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# Simulation of Seismic Response Effect by Anchor Bolt Degradation of MCC Cabinets

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## 1. Introduction

Over the past 100 years, the most significant earthquakes in terms of magnitude and damage in South Korea were the Gyeongju and Pohang earthquakes. Following these events, research has been conducted on the seismic safety of nuclear power plant (NPP) facilities to withstand Beyond Design Basis Earthquakes (BDBE). Since more than half of the domestic nuclear power plants have been in operation for over 10 years, there is increasing interest in the seismic performance of aging NPP facilities. The degradation of NPP facilities due to long-term operation is assessed through regular inspections and periodic safety reviews (PSR) conducted every 10 years. Although the occurrence of facility degradation in containment buildings or auxiliary buildings is relatively low, long-term operation and repeated shutdowns can lead to changes in temperature and pressure, as well as exposure to radiation. The types of degradation reported in NPP facilities include corrosion, fatigue, impact, radiation effects, and thermal fatigue. Since there are numerous components within operating NPPs, such as pressure vessels, pumps, valves, and piping, damage to some facility components may occasionally occur over long-term operation. This study aims to examine the changes in dynamic characteristics and the impact on seismic performance under BDBE conditions when some anchor bolts securing a Motor Control Cabinet (MCC) to a building are damaged due to long-term degradation.

## 2. Anchor Bolt Degradation and Potential Impacts

### *2.1 Cases of Anchor Bolt Degradation*

In some nuclear power plants in the United States and Europe, anchor damage in equipment supporting or securing reactor system components has been reported. For example, in the United States, cases of bolt degradation have been identified in various locations: at Surry Unit 2 in Virginia, the steam generator manway flange; at North Anna Unit 1, the reactor pressure vessel (RPV) upper head; and at the Palisades nuclear power plant in Michigan, the upper core barrel of the reactor internals.

In Europe, similar cases have been reported, including damage to the reactor vessel head bolts at Germany's Philippsburg Unit 2, the reactor coolant pump flange at France's CPY nuclear power plant, and the containment building anchors at the Sizewell B nuclear power plant in the United Kingdom.

Regarding the patterns of bolt degradation, among the 44 cases of bolt defects reported up until 1983, approximately half were attributed to stress corrosion cracking (SCC), followed by boric acid corrosion, fatigue failure, and crevice corrosion in descending order. [1]

### *2.2 Influence of Structural Stiffness Eccentricity on Dynamic Characteristics*

According to previous studies, an analysis of the seismic response of structures based on regular and irregular support stiffness revealed that as eccentric stiffness elements are added to a non-eccentric regular stiffness model, the torsional mode appears at lower modes in the structural modal characteristics, and the contribution of rotational modes to the translational response increases. [2]

Furthermore, in models with stiffness eccentricity, there is a possibility of increased response depending on the characteristics of the support stiffness and input earthquake motion. It is also noteworthy that the ASCE code requires consideration of the effects of mass or stiffness eccentricity in structures.[3,4,5]

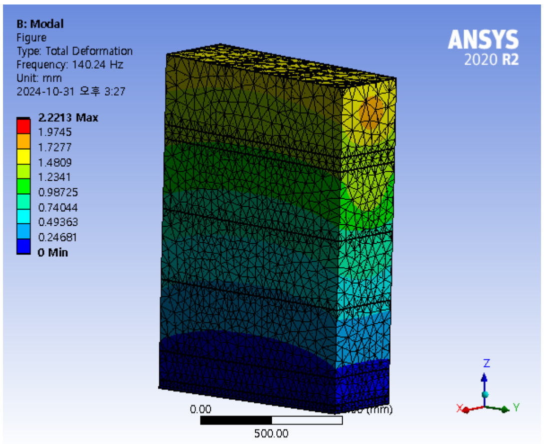
## 3. MCC Structure and Support Details

### *3.1 Description of MCC and Seismic Analysis*

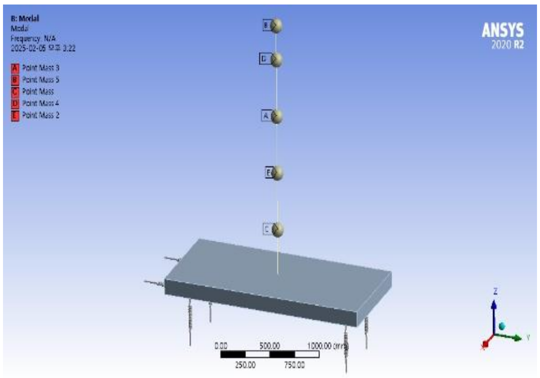
In this study, the Motor Control Center (MCC) was selected among the major safety-related equipment in nuclear power plants, considering the possibility of future three-axis shake table test verification. The MCC, shown in Fig. 1, is manufactured by Seondo Electric and is assumed to have dimensions of approximately 550 × 1700 × 2350 mm and a weight of 1850 kg. For the seismic analysis, the floor response spectrum at a height of 156 ft, which represents a conservative installation location in the APR1400 design, was utilized.

Fig. 1. Shape of Motor Control Center (MCC)

For the analysis, the finite element model (FEM) shown in Fig. 2a was first created using the structural analysis software ANSYS. Additionally, to perform a seismic time history analysis for response sensitivity evaluation, a lumped mass beam model was developed, as shown in Fig. 2b, which maintains nearly identical modal characteristics, including the first and second natural frequencies. [6,7,8]




(a) FEM Model for MCC




(b) Lumped Mass Model for MCC

Fig. 2. Seismic Analysis Models for MCC

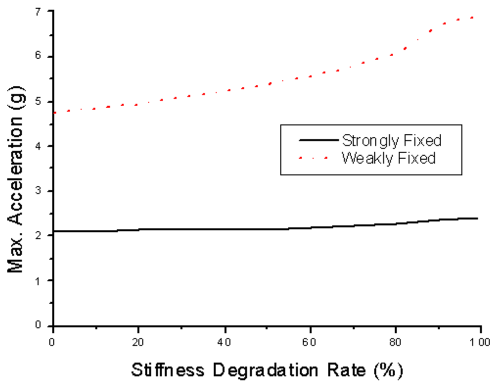
The steel base plate, which does affect little on the MCC dynamic behavior, is added to simulate the base-isolated model for shaking table test planned to be performed some time later. The result of modal analysis for MCC model is shown in Fig.3 for reference. As we see in the trend of modes of structures with unequal support stiffness, the rotational or rocking modes affect more to the dynamic response of the structure. It is very similar to the test result of simple model having stiffness eccentricity reported in the reference paper of 2022 conference.[3]

### *3.2 Response Sensitivity by Anchor Bolt Degradation*

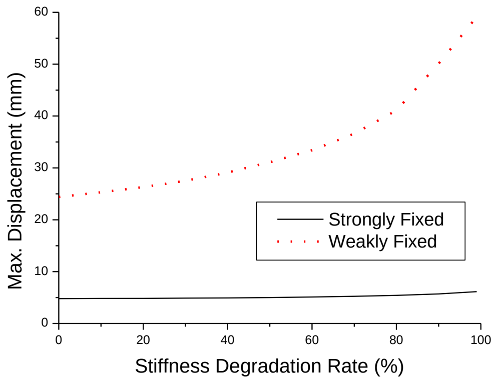
To investigate the impact of anchor bolt aging on the seismic performance of the MCC equipment supports, this study assumes that the equipment is supported at four corner locations with two different average stiffness values. The seismic response sensitivity was examined in a scenario where one of the bolts undergoes aging.

For this purpose, the stiffness of one corner bolt was gradually reduced from 0% to 100% in 10% increments, and a response spectrum analysis was conducted to observe the changes in maximum acceleration and displacement response. The results are presented in Fig. 3. As shown in the figure, both maximum acceleration and maximum displacement exhibited low sensitivity to anchor bolt degradation when the average support stiffness was high. However, as the average support stiffness decreased, the sensitivity increased significantly, leading to a potential decline in seismic performance.

This implies that as the operational years of a nuclear power plant increase, if bolt degradation leads to a reduction in average support stiffness, the impact of localized bolt aging will become more significant.




(a) Maximum Acceleration Response (g)




(b) Maximum Displacement Response (mm)

Fig. 3. Seismic Response Sensitivity by Bolt Aging

## 4. Conclusions

In this study, a sensitivity analysis was conducted to evaluate the impact of anchor bolt degradation on the seismic response of the Motor Control Center (MCC), a safety-grade component in nuclear power plants. The following conclusions were drawn:

1) Partial degradation of the anchor bolts supporting the equipment can cause stiffness eccentricity, altering the dynamic characteristics of the MCC. This leads to an increased influence of rotational or rocking modes.

2) When the average support stiffness of the anchor bolts is sufficiently high, the effect of degradation on maximum seismic response is minimal. However, as the average support stiffness decreases, the sensitivity to bolt degradation increases, potentially leading to reduced seismic performance.

## 5. Acknowledgement

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