

STRUCTURAL DYNAMIC ANALYSIS OF BWR MARK II PLANT UNDER SRV BLOWDOWN OSCILLATION

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SUMMARY

During normal plant operating or accidental conditions of a BWR Mark II nuclear power plant, the pressure level in the reactor pressure vessel (RPV) is regulated by discharging the high pressure steam into the water of the suppression pool through the actuation of the multiple Safety Relieve Valves (SRV). The discharged high pressure steam pushes air column against the water leg in the submerged pipe. The compressed air is eventually forced out of sparger and forms a vibrating bubble transmitting pulsating pressure against the boundaries of the suppression pool. This oscillation excites all structures and creates dynamic stresses in addition to those from other normal and accidental loading conditions.

Based on test results, the high pressure air bubble oscillates in a frequency range varying from 5 to 10 Herz with a peak positive pressure of 23 psi and a peak negative pressure of -14 psi. The blowdown lasts for about 3/4 of a second.

This paper describes investigations conducted for the determination of SRV blowdown effects on structures, equipment and piping systems. The plant selected for this investigation has a combination structural arrangement which combines the Reactor, Auxiliary, Control, Fuel Handling, radwaste and dissel building into one nearly square shaped building with the primary steel containment and its concrete shield structure located at center of the common foundation mat. This combination building is reasonably symmetrical about both the N-S and the E-W axes and therefore could be treated as such to reduce analysis effort in the mathematical modeling and response calculations.

Finite element techniques are used for the structural response investigations. The mathematical model consists of membrane and bending elements representing one half of the combination building resting on series of springs simulating the elastic half space of soil medium underneath the structure. The damping behavior of the structural system has been carefully determined with the assistance of two other studies involving the soil-structure interaction analyses.

The mathematical model is then subjected to the SRV blowdown loads in the digitized form to determine structural responses at critical locations. In-structure response spectrum at selected locations are also generated. The results of these investigations are then used to examine the capabilities of other important items such as the reactor pressure vessel, the reactor internals and the steel containment under the influence of the SRV blowdown load simultaneously with other loads which can be reasonably postulated to occur at the same time.

In conclusion, it is found that structural responses are highly sensitive to the frequency content of the SRV blowdown load. Under SRV load of 10 Herz frequency, the structures have in general exhibited highest responses. The in-structure spectra, however, are found to have high peaks at different frequency points for different SRV load frequencies.

When SRV loads are combined with LOCA and seismic loads, high stresses are found to exist in the areas directly under the SRV load. For certain key structural elements, the aforementioned load combination may become the governing condition for the design of structures.

1. INTRODUCTION

During normal operating and some of the accidental conditions of a BWR Mark II nuclear power plant, the pressure variation inside the Reactor Pressure Vessel (RPV) is regulated by the discharge of the high pressure steam into the suppression pool through the actuation of the Safety Relief Valves (SRV) as described in Reference [8.1]. In the process of the SRV blowdown, the discharged steam compresses the air column inside the relief pipe and pushes the water leg contained in the submerged portion of the relief pipe to flow into the suppression pool. Following the exit of the water leg, the highly compressed air column enters the suppression pool and forms a rapidly expanding air bubble due to the sudden change of the environment. The expansion of the air bubble exerts pressure on the surrounding water and initiates an outward water movement. The momentum of the outgoing water keeps the bubble expanding until it reaches the critical pressure at which point the bubble expansion will cease and contraction will take place. As the bubble contracts, the water moves inwardly and its momentum will keep the bubble contracting until another critical pressure is reached. The expansion and contraction continues until the bubble arises to the surface of the water pool due to the buoyant effect. The bubble oscillation transmits pressure onto the surrounding structures resulting in deformation and vibration of the structures.

This paper presents results of the investigation of structural dynamic responses in a BWR Mark II nuclear power plant subjected to the SRV blowdown loads. The effects of the SRV blowdown loads in combination with other operating and environmental loads on plant structural integrity are also discussed.

2. DESCRIPTION OF STRUCTURES

The structures included in this investigation consist of the RPV and its supporting pedestal, sacrificial shield wall, reactor auxiliary area, fuel handling area, Primary Containment Vessel (PCV) and the foundation mat. The structural arrangement of the plant is essentially symmetric with respect to both the N-S and the E-W axes of the plant. All safety related structures are supported by a common foundation mat. Figures 1 and 2 show the general arrangement of the plant structures.

The steel Primary Containment Vessel is divided into two separate chambers by the diaphragm floor located at an elevation near the top of the RPV pedestal. The upper chamber which houses the Nuclear Steam Supply System (NSSS) and its associated equipment is named Drywell. The lower chamber where the suppression pool is located is named the Wetwell or suppression chamber. The water in the suppression pool is approximately 24 feet deep and the spargers (a special device installed at the end of relief pipes to reduce the impact of the SRV loads) are located at about 12 feet above the bottom of the pool.

3. CHARACTERISTICS OF SRV LOADS

The oscillation characteristics of the pressure bubble is highly random in nature. Based on analytic work and test observations conducted by the nuclear industry, it has been recommended that, for the purpose of structural investigation, the air bubble induced pressure transient may be assumed to have a peak positive pressure of 23 psi and a peak negative pressure -14 psi with an oscillating frequency in the range of 5 to 10 Herz. Based on this recommendation, an idealized pressure transient curve as shown on figure 3 is established and used as input forcing function for this investigation. The frequency characteristics of this idealized loading is shown on figure 4 which is the spectral plot of the pressure transient showing the potential resonance zones.

Two types of the SRV loads are considered most detrimental to the plant structures and therefore are chosen for this investigation. The first type assumes a total blowdown with all 19 SRVs actuating at the same time. The other type assumes any three adjacent SRVs actuating simultaneously. The former generates an axisymmetric and the latter an asymmetric loading distribution patterns.

4. ANALYSIS PROCEDURES

4.1 General

The analysis is performed using the modal analysis method with time history forcing function input digitized from the idealized SRV pressure transient. NASTRAN computer program (8.2) is employed for the calculation using a CDC 7600 computer.

The mathematic model adopted for the investigation is a three dimensional finite element model consists of beam and plate elements representing the stiffness behavior of the plant structures and the foundation mat. Wrinkler's springs and viscous dampers are specified at the bottom of the foundation mat to simulate the elastic behavior and the energy dissipation capability of the supporting soil.

4.2 Description of Mathematic Model

Since the structural arrangement of the plant is nearly symmetric, only one half of the structure is needed to be included in the mathematic model. The foundation mat, RPV pedestal and the PCV to which the SRV loads are directly applied are represented by plate element (bending and stretching). Other walls and slabs are represented by membrane elements. The RPV and its internals are represented by bar elements with due consideration to the hydraulic coupling. The shear lugs, stabilizers and diaphragm floor are represented by spring elements. As mentioned earlier, soil beneath the foundation is represented by Wrinkler springs and dampers in all three mutually orthogonal directions.

The model has 759 grid points, 67 bar elements, 371 membrane elements and 306 plate elements. All grid points are assigned six degrees of freedom.

Dynamic degrees of freedom are assigned to the selected grid points considering their expected dynamic behavior. In general, most of the grid points subjected directly to the dynamic pressure load are assigned dynamic degrees of freedom in the direction of the load. All other dynamic degrees of freedom are evenly distributed among all grid points of the walls, slabs and frames. The model consists of 186 horizontal (radial, X or Y) and 194 vertical dynamic degrees of freedom.

4.3 Equivalent Soil Damping

It is mentioned that the mathematic model used for the investigation of structural responses under the SRV loads is a three dimensional finite element model with springs and dampers specified at the bottom of the foundation mat. It is well known that if only material damping of soil (normally in the range of 2 to 10 percent of the critical damping) is used, the energy dissipation capability of soil is substantially underestimated as pointed out by Richard et al (8.3). To assure reasonable analysis results, a proper evaluation of the equivalent soil damping is essential. In this investigation, the soil damping is established by comparing the dynamic responses of the structures represented by a finite element soil-structure interaction model to those of the same structure however represented by a lump-mass cantilever beam and foundation spring model through a trial and error process. In order to facilitate both the axisymmetric and the asymmetric SRV loads, rocking, horizontal and vertical soil damping values are established as described in detail in the following sections.

4.3.1 Vertical Soil Damping

For the purpose of the establishment of the equivalent vertical soil damping, it is decided that due to the relatively simple behavior of the problem, a more sophisticated analysis approach based on a mathematic model of finite element body of revolution (include both structural and soil element) can be used without undue effort or expense. The responses calculated at some selected points from this analysis are then compared with those calculated using the three dimensional finite element model with springs and dampers.

4.3.1 Vertical Soil Damping (Cont'd)

By adjusting the assumed damping value in the latter analysis the responses at those selected points are asymptotically matched and thereby establishes the proper damping value. It shall be noticed that in both analyses the time history SRV loads of several different frequencies are examined and the one which generated the highest responses is selected for the final analysis. The 10 Hz load was found to be the most critical. The equivalent vertical damping established by this approach was found to be more than 40 percent of the critical damping and is much higher than the 5 percent material damping originally specified for the design of the plant.

4.3.2 Horizontal and Rocking Soil Damping

Due to limitations of the state-of-art and other practical considerations, the approach used for the determination of the equivalent vertical soil damping is not suitable for the determination of the horizontal and the rocking soil damping. The method chosen to determine these values in this investigation is by comparing seismic analysis results of a soil-structure finite element interaction analysis to that of a lump-mass-spring analysis.

The soil-structure interaction model selected is a two dimensional finite element model including both structural and soil elements. The horizontal and the vertical boundaries of the model are specified at sufficient distance away from the structures such that the wave reflection and refraction effects at the boundaries are minimized. The earthquake inputs at the lower horizontal boundary are based on the results of a deconvolution study of the 1940 El Centro and the 1952 Taft earthquakes. Material damping of 5 percent is assigned to all structural and soil elements.

The lump-mass-spring model selected for analysis is identical to the model originally used for the seismic analysis of the plant. It consists of a lump-mass cantilever beam supported at its lower end by a horizontal and a rocking spring. Material damping is again 5 percent for all structural members.

As expected, slightly different horizontal and rocking damping values are calculated depending on the input earthquake record used. For conservatism, the lower damping values of 30 percent horizontal and 20 percent of rocking are used in the final analysis.

5. RESULTS OF DYNAMIC ANALYSIS

Maximum accelerations and response spectrum at several selected points are presented in table 1 and figure 5. As shown in table 1, the maximum vertical and horizontal acceleration at the top of the RPV pedestal reached 0.58g and 0.13g respectively under the axisymmetric SRV load. This level of responses are certainly high enough to justify further investigation to determine its full impact on the operability of essential equipment and the integrity of safety related structures. At the top of the sacrificial shield wall, vertical acceleration of 0.65g and horizontal acceleration of 0.17g are calculated.

The asymmetric SRV load also introduced high dynamic responses, however, its impact are generally less than those introduced by the axisymmetric SRV load.

Spectrum plot at the top of the RPV pedestal is used for further investigation of the structural integrity of the RPV and its internal components.

6. STRUCTURAL INTEGRITY INVESTIGATION

The structural integrity of the reinforced concrete common foundation mat and the RPV pedestal is thoroughly examined to determine their respective ability in performing the intended design function when subjected to the SRV loads together with other pertinent environmental and accident loads. Structural integrity of other important structures such as the PCV and the RPV is also thoroughly reviewed, however, the findings of that part of the review are not included in this presentation.

The structural integrity investigation is carried out through the determination of forces, moments and deformations of the structures under specified loads and load combinations. The calculations are performed based on static approach using equivalent SRV loads in combination with other loads on the structures. The equivalent SRV loads are established using proper dynamic amplification factor multiplying to the maximum amplitude of the SRV pressure transient. Normally the dynamic amplification factor vary depending on the type of the SRV loads, ie Axisymmetric or asymmetric, and the characteristics of the structures to which the SRV load is applied. For this investigation however a factor of 1.5 is found suitable for most of the applications except in a few cases where smaller factor is found more appropriate. For simplicity and conservatism, it is decided that constant factor of 1.5 shall be used throughout in this investigation.

6.1 Original Structural Design Criteria

The reinforced concrete foundation mat and the RPV pedestal were designed and constructed to adequately withstand all operating, environmental, and accidental loads normally encountered in the design of a nuclear power plant. Following are the major loads, load combinations and the associated level of allowable stresses used in the original design:

<u>Load Combination</u>	<u>Allowable Stresses</u>
1. D + O	LT
2. D + O + S1	ST
3. D + O + S2	ST
4. D + O + LOCA	LT
5. D + O + LOCA + S1	ST
6. D + O + LOCA + S2	ST

where D = Dead load

O = Operating loads including live loads, equipment loads, soil loads buoyancy loads and temperature loads

S1= Seismic load of 0.18g maximum ground acceleration

S2= Seismic load of 0.27g maximum ground acceleration

LOCA= Design basis loss of coolant accident loads including pressure and temperature effects

LT= Long term allowable stresses

ST= Short term allowable stresses

6.2 New Structural Design Considerations

Two phenomenon are discovered after the completion of the design and the construction of the plant; they are the SRV blowdown and the Pool Swell associated with the short term loss of coolant accident. The SRV blowdown and its effects on structures are fully described in this presentation. The short term loss of coolant accident effects on structures are included also for the investigation of structural integrity, however, no attempt is made to discuss the detailed behavior of this phenomena. Following are the new loads and load combinations considered in this investigation:

<u>Load Combination</u>	<u>Allowable Stresses</u>
1. D + O + O(S)	LT
2. D + O + O(S) + S1	ST
3. D + O + O(S) + S2	ST

<u>Load Combination</u>	<u>Allowable Stresses</u>
4. D + O + O(S) + L(I)	LT
5. D + O + O(S) + L(I) + S1	ST
6. D + O + L(S)	ST

where O(S) = SRV blowdown loads

L(I) = Long term LOCA loads due to Interdemiate Break Accident

L(S) = Short term LOCA loads

6.3 Method of Investigation

The method used for the determination of forces, moments and deformations of the structures is based on the finite element analysis approach using the same mathematic models as original used for the analysis and design of these structures. The finite element model of the RPV pedestal consists of basically plate elements with a fixed boundary condition assigned at the juncture of the pedestal and the mat. Due to nature of the loads and the geometry of the structure, only one quarter of the pedestal is needed to be included in the model. The finite element model of the common foundation mat consists primarily of plate elements with elastic springs attached to all nodal points underneath the mat. Rigidity of all major walls above the foundation mat is considered in the model such that the deformations of the mat along these walls are properly restrained. The springs which can only take compressive load are evaluated under the vertical operating loads and the seismic load to determine the extent of their effectiveness prior to the application of all other loads to the mat for the final analysis. Linear iteration method is employed for the evaluation of the effectiveness of the springs. Due to nature of the loads and structural configuration, only one half of the mat is needed to be included in the model. Figure 6 show the finite element model of the foundation mat.

6.4 Results of Investigation

6.4.1 Pedestal

The investigation of the pedestal involves the analysis of a total of 27 individual load and 30 load combination cases in order to account for all SRV and short term LOCA loads. The resulted forces, moments and deformations are compared with those calculated originally and are found generally satisfactory except in a very localized area where slight rebar overstress is discovered when the pedestal is subjected to the combination of the horizontal SRV load and the S2 earthquake force. This condition is judged to be of no real concern on the ability of the pedestal to fulfill its intended function to safely support the RPV and its associated components.

6.4.2 Foundation Mat

18 individual load and 38 load combination cases are analyzed to account for all direct and indirect SRV and short term LOCA loads on the mat. As anticipated, the stresses and deformations of the mat under the newly specified load and load combinations are generally below the levels as calculated in the original design. This is due to primarily the exclusion of the accident temperature load in the new investigation since the full impact of the temperature effects will not be realized in the concrete mat until perhaps several days after the accident and by that time the SRV and the short term LOCA loads are no longer in effective. In some cases, such as the load combination of the SRV and the S2 earthquake forces, the bending moment and shear force calculated in some area did exceed those of the same load case by the original calculation by a small percentage, however, they are of no consequence to the mat design since they are not the governing loads anyway.

7. CONCLUSION AND DISCUSSION

The full impact of the SRV and the short term LOCA loads on the RPV pedestal and the found-

ation mat of a BWR Mark II nuclear power plant is thoroughly investigated. The structural dynamic responses are determined using the time history model analysis techniques based on a finite element model for the complete structure resting on elastic springs. The energy dissipation ability of the soil is simulated by the specification of an equivalent damping ratio established through a separate soil-structure-interaction analysis.

The RPV pedestal and the foundation mat are found satisfactory under the SRV and the short term LOCA loads and therefore no backfitting for these part of the plant is required. It shall be noted that the magnitude of the SRV pressure transient, load combinations and associated allowable stresses are established based on information available at the time and mutual agreement among the NSSS supplier, the owner and his architectural engineer. However, since this plant is not under the direct jurisdiction of the USNRC the criteria used and the conclusion reached shall not be considered as necessarily adequate for the investigation of a similar plant in the USA.

8. REFERENCES

- 8.1 "Mark II Containment Dynamic Forcing Function - Information Report" NEDO-21061, Sept. 1975, GE & Sargent & Lundy
- 8.2 "NASTRAN Manuals" The MacNeal-Schwendler Corp. Jan. 1976
- 8.3 "Vibration of Soils and Foundations" F.E. Richard Jr., J. R. Hall Jr., R.D. Woods Prentice-Hall, 1970

Grid Point	Component	Axisymmetric SRV Blowdown	Asymmetric SRV Blowdown
Top of RPV Pedestal	V	0.58	0.40
	H	0.13	0.11
Top of Sacri- ficial Shield Wall	V	0.68	0.49
	H	0.17	0.10
Top of Guide Supporting Ring	V	0.76	0.52
	H		0.11
Pedestal at Diaphragm Floor Level	V	0.45	0.28
	H		0.07

TABLE 1 RESPONSES OF STRUCTURES

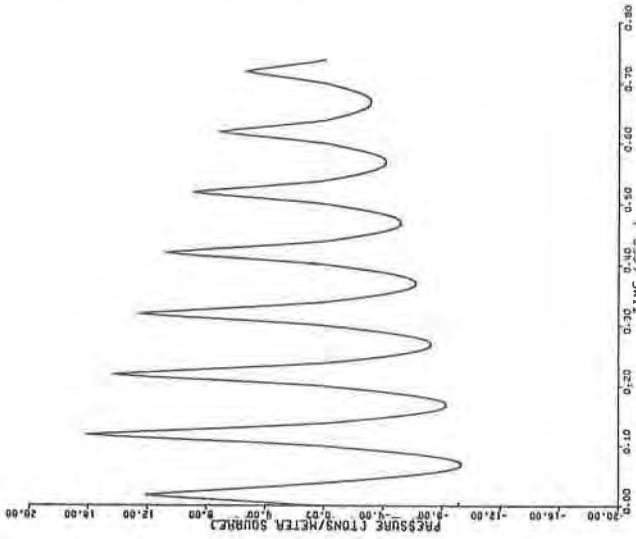


FIG. 3

MS SAV BLOWDOWN DYNAMIC ANALYSIS

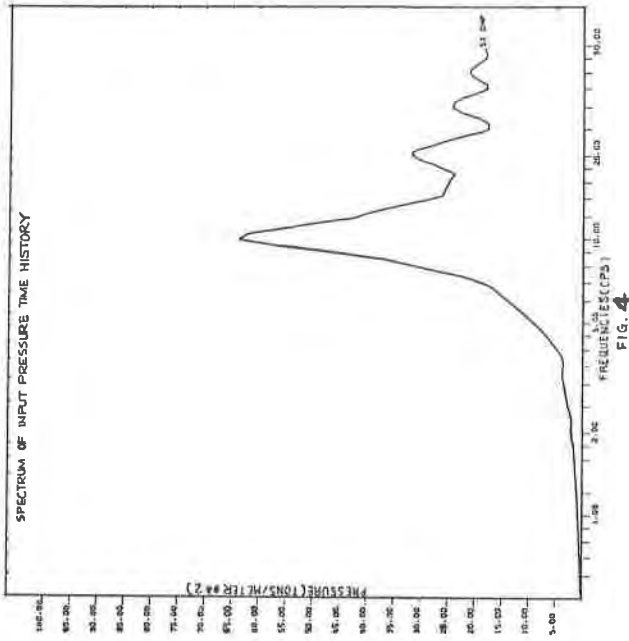
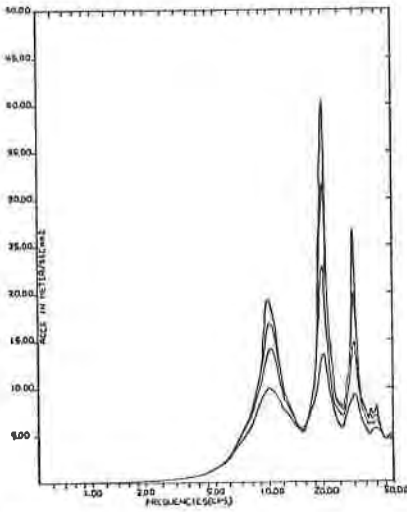
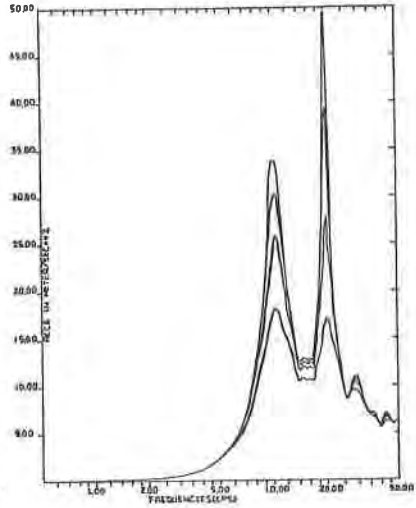


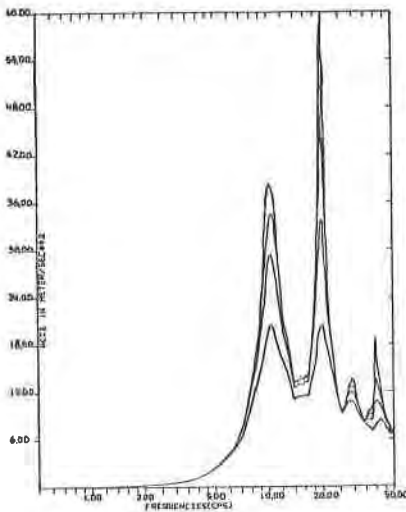
FIG. 4



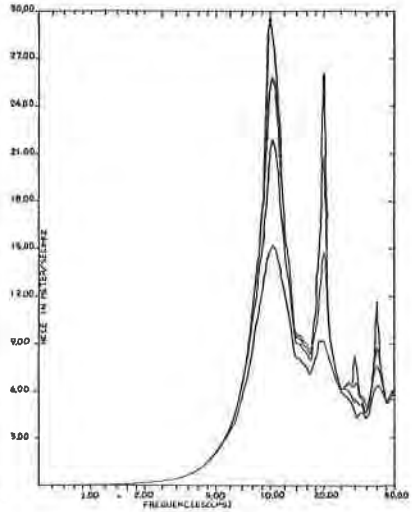
a. Vertical spectrum at mat Axisymmetric head



b. Vertical spectrum at top of pedestal Axisymmetric load

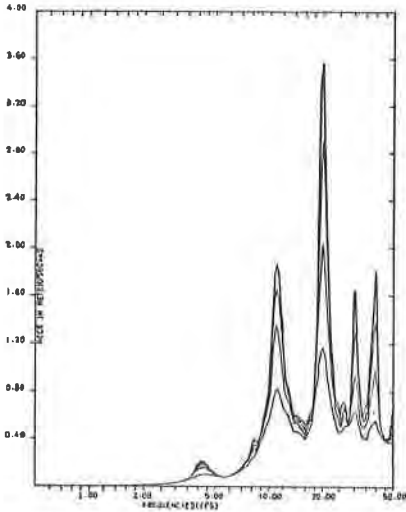


c. Vertical spectrum at top of sacrificial shield wall Axisymmetric load

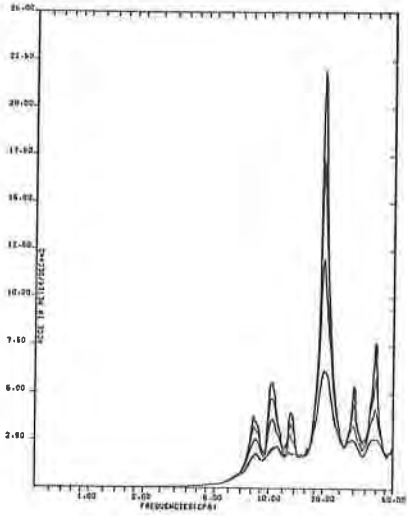


d. Vertical spectrum at diaphragm floor Axisymmetric load

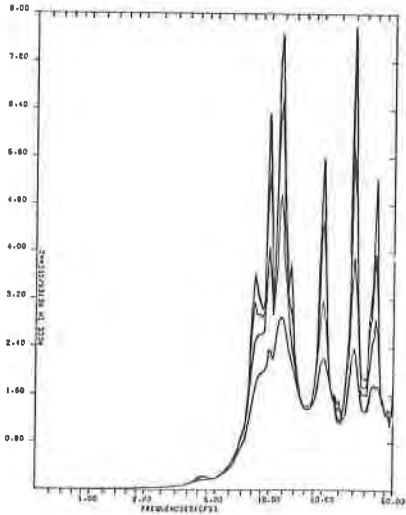
Fig. 5



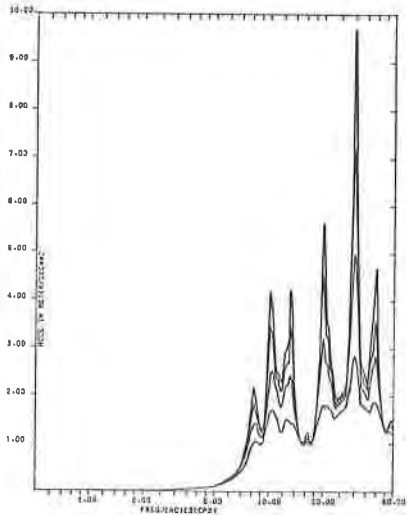
e. Horizontal spectrum
at mat
Asymmetric load



f. Horizontal spectrum
at top of RPV Pedestal
Asymmetric load



g. Horizontal spectrum
at top of sacrificial wall
Asymmetric load



h. Horizontal spectrum
at diaphragm floor
Asymmetric load

Fig. 5

