Proof Test of Base-Isolated Building Using High Damping Rubber Bearing

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INTRODUCTION

Growing expectations have recently arisen concerning the base isolation system, and as a consequence, more than twenty base-isolated buildings have been built in Japan. The present research is intended to prove the effectiveness of the base isolation system by on-site experiments and the observation of actual earthquakes for full-sized structure.

We used a system consisting of six rubber bearings and twelve oil dampers. After several experiments, we conducted the earthquake observations. Totally, thirty earthquakes were recorded from June 1986 to July 1988. From the results of these tests and the earthquake observations, the base isolation system was provided to be very effective in reducing the response acceleration (Tamura et al.,1987).

The system was replaced with the high damping rubber bearings in July 1987. In this paper, we report the dynamic loading test and the earthquake observation of these high damping rubber bearings.

TEST BUILDINGS

Two test buildings, one a base-isolated and the other an ordinary structure were constructed side by side in a yard of Tohoku University. The buildings are full-sized three-story reinforced concrete structures and the dimensions and construction method of the superstructures were exactly the same for both buildings.

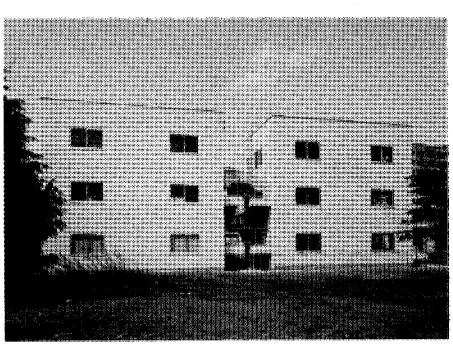

Fig. 1 General view of the test buildings

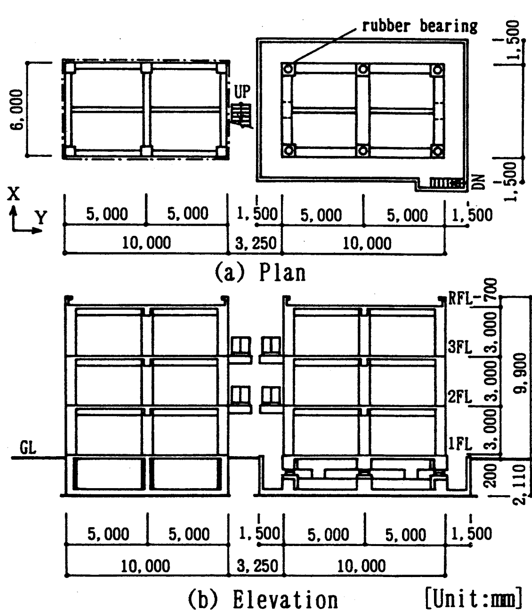

Fig. 2 Plan and elevation of test buildings

The buildings were constructed as frame structures with outer walls made of autoclaved light weight concrete. The plane dimensions of the buildings are 6 by 10 meters, and the total combined floor area is $180m^2$. The buildings were completed in May 1986.

The general view of the buildings is shown Fig. 1. The building on the right is the base-isolated building and the one on the left is the ordinary one. The plan and elevation of the test buildings are shown in Fig. 2, with the installation of the high damping rubber bearings indicated.

The details of the location of the test buildings and soil profiles are discussed in the reference.

BASE ISOLATION ELEMENTS

The high damping rubber bearing functions as both bearing and damper. The damping of the bearing is enhanced by additives to the rubber compound. The configuration of the bearings is the same as that of the former normal bearings. The bearing consists of 18 layers of 6.7-mm thick rubber which diameter is 435 mm, 17 steel plates of 3.0-mm thickness, and 24-mm thick top and bottom flange plates. The dimensions of the bearings used in the test buildings are shown in Fig. 3. These bearings are designed to have the same dynamic properties as the former system involving the normal bearings and oil dampers. The equivalent horizontal stiffness at a 10-cm displacement is 640 kgf/cm, and the equivalent hysteresis damping coefficient is 0.15.

EXPERIMENT

Before setting the rubber bearings under the building, the static loading test was carried out at the laboratory. After installation, a forced vibration test was performed.

Loading test

The horizontal loading test was conducted under the constant vertical load of 50 tf. The load-displacement relation is shown in Fig. 4. The average of the equivalent horizontal stiffness and the equivalent hysteresis damping at each displacement are listed in Table 1. The average of the vertical stiffness under compressive loads of 50 tf ± 15 tf is 910 tf/cm. The horizontal load-displacement relation of the high damping rubber bearing have

Table 1 Equivalent Stiffness and Hysteresis Damping

Displacement (cm)	1	3	5	10	15	20
Horizontal Stiffness (kgf/cm)	2060	1110	823	569	465	409
Hysteresis Damping Ratio (%)	18	15	13	13	12	12

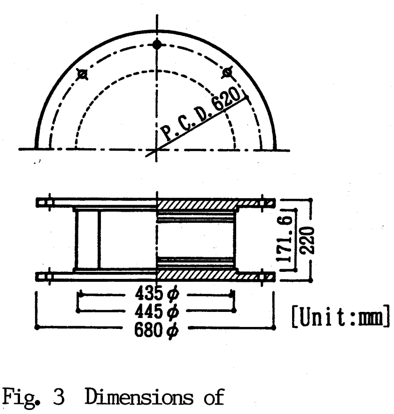

Fig. 3 Dimensions of high damping rubber bearing

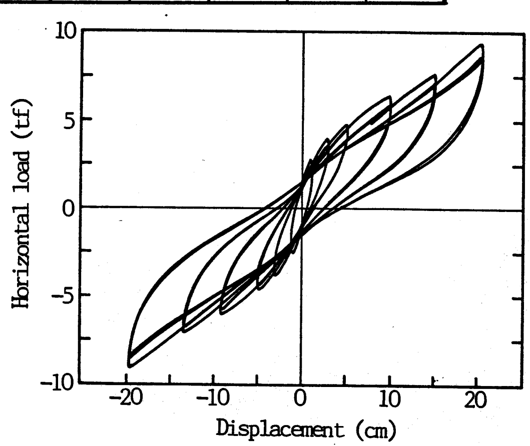

Fig. 4 Hysteresis loop

the property of nonlinearity. The horizontal stiffness at 1-cm was approximately 4 times larger than the stiffness at 10-cm. The damping coefficient decreases according to the increase of the displacement. The average of the equivalent horizontal stiffness and the equivalent hysteresis damping at a 10-cm deformation are 569 kgf/cm and 0.13. These values are slightly lower than the designed values.

Vibration test

A vibration exciter was installed at the center of the roof slab to apply sinusoidal forces horizontally to each building.

Figure 5 shows the change in resonance curves of the base-isolated building in accordance with the levels of eccentric moment of the exciter for the X-direction. As is evident, the resonant frequency clearly decreases with the increase in loading force, i.e., the amplitude of horizontal displacement.

Figure 6 shows the difference in resonance curves caused by increasing and decreasing of sweep frequency. The resonance frequency is low in the case of the decreasing of sweep frequency. As is clear, these results depend on the nonlinearity of the high damping rubber bearing.

The natural frequencies and the damping ratios for both directions obtained experimentally are summarized in Table 2. These values were affected by the amplitude of vibration. The natural frequency decreased, but the damping ratio increased with the increase of the displacement. The damping of at a 10-kgfm eccentric moment is only 1/3 to the damping of at a 200-kgfm. Both values of the natural frequency and the damping ratio for the Y-direction of 1st vibration mode agreed with those for the X-direction.

Table 2 Natural Frequency and Damping Ratio

Direction	X							Y	
Vibration Mode	1 st				2 nd			1st	2nd
Eccentric Moment (kgfm)	10	20	100	200	2	4	10	200	10
Amplitude (mm)	0.38	0.60	1.78	3.27	0.18	0.38	1.08	3.35	0.87
Natural Frequency (Hz)	1.68	1.57	1.33	1.21	5.80	5.69	5.50	1.23	6.45
Damping Ratio (%)	5.1	6.4	10.9	11.9	2.0	2.0	1.8	11.6	2.2

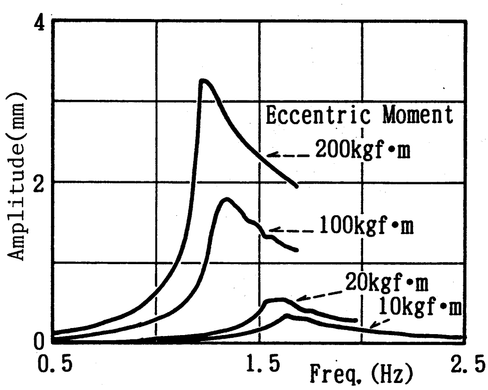

Fig. 5 Resonance curve of different eccentric moment

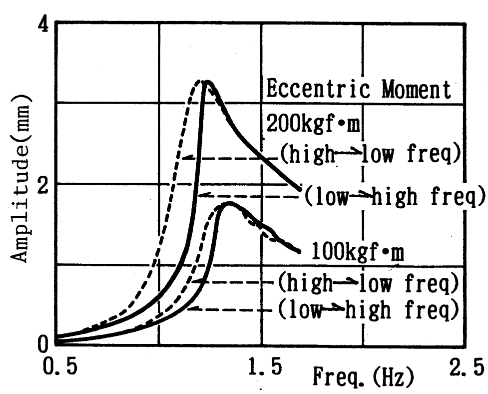

Fig. 6 Resonance curve of different sweep direction

EARTHQUAKE OBSERVATION

Accelerometer setup

At the start of the observation, the accelerations of eleven points were observed. The accelerometers were in the hard soil stratum(GL-27m), on the surface of the surrounding ground, on the base slab of the base-isolated building, and at the first floor and the roof of each building. Total observations were 27 components of earthquake motion, including 20 horizontal and seven vertical. Five accelerometers were added in March 1988, in order to observe vertical components on the base-slab of the base-isolated building and on the 1st floor of each building.

Recorded earthquake data

Seventeen earthquakes were recorded from August 15, 1987 to October 19, 1988. Nine earthquakes occurred off Fukushima Prefecture. Five of them were recorded more than an acceleration of 5 Gal on the ground surface.

The largest acceleration recorded on the ground surface was 27 Gal, and the corresponding peak accelerations at the roofs of buildings were 114 Gal for the ordinary building and the 43 Gal for the base-isolated.

Distribution of maximum accelerations

The maximum accelerations of all components during the earthquake on October 4, 1987 (magnitude = 5.8, epicentral distance = 128 km, focal depth = 51 km) are shown in Fig. 7.

The maximum accelerations on the roof of the ordinary building were 139 Gal in the X-direction and 114 Gal in the Y-direction. Those of the isolated building, however, were only 27 Gal and 43 Gal. The reduction of response acceleration is from 1/5 to 1/3. During the other earthquakes as well, the accelerations of the base-isolated buildings were also reduced.

The accelerograms at several points are shown in Fig. 8 for the X-direction and Fig. 9 for the Y-direction. The accelerograms recorded in the base-isolated building proved that the period of vibration became longer.

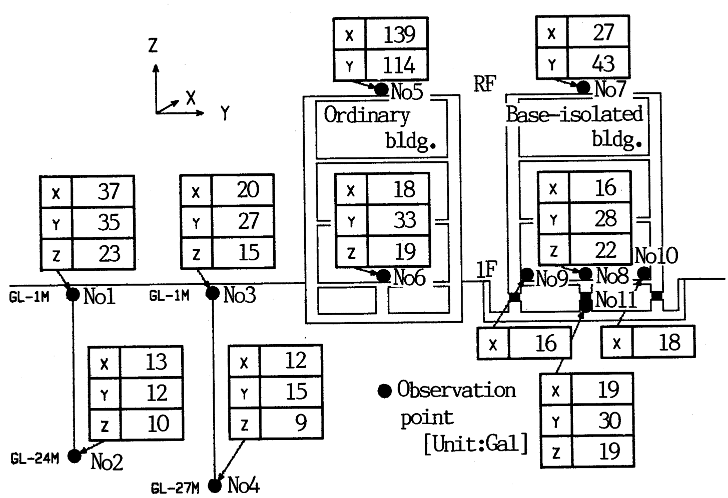

Fig. 7 Maximum acceleration distribution of the earthquake on October 4, 1987

Amplification Factor

The amplification factor of the building(A.F.) is defined as the ratio of the maximum acceleration on the roof to the maximum one on the ground surface. The amplification factors of the both buildings in earthquakes are shown in Fig. 10 for the X-direction and Fig. 11 for the Y-direction.

The solid and dotted lines in figures respectively show the regression for the isolated building and for the ordinary one . The dotted line is almost flat or a little inclined, whereas the solid line presents a clear the tendency to decrease along the X-axis indicating the maximum acceleration on the ground surface. In a case of larger earthquakes, the high damping rubber bearings are distinctly more effective in reducing the response acceleration.

Analysis of Observed Motions

The relative displacement of the base-isolated element was calculated by the integration of the relative acceleration between the base-slab and the 1st floor. The relative displacement by the integration is shown in Fig. 12 for five earthquakes, of which, the maximum acceleration on the ground surface was more than 5 Gal. The maximum value of them is only about 3 mm. Figure 13 shows the shear force - relative displacement relation for the earthquake on October 4, 1987 in the Y-direction. The equivalent stiffness decreases with the increase in displacement.

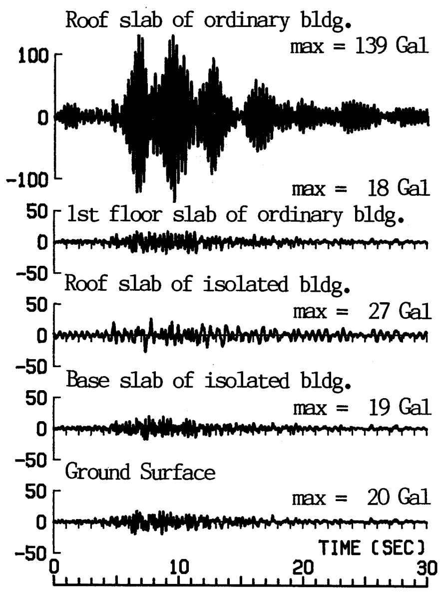

Fig. 8 Time history for X-direction of the earthquake on October 4, 1987

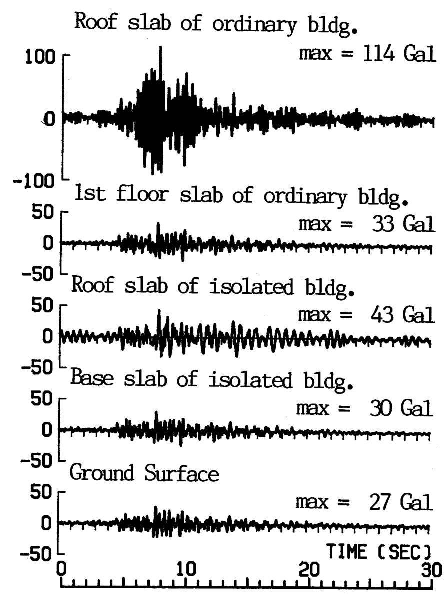

Fig. 9 Time history for Y-direction of the earthquake on October 4, 1987

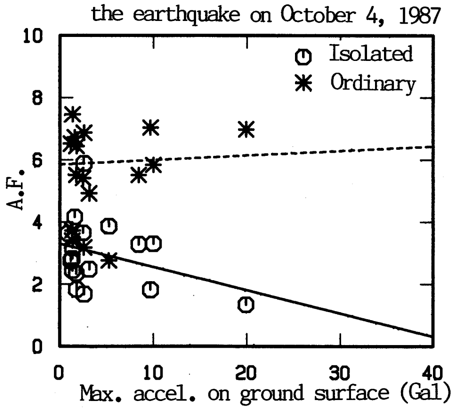

Fig. 10 Amplification factor in X-direction

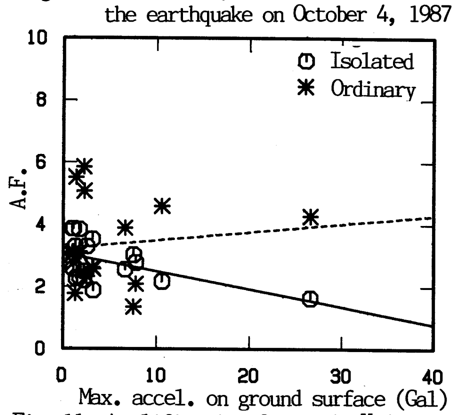

Fig. 11 Amplification factor in Y-direction

Figure 14 presents the Fourier spectra of the ground motion and the earthquake response at the roof of each building for the earthquake on October 4, 1987 in the Y-direction. The fundamental frequency of the isolated building is estimated to be within from 1.5 Hz to 2 Hz, and that of the ordinary one is 4.3 Hz.

CONCLUSION

From these results of the various tests and earthquake observations, following conclusions can be made.

(1) The nonlinearity of the high damping rubber bearing for the horizontal stiffness is revealed at a small displacement.

(2) The damping ratio of the bearing depends on the horizontal displacement. Especially, in the region of a small displacement under a 3-mm, the damping is only 1/3 of the design value.

(3) The amplification factor of the base-isolated building was very small compared to that of the ordinary one.

(4) The amplification factor of the base-isolated building has a tendency to decrease with the maximum acceleration on the ground surface.

ACKNOWLEDGMENT

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REFERENCE

Tamura K., Yamahara H. and Izumi M. "PROOF TEST OF THE BASE-ISOLATED BUILDING USING FULL-SIZED MODEL", Proc. Seismic, Vibration and Shock Isolation - 1988, ASME, PVP-Vol.147, pp.21-28

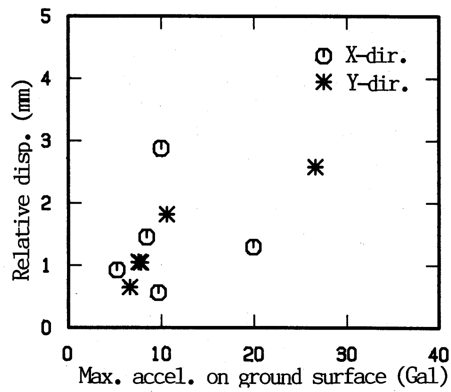

Fig. 12 Relative displacement by integration

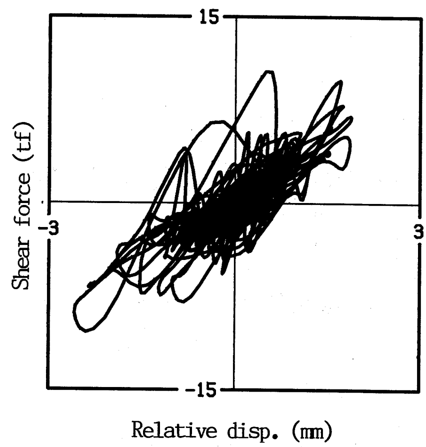

Fig. 13 Load-displacement relationship of isolation element

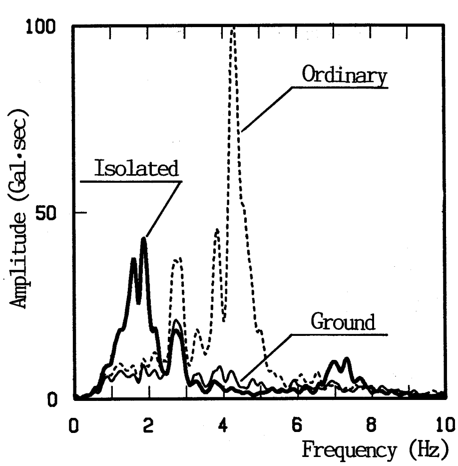

Fig. 14 Fourier amplitude for Y-direction of the earthquake on October 4, 1987