Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

7-10-5

SEISMIC RESPONSE CONTROL OF STRUCTURES BY ACCELERATED LIQUID MASS DAMPER

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SUMMARY

The accelerated liquid mass damper is a kind of mass damper which utilizes the high inertial resistance of a liquid contained in a small tube and oscillating rapidly in accordance with the structural vibration. The shaking table tests of model frames with the damper were performed. The accelerated liquid mass damper provides structures with very large auxiliary effective mass. When the damper is incorporated into a structure with a gapped space, it produces a nonlinear property with regard to natural frequency. The effectiveness of the damper in seismic response control of structures is confirmed.

INTRODUCTION

The accelerated liquid mass damper is a device for controlling structural vibration by the use of the inertial and viscous resistance exerted by vibrating liquid in a small tube, which was devised by one of the authors. The concept of the damper and principles of vibration control being to be reported in a separate paper in the conference, this paper deals with the application of the damper to the control of structural vibration induced by earthquakes.

The response of large displacement encountered by flexible structures can be attributed to so called selective resonance, where a structure picks up the earthquake wave components in the frequency band close to the structure's natural frequency. It is difficult to precisely prescribe a dominant frequency for probable earthquakes in a site. From this point, the best way of avoiding the selective resonance seems to be the provision of strong nonlinearity to the structures. But, in the extent of authors' knowledge, no isolation device nor the hysteretic dampers of yielding metal has succeeded in providing nonlinearity enough to suppress the resonance.

In the gapped form of the Accelerated Liquid Mass Damper, the damper having very large effective mass is installed in a structure with prescribed small gaps. It is so designed that the natural frequency of the system varies in wide range with the increase of displacement amplitude beyond the gaps, thus inducing strong nonlinearity to the structure.

To investigate the response of the structures provided with the gapped damper to earthquake waves, the authors carried out vibration tests of simple models on a shaking table. This report refers to the test results.

DESCRIPTION OF EXPERIMENT MODEL

Model Frame The model frame for shaking table tests is shown in Photo 1. The damper unit is attached to the frame by the diagonal braces. The parameters of the tested frame are shown in Table 1.

Accelerated Liquid Mass Damper Unit The accelerated liquid mass damper unit incorporated into the tested frame is shown in Photo 2 and Fig. 1. The damper unit is composed of a pair of vessels formed by bellows which are connected to each other by a conduit tube of small diameter. Both the vessels are connected to each other by a hollow box, whereinto the bottom of the braces is inserted with adjustable gaps. On the shaking table tests, three types of the damper unit are used and the parameters are shown in Table 2. In every case, the cavity is filled with 60% solution of glycerin.

The auxiliary effective mass and the auxiliary effective damping to the frame for harmonic excitation are given as follows (Ref. 2):

$$M_{eq} = (1 + 1/\lambda)\,\beta^2 m_\ell \qquad (1)$$

$$C_{eq} = \{\lambda\omega/(\lambda - 1)^2\}\,\beta^2 m_\ell \qquad (2)$$

where

$\lambda = \sqrt{\omega/2\nu}\cdot R$: Stoke's parameter in oscillating flow in tube
$\beta = A/a$: ratio of sectional areas
A : sectional area of vessels
a : sectional area of tube
R : radius of tube
m_ℓ : mass of liquid contained in tube
ν : kinematic viscosity of liquid

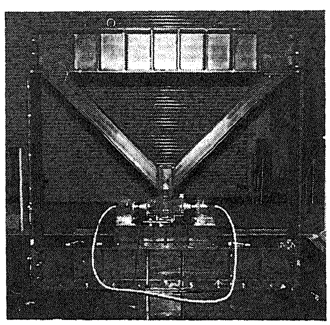

Photo 1 Model Frame

Table 1. Parameters of tested frame

weight	W_o	1100 kgf
mass	M_o	1.123 kg·sec²/cm
spring const.	K_o	640.8 kg/cm
natural freq.	f_o	3.8 Hz
damping facter	h_o	0.47 %

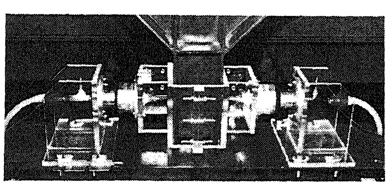

Photo 2 Damper Unit(TYPE III)

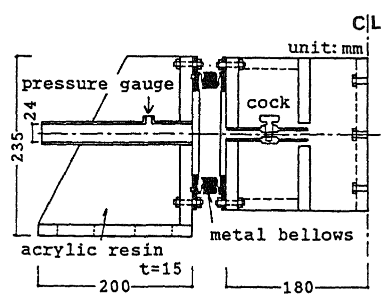

Fig. 1 Damper Unit(TYPE I)

Table 2. Parameters of Accelerated Liquid Mass Damper Units

#	bellows type	A (cm²)	L (cm)	R (cm)	a (cm²)	β=A/a
I	metal bellows	113.0	439	1.25	4.91	23.02
II	rolling seal bellows	44.5	424	0.60	1.13	39.32
III	rolling seal bellows	44.5	324	0.60	1.13	39.32

60% solution of glycerin :
$\nu = 0.128$ cm²/sec
$\rho = 1.150$ gr/cm³

(L : length of tube)

RESPONSE OF DAMPED FRAME TO HARMONIC EXCITATION

To verify the basic properties of the accelerated liquid mass damper unit, the test frame with the damper was subjected to harmonic excitations. The resonance curves of the frame with and without the damper are shown in Fig. 2. Each damper is incorporated into the frame without any gapped space. The experimental auxiliary effective mass and damping derived from the resonance curves are shown in Table 3 with the theoretical auxiliary effective mass and damping estimated by the equation (1) and (2). Experimental effective masses agree well with the theoretical values.

The accelerated liquid mass damper(TYPE III) is incorporated into the frame with a gapped space whose width(d) is 1.0mm. The gapped damper unit does not work while displacement of the frame is smaller than the width of the gapped space(d), but does work when the displacement grows beyond the width of the gapped space(d) (Fig. 3). Then the gapped damper unit induces nonlinear property in the system. The resonance curves of the frame with the gapped damper are shown in Fig. 4. Input acceleration levels are 0.02g and 0.04g. It can be observed that the peak of the original curve (no gapped space) was truncated.

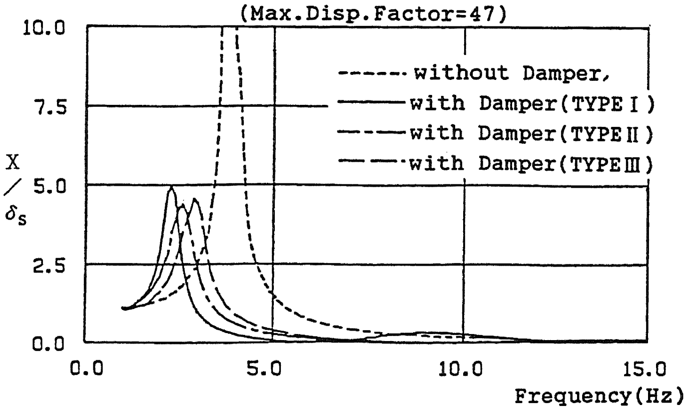

Fig. 2 Resonance Curves of Frame with Damper

Table 3. Comparison of the experimental results with the calculated results

TYPE	f_o(Hz)	experiment results		calculated results	
		M(kg)	C(kg·sec/cm)	M_{eq}(kg)	C_{eq}(kg·sec/cm)
I	2.5	1442	5.68	1415	2.67
II	2.7	1079	5.71	981	4.79
III	3.0	665	5.20	744	3.76

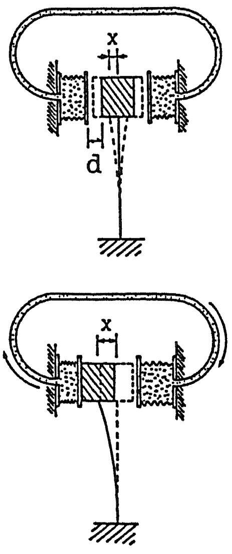

Fig. 3 Model of Gapped Damper

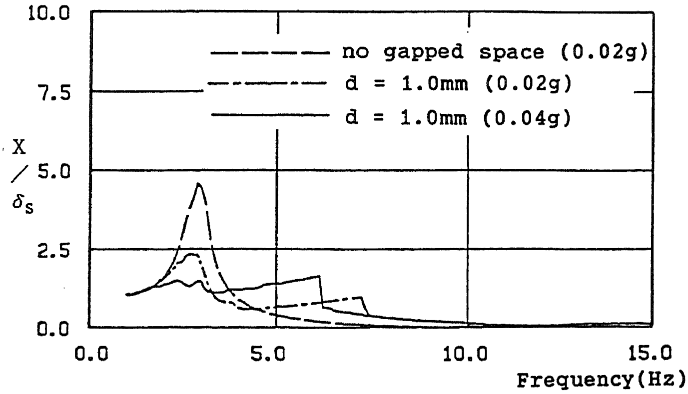

Fig. 4 Resonance Curves of Frame with Gapped Damper(TYPE III)

Results of Shaking Table Tests   The test frame with the accelerated liquid mass damper was subjected to random excitations on the shaking table. Input motions are EL CENTRO (1940) NS and HACHINOHE (1968) NS whose peak amplitudes are normalized to 0.15g. The maximum response accelerations (Amax) and relative displacements (Dmax) are shown in Table 4. Time histories of the frame with and without the damper (TYPE Ⅲ) are shown in Fig. 5 and Fig. 6. The accelerated liquid mass damper can reduce the response of the frame to earthquakes remarkably. The gapped damper reduces relative displacements further, while response accelerations increase a little because of the collision between the frame and the damper.

Table 4. Maximum Response Accelerations and Relative Displacements

INPUT MOTION		EL CENTRO(NS)		HACHINOHE(NS)	
DAMPER TYPE		Amax(g)	Dmax(cm)	Amax(g)	Dmax(cm)
No Damper		0.54	1.01	0.44	0.81
TYPE I	No gap	0.17	0.36	0.17	0.35
	gap=0.15cm	0.19	0.28	0.17*	0.22*
TYPE II	No gap	0.15	0.33	0.20	0.45
	gap=0.13cm	0.22	0.27	0.20	0.34
TYPE Ⅲ	No gap	0.16	0.35	0.22	0.51
	gap=0.10cm	0.21	0.33	0.22	0.40

(*:gap=0.5mm)

Simulation Analysis   In order to simulate the earthquake motions of the frame with the damper (TYPE Ⅲ), the frame was idealized into a lumped mass system. The auxiliary effective mass and damping are obtained from the results of harmonic excitation tests (Table 3).
The equations of the motion are given as follows:
for the phase in which the frame is vibrating within the gap,

$$M\ddot{x} + C\dot{x} + Kx = M\ddot{x}_0 \qquad (3)$$

and for the phase in which the frame moves with the damper by the same displacement,

$$(M + M_{eq})\ddot{x} + (C + C_{eq})\dot{x} + Kx = M\ddot{x}_0 \qquad (4)$$

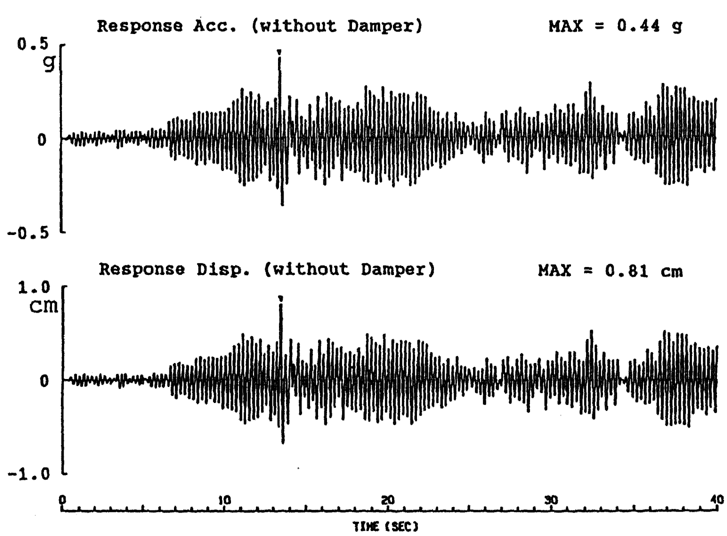

Fig. 5 Time Histories of Frame without Damper to HACHINOHE(NS) 0.15g

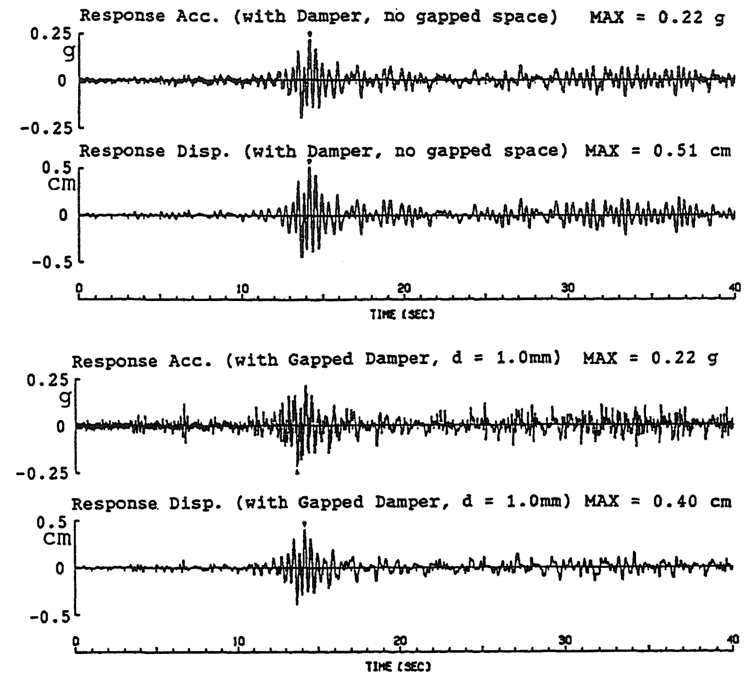

Fig. 6 Time Histories of Frame with Damper(TYPEⅢ) to HACHINOHE(NS) 0.15g

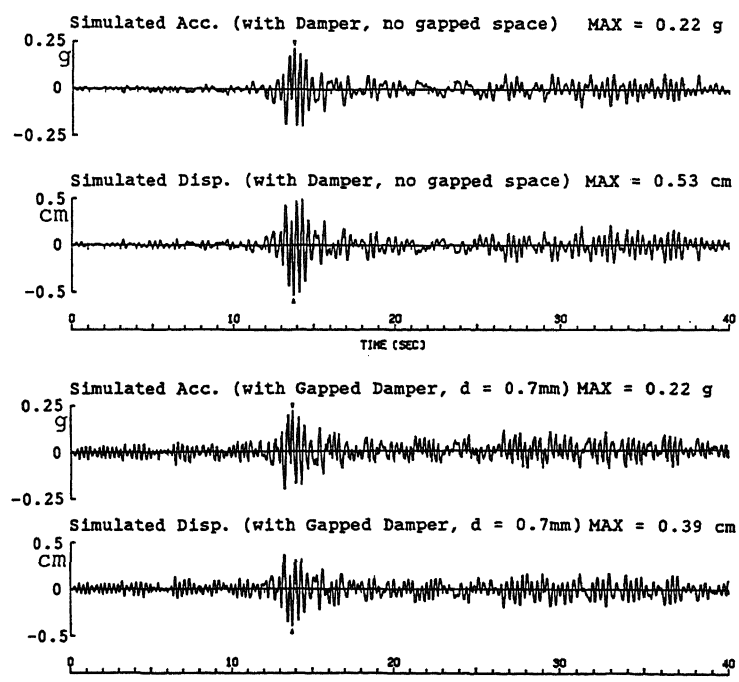

Fig. 7 Simulated Time Histories of Frame with Damper(TYPEⅢ) to HACHINOHE(NS) 0.15g

As shown in Fig. 3, one equation of the motion changes into the other according to the relative displacement between the frame and the damper. The response analysis were carried out using linear acceleration method. On the step when the equation changes, the velocity of the next step is obtained from the law of conservation of momentum. The simulated motions are shown in Fig. 7. Simulated motions are almost the same as the experimental ones shown in Fig. 6, though some discrepancy is seen in the gapped case.

CONCLUSION

From the results of the shaking table tests of model frames with the accelerated liquid mass damper, the followings can be concluded.

(1) The auxiliary effective mass of the damper is given by multiplying the mass in the tube by square of the ratio of the sectional area of the vessel to that of the tube.

(2) The gapped damper produces nonlinear property in the system and truncates the peak of the resonance curves. The gapped damper can prevents the occurrence of "selective resonance".

(3) The accelerated liquid mass damper can reduce the response of the frame to earthquakes. The gapped damper can reduce relative displacements further, while response accelerations increase a little because of the collision between the frame and the damper.

(4) The auxiliary effective mass of the accelerated liquid mass damper is of passive nature and produces no active inertial force by the input ground accelerations.

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