Seismic Isolation System with Rubber Bearings and Friction Dampers

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INTRODUCTION

Many proposals for base isolation systems have been provided for reducing the response of buildings subjected to strong earthquake motions. Laminated rubber bearings are considered to be practical supporting devices for a base isolation system. For a base isolation system using laminated rubber bearings, energy absorbing devices to reduce maximum displacement during earthquake are important. Many types of dampers have been developed, for example, hysteretic dampers using steel bars or lead plugs, viscous dampers, and accelerated liquid mass dampers (Kawamata,1987), and others.

We have developed a new-type friction damper whose friction force can be controlled easily (Uno et al,1988). The friction damper provides a large capability for energy absorption and high durability for cyclic loading. A base isolated reinforced concrete structure with friction dampers and four laminated rubber bearings supporting 470 tons of weight was constructed for tests and observations to grasp the dynamic characteristics of the system. This report describes the results of alternate loading tests on dampers, free vibration tests on a base isolated structure with friction dampers, and earthquake observation of the structure.

FRICTION DAMPER

Figure 1 shows details of the newly developed friction damper. This damper transforms straight-line motion of the mounting devices into rotational motion of friction plates. Friction plates consist of sintered metal discs and

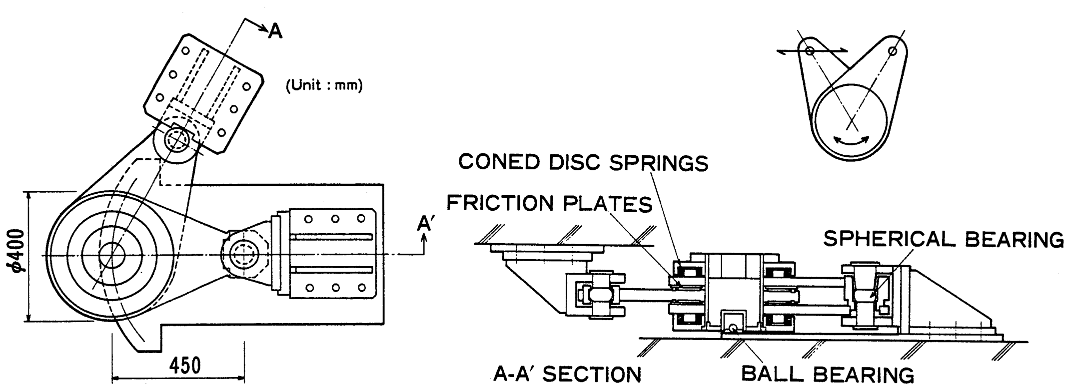

Figure 1 Friction Damper

stainless steel discs. Friction plates are fixed steel plates tightened by screwing a bolt through coned disc springs. The friction force can be controlled by adjusting the tightening torque. The friction damper is supported by the ball bearing, and two spherical bearings connect the damper and the mounting devices fixed on the base and the superstructure; the damper, therefor, does not restrict vertical movement of the superstructure. Friction forces of the damper are independent of velocity of sliding speed, and the friction forces of the damper depend on the direction of loading (Takai et al,1988). The directional property of the dampers shall be considered in designing actual buildings.

LOADING TESTS ON FRICTION DAMPERS

Figure 2 shows the test apparatus for loading tests on the friction dampers. Figure 3 shows a hysteresis loop of ten cycles at a loading speed of 50mm/sec and a clamping force of 70tonf (surface pressure : 8.8kgf/cm2). The friction force of the damper slightly increased by repeating cycles, however, it is considered that this slight change is not a serious problem in practical use. The temperature of the friction plate rose by 20 C during the test, which was measured by a thermo-couple fixed on a side face of a friction plate. The friction force in Figure 3 is dependent on the displacement, that is caused by change of the distance between the loading axis and the rotational axis of friction plates. The amount of change of friction force can be reduced by making the length between the spherical bearings and the rotational axis of friction plates longer.

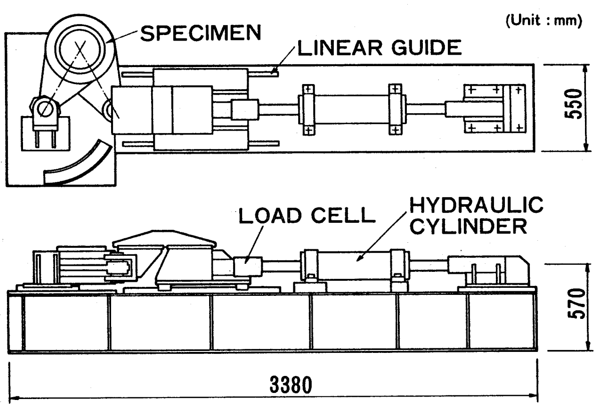

Figure 2 Test Apparatus

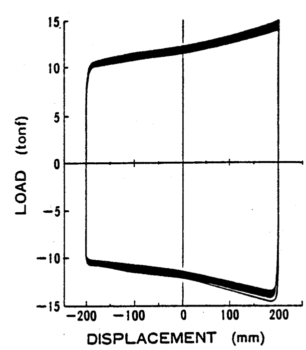

Figure 3 Hysteresis Loop of a Friction Damper

FREE VIBRATION TESTS ON A BASE ISOLATED STRUCTURE

Figure 4 shows the base isolated structure, and Table 1 lists the specifications of the base isolated structure. Dimensions of the superstructure were determined for another experiment that has no connection with this study, and it has columns with a 90cm by 90cm section. The stiffness of the superstructure is stiff enough to consider the system as a single degree of freedom. Four laminated rubber bearings supported the superstructure whose weight was 470 tons. Two free vibration tests were done on the X-direction, one was on the structure without a damper, and the other was on the structure with two dampers which were effective for the X-direction and the friction forces of which were 0.5tonf/unit. Photo 1 shows the friction damper and the laminated rubber bearing installed in the structure. A notched PC steel rod was set between the superstructure and the base. This notched section was cut by pulling the rod with a jack; a free vibration was then generated.

Table 1 Specifications of the Base Isolated Structure

Weight of the superstructure		:	470tonf
Laminated rubber bearing	Thickness of a rubber layer	:	4.0mm
	Thickness of a steel plate	:	2.2mm
	Diameter of a steel plate	:	420mm
	Number of rubber layers	:	38
	Horizontal stiffness	:	0.5tonf/cm
Friction damper	Free vibration test	Friction force : 0.5tonf/unit 2 units were installed for the X-direction (A and C in Figure 4)	
	Earthquake observation	Friction force : 2.25tonf/unit 4 units were installed for the X,Y-directions (A,B,C and D in Figure 4)	

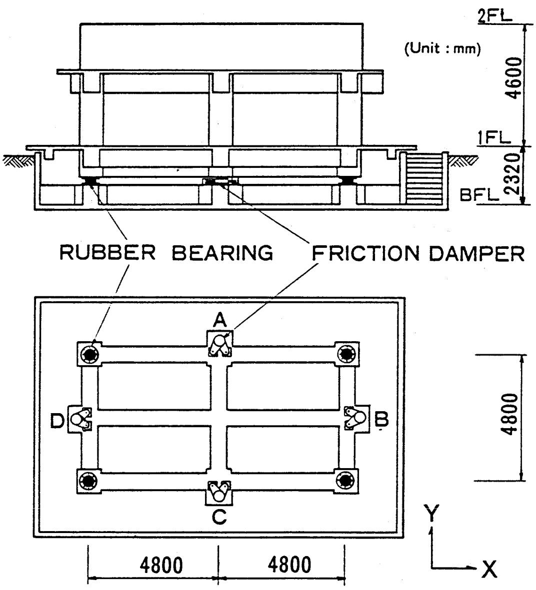

Figure 4 A Base isolated Structure with Friction Dampers

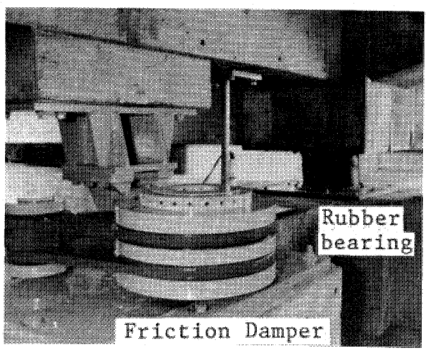

Photo 1 Isolation Devices installed in the structure

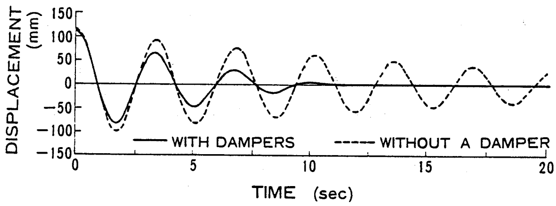

Figure 5 Displacement Time Histories of Free Vibration Tests

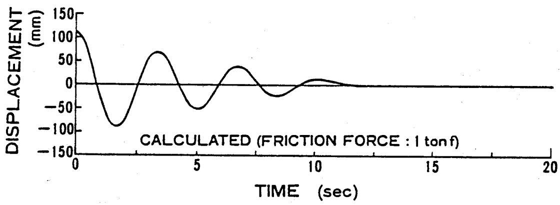

Figure 6 A Calculated Time History (with dampers)

Figure 5 shows the free vibration time histories of the relative displacement between the first floor and the base. The broken line indicates the free vibration waveform without a friction damper, and the solid line indicates the waveform with friction dampers.

Displacement(X) of a free vibration of a single degree of freedom with viscous damping with a damping ratio h and a Coulomb friction force F for each half cycle is

$$X=(X_0+a)e^{-h\omega t}(\cos\sqrt{1-h^2}\ \omega t+\frac{h}{1-h^2}\sin\sqrt{1-h^2}\ \omega t)-a \quad , \qquad 1)$$

in which X_0 is the initial displacement, and

$$a=\frac{F\ \mathrm{sgn}(\dot{X})}{k} \quad , \quad \omega=\sqrt{k/m} \quad ,$$

where m, k are the mass and the stiffness (Jacobsen et al,1958). If a system has no damping, the amplitude of displacement decreases monotonously by 2F/k each half cycle.

Figure 6 shows a displacement calculated using the above expression. The natural frequency and the damping ratio were obtained from the results of free vibration tests without a friction damper. Figure 7 shows the decrease of amplitude of test results and calculation results using the above expression. Equivalent damping ratios are plotted in the figure, and that of the system increases with the decrease of the displacement amplitude. Experimental values agree well with the calculated result. This shows that friction dampers have worked well.

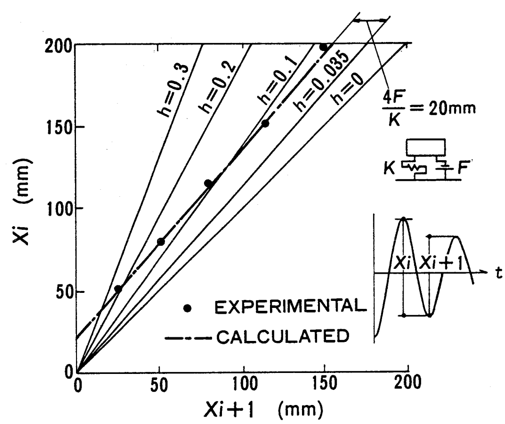

Figure 7 Decrease of Amplitude of a Free Vibration Test

EARTHQUAKE OBSERVATION OF A BASE ISOLATED STRUCTURE

In the base isolated structure , 17 seismometers were installed to observe the acceleration responses of the base, first and second floors, and the relative displacement response between the base and the first floor. Four dampers whose friction forces were 2.25tonf/unit were installed for the X,Y-directions. In several earthquake motions observed, the CHIBAKEN-TOUHOUOKI earthquake on December 17, 1987, was comparatively large. The magnitude, the focal depth, and epicentral distance were 6.7, 58km, and 103km respectively.

Figure 8 shows acceleration records of each floor and relative displacement record between the base and the first floor. The maximum acceleration of the base was 31.3gal and that of the superstructure was at the limit of acceleration about 12-15gal. The dotted lines of figure 8 indicate analytical results based on the simple lumped mass system (see Figure 9). In this analysis, initial stiffness of the skeleton curve was obtained from the loading test results of the isolated structure, and the damping ratio of superstructure was 0.02. The maximum acceleration and relative displacement shown in the analytical results agree with that of the observation records. On comparing observed and analytical waveform, the analytical results agree with the observed records when amplitude was comparatively large, but at the early weak motions, values of analytical results were larger than that of observed records. We consider that this difference was caused by the backlash of the mounting devices and the spherical bearings.

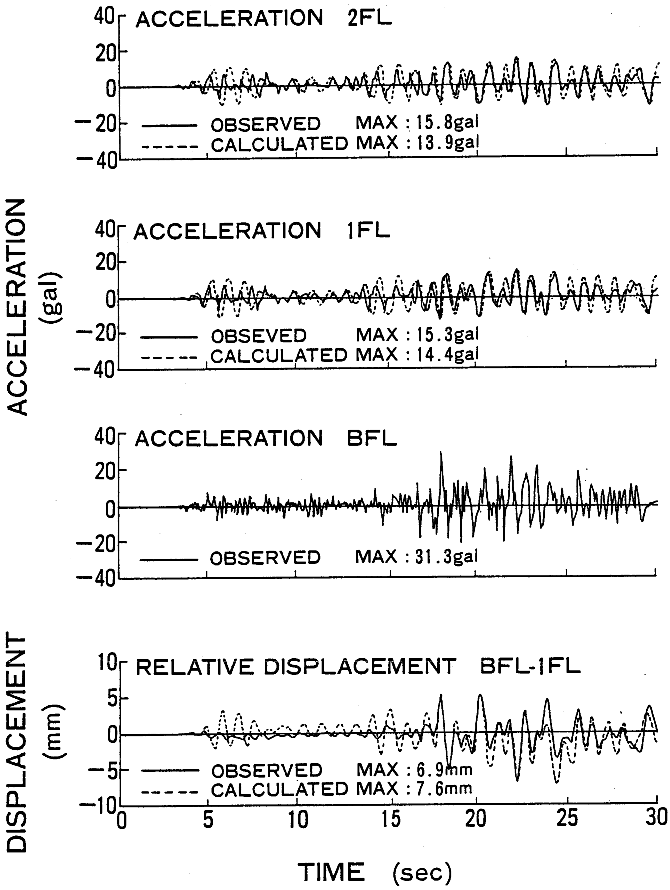

Figure 8 Comparison between Observed Records and Calculated Waveform

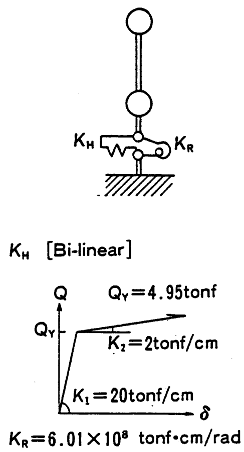

Figure 9 Lumped Mass Model

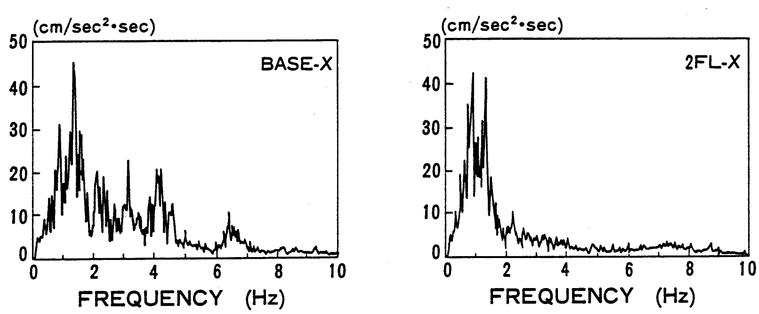

Figure 10 Fourier Spectrum

Figure 10 shows the Fourier spectrum of acceleration records of the base and the second floor. The Fourier spectrum of the superstructure was reduced to between 2Hz and 10Hz.

CONCLUSIONS

The results of loading tests on the newly developed friction dampers shows that it has a stable hysteresis property. Friction forces are slightly increased with repeating cycles, however, it is considered that this slight change is not a serious problem in practical use. From the free vibration tests and earthquake observations of the base isolated structure with laminated rubber bearings and the friction dampers, it was confirmed that this seismic isolation system worked well. The results of the simple simulation analysis agree with the observation records except for early weak motions. The response characteristics of a structure with this system subjected to strong earthquake motions can be estimated easily at the designing stage.

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