RESEARCH AND DEVELOPMENT OF VIBRATION ATTENUATION TECHNIQUE FOR LIGHT WEIGHT STRUCTURE

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ABSTRACT :
Various vibration attenuation systems are suggested as seismic safety technique for architectural and civil structure. In recent years, these vibration reduction technologies begin to be applied to a small scale structure. In case that the technology is applied to a small scale structure, the specifications and const of device must be examined well. In this paper, the vibration attenuation technique for light weight mechanical structure with simple mechanism and low cost is described, and the analytical and experimental results are shown.

KEYWORDS:
Vibration Attenuation, Overturn Prevention, Vibration Control, Base Isolation, Seismic Safety

1. INTRODUCTION

An improvement of seismic safety for architectural and civil structure has been more important from the experience of huge earthquake in urban area in recent years. Furthermore, the seismic safety of lightweight structure such as a computer server rack, a work of art, a vending machine and so on has been regarded as important, too. Especially, an overturn prevention of vending machine which is set a lot in urban area is in particular urgent business at the view point of the city disaster prevention because it is caused for the collateral damage that becomes obstruction of traffic of emergency vehicle. Although a various device for seismic safety of lightweight structure including a vibration attenuation device for vending machine has been developed in Japan, it is classified roughly for a base isolation type, a vibration control type and overturn prevention type.
A base isolation device such as a laminated rubber bearing and sliding bearing is set in between an object structure and a ground, and reduces a seismic force by giving a long periodic behavior like a skyscraper which means to avoid the natural frequency against the characteristic of input wave. Generally, a seismic force in the structure applied a base isolation reduces from 1/3 to 1/10 in comparison with the non base isolated structure. However, it is necessary to consider displacement of device enough, and in addition, a base isolation system become a high cost compared with a vibration control system and overturn prevention system. A vibration control type sets an energy absorber to an object structure, and dissipates seismic energy into an object structure. A various vibration control type such as a high damping rubber, friction, oil and so on has been developed. The structure of system is simplified in comparison with a base isolation system, but a vibration reduction effect is inferior compared with a base isolation system generally though the it is depend on dynamic characteristic of the structure. An overturn prevention system is the simplest, and cost of system is lowest compared with another system. However, there are not the function of vibration reduction and energy absorption generally. The characteristic about each system is summarized in Table 1.
In this study, the vibration attenuation system for lightweight structure which can expect the low-cost and effective vibration reduction has been examined. Here, it is examined that the vibration attenuation system is to be a simple as much as possible. The examination of design specification had already been conducted in two steps. First step of response analysis is for examination of design specification to satisfy the performance demands. In this step, the various functions for vibration attenuation were included to analytical model. Next step, the simple base isolation system to satisfy the design demands were investigated to omit the unnecessary

elements for a simple construction having a effective performance based on the response analysis in before step. This paper describes the analytical and experimental results of new overturn prevention device which has a function of energy absorption. As a performance of device, the device is operated as a overturn prevention system with energy dissipation in small and middle level earthquake, and the system has function of energy dissipation and sliding in large level earthquake.

Table 1 Function characteristic in base isolation, vibration control and overturn prevention system

	Base isolation	Vibration Control	Overturn Prevention
Structural simplicity	△	○	◎
Effect of vibration attenuation	◎	○	×
Cost performance	△	○	◎

2. PRELIMINARY ANALYSIS FOR SIMPLE VIBRATION ATTENUATION SYSTEM

2.1 Analytical model to examine design specification

Figure 1 shows the analytical model to examine the performance of simple vibration attenuation system based on the before analytical step. The function of the proposed system has a friction sliding in base plate, rotational behavior, spring element, and damping element. This model was adopted a rotational mode from three axial directions to be simple.

The performance index is to be dynamic rotational behavior without sliding in small and middle level seismic input, and then, to be dynamic rotational behavior with sliding in large level seismic input. This model became a simple structure.

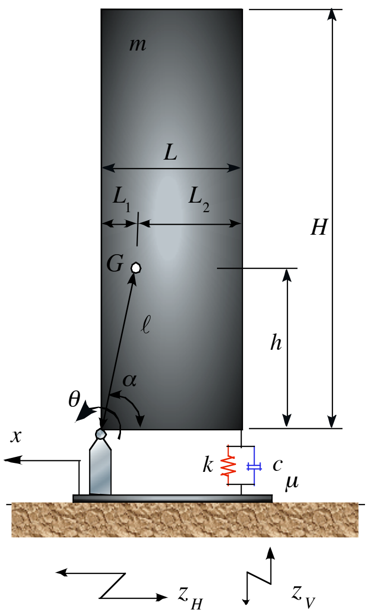


Fig.1 Analytical model used for response analysis to confirm the performance of proposed system

2.2 Analytical method

Equation of motion is expressed in two types as same as before step analytical model. Nomenclature in equation of motion is as follows.

x:Horizontal relative displacement of sliding base for ground
θ:Rotation around support point
g:Center of gravity
z_H:Horizontal ground motion

z_V :Vertical ground motion
μ:Friction coefficient
k:Spring element
c:Damping element

Table 2 Numerical model for seismic response analysis

Hight: H	1.8 [m]
Hight to a center of gravity: h	1.0 [m]
Width: L	0.6 [m]
Horizontal distance of front support point and center of gravity: L_1	0.28 [m]
Horizontal distance of rear support point and center of gravity: L_2	0.32[m]
Distance of front support point and center of gravity: ℓ	$\sqrt{h^2+L_1{}^2}$
Angle of front support point and center of gravity: α	$\alpha = sin^{-1}(h/\ell)$
Mass	600 [kg]
Rotational natural frequency	1~5 [Hz]
Vertical damping ratio	0.1~1.0
Friction coefficient	0.1~0.5

Equation of motion in Phase 1 is obtained from next equations.

$$\dot{x}_b = 0, \quad x_b = const.$$

$$J\ddot{\theta} + kL^2\theta\cos\theta + cL^2\theta\cos\theta + m\ell(g+\ddot{z}_V)\cos(\alpha+\theta) - m\ell\ddot{z}_H sin(\alpha+\theta) = 0 \tag{1}$$

Equation of motion in Phase 2 is expressed as follows. Here, dynamic friction and static friction coefficient are handled as an equal.

$$J\ddot{\theta} + kL^2\theta\cos\theta + cL^2\theta\cos\theta + m\ell(g+\ddot{z}_V)\cos(\alpha+\theta) - m\ell(\ddot{z}_H+\ddot{x}) sin(\alpha+\theta) = 0 \tag{2}$$

$$m\ddot{x} + sgn(\dot{x})\mu m(g+\ddot{z}_V) + m\ell\ddot{\theta} sin(\alpha+\theta) = -m\ddot{z}_H \tag{3}$$

The switching condition with or without friction is obtained from following relations. The system changes from Phase1 to Phase2 in which the next condition is satisfied.

$$\left|\ddot{z}_H + \ell\ddot{\theta} sin(\alpha+\theta)\right| > \mu(g+\ddot{z}_V) \tag{4}$$

The system changes from Phase2 to Phase1 in which the next condition is satisfied.

$$\dot{x}_b = 0 \text{ and } \left|\ddot{x} + \ddot{z}_H + \ell\ddot{\theta} sin(\alpha+\theta)\right| > \mu(g+\ddot{z}_V) \tag{5}$$

JMA Kobe, El Centro, JMA Ojiya, Hachinohe and Akita were used for seismic response analysis to evaluate the proposed system as the same to before step.

2.3 Analytical result

Figure 2 shows the one of example of analytical results. The efficient performance was confirmed in the same specifications. In here, the analytical result using the model in cloth to be a practical use model was indicated. The parameters of analytical model is friction coefficient: 0.1, rotational natural frequency: 2Hz, damping ratio:

0.2. The input wave is JMA Kobe NS and UD. In these figure, each figure shows the next responses. In the left column, horizontal input wave and vertical input wave. In the middle column, horizontal acceleration, velocity and displacement, and then in right column, rotational acceleration, velocity, displacement and displacement in the vibration attenuation device which is shown in the rear support point. It is confirmed that the proposed system reduced the responses of structure to under 1/2 compared with maximum acceleration of horizontal input wave, though the function of the system are reduced to be a simple.

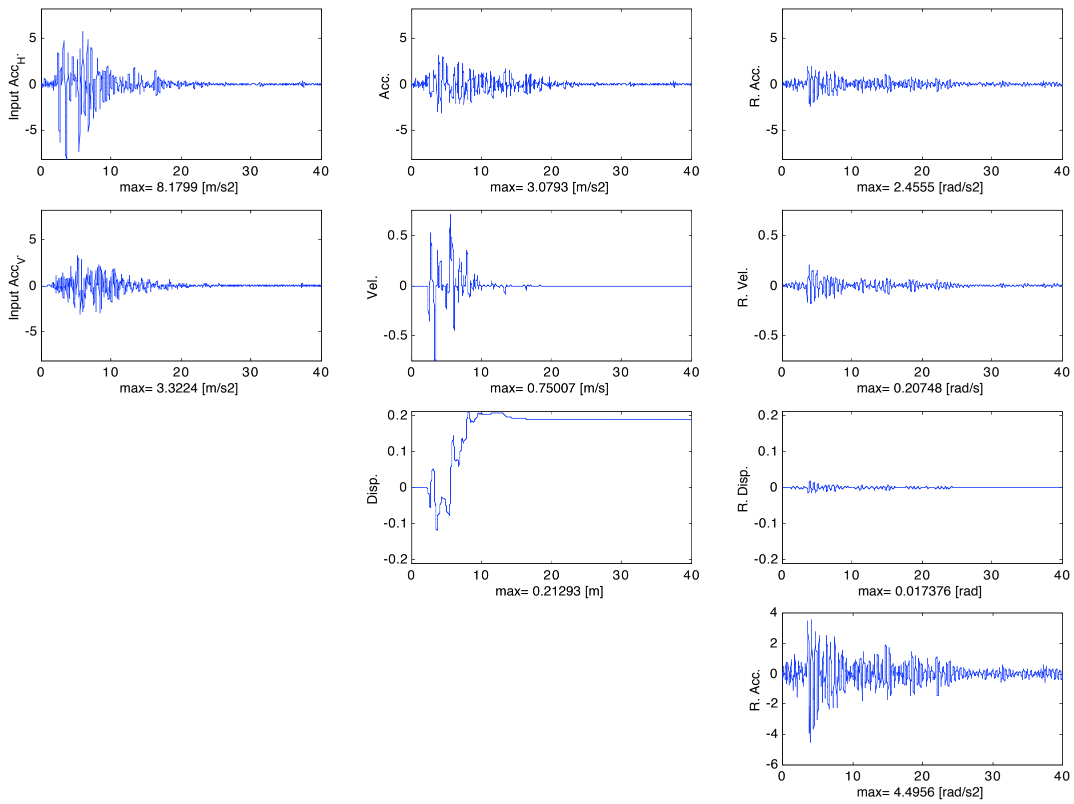


Fig.2 Example of response analysis

3. SHAKING TABLE TEST FOR EVALUATION OF BASIC PERFORMANCE

3.1 Device used for shaking table test

Figure 3 shows the device for overturn prevention of lightweight structure. The device is constructed from a rotation support leg in front side of object structure and a damper with coil spring in rear side. The device is operated as a overturn prevention system with energy dissipation in small and middle level earthquake, and the system has function of energy dissipation and sliding in large level earthquake. Figure 4 shows the damper with coil spring used for the test. The size of damper with coil spring is 55mm diameter and 71 mm height. The flange is set in the upper and lower side of damper, and has two shafts prevent from shear deformation. Figure 5 shows the displacement dependency on stiffness. It is confirmed that the stiffness of damper has displacement dependency and frequency dependency because the viscoelastic material was used as a damping material. However, the nonlinearity of stiffness in the shaking table test is not severe problem because the nonlinearity is not so much strong in the region of practical use of the device. Figure 6 shows the frequency dependency on damping ratio. The figure were summarized by using the test results in 5 mm amplitude. As the result, the damping ratio in small displacement is 0.1 in case that the natural frequency is 2 Hz. The damper is used 2 pieces in the device. Therefore, it is assumed to be about 0.2 in actual device. This damping ratio is similar to the parameter in the preliminary analysis.

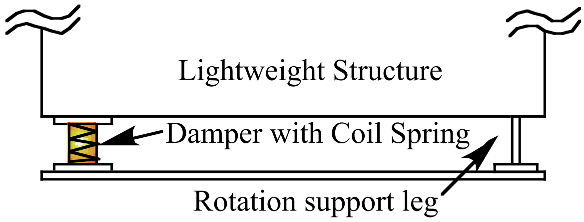


Fig.3 Overturn prevention device for lightweight structure

Fig.4 Damper with coil spring used for the test

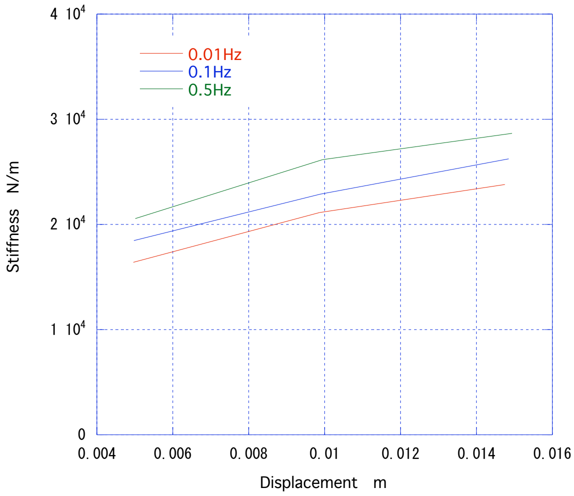


Fig.5 Displacement dependency on stiffness

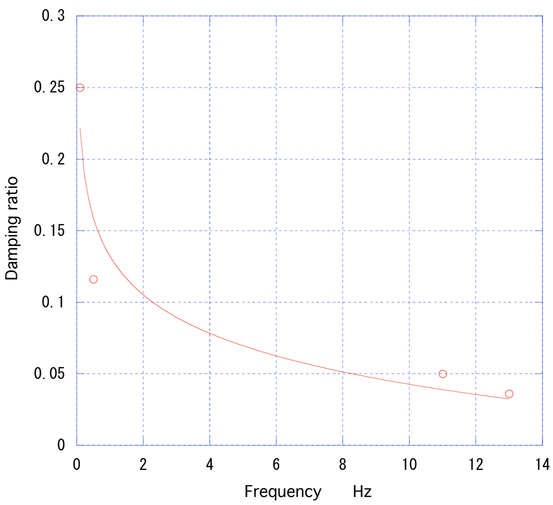


Fig.6 Frequency dependency on damping ratio

3.2 Evaluation of basic performance in shaking table test

The contents of shaking table is shown in Table 3. In the shaking table test, two different seismic waves are used to confirm the basic performance of the device. Figure 7 shows the amplification ratio in sweep wave input which is 0.5Hz to 10Hz frequency band and 30 gal. It is confirmed that the natural frequency is 1.75 Hz against the design natural frequency 2.0Hz. Figure 8 shows the results on JMA Kobe wave induced with original wave level as an example of shaking table tests. It was confirmed that the object structure did not overturn by applying the proposed device against such huge earthquake, though the test object caused overturn without the device in this input level. Besides, the comparison with the maximum acceleration was almost the same, because the object structure including the device had the behavior with rocking motion. Moreover, it was confirmed that the damping ratio was about 11.5%.

Table 3 Contents of shaking table test

Input wave	Contents
Sweep wave	0.5-10Hz 30gal
JMA Kobe	NS(25kine)+UD(12.5kine)
	NS(25kine)+EW(25kine)+UD(12.5kine)
	NS(50kine)+UD(25kine)
	Original level
JMA Ojiya	NS(25kine)+EW(25kine)+UD(12.5kine)
	NS(50kine)+EW(50kine)+UD(20kine)
Free Vibration	

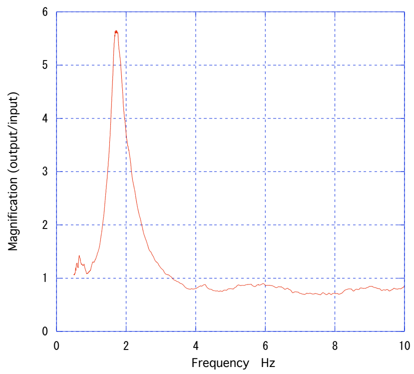


Fig.7 Amplification ratio in sweep wave input

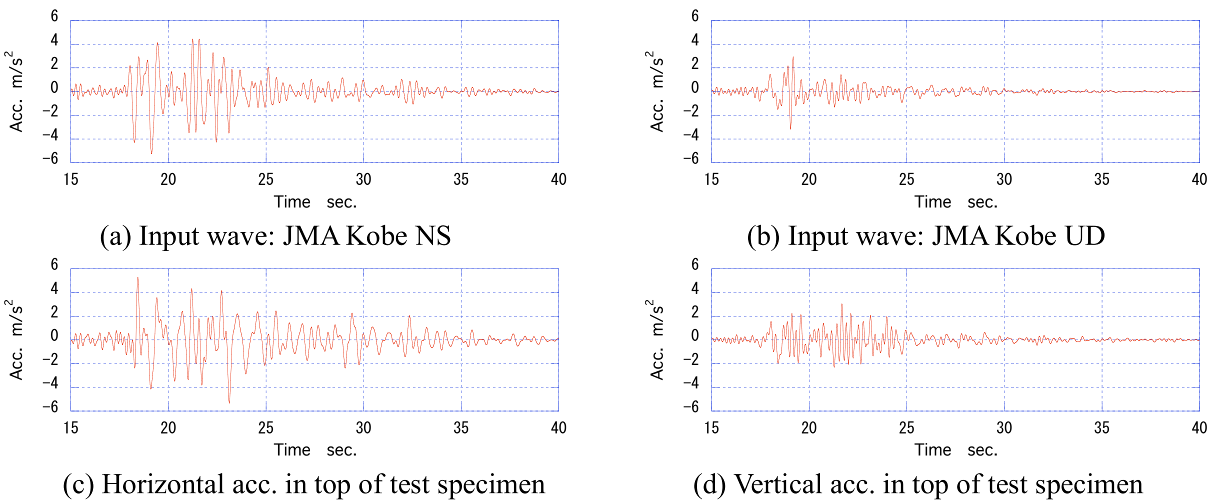
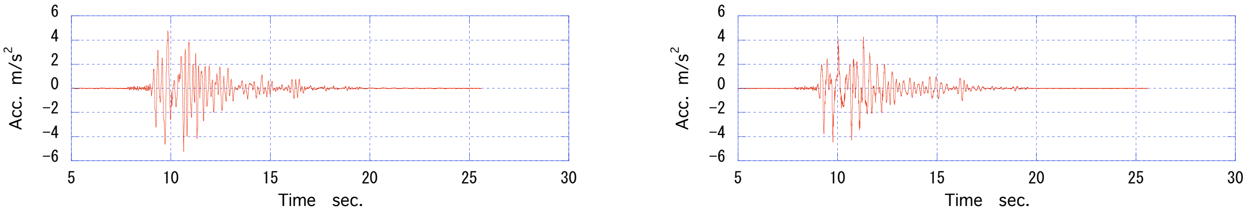


Fig.8 Example of test result in shaking table test

3.3 Comparison between experimental and analytical result

In here, the validity of analytical method and model is verified. Figure 9 shows the comparison with experimental and analytical result in case that the input wave is JMA Kobe NS 25kine and UD 12.5kine level. In the analysis, the natural frequency and damping ratio were set to the obtained values from the experimental results. Table 4 shows the comparison with maximum, minimum and RMS acceleration in each result. As the figures and table were shown, it was confirmed that the validity of analytical method and model was verified because the experimental result and analytical result are almost good agreements.



(a) Experimental result (b) Analytical result

Fig.9 Comparison between experimental and analytical result

Table 4 Comparison with maximum and RMS acceleration

	Max. acc.	Min. acc.	RMS
Experimental result	4.78	-4.46	0.706
Analytical result	4.28	-5.22	0.605

4. CONCLUSIONS

In this study, the vibration attenuation system which can expect the low-cost and effective vibration reduction for light-weight structure has been examined. This paper describes the analytical and experimental results of new overturn prevention device which has a function of energy absorption. From the preliminary analysis, the prefer design indexes were shown, and the test specimen was designed and manufactured. As a result, it was confirmed that the proposed system reduced the responses of structure into under 1/2 against without device in the preliminary analysis. Moreover the basic performance of proposed device was confirmed from the shaking table test. As a result, it was confirmed that the object lightweight structure did not overturn in case that the all of huge earthquake input used for the tests, though the rocking motion was caused in such input level. In near future, the upgrading of performance of proposed system will be conducted to be a stable behavior against huge earthquakes.

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