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PRACTICAL APPLICATION OF HIGH-DAMPING RUBBER DAMPERS TO A SLENDER BUILDING

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ABSTRACT

A necessity of vibration control of buildings has been on the rise in Japan, from the viewpoint of improving habitability or safety during winds and earthquakes. The high-damping rubber dampers (the story-installed type dampers) have implemented for a 11-story building of 44 m height to mitigate vibrations caused by earthquake motion and also vehicle traffic. In this study,the damping performance of full-scale size of rubber dampers designed for the building was investigated, and the seismic responses of the buildings using these dampers were predicted by the analysis.

KEYWORDS

Rubber damper, Vibration control, Slender building, Viscous damping, Cylindrical devise, Winds and earthquakes, Vehicle traffic, Story-installed type, Seismic response

1. INTRODUCTION

A necessity of vibration control of buildings has been on the rise in Japan, from the viewpoint of improving habitability or safety during winds and earthquakes. The devices for vibration control can be classified into two types; the mass dampers (Tuned mass dampers) and the story-installation type dampers such as the friction dampers and the viscoelastic dampers including the high-damping rubber dampers dealt with in this paper.

The research and development of the high-damping rubber dampers by the authors was initiated in 1990, and various tests for the dampers have been carried out (Fujita et al., 1991; Fujita et al., 1992; Fujita et al., 1993; Fujita et al., 1994). These kinds of the damper devices have already begun to be implemented to a several buildings. This paper describes physical characteristics of high-damping rubber material, the various performances of hysteresis loops of the cylindrical damper on basis of the test results for a full-scale damper device of 185 mm outer diameter and about 3,500 mm length, and analytical results for several earthquake motion.

2. CHARACTERISTICS OF HIGH-DAMPING RUBBER

The high-damping rubber employed in the damper devices is SEBS (Styrene-Etyrene-Butadiene-Styrene) rubber which contains compounding ingredients abundantly. Physical characteristics of the material were evaluated by testing shear test samples (see Fig.1) under sinusoidal excitations at prescribed strains, frequencies and temperatures, in the constant-temperature chamber.

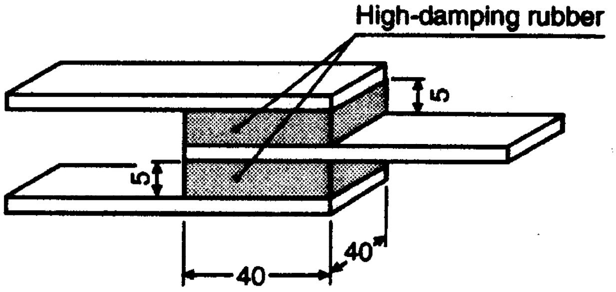

Fig.1 Test Sample

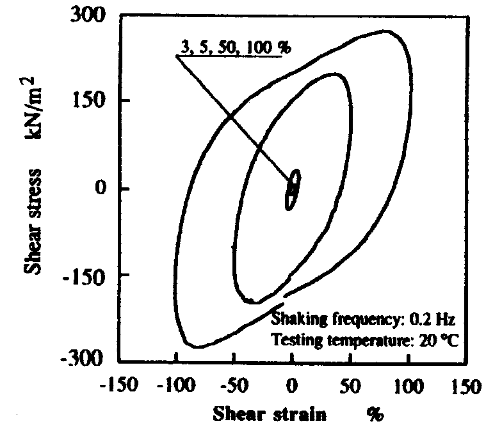

Fig.2 Shear Stress-Strain Relationships

2.1 Shear stress-strain relation

Dynamic shear stress-strain relationships of the high-damping rubber at the temperature of 20 °C subjected to an excitation frequency of 0.2 Hz are shown in Fig.2. The high-damping rubber gives roundish hysteresis loops peculiar to viscoelastic materials in each strain revel.From the shear stress-strain relations, the shear modulus (the storage shear modulus) and the loss factor for the shear strain at each frequency were derived as shown in Fig.3. The shear modulus and the loss factor substantially independent of shear strain amplitudes below 100 %, and the loss factors are more than 1.0. The shear modulus is significantly affected by the frequency.

2.2 Temperature dependency

Fig.4 shows the temperature dependency of the shear modulus and the loss factor in the region of 0 °C ~ 40 °C. As the temperature increases, the shear modulus remarkably decreases, and the loss factor gradually increases. And the change rates of these values with the temperature were not much affected by the shear strain revels.In the use of the material, it is very important to consider the effect of the temperature in addition to the strain and the frequency.

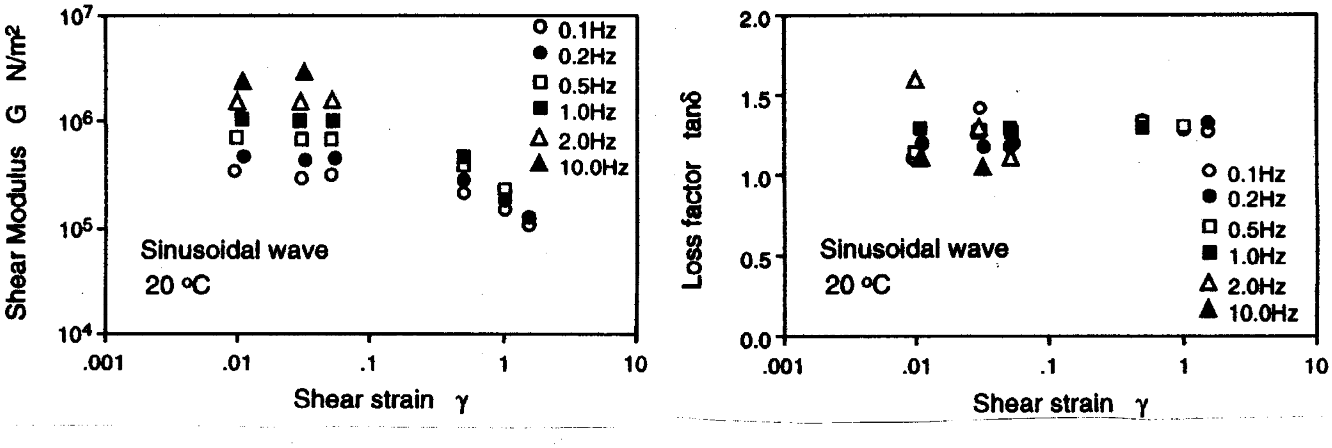

Fig.3 Shear Strain Dependency

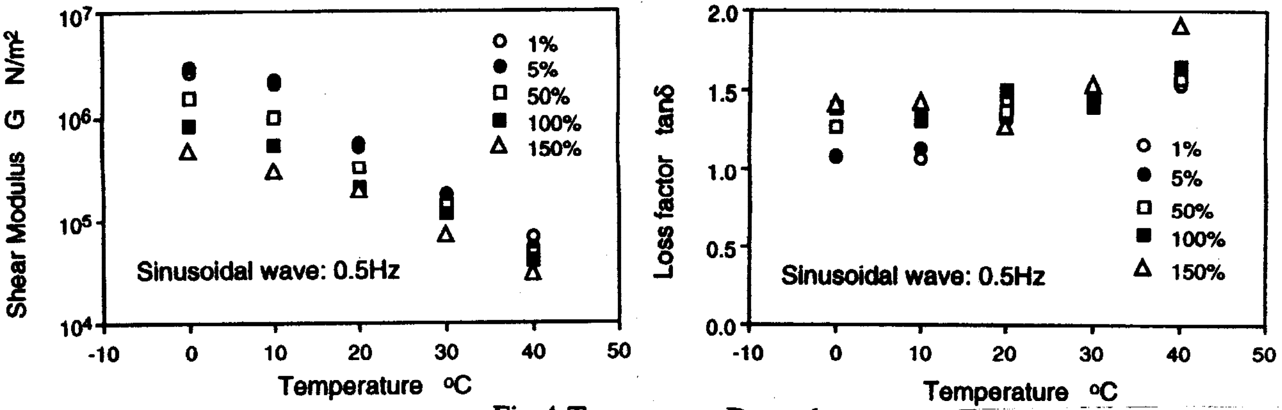

Fig.4 Temperature Dependency

3. DYNAMIC TEST RESULTS FOR CYLINDRICAL DAMPER DEVICES

3.1 Full-scale cylindrical damper used for the tests

The damper device used for the tests is shown in Fig.5. This damper is the cylindrical device filled the high-damping rubber between two steel pipes of different diameter. The size of the high-damping rubber is 145 mm in outer diameter, 102 mm in inner diameter, and 3,000mm in length. The annular rubber units made by NR are used for guiding the deflections of the damper. They work as elastic-bearings in small deflections, and as sliding bearings in large deflections (see Fig.5). The spring joints installed at both ends, that are connected rigidly to the outer steel pipe and the inner steel pipe respectively, function as pin joints having no gap, because they have hard compression/tension stiffness and soft bending stiffness.

This damper is designed to provide a damping coefficient of 3.2×10^6 kN · s/m on the condition of an amplitude of 10 mm, a frequency of 1.0 Hz and temperature of 20 °C, and to withstand a displacement of ±60mm. The value of damping coefficient gives a damping force of 2.0×10^5 kN in the above stated condition.

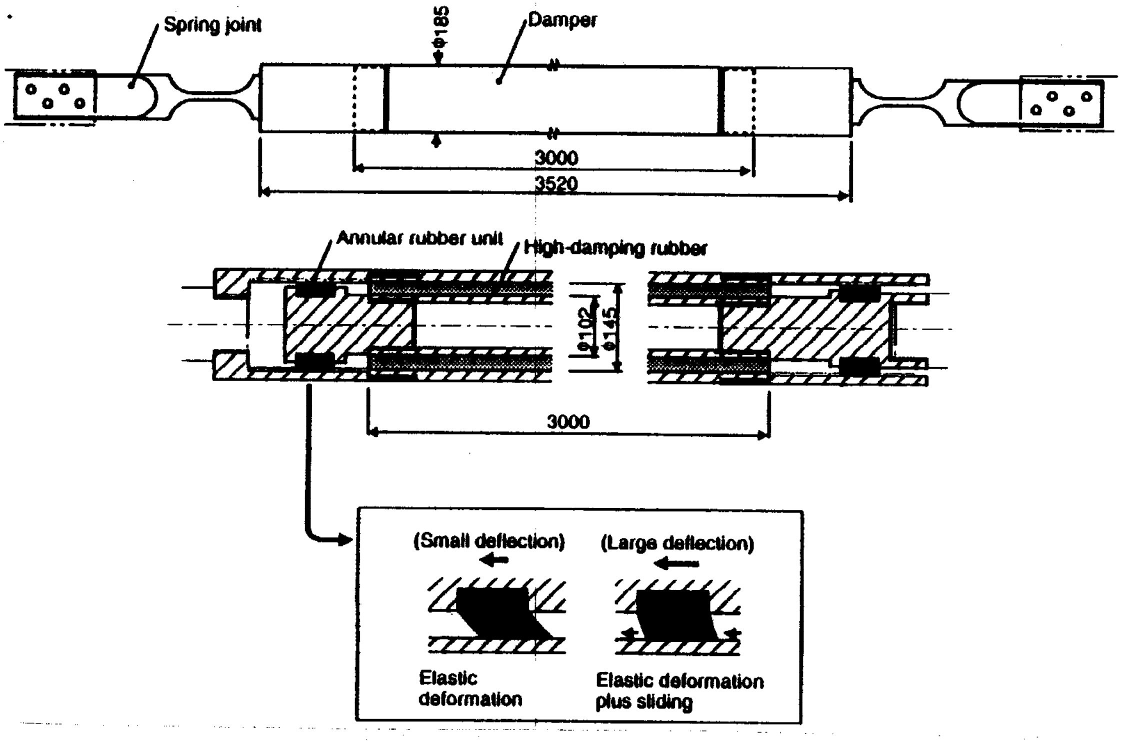

Fig.5 Full-scale Cylindrical Damper

3.2 Test apparatus and test methods

The dynamic tests were carried out using the test apparatuses shown in Fig.6. In the tests, the inclined axial loading test apparatus in addition to the straight axial loading test apparatus (the normal test apparatus), was prepared to check on the functioning of the damper in the state of practical use. The fundamental tests were carried out using the normal test apparatus. The repeated deformation tests were performed using both of the test apparatuses to investigate the durability of the damper including the spring joints.

In all these tests, the temperature of the high-damping rubber material was measured by thermocouples.

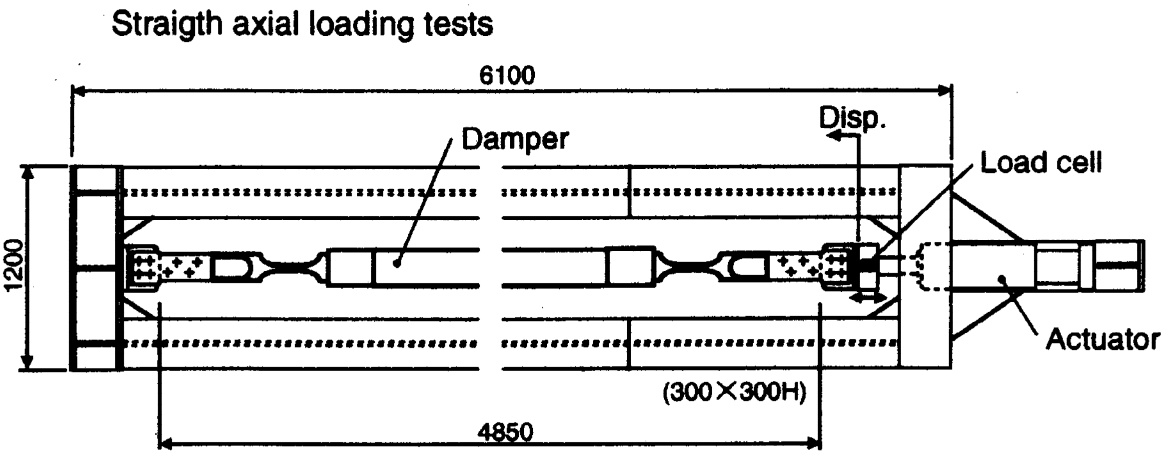

Fig.6 Test Apparatuses

3.3 Fundamental Characteristics

Fig.7 shows the load-deflection loops of the damper at a frequency of 0.1 Hz . High hysteresis occurs over a wide range of amplitude, 0.03 mm $\sim$ 60 mm, i.e., a range of shear strain of 0.14 % $\sim$ 280 %. From these results, it can be considered that the damper is effective not only for seismic excitations but for micro-vibrations.

The effectiveness of the high-damping rubber dampers for micro-vibrations has been demonstrated by the shaking table tests for the steel framed building model using the damper devices of a simple shear type (Fujita et al., 1991).

Fig.8 shows the damping coefficient and the stiffness with respect to the amplitude. These results were evaluated in the rubber temperature of 22 °C $\sim$ 26 °C. The damping coefficient and the stiffness are almost constant, although they decrease with the increase of amplitude in their region above 10mm. And when the frequency rises, the damping coefficient decreases, while the stiffness increases. The damping coefficient at 10 mm and 1.0 Hz is 2.1×10^6 kN · s/m, therefore this result is agree approximately with the design value considering the factor of temperature.

The effects of temperature on the loops have been investigated in the tests using the small-sized models of the cylindrical device (Fujita et al., 1993; Fujita et al., 1994) . The test results confirmed that changes of the loops with the temperature reflected the change of the material.

3.4 Durability for repeated deformations

Fig.9 shows the changes of the damping coefficient and the temperature of the high-damping rubber obtained by the tests . Repeated deformations cause decrease in the damping coefficient , and increase in the temperature. Fig.9 also shows results of a test carried out 12 hours after the repetition tests. In this case, the temperature dropped to around 20 °C, and so the damping factor recovered to the original levels.

The 10,000-cycle repetition tests under a 10 mm amplitude, and the 100-cycle repetition tests under a 50 mm amplitude were carried out using the inclined axial loading test apparatus. In these tests, the damper deforms with spring joints bending. The load-deflection loops under repeated deformations are roundish as well as the results of the nomal test apparatus.And there was no appearance change such as cracks or defects in the high-damping rubber and the spring joints.

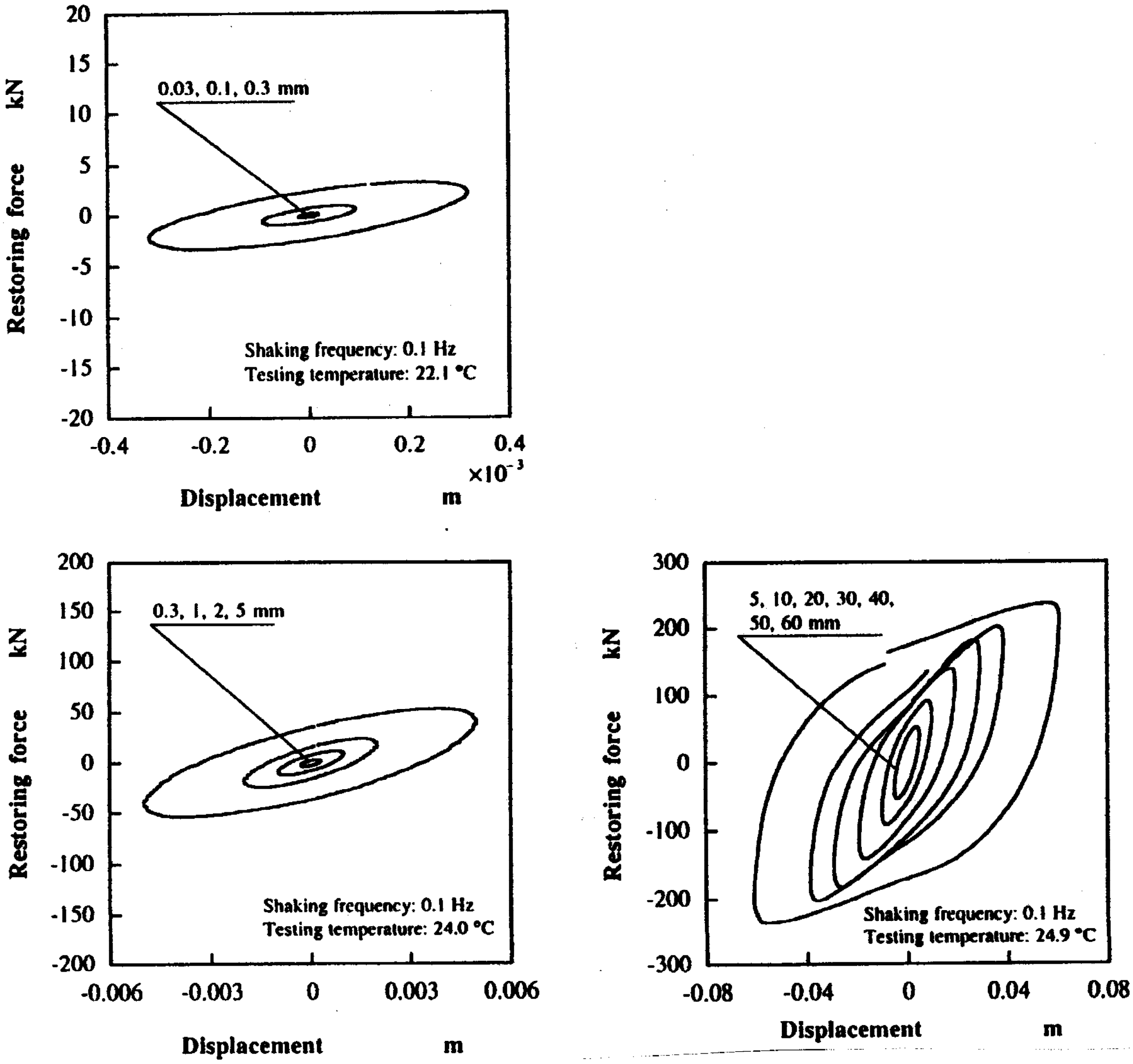

Fig.7 Load-Deflection Loops (0.1 Hz)

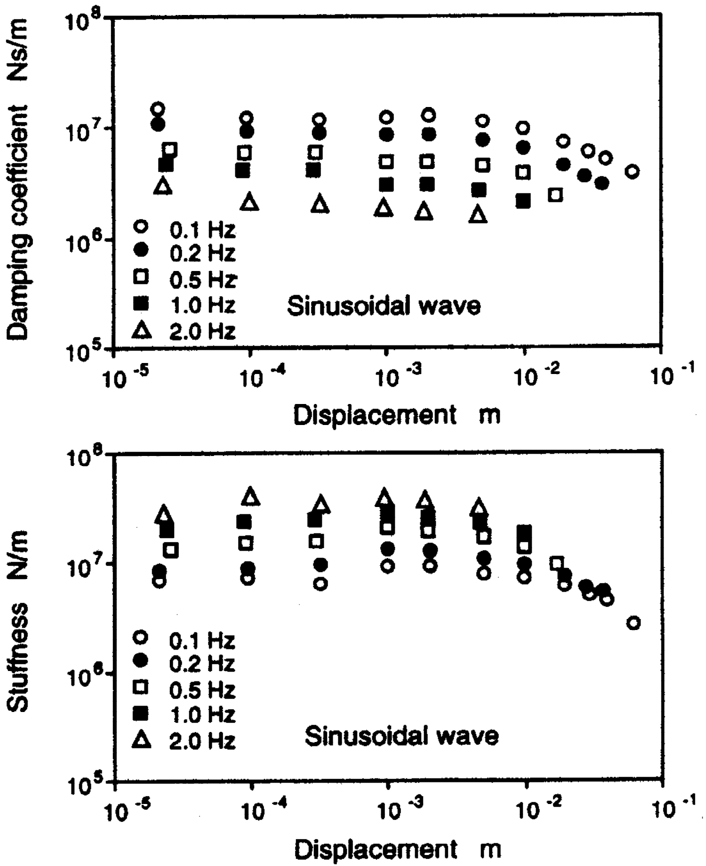

Fig.8 Amplitude Dependency of Damping Coefficient and Stiffness

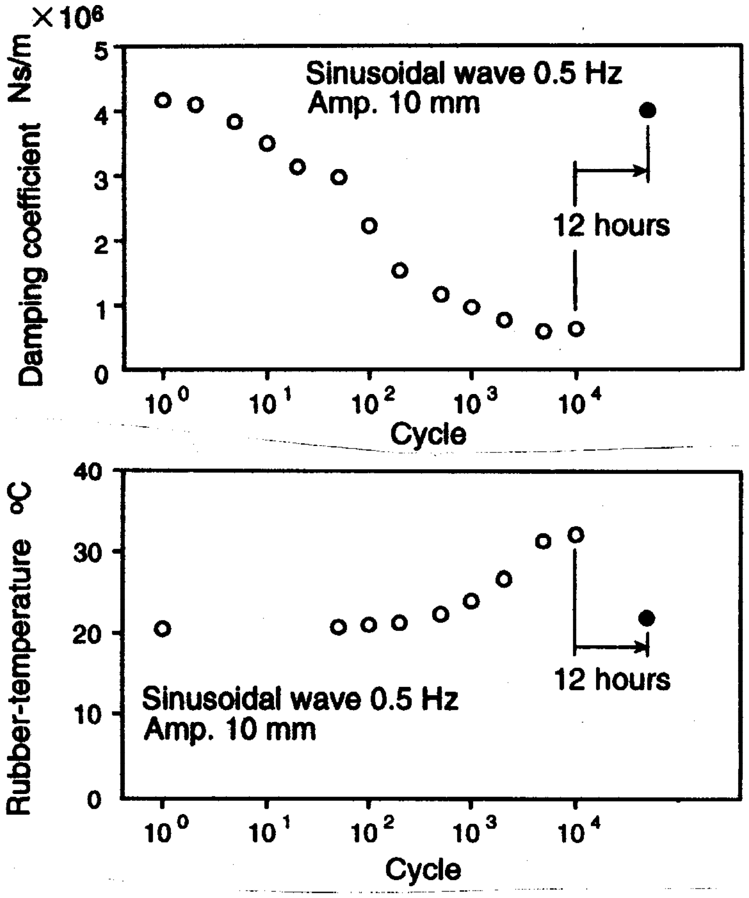

Fig.9 Changes of Damping Coefficient under Repeated Deformation

4. APPLICATION OF THE DAMPERS

The above mentioned cylindrical damper devices in Fig.5 are going to be applied to a 11-story building under construction at present (see Fig.10). This building is a composite structure, and a 44 m height, 6,300 t total weigh, and has a 1.1 Hz first-mode natural frequency. The purpose of the installation of the dampers is to mitigate vibrations of the building caused by earthquake motions and also traffic motions, because the building is constructed close to not only a trunk line but subway lines.

The analytical results for several earthquake inputs showed that the dampers were effective to reduce seismic responses of the building. Fig.11 shows a analytical result for El Centro NS wave revised 250gal. Both the maximum accelerations and the maximum deformations of the building are reduced to about 0.8 of the those in the case without dampers.

The analytical model of the cylindrical dumper devices were made up the stiffness depend on the amplitude and the damping coefficient proportionate to the stiffness. To ignore the temperature dependency the circumstance of the temperature were supposed to constant 20°C, because the devices are in the office.

By using the 40 dampers,the first-modal damping ratio of the building increases from 3 % to 6 % .Under these states, the dampers installed in the building produced damping force of tens of tons, and underwent displacement of 20 mm or so.

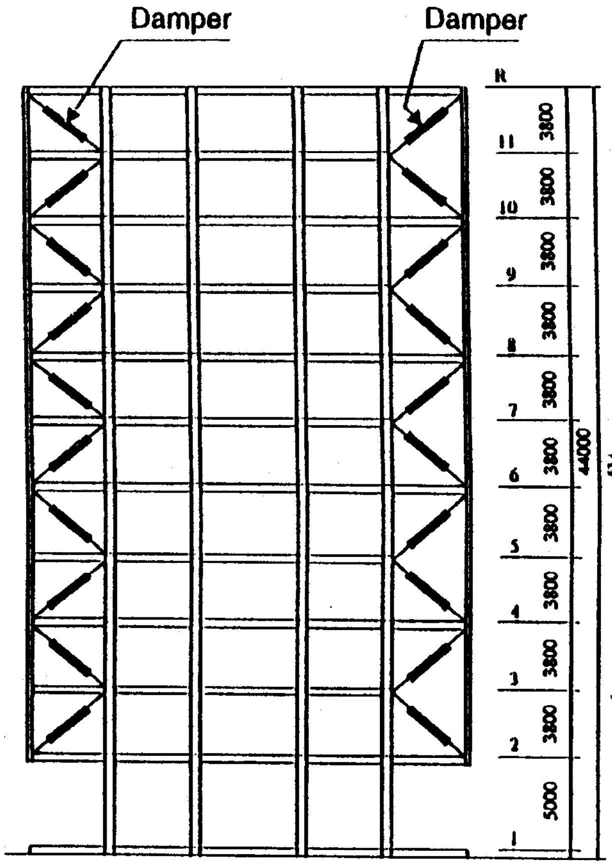

Fig.10 Building Using Cylindrical Dampers

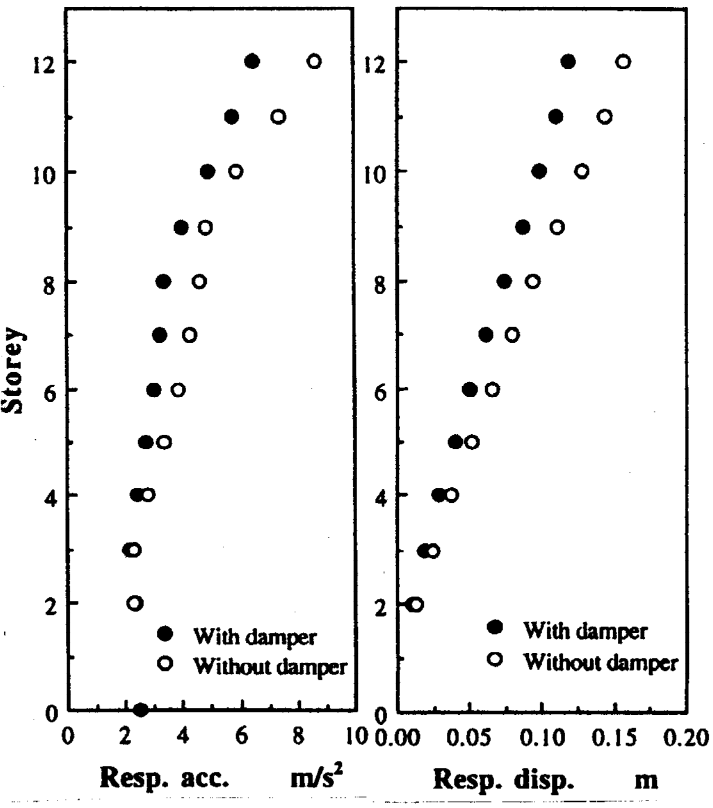

Fig.11 Analytical Results

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5. CONCLUSIONS

The characteristics of the full-scale high-damping rubber damper of cylindrical type were evaluated by various dynamic tests. It was confirmed that the damper could dissipate energy sufficiently over a wide range of amplitude, and reasonably satisfied the design requirements. In the application of these kinds of dampers, it is essential to consider the change of damper's properties by the environmental temperature. However, a remarkable feature of the dampers is their effectiveness for micro-vibrations as well as seismic excitations. From the dynamic analysis seismic responses of the building were sufficiently reduced by installing damper divided in each story of the building.

ACKNOWLEDGEMENT

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