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Vibration Analysis of Base Isolation System for Small Equipments using Friction Bearing

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Abstract

In this paper, vibration analysis of a small base isolation system that consists of friction bearings was investigated by excitation experiments using artificial seismic waves. The peak acceleration amplitude on the base isolation system has decreased to 43-90% compared to input waves. And the root mean square amplitude has decreased to 76-94%. Although a spectral peak around the frequency of 0.5 Hz that is equal to a natural frequency of this system was identified when the input waves with low frequency component were used, it was decreased using friction bearings that generated high friction force. Comparing the response waveforms between acceleration response waveforms by excitation experiment and by numerical analysis using 2DOF model, it is good agreement. This system is useful for reduction of seismic response.

Key Words: Seismic response, Friction bearing, Ball, Marble plate, Natural frequency, Damping ratio

1. Introduction

In order to protect building structures from seismic ground motion, structures are retrofitted by a technique of seismic isolation system [1-4] or vibration control system [5,6]. However, in case that existing building structures are retrofitted for anti-earthquake reinforcement, the technique of increasing structure stiffness is generally used. Therefore seismic response of structures does not decrease remarkably. The equipments set on building inside such as a computer server and an office automation equipment will overturn during a big earthquake, therefore they are higher than their width and depth. So small base isolation systems that can be installed inside building to decrease seismic response have been extensively developed [7]. For example, ball isolation type device [8], roller type using liner rail isolation device [9], friction pendulum isolation device with poly-curvature rail [10, 11] are used. The ball isolation type device shows good reduction of seismic response. However amplification by the resonance is quite big, it is serious problem when the input wave is included the same component of a natural frequency on this device. And some isolation system for adding a friction damping system is developed, it is not easy to install since a mechanism is complicated. So a sliding type isolation device [12] is also used. Although the mechanism is very simple, it dose not have a restring force. So it is impossible to return the original position.

We have developed a simple device using friction force to reduce seismic response [13]. The device consists of two plates having spherical concaves and an oval type metal (marble plate) or a spherical metal (steel ball). In this study, vibration analysis of the small base isolation system that consists of this device is investigated by excitation experiments using artificial seismic waves.

2. Friction Bearing

A friction bearing as new device is shown in Fig. 1. Shape of the plate is square and length of 334 mm and thickness of edge is 62.4 mm. Radius of the concave is 500-600 mm. In this device, the marble plate slides between two plates and vibration of ground is transmitted to the small base isolation system via marble plate. It automatically returns to the original position by resilience of two concave plates. A 50mm steel ball is prepared instead of the marble plate. The restoring force in case of the steel ball is larger than in case of the marble plate. On the other hand, the damping ratio in case of the steel ball is smaller.

The small base isolation system composed of the friction bearing is shown in Fig. 2. This device is placed at each corner. The combination of the friction bearing type on this experiment is shown in Table 1. The same bearings are placed on the diagonal.

Table 1 Combination of the friction bearings for the small base isolation system

	Combination of the friction bearings
Case 1	4 Steel balls
Case 2	2 Steel balls and 2 Marble plates
Case 3	4 Marble plates

3. Excitation Experiment using Artificial Seismic Waves

To know the dynamic characteristics of the small base isolation system, excitation experiment of this system is done using artificial seismic waves. Experimental setup is shown in Photo 1. This system that installed a computer server rack is put on the shaking table. Size of the computer server rack is 1850 mm height, 860 mm width, 1000 mm length. And its weight is 100 kg. The acceleration sensors are installed on the shaking table, this system and the top of computer server rack. Signal from acceleration sensors (Kyowa AS-2GA) are recorded to a PC through an interface (Kyowa PCD-300A). Sampling rate is 0.01 sec/points.

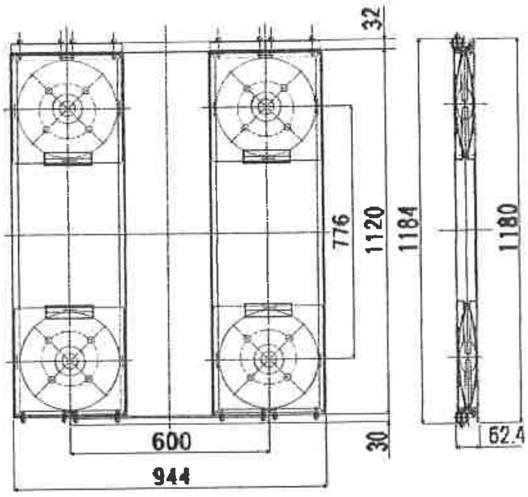
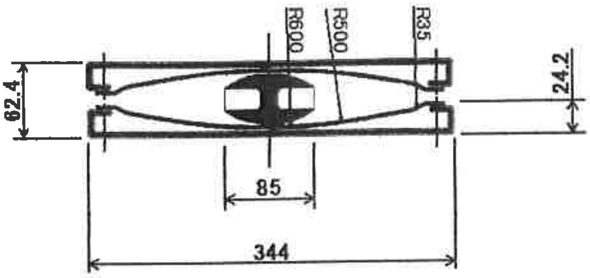


Fig. 1 Example of a friction bearing (mm)

Fig. 2 Size of the small base isolation system using the friction bearings (mm)



shown in Fig. 3, and the Fourier spectra of :y of the input waves is about 10Hz that is [he Fourier amplitude of the input wave 1 n the other hand, the amplitude of the input wave 2 decreases at the frequency of lower than 0.4Hz.

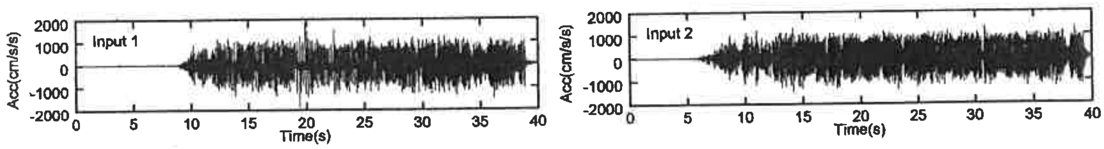


Fig. 3 Artificial seismic waveforms as input wave

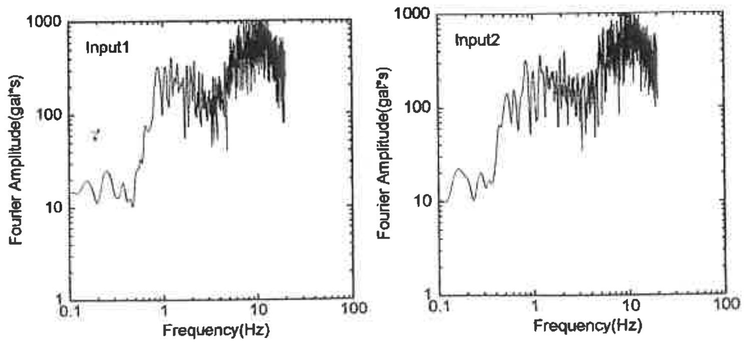


Fig. 4 Fourier spectra of the input waves

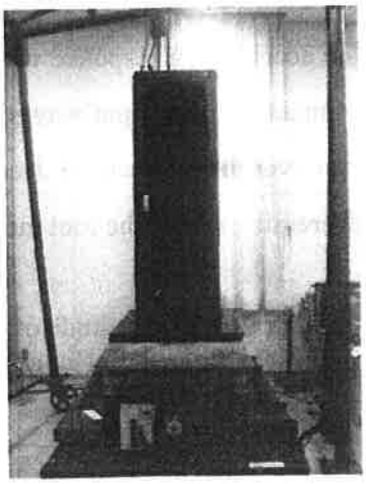


Photo1. Experimental setup

4. Results

4.1 Acceleration response waves

Acceleration response waves on the small base isolation system are shown in Fig.5 - Fig.6. In case of the input wave 1, the response amplitude on this system using four friction bearings with the marble plate (Case 3) is large. On the other hand, in case of the input wave 2, the response amplitude on this system using four friction bearings with the steel ball (Case 1) is larger. Although the response amplitude is decreased until the time of 15 sec, large response amplitude with the frequency of around 0.5 Hz band is identified on the time from 15 to 25 sec.

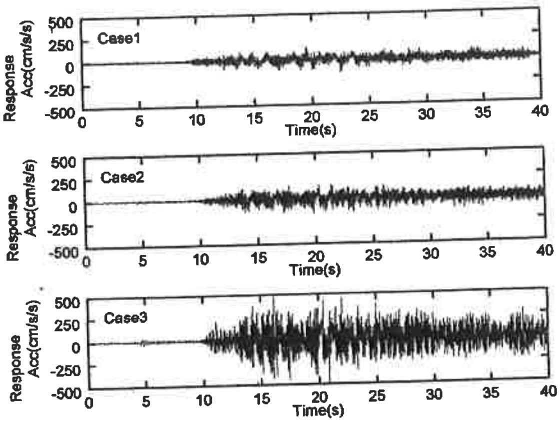


Fig. 5 Acceleration response waveforms (Input wave 1)

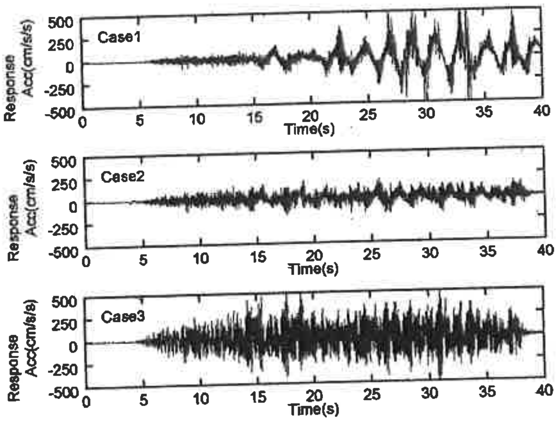


Fig. 6 Acceleration response waveforms (Input wave 2)

4.2 Peak amplitude and root mean square amplitude

Peak amplitude and root mean square amplitude (RMS) of the acceleration response waves are shown in Table 2 - Table 3 and in Table 4 - Table 5, respectively. The peak amplitude of the acceleration response waves on the small base isolation system decreases to 43 - 90 % compared to the input waves. Also the root mean square amplitude decreases to 76 - 94 %. However the best case of decreasing rate of the peak amplitude is not always the best case of decreasing rate of the root mean square amplitude.

Table 2 Peak amplitude of acceleration response wave (Input wave 1)

	Input (cm/s^2)	Response (cm/s^2)
Case 1	1874	152
Case 2	1790	168
Case 3	1891	489

Table 3 Peak amplitude of acceleration response wave (Input wave 2)

	Input (cm/s^2)	Response (cm/s^2)
Case 1	1469	836
Case 2	1376	202
Case 3	1359	574

Table 2 Root mean square of acceleration response wave (Input wave 1)

	Input (cm/s^2)	Response (cm/s^2)
Case 1	5.19	0.297
Case 2	5.47	0.401
Case 3	5.06	1.115

Table 3 Root mean square of acceleration response wave (Input wave 2)

	Input (cm/s^2)	Response (cm/s^2)
Case 1	5.49	1.163
Case 2	5.47	0.520
Case 3	5.42	1.322

4.3 Fourier spectra of acceleration response waves

Fourier spectra of the acceleration response waves recorded on the small base isolation system are shown in Fig. 7 - Fig. 8. In case of the input wave 1, although the shape of the Fourier spectrum between in case 2 and in case 3 is almost same, the level of the Fourier amplitude in case 3 is higher than the one in case 2. In case 1 of the input wave 2, a peak of the Fourier spectrum around the frequency of 0.5 Hz can be identified. Therefore, this frequency band is equivalent to the natural frequency of the small base isolation system, it is generated by the resonance. On the other hand, in case 3 of the input wave 2, the peak of spectrum amplitude by the resonance is restrained using the bearings that generate high friction force. However the decreasing rate at the high frequency band gets worse. So it is important to find optimum conditions for friction force.

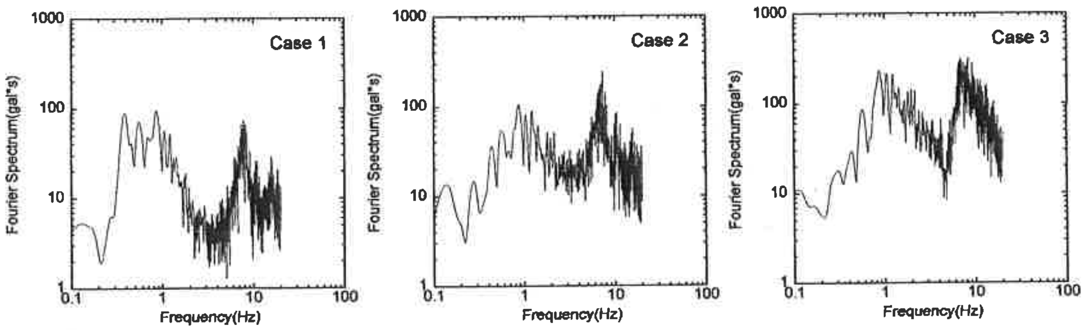


Fig. 7 Fourier spectra of the acceleration response waves (Input wave 1)

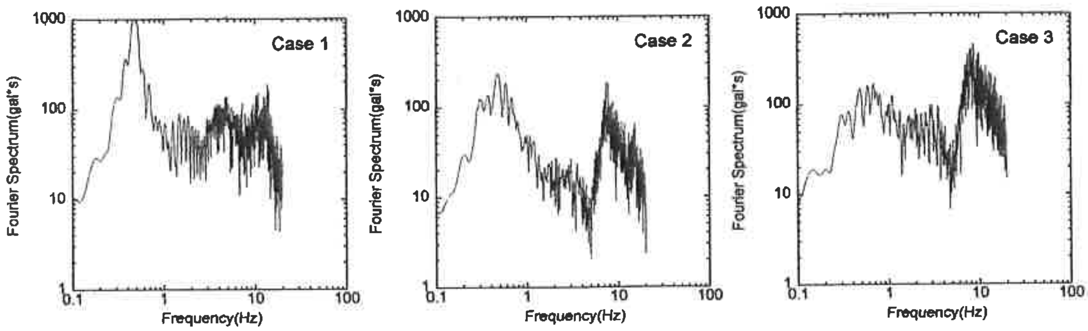


Fig. 8 Fourier spectra of the acceleration response waves (Input wave 2)

4.4 Spectral ratios

The spectral ratios divided by the response acceleration spectrum on the small base isolation system by the input wave spectrum are shown in Fig. 9 - Fig. 10. A spectral peak is identified at the frequency of 0.4 Hz. In case 1 of the input wave 1 and the input wave 2, the spectral ratios have the greatest value. When a number of the friction bearings with the marble plate increases, peak value of the spectral ratio in case of all input waves decrease. Some sharp pulses in the acceleration response waveform from 25 to 35 sec are identified in case 1. Since motion of the small base isolation system by the resonance has exceeded the clearance displacement, a collision occurred between two spherical concaves plates in case 1 of the input wave 2. So the reduction rate at the frequency between 1 and 5 Hz is not so good compared to in case 1 of the input wave 1. In case 3 of all input waves, the value of a spectral peak by the resonance is restrained using the friction bearing with the marble plate that may generate high friction force. However, the decreasing rate at the high frequency band is getting worse.

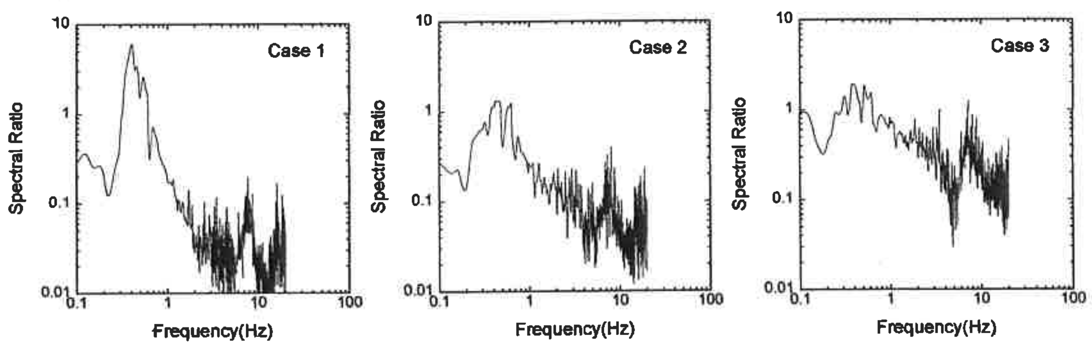


Fig. 9 Spectral ratios (Input wave 1)

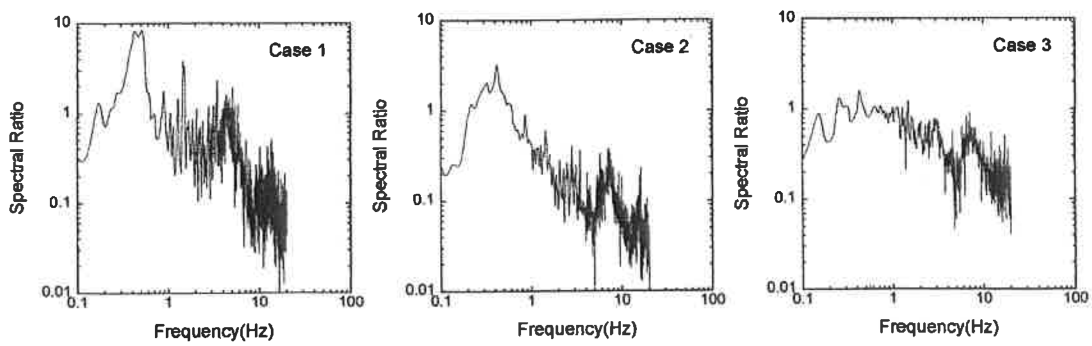


Fig. 10 Spectral ratios (Input wave 2)

5. Estimation of Natural Frequency and Damping Ratio of This System

Fitting the transfer function for the spectral ratio that is as a transfer function of this system by a forwarding model, natural frequency and damping ratio that are very important factor to control this system are evaluated. In this case, a model of 2DOF system shown in Fig. 11 is used for the theoretical transfer function. Since the input wave 2 includes the components of wide band frequency, the spectral ratios that are calculated using the input wave 2 are used for fitting.

An example of comparison between the spectral ratio and the fitting of the transfer function is shown in Fig. 12. And evaluated the parameters are shown in Table 6. The shape of the theoretical transfer function indicates two resonance peaks and an anti-resonance valley. If the valley of spectral ratio at the frequency of 5Hz is considered to be an anti-resonance point, although location of the anti-resonance peak is a little bit different, it is possible to explain the shape of spectral ratio.

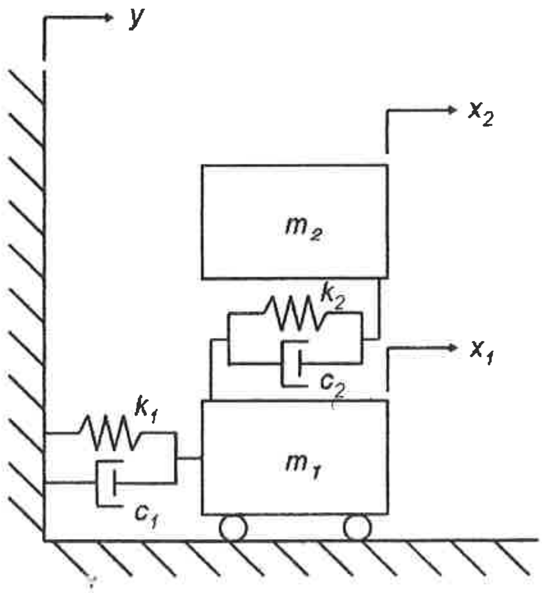


Fig.11 2DOF model for calculating a theoretical transfer function.

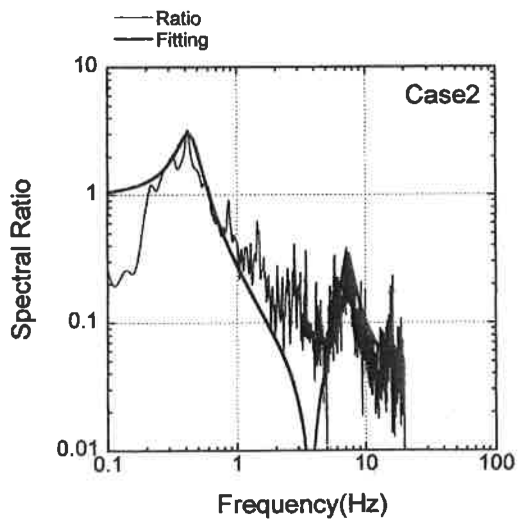


Fig.12 Comparison between the spectral ratio and the theoretical transfer function using 2DOF.

Table 6 Natural frequency and damping ratio

	Natural frequency f_o (sec)		Damping ratio ζ	
	Base isolation	Server	Base isolation	Server
Case 1	0.90	2.42	0.14	0.002
Case 2	0.85	3.70	0.35	0.03
Case 3	0.81	3.72	1.50	0.03

6. Evaluation by Numerical Analysis

To examine the results of experiment, a simulation using a model of 2DOF shown in Fig. 11 is done. And natural frequency and damping ratio for this analysis are used the values shown in Table 6. Calculation is done in frequency domain.

Comparison between acceleration response waveforms by excitation experiment and by numerical analysis are shown in Fig. 13, and its peak acceleration amplitude are shown in Table 7. Since the collision occurred between two spherical concaves plates in case 1, the acceleration response waveform includes high frequency components and the peak acceleration amplitude on excitation experiment is bigger than that on numerical analysis. However the waveform except high frequency band between them is almost same. On the other hand, the waveforms on numerical analysis explain the response waveforms in case 2 and case 3. It means that this numerical analysis is effective.

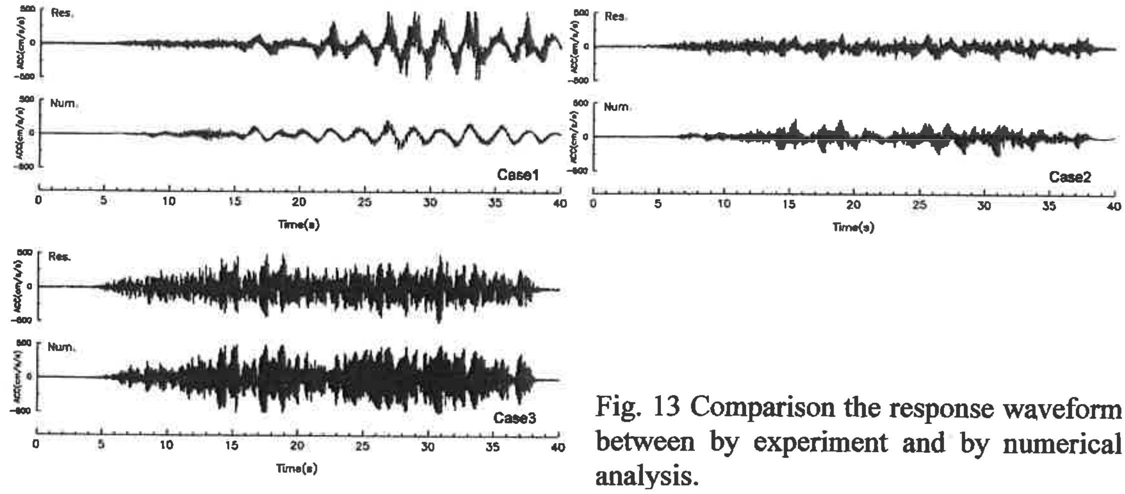


Fig. 13 Comparison the response waveform between by experiment and by numerical analysis.

Table 7 Comparison of peak amplitude in acceleration response wave

	Peak amplitude of acceleration response wave	
	Experiment (cm/s^2)	Numerical (cm/s^2)
Case 1	836	221
Case 2	203	271
Case 3	574	521

7. Conclusion

We developed a device that sandwiched the marble plate or the steel ball between two plates of spherical concave, and built the small base isolation system that consists of this device. In this paper, vibration analysis of this system was investigated by excitation experiments using artificial seismic waves.

From the forced vibration experiment, the natural frequency of this system was evaluated to f_o=0.81 – 0.90 Hz. And the damping ratios in case of four friction bearings with steel ball (low friction) and in case of four friction bearings with the marble plate (high friction) were 0.14 and 1.5, respectively.

In the excitation experiment using artificial seismic waves, the peak amplitude of the acceleration response waves on this system decreased to 43 - 90 % compared to the input waves. Also the root mean square amplitude decreased to 76 - 94 %.

A spectral peak around the frequency of 0.5 Hz on the Fourier spectrum was identified when the input waves with low frequency component were used, a peak on the spectral ratios in case using four friction bearings with the steel ball was identified. Since this frequency band was equivalent to the natural frequency of this system, it was generated by the resonance. It was decreased using the friction bearings that generated high friction force. But the rate of decreasing at the high frequency band gets worse, so it is important to find optimum conditions of friction force.

Comparing the response waveforms between by excitation experiment and by numerical analysis, it is good agreement. This system is effective for reduction of seismic response.

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