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Minimising seismic restraints and snubbers in the piping systems of indian PHWRs by using segmental approach

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ABSTRACT

Nuclear piping systems should survive during all the normal loading conditions as well as during the abnormal loadings such as the earthquake load. Piping systems of Indian Pressurised Heavy Water Reactors (PHWRs) are qualified using minimum seismic restraints and snubbers with the help of segmental approach. This paper gives a brief account of the approach alongwith an example.

INTRODUCTION

The PHWRs in India incorporate various safety features in their designs so as to improve the performance of the plants and the reliability of various systems and components. Piping engineering plays a key role in achieving these goals. This is because piping is one of the major components in such plants which has many diverse features in terms of their difference in sizes, layouts, importance from the point of view of safety etc. Safety related nuclear piping systems in these nuclear power plants are currently designed and evaluated using sophisticated analytical procedures wherein the main thrust is towards using minimum number of simple supports to cater for the various loads.

However, the various kinds of loadings to which these systems are subjected demand different types of supports at different locations. For example, thermal loading requires that the piping system shall be as flexible as possible and, hence, it should be kept free of restraints as far as possible. On the other hand, seismic loading demands for a stiff system so as to keep the system natural frequencies far away from the dominant frequencies of the seismic disturbance.

It is imperative that the supporting system so evolved should cater for both the kinds of loads described above in addition to the other normal loads. It is normally observed that meeting such conflicting requirements makes the life of piping designer miserable. This is so also on account of the site restrictions in locating the supports, provision of enough space around the major supports for their in-service inspection etc. The designer has to keep in mind that there is a need to minimise man-rem consumption during the in-service inspection and the maintenance works on the supports. One of the ways to achieve this is to use minimum number of seismic restraints and to avoid the use of snubbers as far as possible.

Snubbers usually require periodic in-service inspection giving rise to higher radiation doses to the plant personnel. In addition, they also lead to high stress situations for accommodating thermal loading in the event of their inadvertent locking. This, therefore, leads to a reduction in fatigue life of the system and in turn affects its reliability. Nuclear piping systems designed for Indian PHWRs take care of these situations through the use of good and safe engineering practices alongwith the use of segmental approach for their design and analysis.

VARIOUS DESIGN FEATURES OF PHWR PIPING SYSTEMS

The piping systems of PHWRs are categorised into various safety classes depending on their importance from the point of view of safety. The essence here is to have minimum radiological consequences from the various safety class pipings in the event of accidental situations like pipe rupture. Nuclear piping systems are normally classified as Safety Class-1, Safety Class-2 or Safety Class-3 based on the above criterion. As regards their seismic classification, all the three safety class pipings are designed for both the Safe Shutdown Earthquake (SSE) as well as the Operating Basis Earthquake (OBE). The design of these systems is then carried out using the applicable ASME codes keeping in mind the following objectives:

(1) The system should be designed and qualified in such a way that there are minimum design changes envisaged during the process of qualification with an aim to have reduction in the inventory of heavy water. Wherever such changes are contemplated, it should be possible to incorporate them within the available floor space.
(2) The system should be designed with minimum number of supports required for the various kinds of loadings so as to permit free thermal expansion of the piping as far as possible and also to locate supports in such a way that in-service inspection of the system is possible with minimum man-rem consumption.
(3) Operating stresses, due to pressure and thermal loadings, in the system should be kept as low as possible so as to improve the fatigue life of the system and hence the reliability of the system.
(4) In order to have a trouble free system, use of snubbers to accommodate the seismic loading should be avoided as far as possible. This also helps in reducing the thermal stresses developed in the piping system due to their inadvertent locking.
(5) Endeavour should be made to design the piping alongwith its supporting system in such a way that the loads imposed by the piping at various nozzle locations are within the limits as specified by the equipment manufacturer.

BASIS FOR SELECTION OF SUPPORTS

The general requirements of a good supporting system are:

(a) It should contain an optimum number of supports so as to enable the piping to meet the requirements of the design code.
(b) The supports should be simple to design, manufacture and erect.
(c) They should occupy minimum floor space and enable ease of inspection.

For the Safety Class-1 piping systems, these requirements have been met by adopting the design philosophy based on the following four key objectives:

(1) Limit the dead weight stresses in the piping to 0.6 Sm only, leaving a margin of 0.9 Sm for accommodating the seismic load as per para NB-3600 of ASME Code Section III, Division 1, Subsection NB [1]. Here Sm is the allowable stress intensity for the material.
(2) Limit the primary plus secondary stresses due to operating pressure and thermal loadings to 2.0 Sm as against 3.0 Sm as required by para NB-3600 under Service Level A condition. This ensures a better fatigue life for the system.
(3) Avoid the use of snubbers as far as possible.
(4) Use the Segmental Approach for the qualification of the system.

SEGMENTAL APPROACH FOR QUALIFICATION

Analysis of piping systems is usually carried out after preparing the mathematical model of the piping alongwith the various connected equipment. The piping engineer performs the analysis of the piping system by including all the interacting pipings in the same mathematical model. The purpose of this analysis is to evolve an optimal supporting system for the piping system and at the same time qualify it as per the design code. The process of evolving supports often requires many iterative computer runs because the supports for different loadings such as weight, thermal and seismic loadings are arrived at based on different considerations for each kind of load.

Many a times, the model becomes too big to perform iterative studies at the design stage. Hence, an alternative innovative approach called the "Segmental Approach" was evolved, wherein the entire piping system is divided into a suitable number of segments which can be analysed individually taking into account the interaction effects among the various segments. After the analysis of individual segments, they are assembled together to get the response of the entire piping. The method, thus, involves the following steps:

(a) Prepare a mathematical model of the integrated pipings and the associated equipment which can have interaction effects.
(b) Locate initially the dead weight supports on the integrated model based on sound engineering practice and physical understanding of the system. Try to locate the dead weight supports at the places where thermal expansion is very small so that they do not affect the free thermal movement of the system.
(c) Locate initial supports for accommodating the thermal load on the piping. Provide intermediate supports on long pipe runs to suitably distribute the axial expansion of the pipe run on either side.
(d) Divide the piping system into various segments at the locations where the stiffness of the system is relatively higher, for example, at anchors and supports or at any other points

where the stiffnesses can be estimated to be relatively higher between the adjacent segments. This is the most crucial step because it allows one to ignore the mass interaction effects from the adjacent segments. However, the stiffness interaction effects among the various segments are duly considered by evaluating the stiffness offered by the connected piping at the point of segmentation.

(e) Qualify each segment seperately using the stiffnesses offered by rest of the piping at the point of segmentation. Arrive at suitable location of supports for accommodating the various kinds of loads. Carry out suitable layout modifications, if required, for the qualification of the segment. As far as possible, the supports are decided in such a way that the major frequencies of each segment lie outside the amplified zone of the applicable floor response spectra.

(f) Assemble all the segments, with the various supports and the layout modifications as arrived at in step (e) above, to form the integrated model of the entire piping. Analyse the entire system using the integrated model for various loads and fine tune the supports, if required.

This approach has been found to be of great help in arriving at the optimum number of supports in two ways. Firstly, it reduces the time required for each iteration and thereby helps in performing enough number of iterations to arrive at an optimum supporting system. Secondly, as each iteration is performed on individual segments, it enhances the physical understanding of the behaviour of the system.

ILLUSTRATIVE CASE STUDY

Use of the approach described above has been illustrated here by citing the example of qualification of a portion of feed, relief and reflux lines alongwith the bleed condenser equipment for a typical 500 MWe PHWR. The piping system is categorised as Safety Class-1 and seismically, it is designed for both the SSE as well as OBE levels of earthquakes. This system is having pipe sizes varying between 75 mm to 150 mm and the total length of the system is around 93 m. The pipings are connected to the bleed condenser equipment at one end. This equipment, which has a weight of 37T and a height of 7.8 m, has also been modelled in a simplified manner due to its interaction effects with the connected piping. Fig.1 shows the integrated model of the system where at locations L and O anchors have been assumed with prescribed equipment expansions. This system has been divided into four segments A, B, C and D as shown in Figs.2 - 5. Before dividing the system into various segments, the integrated system was analysed for dead weight and thermal loads. An anchor was provided on the long relief line at location M (Fig.1) to distribute the thermal expansion on either sides of the run.

Each segment has been analysed, in detail, with the stiffnesses from the connected piping using the computer code SAP-IV [2]. Mass lumping has been carried out in such a way that all the modes of vibration upto 33 Hz get excited [3]. Envelope of the support point spectra (Fig.6) at various levels has been used for this analysis [4]. Typical spectra for one of the directions for SSE is shown in Fig.6. The damping values used for this analysis are as per ASME Code [4]. Spatial and modal combinations have been performed as per RG 1.92 [5]. Wherever required, stiffness of hydraulic snubbers has been incorporated into the model from the manufacturer's catalogue [6]. Stress combinations for the piping have been performed as per para NB-3600 wherein OBE has been considered in Service Level B and SSE in Service Level C.

Subsequent to the analysis of individual segments, they have been assembled together, alongwith the supports of each segment, to form the integrated model as shown in Fig.1. The integrated model was then analysed with these information and it was observed that the supports arrived at during the qualification of individual segments are adequate to qualify the entire system in totality. This, thus, confirmed the assumption that if the piping system has been segmented properly, the mass interaction effects from the connected piping are negligible. Table-1 shows the major frequencies and mass participations for the integrated system. The maximum stresses under various service levels are shown in Table-2 [7]. A summary of various kinds of supports used is shown in Table-3. The table also shows a comparison of average support spacing, required to accommodate all the loads, with the average support spacing as specified by ASME Code Section III, Subsection NF [8] for only the weight loading.

CONCLUSIONS

The broad methodology for arriving at the supporting system for the PHWR piping systems has been outlined in this paper alongwith an example. It can be observed that for the sample piping system, a total of 28 supports (including 3 snubbers) with an average support spacing of 4.3 m have been used for accommodating all the loadings as against an average support spacing of 3.6 m for dead weight alone as specified by ASME Code. The approach described above, thus, helps in reducing the number of seismic restraints and the snubbers.

REFERENCES

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3. Lin J.K., Molin A.T., On Mass Lumping technique for seismic analysis of piping systems.

4. *ASME Code Section III, Appendix - N*, 1995.

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6. *Paul - Munroe / Remco catalogue*, Pipe support snubbers.

7. Soni R.S. et al., Stress qualification of Feed, Relief, Reflux and regenerative cooler outlet lines alongwith the bleed condenser equipment, *Report BARC/1995/E/010.*

8. *ASME Code Section III, Div.1, Subsection NF*, 1995

Table-1: List of Major Frequencies for the Sample Piping

Mode	Frequency (Hz)	% Mass Participation X	Y	Z
1	8.636	0.	0.036	0.211
3	9.068	1.558	80.856	0.015
4	9.298	81.883	1.521	0.
13	14.450	0.048	1.728	0.002
18	17.470	0.249	0.159	3.152
27	22.680	0.168	0.951	0.005
29	24.570	0.011	0.	87.817
30	25.140	4.768	2.918	0.024
32	25.920	3.120	4.017	0.005
40	32.890	0.026	0.054	0.013
Cumulative Participation		94.128	96.631	93.728

Table-2: Maximum Stresses during various Service Levels

Service Condition	Element No.	ASME Eq.	Stress
Design Condition	118	9	0.77 Sm
Service Level-A	110	10	1.97 Sm
Service Level-B	136	10	2.31 Sm
Service Level-C	118	9	0.79 Sm

Table-3: Details of Supports Required for the Sample Piping

Item	Pipe Size (mm) 75	100	150	Total
Length of piping (M)	33.6	38	21	92.6
<u>supports required</u>				
Translational	3	3	4	10
Guides	6	5	1	12
Anchors	2	1	0	3
Snubbers	1	2	0	3
Total No. of supports	12	11	5	28
Average support spacing for accommodating all the loads	2.8	3.8	4.2	3.6
Average support spacing for dead weight alone as per ASME III, Subsection NF	3.6	4.2	5.1	4.3

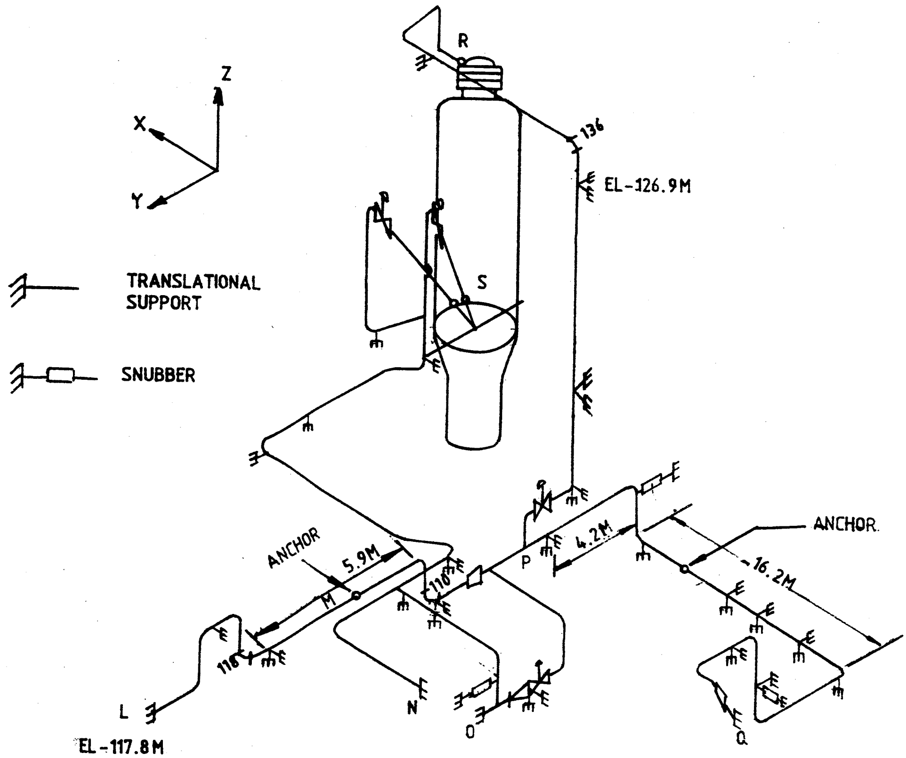

FIG.1.0 : SAMPLE PIPING ANALYSIS

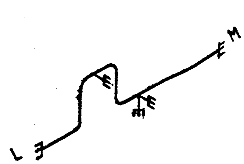

FIG. 2.0 : SEGMENT-A ANALYSIS

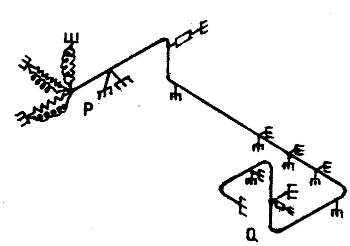

FIG. 3.0 : SEGMENT- B ANALYSIS

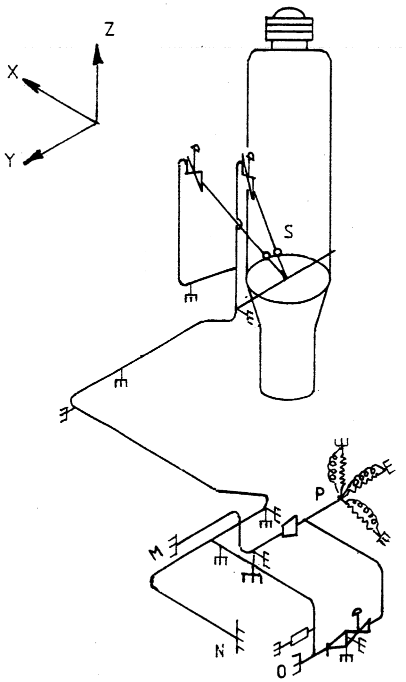

FIG.4.0 : SEGMENT-C ANALYSIS

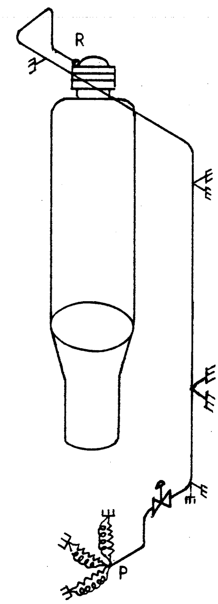

FIG.5·0 : SEGMENT-D ANALYSIS

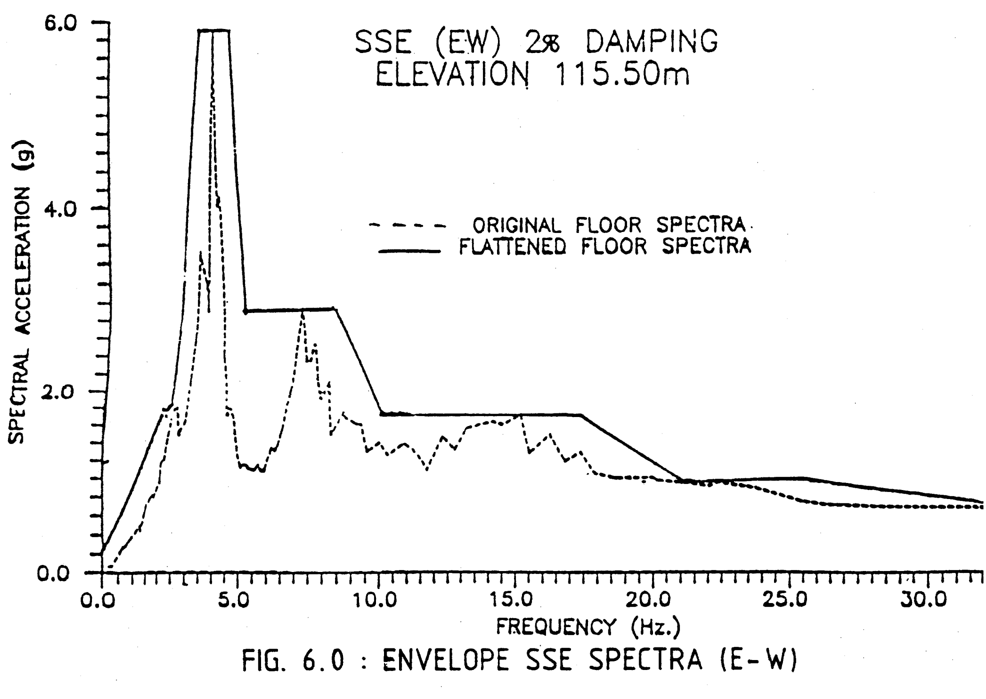

FIG. 6.0 : ENVELOPE SSE SPECTRA (E-W)