Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

Issues of Seismic Isolation Design for the Emergency Response Base Building under Beyond Design Basis Earthquake

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1. Introduction and Background

The East Japan Earthquake occurred in 2011 leaded to the accident at the Fukushima nuclear power plant (NPP). The damage on the earth and human beings is incalculable, and the recovery work of the accident is still going on. The seismic isolation center in the Fukushima site has proven to be an important role in the accident response and recovery work. Based on the case in Japan, the construction of the Emergency Response Base Building (ERBB) at the four nuclear power plant sites was decided by the Korea Nuclear Safety and Security Commission (NSSC) in 2019. The detailed design is being currently carried out.

The design basis earthquake (DBE) for the ERBB is established as 0.5g horizontally and 0.33g vertically shown in Figure 1, which exceeds that of the latest domestic NPPs (0.3g). The beyond design basis earthquake (BDBE) is 1.5 times that of DBE. Thus, the earthquake equivalent to the 0.75g in the horizontal directions and 0.5g in the vertical direction is applied to seismic isolation design of the ERBB. The increase of DBE might be meaningful in development from the existing seismic design concept and an opportunity to apply the seismic isolation design concept to nuclear facility. The ERBB is the first case of applying seismic isolation design to the NPP structure in Korea.

The purpose of this paper is to numerically analyze the axially tensile performance of a seismic isolator under the BDBE by various parametric analyses. The tensile yield stress (linear limit stress) of the seismic isolator was obtained on the most severe conditions of ‘shear strain by the clearance to hard stop (CHS) and maximum tensile force under the BDBE excitation’ among the requirements of KEPIC STC. The main parameters are three axial behavior models.

2. Base-isolation Design

The seismic isolators to be applied to the ERBB are lead-rubber bearings (LRB). Figure 2 shows the numerical model of the ERBB and the arrangement of 42 LRBs. Figure 3 shows the ideal double linear horizontal behavior of the LRB seismic isolator, and Table 1 shows the main characteristics of the LRB seismic isolator with diameter 1400 mm. These characteristic values are applied to nonlinear seismic response analysis.

The CHS or stopping distance is 760mm (2'-6") applied equally to all the ERBBs. The CHS is determined by reason to ensure a sufficient working space during construction and smooth maintenance during operation.

3. Parametric Analysis Conditions

The purpose of the parametric analysis is to check whether the tensile stress of the ~~base~~ seismic isolator calculated under BDBE excitation condition reaches the tensile yield stress. Also, it is to obtain the appropriateness of the numerical model and the optimal tensile stress from the analysis of the horizontal and vertical seismic response of the structure.

The most important parameter is the axial behavior model of the seismic isolator as shown in Figure 4. This means that the axial behavior is expected to be nonlinear in case of the BDBE. The consideration of gravity and the probabilistic set of seismic input motions were also used as important parameters. The axial-linked elements (COMBIN14 or COMBIN39) provided by ANSYS APDL were applied to the axial stiffness model of the seismic isolator. The parametric analyses were also performed to evaluate the suitability of CONBIN 39 elements to demonstrate the validity of the analytical approach for calculating the optimal tensile stress.

The analysis method adopted for the analyses was a transient analysis (nonlinear direct integration method). The behavior of the ERBB structure model except for the seismic isolators maintains the linear range in the parametric analysis, and the seismic responses of interest were the axial hysteresis and tensile stresses of the LRB and the acceleration response spectrum of the floors with interest.

4. Analyses and Conclusions

The results of this parameter analysis are summarized as follows:

- Various parametric analyses were performed to calculate the tensile stress acting on the seismic isolator under the BDBE excitations.
- A reasonable analysis model capable of calculating the optimal tensile stress was determined. To sum up, the best way is to use a tension-side nonlinear model considering the dead load (gravity).
- Seven sets of BDBE seismic input motions were applied to analysis model. The maximum tensile stress of the seismic isolator was calculated as 1.03 MPa, 0.67 MPa, and 0.84 MPa from the highest case, the lowest case, and the average case, respectively.

- To evaluate the appropriateness of the numerical axial-linked element (COMBIN39), four additional parametric analyses were performed. The seismic response to which COMBIN39 was applied was consistent with the seismic response to which COMBIN14 was applied. This showed the appropriateness of the COMBIN39 element.

The author will provide detailed analysis results at the time of presentation.

REFERENCES

[1] ASCE 4-16 (2017), "Seismic Analysis of Safety-Related Nuclear Structures", American Society of Civil Engineers.
[2] KEPIC STC (2017), "Seismic Isolated System", Korea Electrical Power Industry Code.

Table 1. Nonlinear properties of LRB

Properties	Values	Unit
Initial stiffness, K_1	1943	kips/ft
Post-yield stiffness, K_2	150	
Vertical stiffness, K_v	507060	
Characteristic strength, Q_d	151	kips

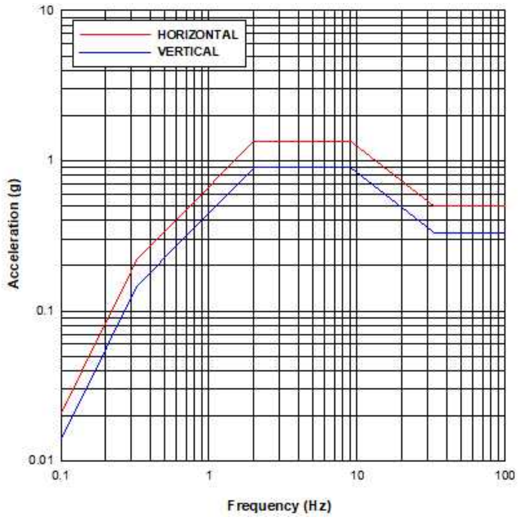


Figure 1. Horizontal & vertical design response spectra based on NUREG/CR-0098

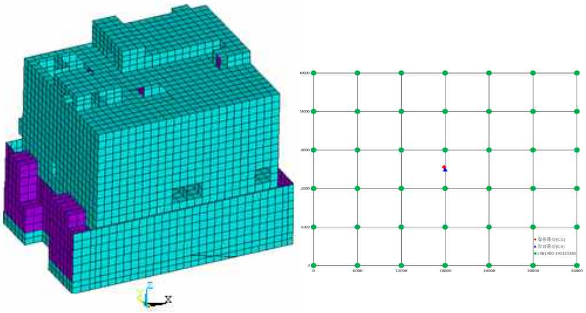


Figure 2. ERBB analysis model & Arrangement of LRB (42 ea)

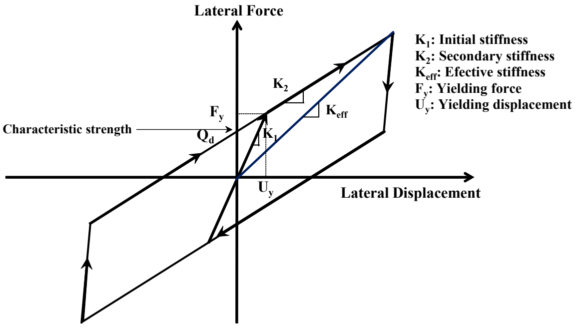
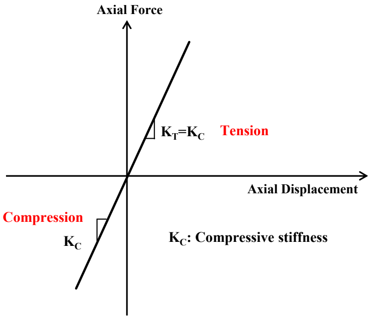
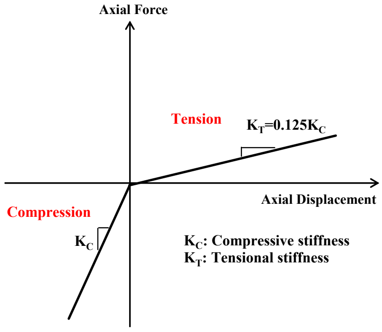


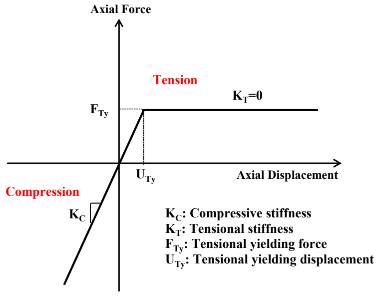
Figure 3. Horizontally idealized hysteresis loop



(a) COMBIN14 (linear axial stiffness)



(b) COMBIN39 (two-way axial stiffness)



(c) COMBIN39 (yielding axial stiffness at tensile pressure of 1MPa)

Figure 4. Parametric analysis models for axial direction