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Effect Of Magnet And Oil Damper On Reduction Of Seismic Response Of Houses

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ABSTRACT

It is important to reduce the seismic response of houses in order to prevent from collapse of houses. Some control methods for seismic response of houses are developed. The oil dampers using the flow resistance of the silicon oil have been developed. In this paper, a Magnet Oil Damper (MOD) in which permanent magnets are added to the oil damper is proposed in order to improve the performance of the oil damper. MOD is installed in two-story house. The effect of MOD is examined experimentally. The peaks of resonance curves are reduced when MOD is used. The effectiveness of MOD is examined by numerical simulation using the analytical model. The response of the house subjected to actual earthquake excitation decreases when MOD is used.

***Keywords* -** Damper, Earthquake resistant, Forced vibration, Frequency response function, Seismic motion

I. INTRODUCTION

In recent years, destructive earthquake disasters have happened in the world. A lot of houses are collapsed under large earthquakes. It is important to reduce the seismic response of houses in order to prevent from collapse of houses. Some reduction methods for seismic response of houses are developed, for example, laminated rubber bearings are used[1]-[3]. Other types of passive dampers are proposed[4]. Design methods for dynamic vibration absorbers[5]-[8] and tuned mass dampers[9][10] are proposed. Some devices utilize nonlinear characteristics, impact[11], friction[12] and plastic deformation[13].

For residence, two-story houses are general in Japan. It is required that construction and maintenance of the dampers are easy, especially for the dampers for low rise houses.

The authors have proposed the oil dampers using the flow resistance of the silicon oil. The oil dampers are fixed on the foundation and connected to ceiling of first floor with connecting rod. The oil dampers are easily installed in the houses even if the houses have been built up. The effect of the oil damper on reduction of seismic response is presented in the previous the papers[14][15].

In this paper, a Magnet Oil Damper (MOD) in which permanent magnets are added to the oil damper is proposed in order to improve the performance of the oil damper. The neodymium magnets are used inside of the oil damper. The effect of MOD is examined experimentally. A model of two-story house is made and MOD is fixed on the foundation. The model is excited horizontally and the resonance curves including the first and second vibration modes are measured. For comparison, a model without damper, with magnet damper (without oil), oil damper (without magnet) and MOD are used. The peaks of the resonance curves are reduced when the dampers are used. When MOD is used, reduction rate is largest. The damping ratio is also obtained. The damping ratio is largest when MOD is used.

Next, the effectiveness of MOD is examined by numerical simulation. Two-story house with damper is modeled as a two-degree-of-freedom system. Seismic responses of the two story house are obtained using actual earthquake excitations as input. It is demonstrated that seismic responses are reduced when MOD is used.

II. EXPERIMENTAL SETUP

Two story houses are focused on and a new type of damper, MOD, using silicon oil and permanent magnets is proposed. The effectiveness of MOD is examined experimentally. An experimental model of two-story house is made and some types of dampers are fixed on the foundation and connected to the model of the ceiling of the first floor with connecting rod. These types of the dampers are easily installed in the houses even if the houses have been built up.

2.1 Design and structure of MOD

A new damper that uses permanent magnets and the silicon oil is designed. Damper is designed to move only in one direction so that movement of the damper is steady.

Figure 1 shows shape and the size of MOD. Figure 2 shows names of parts in the main portion of MOD. Figure 3 shows a photograph of parts of MOD. For a viscous material of the damper, the silicon oil of kinematic viscosity 30000cst is used. Two neodymium magnets are installed in the damper and the inner wall of the pool, respectively, as shown Fig.2.

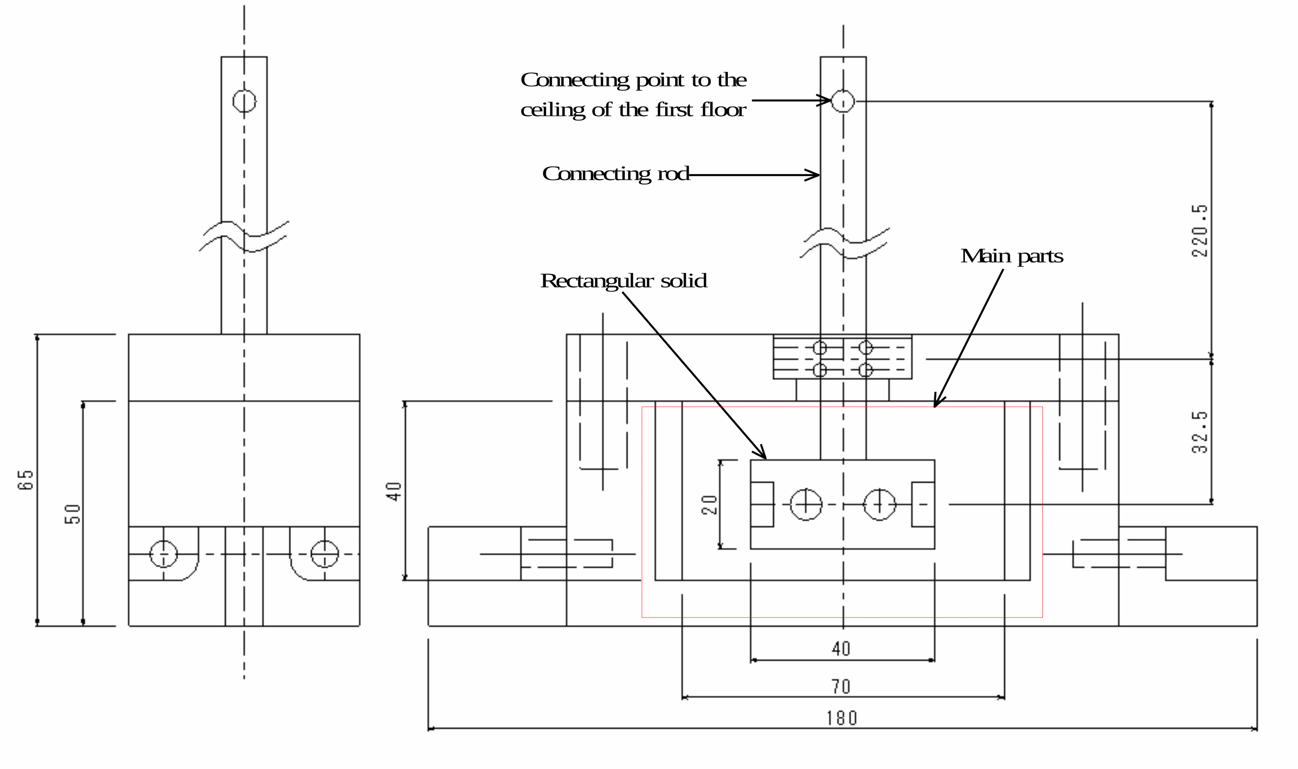

Fig.1 Size and shape of Magnet Oil Damper (mm)

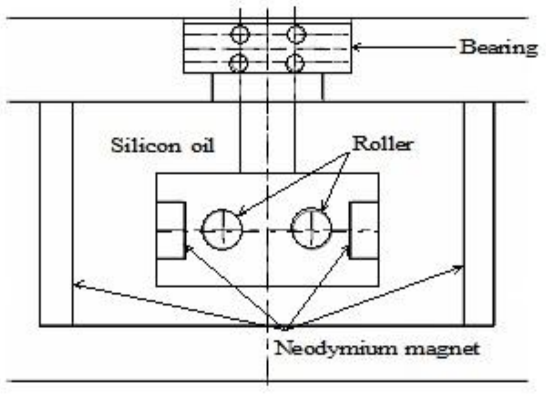

Fig.2 Main Parts of MOD

Fig.3 Parts of MOD

2.2 Principle of MOD

MOD is fixed on the foundation of the experimental model of two-story house. As shown in Fig.1, a connecting rod is installed in the rectangular solid at one end and connected to the model of the ceiling of the first floor at the other end. The connecting point is rolling joint. The self-aligning ball bearing is used. A fit between the bearing and the connecting rod is loose fit considering vertical motion[16]. The connecting rod is shaken around the bearing as fulcrum as shown in Fig.4. As a result, the damping force is caused by resistance on the surface of the rectangular solid and the flow resistance of the silicon oil in the damper according to the movement of the rectangular solid. In addition, the magnets are installed in the rectangular solid and the inner wall

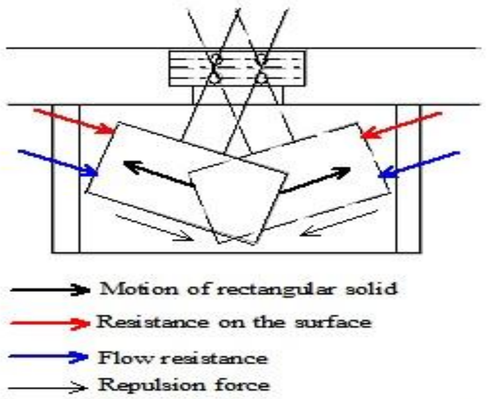

Fig.4 Resistance on motion of rectangular solid

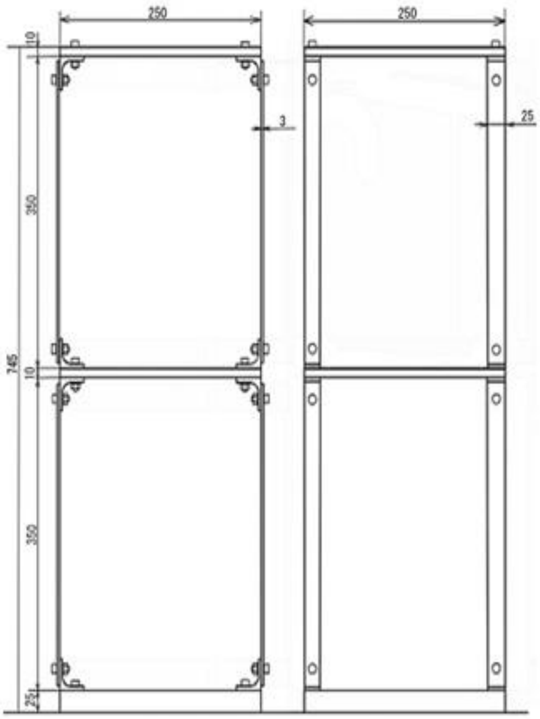

Fig.5 Model of two-story house (mm)

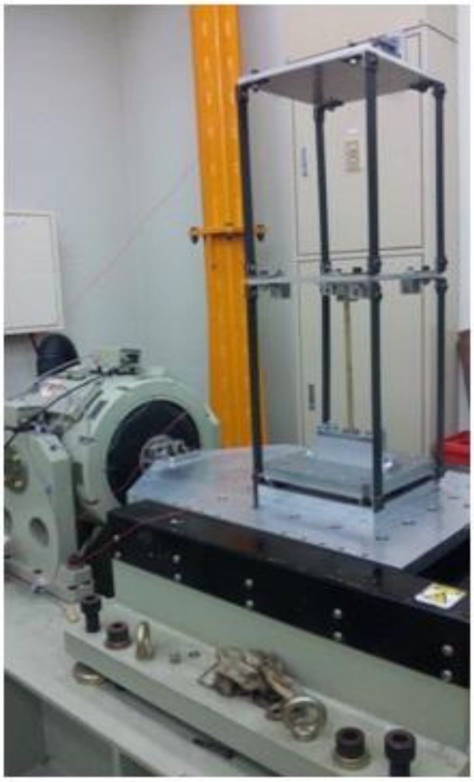

Fig.6 Experimental setup

of the pool with same polar and repulse mutually. These resistances and the repulsion force cause the damping force which reduces the vibration.

2.3 Structural model of house

Figure 5 shows shape and the size of the experimental model of two-story house. The size of foundation is 250×250×25mm. The size of the first floor part and the second floor part is 250×250×10mm. The size of the pillars is 250×25×3mm. The size of the model is determined considering the fundamental natural frequency of ordinary Japanese houses.

2.4 Experimental method

The model of two-story house is set on the shaking table as shown in Fig.6. MOD is fixed on the foundation and connected to the model of the ceiling of the first floor with connecting rod. The model is shaken in horizontal direction. The acceleration pickups are fixed by bolt on side of the foundation, the first floor and the second floor of the model. The excitation frequency is changed from 1 to 25 Hz, and the acceleration response amplitude is measured. The graphs of the acceleration response amplitude ratio of the first floor, and the second floor to the foundation are drawn from the outcome of the experiment. Responses of four conditions (case without damper, case with magnet damper, case with oil damper and case with MOD) are measured respectively. The result of a measurement in each condition is compared. The excitation amplitude is 1mm at 1Hz.

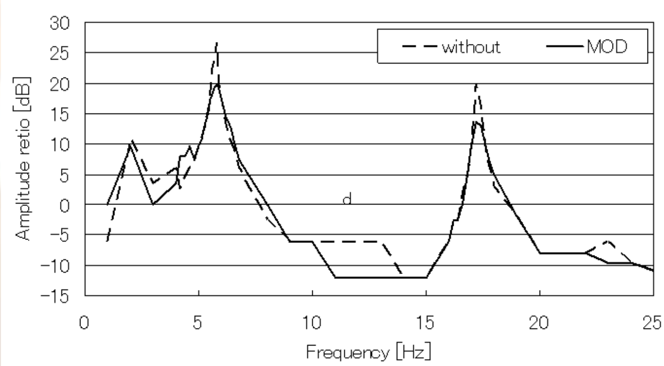

Fig.7 Amplitude ratio of first floor

2.5 Results of experiment

A comparative example of the acceleration response amplitude ratio of the first floor (frequency response function) is shown in Fig.7. Solid line shows results for the case with MOD and broken line shows for the case without damper. The peaks of the first vibration mode and the second vibration mode decrease when MOD is used.

Table 1 shows peaks of the acceleration response amplitude ratios and the damping ratios of the first vibration mode and the second vibration mode. The damping ratio is obtained by the half power method. Comparing four conditions, the acceleration amplitude ratios at the peaks of the first vibration mode and the second vibration mode are reduced when the dampers are used. MOD is the most effective on reduction of the peaks of the first vibration mode and the second vibration mode.

Damping ratio of the system with MOD is about twice that without damper. Reduction effect of MOD on the second floor is comparable to the first floor.

Table.1 Amplitude ratio and damping ratio

Experimental condition	Amplitude ratio (dB)		Damping ratio	
First floor				
Vibration mode	First mode	Second mode	First mode	Second mode
Without	26.6	20.0	0.0345	0.0097
Magnet	24.6	18.1	0.0614	0.0116
Oil	20.8	16.3	0.0790	0.0087
MOD	19.7	13.5	0.0862	0.0174
Second floor				
Vibration mode	First mode	Second mode	First mode	Second mode
Without	26.6	20.6	0.0345	0.0116
Magnet	23.9	19.6	0.0614	0.0116
Oil	20.0	17.8	0.0790	0.0116
MOD	19.7	14.8	0.0776	0.0203

III. NUMERICAL SIMULATION

The effectiveness of the dampers is examined by numerical simulation using an analytical model.

3.1 Analytical model

Two-story house with the damper is assumed to be modeled as a linear two-degree-of-freedom system shown in Fig.8. Equations of motion are given as:

$$\left.\begin{array}{l} m_1\ddot{x}_1 + c_1(\dot{x}_1-\dot{y}) + c_2(\dot{x}_1-\dot{x}_2) + k_1(x_1-y) + k_2(x_1-x_2) = 0 \\ m_2\ddot{x}_2 + c_2(\dot{x}_2-\dot{x}_1) + k_2(x_2-x_1) = 0 \end{array}\right\} \quad (1)$$

where subscript 1 is for the first floor and 2 is for the second floor and m is mass, c is the damping coefficient, k is the spring constant and x is the absolute displacement of the floor, y is the absolute displacement of the ground. Frequency transfer functions are obtained as Eq.(2).

$$\left.\begin{array}{l} \dfrac{X_1(s)}{Y(s)} = \dfrac{A}{B+C} \\ \dfrac{X_2(s)}{Y(s)} = \dfrac{D}{B+C} \end{array}\right\} \quad (2)$$

where

$$A = (2\zeta_1\omega_1 s + \omega_1^{\,2})(s^2 + 2\zeta_2\omega_2 s + \omega_2^{\,2})$$
$$B = \{(s^2+\omega_1^{\,2})(s^2+\omega_2^{\,2}) + \gamma\ \omega_2^{\,2}s^2\} + 2\zeta_2\omega_2 s\{(1+\gamma)s^2 + \omega_1^{\,2}\}$$
$$C = 2\zeta_1\omega_1 s(s^2 + 2\zeta_2\omega_2 s + \omega_2^{\,2})$$
$$D = (2\zeta_1\omega_1 s + \omega_1^{\,2})(2\zeta_2\omega_2 s + \omega_2^{\,2})$$

where $\zeta = c/2\sqrt{mk}$ is the damping ratio and $\omega = \sqrt{k/m}$ is the natural circular frequency. γ is the mass ratio of the second floor to the first floor m_2/m_1.

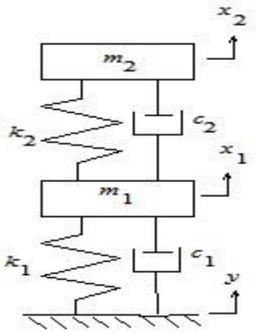

Fig.8 Analytical model

3.2 Estimation of parameters

Acceleration amplitude ratios of the first floor and the second floor are obtained using the frequency transfer functions. Parameters of the analytical model are estimated using the frequency response function obtained experimentally. Parameters are estimated by fitting the peaks of the frequency response function obtained from experiment and that using Eq.(2). The peak of the first vibration mode is focused on to estimate parameters.

It is necessary for each parameter ζ_1 and ζ_2, $f_1(2\pi/\omega_1)$ and $f_2(2\pi/\omega_2)$ to fit the peaks of the frequency response function obtained from the experiment and using Eq.(2). The mass ratio γ is fixed as 0.288 which is the mass ratio of an actual experimental device.

Parameters are obtained using the frequency response function of each floor and determined as the average of these values. The results for each condition are shown in Table 2. Figure.9 shows an example of the frequency response functions of the first floor, with MOD. Solid line shows the frequency response function using Eq.(2) and broken line shows that obtained from experiment. The frequency response function obtained using Eq.(2) agrees well with that from experiment.

Table.2 Parameters estimated form the frequency response

	Damping ratio		Natural frequency (Hz)	
	ζ_1	ζ_2	f_1	f_2
Without	0.0270	0.00001	6.60	14.88
Magnet	0.0352	0.00001	6.60	14.88
Oil	0.0554	0.00001	6.62	14.88
MOD	0.0559	0.00001	6.73	14.88

3.3 Numerical results

The response of the first floor and that of the second floor are obtained using El Centro EW (1940) shown in Fig.10. Figure.11 and Fig.12 show absolute acceleration responses of the first floor without damper and with MOD, respectively. The response is reduced when MOD is used.

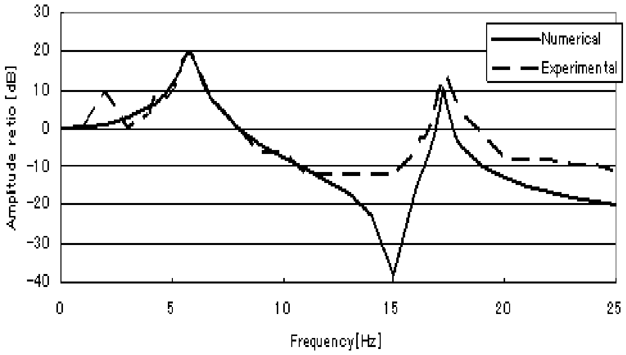

Fig.9 Frequency response function (with MOD, first floor)

Table 3 shows the maximum acceleration responses of the first floor and the second floor for all experimental conditions. For all dampers, the maximum responses are reduced when dampers are used. Reduction rate of the response of the system with MOD is largest. Reduction effect of the dampers on the second floor is comparable to the first floor.

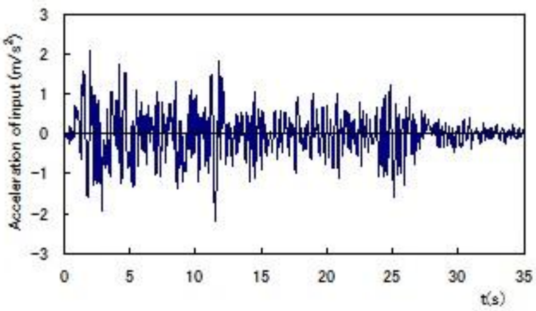

Fig.10 Earthquake record (El Centro EW, 1940)

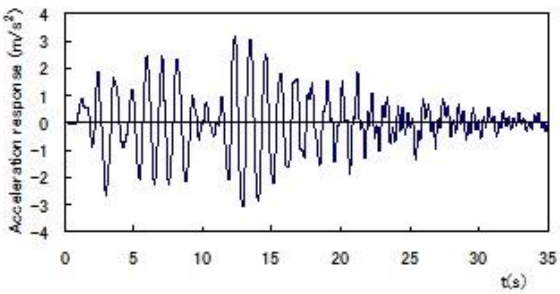

Fig.11 Simulation result of first floor (without damper)

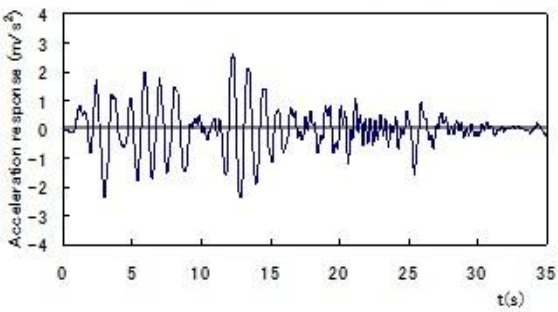

Fig.12 Simulation result of first floor (with MOD)

Table.3 Maximum acceleration response

Experimental condition	Maximum acceleration response (m/s^2)	
	First floor	Second floor
Without	3.18	4.70
Magnet	2.63	3.93
Oil	2.59	4.05
MOD	2.50	3.87

IV. CONCLUSIONS

As new device for reduction of vibration of the two story houses, the Magnet Oil Damper (MOD) is proposed in which permanent magnets are added to the oil damper in order to improve the performance of the oil damper. The validity of MOD is examined by experiment and numerical simulation. For comparison, the magnet damper and oil damper are used.

From experiment, the responses of house are reduced when dampers are used. Reduction rate of the response of the system with MOD is largest. Reduction effect of MOD on the second floor is comparable to the first floor.

In numerical simulation, parameters of an analytical model are determined by fitting the peaks of the frequency response function obtained from the experiment and using Eq.(2). The validity of MOD is examined using the actual seismic wave as the input. In all results, the responses are reduced when dampers are used. Reduction rate of the response of the system with MOD is largest. Reduction effect of the dampers on the second floor is comparable to the first floor.

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