Shaking Table Tests for a 10-story Frame using Combinations of Hysteretic and Viscous Dampers

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ABSTRACT :

A lot of researches on the seismic vibration control system show that they have effect on mitigating seismic damage. Most researches on structures with damper devices subjected to earthquake ground motions have carried out considering with using the one type of dampers, hysteretic or viscous one, only. However, there have been few investigations for the combinations of dampers with different performances in a vertical direction. The authors have presented the "combination-system" which is the seismic vibration control system using both hysteretic and viscous dampers in the previous research. The combination-system is made up of hysteretic dampers placed on the lower stories of the building and viscous dampers placed on the upper stories of it. Being combined with both dampers brings forward seismic control effects by its multiplier effects. This paper reports the results of the shaking table tests using together with these dampers. The experiments, using a 10-story frame, are carried out to substantiate the progress of seismic control effects by applying combination-system. Performance of specimens is discussed by referring to story shear, relative story displacement, story accelerations and absorbing energy of the dampers. In the combination-system, the characteristics of the hysteretic dampers and the viscous dampers are combined well.

KEYWORDS: vibration control, hysteretic damper, viscous damper, shaking table test

1. INTRODUCTION

The seismic vibration controlled structure has damper devices, which are the brace type, the stud type and so on, absorbing vibration energy. Those damper devices are divided into hysteretic and viscous types. These dampers are effective against the shearing deformation of the frame, but they are not effective against the bending deflection. So the new system, which is able to reduce responses of the high aspect ratio buildings, is necessary.

The authors have presented the "combination-system" which is the seismic vibration control system using both hysteretic and viscous dampers, and reported its effectiveness on reducing responses by a comparison between mono-using system and combination-system using numerical simulations of a 40-story steel-building.

Thus, the objective of this paper is to verify the effectiveness of the combination-system by the shaking table test of the compact 10-story frame.

2.TEST STRUCTURE MODEL

2.1. 10-Story Frame Model

2.1.1 Installation of Test Structure

Figure 1 shows the schematic diagram of the test subject. The 10-story frame with miniature capacity adjustable dampers was set up on the horizontal vibration table.

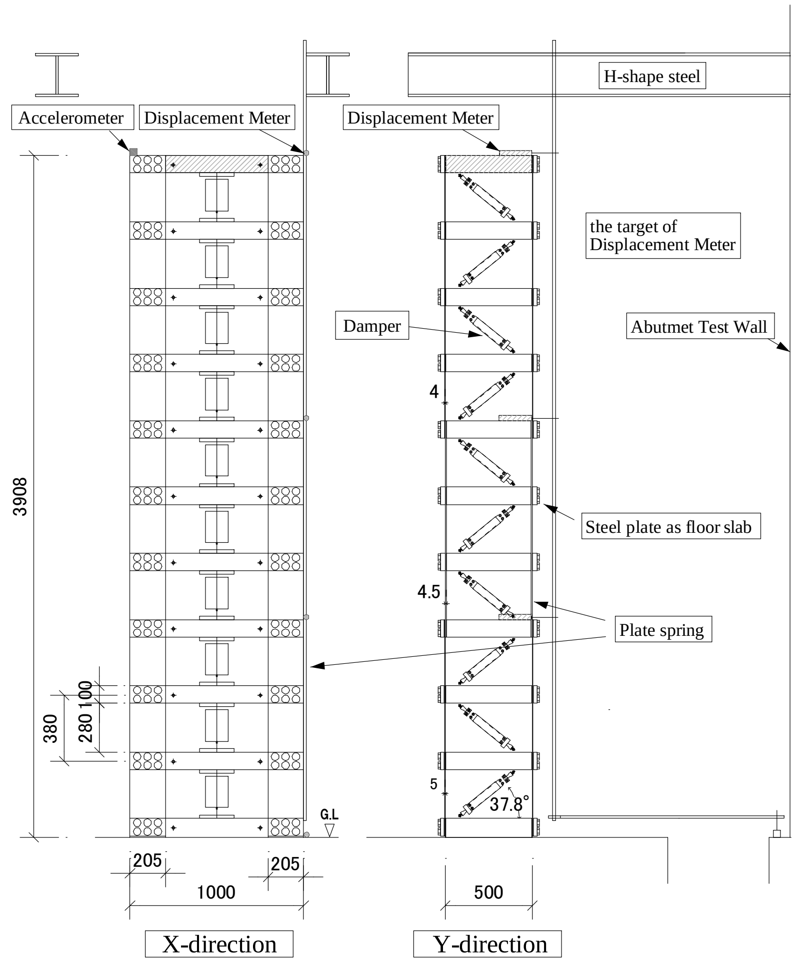

Figure 1. Schematic diagram of test subject

2.1.2 10-story frame model

This experiment system consists of the plate springs as the columns, the steel plates as the floor slab and the brace-type dampers. The plate spring and the steel plate were connected with 6 bolts. The size of this frame is 500mm in width and 4000mm in height. The steel plates 400 kg in weight is used for the each floor, so total weight is 4000 kg. This value means the limit of the shaking table. In addition the sizes of the plate springs or the dampers are fixed three levels by the height of the frame. The dimension and the stiffness of the plate springs are shown in Table 1.

Table 1. 10-story frame characteristics

floor	Breadth (mm)	Thickness (mm)	Stiffness (N/mm)
7 - 10	205	4.0	123
4 - 6	205	4.5	174
1 - 3	205	5.0	239

Each damper was placed on the center of the floor slab in the Y direction. The first natural period of the frame was 0.94 second without damper.

2.2. Hysteretic Damper

In this test, the friction damper was used for the hysteretic damper. The damper consisted of two friction plates and a sliding plate. The friction force, which means the damping force in the system, was obtained by fastening the bolts.

2.3. Viscous Damper

The viscous dampers consist of a square steel tube, a steel plate and viscosity. The viscous force is obtained by the shear force of viscosity that was in the gap between the square tube and the plate. The viscous damper force is given by the Eqn. 2.1 or Eqn. 2.2 involving the Damper Velocity (V), the Shear Area (S) and so on.

$$F = 4.12 \cdot \exp(-0.043 \cdot t) \cdot S \cdot \left(\frac{V}{d}\right)^{1.0} \quad \left[\frac{V}{d} < 1\right] \tag{2.1}$$

$$F = 4.12 \cdot \exp(-0.043 \cdot t) \cdot S \cdot \left(\frac{V}{d}\right)^{0.59} \quad \left[1 \le \frac{V}{d} < 10\right] \tag{2.2}$$

F : Viscous Force (kN)
t : Temperature of Viscosity (20°C)
S : Shear Area (mm2)
d : Shear Gap
V : Damper Velocity (cm/s)

In this test, we set the shear gap at 0.1 cm and adjusted the damper force by the shear area. Then, the temperature of the viscosity was 20 degrees Celsius.

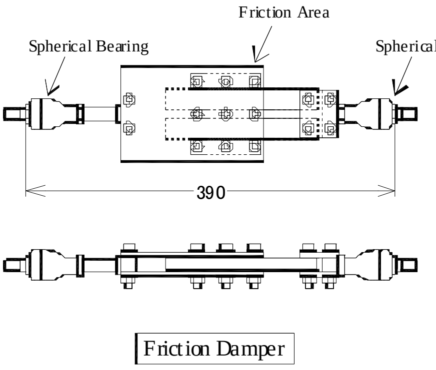

Figure 2. Schematic diagram of friction damper

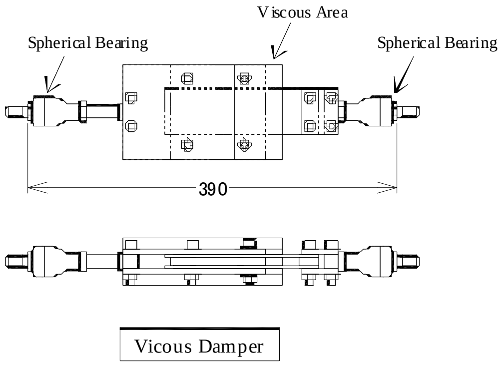

Figure 3. Schematic diagram of viscous damper

3.OVERVIEW OF EXPERIMENT

3.1. Combination of Damper

The combination-system was made up of the hysteretic dampers placed on the lower 6 stories of the frame and the viscous dampers placed on the upper 4 stories of it. Table 2 shows the notations of the 3 models.

Table 2. Notation of model

floor	HHH	VVV	HHV
7 - 10	H	V	V
4 - 6	H	V	H
1 - 3	H	V	H

H : hysteretic damper
V : viscous damper

3.2. Input Wave

To clarify fundamental characteristics of the model, the wave form with white noise was used as input motion. Further, to evaluate seismic behavior of the frame, several earthquake motions were used. The waves simulated from the notification wave having the characteristic of HACHINOHE EW that was the seismic wave recorded at Hachinohe in 1968, JMA KOBE NS recorded at JMA kobe in 1995 and TOMAKOMAI NS recorded at Tomakomai in 2003. These waves are artificial ground motion based on Japanese Building Code. The time axis of the velocity response spectrum (corner period, 0.64 s) of the notification wave was reduced to 1/4 (i.e. corner period, Tc=0.16s) to make it easy to affect the first natural period of the 10-story frame and the frame with the damper. The velocity response spectrums of each wave were fixed 20 cm/s. The table tests were carried out using those waves (Table 3).

Table 3. Input wave

wave	S_V	duration	clock tick	max acceleration
HACHI_20	20 cm/s	46.0 s	0.01 s	292.2 cm/s^2
KOBE_20	20 cm/s	40.0 s	0.01 s	391.1 cm/s^2
TOMA_20	20 cm/s	87.0 s	0.01 s	364.6 cm/s^2

3.3.Items Measured

Items measured are shown in Table 4. The absolute acceleration was measured at the each floor. The absolute displacement was measured at the several floors. The absolute displacement at the story 6-7 was recorded by the video camera, for evaluating the acceleration, the velocity and the displacement by using the animation analysis program.

Table 4. Measuring instrument

Item	Measuring Floor	Measuring Instrument
The Absolute Acceleration	1 F - 11 F	Accelerometer
The Absolute Displacement	1, 4, 7, 11 F 6, 7 F	Displacement Meter Video Camera
The Damper Deformation	1 F - 10 F	Displacement Meter
The Damper Force	1 F - 10 F	Load Cell
The Temperature	1 F - 10 F	Temperature Gauge
The Column Strain	1 F	Strain Gauge

4. PRELIMINARY ANALYSIS

In this section, the combination-system which shows the positive seismic control effects is made by the preliminary analysis. The combination-system is made up of friction dampers placed on the lower six stories of the frame and viscous dampers placed on the upper four stories of it.
The vertical distribution of the damper quantity is divided into three parts (Figure 4). This ratio is applied the story shear coefficient at yield point based on the "Ai distribution" that is the particular acceleration distribution by Building Standard Law.

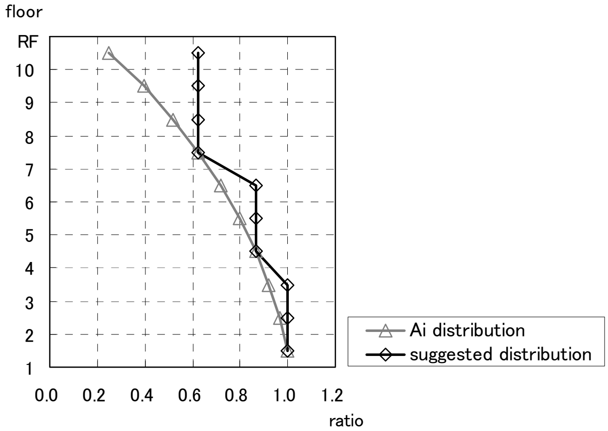

Figure 4. Vertical damper quantity ratio

The input wave in this preliminary analysis was HACHI_20. The damping ratio of the main structure model was 0 %. Performance of specimens is discussed by referring to story shear, relative story displacement, story accelerations and absorbing energy of the dampers.
Figure 5 shows that the friction dampers are effective in reducing relative story displacement, and the viscous dampers are effective in reducing story accelerations. It is clear that both dampers have different characteristic. Through the comparison of the responses between the HHV model and the other models (i.e. the HHH model or the VVV model), it seems that both dampers were combined well.

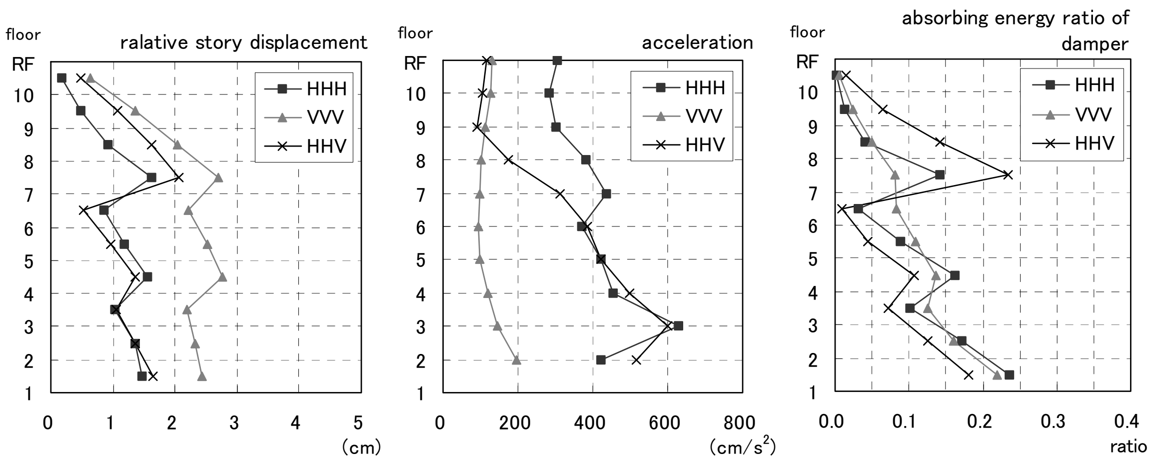

Figure 5. Maximum responses in preliminary analysis (HACHI_20)

5. EXPERIMENT RESULTS

Figure 6 illustrates the distribution of maximum response of the acceleration and the relative story displacement in each model.

From viewpoint of reducing acceleration, VVV model is effective. On the other hand, HHH model seems to have effectiveness against the relative story displacement. The absorbed energy is the almost same value at the lower stories between HHH and HHV; however, on the upper stories, HHV absorbed energy is larger than HHH. This shows the validity of the combination-system.

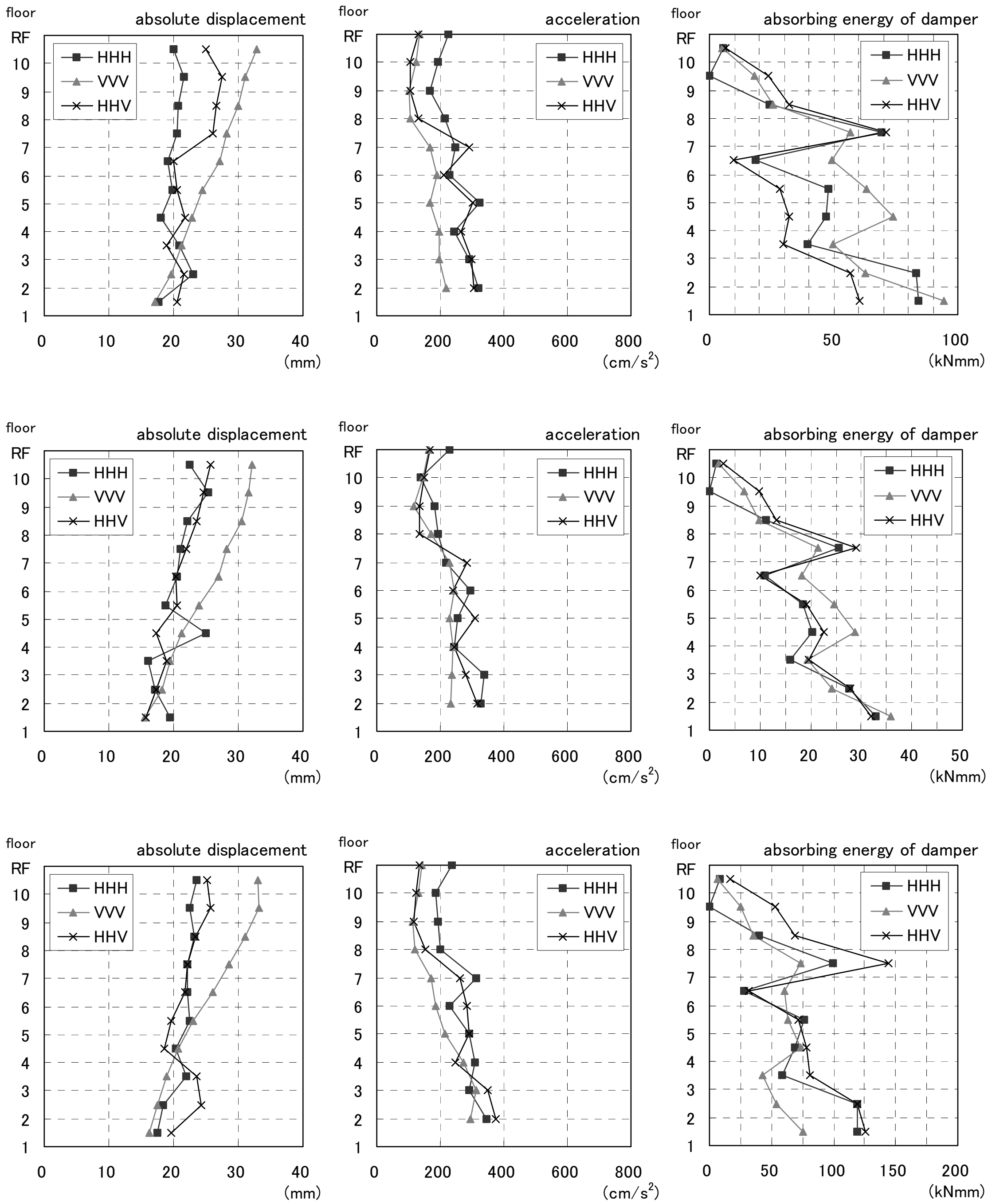

Figure 6. Maximum responses in experiment

6. SIMULATION ANALYSIS

Figure 7 shows the damping curve of the top displacement obtained by the free vibration tests. The damping ratio is set 1.1% using logarithmic decrement. The type of damping (i.e. Rayleigh damping which have 0.4% damping relative to the stiffness and 0.7% damping the mass) is gathered, by the numerical analysis. Figure 8 shows the natural frequency of the model (experiment model and analysis model) obtained by white noise random vibration.

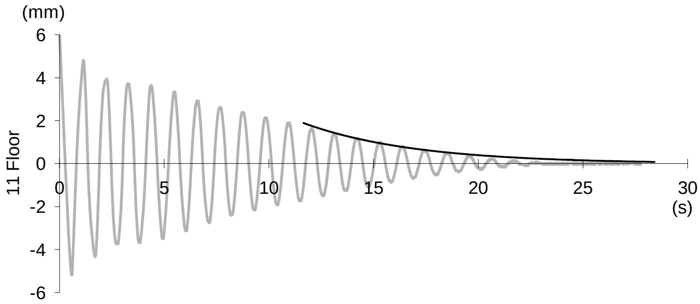

Figure 7. Damping curve of top displacement

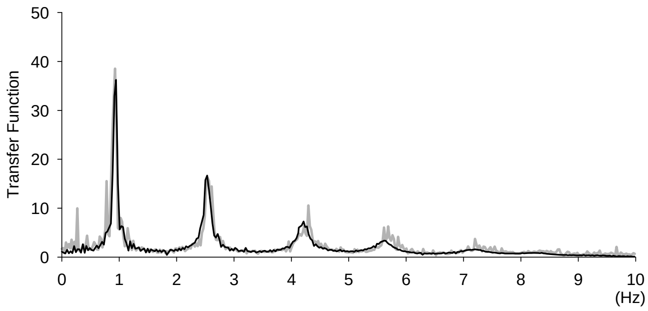

Figure 8. Natural frequency

The maximum responses for each story obtained in the experiment for each combination are shown in Figure 9. It is clear that the tendencies of acceleration responses are similar. The difference between experimental and analytical values of absolute displacement may be due to the incorrect integration using the values of acceleration in the tests.

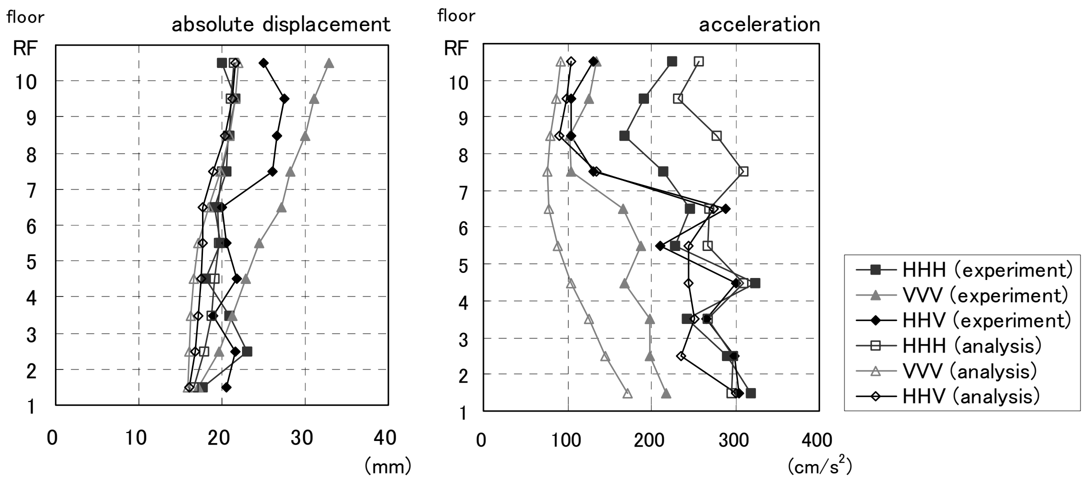

Figure 9. Comparison of maximum responses (HACHI_20)

7. CONCLUSIONS

The performances of buildings using the combinations of the hysteretic dampers and the viscous dampers were shown with the analysis and the experiment for the 10-story frame. The tendencies of the analytical values were similar to that of experimental values. This showed these analysis models were appropriate for confirming the performance of this study's structure. We confirmed that the seismic control effects of the combination-system are better than that of mono-using system. The effectiveness on reducing responses of the combination-system is considered to originate in the energy absorption efficiency of the viscous dampers arranged in the upper levels. Further, we consider that the rise of the energy absorption efficiency of the viscous dampers result from a boost in the natural frequency of the frame by the friction dampers arranged in the lower levels. It seems that it is necessary to analyze the mechanism of response reduction of the combination-system in detail from now on.

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