PROTECTION OF ART OBJECTS IN EARTHQUAKES WITH SEISMIC DEVICES

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ABSTRACT :

There are a lot of unsolved problems on fall down of visual objects during earthquake. Preserving visual objects and cultural properties in a good condition is very important to success our culture to the next generations. This paper discusses the effect of the measures to prevent the object from fall down during earthquakes. Three countermeasures were examined by the shaking table tests. The results showed that all the countermeasures excluded limited isolator case prevent the object from falling down. Though, each case showed characteristic behavior during earthquakes.

KEYWORDS: shaking table test, isolator, earthquake-proof adhesive mat, strings, cultural heritage

1. INTRODUCTION

Preserving the current and past cultural artifacts is important task for us, however, many invaluable treasures have been damaged or lost due to natural disasters. In 2004 Niigata-ken Chuetsu earthquake in Japan, many art objects and earthen wares fell down and broke, one of which was Japanese national treasure earthenware. Even the objects on seismic isolators fell down.

These cultural properties have much important information about our ancestral living, and it's necessary to preserve them in good condition when handing down the story of ancestor's spiritual activity from generation to generation. Once such objects are lost, the culture crystallized in them can never be reconstructed and they are lost forever. However, many problems are unsolved about falling down during earthquake.

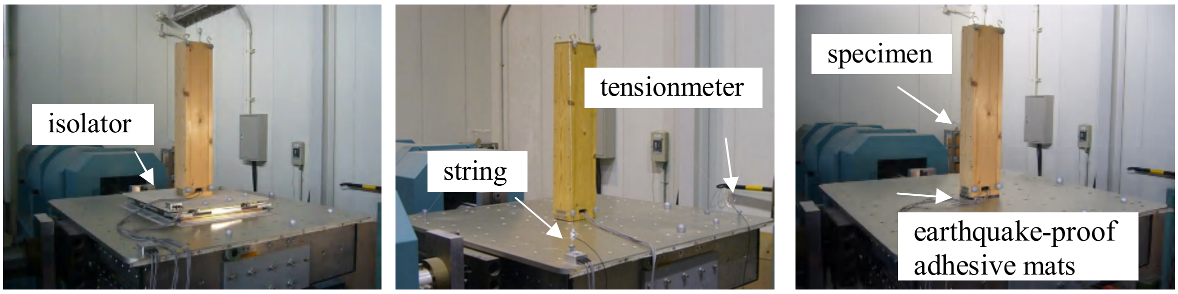
Seismic risk mitigation for art objects has been studied by many researchers (Agbabian 1988, Augusti 1992, Ohmachi 1995, Calio 2003, etc.), and most of them used isolation techniques. Recently, fall down mechanism of other objects than art objects such as furniture (Meguro 2007) or tomb stones (Sawada 1998) was studied using numerical simulations as well as experiments. As the fall down of important objects has become great interest in these days, new devices such as earthquake-proof adhesive mats have been developed.

This paper discusses the dynamic behavior of a visual object during an earthquake with and without devices to provide against earthquakes, and verifies the effects of these measures.

2. SHAKING TABLE TESTS

Three countermeasures were used in this study; they were a seismic isolator, binding strings and earthquake-proof adhesive mats (Figure 1).

A box-type wood specimen of 9×13×62 cm and 2.03 kg was used, which was designed to fall down at a lateral equivalent force within 0.2 G.



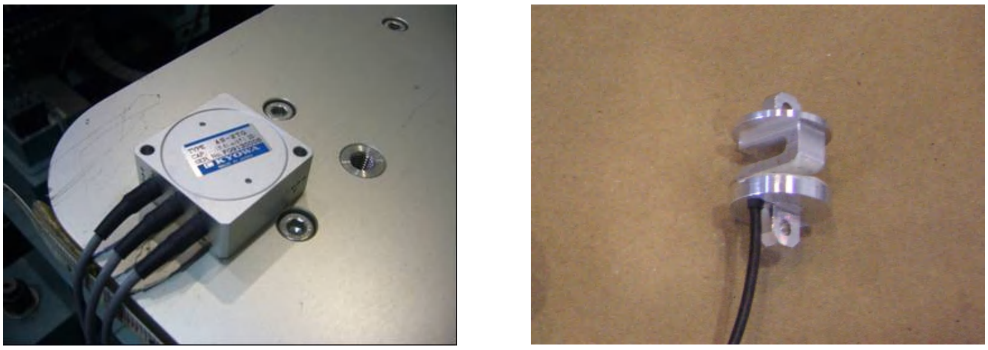
(a) Seismic isolator (b) Binding strings (c) Earthquake-proof adhesive mats

Figure 1 Photographs of the measures

A three-dimensional shaking table was used to simulate an earthquake motion. The table size was 100×100 cm, and the maximum horizontal acceleration was about 1 G. The directions are defined in this paper as shown in Figure 2a.

A sliding-type seismic isolator was used, the table of which was 44×44 cm (Figure 1a). This isolation system consisted from the curved rails and the smooth wheels, which elongated the natural period of the object and enabled self-returning to the original position by the gravity. This system was effective only in the horizontal directions. This type of isolator is widely used in Japanese museums.

(a) Shaking table (b) Earthquake-proof adhesive mats



(c) Accelerometer (d) Tensionmeter

Figure 2 Experimental equipments

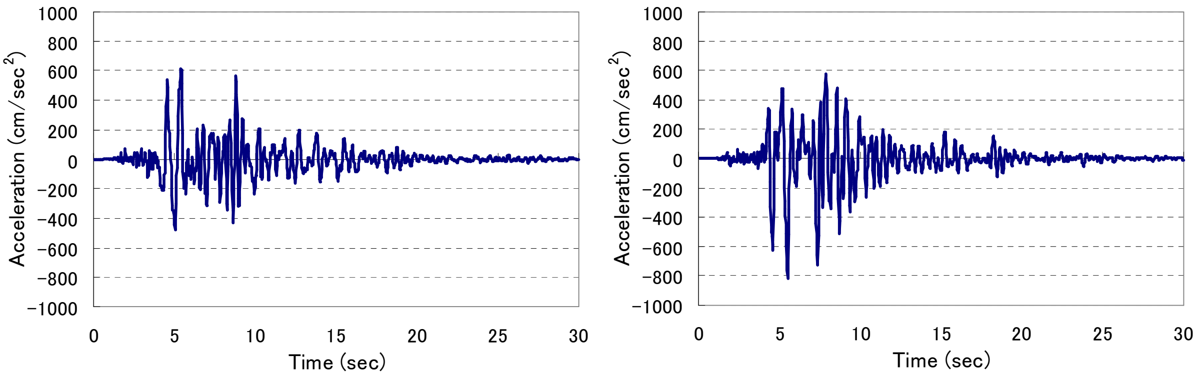
Two types of earthquake-proof adhesive mats were used in this study; one was made of urethane elastomer and the other was made of silicon. An urethane elastmer mat (Figure 2b left) had a dimension of 50×50×5 mm and a silicon type (Figure 2b right) was 50×50×3 mm. Four pieces were attached to the bottom of the specimen. As the mats connect strongly between the object and the table with its natural adhesive force, no glue is needed to attach them, and can be removed by adding the twisting torque to them.

Accelerometers were set to measure the accelerations on the specimen, the isolator and the shaking table (Figure 2c). Two accelerometers were set in the specimen at its top and bottom.

For the cases with biding strings, tensionmeters were also set to the binding strings (Figure 2d), which could measure the tension force within 80 N.

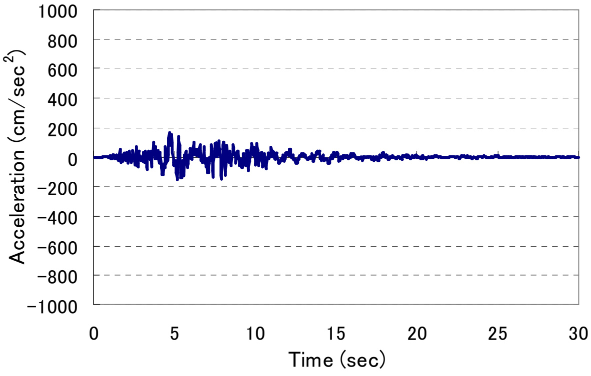
Motion capture system consisting from two cameras and several target points was used to measure the displacement responses. It was one of the non-contact measuring methods suitable for the shaking table tests. Taking videos synchronously by two cameras enabled to determine the dynamic 3-D displacements.

1995 JMA-Kobe earthquake record was used as input earthquake ground motion as shown in Figure 3. The input directions for each component wave were as follows. EW wave was input in X-direction, NS wave was input in Y-direction and UD wave was input in Z-direction. Vertical amplitude motion of input earthquake ground motion was limited for 50% due to the limitation of the shaking table system.



(a) EW wave

(b) NS wave



(c) UD wave (50% of the original wave)

Figure 3 Input earthquake ground motion

3. RESULTS AND DISCUSSIONS

3.1. Specimen without any devices

The specimen showed rocking a few times after 3.3 to 4.8 seconds, and the specimen fell down at 5.0 seconds. The horizontal displacements of the top of the specimen and the shaking table are shown in Figure 3. Quick movement of the specimen showed rather linear response orbit of the specimen.

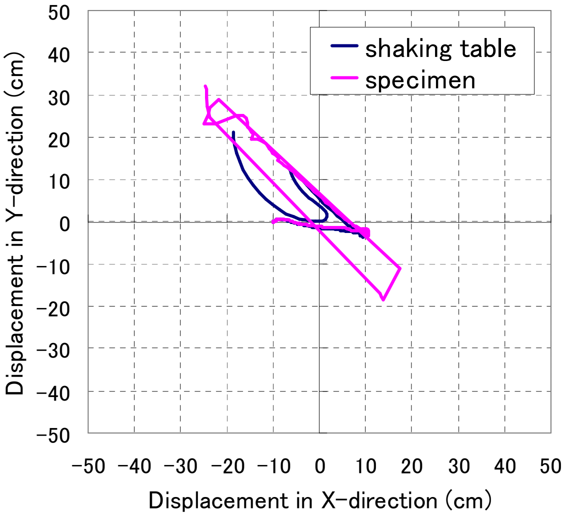
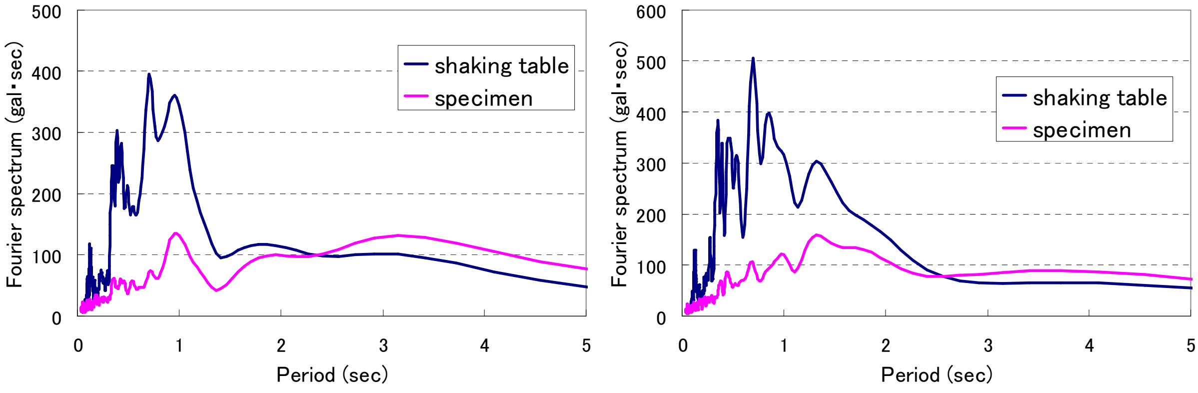


Figure 3 Horizontal displacements orbit of shaking table and specimen

3.2. Seismic isolator

3.2.1 Ordinary case

The specimen showed small rocking vibrations for many times, but it did not fall down until the end. Figure 4 shows Fourier spectra of the shaking table and the specimen. Two horizontal dominant periods of the shaking table were about 0.68 seconds, and those of the specimen were more than 1 second. This result shows the high frequency contents were effectively reduced by the isolator. Table 1 shows that the maximum acceleration in X-direction was reduced more than 70%, and that in Y-direction was also reduced more than 80%. On the other hand, the maximum vertical acceleration of the specimen was a little bit lager than the shaking table, but this value didn't affect for falling down phenomena of the specimen.



(a) X-direction (b) Y-direction

Figure 4 Fourier spectra of the shaking table and the specimen

Figure 5 shows the horizontal relative displacement between the bottom of the specimen and the isolator. The specimen moved on the isolator only 5mm at most during excitations.

Table 1 The maximum acceleration for isolator case

Measured point	X-direction	Y-direction	Z-direction
Shaking table	597	949	125
Isolator	235	239	952
Specimen's bottom	174	167	280

(unit: cm/sec^2)

3.2.2 Limitation to isolator movement

In 2004 Niigata-ken Chuetsu earthquake, the isolator at the museum reached its displacement limit during the earthquake, which caused the earthenware on it to fall down. Then, the effect of the displacement limit on the isolator movement was studied in this article.

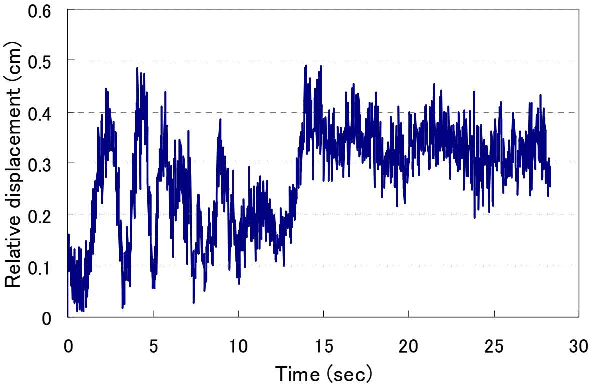


Figure 5 Horizontal relative displacement between specimen's bottom and isolator

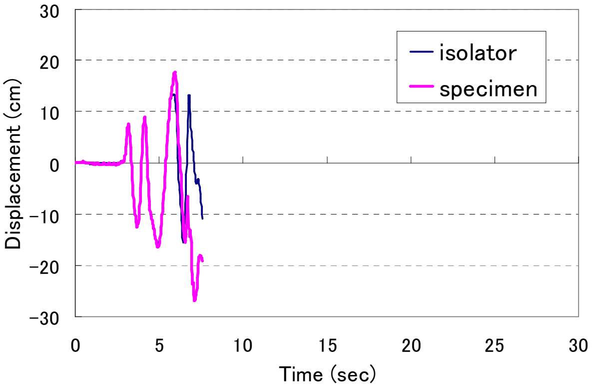


Figure 6 Displacement histories

Four displacement limitation devices were put on the shaking table to limit the movement of the isolator within 15 cm for each horizontal direction. This limit displacement of 15 cm was determined from the results without limitations, witch showed the maximum displacement of 19 cm.

The specimen began rocking after 4.8 seconds and the isolator collided to the limitation devices. Then, the specimen fell down at 6.8 seconds as shown in Figure 6. As the maximum displacement response differs for every earthquake, effective buffers or additional devices are needed to avoid the specimen from fall down.

3.3. Strings

The specimen didn't fall down during excitation. Two tensionmeters were used in this case, and Figure 7 shows the tension stress-time histories in the strings. Two strings were used to constrain the specimen diagonally, and two tensionmeters 1 and 2 were attached to different strings. Both tensionmeter showed similar stress histories.

Figure 8 shows the relative displacement between the specimen's bottom and the shaking table. As the shape of the specimen was box, the radius of gyration became longer than the initial state when the specimen vibrated and tilted on its vertex. This would increase the string tension easily. Though the maximum stress shown in Table 2 is smaller than the ultimate stress of 383 MPa for the strings, larger acceleration or larger mass will cut the strings. The specimen's top didn't move widely by constraint of the strings. On the contrary, the specimen's bottom slid by vibration, and the specimen rotated as shown in Figure 9. More friction was needed to stabilize the specimen.

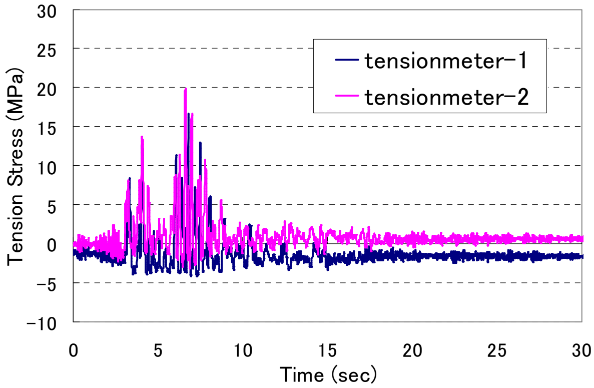


Figure 7 Tension stress in binding strings

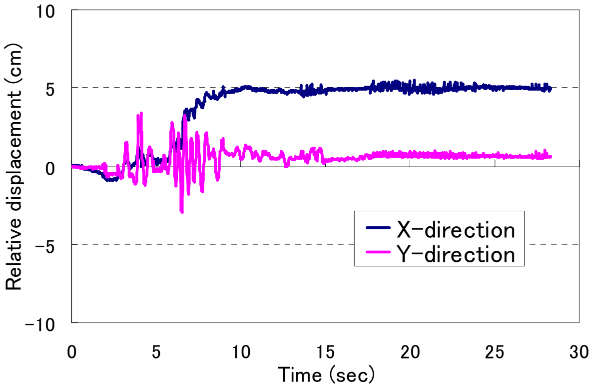


Figure 8 Relative displacement between specimen's bottom and shaking table

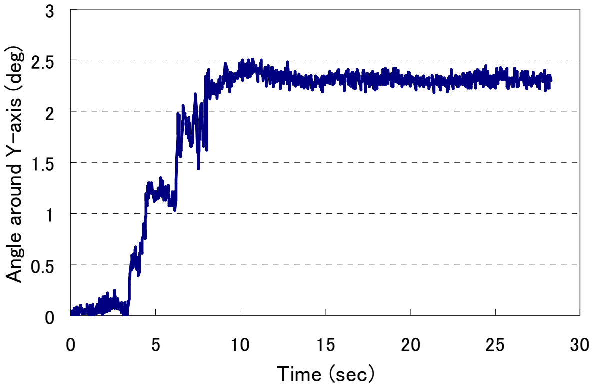


Figure 9 Rotational angle-time histories

Table 2 Stress in the strings

	1	2
Initial stress	-1.03	0.17
Maximum stress	16.54	19.02

(unit: MPa)

3.4. Earthquake-proof adhesive mats

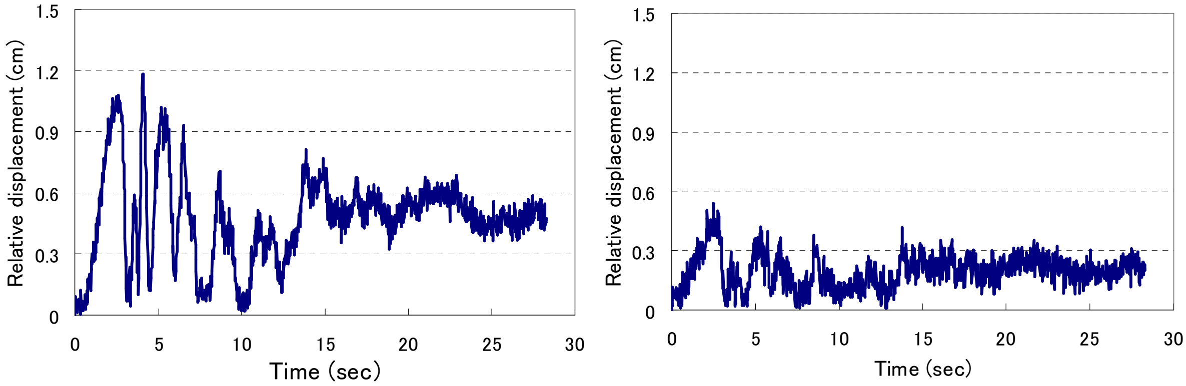
The specimen didn't fall down nor slide during excitation. Table 3 shows the maximum accelerations of the specimens with the earthquake-proof adhesive mats. They were larger than those of the shaking table. The relative displacement of the specimen and the shaking table was smaller than that of the binding string. The specimen vibrated in sway and rocking motion, witch increased the acceleration response of the specimen. The sway vibration was excited due to shear deformation of the mats.

Table 3 Maximum accelerations of specimen with mats

	X-direction	Y-direction	Z-direction
Shaking table	597	949	125
Urethane elastomer	684	1307	161
Silicon	923	948	544

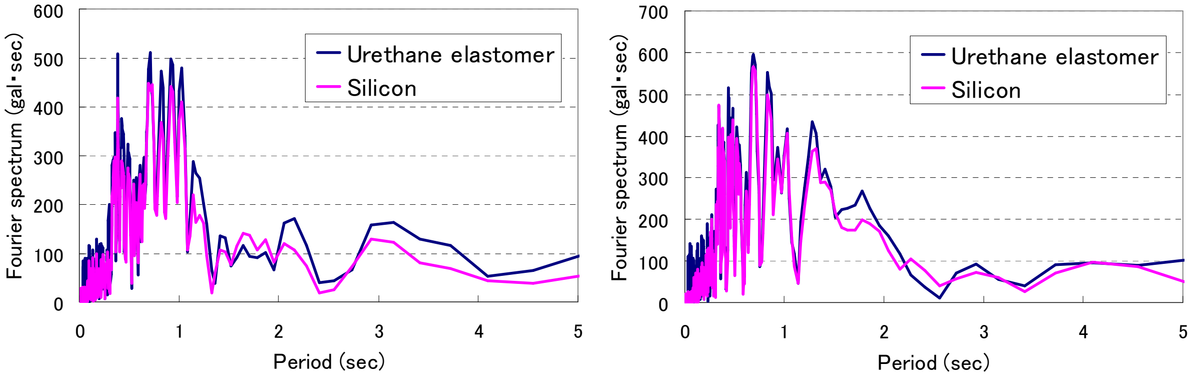
(unit: cm/sec^2)

The relative displacement occurred in both cases (Figure 10), but both mats had enough effect to prevent fall down of the specimen. As the resolution of the motion capture system is about 0.5cm, the residual displacement in Figure 10 thought to be errors of the non-contact measuring system. The maximum vertical acceleration in the case of silicon mats was larger than that of urethane elastomer mats, however, the horizontal acceleration was vise versa.



(a) Urethane elastomer mat (b) Silicon mat

Figure 10 Horizontal relative displacements between specimen and shaking table



(a) X-direction (b) Y-direction

Figure 11 Fourier spectra of specimens with earthquake-proof adhesive mats

The dominant periods of the specimen with both types of earthquake-proof adhesive mats were similar to each other as shown in Figure 11, but the spectra of the specimen with silicon mats was smaller than that with urethane elastomer mats because of higher damping .

The performance of the mats depends on the adhesive conditions. The earthquake-proof adhesive mats showed good adhesive performance between stainless steel table and the box-type wooden specimen in this study, however, the adhesive performance must be checked for other shapes and material of the specimen. The risk of the break due to high acceleration has also to be checked.

It's effective to use more than one measure together to reduce the risk of fall down. For example, binding strings and earthquake-proof adhesive mats reduce the accelerations at both top and bottom of the specimen.

4.CONCLUSIONS

This paper discussed the measures to prevent fall down of the objects during earthquakes using shaking table tests.

1) Without any measures, the specimen showed rocking a few times after 3.3 to 4.8 seconds, and fell down at 5.0 seconds.

2) The isolator protected the specimen from fall down, if the isolator could move perfectly. On the other hand, if the isolator reached its displacement limit or collided with some obstacles, the specimen fell down easily.

3) The specimen with the binding strings didn't fall down, but the rotation around the vertical axis was observed especially at the bottom of the specimen.

4) The specimen didn't fall down with the earthquake-proof adhesive mats; silicon mat reduced the horizontal acceleration more than urethane elastomer mats because of higher damping.

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