Attachment 2
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MK1-03-008
April, 1980

MARK I CONTAINMENT
RING GIRDER MODELLING
AND
STRESS EVALUATION
UTILIZING ECCENTRIC BEAMS

Prepared For:
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Detroit Edison Company
Iowa Electric Light & Power Company
Jersey Central Power & Light Company
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ABSTRACT

This report presents an evaluation of the modelling technique which utilizes an eccentric beam element representation for the ring girders in Mark 1 suppression chambers. Two different types of parametric models have been established for this investigation. The first type includes a representative length of ring girder tributary shell region and saddle support at the location of the torus mitered joint (e.g. Quad. Cities) while the second type contains only a representative length of ring girder and tributary shell region (e.g. Oyster Creek). Unit rotations and unit displacements are applied at the end of the modeled ring/shell segments to examine the normal stresses and shear stresses in the ring girder web adjacent to the suppression chamber shell. These stresses are required in order to evaluate the welds which connect the ring to the shell. Comparisons are made of the results from the offset beam models with the results from a model which uses finite shell elements to represent the ring web and flange. Results are tabulated and plotted for the different models under various loading conditions.

It is concluded that modelling the reinforcing ring with eccentric beams is acceptable. A method of determining section shear stresses for weld evaluation at the ring girder/torus shell junction is presented.

REVISION CONTROL SHEET

SUBJECT: MARK I CONTAINMENT RING GIRDER MODELLING AND STRESS EVALUATION UTILIZING ECCENTRIC BEAMS

REPORT NUMBER: MK1-03-008

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1.0 INTRODUCTION

This report presents the results of an evaluation which demonstrates that the stresses in the welds at the junction of the ring girder and the suppression chamber shell can be computed by modelling the ring girder with offset beam elements just as accurately as by explicitly modelling the ring girder with shell elements.

Since it is desirable to use efficient models of the torus and torus support system, the use of offset beam elements instead of shell elements is desirable for modelling the ring girder. However, when using the offset beam modelling technique, one must proceed with caution to compute the correct values of the stresses in the ring girder and welds connecting the ring to the shell. This report documents an acceptable procedure which can be used for those calculations.

2.0 DESCRIPTION OF MODELS

Two different types of models are investigated. The first type consists of a representative length of ring girder, tributary shell region, and saddle support; while the second type consists of only a representative length of ring girder and tributary shell region.

The dimensions of the saddle models correspond to the Quad-Cities torus and the dimensions of the non-saddle models correspond to the Oyster-Creek torus. A length of $1.56\sqrt{Rt} + t_w$ is used for the tributary shell width where R and t are the radius and thickness of the suppression chamber shell respectively, and t_w is the web thickness of the ring girder.

A typical suppression chamber cross section is shown in Figure 2.0-1 to illustrate the location which has been isolated for investigation of stresses for a saddle configuration.

2.1 Type 1 Model -- Ring Girder with Saddle Support

Three different finite element representations of the ring girder are utilized for this type of configuration. Model 1-A uses an eccentric beam element representation of the ring girder at the miter joint (Figure 2.1-1), whereas Model 1-B uses an explicit shell element representation of the ring girder at the miter joint (Figure 2.1-2). Model 1-C uses an eccentric beam element representation of the top two-thirds of the ring girder and an explicit shell element representation of the rest of the ring girder (Figure 2.1-3). Note that the element representations of the tributary shell regions and the saddle supports for Model 1-A, 1-B, and 1-C are identical.

2.2 Type-2 Model -- Ring Girder without Saddle Support

Two different element representations of the ring girder are used for this type of configuration. Model 2-A uses an eccentric beam element representation of the ring girder at the miter joint (Figure 2.2-1). Model 2-B uses an explicit shell element representation of the ring girder at the miter joint (Figure 2.2-2). Note that the element representations of the tributary shell regions for Model 2-A and 2-B are identical.

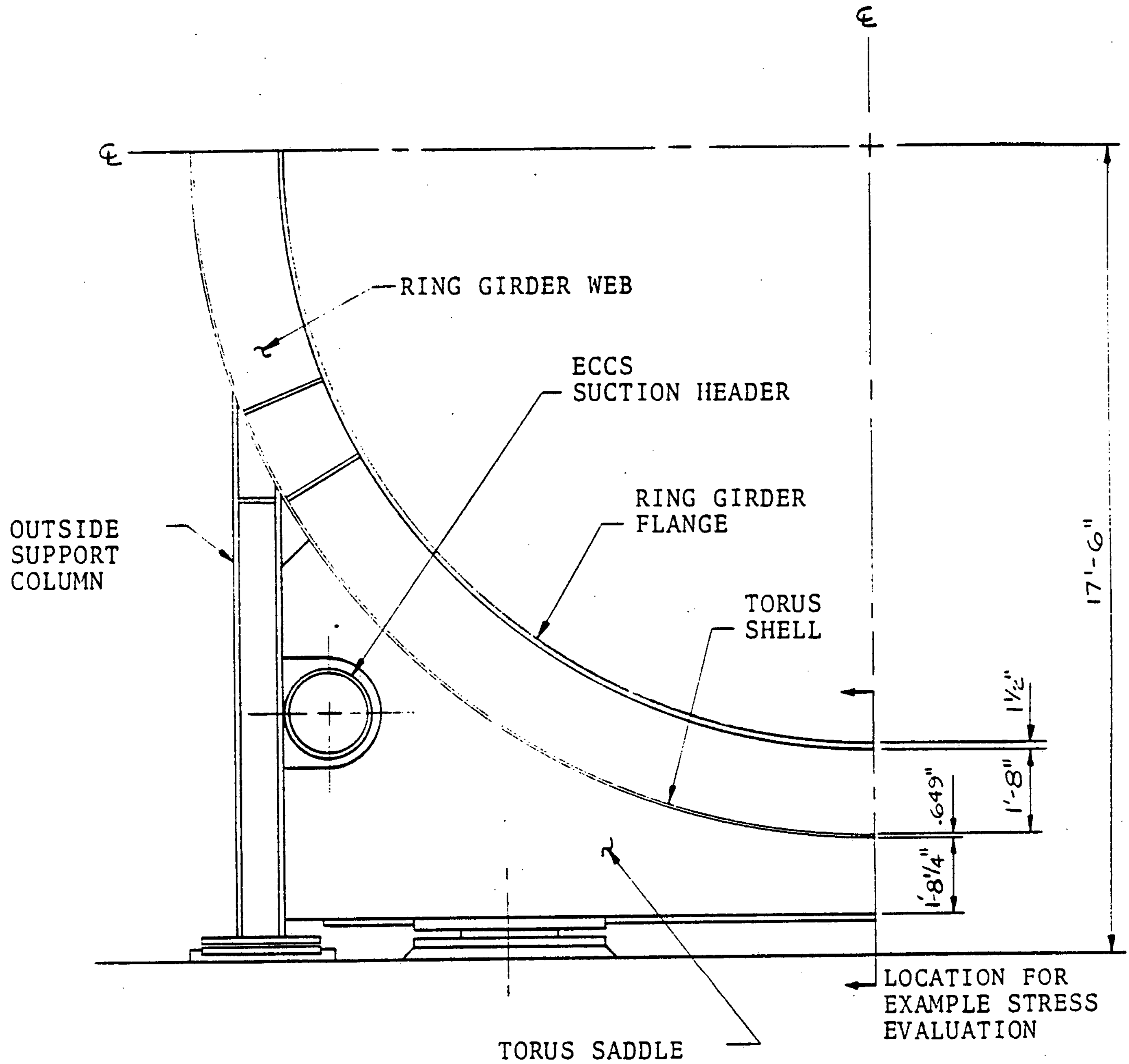
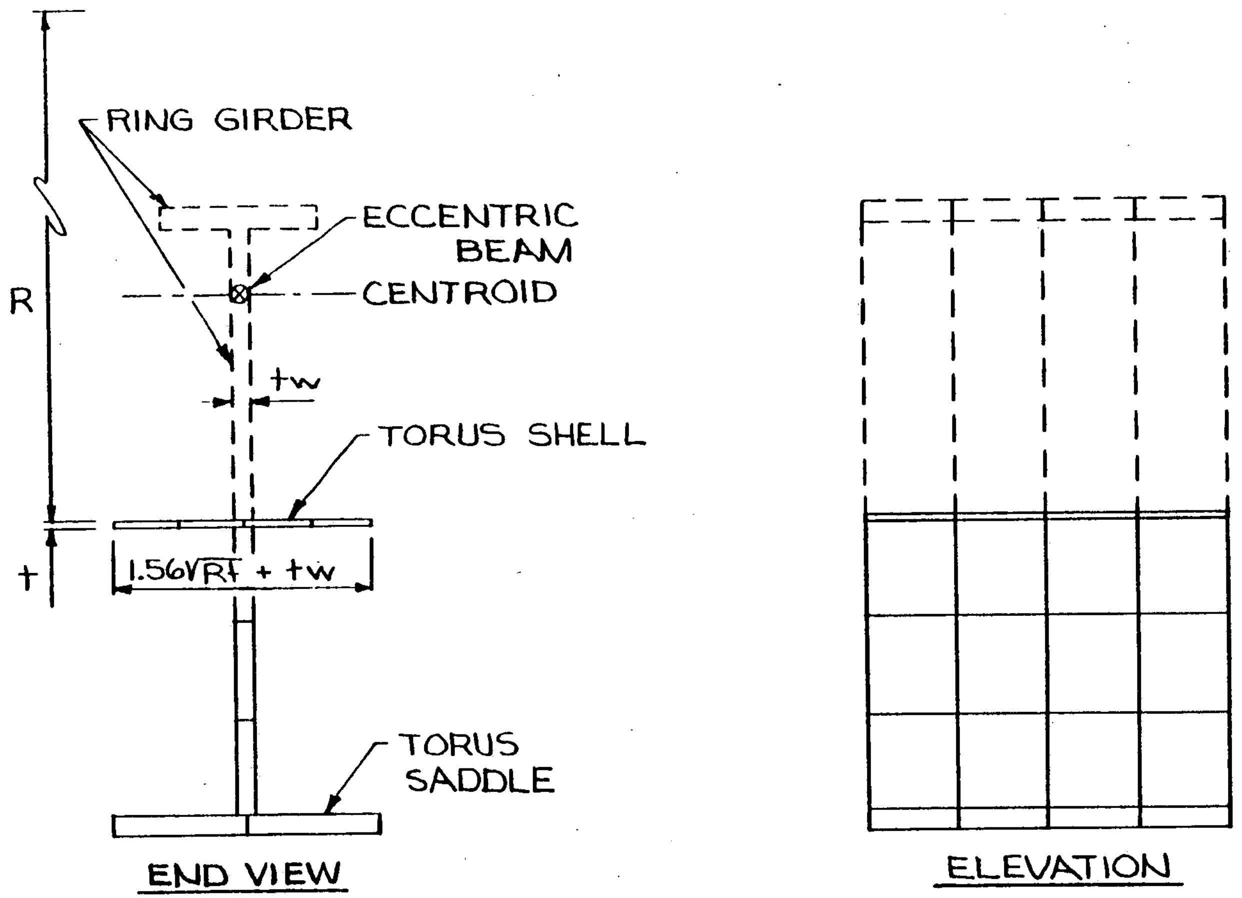


FIGURE 2.0-1

TYPICAL SUPPRESSION CHAMBER WITH SADDLE SUPPORT



– – – : PLATE/SHELL REPRESENTED WITH ECCENTRIC BEAM ELEMENTS

——— : EXPLICIT PLATE/SHELL ELEMENTS

FIGURE 2.1-1

TORUS SADDLE CROSS SECTION WITH BEAM ELEMENT REPRESENTATION OF TORUS RING GIRDER (MODEL 1-A)

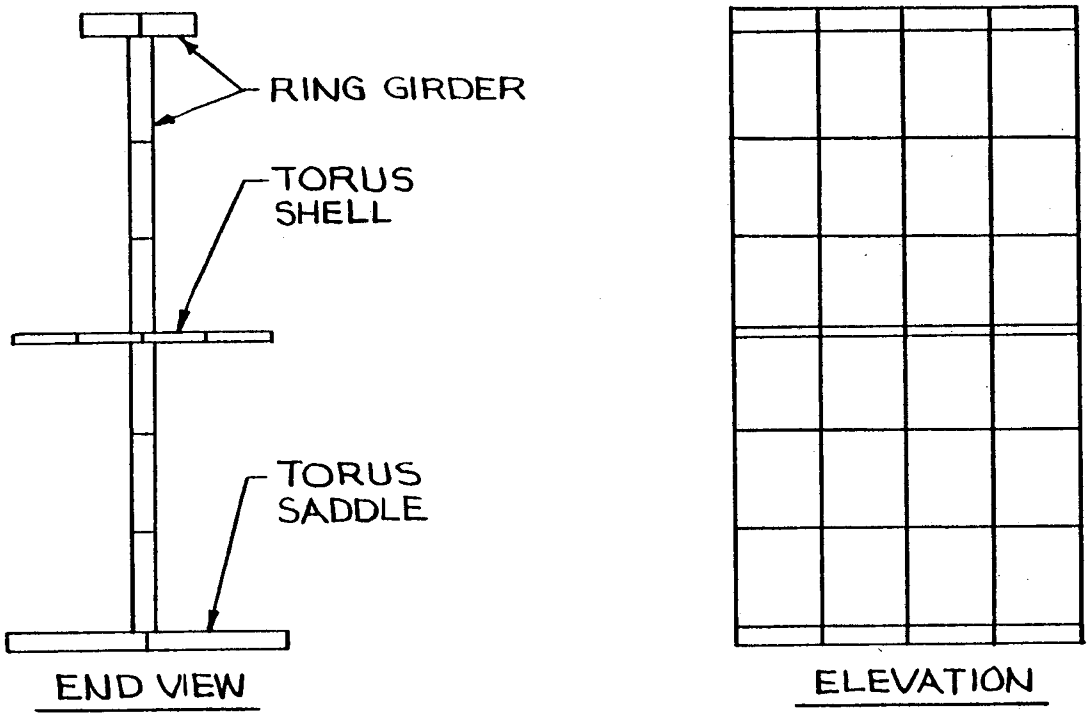
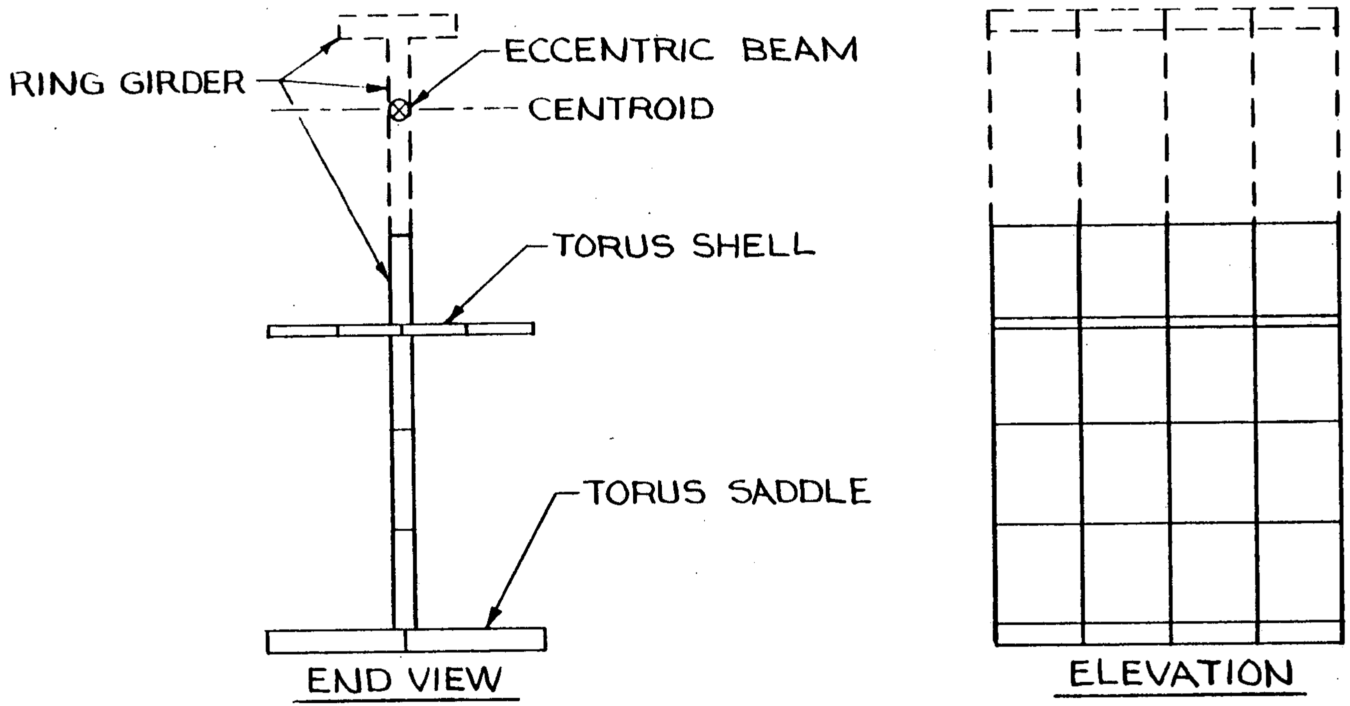


FIGURE 2.1-2
TORUS SADDLE CROSS SECTION
WITH SHELL ELEMENT REPRESENTATION OF TORUS RING GIRDER
(MODEL 1-B)



– – –: PLATE/SHELL REPRESENTED WITH ECCENTRIC BEAM ELEMENTS.

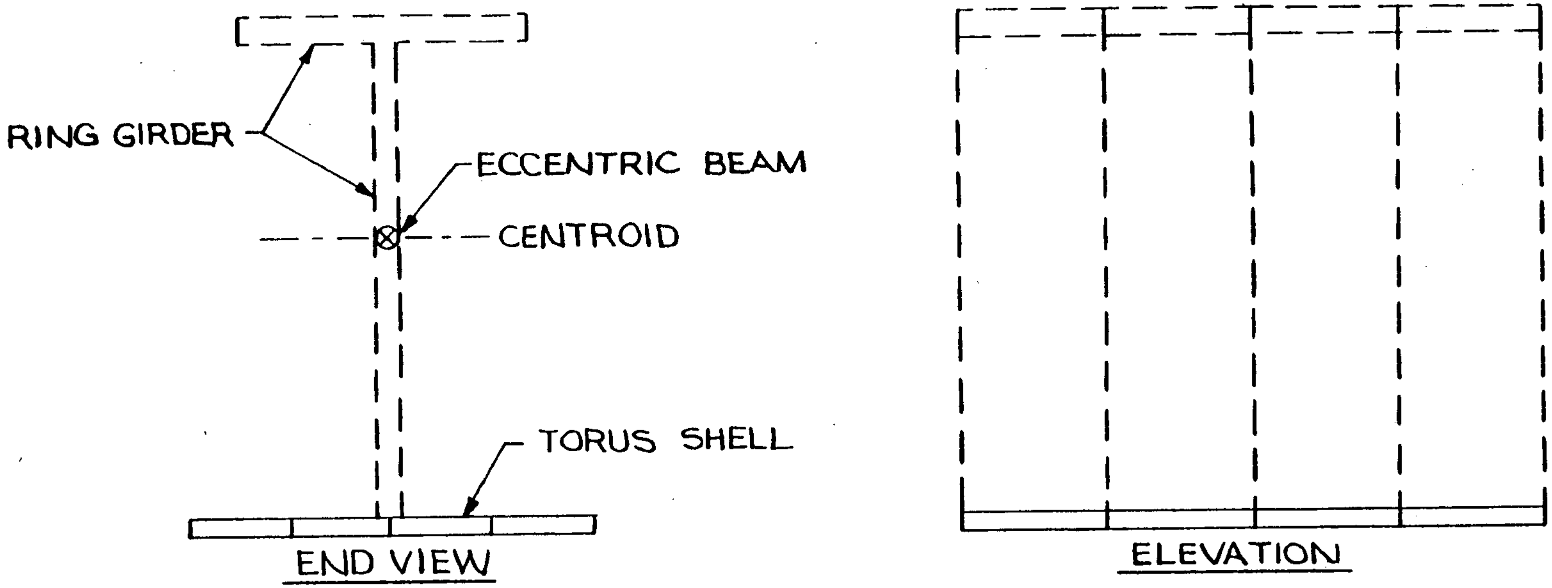
———: EXPLICIT PLATE/ SHELL ELEMENTS.

FIGURE 2.1-3

TORUS SADDLE CROSS SECTION

WITH HYBRID BEAM/SHELL ELEMENT REPRESENTATION OF TORUS RING GIRDER

(MODEL 1-C)



– – – : PLATE/SHELL REPRESENTED WITH ECCENTRIC BEAM ELEMENTS.

——— : EXPLICIT PLATE/SHELL ELEMENTS.

FIGURE 2.2-1
TORUS CROSS SECTION
WITH BEAM ELEMENT REPRESENTATION OF THE RING GIRDER
(MODEL 2-A)

MK1-03-008

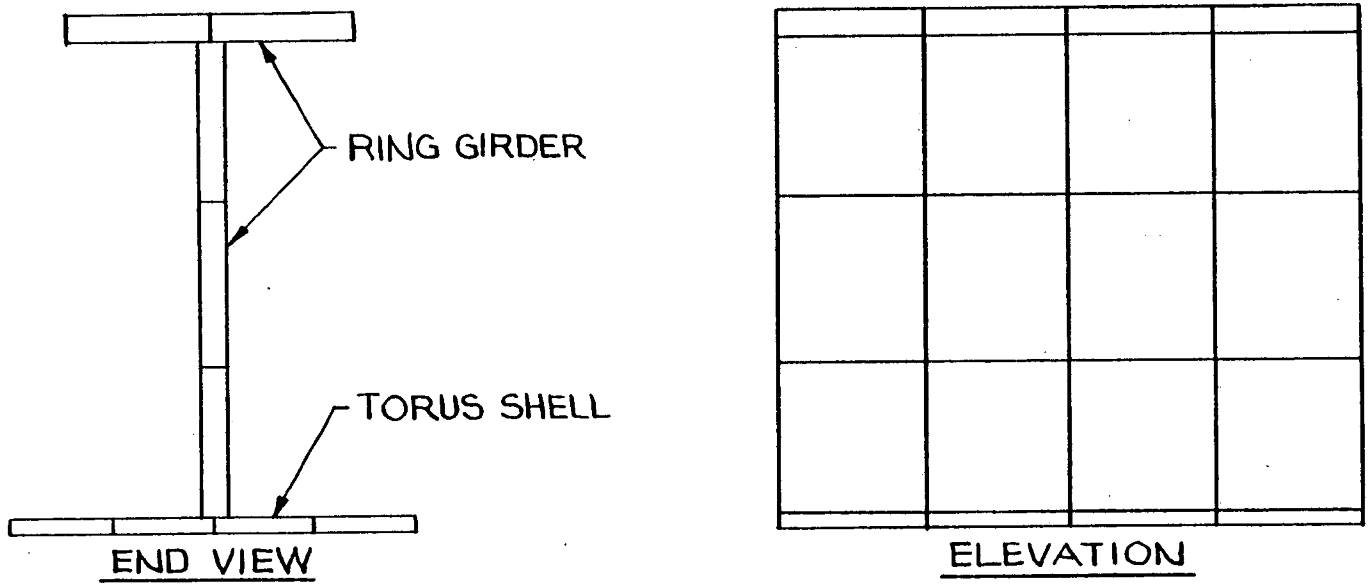


FIGURE 2.2-2
TORUS CROSS SECTION
SHELL ELEMENT REPRESENTATION OF THE RING GIRDER
(MODEL 2-B)

3.0 LOADS AND BOUNDARY RESTRAINTS

Two loading conditions are applied at the boundary of the ring girder models to study the overall structural behavior of the models. Boundary restraints must be applied correctly on the models so that comparisons can be made between different element representations of the ring girders under different loading conditions. The elements selected for comparison of stresses were located away from boundaries so that local effects at the boundaries are avoided.

3.1 UNIT RADIAL DISPLACEMENT APPLIED ON THE BOUNDARY

A set of radial shear displacements (Δ = 1 inch) is applied along the boundaries of all the models. The associated boundary restraints for individual models under this loading case are illustrated in Figure 3.1-1.

The purpose of applying unit radial displacements at the boundaries of the models is to compare the shear stresses from models under this idealized pure shear loading condition.

3.2 UNIT ROTATION APPLIED ON THE BOUNDARY

A set of unit rotations (θ = 0.1 radians) are applied at the boundaries of the models. The associated boundary restraints for individual models under this loading case are shown in Figure 3.2-1.

The purpose of applying unit rotations at the boundaries of the models is to compare the normal stresses from different models under this idealized pure bending moment loading condition.

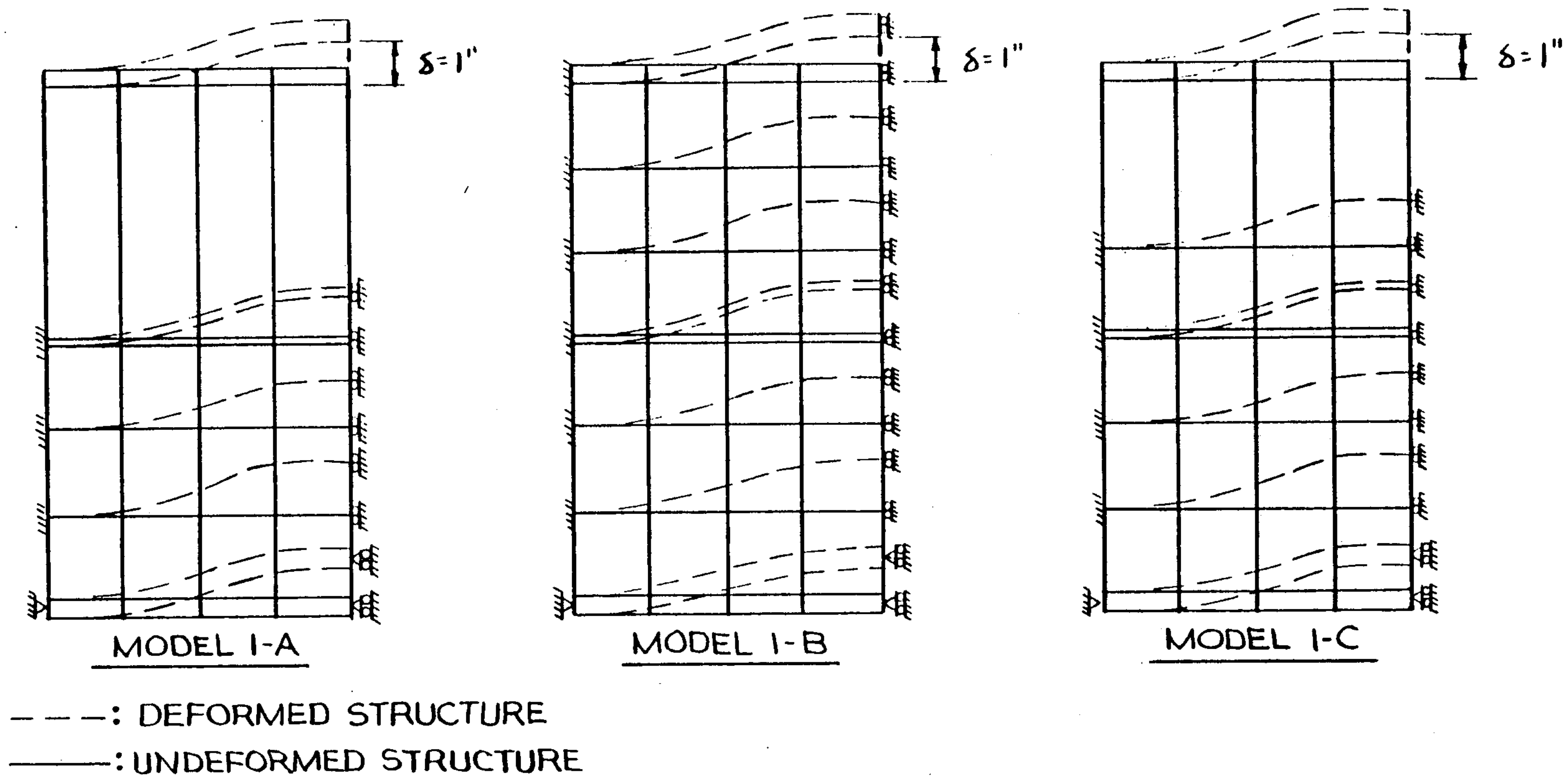


FIGURE 3.1-1

TYPICAL UNIT DISPLACEMENT LOADING AND ASSOCIATED BOUNDARY RESTRAINTS

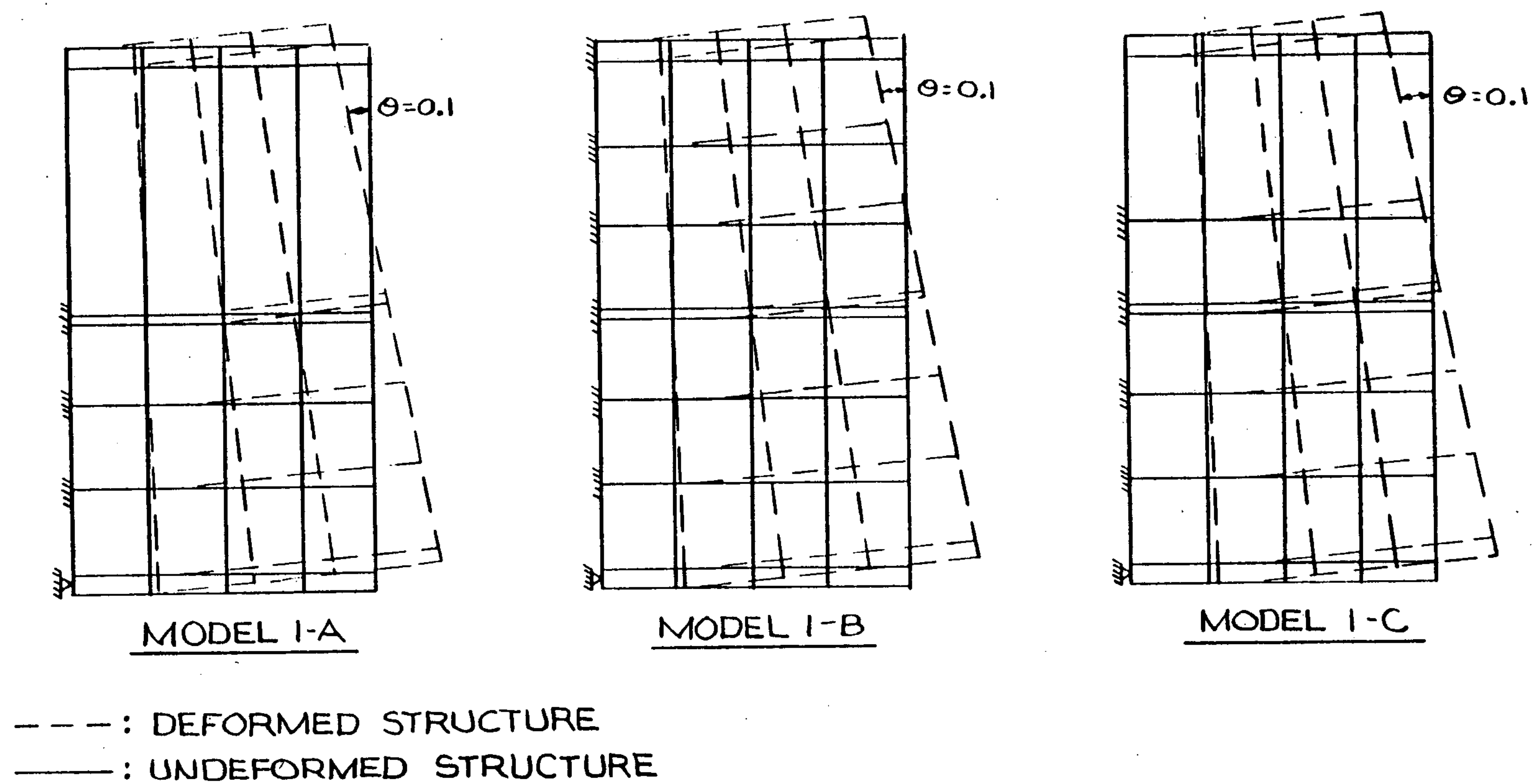


FIGURE 3.2-1

TYPICAL UNIT ROTATION LOADING AND ASSOCIATED BOUNDARY RESTRAINTS

4.0 METHODS OF ANALYSIS

To obtain the stresses at the various locations of each model, three methods are possible. They are referred to as:

- Equilibrium Solution
- Finite Element Analysis
- Discrete Beam Solution

4.1 Equilibrium Solution

This method is based on the nodal equilibrium check table from the structural analysis output and is applicable to all the models. The procedure is to first sum up all the nodal equilibrium check forces at the boundary to obtain the net resultant boundary forces and moments. Then the stresses at that cross section of the model can be obtained by simple beam theory. The stress components can be easily calculated by the formula $\sigma = \frac{P}{A} \pm \frac{MC}{I}$ and $\tau = \frac{VQ}{Ib}$ once the axial force P, the shear force V and the bending moment M are known.

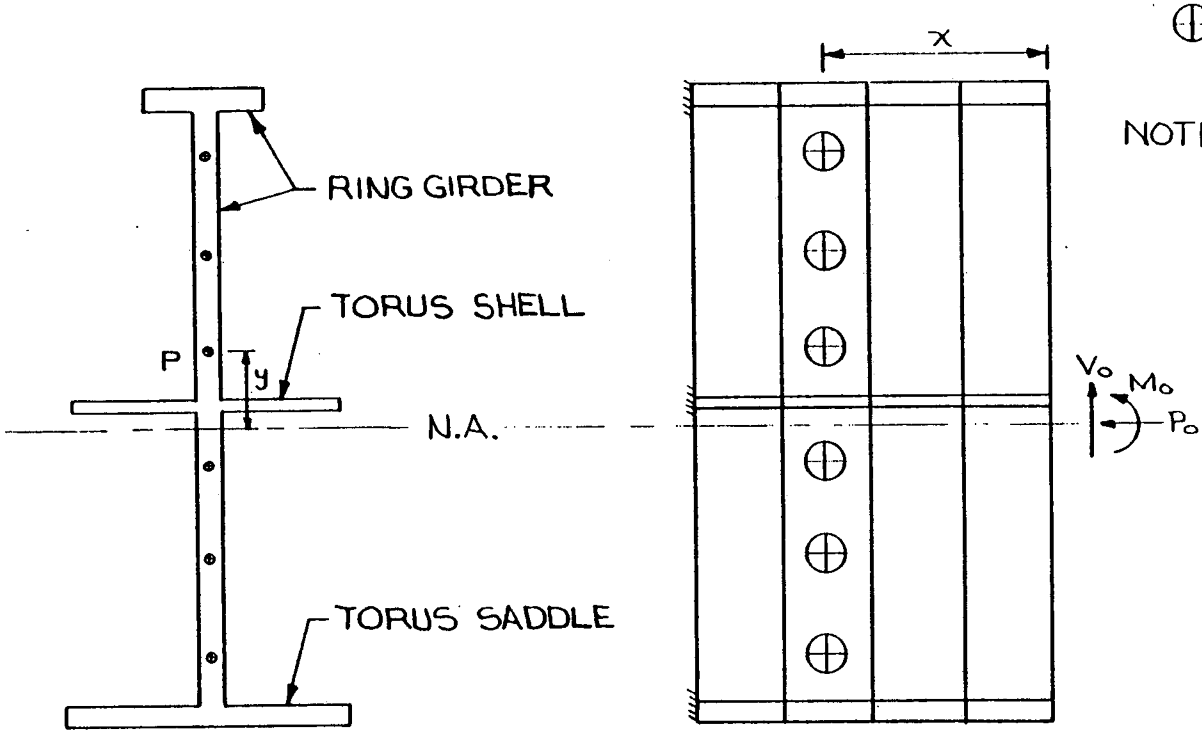
It is noted that, when using this method, the entire model is treated as a beam element, with one composite cross section. The summation of the equlibrium check forces gives the beam end forces. An illustration of this method is given in Figure 4.1-1.

4.2 EXPLICIT FINITE ELEMENT ANALYSIS

To utilize this method, a model with an explicit shell element respresentation of the ring girder is used and the stress components are obtained directly from the finite element results. This method is illustrated by Models 1-B, 1-C and 2-B.

4.3 DISCRETE BEAM SOLUTION

For models with a beam element representation of the ring girder, a discrete beam solution is presented. The procedure is to first determine the beam end forces and moments from the structural analysis outputs, then apply classical beam theory to calculate the stress components at locations of interest for any given cross sections. This method is applicable to Models 1-A, 1-C and 2-A. The formulas used are $\sigma = \frac{P}{A} \pm \frac{MC}{I}$ and $\tau = \frac{VQ}{Ib}$ where the axial force P, the shear force V and the bending moment M are obtained directly from the computer output.



BEAM CROSS SECTION

CANTILEVER BEAM WITH BOUNDARY FORCES

⊕ : STRESS LOCATION FOR COMPARISON.

NOTE: 1. P_o, V_o AND M_o ARE OBTAINED FROM NODAL EQUILIBRIUM CHECK TABLE OF STARDYNE OUTPUT.

2. AT LOCATION OF INTEREST,

$P_x = P_o$

$V_x = V_o$

$M_x = M_o + V_o \cdot x$

3. FOR STRESS AT LOCATION P.

$$\sigma = \frac{P_x}{A} + \frac{M_x \cdot y}{I}$$

$$\tau = \frac{V_x Q_y}{I b}$$

FIGURE 4.1-1

TYPICAL ILLUSTRATION OF EQUILIBRIUM SOLUTION

5.0 RESULTS OF ANALYSIS

It is noted that under a given loading condition, the net resultant boundary forces (and moments) at the restrained end of the models are almost identical regardless of whether the beam element respresentations or explicit shell element representations are used for the ring girder. Therefore, it is assured that the equilibrium solutions at intermediate cross sections for the various models with different ring girder representations are identical (e.g. equilibrium solutions for Model 1-A, 1-B and 1-C are identical).

5.1 Results of Applying Unit Radial Displacement

The shear stress values obtained from all three methods for saddle models are tabulated in Table 5.1-1 and the corresponding shear stress distributions are shown in Figure 5.1-1. As can be seen from Figure 5.1-1, predicted shear stresses vary depending on the modelling technique employed for the ring girder and the sophistication of the method used to recover shear stresses.

The equilibrium solution, illustrated in Figure 5.1-1 as a solid line, is the benchmark to which other solutions are compared. That equilibrium solution results from applying the classical shear equation ($\tau = \frac{VQ}{IB}$) to any of the models, where V is the summation of nodal shear forces on the cross section.

When the ring girder is modelled explicitly with shell elements, the computed shear stress distribution throughout the cross section is in good agreement with the equilibrium solution ($\tau = \frac{VQ}{Ib}$).

For the two models which utilized eccentric beams to model all or part of the ring girder, it is shown that significant deviation from the benchmark solution occurs if stresses are computed by considering the beam as an independent, non-composite structural element by computing average section shear stress ($\tau = \frac{V}{KA}$) where V is the shear force in the beam only, and KA is the assumed effective beam shear area. For the calculations in this report, KA is taken as 85 percent of the area of the web of the section being represented by the beam. Stresses computed in this manner are shown in Figure 5.1-1 to be conservatively high relative to the equilibrium solution.

It is interesting to note that the shear stresses from the Explicit Shell Model and the Hybrid Beam/Shell Model are very close to the equilibrium solution near the junction of the ring girder and suppression chamber. This suggests that explicitly modelling the lower portion of the web might offer the best combination of modelling economy and post-processing ease.

The discrete beam shear stress solution ($\tau = \frac{V}{KA}$) is not very appropriate for this structural configuration since it is not adequate to treat the ring girder as an independent structural element when calculating the shear stresses near the bottom of the ring girder web due to the fact that the ring girder, tributary shell region and the saddle support act as a composite section. However the ring girder can be modelled as an eccentric beam as long as the more sophisticated equilibrium solution ($\tau = \frac{VQ}{IB}$) is used to determine shear stresses rather than applying an average shear stress equation ($\tau = \frac{V}{KA}$) to the beam.

For Models without saddle supports results similar to saddle results are obtained. The maximum beam shear stresses computed with the beam average shear stress formula ($\tau = \frac{V}{KA}$) for the Eccentric Beam Model are high. As with the previously discussed saddle models, application of the discrete beam shear stress solution is not appropriate for determining realistic shear stress distributions.

The shear stress values calculated using various methods for non-saddle models are presented in Table 5.1-2 and the corresponding shear stress distributions are shown in Figure 5.1-2.

The normal stresses of individual models with or without saddles under this loading compare favorably regardless of whether the eccentric beam is treated as an independent member or if an equilibrium solution is employed. The results are shown in Table 5.1-3 for saddle models and Table 5.1-4 for non-saddle models. Corresponding plots are shown in Figure 5.1-3 and Figure 5.1-4 respectively.

5.2 Results of Applying Unit Rotations

For models with saddle supports, the normal stress distributions compare favorably regardless of whether the equilibrium solution is applied or if eccentric beams are treated as isolated, independent structural elements. Due to the fact that discrete beam solution gives good results in this case, it is appropriate to use the normal stresses directly from the structural analysis output for the ring girder and weld stress evaluation, and there is no need to resort to equilibrium solutions or explicit finite element modelling.

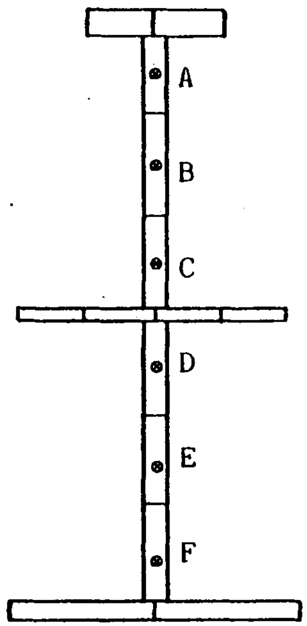
The normal stresses for various models under this loading are tabulated in Table 5.2-1 and the stress distribution curves are shown in Figure 5.2-1.

For models without saddle supports, it is noted that all three methods of analysis (equilibrium solution, finite element analysis and discrete beam solution) give almost identical results in this case, therefore, it is adequate to use the normal stresses directly from the structural analysis output for ring girder or weld evaluation. Results are provided in Table 5.2-2 and Figure 5.2-2 to confirm this.

TABLE 5.1-1

IN-PLANE SHEAR STRESS FOR SADDLE MODELS

UNDER PURE SHEAR LOADING CONDITION



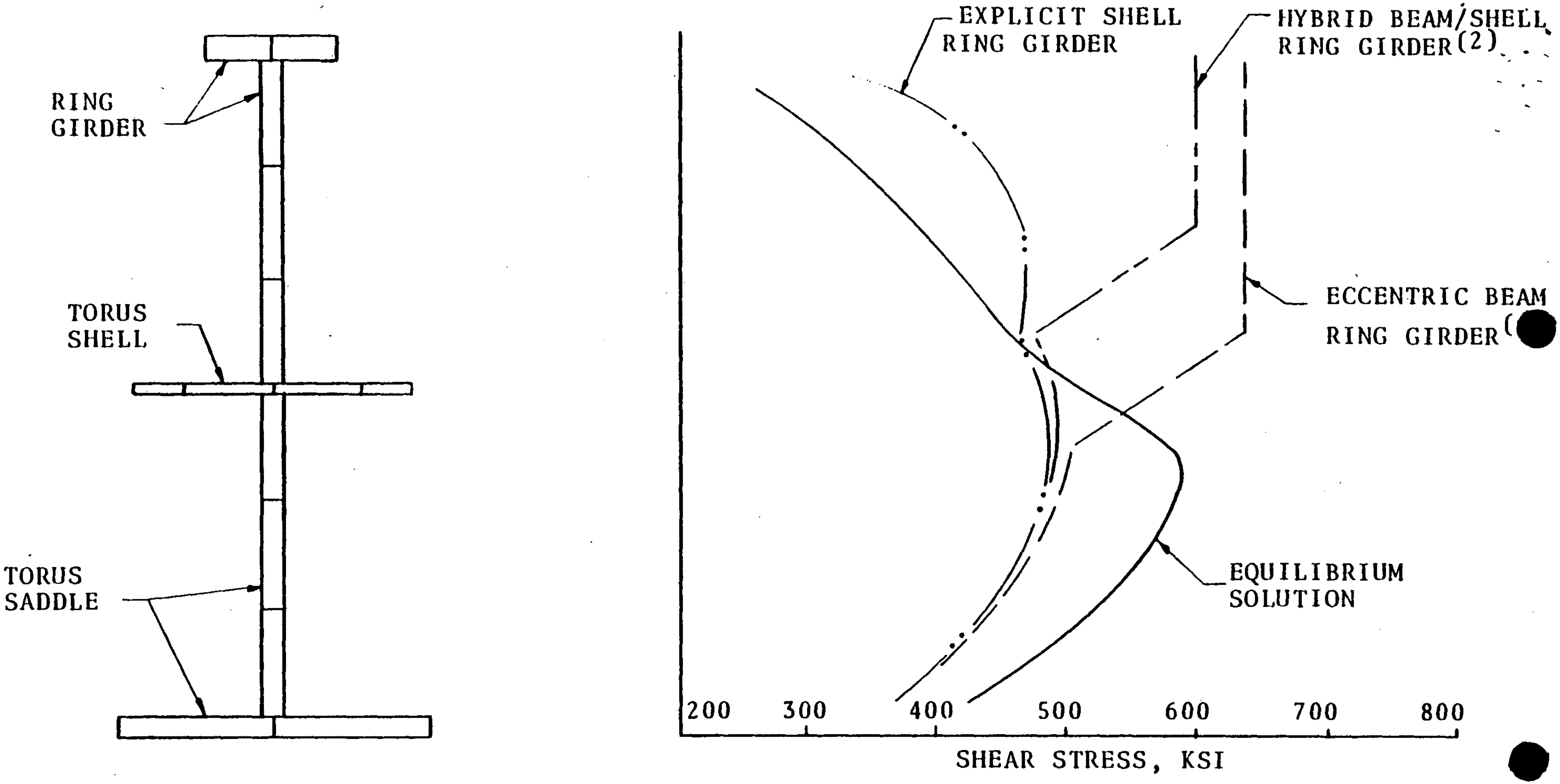
LOCATION OF INTEREST	EQUILIBRIUM SOLUTION	ISOLATED ELEMENT SOLUTION		
		ECCENTRIC BEAM	EXPLICIT SHELL	HYBRID BEAM/SHELL
A	269.6	629.0 (1)	378.5	594.0 (1)
B	389.3	629.0 (1)	463.8	594.0 (1)
C	454.7	629.0 (1)	456.8	468.4
D	584.5	500.2	485.6	486.5
E	552.2	466.1	463.8	463.6
F	461.5	392.5	392.5	392.4

LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

STRESS: IN-PLANE SHEAR STRESSES

NOTE: (1) ASSUMED UNIFORM BEAM SHEAR STRESSES ($\tau = \frac{V}{KA}$)

UNITS: KSI



LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

STRESS: IN-PLANE SHEAR STRESS DISTRIBUTION

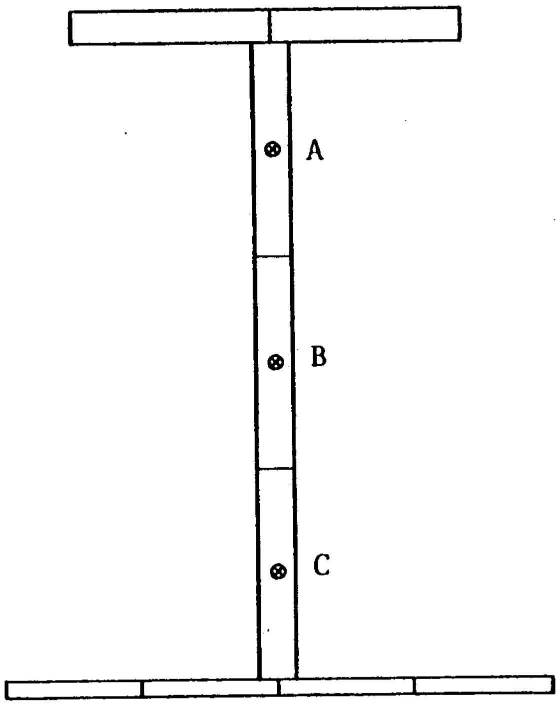
NOTES: (1) ASSUMED UNIFORM BEAM SHEAR STRESS ($\tau = \frac{V}{KA}$) FOR THE RING GIRDER

(2) ASSUMED UNIFORM BEAM SHEAR STRESS ($\tau = \frac{V}{KA}$) FOR THE TOP TWO-THIRDS OF THE RING GIRDER

FIGURE 5.1-1
IN-PLANE SHEAR STRESSES FOR SADDLE MODELS
UNDER PURE SHEAR LOADING CONDITION

TABLE 5.1-2

IN-PLANE SHEAR STRESS FOR NON-SADDLE MODELS UNDER PURE SHEAR LOADING CONDITION



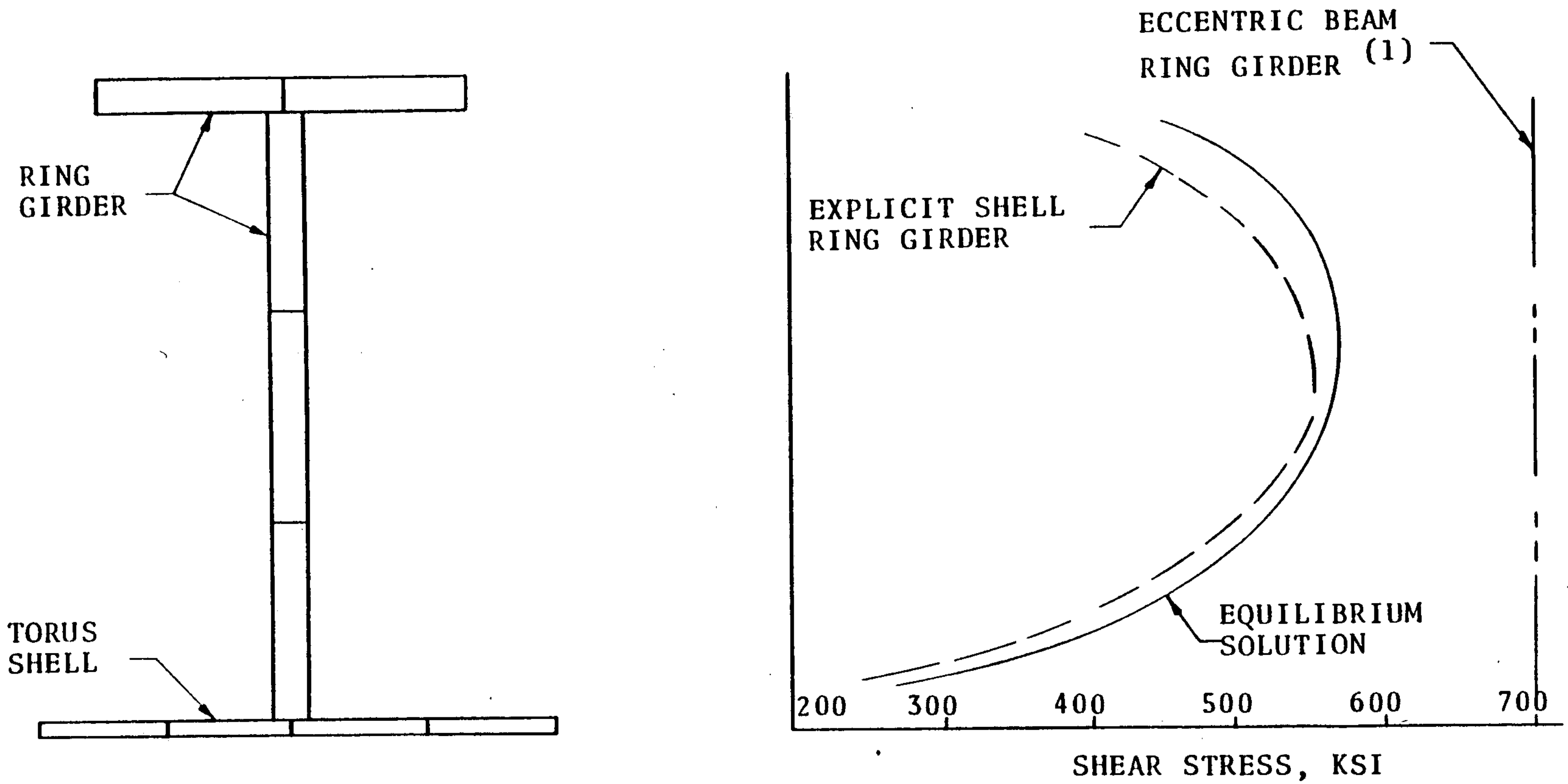
LOCATION OF INTEREST	EQUILIBRIUM SOLUTION	ISOLATED ELEMENT SOLUTION	
		ECCENTRIC BEAM	EXPLICIT SHELL
A	524.0	703.0(1)	474.1
B	565.9	703.0(1)	547.7
C	433.7	703.0(1)	396.4

LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

STRESS: IN-PLANE SHEAR STRESSES

NOTE: (1) ASSUMED UNIFORM BEAM SHEAR STRESSES ($\tau = \frac{V}{KA}$)

UNITS: KSI



LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

STRESS: IN-PLANE SHEAR STRESS DISTRIBUTION

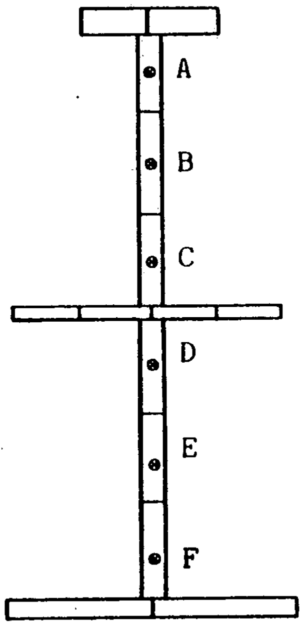
NOTE: (1) ASSUMED UNIFORM BEAM SHEAR STRESS ($\tau = \frac{V}{KA}$) FOR THE RING GIRDER

FIGURE 5.1-2

IN-PLANE SHEAR STRESSES FOR NON-SADDLE MODELS UNDER PURE SHEAR LOADING CONDITION

TABLE 5.1-3

IN-PLANE NORMAL STRESS FOR SADDLE MODELS UNDER PURE SHEAR LOADING



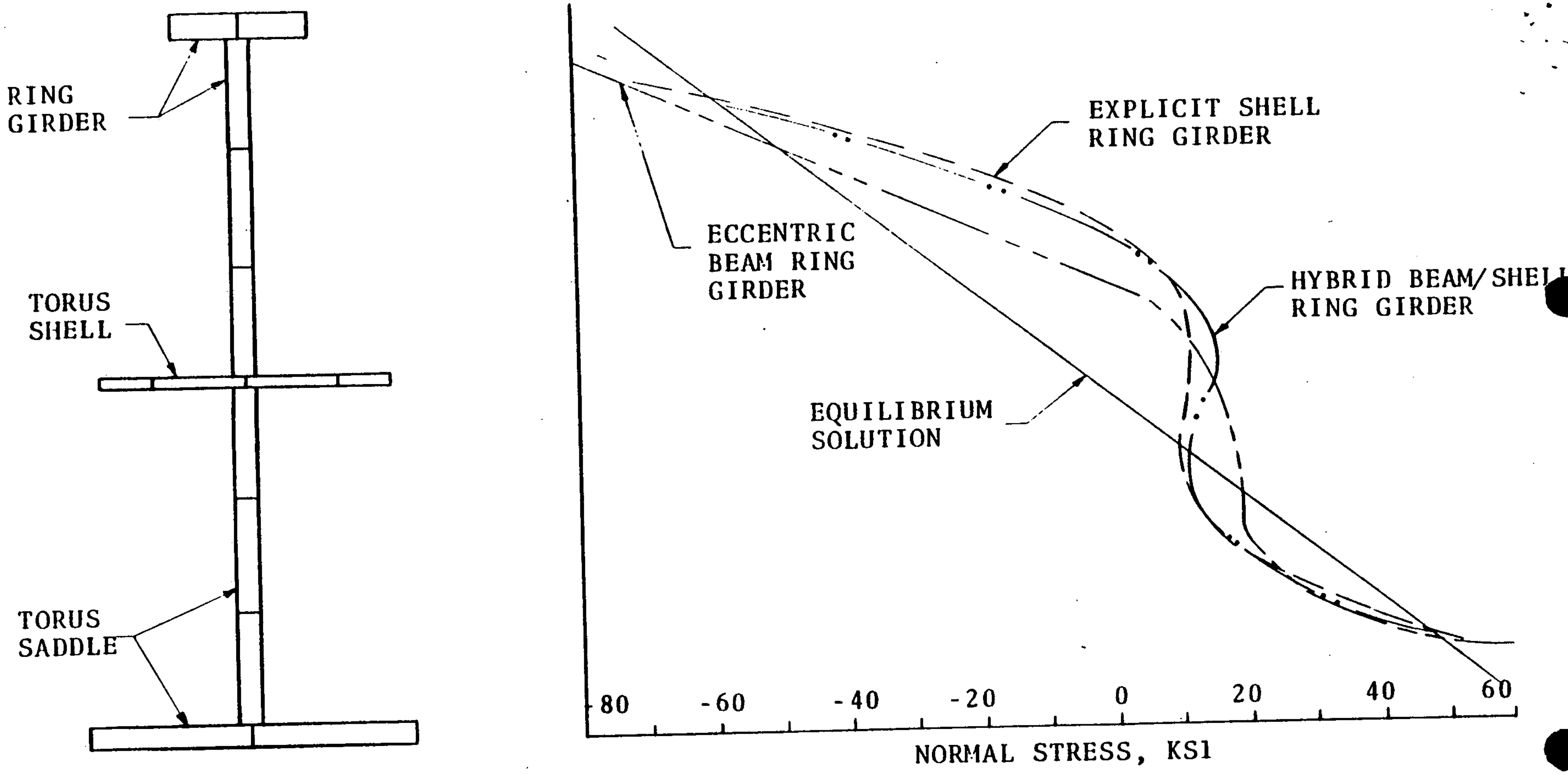
LOCATION OF INTEREST	EQUILIBRIUM SOLUTION	ISOLATED ELEMENT SOLUTION		
		ECCENTRIC BEAM	EXPLICIT SHELL	HYBRID BEAM/SHELL
A	-63.18	-74.80 (1)	-71.64	-72.36 (1)
B	-40.26	-33.43 (1)	-11.72	-16.35 (1)
C	-18.04	6.75 (1)	11.30	13.46
D	5.37	17.13	9.98	12.36
E	27.33	19.52	16.22	16.08
F	50.31	54.06	53.94	53.92

LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

STRESS: IN-PLANE NORMAL STRESSES

NOTE: (1) ASSUMED DISCRETE BEAM SOLUTION ($\sigma = \frac{P}{A} \pm \frac{MC}{I}$)

UNITS: KSI



LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

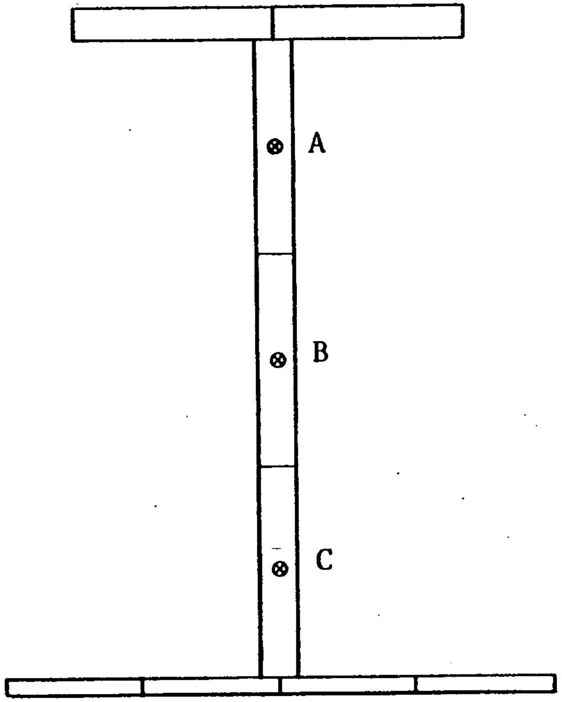
STRESS: IN-PLANE NORMAL STRESS DISTRIBUTION

FIGURE 5.1-3

IN-PLANE NORMAL STRESSES FOR SADDLE MODELS UNDER PURE SHEAR LOADING CONDITION

TABLE 5.1-4

IN-PLANE NORMAL STRESS FOR NON-SADDLE MODELS UNDER PURE SHEAR LOADING CONDITION



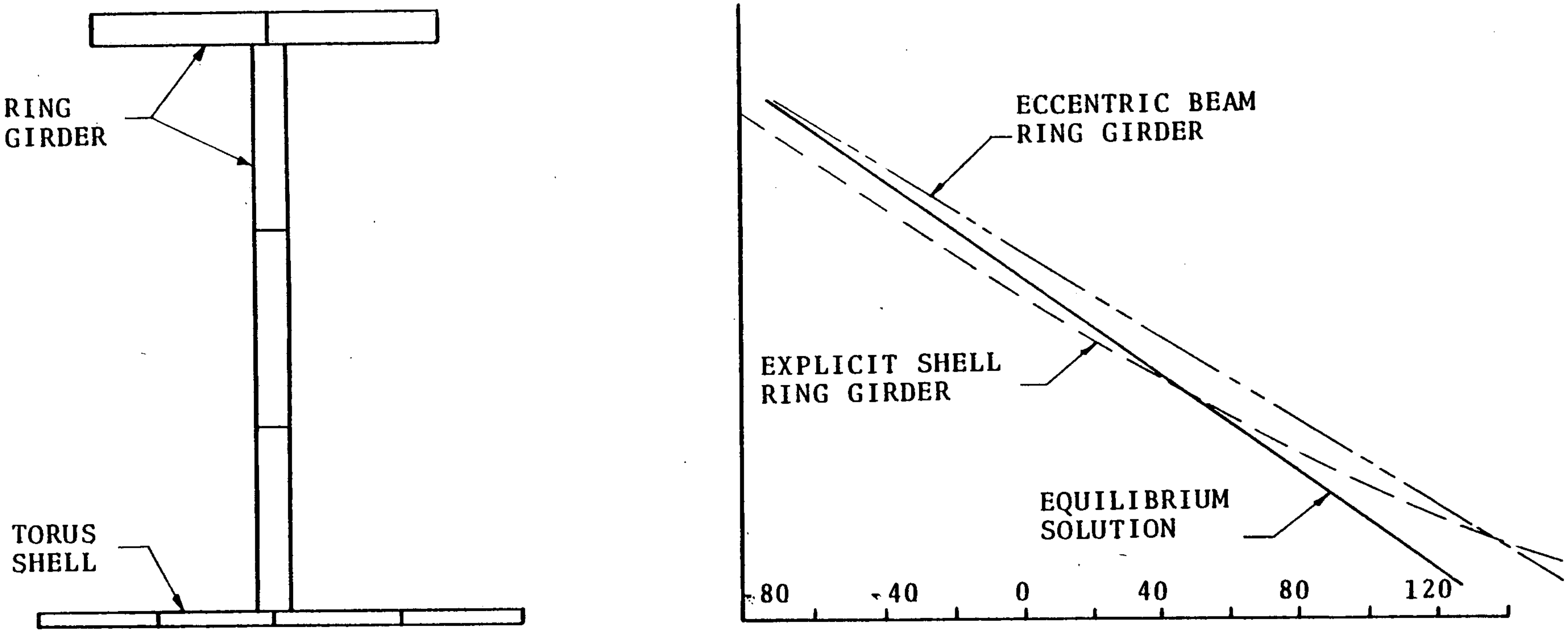
LOCATION OF INTEREST	EQUILIBRIUM SOLUTION	ISOLATED ELEMENT SOLUTION	
		ECCENTRIC BEAM	EXPLICIT SHELL
A	-62.92	-61.07 (1)	-74.56
B	18.58	33.77 (1)	17.81
C	97.92	126.17 (1)	118.20

LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

STRESS: IN-PLANE NORMAL STRESSES

NOTE: (1) ASSUMED DISCRETE BEAM SOLUTION ($\sigma = \frac{P}{A} \pm \frac{MC}{I}$)

UNITS: KSI



LOAD: UNIT SHEAR DISPLACEMENT APPLIED AT THE BOUNDARY

STRESS: IN-PLANE NORMAL STRESS DISTRIBUTION

FIGURE 5.1-4

IN-PLANE NORMAL STRESSES FOR NON-SADDLE MODELS UNDER PURE SHEAR LOADING CONDITION

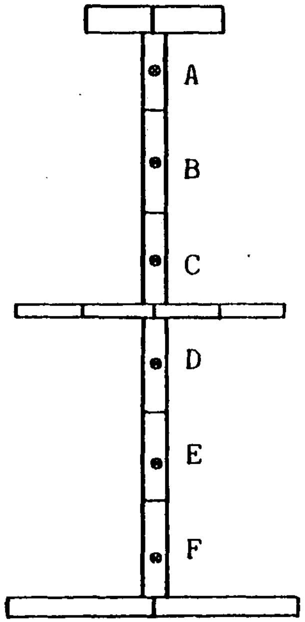


TABLE 5.2-1

IN-PLANE NORMAL STRESS FOR SADDLE MODELS

UNDER PURE BENDING MOMENT LOADING CONDITION

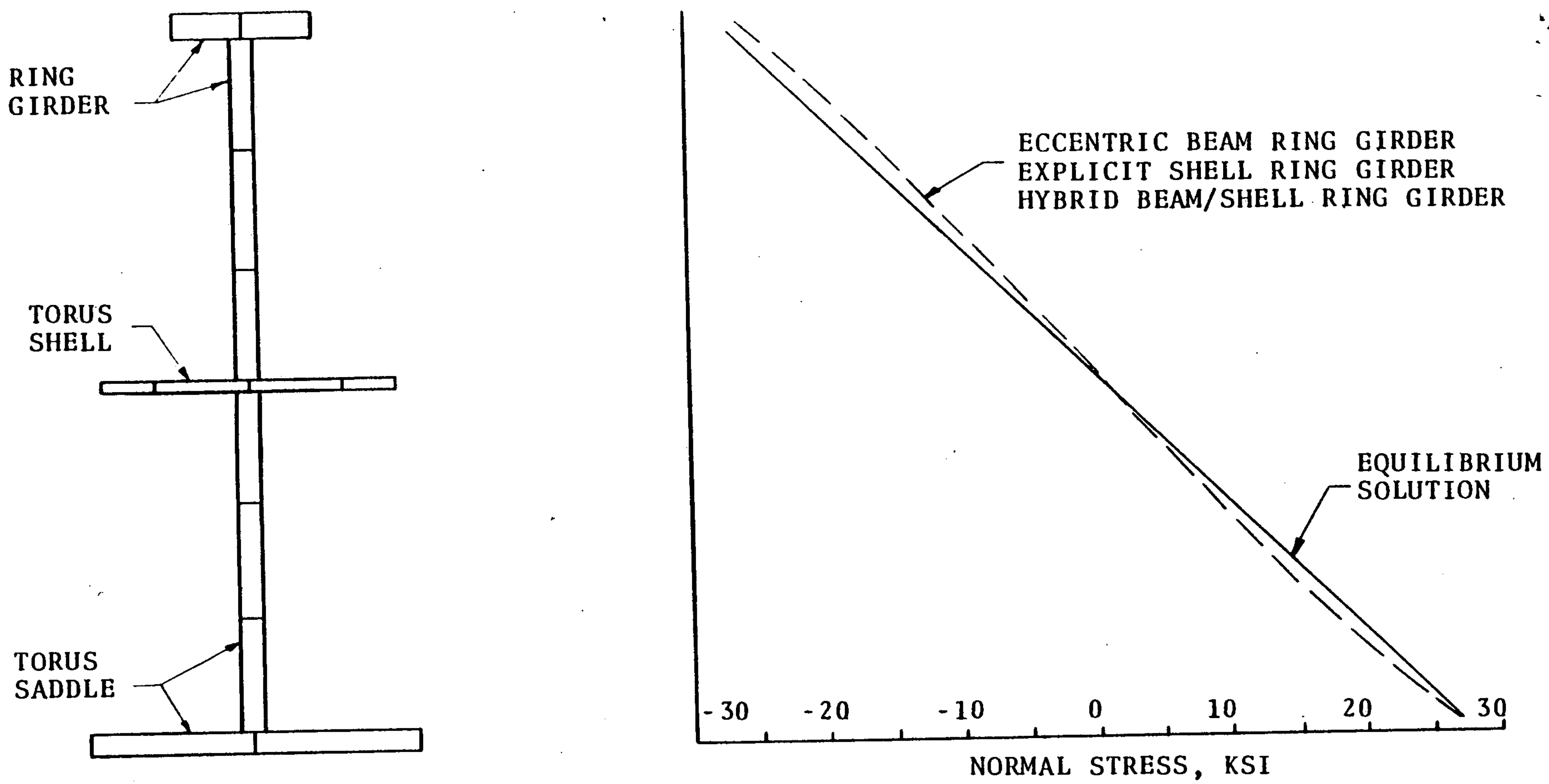
LOCATION OF INTEREST	EQUILIBRIUM SOLUTION	ISOLATED ELEMENT SOLUTION		
		ECCENTRIC BEAM	EXPLICIT SHELL	HYBRID BEAM/SHELL
A	-2283.3	-2098.0 (1)	-2099.0	-2099.0 (1)
B	-1368.3	-1248.0 (1)	-1248.0	-1248.0 (1)
C	-480.9	-422.5 (1)	-422.6	-422.6
D	453.8	427.4	427.4	427.4
E	1330.5	1264.0	1264.0	1264.0
F	2247.8	2116.0	2116.0	2116.0

LOAD: UNIT ROTATION APPLIED AT THE BOUNDARY

STRESS: IN-PLANE NORMAL STRESSES

NOTE: (1) ASSUMED DISCRETE BEAM SOLUTION ($\sigma = \frac{P}{A} \pm \frac{MC}{I}$)

UNITS: KSI



LOAD: UNIT ROTATION APPLIED AT THE BOUNDARY

STRESS: IN-PLANE NORMAL STRESS DISTRIBUTION

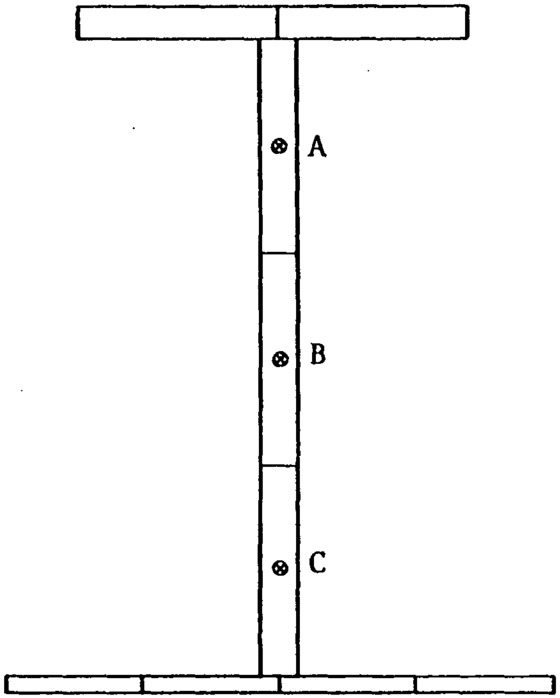
FIGURE 5.2-1

IN-PLANE NORMAL STRESSES FOR SADDLE MODELS

UNDER PURE BENDING MOMENT LOADING CONDITION

TABLE 5.2-2

IN-PLANE NORMAL STRESS FOR NON-SADDLE MODELS UNDER PURE BENDING MOMENT LOADING CONDITION



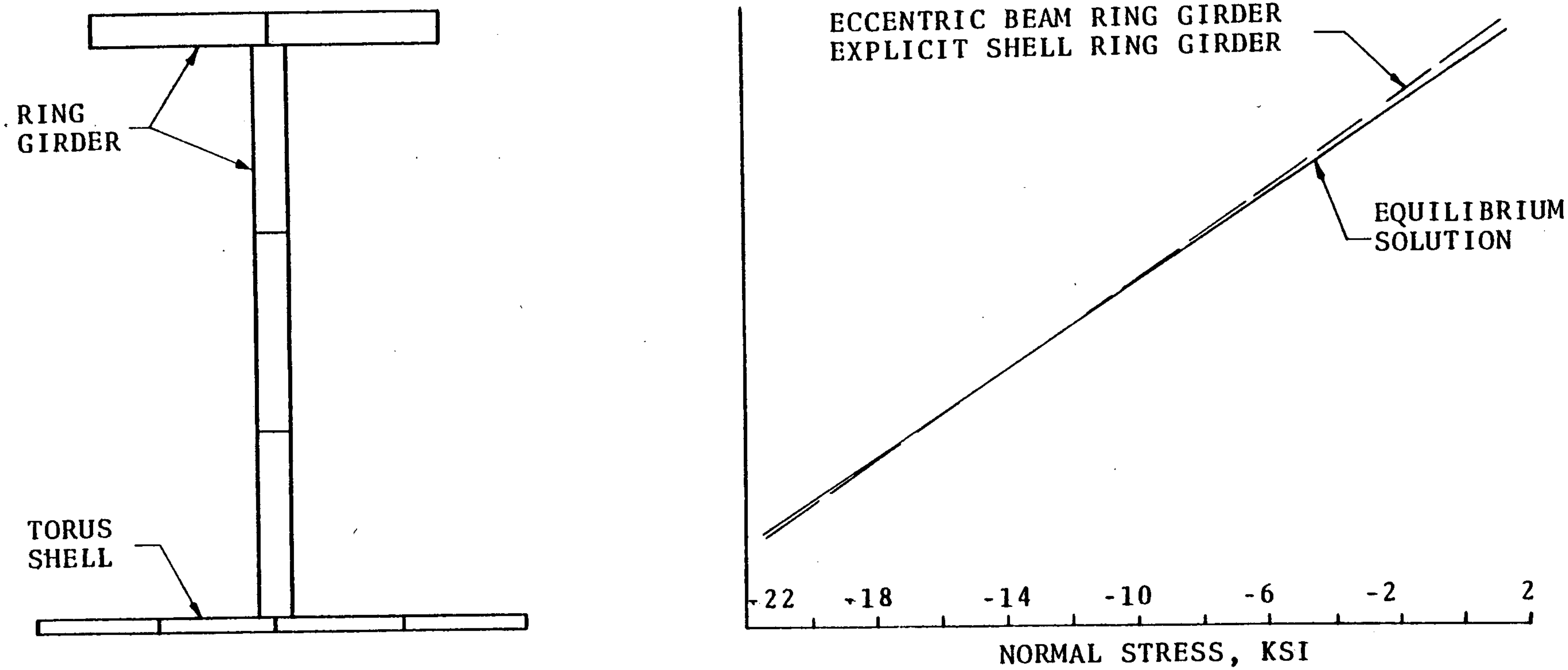
LOCATION OF INTEREST	EQUILIBRIUM SOLUTION	ISOLATED ELEMENT SOLUTION	
		ECCENTRIC BEAM	EXPLICIT SHELL
A	-399.6	-418.5 (1)	-418.5
B	-1237.9	-1241.0 (1)	-1241.0
C	-2098.9	-2087.0 (1)	-2087.0

LOAD: UNIT ROTATION APPLIED AT THE BOUNDARY

STRESS: IN-PLANE NORMAL STRESSES

NOTE: (1) ASSUMED DISCRETE BEAM SOLUTION ($\sigma = \frac{P}{A} \pm \frac{MC}{I}$)

UNITS: KSI



LOAD: UNIT ROTATION APPLIED AT THE BOUNDARY

STRESS: IN-PLANE NORMAL STRESS DISTRIBUTION

FIGURE 5.2-2

IN-PLANE NORMAL STRESSES FOR NON-SADDLE MODELS UNDER PURE BENDING MOMENT LOADING CONDITION

6.0 SUMMARY

As indicated by the previous sections, modelling the ring girder with offset beam elements can be appropriate, and the equilibrium solution is an effective approach to calculating the design shear stresses for the weld stress evaluation. To apply the equilibrium solution, the total nodal equilibrium force at a given cross section of the ring girder (including the tributary shell region) must be known. This can be obtained by summing up the beam end forces and the shell element global corner forces of the individual elements along the section being considered. The design normal stresses can be obtained directly from structural analysis computer output (which utilized isolated-beam stress equations) and no further processing is required.

The evaluation presented in this report demonstrates that the eccentric beam modelling technique for ring girders in Mark I suppression chambers is adequate, and more expensive explicit ring girder representations are not necessary for the purpose of ring girder and weld stress evaluation. However, the hybrid technique of modelling the lower portion of the ring girder web with a single row of shell elements will facilitate stress calculations at the ring girder/torus shell junction. Eccentric beams can be utilized to represent the remaining ring girder cross section to economize on modelling.