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Dynamic Characteristics and Seismic Response Analysis by Mass Eccentricity of Isolated Components

Sangjin Ma, Taemyung Shin*
Dept. of Aeronautical & Mechanical Design Engr., Korea Nat. University of Transportation.
**Corresponding author: tmshin@ut.ac.kr*

1. Introduction

As the interest in earthquake-resistant safety of nuclear power plants has emerged after the Gyeongju and Pohang earthquakes in Korea, technology research has been conducted at the pan-governmental level to improve the earthquake-resistant performance of nuclear facilities. If an earthquake acting on a structure installed in a nuclear power plant is much larger than the design level, the actual performance should be identified through seismic analysis first, and if insufficient, the seismic performance should be improved. Among the seismic performance improvement technologies, there is a structure or device seismic technology that is widely used. It is important to predict the potential impact on safety-related peripheral facilities by grasping the extreme response characteristics in the event of an earthquake.

Among the structures/equipment of nuclear power plants, mass or rigidity may be eccentric due to conditions predicted during design or structural changes during operation. For example, in the case of an emergency diesel generator, the center of mass is partially shifted based on the center of rigidity of the support. This may lead to relatively non-conservative results compared to a dynamic analysis performed on the assumption of non-eccentricity.

Until now, there have been many studies on the dynamic response analysis of seismically isolated structures, but few studies have been conducted on the sensitivity analysis to determine the earthquake resistance of base isolated equipment with increasing mass eccentricity. In particular, when the seismic intensity is greater than the design level, there is a lack of research on the change in response characteristics due to the mass eccentricity of the isolated structure.

2. Seismic Response by Mass Eccentricity

2.1 LRB Design for Equipment

As a result of the previous study, it was found that the energy dissipation effect of the seismic isolator was somewhat increased by addition of lead core. Due to the limitations of manufacturing for thin laminated rubber plate, design isolation frequency become a little higher than the isolation bearing for structures. [1] The small LRB used in this study has a unit support weight of 1 ton and a natural frequency of about 2.3 Hz. For reference, the design detail of the LRB are shown in Fig. 1 and Table 1.

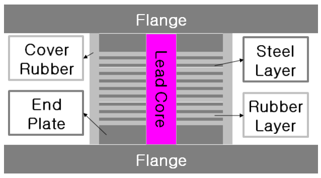


Fig. 1. Cross-sectional shape of the LRB

Table I: Design detail of LRB for equipment

Design Load (ton)	1.0
Outer Diameter (mm)	100
Design Hori. Freq. (Hz)	2.3
Shape Factor, S_1	9.9
Shape Factor, S_2	5.0

2.2 Seismic Input

The input earthquakes in this study are from those used for export-type standard nuclear power plants. Among the safe shutdown earthquake (SSE) and operating basis earthquake (OBE) inputs based on the maximum ground earthquake (PGA) of 0.3g, the 137ft-high floor response acceleration spectrum of auxiliary building where safety facilities are mainly placed was used as an input earthquake. For reference, the OBE zero period acceleration (ZPA) was assumed to be 1/3 of SSE. Fig. 2 shows the shape of the required response spectrum (RRS) and test response spectrum (TRS) of SSE used in analysis. The characteristic of the Design Response Spectrum (DRS) used as an input is that the level of PGA 0.3g is amplified to 1.3g of ZPA by the plant structural model. As shown in the figure, the TRS values measured on the vibration table cover RRS and DRS well in most frequency range, and the frequency characteristics of the layer response acceleration spectrum mainly show peak values near 10 Hz.

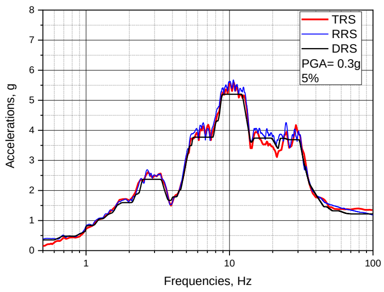


Fig. 2. Seismic Inputs (SSE 0.3g, 5% damping, 137ft)

2.3 Model Description for Sensitivity Analysis

Among the structures and equipment of nuclear power plants, mass or rigidity may be eccentric due to design conditions or predicted structural changes during operation, and a representative example thereof is an emergency diesel generator. It is efficient to consider it as a concentrated mass type structure due to its dynamic characteristics. To investigate the effect of mass eccentricity on seismic response, sensitivity analysis was performed by changing the location of mass center. In addition, mass eccentricity was defined as 0% when the center of mass is located in the center and 100% when it is located at the edge of structure.

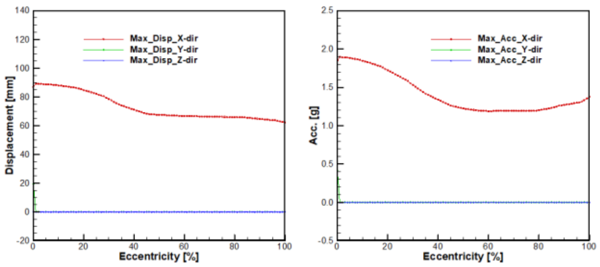
2.4 Seismic response Characteristics by Mass Eccentricity

Mode analysis was performed while changing the mass eccentricity of the structure in the range of 0 to 100%. While the eccentricity increases, the dynamic mode characteristics shows that the translational mode becomes to be merged into the rotational mode. And the amount of merging into the rotational mode gradually increases. Similar trend is found in higher mode of 4^{th} like that the vertical mode merged into rocking mode. In the second and fifth modes, which are considered to be axial non-eccentric modes, there are no changes in the natural frequency.

Table II: Problem Description

Mode	Eccentricity 0%		Eccentricity 100%	
	Freq. [Hz]	Mode Shape	Freq. [Hz]	Mode Shape
1	2.30	Translation	1.69	Rotation
2			2.30	Translation
3	3.34	Rotation	4.56	Rotation
4	36.91	Vertical	22.94	Rocking
5	52.06	Rocking	52.06	
6			83.78	

Fig. 3 is the result of response spectrum analysis of varied mass eccentricity using the input earthquake shown in Fig. 2. As the mass eccentricity increased, the maximum displacement and acceleration responses in the horizontal direction decreased.



(a) Max. Displacement (b) Max acceleration

Fig. 3 Response trend by mass eccentricity.

This is judged to be due to the increase in the contribution of the rotational mode to the translational response.

3. Conclusions

In this paper, the trend of dynamic characteristics and seismic responses of isolated structure was analyzed when the mass eccentricity of structure increased. As a result, the followings are concluded.

1) As the contribution of the rotation mode increased, the rotation mode was merged in the translational mode. In addition, rotation and bending behavior were confirmed in a relatively low-order mode.

2) As the mass eccentricity increased, the maximum displacement and acceleration in the horizontal direction changed.

Therefore, when considering the design of structures with mass eccentricity, some cares should be taken in the response trend change for conservatism.

Acknowledgments

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