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# DEVELOPMENT OF COMPACT VIBRATION ISOLATION EQUIPMENT APPLICABLE TO EXISTING RESIDENCES—RESTORING MECHANISM UTILIZING ROLLER BEARINGS—

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## SUMMARY

A joint research project was carried out over a period of two years (2002~2003) to develop a practical device to alleviate human and property losses due to earthquakes. As a result of our efforts, we succeeded in creating a device (currently patent pending) made from readily available materials that can be easily installed without heavy construction equipment or special skills. The basic performance of the device has also been verified with seismic vibration testing.

## INTRODUCTION

In Japan, attention has focused on the inferiority of structures erected prior to revision of the building code in 1980 to withstand earthquake damage. Since the major earthquake disaster in south Hyogo prefecture, there has been a pressing need for a means to provide protection particularly for standard home dwellings. As one means of improving upon the ability of buildings to withstand seismic vibrations, vibration isolation technology has an established basic theory and scores of successful examples on large scale structures. As such, several home manufacturers and general contractors have indicated plans for using the vibration isolation system for new home construction. The effectiveness of vibration isolation to not only substantially enhance seismic performance but also maintain indoor safety is widely recognized, but the high cost considerations for use in small-scale, average family homes has been one obstruction to

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popularizing its widespread use.  As such, retrofit construction methods using vibration isolation technology have not been fully considered for the average residential home, so the current situation has not been conducive to promoting this technology as a viable choice for anti-earthquake strengthening of these structures.

The objective of our research was to develop an inexpensive, compact mechanism to enhance the seismic performance and livability of existing residential homes, and to propose methods for its fitting and installation. The continued lull in demand for new home construction in Japan has given rise to a desire to extend the life of existing homes which makes our research all the more important, pressing and necessary.  Herewith is a report on the results on the performance and effectiveness of the basic mechanism confirmed with accelerated seismic tests using large-scale / small scale shaking tables.

## DEVELOPMENT OF THE VIBRATION ISOLATION MECHANISM

### Basic development concept

The basic development concept of our research is as follows:

a. Give consideration to portability, keeping in mind ease of installation in existing residential homes. This would require that the mechanism be both compact and light enough to be hand-carried.
b. Standard, readily available materials would be used to hold down the cost.
c. Simple construction to reduce the risk of breakdown and simplify maintenance.
d. To meet the varied needs of residential dwellings, separate the different assemblies for isolation, restoration, and energy absorption, thus simplifying the design for each structure.

### Fabrication of a prototype

A prototype was fabricated based on this basic concept. An external view is shown in Photo 1. The overall characteristics are as follows:

a. Moves in a horizontal direction.
b. Though the movable range is +/- 200 mm, the table size is small at 300mm x 300mm.
c. Thickness is less than 80mm and the weight is lightweight around 30kgf.
d. Designed to withstand a load of over 5 tons.
e. Several cylinder-shaped rollers are employed to provide stable isolation performance in residential homes of different weight bearing loads.
f. Safety measures are included to counter upward/downward movement.
g. Expansion of the spring is designed to be non-linear, which reduces the fixed cyclic reliance of the spring providing speedy restoration.

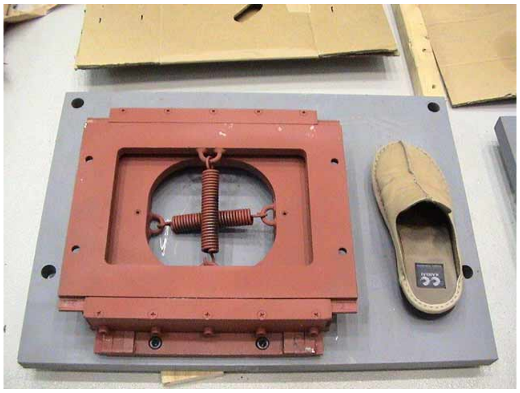
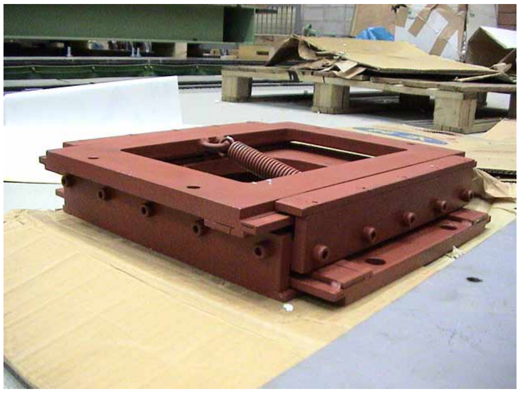



Photo 1. External View of Prototype

## PERFORMANCE OF THE PROTOTYPE VIBRATIONISORATION DEVICE

### Accelerated vibration tests with Large-scale shaking table

*Outline of test*

Tests to determine the basic performance of the prototype vibration isolation device were carried out using a large-scale Shaking Table with a 4m x 4m size table capable of applying simultaneous accelerated vibration in a single horizontal direction and vertically with up to a 20 ton load. First, an 8-ton, wooden frame residential test structure made from actual size materials was mounted on the shaking table (photos 2 & 3). Harmonic excitation and, accelerated vibration in an N-S direction like that of the Imperial Valley Earthquake was applied and the seismic response characteristics were measured without using the prototype vibration isolation device in place. At this stage, applying vibration with a large acceleration rate was avoided to prevent changes to the seismic response characteristics of the test structure. Next, the vibration isolation devices were inserted at the four corners of the test structure between it and the shaking table to better understand problems encountered during installation of the device(photo 4). Here, for comparison with the aforementioned prototype device, testing was also done with vibration isolation assemblies that utilize oil to reduce the input of seismic vibration to the roof area (photo 5). Seismic response characteristics were measured for both sets of devices using accelerated vibration based on input data from the Imperial Valley Earthquake (N-S direction), data from the Hyogo-ken Nambu Earthquake (Kobe Ocean Meteorological Tower; E-W and Up-Down directions; acceleration reduction to a maximum of 80%).

Photo 2. NW side of Test Structure

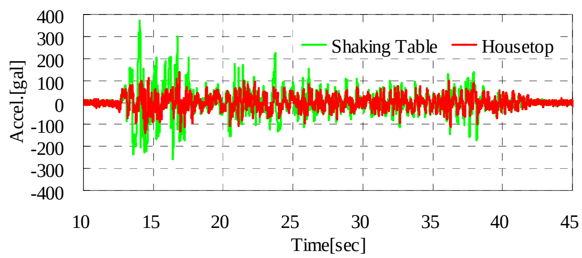
Photo 3. SE side of Test Structure

Photo 4. View of Prototype Device Installed

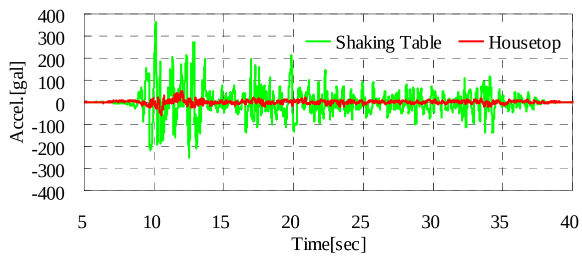
Photo 5. Oil-Type Vibration Isolation Device

*Results of horizontally applied seismic vibration*

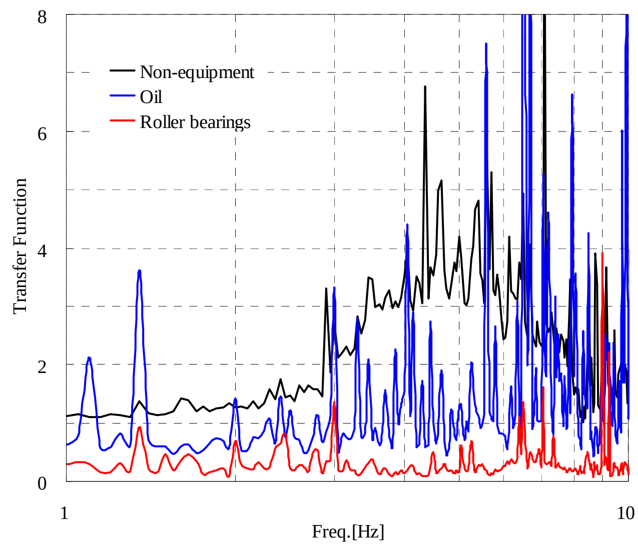
The results of the time response acceleration measured at the roof of the test structure that used an oil assembly type vibration isolation device, and the top of the Shaking Table is shown in Fig. 1, graph (a). The same measurements were also taken with the prototype device installed and these results are shown in Fig. 1, graph (b). Note that the results shown here are for tests done with data based on the Imperial Valley Earthquake (N-S direction). In this test, the maximum response acceleration using the oil assembly type vibration isolation device was reduced to 34% of the input acceleration whereas when the prototype device was used the reduction was to 14% of the input acceleration. Transference characteristics are compared in Fig. 1, graph (c). This graph also shows the transference characteristics when no vibration isolation device is used. In the shown range of 1Hz to 10Hz, vibration isolation of the input acceleration is greatest with the prototype device, which indicates its higher level of performance.




(a) Current Product (Oil type)




(b) Prototype (Roller type)




(c) Comparison of Transference Characteristics

Fig. 1 Performance Comparison of Prototype and Current Oil type Product

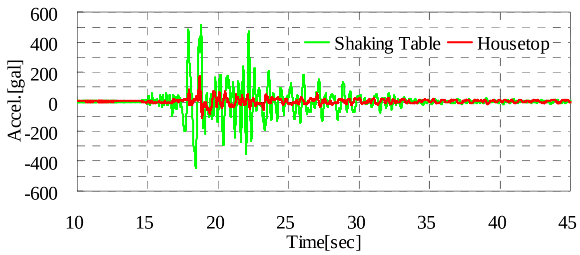
[Seismic wave: IMPERIAL VALLEY EARTHQUAKE (N-S)]

*Results of simultaneous horizontally & vertically applied seismic vibration*

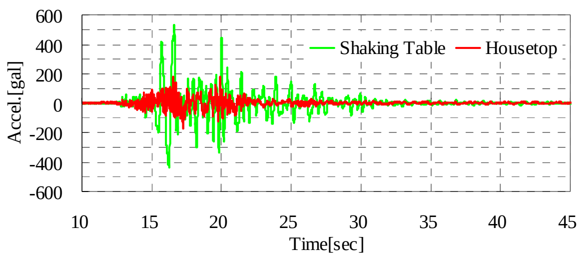
Next, data from the Hyogo-ken Nambu Earthquake (Kobe Ocean Meteorological Tower; E-W direction only; acceleration reduction to a maximum of 80%) was input for the Shaking Table and the and the results of the time response acceleration measured at the roof of the test structure equipped with the prototype vibration isolation device, and the top of the Shaking Table is shown in Fig. 2, graph (a).

The same measurements were also taken using simultaneous horizontally (E-W direction) & vertically applied seismic vibration and these results are shown in Fig. 2, graph (b). Note that the results shown here are for the horizontal application of seismic vibration only. Transference characteristics are compared in Fig. 2, graph (c). Erratic movement of the test structure in a relatively high frequency area is also apparent in Fig. 2, graph (c). This is contributed to excited out-of-plane vibrations of the test structure flooring.

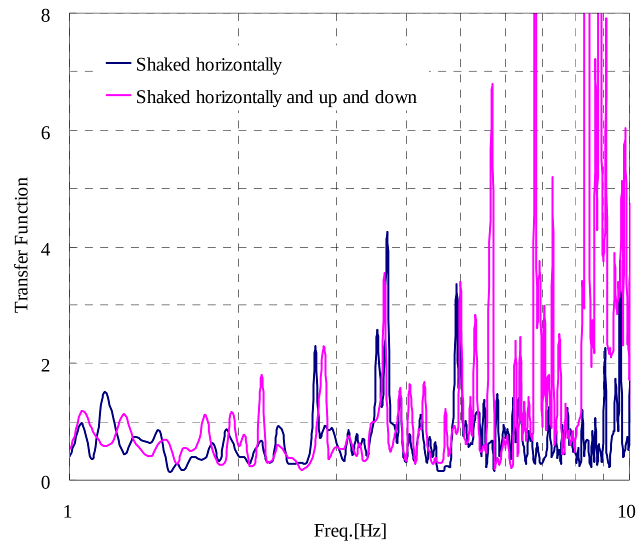
Both graphs (a) and (b) in Fig. 2 show that the maximum response acceleration was reduced to about 33% of the input acceleration. This means that although the prototype device doesn't provide any vibration isolation in an up-down direction, its vibration isolation in a horizontal direction is still effective even if there is simultaneous motion in an up-down direction.




(a) Simultaneous horizontally
vertically applied seismic vibration




(b) Simultaneous horizontally and
vertically applied seismic vibration




(c) Comparison of Transference Characteristics

Fig. 2 Performance Comparison of Applied Seismic Vibration
[Applied Seismic Wave: Hyogo-ken Nambu Earthquake (Kobe Ocean Meteorological Tower; E-W direction only; acceleration reduction to a maximum of 80%)]

**Diagonally Applied Seismic Vibration Tests with Small-scale Shaking Table**

*Outline of test*

Tests to verify the isolation performance of the prototype vibration isolation device with input from a diagonal direction were carried out using a small-scale Shaking Table equipped with a 1m x 1m size table capable of applying accelerated vibration in a single horizontal direction with up to a 500kgf load.

First, the prototype vibration isolation device is secured to the top of the Shaking Table so that the line from directly opposite corners of the prototype coincides with the direction of the applied seismic vibration. A weight of approximately 700kgf is placed on top of the prototype and seismic vibration is applied in a horizontal direction. Load and displacement measurements are taken. Next, the weight is replaced with a steel plate weighing approximately 75kgf and harmonic excitation is carried out. Photo 6. shows the setup for this test. Two prototype units are used for the 700kgf test and one unit is used for the 75kgf test.

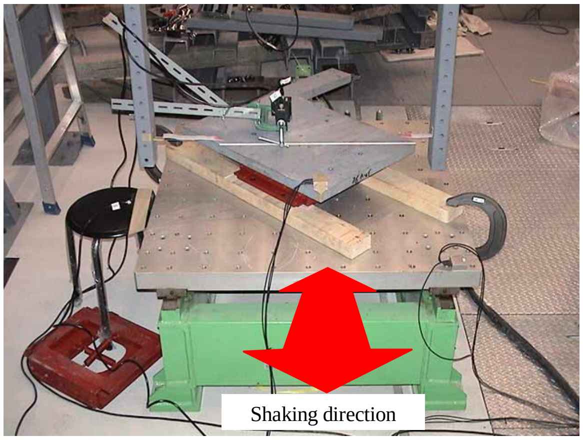



Photo 6. Setup for Diagonal Application of Seismic Vibration

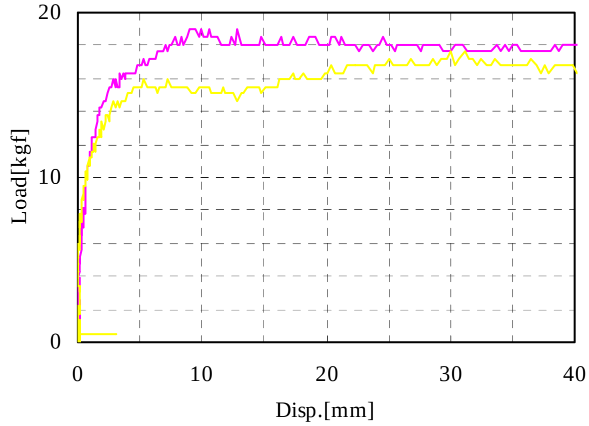



Fig. 3 Load/Displacement for the 700kgf Test (Using Two Prototype Units)

*. Results of Diagonally Applied Seismic Vibration Tests*

Fig. 3 shows the load/displacement test results using a 700kgf weight. From the results, the movement friction coefficient is calculated to be 0.0035. The graph in Fig. 4 shows the applied seismic vibration acceleration and the actual measurement for the response acceleration at the 75kgf test. The same graph also shows that the input acceleration is reduced to about 60 gal over all applied seismic vibration frequencies. Fig. 5 shows the applied seismic vibration displacement and the actual measurement for the response displacement at the 75kgf test. When compared to the degree of acceleration, the reduction rate tends to decline at lower frequencies, but the response displacement is less than half of the applied seismic vibration displacement and the response displacement when the frequency exceeds 1Hz does not reach 5mm though vertical load is only 75kgf.

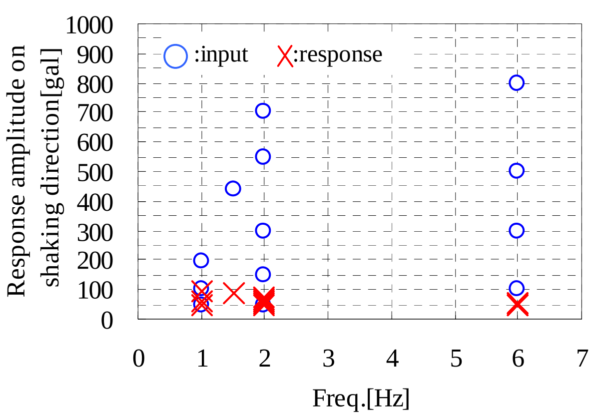



Fig. 4 Comparison of applied seismic vibration and response acceleration

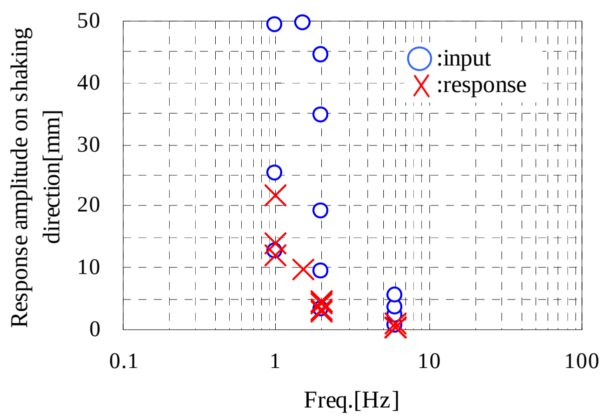



Fig. 5 Comparison of applied seismic acceleration displacement and response displacement

## EXPANDED USES FOR THE PROTOTYPE VIBRATION ISOLATION DEVICE

### Basic Tests Aimed at Expanding the Use of the Vibration Isolation Device

*Tests for Shelving*

The prototype vibration isolation device was developed primarily for retrofitting of existing residential structures but is easily adapted to new home construction as well. And since it is both light and compact, it can be easily adapted to other uses where protection by vibration isolation is desired such as floors, furniture, sensitive electronic equipment, telecommunication equipment, historical artifacts, etc. making it

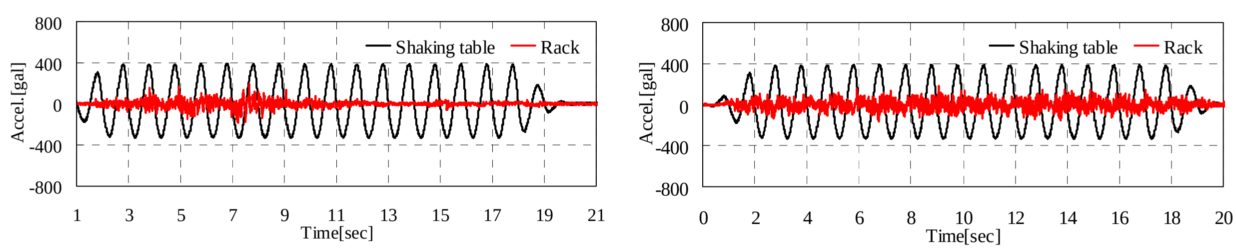
quite versatile.  Here, performance of the prototype when setup under shelving was verified using a large-scale Shaking Table.
Photo 7. shows the overall setup for the test and Photo 8. shows the prototype device installed underneath the shelving legs.  The shelving is made from steel and the total weight is approximately 300kgf.
Harmonic excitation is done in a single horizontal direction and seismic vibration based on the Hyogo-ken Nambu Earthquake (Kobe Ocean Meteorological Tower; N-S direction, Up-Down direction and acceleration reduction to a maximum of 100%) added.  The response acceleration of the shelving is measured at the foot of the shelving and the center of the $2^{nd}$ shelf from the top (referred hereinafter as $2^{nd}$ shelf center).  The condition of the PET bottles lined up on the shelves is also confirmed.

*Result of the Tests to the Shelving*

Fig. 6 shows an example of the response acceleration of harmonic excitation applied in a single horizontal direction.  No meaningful difference is noted in the response acceleration between the shelving feet and the $2^{nd}$ shelf center.  The absolute displacement between the Shaking Table and the shelving this time, and the relative displacement of the shelving to the Shaking Table calculated from that result is shown in Fig. 7.  Like the acceleration rate, the response amplitude is also greatly decreased
Not one of the PET bottles fell down.  Fig. 8 shows an example of the response acceleration for the shelving feet and the $2^{nd}$ shelf center when harmonic excitation based on the Hyogo-ken Nambu earthquake data is applied both horizontally and vertically.  A high number of vibrations were recorded at the $2^{nd}$ shelf center but these are considered to be due to vertical vibrations only.

Photo. 7 Overall View of Test

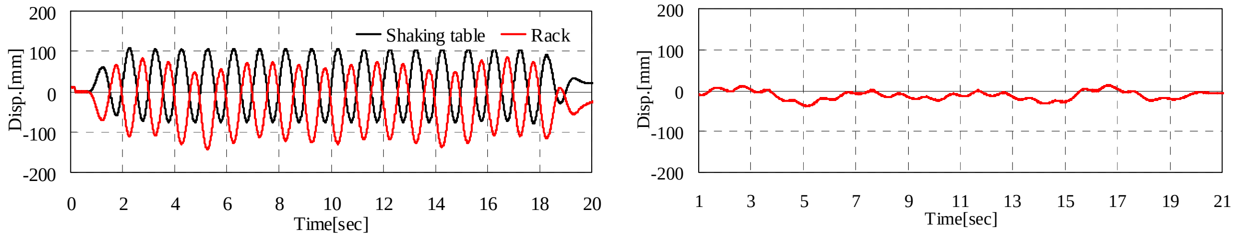
Photo. 8 View of Device Installed at Shelving Feet




(a)Response Acceleration of Shaking Table/Shelving Feet

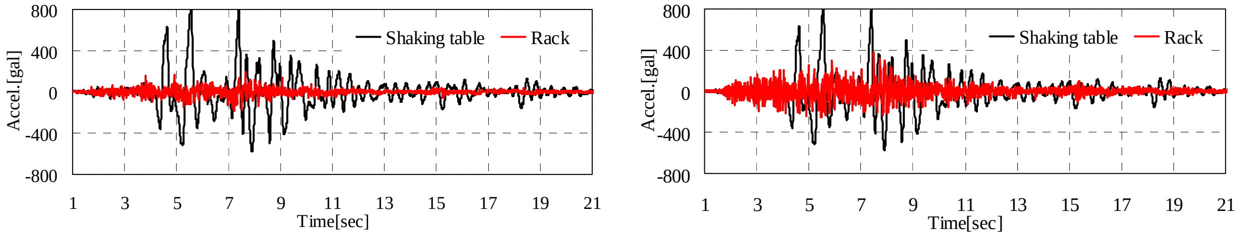
(b) Response Acceleration for Shaking Table/$2^{nd}$ Shelf Center

Fig. 6 Example of Response Acceleration for Single Direction Harmonic Excitation



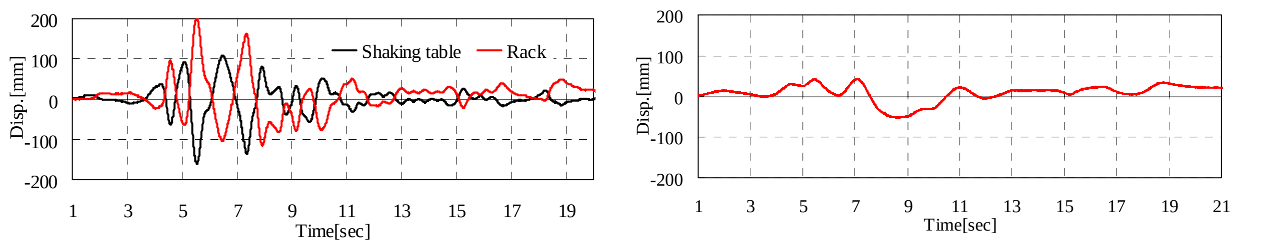

(a) Absolute Displacement of Shaking Table/Shelving (b) Relative Absolute Displacement of Shaking Table/Shelving

Fig. 7 Example of Response Displacement for Single Direction Harmonic Excitation




(a) Response Displacement for Shaking Table/Shelving (b) Response Displacement for Shaking Table/2nd Shelf Center

Fig. 8 Response Acceleration for Simultaneous Horizontal/Vertical Input
(Hyogo-ken Nambu earthquake)




(a)Absolute Displacement of Shaking Table/Shelving (b)Relative Displacement of Shaking Table/Shelving

Fig.9 Response Displacement for Simultaneous Horizontal/Vertical Input
(Hyogo-ken Nambu earthquake)

The absolute displacement between the Shaking Table and the shelving this time, and the relative displacement of the shelving to the Shaking Table calculated from that result is shown in Fig. 9. There are no damaging response amplitudes and not one of the PET bottles fell down.

## CONCLUSION

We developed an inexpensive vibration isolation device that is also both compact and lightweight for ease of installation. Shaking Tables and relative equipment were used to test and verify the performance of the device and lead us to conclude as follows:

(a)Even at low level harmonic excitation of 2Hz-10gal and 3.5Hz-10gal, the effectiveness of the device can be clearly confirmed with the naked eye, meaning there is very little reliance on the input level.
(b)Even when actual earthquake wave data is input, the acceleration rate is reduced as low as 14% of the input acceleration rate. In contrast, oil assembly (viscous) devices only reduced the acceleration rate to 34% of the input rate.
(c)Even with simultaneous horizontal and vertical seismic vibration applied, the device still displayed a reduction of the acceleration in the horizontal direction equivalent to that obtained when seismic vibration was applied in a horizontal direction only, proving the device safe and effective even with up-down movement.
(d)Even against forces inserted diagonally (45%) to the device, where there was the most concern, the passive friction coefficient was about 0.0035 and the isolation performance was very good. It is easy to surmise that the passive and active friction coefficients are even smaller when forces are applied from other angles.
(e)Since there is little reliance on the load weight, in addition to buildings, the device is applicable for other equipment and things that may need protection from seismic vibration.

Plans are being made for a presentation on the actual method of installation for existing residential structures. We also are planning improved developments for restoration assemblies and energy absorption assemblies

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