Structural Dynamic and Thermal Stress Analysis of Nuclear Reactor Vessel Support System

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ABSTRACT

A nuclear reactor vessel is supported by a Z-ring and a box ring girder as indicated in Figures 1 and 2.

The two proposed structural configurations to transmit the loads from the Z-ring and the box ring girder to the foundation are shown in Figures 3 and 4. Figure 3 illustrates the cantilever concrete ledge transmitting the load from the Z-ring and the box girder via the cavity wall to the foundation while Figure 4 depicts the loads being transmitted through one of the six steel columns. Both of these two supporting systems were analyzed by using rigid format 9 of NASTRAN for dynamic loads and the thermal stresses were analyzed by AXISOL Ref. 1. The six column configuration was modeled by a combination of plate and bar elements and the concrete cantilever ledge configuration was modeled by plate elements. Both configurations were found structurally satisfactory; however, nonstructural considerations favored the concrete cantilever ledge.

Each of the NASTRAN models has about 600 dynamic degrees of freedom. Because of structural and loading symmetry, only 30 and 15 degree, circumferentially, models as shown in Figures 3 and 4 were required. The bulk data was re-sequenced by BANDIT to minimize the run time. Time steps in the range of 2 to 10 MS were used for different runs and the total response times were kept at about 130 MS. Various structural damping coefficients were applied in this analysis. Many structural and X-Y plots were produced. Average run time was about 20 minutes CPU and 40 minutes wall clock.

The basic computer hardware consists of a UNIVAC 1108 central processor with 131K core memory, 2-22, 020, 096 words FASTRAND, 5-FH432 drums, 8-UNISERVO VIII magnetic tapes and two 30-inch CALCOMP drum plotters.

STRUCTURAL CONFIGURATIONS

The 6-column configuration is shown in Figures 1, 2 and 4. These steel columns are built up sections with two horizontal supports at the third points. Each column is bolted to the Z-ring. The concrete cantilever ledge configuration is shown in Figure 3. The box ring girder shown in Figure 2 is supported by the concrete ledge.

STRUCTURAL MODELING

In a 30 degree column configuration model, the Z-ring is modeled by 7 plate elements per 2 degrees of azimuth for a total of 150 plate elements while the box ring girder and column are modeled by 15 and 18 bar elements respectively. The concrete cantilever configuration was modeled by 18 plate elements per 3.75 degrees of azimuth or total of 72 plate elements. All the connecting bolts are assumed rigid.

DYNAMIC LOADING

The dynamic loads consist of an up load and a down load as shown in Figure 5. The load paths for the two proposed structural concepts are shown in Figures 2 and 3. These dynamic loads are specified on TLOAD1 cards and combined on DLOAD cards.

DYNAMIC RESPONSE

The transient dynamic stresses, element forces, deflections, velocities and accelerations were printed and plotted for selected critical elements and grid points.

The dynamic load factor, DLF, is the ratio of the peak dynamic displacement to the static displacement produced by a static load with magnitude equal to the peak dynamic load. The DLF for the 6-steel columns and the concrete cantilever ledge are calculated to be about 1.6 and 1.2 respectively. The results are summarized in Tables 1 and 2.

THERMAL STRESSES ANALYSIS

AXISOL, which is a finite element computer program for stress or strain structural problems, was used for the thermal analysis. The structural model and resulting thermal stresses are shown in Figure 6. The thermal stresses in the concrete ledge are significant. These stresses were combined with the dynamic stresses and shown in Table 1.

SUMMARY

The analyses reported in this paper pertain to the preliminary structural design phase. The results obtained from NASTRAN and AXISOL are satisfactory for this purpose. Due to the versatility of the NASTRAN input format, design changes, additional analyses or modeling refinement can easily be effected. Some simple lumped mass models with one to five degrees of freedom with nonlinear material properties were analyzed independent of NASTRAN. The basic structural dynamic responses were within 10 - 20% of NASTRAN results. The satisfactory results of this analysis clearly indicate the applicability and usefulness of NASTRAN to heavy civil engineering type of structural design and analysis.

Reference

1. Prof. E. Wilson, University of Calif. AXISOL Axisymmetric Solid Finite Element Structural Analysis Program.

Summary of Maximum Deflections, Stresses and Dynamic Load Factors

1% and 2% uniform structural damping
$E = 23.0 \times 10^6$
Poisson's ratio = .3
Mass density = $.000733 \frac{\#\text{-Sec}^2}{\text{In}^4}$
Box girder filled with concrete

* Static load set equal to peak dynamic down load
** - Compression, + Tension

Location	Max Stress (ksi) Max Force (10^6#)			MAX Deflection (in)		Power, megawatt-sec	DLF, Ratio of Dynamic and Static Deflections
	Column		Beam	Column	Beam		
	Forces	Stress	(ksi)	(in)	(in)		
Support	-49.1	-43.0**	14.8	.93	.93	350	
	+34.7	+30.5**			(.77)*		
	Base	Base					
Quarter Span	-45.5	-40.0	3.0		.96	2%	
					(.80)	Damping	1.2
Mid Span	+38.8	+28.8	6.7		.97		
	TOP	TOP			(.81)		
Support	-46.1	-40.5	14.3	.88	.88	150	
	+41.5	+36.4			(.58)		
Quarter Span	Base	Base	2.8		.91	2%	1.5
	-43.6	-38.3			(.60)	Damping	
Mid Span	+39.0	+34.1	6.3		.92		
	TOP	TOP			(.61)		
Support	-53.0	-46.7	15.9	1.00	1.00	350	
	+35.0	+31.1			(.77)*		
	Base	Base					
Quarter Span	-48.9	-42.8	3.1		1.03	1%	1.3
	+33.1	+29.1			(.80)	Damping	
Mid Span	TOP	TOP	7.0		1.05 (.81)		
Support	-51.0	-43.8	15.7	.95	.95	150	
	+51.7	+45.3			(.58)		
	Base	Base					
Quarter Span			2.9		1.00	1%	1.66
	-46.7	-41.0			(.60)	Damping	
	+47.4	+41.0					
Mid Span	TOP	TOP	6.6		1.01		
					(.61)		

Table 1

MAXIMUM PRINCIPAL STRESSES

Case Number & Description	KIPS/Sq. In.				Remarks
	σ_r	$\sigma\theta$	σz	τ	
A. 150 megawatt-sec	-3.2 +2.3	-1.0 + .9	-.4	1.65	Maximum Shear at 40" Ledge & Max. Bending Stress, σ_r, in Cavity Wall.
B. 350 megawatt-sec	-3.3 +2.55	-1.0 + .9	-.4	1.70	
C. 20 x 10^6 # Static Load at the Cantilever Ledge Tip	-2.21 +1.60	- .72 + .56	-.25	1.16	
D. Thermal with Heating	- .19 + .19	-2.1 +1.0	-.04	.05	At Upper Cantilever Tip.
E. Thermal without Heating	- .08 + .08	- .9 + .4	-.04	.01	
F. Combination of A&D	-3.39 +2.49	-3.1 +1.9	-.44	1.70	
G. Combination of A&E	-3.28 +2.38	-1.9 +1.3	-.44	1.66	
H. Combination of B&D	-3.49 +2.64	-3.1 +1.9	-.44	1.75	
I. Combination of B&E	-3.38 +2.63	-1.9 +1.3	-.44	1.71	
J. Combination of C&D	-2.40 +1.79	-2.82 +1.56	-.29	1.21	
K. Combination of C&E	-2.29 +1.68	-1.62 + .96	-.29	1.17	

σ_r is the radial bending stress.
σ_z is the vertical bending stress.
$\sigma\theta$ is the hoop stress.
τ is the shear stress.
-compression.
+tension

Table 2

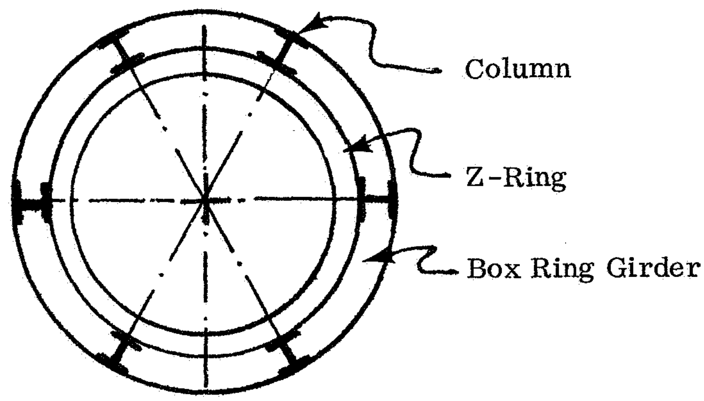


Figure 1
Key Plan

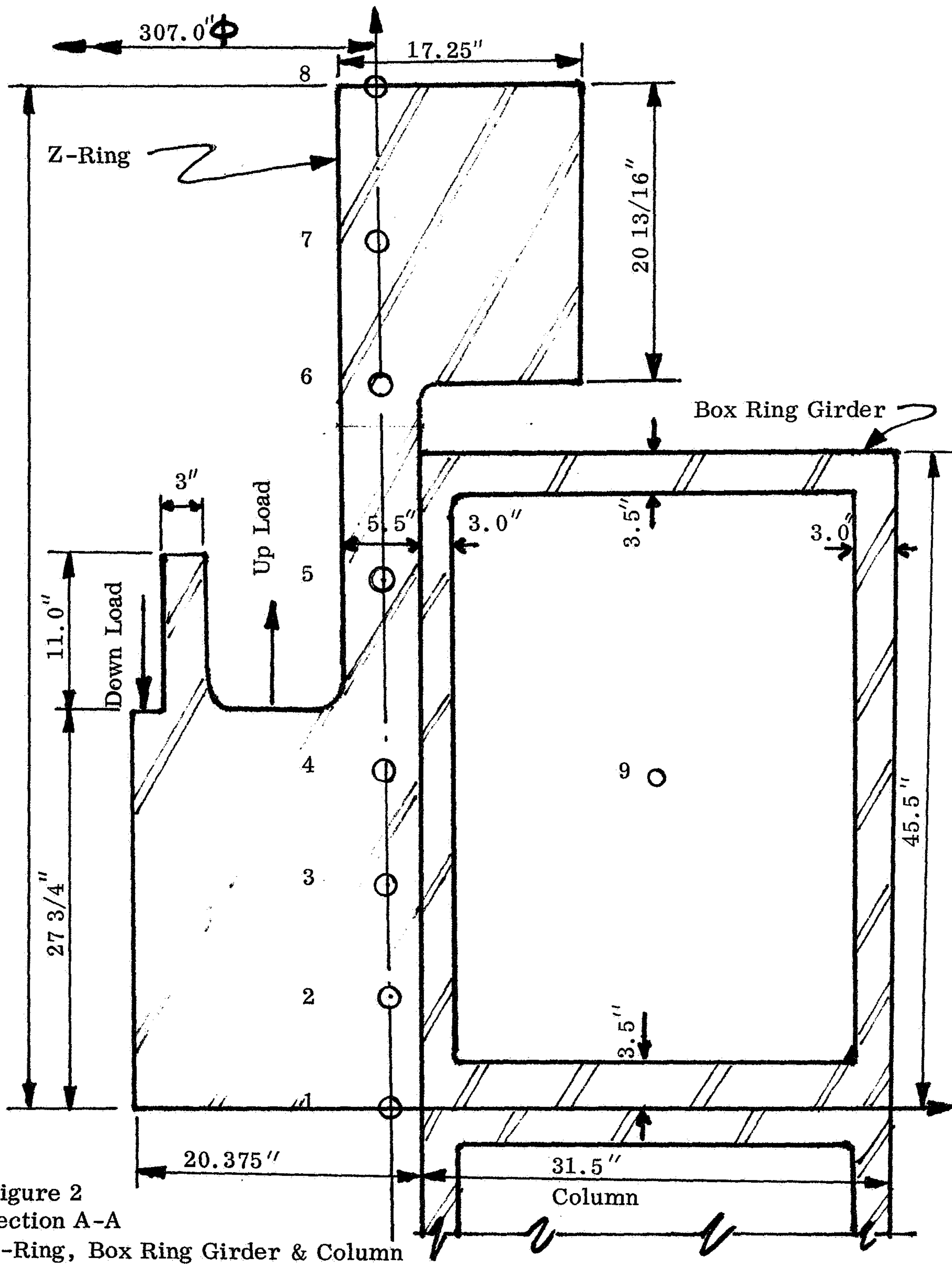


Figure 2
Section A-A
Z-Ring, Box Ring Girder & Column

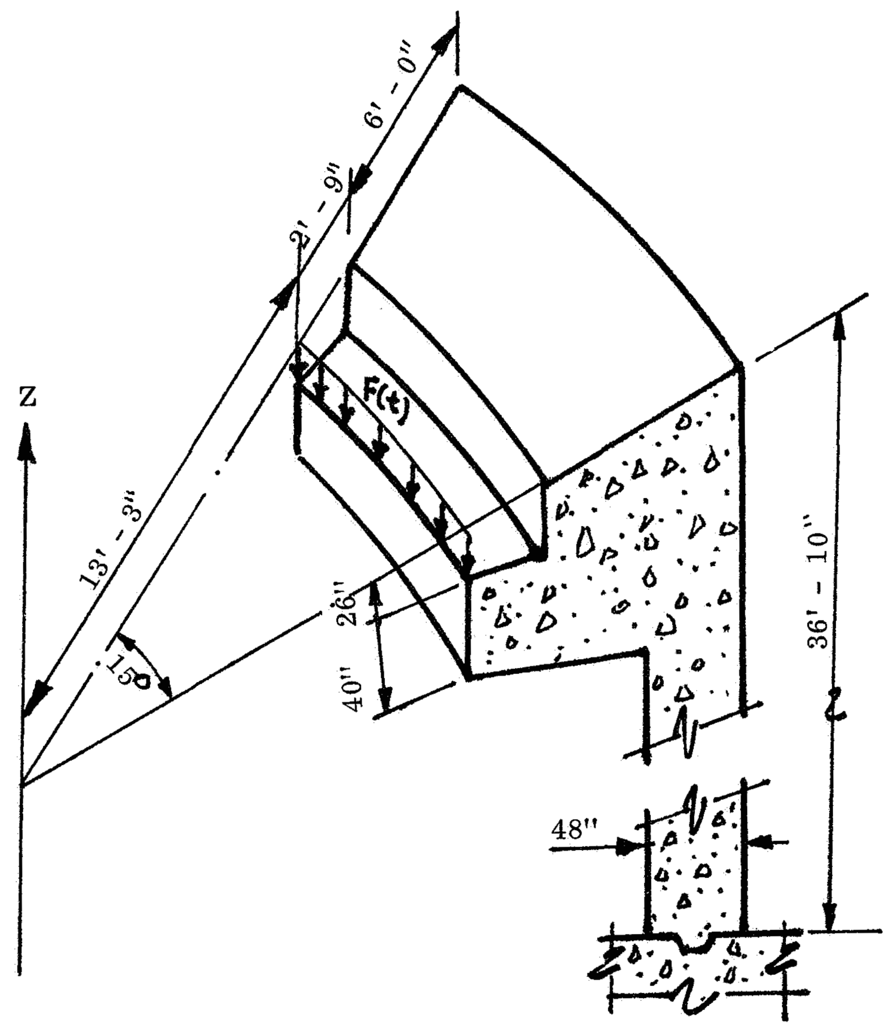
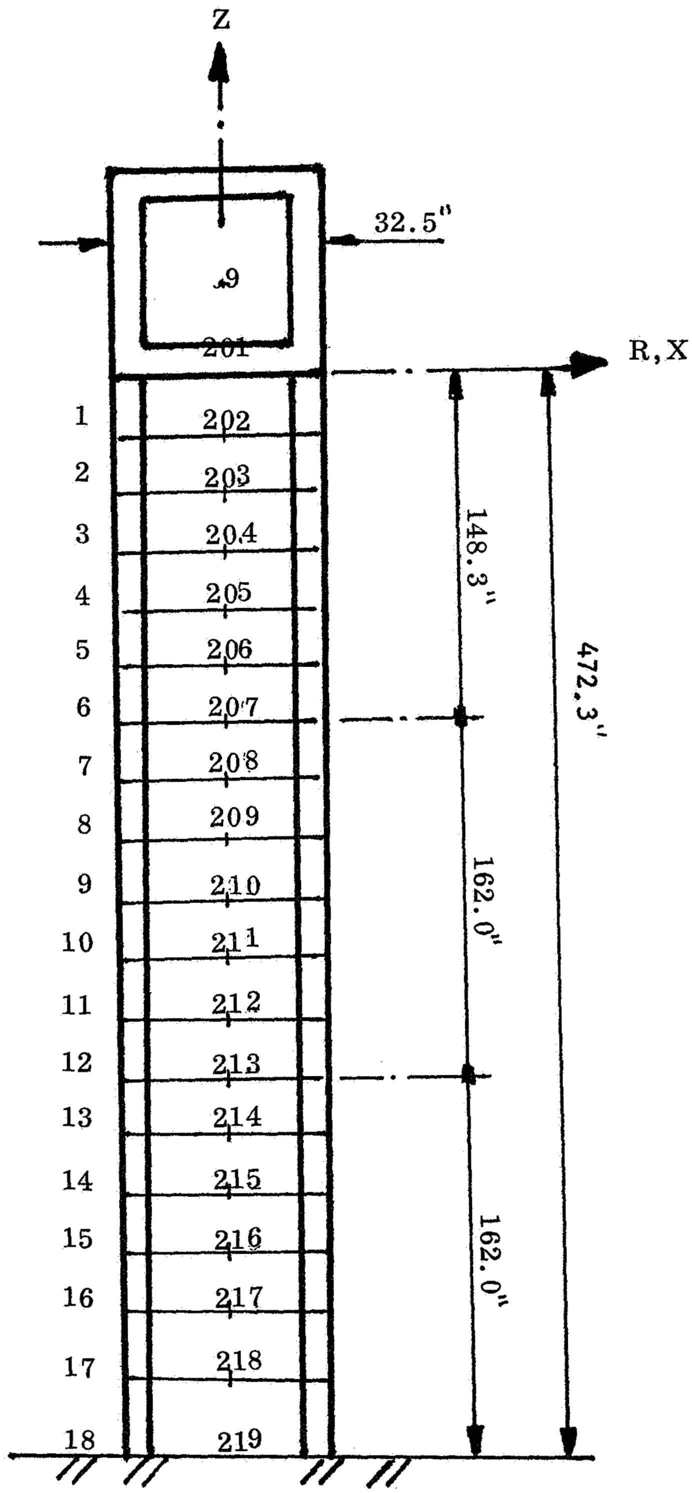


Figure 3
Concrete Cantilever Ledge



COLUMN ELEVATION

Figure 4
Fixed at 219 pinned at 207 & 213 MPC at 9 & 201

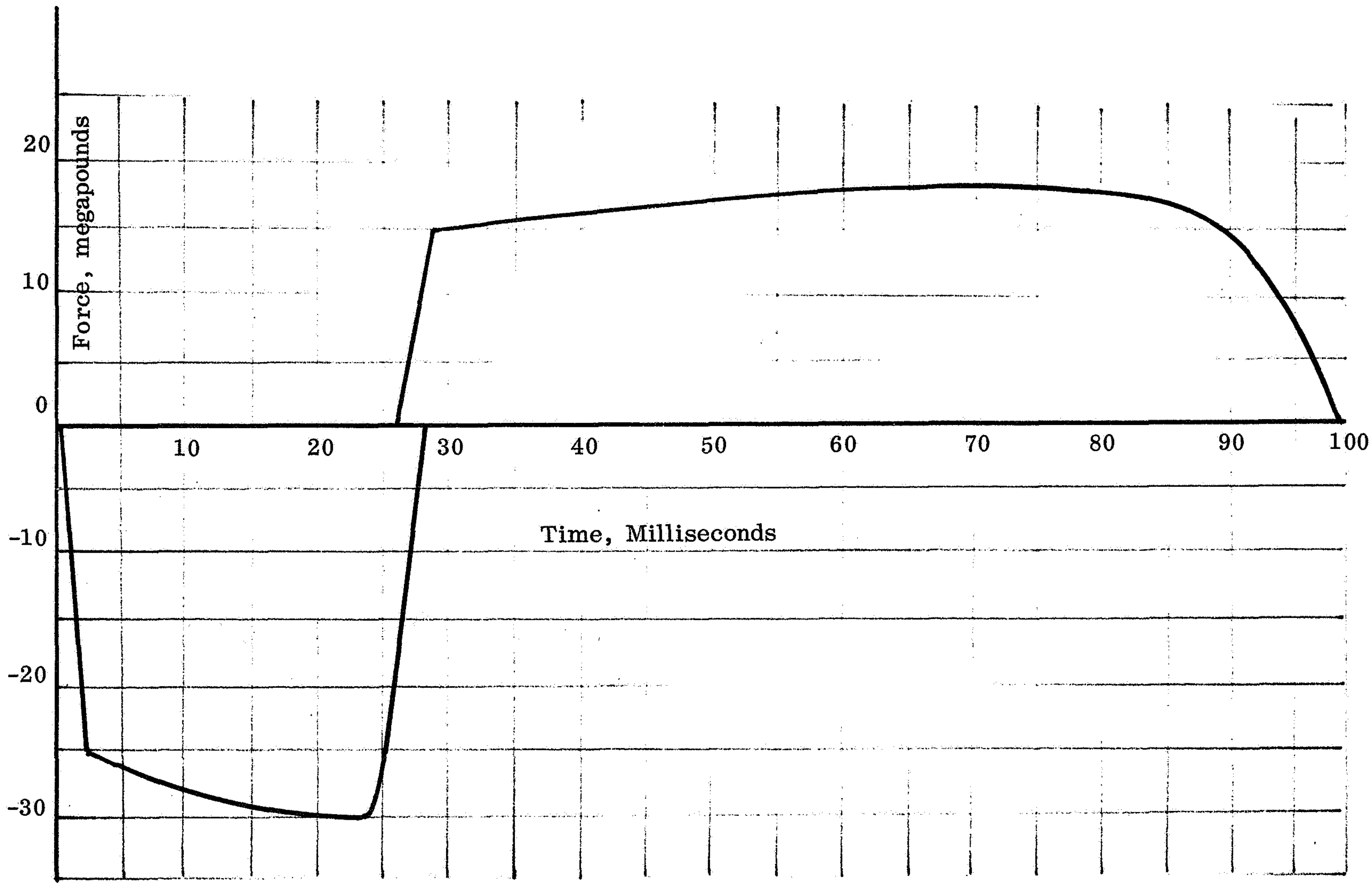


Figure 5
Dynamic Load

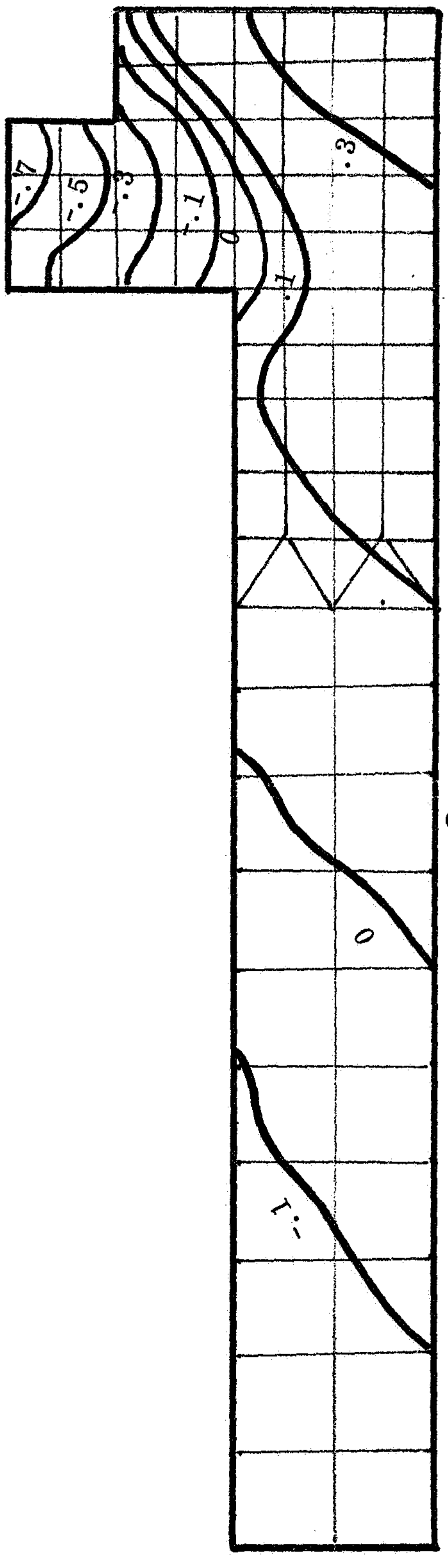


Figure 6
Concrete Ledge Thermal Stress
Hoop Stress Contour
KIPS/Sq. In.