EFFECTS OF PASSIVELY VARIABLE OIL DAMPER ON RESPONSE REDUCTION OF SEISMICALLY ISOLATED HOUSES UNDER HIGH VELOCITY EARTHQUAKE MOTION

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Abstract

In this study, a passively controlled i.e. variable oil damper with velocity is applied to isolated systems to reduce the response against earthquakes with high velocity. The viscous characteristics are changed through controlling flow of fluid mechanically. When the relative velocity of isolated layers will exceed a certain values and the viscous force will be large at that time. A variable oil damper which is manufactured is tested and it is demonstrated that the damper is practically applicable to the system. Through the numerical calculation, the response of seismically isolated houses under the earthquake motions, the effects of the damper on the response are investigated.

Introduction

Recently earthquake motions whose maximum velocities exceed 100 cm/s have been observed. When the earthquake motions with large amplitude and/or long period component act on seismically isolated buildings, displacement responses of isolated layers will be large. In case of family houses, clearances at surroundings or isolated layers are not enough to the large displacement response. As a result, a collision of isolated layer or a failure of isolator will probably occur during severe earthquakes. Countermeasures for response reduction of isolated layer with energy absorption devices are necessary, to keep safety during a main and aftershocks and sustainability of residence after earthquakes.

Adding energy absorption devices, maximum displacement responses of isolators remains less than the ultimate one. At that time, it seems that the acceleration response of superstructures is much larger than that without one. In order to reduce the responses of both isolator displacement and superstructure acceleration, oil dampers are more appropriate than other devices. As controlled oil dampers, the researches and applications of a magneto-rheological (MR) fluid damper (Yoshioka et. al., 2002; Fujitani et. al., 2005) and oil damper systems (Kurino, 2002) are conducted. The MR damper and the systems are controlled semi-actively. Recently the oil damper system with passive control (Kurino, 2004 & 2006) to reduce the response against earthquakes and strong winds has been developed.

In this study, a passively controlled i.e. variable oil damper with velocity is applied to isolated systems to reduce the response against earthquakes with high velocity amplitude and long period component. The viscous characteristics are changed through controlling flow of fluid mechanically. When the relative velocity of isolated layer will exceed a certain value, the damping force will be large at that time. A variable oil damper which is manufactured is tested to make sure that its performance is effective on practical uses. Through the numerical calculation, the response of seismically isolated houses under the earthquake motions, the effects of the damper on the response reduction are investigated.

Earthquake Motion and Seismically Isolated Model

Predominant periods of isolated houses are designed to be about 3 to 4 seconds. Earthquake motions in Japan which have a large amount of velocity response in these periods are observed (JMA; NIED-K-NET; Nakamura *et al.*, 1996; Osaka Gas, 1995). Recently earthquake motions which have a long period component are proposed (AIJ, 2007). These earthquake motions will occur in large-scaled alluvial plains, that is., Kanto and Osaka sedimentary basins due to a huge earthquake along the shore of the Pacific Ocean side. A list of simulated and observed earthquake motions is presented in Table 1. And psued-velocity response spectra of these motions are drawn in Fig. 1. The observed earthquake motions have large velocity response spectra with 1 to 3 seconds in period.

The seismically isolated house model has three degrees of freedom. The house is two-story superstructure with 2,700 mm in story height. The lowest mass is corresponding to that in a 1st floor level. The lowest story is an isolated layer. The mass ratios of the overall system along the height are 1.0, 1.0 and 0.6.

Two types of seismically isolated models, rolling and sliding types are selected. These are used in the isolation systems of practical family houses in Japan. Characteristics of combination of isolators are summarized in Table 2. The rolling type is composed of a roller with coefficient of friction of 0.005, a restoring device whose natural period is 3 s and a viscous damper of 25% in damping factor. The sliding type is composed of a slider with coefficient of friction of 0.05 and restoring device whose natural period is 4 s.

Table 1. A list of earthquake motions

	Name of earthquake & place	Name of earthquake wave	A (cm/s^2)	V (cm/s)	D (cm)	Duration time (s)
Simulated Motions	Kanto EQ, Tokyo	KAN-SAT-TOK-NS	244	24	16.2	77.5
	Kanto EQ, Yokohama	KAN-SAT-YKL-NS	499	34	17.9	24.1
	Tokai & Tonankai EQ Nagoya, San-nomaru	TOKTON-CHU-SAN-EW	186	51	20.4	119.9
	Ditto, Nagoya station	TOKTON-AIC-NST-EW	117	27	9.8	80.6
	Ditto, Suijoh branch	TOKTON-AIC-SJB-EW	187	50	19.1	85.6
Observed Motions	1995 hyogoken-nanbu EQ, JR Takatori	Takatori-NS	642	131	46.9	11.3
	Ditto, Osaka Gas, Fukiai	Fukiai-NS	802	124	45.6	6.8
	2003 Off Tokachi EQ K-NET, Tomakomai	Tomakomai-HKD129-EW	73	35	29.0	89.5
	2004 Mid Niigata prefecture EQ, JMA, Kawaguchi	Kawaguchi-EW	1676	148	42.3	26.5
	2007 Niigataken Chuetsu-oki EQ, K-NET, Kashiwazaki	Kashiwazaki-NIG018-NS	667	109	55.0	6.6

A: Max. Acceleration, V: Max. Velocity and D: Max. Displacement

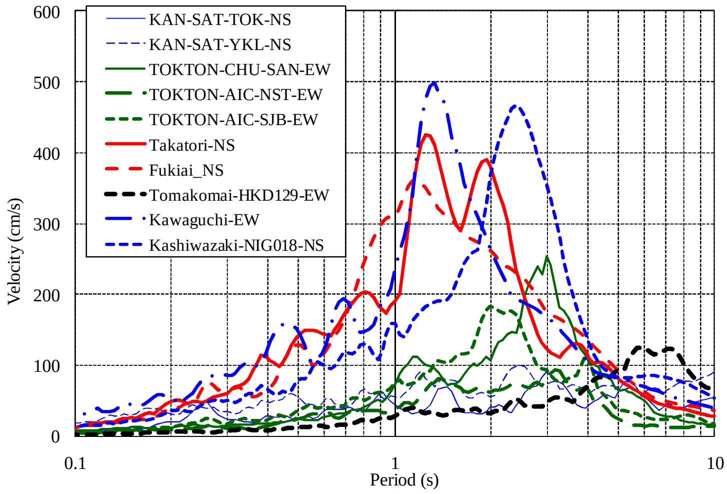
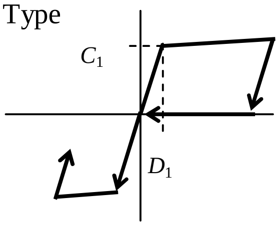
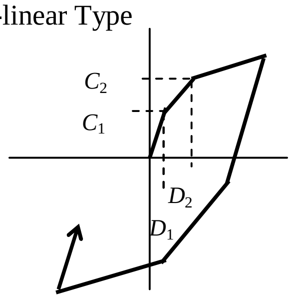


Figure 1. Pseudo velocity response spectra (damping factor = 5%)

Table 2. Characteristics of isolated layer

System	Friction Coefficient	Period with Second Stiffness of Isolator	Viscous Damping Factor	Model Name
Rolling	0.005	T_t=3s	h_v=25% (Proportional to Stiffness at Period of T_t)	R-hv25
Sliding	0.05	T_t=4s	h_v=0%	S-hv00
Sliding	0.05	T_t=4s	h_v=50%	S-hv50

Table 3. Characteristics of superstructure

Kind of Model	Characteristics of C and δ Curve
1) Slip Type 	Stiffness :Initial Stiffness: k_1 Second Stiffness : k_2=0.05k_1 Yield Point: 1st Story : δ_1=H/120, C_1=0.56 2nd Story: δ_1=H/120, C_1=0.8 Damping Factor: h=0.05 (Proportional to Initial Stiffness)
2) Tri-linear Type 	Stiffness :Initial Stiffness: k_1, Second Stiffness : k_2=0.4k_1, Third Stiffness : k_3=0.05k_1 1st Yielding Point:1st Story : δ_1=H/200, C_1=0.2 2nd Story: δ_1=H/200, C_1=0.3 2nd Yielding Point:1st Story : δ_2=H/75, C_2=0.333 2nd Story: δ_2=H/75, C_2=0.5 Damping Factor: h=0.05 (Proportional to Initial Stiffness)
Note; δ: Story drift, H: Height of story, C: Ratio of shear force to weight	

Relationships between story shear force (Q) and story drift (δ) in the family house of two stories and characteristic values are summarized in Table 3. The shear force is expressed to non-dimensional shear force (C), dividing by total weight of higher part than the story. One of the superstructure model is a slip type which is a representative of steel structures with braces, and the other is a tri-linear type which is a representative of steel frames. The stiffness of non structural members is not included in the characteristic values. The damping factors are assumed to be 5 %, and the damping force is set to be proportional to stiffness of stories.

Idea on Response Reduction against Earthquake

The displacement and velocity responses at isolated layer of the system in Table 2 are shown in Fig. 2. The response against earthquake motions including long period component is not so large. In case that the maximum peak velocity of earthquake motion is larger than 100cm/s, the maximum displacement responses exceed 50cm and some responses of maximum velocity are about 200cm/s.

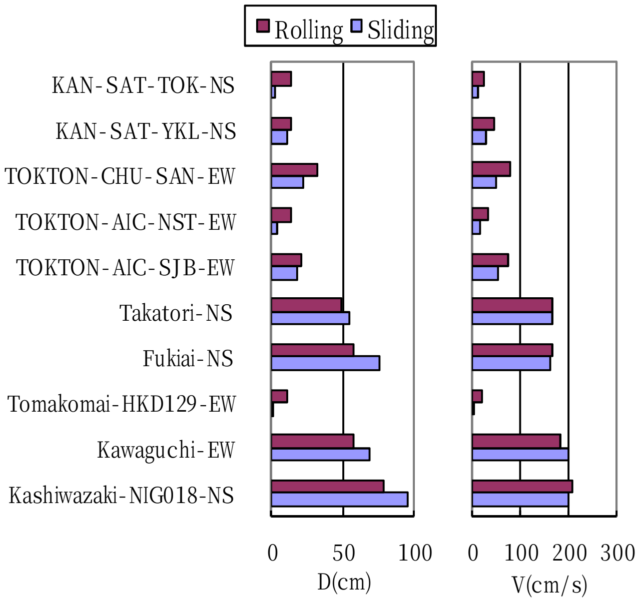


Figure 2. Maximum relative displacement and velocity response of isolated layer

To keep a function of isolation during and after earthquakes, the isolators should be protected from failure. In order to protect isolators from damage, the displacement response of isolators should be kept not to exceed the limit displacement of isolators. To reduce the response at isolated layer against earthquake motions with high velocity, following countermeasures should be considered.

a) To add kinds of shock absorbing devices

b) To add passive hydraulic damper

In case of shock absorbing devices, the stiffness of the devices need be larger than that of the isolator, to reduce the displacement response (Iiba, 2008). At this time, the shear force of the isolated layer with the devices is much larger than that without ones.

The stiffness of shock absorbing device is assumed to be linear and quadratic as shown in Table 4. The device is able to be operated at a certain displacement of isolated layer (δs). When the displacement of isolated layer is less than δs, the system will have the ordinary isolated system. On the other hand, when the displacement is equal to or more than δs, the displacement restraint device will be effective. To investigate the effect of device, the relationship between the non-dimensional shear force and displacement is assumed to be the δs and the displacement at C=1.0 point (δ_e), as shown in Table 5. Considering the clearance of the isolation system for the house, the maximum δ_e is adjusted to be 350mm.

Table 4. Mechanical models for shock absorbing device

Type	Property	Function
STP_A	Linear	$C = a(\delta - \delta_s)$
STP_B	quadratic	$C = a(\delta - \delta_s)^2$

Table 5. Operated displacement and displacement at *C*=1.0

Displacement at operating point (δ_s)	Displacement at C=1.0 point (δ_e)
300mm	350mm

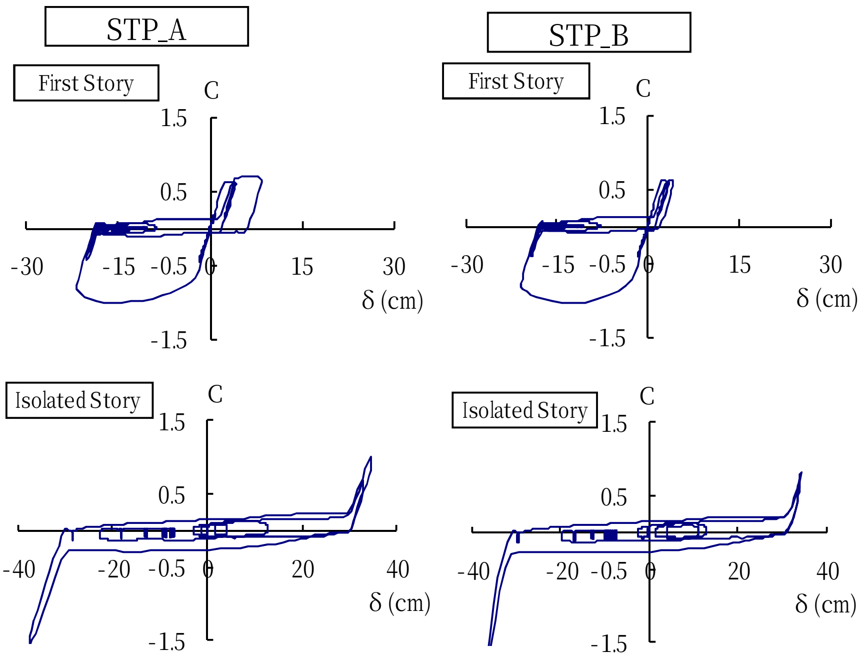


Figure 3. Example of response of S-hv50（superstructure: slip, EQ : Kawaguchi-EW）

The response of displacement at isolated layer and at first story is drawn in Fig. 3. While the maximum displacement without device is 69cm, the displacement with the device is less than 40cm. On the other hand, the response of superstructure is so large. As a result, a large story drift (about 1/12) occurs at the 1st story. The story drift exceeds the safety limit of the house.

Characteristics and Dynamic Test Result of Variable Oil Damper

As the countermeasure to reduce the response at isolated layer, the oil damper is added. The variable damper which is passively controlled is used. When the velocity response at isolated layer is low, the damper has a low damping coefficient. When the velocity exceeds a certain value, the damping coefficient is changed to high immediately, as drawn in Fig. 4. The high damping coefficient can reduce the isolated response. The oil flow is controlled by valve switching through the volume of flow which is corresponding to the velocity of damper, as illustrated in Fig. 5

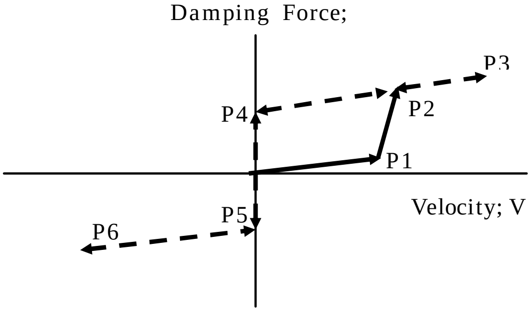


Figure 4. Force vs. velocity characteristics of variable damper

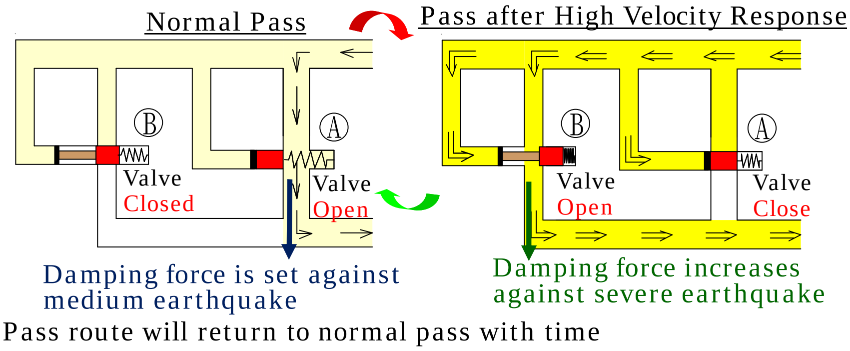


Figure 5. Characteristics of oil flow of variable damper

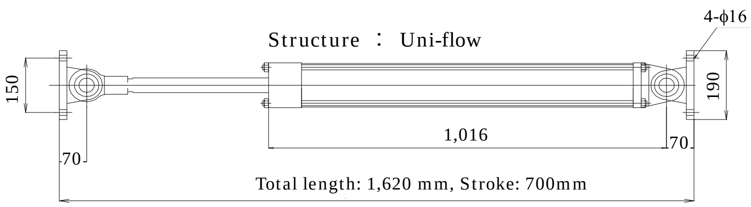
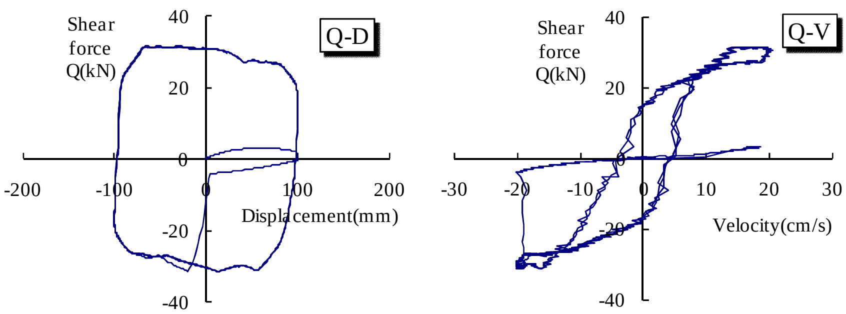


Figure 6. Schematic view of variable damper

The variable damper was manufactured. Figure 6 presents a schematic view and dimensions of the damper. The damper is a uni-flow-type and its stroke is 700mm. The damper was set to the actuator, as shown in Photo 1. A sinusoidal wave was given by the actuator. The relationship between force and displacement and that between force and velocity are drawn in Fig. 7. When the velocity exceeds 15 cm/s, the damping coefficient is change to high. It is demonstrated that the damper shows the good performance which is expected.

Photo 1. Dynamic test on variable damper



a) Force vs. Displacement b) Force vs. Velocity

Figure 7. Force vs. displacement characteristics under dynamic oscillation

Response of House Model with Variable Oil Damper

For the parametric study in numerical calculation, values shown as Table 6 are set. These values are corresponding to the turning points at damper characteristics as drawn in Fig. 8. At point P1, the damping coefficient is changed when the velocity exceeds V_1. The V_1 is set to 40 and 50 cm/s. And the damping force at point P2 is set to be 30 kNs/m. The initial damping force; F_1 is set to be $F_2/30$ or $F_2/3$ when the velocity is less than V_1.

The response of the model with V_1=50cm/s is compared among the number of dampers in Figs. 9 and 10. With increasing the dampers the displacement response at isolated layer is decreased. On the other hand, the displacement at 1st story is increased. When the number of damper is less than 2, maximum displacement at 1st story is less than 60mm (story drift angle; less than 1/45), the safety of superstructure is kept. When 3 dampers are set to the system, maximum displacement is about 170mm (story drift angle; about 1/16).

Table 6. Parameters for numerical analysis

Velocity; V (cm/s)	V_1=40, 50 V_2=V_1+5 V_3=100 V_4=5
Damping force; F (kN)	F_2=30, F_1=F_2/30 or F_2/3, F_3=F_2+C_3*(V_3-V_2), F4=F_2-C_3*(V_2-V_4)
Damping coefficient; C(kNs/cm)	C_1=F_1/V_1, C_2=4.5, C_3=0.125, C_4=C_2
Amount of dampers	0.1W / F2, 0.2W / F2, 0.3W / F2 W:Total weight of seismically isolated house When W is 300kN, above values are 1, 2, 3, respectively.

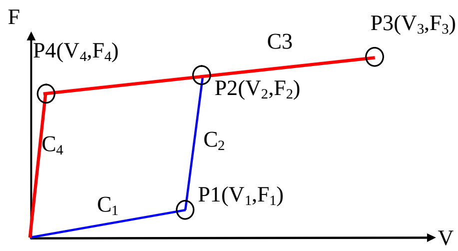


Figure 8. Control points of variable damper

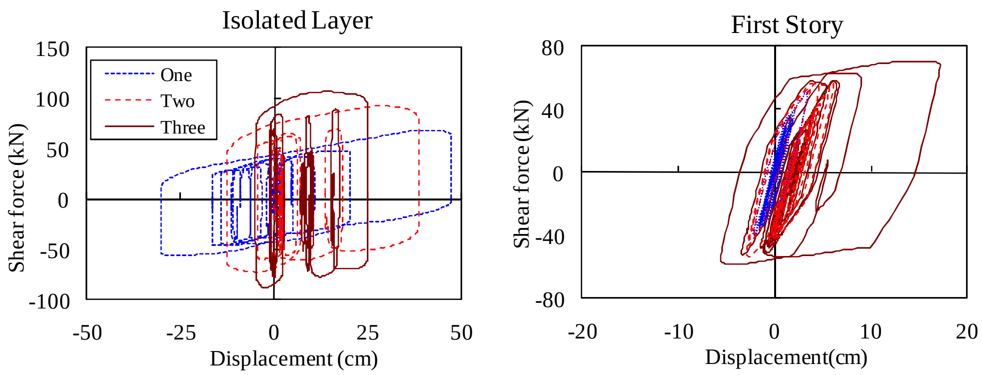


Figure 9. Shear force vs. displacement at isolated layer and 1st story (system; S-hv0, superstructure; trilinear, EQ : Tkatori-NS）

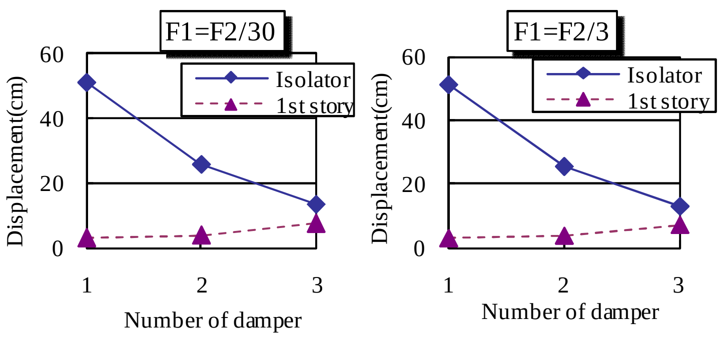


Figure 10. Maximum Displacement at isolated layer and 1st story (system; S-hv0, superstructure; trilinear, EQ : Kashiwazaki-NIG018-NS)

Conclusions

To keep a function of isolation during and after earthquakes, the isolators should be protected from failure. In order to protect isolators from damage, the displacement response of isolators should be kept not to exceed the limit displacement of isolators. To reduce the displacement response at isolated layer, the variable damper, whose viscous coefficient is passively changed by the velocity at isolated layer, is manufactured and tested dynamically. It is demonstrated that the variable damper shows the good performance which is expected.

Through the numerical calculation, the variable damper is effective to reduce the displacement response at isolated layer. Under earthquake motions with high velocity, the displacement response at isolated layer is gradually decreased according to the amount of dampers. On the other hand, the displacement response at 1^{st} story of superstructure is increased. When the amount of damper is larger, maximum displacement at 1^{st} story exceeds the safety limit.

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