Shaking Table Test for Evaluation of Human Loss by Furniture during Strong Motion

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SUMMARY:
Shaking table tests were performed for the sake of evaluating human loss and injury caused by furnishings during strong earthquakes. Model furnishings were designed based on real furniture and the authors laid them on to the dummy doll on the shaking table under some input motions. The dummy doll was originally designed for crush test of automobiles and installed chest deformation sensor and head acceleration sensors. Tactile pressure sensor was also used for evaluating static load on the chest. It was clarified that in the case of heavy furniture, turnover onto the head and/or chest would lead human loss.

Keywords: Shaking table test, Indoor safety, Human loss

1. INTRODUCTION

In Kobe Earthquake, more than five thousand people crushed to death by furniture or debris from collapsed buildings. The possibility of next major earthquake, especially near field earthquake in Tokyo and Tokai, Tonankai, Nankai coupled earthquake is strongly concerned in Japan. Therefore, it is important to evaluate safety of rooms during strong motion. In this study, the authors tested dangerousness of turnover of furniture by using dummy doll and shaking table. Evaluation of human safety using dummy doll is common in automobile crush test (Automotive Engineers of Japan (2006)), and/or playground equipment safety evaluation (Consumer Product Safety Commission (1990)). Miyano et al. (2008) have tested static load and deformation of chest by dummy doll, but acceleration and velocity was still important remaining agenda. Uchida et al. (2010) used head model for evaluation of ceiling fall impact, however, impact of furniture has not evaluated yet, quantitatively. Therefore, the authors evaluated the human safety against turnover of furniture by using dummy doll with shaking table test.

2. SHAKING TABLE TEST

The authors performed shaking table test for three times for the sake of evaluating safety of human against turnover of furniture. The first test was performed in August, 2010 at Building Research Institute (BRI). Second one was performed in December, 2010 at BRI. Third one was performed in January 2012 at Fujita Technical Center at Atsugi, Japan.

2.1. Test on Static Load

The First test was performed on 26 and 27 August, 2010 at long stroke shaking table, BRI. Example photos are shown in Photo 1 and 2. Used test furnishings were bookshelf and television. Their outlines are listed in Table 1. Outline of input motions are shown in Table 2.

Secondary test was performed on 23 and 24 December, 2010 at long stroke shaking table, BRI. At this test, deformation of the chest was measured by using hi-speed video camera: 300 fps. However, it was clarified that quantitative evaluation of deformation of chest with video camera was very difficult. Therefore, the next third test was planned.

Photo 1. One scene of bookshelf turnover test.

Photo 2. One scene of television turnover test.

Table 1. Outline of the test pieces

	height	width	depth	mass	with book
Bookshelf	1.8 m	0.6 m	0.45 m	46 kg	68 kg
Television	1.1 m	0.9 m	0.45 m	30 kg (TV)	45 kg (TV table)
Dummy doll	1.7 m	-	0.22 m	75 kg	-

Table 2. Used input motions

No.	Name	Outline
1	Sine wave: T=4.0 s	Gradually increasing displacement
2	Sine wave: T=2.0 s	Gradually increasing displacement
3	Furumura-Saito	Expecting Tokai-Tonankai-Nankai combined motion at Shinjuku RC 40F
4	Sannomaru-Saito	Expecting Tokai-Tonankai-Nankai combined motion at Sannomaru RC 36F

2.2. Test on Head Acceleration and Chest Deformation

The third test was performed from 13 to 15 January, 2012 at Technical Center of Fujita Corporation, because the long stroke shaking table at BRI could not be used by aftermath of the 2011 Great East Japan earthquake. Used equipments are shown in Photo 3 and 4. In this test, acceleration meter of head centroid and deformation sensor of the chest were installed in the dummy doll.

Photo 3. Used bookshelf and closet.

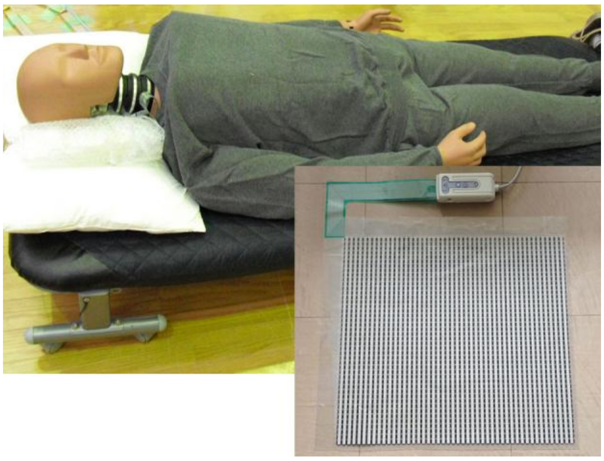


Photo 4. Dummy doll and installed sheet sensor.

Bookshelf and closet were designed expecting the worst case i.e., very heavy and would give critical damage to the human. Example photos are shown in Photo 5 and 6. Outline of the test pieces are shown in Table 3. In this test, because of the limitation of the stroke of the shaking table, input motion listed in Table 4 were used.

Photo 5. One scene of the test. (Bookshelf and bed)

Photo 6. One scene of the test. (Bookshelf and desk)

Table 3. Outline of the test pieces

	height	width	depth	mass	without weight	with book
Bookshelf	2.4 m	0.9 m	0.3 m	110 kg	92 kg	194 kg
Closet	1.8 m	1.2 m	0.6 m	180 kg	-	-
Dummy doll	1.7 m	-	0.22 m	77 kg	-	-

Table 4. Used input motions

No.	Name	Outline
1	Sine wave: T=1.43 s	Gradually increasing displacement
2	Sine wave: 0.6 m/s^2	Gradually increasing displacement
3	BCJ-L2 20F	Floor response of BCJ-L2 80%, at RC 20F, Rayleigh damping 2.0%
4	BCJ-L2 36F	Floor response of BCJ-L2 60%, at RC 36F, Rayleigh damping 2.0%
5	Tsukuda-Saito	Observed floor response of Great East Japan eq. at Tsukuda, RC 37F, 200%

3. METHOD OF EVALUATION

Main causes for death by furnishings are listed as asphyxiation by static load, injury by acceleration, and visceral burst by velocity of compression. The authors entertained following indexes for human injury evaluation.

3.1. Static Loading on the Chest

Load on the chest was measured by tactile sheet sensor every 1/80 second interval. The sensor was installed between sweatshirt and dummy doll.

3.2. Combined Acceleration at Head

The 3D acceleration meter was installed inside of the head of the dummy doll at the third test. The observation frequency was 5,000 Hz. The U.S. National Highway Traffic Safety Administration (NHTSA) and Consumer Product Safety Commission (CPSC) recommended that 200 G's would be the critical acceleration for human death (Automotive Engineers of Japan (2006)).

3.3 HIC Score for Head Injury

Head injury criterion (HIC) was defined by NHTSA as follows:

$$HIC = \max\left\{(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\} \tag{1}$$

where, $a(t)$ is combined acceleration at barycenter of head, $(t_2 - t_1)$ is time interval that indicates maximum value for HIC and no more than 15 milliseconds.

3.4. Chest Tolerance for Compression

The authors used following equation for relation between Abbreviated Injury Scale (AIS) and chest compression ratio C_{max} referring Automotive Engineers of Japan (2006).

$$AIS = -3.78 + 19.56 \cdot C_{max} \tag{2}$$

Relation between AIS scale and degree of injury is shown in Table 5, which is also after Automotive Engineers of Japan (2006).

Table 5. Relation between AIS scale and degree of injury (Automotive Engineers of Japan (2006))

AIS scale	Degree of injury
0	No injury
1	Minor injury
2	Medium injury
3	Serious injury
4	Critical injury
5	Moribundity
6	Death

3.5. Viscosity Criteria for Chest

Visceral burst is related velocity of compression of the chest. After Automotive Engineers of Japan (2006), the authors used following equation.

$$VC_{max} = \max[V(t) \cdot C(t)] \tag{3}$$

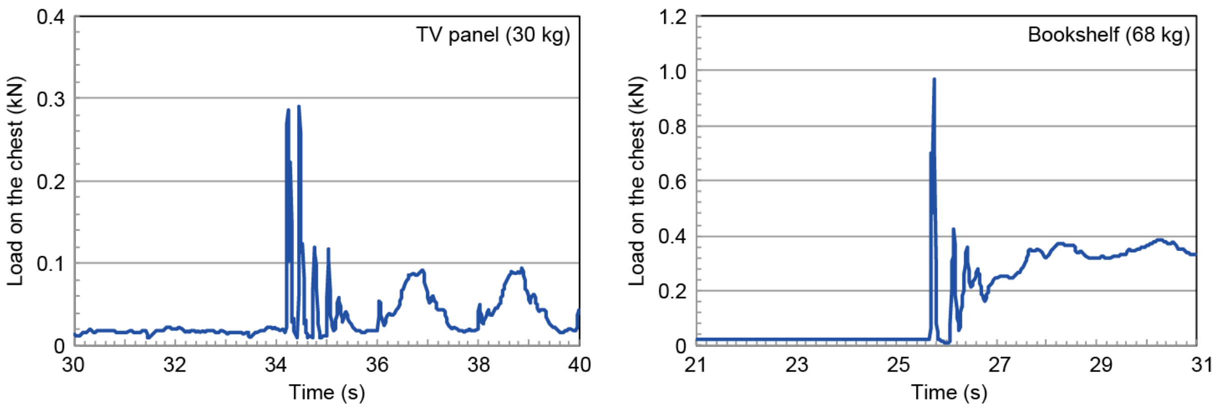
where, VC_{max} = 1 is equivalent to AIS = 4. $C(t)$ is compression ratio of the chest, $V(t)$ is expressed as follows using deformation of the chest $D(t)$:

$$V(t) = \frac{d[D(t)]}{dt} \tag{4}$$

4. TEST RESULTS

Figure 1 shows time domain process of load on the chest measured by tactile sheet sensor. Figure 1 (a) shows the case of TV panel. There seems the panel bounded 4 times between 34 second to 35 second of the test. The peak value in the bounce was almost the same as total weight of the panel, but in this case, that would be underestimation because the size of the panel was larger than the size of the sheet sensor. After the bounce, peak value was about 1/3 of panel weight. That means that 1/3 of panel weight was supported on the sensor area.

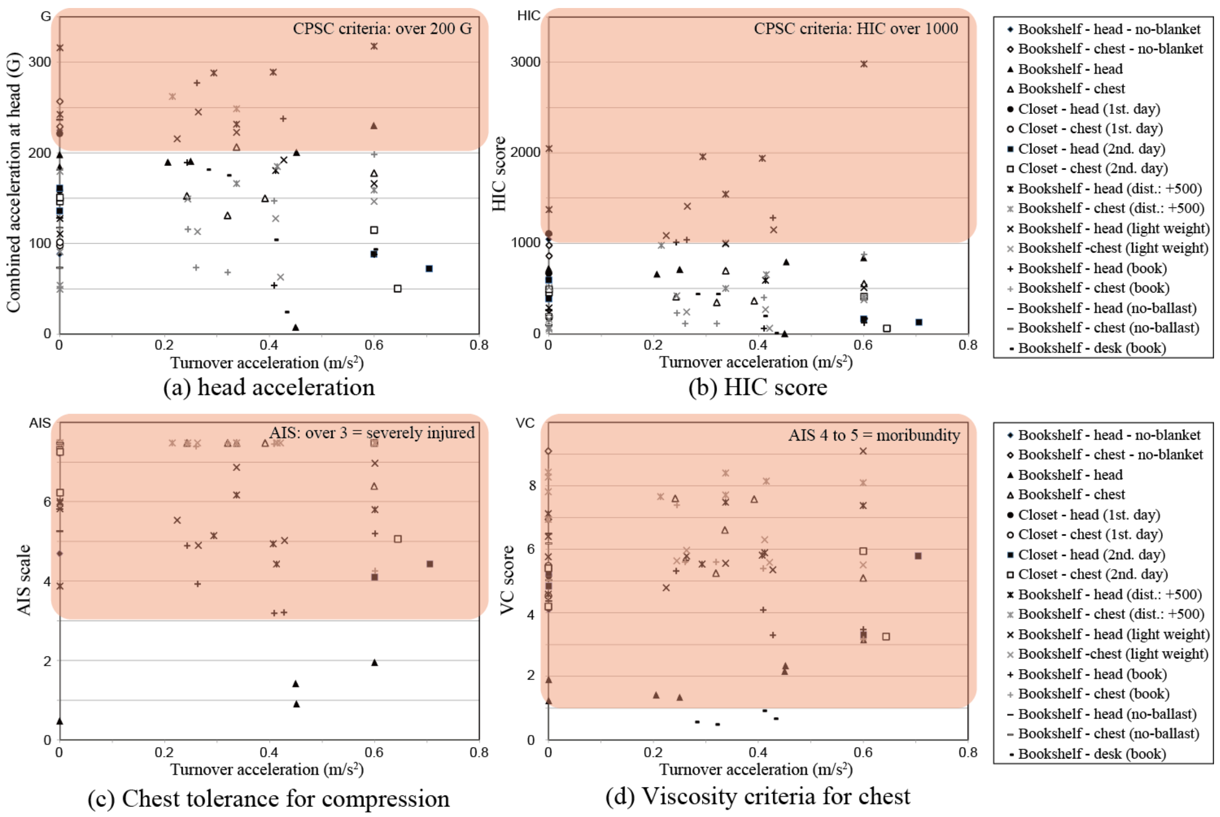
Figure 1 (b) shows the result of bookshelf. There seems the bookshelf bounded 3 to 4 times around the time of 26 second of the test. The peak value is almost 1.0 kN and the value is larger than total weight of the bookshelf. That would be the dynamic effect. After the bounce, the value indicates around 0.32 to 0.4 kN. That is consistent to the theoretical value of simple beam.



(a) TV panel turnover on the bed. (b) Bookshelf turnover on the bed.

Figure 1. Loads on the chest: Results of tactile sheet sensor.

The time interval of measurement by the tactile sheet sensor (1/80 second) was too rough to calculate velocity and acceleration of the impact, the third test was performed and the results are shown in Figure 2. Horizontal axes show the acceleration when the equipments overturned. Zero value means the case turnover by man-power with rope i.e., static test.



(a) head acceleration (b) HIC score

(c) Chest tolerance for compression (d) Viscosity criteria for chest

Figure 2. Comparison of some injury indexes for turnover of bookshelf and closet.

Figure 2 (a) shows the peak value of combined head acceleration during each test. 200 G's is the criterion for death by impact. Shelf board hits the head directly or not might be the difference of the result. Figure 2 (b) shows HIC score calculated by Equation (1). The largest value was indicated by the test that the distance of bookshelf and bed is far from normal position. That means that even when static load is smaller, impact would lead to death.

Figure 2 (c) shows AIS scale calculated by Equation (2). Except the case of bookshelf hits the head only, the value indicates 3 or over. That means in almost all the cases human get severe injury by turnover of heavy bookshelf or closet. In the worst case, the value indicates large enough to death. Figure 2 (d) shows VC score for visceral burst. Excepting the case of bookshelf with real book from behind to desk working, the value indicates over 1.0. That means in almost all the cases human get visceral burst by overturning of bookshelf and/or closet.

5. RESULTS

Shaking table tests were performed for the sake of evaluating human safety during strong motion. It was clarified that when heavy furnishings hit the head, it would lead human into death. For the chest tolerance, the test results were more severe than that for head. In almost all the case in the test, viscosity criteria indicate that turnover of furnishings lead to visceral burst of the human.

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REFERENCES

Automotive Engineers of Japan (2006), Impact Biomechanics for Engineers and Medical Staff, Automotive Engineers of Japan.

Consumer Product Safety Commission: CPSC Document #1005: Rubber Bounce Back Playground Surface, http://www.ncnwest.com/rbr/cpsc1005.htm

Miyano, M., Ikuta, E., Nagashima, F., Tanaka, H., Kajiwara, K., and Okuno, M. (2008), Study on Measurement Way of the Human Body Damage Caused by Earthquake - Dummy Development for Thoracic Compression Experiment -, Journal of Institute of Social Safety Science, No.10, pp.49-54.

Nakaizumi, H., Takahashi, T., and Saito, T. (2011), Development of Safe and Secure Environment in High-rise Residential Buildings against Large Earthquakes, Part 4 Possibility of chest injury caused by overturning of furniture, Summaries of the Technical Papers of Annual Meeting, Architectural Institute of Japan, Vol.B-II, pp.951-952.

Uchida, T., Kawaguchi, K., Ogi, Y., and Ohya, S. (2010), Fundamental Research on the Safety Criteria of Non-structural Components in Large Enclosures Using Human Tolerance Index, Part 3 Results of the experiments, Summaries of the Technical Papers of Annual Meeting, Architectural Institute of Japan, Vol.B-I, pp.881-882.