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Seismic Response Assessment of a Base-isolated Frame Structure using Shaking Table Tests

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1. Introduction

Seismic isolation is one of the ways to dramatically improve the seismic safety of important infrastructures such as nuclear power plants. However, due to the complex material properties of the seismic isolator and the nonlinear behavioral characteristics of the seismic isolation system, there are many limitations in applying it to the actual nuclear power plant structures. In this study, the in-structure response characteristics of the base-isolated frame structure were evaluated through shaking table tests. For the shaking table test, a two-story steel frame structure was fabricated, and a lead-rubber bearing (LRB) was selected as a seismic isolator. An input earthquake that satisfies the design response spectrum suggested in the US NRC Regulatory Guide 1.60 [1], and a modified spectrum using a similitude law was used to analyze the effect of high-frequency components. In this study, the in-structure response characteristics were derived according to the nonlinear characteristics of the base-isolated structure. Since there is a clear limit in evaluating the complex behavioral characteristics of seismic-isolated structures with indirect approaches through numerical analysis, etc., the results from this study are expected to be important reference data for evaluating the seismic risk of base-isolated structures.

2. Methods and Results

In order to experimentally evaluate the in-structure response spectrum of the base-isolated frame structure, tests were performed using a shaking table located at Pusan National University. A two-story steel frame structure was set as the target structure, and the seismic isolator was designed based on the natural frequency of the containment building of the nuclear power plant.

2.1 Shaking Table Tests of Base-isolated Structure

The target structure consists of 12 tons of steel frame, 10.8 tons of steel blocks, and 25 tons of concrete slab. In order to express the high rigidity of the nuclear power plant, concrete slabs were placed on each floor to prevent the torsional behavior of the steel frame. The weight of the entire superstructure is supported by four seismic isolators installed under each corner of the foundation slab. A picture of the fabricated base-isolated steel structure is shown in Fig. 1.

Fig. 1. Base-isolated frame structure for shaking table tests

2.2 Design of Lead Rubber Bearing

The seismic isolator, which has low horizontal stiffness compared to the superstructure, basically serves to isolate the structure from ground motion. In addition, the seismic energy transmitted to the superstructure can be reduced by extending the natural period of the superstructure through the seismic isolator. The LRB is one of the representative seismic isolators and is a device in which a lead column is inserted in a laminated rubber in a vertical direction. The relatively low seismic force is controlled by the initial rigidity of the seismic isolator dominated by the lead column, and stability to a high level of seismic force that may occur in the structure is secured by absorbing a large about of horizontal energy through the laminated rubber. The design drawing of the LRB seismic isolator is shown in Fig. 2 and the LRB consists of a lead column with a diameter of 35 mm, an outer diameter of 200 mm, and a total rubber height of 30 mm. The target properties used in the LRB design are summarized in Table 1.

Table I: Design properties of the lead rubber bearing

K_1	37.19 kN/mm
K_2	0.41 kN/mm
Q_d	7.67 kN
K_{eq}	0.667 kN
H_{eq}	0.242

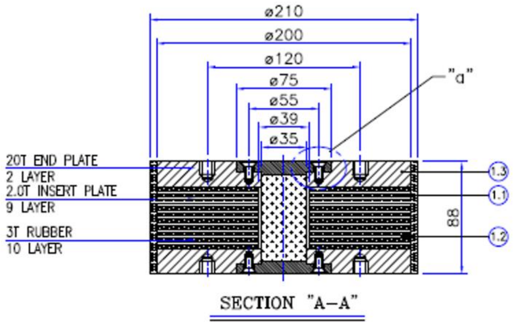

Fig. 2. Schematic of the lead rubber bearing

2.3 In-structure Response of Base-isolated Structure

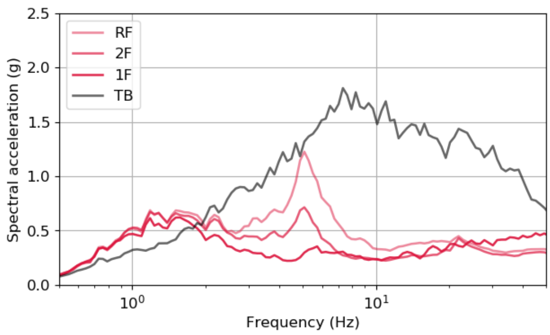

Fig. 3. In-structure response spectrum at 0.47g PGA

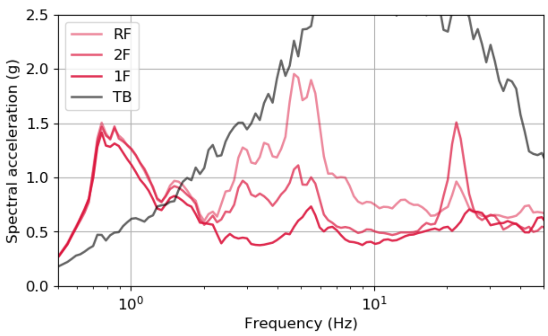

Fig. 4. In-structure response spectrum at 0.94g PGA

According to a previous study on the behavior of seismic isolation structures through numerical analysis [2], at the same PGA level, responses vary in the structure frequency according to the floor height, and the change in the PGA level affects the response of the isolation layer frequency range. The same tendency is confirmed in the shaking table experiment conducted in this study. Figs. 3 and 4 show each in-structure response spectrum at PGA levels of 0.47g and 0.94, respectively. The response of the isolation layer frequency has almost the same spectral acceleration regardless of the height, and the response of the structure frequency is amplified according to the height. In particular, the main frequency range of the isolation layer tends to change according to the PGA level of the input earthquake. At the PGA level of 0.47g, the response of the isolation layer dominates in the range of 1-2 Hz, whereas the response is dominated in the range of 0.7-0.8 Hz at the PGA level of 0.94g. The reason for this phenomenon is the non-linear behavior characteristic of the isolator that occurs because the displacement of the seismic isolator increases, the effective frequency that governs the overall behavior of the structure decreases, and the frequency of the seismic isolation layer decrease.

3. Conclusions

In this study, the response characteristics of the base-isolated frame structure are analyzed through shaking table experiments. The complex behavioral characteristics of the base-isolated structure caused by the nonlinear properties of isolator are confirmed. These results are expected to be used as a useful reference material to predict the dynamic characteristics of the base-isolated structures.

ACKNOWLEGEMENT

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