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PERFORMANCE EVALUATION BY SEISMIC RETROFIT OF MCC EQUIPMENT IN NUCLEAR PLANTS UNDER BDBE CONDITION

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ABSTRACT

The objective of this paper is to compare the seismic performance of the Main Control Consoles (MCC) of nuclear power plant(NPP) for the BDBE (beyond design basis earthquake) when seismic retrofit technologies are applied. The input earthquake used in the analysis is based on the floor response spectrum of DBE used for the design of domestic export-type NPPs. The technologies considered in this study include lead rubber bearing (LRB) and friction pendulum system (FPS) to be used for the seismic enhancement of equipment. The maximum acceleration and displacement responses of the equipment finite element model are evaluated in comparison with the seismic response of the fixed condition. In BDBE condition, these retrofit options are also cost-effective solutions for individual equipment of the operating NPPs. Sometimes, however, depending on the building or location where the device is installed, the impact of seismic isolation technology on the seismic response must be carefully analyzed to determine whether its application is appropriate.

INTRODUCTION

After the 2016 earthquakes in Gyeongju and Pohang, South Korea**,** interest in the seismic safety of nearby nuclear power plant structures has increased. In particular, studies have been conducted to enhance the seismic safety of safety-related equipment in operating nuclear power plants against BDBE, along with evaluations of the feasibility of applying seismic isolation technology. In this study, the seismic acceleration and displacement responses of an MCC cabinet**,** one of the electrical components, were predicted under BDBE conditions for certain operating nuclear power plants. Additionally, strategies for reducing seismic responses were analyzed. To enhance the seismic performance of equipment, reinforcing the stiffness of the device or its support structure is typically considered. Generally, increasing structural stiffness reduces member stress, thereby improving seismic stability. However, since this also raises the structure's natural frequency, it may lead to an increase in acceleration responses depending on the characteristics of the design earthquake spectrum. Therefore, the effects of such reinforcement must be evaluated in advance.

This paper aims to identify and analyze seismic reinforcement measures to improve the seismic performance of equipment in nuclear power plants. Specifically, it assumes the application of a recently developed small seismic isolation bearing, designed for nuclear power plant equipment, as a reinforcement method For the target equipment, the MCC cabinet was selected among safety-related equipment, considering the potential for future full-scale seismic testing using a shaking table. First, the effect of reinforcing the stiffness of the MCC support structure was examined. Additionally, the impact of applying seismic isolation technology using Lead Rubber Bearings (LRBs) and Friction Pendulum System (FPS) bearings on the seismic response of the equipment was investigated.

The input earthquake used in the analysis is based on the floor response spectrum of the Design Basis Earthquake (DBE) used for the design of domestic export-type nuclear power plants (NPPs). Additionally, the location and level where the MCC is installed was categorized into a two places in the auxiliary building. The design seismic floor responses were generated for each installation height, and these responses were applied to the equipment to observe changes in its seismic performance. Under BDBE conditions in some operating NPPs, these seismic retrofit options may or may not be effective, depending on the installed building location within the plant.

MODELLING AND MODAL ANALYSIS OF MCC CABINETS

To analyze the performance improvement achieved through seismic reinforcement of operating nuclear power plant equipment, the selected target device is a 480V Motor Control Center (MCC). Table 1 presents the specifications of the equipment, while Fig. 1 provides a reference image of the equipment used in the shaking table test.

The MCC cabinet consists of three single cabinets attached side by side in a fixed configuration. The base of the cabinet is anchored to an independent 2-ton support plate using anchor bolts.

Table 1. Specification of MCC

Model Name	Dimensions, (mm)			Weight (kg)	Remarks
	Length(L)	Width(W)	Height(H)		
480V MCC	550	1 695	2 350	1 934	(including JIG)

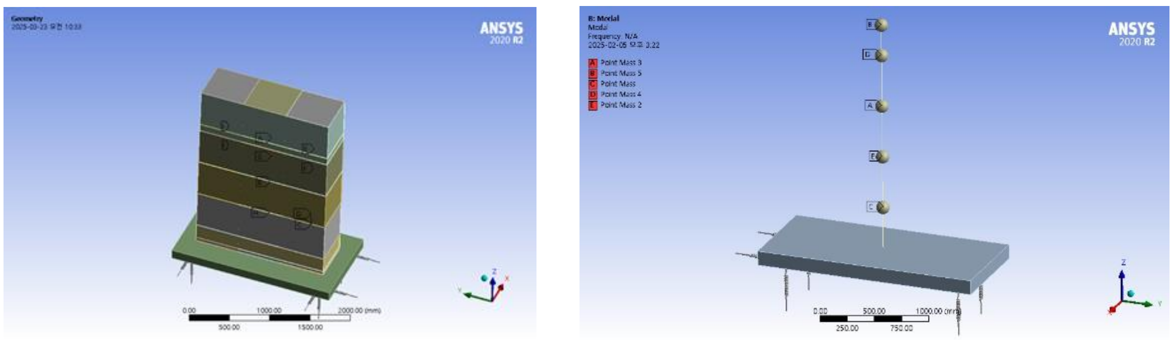
Figure 1. Shapes of MCC cabinets.

In this study, the ANSYS program was used to perform seismic analysis by applying seismic reinforcement technology to a simplified MCC model [1]. First, a finite element model (FEM) with a fixed-base condition was created, and a modal analysis was conducted.

The geometry of the analysis model is shown in Fig. 2 for reference. In a real cabinet, many control-related parts are complexly arranged on the internal installation plate. However, in this study, the devices mounted inside the cabinet, cables, and their supports were simplified as much as possible for analysis purposes. The thickness of all the inner and outer plates of the cabinet is assumed to be the same, and the main parts, such as the controller and power connector components, which are installed from top to bottom, are modeled as concentrated masses, adjusted to match the center of mass position. For the response spectrum analysis using the FEM model, one cabinet was modeled first, and then three cabinets were replicated side by side, assuming the same structure, to form the completed MCC model.

To account for the potential future shaking table tests, the model includes a base support plate with an approximate weight of 2 tons, representing the support system of the MCC structure. Additionally, to analyze the effects of structural reinforcement and seismic isolation as reinforcement measures, a simplified three-directional spring was modeled at the bottom of the support structure, and seismic analysis was performed accordingly.

As a result of the modal analysis, the values obtained are summarized in Table 2. The fundamental frequencies of the lower-order modes in the cabinet's thickness and width directions were approximately 10.5 Hz and 25 Hz, respectively. These results closely matched those obtained from previous shaking table tests [2]. Next, to efficiently perform response spectrum analysis and time history analysis under both fixed-base and base-isolated conditions, a lumped mass beam model was developed to have dynamic characteristics nearly equivalent to those of the FEM model [3]. Seismic inputs were applied using the floor response design spectra at two different locations and levels in the auxiliary building of the APR1400 nuclear power plant, which is an export model.



a) FEM Model b) Lumped mass model

Fig.2 Seismic Analysis Models for MCC

ANALYSIS FOR SEISMIC RETROFIT

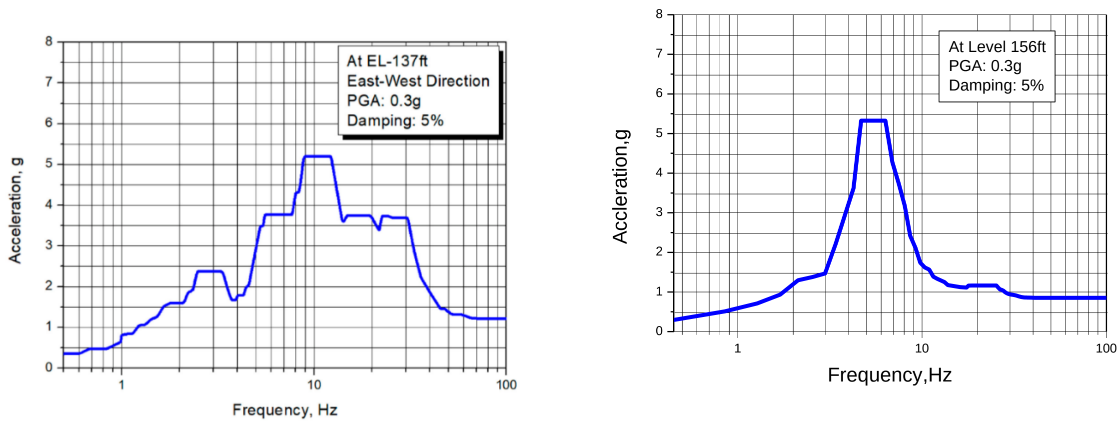
1) Applied Seismic Retrofit Technologies and Seismic Inputs for Review

In this study, the seismic performance of LRB and FPS bearings, which had been developed for relatively lightweight equipment in nuclear power plants, was investigated by comparing them with the original equipment. The recently developed LRB-type small seismic isolation bearings were designed for capacities ranging from 1 ton to 10 tons. In particular, the effectiveness of the 1-ton capacity LRB bearing has been validated through shaking table tests. The material properties of these bearings are presented in Table 3 [4,5].

a) LRB b) FPS

Fig. 3. Shape of Small LRB and FPS Bearings for Equipment

Additionally, the FPS-type seismic isolation bearing was assumed to be a small unit with a diameter of approximately 30 cm [6]. Both LRB and FPS bearings are assumed to be installed under the main structure of the MCC. For analytical purposes, it was modeled with a single equivalent stiffness assumption.
The input earthquakes used for the seismic analysis were SSE earthquakes at the level of 0.3g with 5% damping ratio, which corresponds to the design basis earthquake (DBE) for export nuclear power plants and are considered as Beyond Design Basis Earthquakes (BDBE) in some operating nuclear plants in Korea.
To conservatively account for the actual installation locations of the MCC at the two floor levels of 137ft and 156ft, two floor response spectra (FRS) from different levels and locations within the auxiliary building were used as inputs for the earthquake analyses. Fig. 4 shows the seismic response spectra applied in the analysis for each of these conditions.

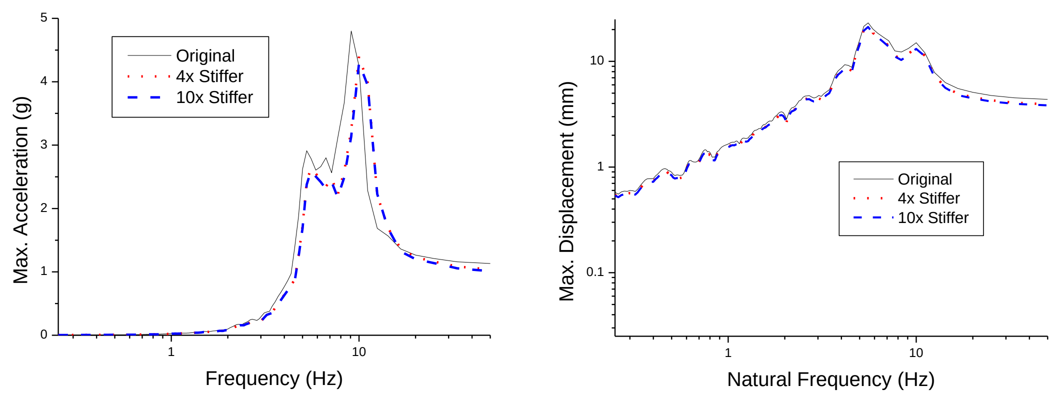


a) Floor Response Spectrum I

b) Floor Response Spectrum II

Fig. 4. Input Earthquakes for Analysis

2) Comparative Analysis for Seismic Retrofit



a) Max. Acceleration

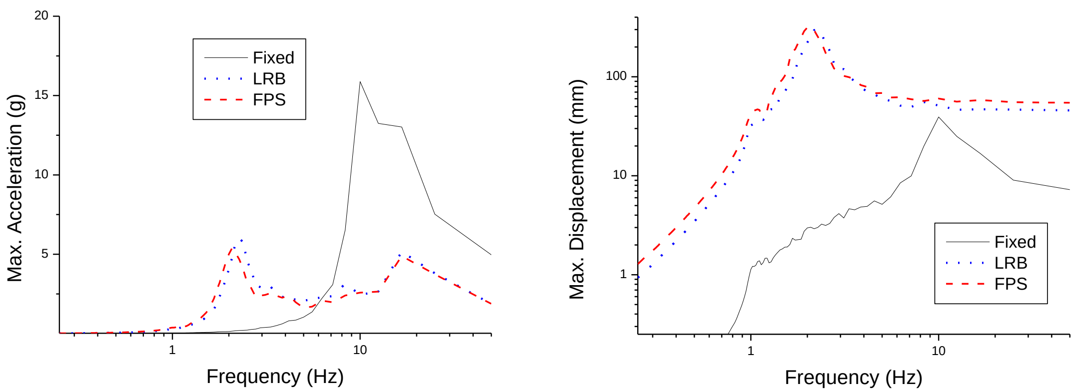
b) Max. Displacement

Fig.5 Seismic Responses of MCC by Stiffened Support at 156ft level in Auxiliary Building

First, to examine the effects of seismic reinforcement, the stiffness of the model's support structure was increased by factors of 4 and 10, and the changes in the maximum seismic response of the equipment due to stiffness reinforcement were analyzed. Fig. 5 compares the acceleration and displacement responses of the MCC when its support structure is reinforced. As shown in the figure, the impact of stiffness reinforcement on the seismic response is minimal.

Next, the recently developed small Lead Rubber Bearings (LRB) and Friction Pendulum System (FPS) bearings, designed for equipment seismic isolation, were applied to observe changes in seismic performance compared to the fixed-base condition. Due to manufacturing limitations of laminated rubber bearings, the designed natural frequency of the small LRB was approximately 2.3 Hz. Similarly, due to size constraints of the friction surface, the designed natural frequency of the small FPS was assumed to be around 2.0 Hz.

Fig. 6 presents a comparison of the maximum acceleration and displacement responses obtained from seismic analyses under three conditions: fixed support, LRB isolation, and FPS isolation. The results indicate that the application of seismic isolation technology increases displacement response, but reduces maximum acceleration response to approximately one-third of the base-fixed condition value. Therefore, the small LRB or FPS developed for equipment can be a good option for seismic retrofit of the MCC cabinet structure to enhance the seismic capacity at the installed floor level in the building. This trend is similar to the results of seismic base-isolation cases of most building structures.

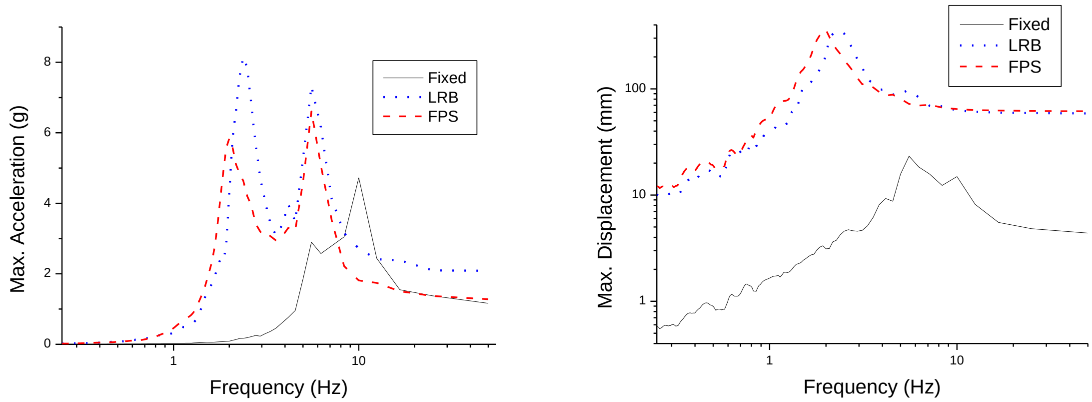


a) Max. Acceleration   b) Max. Displacement

Fig.6 Comparison of MCC Seismic Responses by Base-isolation Based on FRS-I

However, unlike the case of FRS-I, Fig. 7 shows that the acceleration response of the base-isolated MCC actually appears to increase by about 50% to 80% compared to the original base-fixed condition. When the seismic responses are analyzed using the different FRS from the previous one, the application of seismic isolation did not result in a satisfactory response reduction. Except for some frequency ranges from 7 Hz to 11 Hz, the seismic response of the base-isolated MCC mostly appears to increase, as depicted in Fig. 7a . The displacement response is expected to be much greater than that of the base-fixed MCC, as shown in Fig. 7b.

This suggests that the LRB and FPS bearings for seismic isolation are not always good options for the seismic retrofit of equipment in the plant. Sometimes, depending on the installed location, they may not be a suitable alternative for improving seismic performance, as reviewed in such cases. This is based on the difficulties of design and fabrication for the isolation bearings to achieve sufficiently low natural frequencies. Therefore, when using base isolation bearings for the seismic retrofit of small-sized or lightweight equipment in operating nuclear plants, care should be taken regarding the potential adverse effects on the seismic response. These effects can be checked through detailed seismic analysis using appropriate design seismic inputs obtained from the building structure model.



a) Max. Acceleration b) Max. Displacement

Fig.7 Comparison of MCC Seismic Responses by Base-isolation Based on FRS-II

CONCLUSIONS

The study compares the seismic performance effects of applying some seismic retrofit technologies to the MCC cabinet, a safety-related device in nuclear power plants. Through comparative analyses of support stiffness reinforcement and equipment base-isolation, the following results were obtained:

1) The seismic retrofit by support stiffness reinforcement has little effect on the change in response.
2) Depending on the dynamic characteristics and level of the input floor response, seismic base-isolation of the equipment can be a very effective or less effective option for seismic retrofit.
3) Detailed seismic analysis is required for the seismic retrofit decision regarding equipment base isolation in operating nuclear plants.

In the near future, nonlinear analysis considering bilinear stiffness and verification tests using a 3D shaking table are planned. Additionally, since we have only considered seismic isolation for horizontal earthquakes, which dominate the response, we plan to analyze seismic isolation for vertical earthquakes in the future.

ACKNOWLEDGEMENTS

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