ZEB Demonstration Building in Taisei Technology Center

Taro MIZUTANI, Kaori TATEYAMA, Ryota MASEKI, Aiko NII

Taisei Corporation

1 INTRODUCTION

This building, which is called ZEB Demonstration Building, is an office building which has been constructed in order to verify Zero Energy Building (ZEB) in Taisei Technology Center in Japan. In order to acquire the net zero energy building even in the densely urban area, many advanced environmental technologies are incorporated into the building. The plan dimensions of the building are about 30 m x 14 m. The building height is 16.25 m and the building has 3 stories. The short-stroke seismic isolated system is applied to this building.

[Outside View] [Inside View]

Figure 1 - ZEB Demonstration Building with Short-Stroke Seismic Isolated System

After the Great East Japan Earthquake, apprehension about long-period and long-duration earthquakes and huge earthquakes leads to growing demands for seismically isolated buildings for the purpose of protecting property and functions or achieving Business Continuity Planning after earthquakes. Seismically isolated buildings, which can mitigate the response displacements of isolation interface in comparison with the conventional seismically isolated building in order to maximize the building areas, are highly required especially for relatively small sites often located in densely urban areas.

However, adding more damping to isolation interface for the purpose of mitigating response displacement during major earthquake generally results in larger response acceleration during minor or moderate earthquake. Generally, mitigating the response displacement of the isolation interface and mitigating the response acceleration of the superstructure are mutually exclusive.

This paper shows a solution to the problem by using a newly developed seismically isolated system with a passive-switching oil damper and introduces ZEB Demonstration Building.

2 DEVELOPMENT OF SHORT-STROKE SEISMIC ISOLATED SYSTEM

2.1 *Outline of short-stroke seismic isolated system*

The short-stroke seismic isolated system is a variable-performance type seismic isolated system with the passive-switching oil damper. This system can minimize the required clearance between buildings and moat walls and maximise the building areas in order to make the maximum use of sites. The newly developed passive-switching oil damper, which is a kind of variable type oil damper, can control the response displacement of isolation interface within design limit during major earthquakes and also keep the response acceleration lower than acceptable level during minor or moderate earthquakes. The lower damping coefficient is assigned to the passive-switching oil damper in the initial condition to prepare for more frequent minor or moderate earthquakes. In the case of major earthquake, the passive-switching oil damper mechanically switches from the lower damping coefficient to the higher one once the response displacement exceeds a designated displacement. The principle of short stroke seismic isolated system is shown in Fig. 2.

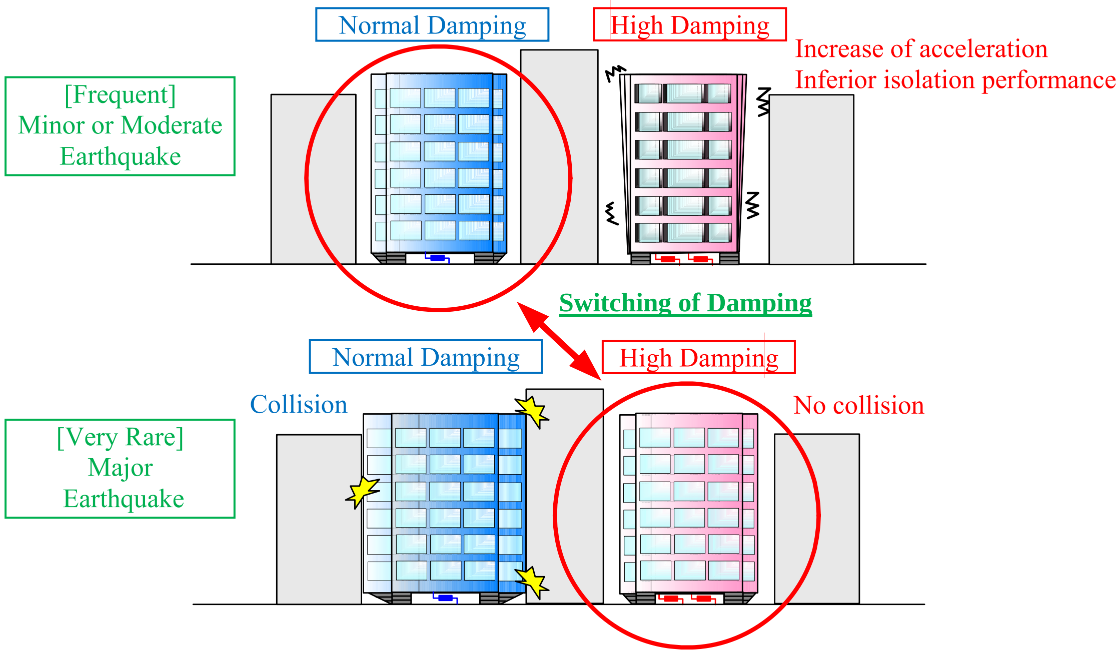


Figure 2 - Principle of Short Stroke Seismic Isolated System

A variable-performance type seismic isolated system with an electromagnetic-powered variable oil damper has already been put to practical use in Japan. However, the variable-performance type seismic isolated system requires a control system including sensors and computers and a monitoring system for high reliability. Besides, appropriate maintenance of those systems is essential. On the other hand, the short-stroke seismic isolated system with the passive-switching oil damper doesn't require any control system or any monitoring system. Besides, high reliability and simple maintenance can be easily acquired.

2.2 *Passive-switching oil damper*

Fig. 3 shows the appearance and the oil-pressure route of the passive-switching oil damper. A displacement detection rod for measuring displacement, a mechanical shut-off valve for variable damping coefficient and a low damping valve for the initial damping condition are added to a conventional oil damper.

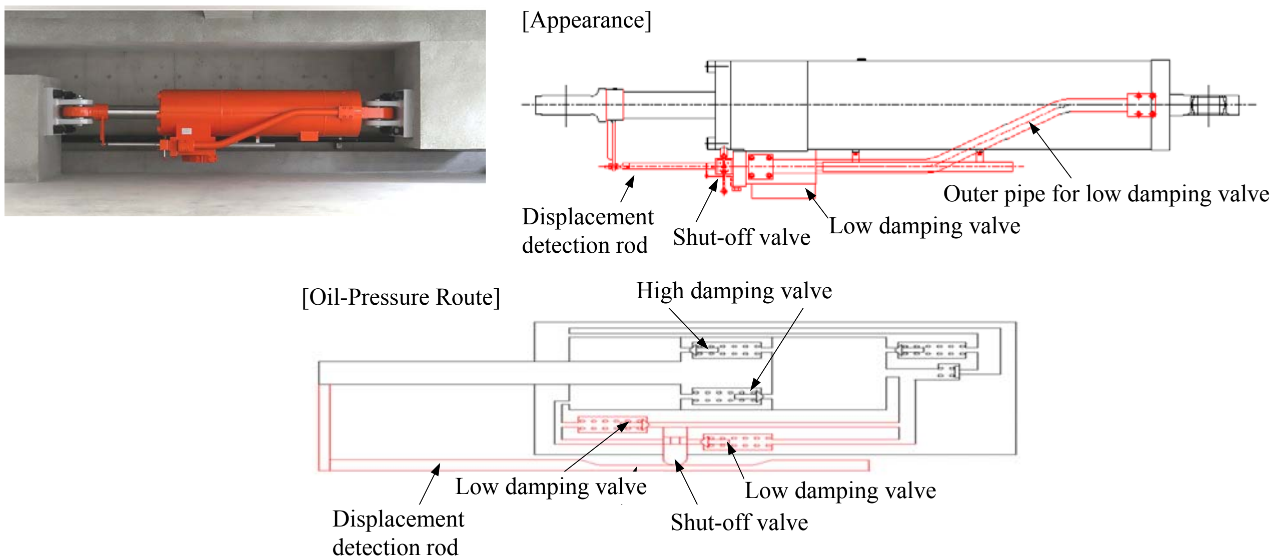


Figure 3 - Appearance and Oil-Pressure Route of Passive-Switching Oil Damper

Fig.4 shows the mechanical principle of the passive-switching oil damper. If the damper displacement is smaller than the designated displacement for switching, the shut-off valve keeps open and the oil can flow through both the low damping valve and the high one so that the low damping coefficient mode can be acquired. If the damper displacement exceeds the designated displacement for switching, the shut-off valve gets mechanically closed and the oil can flow through the high damping valve only so that the damping coefficient is mechanically switched from the lower one to the higher one. Once the shut-off valve gets closed, the shut-off valve keeps closed and the damping coefficient keeps high. After major earthquakes which activate this system, the initial low damping mode is recovered by using a manually operated lever. The maintenance and the handling of the passive-switching oil damper are relatively easy because it doesn't require any energy supply from outside at all.

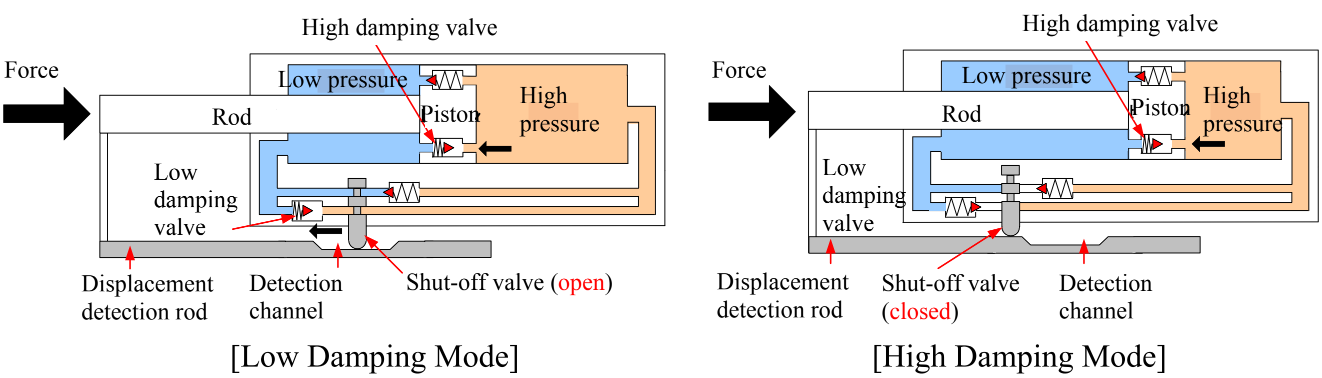
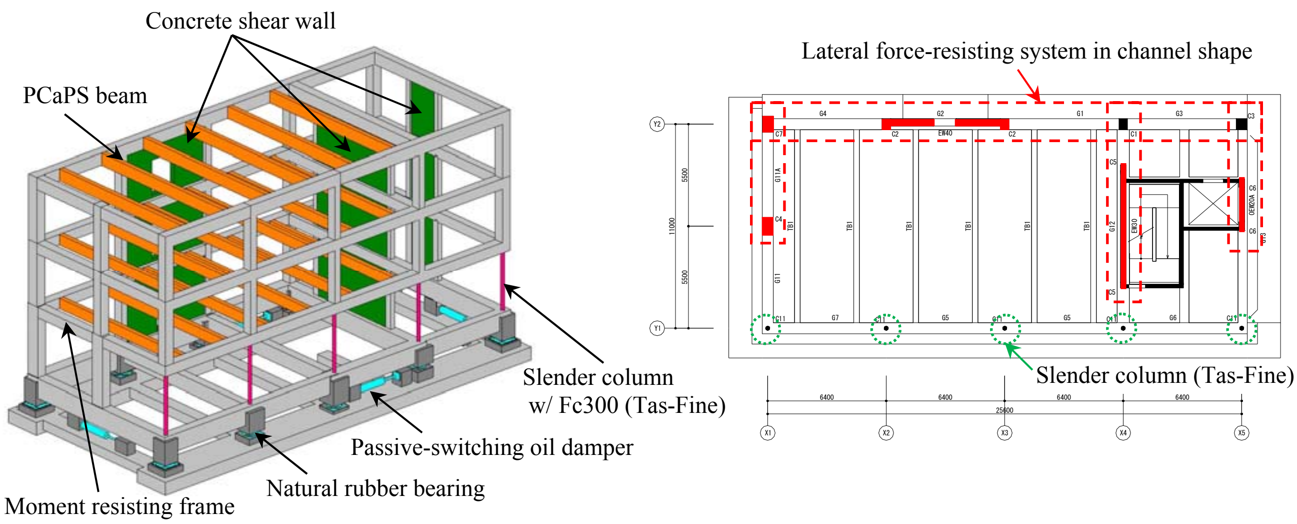


Figure 4 - Mechanical Principle of Passive-Switching Oil Damper

3 APPLICATION OF SHORT-STROKE SEISMIC ISOLATED SYSTEM

3.1 *Structural system of superstructure*

Fig. 5 shows the structural system of the superstructure. The adopted seismic force-resisting system is reinforced concrete shear wall with moment resisting frame. The adopted foundation system is continuous footing. Nominal concrete strength of Fc 27 N/mm^2 to 36 N/mm^2 is used for in-situ concrete.



[Outline of Structural System] [Structural Plan]

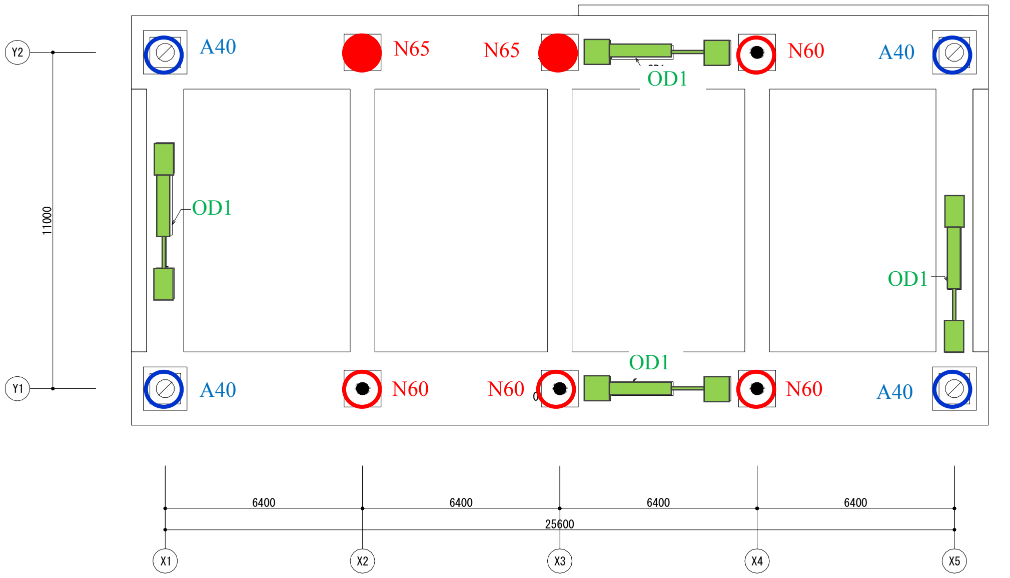
Figure 5 - Structural System of Superstructure

The slender columns (Tas-Fine) with ultra-high strength concrete of Fc 300 N/mm^2 are incorporated into the entrance hall in the first floor. By adopting the slender columns which have the diameter of 220 mm and its height is 3750 mm (height /diameter = 17), the entrance hall can get open and spacious. Although the uneven distribution of lateral stiffness due to the slender columns located in one side usually causes torsional behaviour during earthquake, the torsional behaviour is significantly mitigated by adopting the seismically isolated system and arranging the lateral force-resisting system in the channel shape.

3.2 *Outline of short-stroke seismic isolated system*

The seismically isolated system is composed of isolators and dampers. As for isolators, the natural rubber bearing and the flat sliding bearing are adopted. As for dampers, the passive-switching oil damper is adopted. Fig. 6 shows the device arrangement of isolation interface. The design clearance between the building and the moat wall is 300mm which is almost half of the typical clearance of conventional seismically isolated structures. The response displacement due to major earthquake which has 500 years return period is less than 200mm.

Fig. 7 shows the damping property of the passive-switching oil damper. The maximum damping force is 750 kN in the higher damping mode. The designated displacement for switching is 100 mm. If the response displacement exceeds the designated displacement of 100 mm, the damping mode switches from the lower mode to the higher one. Table 1 shows the damping ratio of the first mode derived from the complex eigenvalue analysis with the superstructure seismic mass of 22,800 kN. The effective damping coefficient in Table 1 is calculated from the equivalent damping performance at the response velocity of about 55 cm/sec due to major earthquake which has 500 years return period.



Natural Rubber Bearing				Flat Sliding Bearing (low friction type)				Passive-Switching Oil Damper			
ID	Symbol	Diameter (mm)	Nos. of Units	ID	Symbol	Diameter (mm)	Nos. of Units	ID	Symbol	Nos. of Units	
N60		600	4	A40		400	4	OD1		X	2
N65		650	2							Y	2

Figure 6 - Plan of Isolation Interface

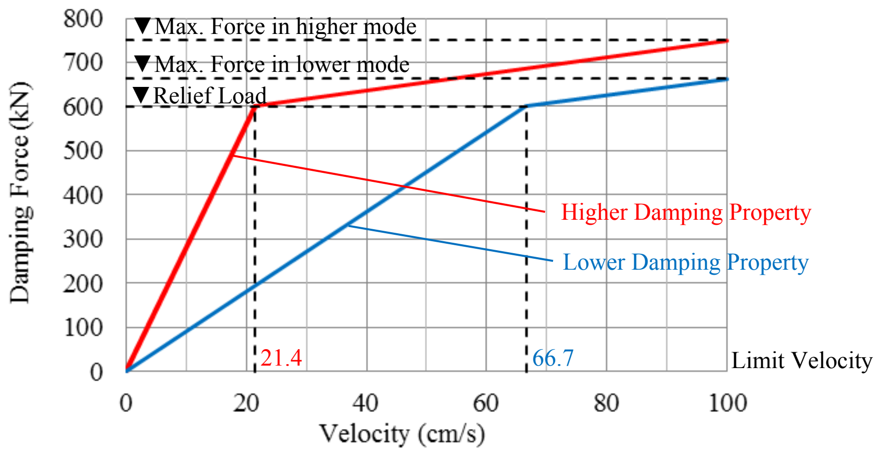


Figure 7 - Damping Property of Passive-Switching Oil Damper

Table 1 – Damping Ratio of First Mode

Damping Coefficient	Damping Ration of First Mode (%)	
	Higher Damping Mode	Lower Damping Mode
Initial Damping Coefficient C1	96.6	28.0
Equivalent Damping Coefficient Ce	41.2	-

3.3 *Performance of short-stroke seismic isolated system*

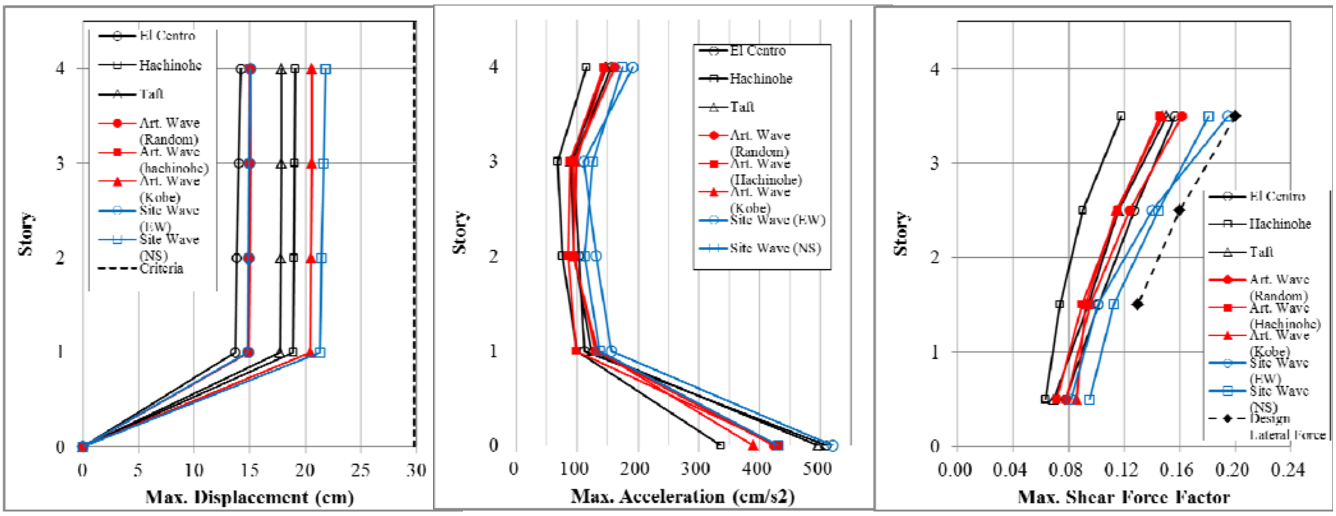
A four-mass stick model whose mass represents each floor from the first floor to the roof is used for non-linear time history analysis. As for the modelling of the isolation interface, the natural rubber bearing is modelled as linear spring and the flat sliding bearing is modelled as bi-linear spring. The oil damper is modelled as viscous element and the bi-linear damping property against relative velocity is assigned. The lower damping coefficient is assigned to the passive-switching oil damper in the initial condition. After exceeding the designated displacement of 100 mm, the passive-switching oil damper keeps the higher damping coefficient. In addition, the delay time of 0.3 seconds for switching from the lower mode to the higher one is also taken into account. As for the seismic ground motion, three recorded waves, three artificial waves and the site wave which is the maximum credible ground motion in the site are considered. The three recorded waves are multiplied by factors to have the maximum velocity of 50 cm/sec according to Japanese regulations. The three artificial waves are generated from the corresponding response spectrum of 500 years return period defined by Japanese regulations.

The first natural periods of the superstructure in X-direction and Y-direction are 0.38 seconds and 0.35 seconds, respectively. The equivalent periods of isolation interface at shear strain of 100 % (117 mm) and 250 % (293 mm) are 4.34 seconds and 4.48 seconds, respectively. Fig.8 shows the maximum response values in X-direction against the recorded waves, the artificial waves and the site wave. The maximum response displacement of the isolation interface almost satisfies the target displacement of 200 mm and is enough smaller than the clearance of 300 mm between the building and the moat wall.

In order to verify the effect of the variations of the designated displacement for switching and the variations of delay time for switching, the additional analyses which consider those variations are conducted for adopting the passive-switching oil damper in addition to the variations of the isolation device performance. As for those variations, some analyses are conducted considering the variations of the displacement for switching (100 mm ＋- 5 mm) or the variations of the delay time for switching (0.3 seconds +- 0.3 seconds). Because the results of the analyses show that the effect of those variations on the maximum response values is very small (about 1 to 2 %), it is confirmed that the effect on the structural integrity is also very small.

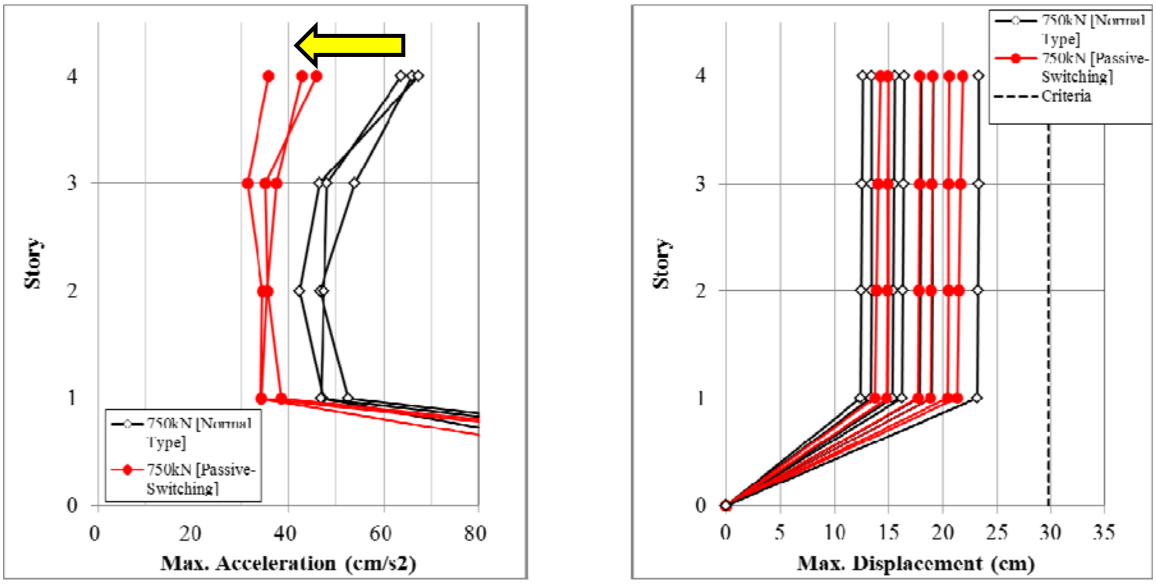
The analysis which takes account of switching time lags among passive-switching oil dampers due to the torsional behaviour of the superstructure and the isolation interface is performed by using a simplified 3-D analysis model. The result of this case shows that the effect on the maximum response is also very small.

In order to confirm the effect of the passive-switching oil damper on the mitigation of response acceleration, the response values with the passive-switching oil damper are compared with ones with a conventional oil damper which has the same maximum damping force (750 kN). Fig. 9 shows the comparison between the maximum response values with the passive-switching oil damper and ones with the conventional oil damper. For moderate earthquake, the three recorded waves are multiplied by factors in order to have the maximum velocity of 25 cm/sec. Although the maximum displacement due to major earthquake with the passive-switching oil damper is almost same as one with the conventional oil damper, the maximum acceleration due to moderate earthquake with the passive-switching oil damper is decreased significantly by 30 to 40 % in comparison with one with the conventional oil damper.



[Displacement] [Acceleration] [Lateral Shear Force Factor]

Figure 8 - Maximum Response Values (major earthquakes)



[Acceleration: moderate earthquake] [Displacement: major earthquake]

Figure 9 - Comparison of Maximum Response Values between Passive-Switching Oil Damper and Conventional Oil Damper

4 CONCLUSION

The passive-switching oil damper has been developed and the short-stroke seismic isolated system with the damper has been implemented in the ZEB demonstration building. The design clearance of 300 mm between the building and the moat wall is acquired, which is almost half of the typical clearance of conventional seismically isolated structures. Besides, the superior performance on the response acceleration during minor or moderate earthquake is also acquired by virtue of the passive-switching oil damper. The passive-switching oil damper has possibilities of various kinds of applications such as seismic retrofit, upgrade of existing seismically isolated building, or countermeasure against huge earthquake.

Acknowledgements

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