A DEPLOYABLE DISPLAY STAND FOR ART OBJECTS VIABLE IN SEVERE EARTHQUAKE SHAKING

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Paper No. 325. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

ABSTRACT

To mitigate earthquake damage to art objects and artifacts, a new type of display stand has been developed and its efficiency has been tested by vibration-table experiments and numerical simulations. The stand is a kind of deployable (adaptive) structures, made up of an earthquake sensor, a deployable guard-frame and a display table under which the frame is invisibly folded in normal use. When the sensor detects shaking stronger than 55 gals in acceleration, the frame is unfolded to catch hold of the object in 0.2 sec so as to prevent overturning. The performance tests has proved that the stand is efficient even for severe shaking with a peak acceleration as much as 2g.

KEYWORDS

Art objects; display stand; deployable structure; severe shaking; performance tests; earthquake sensor.

INTRODUCTION

Present efforts to mitigate earthquake damage to art objects and artifacts are insufficient in Japan as well as, probably, in other earthquake-prone countries. Most of these objects are fragile, and easily overturned when subject to strong shaking. Meanwhile, conventional measures such as application of restraining strings and base-isolation (Agbabian et al, 1988) may be effective for small to medium shaking, but presumably not so effective for severe shaking. In fact, many art objects and artifacts including glasswork, china and porcelain have often been inflicted various earthquake damage from slight scratch to total collapse.

To protect art objects and artifacts from earthquakes, new types of earthquake-proof display stands are necessary to be developed. Requirements for the display stands are;

1. In normal use when earthquakes are not felt, they should not obstruct appreciation of the objects concerned.
2. During earthquakes, they should protect the object without any damage due to severe shaking.
3. Recovery from the earthquake mode to the normal mode should be easily operated even by a layman.

From this point of view, new display stands have been developed and demonstrated its efficiency by means of vibration-table experiments and numerical simulations. To satisfy the requirements, the concept of deployable (adaptive) structures (Wada, 1990) was applied in the development, with a main target for fragile objects such as glass vases and ceramic potteries of medium size.

DEPLOYABLE STANDS

Two types of deployable stands have been developed on an experimental basis. One is to deploy a sponge rubber net around an object, and the other is to deploy a guard–frame. Hereafter, the former is called a deployable net type, and the latter a deployable frame type.

Deployable Net Type

This stand is 30 cm square and 4 cm thick. The surface of the stand is covered with a 3mm–thick sponge rubber mat which is split so as to form a net when lifted at all sides. In the normal mode, an aluminum ring connected with three struts are folded under the mat. The normal mode is maintained by a mechanical lock until the lock becomes released by uplift of the art object. The release of the lock leads to the earthquake mode in which the struts and ring system is rapidly deployed with the rubber net extended around the object. The configuration of the stand in the earthquake mode is shown in Fig. 1. The mode change is triggered by uplift of the vase bottom resulting from earthquake–induced rocking motion.

Fig. 1 The Stand of Deployable Net Type in Earthquake Mode

Performance tests by means of vibration–table experiments and numerical simulations revealed some problems of the stand, which follow. After the deployment, the object tends to show swing motion with the rubber net when it is subject to horizontal shaking. Thus, with an increase in intensity of input shaking, the stand may cause impact of the object with the struts or the ring. Moreover, the stand is not so efficient for slender objects, because they are not stably held in the conical net.

Deployable Frame Type

This type of stand is 30x30x8 cm in outside–dimensions, and 2.5 kg in weight. Normally, the guard–frame whose top is covered with 30mm–thick sponge rubber mat is level with the display stand, from which it does not obstruct appreciation of the object concerned, as shown in Fig. 2. Under the display stand, an earthquake sensor is invisibly installed. The sensor is only a steel ball placed on a counter–

sink. When the ball becomes off the countersink due to strong shaking, the frame is triggered to unfold itself and catches hold of the object, as shown in Fig. 3. The trigger level can be adjusted by selecting appropriate sizes of the ball and countersink.

Fig. 2 The Stand of Deployable Frame Type in Normal Mode

Fig. 3 The Stand of Deployable Frame Type in Earthquake Mode

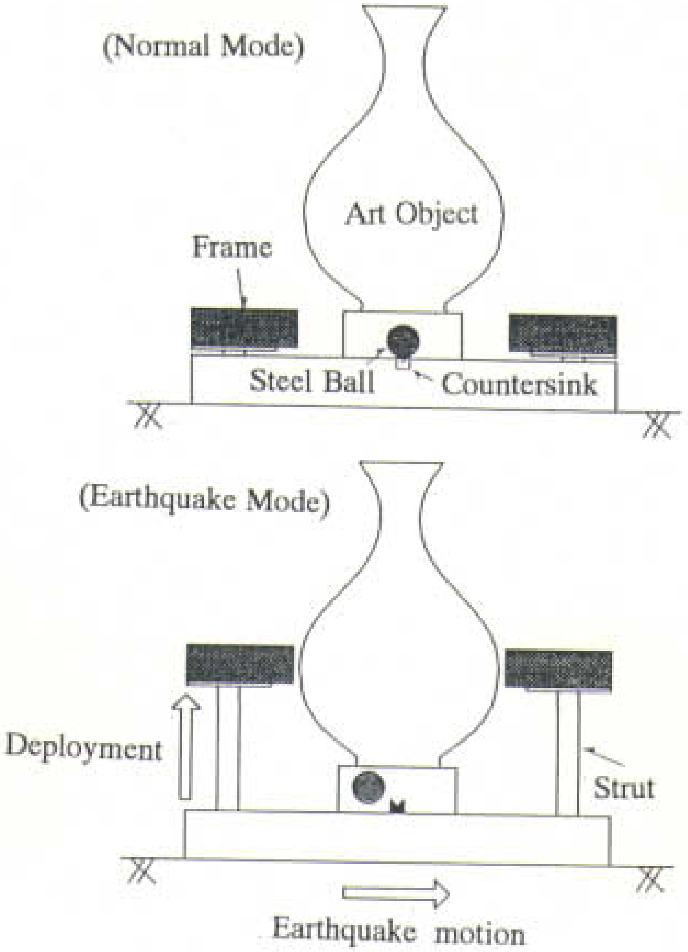

Fig. 4 Schematic Explanation of Normal and Earthquake Modes of the Stand

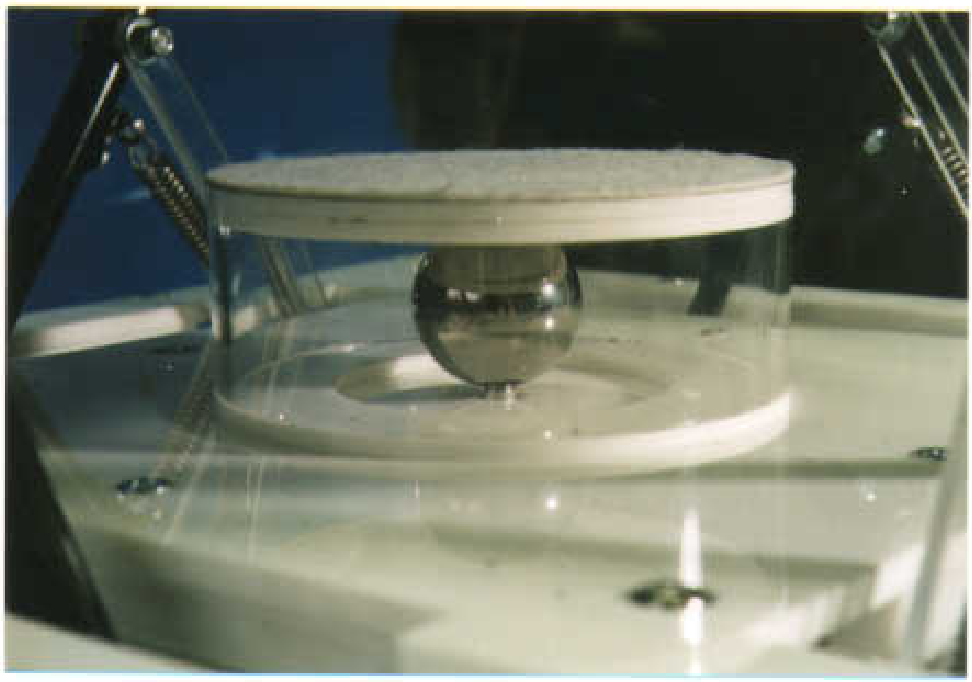

Fig. 5 Earthquake Sensor Installed under the Display Stand

Normal and earthquake modes of the stand are schematically shown in Fig. 4. Height and opening width of the guard–frame is adjustable between 6 and 16 cm, and 10 and 17 cm, respectively. As this type of stand is easily folded in comparison with the deployable net type, it has an advantage in the mode–recovery operation; that is, from the earthquake mode to the normal mode.

PERFORMANCE TESTS

Through a series of vibration experiments and numerical simulations using the distinct element method, performance tests were conducted, with the results shown below.

Trigger Level

When a steel ball of 25 mm in diameter and a countersink of 1.5 mm in diameter were used for the sensor as shown in Fig. 5, the trigger level was found to be between 55 and 60 gals in the frequency range from 1 to 9 Hz. The level is satisfactory for the present purpose, because overturning of art objects is known to take place at around the above–mentioned acceleration level (Okamoto, 1984).

Lapse Time of Deployment

As soon as the sensor detects shaking stronger than the trigger level, the guard–frame is released to deploy itself at a prescribed height. Lapse time of the deployment can be seen in the acceleration time histories shown in Fig. 6, in which horizontal and vertical motions of the guard are shown in (a) and (b), respectively. From Fig. 6, the lapse time of the deployment is found to be about 0.2 sec. The time seems to be satisfactory, because overturning of the object cannot take place in such a short time.

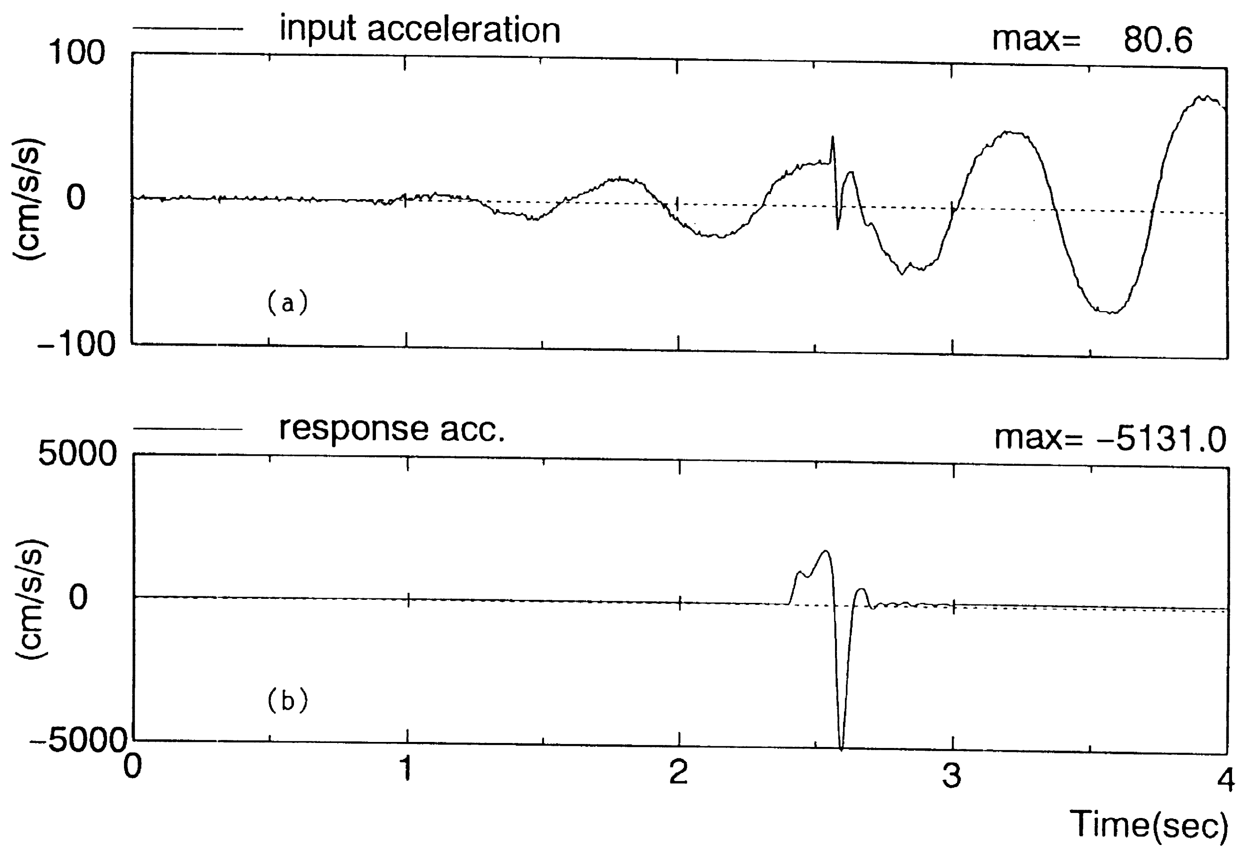

Fig. 6 Accelerograms of (a) Horizontal Table Motion, and (b) Vertical Motion of the Deployable Frame

Earthquake Response of an Object

Based on the distinct element idealization shown in Fig. 7, earthquake response of an object was simulated to check efficiency of the deployable stand. As for spring stiffness, damping property of dash pots and friction coefficient of sliders, those listed in Table 1 were used at a vase–frame contact and a vase–stand contact, respectively. Validity of those element properties was first checked by simulating the above–mentioned vibration experiments, followed by comparison with the observation in the experiments.

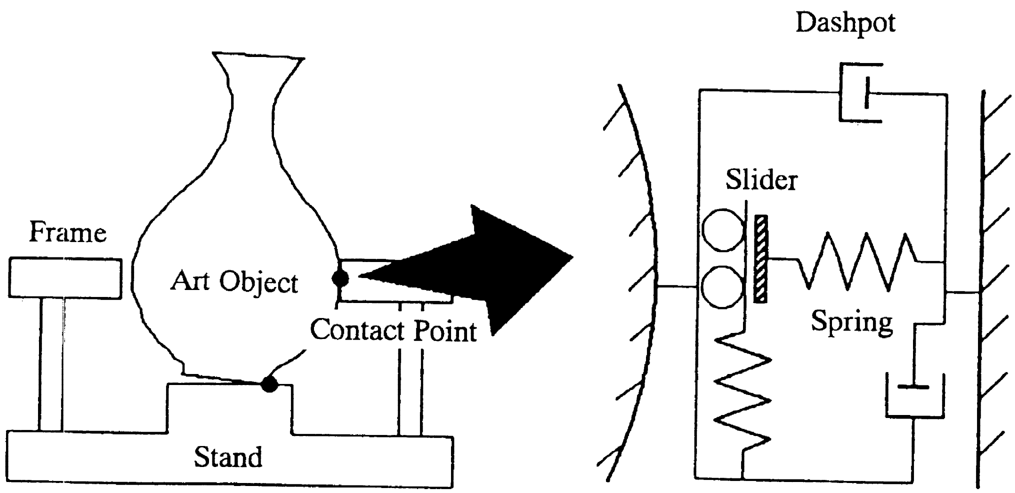

Fig. 7 Numerical Idealization of the Vase–Stand System

Table 1 Parameters Used in Numerical Simulation

(a) Parameters at the Vase–Stand Contact

Normal Spring Const.	3.8×10^7 (gf/cm)
Tangential Spring Const.	9.5×10^8 (gf/cm)
Normal Damping Ratio	0.45
Tangential Damping Ratio	0.30
Frictional Coef. of Slider	0.31

(b) Parameters at the Vase–Frame Contact

Normal Spring Const.	5.0×10^4 (gf/cm)
Tangential Spring Sonst.	2.5×10^4 (gf/cm)
Normal Damping Ratio	0.10
Tangential Damping Ratio	0.50
Frictional Coef. of Slider	0.55

Simulated earthquake response to strong motion in the 1995 Hyogoken–nanbu earthquake are shown in Fig. 8. The input vertical acceleration shown in (b) is the one observed at Kobe Meteorological Observatory, while the input horizontal motion shown in (a) is the response of an SDOF system to the observed horizontal acceleration calculated with a natural period T=0.5s and damping ratio h=0.05.

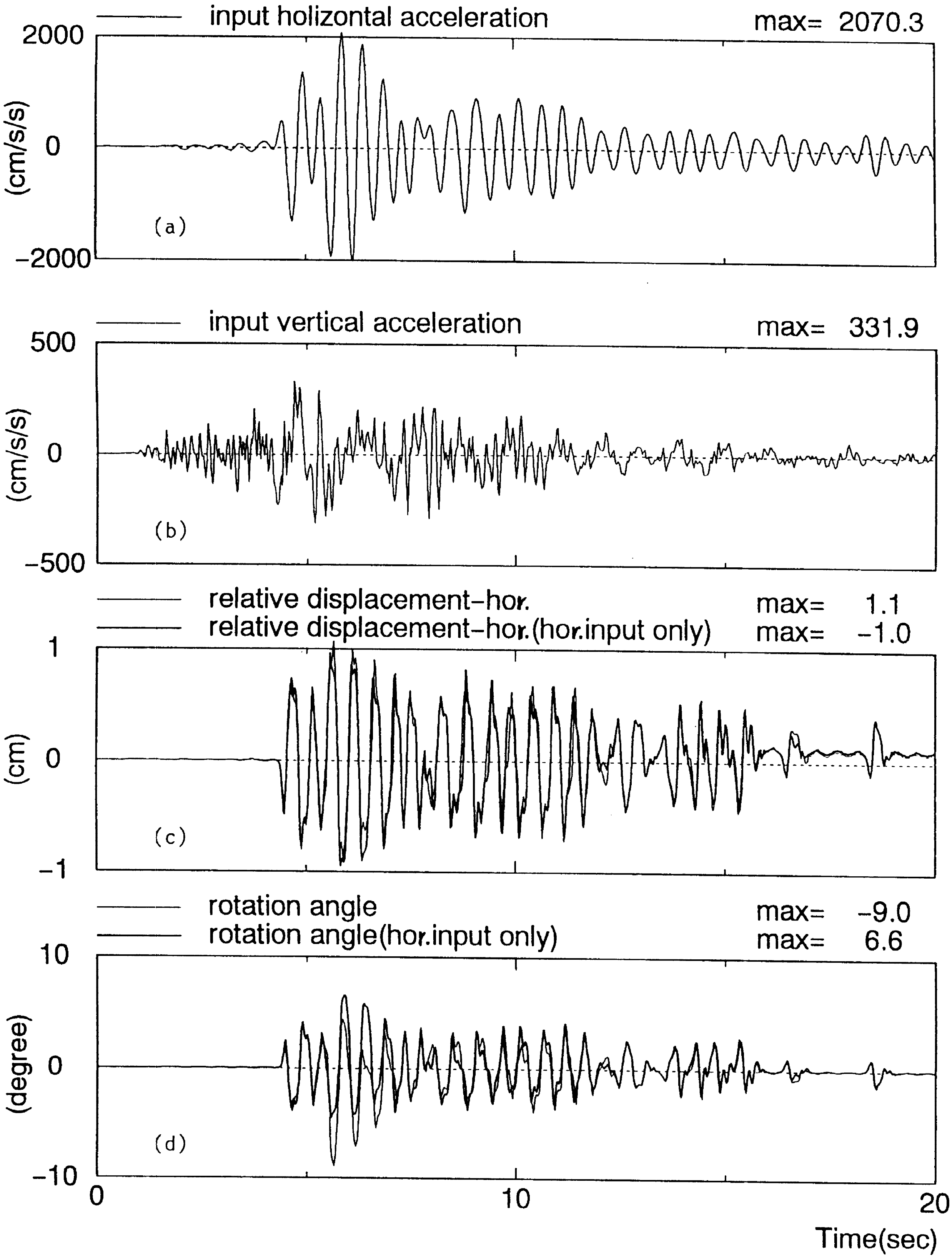

Fig. 8 Simulated Time Histories of the Vase–Stand System
(a) Input Horizontal Floor Motion,
(b) Input Vertical Floor Motion,
(c) Aperture between the Vase and the Stand
(d) Rotation Angle of the Vase

This is due to a supposition that the stand is used on a floor of a museum having those parameters. Thick and thin lines in (c) and (d) show simulated results from horizontal input only, and both horizontal and vertical inputs, respectively. According to the simulation, the rotation angle of the vase shown in (d) is less than 10 deg, even for the floor response as large as 2g, demonstrating efficiency of the deployable frame.

CONCLUSIVE REMARKS

The present study has proved that the deployable display stand can hold objects harmlessly, and that it works well without any limit in the shaking intensity in both horizontal and vertical directions unless the stand itself is broken. In the authors belief, the concept of the deployable display stand is widely applicable to protecting various kinds of important objects from severe earthquake shaking.

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