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STUDY ON SEISMIC PERFORMANCE FOR WAYS TO SET VENDING MACHINES IN OUTDOOR SPACES BASED ON SHAKING TABLE TEST

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ABSTRACT :

This paper describes the results of 3D shaking table tests on the seismic behaviors of ways to set a vending machine. The major purpose of this study is to verify the actual seismic performance of the setting way with concrete blocks in an outdoor space. The tests were conducted with JIS-level and largest-scale earthquake motions. The following are revealed about the seismic behaviors of vending machines through the series of tests: 1) Even if a way to set a vending machine lacks resistance to overturning, it has enough seismic performance to resist overturning against the seismic load assumed in JIS; 2) The seismic behavior mode of a way to set a vending machine depends on the combination of resistance to overturning and setting surface.

KEYWORDS: Vending machine, Shaking table test, JIS, Seismic Performance, Rocking, Sliding

1. INTRODUCTION

Vending machines are installed in various conditions, regardless indoor or outdoor. Despite this, there have been very few studies on the seismic behaviors of them.
In Japan, the way to install vending machines is specified in Japanese Industrial Standard (JIS) [1], but there are actually a lot of cases not to conform to it.
Some industry groups have developed guidelines based on their own knowledge, and promoted to improve the ways to set machines. However, there has not been enough verification of the effectiveness of ways along their guidelines.
Therefore, to verify the actual seismic performance of the existing ways which do not meet JIS, 3D shaking table tests were conducted for typical setting ways with simulated earthquake motions (Photo 1). In this study, the seismic behaviors of vending machines were classified in terms of the predominant behavior mode, which is slide or rocking or both, from the results of the tests where the setting ways with concrete blocks in an outdoor space were simulated. Then the effects of differences of the size of a machine, the resistance to overturning, and the setting surface on the machine's behavior were investigated.
The setting way with concrete blocks is to put two ready-made blocks on the setting surface not fixedly and fix the legs of a machine to the concrete blocks with anchor bolts and brackets, as shown in Figure 1. The concrete blocks function for a vending machine to lengthen its turning radius and lower its center of gravity and improve its resistance to overturning.

Photo 1 Testing situation

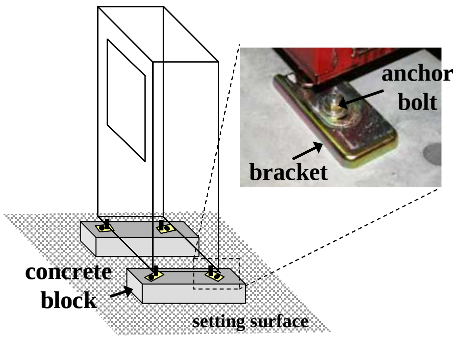


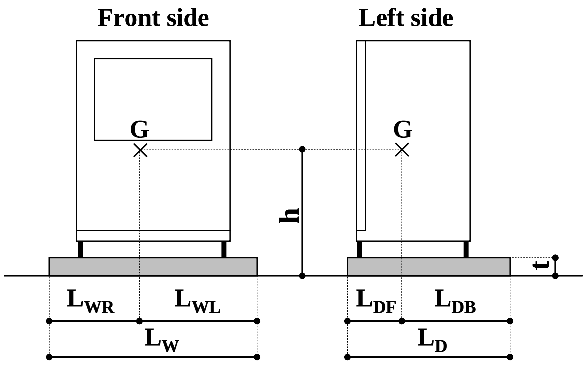
Figure1 Setting of test object

2. SEISMIC RESISTANCE SPECIFIED IN JIS STANDARD

The installation in JIS is aimed at the way to install vending machines by anchoring to a concrete base directly. It requires the way to satisfy the following conditions against the given seismic force (horizontal 0.4g, vertical 0.2g).

1) The maximum stresses in the anchor bolts and brackets are below the allowable level.
2) The concrete base is not separated from the ground. (Ensuring of resistance to overturning)

To ensure the resistance to overturning, the resistance to overturning against seismic force is specified as the required mass (Mce), which is determined by the size of a concrete base and the relative position of a machine and a concrete base (Figure 2). In JIS, it is required that the mass of a concrete base (Mc) is larger than the required mass.



G: center of gravity of vending machine

$$\mathbf{M_{CE}} = \max(\mathbf{M_{CR}}, \mathbf{M_{CL}}, \mathbf{M_{CF}}, \mathbf{M_{CB}})$$

$$\begin{cases} \mathbf{M_{CR}} = \dfrac{2\mathbf{k}(\mathbf{h}+\mathbf{t})-(2-\mathbf{k})\mathbf{L_{WR}}}{(2-\mathbf{k})\mathbf{L_W}-2\mathbf{k}\,\mathbf{t}} \times 2\mathbf{M} \\ \mathbf{M_{CL}} = \dfrac{2\mathbf{k}(\mathbf{h}+\mathbf{t})-(2-\mathbf{k})\mathbf{L_{WL}}}{(2-\mathbf{k})\mathbf{L_W}-2\mathbf{k}\,\mathbf{t}} \times 2\mathbf{M} \\ \mathbf{M_{CF}} = \dfrac{2\mathbf{k}(\mathbf{h}+\mathbf{t})-(2-\mathbf{k})\mathbf{L_{DF}}}{(2-\mathbf{k})\mathbf{L_D}-2\mathbf{k}\,\mathbf{t}} \times 2\mathbf{M} \\ \mathbf{M_{CB}} = \dfrac{2\mathbf{k}(\mathbf{h}+\mathbf{t})-(2-\mathbf{k})\mathbf{L_{DB}}}{(2-\mathbf{k})\mathbf{L_D}-2\mathbf{k}\,\mathbf{t}} \times 2\mathbf{M} \end{cases}$$

k: horizontal seismic coefficient (0.4)
M: center of gravity of vending machine

Figure 2 Specification of required mass in JIS

3. PARAMETER OF TEST OBJECT

The specifications of the objects targeted for tests are shown in Table 1. The parameters of the object are three: the size of a vending machine, the resistance to overturning toward the front side, and the type of the setting surface.

Table 1 Specifications of vending machines and concrete blocks

		Type-A		Type-B		Type-C	
		Up to JIS	Below JIS	Up to JIS	Below JIS	Up to JIS	Below JIS
Mass [kg]	Vending machine (fully loaded)	696		594		504	
	Concrete blocks	143	124	143	124	143	124
Size of vending machine [mm] (Wide×Height×Depth)		1800×1228×799		1800×1161×688		1800×1161×583	
Size of concrete block [mm] (Wide×Height×Length)		300×100×1000	300×100×900	300×100×1000	300×100×900	300×100×1000	300×100×900

3.1. Size of Vending Machine

The vending machines in widespread use for selling beverages were chosen. They are almost the same in height and width but different in depth. The depth of the machines comes in different three sizes: 799mm (Type-A), 688mm (Type-B), and 583mm (Type-C).

3.2. Resistance to Overturning

The resistance to overturning of the test object was determined by whether the mass of concrete blocks (M_C) are larger than the required mass ($M_C>M_{CE}$; Up to JIS) or not ($M_C<M_{CE}$; Below JIS). Figure 2 and Figure 3 show the relative position of a machine and blocks and the center of gravity of each test object, respectively. These are exclusively for the depth-wise direction which it is likely for machines to overturn toward. Figure 3 suggests that the

height-wise position of the gravity center is stable than the depth-wise position toward the variation in the size of a vending machine.

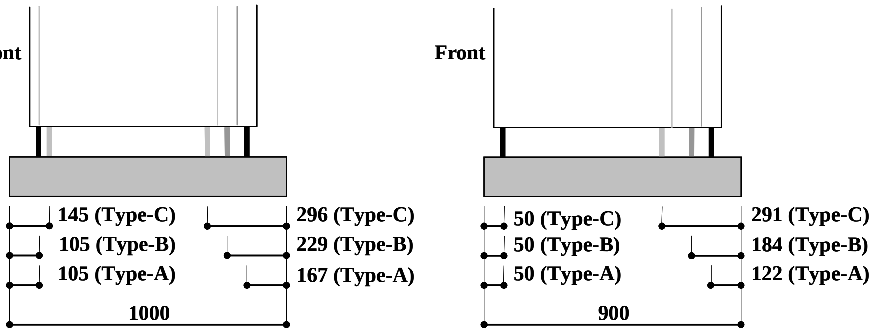


Figure 2 Position of vending machine on blocks

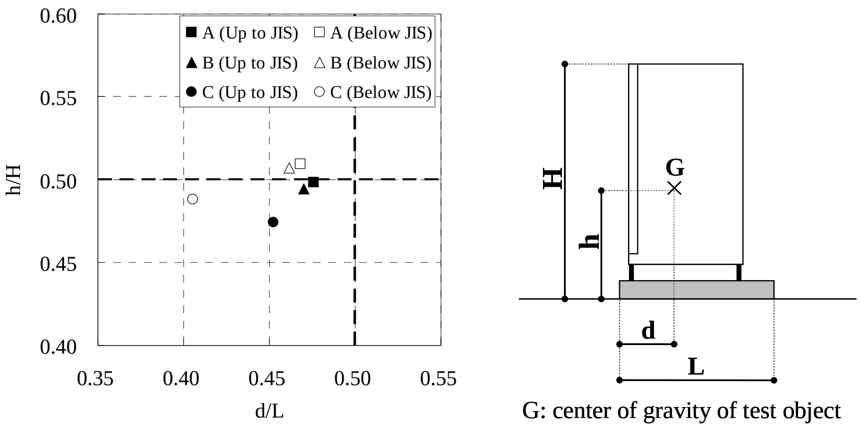


Figure 3 Center of gravity of each test object

3.3. Type of Setting Surface

Three types of the setting surfaces were prepared: concrete paving, asphaltic paving, and tiling.

4. SHAKING TABLE TEST

A series of the tests was performed with simulating the actual setting condition and a machine full of real cans. The excitation by the simulated waves was applied simultaneously in three directions, two horizontal and vertical directions. The 16 cases shown in Table 2 were targeted at in the series of the tests.

Table 2 Test cases

		Resistance to overturing	
		Up to JIS	Below JIS
Setting surface	Concrete	Type-A, B, C	Type-A, B, C
	Asphalt	Type-B, C	Type-B, C
	Tiling	Type-B, C	Type-B, C

4.1. Measurement

The measurement points are shown in Figure 4. The accelerations in parts of a test object and the horizontal displacements at the top were measured, and besides, the acceleration, velocity and displacement on the table were also measured. Optical displacement meters were used to measure the horizontal displacements at the top of a test object. The velocity and displacement on the table were output from the control system for the shaking table. To monitor the behaviors of objects closely later, video images of the tests were recorded.

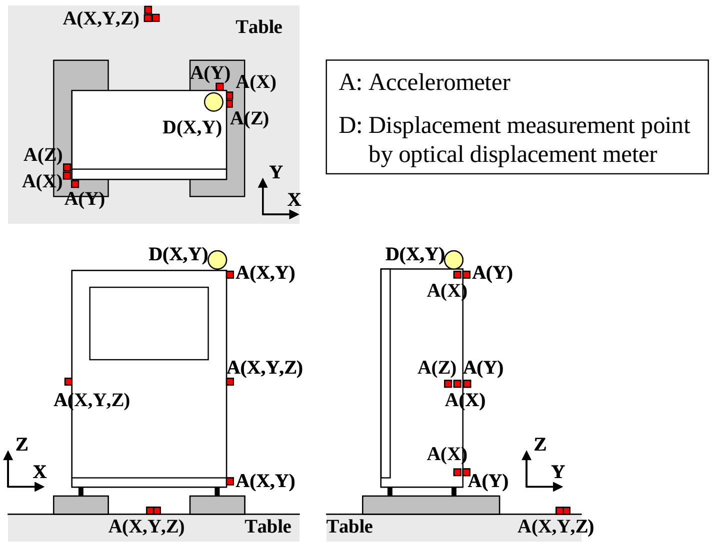


Figure 4 The measurement point

4.2. Input Wave

Input waves used for the shaking table tests are three shown in Table 3.
ART-JIS wave is the artificial earthquake motion created as the earthquake motion whose maximum acceleration is equivalent to JIS level (horizontal 0.4g, vertical 0.2g). The acceleration response spectra of the horizontal motions of ART-JIS are based on that of the earthquake motion stipulated in current Japanese seismic design code (Z=1.0, Soil type 2) as a motion which occurs extremely rarely [2]. The spectrum of the vertical motion is determined from that of the horizontal motion by the method [3]. The target acceleration response spectra of ART-JIS are shown in Figure 5. Waves in three directions are created with independent random phase spectra so that they provide the specified acceleration equally in all directions.
JMA-Ojiya wave and JMA-Kobe wave are the earthquake motions recorded by Japan Meteorological Agency (JMA) in the 2004 Niigataken-Chuetsu earthquake and the 1995 Hyogoken-Nambu earthquake, respectively. They were selected as typical earthquakes which caused severe damage to buildings and infrastructures in order to investigate seismic behaviors of machines subjected to the largest-scale earthquake motion.
The maximum amplitudes of acceleration of the waves are also shown in Table 3.
Figure 6 shows the response acceleration orbit at the gravity center of the machine whose four legs were all fixed during the excitation of ART-JIS wave. In Figure 6, the contour of the acceleration level specified in JIS is shown together. Figure 6 suggests that the response acceleration of the vending machine is equivalent to JIS-level and that ART-JIS wave provides JIS-level seismic load.

Table 3 Input waves

Wave name	Explanation	Max. Acceleration (cm/s^2)		
		X	Y	Z
ART-JIS	Artificial earthquake motion of JIS level (horizontal 0.4g, vertical 0.2g)	599	635	210
JMA-Ojiya	Earthquake motion recorded in Ojiya by JMA (Niigataken-Chuetsu Earthquake, 2004)	898	779	731
JMA-Kobe	Earthquake motion recorded in Kobe by JMA (Hyogoken-Nanbu Earthquake, 1995)	617	818	332

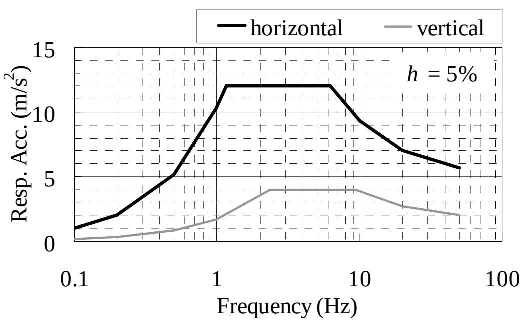


Figure 5 Target response spectra for ART-JIS

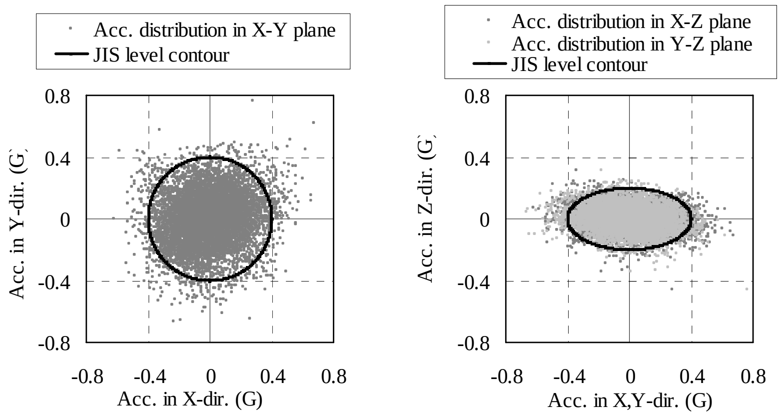


Figure 6 Seismic level of ART-JIS

5. RESULTS OF TESTS

5.1. Dynamic Characteristics of Objects

The dynamic characteristics of test objects in Y-direction of estimated from the result of random white noise excitation are shown in Table 4. Natural frequencies of objects below JIS tend to be higher than those of objects up to JIS on a concrete surface, while objects on a tiling surface tend to be opposite. Besides, those of objects on an asphalt surface are all around 10Hz. Meanwhile, damping factors are about 20% to 30%, which are relatively large. It seems that this is caused by clashes among cans in a vending machine and sloshing of beverage in cans. Some objects have comparatively low frequencies and small damping, which is attributed to looseness between a test object and the table.

Table 4 Dynamic characteristics of test objects

Vending machine	Resistance to overturning	Setting surface	Natural freq. [Hz]	Damping [%]
Type-A	Up to JIS	Concrete	7.0	18
	Below JIS	Concrete	8.6	16
Type-B	Up to JIS	Concrete	3.3	7
		Asphalt	10.8	22
		Tiling	9.0	22
	Below JIS	Concrete	11.0	32
		Asphalt	9.8	26
		Tiling	5.9	9
Type-C	Up to JIS	Concrete	6.1	20
		Asphalt	10.8	30
		Tiling	11.5	23
	Below JIS	Concrete	9.9	22
		Tiling	5.9	13

5.2. Responses to JIS-level Wave

For the excitation of ART-JIS wave, the test objects below JIS exhibited rocking behaviors slightly. In the cases of the machine of Type-C which has the smallest resistance to overturning toward the front side, the uplifts were observed at the edge of the blocks. However, in all cases, the residual displacements of the objects were a few centimeters, and the anchor bolts and brackets were not damaged. These results suggest that, even if the ways to set machines lack the resistance to overturning, they have enough seismic performance to resist overturning against the seismic load assumed in JIS.

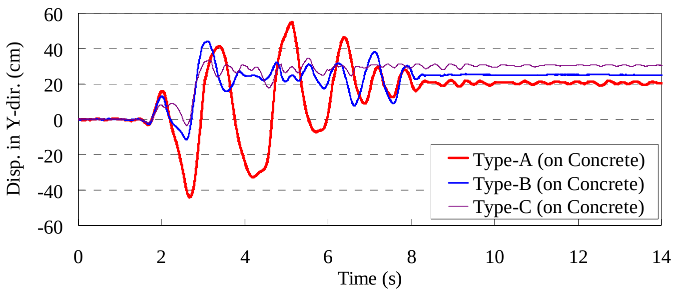
5.3. Response to Large-scale Earthquake Wave

For the excitation of JMA-Ojiya and JMA-Kobe wave, in all cases, the objects moved with large sliding and rocking behaviors, and their fixing brackets of the machine's legs were slipped, but the anchorage to the blocks were not damaged. The maximum horizontal displacements and the residual displacements are shown in Table 5. In addition, we observed the behaviors of the object in the tests and classified the predominant behavior mode in each test by the results and the video images. The behavior modes are shown in Table 5 together. From Table 5, it is suggested that the gap between maximum displacement (u_{max}) and residual displacement (u_r) is wide in the cases where rocking mode is predominant. The comparison of the measured response time histories of the Y-direction relative displacements at the top of the objects subjected to JMA-Kobe wave is shown in Figure 7.

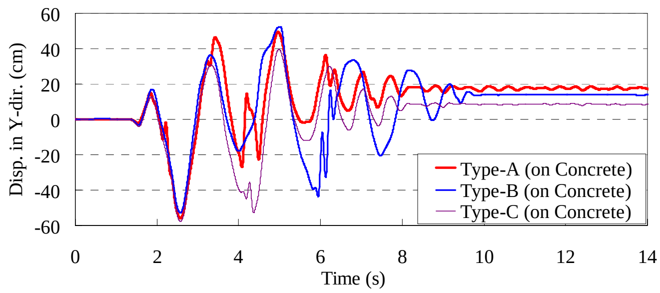
Table 5 Response displacements and predominant mode in each case

Vending machine	Setting surface		JMA-Ojiya		JMA-Kobe	
			Up to JIS	Below JIS	Up to JIS	Below JIS
Type-A	Concrete	u_{max} [cm]	**19.3**	**21.1**	**60.0**	**58.0**
		u_r [cm]	**3.1**	**8.4**	**28.3**	**22.4**
		Mode	**R**	**R**	**LR**	**LR**
Type-B	Concrete	u_{max} [cm]	**20.0**	**(ERROR)**	**45.0**	**64.2**
		u_r [cm]	**8.8**	**(ERROR)**	**28.8**	**24.0**
		Mode	**R**	**R**	**R**	**LR**
	Asphalt	u_{max} [cm]	**12.7**	**8.3**	**45.0**	**63.2**
		u_r [cm]	**10.7**	**3.6**	**30.9**	**10.8**
		Mode	**S+SR**	**R**	**S+R**	**S+LR**
	Tiling	u_{max} [cm]	**16.3**	**17.0**	**43.0**	**47.8**
		u_r [cm]	**13.2**	**11.1**	**38.8**	**42.0**
		Mode	**S+SR**	**S+SR**	**LS+R**	**LS+R**
Type-C	Concrete	u_{max} [cm]	**16.3**	**20.9**	**36.1**	**57.7**
		u_r [cm]	**1.8**	**9.3**	**33.5**	**16.0**
		Mode	**R**	**R**	**S+R**	**LR**
	Asphalt	u_{max} [cm]	**9.7**	**13.8**	**42.9**	**33.6**
		u_r [cm]	**8.0**	**9.6**	**37.4**	**13.9**
		Mode	**S+SR**	**S+R**	**LS+R**	**S+LR**
	Tiling	u_{max} [cm]	**14.2**	**15.4**	**46.4**	**43.8**
		u_r [cm]	**7.4**	**11.3**	**45.8**	**33.6**
		Mode	**S+SR**	**S+R**	**LS**	**LS+R**

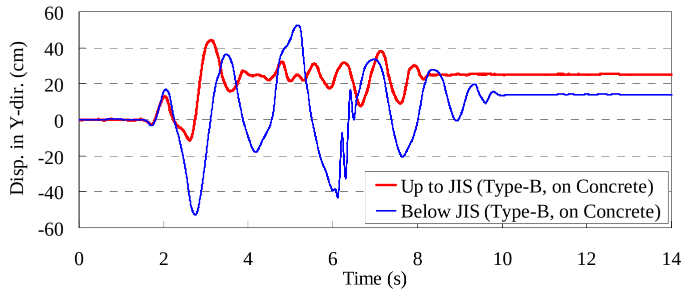
u_{max} : maximum horizontal displacement (radius component), u_r : residual displacement (radius component)
S: Sliding, R: Rocking, SR: Small Rocking, LS: Large Sliding, LR: Large Rocking



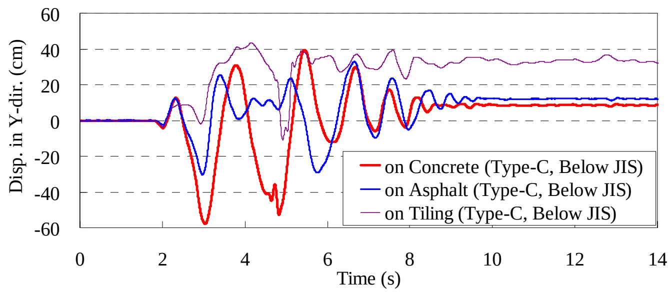
(a)Difference of size of machine (Up to JIS)



(b) Difference of size of machine (Below JIS)



(c)Difference of resistance to overturning



(d) Difference of setting surface

Figure 7 Comparison of relative displacements in Y-direction of objects subjected to JMA-Kobe wave

5.4. Comparison and Considerations in Seismic Behavior

We try to compare the seismic behaviors in the tests, and to consider the seismic performance of the ways to set machines with concrete blocks on the basis of Table 5 and Figure 7 and the video images.

5.4.1 Effect of size of vending machine

Figure 7 (a) suggests that, the deeper machines are, the more they tend to exhibit larger rocking behavior in the setting ways up to JIS. Contrary to this, the thinner machines are, the more they tend to exhibit a sliding behavior. Meanwhile, in the setting ways below JIS shown in Figure 7 (b), the rocking behavior of Type-B machine was the largest. In the tests on tiling surface, the behavior modes of Type-B and Type-C machines were similar.

From the facts described above, it is suggested that the size of a vending machine has a small effect directly on the seismic behavior of a machine.

5.4.2 Effect of resistance to overturning

As in Figure 7 (c) and Table 5, the ways below JIS tend to exhibit rocking mode, compared to the ways up to JIS. In particular, in the case of Type-B on concrete surface, the rocking behavior was so large as to overturn. In the cases on tiling surface, the sliding mode was predominant, and the effect of resistance to overturning on the seismic behavior of a machine seems to be smaller than on concrete.

5.4.3 Effect of setting surface

As for the effect of setting surface, Figure 7 (d) and Table 5 show that rocking behavior tends to appear in the following order: concrete, asphalt and tiling. Sliding behavior and residual displacement have the opposite tendency. It is suggested that these tendencies are affected by the frictional coefficient between setting surface and concrete blocks.

When the effect of resistance to overturning is considered together, the seismic behavior mode of the way to set a vending machine depends on the combination of the resistance to overturning and the setting surface.

6. CONCLUSIONS

To verify the actual seismic performance of the setting way with concrete blocks in an outdoor space, 3D shaking table tests were conducted with the simulated earthquake motions. From the results of the tests, the following were revealed about the seismic behaviors of vending machines.

Against the seismic load assumed in JIS:

1) Even if ways to set machines lack resistance to overturning, they have enough seismic performance to resist overturning.

Against the seismic load by large-scale earthquake beyond JIS level:

2) The size of a vending machine has a small effect directly on the seismic behavior of a setting way.

3) The setting way whose resistance to overturning is low tend to exhibit rocking behavior.

4) The seismic behavior mode of a way to set a vending machine depends on the combination of resistance to overturning and setting surface.

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