SEISMIC DESIGN OF SODIUM PIPING OF PFBR BY MULTI SUPPORT RESPONSE SPECTRA METHOD

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ABSTRACT

Proto Type Fast Breeder (PFBR) reactor is a 500 MWe nuclear power plant currently under construction in India. The medium used in PFBR for transport of heat is liquid sodium. Sodium piping is used for transportation of heat from primary sodium to secondary sodium and again from secondary sodium to water. Apart from these main sodium piping, there are other piping for filling and draining of tanks and vessels with sodium, purification of sodium, safety grade decay heat removal, Cover gas(argon) piping and steam water piping. In PFBR, all sodium piping have been analyzed and designed for seismic conditions to ensure safety against radioactive release. Sodium piping operates at low pressure and high temperature. Generally, the thickness of piping is less because of low pressure and this coupled with high operating temperature leads to highly flexible piping layouts. However, they have to be stiff enough to resist the forces induced by seismic excitations. Often this conflicting requirement is met with provision of snubbers. It is well known that snubbers are not only expensive, but they also interfere with normal operation and their maintenance is very cumbersome. Further the piping is supported at many locations and are subject to different excitations having different spectral characteristics. Conventional method of using enveloped response spectrum leads to very conservative results and would lead to many snubbers. Hence analysis by multi support excitation methods(Independent support) are employed for such piping whose support spectra show large differences in their spectral magnitude. The independent support method requires the grouping of supports and this leads to different combination rules. Also, the response of piping due to differential pipe movements(Seismic anchor movement) has to be combined suitably with response from inertial component. Finally, the piping has to be qualified as per the safety classification and seismic categorization and as per applicable design code. This paper discusses the methods involved in the seismic resistant design of sodium piping of PFBR by multi support response spectra method with the results. Various technical issues involved in multi support excitation analysis of sodium piping are highlighted.

INTRODUCTION

In PFBR, the heat produced by the nuclear fission of Uranium and Plutonium oxide fuel immersed in the hot pool primary sodium of main vessel is transported to the secondary sodium in the Intermediate Heat Exchanger(IHX) and this secondary sodium heat is in turn transported to the water through the Secondary Sodium Pumps(SSP) and Steam Generator(SG), which is also a heat exchanger. IHX is located in the Reactor Containment Building(RCB). SSP and SG are located in the Steam Generator Buildings(SGBs). Piping in PFBR has been classified as Primary piping, Secondary sodium piping and Intermediate sodium piping. Piping which have radioactive sodium is called primary sodium piping. Secondary and Intermediate sodium piping get heat from primary sodium piping and may be radioactive, in case of failure or leakage in the heat exchangers. Steam-water piping involves the conventional piping for water and steam transportation viz. boiler feed pumps to steam generators and steam generators to turbine and their accessory piping. In PFBR piping systems, seismic design has been carried out only for sodium piping which have radioactive hazard. The structural integrity of these sodium piping systems has to be ensured under seismic excitation for two levels of earthquake viz. Operating Basis Earthquake(OBE) and Safe Shutdown Earthquake(SSE) as per respective codal requirements. Sodium piping of PFBR has low pressure because of which the thickness of sodium piping is very low. This low thickness of piping coupled with high temperature of sodium offers high flexibility characteristics. This high flexibility, though suitable for bringing down the thermal stresses is against the requirement of high rigidity needed to counter the seismic forces. Since the sodium piping is supported at different elevations, the forces due to multi support excitations are also very high. In addition, the seismic forces due to differential pipe movements at different elevations of the building also bring the seismic stresses to high levels. Hence, snubbers which allow gradual thermal expansion but not the sudden seismic forces, are placed at appropriate piping locations to bring down the seismic stresses.

This paper discusses the analysis methodology, design criteria and results of a typical piping(SSP to IHX line) by the multi support response spectra method. The technical issues involved in the analysis of sodium piping by the multi support response spectra method are also discussed.

DESCRIPTION OF SSP TO IHX LINE

DESIGN PARAMETERS AND DESIGN CRITERIA

SSP to IHX line(Fig.1) is of NB550 with a thickness of 8mm and the material is SS 304LN. Piping inside RCB which houses the IHX in the main vessel is provided with a guard pipe(OD652*4mm). Bend radius of the piping is 1.5D, with an inner layer insulation of 40mm(IS 8183 Gr.3) and outer layer insulation of 65mm(IS 8183 Gr.2). SSP[2] to IHX[3] line is safety class 3 and seismic category 1 line. The design temperature of the piping is 530˚C and pressure is 0.1MPa. The seismic design of pump to IHX line is done as per ASME Sec III Div.1 Subsection NC.

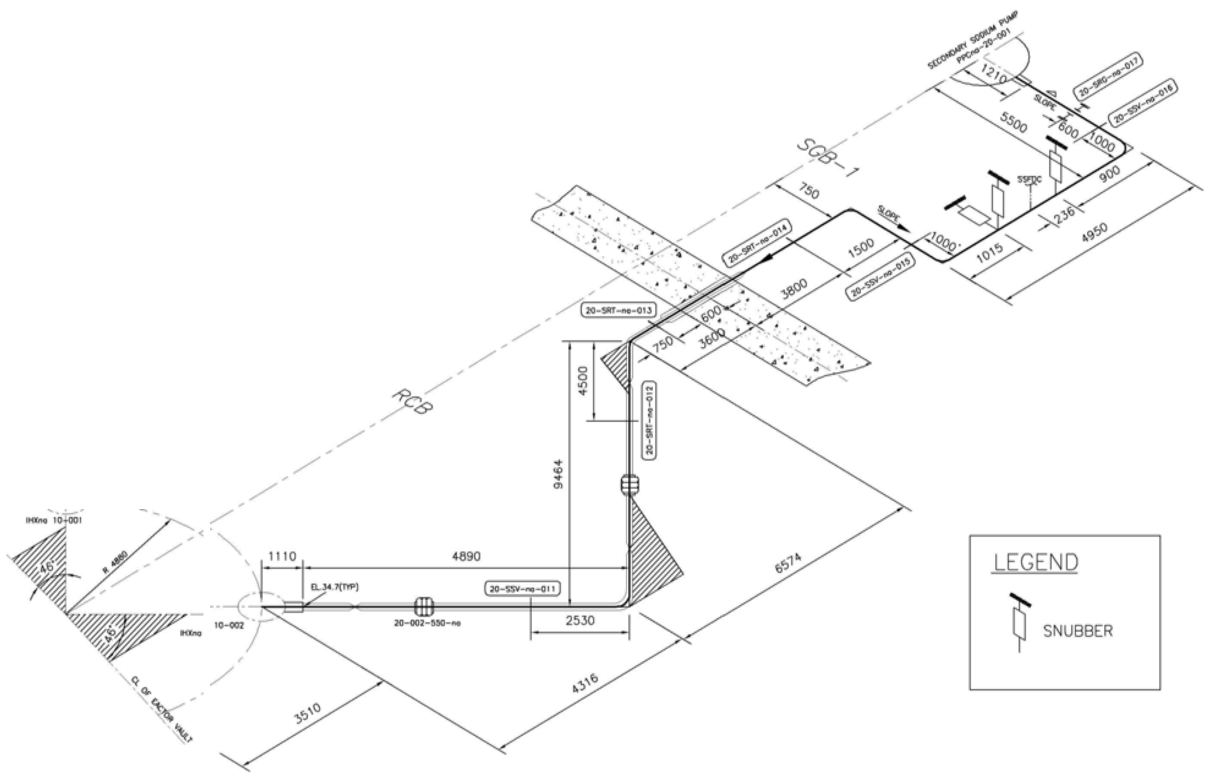

Fig.1 – Piping layout and snubber location for Secondary sodium main system – Pump to IHX line

OBE & SSE are put under service loading of level C & D respectively. The following equations are to be satisfied to ensure the structural integrity of pump to IHX line subjected to seismic excitations of OBE and SSE :

OBE :

$B_1*(P_D D/2t) + B_2' * (D_O/2I)*M_E \leq 2.1\ S_m$

$C_2 * (M_{AM} D_O/2I) < 4.2\ S_m$

$F_{AM} / A_M < 0.7\ S_m$

SSE :

$B_1*(P_D D/2t) + B_2' * (D_O/2I)*M_E \leq 3.0\ S_m$

$C_2 * (M_{AM} D_O/2I) < 6.0\ S_m$

$F_{AM} / A_M < 1.0\ S_m$

where,

B_1, B_2', C_2 – Stress Indices

P_D- Pressure; D_o – Dia of the pipe; t – Thickness of the pipe; I – Moment of inertia
M_E – resultant moment of earthquake and sustained load
M_{AM}- Resultant moment due to anchor motions
F_{AM}-Longitudinal force due to anchor motions
A_M-Cross-sectional area of the pipe

SEISMIC ANALYSIS

Response spectrum method can be done either with a single enveloped floor response spectrum(FRS) or with a multi spectrum(Independent Support Motion). Independent support motion method is used to determine the response of present pipeline. In response spectrum method, FRS are extracted at all the support locations from the dynamic analysis of Nuclear Island Building(NIB). These FRS are broadened (15% on either side of the peaks) to account for the uncertainties in the structural frequencies owing to variation in the material properties, soil properties and approximations introduced by modeling. Analyses have been done for both horizontal and vertical directions. The required floor response spectra (FRS) at the supports has been taken as input [5]. These FRS in horizontal and vertical direction for OBE(5% damping)[5] and for SSE(5% damping) are shown in Fig.2. respectively. With these FRS as input, the responses (displacements and stresses) are determined using natural modal data obtained from the natural frequency analysis.

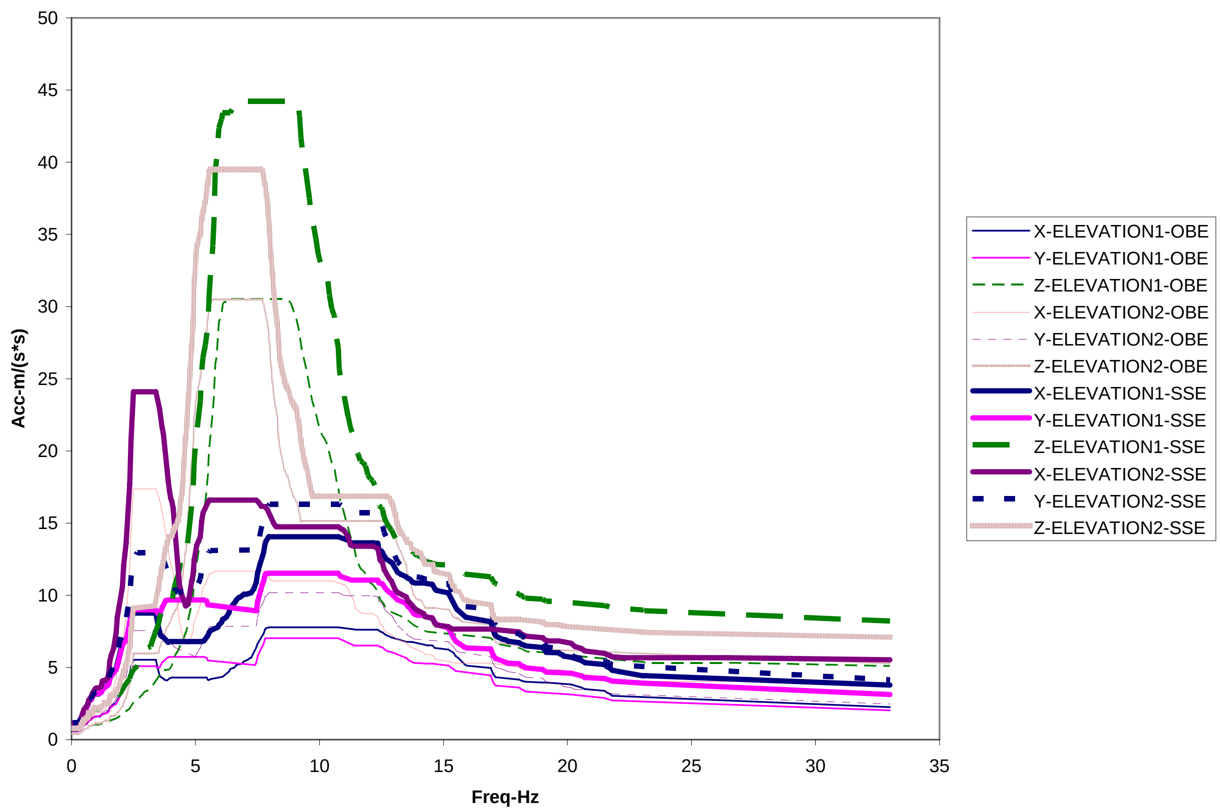

Fig.2 – Broadened and enveloped FRS for OBE and SSE(5% Damping)

FINITE ELEMENT MODELING

The piping is modeled as pipe elements using CAESAR code. The FEM model of piping is shown in Fig 3. The downcomer pipe of IHX, which is connected to the piping directly is also modeled as a pipe. The downcomer bottom end is welded to the inner dia of bottom tube sheet of IHX and the shroud shell is welded to the outer dia of the bottom tube sheet of IHX. All degrees of freedom(DOF) are connected between the downcomer pipe bottom end and the shroud shell bottom end in the model. The shroud shell is fixed at the reactor vault. The SSP is also modeled as a pipe with adjusted density taking into consideration the total mass. Piping is connected to the suction nozzle of the SSP.

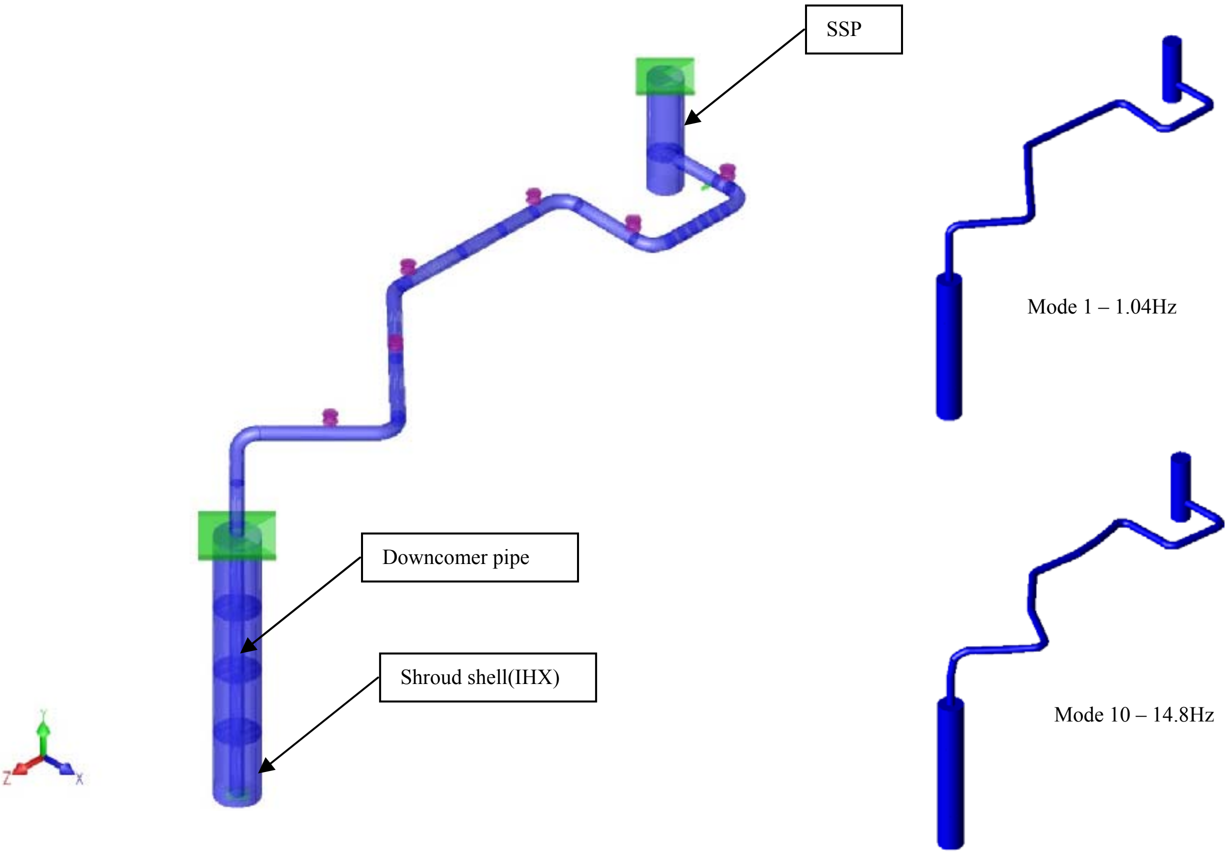

Fig.3 – Finite Element Model(Translucent image to show the inner Downcomer pipe) for Pump to IHX line and significant mode shapes

RESPONSE ANALYSIS

Seismic analysis of Pump to IHX line is carried out using FE code CAESAR by independent support motion method. Generally piping is supported at different levels. The response of the piping constitutes two different parts viz. inertial components and pseudo-ststic components due to the differential support movement. Inertial components is computed by two steps viz. natural frequency analysis followed by response analysis. Towards this free vibration analysis has been carried out as a first step. Natural frequencies, mass participation and mode shapes have been extracted. Subsequently seismic analysis is carried out for both OBE and SSE and displacements & bending moments are extracted at the various locations of interest(restraints and hangers) and checked against the allowable limit. Stress intensities have been calculated using the equations shown in Design parameters and Design criteria section. The stress indices B_1, B_2' have been calculated as per ASME Sec III NC. Design check has been carried out for the different loading. The effect of seismic anchor movement is evaluated separately by performing series of static analysis for enforced support movement. The following summary gives the seismic analysis approach:

Method - Independent support motion method

Combination Methods[6] :

Modes - GROUP

Spatial - SRSS

Directional - SRSS
Seismic Anchor Movement - SRSS
Pseudo modes - SRSS

A few significant mode shapes associated with the natural vibration of Pump to IHX line are shown in Fig.3. The fundamental frequency of 1.05Hz occurs as a global bending mode of the piping. Some of the important natural frequencies are shown in Table 1. Table 2 gives the forces and moments for the suction nozzle of SSP. Table 3 shows design check. The location of snubbers added for meeting seismic requirements are shown in Fig.1. Snubbers are linear supports designed to limit unwanted sudden movements such as earthquake, but at the same time allow slow movements such as thermal expansion. Though the codal requirement for the piping is met without any restraints / snubbers, three snubbers have been added in order to bring down the forces and moments due to OBE&SSE on the pump nozzle.

Table.1: Natural frequencies

Mode No.	Natural Frequency [Hz]	Mode No.	Natural Frequency [Hz]
1	1.0	18	20.9
5	8.6	20	25.8
9	12.0	22	29.0
14	17.5	23	36.9

Table 2: Forces Acting at Pump suction nozzle

Description		Forces in N and Moments in Nm					
		Axial Force, P	Shear Force, V_1	Shear Force, V_2	Torsional Moment, T	Moment, M_1	Moment, M_2
PPCna 20-001 (Suction side)	OBE	9133	13450	6008	3273	15581	8570
	SSE	15451	23408	8531	5028	22071	14754

Table 3: Check for code compliance

Sl No.	Code Equation Number and Description	Service Level	Maximum Stress Intensity (MPa)	Node Number	Allowable Stress Intensity (MPa)	Remarks
1	NC-3654.2(b)(3) (Pr + SL + OBE)	C	147	970	216.3	Acceptable
2	NC-3654.2(b)(4) (OBESAM) EQ. 1 EQ. 2	 C C	 248 0.05	 920 920	 432.6 72.1	Acceptable
3	NC-3655.2(b)(3) (Pr + SL + SSE)	D	255	970	309	Acceptable
4	NC-3655.2(b)(4) (SSESAM) EQ. 1 EQ. 2	 D D	 368.1 0.07	 920 920	 618 103	Acceptable

CONCLUSION

The seismic analysis of Secondary sodium main system – SSP to IHX line is carried out. Analyses have been done for seismic loads including SAM. Seismic analyses have been done by Independent spectrum method. Natural frequencies are extracted and reported. Design check has been performed as per ASME Section III Div1 subsection NC. Though analyses results indicate that code compliance for seismic load is met without any snubbers, three snubbers have been added to bring down the forces and moments on the pump nozzle.

REFERENCES

[1] Secondary sodium main system, Support locations on Isometric Piping Layout for East Loop (SGB – 1), PFBR / 33140 / GA / 1117 / R-0.

[2] Intermediate Heat Exchanger – Assembly and details, PFBR/32130/GA/1100/Rev.2.

[3] Secondary Sodium Pump – General assembly, PFBR/33110/GA/1100/Rev.2.

[4] ASME Boiler and Pressure Vessel code Section III, Nuclear Power Plant Components, Division 1 NC (2001).

[5] P.Gopalakrishnan et al, *"Floor Response Spectra Generation for NIB-Vol. 1"*, PFBR/20000 / DN / 2010 / R – 3

[6] USNRC, *"Report of the U.S. Nuclear Regulatory Commission Piping Review Committee-Evaluation of other Dynamic Loads and Load Combinations"*, NUREG 1061 Vol.4, Dec.1984