RESPONSE CONTROL BY DAMPER DEVICES OF HIGH-RISE BUILDING UNDER LONG-PERIOD GROUND MOTION

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ABSTRACT

This study attempts to apply Performance Curve method to design dampers for high-rise buildings in order to reduce the response under long-period ground motions; and to analyze the effects of response control of the high-rise buildings using damper devices.

In order to analyze the dynamic response, the target high-rise building is a 37-story building located in Tokyo; and five different earthquakes, namely BCJ-L2, El Centro 50 kine, Kobe, Osaka and Nagoya are used. Likewise, the target high-rise building is modeled as multi-degree of freedom (MDOF) systems, and to perform its dynamic response using damper devices, such as steel, oil and viscous dampers, the software called MDOF-OS was modified by the writer based on the software coded by Dr. Taiki Saito. Its algorithm is mainly based on Operator Splitting (OS) method because of its good accuracy and stability for large time integration steps. In this analysis, the target high-rise building without dampers reaches the maximum response under Nagoya earthquake because of being the strongest long-period ground motion.

Finally, steel and oil dampers are designed using a Performance Curve method developed by Prof. Kasai to be added into the target high-rise building in order to reach a good seismic performance under Nagoya earthquake. And a comparison among these dampers is carried out in order to analyze the effect of response control.

Keywords: High-rise building, long-Period ground motion, passive control, Performance curve method.

INTRODUCTION

In the last decades, the response of high-rise buildings caused by long-period ground motions has been a subject of research, considering that responses of structures with long natural period, such as high-rise buildings become very large in case of long-period ground motions; it is desirable to control the response of these structures to avoid damages and insure the life safety. In that sense, the response control must especially be applied on existing high-rise buildings, and these measures must also be taken in account in the design of new high-rise buildings.

In order to control the response of these structures, many types of passive dampers devices were developed in Japan, these devices are connected to the frame to dissipate the seismic input energy, therefore reducing the kinetic energy and vibration of the building.

Prof. Kasai developed and proposed a simple and useful design procedure for buildings with dampers, so-called Performance Curve method, which is described in the Manual for Design and Construction of Passively-Controlled Buildings published by Japan Society of Seismic Isolation (JSSI). However, few researches of application of response control devices to high-rise building to solve the aforementioned problem of high-rise buildings under long-period ground motions were carried out.

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DATA

Target High-rise Building

The target high-rise building is located in Chuo-ku, Tokyo; and its construction end was in 1991. The total height is 119 m, compose by 40 floors, as is shown in Figure 1. In order to model this building, one basement and two minor upper floors are neglected, so that it is supposed as 37-story building, as is shown in Figure 3, with a total height of 108.9 m. On the other hand, this structure is symmetric in plan as is shown in Figure 2.


Figure 1. Building Photo

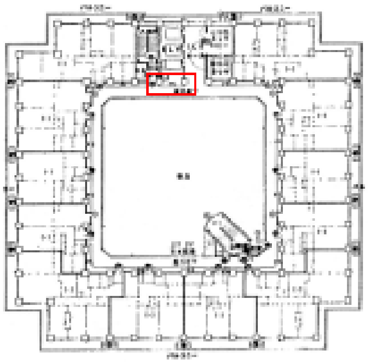


Figure 2. Plan view

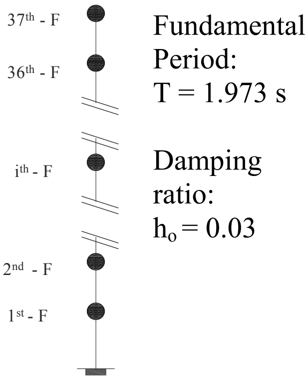


Figure 3. 37-DOF System

Input Earthquake Ground Motions

Table 1. Summary of used Input Earthquake ground motions

Earthquake	Type earthquake	Characteristics
BCJ-L2	Design earthquake	Building Center of Japan (Level 2). Artificial wave.
El Centro 50 kine	Design earthquake	1940 Centro Earthquake, NS component. Amplified to obtain a maximum velocity of 50 cm/s.
Kobe	Observed earthquake	1995 Hyogoken Nanbu Earthquake, NS component.
Osaka	Long-period ground motion	An artificial wave set in NS component, simulated for Nankai Earthquake.
Nagoya	Long-period ground motion	Artificial wave set in EW component, simulated for Tokai-Tonankai Earthquake.

Since this study attempts to analyze the effect of damper devices into the target high-rise building, Nagoya earthquake is selected because of being the strongest long-period ground motion.

Long-period ground motions greatly influence structures with long fundamental period, approximately from 2 up to 6 s, as is shown in velocity spectra comparison as is shown in Figure 4.

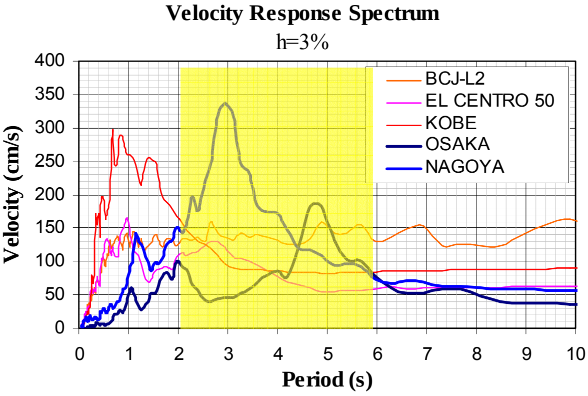


Figure 4. Comparison among earthquake ground motions

THEORY AND METHODOLOGY

Performance Curve Method

A damping structure controls any displacement, velocity and acceleration response of a building by means of stiffness and viscosity added by dampers attached to the main resisting frame when an earthquake occurs. The performance curves are the visualized response conditions in a single-mass system. The frame stiffness has been used as a reference for all the stiffness values and to plot the performance curves as is shown in Figure 5.

The displacement reduction ratio, R_d, is the initial parameter to find out the optimum amount of dampers into the performance curve and it is defined by the following Equation:

$$R_d = \frac{\text{Maximum target drift}}{\text{Maximum response drift}}$$

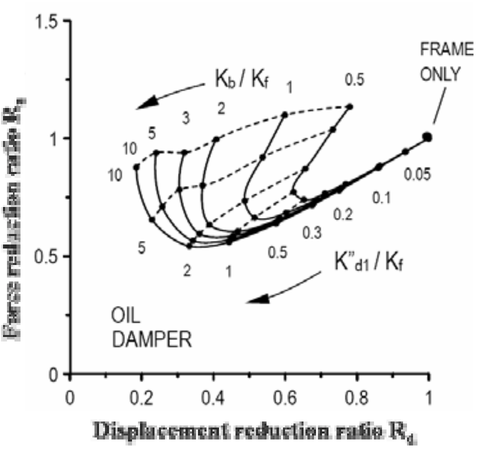
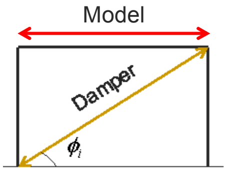


Figure 5. Performance curve

Design of dampers

A general procedure to design dampers is described as follows:

- Target performance and design conditions.
- Calculating the displacement reduction ratio.
- Plotting the damping performance curve.
- Determining the required damper scales for each story. The amount of dampers from the performance curve is obtained to equivalent single degree of freedom system; therefore the actual amount of dampers is obtained by means of a linear proportional distribution along MDOF system.
- Converting to the damper axial values and determining the specifications. The MDOF system assumes a horizontal displacement of dampers; thereby a conversion of forces and displacements from horizontal to diagonal direction using the incidence angle is done in order to design dampers at each floor.
- Designing dampers.



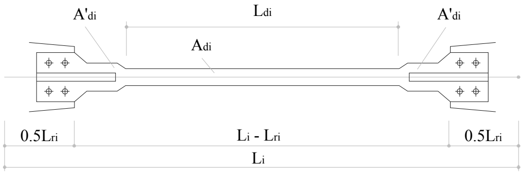


Figure 6. Steel damper used in this study. (Buckling Restrained Damper)

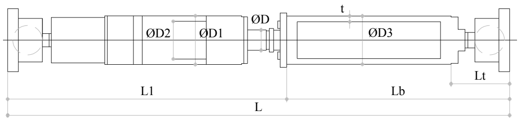


Figure 7. Oil damper device used in this study.

RESULTS AND DISCUSSION

Dynamic Response of the Target High-rise Building without Damper Devices

The maximum values of dynamic response under the above earthquake ground motions are shown in Figure 8 and 9, and summarized in Table 6 which shows that the maximum response is obtained under Nagoya earthquake, being the maximum drift 1/80 rad at the 14-floor and the ductility factor is 1.594.

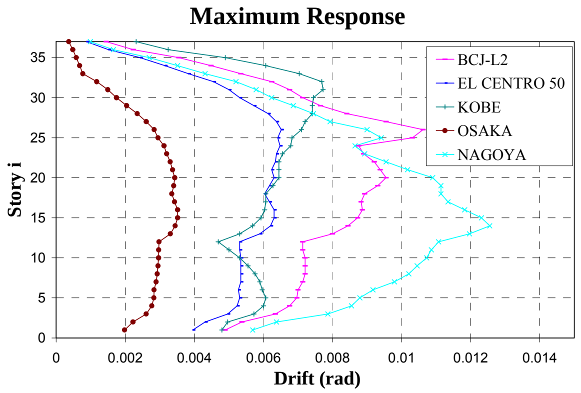


Figure 8. Maximum Story drifts

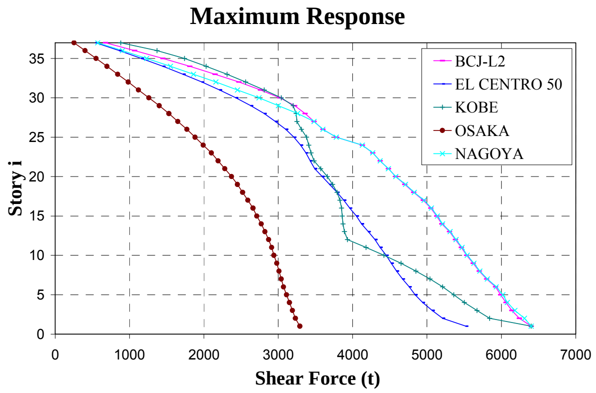


Figure 9. Maximum Story shear forces

Table 2. Maximum values of dynamic response under earthquake ground motions

Earthquake ground motion	Base shear force *t*	Maximum drift *rad*	Ductility (μ)
BCJ-L2	6400	1/94 at 26-F	1.346
El Centro 50	5520	1/153 at 26-F	0.836
Kobe	6400	1/129 at 31-F	1.195
Nagoya	6400	1/80 at 14-F	1.594
Osaka	3290	1/284 at 15-F	0.423

Design of dampers

The maximum story drift for designing high-rise buildings is 1/100 rad, and the obtained maximum story drift under Nagoya earthquake is 1/80 rad; therefore the reduction ratio, R_d, is 0.80. The obtained results for steel and oil dampers are shown in Table 3 and 4, respectively.

Steel dampers

Table 3. Specifications of steel dampers devices used in the design

Type	L mm	Lr mm	Ld mm	Plate	Ad cm^2	A'd cm^2
A	4066	407	3253	PL-22x250	55.0	137.5
B	4066	407	3253	PL-28x300	84.0	210.0
C	4066	407	3253	PL-30x320	96.0	240.0
D	4066	407	3253	PL-32x380	121.6	304.0
E	4066	407	3253	PL-38x400	152.0	380.0
E'	5327	533	4262	PL-38x400	152.0	380.0

Oil dampers

Table 4. Specifications of oil dampers used in the design

Type	Fdy KN	Cd KN.s/cm	Vd cm/s	L mm	L1 mm	Lb mm
A	1500	1350	900	4066	3000	1066
B	1000	900	300	4066	3000	1066
C	1500	1350	900	5327	3000	2327
D	1000	900	300	5327	3000	2327

The design of steel and oil damper was carried out and the arrangements of dampers at each floor are shown in Figure 10 and 11, respectively.

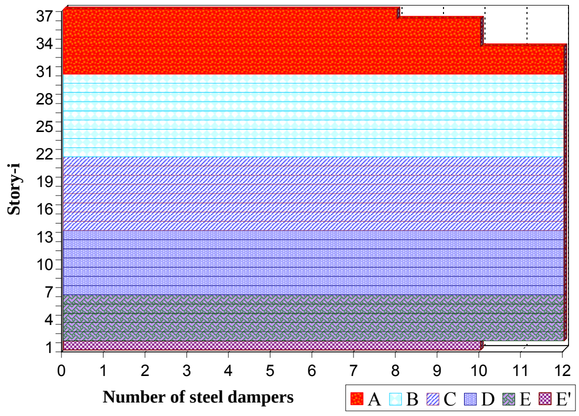


Figure 10. Arrangement of steel dampers

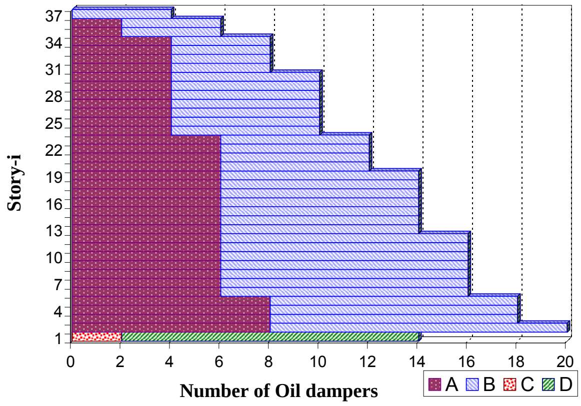


Figure 11. Arrangement of oil dampers

Dynamic Response of the Target High-rise Building with Damper Devices

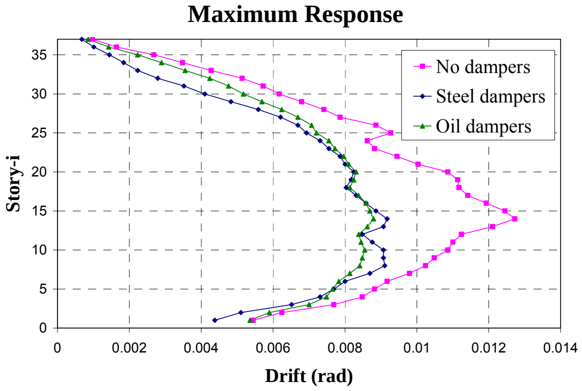


Figure 12. Comparison among maximum drifts

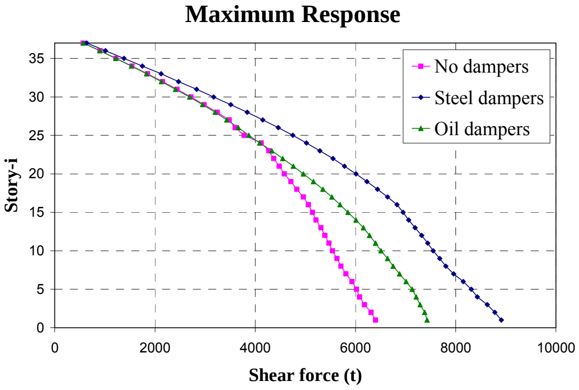


Figure 13. Comparison among maximum forces

As was supposed, the adding of dampers reduces considerably the dynamic response under Nagoya earthquake (the strongest long-period ground motion) in both cases, adding steel and oil dampers. The obtained maximum drift at the fourteen-floor is reduced closely to the target maximum drift, these differences are in 8% and 10% under the maximum target drift, 1/100 rad, as is shown in Table 5, with the adding of steel and oil dampers, respectively; these differences demonstrate the high control on buildings. Also, ductility factors are reduced in 19% and 24% adding steel and oil dampers, respectively.

Table 5. Summary of maximum response before and after adding dampers

Condition	Base shear-force t	Maximum drift rad	Ductility (μ)
No dampers	6400	1/80 at 14-F	1.594
Steel dampers	8910	1/109 at 14-F	1.293
Oil dampers	7430	1/114 at 14-F	1.216

CONCLUSION

In this study, an analytical investigation on passive response control using steel, oil and viscous dampers has been presented in order to analyze their effects on an actual high-rise building in Tokyo.

The target high-rise building without dampers reaches the maximum response under Nagoya earthquake because of being long-period ground motion. It verifies that buildings with long fundamental period, approximately from 2 up to 6 seconds, are greatly influenced by long-period ground motions.

The design of dampers was carried out for Steel and Oil dampers using Performance Curve method developed by Prof. Kasai. The responses under long-period ground motion after adding the above dampers satisfy the design safety requirement.

This procedure can be applied in general for high-rise buildings to design dampers in order to reduce the response under long-period ground motions, which are supposed to greatly influence these structures. This allows us avoiding severe damaged on high-rise buildings and insure the life safety, which are the desired targets in the design.

REFERENCES

Chopra A., 2007. Prentice Hall, Inc., New Jersey.

Higashino M. & Okamoto S., 2006. Taylor and Francis Group, New York.

JSSI Manual, 2004. Japan Society of Seismic Isolation (JSSI), Tokyo (in Japanese).

Kasai K., Fu Y. & Watanabe A., 1998. Journal of Structural Engineering.

Kasai K. & Kibayashi M., 2004. Proc., 13WCEE.

Kibayashi M., Kasai K. &, Tsuji Y., Kikuchi M., Kimura Y., Kobayashi T., Nakamura J. and Matsubsa Y., 2004. Proc., 13WCEE.

Tada M. & Pan P., 2006. International Journal for Numerical Methods in Engineering 2006.

Soda S., 2008. Lecture notes of International Institute of Seismology and Earthquake Engineering, Building Research Institute.

Iiba M. & Inoue N., 2008. Lecture notes of International Institute of Seismology and Earthquake Engineering, Building Research Institute.