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AN EARTHQUAKE ISOLATOR EFFECTIVELY CONTROLLING THE DISPLACEMENT BY EMPLOYING THE BALL SCREW TYPE DAMPER WITH MAGNETIC DAMPING

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SUMMARY

In this paper, new earthquake isolator which consists of laminated rubbers and ball screw type dampers with magnetic damping is introduced. The response acceleration can be effectively attenuated, because the rotating mass of the ball screw type damper with magnetic damping, in which the ball screw transforms the linear motion of the base into rotation, works as a virtual appendant mass and can elongate the first mode period of the system. Both this virtual appendant mass effect and the large damping ratio available by the magnetic damping can repress the relative displacement in the base.

INTRODUCTION

Recently, the study and the practical use of earthquake isolation technology, which enables the superstructure to stay in the absolute space during earthquake by means of laminated rubbers bearing and many kinds of dampers, have been rapidly developed. Although the response acceleration of the superstructure can be attenuated by virtue of the earthquake isolation device, very large displacement of the base relative to the ground may occur. In order to control this large relative displacement, authors have tested hysteretic, frictional and viscous type dampers. But these dampers have not reduced the relative displacement so much as we expected.(1)

In this paper, new type of earthquake isolator that consists of laminated rubbers and ball screw type dampers with magnetic damping is introduced. Not only the response acceleration can be reduced as much as the conventional earthquake isolator consisting of laminated rubbers and viscous oil dampers, but also the relative response displacement at the base may be attenuated by 20 or 30 %, comparing with the case of the conventional one.

Response spectra of the floor response waves, designing indexes for apparatus and equipments in the structure are introduced. Those spectra are compared with those of the conventional isolator, which consists of laminated rubbers and oil dampers, and the non-isolated case.

BALL SCREW TYPE DAMPER WITH MAGNETIC DAMPING

The ball screw type damper with magnetic damping is schematically illustrated in Fig. 1. While a relative linear motion occurs between the top and the bottom mounting eyes, the screw shaft rotates by virtue of the ball nut. That is to say; the relative linear motion caused by an earthquake can be transformed into the rotation. The alminium disk rotate across the magnetic fluxes generated by rare-earth magnets(e.g. samarium-cobalt magnets), so that eddy-currents are generated in the alminium disk. A damping torque *T* produced by eddy-currents is proportional to the occuring angular velocity and described as follows[2]:

$$T = \frac{nB^2 hA\mu S^2}{\rho}\dot{\theta} = C_0\dot{\theta} \tag{1}$$

where *n*: number of magnetic fluxes, *B*: magnetic flux density, *h*: thickness of the disk, *A*: area of magnetic flux, *s*: distance between the center of disk and the center of magnetic flux, μ: dimensionless damping coefficient decided by the experiment, ρ: resistivity of the alminium disk and C_0: equivalent torsional damping coefficient. Tab. 1 shows the numerical values of the ball screw type damper with magnetic damping employed in the calculations.

The resisting force *F* generated at the ball screw type damper with magnetic damping can be described as follows:

$$F = \frac{4\pi^2}{L^2}(J\ddot{u}+C\dot{u}) \tag{2}$$

where *J* and *C* denote the equivalent moment of inertia and the equivalent damping coefficient respectively, summing up 20 ball screw type dampers with magnetic damping. Every ball screw type damper with magnetic damping is attached to the mounting mass of the earthquake isolator through the hard spring. The reason why the hard spring may be introduced, is because the exceeding mass effect of the ball screw type damper in the range of high frequencies can be moderated.

MATHEMATICAL FORMULATIONS

The equations of motion of the system consisting of the 7 storied building, whose specific values are listed up in Tab.2 and the ball screw type dampers with magnetic damping as illustrated in Fig. 2 can be written as follows:

$$\begin{aligned}
&\beta J\ddot{u}+\beta C\dot{u}+K_s(u-x_0)=0\\
&m_0\ddot{x}_0+C_1(\dot{x}_0-\dot{x}_1)+K_1(x_0-x_1)+K_s(x_0-u)+K_0x_0=-m_0\ddot{z}_0\\
&m_i\ddot{x}_i+C_i(\dot{x}_i-\dot{x}_{i-1})+C_{i+1}(\dot{x}_i-\dot{x}_{i+1})+K_i(x_i-x_{i-1})+K_{i+1}(x_i-x_{i+1})=-m_i\ddot{z}_0,\quad (i=1,\cdots,6)\\
&m_7\ddot{x}_7+C_7(\dot{x}_7-\dot{x}_6)+K_7(x_7-x_6)=-m_7\ddot{z}_0
\end{aligned} \tag{3}$$

where $\beta = (2\pi/L)^2$, K_s: spring constant of the spring attached between the mounting mass and the ball screw type damper with magnetic damping, Z_0: ground motion, m_0: mass of the mounting in the earthquake isolator, K_0: spring constant in the earthquake isolator and m_i, C_i, K_i: mass, damping coefficient and stiffness in each story.

The equations of motion of the system consisting of oil dampers can be obtained by excluding the first equation and putting K_s into zero in Eqs. (3). The equations of motion of the non-isolated building can also be obtained by excluding the first and the second equations and putting K_0 into zero in Eqs. (3).

RESPONSES TO THE GROUND MOTION

El Centro(NS) and Akita(NS) normalized to be 400 gals at the maximum acceleration are employed as an input. Acceleration waves and response spectra are shown in Fig. 3 and Fig. 4 respectively.

Under above mentioned ground motions, responses of the 7 storied building have been calculated for three cases, that is non-isolated, isolated by employing laminated rubbers with oil dampers and isolated by employing ball screw type dampers with magnetic damping. Time histories of the response are shown in Fig. 5. Maxima of responses at the 7th story and the mounting mass are listed up in Tab. 3. Tab. 3 shows that the ball screw type dampers with magnetic damping can effectively attenuate the relative displacement at the mounting mass of the earthquake isolator.

Response spectra of the floor response waves recorded at the 7th story are shown in Fig. 6. In Fig. 6, two curves denote 2% and 5% respectively in damping ratio.

As to displacement response spectra, both isolated cases have narrower band peaks than the non-isolated case.

Acceleration response spectra belonging to both isolated cases have wider band characteristics, comparing with those of the non-isolated case. This means that we could expect the filtering effect through the structure not so much as the non-isolated one, and that apparatus and equipments have to be carefully installed in the building.

CONCLUSIONS

Computer simulations on the seismic response of the 7 storied building isolated by employing laminated rubbers and ball screw type dampers with magnetic damping have been carried out. Results of computer simulations reveals that

1. the relative displacement at the base can be attenuated by 20 or 30%, compared with the case of the isolator consisting of laminated rubbers and oil dampers, and
2. acceleration response spectra of floor response waves recorded at the 7th story may be similar to the case of laminated rubbers with oil dampers and may have wider band characteristics compared with the non-isolated case.

REFERENCES

1. Arakawa, T., Koh, T., Ohmata, K., Shimosaka, H. and Shimoda, H., "Vibration Characteristics and Earthquake Responses of Structures and Equipments Supported on Seismic Isolator", 7th JEES, Art. 272 (1986)
2. Ohmata, K., Shimoda, H. and Hosoya, A., "Characteristics of Ball Screw Type Damper with Magnetic Damping", Bulletin of JSME, Vol. 29, No. 253, (1986)

Tab. 1 Specified values of the ball screw type damper with magnetic damping

Lead of ball screw L	1. 0 (cm)
Moment of inertia of flywheel J_θ	$2.55*10^{-3}$ (ton•s²•cm)
Torsional damping coefficient C_θ	$3.163*10^{-3}$ (ton•cm•s/rad)
Number of damper	20

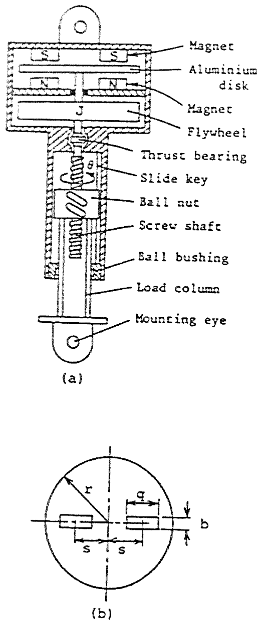


Fig. 1 Ball screw type damper with magnetic damping

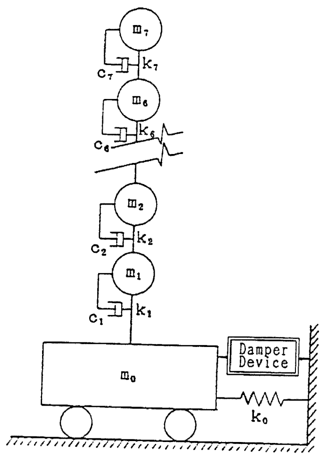


Fig. 2 Model of the isolated building

Tab. 2 Specified values of the 7 storied building

Story	Weight (ton)	Stiffness (ton/cm)
7	568	776
6	400	890
5	424	1349
4	433	1349
3	433	1390
2	461	1624
1	461	1618
0	900	40

Tab. 3 Maxima of response

model	Story No.	ElCentro (1940) NS		Akita (1983) NS	
		Disp. (cm)	Acce. (gal)	Disp. (cm)	Acce. (gal)
Non Isolated	7	6. 53	1017. 4	4. 87	703. 9
Isolation (Oil Damper)	7	19. 48	382. 1	44. 05	444. 6
	0	17. 72	373. 7	40. 12	392. 9
Isolation (Magnetic Damper)	7	12. 78	435. 4	29. 68	429. 2
	0	11. 22	409. 9	25. 73	345. 7

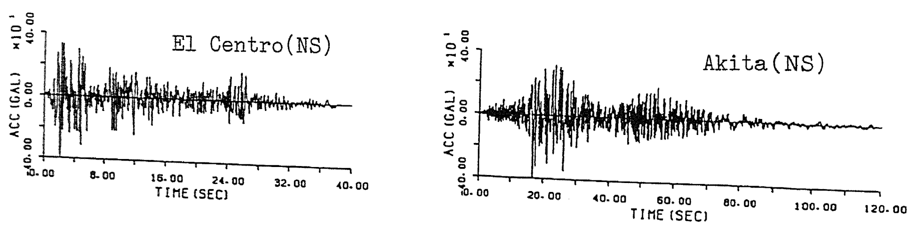


Fig. 3 Input earthquake

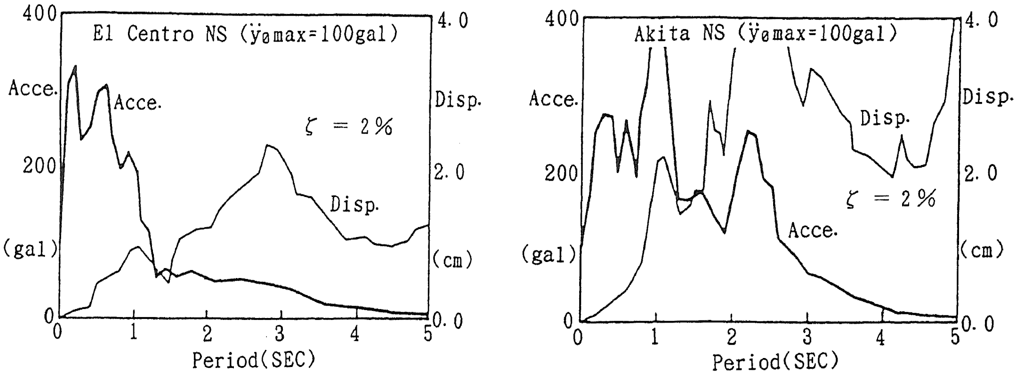
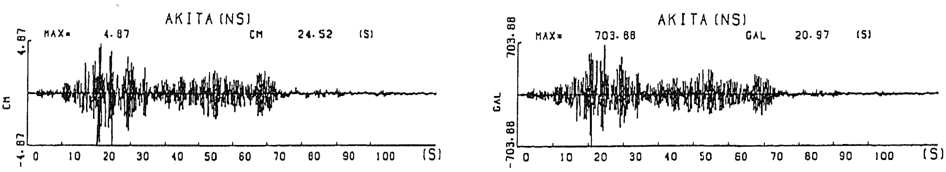


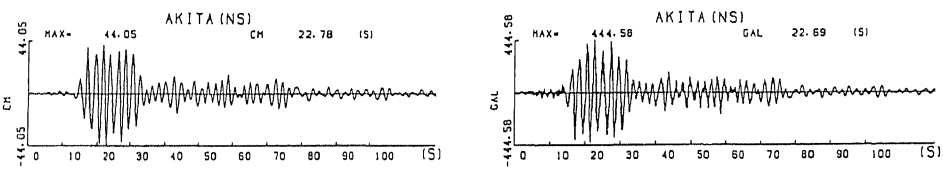
Fig. 4 Response spectra of input earthquake

Displacement

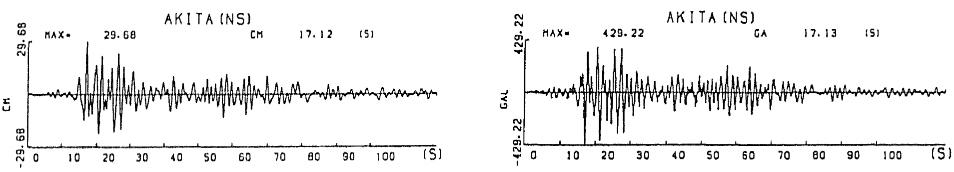
Acceleration



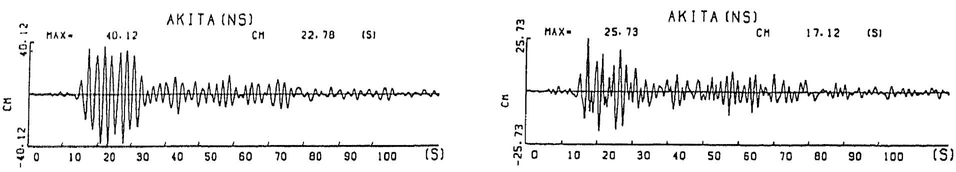
(a) Non isolated (7th story)



(b) Oil damper (7th story)



(c) Magnetic damper (7th story)



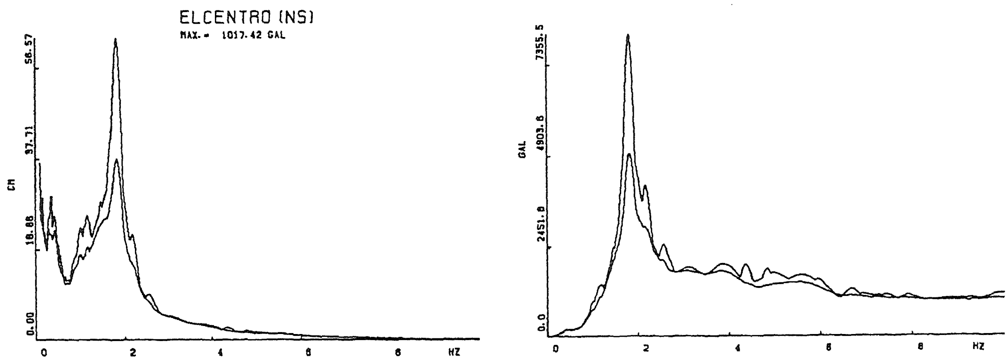
Oil damper

Magnetic damper

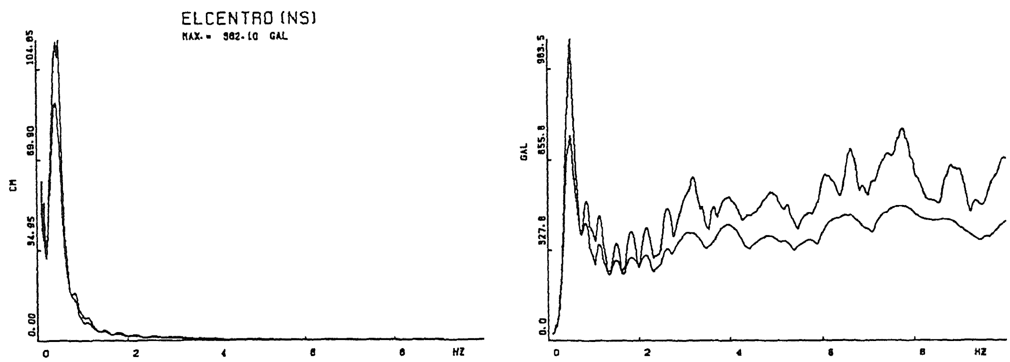
(d) Displacement at the mounting

Fig. 5 Response of the building under the seismic excitation

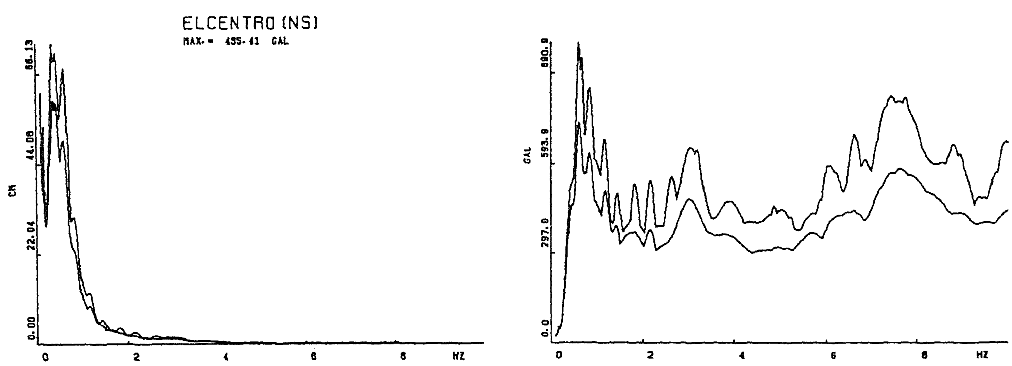
Displacement Acceleration



(a) Non isolated



(b) Oil damper



(c) Magnetic damper

Fig. 6 Response spectra of floor response waves recorded at the 7th story