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Effect of Variation in the Stiffness of Lead Rubber Bearing on Seismic Response of Base-Isolated NPP Structures

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1. Introduction

In the nuclear power plants (NPPs), the base isolators can be used to effectively decrease the seismic force (acceleration, shear force, floor response spectra) except the displacement.

The mechanical properties for the lead rubber bearing (LRB) can be changed by age-related degradation and temperature. And the variation for LRB occurred by manufacture and construction. The seismic behavior of upper structure in a base isolated structure can be different by the variation. Especially a rotation of structure can be occurred by difference between stiffness center of isolator and mass center of upper structure. For this reason, the seismic behavior of isolated structure has an effect on the variation of isolator. Therefore it is needed to check the accidental displacement for the isolated structure due to variation in the stiffness of isolator.

The purpose of this study is to investigate the seismic behavior of NPP structure considering the variation for ensuring the stability of isolated structure.

The seismic behavior for the NPPs with variation of LRB was investigated by performing a time history analysis.

2. Variation of base isolator

The variation of isolator is closely related to the change of property such as horizontal stiffness, vertical stiffness and characteristic load.

The variation of isolator is generally occurred by the manufacture phase, construction phase, aging and temperature. When the variation of isolator is high the additional displacement of structure can occur therefore the variation of isolator should be controlled. The variation by aging can be decreased by replacing the degraded isolator.

The analysis of the isolated structure should address variations in the mechanical properties of the different materials used in the isolated structure [1].

According to the ASCE-4 [2], it was suggested that the mechanical properties of isolators should not change by more than 20% over 50~100year period in the range 4℃~26℃ to protect the additional displacement of isolated structure by the variation of isolators.

3. Input motion and analytical model

3.1 Input ground motion

As an input motion, two acceleration response spectra with different frequency contents were selected to evaluate the seismic response for the base isolated structure. NRC Reg. guide 1.60 [3] and the 1999 Chi-chi, Taiwan, earthquake were used as shown in Fig. 1.

The transversal component of earthquake exists with first component simultaneously. So the 3-dimmesional earthquake ground motion including the vertical component was applied in this study to consider the realistic ground motion.

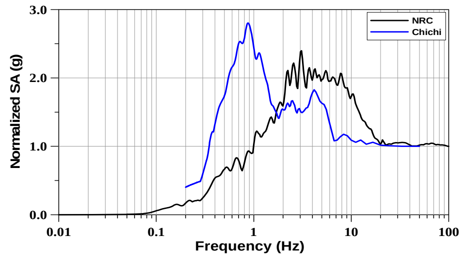


Fig. 1. Input spectral acceleration

3.2 Analytical model

The containment and auxiliary building of APR-1400 were chosen as an analytical model. For the seismic analysis, SAP2000 [4] was used. Two buildings are located in the same foundation as shown in Fig. 2(a). The structure model were represented by lumped-mass stick models for the seismic analysis. The mass of each floor includes the mass of walls, slabs, columns, and heavy equipment. The nuclear island and the mat foundation was modeled by solid element.

The 454 LRBs were modeled using the equivalent beam element. The total effective stiffness and effective damping ratio were to 34625.76kN/cm and 0.25, respectively.

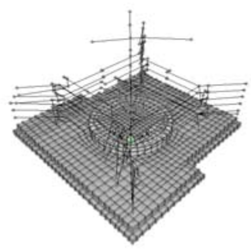
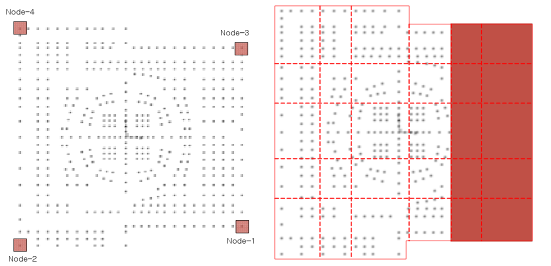
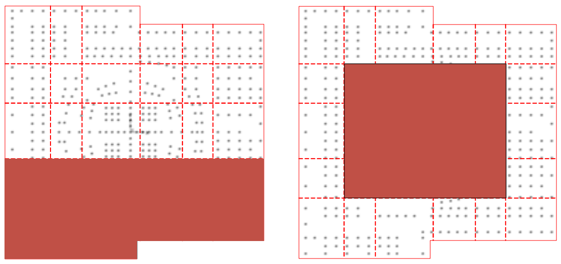


Fig. 2. Analytical model

In this study, the stability of isolated structure was evaluated assuming that the variation of property for the isolators had a different pattern. The example models were divided into four cases considering the severe pattern of variation for the LRB as shown in Fig. 3. It is represented that the horizontal stiffness of shade area is increased by 20% and the other area is decreased by 20%.



(a) Basic (b) Case -1



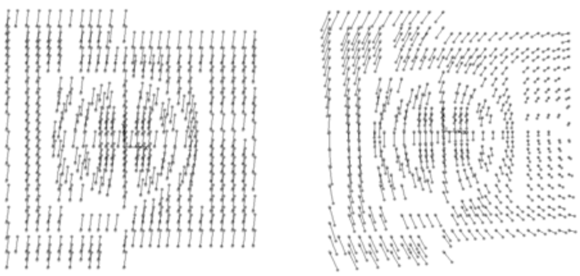
(c) Case -2 (d) Case -3

Fig. 3. Pattern of variation in mechanical property of LRB

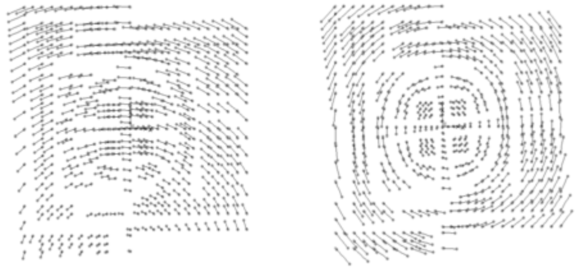
4. Seismic analysis considering variation of isolator

4.1 Eigenvalue analysis

The mode shape of example models represented figure 4. The 1st mode shape of basic model was the translation on the Y-axis. The 1st mode of ALT-1 and ALT-2 was the translation and rotation. The dominant mode of ALT-3 is rotation. It was observed that the mode shape of example model was changed by the eccentricity.



(a) Basic (0.4Hz) (b) Case -1 (0.37Hz)



(c) Case -2 (0.37Hz) (d) Case -3 (0.38Hz)

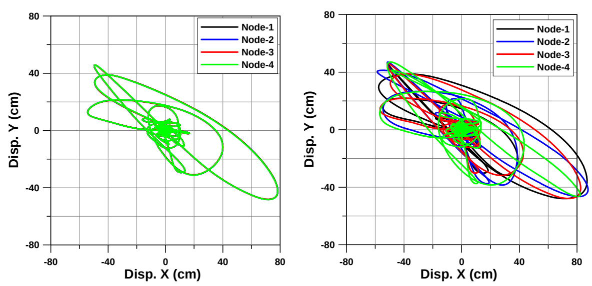
Fig. 4. Mode shape for the example models

4.2 Seismic responses

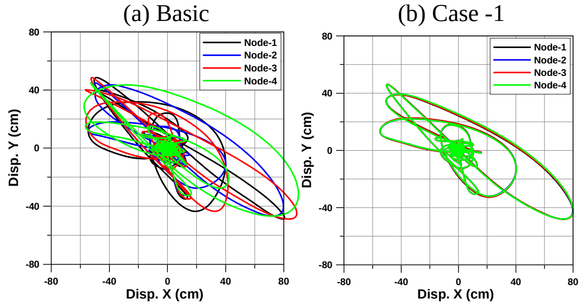
The change of response due to variation is high at the corner of structure. So the seismic response was calculated at the node of the corner of the basemat as shown in Fig 3 (a).

From the Fig. 5, for the basic model, the nodal displacements at the basemat were similar. But it was observed that the nodal displacements of other models were different because of the variation in the stiffness for the LRB. For the Case-1, the maximum displacement occurred at node 2. And it was showed that the displacement of node 3 was the largest.

Table 1 shows that the design displacement and the analysis displacements under the peak ground acceleration 0.5g. Maximum horizontal displacements were determined from the square-root-sum-of-squares response calculated at each time-step during the time history analysis using the displacement components in each orthogonal direction. The maximum displacement of Case-1 under NRC input was about 6% larger than basic model. And the maximum displacement of Case-2 under Chi-chi input was about 11% larger than basic model. This results means that the horizontal displacement of structure is increased by rotation.



(a) Basic (b) Case -1



(c) Case -2 (d) Case-3

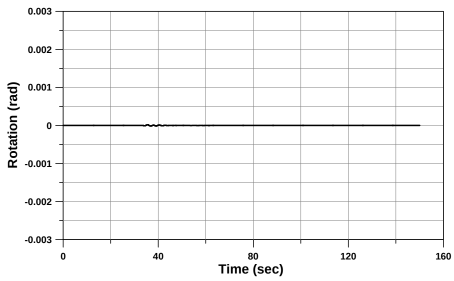
Fig. 5. Displacement path response by chichi earthquake

It was observed that the displacement of Case-1 and Case-2 was higher than basic model and the nodal trace for case-1 and case-2 was different because of the rotation of structure. The more trace displacement increases, the nodal velocity will be more increased. This results showed that the kinetic energy of the each isolator was different under seismic load. Therefore the damage of isolator can be focused the specified area.

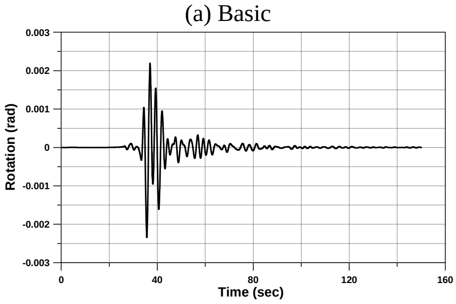
Table 1: Maximum displacement of example models

	Basic	Case-1	Case-2	Case-3
Design disp.	15 cm			
Max. disp. by analysis (NRC)	43.8cm	46.4cm	47.9cm	44.0cm
Max. disp. by analysis (Chichi)	90.1cm	98.3cm	99.9cm	91.1cm

Fig. 6 presented the rotation at the plate on the isolator. The rotation for the basic model was almost zero while the rotation for ALT-1 and ALT-2 was 0.001 rad and 0.002rad, respectively. It was observed that the displacement for Case-1 and Case-2 was increased by the rotation of structure. If the margin of CHS is not enough, the basemat of isolated structure will contact with the hard stop.



(a) Basic



(b) Case-2

Fig. 6. Rotation response by chichi earthquake

5. Discussion

The mode shape and the seismic response of isolated structure were changed by the variation of properties. This variation lead to the eccentricity of isolated structure. Especially the rotation were occurred by the eccentricity. The isolator has been designed considering the shear deformation except the rotation of structure. Therefore the stability of structure under seismic load cannot be ensured by the eccentricity due to the variation.

For example, the maximum displacement of isolated structure under the seismic load can be increased by the variation for isolators. The clearance to the hard stop (CHS) was decided based on the EDB displacement of isolators. If additional displacement by rotation of structure was not considered in design, the isolated structure can hit the hard stop under seismic load with low frequency content. This impact can cause the high frequency vibration which can have an influence on the equipment located in structure.

6. Conclusion

It is essential that the variation of isolator is occurred by manufacture, aging and temperature. The seismic response analysis of four models with different eccentricity was performed to evaluate the relation between the seismic behavior of isolated structure and the variation of isolator.

From the analysis results, it was represented that the response of isolated structure can be increased by the variation of property for the isolators. The additional displacement at the corner of basemat can be occurred by the rotation of structure. Therefore the isolator should be carefully designed considering the rotation of structure for ensuring the stability of structure/equipment.

It is difficult to control the variation of property for the isolator due to the aging and temperature. For the maintenance of isolated structure, it was concluded that the isolators should be replaced when the total variation including the aging of isolator is higher than the allowable variation.

Acknowledgement

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REFERENCES

[1] NUREG-draft, Technical Considerations for Seismic Isolation of Nuclear Facilities, U.S. Nuclear Regulatory Commission, 2011.
[2] ASCE-4, Seismic Analysis of Safety-Related Nuclear Structures, American Society of Civil Engineers, Section 7.7 (draft), 2013.
[3] Regulatory Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants, U.S Nuclear Regulatory Commission.
[4] Computer and Structures, Inc., SAP2000 Analysis reference, Berkeley, CA. 2011.