

## ENERGY ABSORPTION CHARACTERISTICS OF HIGH DAMPING RUBBER DAMPER FOR VIBRATION CONTROL OF HIGH RISE BUILDINGS

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### ABSTRACT

The research and development of a new type of high damping rubber damper for high rise buildings/structures to mitigate earthquake or wind-induced structural response is described in this paper. The static tests were carried out to investigate restoring force characteristics using scale model of high damping rubber damper. The repetitive tests and the temperature dependency tests were carried out to investigate variance of performance of energy absorption. It is confirmed that the damping force characteristics of the damper can be considered as that of linear viscous damping and the damper sufficiently dissipates energy for vibrations of mm order to that of generating 200% shear strain. The design methods, based on assuming linear viscous damping for the damper, has been developed. The designed values such as stiffness and damping coefficient of the damper agree well with the experimental results.

### 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. Tall buildings/structures can be caused excessive structural deflexions, at their resonant frequencies, by excitation from the strong earthquake motion or a wind effect. In addition to that, for the weak earthquake, occurs several times a year in Japan, or for the weak wind, it is considered that the structural seismic comfortableness would be strongly needed in near future. 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).

The research and development of a new type of high damping rubber damper for high rise buildings/structures 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 TEST MODEL

New type of high damping material comprising SEBS (Styrene-Etyrene-Butadien-Styrene) rubber as a main composition is used for the Cylinder Type Damper dissipating energy in axial direction has been developed in this program. 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.

Figure 1 shows the Cylinder Type Damper used for the tests. High damping rubber layer of 76.5x10Txφ34mm in dimension is inserted between cylinder and shaft. Figure 2 shows test equipment and instrument system. To clarify the temperature dependency of the high damping rubber, the constant-temperature oven was employed in the tests and environmental temperature was almost kept constant. 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 , and the temperature of the rubber material , cylinder surface , shaft and environmental temperature in constant-temperature oven were measured by the thermocouples .

### 3 EXPERIMENTAL RESULTS

#### 3.1 Restoring force characteristics

Characteristics of high damping rubber damper have been evaluated by the following methods . Since it has been confirmed in the previous tests (Fujita 1992) 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 Figure 3 , these Values can be defined as follows.

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

$$C = E_D / \pi \omega X_m^2 \quad (2)$$

where  $X_m$  is the maximum displacement ,  $F_m$  is the maximum force ,  $E_D$  is the dissipated energy per cycle and  $\omega$  is the frequency of excitation .

Figure 4 shows the amplitude dependencies on the stiffness . From the result , even though the amplitude dependency appears to the stiffness especially in the small amplitude area . Figure 5 shows the velocity dependency in accordance with the damping forces . In the tests , it is confirmed that the damping force characteristic is very similar to those of linear viscous damping , and almost proportional to the velocity . In this figure , the solid line shows the constant damping coefficient as follows .

$$C = 6.0 \cdot 10^4 \text{ N}\cdot\text{s/m}$$

#### 3.2 Variance in the properties for repetitive tests

The repetitive cyclic loading tests of the 0.2Hz and 0.5Hz sinusoidal wave were carried out to investigate the variance in the properties of the cylinder type damper . Figure 6.(a) , 7 (a) indicates the variances in the stiffness and the damping coefficient for such cyclic loading and Fig.6(b) , 7(b) shows the rise of material temperature from environmental one and the total dissipated energy . For 50% shear strain , it is observed that there are few changes in the material temperature at 0.2 and 0.5 Hz . For over 50% shear strain , the material temperature rises until nearly 400 cycles at 0.2 Hz , but at 0.5 Hz continuously rises on even 500 cycles . Later the material temperature reaches an equilibrium condition because the heat induced material becomes equal to heat radiation . In the case of 50% shear strain at 0.2 and 0.5 Hz , although about 2.0°C increased temperature is measured , the stiffness and the damping coefficient of the damper are not much affected , so it is suitable to use like this condition . Moreover , the damping coefficient of the damper is considered to be having a proportional viscous damping to stiffness .

#### 3.3 Temperature dependency

Figure 8 , 9 shows the temperature dependency in the case of 0.2 and 0.5 Hz sinusoidal wave actuation on the stiffness and the damping coefficient . From the results , it is investigated that the temperature dependency of this material is very large . On application of the high damping rubber damper to high rise buildings/structures, environmental temperature in practical use is very important parameter to design the damper.

#### 3.4 Limit performance of the cylinder type damper

Figure 10 shows the limit performance of the damper in the case of 25°C environmental temperature and 0.1 Hz sinusoidal wave actuation . As indicated in the figure , it is confirmed that cylinder type damper has the excellent energy absorption ability over 300% shear strain . 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.

## 4 Design

### 4.1 Properties of high damping rubber for design

Figure 11 shows the amplitude dependency of shear modulus  $G(\gamma)$  and loss factor  $\tan\delta(\gamma)$  in the case of 25°C environmental temperature. Figure 12 shows the temperature-correction coefficients  $C_G(T)$  and  $C_{\tan\delta}(T)$  evaluated from temperature dependency tests. Properties used for design of high damping rubber damper, shear modulus  $G^*$  and loss factor  $\tan\delta^*$ , is as follows.

$$G^* = G(\gamma) \cdot C_G(T) \quad (3)$$

$$\tan\delta^* = \tan\delta(\gamma) \cdot C_{\tan\delta}(T) \quad (4)$$

where  $\gamma$  is the shear strain and  $T$  is the environmental temperature.

The design is carried out by assuming linear viscous damping for the damper, therefore, design value of the damper, stiffness  $K$  and the damping coefficient  $C$ , can be calculated from  $G^*$  and  $\tan\delta^*$  and shape of the damper.

### 4.2 Comparison with the prediction and the experiment

The damper used for this test has high damping rubber layer of 76.5x5T x  $\phi$ 34mm in dimension. Figure 13(a) shows the comparison of stiffness with the experimental results and designed value. Figure 13(b) shows the comparison of damping coefficient with the experimental result and designed value. As indicated in the figure, the designed value agree well with the experimental data, so it is confirmed that the design method can be applied to the design of the high damping rubber damper.

## 5 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 damping force characteristic of the damper is considered to be very close to one of linear viscous damping.
- (2) The properties of high damping rubber are generally affected by the increased temperature of materials during deformation; in practical use, the increased temperature was small, so damping characteristics of the damper was not much affected by the variance of temperature.
- (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 mm order to those of generating 200% shear strain as a linear viscous damping.
- (5) The design methods, based on assuming linear viscous damping for the damper, has been developed. The designed values such as stiffness and damping coefficient of the damper agree well with the experimental results.

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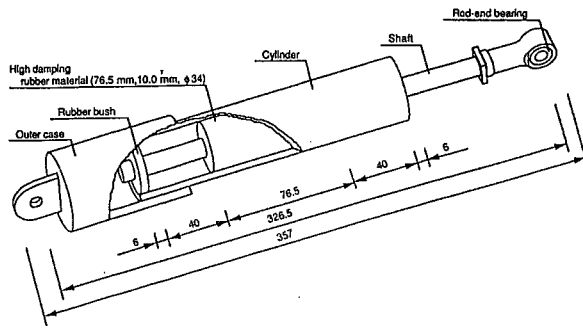


Fig.1 Cylinder type damper used for the test

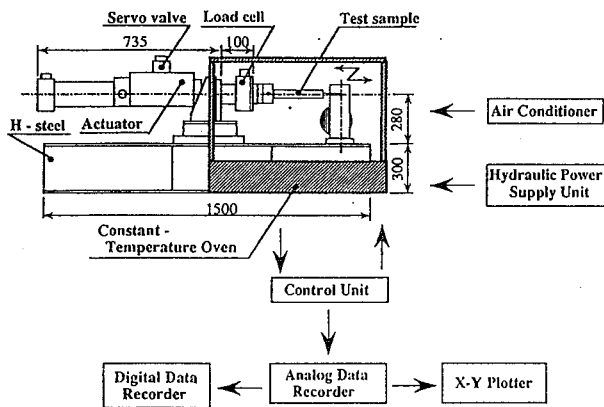


Fig.2 Equipment set up for the static test

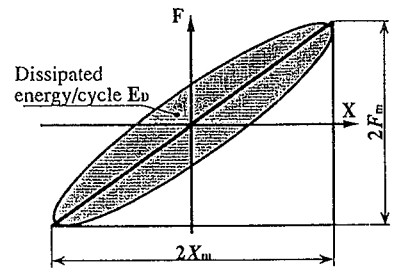


Fig.3 Definition of stiffness and damping coefficient for restoring force loop

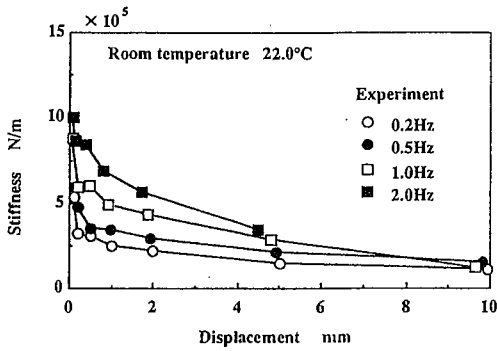


Fig.4 Amplitude dependency on stiffness

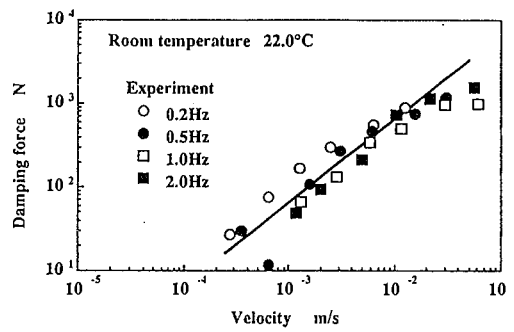


Fig.5 Velocity dependency on damping force

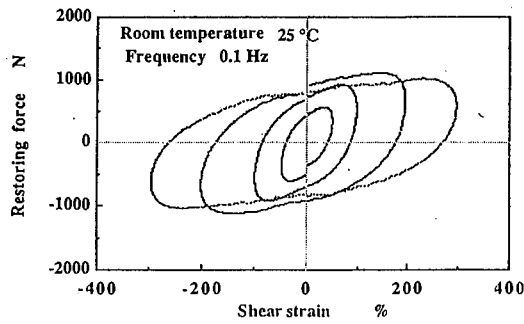


Fig. 10 Restoring force characteristics of the damper for limit performance

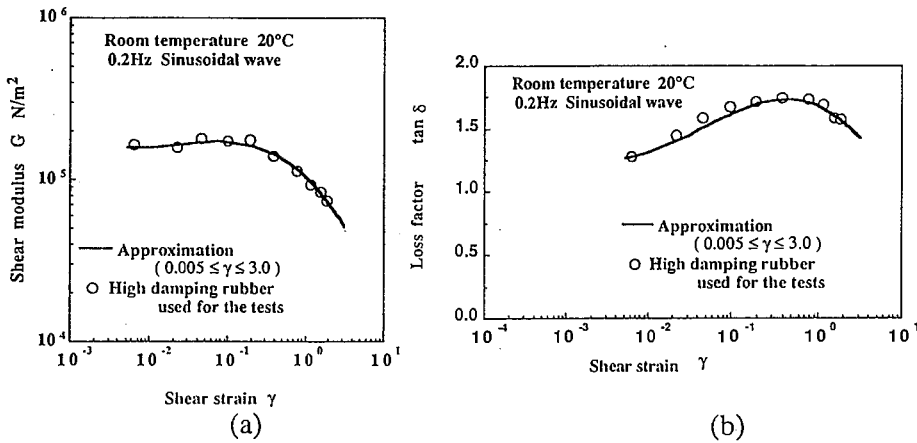


Fig. 11 Amplitude dependency of properties for design

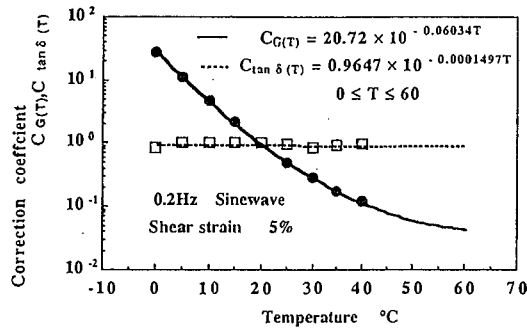


Fig. 12 Temperature-correction coefficient

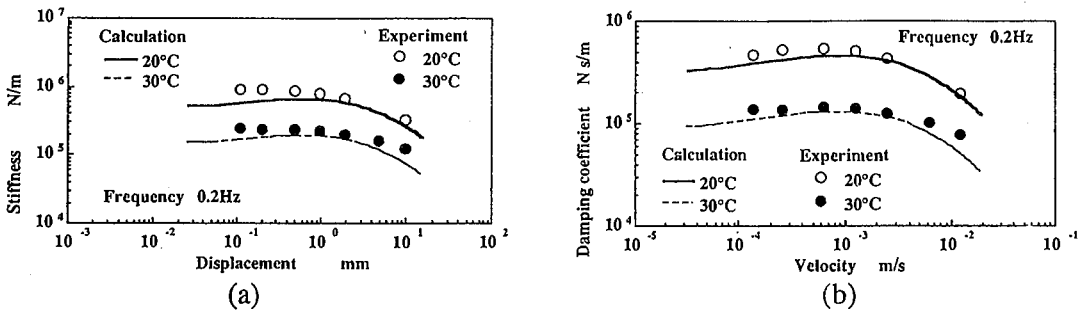


Fig.13 Comparison with the experimental result and designed value

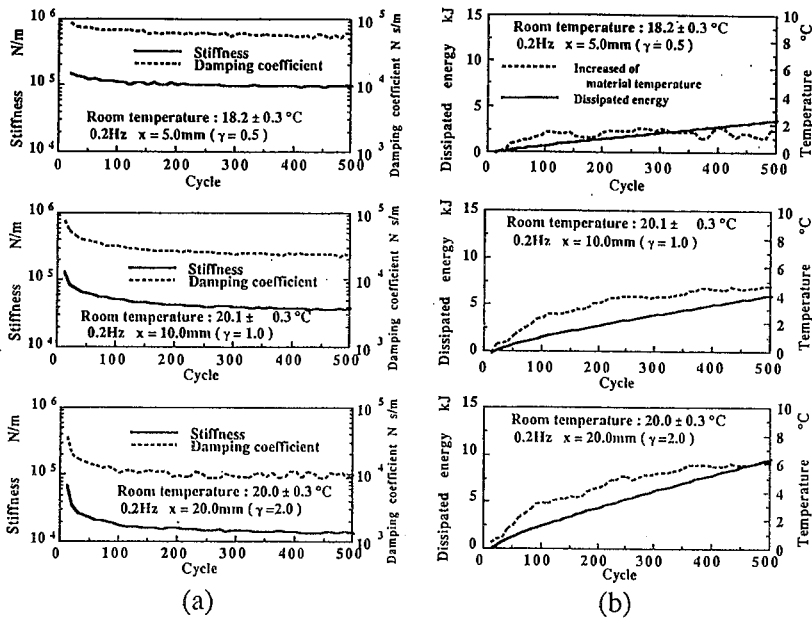


Fig.6 Variance in characteristics for repetitive tests at 0.2Hz

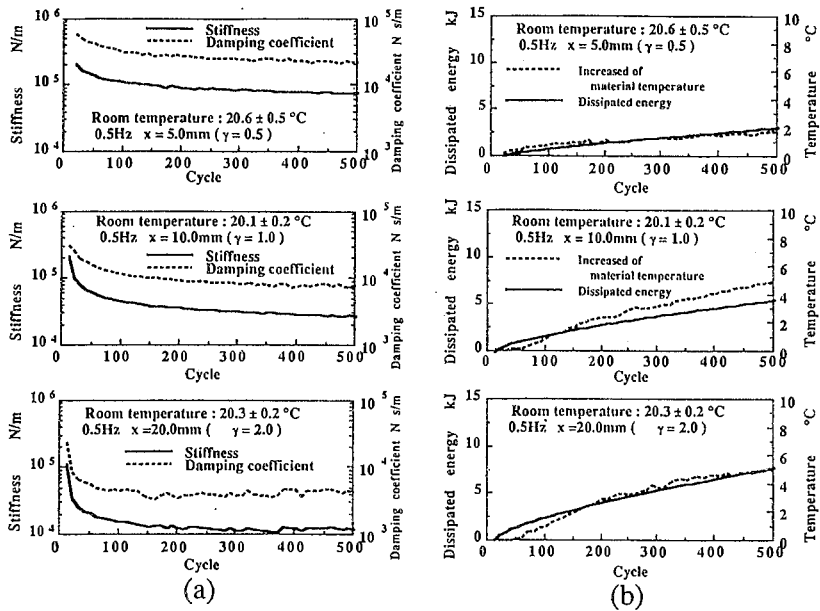


Fig.7 Variance in characteristics for repetitive tests at 0.5Hz

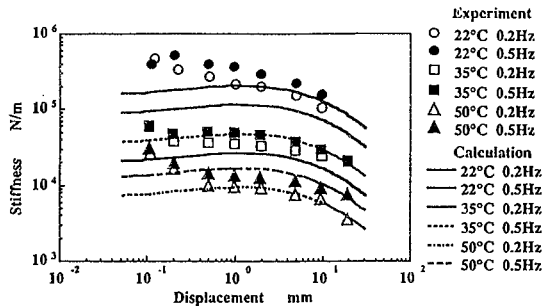


Fig.8 Temperature dependency on stiffness

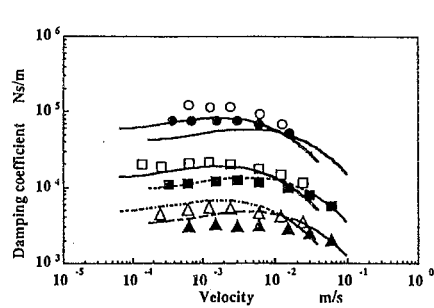


Fig.9 Temperature dependency on damping coefficient