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Finite Element Models for the Single-Web Sheave Design for the Shippingsport Vertical Lift Bridge	August, 1997
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This work was conducted jointly with the Bureau of Bridges & Structures and District 3.

16. Abstract
Finite element models for the Shippingport Vertical Lift Bridge over the Illinois River at LaSalle were created using a single-web design for the sheaves. The models used both linear and sinusoidal load distributions along the periphery of the sheave. A model of the cable tray was also created. Using an analysis developed at the University of Illinois, 4/5P downward loading and 1/5P per side was used for loading each semi-circular channel. The models were additionally rotated 18° for maximum loading. Peak tensile stresses generated in the cable tray were at 7.6 ksi, and the peak tensile web stress was 3.3 ksi. A hub analysis was also conducted using internal pressures of 8,000 psi and 4,000 psi generated by the FN3 shrink required by the AASHTO Movable Bridge Code. Peak stresses in the forged ASTM A668 Class C hub were 23.1 ksi at 8,000 psi pressure, whereas it was only 12.2 ksi peak tensile stress at 4,000 psi.

17. Key Words	18. Distribution Statement
sheave; shafting; trunnion; shrink fit; hub; plate; finite element models; stresses; load distribution function; vertical lift bridge; movable bridge; Shippingsport Bridge; Illinois River	Unlimited.

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Analysis of the Shippingsport Vertcal Lift Bridge
Sheave Components - May 1997 - Report 2 -

CONTENTS

Introduction

This report is the second part of the Shippingsport bridge sheave analysis. The first report should be referred to for a complete description of the applied loading. The objective of this analysis is to evaluate a new design of the sheave, which is primarily constructed around a single center web. This single web design is an alternate to the three web design that was investigated in the first report.

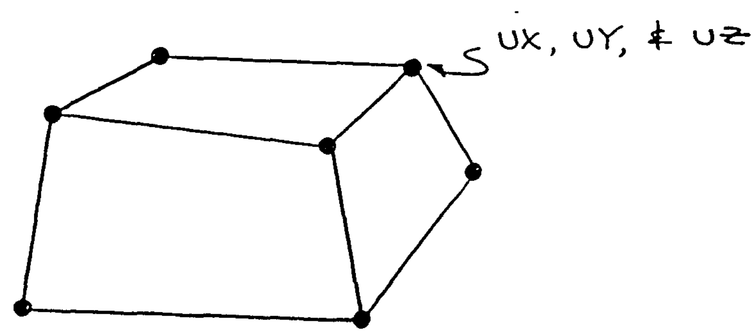
The approach used in this analysis is simular to the first analysis in that two different load distributions along the cable tray were used; linear and sinusoidal. Also like in the first report, two sheave orientations were also investigated. The two orientations that were analyzed are zero offset and an 18 degree rotational offset.

A local model of the cable tray is also presented in this report. This model is constructed using 3-D solid elements, commonly called 8-noded bricks. These elements have 3 degrees of freedom at each node; translations in X, Y, and Z.

Finally, the central hub of the sheave was analyzed again using 3-D solid elements. The loading for the sheave hub is comprised of an 8000 psi shrink fit pressure superimposed with the pressure distribution created from the weight of the counter balance.

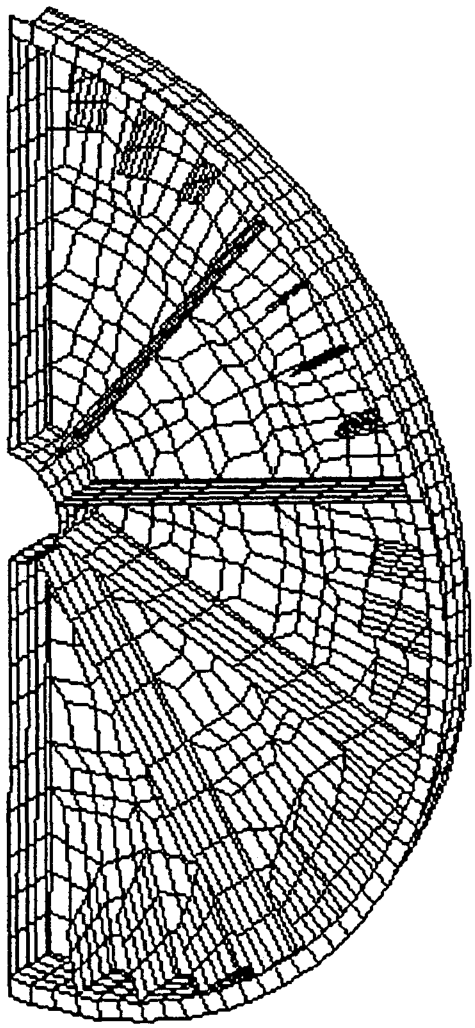
The following properties for the steel materials were used in this analysis:

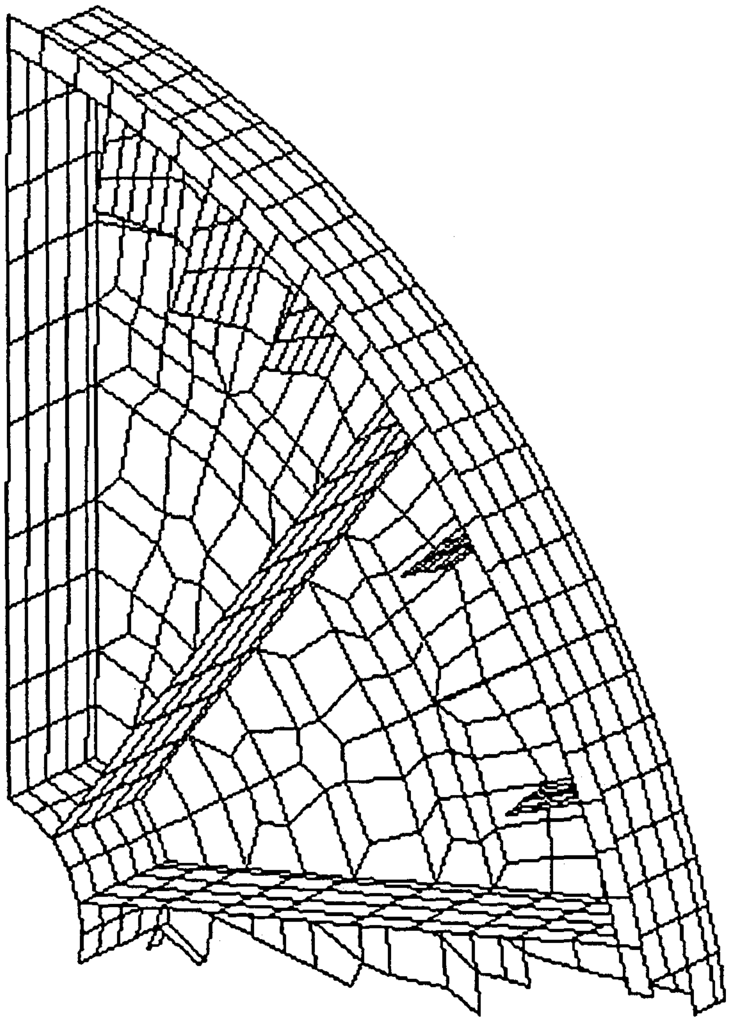
Modulus of Elasticity	(psi)	30,000,000
Poisson's Ratio		.3

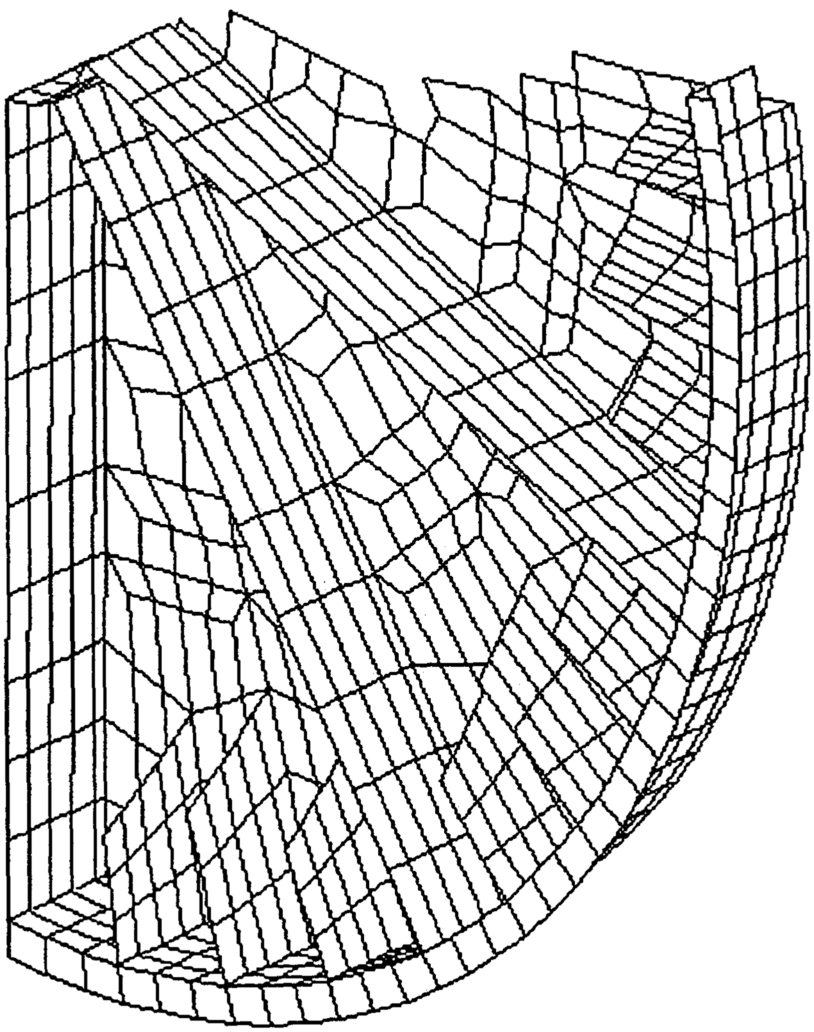


8-NODED BRICK

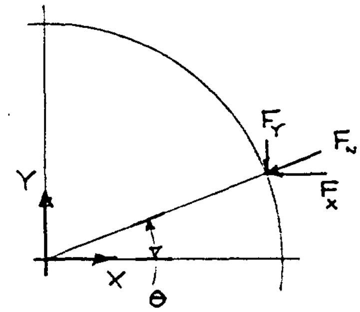
FEA 1/4 MODEL OF THE SHEAVE - NO OFFSET







LINEAR LOAD DISTRIBUTION



$$p = \frac{2T}{D}$$

FOR THE FEA 1/4 MODEL,

$$T = \frac{221{,}653 \text{ LB}}{2} = 110{,}826.5 \text{ LB}$$

$$p = \frac{2(110{,}826.5)}{150} = 1478 \text{ LB/IN}$$

$$F_N = p \times \ell$$

FOR 12° INCREMENTS,

$$\ell = r \times \theta$$

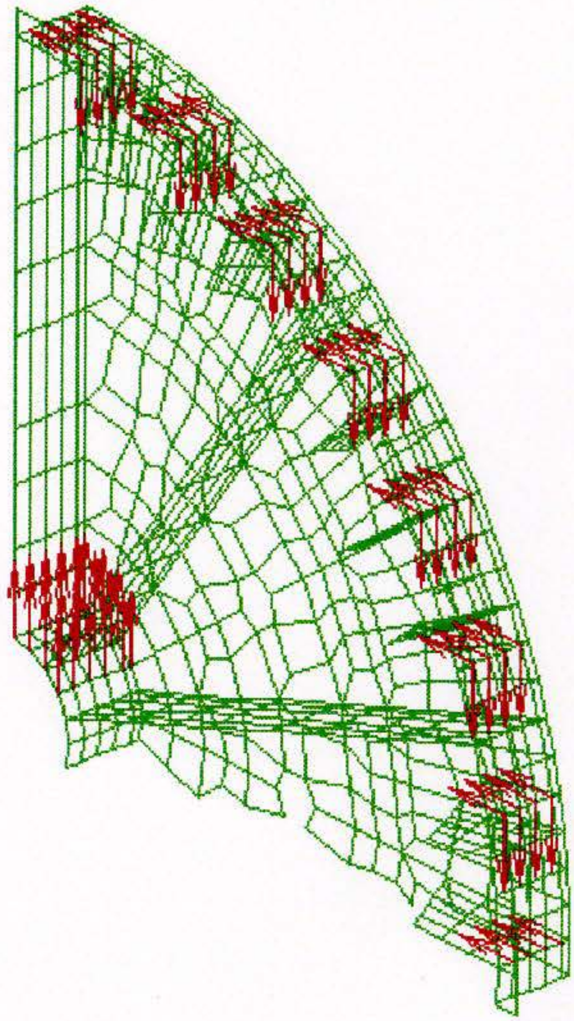
$$\ell = 75 \text{ IN } (.2094 \text{ RAD}) = 15.705 \text{ IN}$$

$$F_N = 1478 \frac{\text{LB}}{\text{IN}} (15.705 \text{ IN}) = 23{,}212 \text{ LB}$$

#	θ LOCATION FOR LOAD	p	F_N	F_X	F_Y
1	84°	1478 LB/IN	23,212 LB	2426 LB	23,085 LB
2	72°	↓	↓	7173	22,076
3	60°			11,606	20,102
4	48°			15,532	17,250
5	36°			18,779	13,644
6	24°			21,205	9441
7	12°			22,705	4826
8	0°			23,212	0

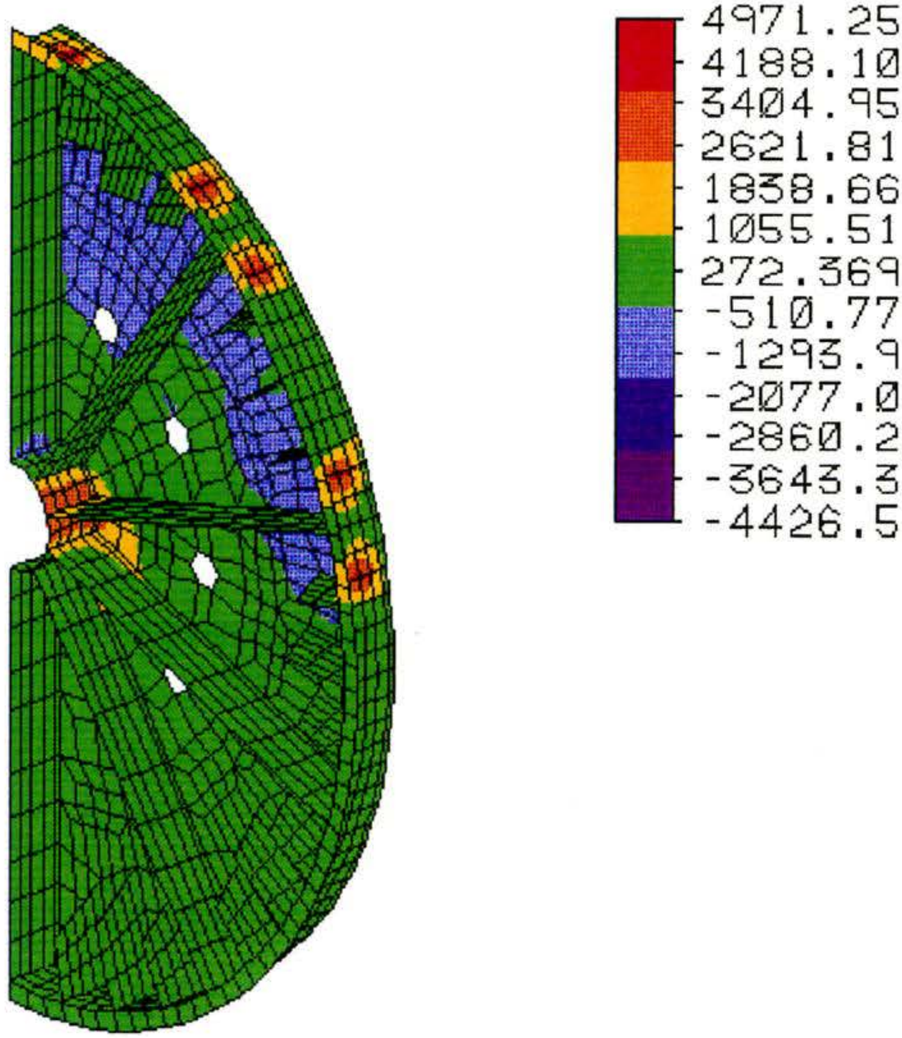
110,424 LB ✓

LOAD CASE 5



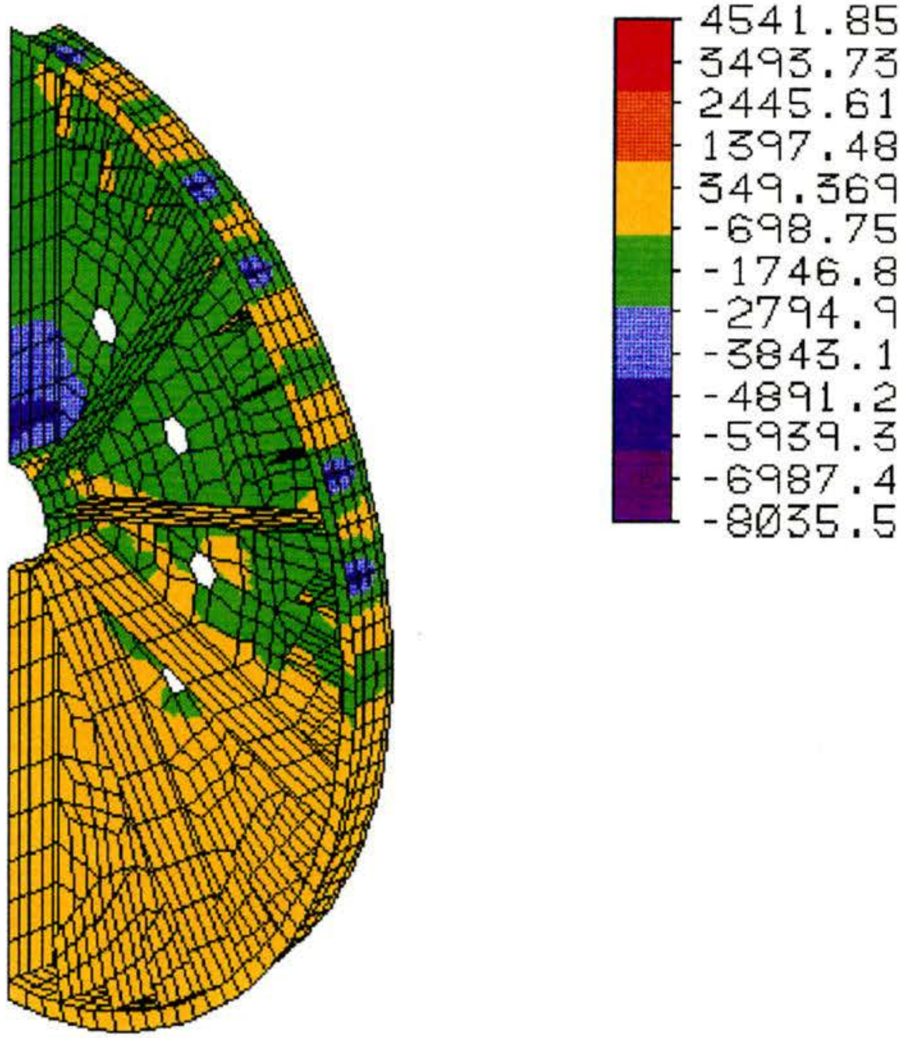
LOADING PLOT

C 5



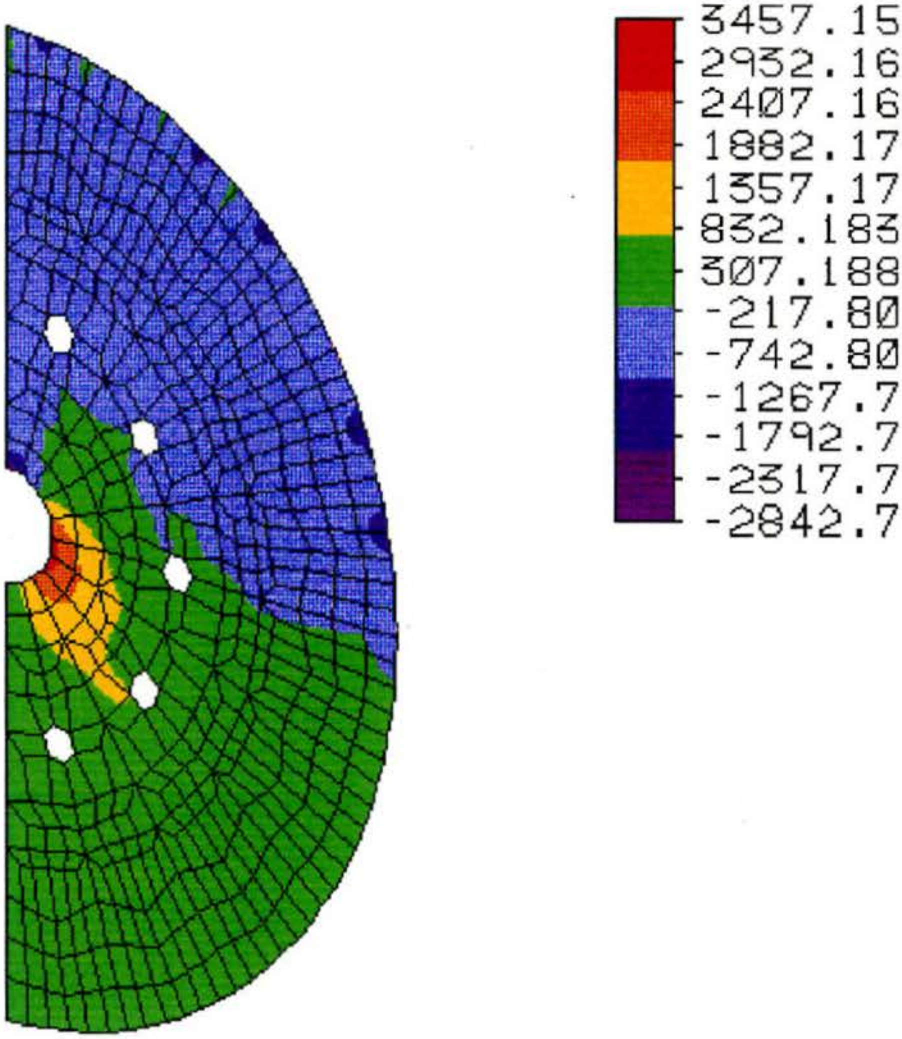
MAXIMUM PRINCIPLE TENSILE STRESS (psi)

LC 5



MAXIMUM PRINCIPLE COMPRESSIVE STRESS (psi)

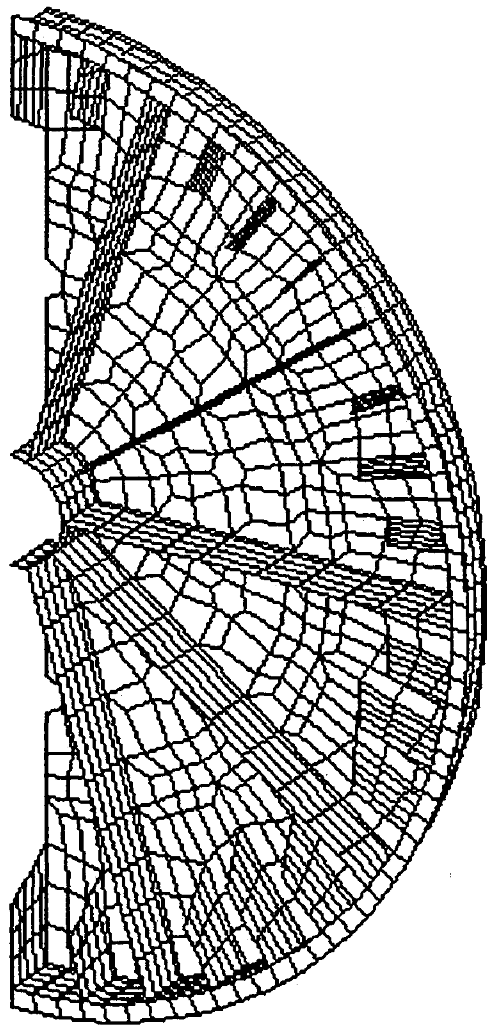
LC 5



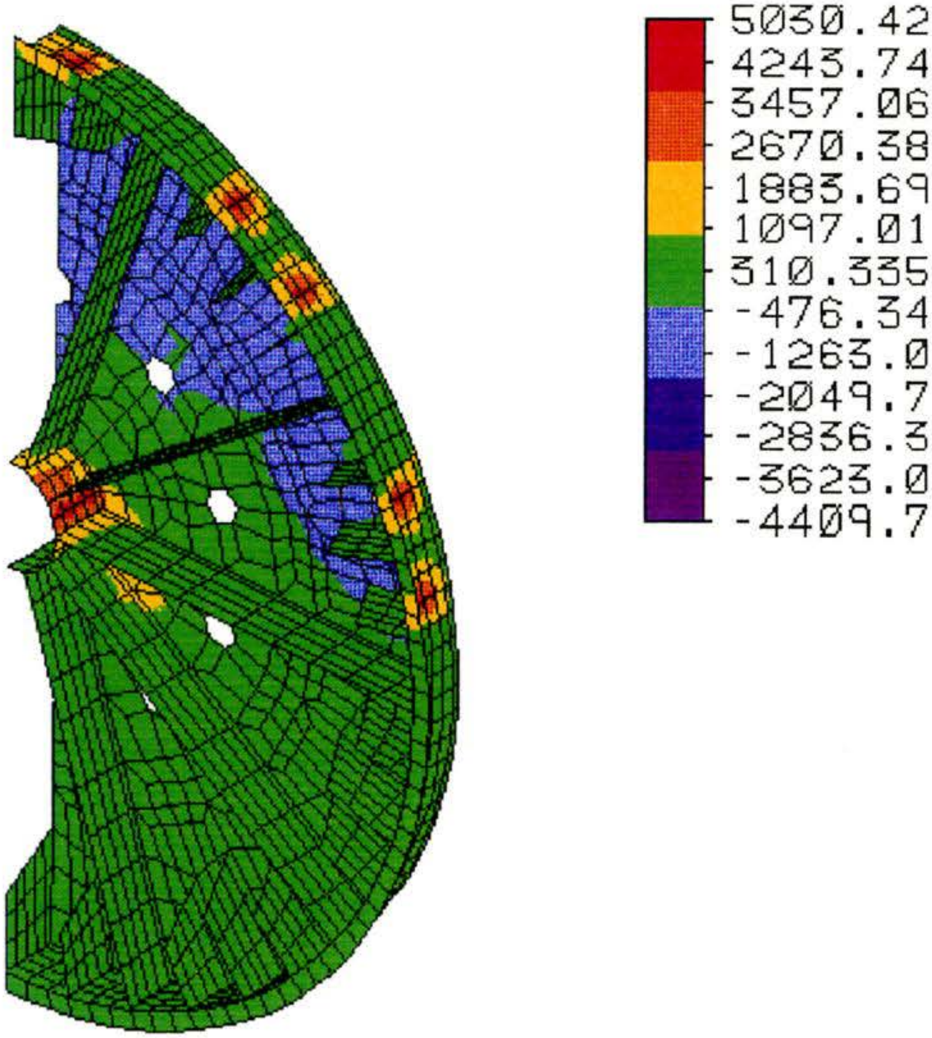
CENTER WEB

MAXIMUM PRINCIPLE TENSILE STRESS (psi)

LC 6 - 18° OFFSET

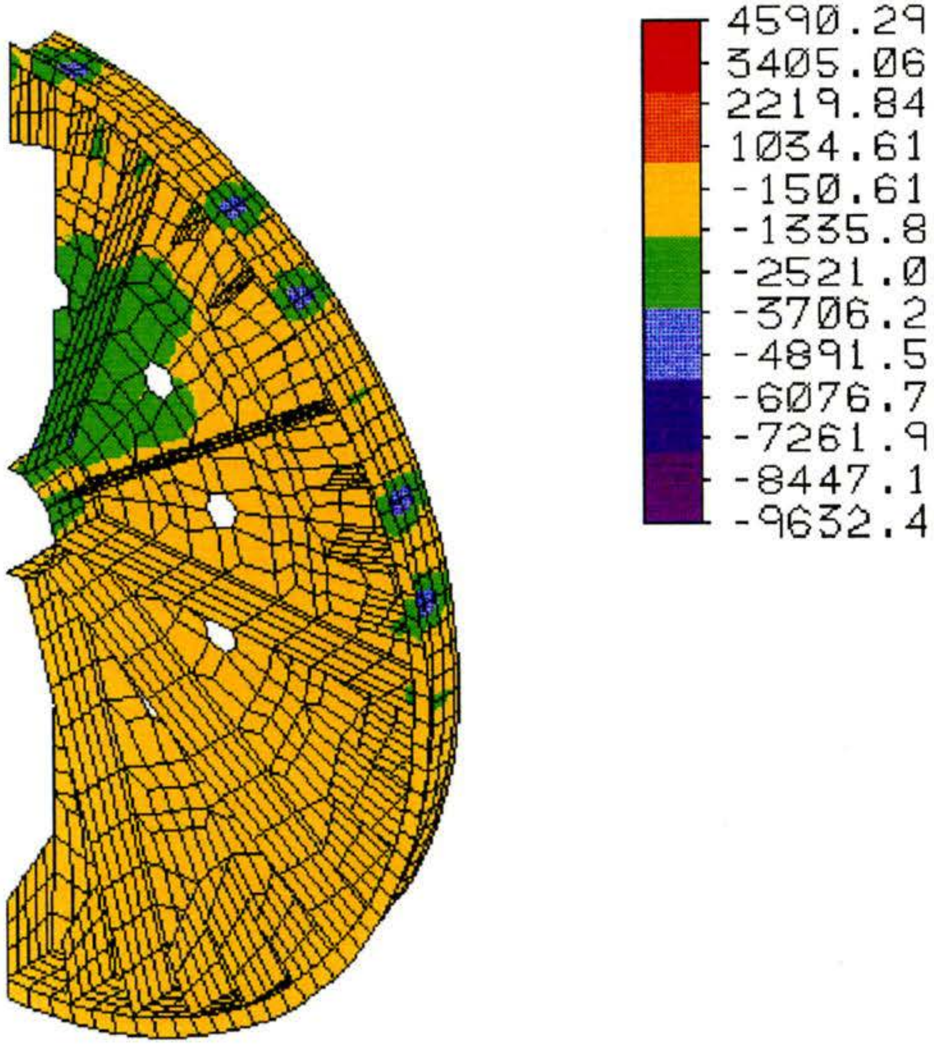


LC 6



MAXIMUM PRINCIPLE TENSILE STRESS (psi)

LC 6



MAXIMUM PRINCIPLE COMPRESSIVE STRESS (psi

SINUSOIDAL LOAD DISTRIBUTION

$$P_{MAX} = \frac{4T}{\pi R}$$

$$P_{MAX} = \frac{4(110{,}826.5 \text{ LB})}{\pi \ (75 \text{ IN})} = 1881 \text{ LB/IN}$$

$$P = P_{MAX} (\sin \theta)$$

FOR 12° INCREMENTS,

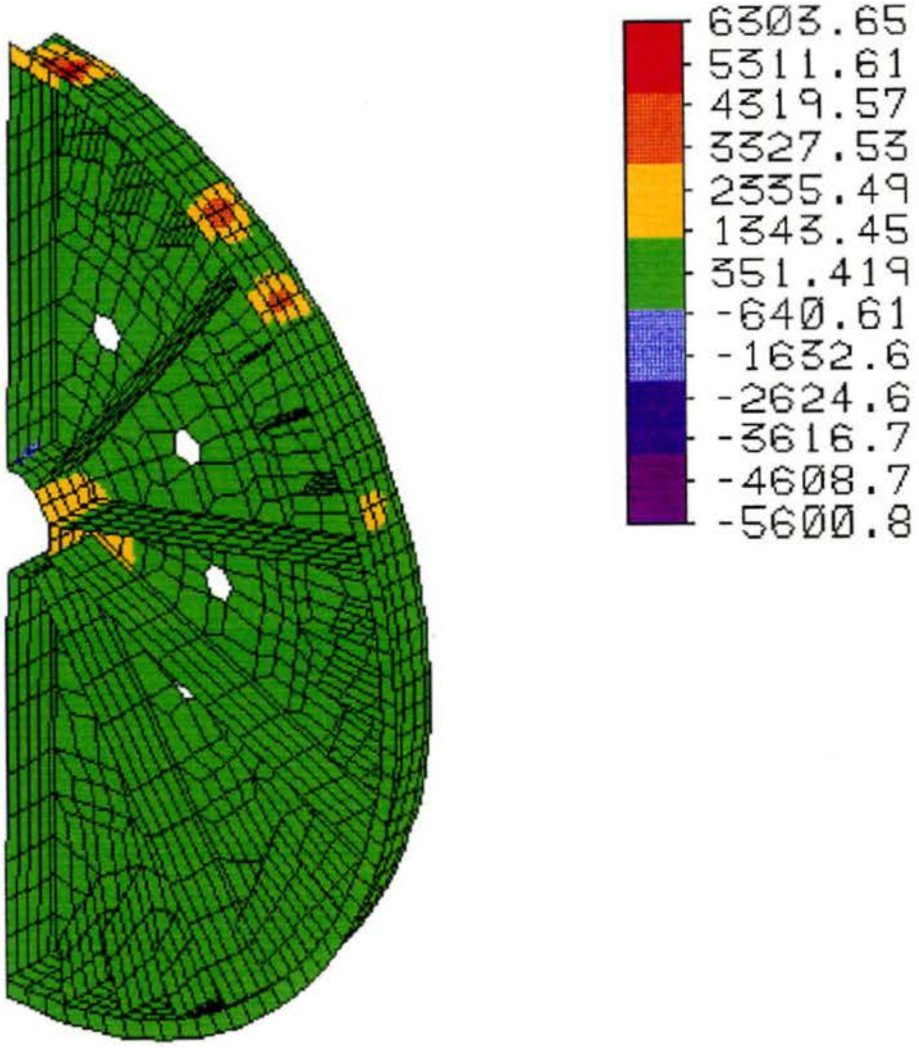
$$\ell = 15.705 \text{ IN}$$

$$F_N = P \times \ell$$

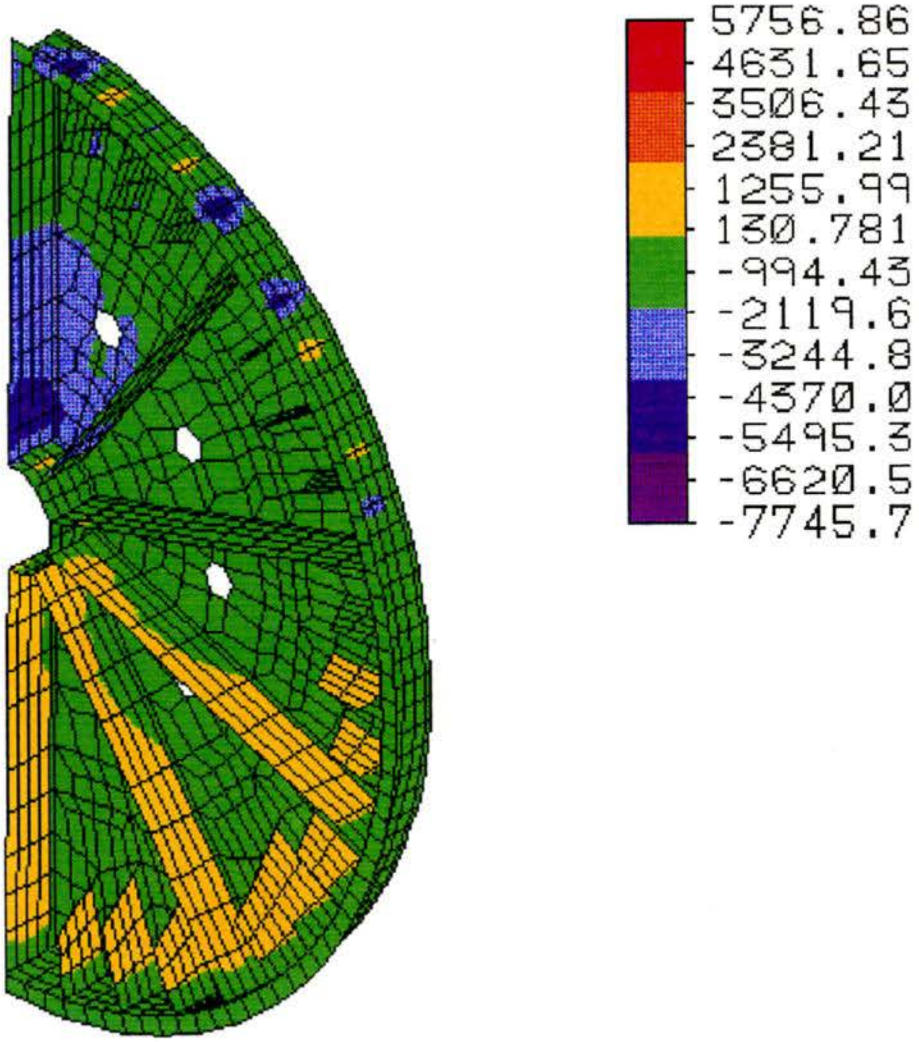
#	θ LOCATION FOR LOAD	P	F_N	F_x	F_Y
1	84°	1871 LB/IN	29,384 LB	3071 LB	29,223 LB
2	72°	1789	28,096	8682	26,721
3	60°	1629	25,583	12,792	22,156
4	48°	1398	21,956	14,691	16,316
5	36°	1106	17,370	14,053	10,210
6	24°	765	12,014	10,975	4887
7	12°	391	6141	6007	1277
8	0°	0	0	0	0

110,790 LB ✓

LC 7

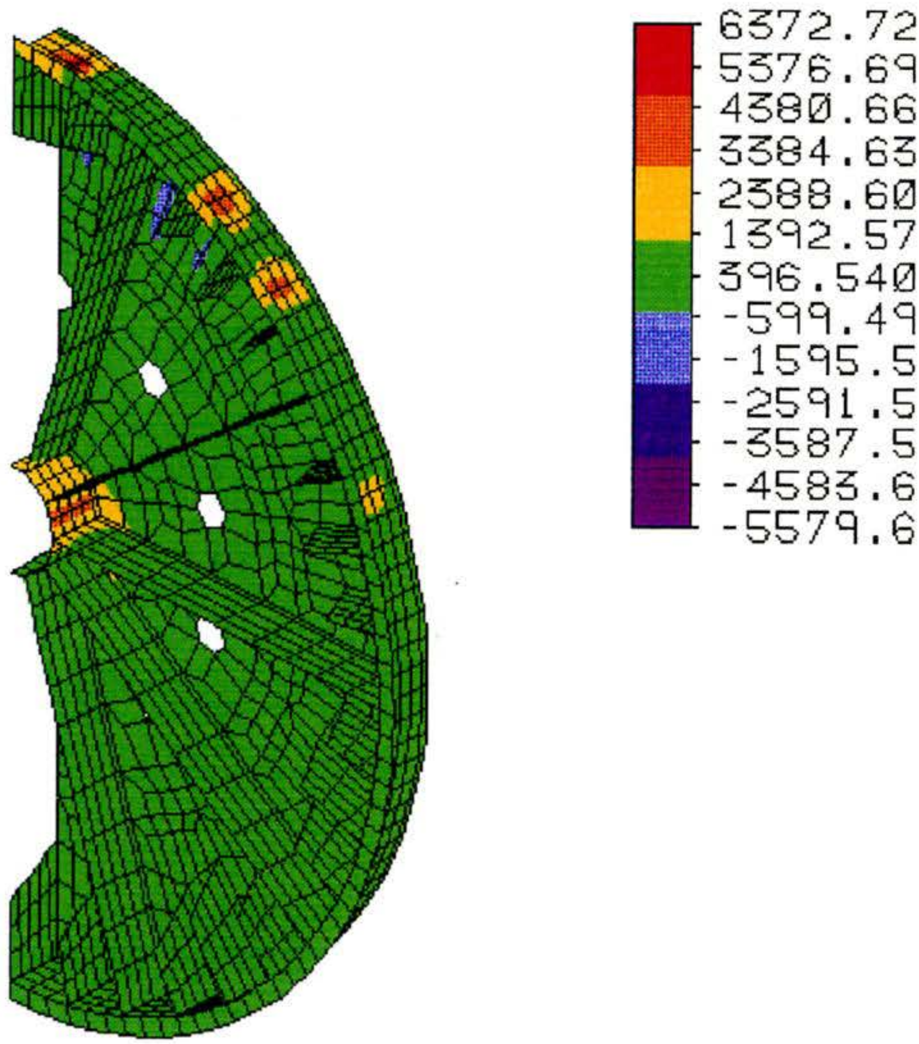


MAXIMUM PRINCIPLE TENSILE STRESS (psi)



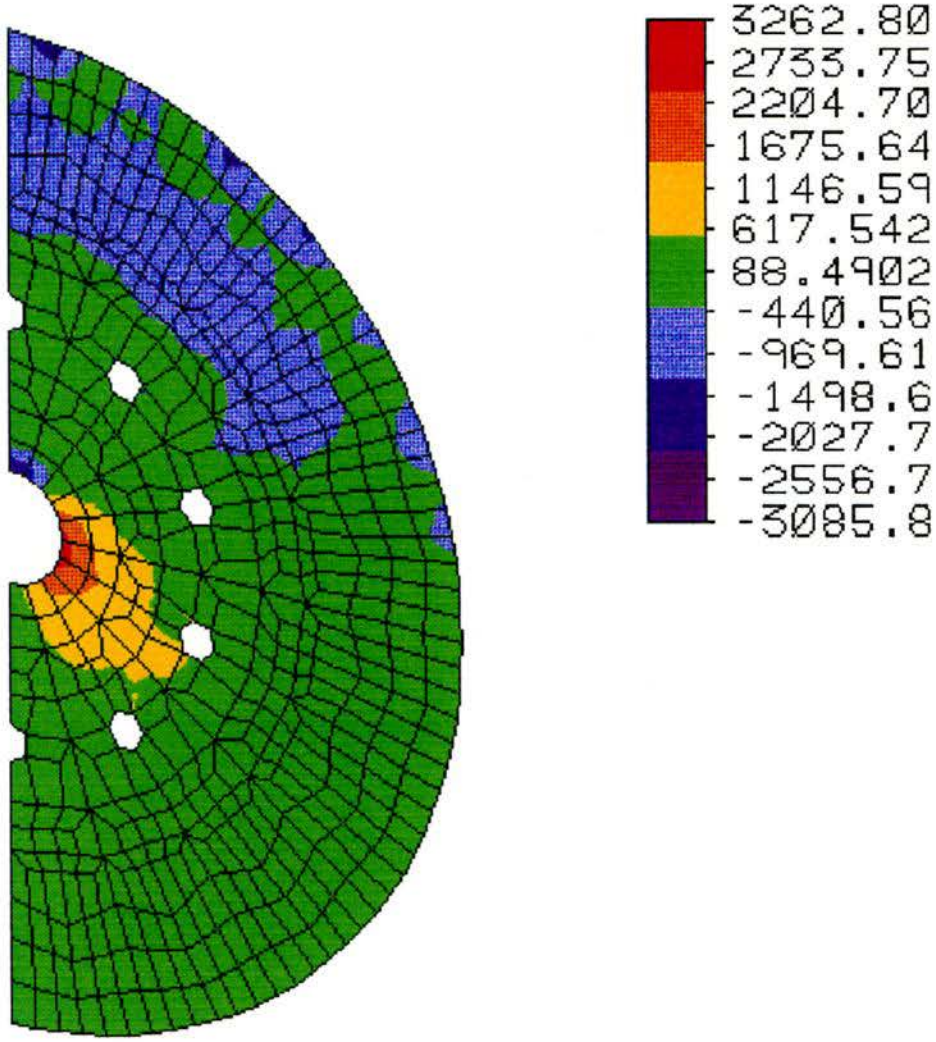
MAXIMUM PRINCIPLE COMPRESSIVE STRESS (psi)

LC 8 - 18° OFFSET



MAXIMUM PRINCIPLE TENSILE STRESS (psi)

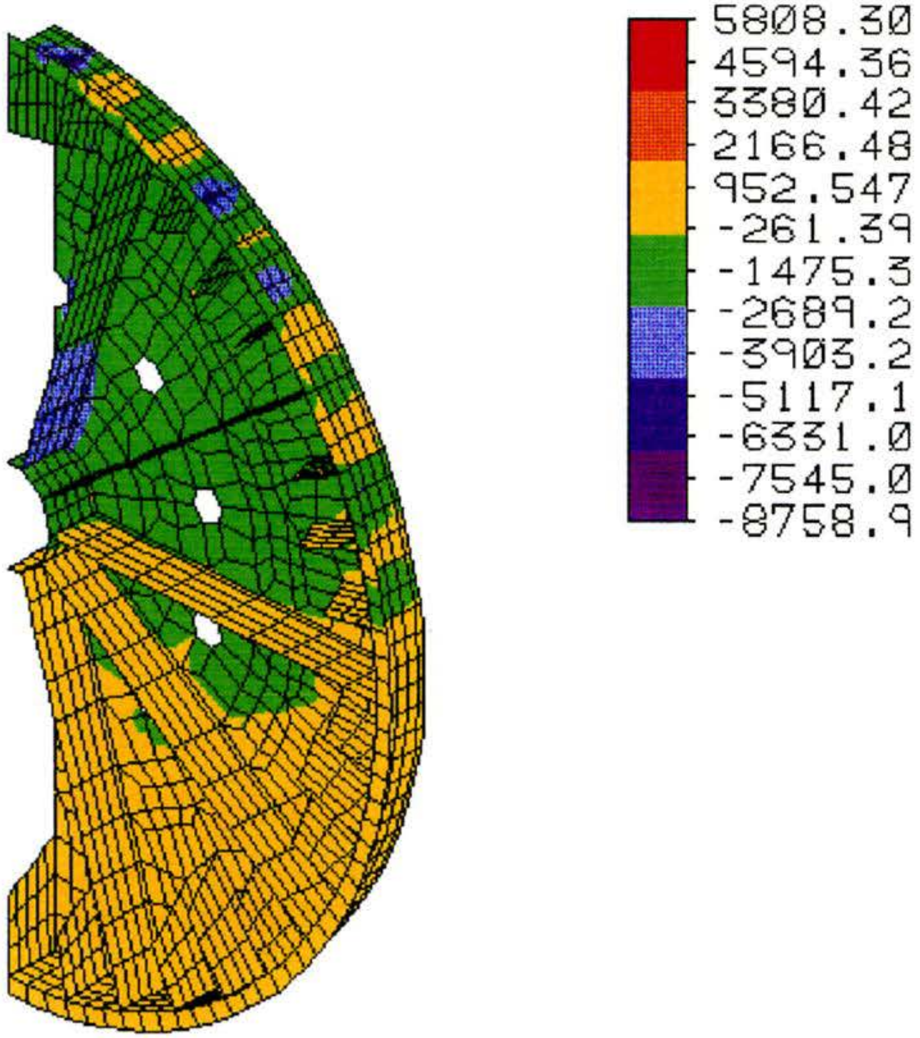
LC 8



CENTER WEB

MAXIMUM PRINCIPLE TENSILE STRESS (psi)

LC 8



MAXIMUM PRINCIPLE COMPRESSIVE STRESS (psi)

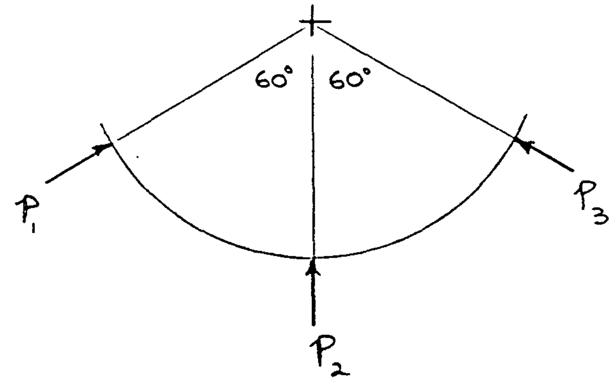
CABLE TRAY LOADING

BASED ON THE LINEAR LOAD DISTRIBUTION

{REF. P. 32 REPORT 1}

$P_1 = P_3 = 73.9 \text{ LB/IN}$

$P_2 = 295.6 \text{ LB/IN}$

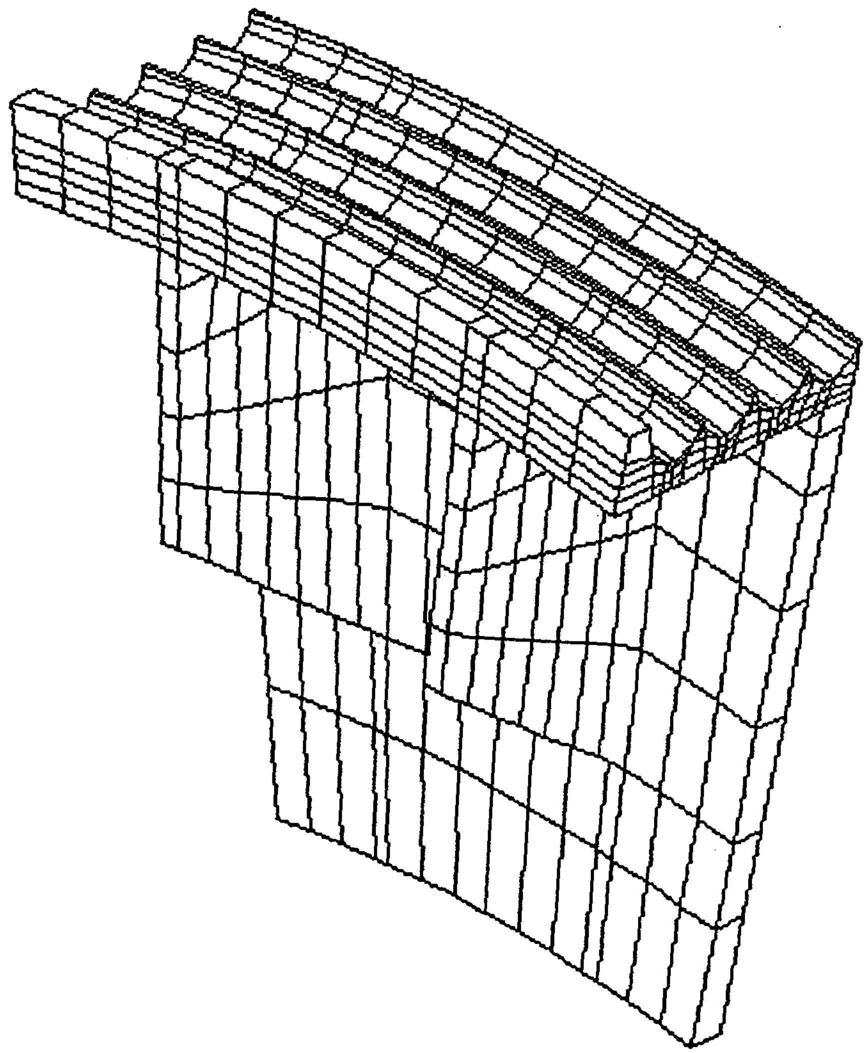


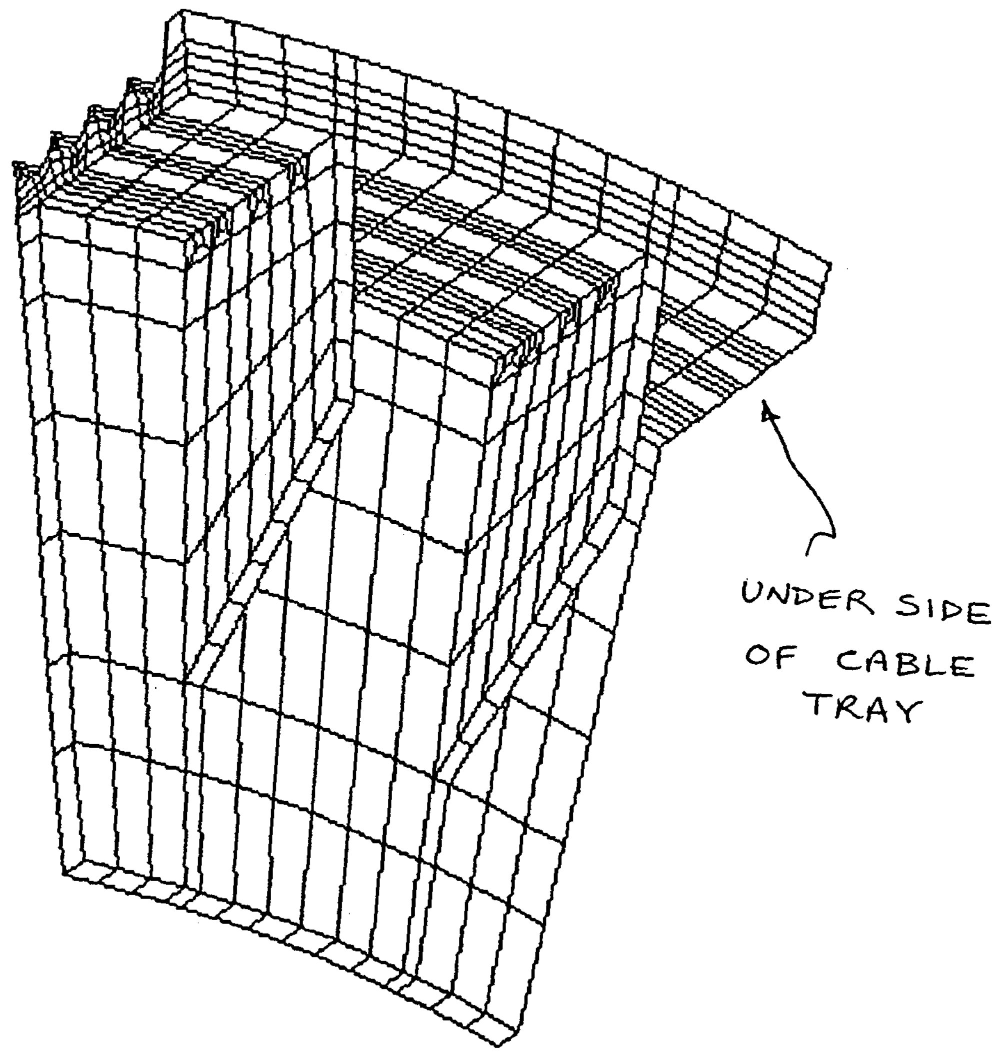
FOR MODEL,

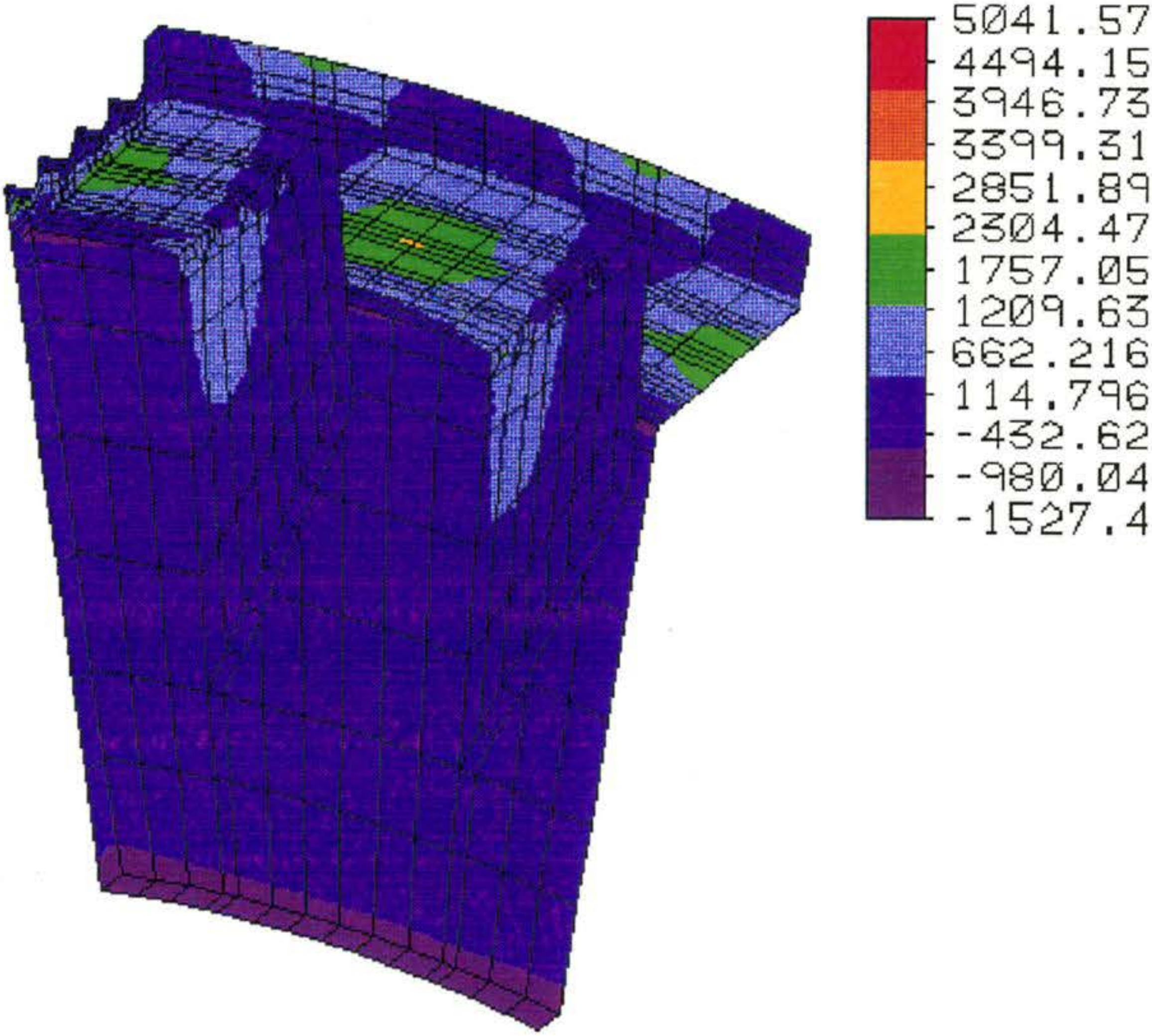
$$q_1 = q_3 = \frac{73.9 \text{ LB/IN}}{.347 \text{ IN}} = 213 \text{ psi}$$

$$q_2 = \frac{295.6}{.347} = 852 \text{ psi}$$

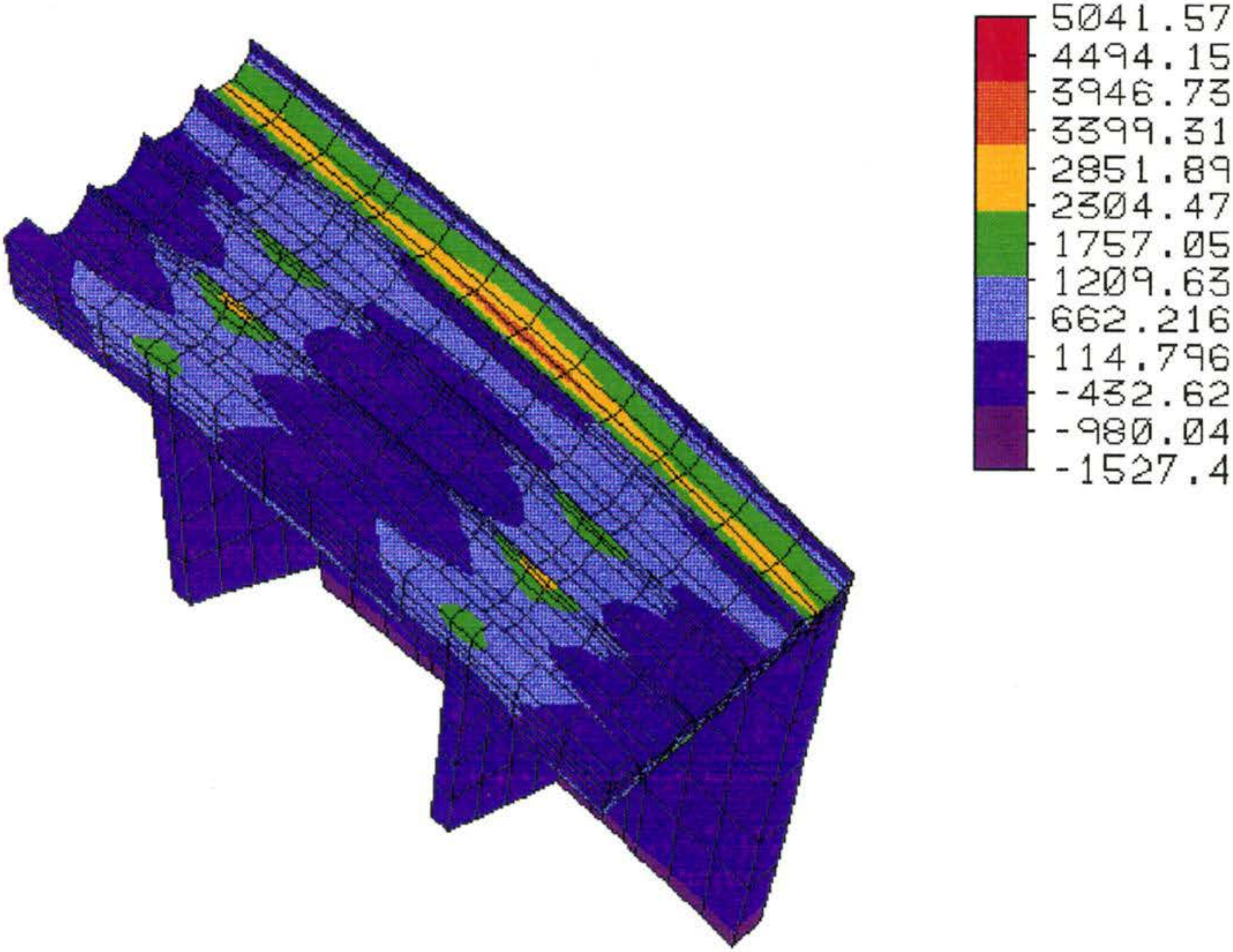
CABLE TRAY LOCAL MODEL



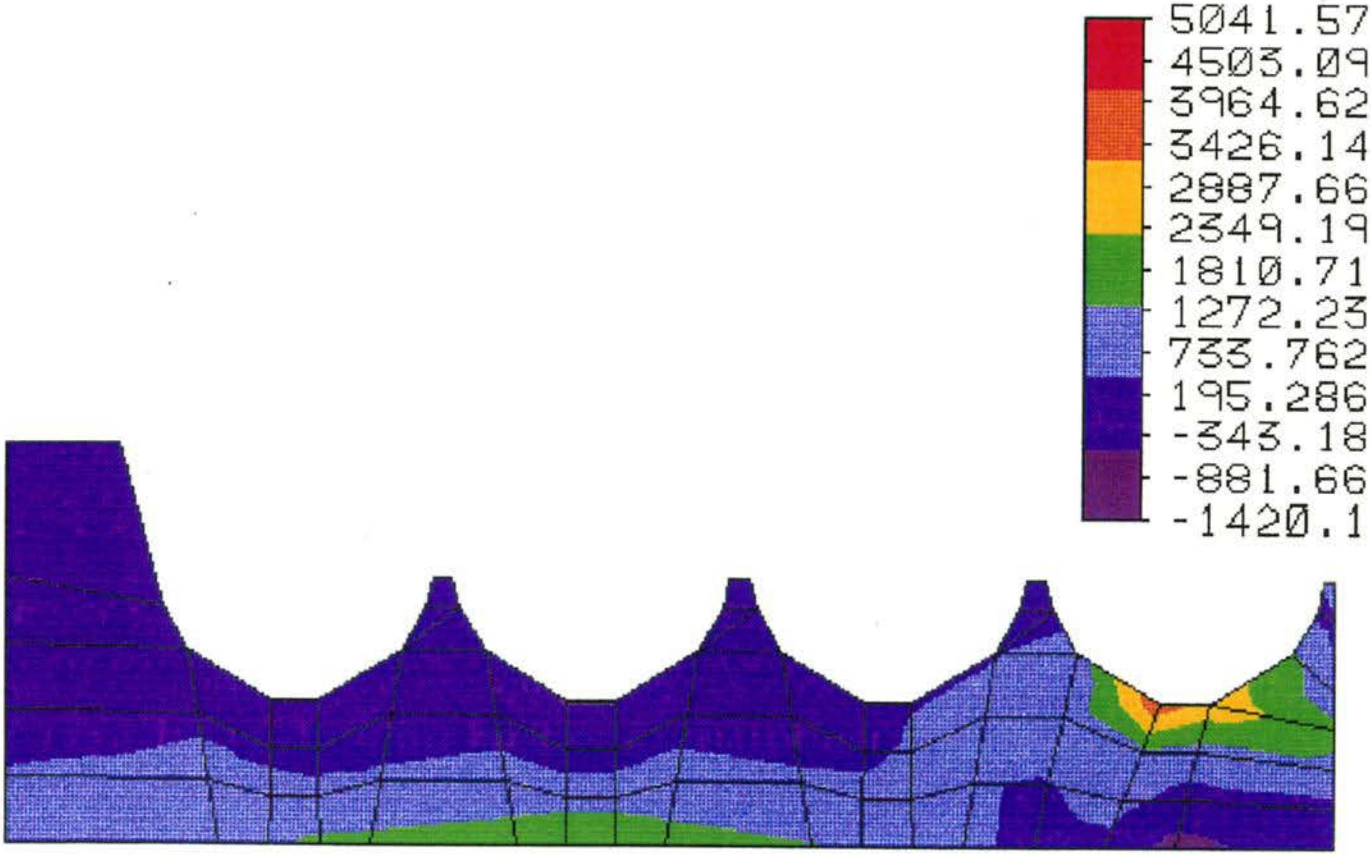

UNDER SIDE
OF CABLE
TRAY



MAXIMUM PRINCIPLE TENSILE STRESS (psi)



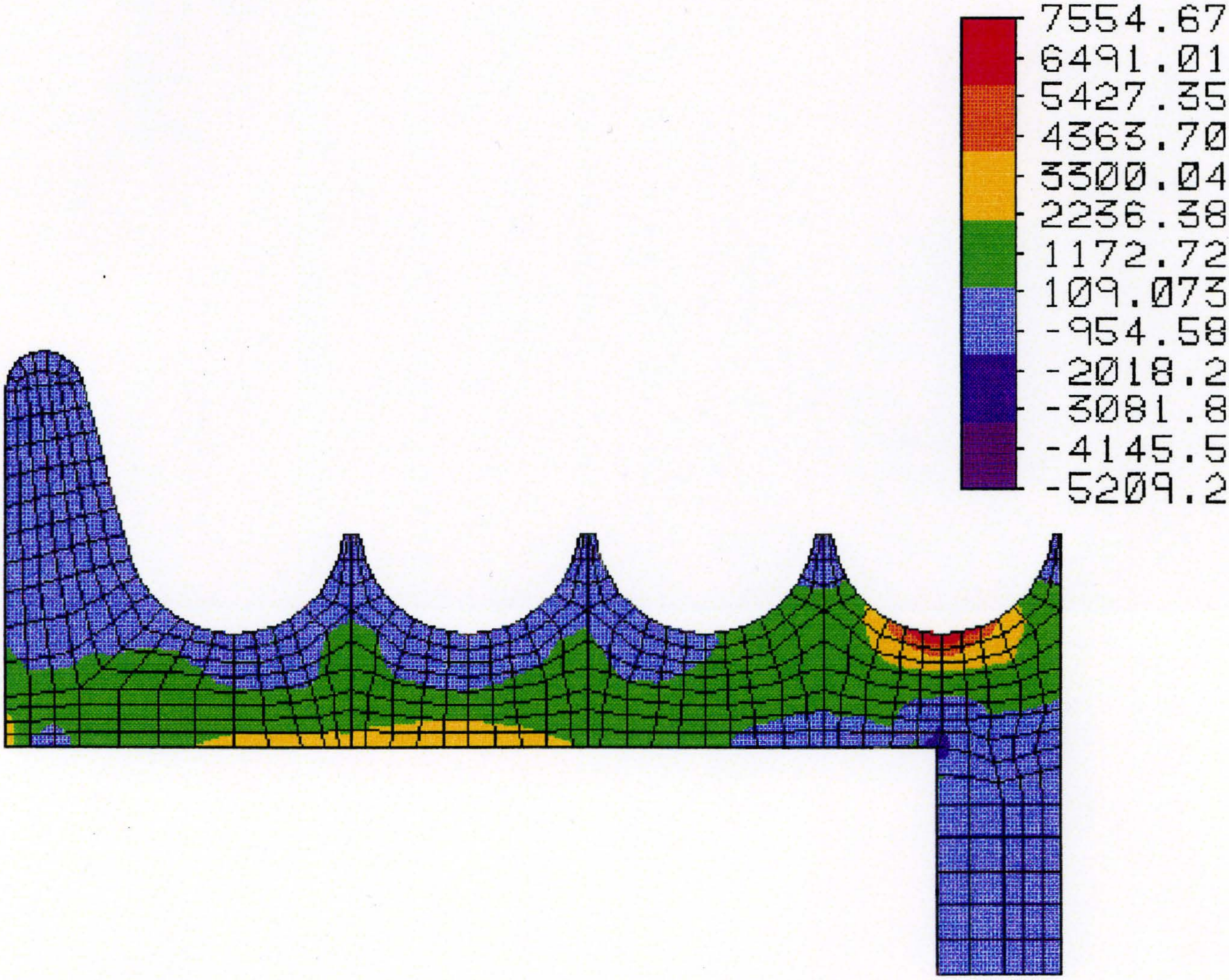
MAXIMUM PRINCIPLE TENSILE STRESS (psi)



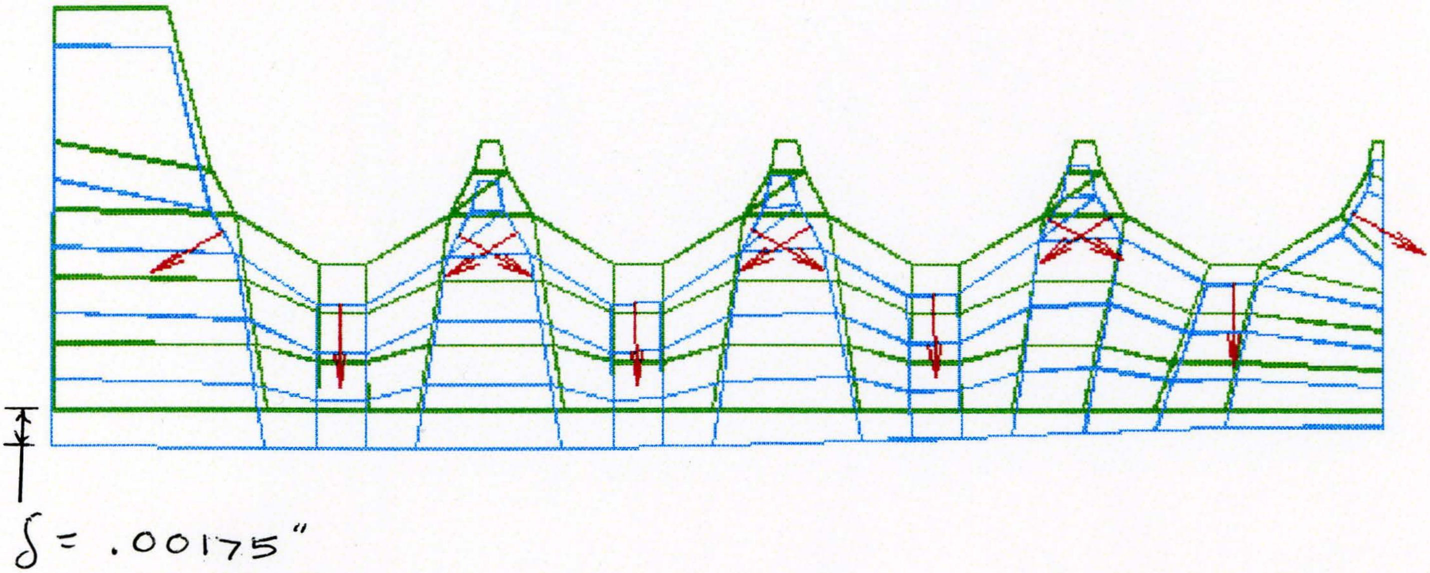
CROSS SECTION OF PEAK STRESS AREA

MAXIMUM PRINCIPLE TENSILE STRESS (psi)

CABLE TRAY - FINER MESH

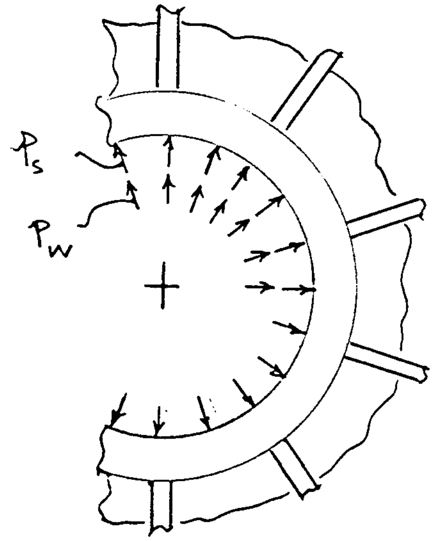


MAXIMUM PRINCIPLE TENSILE STRESS (psi)



DEFLECTED SHAPE SUPERIMPOSED ON THE MODEL

HUB ANALYSIS WITH 8000 psi & 4000 psi SHRINK FIT PRESSURE



FOR $P_{SHRINK} = 8000$ psi

$$P_{WEIGHT} = \frac{443{,}306 \text{ LB}}{14.0 \text{ IN } (20.0 \text{ IN})}$$

$$P_W = 1583 \text{ psi}$$

LET HALF OF P_W ADD TO THE SHRINK FIT PRESSURE AT THE TOP, AND HALF SUBTRACT FROM THE BOTTOM.

NOW,

$$P_{TOP} = 8000 + \frac{1583}{2} = 8792 \text{ psi}$$

$$P_{BOTTOM} = 8000 - \frac{1583}{2} = 7208 \text{ psi}$$

TORQUE CAPACITY IS;

$$T = F \times R$$

$M_{FRICTION}$

$$T = \left[8000 \text{ psi} \left(\pi (14 \text{ IN})\, 20 \text{ IN}\right) .1\right] 7 \text{ IN} = 4{,}926{,}00 \text{ IN-LB}$$

(410,500 FT-LB)

FOR $P_{SHRINK} = 4000$ psi ,

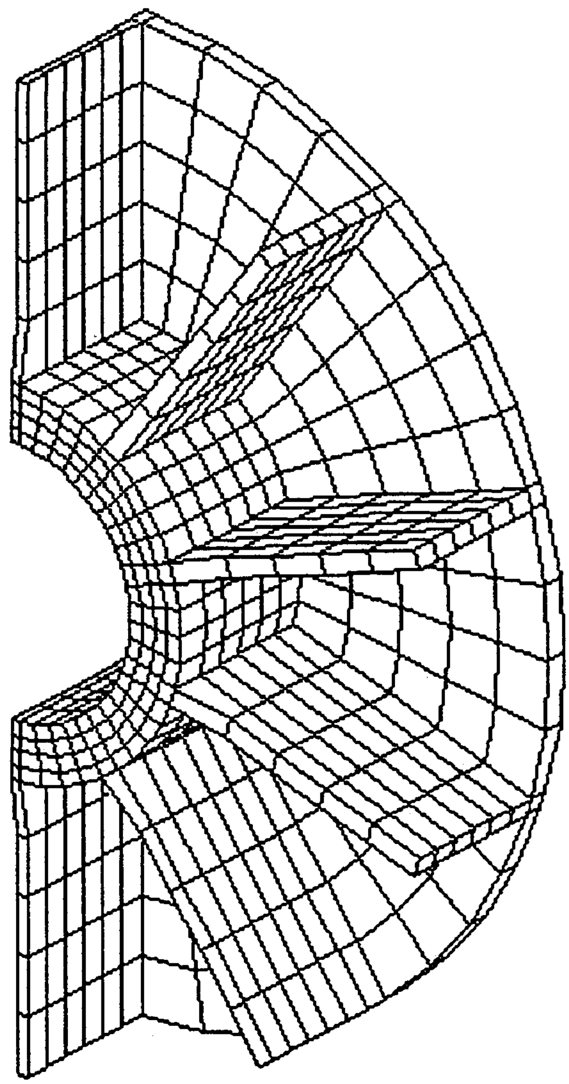
$$P_{TOP} = 4000 + \frac{1583}{2} = 4792 \text{ psi}$$

$$P_{BOTTOM} = 4000 - \frac{1583}{2} = 3208 \text{ psi}$$

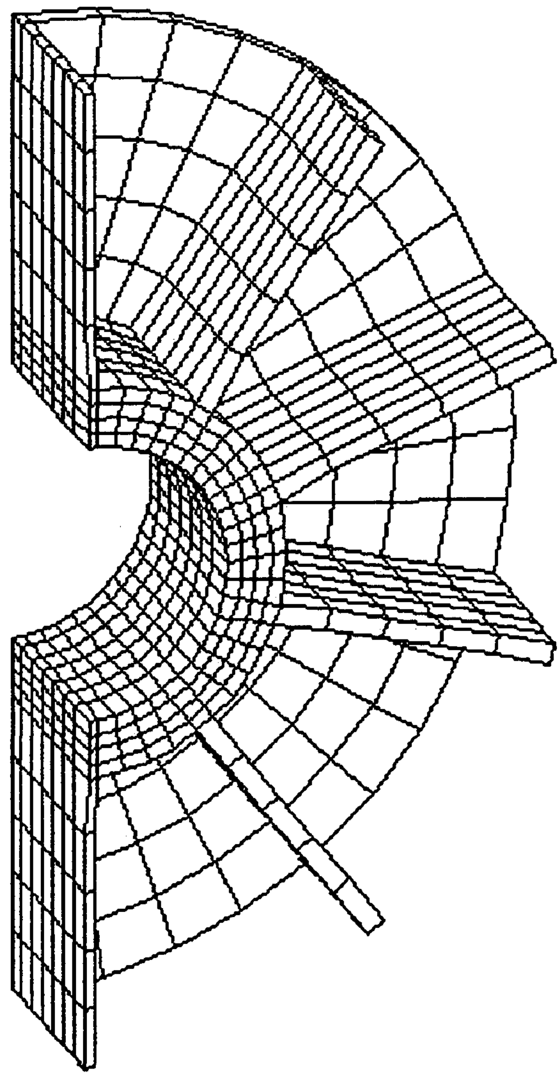
$$T_{CAPACITY} = \frac{1}{2}(4{,}926{,}000) = 2{,}463{,}000 \text{ IN-LB}$$

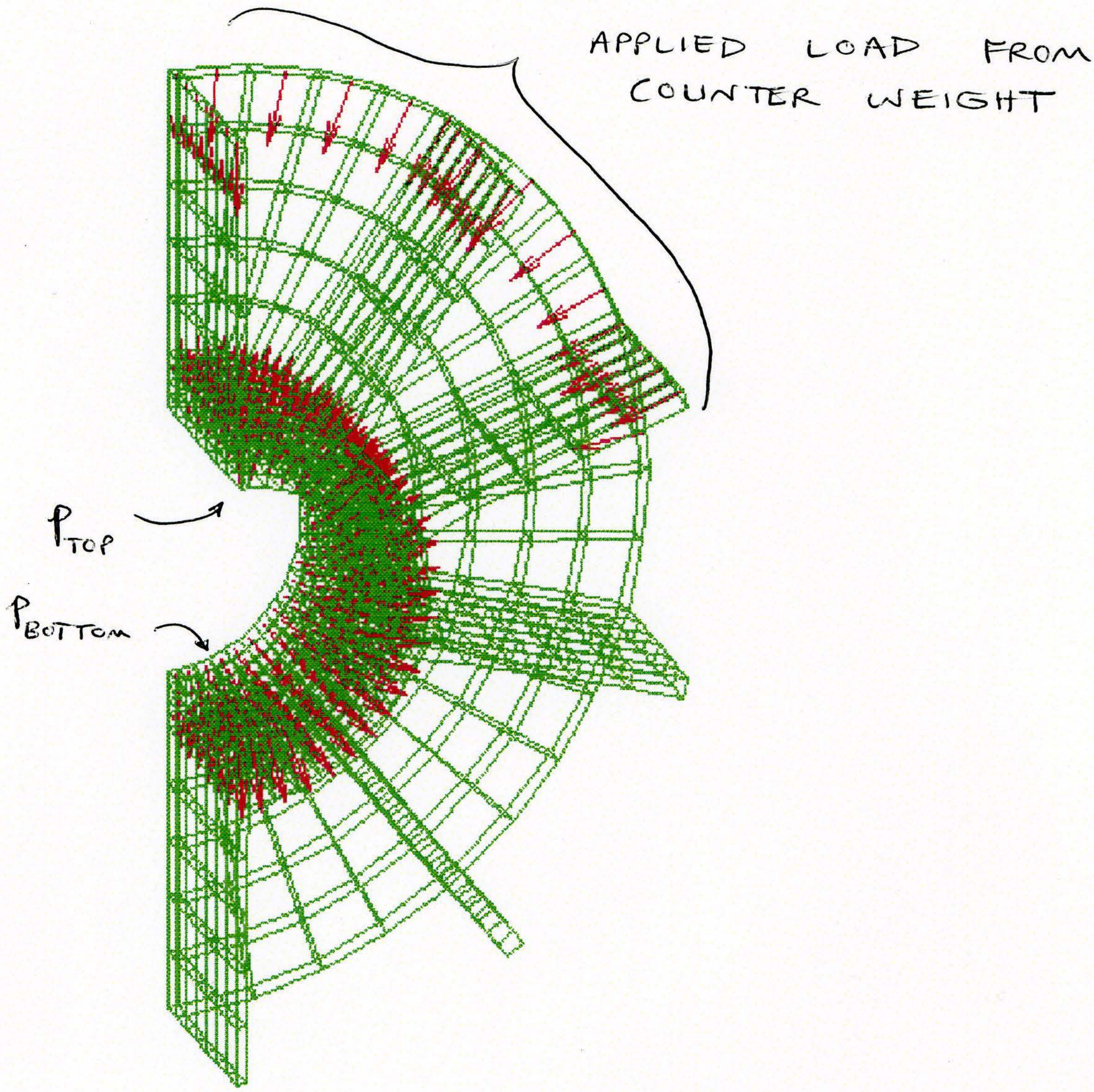
(205,250 FT-LB)

FEA 1/4 MODEL OF CENTRAL HUB



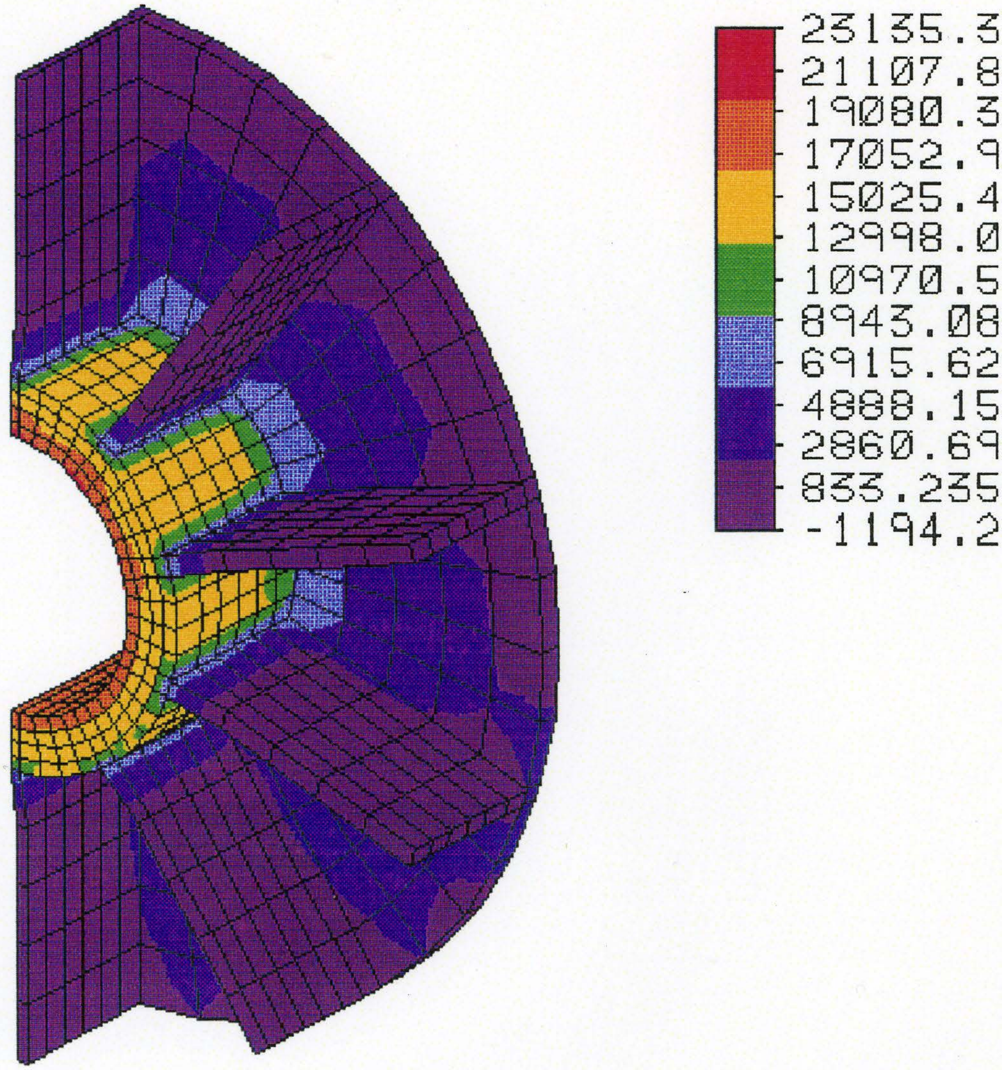
FEA HUB MODEL





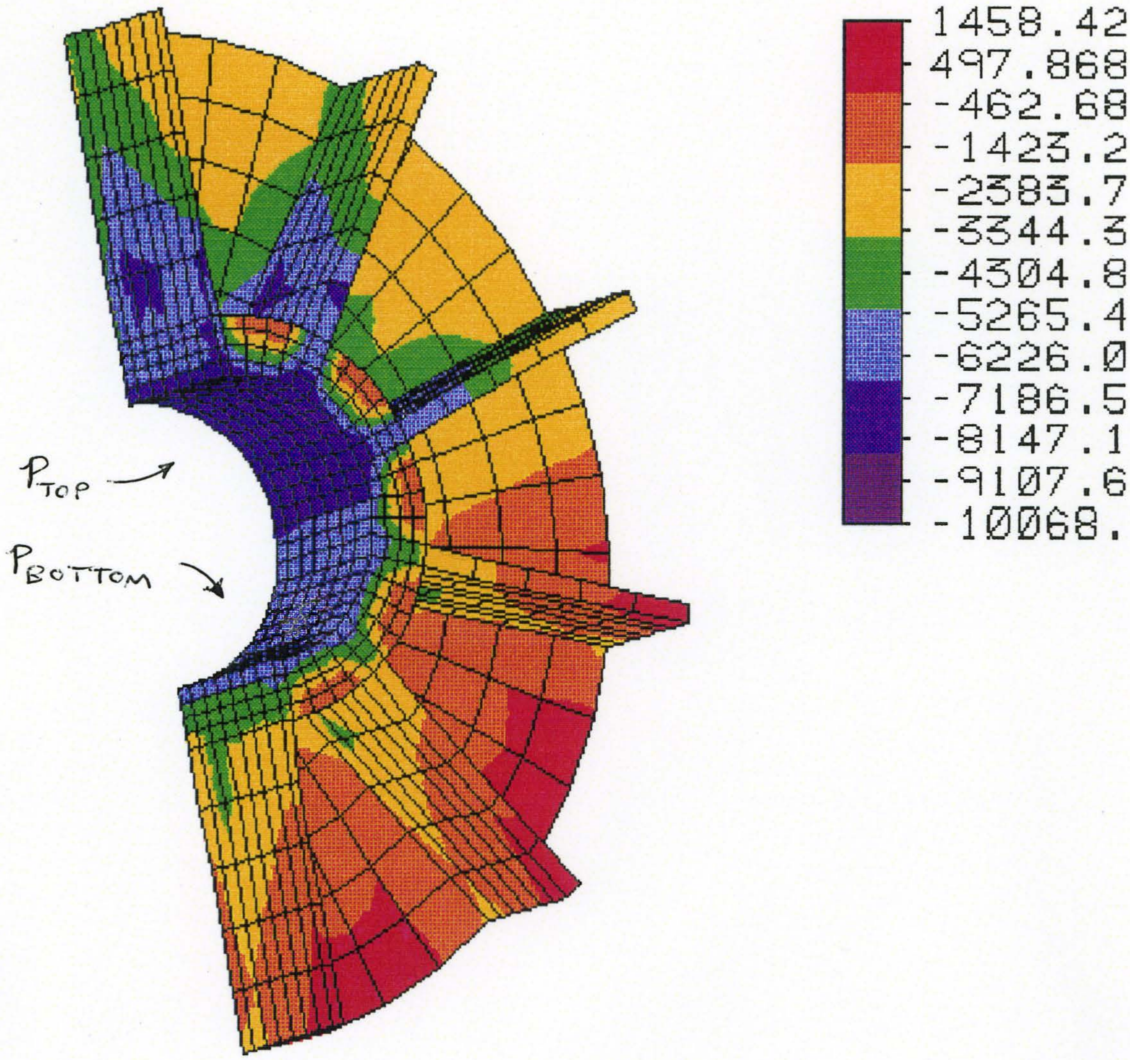
LOADING

P_{SHRINK} = 8000 psi



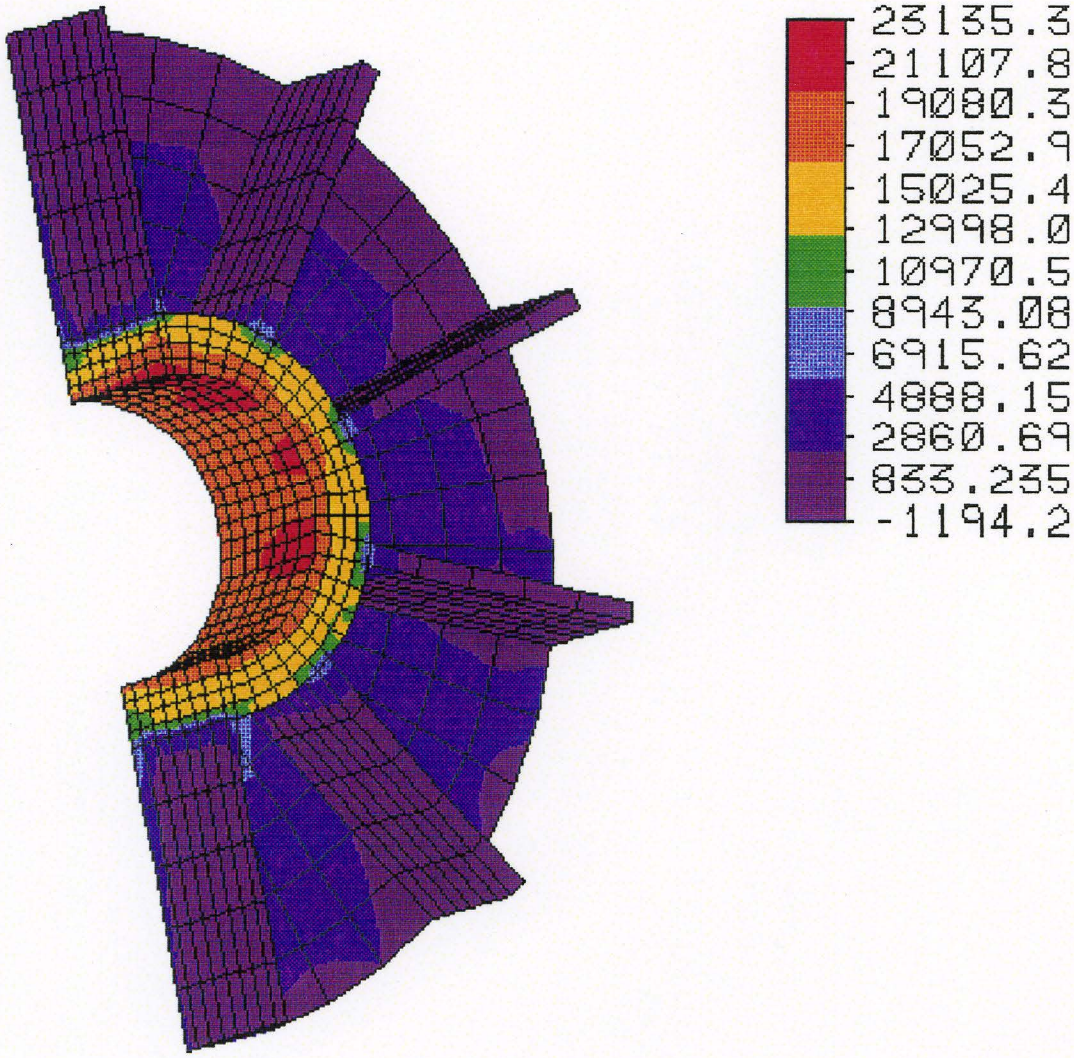
MAXIMUM PRINCIPLE TENSILE STRESS (psi)

$P_{SHRINK} = 8000$ psi



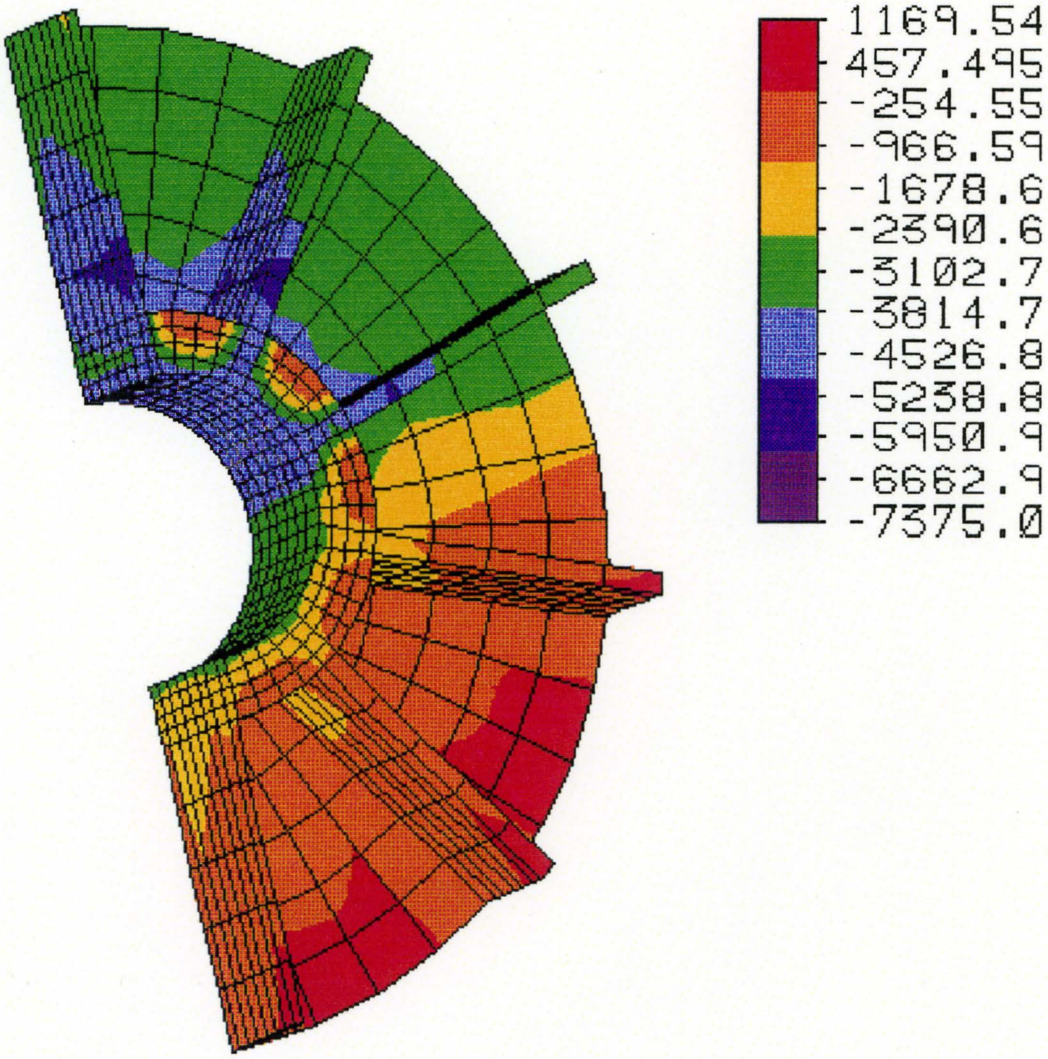
MAXIMUM PRINCIPLE COMPRESSIVE STRESS (psi)

P_{SHRINK} = 8000 psi



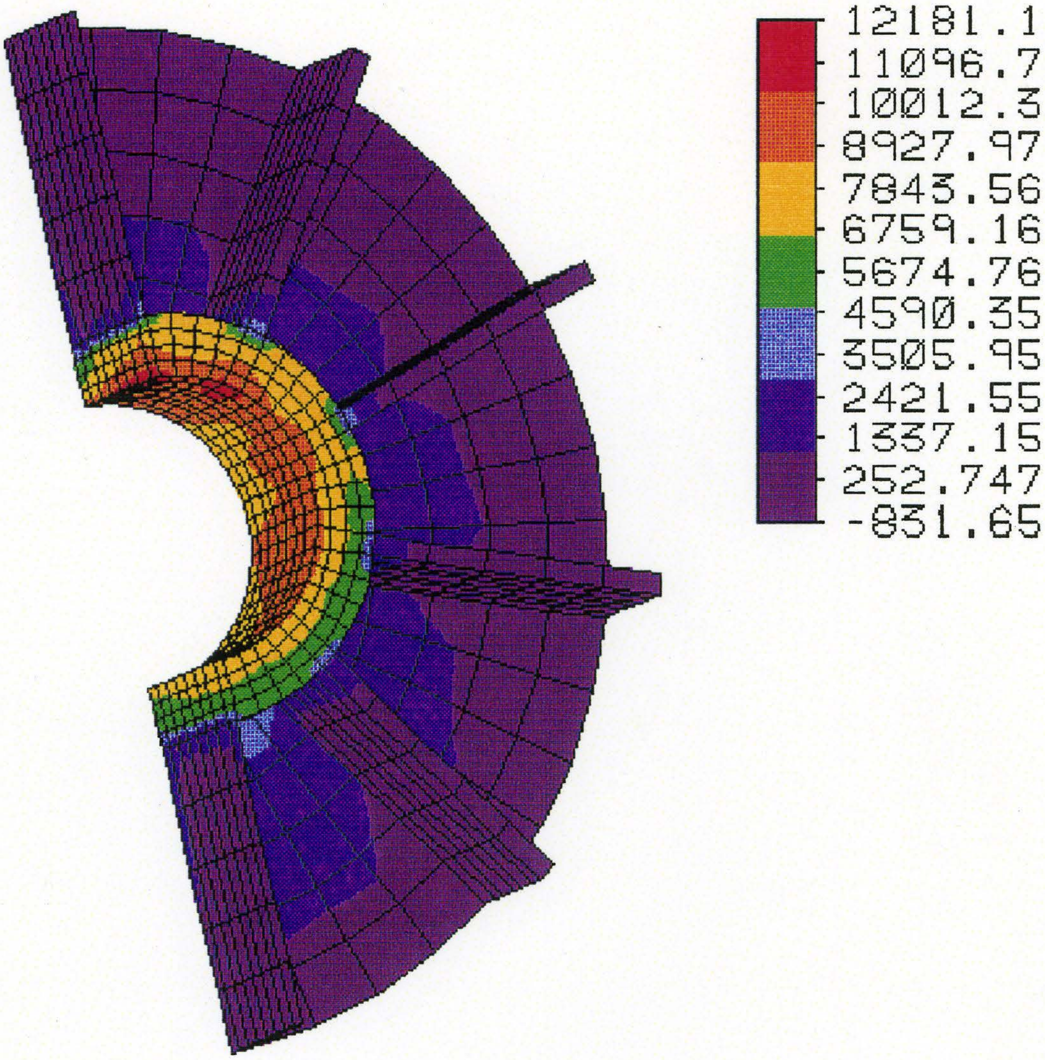
MAXIMUM PRINCIPLE TENSILE STRESS (psi)

$P_{SHRINK} = 4000$ psi



MAXIMUM PRINCIPLE COMPRESSIVE STRESS (psi)

P_{SHRINK} = 4000 psi



MAXIMUM PRINCIPLE TENSILE STRESS (psi)

Summary

The following summary is separated into sections that correspond to the sheave's main components that were reviewed in this analysis.

- SHEAVE -

The single web sheave model was created using 3-D plate elements that require a thickness input. Part of the model verification was to check this input against the various plate thickness used in this new design. Load cases 5 - 8 were run using combinations of the derived load distributions and rotational location of the sheave during operation. The loading was verified by using a single boundry element in the vertical direction. Since loads were placed at the central hub to react to the main cable tray loading, this boundry element is there only to balance the model. The magnitude of this boundry element was confirmed to be within 300 pounds for all four load cases. This small amount confirmed the vertical component of the loading was balanced between the cable tray and the central hub.

The output of the sheave FEA model gave an estimated weight of 5200 pounds for a quarter model, or 10.4 tons for the entire sheave. The output stress plots are presented on pages 7 through 18 and are sorted by the specific load case. The following tables are the summary of peak stresses for the previous 3-web design and the single web design that was analyzed in LC 5 through 8. SIG1 corresponds to the maximum principle tensile stress and SIG3 corresponds to the maximum principle compressive stress.

3-web Design

		-- Front Web --		Front Web Removed	
		SIG1	SIG3	SIG1	SIG3
Linear Load	- No Off	3750	6340	5200	6000
	- 20 Deg	3640	10,000	5420	8000
Sine Load	- No Off	3050	5400	6000	6000
	20 Deg	3250	10,000	6000	8500

Single Web Design

		SIG1	SIG3
Linear Load	- No Off	4971	8036
	- 18 Deg	5030	9632
Sine Load	- No Off	6304	7746
	18 Deg	6373	8759

- CABLE TRAY -

The loading for the cable tray of the single web sheave design is based on the load derivation that was presented in the first report. In the case of the single web design, it is not accurate to reduce the model to a 2-D cross section. The gussets located every 9 degrees require a 3-D approach. The local model shown on page 20 captures two of the gussets so that the unsupported portion of the cable tray is represented in the simulation. The stress plot on page 22 shows a peak stress of 2000 psi tensile on the underside of the cable tray. The plots on 23 and 24 indicate a peak stress of 3500 psi at the base of the first cable groove. Since this stress gradient peaks up rapidly, it was decided to use the end deflection to load a finer mesh 2-D model. This gave a peak stress of 6500 psi at the base of the groove and is shown on page 25. This approach is somewhat conservative since it neglects the support from the material on both sides of the cross section.

- CENTRAL HUB -

Two load cases for the central hub were investigated. The attachment method for the hub to the trunnion shaft was revised to be a shrink fit. The two load cases, were developed with an 8000 and 4000 psi shrink pressure. For these two shrink pressures, an estimated torque capacity was calculated and is 410,000 foot-pounds for the 8000 psi and 205,000 foot pounds for the 4000 psi shrink pressure.

The stress plots for the two load cases are shown on pages 32 - 36. Page 33 gives a good view of how the pressure re-distributes as the counter weight loading is applied to the hub. On page 34, the tensile stress around the hub ID goes through little change. This indicates that most of our stress is due to the shrink fit and not the applied load. When comparing the stress plot on page 36 (p shrink = 4000) to that on page 34 (p shrink = 8000), the maximum tensile stress reduces to 12,000 psi from 23,000 psi. Whether or not the shrink pressure can be reduced will depend on what torque capacity is required.

This analysis and the presented results are based on the primary loading as being due to the cables, counterbalance, and center bridge section. If any significant additional loads do exist, they can be analyzed and superimposed with the above results.