SEISMIC ANALYSIS OF THE PFBR ROOF-SLAB

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INTRODUCTION

A static deflection of 3 mm of the roof-slab under the hanging weights has become the functional limit for the design of the roof-slab. It supports a huge mass of LRP, IHX's, primary sodium pumps, main vessel with primary sodium, and is connected to the concrete vault. This has led to the fact that the roof-slab vibrates at about 10 Hz in the vertical modes of free vibration, and the study of the modal responses of the base excitation during an earth quake has become an important issue in addition to finding out the associated stresses in the parts of the roof-slab.

GEOMETRY AND MATERIAL PROPERTIES

FEM mesh of the roof-slab geometry is shown, along with four IHX's, two primary sodium pumps and a main vessel, in Fig.1.

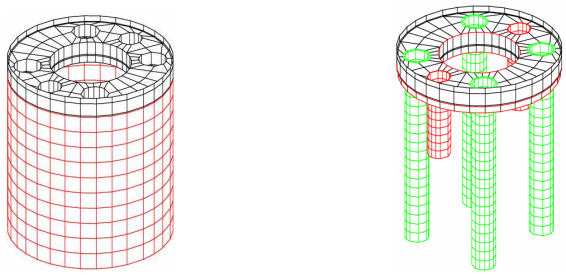


Figure 1. FEM Mesh Of The Roof-Slab Geometry With Main Vessel and IHX's, Primary Sodium Pumps

At 373K, Carbon Steel material (A48 – P2) of the roof-slab has the following properties:

$E = 2.0 \times 10^{11}$ N/m^2
$\nu = 0.3$
$\rho = 7.8 \times 10^{3}$ kg/m^3
$S_m = 1.5 \times 10^{8}$ N/m^2
$S_u = 4.5 \times 10^{8}$ N/m^2

Plates and shells of the roof-slab have a thickness h = 0.03 m except for LRP and SRP.

INPUT DETAILS

For the purpose of simulation of the fundamental mode shapes of the hanging components at the corresponding natural frequencies of the roof-slab, the length of a hanging component has been fixed, based on its fundamental frequency of Ref. [1], using a FEM package. These lengths of the individual components are inputs of the analysis.

	thickness(m)	diameter(m)	length(m)	fundamental frequency(Hz)	mass participation in beam modes of free vibration
IHX	0.020	1.895	16.3	4	38%
PUMP	0.020	1.830	6.9	9	39%
MV	0.025	12.900	13.6	6	35%

The associated pseudo response spectra of Fig.2 are used in the OBE analysis and of Fig.3 are used in the SSE analysis.

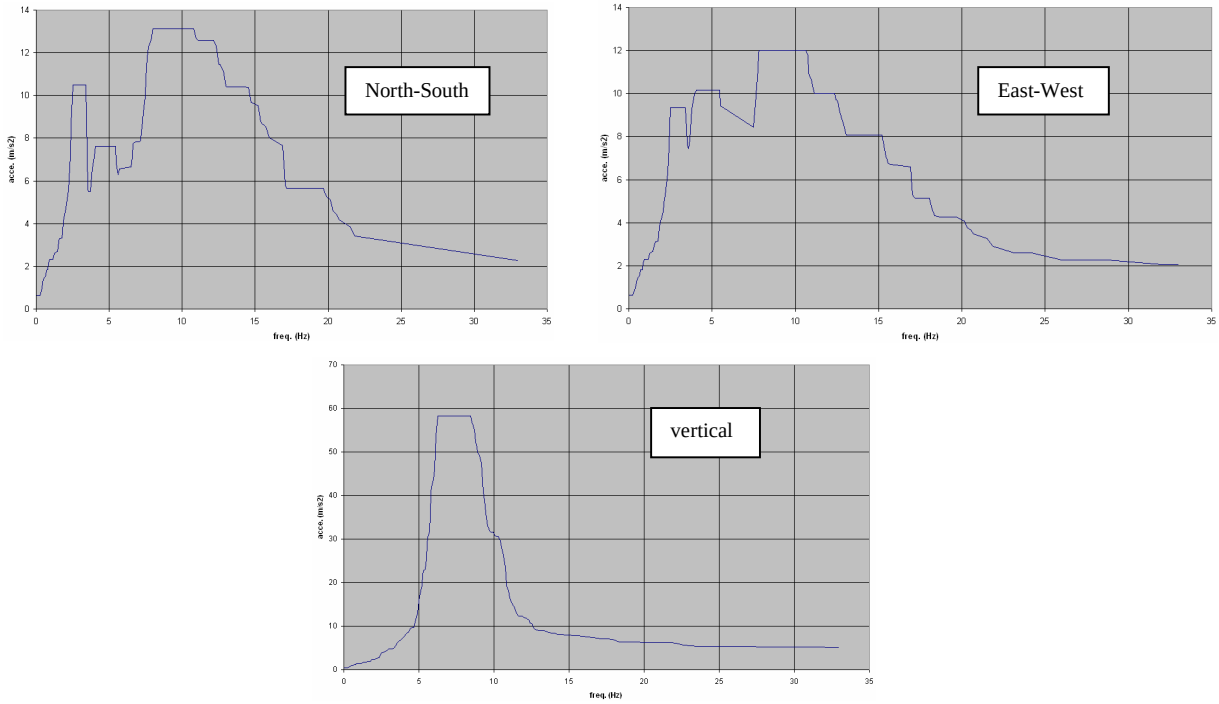


Figure 2. OBE: Pseudo Response Spectra - Broadened

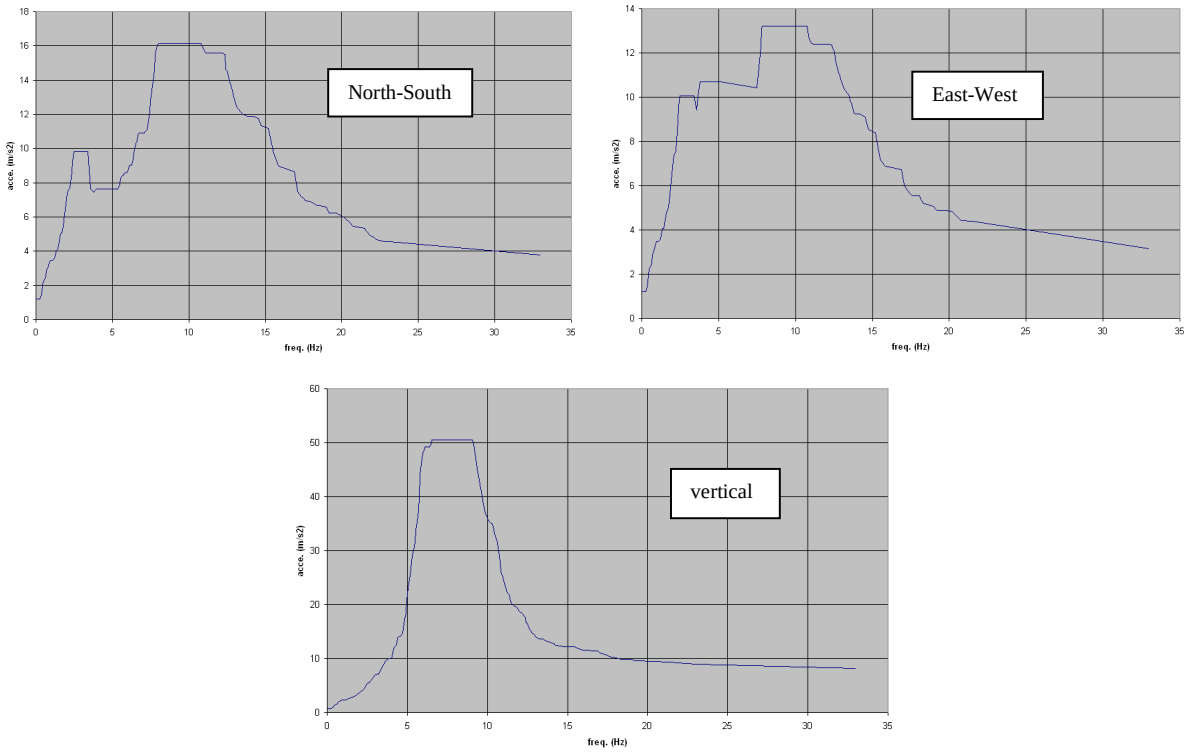


Figure 3. SSE: Pseudo Response Spectra - Broadened

FEM ANALYSIS

For the purpose of analysis, an LRP mass of 4.54×10^5 kg is lumped all over the inner edge of the top plate, a mass of 6.1×10^5 kg of concrete is lumped all over the bottom plate, an IHX mass of 4.5×10^4 kg is distributed all over the IHX model of thin shell elements, a primary sodium pump mass of 9.0×10^4 kg is distributed all over the pump model of thin shell elements. 70% of the total mass of 2.1×10^6 kg of the main vessel plus primary sodium is distributed all over the main vessel model of thin shell elements, and the rest is lumped on the bottom edge of the main vessel.

Using COQ4 elements of CASTEM FE analysis program for plates & shells and lumping or distributing the masses as above, natural frequencies of the roof-slab for the free vibrations with the beam mode in the North-South, East-West and vertical directions, and the associated mass participation factors have been computed with the outer shell top edge totally blocked (i.e, no displacement and rotation of this edge). Natural frequencies upto 33 Hz are fed to carry out the OBE (damping of 2% for welded structures) and SSE (damping of 4% for welded structures) analyses, and this is carried out using the pseudo response spectra obtained from the acceleration-time history record.

$\overline{P}_m$, the general primary membrane stress intensity, in the plate and shell parts of the roof-slab is computed for the events of OBE and SSE. In addition to this, $\overline{P}_m$ is also computed under the action of gravitational pull.

Free vibration analysis is done using the VIBRATION operator of the CASTEM Finite Element Package, which searches for the eigenvalues and eigen modes of a physical system represented by its stiffness and its mass, whereas seismic analysis is done using the SISSIB procedure of the CASTEM Finite Element Package, which calculates the seismic response of a structure by means of a spectrum analysis.

RESULTS

For the beam modes of vibration in the north-south, east-west and vertical directions, associated mass participation factors are tabulated in the following table where the total mass is 3.60572×10^6 kg including the hanging components.

Frequency (Hz)	Mass Participation in % (North-South)	Mass Participation in % (East-West)	Mass Participation in % (vertical)
2.417	2.315		
2.746	2.013		
5.316		45.103	
5.342	47.184		
6.543			2.414
6.802		3.616	
10.830		7.209	
10.907	7.105		
11.177			33.288
16.193		7.753	
16.966	16.791		
17.215		6.660	
17.579		7.120	
18.218		5.036	

Natural modes of free vibration of the roof-slab in the north-south, east-west and vertical directions are shown in Figs. 4 and 5.

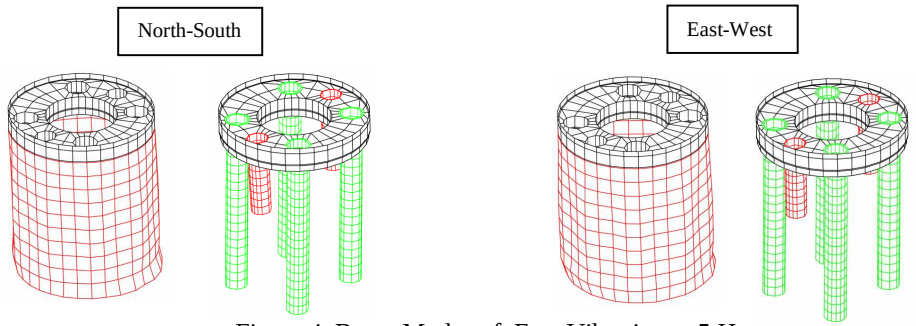


Figure 4. Beam Modes of Free Vibration at 5 Hz

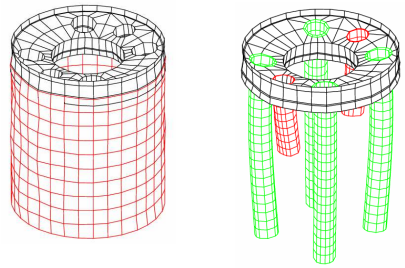
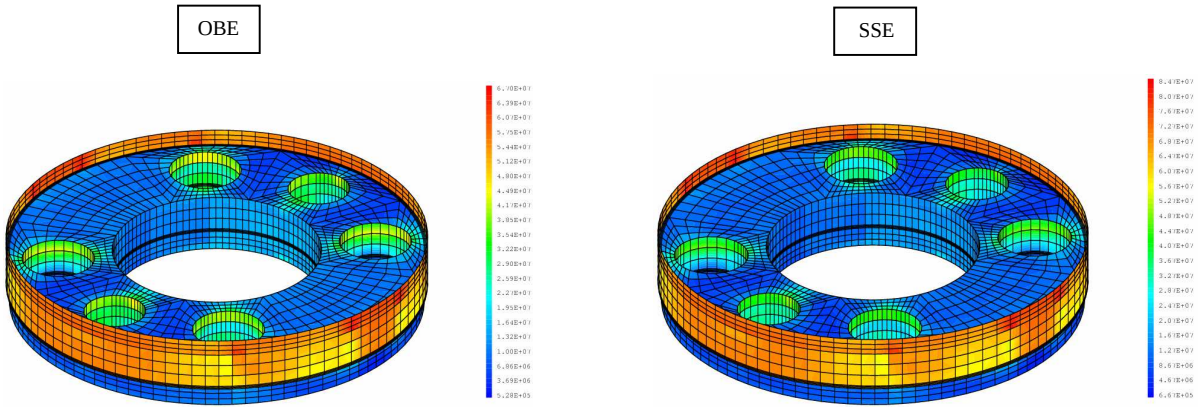


Figure 5. Free Vibration in the Vertical Direction at 11 Hz

It is observed that the general primary membrane stress intensity, $\overline{P}_m$, is maximum in the outer shell above the top plate of the roof-slab in the location between the IHX cut-outs of the top plate and over the stiffeners between the LRP and the outer shell, and this maximum value is tabulated here.

$\overline{P}_m$ (Weight)	$\overline{P}_m$ (OBE)	$\overline{P}_m$ (SSE)
30 MPa	70 MPa	80 MPa

Fig.6 shows the general primary membrane stress intensity plots at the above locations of the roof-slab in the events of OBE & SSE, and also under its own weight in the units of Pascal. These locations are the red spots in the figures below.



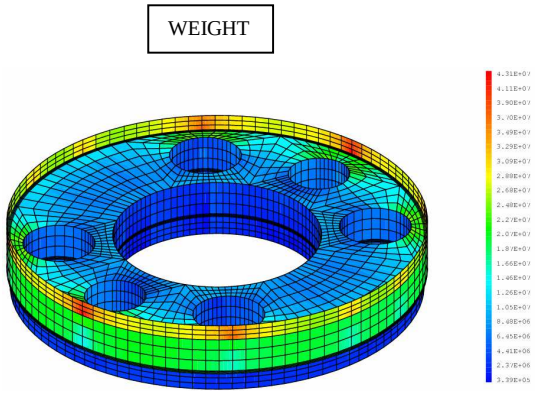


Figure 6. General Primary Membrane Stress Intensity Plot of the Roof-Slab

This shows that $\overline{P}_m$(W+OBE) and $\overline{P}_m$(W+SSE) are maximum in the outer shell above the top plate in the location between the IHX cut-outs of the top plate and over the stiffeners between the LRP and the outer shell, and always less than 150 MPa for OBE and 315 MPA for SSE. This satisfies the RCC-MR limits: $\overline{P}_m$(W+OBE) < S_m and $\overline{P}_m$(W+SSE) < 0.7S_u Ref. [2].

It has been found that the in-plane shear stresses (N_{12} /h) are maximum on the stiffener sides connected to the outer shell below the top plate in the location between the IHX cut-outs. Maximum shear stresses in the above stiffeners for the events of OBE and SSE are tabulated below.

	W+OBE	W+SSE
maximum in-plane shear stresses	10 MPa	20 MPa

It has been found that the tensile forces per unit length in the axial direction (N_{22}) are maximum at the outer shell top edge in the location between the IHX cut-outs of the top plate and over the stiffeners between the LRP and the outer shell, and the maximum tensile forces per unit length for the events of OBE and SSE are tabulated below.

	N_{22}(N/m)
W+OBE	3.0×10^6
W+SSE	3.3×10^6

This in turn yields a maximum tensile stress of 100 to 110 MPa in the axial direction in the outer shell at the location of its connection to the support structure over the stiffeners between the LRP and the outer shell.

CONCLUSION

It is observed that the general primary membrane stress intensity, $\overline{P}_m$, is maximum in the outer shell above the top plate of the roof-slab in the location between the IHX cut-outs of the top plate and over the stiffeners between the LRP and the outer shell, and satisfies the RCC-MR limits $\overline{P}_m$ (W+OBE) < S_m and $\overline{P}_m$ (W+SSE) < 0.7S_u. It is also observed that the natural frequency of the roof slab for the free vibration either in the north-south or east-west direction is 5 Hz when the mass participation for that direction is about half of the total mass of 3600×10^3 kg, whereas 11 Hz is the natural frequency of free vibration in the vertical direction when the mass participation is about one third of the total mass. IFTM load has not been considered in the analysis because IFTM load will not contribute to the vertical excitation of the roof-slab due to its support on the roof-lab at the location of its outer periphery.

REFERENCES

[1] P. Chellapandi "*Seismic Analysis of Reactor Assembly*" PFBR /31000/DN/1035/R-B
[2] RCC-MR subsection RB for class 1 components,design and construction rules for mechnical components of FBR nuclear islands,(2002), AFCEN, Paris, France