Vibration Tests on a 3-story Steel Building Model with Hysteresis Dampers

by

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ABSTRACT

A hysteresis damper made of steel with low yield strength is sometimes used to absorb the seismic energy exerted into the structures. Forced vibration tests on a 3-story steel building model with hysteresis dampers were carried out to study the dynamic properties of this kind of dampers. We caliculated the energy amount absorbed by the dampers by using two types of analytical models, hysteresis model and an equivalent linear model. It was shown that both of the analytical models could provide good predictions of test results.

1. Introduction

One of the mechanisms to be used for reducing the structural damage by earthquakes is a passive damper for vibration control. A hysteresis damper made of steel with low yield strength is used to absorb the energy exerted into the structures. There are not so many papers on the dynamic behavior of real structures installed with this kind of damper. In our research, forced vibration tests on a 3-story steel building model with hysteresis dampers as part of the studs were carried out and its dynamic properties were investigated. We made a prediction of energy absorption by the damper using a hysteresis model and an equivalent linear model as well.

2. Summary of Tests

2.1 3-story Steel Building Model

In order to observe structural behavior, failure mechanisms and soil- structure interactions during an earthquake, weak model structures and one observation tower were constructed on the grounds of the Chiba Experiment Station of Institute of Industrial Science, University of Tokyo about 10 years ago. A 3-story steel building model S1 is one of those structures. The shapes, dimensions and parameters of the model are shown in Fig.1. The parameters of the model are given in Table 1.

2.2 Hysteresis Dampers

The hysteresis dampers we used for the tests are a kind of shear-type dampers consisting of steel panels with low yield strength. The shape and dimensions of the damper and the stud are

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shown in Figs.2 and 3. The mechanical and chemical properties of the material of dampers are shown in Tables 2 and 3, respectively. In order to investigate the effects on this hysteresis damper, we set 6 dampers on the model as a part of the studs and carried out forced vibration tests. The upper part of each stud was bolted to the H-shaped beam of the frame and the lower part to concrete slab of the floor. The details of the installation of the stud are shown in Fig.4.

2.3 Forced Vibration Tests

A vibration excitation device was set at the center of the roof slab of S1. Forced vibration tests including the phased sweep tests were performed in the direction of the weak axis. All test cases are shown in Table 4. In the cases of Test 3,4 and 5, all studs were reinforced by some angles, and braces are installed within the strong axis direction to increase the rotational stiffness. After carrying out Test 3, all used dampers were changed to new ones and the next test Test 4 was performed. After that, dampers set on the 1st floor were changed again and Test 5 was performed. The outline of each test is shown in Fig.5.

2.4 Measurements of Tests

The following data on the frame, dampers and studs were recorded as digital quantities using sampling period of 5 msec (some were by 10 msec) .

(1) Global accelerations at the center of each slab and basement(horizontal and vertical)
(2) Relative displacements at the center of each slab to the floor below(translational and rotational)
(3) Flexural strains on each column
(4) Relative shear displacements of each panel
(5) Horizontal relative displacements of each partitioned upper stud and lower stud to each slab
(6) Flexural strains on each partitioned lower stud
(7) Axial strains on each stud
(8) Axial strains on each column

3. Test Results

3.1 Results of Resonance Tests

Table 5 shows the natural frequencies and modal damping factors for each of these frequencies of S1 observed in Test 1. Figs.6 and 7 show the global displacements of the top of S1 for a unit vibratory force. These figures show that the natural frequencies of the structural model with hysteresis dampers increase by the addition of the stiffness, while the magnitudes of the response decrease with the addition of the dampers. In the cases of Test 3, 4 and 5, it seemed that hysteresis dampers were more effective than the case of Test 2. In the case of Test 3, panels installed at the south part of the second floor buckled and were torn off during the forced vibration tests with forced moment 20 kgf.m and vibrated frequency 2.09Hz. It was found after the test that the yield stress of the panel installed at the first floor for this test was higher than others, thus damage was concentrated on the panel at the second floor.

In the case of Test 4, Only the panel installed at the north part on the first floor yielded and buckled. The yield stress of the panel set up at the south part on the first floor was higher than that installed at the north part on the same floor. Fig.8 shows the hysteresis loop of the panel at the north part on the first floor.

In the case of Test 5, both of the panels installed at the first floor yielded at almost the same time. After yielding, both of them vibrated properly showing stable hysteresis loops(Fig.9). Both of them buckled and the panel at the south part was torn off. The time history of the amount of energy absorption per unit cycle of the panel at the first floor for Test 5 is shown in Fig.10.

4. Analysis for a framed structure with hysteresis damper

Prediction of the displacement response and energy absorption of a framed structure with hysteresis dampers where a harmonic force acts on the top of the structure is performed by use of the following models. Two types of model, hysteresis model and equivalent linear model, were used.

4.1 Hysteresis Model

The hysteresis damper was modeled as the restoring force model of reference [1]. In this model, the skeleton curve was represented by three straight lines, and the hysteresis part by a Ramberg-Osgood function. The first, second and third gradients of the stiffness of the panel(KP, KP2 and KP3) were assumed by using the nominal value, the value obtained by the experiments, and zero, respectively. The yield shear force of the panel(Qy) was determined by using the general yield method. The Ramberg index r and coefficient ψ for controlling the movement of target points were assumed to take values of 8 and 0.25, respectively, based on the test results.

4.2 Equivalent Linear Model

Damper restoring force was modeled as a bilinear model. The horizontal vibration displacement amplitude at the center of the slab on the second floor was assumed to be a certain value denoted by "a", while the whole building were replaced by an equivalent linear model shown in Fig.11. The equivalent stiffness per a stud with panel (Keq) and equivalent viscous damping coefficient(Ceq) were obtained from the following equations (1) and (2).

$$Keq = K_2 + \frac{(K_1 - K_2)}{aK_1} Qy \tag{1}$$

$$Ceq = \frac{Qy(K_1 - K_2)(aK_1 - Qy)}{\pi^3 a^2 f^2 K_1^{\ 2}} \tag{2}$$

where

$$K_1 = \frac{K_P K_H}{K_P + K_H}, \quad K_2 = \frac{K_{P2} K_H}{K_{P2} + K_H}$$

K_H:Stiffness of a stud with its one end were fixed with the slab

Under the assumption of no modal interference, the displacement amplitude "a" is calculated again by using the equation (3). The computation is performed over and over again until the amplitude "a" converges. The amount of energy absorption per damper per cycle is denoted by Ecyc and expressed by equation (4).

$$a = m_0 r \sum_{j=1}^{3} \frac{u_1^j \, u_3^j}{K^j \sqrt{[1-(\frac{\omega}{\omega_j})^2]^2 + [2\, h_j (\frac{\omega}{\omega_j})]^2}} \tag{3}$$

$$E_{CYC} = 4\pi^3 a^2 f^2 C_{EQ} \tag{4}$$

where

K_j:Reference stiffness of the j mode, f_j:Natural frequency of the j mode

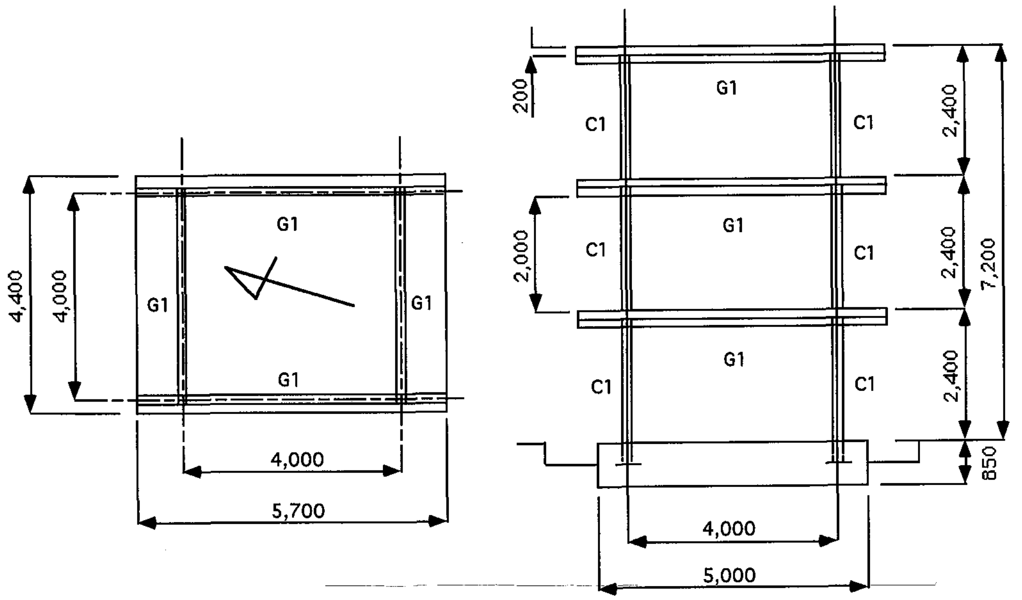
h_j:Damping factor of the j mode, $m_0 r$:Vibratory moment

4.3 Results of the Response Prediction

Figs.12 and 13 show the relative displacements of each floor and the relationship of load and shear deformation of panels obtained by the analysis based on the hysteresis model. The forced moment at the top of the building was 10 kgf.m and the frequency of the cyclic force at that time was 2.17Hz that is the same as the case of Test 5. These figures show that the analytical results match with the test results well. Fig.14 shows that the relative displacement of the first floor obtained by using the hysteresis model and equivalent linear model. In the figure, the results of Test 4 and Test 5 are shown together. The energy absorption per damper per cycle is shown in Fig.15. These figures show that both of the analyses give good results when both of the dampers yield while the results of the analyses are not suitable for the case when only one of the dampers yielded. The reason behind this was that twisting motion occurred around the center of each slab of the structure. It is also found that the equivalent linear model evaluates the energy absorption a little greater than the hysteresis model.

5. Conclusions

Forced vibration tests on a 3-story steel building model with hysteresis dampers as part of the studs were carried out. From the results, it was found that the most likely yielding part of the building was its first floor. It was observed also that more energy absorption would be expected when both of the dampers installed on the same floor yielded at the same time. Two types of models, hysteresis model and equivalent linear model, were used. These models were employed to predict the energy dissipated by dampers. These analytical results were compared with the experimental results and it was shown that both of the analysis models provide good predictions of the test results.



(1) Plan (2) Elevation

Fig.1 Shapes and Dimensions of the Model S1

Table 1 Parameters of the Model S1

Stories	3
Weight of Each Floor	1F:12.6(ton), 2F:12.8(ton), 3F:12.6(ton)
Steel Grade	JIS ss400
Steel Members Used	C1:H-125×125×6.5×9
	G1:H-200×100×5.5×8
	Additional Bracing L-65×65×6
Base Shear Coefficients for Design	weak axis direction of the column 0.2
	strong axis direction of the column 0.43

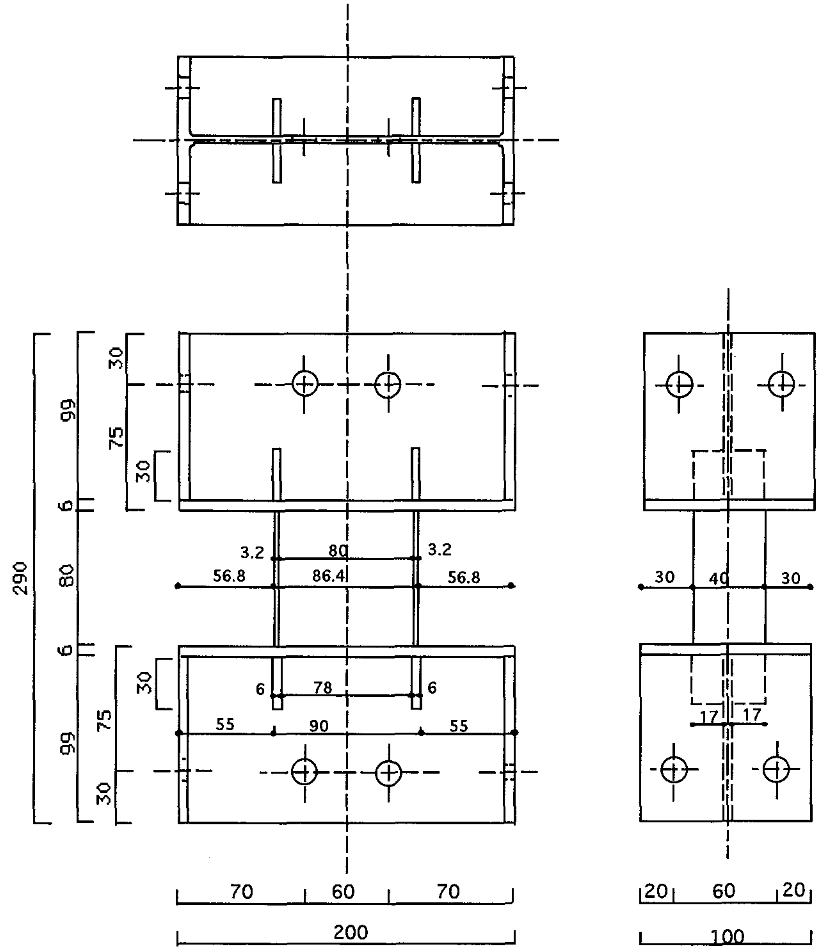


Fig.2 Shape and Dimensions of the Damper

Table 2 Mechanical Properties of the Materials of Dampers

Yield Strength	Maximum Strength	Uniform Stretch	Shear Yield Strength
0.82(ton/cm^2)	2.51(ton/cm^2)	40.7(%)	0.48(ton/cm^2)

Table 3 Chemical Properties of the Material of Dampers

C	Si	Mn	P	S
0.004	0.05	0.08	0.005	0.006

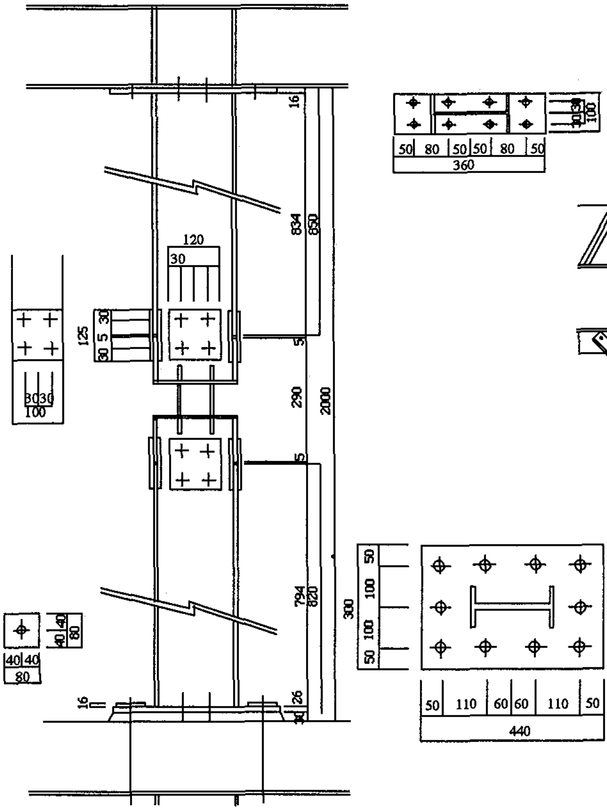


Fig.3 Shapes and Dimensions of the Stud

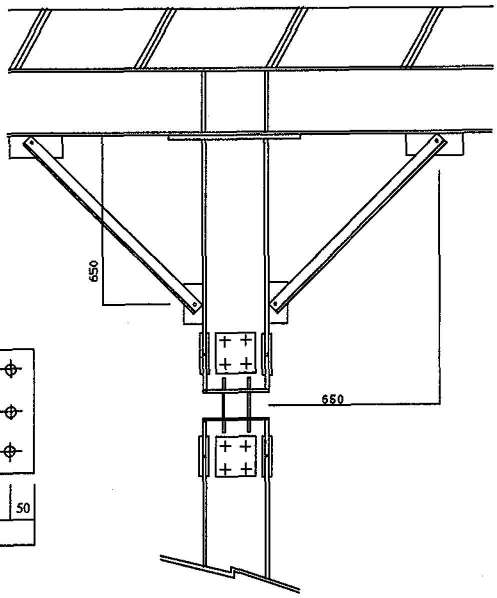


Fig.4 Details of the Installation of the Stud

Table 4 Test Cases

	Dampers	Additional Braces	Vibratory Force(kgf) or Vibratory Moment(kgf·m)	Frequency	Sampling Period
Test 1	×	×	[9.4,17.5] kgf	0.5~50 Hz	30sec
Test 2	○	×	[2,6,8] kgf·m	1.0~5.8 Hz	30sec
Test 3	○	○	[2,4,6,8,20] kgf·m	1.7~2.4 Hz	30sec
Test 4	○	○	[10] kgf·m	1.9~2.4 Hz	30sec
Test 5	○	○	[10] kgf·m	2.17 Hz	9min

vibration excitation device Test 1 :Sanetsu APS-113
Test 2-5 :Ito Corp. BCS-A-200

Table 5 Natural Frequencies and Mode Damping Factors of S1 Observed in Test 1

	Natural Frequency(Hz)	Damping Factor(%)
1st	0.94	0.87
2nd	2.76	0.4
3rd	4.1	1.07

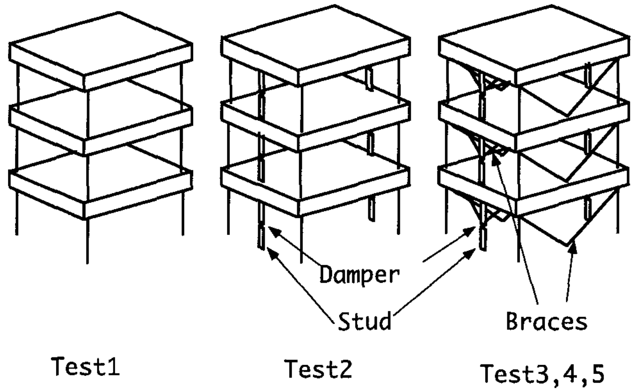


Fig.5 Outline of each of the Tests

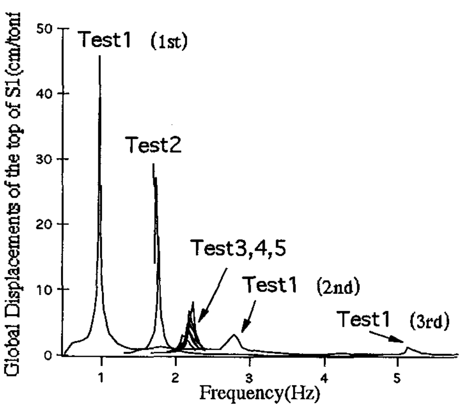


Fig.6 Global Displacements of the Top of S1 for a Unit Vibratory Force (Test 1-5)

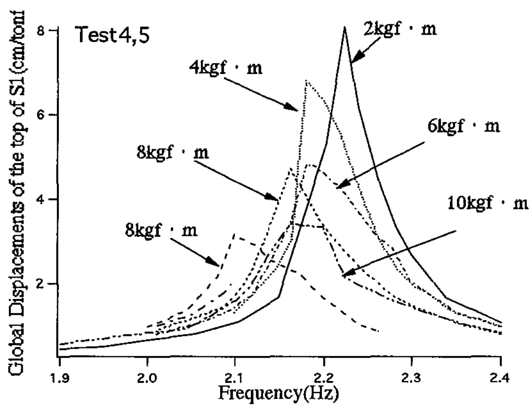
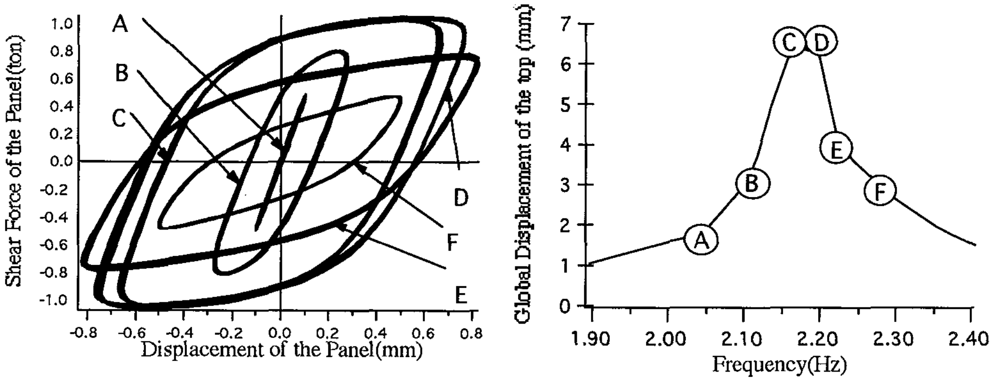


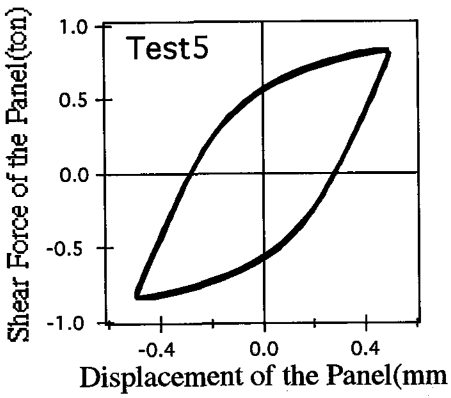
Fig.7 Global Displacements of the Top of S1 for a Unit Vibratory Force (Test 4, 5)



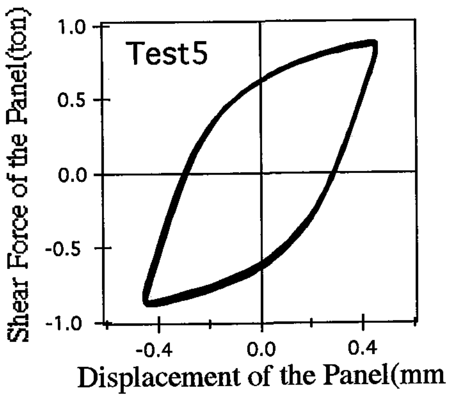
(1) Load-Displacement Curves

(2) Resonance Curves

Fig.8 Load-Displacement Curves and Resonance Curves of the Panel Set Up at the North Part on the First Floor for Test 4



(1) North Panel



(2) South Panel

Fig.9 Load-Displacement Curves of the Panel Set Up on the First Floor for Test 5

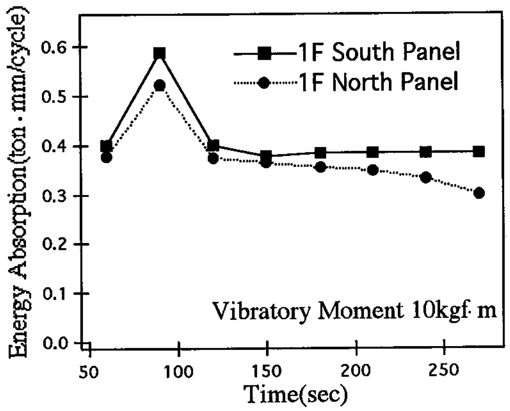


Fig.10 Time History of the Amount of Energy Absorptioin per Unit Cycle of the Panel Set Up on the First Floor for Test 5

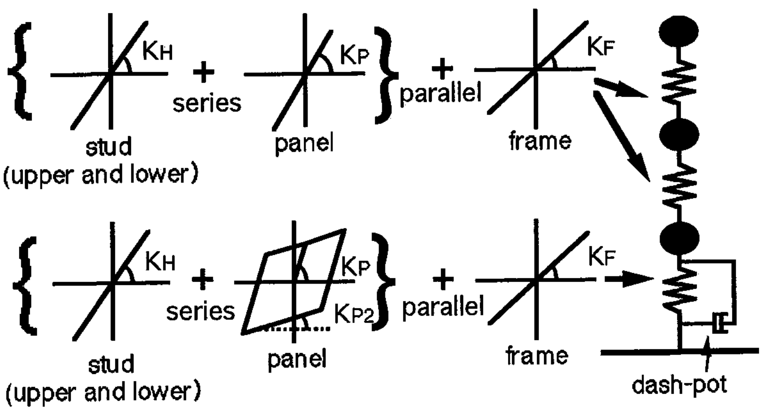
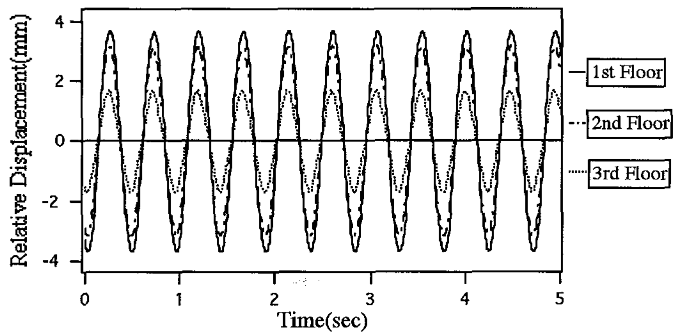
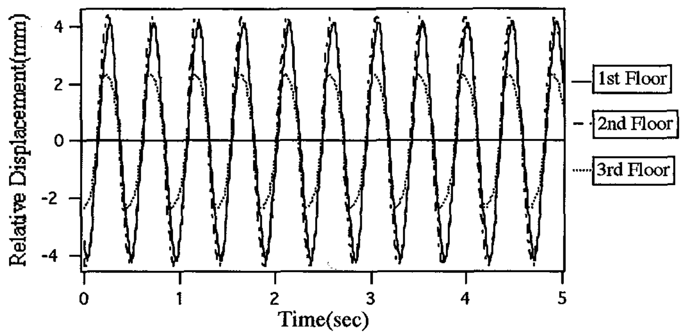


Fig.11 Equivalent Linear Model

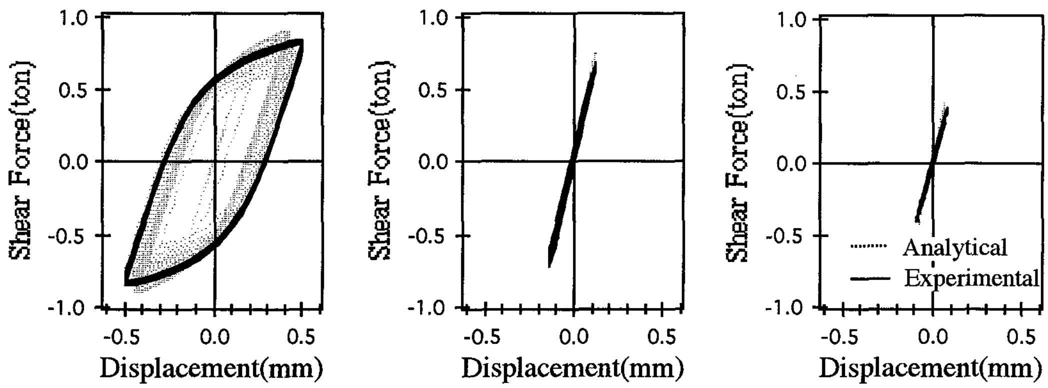


(1) Analytical Results



(2) Experimental Results(Test 5)

Fig.12 Time History of Relative Displacement of Each Floor



(1) 1st Floor (2) 2nd Floor (3) 3rd Floor

Fig.13 Load-Displacement Curves

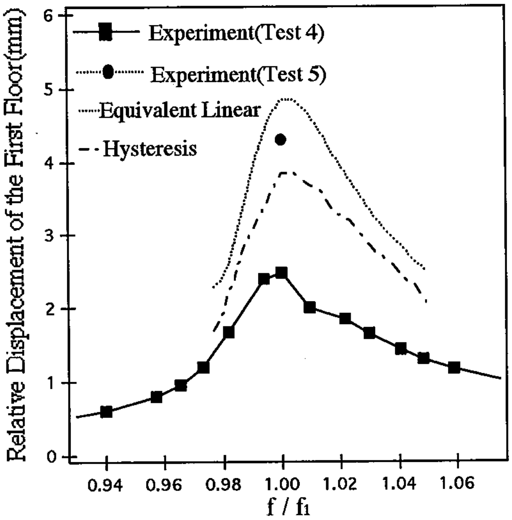


Fig.14 Relative Displacement of the First Floor Obtained by Tests 4 and 5, and Computed by Using Models

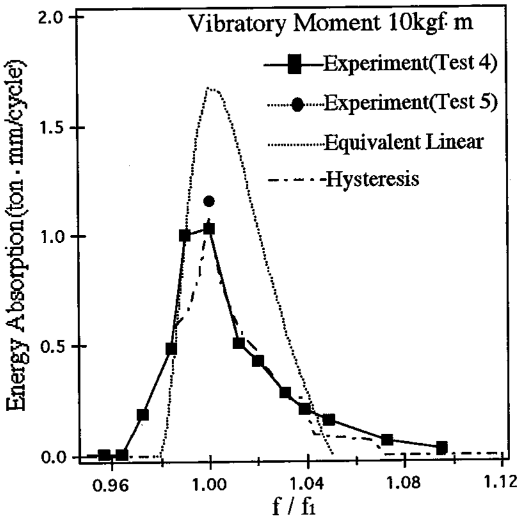


Fig.15 Sum of the Energy Absorption per Cycle of Both of the Panels Set Up on the First Floor Obtained by Tests 4 and 5, and Computed by Using Models

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