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Fundamental Characteristics of Reduction System for Seismic Response using Friction Force

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Abstract: A new device of reduction for seismic response using friction force was developed. In this paper, fundamental characteristics of reduction system for seismic response using this device were investigated by excitation experiment using artificial seismic waves. The peak acceleration amplitude on this system has decreased to about 50-90% over the input waves. Although a spectral peak around the frequency of 0.5Hz that is the natural period of this system was identified, the value of a spectral peak was decreased using bearings with the high friction force. This device is useful for reduction of seismic response.

Key words: Friction force, seismic response, natural period, damping ratio, amplitude.

1. Introduction

It is important for seismic disaster prevention to reinforce the building structure. But if the strength of building structure is increased for anti-earthquake reinforcement, the seismic response does not always decrease remarkably. The office automation equipments installed inside the building such as a computer rack are unstable because of large height against width and depth. So it is easy to turn over by earthquake shaking. Therefore it is needed to develop the reduction system of seismic response for small structure installed inside floor [1-3]. We developed a new device that sandwiched marble or spherical shape bearing between two plates of spherical concave, and built a reduction system of seismic response using this device[4)]. In this paper, fundamental characteristics of this system are investigated by excitation experiment.

2. Friction Bearing

An example of friction bearing developed for this study is shown in Fig. 1. It consists of two plates with spherical concaves and marble shape bearing. The size of plate is 344 mm×344 mm, thickness of this device is 62.4 mm. And the radius of concave changes from 500 mm to 600 mm, continuously. In this system, marble shape bearing slides between two plates and vibration of the shaking table is transmitted to the upper plate via marble shape bearing. Because the restoring force is generated when marble shape bearing uplifts, two plates return original position.

And the friction bearing that used a spherical metal instead of marble shape is also developed (Fig. 2). Compared the bearing between marble shape type and spherical metal type, spherical metal generates large restoring force. On the other hand, marble shape type generates high damping ratio because of sliding friction and rolling friction.

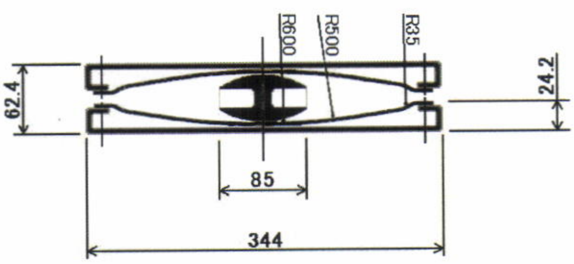

Fig. 1 An example of friction bearing with marble shape metal.

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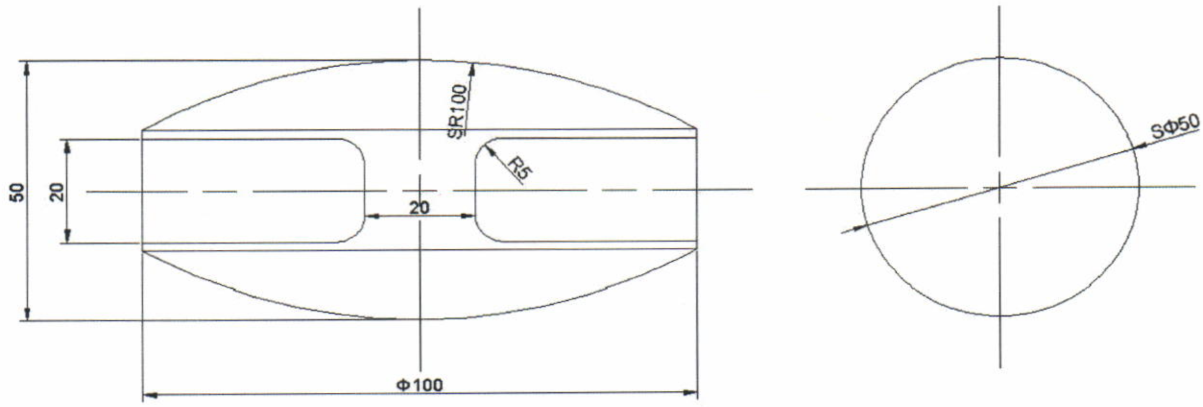

Fig. 2 Size of marble shape type bearing (left) and spherical metal (right).

A reduction system of seismic response, that is called isolated plate, was made by this device. The device was set up at each corner shown in Fig. 3. And the combination of bearing for isolated plate is shown Table 1, the same type bearing was installed at the line of diagonal.

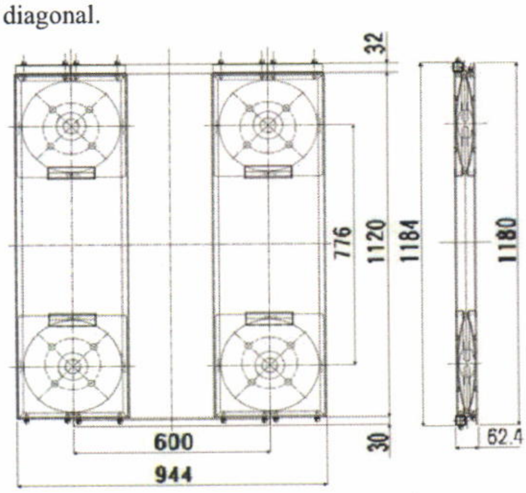

Fig. 3 The isolated plate using friction bearings.

Table 1 Combination of bearing in this study.

	Combination of bearing
Case 1	spherical metal type: 2
Case 2	spherical metal type: 2 + marble shape type: 2
Case 3	marble shape type: 2

3. Natural Period and Damping Ratio of This System

As the friction bearing consists of pendulum mechanism, this isolated plate has a natural period. And when the bearing slides a plate with spherical concaves, the friction force occurs between them. So the damping is generated. This isolated plate is controlled by these parameters. So, natural period and damping ratio of this system are estimated by free vibration test.

The free vibration is generated when upper plate that added some displacement from original position is released. The signal from acceleration sensors installed on upper plate was recorded to the PC through the interface (Kyowa PCD-300A). The sampling rate is 0.01sec/points.

Acceleration response waveforms of free vibration at each condition were shown in Fig. 4, and natural period and damping ratio estimated by this experiment were shown in Table 2. The natural period in case 1 is longest in this experiment, and is going to short in case 2 and case 3. The damping ratio when spherical metal type bearing was used is small. As number of marble shape type bearing increases, the damping ratio is going to large. It means that large friction force is generated when marble type bearing slips on spherical concaves plate.

Table 2 Damping ratio and Natural period of this system.

	Damping ratio h	Natural period T(s)
Case 1	0.004	2.281
Case 2	0.086	2.006
Case 3	0.105	1.333

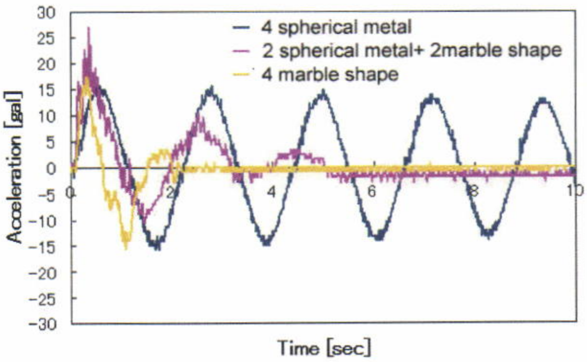

Fig. 4 Waveforms of free vibration experiment on the isolated plate.

4. Excitation Experiment Using Artificial Seismic Wave

To understand fundamental characteristics of this system, excitation experiment is done using artificial seismic waves. The isolated plate that put a computer server rack with 1850 mm×860 mm×1000 mm size and 100 kg weight is installed on the shaking table. The acceleration sensors are installed on the shaking table, isolated plate and top of a computer server rack. The direction of excitation is one dimension horizontally.

The waveforms of artificial seismic wave as input wave are shown in Fig. 5 and its Fourier spectra are shown in Fig. 6. The predominant frequency of input waves is about 10 Hz that is natural frequency of the general mechanical structure. The Fourier amplitude of input wave 1 decreases at the frequency lower than 1 Hz. On the other hand, the amplitude decreases at the frequency lower than 0.4 Hz on input wave 2.

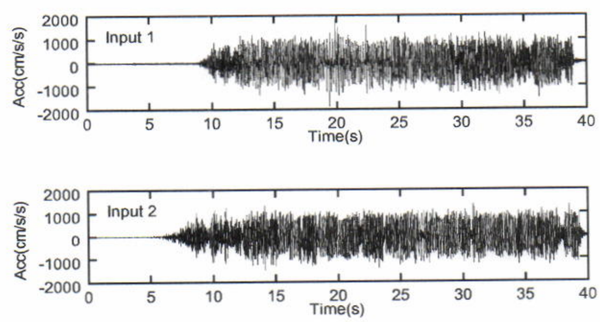

Fig. 5 Waveforms of artificial seismic wave for excitation experiment.

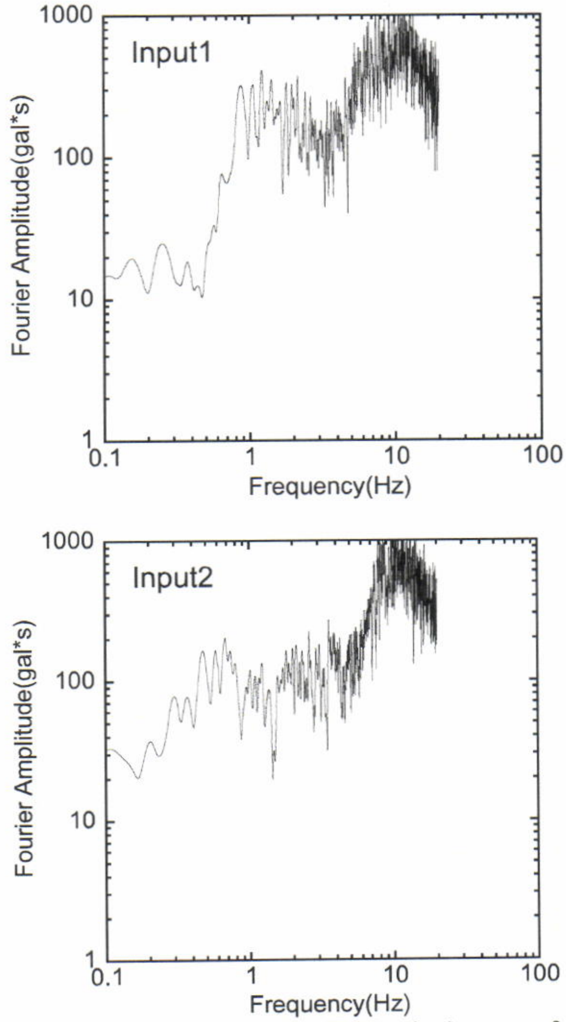

Fig. 6 Fourier spectra of artificial seismic waves for excitation experiment.

5. Results

5.1 Acceleration Response Waveforms

The acceleration response waveforms on isolated plate are shown in Figs. 7-8. The amplitude of response wave in case 3 that used four bearings of marble shape type is largest in the case of input wave 1. On the other hand, in the case of input wave 2, the response amplitude in case 3 is larger than in case 2. But in case 1, although the response amplitude decreases until the time of 15 sec, the large response amplitude with the frequency of around 0.5 Hz band is identified at the time from 20 to 40 sec.

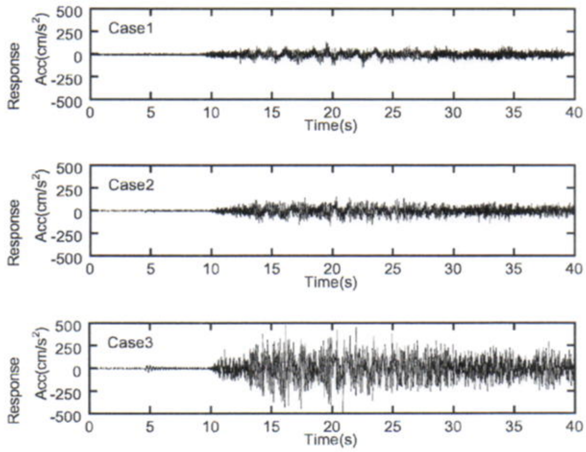

Fig. 7 Acceleration response waveforms on the isolated plate using input wave 1.

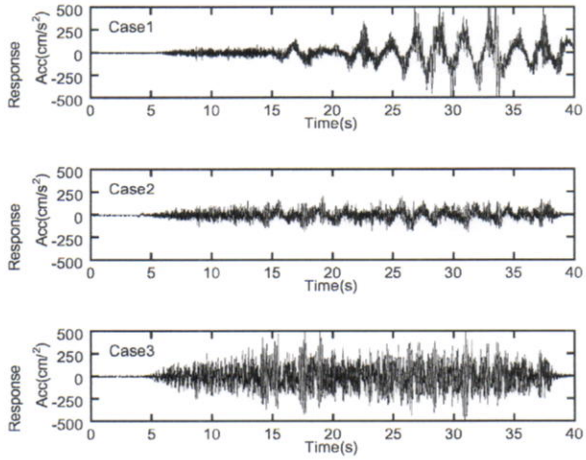

Fig. 8 Acceleration response waveforms on the isolated plate using input wave 2.

5.2 Peak Acceleration Response Amplitude

The peak acceleration response amplitude and the root mean square amplitude are shown in Tables 3-6, respectively. The peak acceleration response amplitude on isolated plate decreases to about 10%-50% of the peak amplitude of input wave. Also the root mean square amplitude decreases to about 5%-25%. But the best case of decreasing rate of the peak acceleration response amplitude is not always the best case of decreasing rate of the root mean square amplitude. Anyway, this system has good ability to reduce seismic response in acceleration dimension.

Table 3 Peak amplitude value using input wave 1.

	Peak amplitude of input wave 1 (cm/s^2)	Peak response amplitude (cm/s^2)
Case 1	1874	152
Case 2	1790	168
Case 3	1891	489

Table 4 Peak amplitude value using input wave 2.

	Peak amplitude of input wave 2 (cm/s^2)	Peak response amplitude (cm/s^2)
Case 1	1469	836
Case 2	1376	202
Case 3	1359	574

Table 5 Root mean square amplitude using input wave 1.

	RMS amplitude of input wave 1 (cm/s^2)	RMS response amplitude (cm/s^2)
Case 1	5.19	0.297
Case 2	5.08	0.401
Case 3	5.06	1.115

Table 6 Root mean square amplitude using input wave 2.

	RMS amplitude of input wave 2 (cm/s^2)	RMS response amplitude (cm/s^2)
Case 1	5.49	1.163
Case 2	5.47	0.520
Case 3	5.42	1.322

5.3 Fourier Spectra of Acceleration Response Waveforms

The Fourier spectra of acceleration response waveforms recorded on isolated plate are shown in Figs. 9-10. In the case of input wave1, although the shape of Fourier spectrum between in case 2 and in case 3 is almost same, the level of Fourier amplitude in case 3 is higher than in case 2. In case 1 using the input wave 2, a spectral peak around the frequency of 0.5 Hz can be identified. Because this frequency band is equivalent to natural frequency of the isolated plate system, it is generated by resonance.

5.4 Spectral Ratios

The spectral ratios dividing the response acceleration spectrum on the isolated plate by the input wave 1 spectrum and dividing the response acceleration spectrum by the input wave 2 spectrum are shown in Figs. 11-12, respectively. A spectral peak is identified at the frequency of 0.5 Hz, and is independent of input waves. And its value of case 1 which is low damping is largest in all case. Increasing the number of marble type bearing, its value deceases. Increasing the damping ratio h, the peak value at the resonance frequency decreases in single degree of freedom system, theoretically. It is a good relation between experimental results and theoretical trend.

The good reduction rate at the frequency between 1 and 10 Hz is in case 1 by input wave 1, is in case 2 by input wave 2. Because the motion of isolated plate by resonance has exceeded the clearance displacement, the collision occurred between two spherical concaves plate in case 1 using input wave 2. As the acceleration response waveforms shown in Fig. 8, the high frequency waveform was generated. So the reduction rate at the frequency between 1 and 5 Hz is not so good compared to in case 1 using input wave 1.

And, in case 3 using input wave 2, the value of a spectral peak by resonance is restrained using the marble type bearing that is possible to generate the high friction force. But the decreasing rate at the high frequency band is getting worse. So it is important to find the optimum conditions for bearing shape.

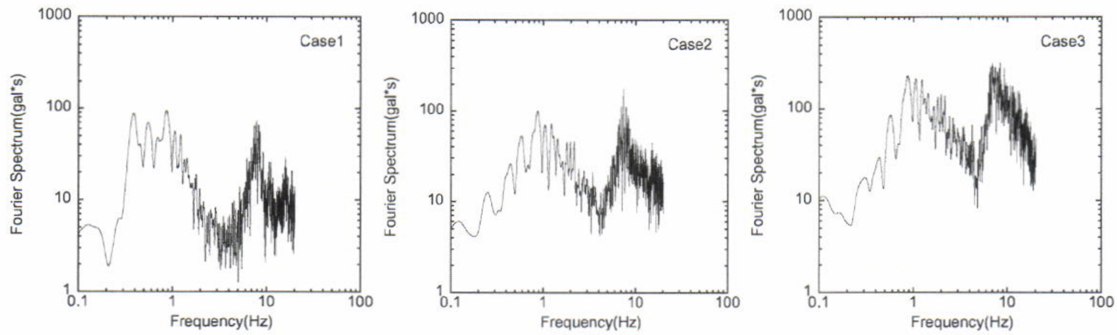

Fig. 9 Fourier spectra of acceleration response on the isolated plate using input wave 1.

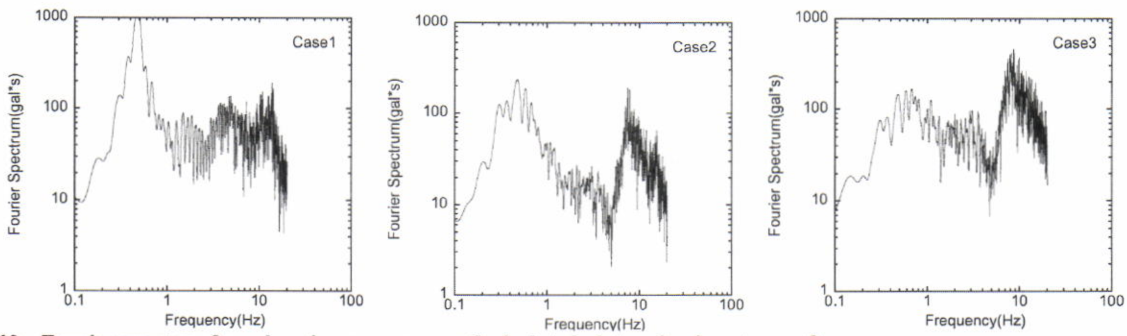

Fig. 10 Fourier spectra of acceleration response on the isolated plate using input wave 2.

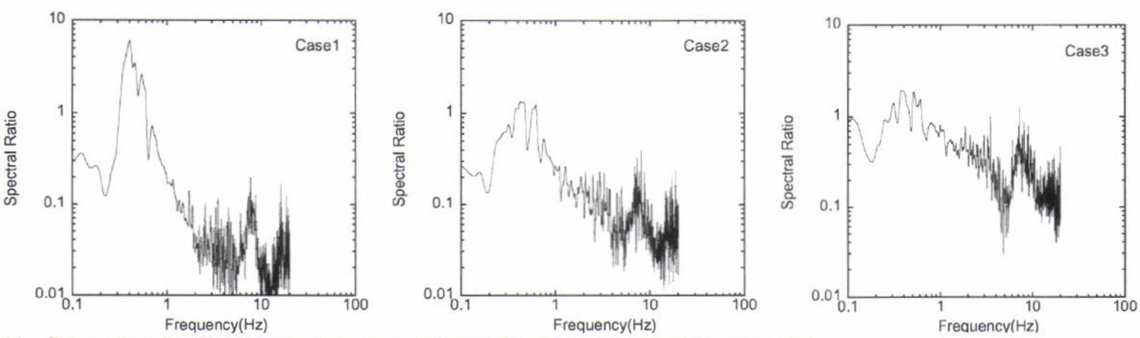

Fig. 11 Spectral ratios dividing the response spectrum by the spectrum of input wave 1.

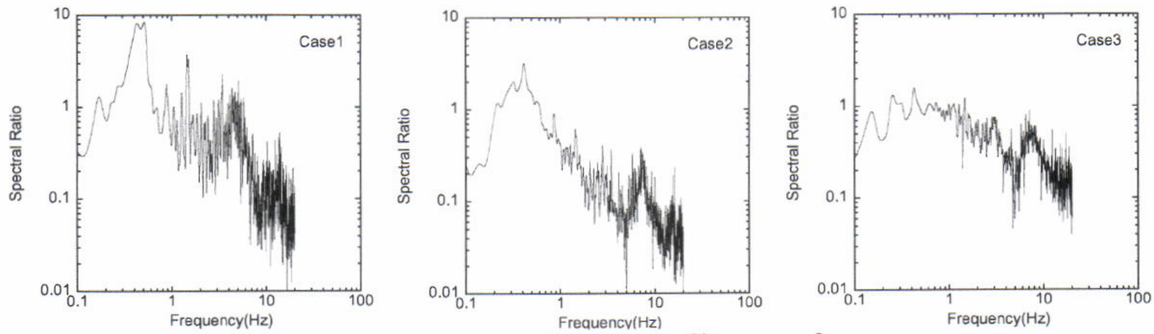

Fig. 12 Spectral ratios dividing the response spectrum by the spectrum of input wave 2.

6. Conclusions

We developed a new device that sandwiched marble or spherical shape bearing between two plates of spherical concave, and built a reduction system of seismic response using this device. In this paper, fundamental characteristics of this system are investigated by excitation experiment.

The natural period and damping ratio of this system are estimated by free vibration test. The natural period is almost 2.0 sec. The damping ratio is depending on the bearing type, is 0.004-0.105. It becomes large when marble shape type is used.

In the case of excitation experiment using artificial seismic waves, the peak acceleration amplitudes of response wave indicate 10-50% and the root mean square amplitudes indicate 5-25% over the input waves.

A peak of spectrum around the frequency of 0.5 Hz can be identified when the input waves with low frequency component are used. Because this frequency band is equivalent to natural period of the isolated plate system, it is generated by resonance. The peak of spectrum amplitude by resonance is restrained using a bearing that is possible to generate the high friction force. But the rate of decreasing at the high frequency band gets worse. So it is important to find the optimum conditions for bearing.

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