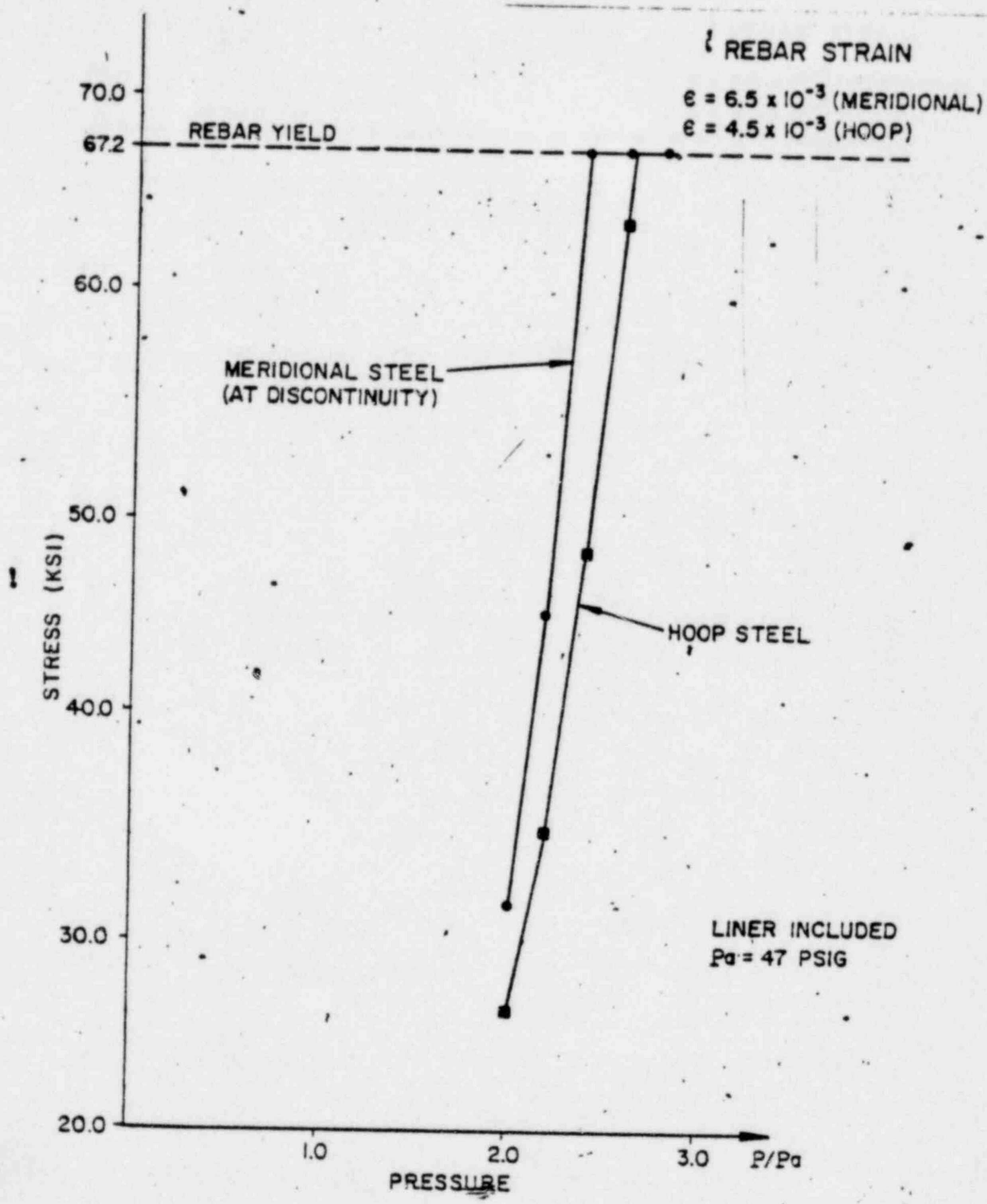

MAXIMUM REBAR STRESSES VS PRESSURE

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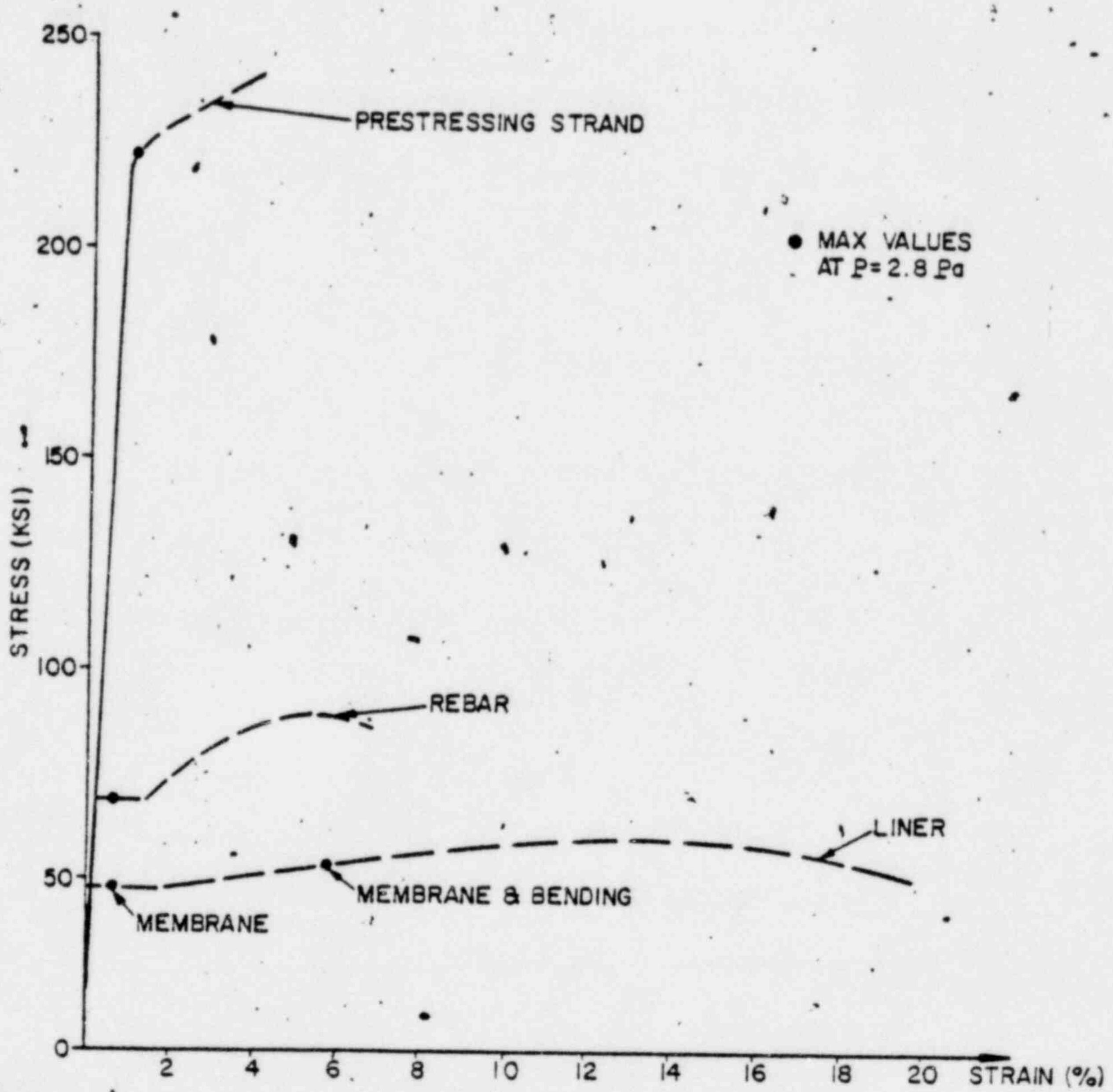

MAXIMUM COMPONENT STRAINS AT P = 2.8 Pa

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AT $P = 2.55 P_a$ = 120 PSIG = 135 PSIA

PARAMETER	MARGIN FACTOR
SHEAR: BASEMAT	1.27
SHEAR: CONTAINMENT	1.28
SHEAR: EQUIPMENT HATCH	1.29
CONCRETE COMPRESSION: BASEMAT	3.85
CONCRETE COMPRESSION: CONTAINMENT	5.83
REINFORCEMENT:	1.32
EQUIPMENT HATCH (CBI)	1.0 (CONSERVATIVE)
SOIL PRESSURE	1.95
LINER FIBER STRAIN	2.10
REBAR STRAIN	4.74

MARGIN FACTORS FOR OTHER NONCRITICAL PARAMETERS

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CONCLUSIONS:

1- ULTIMATE PRESSURE CAPACITY:

120 PSIG = 135 PSIA (WITHOUT LINER)

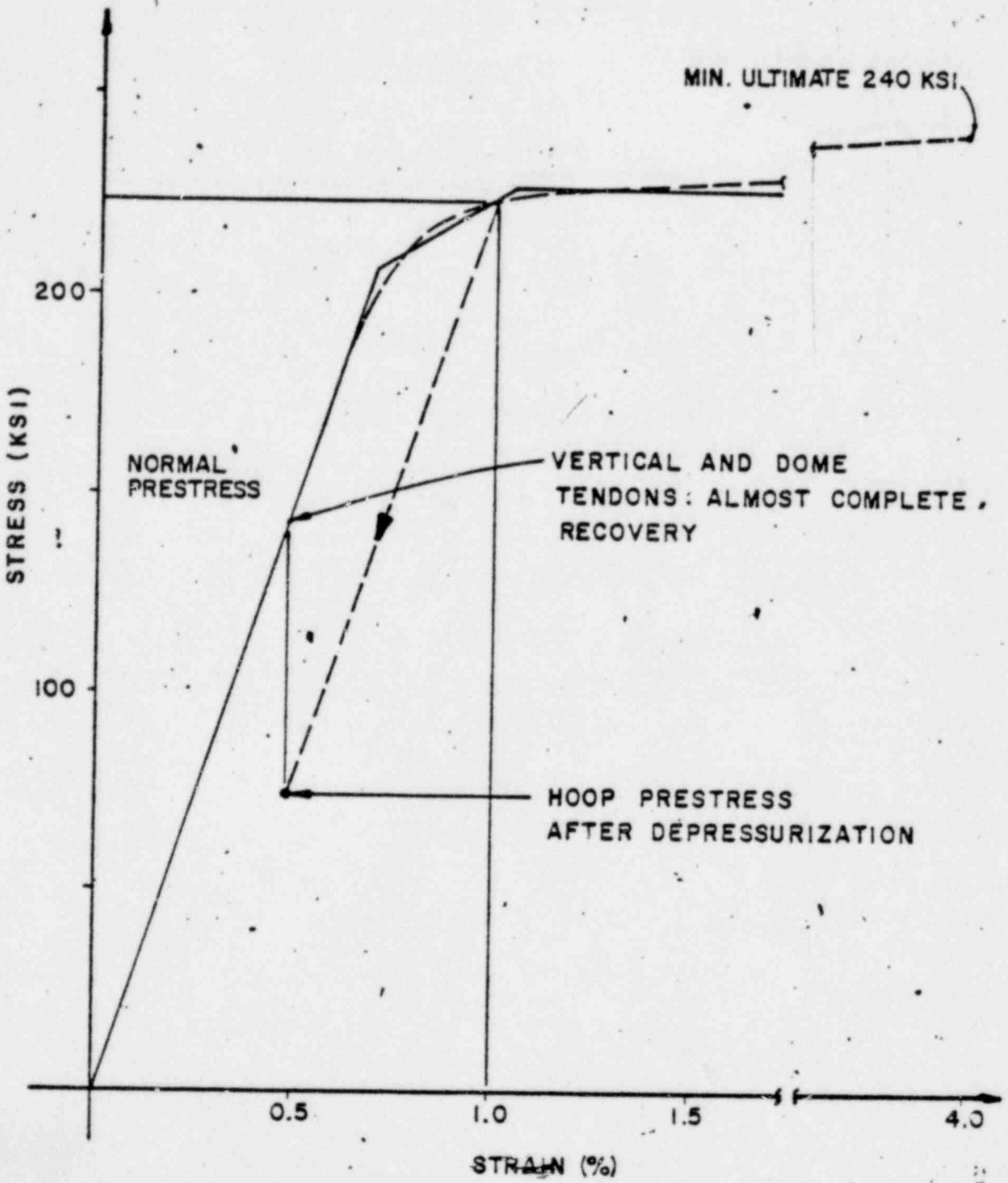
134 PSIG = 149 PSIA (WITH LINER)

2- FAILURE MODE : HOOP TENDON YIELDING

3- TEMPERATURE EFFECTS : PROBABLY NOT SIGNIFICANT

4- POSSIBLE REMEDIES : NONE RECOMMENDED

5- EFFECT OF RATE OF PRESSURE / TEMPERATURE RISE : PROBABLY NOT SIGNIFICANT



TENDON STRESS RECOVERY AFTER DEPRESSURIZATION

EVALUATION OF CAPABILITY OF INDIAN POINT CONTAINMENT VESSELS - UNITS 2& 3

PURPOSE OF EVALUATION - TO MAKE A CONSERVATIVE ASSESSMENT OF THE CAPABILITY OF THE INDIAN POINT CONTAINMENT VESSELS - THE CAPABILITY WAS EVALUATED BASED ON CONDITIONS REPRESENTATIVE OF A CLASS 9 EVENT

- THE EVALUATION WAS PERFORMED ON A REALISTIC BASIS
- ACTUAL MATERIAL PROPERTIES WERE USED
- THE STRENGTH OF THE LINER WAS INCLUDED IN THE EVALUATION

DEFINITION OF CAPABILITY - THE MAXIMUM COMBINATION OF TEMPERATURE AND PRESSURE TO PRODUCE A GENERAL YIELD STATE. (ESSENTIALLY THE LIMIT OF ELASTIC RESPONSE)

THIS IS A CONFIDENT LOWER BOUND OF FUNCTIONAL CAPABILITY WITHOUT ACCOUNTING FOR ADDITIONAL AVAILABLE STRENGTH DUE TO STRAIN HARDENING - THE ACTUAL CAPABILITY IS HIGHER.

CONCLUSIONS - INDIAN POINT UNIT 2 AND 3 CONTAINMENTS CAN WITHSTAND A PRESSURE = 126 PSIG OR 2.7 TIMES THE DESIGN ACCIDENT PRESSURE.

United Engrs & Constrs
6-17-82

EVALUATION OF CAPABILITY OF INDIAN POINT CONTAINMENT VESSELS UNITS 2 & 3

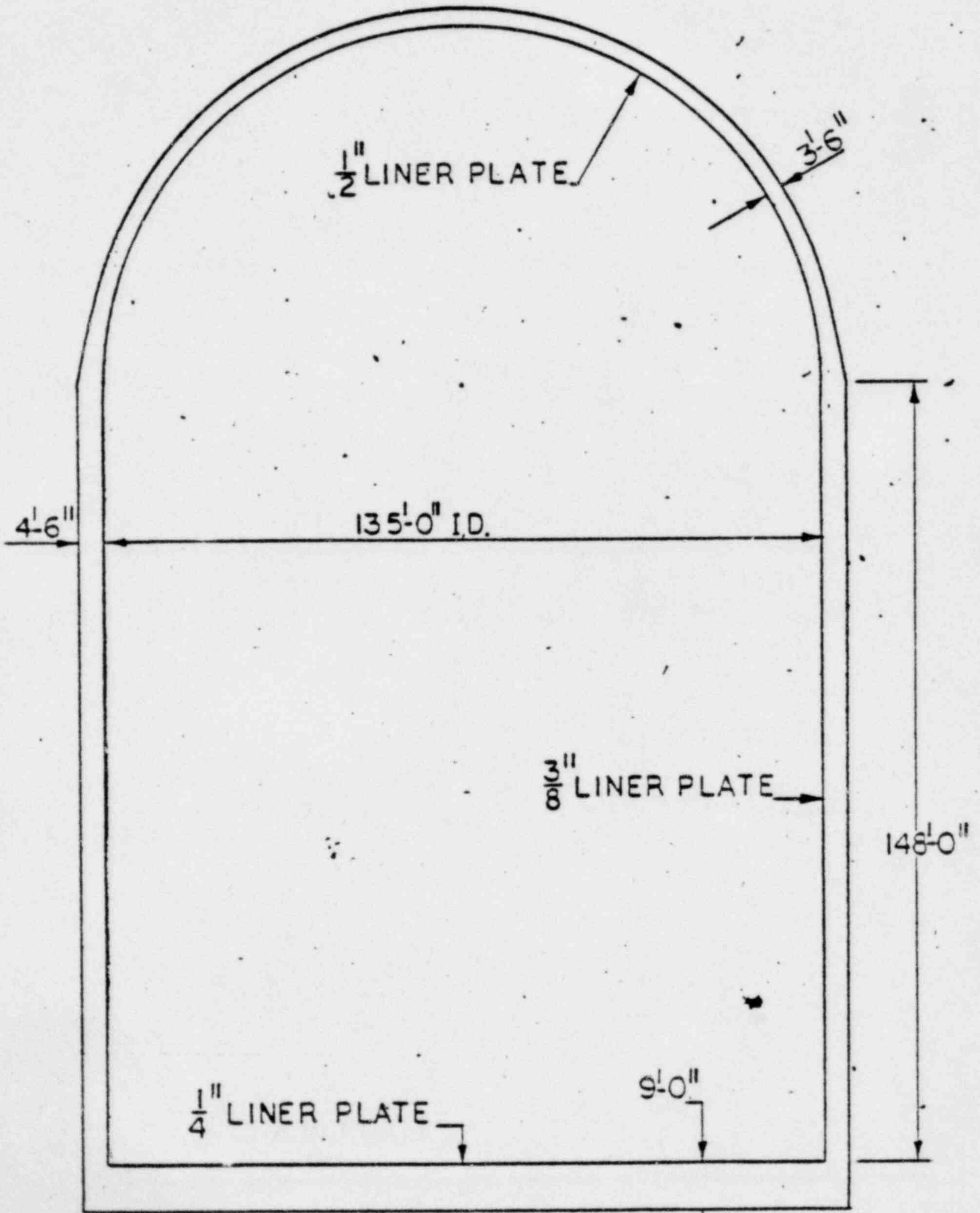
OUTLINE

I. CONTAINMENT DESCRIPTION
   - OVERLAYS
   - SLIDES

II. CONTAINMENT BEHAVIOR UNDER TEMPERATURE AND PRESSURE LOADING

III. STRUCTURAL EVALUATION OF CAPABILITY
   - DEFINITION OF CAPABILITY
   - MATERIAL PROPERTIES
   - LOADING
   - METHOD OF EVALUATION

IV. RESULTS
   - PRESSURE - TEMPERATURE - DISPLACEMENTS PLOTS
   - MAXIMUM PRESSURE



INDIAN POINT CONTAINMENT BUILDING

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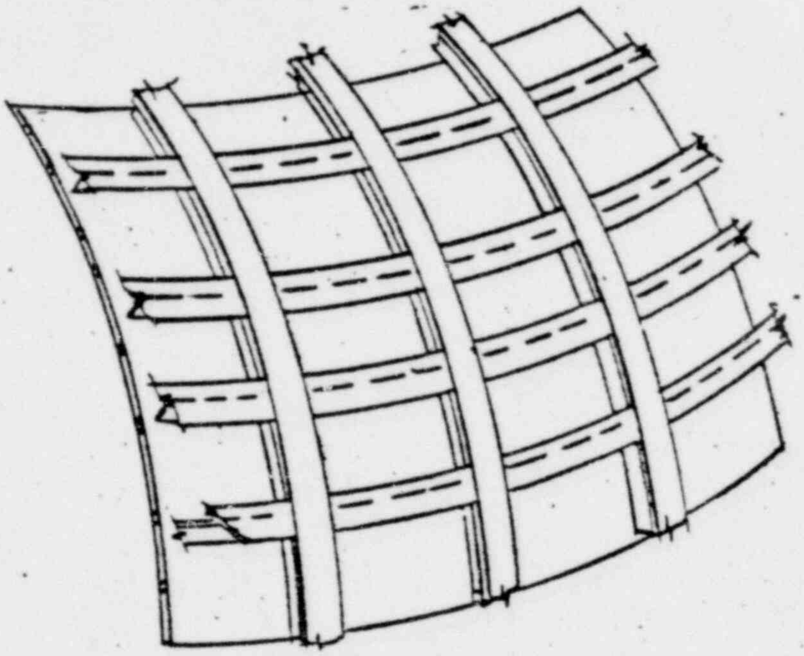
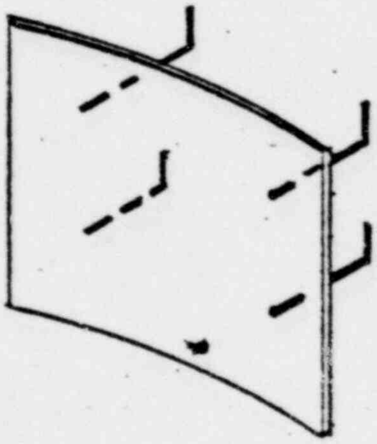
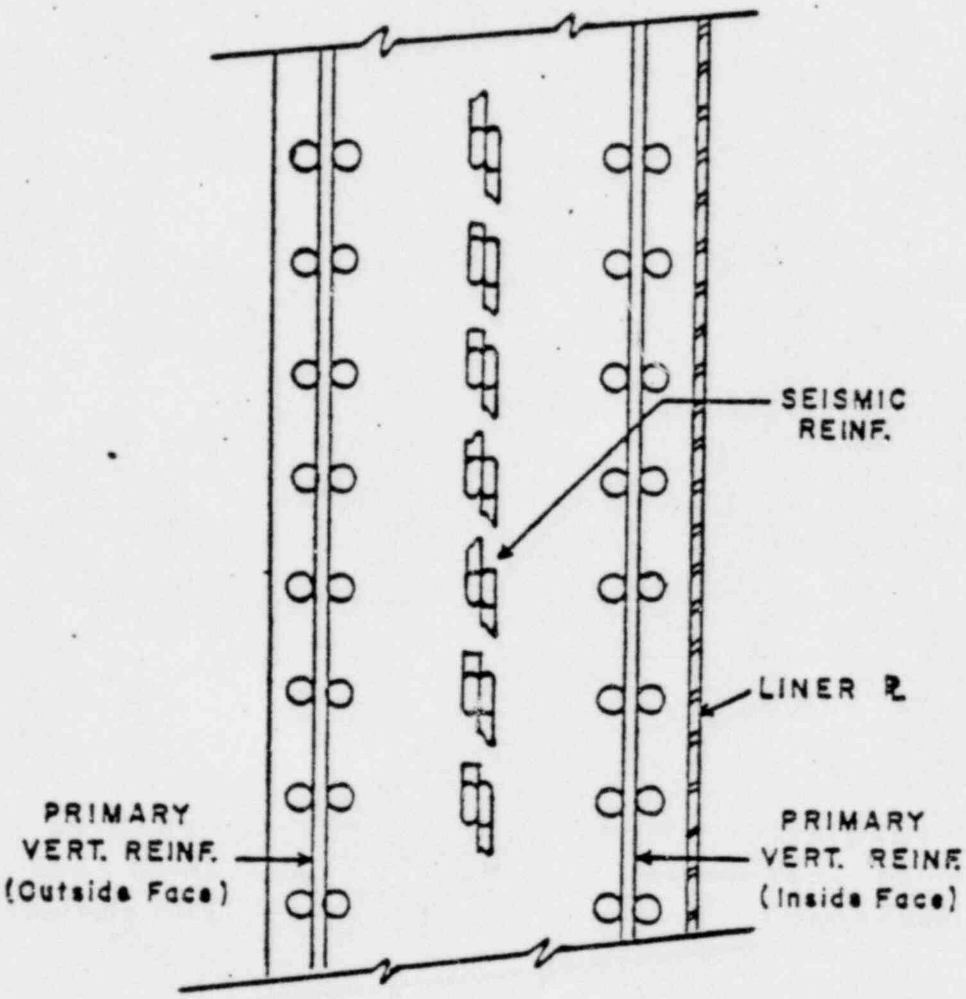


ATTACHMENT TO DOME

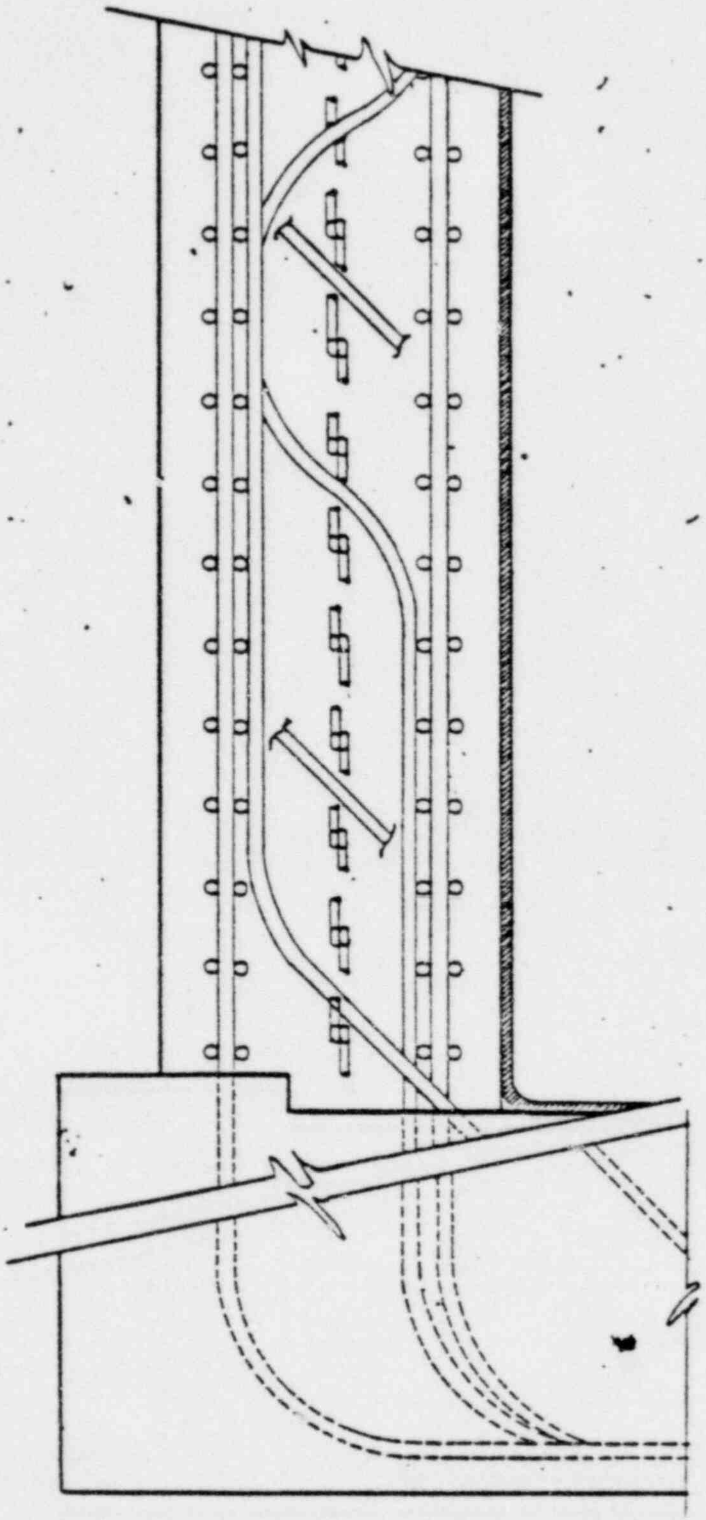


ATTACHMENT TO CYLINDER

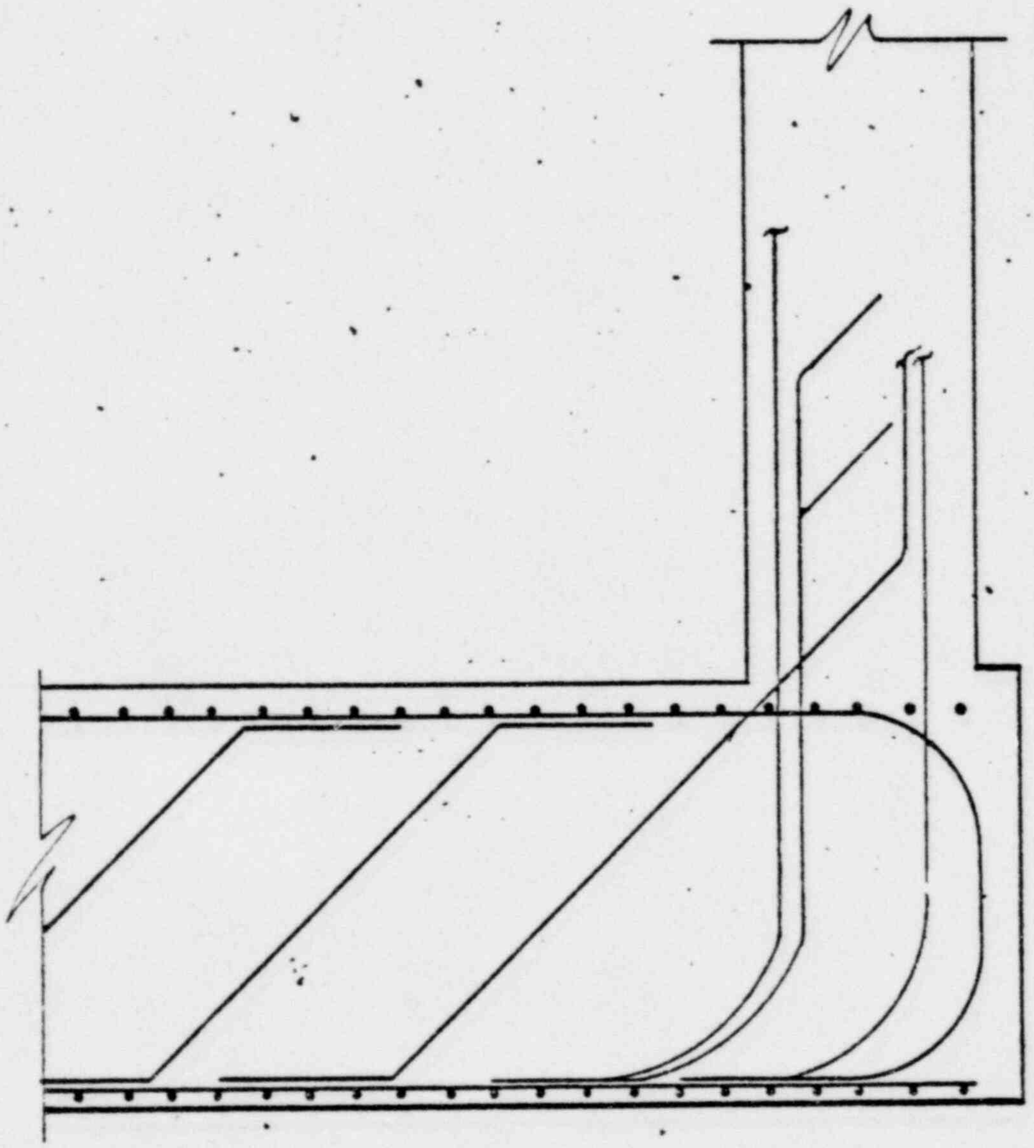
ATTACHMENT OF LINER TO CONCRETE



SECTION OF CYLINDRICAL SHELL
I.P. UNIT 2

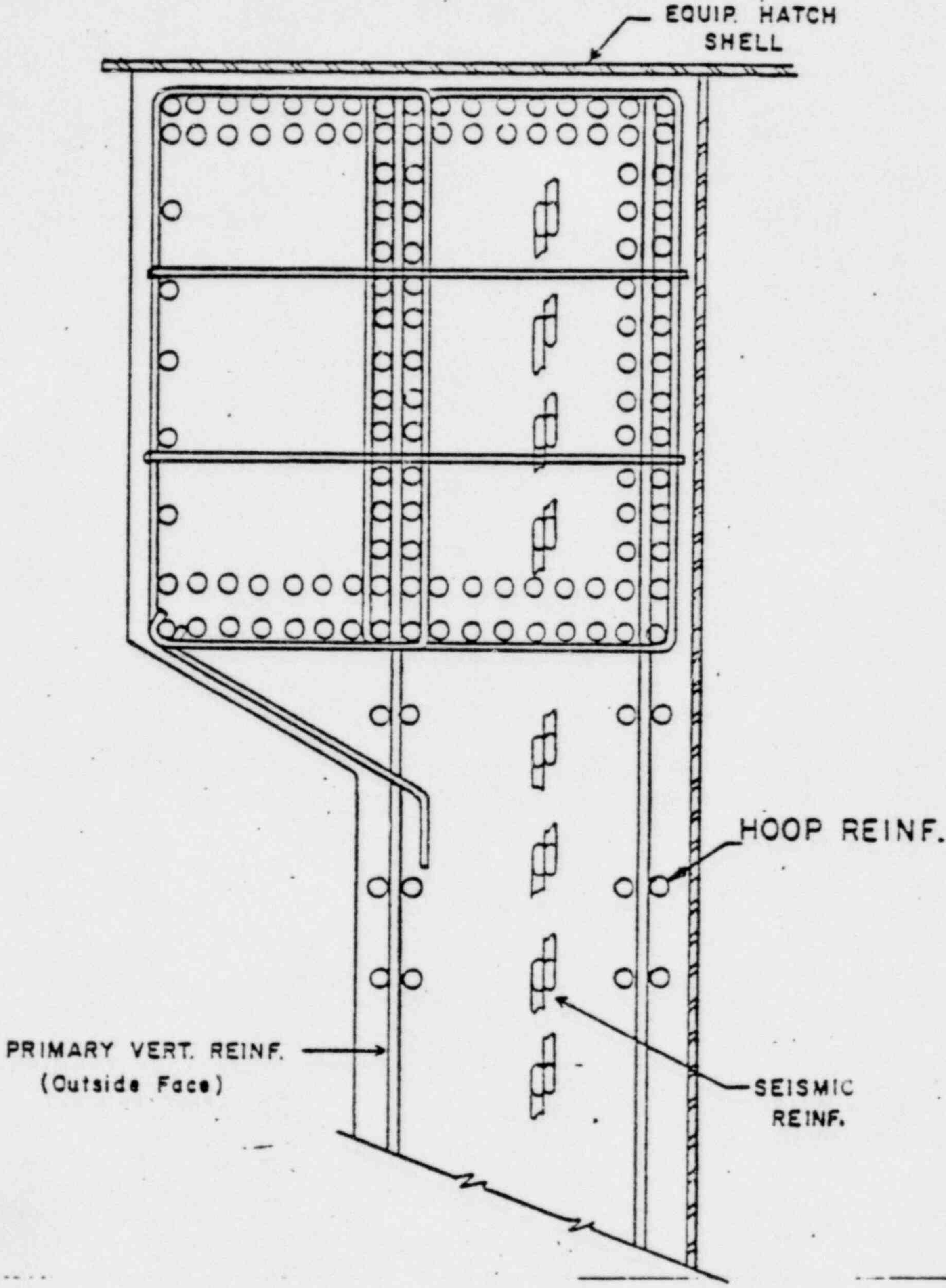


DISCONTINUITY REGION AT
BASE OF CONTAINMENT SHELL

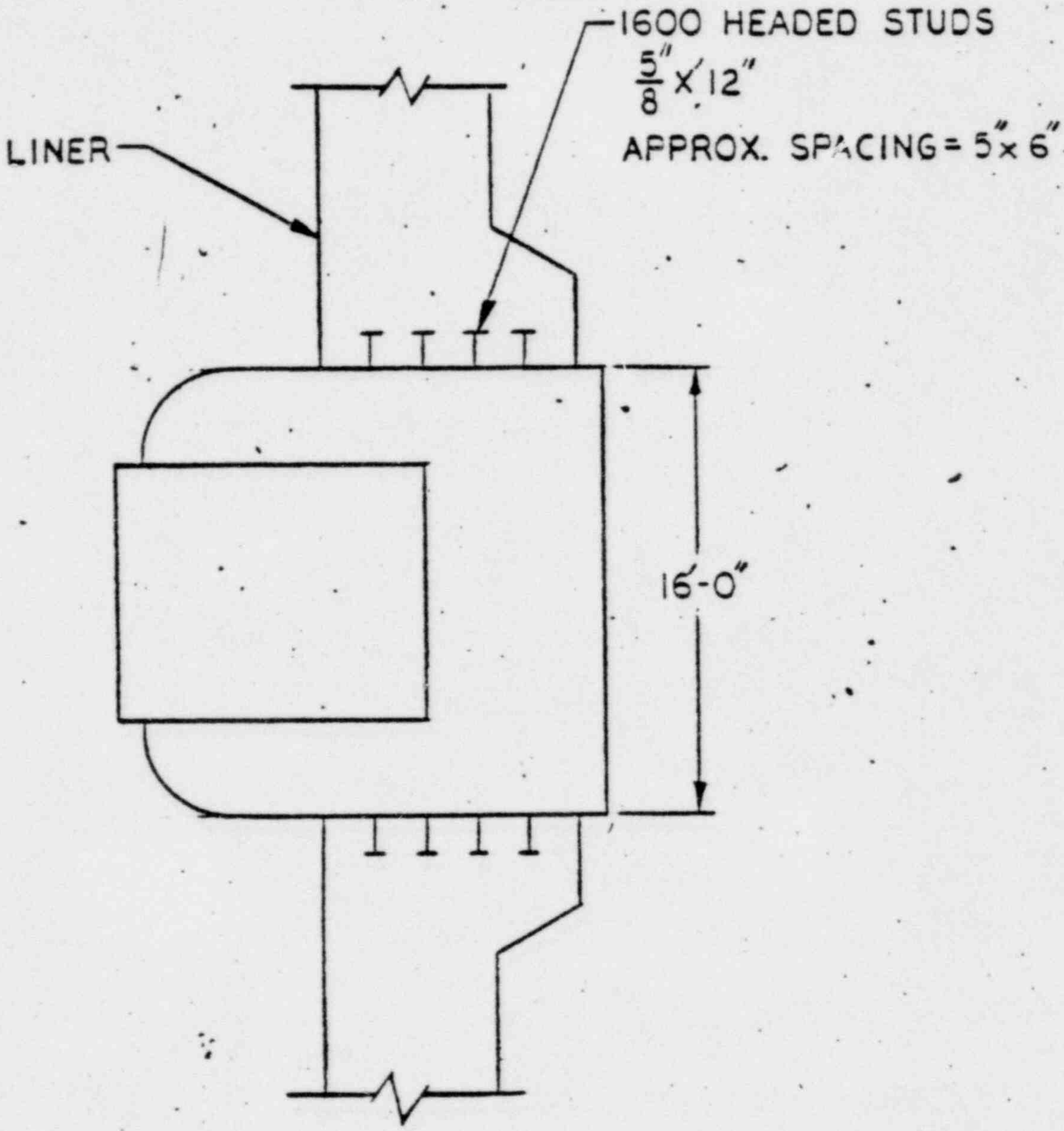


SECTION THROUGH MAT BELOW

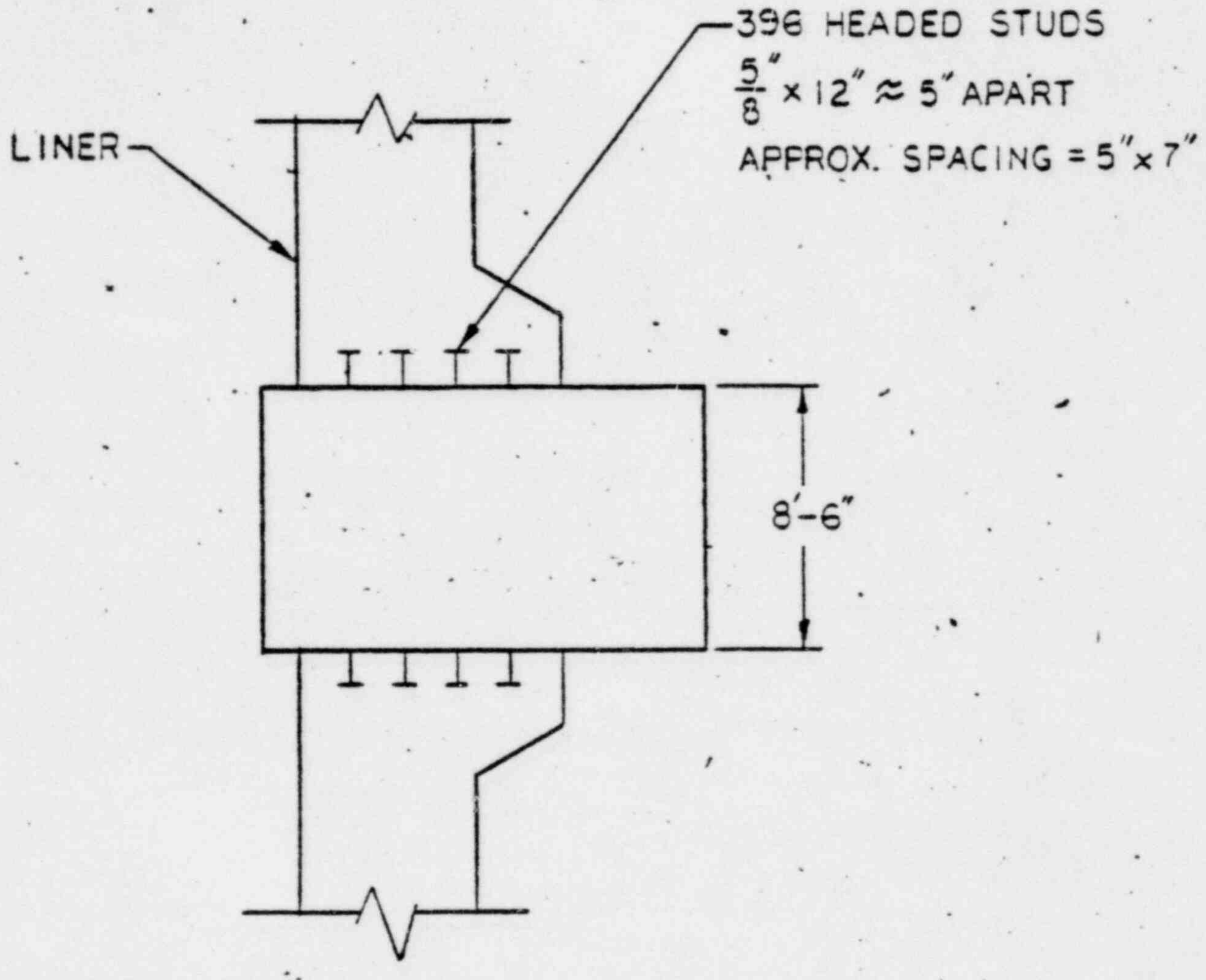
CONTAINMENT WALL



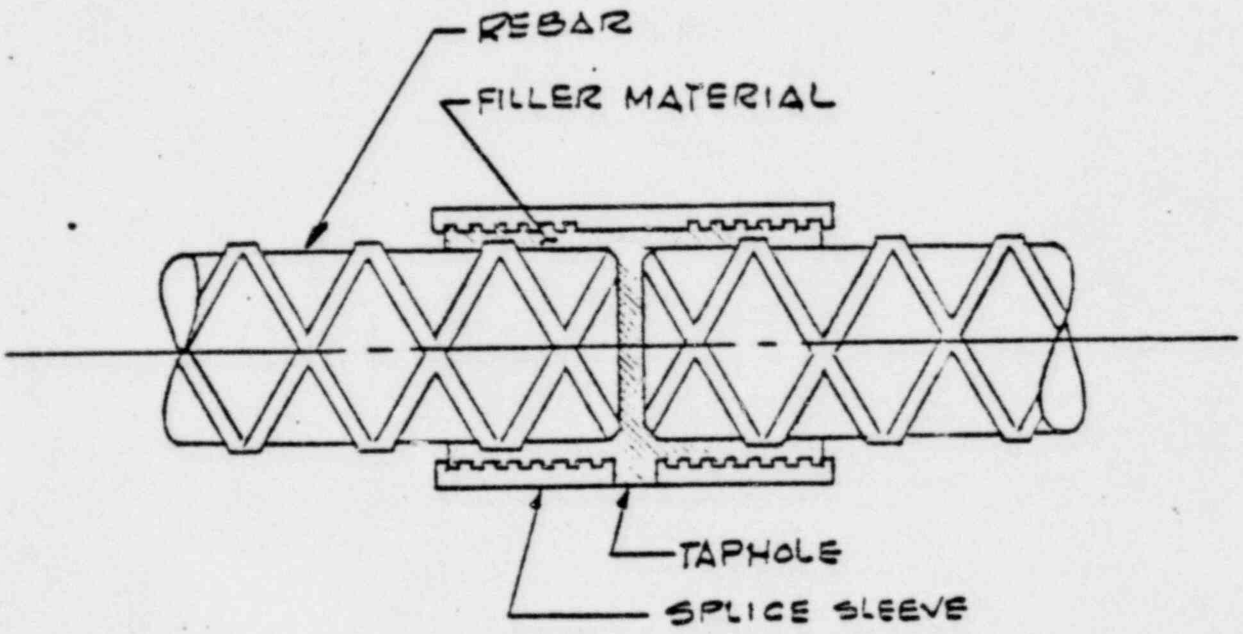
SECTION THROUGH DISCONTINUITY REGION AROUND EQUIPMENT HATCH



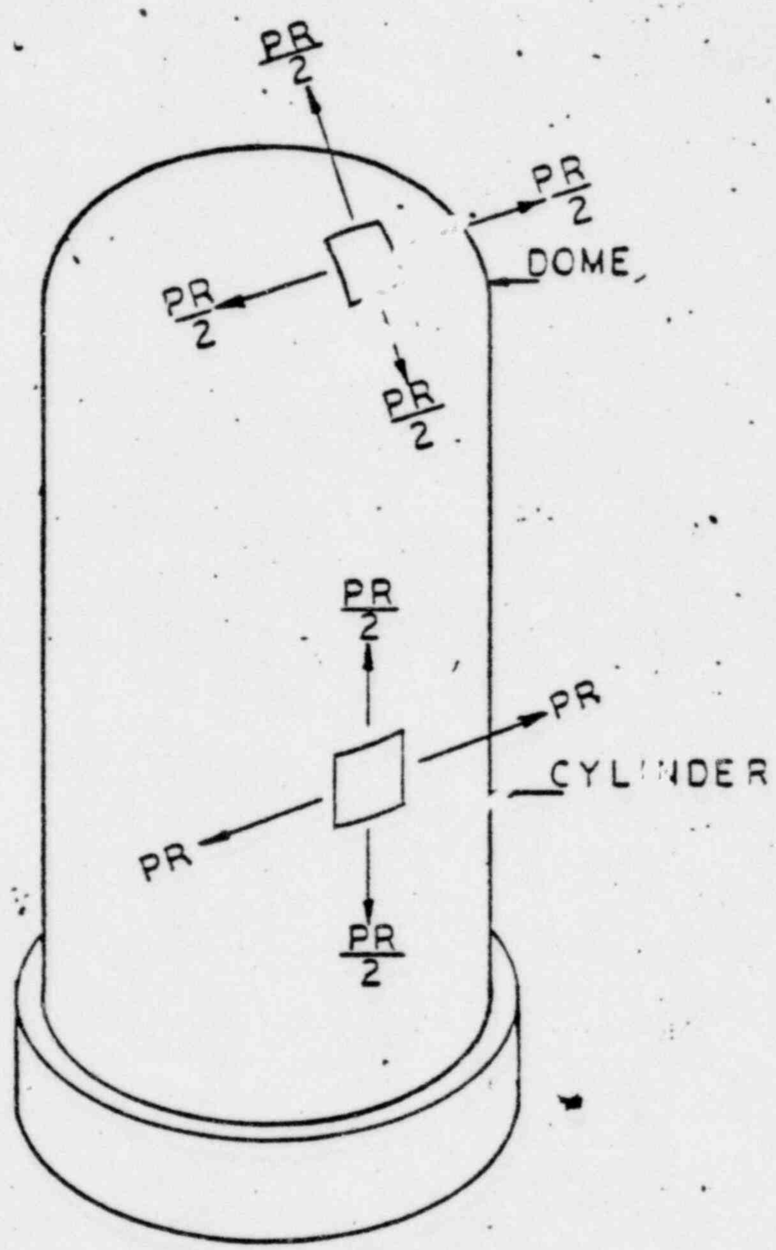
SKETCH OF EQUIPMENT HATCH



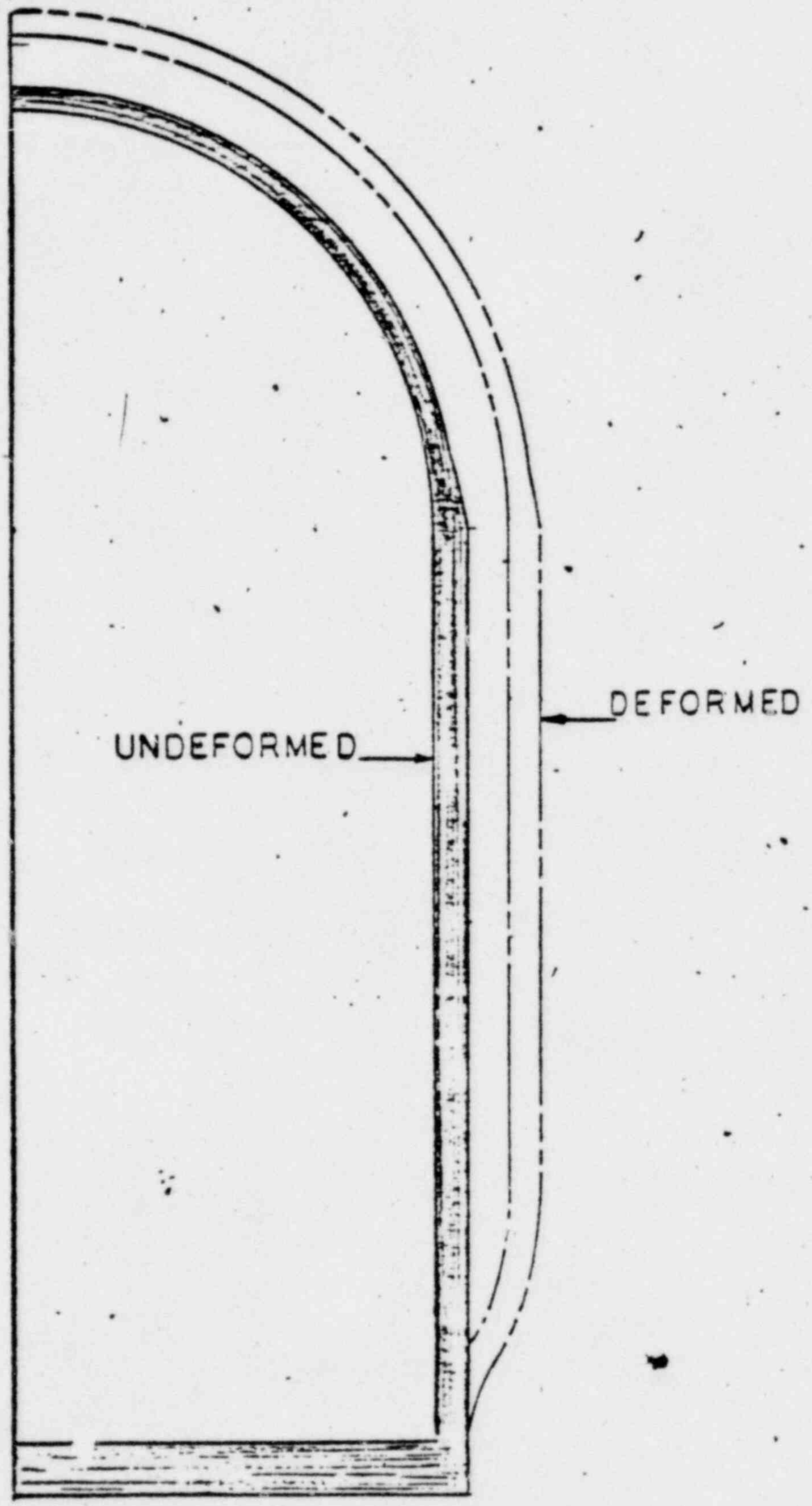
SKETCH OF PERSONNEL AIRLOCK



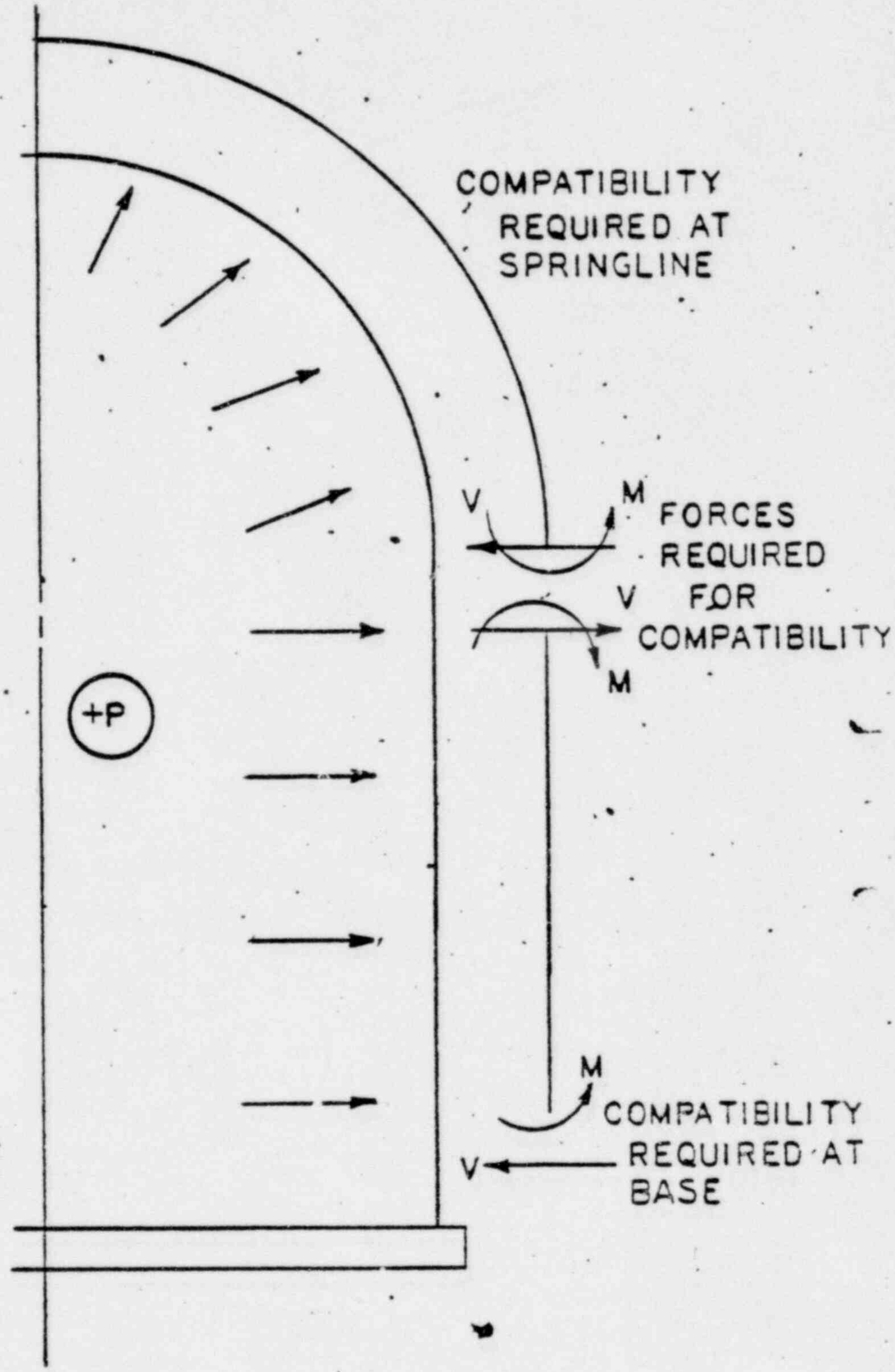
TYPICAL CADWELD SPLICE



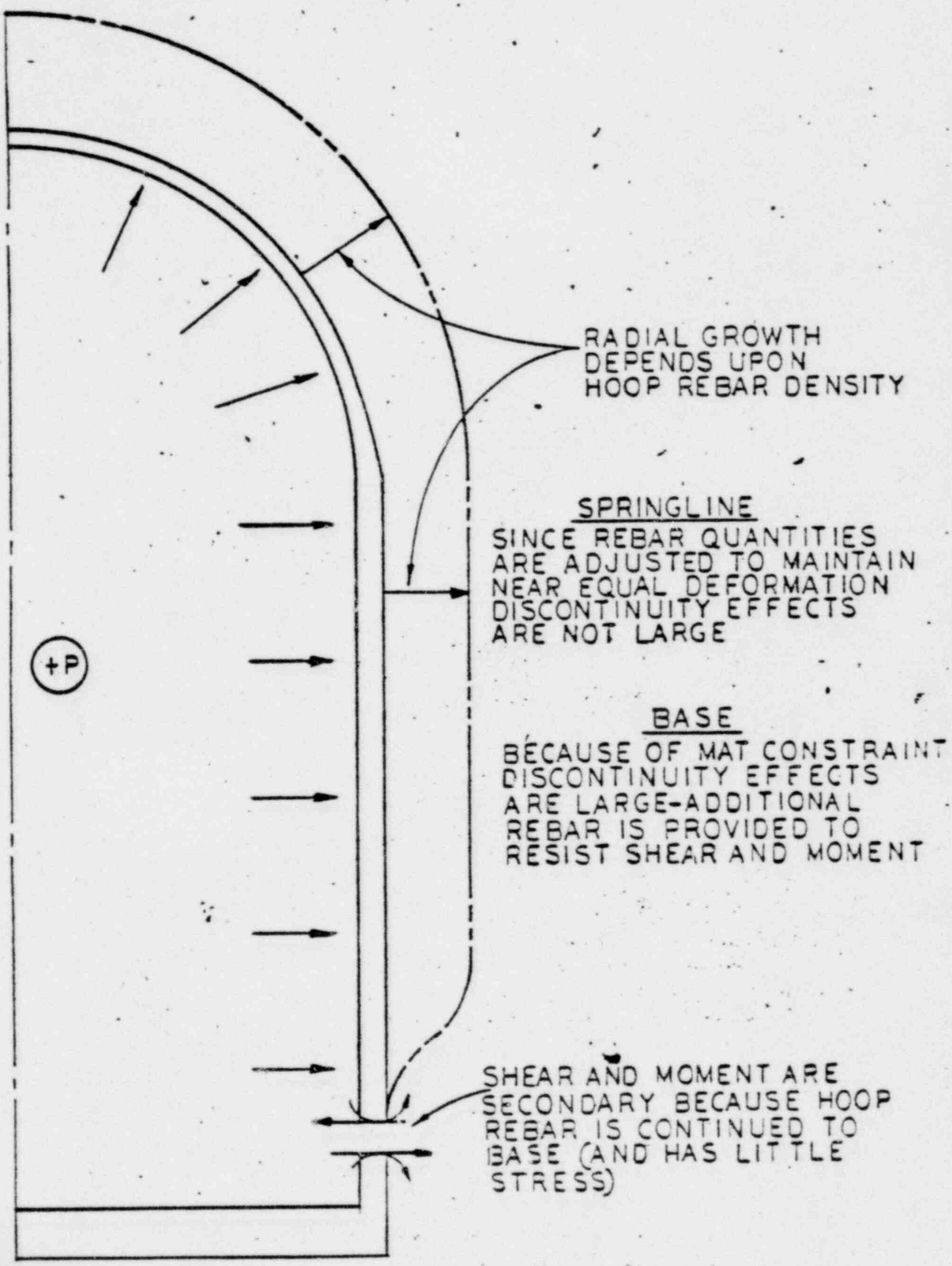
MEMBRANE FORCES IN CONTAINMENT
DUE TO PRESSURE



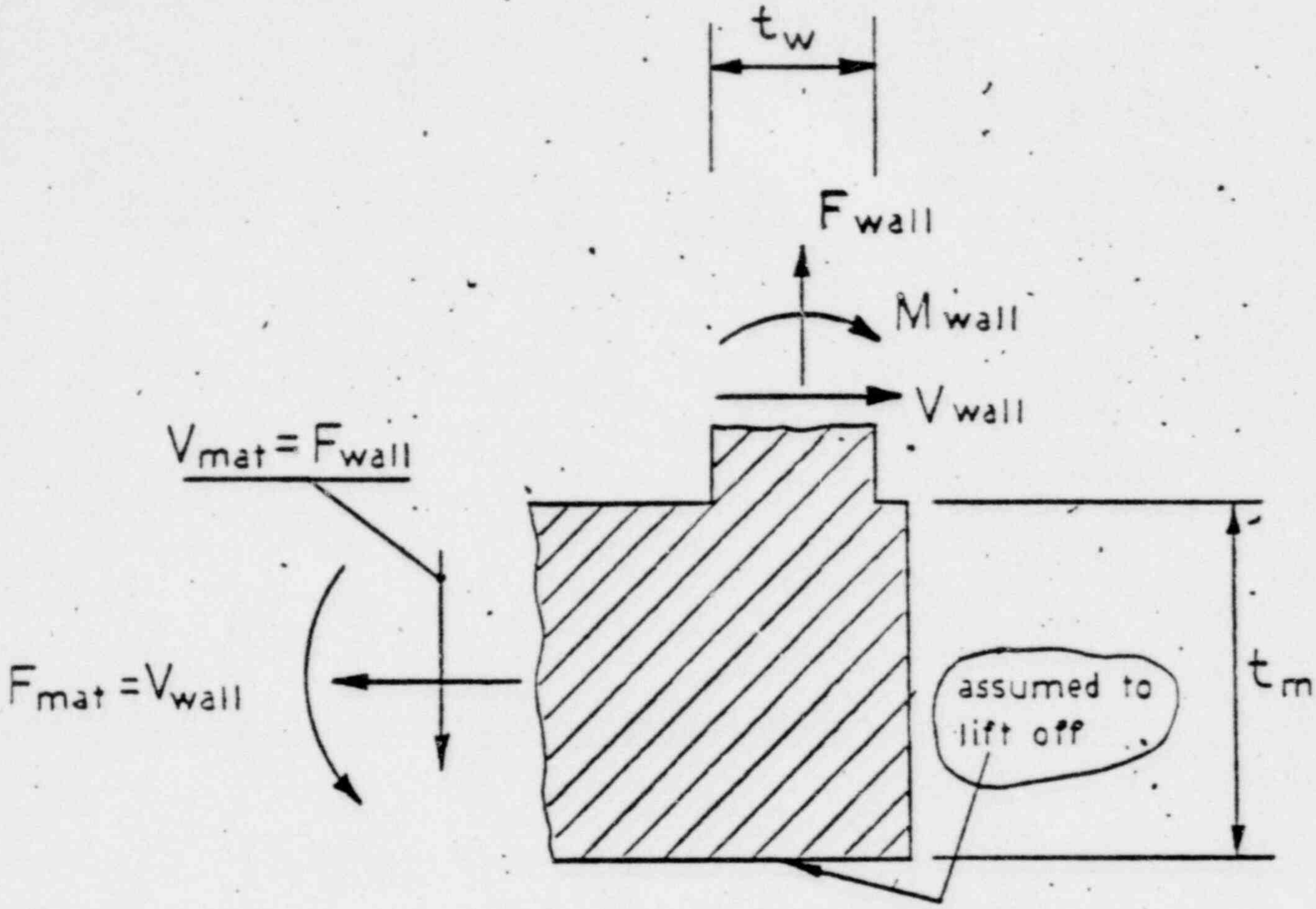
SKETCH OF DEFORMED SHAPE UNDER TEMPERATURE AND PRESSURE LOADING



DEFORMED SHAPE OF CONTAINMENT BEFORE IMPOSITION OF COMPATIBILITY



DEFORMED SHAPE OF CONTAINMENT AFTER IMPOSITION OF COMPATIBILITY (EXAGGERATED)



$$M_{mat} = M_{wall} + V_{wall}\,\frac{t_m}{2} - F_{wall}\,\frac{t_w}{2}$$

DISCONTINUITY REGION SHOWING MAT FORCES

III STRUCTURAL EVALUATION OF CAPABILITY

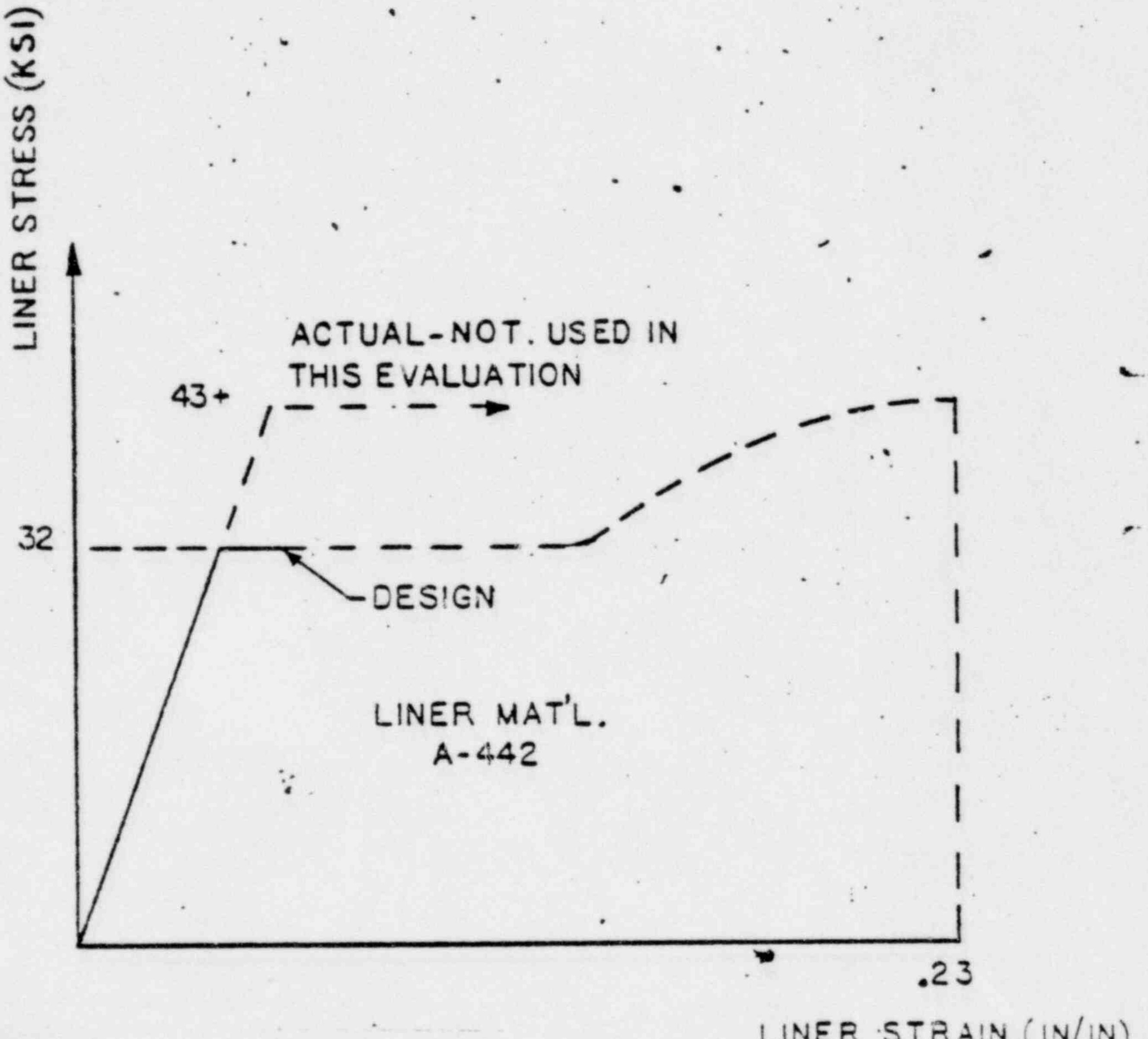
DEFINITION - CAPABILITY IS DEFINED AS THE MAXIMUM COMBINATION OF TEMPERATURE AND PRESSURE TO PRODUCE A GENERAL YIELD STATE. (THIS IS ESSENTIALLY THE LIMIT OF ELASTIC RESPONSE).

THIS IS A CONFIDENT LOWER BOUND OF FUNCTIONAL CAPABILITY WITHOUT ACCOUNTING FOR ADDITIONAL AVAILABLE STRENGTH DUE TO STRAIN HARDENING.

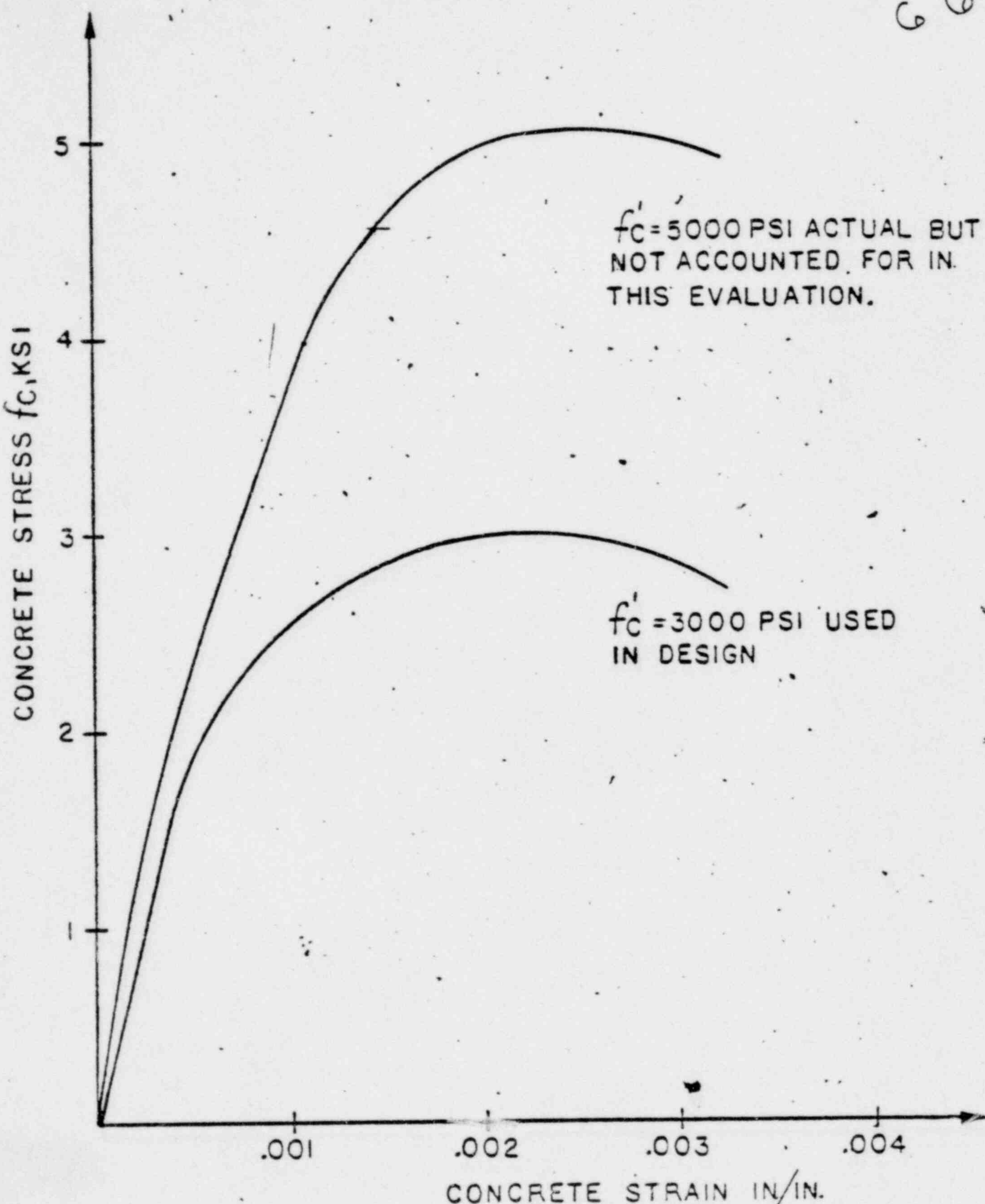
THE ACTUAL CAPABILITY IS HIGHER

MATERIALS

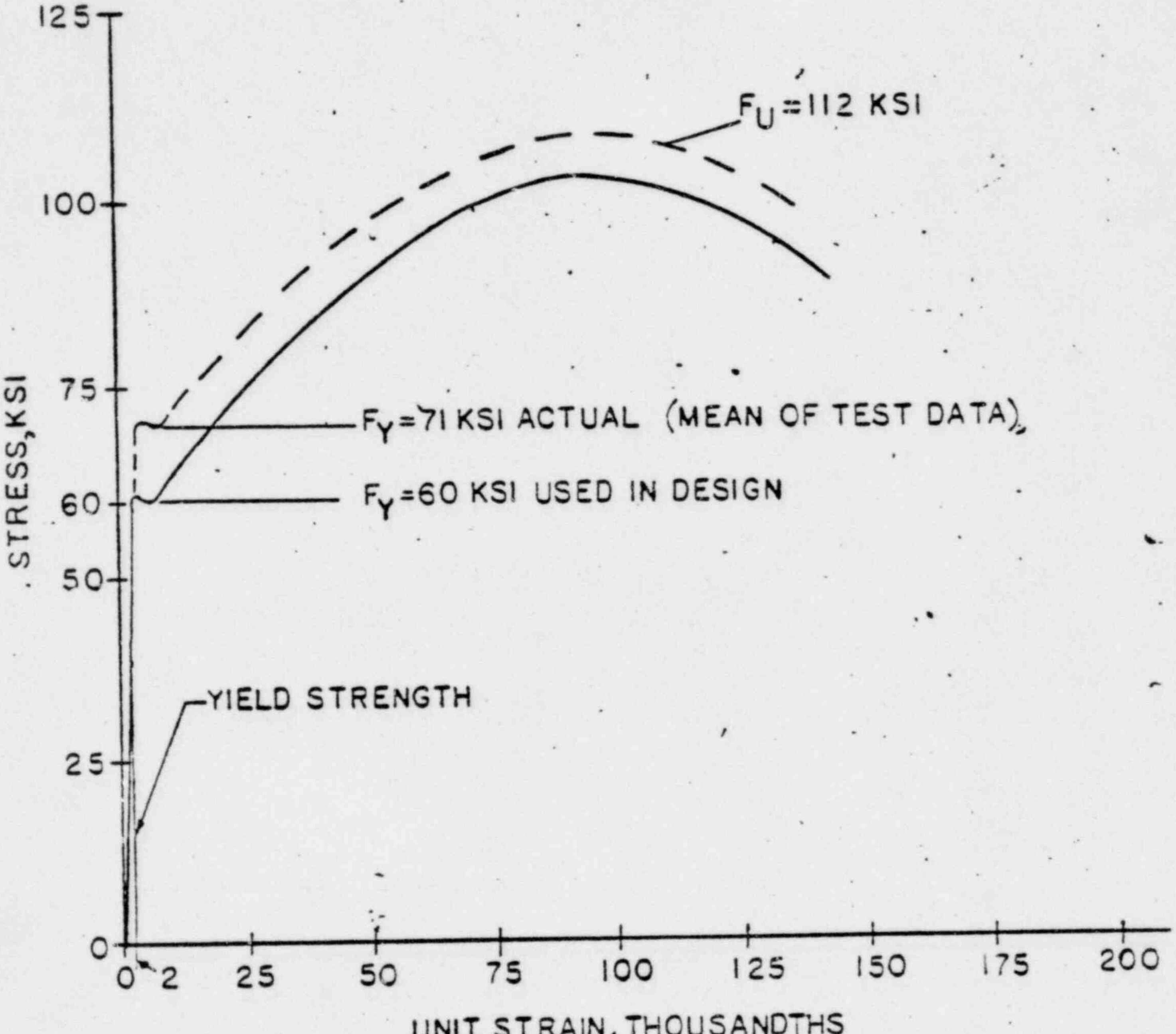
CONCRETE	F'_C = 3000 PSI	
LINER STEEL	A-442	F_Y = 32000 PSI
REINFORCING STEEL	A-615-60	F_Y = 60000 PSI



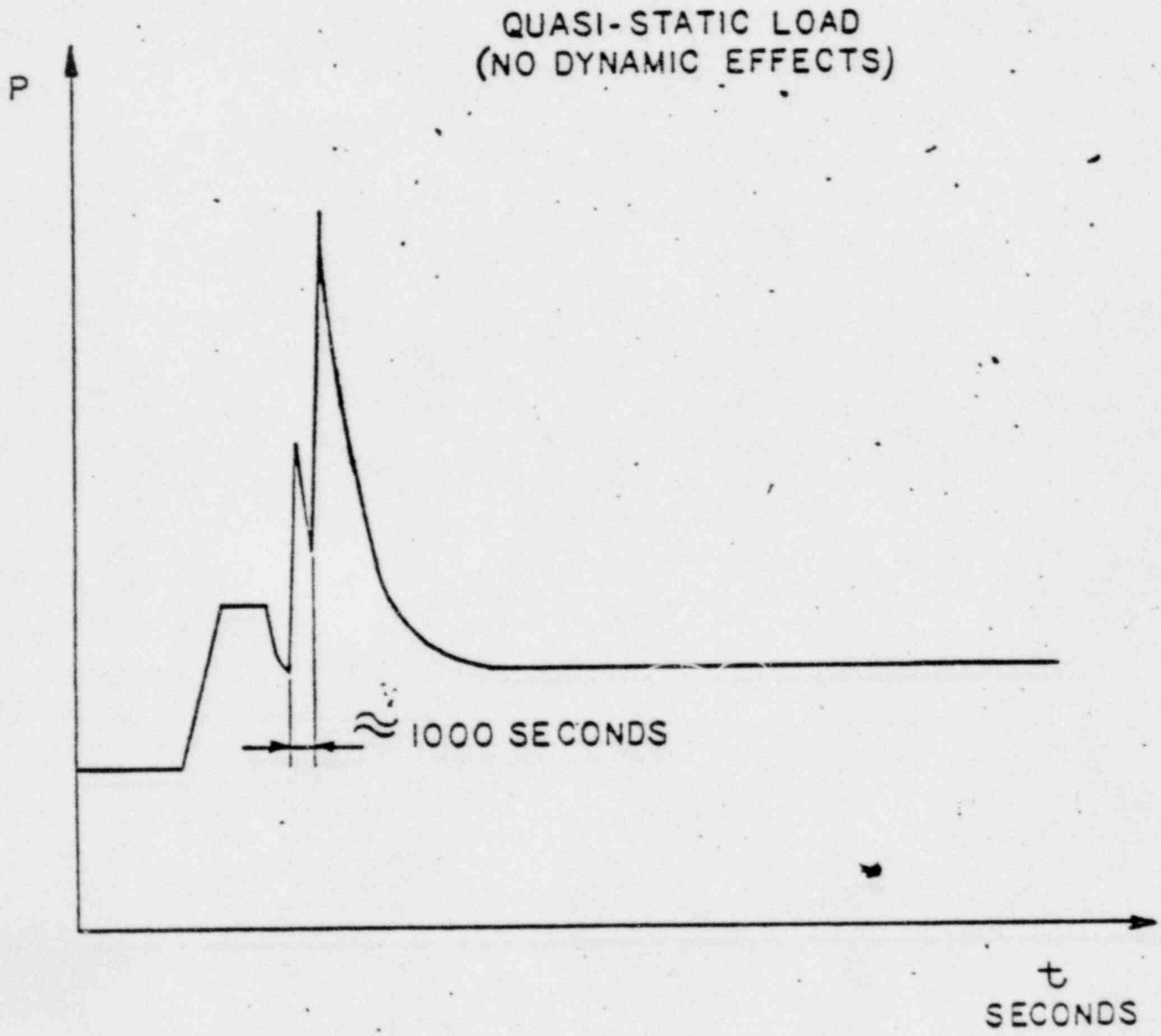
STRESS STRAIN DIAGRAM FOR LINER



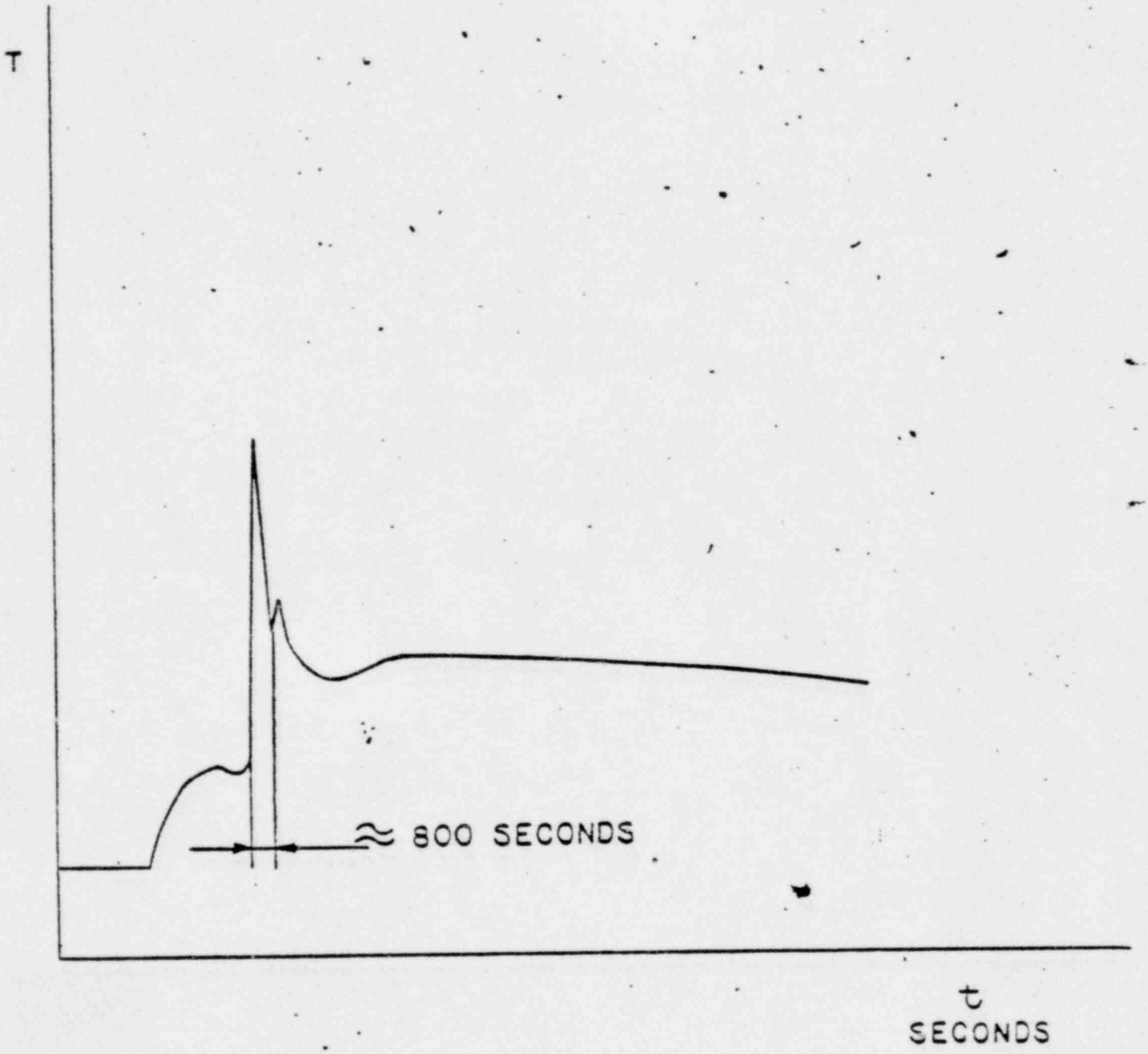
STRESS-STRAIN CURVE FOR CONCRETE



STRESS-STRAIN CURVE OF ASTM A-615-60 STEEL



TYPICAL PRESSURE TRANSIENT
USED IN EVALUATION



TYPICAL TEMPERATURE TRANSIENT
USED IN EVALUATION

METHOD OF EVALUATION - HAND CALCULATIONS

JUSTIFICATION

- EXPERIENCE IN DESIGN AND ANALYSIS OF CONTAINMENT VESSELS

- AGREEMENT BETWEEN HAND CALCULATIONS AND COMPUTER SOLUTIONS FROM PREVIOUS ANALYSES.

REGIONS OF CONTAINMENT EVALUATED

- MEMBRANE
  DOME & CYLINDER

- DISCONTINUITY REGION AT SPRINGLINE

- DISCONTINUITY REGION AT BASE OF CYLINDER

- BASE MAT

- LARGE PENETRATIONS
  EQUIPMENT HATCH
  PERSONNEL AIRLOCK

- SMALL PENETRATIONS - TYPICAL

- LINER

MEMBRANE REGION

DOME

HOOP FORCE = $\frac{PR}{2}$ MERIDIONAL FORCE = $\frac{PR}{2}$

CYLINDER

HOOP FORCE = PR (GOVERNING CONDITION)

MERIDIONAL FORCE = $\frac{PR}{2} - D$

STATICALLY DETERMINATE FORCE SYSTEM INDEPENDENT OF MATERIAL PROPERTIES.

DISCONTINUITY REGION AT SPRINGLINE

MERIDIONAL SHEARS AND MOMENTS ARE SECONDARY AND ARE NOT LARGE DUE TO A DESIGNED COMPATIBLE HOOP STIFFNESS AT DOME CYLINDER JUNCTION.

THIS REGION IS NOT CRITICAL

DISCONTINUITY REGION AT BASE OF CYLINDER

MERIDIONAL SHEARS AND MOMENTS ARE SECONDARY AND ARE LARGE. BEAM ON ELASTIC FOUNDATION EQUATIONS WERE USED TO COMPUTE THE RESPONSE.

SHEARS AND MOMENTS WERE EVALUATED IN THE PRESENCE OF MERIDIONAL TENSION.

THIS REGION IS NOT CRITICAL

BECAUSE OF ADDITIONAL MERIDIONAL REBAR NEAR THE INSIDE SURFACE OF THE WALL THE TOTAL QUANTITY OF MERIDIONAL REBAR IS FAR GREATER THAN REQUIRED TO RESIST MERIDIONAL FORCES ALONE.

HOOP REBAR IS NOT REDUCED AT THE BASE AND IS SUFFICIENT TO RESIST THE ENTIRE HOOP FORCE. THESE HOOP BARS AT THE BASE ARE NOT RELIED UPON TO TRANSMIT LOAD.

SHEAR REINFORCEMENT IS ALSO ADDED TO FULLY RESIST THE RADIAL SHEAR FORCES.

CONCLUSION - BASE OF CYLINDER IS PROVIDED WITH A HIGHLY REDUNDANT SYSTEM OF REBAR. ITS STRENGTH IS SUBSTANTIALLY GREATER THAN REGIONS OF THE SHELL REMOTE FROM THE BASE MAT.

BASE MAT

CALCULATIONS WERE PERFORMED FOR

- SHEAR
- BENDING
- TENSION

EVALUATION WAS PERFORMED TO CHECK SHEAR AND MOMENT IN PRESENCE OF TENSION

THIS REGION IS NOT CRITICAL

LARGE PENETRATIONS

- EQUIPMENT HATCH AND PERSONNEL AIRLOCK EVALUATED FOR PRIMARY MEMBRANE PLUS BENDING
- ANCHORAGE OF EQUIPMENT HATCH AND PERSONNEL AIRLOCK TO CONCRETE WAS EVALUATED

THESE REGIONS ARE NOT CRITICAL

SMALL PENETRATIONS

- REPRESENTATIVE PIPING PENETRATIONS WERE EVALUATED FOR PRESSURE AND APPLIED PIPING REACTIONS
- ANCHORAGE TO CONCRETE WAS ALSO EVALUATED
- THE REGIONS EVALUATED ARE NOT CRITICAL

QUALITATIVE ASSESSMENT OF REBAR CAPABILITY
ADJACENT TO BOTH LARGE AND SMALL PENETRATIONS

- ADJACENT TO PENETRATIONS THERE IS A SHARP INCREASE IN BOTH FORCES AND MOMENTS OVER THOSE WHICH WOULD EXIST IN THE ABSENCE OF A HOLE.
- FORCES AND MOMENTS DECREASE RAPIDLY WITH DISTANCE AWAY FROM HOLE
- FOR SMALL PENETRATIONS (DIAMETER EQUAL TO OR LESS THAN SHELL THICKNESS) MOMENTS ARE NEGLIGIBLE AND FORCE CONCENTRATIONS ARE RESISTED BY AN INCREASED DENSITY OF REBARS (THE REBAR STRESS CONCENTRATION IS SUBSTANTIALLY LESS THAN THE FORCE CONCENTRATION)
    - IF YIELDING DID OCCUR IT WOULD ONLY OCCUR IN THE REBAR IMMEDIATELY ADJACENT TO THE HOLE.
    - THE MAGNITUDE OF THIS STRAIN IS LIMITED SINCE THE REMAINDER OF THE SECTION IS ELASTIC.
    - STRUCTURAL INTEGRITY TESTS HAVE NOT DISCLOSED ANY EXCESSIVE CRACKWIDTHS NEAR PENETRATIONS.
- FOR LARGE PENETRATIONS A BOSS REGION IS PROVIDED TO PLACE A MUCH LARGER QUANTITY OF REBAR THAN COULD BE PLACED IN AN UNTHICKENED SHELL.
    - YIELDING WOULD BE LOCAL
    - REMAINING SECTION IS ELASTIC

- STRUCTURAL INTEGRITY TEST - NO EXCESSIVE CRACK-WIDTHS

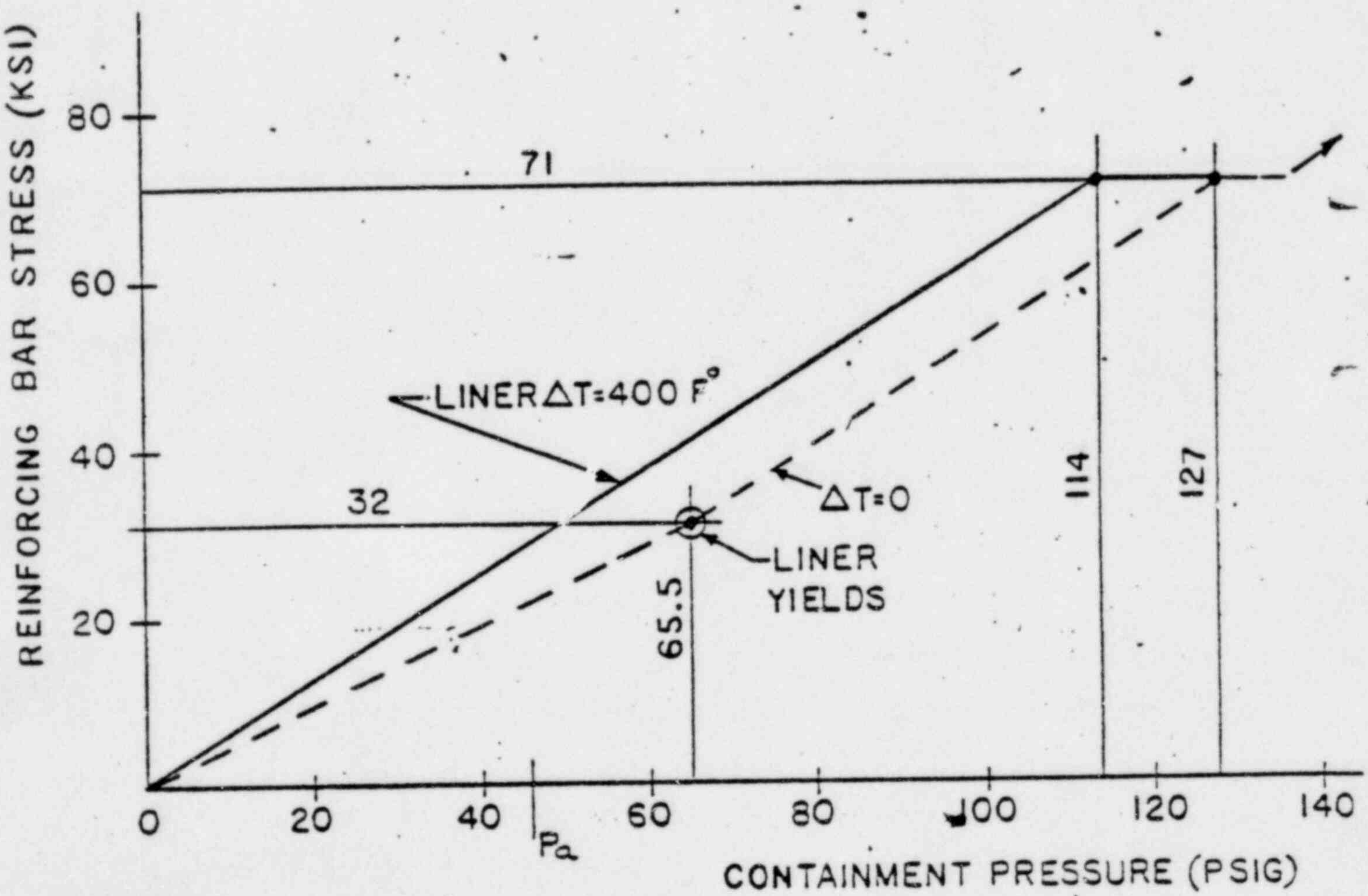
QUALITATIVE CONCLUSION - CAPABILITY OF REBAR ADJACENT TO PENETRATIONS IS <u>NOT</u> CRITICAL.

LINER

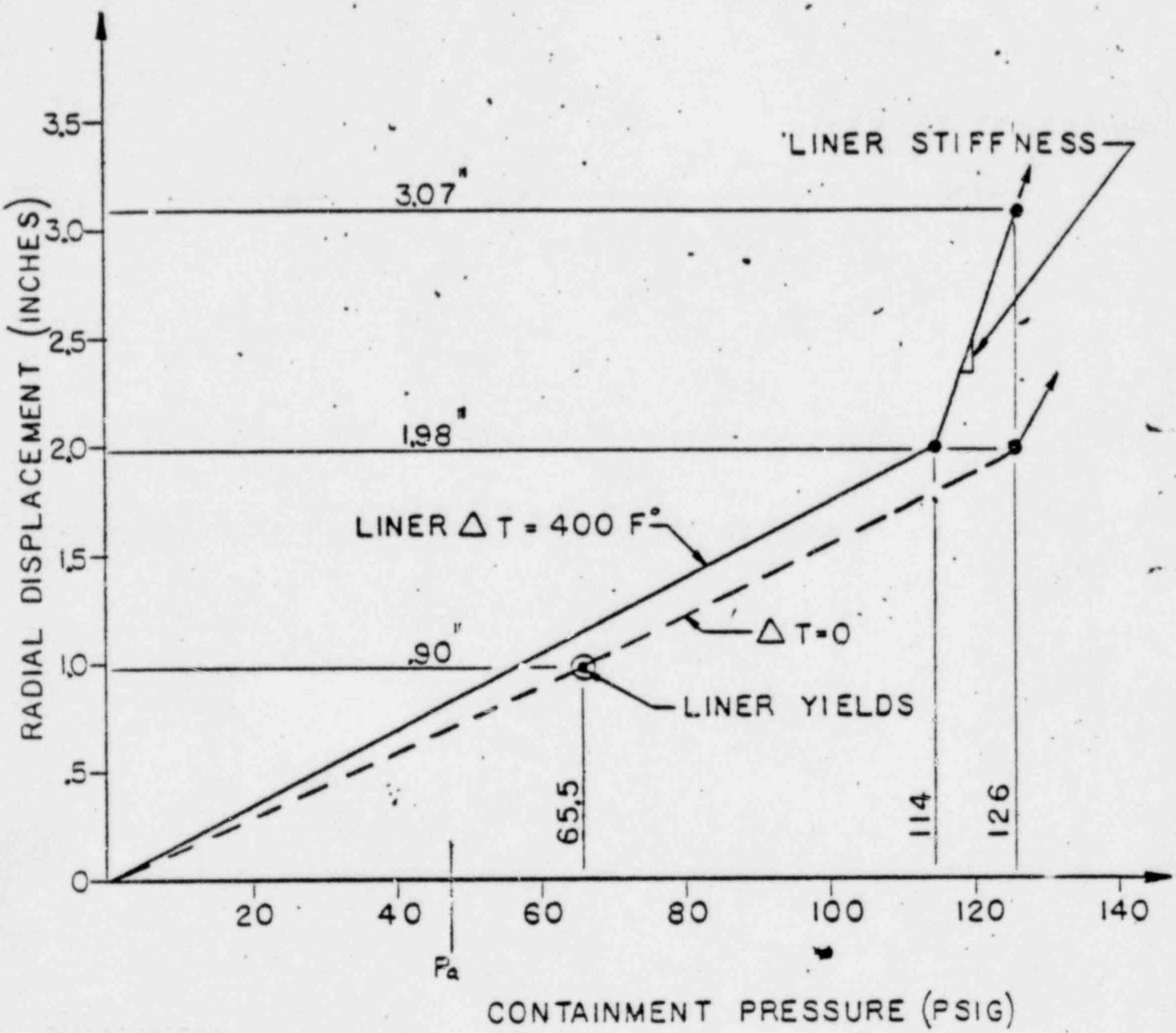
- STRAINS WERE EVALUATED TO INSURE INTEGRITY OF THE LINER

- ANCHORS WERE CHECKED TO INSURE AGAINST A PROGRESSIVE FAILURE OF THE LINER ANCHORAGE SYSTEM

THE LINER IS NOT CRITICAL



PLOT OF HOOP REBAR STRESS VERSUS CONTAINMENT PRESSURE—REGION OF CYLINDER WHERE SEISMIC REBAR IS REDUCED



PLOT OF RADIAL DISPLACEMENT VERSUS CONTAINMENT PRESSURE — REGION OF CYLINDER WHERE SEISMIC REBAR IS REDUCED

INDIAN POINT CONTAINMENTS UNITS 2 & 3
CONSERVATISMS IN ORIGINAL DESIGN

- PRIMARY CONSERVATISMS APPLIED IN ORIGINAL DESIGN OF THE GOVERNING REGION (BELOW SPRINGLINE) OF THE CONTAINMENT SHELL.

  1. APPLICATION OF LOAD FACTORS (1.5)
  2. APPLICATION OF CAPACITY REDUCTION FACTORS (1.11)
  3. STRENGTH OF LINER NOT ACCOUNTED FOR (1.15)
  4. MINIMUM STRENGTH OF MATERIALS CONSIDERED (1.18)
  5. SEISMIC REBAR RESISTING LOCA LOADS (1.12)
  6. DESIGNER CONSERVATISM (1.06)

- OTHER CONSERVATISMS APPLICABLE TO REGIONS WHICH DO NOT GOVERN

  1. SEISMIC LOADS COMBINED WITH LOCA LOADS (MAXIMUM EFFECT AT BASE OF SHELL)
  2. SEISMIC LOADS CONSERVATIVELY DETERMINED - EXAMPLE SSE UNIT 2 DAMPING - 2%
  3. REDUNDANCY AT BASE PROVIDED - SHEAR FORCE AND BENDING MOMENT ARE SECONDARY AND EXIST ONLY BECAUSE OF BASE CONSTRAINT - THEY ARE NOT REQUIRED FOR EQUILIBRIUM.

P_A (DESIGN) = 47 PSIG

P (CAPABILITY) = 47 • (PRODUCT OF FACTORS ABOVE)

P (CAPABILITY) = 47 • 2.7

P (CAPABILITY) = 126 PSIG

WHERE CAPABILITY IS THE LIMIT OF ELASTIC RESPONSE

NOTE THAT THE LIMITING REGION OF THE CONTAINMENT IS ONE OF HIGH DUCTILITY LOCATED AWAY FROM DISCONTINUITIES.

DISCONTINUITY REGIONS OF THE CONTAINMENT HAVE AT LEAST THE CONSERVATISM AS THE MEMBRANE REGION. THE ORIGINAL DESIGN WAS BASED ON THE ACI 318-63 CODE WHICH MANDATES ADDITIONAL CONSERVATISM IN REGIONS OF LOW DUCTILITY. SHEAR, ANCHORAGE AND COMPRESSION WILL NOT GOVERN DESIGN.

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ZION CONTAINMENT BUILDING
STRUCTURAL ANALYSIS

C. A. ANDERSON & J. G. BENNETT
LASL

JUNE 17, 1980

ZION CONTAINMENT BUILDING ANALYSIS

- LINEAR ELASTIC NUMERICAL ANALYSIS FOR SCOPING THE PROBLEM:
  - NATURAL FREQUENCIES
  - MODE SHAPES
  - STATIC RESPONSE TO GRAVITY LOADS, POST-TENSIONING LOADS, AND INTERNAL PRESSURE LOADS.
- NONLINEAR NUMERICAL ANALYSIS FOR:
  - STATIC PRESSURE LOADING INTO INELASTIC REGION OF MATERIAL BEHAVIOR
  - TRANSIENT OVERPRESSURE LOADING
- LIMIT STATE ANALYSIS TO PREDICT FAILURE LOADS

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RESULTS OF LINEAR ANALYSES

- Identified moment distribution.
- Frequencies and mode shapes (12, 21, 24, and 27 Hz).
- Verified moment reversal at 67 psi internal pressure.
- Good comparison with pressurization tests on Zion containment.
- Established additional data points on pressure-moment interaction curve.

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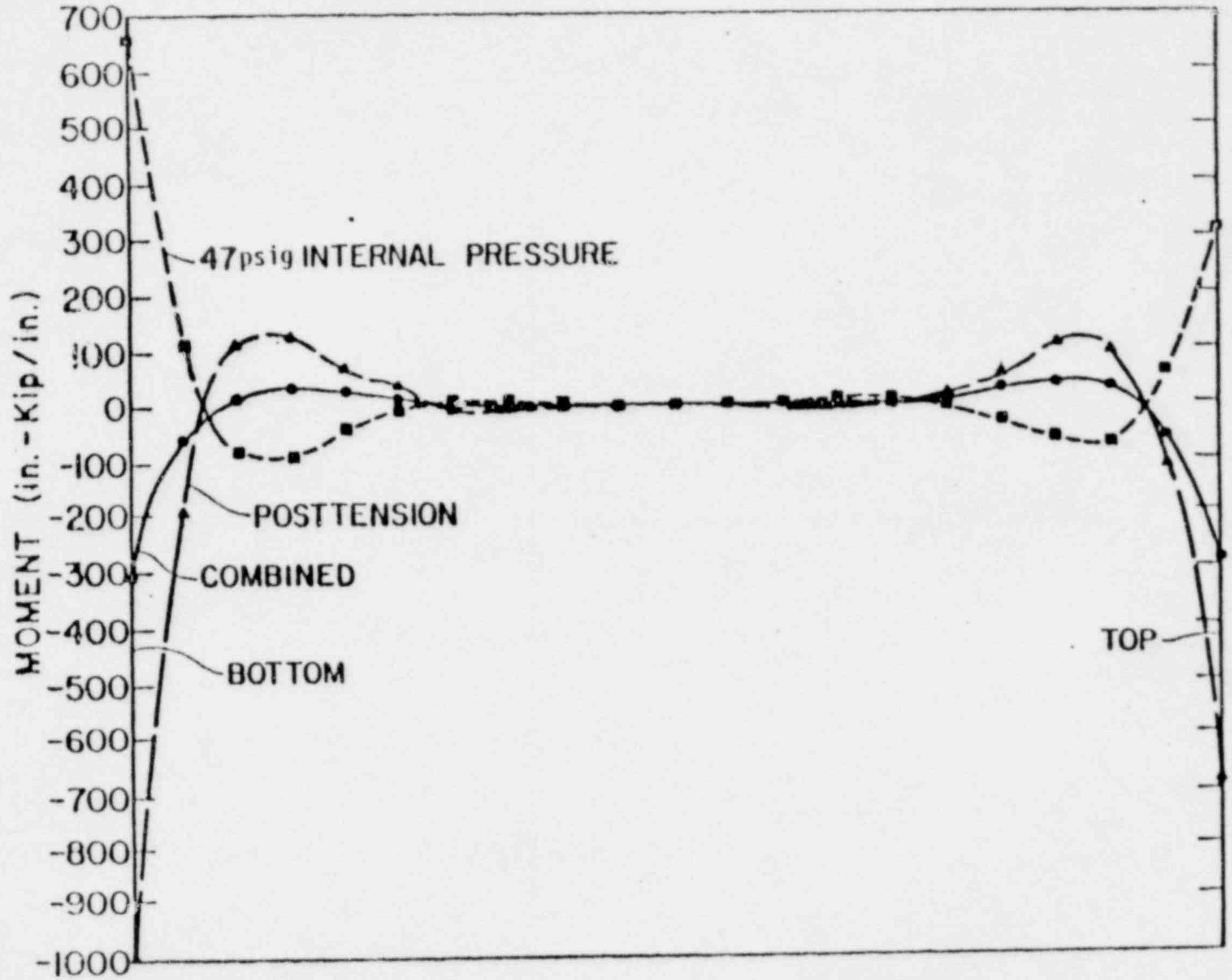

Moment distribution in the cylindrical portion of the containment building under various loadings from the linear model.

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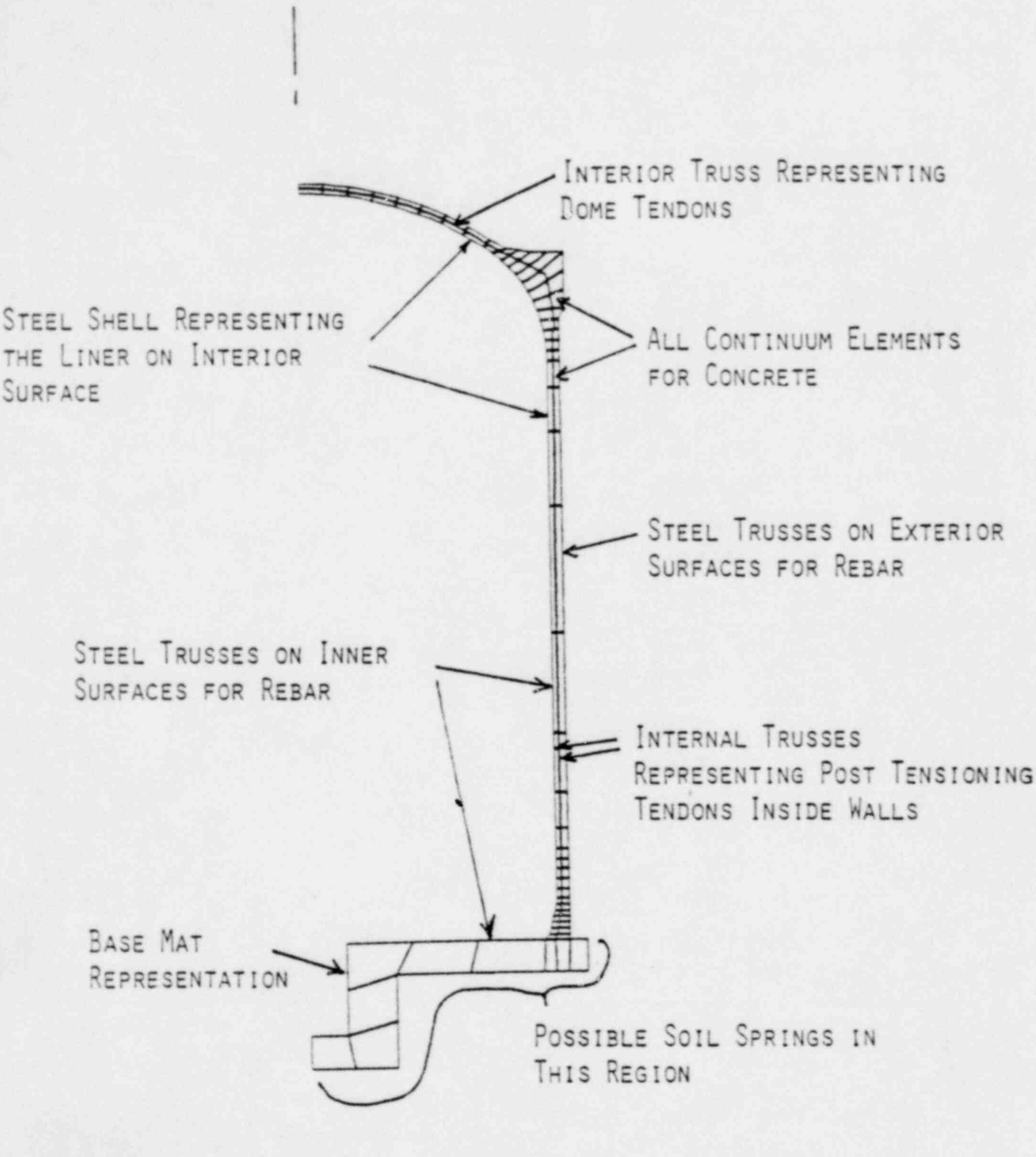
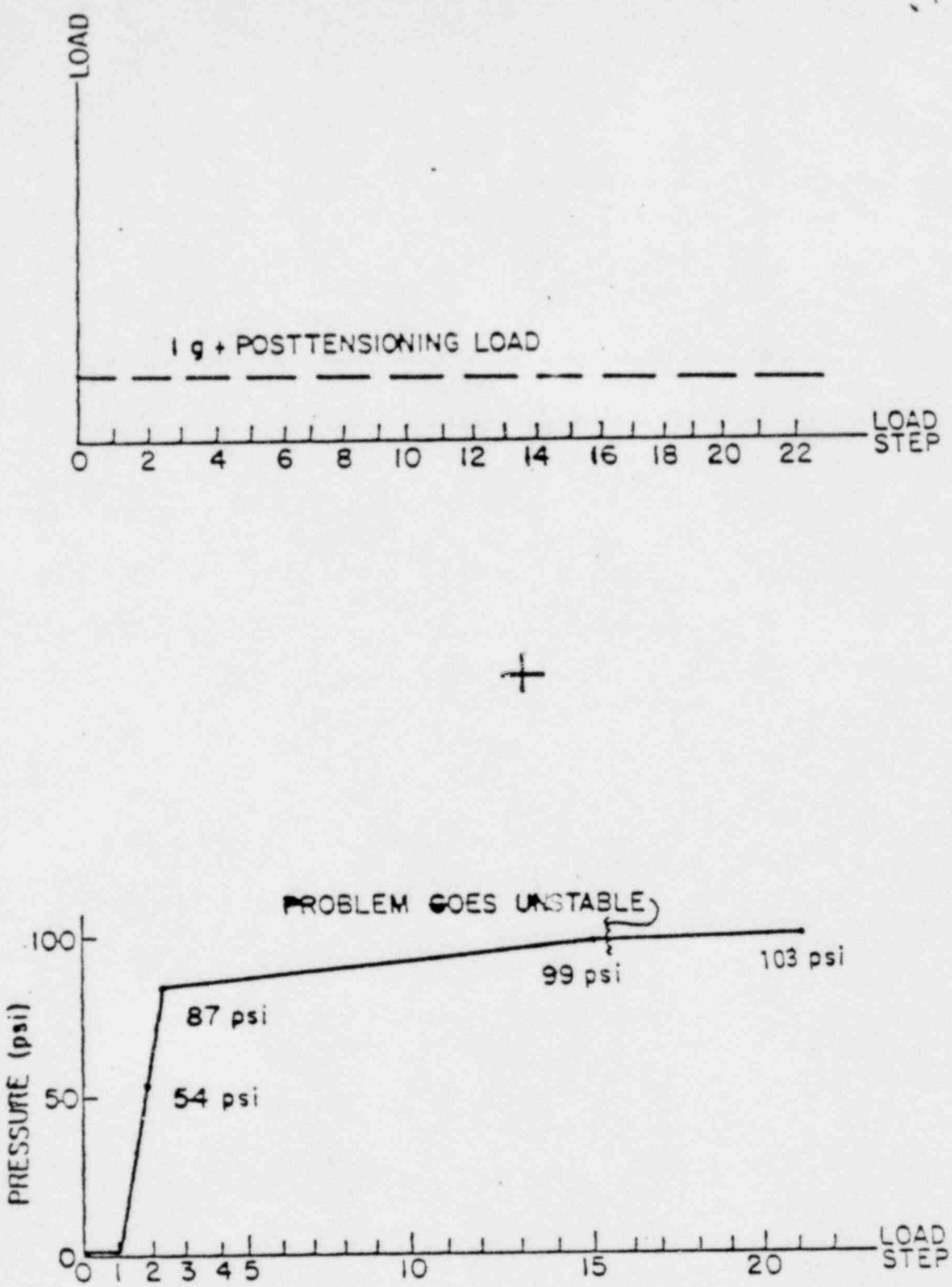


NONLINEAR AXISYMMETRIC ZION NUCLEAR PLANT CONTAINMENT MODEL

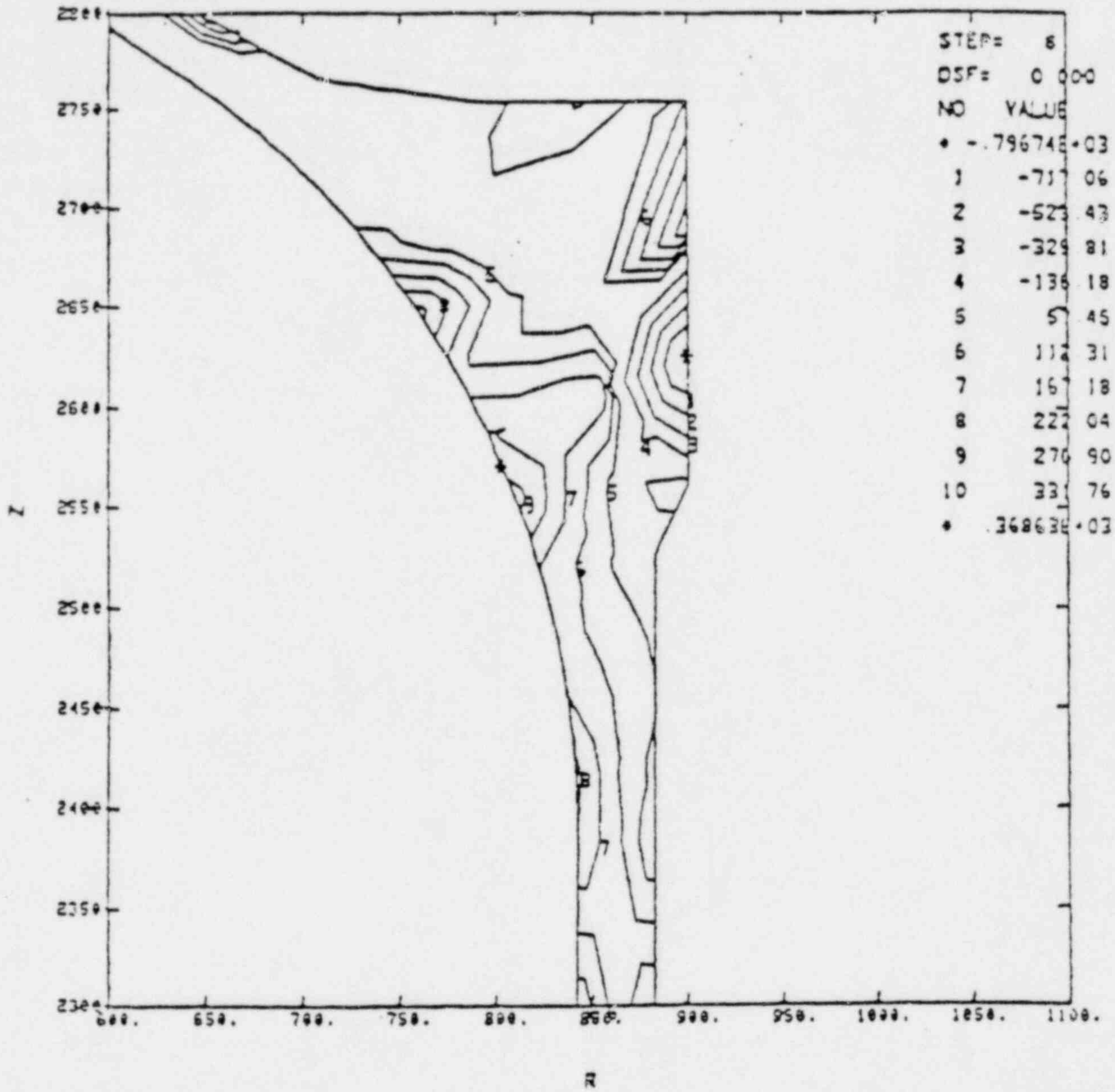
TABLE II

CONCRETE MATERIAL PROPERTIES

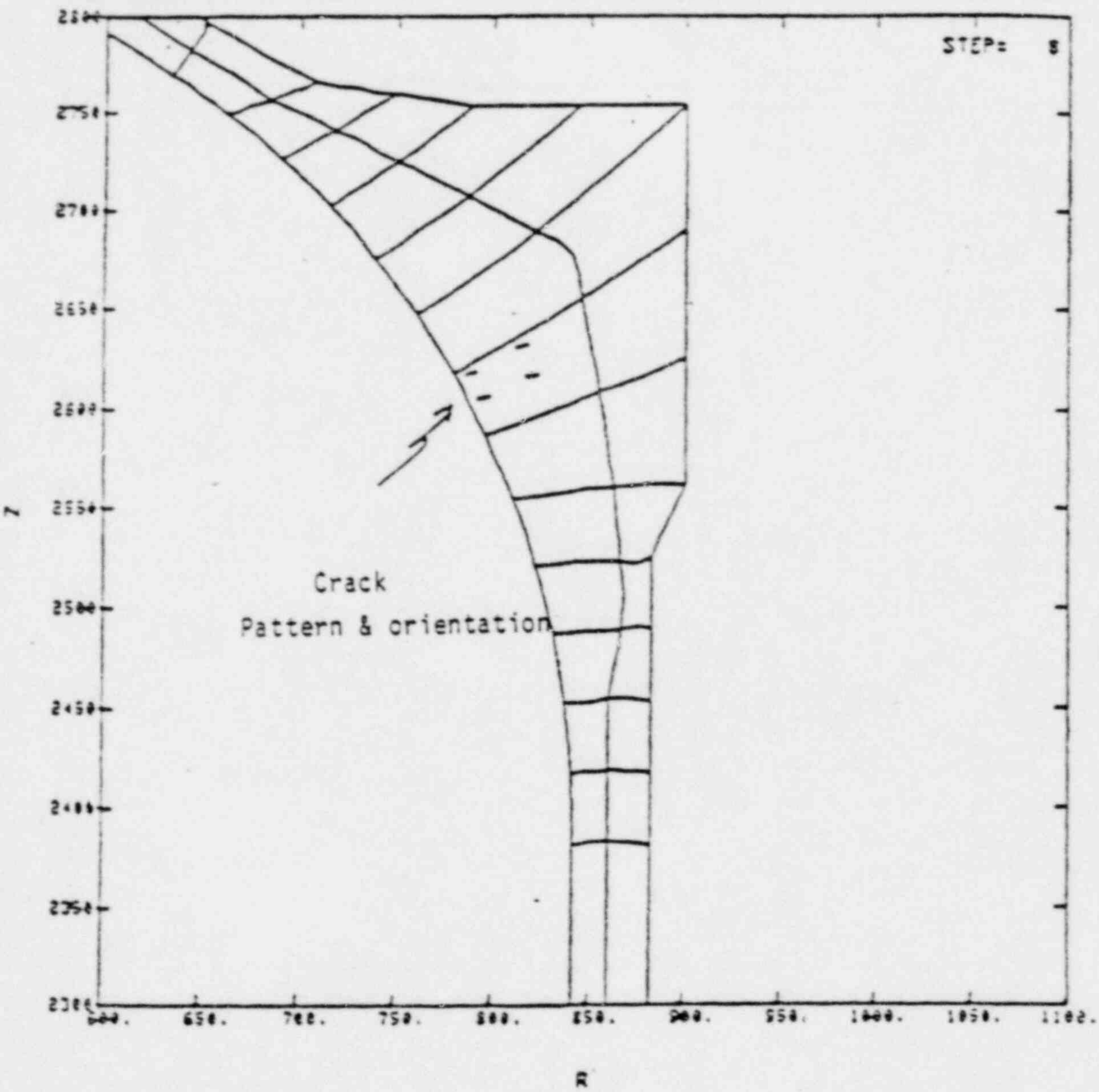
Tangent modulus of elasticity at zero strain	5×10^6 psi (35 GPa)
Poisson's ratio	0.2
Uniaxial cutoff tensile stress	500 psi (3.5 MPa)
Uniaxial maximum compressive stress	5 500 psi (38 MPa)
Corresponding uniaxial compressive strain	0.003
Uniaxial ultimate compressive stress	4 000 psi (28 MPa)
Corresponding ultimate compressive strain	0.004 5



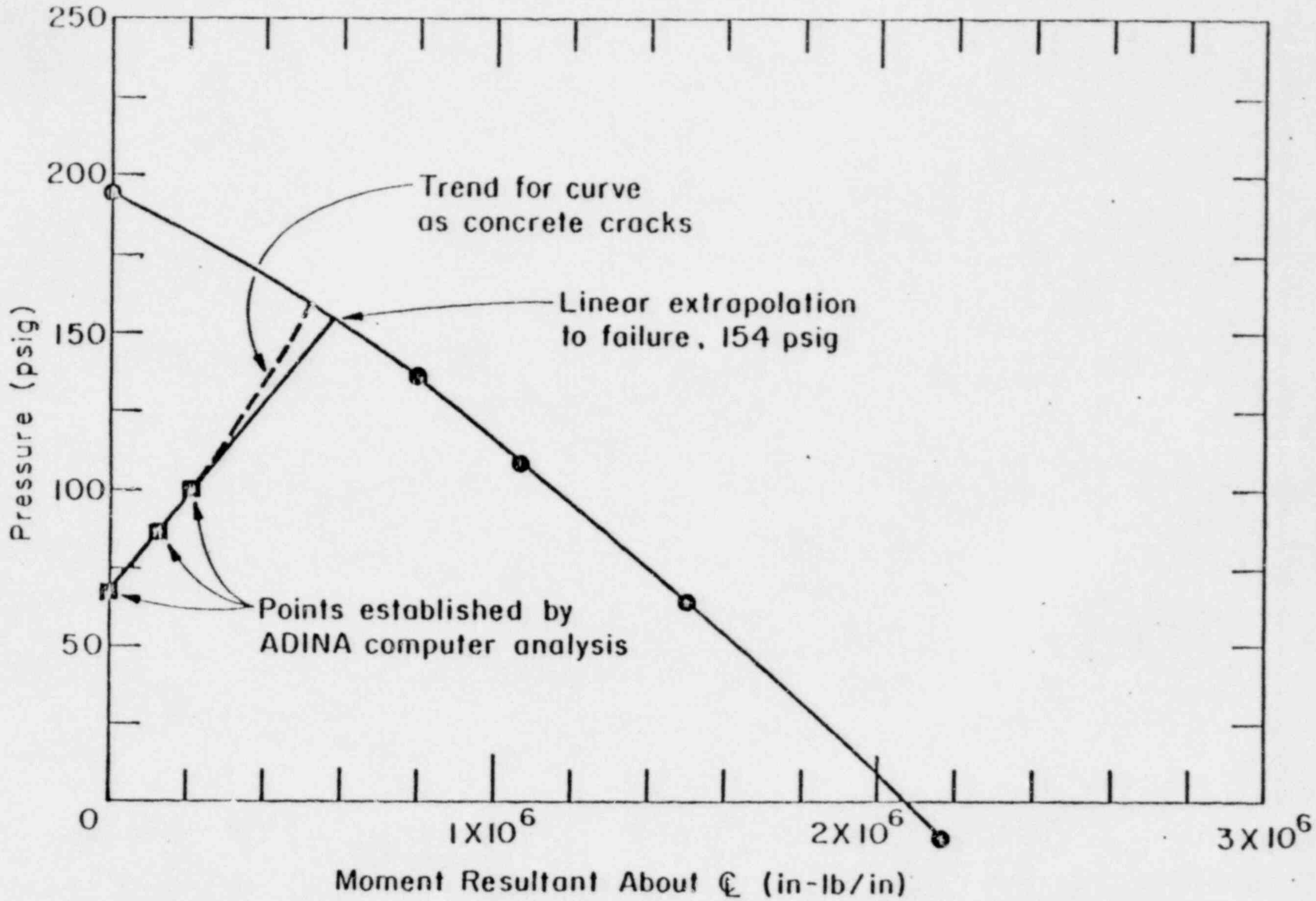
Static load step history applied to finite element model.



Maximum principal stress contours internal pressure 92 psig (0.63 MPa).



Initial crack pattern for the static load case at 92 psig(0.63 MPa).



Pressure-moment interaction curve at clyinder-ring intersection.

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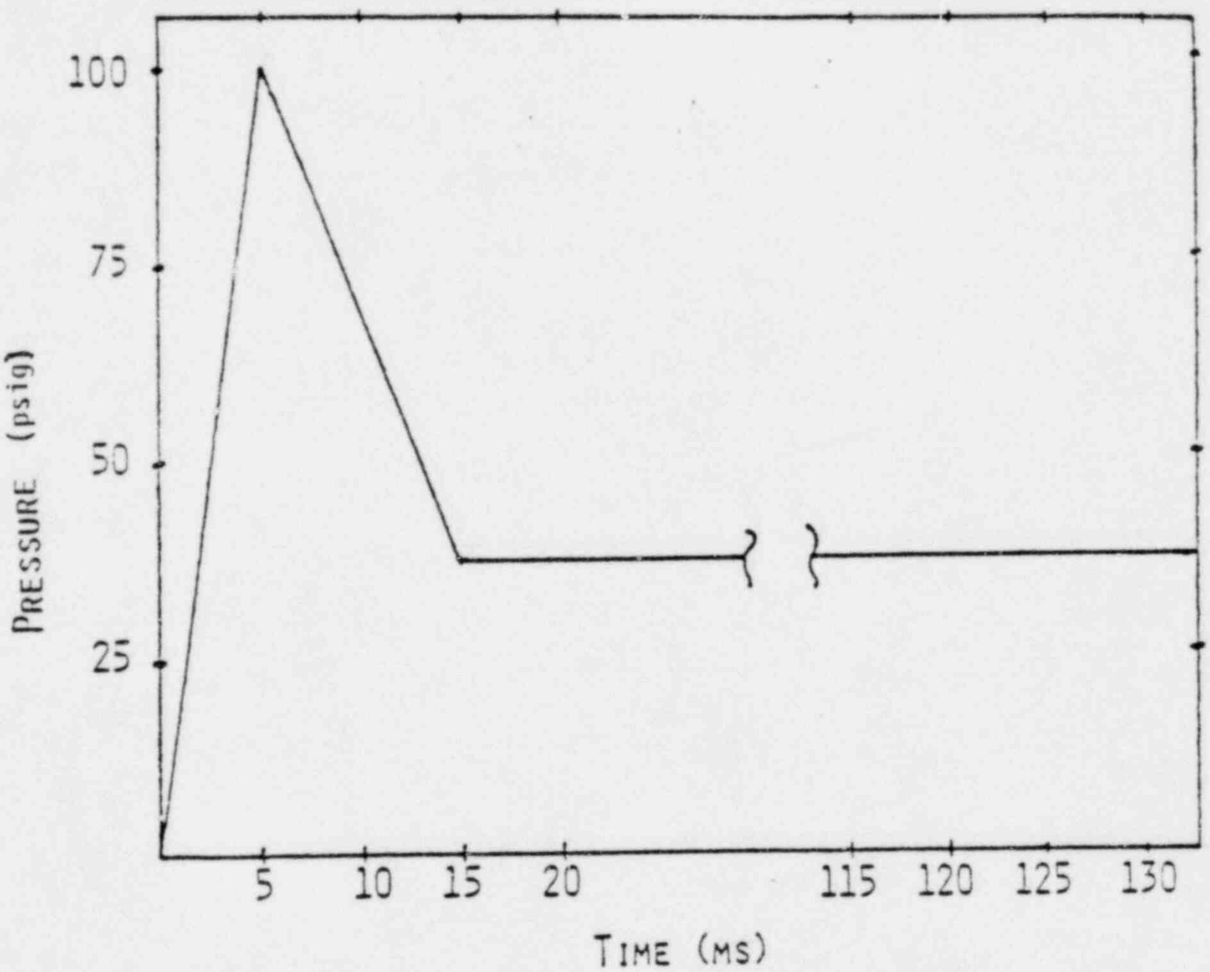
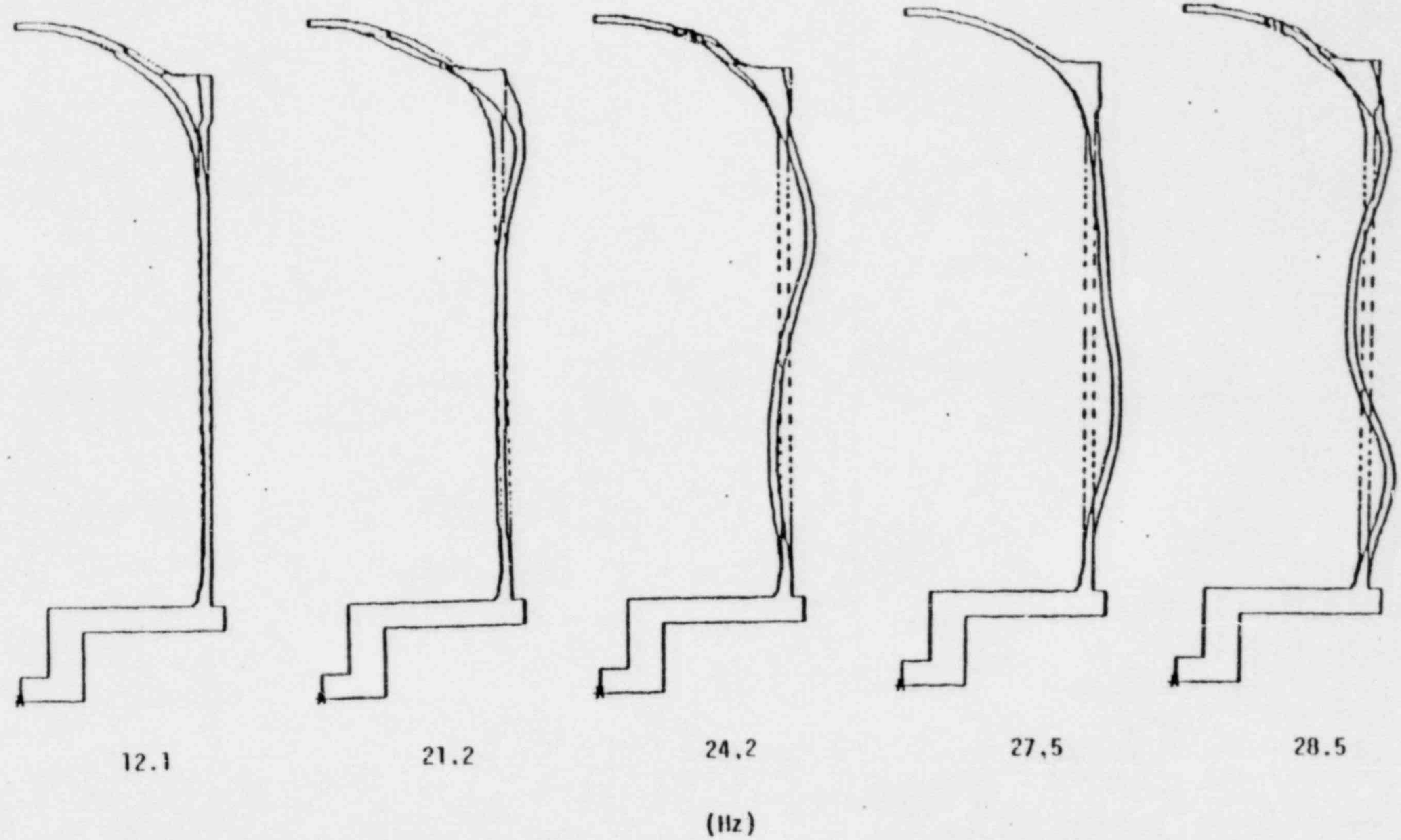
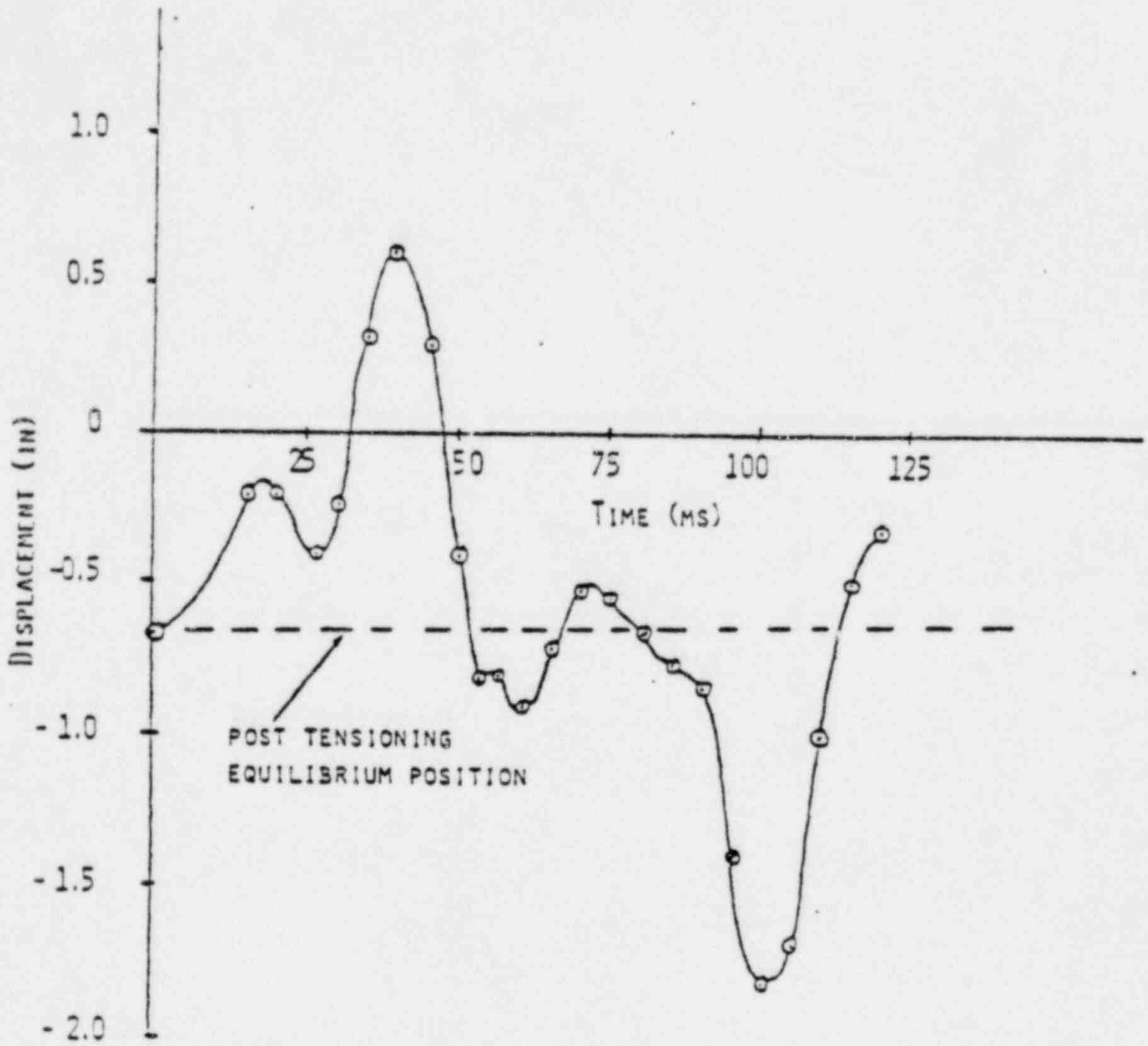


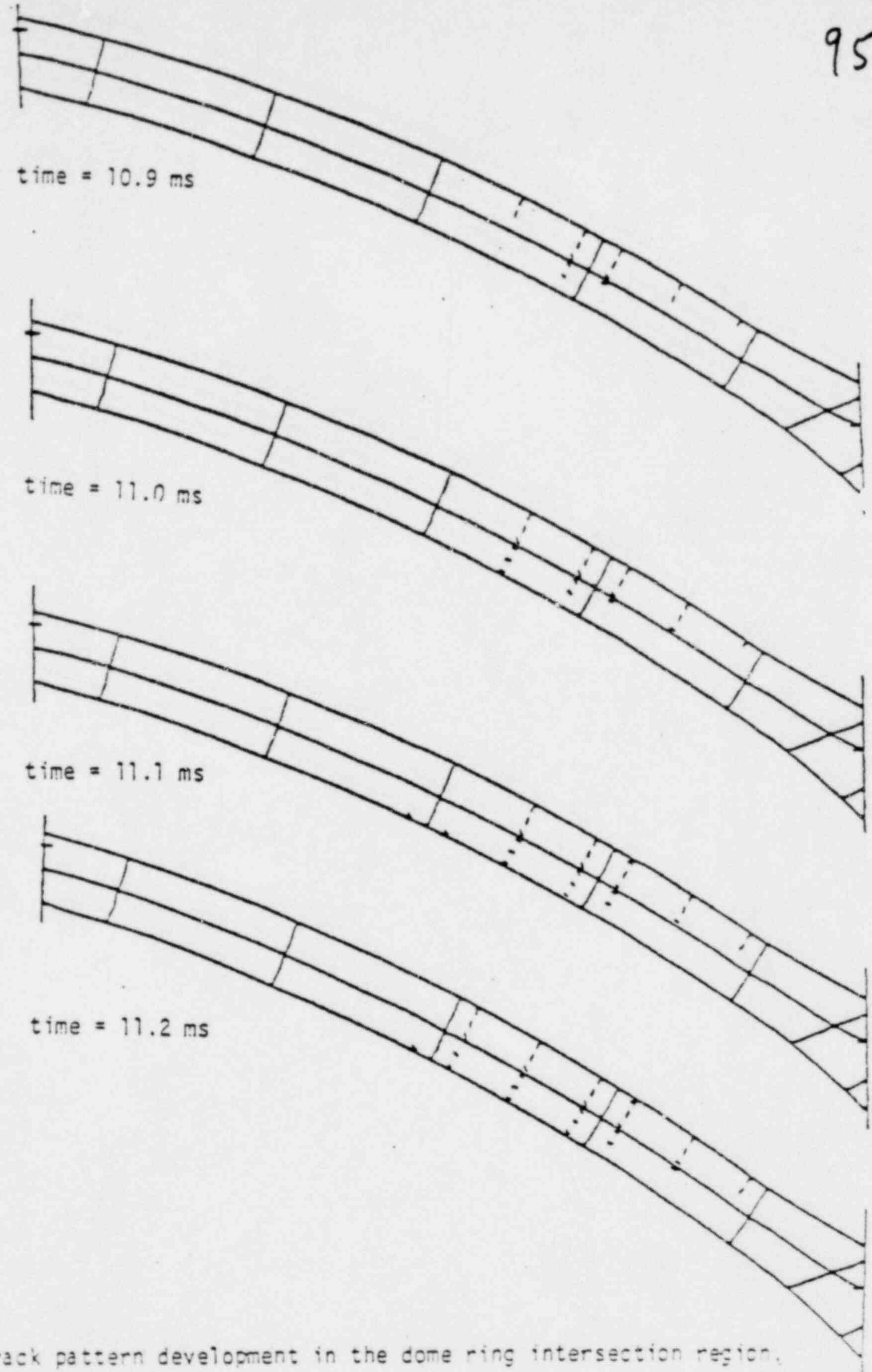
100 psi peak pressure time history applied to finite element model.



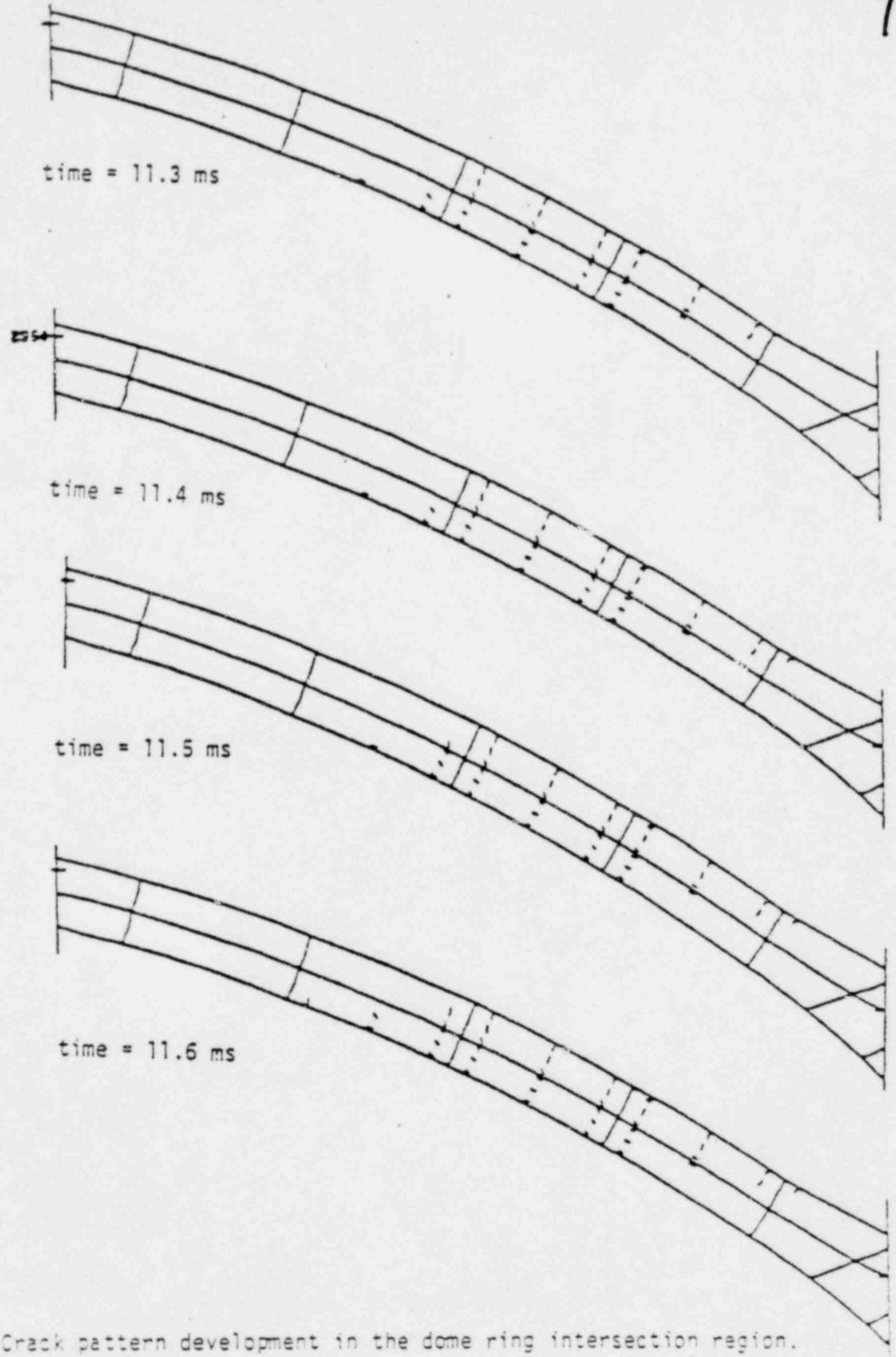
First five mode shapes and frequencies.



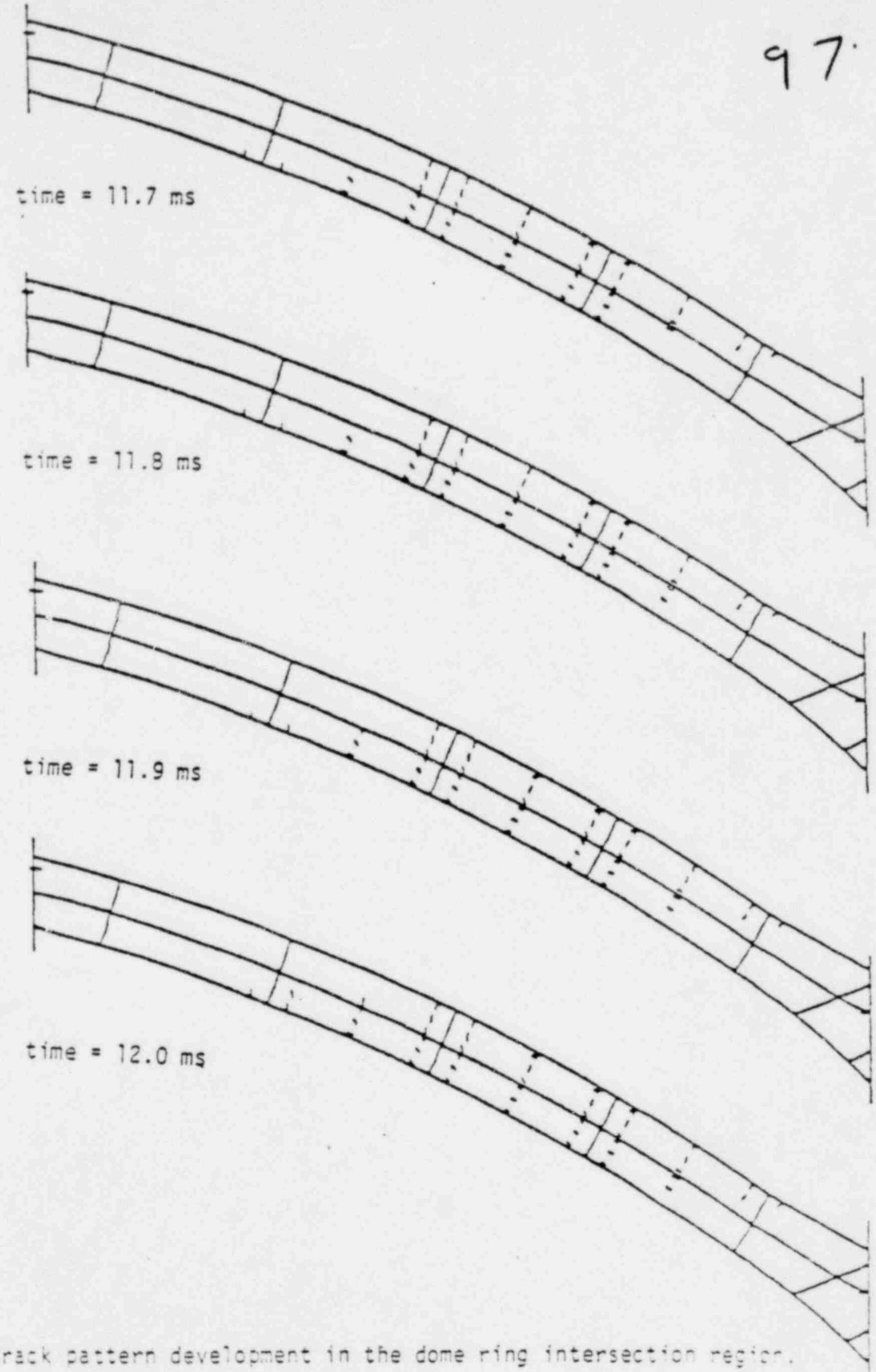
Transient response of dome apex to 100 psig pressure impulse.



Crack pattern development in the dome ring intersection region.



Crack pattern development in the dome ring intersection region.



Crack pattern development in the dome ring intersection region.

SUMMARY OF ALL RESULTS

- FOR STATIC PRESSURE LOADING WE PREDICT THE FOLLOWING:

Summary of Static Response

Pressure (psig)	Description
67	Sidewall and dome moment sign reversal
92	First concrete cracking occurs
123	Estimated liner yield
154	Failure pressure (liner separates)

- FOR TRANSIENT OVERPRESSURE LOADING WE PREDICT THE FOLLOWING:

100 PSI PEAK
- CONCRETE SEVERELY CRACKED EVERYWHERE
- REINFORCEMENT INTACT
- TENDONS WELL BELOW ULTIMATE

200 PSI PEAK
- CATASTROPHIC FAILURE INCLUDING REINFORCEMENT YIELDING AND TENDON FAILURE

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Indian Point 2/3

Containment Building Evaluation

Sandia National Labs

W. A. Von Riesemann

M. Huerta

E. P. Chen

D. V. Swenson

NRC, Bethesda

June 17, 1980

- Literature Survey
- Design Drawings
- Modelling
- Analyses
  - Static Linear and Nonlinear
  - Dynamic Nonlinear
- Penetrations
- Conclusions

(Details are given in report - today's presentation will cover highlights only)

Literature Survey

- Analytical

  MIT - 111.5 PSIG

  (5.0 ft wall, 3.5 ft dome)

  WASH 1400 - 75 to 120 PSIG

- Experimental

  Canada - 159 PSIG

  Japan - 135 PSIG

  Poland - 75 PSIG

(See references for assumptions and limitations)

Design Drawings

United Engineers & Constructors supplied over 200 drawings & several reports.

Cooperation was excellent.

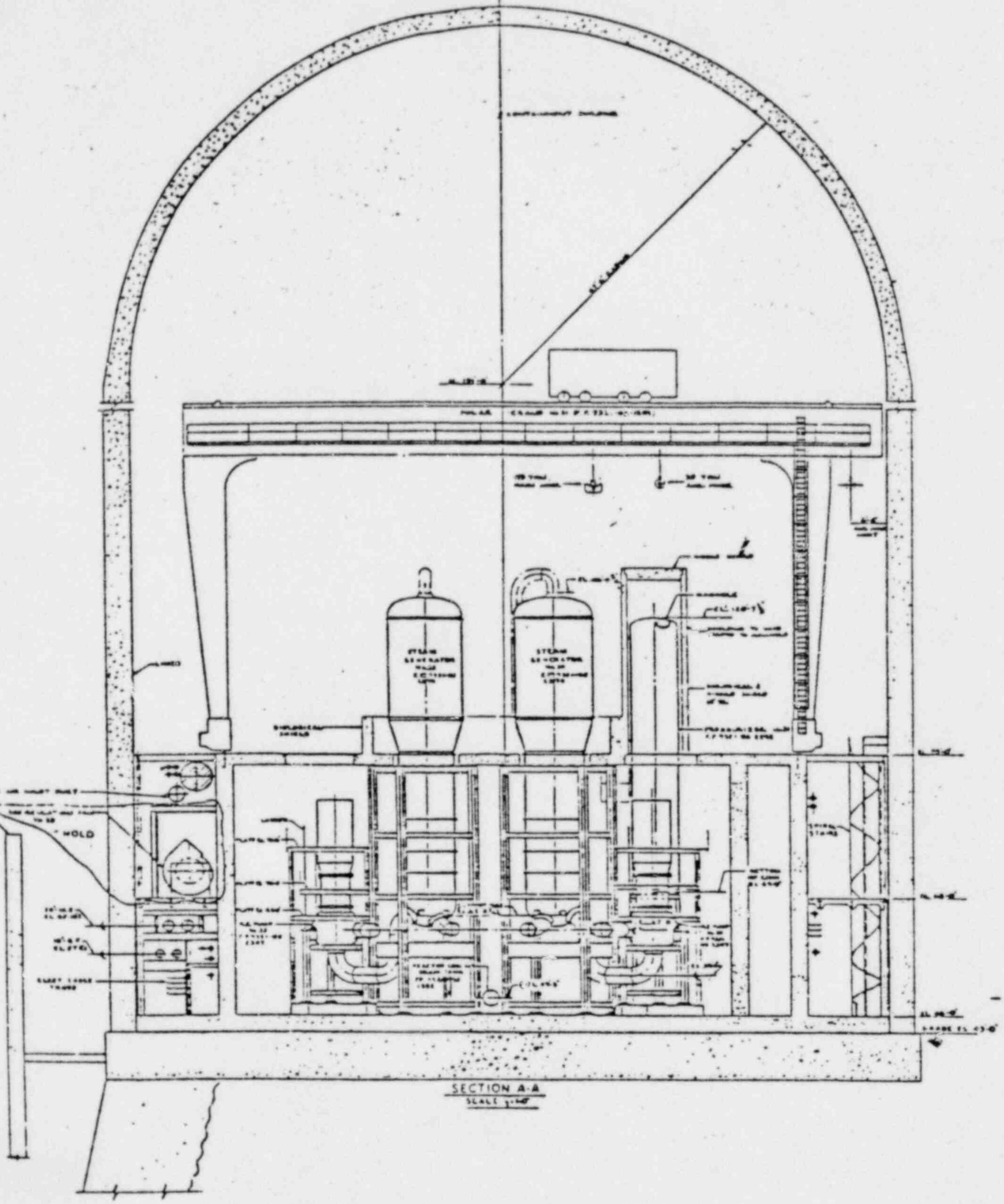


FIGURE 1A. CROSS-SECTION OF THE CONTAINMENT BUILDING

INDIAN POINT CONTAINMENT BUILDING

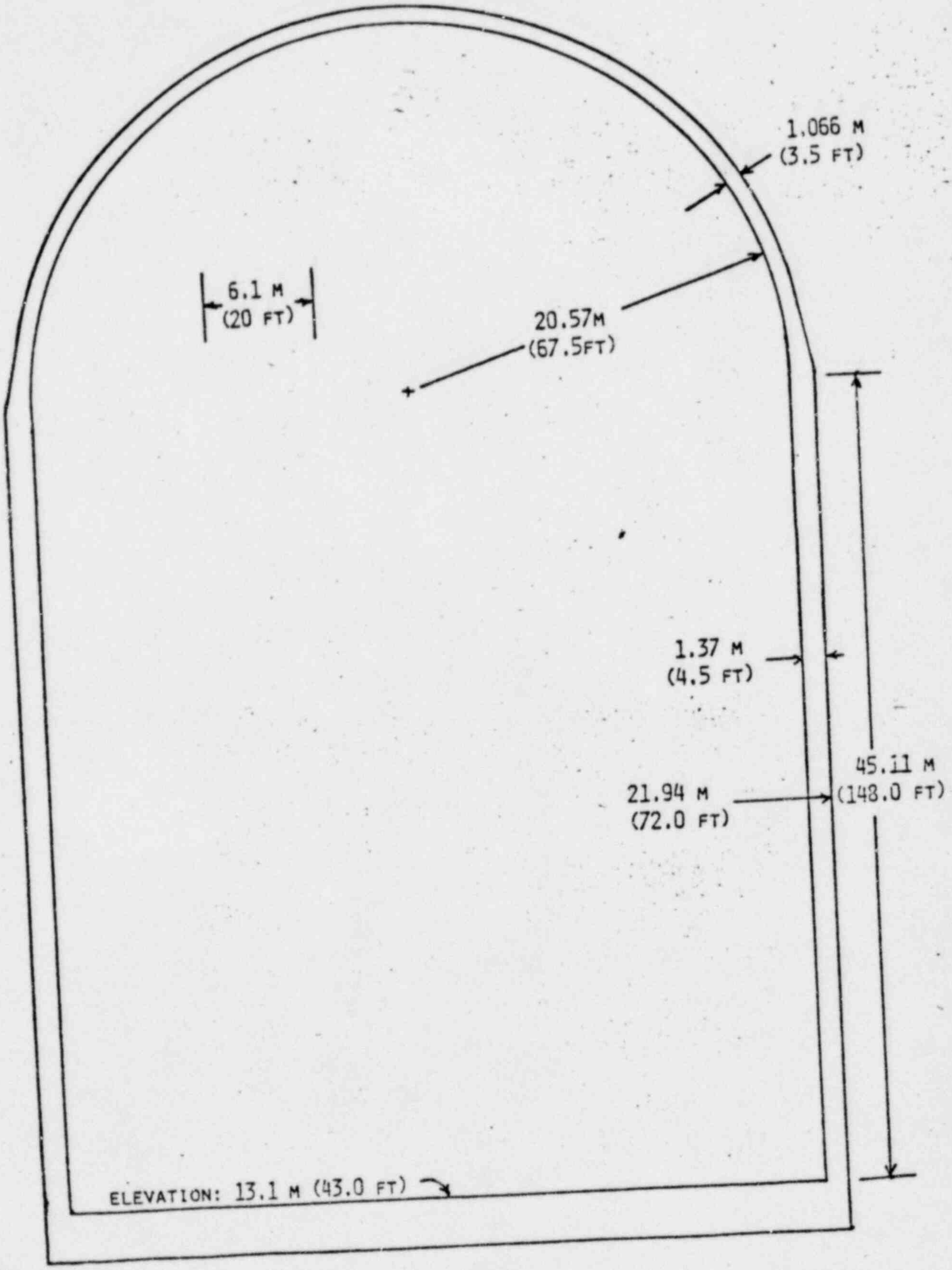


FIGURE 1B. SCHEMATIC OF THE CONTAINMENT BUILDING.

Modelling

- Dimensions - See figures
- Assumptions
  - Axisymmetric structure
  - Axisymmetric loading
  - Uniform basemat
  - Rebars simplified
  - Liner
- Material Properties
  - Rebar - Yield strength 60 ksi
  - Concrete - Compressive strength 3 ksi
    - Tensile strength 20 psi

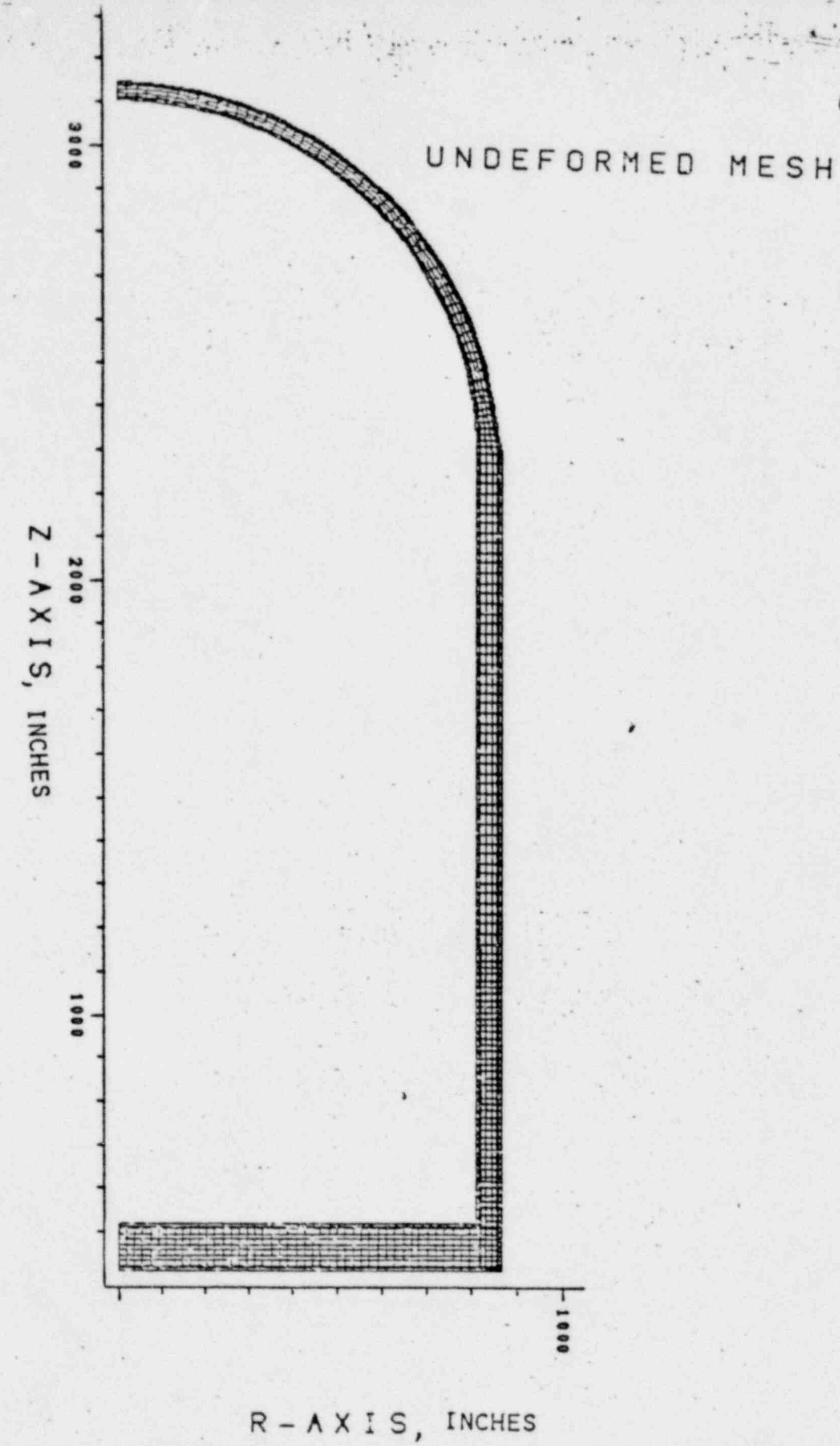


FIGURE 2. FINITE ELEMENT MESH FOR THE BUILDING.

Static Analyses

- Simplified

  Rebar only - 123 PSIG - ultimate

  extrapolation of code - 117.5 PSIG

- Finite Element Model

  108 PSIG

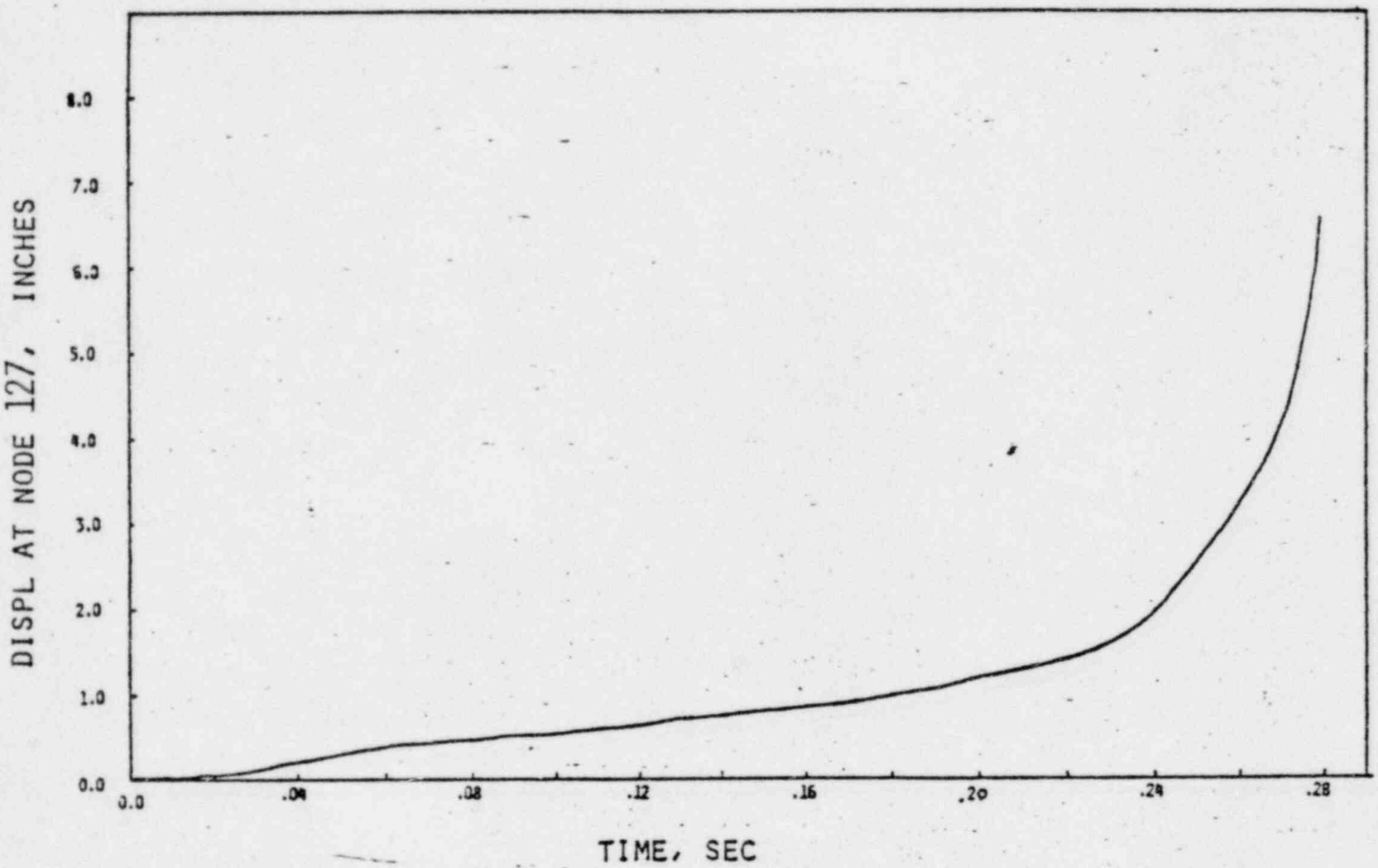


FIGURE 7. RADIAL DISPLACEMENT OF THE WALL DUE TO THE QUASI-STATIC PRESSURE INPUT.

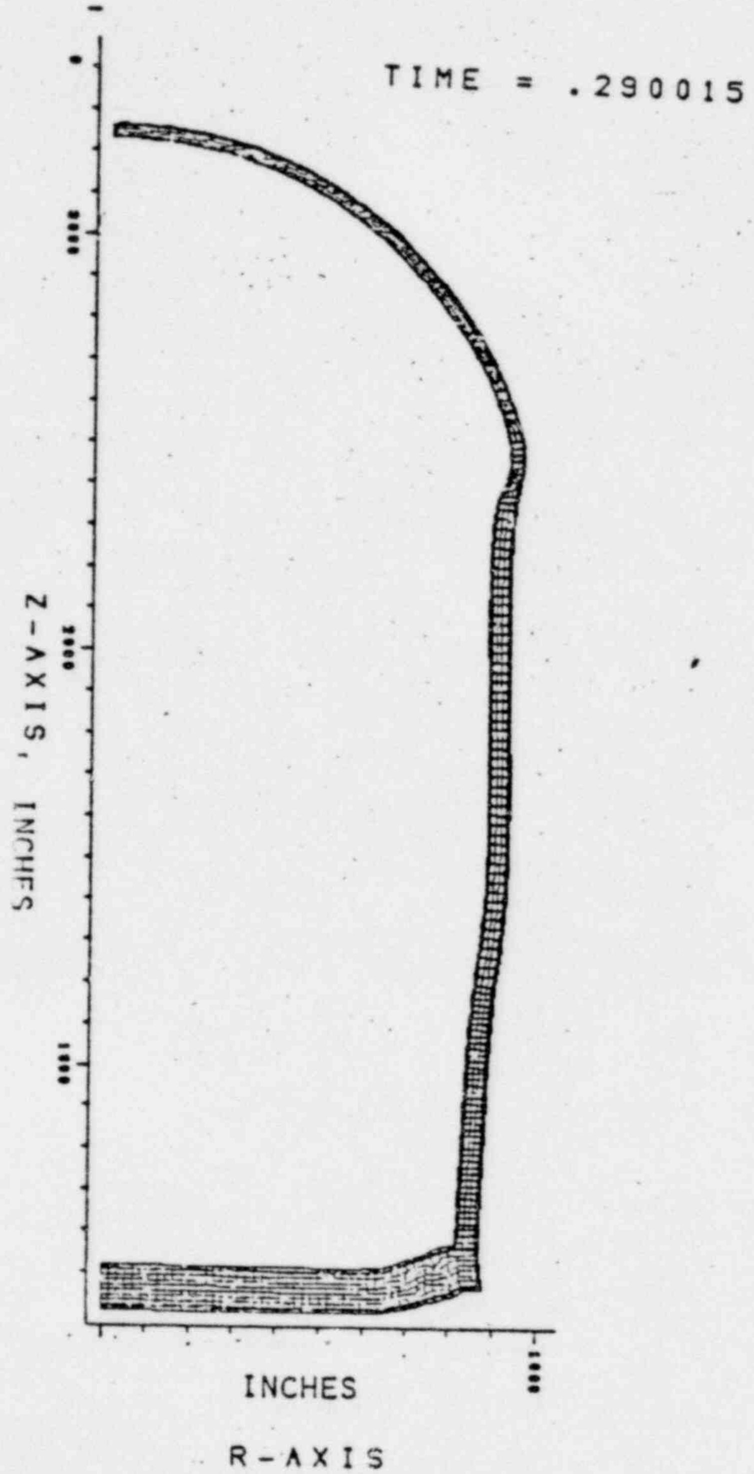
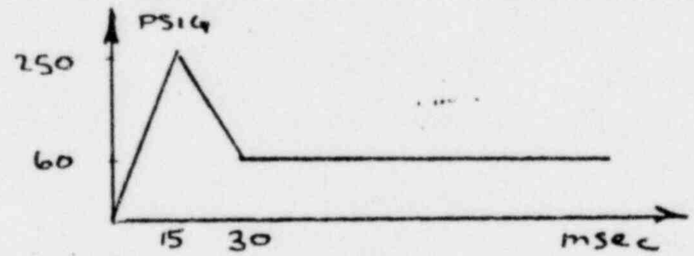


FIGURE 8. CALCULATED DEFORMED MESH FOR THE QUASI-STATIC PRESSURE INPUT. DEFORMATIONS ARE MAGNIFIED 10x

Dynamic Analyses

- HONDO Finite Element Code
- Nonlinear Materials
- Uniform Pressure Pulse Over The Interior



- Results (Figure 9)

  Radial Displacement 7 inches

  Strain 1%

  Severe Concrete Cracking

  But possibly able to contain pressure

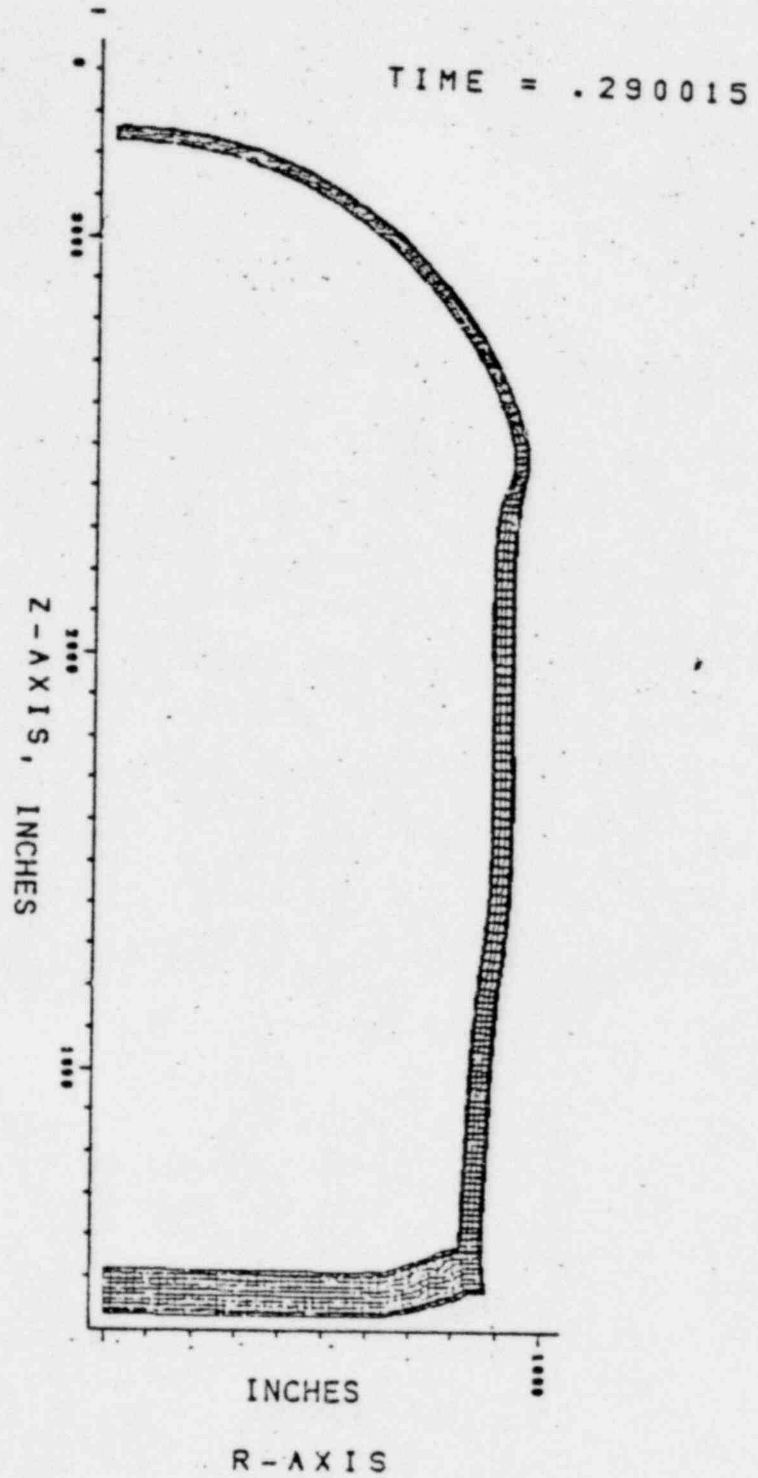


FIGURE 8. CALCULATED DEFORMED MESH FOR THE QUASI-STATIC PRESSURE INPUT. DEFORMATIONS ARE MAGNIFIED 10x

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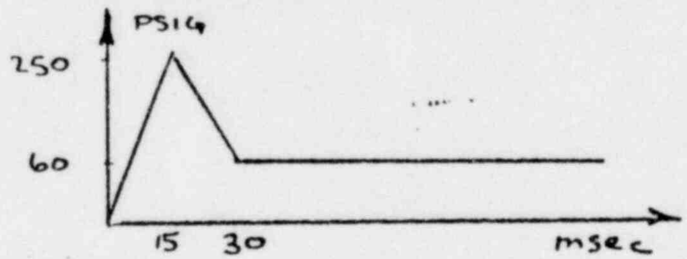
DYNAMIC ANALYSES

- HONDO FINITE ELEMENT CODE
- NONLINEAR MATERIALS
- UNIFORM PRESSURE PULSE OVER THE INTERIOR



- RESULTS (FIGURE 9)

  RADIAL DISPLACEMENT 7 INCHES

  STRAIN 1%

  SEVERE CONCRETE CRACKING

  BUT POSSIBLY ABLE TO CONTAIN PRESSURE

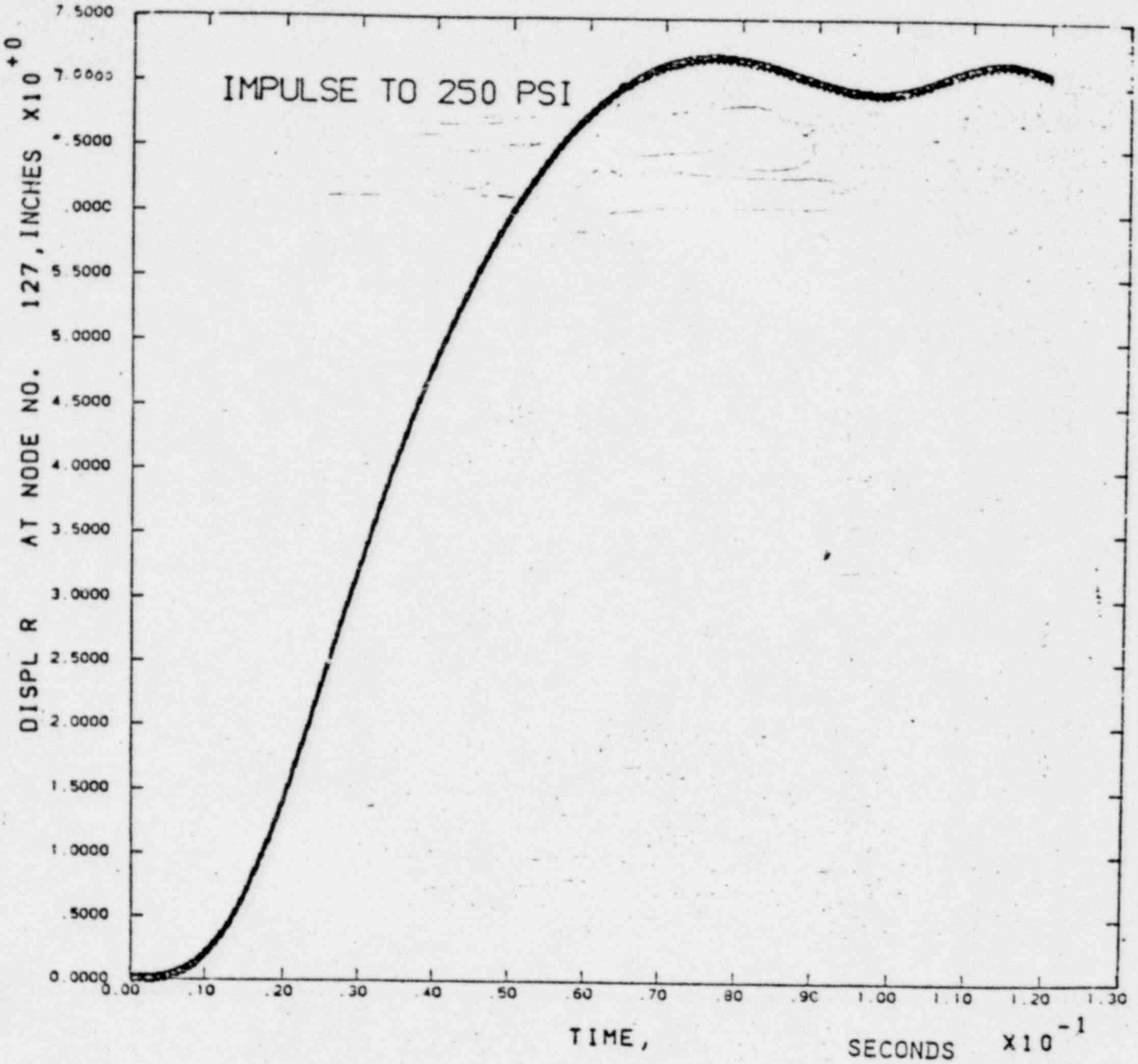


FIGURE 9. RADIAL DISPLACEMENT OF THE WALL CALCULATED FOR THE IMPULSE PRESSURE LOADING.

CONCLUSIONS

STATIC LOADING 110 PSIG

DYNAMIC LOADING DEPENDS ON PULSE SHAPE

PENETRATIONS - NO APPARENT PROBLEMS

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VIEWGRAPHS ACCOMPANYING

PRESENTATION BY DR. R. ALCOUFFE

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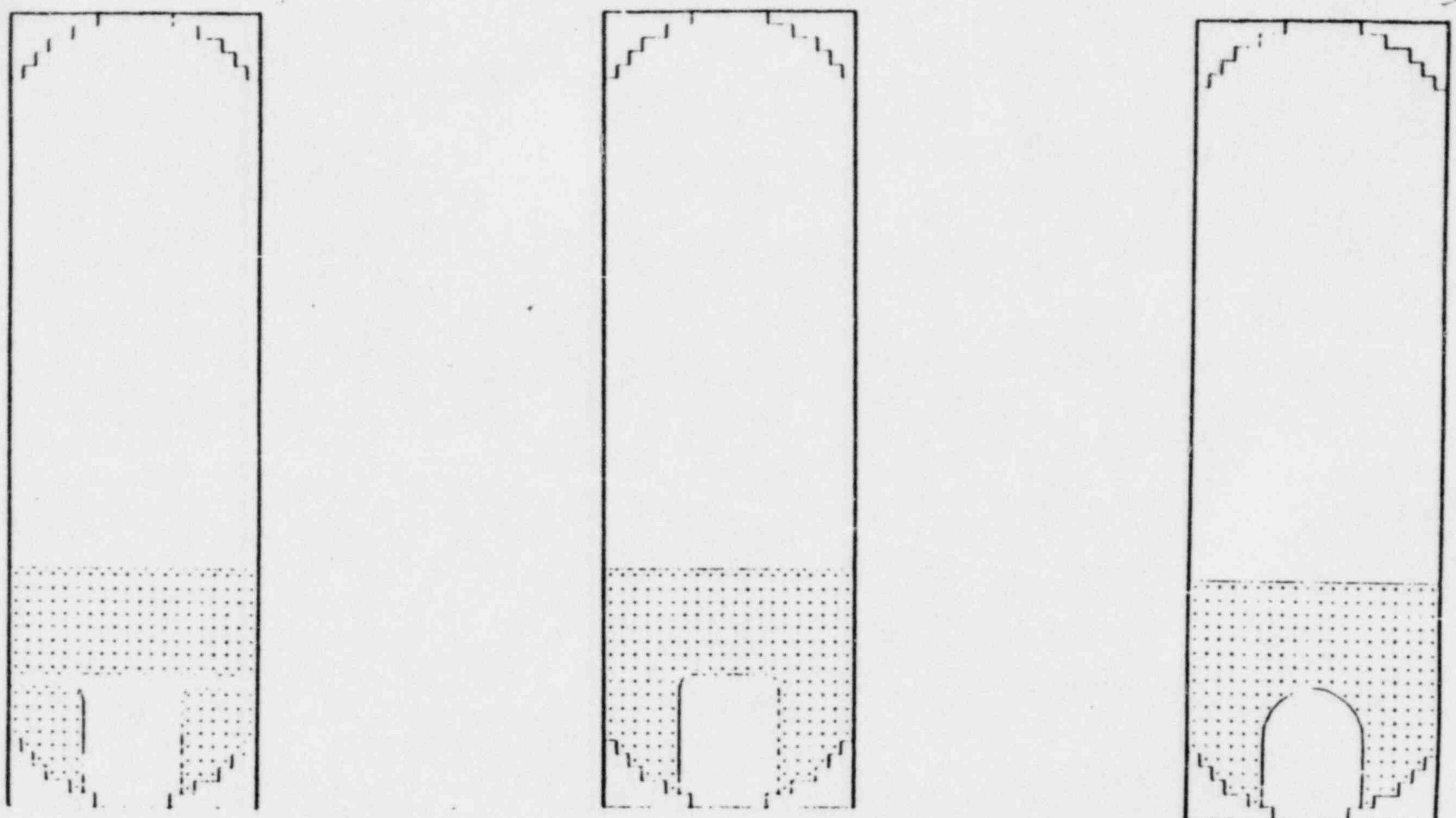
JUNE 17, 1980



(a) (b) (c)

Fig. 60. Interface positions and velocities for the three cases at t = 0 ms.

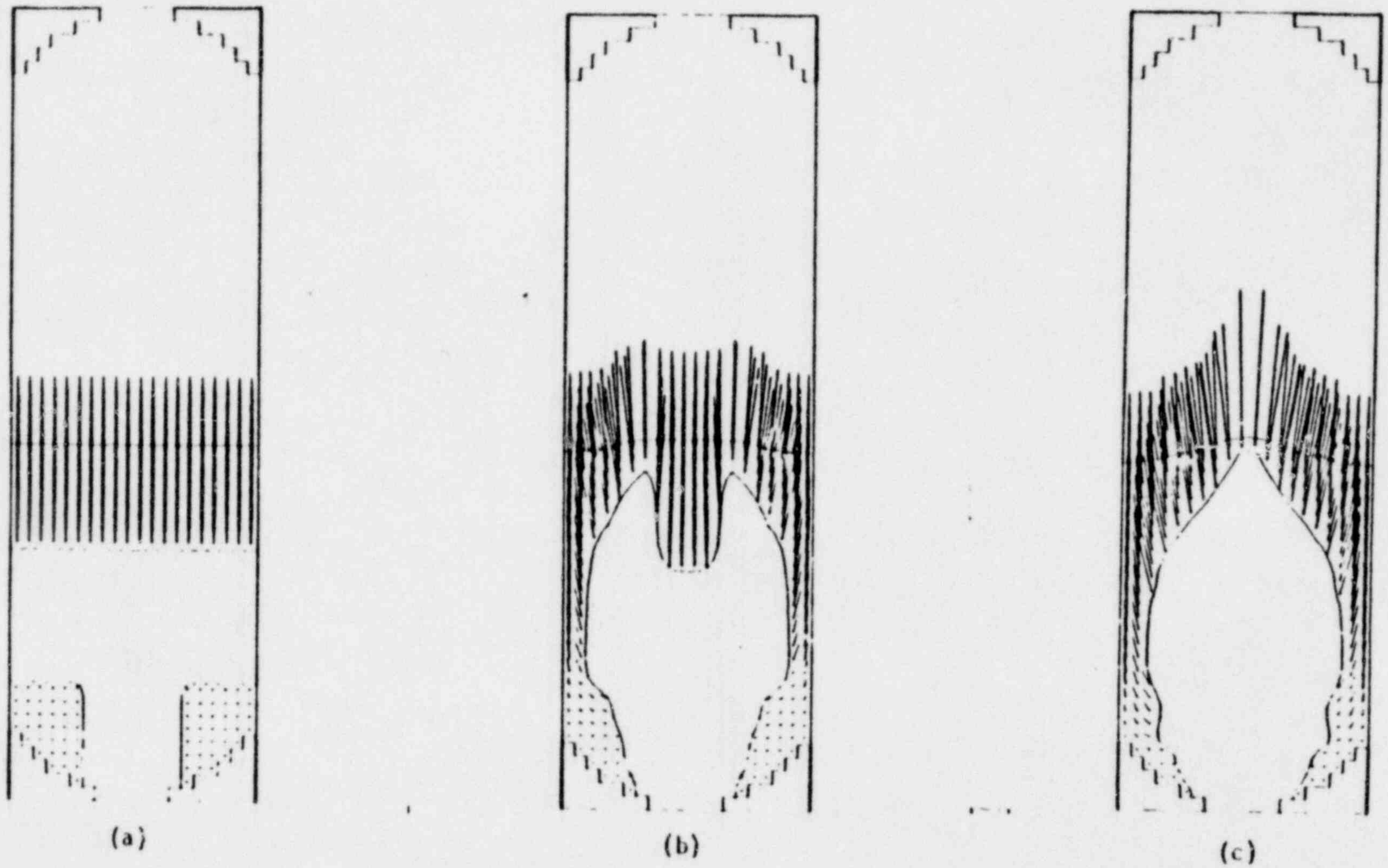


Fig. 61. Interface positions and velocities for the three cases at t = 20 ms.

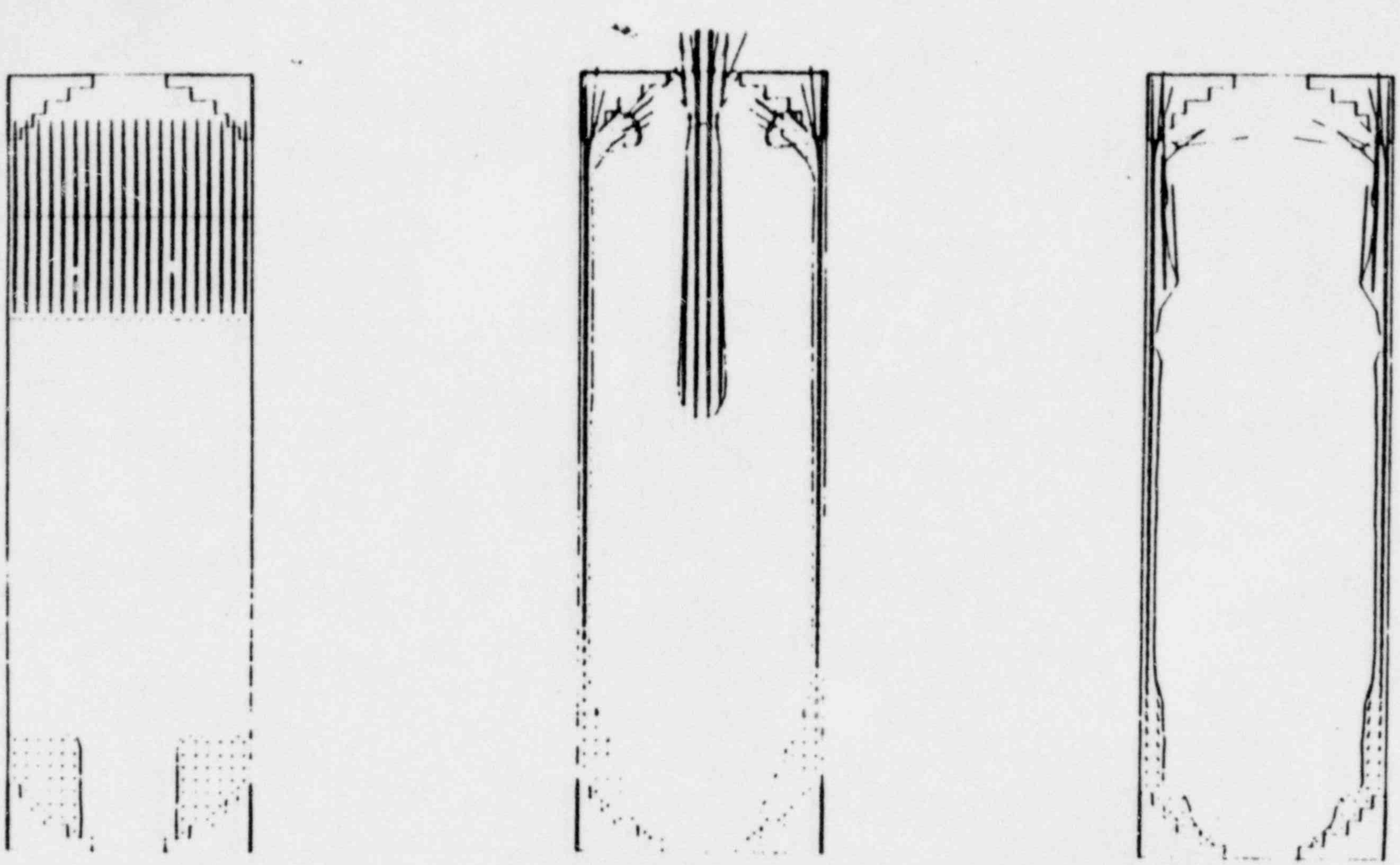


Fig. 62. Interface positions and velocities for the three cases at t = 50 ms.

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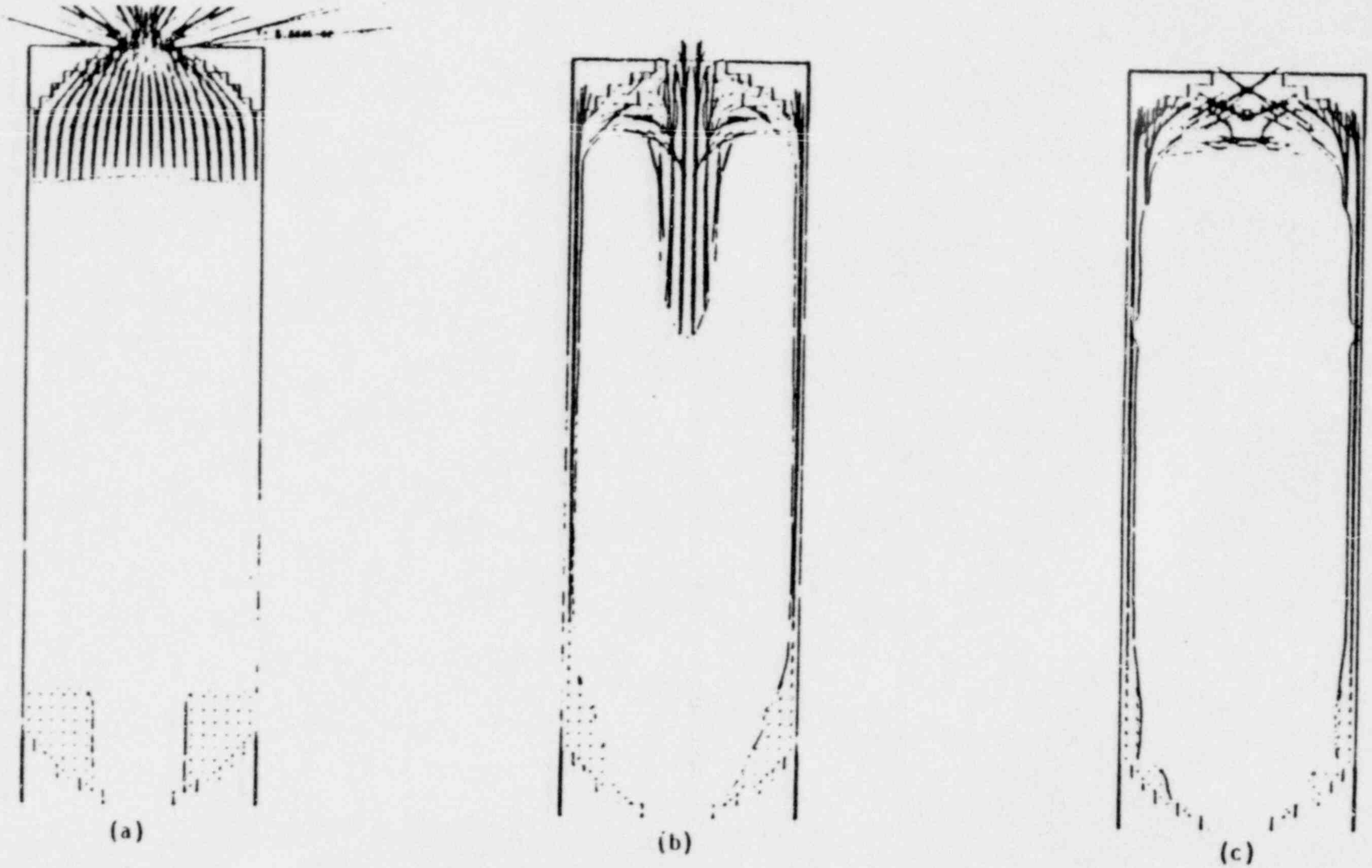

Fig. 63. Interface positions and velocities for the three cases at t = 60 ms.

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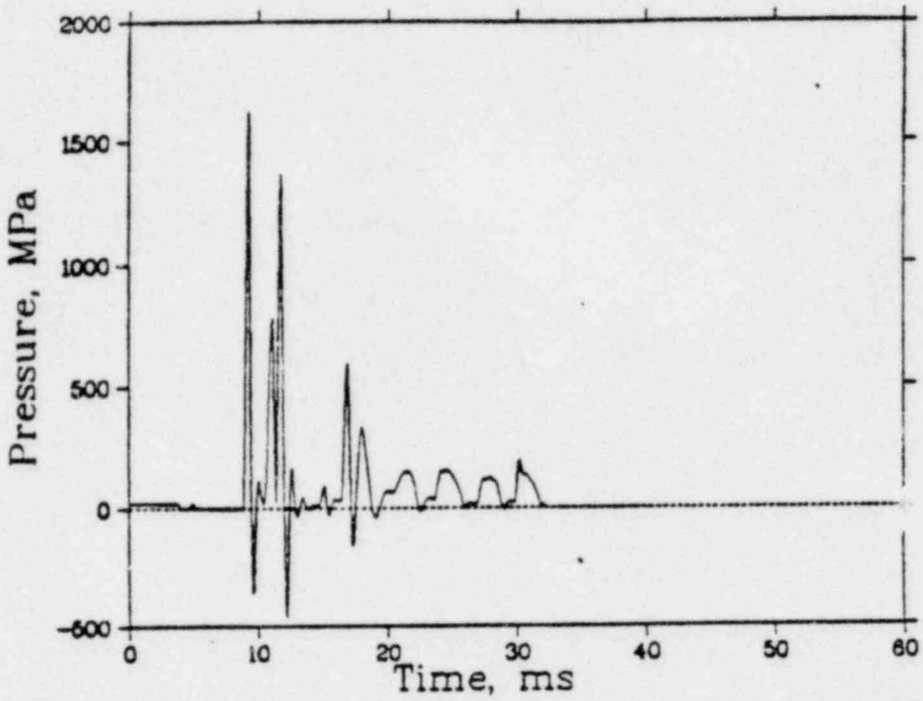

Fig. 65a. Rings 1-3 4.4MN-s impulse for case b.

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PRESSURE VESSEL RESPONSE

TO STEAM EXPLOSIONS

C. A. ANDERSON

LASL

JUNE 17, 1980

PRESSURE VESSEL LOAD SCENARIOS

- STATIC UNIFORM PRESSURE DISTRIBUTION
- STATIC STEPPED PRESSURE DISTRIBUTION
- SOLA-VOF GENERATED COHERENT FUEL SLUG.
- SIMMER GENERATED DIFFUSE FUEL SLUG.

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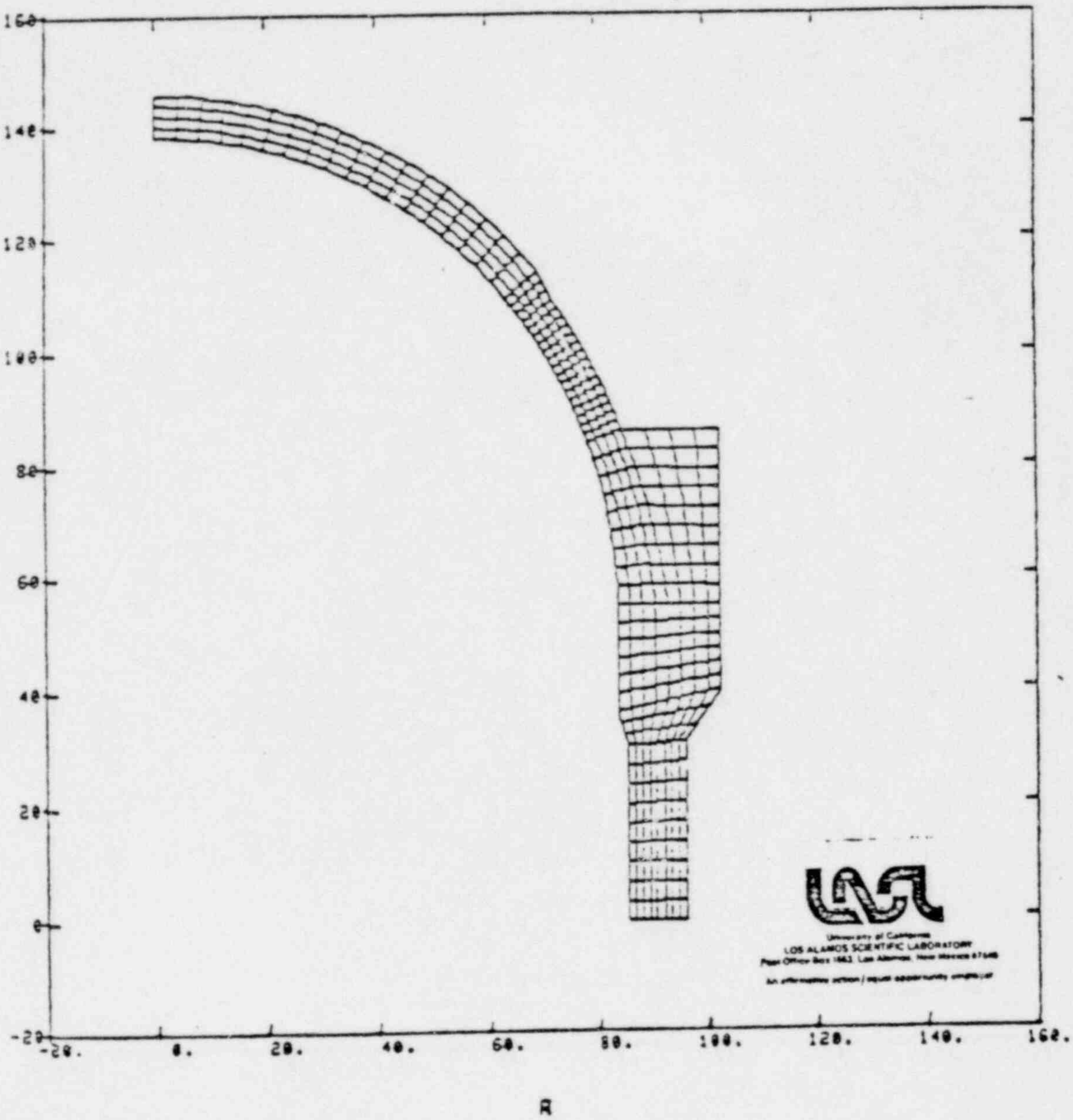

FINITE ELEMENT MESH.

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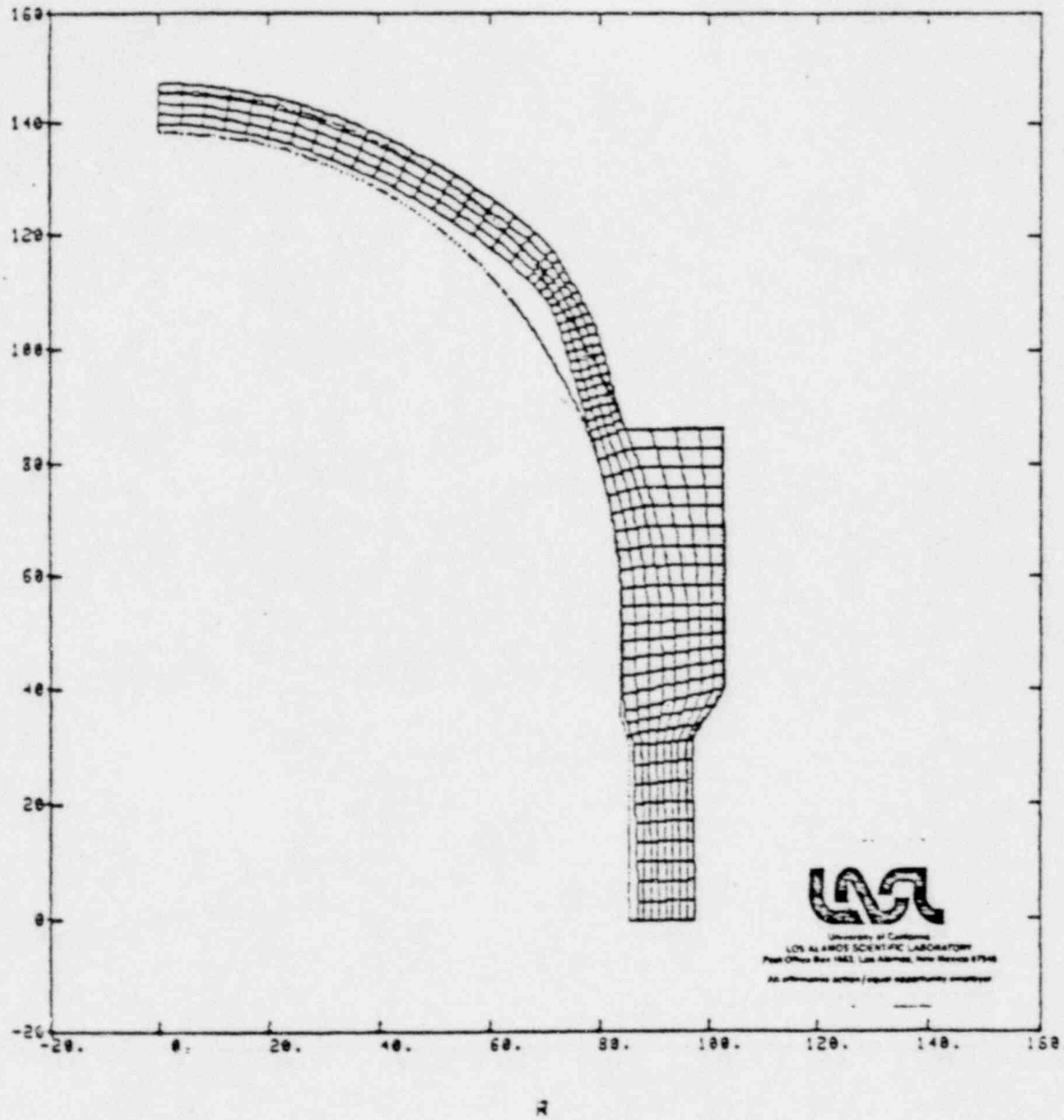
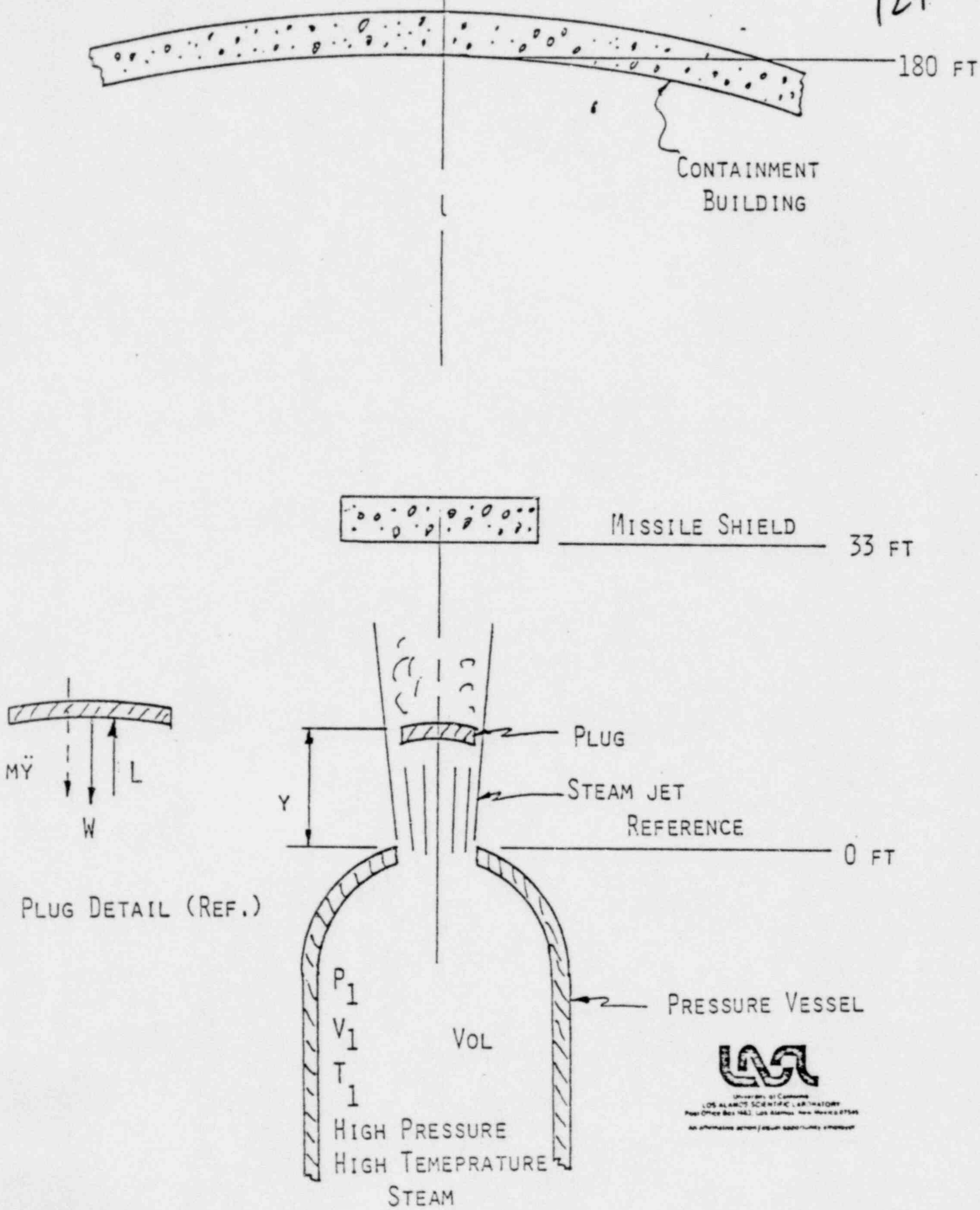


DEFORMED SHAPE DUE TO UNIFORM DYNAMIC PRESSURE.

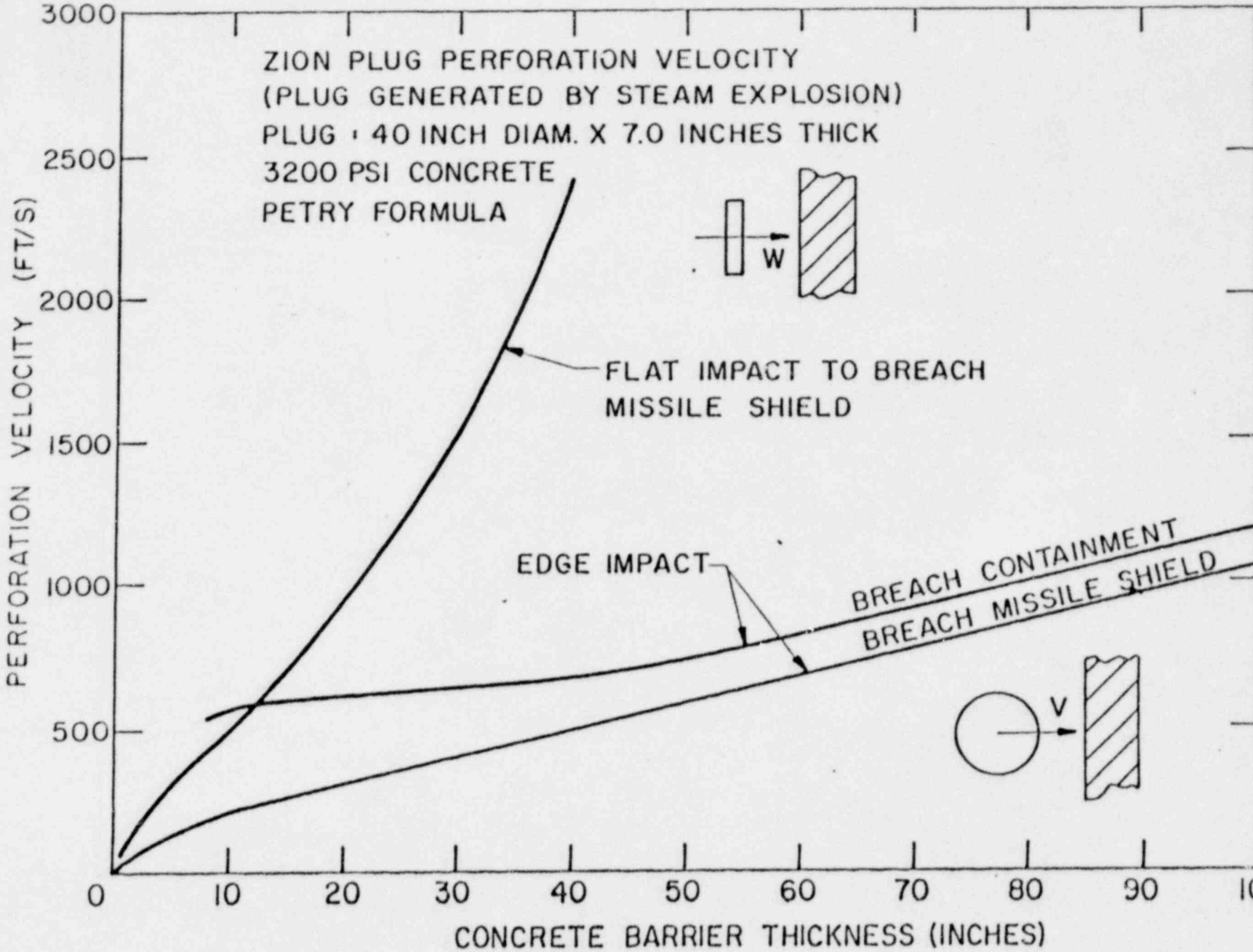
VESSEL FAILURE MODES UNDER VARIOUS LOADING SCENARIOS

Loading Scenario	Peak Pressure	Deformation Mode	Insult To Containment
Static Uniform	6 400 psi	Failure of Cylinder	None-concrete cylinder protects containment
Static Stepped	12 600 psi	Stretch at head apex	None-IPS*
Dynamic Uniform (SIMMER)	11 000 psi	Hinge at perimeter (Indian Point Vessel Only)	None-IPS
Dynamic Diffuse (SIMMER)	18 000 psi	Stretch at head apex	None-IPS
Dynamic Coherent	10^6 psi	Plug shearing of head	Potential missile through shield .

*Insufficient plastic strain



SCHEMATIC DIAGRAM SHOWING COMPONENTS


ZION PLUG PERFORATION VELOCITY
(PLUG GENERATED BY STEAM EXPLOSION)
PLUG : 40 INCH DIAM. X 7.0 INCHES THICK
3200 PSI CONCRETE
PETRY FORMULA
W
FLAT IMPACT TO BREACH MISSILE SHIELD
EDGE IMPACT
BREACH CONTAINMENT
BREACH MISSILE SHIELD
V
PERFORATION VELOCITY (FT/S)
3000
2500
2000
1500
1000
500
0
10
20
30
40
50
60
70
80
90
100
CONCRETE BARRIER THICKNESS (INCHES)

125

Meeting 6

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