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Comparative Analysis of Seismic Response of Different Base Isolated Systems by Shaking Table Test

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ABSTRACT

This study performed a set of shaking table tests to analyze seismic response of base isolated structure in accordance with the type of the isolators. The base isolated structure is made of 100 ton concrete block to reflect effect of inertia by superstructure mass, and supported by 3 types of base isolated systems including LRB, EQS and FPS. Seismic response test on the base isolated structure was performed and behavior characteristic of each base isolated system was analyzed. As a result, while there was difference in response pattern by incident seismic wave, decrease of acceleration by EQS base isolated system was the largest while displacement was the lowest.

INTRODUCTION

Studies to apply base isolated structure to nuclear power plant to prevent damages from earthquake fundamentally have been progressed domestically and internationally. As for previous studies on analyzing base isolated system and behavior characteristics, Fenves et al.(1998) performed static test and dynamic test on base isolated system to analyze features of base isolated system and to prepare interpretation model and Kim et al.(2014) carried out the analysis of floor response spectrum by shaking table test of base isolated steel structure. To consider the effect of inertia by superstructure mass, the study manufactured 100 ton concrete block and also manufactured special vibration table for shaking table test.

For accurate behavior analysis of base isolated structure, it needs to make experimental test reflecting inertia effect by superstructure mass. But, normal base isolated system test performs shearing force test on base isolated system to analyze its features.

This study applied same design period and surface pressure condition and designed 3 base isolated systems having LRB(lead rubber bearing), EQS(eradi quake system) and FPS(friction pendulum system). It was followed by shaking table test with applying superstructure mass on base isolated system. And, the study analyzed base isolated system features by means of comparison of seismic response of base isolated system.

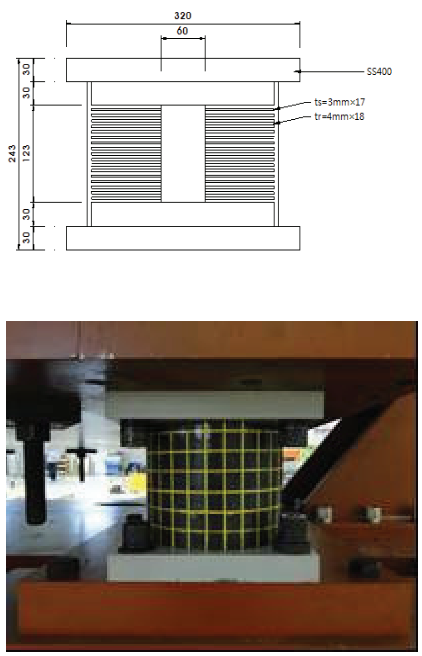
SHAKING TABLE TEST

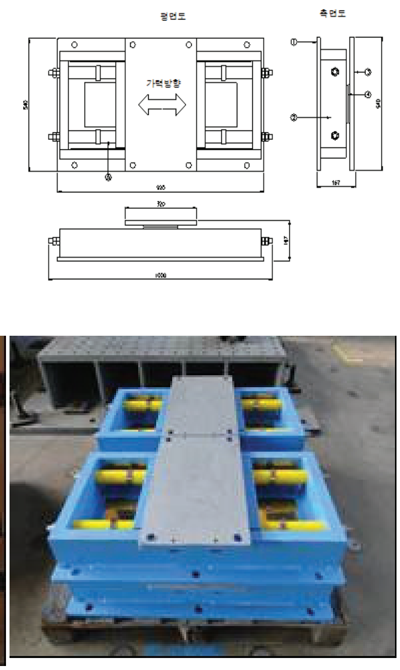
Isolators

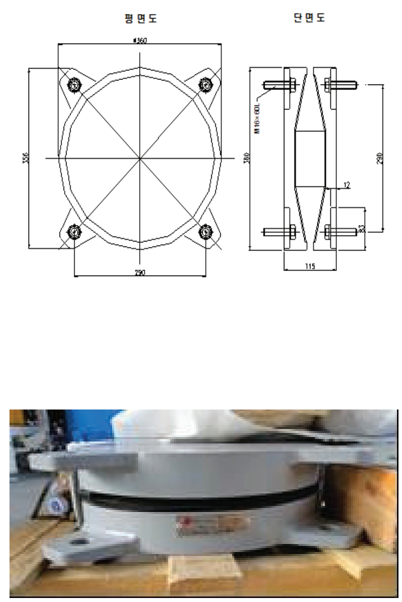
Base isolated system used for test are LRB made of lead-rubber and MER(mass energy regulator) applied EQS and FPS using pendulum movement of friction surface. These devices were designed with design load of 250KN and period of 1.75sec. Specifications of each device are in Table 1. and Figure 1. shows types of device. In testing, the base isolated system was depressed by 4 concrete blocks to distribute load of 100 ton.

Table 1. Specification of isolators

isolator	Design period(sec)	Max. displacement (mm)	K_{eff} (kN/mm)	K_1 (kN/mm)	K_2 (kN/mm)	F_y (kN)
LRB	1.75	200	0.323	19.59	0.26	5.6
EQS	1.75	200	0.292	13.86	0.23	11.0
FPS	1.75	200	0.313	6.25	0.25	6.3







(c) FPS

(a) LRB

(b) EQS

Figure 1. types of isolators and drawings

Shaking Table

For vibration test of the object of 100 ton, a special sliding table with LM guide was manufactured. The sliding table could perform 1 directional vibration test by connecting hydraulic actuator which can enforce maximum 120 ton. Figure 2. Shows configuration and dimension of the table.

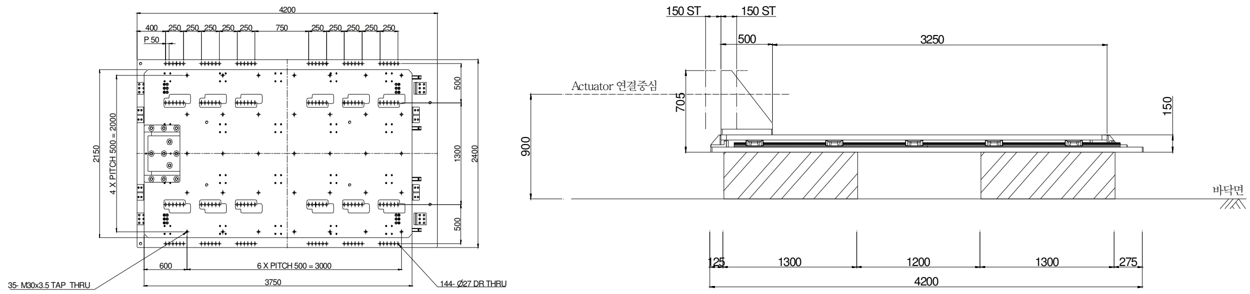
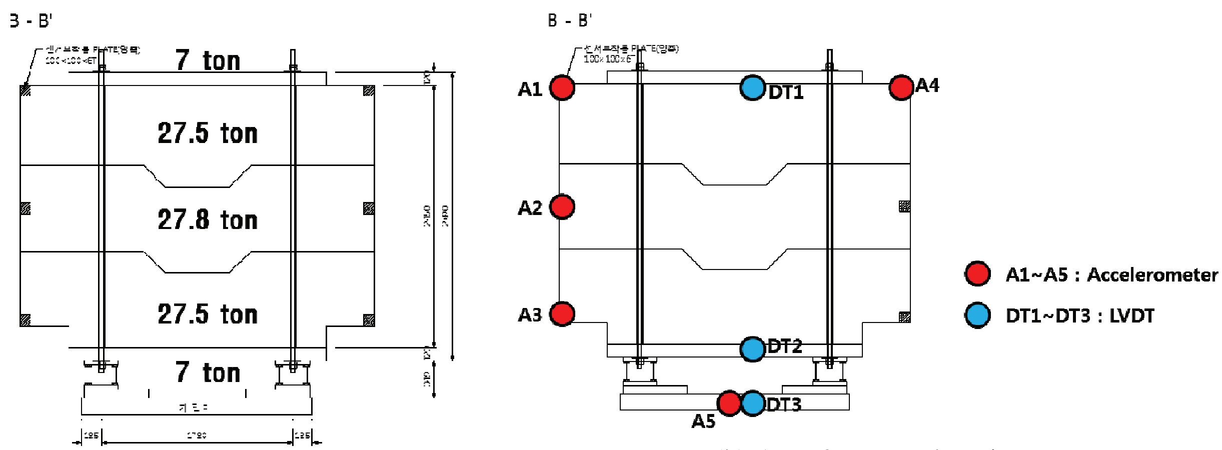


Figure 2. Shaking Table

Concrete Block

Concrete block installed on the top of the base isolated system as a loading object are manufactured in 3 pieces considering delivery and the capacity of crane in the lab and then assembled for use. It was manufactured in shear key type as in Fig. 3 (a), and was solidly combined using prestressing steel bar to be moved as one mass.



(a) concrete block (b) Acc. & LVDT location

Figure 3. Experiment set up

TEST METHOD

Input Motions

Seismic wave used for the test are 3 real earthquake records including El Centro, Taft and Kobe.It attempts to analyze the relation between acceleration level of input motion and seismic response of base isolated structure by changing PGA values of seismic wave. The acceleration level of each seismic wave was adjusted to PGA level equivalent to 50%, 75%, 100% and 125% of PGA based on El Centro seismic wave. The acceleration level of input motion by seismic wave is in the following table.

Table 2. Input motion

Input motion	Test name	PGA(g)	PGA ratio(%)	Test time(sec)
El Centro	E-1	0.17	50	60
	E-2	0.26	75	60
	E-3	0.35	100	60
	E-4	0.44	123	60
Taft	T-1	0.17	97	60
	T-2	0.26	146	60
	T-3	0.35	194	60
	T-4	0.44	243	60
Kobe	K-1	0.17	21	30
	K-2	0.26	31	30
	K-3	0.35	41	30

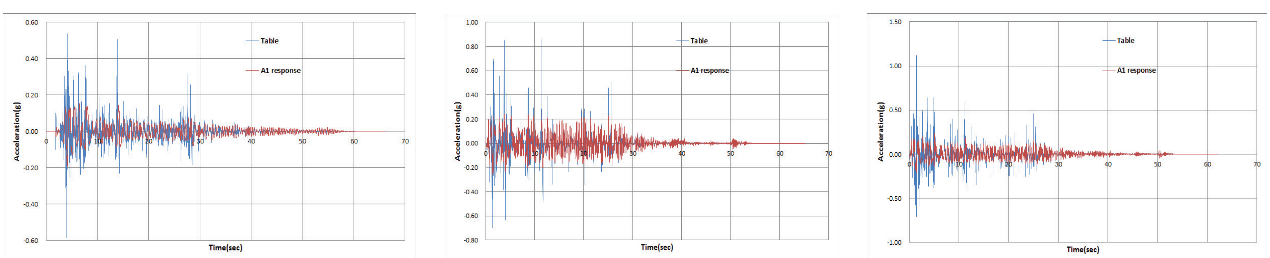
Test Response

Acceleration and displacement data were recorded during shaking table test. Measuring sensors are attached on the base isolated system on the sliding table as shown in Figure 3(b). Acceleration recorded 128 data per second, and displacement recorded 50 data per second.

TEST RESULTS

Acceleration response

In seismic test, to check decrease of acceleration by each base isolated system, acceleration response of sliding table, and A1 location response of base isolated system were compared. Table 3. shows acceleration response and decrease rate. Figure 4. shows response graph in case of inputting El Centro PGA 100% seismic wave representatively.



(a) LRB (b) EQS (c) FPS

Figure 4. Acceleration time history - El Centro PGA 100%

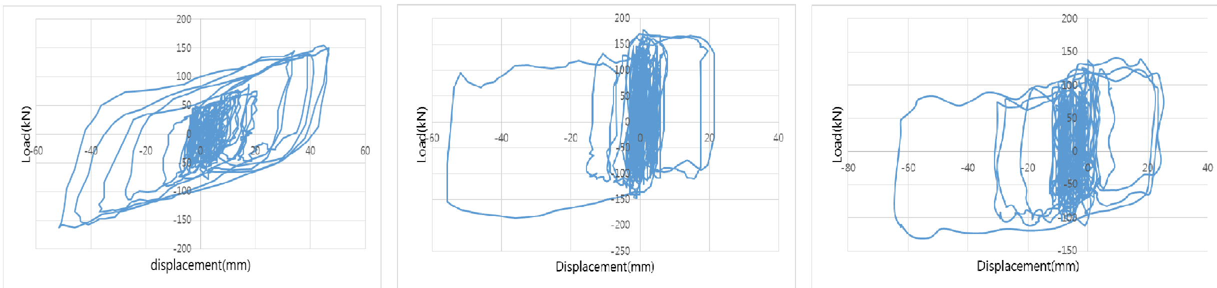
By type of input motion, the acceleration reduction ratio of each base isolated system is distributed between 60 and 82%. It is confirmed that when the maximum acceleration of input motion increased, the response acceleration did not exceed maximum 0.3 g.

Table 3. Acceleration reduction ratios by isolator type

Input motion	Test name	Data location	LRB	EQS	FPS
El Centro	E-1	Table max. acc.(g)	0.39	0.79	0.68
		A1 acc.(g)	0.12	0.26	0.2
		Acc. Reduction ratio(%)	68.1	66.4	70.8
	E-2	Table max. acc.(g)	0.43	0.9	0.66
		A1 acc.(g)	0.17	0.28	0.19
		Acc. Reduction ratio(%)	60.5	68.6	71.6
	E-3	Table max. acc.(g)	0.58	0.86	1.12
		A1 acc.(g)	0.2	0.26	0.24
		Acc. Reduction ratio(%)	65.5	69.5	78.6
	E-4	Table max. acc.(g)	0.65	1.06	1.03
		A1 acc.(g)	0.21	0.29	0.26
		Acc. Reduction ratio(%)	67.7	72.7	74.9
Taft	T-1	Table max. acc.(g)	0.34	0.63	0.53
		A1 acc.(g)	0.1	0.27	0.18
		Acc. Reduction ratio(%)	70.6	57.5	65.2
	T-2	Table max. acc.(g)	0.58	1.05	0.74
		A1 acc.(g)	0.15	0.27	0.31
		Acc. Reduction ratio(%)	74.1	74.6	58.6
	T-3	Table max. acc.(g)	0.71	1.05	0.93
		A1 acc.(g)	0.16	0.29	0.21
		Acc. Reduction ratio(%)	77.5	72.7	77.6
	T-4	Table max. acc.(g)	0.72	1.11	1.078
		A1 acc.(g)	0.2	0.284	0.228
		Acc. Reduction ratio(%)	72.2	74.4	78.8
Kobe	K-1	Table max. acc.(g)	0.37	0.58	0.5
		A1 acc.(g)	0.14	0.25	0.18
		Acc. Reduction ratio(%)	62.2	57.9	63.3
	K-2	Table max. acc.(g)	0.49	0.97	0.79
		A1 acc.(g)	0.2	0.29	0.24
		Acc. Reduction ratio(%)	59.2	70.2	68.9
	K-3	Table max. acc.(g)	0.69	1.29	0.98
		A1 acc.(g)	0.25	0.28	0.24
		Acc. Reduction ratio(%)	63.8	78.2	75.6

Displacement Response

To check displacements of base isolated systems in vibration test, the relative displacement of load measured at actuator and DT1 location was expressed in graph and the maximum displacement was sorted out in a table 4.



(a) LRB (b) EQS (c) FPS

Figure 5. Load-displacement curve - El Centro PGA 100%

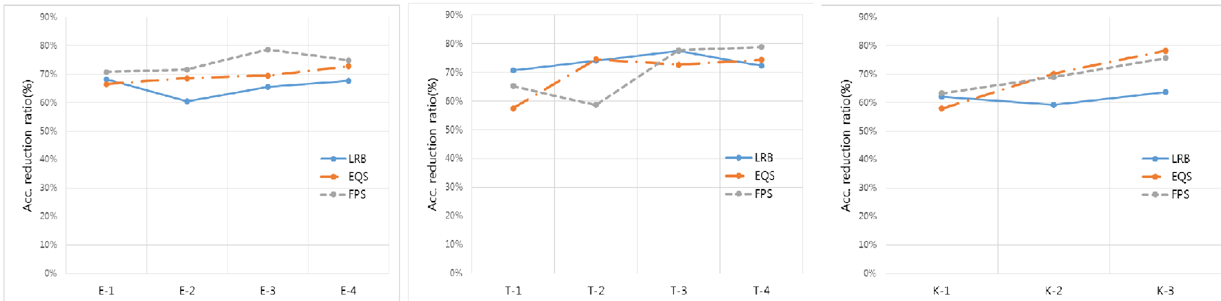
Table 4. Max. relative displacements of isolator types

Input motion	Test name	Displacement(mm)		
		LRB	EQS	FPS
El Centro	E-1	30.25	8.74	15.65
	E-2	42.95	28.34	42.97
	E-3	51.73	55.62	64.43
	E-4	65.33	77.12	73.25
Taft	T-1	26.25	10.73	17.64
	T-2	42.86	25.49	31.36
	T-3	73.1	47.76	69.31
	T-4	124.85	83.88	124.94
Kobe	K-1	42.95	12.72	21.5
	K-2	87.83	42.98	68.38
	K-3	114.22	80.12	100.58

EVALUATION TEST RESULTS

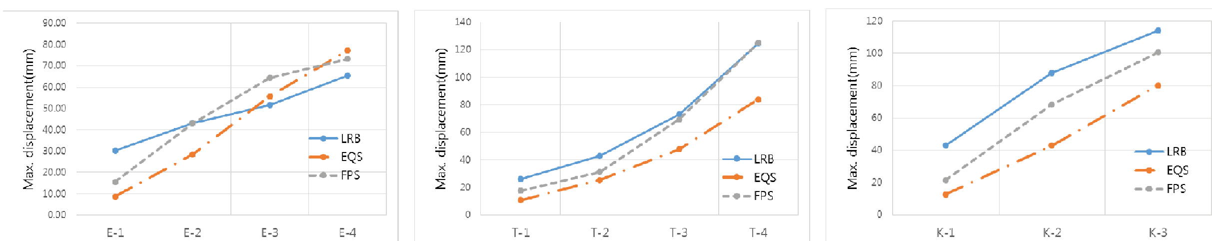
When acceleration response decrease rate by base isolated system is expressed against acceleration level of each seismic wave, as in the following figure, if acceleration level increases, acceleration reduction ratio by base isolated system increased. And, the acceleration reduction rate by EQS and FPS became larger than LRB.

As for displacement, except for the tests on PGA 100% and 125% of EL Centro seismic wave, the maximum displacement was relatively small for EQS and LRB had large displacement.



(a) El Centro (b) Taft (c) Kobe

Figure 6. Acc. reduction ratio of each input level



(a) El Centro (b) Taft (c) Kobe

Figure 7. Maximum displacement of each input level

CONCLUSION

For vibration test of 100 ton base isolated structure, a special sliding table was manufactured and 3 base isolated systems such as LRB, EQS and FPS were used. As a result of acceleration and displacement response measured by vibration test, the following conclusions were drawn.

- As a result of vibration test on LRB, EQS and FPS, the acceleration reduction ratio was 60~82%, and the maximum response acceleration did not exceed 0.3g. If acceleration level of input motion increases, acceleration reduction ratio by base isolated system increases. While there is slight different by input motion, it was found that EQS had considerable acceleration decrease effect.
- For EQS and FPS, it is difficult to find 1st hardness value of frictional base isolated system. When the maximum displacement was checked, the displacement of EQS device was the lowest and LRB had the largest displacement.
- While current nuclear power plant's base isolation design has focused on LRB design standards, it is determined that various base isolated systems need to be reviewed considering use performance, quality and reliability of the device.

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