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Vertical Seismic Responses of Seismically Isolated APR1400 Structures supported by Laminated Rubber Bearings

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1. Introduction

The low horizontal shear stiffness of the isolator bearing is, typically, accompanied by large lateral displacements in the seismically isolated system. These large lateral displacements might lead to reductions in the vertical stiffness of the elastomeric or lead–rubber bearing (LRB). This paper summarizes the analytical study results performed with APR1400 model isolated with LRBs aimed at investigating the influence of vertical ground motion.

Three types of earthquake motions are used as input motion. Floor response spectra are computed at the specific points of the structure to compare the vertical responses of seismically isolated structure to those of fixed base structure.

2. Vertical Stiffness of LRB

The vertical stiffness formulation is based on the total vertical displacement, that is, the vertical displacement due to the applied compressive load. Effective vertical stiffness of LRB can be computed by summation of compressive stiffness of rubber and lead as follows

$$K_v = K_{vr} + K_{vl} = \frac{E_c A_r}{t_r} + \frac{E_l A_l}{h_l} \quad (1)$$

where, K_{vr} = stiffness of rubber; K_{vl} = stiffness of lead; E_c = compression modulus of rubber, $A_r = \pi D^2/4$ rubber area; t_r = total thickness of rubber; E_l = elastic modulus of lead, A_l = lead area; and h_l = height of lead.

3. Seismic Analysis

3.1 Analytical Model

APR1400 structure is represented by equivalent beam stick and lumped masses. The foundation mat is modeled by solid elements. The model was designed as supported by 454 LRBs. Fig. 1 shows the analytical model. The analytical model was constructed by using SAP2000 of finite element computer program.

The horizontal and vertical stiffnesses of LRB were expressed by a bi-linear model and a linear model, respectively. It is assumed that the yield stress of lead is 10MPa and compressive pressure of each isolator is 5MPa. Four different models were constructed in accordance with the different horizontal natural period of the system. Table I shows the parameters for the different models. In the table, the period means a target fundamental modal period of the structure in horizontal. Symbols shown in the table indicate stiffness parameters of the isolator model shown in Fig. 2 and equation (1).

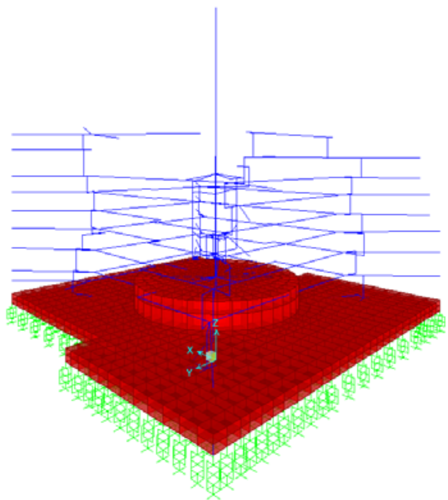


Fig. 1. Analytical model

Table I: Design Parameters for Isolators

	Model 1	Model 2	Model 3	Model 4
Period(sec)	1.5	2.0	2.5	3.0
k_1(kN/mm)	120.951	68.544	43.499	30.631
k_2(kN/mm)	12.095	6.854	4.350	3.063
Q_d(kN)	745	560	445	373
F_y(kN)	847	617	478	429
δ_y(mm)	7	9	11	14
δ_m(mm)	124	165	207	248
k_{eff}(kN/mm)	18.098	10.238	6.500	4.567
k_v(kN/mm)	24885.1	14864.7	9952.7	7173.4
E_c(MPa)	0.77	0.6	0.45	0.39
Shape factor, S_1	20	20	20	20
t_r(mm)	128	176	208	256
D(mm)	1600	1600	1600	1600

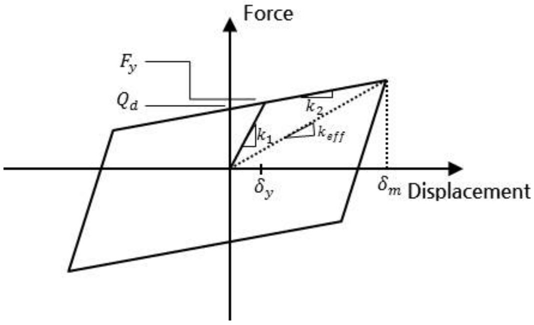


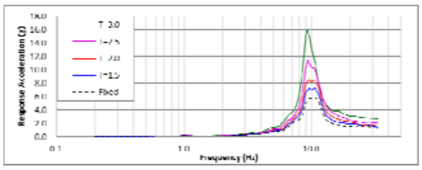
Fig. 2. Force-displacement relationship of bi-linear model

3.2 Input Motion

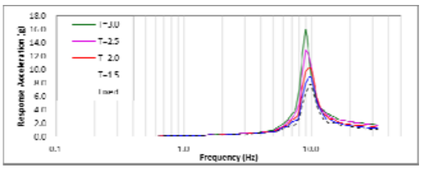
For the time history analysis, two earthquake records and one artificial earthquake were used as input motions. El Centro earthquake and Bam earthquake were selected as real earthquake motions. In addition, a set of artificial earthquake was generated synthetically to be consistent with design response spectra. Three directional motions were concurrently input. The input motions are scaled to have 0.5g and 0.33g of peak ground acceleration in horizontal and in vertical, respectively.

3.3 Seismic Responses

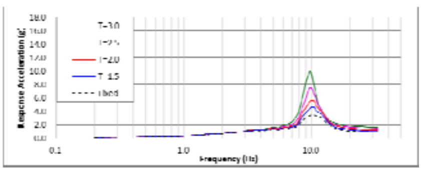
The seismic responses were obtained through nonlinear time history analyses by using Newmark's direct integration method with $\gamma = 0.5$ and $\beta = 0.25$.



(a) Bam Earthquake



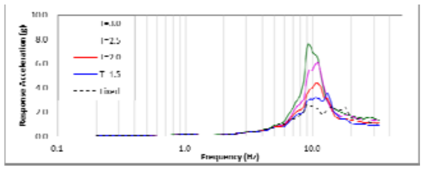
(b) El Centro Earthquake



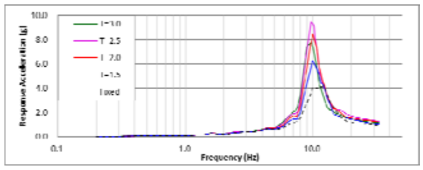
(c) Random Earthquake

Fig. 3. FRS at the location of Polar Crane

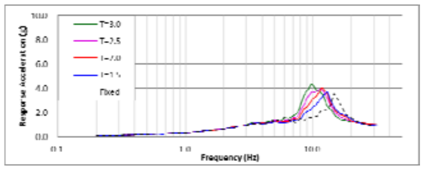
Fig. 3 and Fig. 4 show the vertical floor response spectra (FRS) obtained from seismic analyses at the specific points in containment building and control building. The figures show that the seismic responses of the isolated models are larger than that of fixed base model. Longer horizontal period yields lager vertical response.



(a) Bam Earthquake



(b) El Centro Earthquake



(c) Random Earthquake

Fig. 4. FRS at the location of Control Room

4. Conclusions

The vertical responses of seismically isolated structure with LRBs might be increased than in the fixed base structure. This fact should be considered in the design stage. The vertical stiffness of the LRB should be reasonably estimated to design a seismically isolated nuclear structure.

Acknowledgements

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