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Dynamic Buckling Investigations of Main Vessel and Safety Vessel under Extreme Seismic Conditions

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ABSTRACT: The main vessel of the pool type Prototype Fast Breeder Reactor (PFBR) is a large diameter thin walled structure which contains large amount of liquid sodium. The main vessel tends to be very flexible due to low operating pressure and high thermal stresses during transients. This poses a challenging design requirements under seismic conditions which require rigid structures. In addition to this, hydrodynamic forces are developed on the walls of these shell structures due to the liquid sodium under base excitation. This forces would lead to the risks of buckling which is one of the main failure modes of these kind of structures. Hence it is required to assure the structural integrity of the main vessel against buckling risks. The presence of thin annular shells like thermal baffles increases the hydrodynamic forces. Also sodium enters into the interspace between safety vessel and main vessel in case of extremely unlikely event of main vessel leak. Thus the buckling risks of main vessel, thermal baffles and safety vessel are to be assured under all conditions. This paper deals with the estimation of dynamic pressure on main vessel.

1.0 INTRODUCTION

When a large thin walled structure containing fluid is subjected to ground motions (earthquake), dynamic pressure is exerted on the walls of the structure. The hydro dynamic forces thus developed will be acting outward on one side of the tank and inward on the opposite side. This forces would lead to risks of buckling which is one of the main failure modes of these kind of structures (ref 1).

The main vessel of Prototype Fast Breeder Reactor (PFBR) is a large diameter thin walled structure which contains large quantity of liquid sodium (Fig 1). Hydrodynamic forces will be developed on the walls of thin shells of PFBR under seismic conditions. The integrity of main vessel against the buckling risks due to this hydrodynamic forces has to be demonstrated. The presence of thermal baffles which are concentric to the main vessel and coupled to main vessel by the sodium within the annular space, increases the dynamic pressure during any seismic event.

The dynamic pressure distribution on the main vessel is to be accurately estimated for further analysis to estimate the buckling load factors. This dynamic pressure distribution is greatly affected by the presence of annular liquid sodium formed between the gaps of main vessel and thermal baffles. Also sodium enters into the interspace between safety vessel and main vessel in case of extremely unlikely event of main vessel leak. Thus the buckling risk of main vessel has to be estimated under all the conditions which are listed below.

- Normal operating condition + S1
- Normal operating condition + S2
- S1 under main vessel leaked condition (Sodium within the interspace between safety vessel and main vessel) (S2 during this event is considered as beyond design basis event)

This paper deals with the finite element modelling of reactor assembly with sodium, the modal analysis and the seismic response calculation with particular reference to dynamic pressure. Analyses has been done for S1 level of earthquake of 0.078 g ZPA and S2 of 0.156 g ZPA. The general purpose code CASTEM 2000 has been used.

2.0 MODELLING FEATURES

Axisymmetric modelling is employed for these analyses. Two nodded shell elements (COQUE) are used to model the thin shell structures of PFBR. Four nodded liquid elements (LIQU4) have been used for modelling the liquid sodium. The connection elements LICO has been used to model the connection between fluid and structure. Further the free surface is modelled with surface elements. Normally sloshing frequencies will be very low and hence their participation on dynamic pressure will be very less. The finite element mesh is shown in fig 3. The inter-vessel space between outer baffle plate & main vessel and inner baffle plate and outer baffle plate is 95 mm. The following are some of the important features of modelling

- The core support structure and roof slab are modelled as equivalent plates whose density has been adjusted to conserve the mass coming through respective structures.
- The internals like baffle plates have been modelled since their effect on the main vessel dynamic pressure is of interest.
- The inner vessel is not modelled since it will not affect the dynamic pressure distribution on main vessel.
- The safety vessel is also modelled which is necessary to estimate the dynamic pressure on the main vessel when the interspace between safety vessel and main vessel is filled with sodium, in case of main vessel leak

3.0 ANALYSIS

The seismic analysis is done by response spectrum method. The required Floor Response Spectra (FRS) at roof slab support location has already been obtained (ref 2) from the stick model of PFBR complex. The FRS at roof slab support is given in figure 2 for S2 of 0.156 g ZPA. The natural modal analysis is done as the first stage. From the first stage, the parameters necessary for the second stage (response calculation) like natural frequency values, modal participation factors, generalized mass etc. are extracted. The contribution from all the modes below 33 Hz are combined by Square Root of Sum of Squares (SRSS) method . The direction combination is also done by SRSS method.

Four types of studies have been completed to understand the effect of thermal baffles and safety vessel on the dynamic pressure distribution on main vessel.

case -1 Main vessel leaked condition with sodium in the inter-vessel space, thermal baffle plates not modelled, for S1

case -2 Sodium in the main vessel, thermal baffle plates not modelled, for S1

case -3 Main vessel leaked condition with sodium in the inter-vessel space, thermal baffle plates modelled, for S1

case -4 Normal operating condition + S1

case -5 Normal operating condition + S2

4.0 RESULTS AND DISCUSSION

The dynamic pressure due to all modes are extracted. It is to be noted that the dynamic pressure will be developed on both the sides of the main vessel when sodium is present on both sides of the main vessel. So, the differential pressure is to be calculated for realistic estimation in the modal basis itself. The modal combination rule has been applied on this differential pressure. The dynamic pressure along the main vessel wall is given in table - I for case 1 & case 2. The table - II shows the dynamic pressure for case 3, case 4 and case 5. The distribution is also shown in fig 4. The maximum dynamic pressure is 1625 mbar, 1790 mbar and 2205 mbar for case 3, case 4 and case 5 respectively, occurring at outer baffle plate support location. These values are much higher than the corresponding values (486.5 and 324.8 mbar) when baffle plates are not present. This indicates that the presence of small annular sodium induces more dynamic pressure.

5.0 CONCLUSION

The analyses for estimation for dynamic pressure on main vessel under the extremely unlikely event of main vessel leak has been completed for S1 level (0.078 g ZPA for Kalpakkam site). Also dynamic pressure distributions on main vessel during S1 and S2 (0.156 g ZPA) for normal operating conditions have been estimated. The dynamic response has been calculated for horizontal excitation as vertical contribution in the cylindrical portion of main vessel on the dynamic pressure will be very less. The SRSS method is used for both modal and directional combination. The dynamic distribution forms the important input to evaluate the buckling risks of main vessel under seismic conditions. Also parametric studies have been done to understand the effect of the presence of thin annular sodium in the inter-vessel space between thermal baffle plates, main vessel and safety vessel. The results indicate that the small annular sodium induces more dynamic pressure on the walls of main vessel which has to be checked for buckling risks.

6.0 REFERENCES

1. Cumberscure,A., Quevel,J.C., Alliot,P., and Herrman,R., "Dynamic behaviour of liquid storage tanks", *Transactions of 9 th Int. Conf. on Structural Mechanics in Reactor Technology (SmiRT - 9),* 1987.
2. Selvaraj,T., Ravi,R.,Chellapandi,P., Chetal,S.C., and Bhoje,S.B., "Generation of floor response spectra for PFBR", *Transactions of 14 th Int. Conf. on Structural Mechanics in Reactor Technology (SmiRT - 14)*, LYON,FRANCE, K21/2, 1997, pp 293 - 300

Table I Dynamic pressure (mbar) distribution without thermal baffle plates

Elevation from bottom of main vessel [m]	Case 1 (sodium on both sides and without baffle plates for S1)	case 2 (Sodium only on main vessel side and without baffle plates for S1)
0.395	850.0	284.2
0.794	972.8	309.4
2.747	733.4	369.6
3.56	476.1	376.6
4.4	372.1	371.0
4.9	419.6	362.6
5.9	497.7	346.0
6.4	456.6	324.8
6.95	486.5	299.6
8.05	517.1	238.0
8.6	472.4	210.0
9.0	399.7	162.4
9.8	177.3	75.4

Table II Dynamic pressure (mbar) with thermal baffle plates

Elevation from bottom of main vessel [m]	Case 3 (sodium on both sides and with baffle plates for S1)	case 4 (Normal + S1)	Case 5 (Normal + S2)
0.395	833.3	231.8	283.0
0.7937	925.7	258.4	313.0
1.334	982.8	280.0	339.1
1.994	893.2	281.4	358.0
2.747	714.0	301.0	371.2
3.560	544.6	303.8	374.8
4.4	463.4	295.4	366.2
4.9	449.4	287.0	356.7
5.4	448.0	277.2	344.6
5.9	463.4	266.1	330.8
6.4	1516.8	1790.2	2205.4
6.95	1601.4	1763.6	2172.8
7.5	1625.5	1638.9	2020.3
8.05	1550.9	1416.4	1747.7
8.6	1344.0	1163.5	2438.6
9.0	1103.2	995.4	1230.8
9.4	795.2	788.2	975.9
9.8	427.1	453.6	560.6

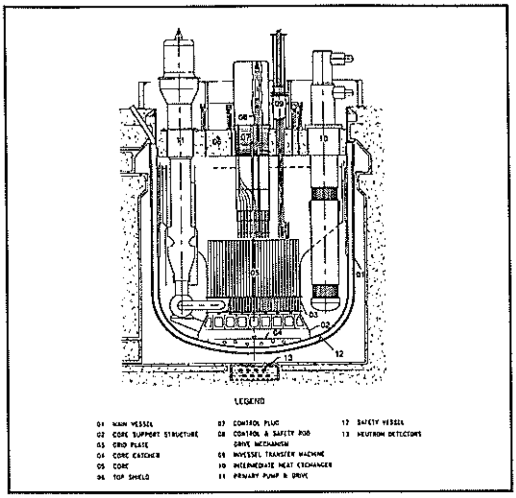

Fig 1 Reactor Assembly of PFBR

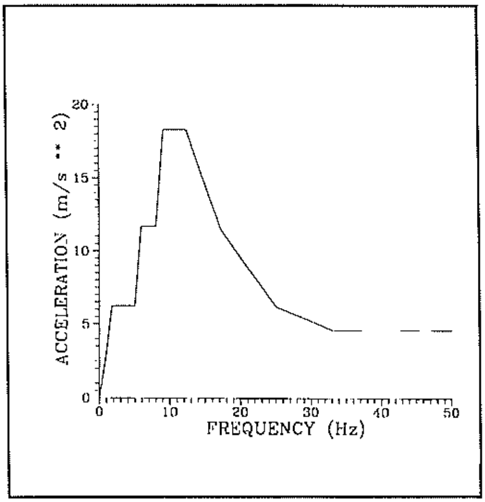

Fig 2 Floor Response Spectra (0.156 g SSE)

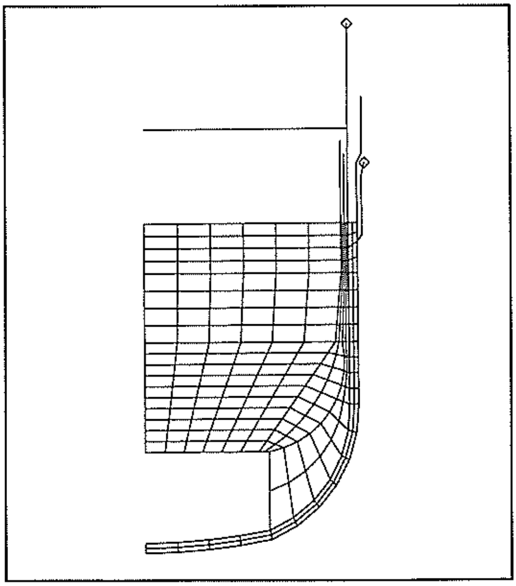

Fig 3 Finite Element Mesh

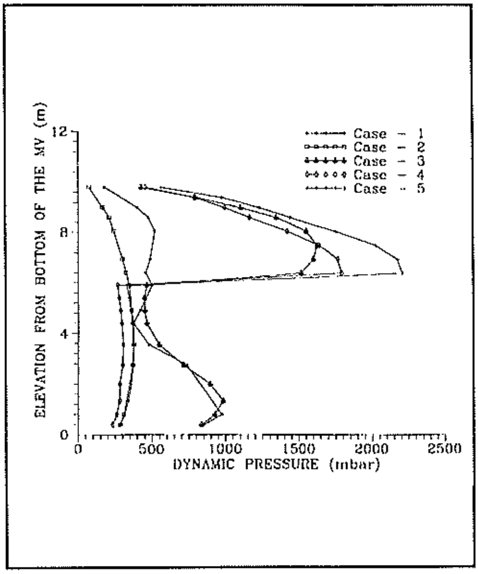

Fig 4 Dynamic Pressure Distribution on Main Vessel