Coupled Seismic Analysis of a Pressurized Heavy Water Reactor Building

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ABSTRACT

The conventional approach for the design of various equipments is to use the applicable floor response spectra generated from the reactor building model wherein the equipments are not modelled alongwith the civil structure. However, for major heavy equipments like primary steam generators, primary heat transport pumps, pressuriser, calandria-end shield assembly etc. of a PHWR, this may not be adequate as these equipments affect the response of primary structure and vice versa. A coupled analysis has been, therefore, carried out to get a more realistic picture of stresses at the equipment supports. Effects of coupling/decoupling these equipments with reactor building have been studied and the results have been compared.

INTRODUCTION

Nuclear plant facilities are safety related structures which are designed to resist all the kinds of postulated loadings. The last three decades have witnessed an accelerated growth in our understanding of the response of structures and equipments to earthquake motions. The state-of-the-art of the aseismic design of structures and components has been changing very rapidly. Sound and safe design of safety related equipments and systems has significant influence in achieving the overall safety of the plant.

The functioning of mechanical and other equipments during and after an earthquake may not only be necessary to avoid catastrophic consequences but also to guarantee the safe shutdown in the event of a maximum credible earthquake. With this in view, bulk of research as on today has been directed towards the safe design of secondary systems.

In the seismic analysis of nuclear facilities, it is common practice to decouple the secondary system from the primary structure (Ref.1). This decoupled model is then used to generate floor response spectra which in turn are used for the subsequent analysis of secondary systems. Design of secondary systems is then carried out preferably in a manner to avoid the dominant spectral peak of the floor response spectrum. The designer at this stage must recognise the decisions that went into the generation of equipment support motions so as not to design his equipment in an overly conservative fashion. This is because the motion of the support point of any equipment is highly controlled by the filtering effects of the structure. Thus the trade off is between more engineering or overdesign. This aspect of the problem should be pursued more vigourously.

In many instances, although the modal behaviour of the structure may remain unchanged, however, the retroaction effect of the equipment is such as to modify the amplification ratio from the structure to the equipment. In other cases, the modal behaviour of structure itself is changed due to the retroaction effects of heavy equipments. Hence, the dynamic interaction between primary and secondary systems is an important consideration in the design of secondary systems. Extreme reduction in response of the secondary system may result from tuning and hence feedback between the two systems. The extent of this feedback depends on the mass ratio and frequency ratio of equipment & supporting structure. This problem of heavy interaction and dynamic feedback has been addressed by means of a coupled analysis in the present paper. This kind of analysis is more important particularly for the cases when the design of secondary systems becomes a difficult task through the use of floor response spectra broadened in accordance with USNRC guidelines and also in the cases where the problem is of a multi-support excitation in nature.

MATHEMATICAL MODELLING

The conventional approach for the seismic analysis of important safety related structures like the reactor building is to use a lumped mass beam model which gives conservative results. In this approach, various equipments are treated as rigid masses attached to the primary structure. This assumption may, however, be inadequate if there is a dynamic interaction between the equipment and the reactor building. In order to evaluate the effect of this interaction on the equipment response as well as the building response, a mathematical model which incorporates the modelling of equipments is required to be analysed as per the USNRC gudelines (Ref.1). Such a model is called the "Coupled Model" in the sense that the modelling of equipments also is done alongwith the reactor building.

Moreover, when the equipment is connected to the primary system at more than one point, the development of a simple decoupling criteria becomes difficult. This is because for the multiply supported equipments, the important consideration is rather the absolute stiffness characteristics of the secondary system irrespective of its mass ratio. If the stiffness of secondary system is relatively large, then the primary structure would be restrained from distorting freely and more importantly the multiple support excitations to the decoupled subsystem could induce unacceptably high stresses by imposing a displacement pattern to the subsystem that would not be compatible with its stiffness characteristics. To overcome this difficulty, major multiply supported equipments such as primary steam generators, primary heat transport pumps and calandria-end shield assembly have been coupled with the reactor building model as shown in Fig.1.0.

The reactor building of a typical 500 MWe PHWR has been represented by four lumped mass cantilever structures resting on the top of raft. Details of modelling regarding the primary structure are explained in Ref.2. Sufficient number of modes have been taken for vibration in each direction not only from the point of view of achieving the convergence in the response of primary structure, but also to have a positive assurance that all the equipment frequencies upto 33 Hz are excited.

There are four primary steam generators housed in concrete boxes and supported near EL-130.0M floor and EL-115.5M floor. Each steam generator weighs around 245 Tons. Modelling of all the S.G's was carried out through the use of a single lumped mass beam. Decision regarding this kind of modelling was arrived at by conducting a separate 3-D dynamic analysis of two steamn generators and the S.G box(Ref.3). This model accounts for the exact supporting arrangement of steam generators. Stiffness effects due to tie rods and S.G. supporting beams have been modelled through the use of equivalent spring elements.

The four PHT pumps which are supported at EL-115.5M floor have also been modelled by a single lumped mass beam. The snubbers near the C.G. of pump and their bottom supports have been modelled adequately through the use of spring elements in a manner so as to preserve their dynamic characteristics.The piping connecting the pumps and steam generators has been modelled through the use of appropriate truss elements which was decided based on a separate study of dynamic interaction between pumps and S.G's through piping. The pressuriser which is resting on EL-115.5M floor has been represnted as a cantilever structure.

The calandria-end shield assembly is housed in the calandria vault. There is one end shield on either side of the calandria equipment. Each end shield is supported on annular diaphragm plates which in turn are grouted to the concrete. The calandria equipment is located by means of four key assemblies at its center (Fig2.0). This assembly is flexible for vibration in N-S direction while it is rigid for vibration in E-W & vertical directions and therefore it is treated as rigid mass in the later cases. For N-S direction, it has been represented as a set of spring-mass systems in order to account for its mass and stiffness distribution along the height. Effect of added mass due to light water outside the calandria equipment has been duly taken care of. The stiffness of spring mass system has been found out by evaluating the equivalent stiffness of diaphragm plates, calandria annular plates and calandria keys. Stiffnesses of these components were evaluated from separate static analyses.

METHOD OF ANALYSIS AND RESULTS

The analysis has been carried out using three different approaches viz. response spectrum analysis using coupled model, time history analysis using coupled model and the analysis of equipments using applicable floor response spectra generated from the decoupled analysis of reactor building. Computer code SAP-IV (Ref.4) has been used for the analysis. Response spectrum analysis was carried out for 6.5% damping ground motion spectrum. The time history analysis was carried for three independent ground motion time histories. Analysis of equipments using the applicable floor response spectra was carried out after suitably broadening the floor spectra as per the USNRC guidelines (Ref.5). In all the analyses, the damping characteristics of primary structure as well as the equipments have been duly accounted for by evaluating the energy based equivalent modal damping.

Results of these analyses are as depicted in Tables 1.0 and 2.0. Table 3.0 compares the response of civil structure for the response spectrum method and the three time history analyses.

CONCLUSIONS

The study conducted herein demonstrates a striking reduction in the equipment support forces for the case of coupled analysis as compared to their design based on floor response spectra. This is because of dynamic feedback between the primary and secondary systems. The extent of this reduction in response increases with increasing mass ratio and for frequency ratio approaching unity. Intuitively this can be explained as follows: in the case of coupled analysis, each structural frequency is surrounded by a number of equipment frequencies and as a result the vibration energy in the coupled system is dispersed over a band of frequencies rather than being concentrated at the structural frequency only. This, therefore, gives rise to a reduced amplifying effect to the floor motions which helps in reducing the equipment response.

This also suggests that the floor response spectra generated for simple and highly idealised models of primary structures are overly conservative particularly after such FRS are peak broadened in accordance with the USNRC requirements. Admittedly, the database on which the conclusions are derived is limited. Hence, it is conceivable that a number of such exercises are required for better understanding of the dynamic interaction between primary and secondary systems.

REFERENCES:

1. USNRC Standard Review Plan 3.7.2, Seismic System Analysis, 1981.
2. R.S.Soni, G.R.Reddy, H.S.Kushwaha, A.Kakodkar, et al., "Seismic Analysis of 500 MWe PHWR Building under Horizontal and Vertical Ground Motions", BARC-1345, 1986.
3. A. Neelwarne, R.S.Soni, H.S.Kushwaha, A.Kakodkar, "Modelling of Steam Generators of 500 MWe PHWR for Coupled Analysis", Internal Report.
4. SAP-IV: Structural Analysis Program-IV, Bathe, K.J & Wilson.
5. USNRC Guide 1.122, Development of Floor Design Response Spectra for Seismic Design of Floor Supported Equipments.

Table 1.0: Free Vibration Parameters (N-S Direction)

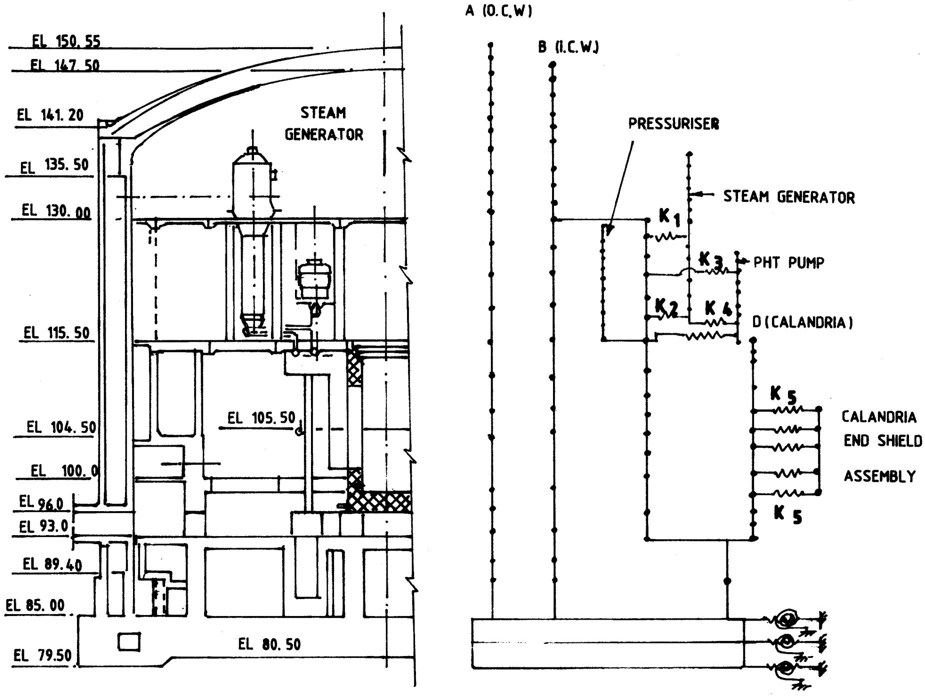
Mode	Frequency (Hz)	Modal Damping,%	Mode	Frequency (Hz)	Modal Damping,%
1	3.88	5.90	11	13.50	5.13
2	4.66	7.05	12	14.94	7.81
3	5.75	7.08	13	19.82	5.05
4	6.46	6.43	14	20.38	6.82
5	8.61	3.04	15	22.25	7.26
6	9.66	3.85	16	22.71	4.70
7	9.82	4.42	17	25.61	3.51
8	10.22	5.35	18	26.32	3.96
9	11.43	3.34	19	27.17	7.90
10	12.83	7.31	20	27.90	7.95

Table 2.0: Comparison of Forces at Equipment Supports (N-S)

Method of Analysis	Force in K1 (T)	Force in K2 (T)	Force in K3 (T)	Force in K4 (T)	Force in K5 (T)	Base Shear Pressu.
Coupled RS Analys	670	248	261	93	1150	226
Coupled TH Anal#1	669	264	228	61	735	119
Coupled TH Anal#2	621	209	222	50	774	122
Coupled TH Anal#3	630	218	204	53	791	111
Decoupled F.R.S.Anal	480	440	300	120	1363	128

Table 3.0: Comparison of Response in Primary Structure (N-S)

Method of Analysis	Total Base Shear (T)	Total Base Moment (T-M)
Coupled RS Anal.	31210	1165700
Coupled TH Anal# 1	35610	1179400
Coupled TH Anal# 2	35100	1218690
Coupled TH Anal# 3	35503	1257750



HALF SECTION OF REACTOR BUILDING

MATHEMATICAL MODEL FOR COUPLED ANALYSIS

FIG. 1 MATHEMATICAL MODEL OF REACTOR BUILDING FOR COUPLED ANALYSIS

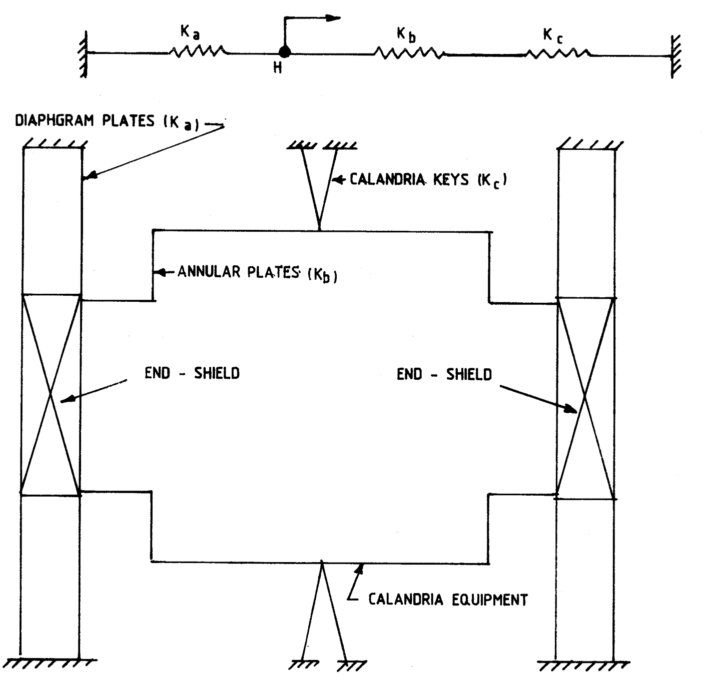


FIG. 2 SCHEMATIC DIAGRAM OF CALANDRIA-END SHIELD ASSEMBLY