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Evaluation of Coupling Effects between Primary and Secondary System by Seismic Analysis

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1. Introduction

Base isolation is used as a seismic protective system in the design of next generation nuclear power plants. Nuclear structures, secondary systems and components must remain undamaged in the event of safe shutdown earthquake (SSE) shaking. Earthquake shaking associated with the SSE will result in high seismic response demands in the stiff nuclear power plant (NPP) structural systems and extremely high demands on the safety-related secondary systems like pipelines. Seismic isolation of nuclear structures or primary systems can substantially mitigate these high demands on primary structural components and main piping systems, by reducing the natural frequency of the NPP. Lot of studies have been conducted on base isolation as a seismic protective measure to structures. There are four applications of base isolation to NPPs in France and another two in South Africa [1,2]. All the previous studies showed significant reductions in the seismic response of secondary systems through the use of properly designed seismic isolation systems [1,2]. This paper presents the results of coupled and decoupled analysis of piping systems connected between a base isolated nuclear reactor and an auxiliary building which shares a common base mat, with a conventionally constructed turbine building. The coupled and decoupled models are analyzed for safe shutdown earthquakes. Seismic responses of main steam pipelines connected between a seismically isolated reactor building and conventional turbine building are established.

2. Seismic Analysis of Coupled and Decoupled Systems

The steam pipeline is connected at one end to the steam generator in the containment building and the other end to the turbine in the turbine building. The pipeline is supported in between by the auxiliary building. The containment building has prestressed cylindrical wall and hemispherical dome concrete structure. The containment building is surrounded by auxiliary building. Both the containment building and auxiliary buildings are seismically isolated. The auxiliary building usually has four quadrants. The turbine building is a conventional steel structure with reinforced concrete turbine pedestal.

A lumped-mass stick model of APR1400 reactor building is used for the seismic analysis. The reactor building model is composed of sticks representing the containment building structure and the internal structures including the primary and secondary shield wall, in-containment refueling water storage tank (IRWST) and reactor coolant system (RCS). The total height of the containment structure is 77.19m and the natural frequency of its first mode is 3.84Hz. The other stick represents the auxiliary building and the natural frequency of its first mode is 6.29Hz. The two sticks are structurally independent and are connected only at the base. The mass of the NPP reactor building is approximately 69,564,287kg. The coupled model of APR1400 main steam pipeline system and considered nodal points are shown in Fig. 1

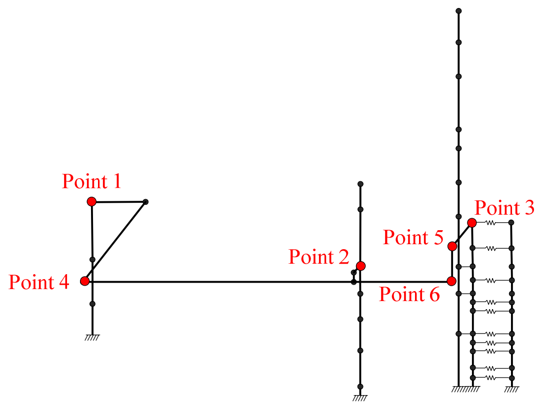


Fig. 1. The coupled model of APR1400 main steam pipeline system and considered nodal points

The numerical models include representations of bearings. Linear elements are used for the bearings. Natural frequency and damping ratio are 0.5Hz and 10%.

A lumped mass stick model, whose first two natural frequencies are 1.34 and 1.69Hz, is used to model the turbine building[3]. The pipelines are assumed to be connected to the concrete pedestal. The roof of the turbine building is not considered, since the basic aim is to study the effect of seismic loading on pipelines. The pipelines are modeled as steel pipes having 813mm outer diameter and 12.7mm thickness. The steam pipe line connects the steam generators which are rigidly fixed to the primary and secondary shield walls. The pipeline passes through the auxiliary building to the turbine building, where it is fixed to the turbine.

Artificial earthquake ground motions which comply with the design ground response spectra (DGRS) requirements of USNRC RG. 1.60 [4] and SRP. 3.7.1 [5] are generated. Envelope function of artificial earthquake complies with the ASCE 4-98 [6] standards. The duration of strong ground motion is 13sec which satisfies the requirements of SRP. 3.7.1[5] and the total time duration is 24sec. The peak ground acceleration is 0.3g and the time step is 0.01sec.

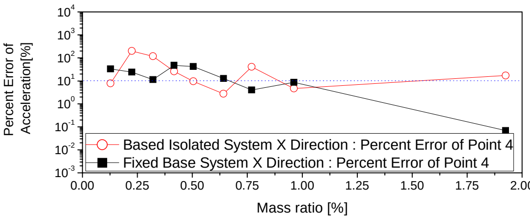
Time history analysis is conducted on the pipeline structure coupled with the nuclear building and the turbine building. The analysis is repeated for the decoupled model of the pipeline using the input accelerations generated at the appropriate levels. The results of both coupled and decoupled analysis are compared.

3. Comparison of Results of Coupled/Uncoupled Model

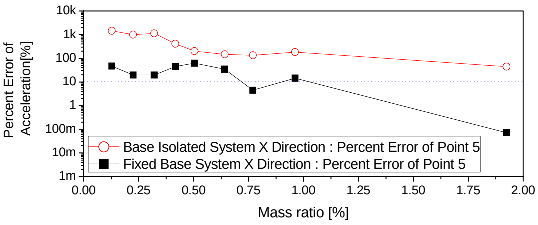
o find out the difference of the response of coupled model and that of uncoupled model, in this paper, percent error like expression (1) was used. Here, $R_{coupled}$ and $R_{uncoupled}$ represent the maximum value of the response of coupled system and that of uncoupled system.

$$\text{Percent error} = \frac{\left[\left|R_{coupled}\right|_{\max} - \left|R_{uncoupled}\right|_{\max} \right]^2}{\left|R_{coupled}\right|_{\max}^{2}} \quad (1)$$

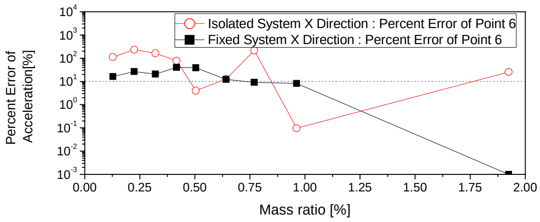
The results of analysis of seismic response for horizontal direction indicated that in case secondary system which has two or more supporting points like the main steam pipeline of Fig. 1 is linked with primary system, the acceleration response error of the coupled/uncoupled system of fixed based model is smaller than base isolated model. Fig.2 shows the comparison of the percentage errors of the maximum acceleration responses of coupled system and uncoupled system of each analysis model.



(a) Point 4



(b) Point 5



(c) Point 6

Fig. 2. Comparison of percent error of peak acceleration response in longitudinal direction

The figure indicates that in case of maximum displacement response, in based isolated model, the error of longitudinal direction is smaller. However, in case of transverse direction, both fixed base model and base isolated model have shown significant error. The errors of maximum acceleration response and maximum displacement response were similar to the mass ratio of primary system and secondary system or did not show any particular trend.

4. Conclusions

The steam piping system, containment building, auxiliary building and turbine building of next generation nuclear power plant APR1400 is modeled using lumped stick model. The properties of base isolation using linear elements are included in the models of base isolated containment building and auxiliary building. Coupled and decoupled seismic analyses are conducted.

As a result of seismic response analysis, the errors of maximum acceleration responses differ between longitudinal direction and transverse direction, and in fixed based model, the lower mass ratio, the smaller response error. However, in based isolated model, response difference is significant between coupled and uncouple models.

In case of maximum displacement response, both fixed base model and base isolated model showed significant error for transverse direction. Therefore, it is estimated that for highly reliable analysis of seismic response, coupling should be considered.

ACKNOWLEDGMENT

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