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SEISMIC BEHAVIOR OF KITCHEN FURNITURE IN HIGH-RISE BUILDING DUE TO LONG-PERIOD GROUND MOTION

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ABSTRACT

In order to examine indoor seismic safety of high-rise residential buildings, shaking table test and simulation are conducted for seismic behavior of kitchen furniture due to long-period ground motion. From the shaking table test, large displacement of a refrigerator, overturning of a cupboard, opening of the doors or drawers are observed at the acceleration of 0.3 *g* or more. The behavior of the furniture in the shaking table test is well reproduced by the rigid body simulation. The behavior of a number of furniture at a kitchen in a high-rise building is simulated to long-period ground motion of an anticipated giant earthquake. The simulation results show that the furniture continues to move largely, suggesting that fear, injury and difficulty in evacuation may occur during the shaking.

Introduction

The metropolitan areas in Japan are located on large basins where long-period ground motion is easily excited by a large shallow earthquake. In the metropolitan areas, many high-rise buildings have been built up and may vibrate largely by the long-period motion. The authors have discussed indoor seismic safety of high-rise office buildings (Masatsuki et al. 2008). The number of high-rise residential buildings in addition to the office buildings is recently increasing. For example, in the Tokyo metropolitan area, about 500 residential buildings with 20 or more stories have been constructed. Indoor seismic safety of the residential buildings shaken by the long-period motion should be examined. In the residential building, the kitchen is one of the most vulnerable to shaking because it has many contents such as tableware, a cupboard, a refrigerator and gas rings. In order to evaluate indoor seismic risk of housing space, this paper examines the behavior of kitchen furniture in a high-rise building due to the long-period motion by means of the shaking table test and simulation.

Shaking Table Test

In order to study fundamental characteristics of behavior of furniture, shaking table tests

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are conducted using a large-stroke shaking table with maximum displacement of 1m. The maximum acceleration and velocity are 1000 cm/s^2 and 150 cm/s, respectively. The shaking direction is two horizontal. The size of the table is 3.2 m by 2.5 m. The payload is one ton. The appearance of the table is shown in Figure 1. The test models are a refrigerator, a cupboard, a table, a chair and a built-in kitchen as shown in Figures 2. The shaking is given to one horizontal direction with sinusoidal waves. The tests are conducted for fourteen cases of shaking with acceleration of 200 to 450 cm/s^2 and period of 2 to 4 second.

The results of the tests are summarized in Table 1. The refrigerator moves largely when the acceleration is 300 cm/s^2 or more (See Fig. 3(a)). The cupboard shows rocking movement at the acceleration of 250 cm/s^2 and falls down at the acceleration of 300 cm/s^2 (See Fig. 3(b)). The door and drawer of the built-in kitchen open at the accelerations of 300 cm/s^2 and 350 cm/s^2, respectively. The doors of the refrigerator and the cupboard open at the acceleration of 350 cm/s^2 when foods or tableware are put in them. The results show that large displacement of the refrigerator, overturning of the cupboard, opening of the doors or drawers are expected at the acceleration of 300 cm/s^2 or more, which may cause falling of tableware and injury of the residents.

Figure 1. Appearance of shaking table.

(a) Refrigerator (b) Cupboard (c) Built-in kitchen (d) Table and chair

Figures 2. Models used in shaking table test.

Table 1. Results of shaking table tests.

Acc. (cm/s/s)	Period (sec.)	Refrigerator					Cupboard					Built-in kitchen		Table	Chair
		Body	Door		Drawer		Body	Door		Drawer		Door	Drawer		
			without weight	with 3kg weight	without weight	with 3kg weight		without weight	with 3kg weight	without weight	with 3kg weight				
200	4	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	3	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	2.5	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	2	×	×	×	×	×	×	×	×	×	×	×	×	×	×
250	3	△	×	×	×	×	△	×	×	×	×	△	×	×	△
	2.5	△	×	×	×	×	△	×	×	×	×	△	×	×	△
	2	△	×	×	×	×	△	×	×	×	×	△	×	×	△
300	3	◎	×	×	×	△	●	×	×	×	×	○	○	×	○
	2.5	◎	×	×	×	△	●	×	×	×	×	○	○	×	○
	2	◎	×	×	×	△	○	×	×	×	×	○	○	×	○
350	2.5	◎	×	○	×	○	—	×	×	×	×	○	◎	○	○
	2	◎	×	○	×	○	●	×	×	×	×	○	◎	○	○
400	2	◎	×	◎	×	◎	—	×	△	×	△	○	◎	◎	◎
450	2	◎	×	◎	×	◎	—	×	△	×	○	○	◎	◎	◎

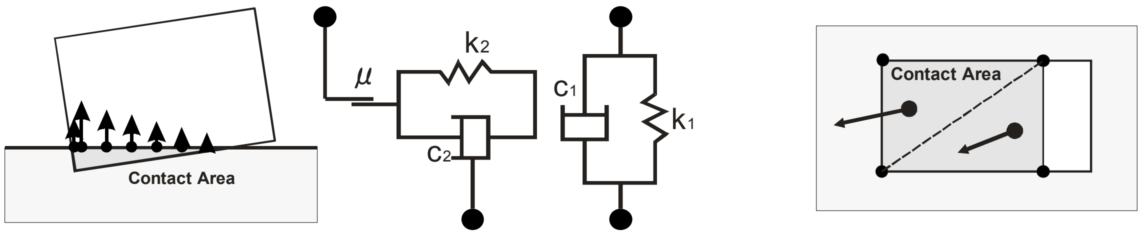
●:Overturned, ◎:Moved (more than 50cm), ○:Moved (10～50cm)
△:Slightly moved, ×:Not moved, —:Not tested

(a) Displaced refrigerator (b) Overturned cupboard

Figures 3. Examples of shaking table tests.

Simulation of Shaking Table Test

The behavior of the furniture in the shaking table tests is simulated by a rigid body simulation program called Springhead (Hasegawa and Sato 2004). Springhead computes contact forces by penalty method (Erleben et al. 2005). In Springhead, a contact area is divided into several triangle elements and springs and dampers are set at the triangle element (See Figs. 4), and the contact force for each element is computed and used in the simulation. Therefore, Springhead is able to calculate fast and accurately contact forces such as dynamic and static friction force. In the simulation, rolling mechanism such as a caster is also considered. Springhead use GJK algorithm (Gilbert et al. 1988) for the contact detection. GJK algorithm is able to detect fast the contact volume of arbitrary convex objects. Dynamic parameters of the furniture used in the simulation such as friction, spring and damper coefficients are determined from the comparison of the computed behavior with the behavior in the shaking table tests.



(a) Springs and dampers are set at contact area

(b) A contact area is divided into several triangle elements and the reaction force is computed for each element.

Figures 4. Schematic diagram of springhead.

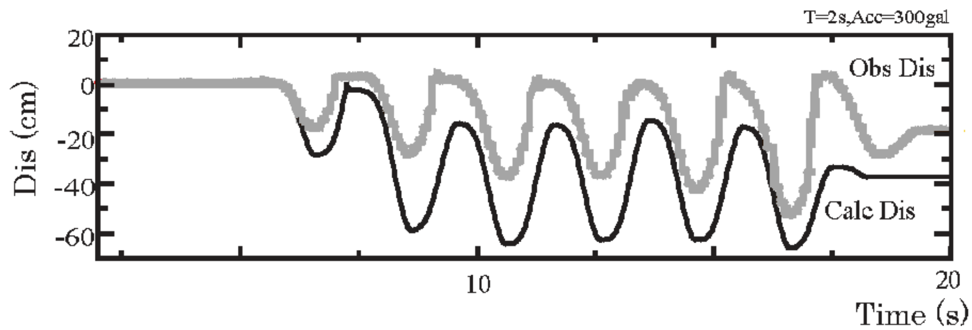


Figure 5. Comparison of shaking table test and simulation.

Figure 5 shows the comparison of shaking table test and simulation of the refrigerator shaken by 300 cm/s^2 with period of 2 seconds. The gray and black lines show the observed displacement of the test model in shaking table test and the computed displacement, respectively. Although larger rebounding due to a bump to the wall is seen in the simulation, the simulated displacement is consistent with the observed one. For the other cases, the agreements of the simulations with the observations are also confirmed.

Simulation of Seismic Behavior of Furniture at Kitchen

The behavior of furniture at an office room in an upper floor of high-rise buildings is simulated due to an anticipated giant earthquake. The simulated ground motion at Nagoya for the M8.3 Tokai-Tonankai earthquake (Chubu Regional Bureau, MLIT 2004) is used to calculate the floor response of the 30-story building. Figure 6 shows the time histories of the floor response at the 30 story. The floor response is about 0.5 *g* in peak

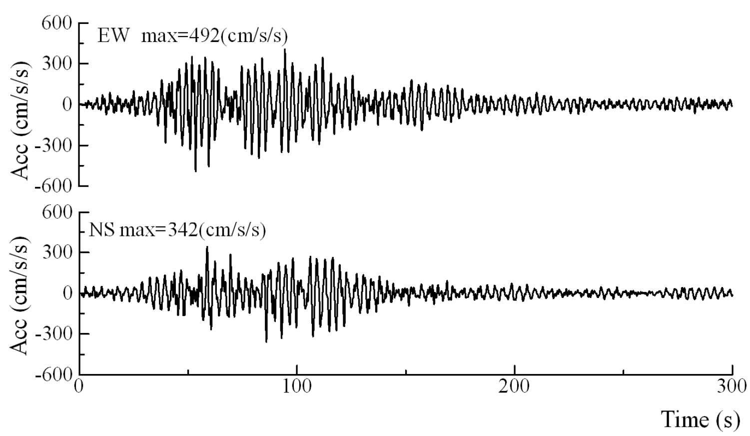
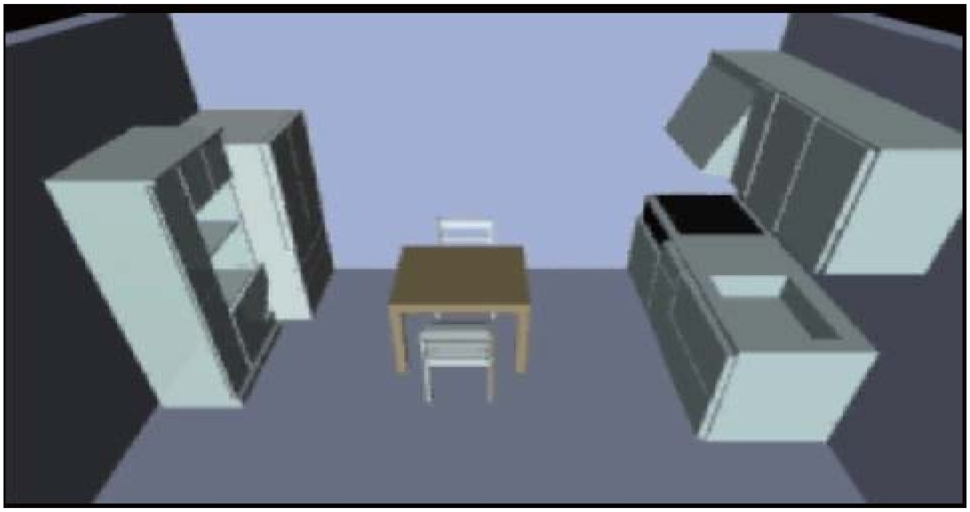
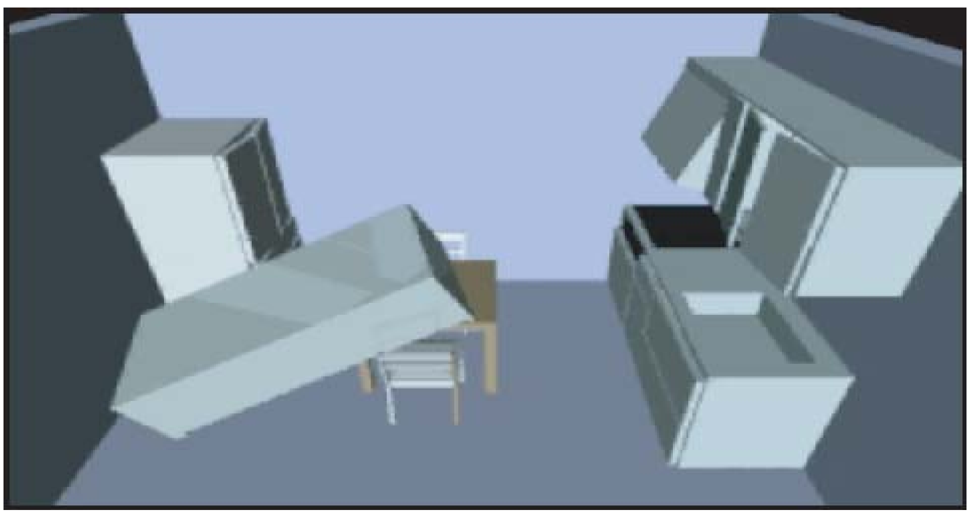


Figure 6. Time histories of floor response.

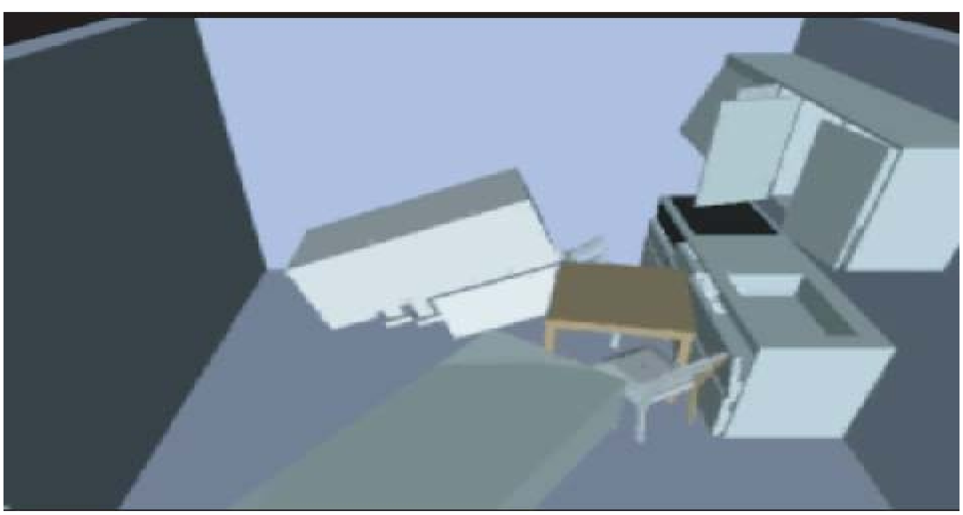
0 second



40 seconds



80 seconds



Figures 7. Behavior of kitchen furniture on upper floor of high-rise building.

acceleration and 170 cm/s in peak velocity. The duration time is longer than 100 seconds. The model of the simulation is constructed based on the standard kitchen space. The area of the model is 12 m^2. There are one cupboard, one refrigerator, one table, two chairs, and one built-in kitchen.

Figures 7 show the result of the simulation. The cupboard and refrigerator start the rocking vibration at 30 to 40 seconds after the beginning and overturns over the table at 40 to 50 seconds. They moved down from the table at 70 seconds and are displaced continuously. The doors of the built-in kitchen are opened at 40 seconds, and are opened and shut continuously. The displacements and open-and-shut are observed for 100 seconds. This behavior of the furniture may cause injury of people in the kitchen.

Conclusions

The behavior of kitchen furniture in a high-rise building due to long-period ground motions is examined in order to evaluate indoor seismic safety of high-rise residential buildings. The shaking table tests are conducted to understand fundamental behavior of furniture by long-period shaking. The behavior of the furniture in the shaking table tests is well simulated by a rigid body simulation program, indicating validity of the simulation method used. Then the behavior of a number of furniture is simulated at a kitchen on an upper floor of a 30-story high-rise building during an anticipated giant earthquake. Large displacements and continuous open-and-shut of doors are observed for 100 seconds. This behavior of the furniture may cause injury of people in the kitchen.

Acknowledgments

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