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SEISMIC BEHAVIOR AND HAZARD EVALUATION OF MEDICAL EQUIPMENT WITH CASTERS

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SUMMARY

The objectives of the study are to clarify the behavior of full-scale medical equipment with casters during earthquakes by means of shaking table tests and to evaluate earthquake resistance of incubators with casters against toppling and sliding by using reduced-scale models. Effects of caster conditions on toppling and residual displacements are discussed. Relationship between floor accelerations and equipment aspect ratios is derived for checking equipment toppling. Seismic hazard of medical equipment is examined by applying the test results to two hospital buildings.

INTRODUCTION

Earthquake resistance of medical equipment is required for the preservation of hospital functions during and after major earthquakes. Patients and occupants have to be protected from injury and evacuation blocking due to toppling and sliding of medical equipment. In the 1978 Miyagiken-Oki Earthquake and in the 1983 Nihonkai-Chubu Earthquake, some cases of incubator sliding and hemodialyzer malfunction were reported. Some of medical equipment have casters for convenience of medical care. The caster conditions of medical equipment may profoundly affect the behavior and resistance during earthquakes.

We carried out shaking table tests of full-scale medical equipment with casters to clarify the seismic behavior, and shaking table tests of reduced-scale model specimens to evaluate earthquake resistance against toppling and sliding (Refs. 1 and 2). Seismic hazard of medical equipment is assessed by applying the test results to low-rise and medium-rise hospital buildings.

EXPERIMENTAL SETUP

Specimens and Floor Condition Specimens for full-scale tests were incubators for immature baby (Photo 1), NICU (neonatal intensive care unit) incubators (Fig. 1 and Photo 1), baby cots, patient beds, ICU beds, bed side tables, over-bed tables, a wheel chair, etc. All the specimens except a wheel chair have four casters. Specimens for reduced-scale tests, as shown in Fig. 1, were models of incubators for immature baby and NICU incubators in accordance with similitude ratios of Tab. 1. They included models with casters and without casters. And gravity heights of some models were varied. The polyvinyl chloride sheeted plywood plates was set up on the floor of the shaking table.

Input Earthquake Motion We assumed the Construction Engineering Department Building of Tohoku University at Sendai City as a hospital, where strong motion accelerograms were observed and much furniture tumbled down during the 1978 Miyagiken-Oki Earthquake (Ref. 3). Maximum accelerations of NS component on the 9th and 1st stories are 1040 and 260 gal, respectively (Ref. 4). Table 2 presents an outline of the building and soil conditions. These accelerograms were adopted as input signals of the shaking table. Maximum accelerations of the signals for full-scale models were ab ut 300 gal. For scale models, input signals were gained by reducing time scale of the original records to 1/1.67 times and their maximum accelerations were varied from 150 to 1000 gal.

Caster Conditions Caster conditions are classified as follows; 1) Without casters. Four casters were locked(All locked). 2) Diagonally opposite two casters were locked(Diagonally locked). 3) Two casters on the longer side of the specimen were locked(Front locked). 4) Four casters are unlocked(Free).

SEISMIC BEHAVIOR OF MEDICAL EQUIPMENT

The full-scale model tests subjected to moderate earthquake motions were carried out. Main remarks of the test results are as follows;

1) Maximum accelerations of the incubators with free casters were about half of those with diagonally locked casters, and were about one third of those with front locked casters.

2) Sliding in an excited direction was observed in the cases of free and front locked casters. In the latter case, the sliding amount during excitation accumulated on an unlocked side. In the diagonally locked case, rotation about a vertical central axis of equipment was much more remarkable than sliding.

3) The NICU incubators with diagonally locked casters, which had a steel stand over the incubator with monitoring instruments for medical care, tilted up but did not tumble down. Torsional oscillation of the stand occurred and is considered to enlarge the rotational amount of the incubators.

SEISMIC RESISTANCE OF MEDICAL EQUIPMENT

Validity of Scale Model Tests Figure 2 shows acceleration comparison between the incubator prototype and the scale model with diagonally locked casters. Figure 3 shows comparison of residual displacements after excitations. They verified the adopted similitude law and the proper modeling.

Residual Displacement Figure 4 shows the residual displacements in the cases of free and diagonally locked casters. In the free case, the sliding amount in the excited direction predominated. With increase of maximum accelerations, rotation about the vertical axis became distinguished. In the case of diagonally locked casters, the rotation amount was predominant. When rocking motion occurs, the model rotates about the vertical axis at the corners of the locked casters. Figure 5 presents the residual displacements of the gravity center, the residual rotational angles and the largest residual displacements of four corners in the cases of free and diagonally locked casters. The residual displacements of the gravity center are approximately proportional to maximum accelerations. The rotational angles in the diagonally locked case are much larger than those in the free case. The rotational angle in the diagonally locked case approaches a constant angle with increase of maximum accelerations. The angle is equal to that between a diagonal and the excited direction. The models in this state are most stable against sliding and rotation. When maximum accelerations are moderate, the maximum displacements of the corners in the diagonally locked case are larger than those in the free case. When maximum accelerations become large, the maximum displacements have the reverse results.

The residual displacements of Fig. 5 do not necessarily mean the maximum ones during shaking. According to the test observation, the sliding displacements during excitation sometimes exceeded the residual ones in the case of free casters. In the case of diagonally locked casters, the residual displacements tended to give the maximum ones during shaking.

Resistance Against Toppling Relationship between maximum floor accelerations and aspect ratios of the model B/H is shown with symbols of toppling and no toppling in Fig. 6. Symbols B and H mean a half width of the models along the excited direction and a height of the gravity center, respectively. A broken line shows West's formula $a=(B/H)g$ derived from two dimensional toppling theory of rigid bodies. Where a is toppling acceleration and g is the gravity acceleration. Strictly speaking, the formula means acceleration where a rigid body begins to tilt up due to rocking motion and does not necessarily specify toppling acceleration. Solid lines show borders between toppling and no toppling. In the case that all four casters are locked, the West's formula can be used as approximate for engineering purpose and gives a little conservative evaluation of toppling with 25% errors. The models with diagonally locked casters are 3.3 times more resistant than those with all locked casters and 4.1 times more resistant than values evaluated by the West's formula. In the case of diagonally locked casters, the model becomes stable against toppling with increase of the apparent value of B due to rotation about the vertical axis. In the case of front locked casters, the straight border is not determined. This model behaves like the model with locked casters when excited to a locked side, and slides much like the model with unlocked casters when excited to another unlocked side.

SEISMIC HAZARD ASSESSMENT OF MEDICAL EQUIPMENT

Seismic hazard of medical equipment in two hospitals is examined by applying the test results of the scale model. The one is a hypothetical hospital whose building and site condition are the same as those of the 9-story Construction Engineering Department building in Tohoku University. The other is a 5-story Namioka town hospital where the shear failure of the columns occurred in the 1983 Nihonkai-Chubu Earthquake. Figures 7 and 8 present toppling assessment of medical equipment in the 9-story and the 5-story hospitals, respectively. They include a elevation of a NS direction and the maximum acceleration of each floor. The maximum accelerations in the 9-story hospital are determined by utilizing average distribution of several earthquake observation records including the 1978 Miyagiken-Oki Earthquake (Ref. 5). In the 5-story hospital, the maximum accelerations are determined based on earthquake response analysis in Ref. 6. A mass-spring-dashpot system and a bi-linear stiffness were adopted in the analysis. With increase of aspect ratios, the toppling risk of medical equipment decreases. In the case of slender equipment with all locked casters, equipment is evaluated to topple down even on the 1st floor. In the case of diagonally locked casters, some of equipment on the upper stories are considered to topple down in the 9-story hospital.

On the basis of Fig. 5, the maximum residual displacements in the case of diagonally locked casters are evaluated 30, 80 and 90 cm on the lower, medium and upper stories in the 9-story hospital, respectively. In the case of free casters, those are 10, 40, 120 cm. From sliding viewpoints, the case of free casters is assessed advantageous except the upper stories. But the maximum displacements during shaking are probable to exceed the evaluated ones, and the sliding directions tend to be scattered during earthquakes. Therefore the equipment with free casters has much risk of equipment collision and evacuation blocking. On the other hand, in the case of diagonally locked casters, the evaluated displacements are approximately equal to the maximum ones. The equipment tends to slide in the same direction. The risk of collision and evacuation blocking is little in the case of diagonally locked casters.

CONCLUSIONS

The main concluding remarks are summarized as follows;

1) Sliding in the excited direction occurs with a little rotation in the case of free casters. Rotation about the vertical axis is remarkable in the case of diagonally locked casters.
2) The case of diagonally locked casters is more resistant to toppling than the case of all four locked casters. In the former case, rotation about the horizontal axis is converted to that about the vertical axis. This phenomenon prevents the medical equipment from toppling.
3) Some of incubators with diagonally locked casters on the upper stories of the 9-story hospital are considered to topple down during severe earthquakes.
4) Diagonal caster locking should be recommended by reason for preventing the medical equipment from toppling, colliding and blocking evacuation.

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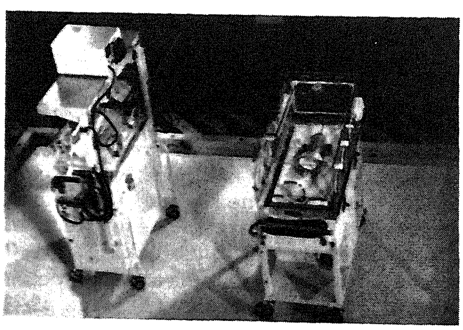

Photo 1 NICU Incubator and Incubator

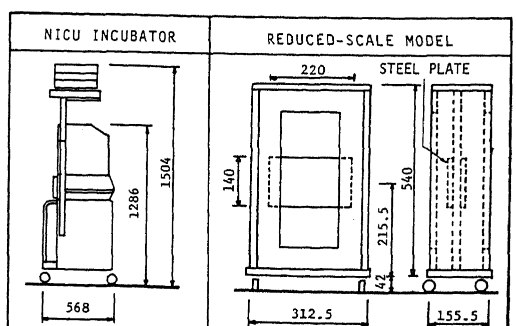

Fig. 1 Dimension of Specimens

Table 1 Similitude Ratios

	Dimension	Ratios A	Ratios B
Length	L	1/2.7	1/3
Time	T	$1/\sqrt{2.7} \fallingdotseq 1/1.64$	$1/\sqrt{3} \fallingdotseq 1/1.73$
Mass	M	---	---
Velocity	L/T	$1/\sqrt{2.7} \fallingdotseq 1/1.64$	$1/\sqrt{3} \fallingdotseq 1/1.73$
Acceleration	L/T^2	1	1

Table 2 Building and Site Conditions of a Hypothetical Hospital

Items	Remarks
Kind of Structure	Steel Encased Reinforced Concrete Structure
Stories	High rise Part 9-Stories Low rise Part 2-Stories
Fundamental Period (NS Direction)	0.44 - 0.48 sec (from Vib. Generator Test)
Foundation	Precast Reinforced Concrete Pile Foundation (Pile length 12m)
Geological Condition of Site	Aobayama River Terrace at Sendai City
Soil Condition (Depth, Soil and N-value)	Cut and Filled Soil Ground (G.L.~ -6m, clay, 5~24: -6m~-22m, Loam, 13~50: -12m~, Silt, 14~50)

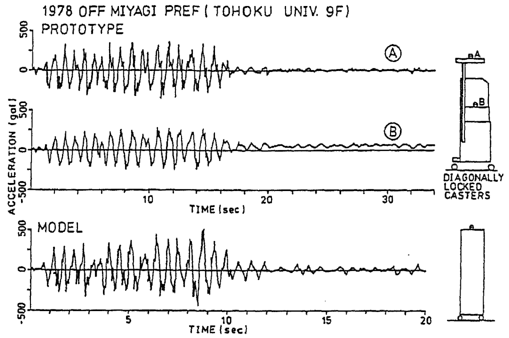

Fig. 2 Response Acceleration Comparison of Prototype and Model

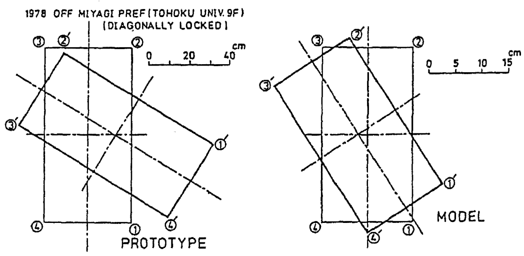

Fig. 3 Residual Sliding Comparison of Prototype and Model

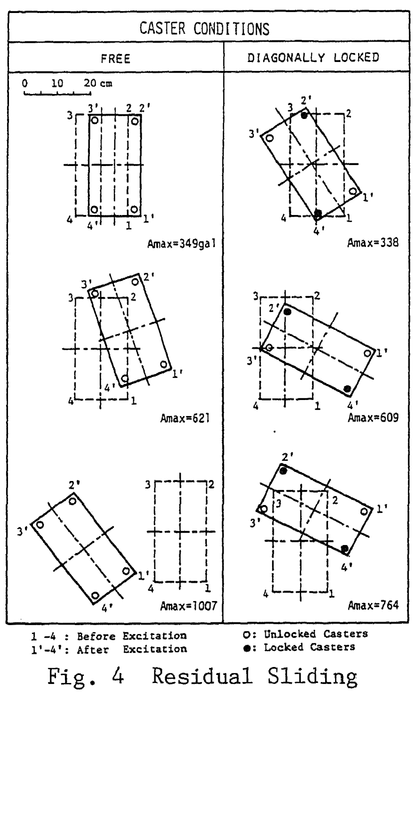

Fig. 4 Residual Sliding

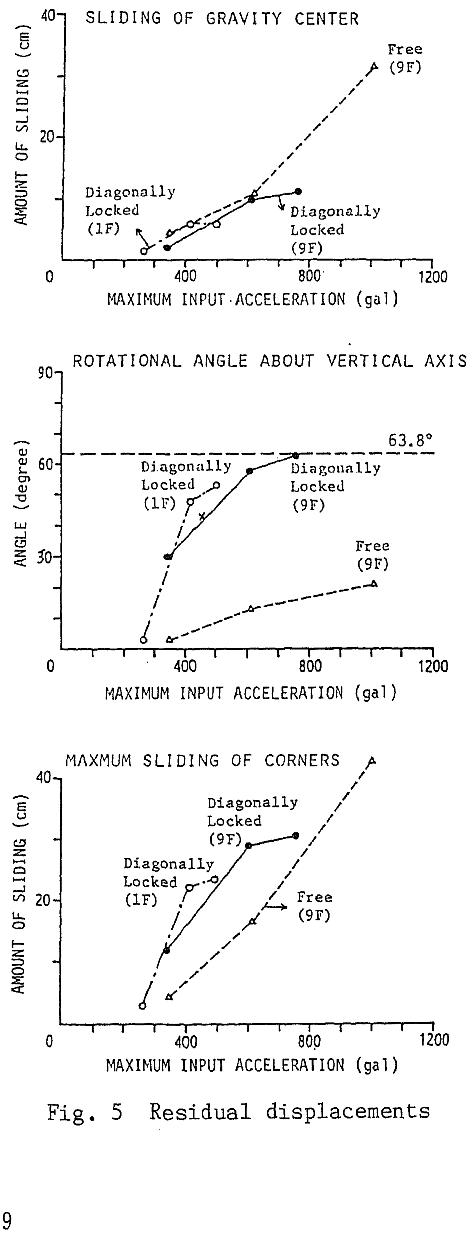

Fig. 5 Residual displacements

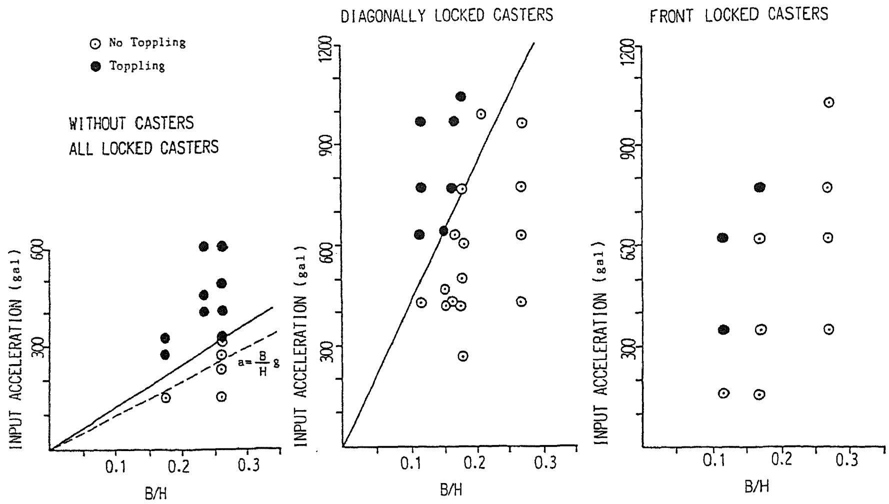

Fig. 6 Relationship Between Aspect Ratio and Maximum Floor Acceleration

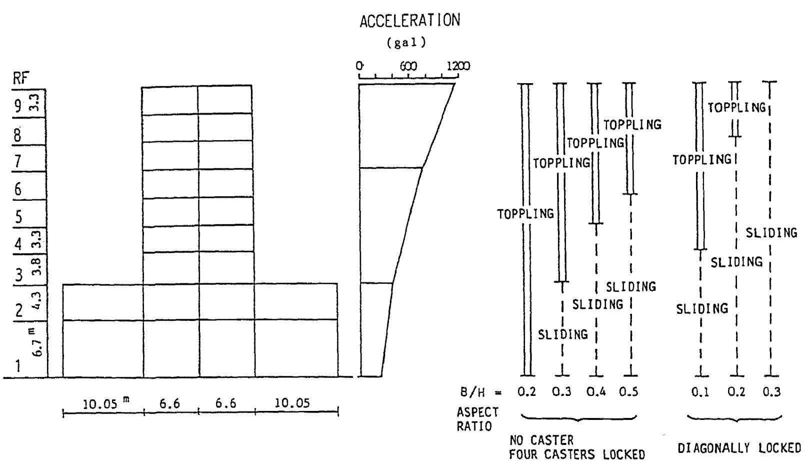

Fig. 7 Toppling Assessment of Medical Equipment
in a 9-story Hypothetical Hospital Building

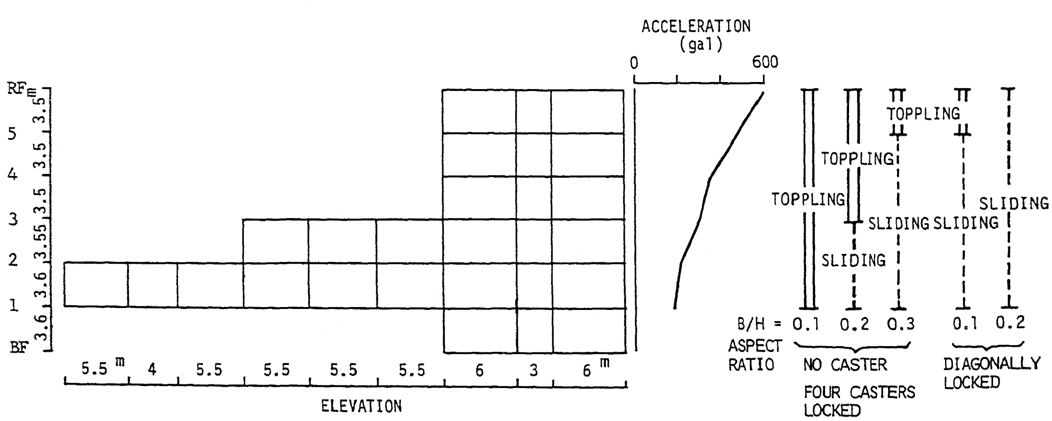

Fig. 8 Toppling Assessment of Medical Equipment
in a 5-story Namioka Town Hospital Building