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HYDRODYNAMIC LOAD ANALYSIS FOR A SIMPLIFIED BOILING WATER REACTOR (SBWR) STRUCTURAL DESIGN

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1. INTRODUCTION

In addition to the simplicity and the passive features that enhance safety and reliability, improve performance and increase economic viability, the SBWR adopts pressure suppression pool (SP) to absorb the blow down energy in case of LOCA or energy discharge from Safety Relief Valve (SRV) actuation. For the SBWR design, to furnishes water for long term core coverage from the SP, it is located at an elevation that is relatively higher than the SP of a conventional BWR plant, In addition, the pool is supported by the floor slab instead of by the base mat as a conventional BWR plant.

Energy discharge from SRV results in oscillatory pressure on the pool boundary. During the LOCA blow down, the drywell air is expelled through the vents into the SP, followed by steam flow through vents with condensation oscillation (CO) pressure. As steam flow decreases, the condensing steam front collapses periodically in the vent and pool. This is called chugging (CH). Commonly, these loads are called hydrodynamic loads. These loads are time dependent and are defined in the form of time histories. They also vary in magnitude along the pool boundary of the SP. For structural design, these hydrodynamic loads are to be combined with other concurrent pressure, thermal effects, dead load, and seismic loads. It is more convenient to do the combination in the internal forces in the structural element in terms of the normal forces, shear forces and bending moments that are calculated individually from the pressure, thermal load, dead load, seismic loads and hydrodynamic loads. To facilitate stress analysis of the internal forces in the structural elements, the time dependent pressure loads are converted to equivalent pressure through the use of Dynamic Load Factors (DLF). DLF is defined as the ratio of the peak dynamic response (force or moment) to the static response (force or moment). This is a generalization of the definition given in References 1 and 2. This paper discusses how the DLF's are calculated for the containment structure under the hydrodynamic loads.

2. GENERAL DESCRIPTION OF THE SBWR CONTAINMENT AND REACTOR BUILDING

The reactor building (RB) consists of the reinforced concrete containment vessel (RCCV) of 31.5m ID and three rectangular boxes supported on a common basemat of 66.3m x 66.3m with interconnected slabs at various elevations as shown in Figure 1. The structures are primarily of reinforced concrete construction with the exception of intermediate box which consists of steel frame with partition walls. The RCCV consists of the reactor pressure vessel (RPV) pedestal, SP floor slab, the cylindrical containment wall and the drywell top slab. The drywell top slab supports the service pool, isolation condenser (IC) and passive containment cooling system (PCCS) pools. The IC or PCCS pool girders on the drywell top slab provide strength to resist containment pressure loads. The top slab has a large opening of radius 9.4m in the middle for the drywell head. The vent wall structure and the diaphragm floor slab are steel structure filled with concrete. The RPV pedestal supports the reactor vessel, reactor shield wall, vent wall structure and the suppression pool. It is also a part of containment pressure boundary.

3. ANALYTICAL MODEL

The model for both the static and the dynamic analysis consists of axisymmetrical shells that represent vent-wall structure, reactor pedestal, reinforced concrete containment vessel, safety envelop structural wall and the external reactor building wall. These shells are interconnected by diaphragm floor slabs. The actual vent-wall structure, reactor pedestal and the RCCV are cylindrical shell structures. The safety envelope structure and the reactor building walls are square shape; they are approximately represented by cylindrical shells. The steel frames that form the intermediate box are neglected in the model.

The axially symmetrical model, as shown in Figure 2, consists of 117 nodes and 106 shell elements.

A free vibration analysis of the model by COSMOS/M (Ref. 3) gives the first 10 zero harmonic frequencies with cut off at 62 Hz as shown in Table 1. The mode shapes for the first six zero harmonics are given in Figure 3.

4. HYDRODYNAMIC LOADS CONSIDERED IN THE ANALYSIS

Actuation of SRV due to energy discharge into SP results in oscillation pressure on the SP boundary. A typical time history for SRV pressure is shown in Figure 4. During the LOCA blow down, the steam flow through vents creates condensation oscillation (CO) for which the time histories are shown in Figure 5. As steam flow decreases, the condensing steam front collapses periodically in the vent and the pool. This is called chugging (CH) for which the time histories are shown in Figure 6. The distribution and variation of pressure amplitude along the pool boundary for SRV, CO and CH are summarized in Table 2. From the Fourier transform of SRV,CO and CH as shown in Figure 7, The SRV time history has dominant frequencies around 8 Hz, while CO has significant frequency contents as low as 2Hz and CH has high frequency contents above 20Hz.

5. DYNAMIC ANALYSIS

Two different finite element computer programs, CAPLA and COSMOS/M, were used to perform the dynamic and static analyses. CAPLA (Ref. 4) was developed by Hitachi for performing compartment pressurization dynamic analysis in Japan. COSMOS/M is a finite element analysis program developed by the Structural Research and Analysis Corporation.

The maximum dynamic responses in terms of normal forces and moments in several selected sections were obtained from the dynamic analysis for the time dependent SRV, CO and CH loads. The corresponding static values were obtained by static application of the hydrodynamic loads. The DLF's were calculated as the ratio of the peak dynamic response (force or moment) to the static response (force or moment).

The dynamic load factors (DLF) for several selected locations in the containment are summarized in Table 3.

6. SUMMARY OF RESULTS

Hoop forces, meridional forces and bending moment obtained from the dynamic analyses were compared with the corresponding static values to arrive DLF's. Some typical results are summarized as follows:

(1) For the region such as RCCV wall and pool slab where pressure loads are applied, the DLF's are slightly more than 2. A typical graphic representation is shown in Figure 8.

(2) For the vent-wall structure, the DLF is much higher than 2. However, the static values (e.g., hoop and meridional forces) are relatively small comparing with the corresponding values in the RCCV. The calculated dynamic values also are furnished to structural design in addition to the DLF when very high DLF's are encountered by which the structural designer can use the dynamic values for doing the design.

(3) For the region such as pedestal where there is no pressure loads are applied, the static values are extremely small. The dynamic responses, sometimes, can be one or two orders higher than those from the static analyses. However, the dynamic responses in pedestal are very small in comparison with the dynamic responses in the RCCV.

References:

1. Biggs, J.M., (1964), Introduction to Structural Dynamics, McGraw-Hill, New York

2. Clough, R.W. and Penzien, J., (1975), Dynamics of Structures, McGraw-Hill, New York

3. COSMOS/M, (1991), Finite Element System User Guide, 5th Edition, Structural Research and Analysis Corporation, Santa Monica, CA

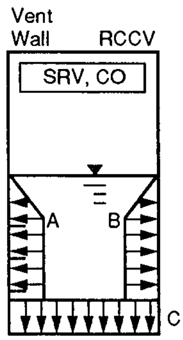
4. CAPLA, (1980), Coupling Analysis Program for Liquid Storage Axisymmetric Shell User's Guide, Hitachi Works, Hitachi

Table 1 Frequencies of the first 12 Zero Harmonic Modes

Mode Number	Frequency (Hz)	Period (Sec)
1	12.07	0.0829
2	27.63	0.0362
3	34.21	0.0292
4	39.13	0.0256
5	41.67	0.0240
6	45.1	0.0222
7	50.1	0.0200
8	53.5	0.0187
9	55.4	0.0181
10	56.9	0.0176
11	58.8	0.0170
12	61.8	0.0162

Table 2 Hydrodynamic Load Distribution

Load Case		Distribution Ratio	Time History Peak Value	Actual Load Distribution for Static Analysis	
SRV	01	A = 1.0, B = 1.0, C = 1.0	0.87 kg/cm^2	A	0.87 kg/cm^2
				B	0.87 kg/cm^2
				C	0.87 kg/cm^2
CH	03	A = 2.86, B = 1.0, C = 1.0	0.28 kg/cm^2	A	0.801 kg/cm^2
				B	0.28 kg/cm^2
				C	0.28 kg/cm^2
	04		0.275 kg/cm^2	A	0.787 kg/cm^2
				B	0.275 kg/cm^2
				C	0.275 kg/cm^2
	05		0.315 kg/cm^2	A	0.901 kg/cm^2
				B	0.315 kg/cm^2
				C	0.315 kg/cm^2
	07		0.28 kg/cm^2	A	0.801 kg/cm^2
				B	0.28 kg/cm^2
				C	0.28 kg/cm^2
CO	03	A = 1.0, B = 1.0, C = 1.0	1.30 kg/cm^2	A	1.30 kg/cm^2
				B	1.30 kg/cm^2
				C	1.30 kg/cm^2
	04		1.35 kg/cm^2	A	1.35 kg/cm^2
				B	1.35 kg/cm^2
				C	1.35 kg/cm^2



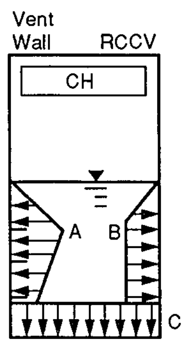


Table 3 Dynamic Load Factor (DLF) for Suppression Pool Hydrodynamic Load

	Meridional Force N_m			Hoop Force N_h			Meridional Moment M_m			Hoop Moment M_h		
Location	SRV	CO	CH	SRV	CO	CH	SRV	CO	CH	SRV	CO	CH
SP Slab	1.3	1.3	1.1	3.5	3.1	2.8	1.9	1.7	1.4	2.0	2.1	2.3
RCCV WW	4.5	2.9	5.2	1.4	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0
RCCV U/DW	5.4	5.4	13.5(1)	2.7	4.36	8.2	3.2	1.94	2.52	6.3	2.94	2.52
Vent Wall	6.15	4.76	32.8(2)	7.2	6.3	6.3	2.0	3.1	1.1	2.0	3.8	1.4

(1) In lieu of DLF, the dynamic values of ±500 Kg/cm may be used.

(2) In lieu of DLF, the dynamic value of ±900 Kg/cm may be used.

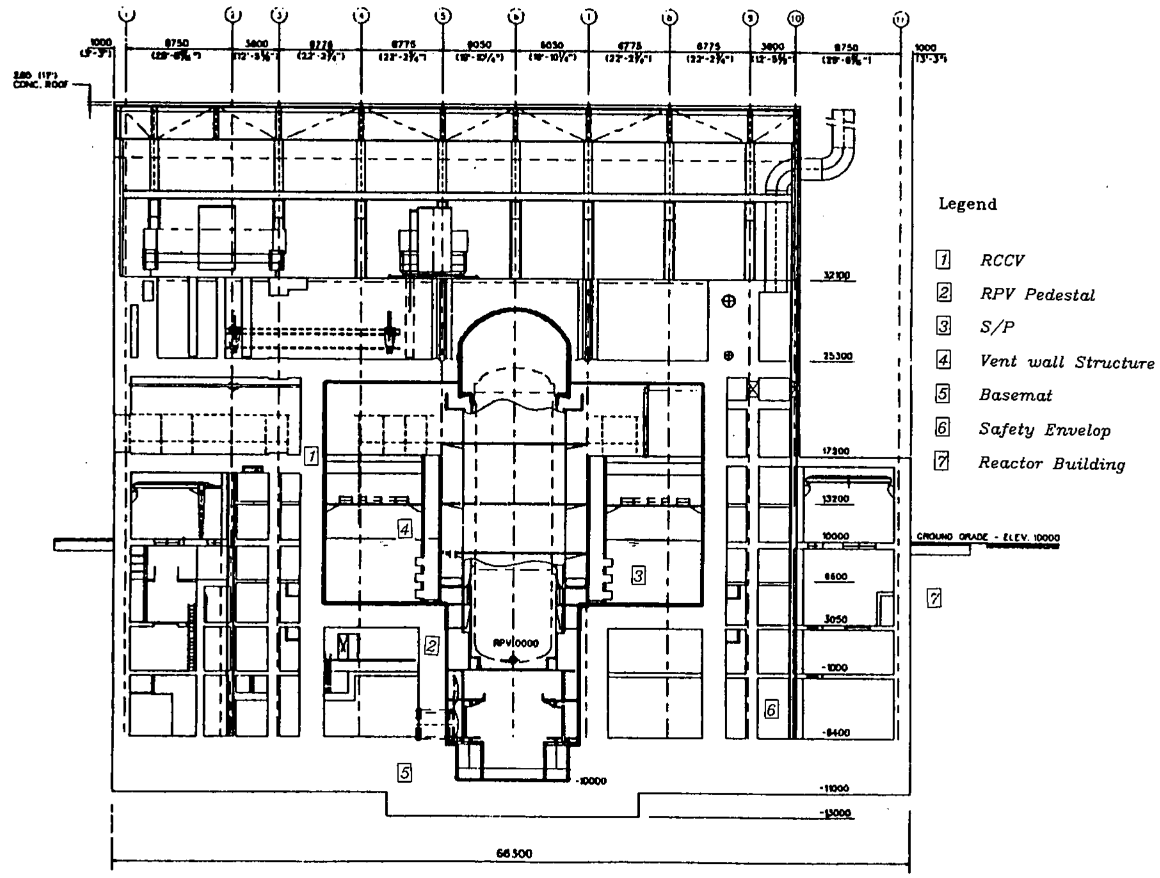


Figure 1 SBWR Containment and Reactor Building

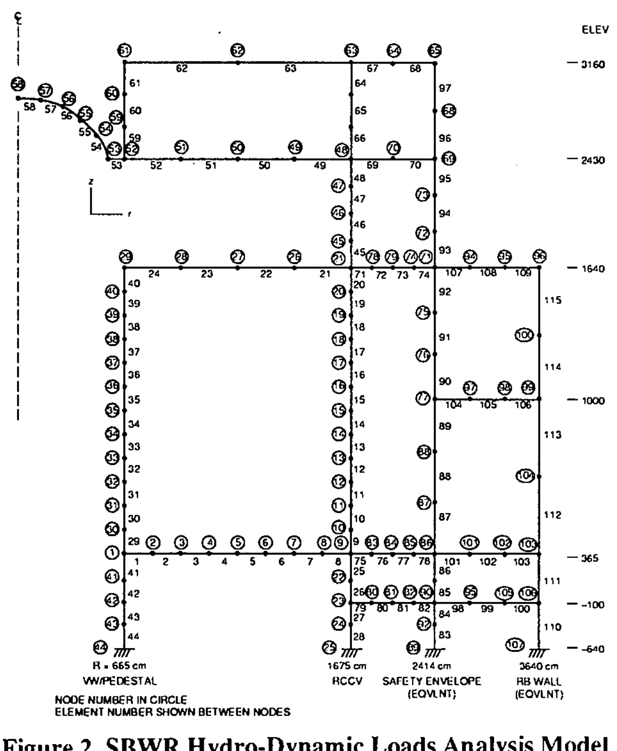


Figure 2. SBWR Hydro-Dynamic Loads Analysis Model (Axially Symmetric Shell Model)

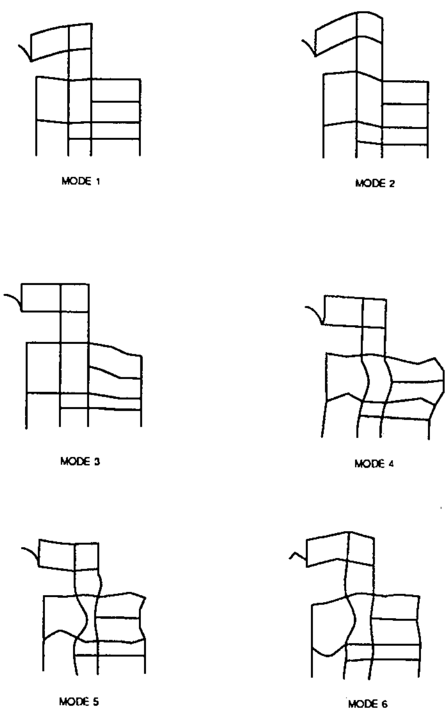


Figure 3 Mode Shapes for Zero Harmonics

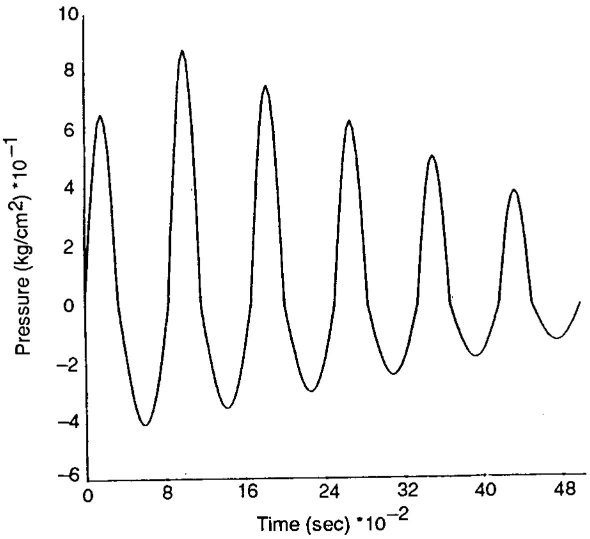


Figure 4 SRV Time History

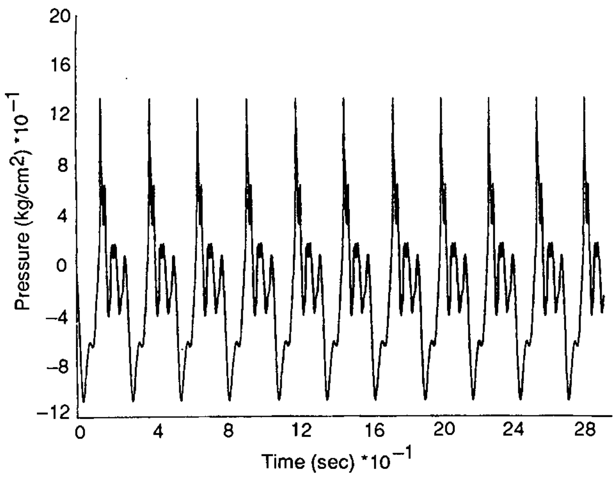


Figure 5 CO Load Time History

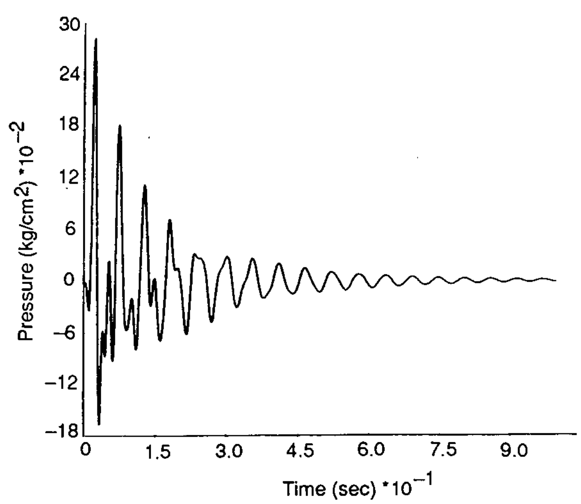


Figure 6 CH Load Time History

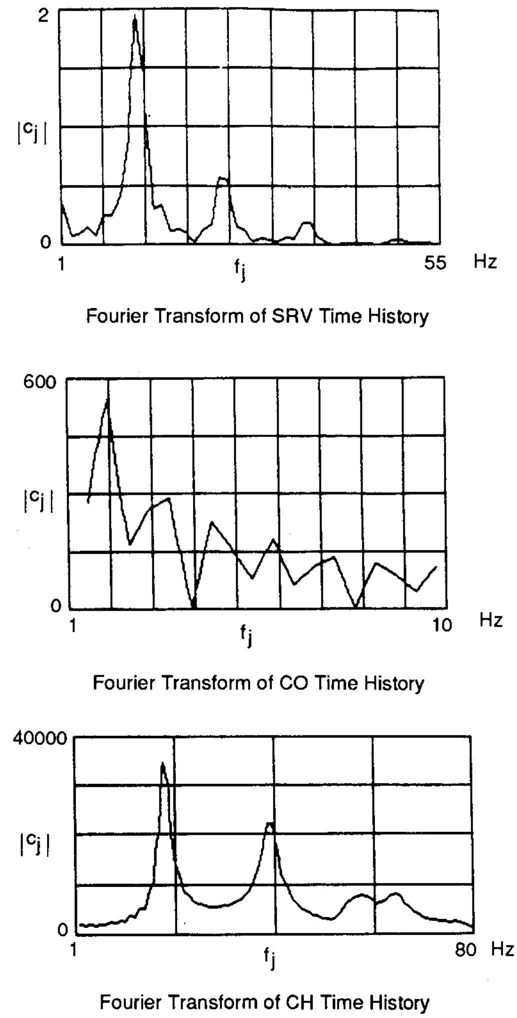


Figure 7 Fourier Transform of Hydrodynamic Load

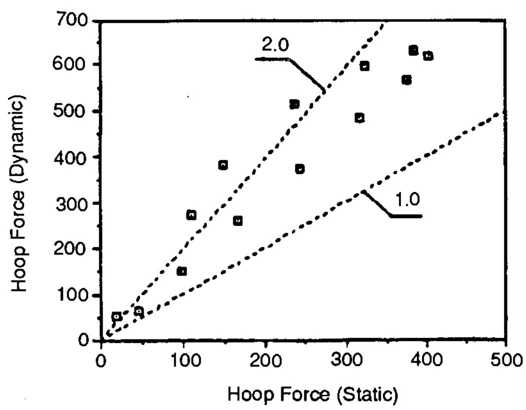


Figure 8 Comparison of Dynamic and Static Results (Hoop Force due to SRV) in RCCV wall