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Lawrence Livermore Laboratory

SUMMARY OF CALCULATIONS OF DYNAMIC RESPONSE CHARACTERISTICS AND DESIGN STRESS OF THE 1/5 SCALE PSE TORUS

Don Arthur

9 February 1977

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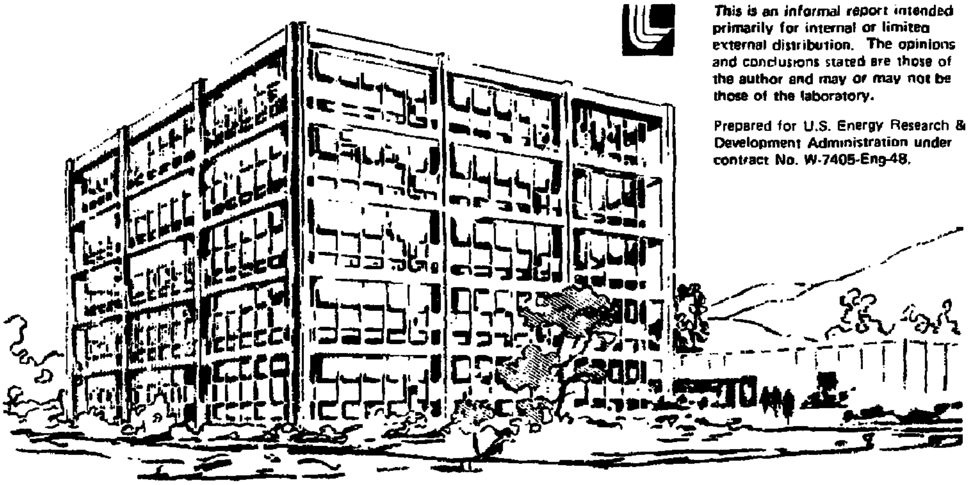

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SUMMARY OF CALCULATIONS OF DYNAMIC RESPONSE CHARACTERISTICS AND DESIGN STRESS OF THE 1/5 SCALE PSE TORUS

Don Arthur

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The Lawrence Livermore Laboratory is currently involved in a 1/5 scale testing program on the Mark I BWR pressure suppression system. The program, funded by the U.S. Nuclear Regulatory Commission, encompasses the design and fabrication of the test facility as well as the actual experimentation.

A key element of the test setup is a pressure vessel that is a 90° sector of a torus. Although it is a 1/5 scale model of the toroidal wetwell in a Mark I BWR, the 90° sector is massive in its own right: its walls are 3/4 inch thick steel and it weighs approximately 40,000 lb. when half full of water.

Proper performance of the 90° torus depends on its structural integrity and structural dynamic characteristics. It must sustain the internal pressurization of the planned tests, and its dynamic response to the transient test loads should be minimal. If the structural vibrations are too great, interpretation of important load cell and pressure transducer data will be difficult.

The purpose of this report is to bring together under one cover calculations made by myself and others* pertaining to the structural dynamic characteristics and structural integrity of the 90° torus. The remainder of the report is divided into three sections and an appendix: SYSTEM DESCRIPTION in which the torus and associated hardware are briefly described; STRUCTURAL DYNAMICS in which calculations of natural frequency and dynamic response are presented; STRUCTURAL INTEGRITY in which stress calculations for design purposes are presented; and the appendix which contains an LLL internal report comparing the expected load cell response for a three and four-point supported torus.

*Alex Blake, Staff Engineer at LLL
Art Williams, Project Engineer at EG&G
Tri-Valley Engineering, Consultant retained by EG&G
Robert Murray, Engineer, Structural Mechanics Group at LLL

SYSTEM DESCRIPTION

The torus and associated hardware are shown in Figures 1 and 2. The torus itself is made up of two 45° sections bolted together at the center. The two ends are covered with flat, bolted end plates. The torus is supported by two main trunnion supports at its center and a third vertical support link at one end.

Inside the torus is a ringheader split into two 45° sections. The two ringheader sections are joined in the middle by a flexible coupling. Structurally they can be considered independent of one another. Each 45° ringheader segment has six pairs of downcomers extending downward. Each downcomer pair is joined together by a tie rod.

Vertical support of the ringheader is achieved with four vertical support columns (two for each 45° ringheader section) that attach to reinforcing rings at the bottom of the torus. Lateral support of each 45° section comes from its vent pipe which slopes upward and attaches rigidly to the drywell. The bellows on each vent pipe prevents forces from being transmitted across the torus/vent connection.

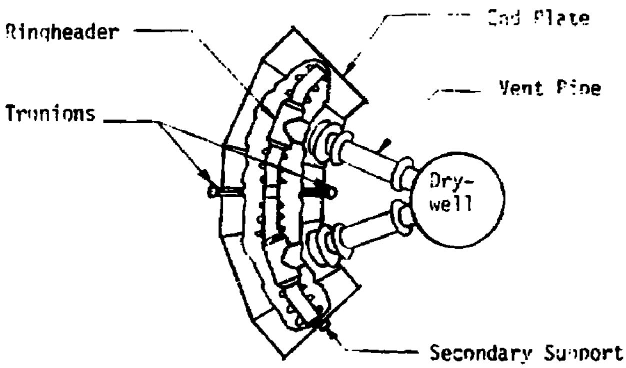


FIGURE 1. PLAN VIEW OF 90° TORUS

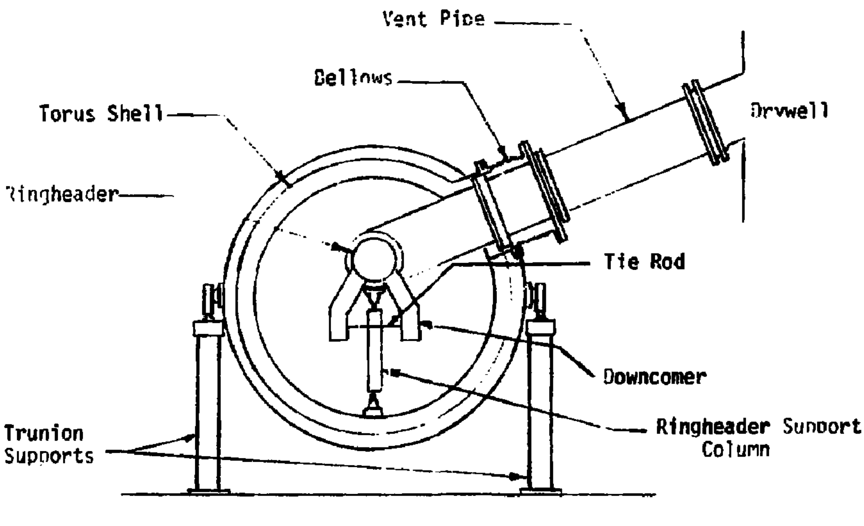


FIGURE 2. CROSSECTION OF 90°TORUS

STRUCTURAL DYNAMICS

Table 1 summarizes the results of the dynamic analyses performed on the ringheader, the torus, and the test pit foundation. Each analysis is briefly discussed below.

Ringheader Internal Pressurization

One of the loads on the ringheader and vent pipe assembly is the internal pressure due to pressurization of the drywell. The drywell experiences a maximum pressure of approximately 42 psi with a rise time slightly greater than 10 seconds.

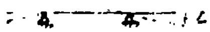
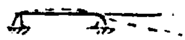
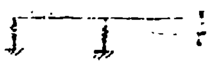
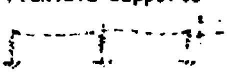
Tri-Valley Engineering performed a modal analysis and a static analysis of this structure's response to 42 psi internal pressure, both by the finite element method.[1,2] The latter included the upward thrust at the open ends of the downcomers.

The modal analysis indicated there were no natural frequencies low enough to dynamically amplify the structural response to the drywell pressure time history (10 second rise time). The lowest frequency found was 20 Hz. This was an antisymmetric horizontal vibration which, in any event, would not respond to internal pressure loading or to the vertical pool swell loading.

Tri-Valley's static analysis indicated the maximum displacement due to internal pressure and downcomer thrust loads was .017 inches. This value is conservatively high for two reasons: (1) they used a ringheader wall thickness slightly smaller than that in the final design; and (2) Tri-Valley did not include the stiffening effect of the larger diameter portion of the ringheader at the vent pipe junction. In both cases the discrepancies are due to the fact that the ringheader design was evolving while the analyses were being performed.

TABLE 1

SUMMARY OF DYNAMIC ANALYSES

ITEM	MODE SHAPE	FREQUENCY (Hz)	LOAD	MAXIMUM DEFLECTION (IN.)
Ringheader & vent pipe	*	*	42 psi interal pressure	0.017 (due to static pressure)
Ringheader Bending		220.	Pool swell (39 lb/in)	0.0014
Rigid Ringheader on Flexible support		330.	39 lb/in	0.0006
Ringheader Ovalization		210.	39 lb/in	0.015
Downcomer		530.	109 lb.	0.002
Torus	 3 Rigid Supports	48.	———	———
"	 3 Flexible Supports	36.	Expected Hydrodynamic Load Function	0.012
"	 4 Flexible Supports	105.	"	0.001
Test Pit Foundation	———	———	Maximum Test Loads Applied Simultaneously	0.006

*See text. The 20 Hz horizontal vibration mode calculated by Tri-Valley will not respond to test loads.

Ringheader Response to Pool Swell

The pool swell that will occur during the tests will put a vertical load on the ringheader. The magnitude of this load was extrapolated from the G.E. 1/12 scale tests[3] to be 8280 lb. distributed over the 90° ringheader. The equivalent linearly distributed load is 39 lb/in. At the request of NRC, I made estimates of natural frequency and static response to the pool swell load based on three different response mechanisms: vertical bending of the ringheader, vertical motion of a rigid ringheader on flexible supports, and ringheader ovalization. These calculations are based on the idealized models shown in Figures 3 through 6 and were performed by simple "handbook" methods. The results are summarized in Table 1.

The static bending response of the ringheader to the pool swell load was calculated by assuming each 45° section to be a straight beam with a uniform crossection. This model is shown in Figure 3.

Figure 4 illustrates the model used to estimate the 220 Hz bending frequency. Since the center part of each 45° section is very rigid due to the enlarged vent tee, its influence was modeled as the rotational spring k in Figure 4. The 27 inch long beam represents the ringheader outboard of the vertical support.

Another approach to calculating the ringheader response to pool swell is to assume the support columns are the flexible elements. This model is shown in Figure 5. The frequency calculated by this method is 330 Hz and the deflection is 0.0006 inches.

The pool swell load can be decomposed into components causing beam bending and ovalization of the ringheader as shown in Figure 6. The natural frequency of the ringheader ovalization mode was estimated using an equation[4] which takes into account the stiffening rings in the

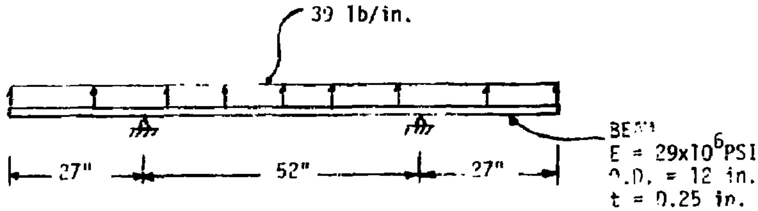


FIGURE 3. ANALYTICAL MODEL FOR STATIC BEAM BENDING RESPONSE OF RINGHEADER TO POOL SWELL

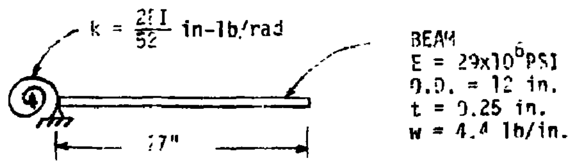


FIGURE 4. ANALYTICAL MODEL FOR RINGHEADER NATURAL FREQUENCY IN VERTICAL BENDING

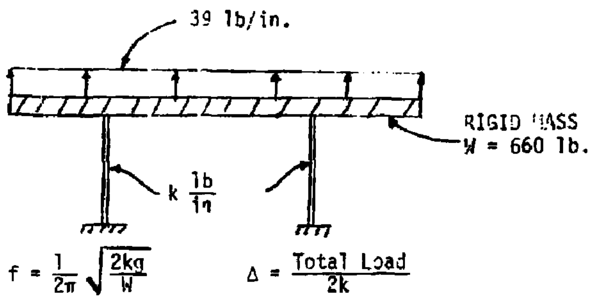


FIGURE 5. ANALYTICAL MODEL FOR RIGID RINGHEADER ON FLEXIBLE VERTICAL SUPPORTS

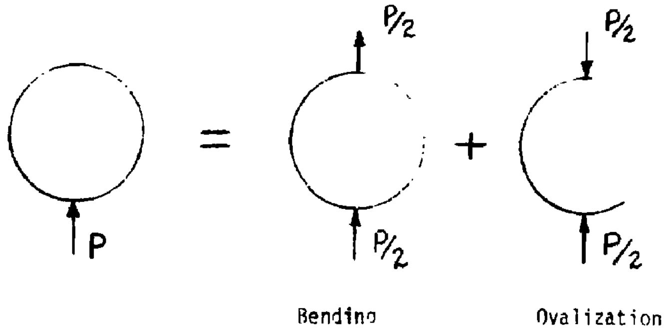


FIGURE 6. DECOMPOSITION OF POOL SWELL LOAD ON RINGHEADER INTO BENDING AND OVALIZATION COMPONENTS

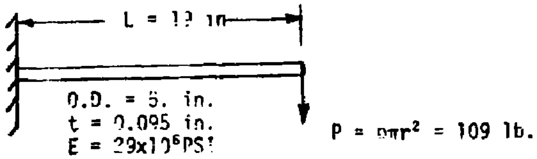


FIGURE 7. ANALYTICAL MODEL FOR DOWNCOMER NATURAL FREQUENCY AND DEFLECTION

header. The deflection was conservatively estimated using the standard formula for a plain ring.

Downcomer Bending

Another analysis requested by the NRC concerns the downcomer. I assumed the downcomer to be a straight, unsupported cantilever beam with the crossection of the actual downcomer, as shown in Figure 7. The natural frequency estimate of 530 Hz is based on the handbook formula for such a beam. The deflection is based on a postulated 6 psi pressure drop across the open end of the tube. The resulting force is conservatively directed normal to the beam's axis rather than parallel to it.

Torus Vertical Bending

The expected hydrodynamic load function on the 90° torus has a maximum downward force of 43,000 lb. and 15,200 lb. upward. These loads were extrapolated from the GE 1/12 scale data.[3] I performed eigenvalue analyses and dynamic response calculations of the torus' response to this forcing function by the finite element method. The purpose of these calculations was to estimate what the support load cell measurements would look like and to compare load cell response for the planned three-point torus system with a proposed four point system (two in the middle and one on each end). The entire report on this analysis appears in the appendix below. The main results are given in the following paragraphs and in Table 1.

First, the lowest natural frequency of the torus was calculated assuming a rigid 3 point support system. This estimate of 49 Hz agreed well with prior calculations.

Next, the response of the torus to the expected hydrodynamic load function was calculated using a more realistic model with three flexible supports. The lowest natural frequency was 36 Hz. The maximum displacement was 0.012 in. (at the free end). The calculated load cell signal for the 36 Hz system displayed some "overshoot" and "ringing" but appeared acceptable.

Finally, I analyzed the response of a more rigid 4 point supported system. The fundamental frequency was 105 Hz and the maximum displacement was 0.001 in. The load cell signal for this system also had some "overshoot" and "ringing", but in general, was "cleaner." My overall conclusion was that it would be worth the expense to provide for a 4 point support system as a backup. The backup support system has been provided.

Test Pit Foundation

During the design of the reinforced concrete test pit, a finite element structural analysis of the pit floor was performed[5] to show that deflections would be minimal. Since the floor is one foot thick and has an additional three by three foot beam under the 90° torus, its response to the test loads was assumed to be static. The foundation deflections were conservatively estimated by applying all the peak test loads to it simultaneously and calculating the deflections (by computer code). Specifically, the following downloads were applied: 50 kips under each of two trunnions supporting the 90° torus; 25 kips under each end of the 90° torus; and 18 kips each under both supports for the 7-1/2° sector. All the computed deflections were equal to or less than 0.006 in.

STRUCTURAL INTEGRITY

Previously made calculations which demonstrate structural integrity are discussed in this section. Table 2 summarizes these calculations.

Ringheader

The ringheader deflection due to a 39 lb/in. pool swell load was estimated earlier. I also calculated the maximum bending stress in the ringheader due to this load. As Table 2 indicates, it is negligible.

Downcomer

The downcomer deflection due to a postulated lateral thrust load was also calculated in the previous section. By a similar procedure, I estimated the maximum bending stress in the unsupported downcomer. As Table 2 indicates, it was negligibly small.

Torus End Plate Bolts

The torus end plates are bolted to the torus flange with 36, 3/4 inch diameter, SAE Grade 8 bolts. The analysis of these bolts was by EG&G.[6]

The total pressure load on the end plate is

$$F = p\pi r^2 = (50)\ \pi\ 38.67^2 = 2.35 \times 10^5 \text{ lb.}$$

The proof load of these bolts is 40,100 lb. each. Since the bolts will be torqued to 80 per cent of proof, the maximum joint capability is

$$F_{ALL} = (40{,}100)(36)(.8) = 1.155 \times 10^6 \text{ lb.}$$

The factor of safety is therefore:

$$F.S. = \frac{1.155 \times 10^6}{2.35 \times 10^5} = 4.9$$

Torus Flange

Figure 8 illustrates the flange design that is common to the bolted connection in the center of the torus and the two end plate connections. EG&G

TABLE 2

SUMMARY OF DESIGN STRESS CALCULATIONS

Structure	Design Load	Calculated Stress	Allowable Stress
Ringheader	Pool swell 39 lb/in.	negligible bending stress (530 psi)	------
Downcomer	109 lb. lateral thrust load	negligible bending stress (1180 psi)	------
Torus End Plate Bolts	50 psi Internal	2.35×10^5 lb. (end plate load)	1.155×10^6 lb (capability)
Torus Flange	50 psi Internal	Longitudinal S_H = 10,800 psi	23,850 psi
		Radial S_R = 1700 psi	15,900 psi
		Tangential S_T = 520 psi	15,900 psi
		Weld Shear τ = 1980 psi	9,180 psi
Torus Wall	50 psi Internal	Longitudinal σ_ℓ = 7325 psi	17,200 psi
		Hoop σ_h = 14,650 psi	
Quartz Camera Port	50 psi Internal	σ_{max} = 710 psi	3,500 psi
Trunnion Support Pin	40,000 lb. per pin	σ = 60,000 psi	140,000 psi (yield)

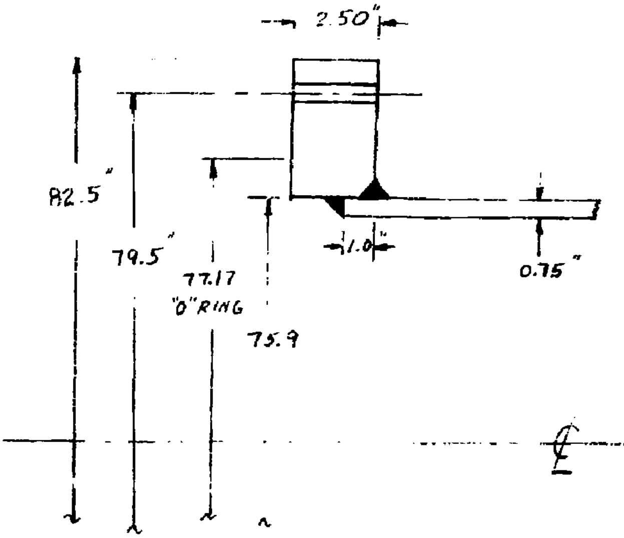


FIG. 8. Torus Flange Design

performed the stress analysis[6] of this flange per the ASME Boiler and Pressure Vessel Code (Reference 7). The calculations are quite involved; they utilize numerous symbols, equations, and charts. Instead of repeating the calculations here, I refer the reader to reference 7. Specifically, the rules for stress calculation in Mandatory Appendix II, Division 1 of Section VIII (pp. 233-260) apply. The flange was designed as an integral-type since it is identical to the design shown in Figure UA-48(8) (p. 237 of the above). As Table 2 indicates, the computed stresses were well within the limits prescribed by the Code.

Torus Wall

The torus shell was analyzed by EG&G as a mitered pipe.[6] Appendix D of reference 8 spells out stress intensification factors for mitered pipe. The nominal membrane stresses in the torus' wall are:

$$\text{longitudinal} \quad \sigma_\ell = \frac{pr}{2t} = \frac{(50)(37.58)}{2(0.75)} = 1250 \text{ psi}$$

$$\text{hoop} \quad \sigma_h = \frac{pr}{t} = \frac{50(37.58)}{(0.75)} = 2500 \text{ psi}$$

The stress intensification factor as given by Appendix D is

$$= (0.9)\left[\frac{2\,r_m}{(1+\cot\theta)t}\right]^{2/3} = (0.9)\left[\frac{2(37.58)}{(1+\cot 11.25)(0.75)}\right]^{2/3} = 5.86$$

Therefore, the design stresses are

$$\sigma_{\ell_{max}} = 7325 \text{ psi}$$

$$\sigma_{h_{max}} = 14{,}650 \text{ psi}$$

As table 2 indicates, the calculated stresses are less than the allowable.

Torus Wall Penetrations

This analysis is an update of one performed by EG&G.[6] UG-37 of Section VIII, Division 1 of reference 7 requires that openings in pressure vessels be reinforced by adding extra material around the opening or by increasing the nominal wall thickness. The latter case applied here.

The amount of reinforcement area required is given on page 30 of reference 7:

$$A = (d)(t_r)(F)$$

The amount of area allowed as reinforcement under UG-40 (pp. 33) is:

$$A_1 = (E_1 t - F t_r)d.$$

where E_1 = 1.0

F = 1.0

t = nominal wall thickness

t_r = minimum thickness required by internal pressure = .108 in.

d = diameter of opening

If the ratio (A_1/A) is equal to or greater than unity, the extra wall thickness is adequate to reinforce the opening:

$$\frac{A_1}{A} = \frac{(t - t_r)d}{d\ t_r} = \frac{t}{t_r} - 1 = \frac{.75}{.108} - 1 = 5.9$$

<u>Camera Port</u>

The camera port was analyzed by EG&G as a circular plate, simply supported, with uniform pressure on one side.[6] The plate is 6.78 inches in diameter, one inch thick, and it's Poisson ratio is 0.244 (for quartz). The handbook solution of this problem yields a maximum stress of 710 psi. The allowable stress for quartz is 3500 psi.

<u>Trunnion Support Pin</u>

EG&G performed the stress analysis on this pin.[6] The worst conceivable load occurs during the maximum hydrodynamic "down" load. This amounts to 40,000 lb. per pin (there are two pins) when dead weight is included. The pin is treated as a beam. It is a solid circular shaft 2.5 inches in diameter and 2.3 inches long. The maximum bending stress is:

$$\sigma = \frac{M_c}{I} = \frac{(40{,}000 \times 2.3)\ \frac{2.5}{2}}{\frac{\pi\ 2.5^4}{64}} = 60{,}000\ \text{psi}$$

The steel (HY-130) has a yield strength of 140 ksi.

REFERENCES

1. Tri-Valley Engineering Evaluation of the Dynamic Response of the Vent and Header Piping Systems for a 1/5 Scale MARK I Containment Suppression Chamber, Livermore, California, May 1976.

2. Addenda to the above, July 1976.

3. T. R. McIntyre, M. A. Ross, L. L. Myers, Mark II - Pressure Suppression Test Program, General Electric Company, San Jose, California, May 1976.

4. Private communication from Alex Blake of LLL, 1977.

5. Private communication from R. C. Murray of LLL, February 1977.

6. Private communication from Art Williams of EG&G to John Pitts, LLL, June 1976.

7. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, ASME, New York, NY., 1974 Edition.

8. American Society of Mechanical Engineers, American National Standard Code for Pressure Piping - Power Piping, ANSI B31.1 - 1973 TO ASME, New York, NY., 1973.

APPENDIX

STRUCTURAL DYNAMIC RESPONSE OF THE 1/5 SCALE PSE TORUS

C. F. Arthur

The work described in this note is an extension of the dynamic analysis reported in Reference 1. The dynamic response of the toroidal test tank to the hydrodynamic internal load function was calculated, as before, but with a much more refined analytical model.

The reasons for doing this analysis are twofold: (1) the more refined model will provide a greater understanding of the torus' response, the requirements on the load cells, and the problems we will face in reducing the load cell data; and (2) it is of interest to compare the response of the proposed three point torus support system with that of a redundant four point support system.

The analysis was done with the SAP4 code. The toroidal tank was modeled with three-dimensional beam elements. Simple springs represented the torus supports and associated load cells. The hydrodynamic load function was the same one used in reference 1 and originally reported by McCauley and Martin[2].

PRINCIPLE RESULTS

The calculated fundamental natural frequency of the torus with three flexible supports is 36 Hz. The addition of a fourth support raises this to 105 Hz. Because of this, the four point support system responds to the load function in a more "quasi static" fashion. Although the three point support system may well prove to be adequate, in so far as load cell measurements are concerned, this analysis indicates the four point support system will yield "cleaner" load cell signals which follow the input load function better.

At this time the loading function is somewhat uncertain. The rise time and overall duration of the load could prove shorter than assumed here. The load function might also be slightly asymmetric about the primary supports. If any of these things do happen, the advantage of four supports over three could be greatly enhanced.

The four point support system would also provide the additional advantage of allowing a preload to be built into the support system. The preload would be used to reduce detrimental effects on load cell measurements of "gaping" (i.e., looseness), should it occur in the support linkage.

Based on the results of this analysis, I recommend that a four point support system be provided as an alternative.

It should be pointed out that a four point support system introduces thermal stress problems, due to its redundancy. This is documented in reference 3. However, if the need for four supports was sufficient, engineering solutions to the thermal stress problems could be found.

ANALYTICAL APPROACH

The analytical approach is based on a number of assumptions:

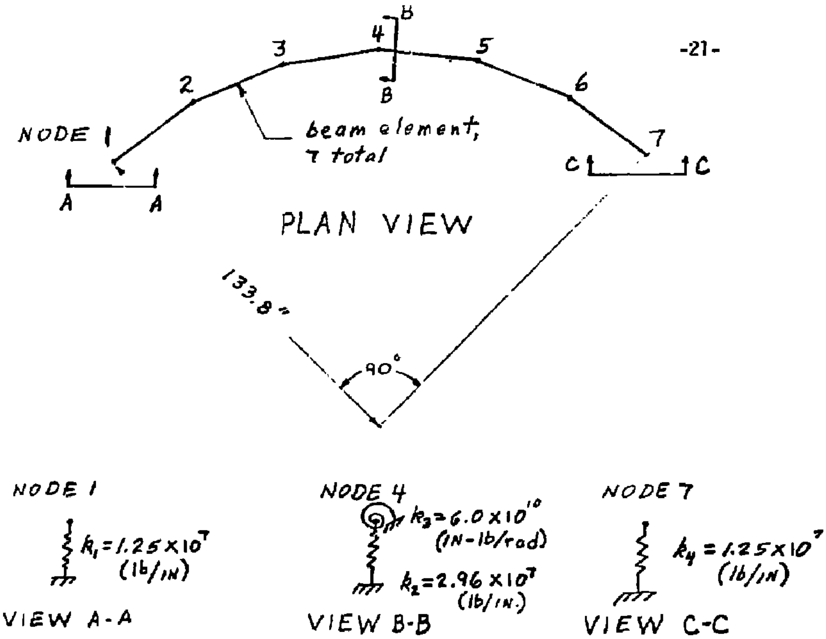
1. The deformation of the torus can be adequately described by three-dimensional beam elements which include torsion and transverse shear effects.
2. The mass can be adequately modeled by "smearing" the structure and water weight uniformly over the torus' length. The heavy end plates were an exception to this. They were lumped at their actual position.

3. The loading function can be uniformly smeared over the length of the torus.
4. The stiffening effect of the torus internals and vent pipes can be neglected.
5. The foundation motions will be negligibly small.

Figure 1 shows a schematic of the analytical model as well as all the pertinent properties. Two support systems are defined. Case 1 corresponds to the three point support: two primary supports located on either side of the torus at node 4 and a secondary support at node 1. Case 2 corresponds to the addition of a secondary support at node 7, identical to the one at node 1.

The secondary support springs, k_1 and k_4, are estimates based on the stiffness of a 25 kip load cell. The spring in the center, k_2, is based on a previous estimate (reference 1) of the combined vertical stiffness of the two primary supports and 100 kip load cells. k_3 is a torsional spring that results from the fact that the torus' center is actually supported by two springs, each equal to 1/2 k_2 and separated by a distance assumed to be 90 inches.

Two modal analyses were done on modified versions of the torus beam model to verify that it was reasonable. In one, the support springs at nodes 1 and 4 were made perfectly rigid, and node 7 was unsupported. The fundamental mode of this system was 48.2 Hz. The frequency predicted in reference 4 under similar circumstances was 49.0 Hz. The second verification analysis was performed with node 4 completely "fixed". This amounted to a cantilevered 45° torus segment. The calculated frequency was 70.6 Hz, as



NOTE: k_4 IS PRESENT ONLY IN CASE 2

LUMPED MASSES: @NODES 1 & 7 $m = 17.27 \frac{\text{lb-sec}^2}{\text{in}}$

@NODES 2,3,4,5,6 $m = 13.82 \frac{\text{lb-sec}^2}{\text{in}}$

TOTAL WEIGHT = 40,000 lb.

BEAM ELEMENTS: $E = 29 \times 10^6$ psi, $G = 11.4 \times 10^6$ psi, $\nu = 0.27$

TUBULAR CROSS-SECTION OD = 74.4 in, t = 0.75 in

BENDING INERTIA $I = 1.18 \times 10^5$ in^4

TORSIONAL INERTIA $J = 2.35 \times 10^5$ in^4

SHEAR AREA (1/2 actual) $A_s = 86.8$ in^2

DAMPING: UNIFORM 1%

FIGURE 1

FINITE ELEMENT MODEL OF TORUS

compared to 75 Hz calculated by Blake in reference 5. The agreement in both cases was excellent and indicated that both the model and SAP4 would yield reasonable results.

As noted above, two time-history analyses were performed with SAP4. Case 1 corresponded to the three support system; Case 2 corresponded to the four support system. The analyses were done by modal superposition and in both cases included the first ten frequencies spanning the frequency range 0-280 Hz. The integration time step size was 0.7 msec. Damping was nominally chosen to be a uniform 1% of critical.

The hydrodynamic load function was applied to the model as a set of discrete forces perpendicular to the plane of the torus (i.e., into the plane of the paper in Figure 1). The total force was divided up among the nodes by the method of tributary area. Thus, nodes 2 through 6 each had 1/6 of the load, and nodes 1 and 7 had 1/12 each.

RESULTS

As noted above, the time-history calculations were done by the method of modal superposition. In both cases 1 and 2, a single normal mode had a dominating influence on the torus response. Table 1 indicates the natural frequencies and mode shapes of these dominant natural modes.

Table 2 indicates the peak absolute vertical displacements calculated at each end of the torus and at its center. They all occurred at approximately the time of maximum downward force on the torus, 121 ms.

The remaining data are calculated force-time histories for the load cells that support the toroidal tank. They were derived from the results of the computer runs in the following way. Figure 2a illustrates the

TABLE 1

FUNDAMENTAL NORMAL MODES

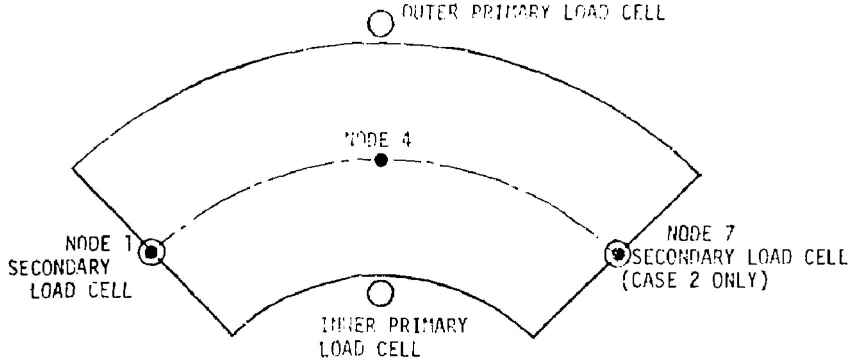
	MODE SHAPE	FREQUENCY
CASE 1		35.7 Hz.
CASE 2		104.9 Hz.

TABLE 2

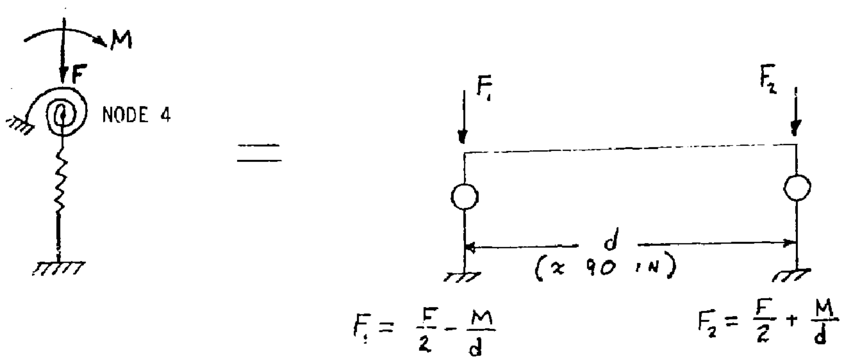
PEAK VERTICAL DISPLACEMENTS*

	NODE 1	NODE 4	NODE 7
CASE 1	-0.7×10^{-3} in	$+1.8\times10^{-3}$ in	$+11.7\times10^{-3}$ in
CASE 2	$+0.9\times10^{-3}$ in	$+0.9\times10^{-3}$ in	$+0.9\times10^{-3}$ in

*POSITIVE DOWNWARD. ALL OCCURRED APPROXIMATELY AT TIME OF MAXIMUM DOWNLOAD, 121 ms.



2a. PLAN VIEW



2b. TRANSFORMATION OF ANALYTICAL MODEL
FORCE AND MOMENT TO LOAD CELL FORCES.

FIGURE 2

arrangement of the torus load cells as well as the position of nodes 1, 4, and 7 in the analytical mode. As noted previously, the analytical model had vertical support springs at node 1, node 4, and node 7 (the latter for case 2 only). It also had a rotational spring at node 4. The force-time histories output for the springs at node 1 and 7 corresponded to the secondary load cells. The computer output of force and torque for the two springs at node 4 had to be transformed into the effective forces in the two primary load cells. Figure 2b illustrates this transformation.

Figures 3 through 6 show the calculated response of the load cells for case 1 (three point support system) compared to the total load input. Note that these figures include only the dynamic component of force; the load cell reading due to dead weight or static load is not included. Figure 3 shows the summation of all three load cells. Figure 4 shows the response of the secondary load cell. Figures 5 and 6 show the response of the inner and outer primary load cells. The ringing in these signals corresponds to the fundamental mode of the system shown in Table 1.

Figures 7 through 10 show the same kind of information for case 2 (four point support system). Again, the calculated forces reflect only the dynamic component of force in the load cells. Although two secondary load cells are present in this system, the force history for only one is given (Figure 8). Due to symmetry the responses of the two secondaries are identical. As before, the ringing in these signals is due to the normal mode shown in Table 1.

DISCUSSION AND CONCLUSIONS

The primary difference between the three and four point supported torus is the higher natural frequency of the latter: 36 Hz versus 105 Hz. As Figures 3 and 7 indicate, the measured forcing function will be much "cleaner"

Figure 3

CASE 1 - SUMMATION OF ALL THREE LOAD CELLS
(DEAD WEIGHT NOT INCLUDED)

LOAD CELL SUMMATION
FILE(S):FTOT (A)-INP

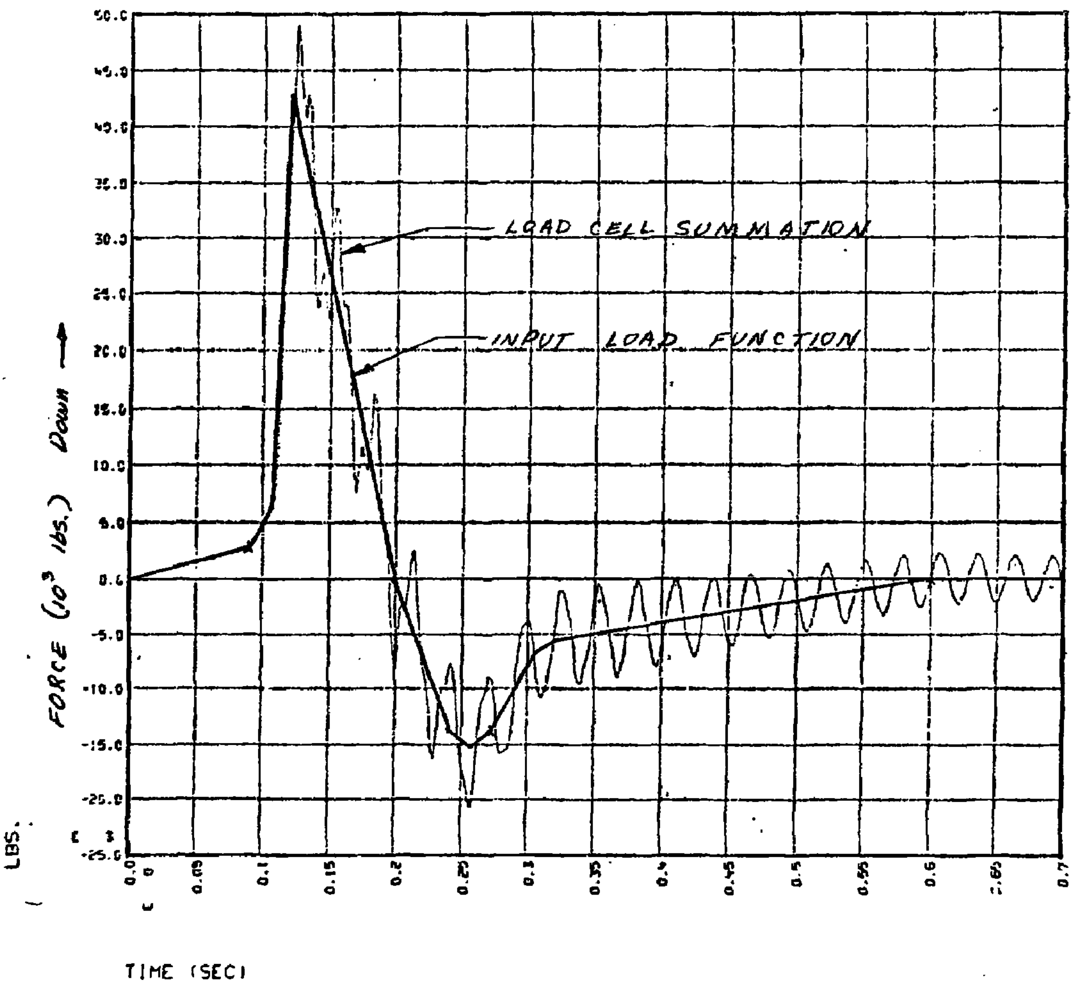


Figure 4

CASE I - SECONDARY LOAD CELL

(DEAD WEIGHT NOT INCLUDED)

SECONDARY L/C

FILE(S):INP (A)-SP1

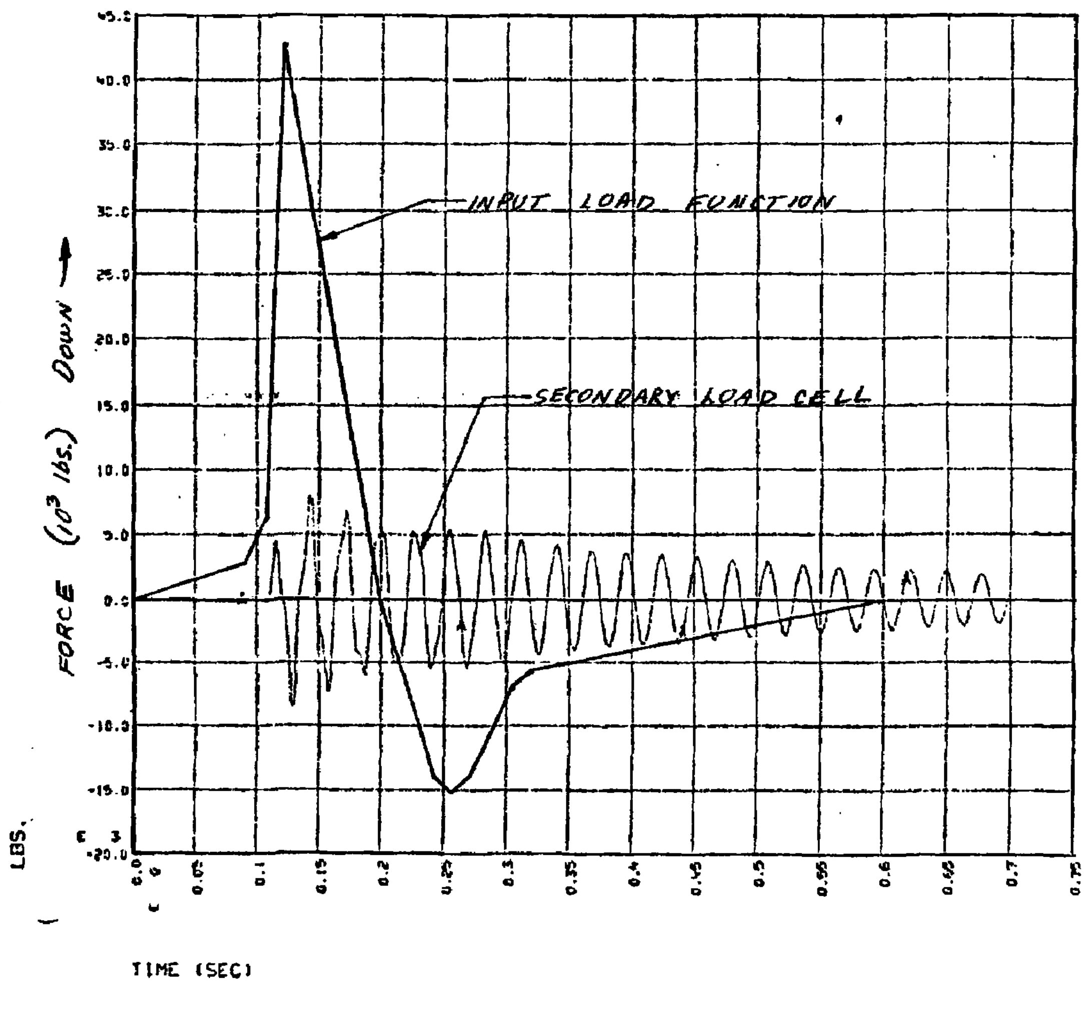


Figure 5
CASE I - INNER PRIMARY LOAD CELL
(DEAD WEIGHT NOT INCLUDED)

TORUS RESPONSE - THREE PT. SUPPORT
FILE(S): IAF (A)-LCI

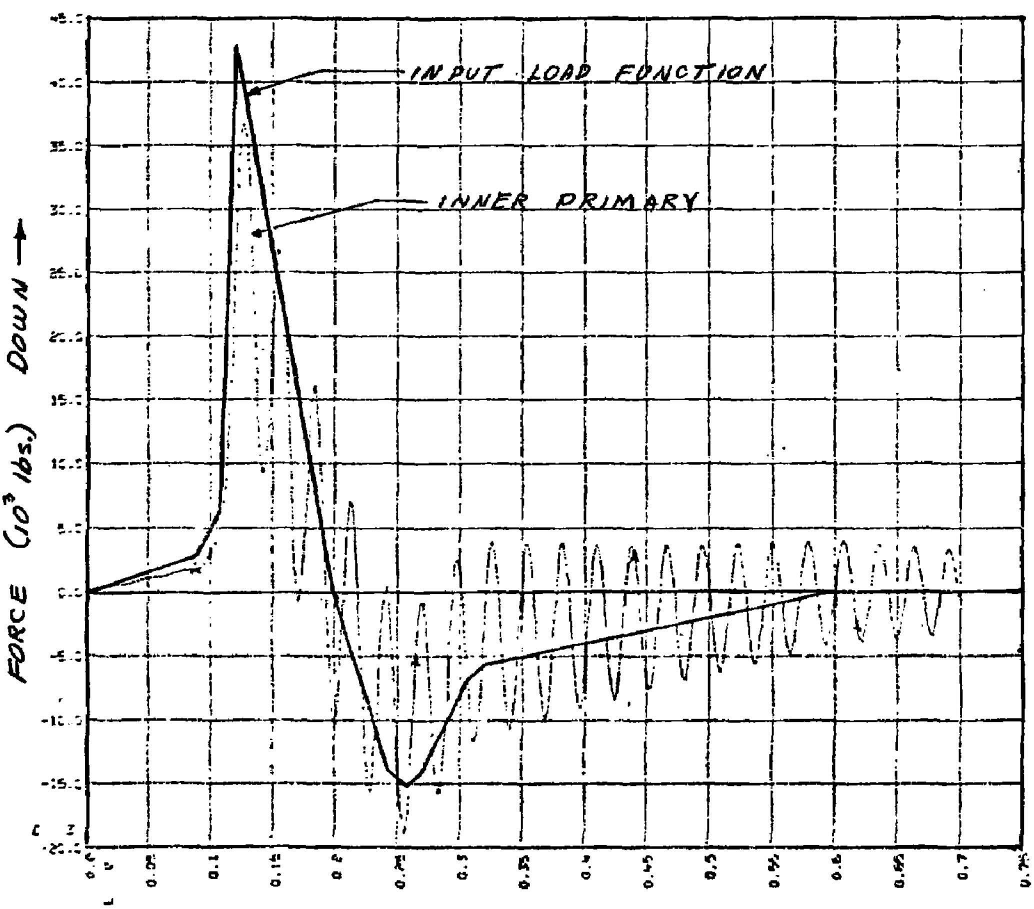


Figure 6
CASE I - OUTER PRIMARY LOAD CELL
(DEAD WEIGHT NOT INCLUDED)

OUTER PRIMARY L/C
FILE(S): INP (A)-LCO

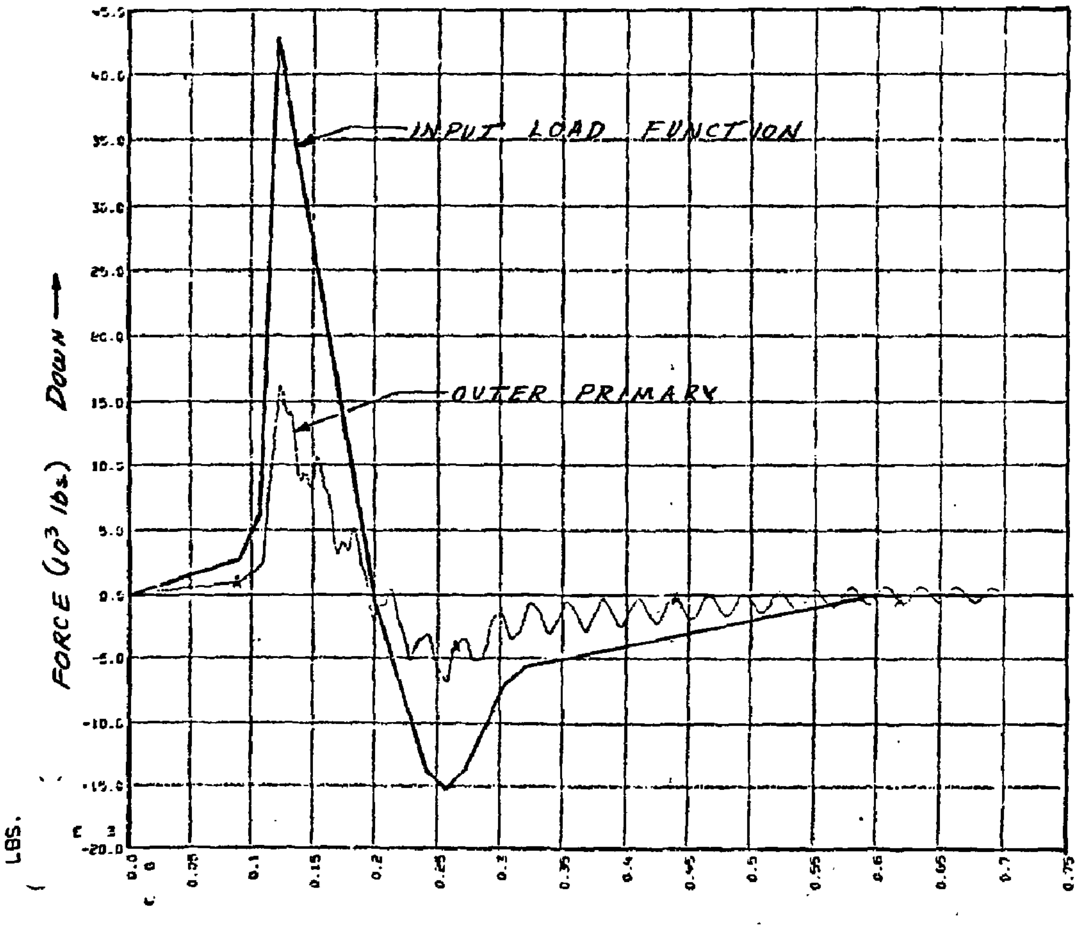


Figure 7

CASE 2 - SUMMATION OF ALL FOUR LOAD CELLS (DEAD WEIGHT NOT INCLUDED)

FOUR PT SUPPORT - L/C SUMMATION

FILE(S):FTOT (A)-INP

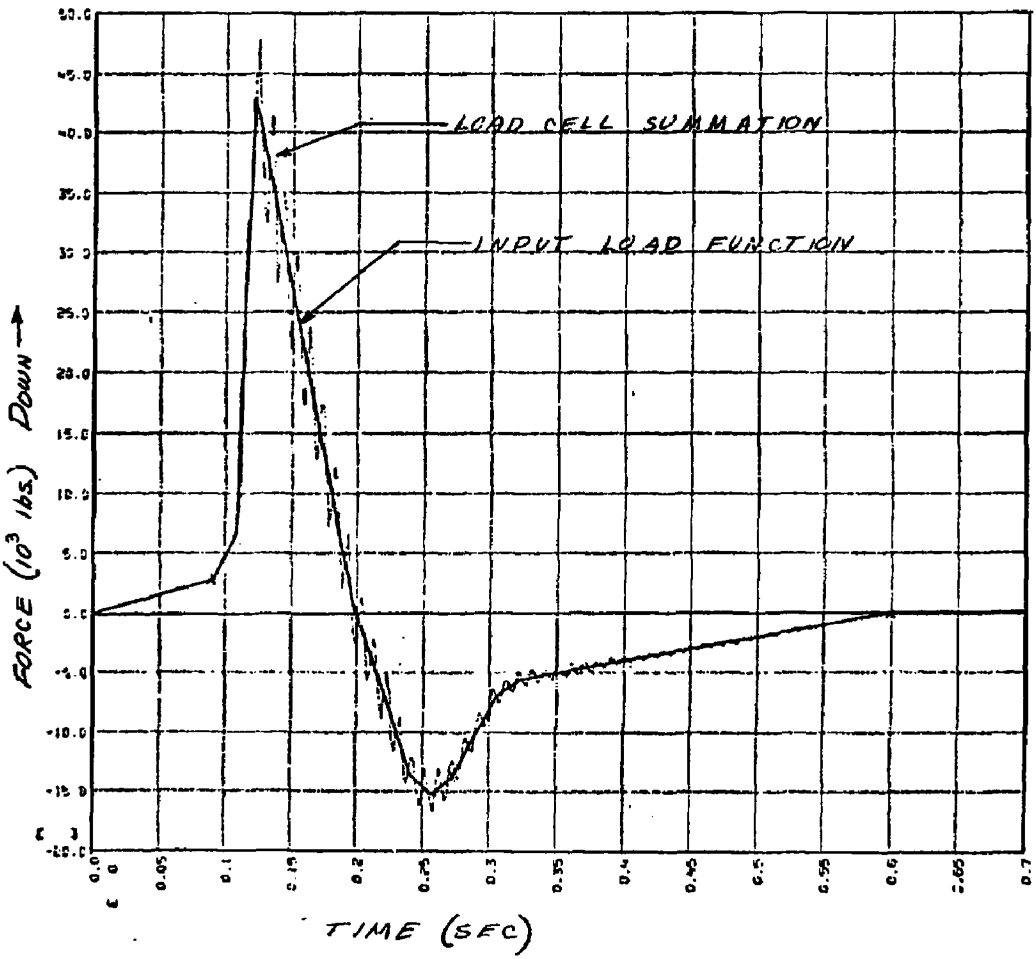


Figure 8

CASE 2 - SECONDARY LOAD CELL
(FORCE HISTORY IS IDENTICAL
AT BOTH SECONDARIES)
(DEAD WEIGHT NOT INCLUDED)

FOUR PT SUPPORT

FILE(S):INP (A)-SP1

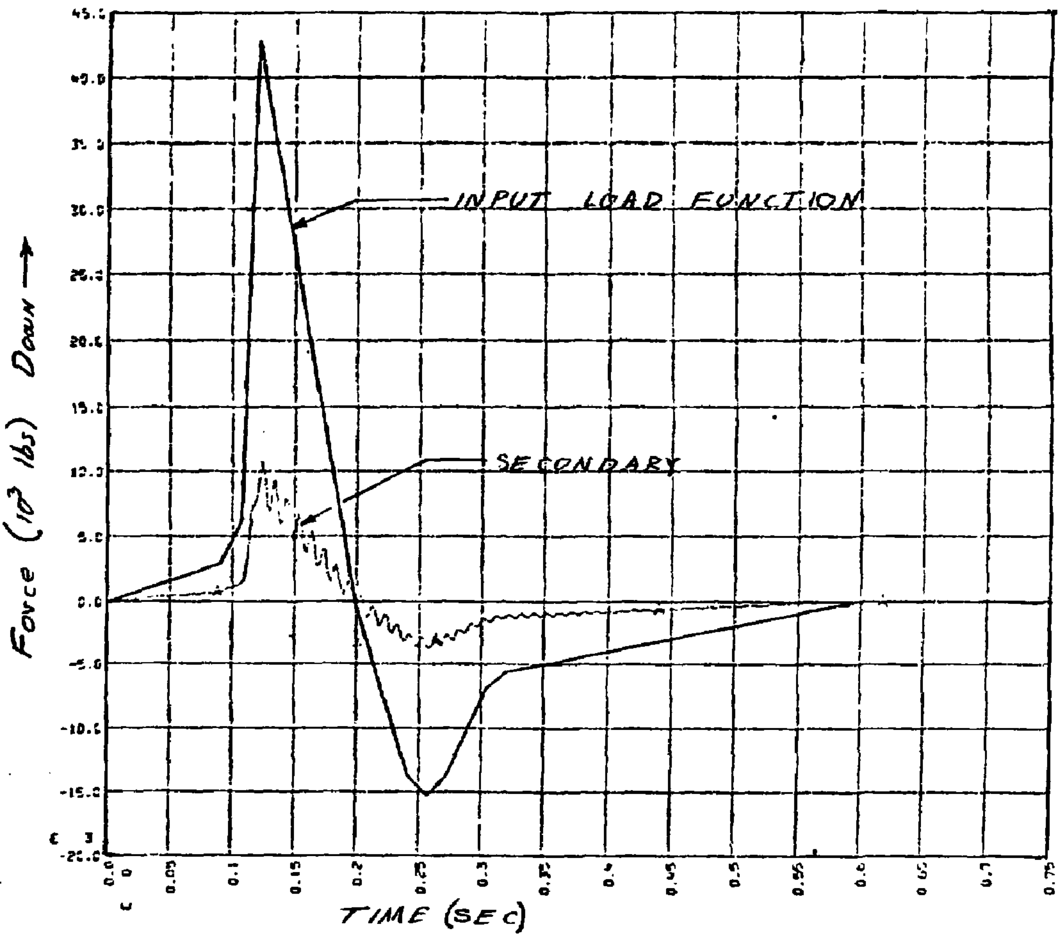


Figure 9
CASE 2 - INNER PRIMARY LOAD CELL
(DEAD WEIGHT NOT INCLUDED)

FOUR PT SUPPORT
FILE(S):INP (A)-LC1

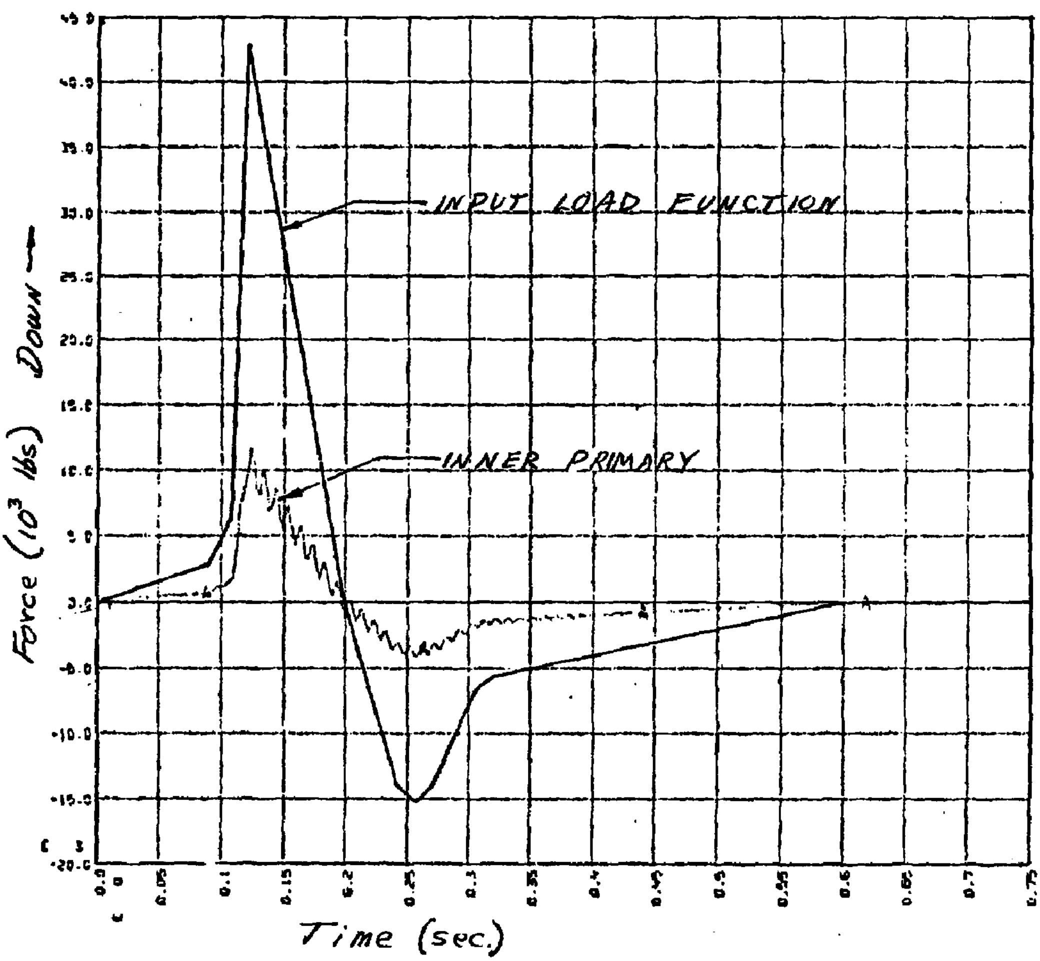
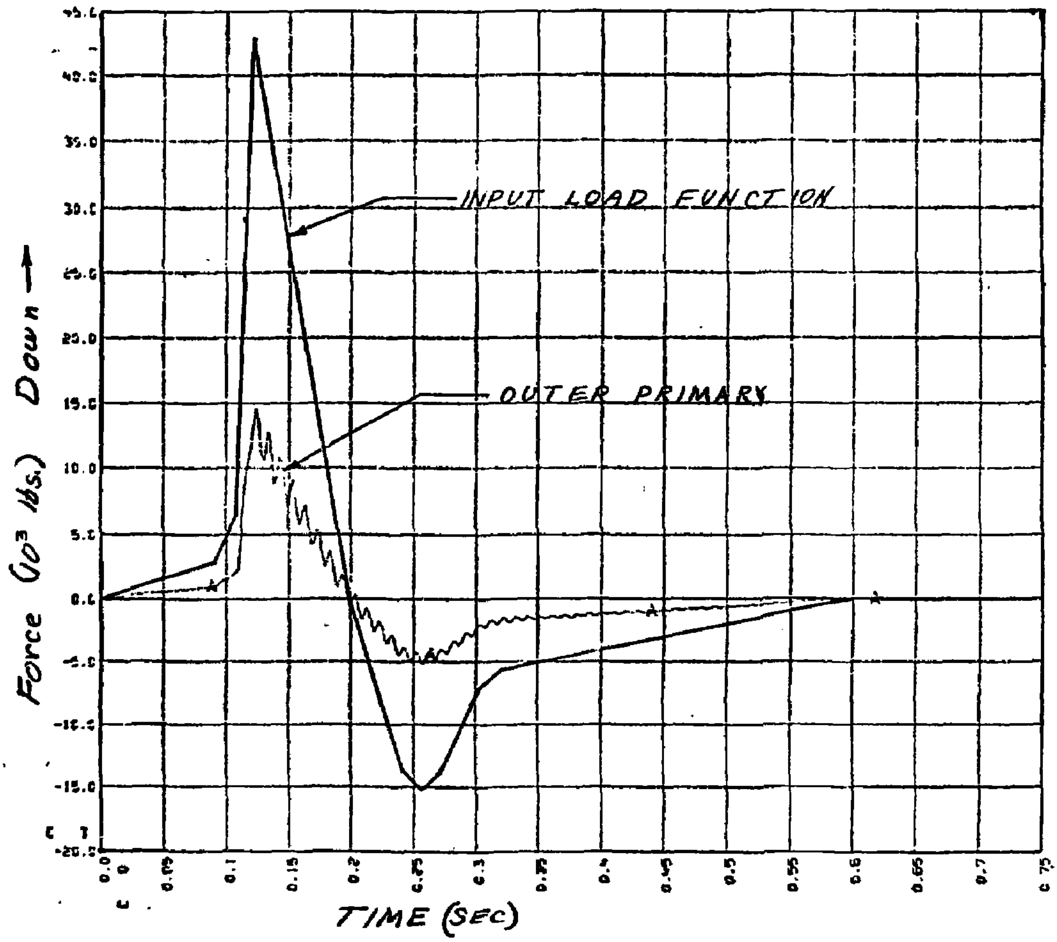


Figure 10
CASE 2 - OUTER PRIMARY LOAD CELL
(DEAD WEIGHT NOT INCLUDED)

FOUR PT SUPPORT
FILE(S):INP (A)-LCO



and will follow the true forcing function much better when the torus is supported at four points instead of three.

It is possible that the loading function will not be as well behaved as we predict. For example, it could have more high frequency content than is presently predicted, or perhaps it could be slightly unsymmetrical in its distribution on the torus. If either of these things happen, the advantage of the four point support over the three point will be much greater. The higher natural frequency of the four point system ould permit it to respond in a more quasi static manner than the three point system. An unsymmetrical loading function would cause the three point system to ring even more than it did in this analysis because its fundamental normal mode is unsymmetrical.

The four point system also has the advantage that it provides a way to preload the torus supports. If the secondary support linkage has a tendency to "gap" during dynamic response, the load cell readings may be affected by the resulting impact. A preload in the supports could eliminate the "gaping".

It is also interesting to note that the four point support system has the effect of spreading the dynamic load more uniformly over all the load cells. For example, the maximum downward load ranges from 7.5 kips to 36.5 kips among the load cells of the three point support system. The maximum downward load with a four point system ranges from 10 kips to 14.5 kips.

All this is not to say that the three point support system will be inadequate. Rather, the four point system could provide greater assurance that the load cell measurements will be meaningful. For this reasons, I recommend that a four point support system be provided for, as an alternate.

REFERENCES

1. D. Arthur, "Preliminary Production of Torus Load Cell Measurements - 1/5 Scale PSE," Lawrence Livermore Laboratory, Livermore, California, ENN 76-78, 10 August, 1976.

2. E. W. McCauley and R. W. Martin, "An Estimate of the Pressure Induced Torus Vertical Loads - 1/5 Scale PSE," Lawrence Livermore Laboratory, Livermore, California, ENN 76-60, Rev. 1, 17 June 1976.

3. J. K. Meier, "Thermo Stresses in the 1/5 Scale Torus," Lawrence Livermore Laboratory, Livermore, California, ENN 76-85, September, 1976.

4. "Preliminary Evaluation of the Dynamic Response Characteristics of a 90° Torus Segment for a 1/5 Scale Mark I Containment Suppression Chamber," Tri-Valley Engineering, Livermore, California, Report #100003-001, July, 1976.

5. Alex Blake, "Frequency Check for NRC Torus," Informal Calculations at Lawrence Livermore Laboratory, Livermore, California, 17 June, 1976.

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