Seismic Response of Steel Framed Buildings Using Viscoelastic Damper

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ABSTRACT

The research and development of a new type of viscoelastic damper for high rise buildings/structures to mitigate earthquake or wind-induced structural response is discribed in this paper. Tall buildings/structures can be caused excessive structural deflexions, at their resonant frequencies, by excitation from the strong earthquake motion or a wind effect. And also, for the weak earthquake, occurs several times a year in Japan, or for the weak wind, it is considered that the structural aseismic comfortableness would be strongly needed in near future. The viscoelastic damper, developed in this program, dissipates energy sufficiently and the responses of the building are significantly reduced.

1 INTRODUCTION

Nowadays as we enter a new era of a high level of information-oriented society, in Japan, the number of high rise buildings having multi-functions has been increasing. These high rise buildings of so-called "*intelligent buildings*" exist not only as simple buildings but also work as systems to fulfill their primary functions. The necessity for protective functions of these buildings against earthquake or wind-induced vibrations has been on the rise. In this field, many means of mitigating structural responses, such as seismic base isolation, passive/active mass damper and energy absorbing device installed in the structure, have been studied (Fujita, T., 1985, Zhang, R. et al., 1989).

This paper describes the developed viscoelastic dampers comprising two viscoelastic layers bonded between three parallel rigid plates and disipating energy when displaced in shear and the experimental tests using a shaking table carried out for the five-storey steel framed building model to investigate the performance of the damper installed, in pairs, in each floor. In the sinusoidal excitation tests, it was confirmed that the dampers provided the equivalent viscous damping about 17.9 % of critical for the first mode of the building and the higher modes completely disappeared in this case. In the seismic excitation tests, the maximum response acceleration measured on each floor slab of the building model was reduced to the values from 2/5 to 1/2 of that in the case of without damper. And it was confirmed that the damper gave almost linear viscous damping to the building model. In addition, this damper absorbed energy sufficiently not only for storong earthquakes mentioned above but also for weak earthquakes including microvibrations.

2 TEST MODEL

2.1 Steel framed building model and viscoelastic damper

Figure 1 shows the five-storey steel framed building model standing 3,580 mm high with a total mass of 6,029 kg used for the shaking table tests. The first four natural frequencies of this building model are 2.52 Hz, 7.50 Hz, 12.0 Hz and 15.5 Hz. The fifth mode was not obsereved in the tests.

Figure 2 shows the viscoelastic damper used for the tests. This damper comprises two viscoelastic layers of $70 \times 70 \times 10^T$ mm in dimension bonded between three parallel rigid plates, and disipates energy when displaced in shear. The dampers are installed, in pairs, in each storey of the building model and connected to the upper and lower floor slabs by the fixing bolts.

2.2 Shaking table tests

The skaking table tests for sinusoidal waves and for actual seismic waves including the band-passed white noize (1 - 25 Hz) in the horizontal direction were implemented for the building model with or without dampers. In the seismic excitation tests, El Centro NS (Imperial Valley Earthquake, 1940), Taft NS (Kern County Earthquake, 1952), Akita NS (Nipponkai Chubu Earthquake, 1983) and band-passed White Noize (1 - 25 Hz) were used.

Response accelerations on each floor slab of the building model including the shaking table, relative storey displacements and strains occurred at the steel flanges of the dampers were measured, as shown in Fig. 3. And furthermore temperatures rised when the dampers undergoing deformation were caputured by thermocouples.

3 EXPERIMENTAL RESULTS

3.1 Damping effect against sinusoidal/seismic excitations

Figure 4 shows response acceleration and relative storey displacement resonant curves for the building model with or without dampers against the 1.0 m/s^2 input. It must be mentioned that the results when without dampers were obtained from the results to smaller excitation by linear scaling to avoid the building model without dampers being failed with the same amplitude of input. The maximum responses of the building model with dampers were sufficiently reduced to 1/20 of the response at 1st mode when dampers were not provided . The higher modes disappeared in that case and the 1st modal damping ratio was found to be around 18%. In general, since the structure's increase in stiffness, which is contributed by the viscoelastic dampers employed, might decrease the structure's seismic performance, the capacity of the dampers should be carefully chosen; however, it is obvious that the damper, which is used for the tests, have a very low stiffness as compared with the energy absorbing performance itself.

An analytical model of the building model with dampers is a 5 degree-of-freedom system, in which the displacement for each storey is considered. The restoring force characteristics of the viscoelastic dampers are defined as a displacement dependent restoring force characteristic with a linear damping force characteristic. The displacement dependent stiffness $K(x)$ for a pair of damper and the linear damping coefficient c, which were defined by the dynamic tests using an acutuator, are expressed as follows.

$$K(x) = K_0 \circ \gamma(x) \quad \text{N/m} \tag{1}$$

$$\gamma(x) = 1.2 \circ \exp(-7 \text{X} 10^2 \circ |x|) + 1.0 \tag{2}$$

$$K_0 = 1.0 \text{ X } 10^6 \ \text{N/m}, \qquad c = 6.5 \text{ X } 10^4 \ \text{N} \circ \text{s/m} \tag{3}$$

Figure 5 shows the maximum response accelerations and displacements of the building model under El Centro NS excitations for various input levels up to 6.77 m/s^2, which is the maximum input level produced by the shaking table used. By adding dampers to the building model, the maximum responses were sufficiently reduced, there being at least 50 per cent reduction not only in El Centro NS input case but also in all cases. It is also interesting to note that the response curves of the damped building are almost linear against the input up to the level of 5 m/s^2 (=50 kine) . This means that the dampers have the characteristics like those of linear viscous dampers and also the analytical results agree well with the experimental results, as shown in Fig. 6, exept in the case of 6.77 m/s^2 excitation.

The properties of viscoelastic dampers are generally affected by the increased temperature of materials during deformation; however, even in the case of El Centro NS 6.77 m/s^2 excitation, which is considered to be very severe condition in comparison with actual seismic excitation, only 0.4 °C increased temperature is measured. This means, in designing the damped structures, that it must be more careful to changes in atmospheric temperature rather than for variances in temperature during deformation.

Figure 7 shows the restoring force characteristic for each damper against El Centro NS 6.77 m/s^2 excitation. It is also confirmed from this result that the damping force characteristic can be considered as linear viscous damping because the shape of the restoring force loop is almost elliptical. Also, it is clearly observed that the stiffness of the damper depends on its deflexion. In the tests, since the viscoelastic dampers, installed in the building model, have got equal energy dissipation capacities, it is observed from Fig. 7 that the energy absorbed is quite defferent in each of dampers. It must be studied more closely that the capacities and installations of the dampers should be optimized for practical use.

The damping effect for the equipments utilized in the building with viscoelastic dampers is also investigated by calculating the acceleration floor response spectra for El Centro NS 6.77 m/s^2 excitation as shown in Fig. 8. In calculating each spectrum, it is assumed that the damping ratio of the internal equipment is 0.01. The solid lines, dotted lines and dashed-dotted lines indicate the experimental results for non-damped building model, the experimental results and the analytical results for the damped building model, respectively. The response acceleration of the internal equipment is significantly reduced in the range of the 1st and 2nd natural periods.

3.2 Damping effect against microtremors

The technology of installing viscoelastic dampers in buildings to mitigate seismic responses mentioned above is basically considered as the technology for weak earthquakes, occur several times a year in Japan, and distructive storong earthquakes and for wind-induced vibrations. This technology is one of means of enhancing structural seismic performance.

Recently, it is considered to be very important to attenuate ambient vibrations in industrial facilities such as semiconductor manufacturing factories. In these facilities, the reductions of ambient vibrations including microtremors is important for improving the yield rate of complete IC chips and so on (Fujita, T., 1986).

In additiion to the seismic excitation tests above mentioned, the test for ambient vibration was carried out to investigate the damping performance of the visoelastic dampers for micro-vibrations. Figure 9 shows the response time histories of the building model under the ambient vibration excitations for the input level of 0.09 m/s^2 in acceleration and 15 μm in displacement. The response acceleration and the absolute displacement of ground floor, 1st floor, 3rd floor and roof is respectively measured by the micro-vibration pick-up. By adding dampers to the building model, the maximum responses were significantly reduced, there being about 50 per cent reduction to such level of input. This means that the viscoelastic damper employed in the tests dissipates energy not only for seismic excitations but also for micro-vibrations; however, if the damping effect for such micro-vibraions is required, it should need more ingenious thechnical contrivances of installations of the dampers for practical use.

4 CONCLUSIONS

Damping effect of the viscoelastic dampers installed in the building model was found to be very remarkable against seismic excitations and micro-vibrations. In both of the seismic and the micro-vibration situations, the viscoelastic dampers provide the building 50 per cent reductions in the responses. From this result, it can be considered that the viscoelastic dampers is also effective for wind-induced vibrations. In the near future, technology of structurual control to mitigate responses due to earthquake, wind and ambient vibration must become an indispensable factor for many high-rised building and industrial facilities which contain a lot of high technology-oriented equipment sensitive to such vibrations, because this kind of equipment generally does not satisfy earthquake resistance requirements by its own strength and functions of the equipment or system must be ensured agaist such situations in any time.

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Fig. 1 Five-storey Steel Framed Building Model

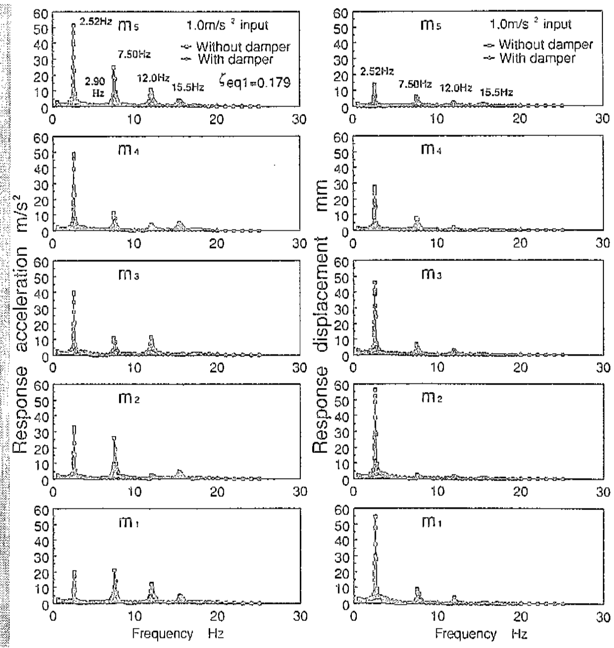

Fig. 4 Resonant Curves for Building Model with or without Dampers

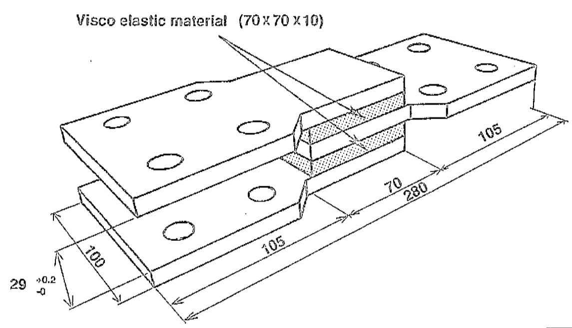

Fig. 2 Viscoelastic Damper

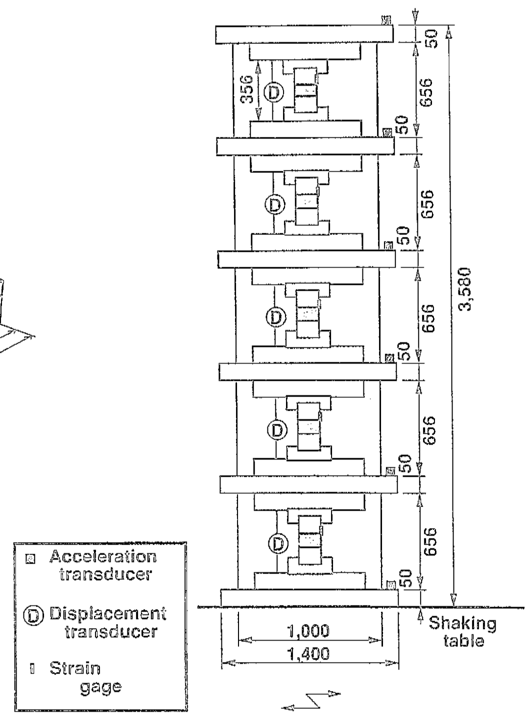

Fig. 3 Schematic View of Building Model and Measurement Points

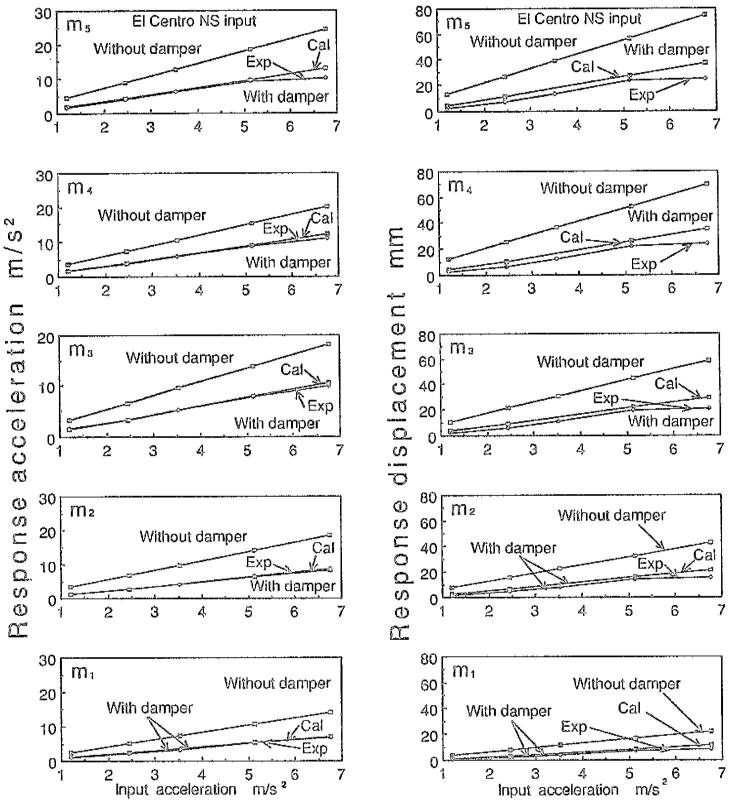

Fig. 5 Maximum Seismic Responses in Building Model

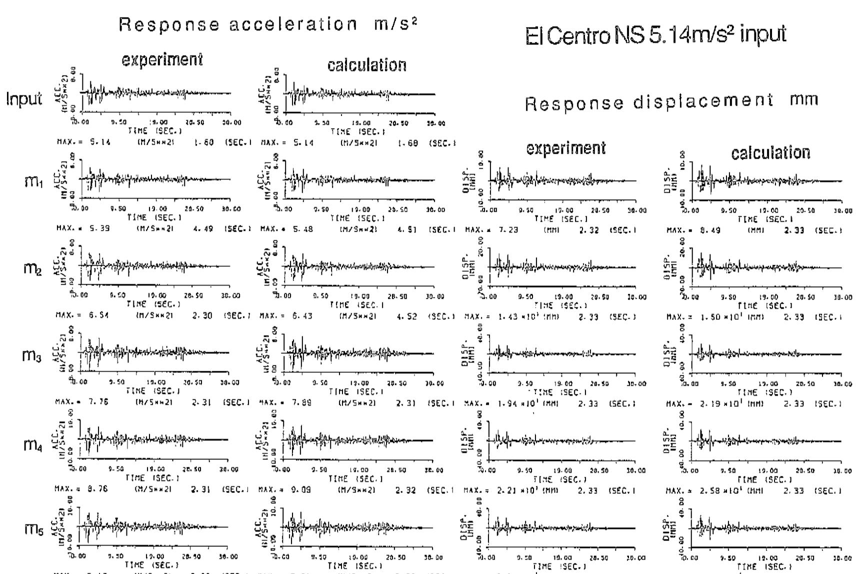

Fig. 6 Comparison of Analytical Results with Experimental Results for Response Time Histories of Building Model with Viscoelastic Dampers in the Case of El Centro NS 5.14 m/s² Input

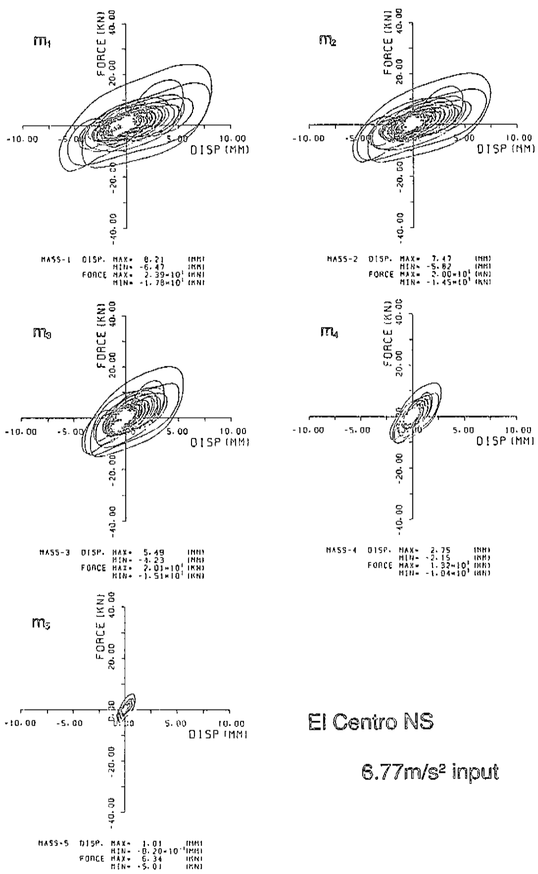

Fig. 7 Restoring Force Characteristics of Dampers in the Case of El Centro NS 6.77 m/s² Input

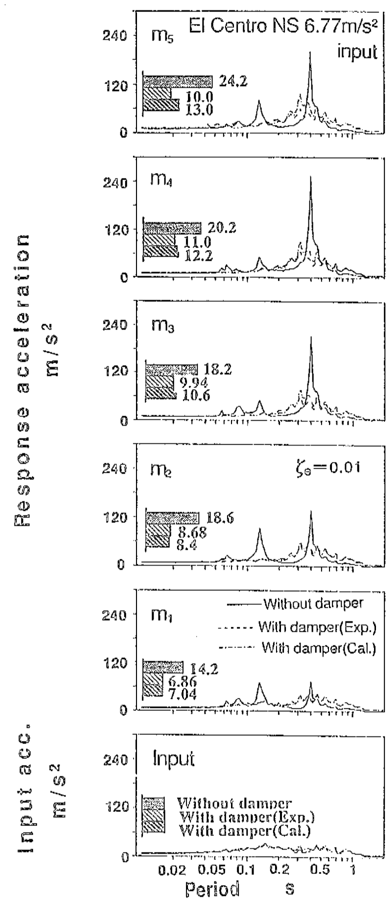

Fig. 8 Acceleration Floor Response Spectra for Building Model

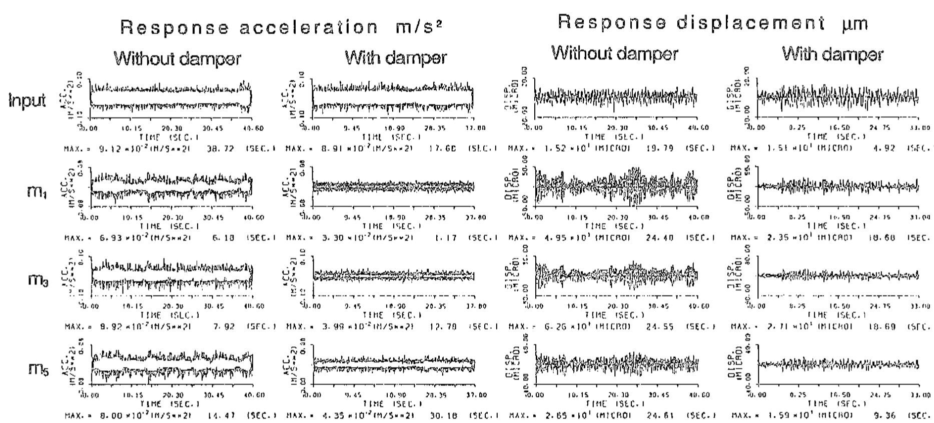

Fig. 9 Damping Effect against Microtremors