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Development of high damping rubber damper for vibration attenuation of high-rise buildings

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ABSTRACT: Two new types of high damping rubber damper have been developed in this research program. One is the sandwich type damper and the other is the cylinder type damper. The static tests for both types of the damper were carried out to investigate restoring force characteristics. The dynamic tests using a shaking table were also carried out for a five-storey steel framed building model to investigate the performance of the damper installed, in pairs, in each floor using the sandwich type damper. It is confirmed that the damping force characteristics of both dampers can be considered as those of linear viscous damping and the dampers sufficiently dissipate energy for vibrations of μm order to those of generating 300% shear strain.

1 INTRODUCTION

During the last few years structural control technology to mitigate vibration of high rise buildings induced by earthquake or wind has become necessary. These high rise buildings so-called "***intelligent buildings***" exist no only as simple buildings but also work as systems to fulfill their primary functions. This technology is firstly considered to be used to improve the comfortableness within buildings by reducing the wind effect or the weak earthquake motion occurs several times a year in Japan. In addition to that, it would be strongly needed in near future to increase the seismic reliability of high rise buildings for destructive inputs such as 50 kine level seismic waves.

The research and development of a new type of high damping rubber damper for high rise buildings to mitigate earthquake or wind-induced structural response is described in this paper. This damper is considered to be suitable not only for destructive seismic motions but also having potential to be used for improving seismic comfortableness against the small amplitude of external forces.

2 STATIC TESTS

2.1 Test samples, equipment and method

Two types of high damping rubber damper have been developed in this program. Figure 1 shows the sandwich type damper comprising two high damping rubber layers of 70 X 70 X 10^T mm in dimension inserted between three parallel rigid plates and dissipating energy when displaced in shear (Fujita 1991). Figure 2 shows the cylinder type damper designed to have approximately a half stiffness as compared with the sandwich type damper if the same rubber material used.

New type of high damping rubber material comprising SEBS (Styrene-Etyrene-Butadiene-Styrene) rubber as a main composition is used for the damper. This material is considered to be having a very low stiffness, a high damping capacity and a strong adhesive property as compared with the other types of high damping or viscoelastic dampers proposed so far. It must be mentioned that the material used for the both of dampers is slightly different in each other; the evolutional material, having a falf of shear modulus with the same loss factor is applied to the cylinder type damper.

Figure 3 shows test equipment and instrument system. Since it is considered that the cylinder type damper is disadvantageous structure in the effect of heat radiation compared with the sandwich type damper, the constant-temperature oven was employed in the tests for the cylinder type damper to clarify the temperature dependency on various characteristics.

In the measurements, the restoring force and the displacement of damper was respectively measured by the load cell and the displacement transducer which have been built into actuator. In the case of the cylinder type damper, the rubber material, cylinder surface, shaft and internal temperature of constant temperature oven were measured by the thermocouples.

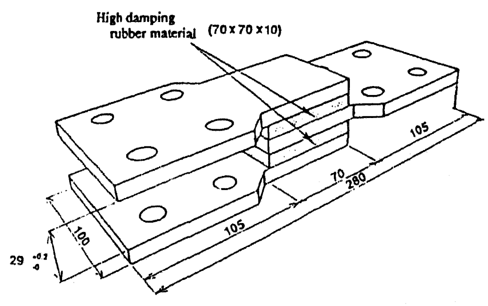


Fig. 1 Sandwich type damper used for the test

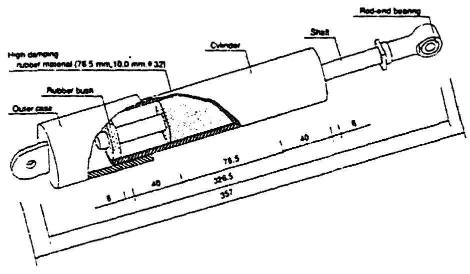


Fig. 2 Cylinder type damper used for the test

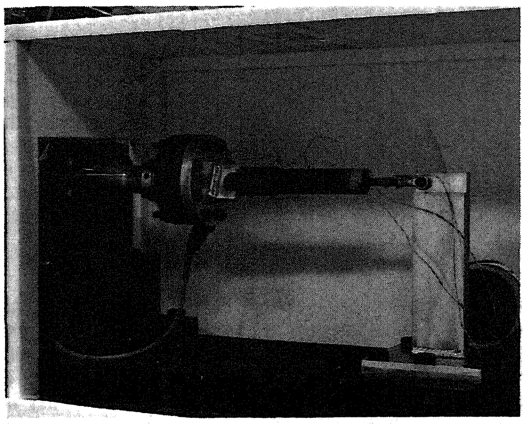


Fig.3 Equipment set up for the static test

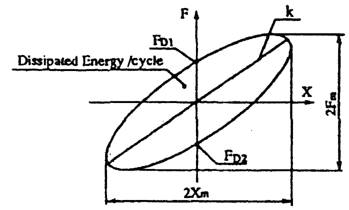
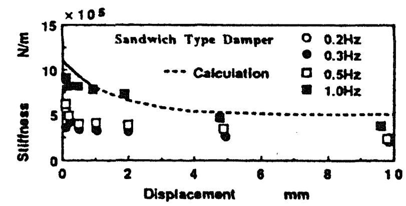
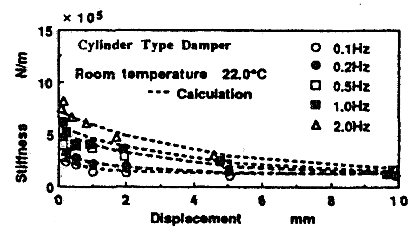


Fig.4 Definition of stiffness and damping coefficient for restoring force loop

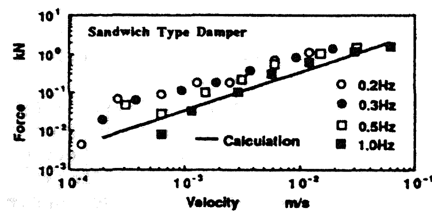


(a)

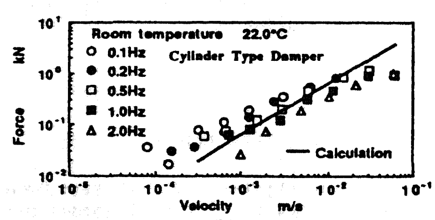


(b)

Fig. 5 Amplitude dependency on stiffness



(a)



(b)

Fig. 6 Velocity dependency on damping force

2.2 Restoring force characteristics

Characteristics of two types of high damping rubber damper have been evaluated by the following methods. Since it has been confirmed in the previous tests that this damper is having a damping force characteristic like one of linear viscous damper, the restoring force characteristics of the damper can be expressed by the stiffness K and the linear damping coefficient C. For a typical restoring force characteristic as shown in Fig. 4, these values can be defined as follows.

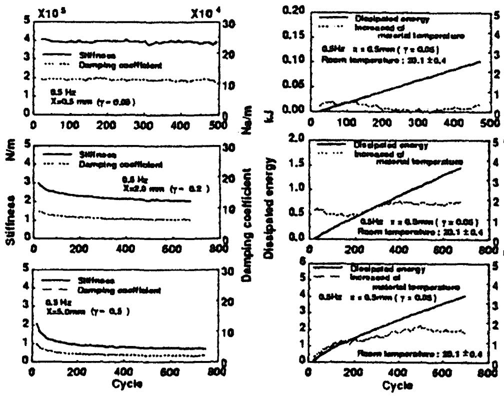
$$K = F_m / X_m \qquad (1)$$

$$C = (F_{D1} + F_{D2}) / 2V_0 \qquad (2)$$

where X_m is the maximum displacement, F_m is the maximum force and F_{D1}, F_{D2} are the restoring forces at the maximum velocity V_0.

Figure 5 shows the amplitude dependencies on the stiffness. Figure 5(a) shows the results for the sandwich type and (b) for the cylinder type. From the results, even though the amplitude dependency appears to the stiffness for both dampers especially in the small amplitude area, the stiffness almost reaches to the constant value beyond 2~4 mm. This means that if the both dampers are permanently used under such shear strains, they have advantageous characteristics as linear design can be applied to the design step of buildings.

Figure 6 (a), (b) show the velocity dependencies in accordance with the damping forces. In the tests, it is confirmed that the both damping force characteristics are very similar to those of linear viscous damping, and almost proportional to the velocity. In the both figures, the solid lines show the damping forces requested from each damping coefficient as follows;



(a) (b)

Fig. 7 Variance in characteristics for repetitive tests

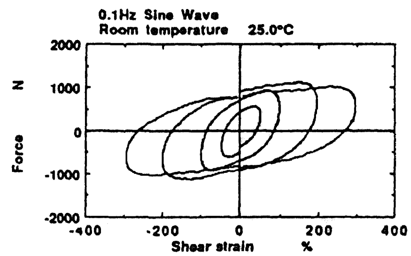


Fig. 8 Restoring force characteristics of the damper for limit performance

Sandwich Type Damper : $C = 3.25\times10^4$ N·s/m
Cylinder Type Damper : $C = 6.0\times10^4$ N·s/m

2.3 Variance in the properties for repetitive tests

Figure 7 shows the results of repetitive cyclic loading tests of the 0.5 Hz sinusoidal wave for the cylinder type damper. Figure 7 (a) indicates the variances in the stiffness and the damping coefficient for such cyclic loadings and Fig. 7 (b) directly shows the rise of material temperature from environmental one and the total dissipated energy. From the results, it is observed that there are few changes in the material temperature up to 20 % shear strain, but for over 50 % shear strain, the material temperature rises rapidly until nearly 500 cycles. Later the material temperature reaches an equilibrium condition because the heat induced in material becomes equal to heat radiation. In this case, although 2.1 °C increased temperature is measured, the stiffness and the damping coefficient of the damper are not much affected. Moreover, the damping coefficient of the damper is considered to be having a proportional viscous damping to the stiffness.

2.4 Limit performance of the cylinder type damper

Figure 8 shows the limit performance of the damper in the case of 25.0°C environmental temperature and 0.1Hz sinusoidal wave actuation. As indicated in the figure, it is confirmed that the cylinder type damper has the excellent energy absorption ability, which is considered to be very similar to linear viscous damping, up to 200 % shear strain. Even though the restoring force and damping force is seemed to be decreased for over 300 % shear strain and the assumption of viscous damping cannot be applied to the such large deformation, the damper still dissipates energy sufficiently. The limit performance of the damper should be examined more closely because the size of damper directly depends on which deflexion domain permanently used in practical applications.

3 SHAKING TABLE TEST

3.1 Test samples, equipment and method

Figure 9 shows the five-storey 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 is not observed in the tests. The damper used for the tests is the sandwich type damper as shown in Fig. 1. 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. The shaking table tests for actual seismic waves in the horizontal direction were implemented for the building model with or without dampers.

3.2 Damping effect against seismic excitations

Figure 10 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 are sufficiently reduced, there being at least 50 % reduction not only in this 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 figure also shows analytical results obtained by applying a displacement dependent stiffness $K(x)$ for a pair of damper as written below and a linear viscous damping assumption described in 2.2 to 5-degree-of freedom model. Since the analytical results agree well with the experimental results, it is considered that this assumption could be used for estimating seismic responses.

$$K(x) = 1.0\times10^6\{1.2\cdot exp(-7\times10^2\cdot |x|) + 1.0\} \qquad (3)$$

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 was 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.

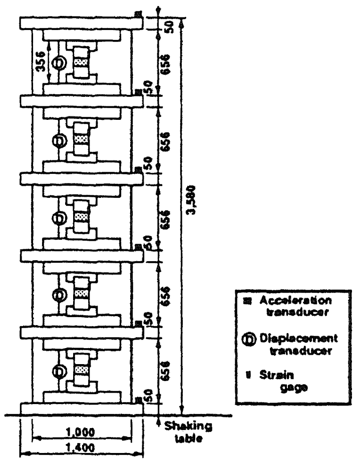


Fig. 9 Schematic view of building model and measurement points

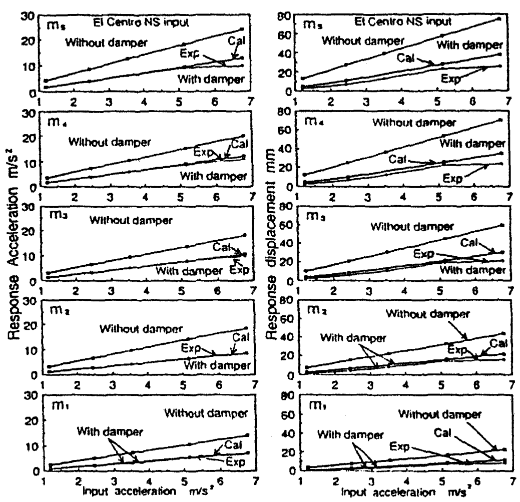


Fig.10 Maximum seismic responses on building model

3.3 Damping effect against small amplitude vibration

In addition to seismic excitation tests above mentioned, the test for ambient vibration was carried out to investigate the damping performance of the dampers for very small amplitude vibration. Figure 11 shows the time history responses of 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 are significantly reduced, there being about 50 % reduction to such level of input. This means that the damper employed in the tests dissipates energy not only for seismic excitations but also for such small amplitude vibrations.

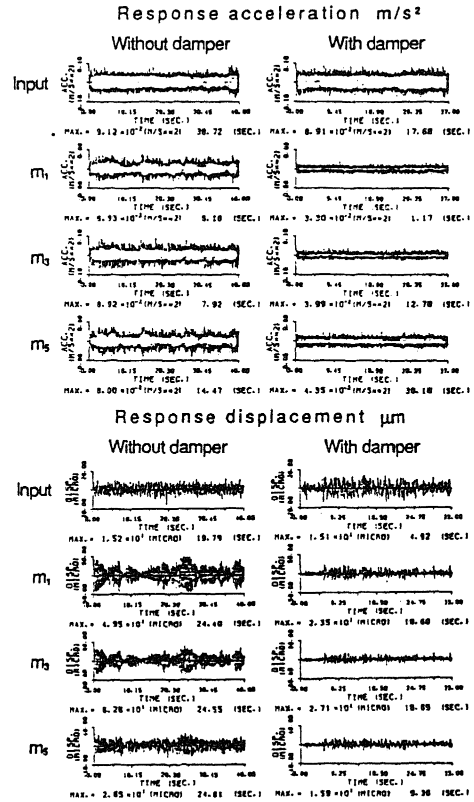


Fig.11 Damping effect against small amplitude vibration

4 CONCLUSIONS

The new type of high damping rubber damper for high rise buildings has been developed in this research. This damper is considered to be having some advantageous characteristics as follows.

(1) The stiffness and the damping force characteristics of the damper are not much affected by the variance of temperature.

(2) As the damping force characteristic of the damper is considered to be very close to one of linear viscous damping, linear design methods can be applied.

(3) This damper is considered to be having a very low stiffness, a high damping capacity and a strong adhesive property as compared with the other types of high damping or viscoelastic dampers proposed so far.

(4) This damper sufficiently dissipates energy for vibrations of μm order to those of generating 200% shear strain as a linear viscous damping. In addition, for excessive deflexions over 300% shear strain, the damper still absorbs energy as hysteretic damper.

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