Dynamic Characteristics of LRB for Seismic Isolation of Nuclear Facility Components

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1. Introduction

By the effect of Fukushima accident and Pohang earthquake occurred, domestic nuclear power plants(NPP) have been forced to upgrade the level of seismic performance. Efforts are being made to protect existing NPP from events even beyond design basis earthquake (BDBE)[1, 2]. As one of the enhancement measures, we apply seismic isolation technology for structures, system, and components (SSCs).

Among them, design, manufacturing and test of a small size lead rubber bearing(LRB) for SSCs is focused in a study. And static test and dynamic test were conducted using the tentatively manufactured LRB specimen. This paper summarizes and discusses the procedures and results of LRB dynamic test for nuclear facility components.

2. Design of Lead Rubber Bearings

Design and static performance test of laminated rubber bearings have been conducted in previous studies. The results of the preceding study showed that the energy dissipation of the isolator was insufficient. Also, the isolator has poor shape factor compared to large ones for building or bridge due to the limitation of thin rubber layer fabrication. Therefore, LRB with lead core inserted in the isolator center was attempted to enhance energy dissipation function as a design change. The approach of small LRB design is as follows.

Horizontal isolation frequency of LRB for structures has been normally designed to be about or less than 1Hz. However, it is difficult to satisfy both desirable shape factor and manufacturability for small LRB with design frequency less than 1Hz. In case of NPP equipment, their natural frequencies are known to distribute relatively in a higher range compared to large structure. So, the horizontal isolation frequency is determined to slightly rise for improving the shape factor.

In the study, two design options(OPT1, OPT2) are proposed, with an upper weight of 1ton and design horizontal frequency of 2.0Hz and 2.3Hz, respectively. The cross-sectional shape and design specification are described in Table 1 and Fig. 1.

Table 1. Design Options of LRB for Equipment

Properties	OPT1	OPT2
Design Load (ton)	1ton	1ton
Outer Diameter (mm)	76mm	100mm
Design Hori. Freq. (Hz)	2.0	2.3

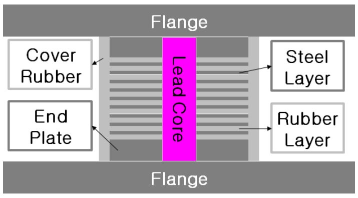


Fig. 1 Cross-Sectional Shape of the LRB

3. Dynamic Performance Tests

The shaking table tests for real size LRBs are performed to check dynamic characteristics and to verify the design. It is done by measuring the 3D responses (acc., vel., disp.) of the base isolated lumped mass model under design earthquakes. Fig. 2 shows a schematic diagram of the test carried out with a set of four LRB specimens. Three 3-axial accelerometers are installed, one at the base of the shaking table, two at the top and bottom of the upper rigid mass, respectively.

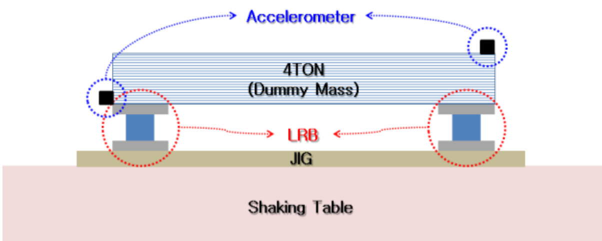


Fig. 2 Schematic Diagram of 3D Shaking Table Test

3.1 Test Method and Procedures

The tests are conducted in the order in accordance with IEEE 344[3] as shown in Table 2.

Table 2. Shaking Table Test Procedures

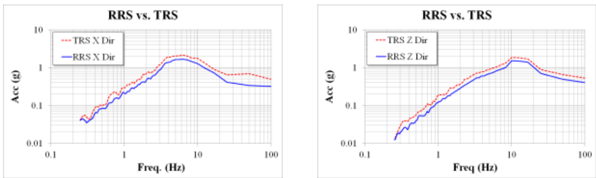
Order	Input	Order	Input
1	Random Vib.	6	SSE-X
2	OBE-X	7	SSE-Y
3	OBE-Y	8	SSE-Z
4	OBE-Z	9	SSE 3-Axis
5	OBE 3-Axis	10	Random Vib.

3.2 Input Seismic Data

As seismic input data for the dynamic test, design basis earthquakes(DBEs) for APR 1400 auxiliary building are used. The 4 input sets are Safety shutdown earthquake(SSE) and operating basis earthquake(OBE), at ground level of 100ft and at floor level of 137ft. The peak ground acceleration(PGA) of SSE is 0.3g and, OBE is assumed to be 1/3 of the SSE.

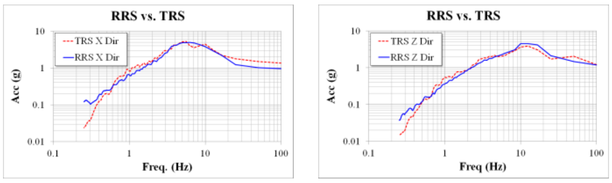
Fig. 3, 4 show the required response spectrum(RRS) and test response spectrum(TRS) shape of OBE and SSE used as input data at 137ft. In the test, because the maximum horizontal displacement in SSE case is anticipated to exceed the limit of shaking table(100mm), we managed to control the input data to keep within the limit. It's done by using high pass filtering with cut-off frequency of 0.6Hz only for the SSE time history input.

For actual seismic qualification test, the input seismic data should be applied by amplifying 10% considering conservatism of the shaking table[3]. Despite the maximum amplification(about 30%) of the input seismic data by direction in this tests, the TRS cannot envelop the RRS in some frequency bands for the SSE at 137ft. And the cross-correlation check among the directional input data satisfied the threshold of 0.3[3].



X Dir. Z Dir.

Fig. 3 RRS vs. TRS of OBE (137ft)

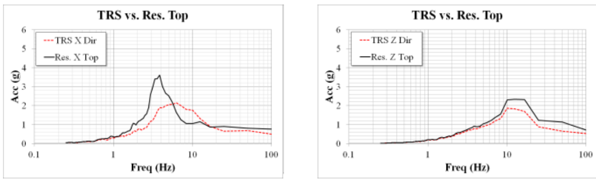


X Dir. Z Dir.

Fig. 4 RRS vs. TRS of SSE (137ft)

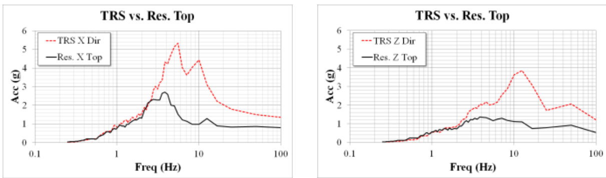
3.3 Test Result

Fig. 5, 6 compare the TRS and the response spectrum of OPT2 at top of mass for X and Z directions of OBE and SSE at 137ft, respectively. The trends of acceleration responses in horizontal direction(X, Y) appeared to be similar. It is estimated that the response amplification in X direction of OBE is caused by high primary stiffness of the LRB, which experiences yet the yield stiffness of lead. However, it shows well the design performance in SSE by reducing response to about half of TRS at top of mass. It is caused by low secondary stiffness of LRB, by both of thin rubber layer and lead core. The responses in vertical direction for SSE tend to be similar to the results of horizontal direction.



X Dir. Z Dir.

Fig. 5 OBE TRS vs. Acc. Spectrum at Top of Mass (137ft)



X Dir. Z Dir.

Fig. 6 SSE TRS vs. Acc. Spectrum at Top of Mass (137ft)

4. Conclusions

The following conclusions can be obtained from the result of 3-axial shaking table tests.

In the design of seismic isolator for fragile equipment of NPP against BDBE, it has been observed that the acceleration response may be amplified by the effects of the primary stiffness of the LRB for OBE. On the other hand, the acceleration response reduction is appeared to be about satisfactory for SSE. This is well consistent with the objective of the research which is for improvement of seismic performance of the NPP equipment emphasized in the event of BDBE.

It is deemed that the acceleration response of equipment in OBE and SSE can be improved further through design changes and optimization with a detailed review of material properties and shape design.

Acknowledgement

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