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SEISMIC QUALIFICATION OF NUCLEAR EQUIPMENT

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SUMMARY

The present paper deals with seismic qualification of nuclear steam generator subjected to earthquake loading. One complete bank, comprising of steam generator, PHT pump and its motor, steam and feed water pipes, heavy water inlet and outlet pipes, and reactor inlet and outlet headers, has been considered for the analysis. Seismic loading has been taken in the form of response spectra. Variations in the resopnse on account of: a) multi-support vs. single support excitation, b) with and without floor flexibility, and c) including and excluding feeder pipes have been studied, and the outcome has been quantified and presented in this paper.

INTRODUCTION

Seismic qualification of nuclear equipment has become mandatory from safety considerations. Qualification requirements have become more stringent for primary equipment. Inadequacies of test facility on one hand and complexity of equipment on the other have led to achieving seismic qualification using analytical tools. Sophisticated computer codes, capable of handling large size problems, are being used frequently. The computed response of any system, thus, largely depends upon seismic input excitation, modelling, simulation of boundary conditions and interaction with other connected sub-systems. Modelling of large and complex equipment/systems requires a great deal of understanding of the physical behaviour of the system (Ref.1,2,3), and is helpful in attempting modifications to achieve the desired response in limited iterations. The design office approach to tackle any problem is, normally, different from that used by researchers in view of the tight schedules and production targets. Whereas an overdesign may impose penalty on cost and space envelope, the underdesign would mean inviting risk. It, therefore, becomes important for the designers to know the quantitative effect of various simplifications and assumptions made during modelling on the response of the system.

Various simplifications and assumptions are made during the modelling and analysis. In this paper, an attempt has been made to quantify this effect on the response of steam generator and the connected assemblies. Variations in the parameters, like a) single support excitation vs. multi-support excitation, and b) floor flexbility vs. rigid floor at the point of support, have been considered. In addition the effect of feeder pipes on the response of the system has also been discussed.

One bank comprising of steam generator, primary heat transport (PHT) pump and its motor, steam pipe, feed water pipe, heavy water inlet and outlet pipes, reactor inlet and outlet headers (RIH & ROH) and the bunch of associated feeder pipes, as shown in Fig.1 has been considered for the analysis. Steam generator is supported at boiler room floor as well as pump room floor. Support assemblies are different in different steam generator systems considered for the analysis. Heavy water inlet pipe connects reactor outlet header to steam generator whereas heavy water outlet pipe connects steam generator to primary heat transport pump which in turn is connected to reactor inlet header. Steam pipe is connected to the top of the steam generator, and feed water pipe is connected above the tube sheet. The feeder pipes connect the reactor to inlet and outlet headers.

MATHEMATICAL MODELLING AND ANALYSIS

Seismic qualification study of the system described above calls for modelling of the total assembly with the seismic input at appropriate boundaries. Tangent Pipe, Bend Pipe and Boundary elements have been used for modelling the system. Three steam generator and main PHT systems have been considered. Their supporting arrangements have been shown in Figs.2,3 and 4. Basic system model, although being same in all the three cases, differs mainly in the style of steam generator supporting arrangements described below :

Model 1 - Steam generator is supported on craddle (using spring assemblies, key and key ways) at boiler room floor as shown in Fig.2. Three snubbers, two transverse & one vertical, have been provided at pump room floor so as to permit thermal movement and to arrest motion due to seismic loads.

Model 2 - Steam generator is supported at tube sheet location by brackets which in turn are supported at pump room floor. Lateral restraints are provided by tie rods at boiler room floor as shown in Fig.3.

Model 3 - Steam generator is suspended from two cross beams through two bolts. The cross beams are in turn supported by concrete walls running vertically between pump room and boiler room floors. Lateral restraints are provided by tie rods both at boiler room floor as well as pump room floor as shown in Fig.4.

For model 1 the analysis has been carried out for the following cases:

1. a. using single support excitation (enveloping response spectrum).

   b. using multi-support excitation (different response spectrum at different support levels).

2. a. considering supporting floor as rigid.

   b. considering actual floor stiffness values.

3. a. including the effect of feeder pipe stiffnesses.

   b. excluding the effect of feeder pipe stiffnesses.

Model 2 and 3 have been analysed using multiple support excitation including actual floor stiffnesses to study the effect of supporting arrangement on the response.

RESULTS AND DISCUSSIONS

It is not feasible to present the complete results in this paper in view of space constraints. However, in order to understand and appreciate the influence of the considered parameters on the response, salient comparative results have been presented and discussed.

Single Support vs. Multi-support Excitations The results of analysis using both single support excitation and multi-support excitation for steam generator model 1 have been listed in Table 1 and Table 2. Actual stiffnesses of the supporting floor have been included.

Table 1 Snubber Forces for Single Support Excitation (SSE) and Multi-Support Excitation (MSE)

Snubber Location	Snubber Forces(T) SSE	MSE
SG Tubesheet - X	102	89
- Y	140	110
- Z	28	18
RIH	7	6
ROH	5	4
PHT Pump	56	41

Table 2 Deflections for Single Support Excitation (SSE) and Multi-Support Excitation (MSE)

Location	Deflections (mm) SSE	MSE
SG Top - X	5.1	4.0
- Y	3.3	2.9
SG Bottom - X	7.8	6.1
- Y	3.1	2.7
RIH - X	15.0	12.4
ROH - X	8.4	6.9
PHT Pump - X	9.1	6.0

It is observed that in case of the single support excitation, the snubber forces are higher by 15 to 50% than those of the multi-support excitation, while deflections are higher by 15 to 30%. Thus, the design based on results of single support excitation would result in higher sizes of the snubbers as well as their supporting sturctures, and higher stresses in the piping and other components. Use of single support excitation, therefore, leads to overdesign imposing penalty on cost and space envelope.

Floor Rigid vs. Actual Floor Stiffness Results of the analysis using multi-support excitation have been listed in Table 3 for rigid floor case and in Table 4 for the case considering actual stiffnesses of floor.

Table 3 Snubber Forces for Floor Rigid Case (FR) and Floor Actual Stiffness Case (FAS)

Snubber Location	Snubber Forces(T) FR	FAS
SG Tubesheet - X	16	89
- Y	19	110
- Z	5	18
RIH	3	6
ROH	2	4
PHT Pump	4	41

Table 2 Deflections for Floor Rigid Case (FR) and Floor Actual Stiffness Case (FAS)

Location	Deflections (mm) FR	FAS
SG Top - X	0.9	4.0
- Y	1.0	2.9
SG Bottom - X	0.1	6.1
- Y	0.1	2.7
RIH - X	0.1	12.4
ROH - X	5.2	6.9
PHT Pump - X	3.5	6.0

It is observed that for analysis corresponding to the case when supporting structure is considered fixed to the floor and the floor is treated to be rigid, the snubber forces are lower by 50 to 90% as compared to the case when actual stiffness properties of the supporting floors are accounted for. The deflections are also lower by 50 to 98%. It is obvious that discounting the effect of the supporting floor stiffness would lead to underdesign of the system and would obviously invite risk.

Including or Excluding Feeder Pipe Stiffness Consideration of complete feeder pipes approximately 600 in number will make the mathematical model prohibitive for analysis. Hence an attempt has been made to incorporate their effect as lumped stiffnesses on the respective headers. It may, however, be noted that the stiffness of a group of feeder pipes is relatively very low (in the range of 10 to 40 kg/mm). By comparing the result of the analyses for a) including the effect of feeder pipes as lumped stiffnesses, and b) excluding the effect of feeder pipes, it is observed that variations are local and limited to header response only (10 to 15%) whereas the effect on the response of steam generator is insignificant.

Variations on Account of Supporting Arrangement Model 1, 2 and 3 have been analysed using multi-support excitation including the effect of floor flexibility. The observations based on the results of the analyses are as follows:

Model 1 - 12 additional snubbers are required in steam pipe and feed water pipe to achive the desired response.

Model 2 - No snubber is needed.

Model 3 - Only one snubber is needed in steam line.

The deflections of steam generator for model 2 and 3 are lower compared to those for model 1. It is of intrest to note that for model 2 and 3, not only the deflectins are lower, even the snubber requirement has been minimised. It may be mentioned that the snubbers not only occupy precious space but their maintenance, being in the primary area, does pose a serious problem.

CONCLUSIONS AND RECOMMENDATIONS

1. Seismic response of steam generator system is dependent on layout to a large extent. The requirement of snubbers can be minimised by adopting appropriate supporting arrangement.

2. Floor stiffnesses, supporting the system, must be computed accurately and used in the analysis. Considering supporting floor as rigid leads to underdesign and hence not recommended.

3. It is preferred to carryout analysis using multi-support excitation as compared to single support excitation (enveloping spectra) in order to achieve space and cost effectiveness.

4. Involvement of seismic qualification engineer at the time of layout is recommended.

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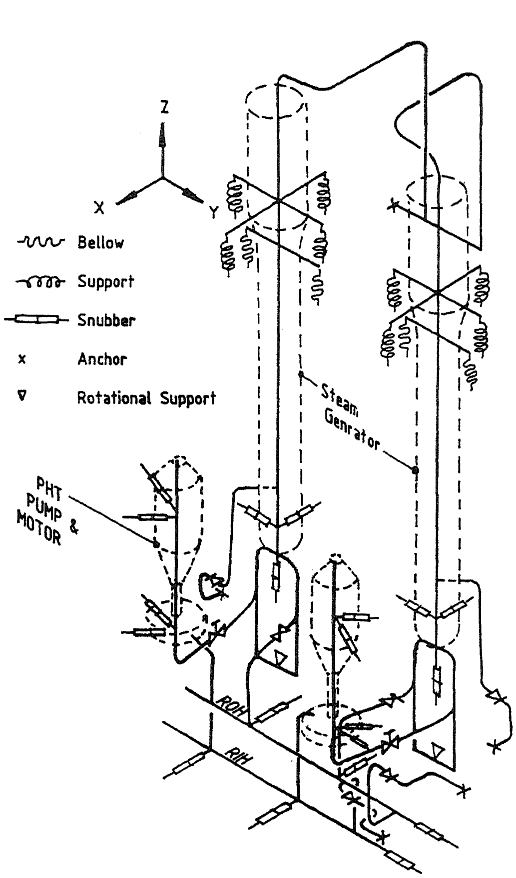


Fig. 1 One Bank of Main PHT System

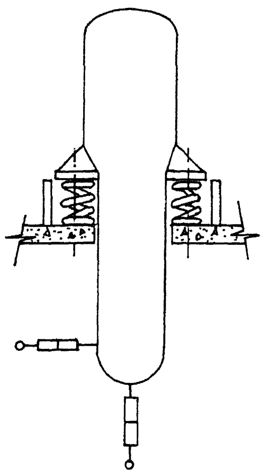
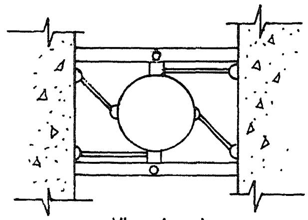


Fig. 2 Model 1 - Craddle Support



View A - A

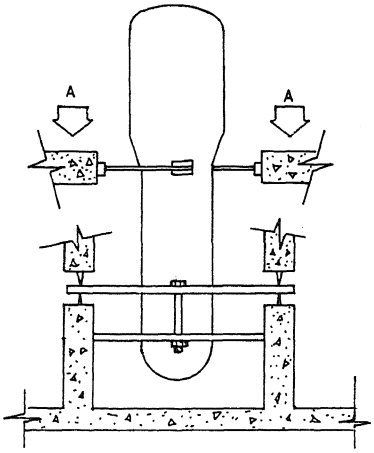
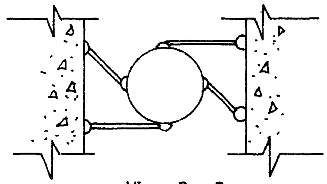


Fig. 4 Model 3 - Beam Support



View B - B

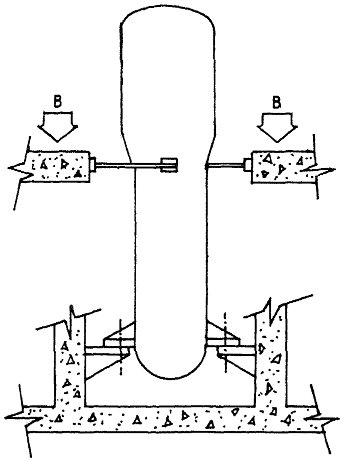


Fig. 3 Model 2 - Bracket Support