Seismic Loss of Functionality in High-Rise and Low-Rise Office Buildings: Server Room Damage of E-Defense test

S. Nagashima, K. Yoshida, H. Nishii, M. Suzuki & K. Toyota
NTT FACILITIES, INC., Japan

M. Yoshizawa, T. Nagae, K. Fukuyama, T. Inoue & K. Kajiwara
National Research Institute for Earth Science and Disaster Prevention, Japan

SUMMARY:
A shaking table test of high-rise and low-rise office buildings was conducted at the E-Defense three-dimensional shake table facility. The objectives of this experiment are to investigate the seismic loss of functionality of buildings due to interior space damage subjected to a subduction earthquake and a fault earthquake. The high-rise building is remodelled and scaled down to a steel frame specimen with three substitute layers which enables to achieve a 120m high building and also to achieve a 4-story building. This paper reports the seismic loss of functionality of telecommunications equipment which is installed in a server room of a building specimen. Focusing on the raised floors in a server room, types of server rack and methods of anchoring, verification and analysis of damage subjected to a great earthquake are studied.

Keywords: High and low rise building, Shaking table test, Loss of functionality, Telecommunications equipment

1. INTRODUCTION

In the 2011 Great East Japan earthquake (Mw 9.0) which occurred on March 11, the strong tremors with an intensity of 5-upper on Japanese seismic intensity scale were observed in Tokyo which is located far from the epicentre about 400km. Even though structural members of buildings in the metropolitan area were very little damage, the seismic loss of functionality of buildings due to damage of non-structural members and equipment was caused in a wide area. Damage of sprinkler-heads, fall of ceiling boards on upper floors, movement of furniture on casters such as a photocopy machine, and fall of books were caused by sympathetic vibration with long-period ground motion in high-rise buildings around Shinjuku area (Emerging problem of architecture, Hisada et. al. 2012). Considering to those damage examples, it is important to investigate the seismic loss of functionality of buildings subjected to a great earthquake which is more likely to occur in metropolitan area from the standpoint of maintaining urban functions.

Recently, we are heavily dependent on telecommunications equipment which has advanced and important functions, so it is necessary to maintain the function of telecommunications equipment subjected to a great earthquake. Even though the seismic-resistant capacity of telecommunications equipment is prescribed in the NTT standard, the NEBS standard and JIS C 6011-2 which are evaluation method using a shaking table test, these standards mainly target at middle and low rise seismic-resistant buildings. As it is increasing that telecommunications equipment is installed in long-period buildings such as high-rise and base-isolated buildings, it is necessary to obtain knowledge of maintaining the function of telecommunications equipment in long-period buildings.

In order to investigate the seismic loss of functionality of buildings due to interior space damages, shaking table test of high-rise and low-rise office buildings was conducted at the E-Defense. This test is a part of experimental research project, "Research Project on Damage Reduction Measure for Long-Period Ground Motion". The detail of project is shown in the companion paper (Yoshizawa et. al. 2012).

This paper reports the seismic loss of functionality of telecommunications equipment which is installed in the server room.

2. SPECIMEN

2.1. Description of the Building Specimen

The building specimen was designed and constructed to enable to achieve the same natural period of 3-4 seconds equivalent to a 120m high building and also to achieve the same natural period of 0.5-0.8 seconds equivalent to a 4-story building. The photograph of the building specimen is shown as Figure 1. The remodeled and scaled down method of high-rise building is shown as Figure 2. The 31-story building was remodeled and scaled down to three substitute layers, the mass 1 achieves the lower floor behavior and the mass 3 achieves the upper floor behavior. The substitute layers stiffness was adjusted by rubber bearings to fit to the same natural period. Figure 3 shows the elevation of the building specimen. In case of low-rise building test, the substitute layers were fixed with steel members. The detail of building specimen is shown in the companion paper (Yoshizawa et. al. 2012).

Figure 1. Building specimen

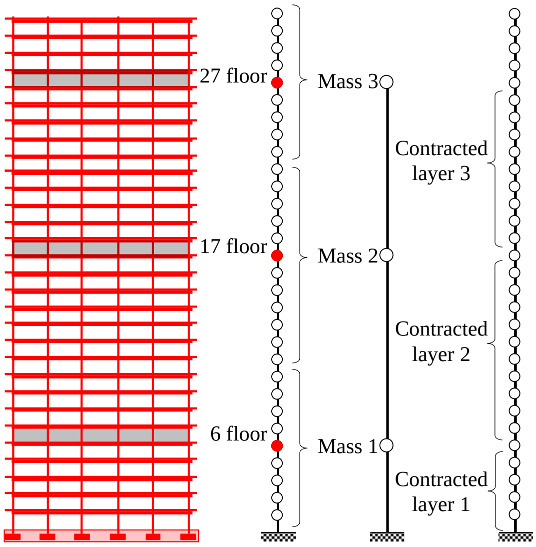
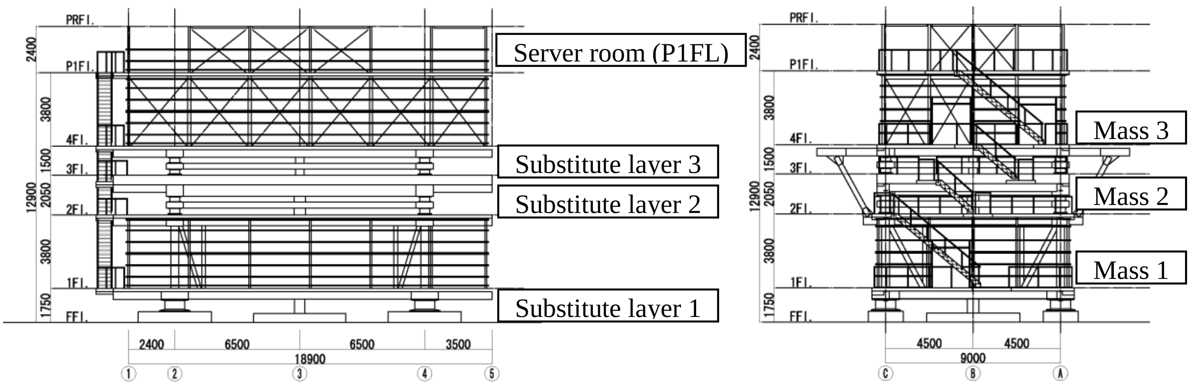


Figure 2. Remodeled and scaled down method of high-rise building



Long sides of the building specimen (Y-direction)   Short sides of the building specimen (X-direction)

Figure 3. Elevation of the building specimen

2.2. Description of the Telecommunications Equipment

The server room was set up on the P1FL of the building specimen. Assuming the server room in the office, telecommunications equipment was installed on the 450mm high raised floor. Fitting to the condition of real buildings, the floor slab was coated with a dust-proof paint. Figure 4 shows the photograph of the server room. Figure 5 shows the elevation of the telecommunications equipment.

Table 1, 2 shows the description of server rack and telecommunications equipment.
An aluminum rack mount raised floor for a dedicated server room (Type A), a steel rack mount raised floor for a dedicated server room (Type B) and a normal raised floor (Type C) were set up. Each type is commonly used in server rooms in Japan. The server racks were anchored to the raised floor with bolt, turnbuckle and Z-shape hardware. For incorrect set up example of server rack and raised floor, non-anchoring rack (Type C-3), seismic isolation table on the upper floors in the high-rise building (Type D) and raised floor which is lost adhesive force due to age-related deterioration were set up. Four kinds of rack which have different seismic capacity were installed on the raised floor. Except for air-conditioning equipment, server rack's mass was adjusted to mount steel plates.
32 channels of acceleration data were collected in the server room.

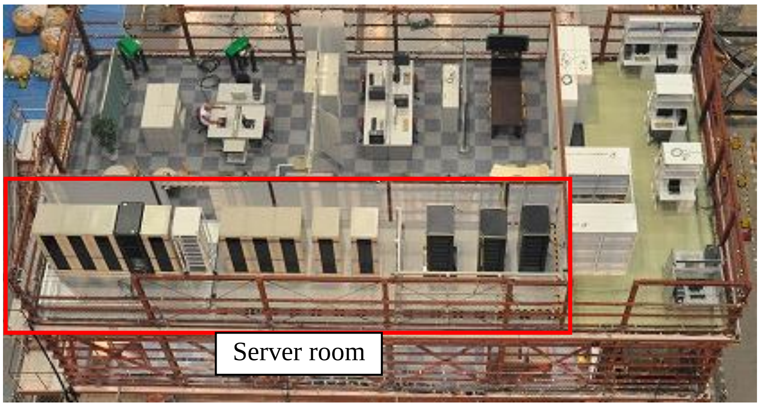


Figure 4. Server room

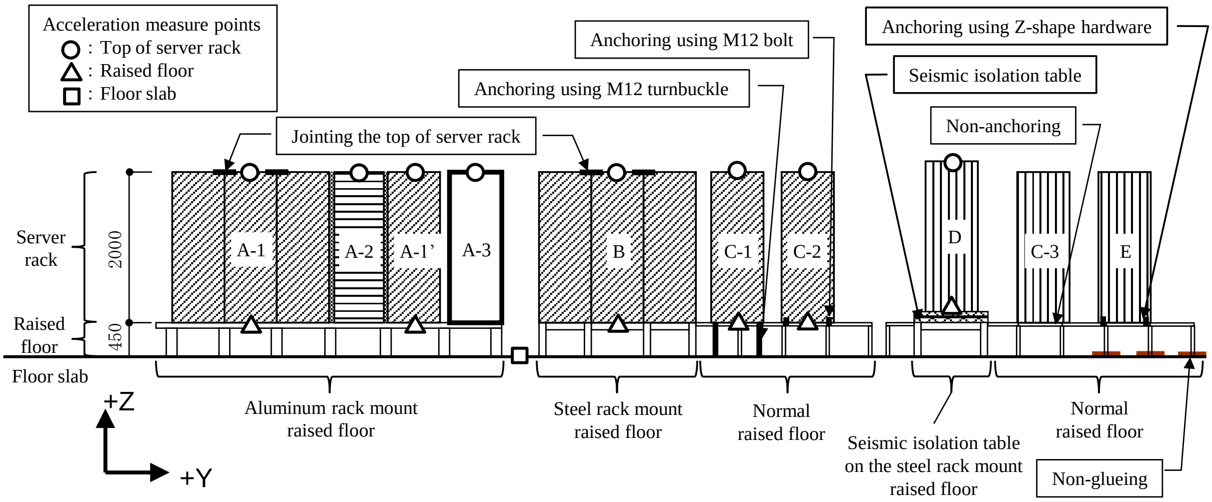


Figure 5. Elevation of the telecommunications equipment

Table 1 Description of server rack

Server rack type	Width × Depth × Height (mm)	Gross mass (N)	Side panel and door
Seismic-resistant type	700×900×2000	4903	Solid side panels, Plexiglass Door
Normal type	700×917×2000	2942	Vented Side Panels, Perforated Door
Open type	698×879×2000	2942	
Air-conditioning equipment	600×1017×2000	4364	Solid side panels, Perforated Door

Table 2 Description of the telecommunications equipment

Type	Raised floor	Server rack type	Anchoring method	
			Between rack and raised floor	Between raised floor and floor slab
A-1	Aluminum rack mount for a dedicated server room	Seismic-resistant type Jointing the top of rack	Anchoring at each corner using M12 bolt	Anchoring using M12 post-installed anchor
A-1'		Seismic-resistant type		
A-2		Air-conditioning equipment		
A-3		Open type		
B	Steel rack mount for a dedicated server room	Seismic-resistant type Jointing the top of rack	Anchoring at each corner using M12 bolt	Anchoring using M12 post-installed anchor
C-1	Normal raised floor	Seismic-resistant type	Between rack and floor slab; anchoring at each corner using M12 turnbuckle Between turnbuckle and floor slab; anchoring using M10 post-installed anchor	
C-2		Seismic-resistant type	Between rack and raised floor panel; anchoring at each corner using M12 bolt	Glueing using adhesive
C-3		Normal type	Non-anchoring	Glueing using adhesive
D	Seismic isolation table on the steel rack mount	Normal type	Between rack and seismic isolation table and raised floor; anchoring at each corner using M12 bolt	Anchoring using M12 post-installed anchor
E	Normal raised floor lost adhesive force	Normal type	Between rack and panel; anchoring at each corner using Z-shape hardware	Non-glueing

3. INPUT EARTHQUAKE

The shaking table tests were conducted using three kinds of input earthquake waves. As long-period ground motion, the record of the 2011 Great East Japan earthquake observed in Nishi-Shinjuku observation point, which is one of the Metropolitan Seismic Observation network (MeSO-net), was adopted. Even though the 2011 Great East Japan earthquake caused large tsunami, it is said that the main-shock did not excite long-period components. Therefore, in addition to the main-shock, the record of after-shock (Ibaraki-ken Oki earthquake (M7.7) which occurred about one-half hour after the main-shock) observed in Nishi-Shinjuku was adopted. It is considered that the record included long-period components which are assumed in the metropolitan area. However this after-shock record showed low level of long-period components, so the adopted record had to be increased magnitude to achieve conditions. In order to obtain the comprehensive knowledge of the seismic loss of functionality of buildings due to interior space damage, the record of the 1995 Hyogo-ken Nanbu Earthquake (JMA-Kobe), which included short-period components, was adopted (Yoshizawa et. al. 2012). The shaking table test was conducted in the order of table 3.

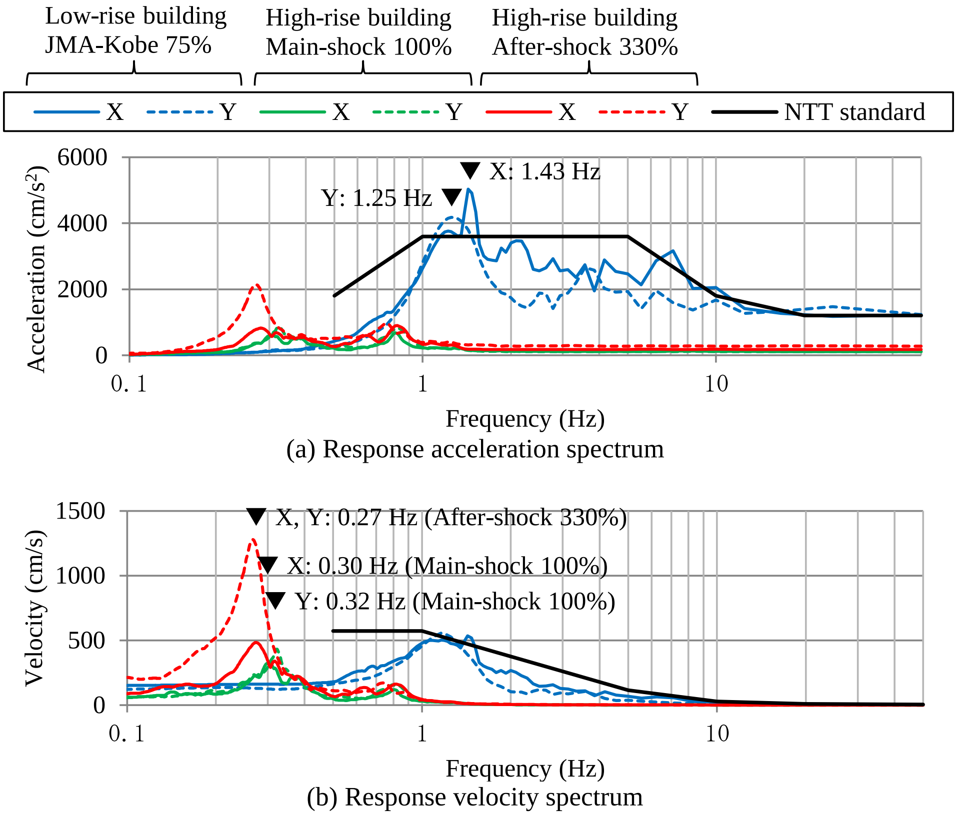
Table 3 Experimental schedule

Building specimen	Date	Input earthquake wave	Maximum acceleration (cm/s^2)	Maximum velocity (cm/s)
High-rise building	2011/10/4	JMA-Kobe 25%	223	26
		Main-shock 50%	49	8
		Main-shock 100%	98	17
		After-shock 150%	52	20
	2011/10/7	After-shock 75%	26	10
		After-shock 330%	114	44
Low-rise building	2011/10/12	After-shock 330%	114	44
		JMA-Kobe 25%	223	26
		JMA-Kobe 50%	445	53
		JMA-Kobe 75%	668	79

4. RESULT OF SHAKING TABLE TEST

4.1. Spectral analysis

Using the measured acceleration data on the P1FL, the response spectrum was calculated. Figure 4 shows the comparison of the response spectrum of the main-shock of 100% and the after-shock of 330% in the high-rise building, the JMA-Kobe of 75% in the low-rise building and the NTT standard spectrum.
In the low-rise building, the frequencies of the maximum amplitudes are 1.43 Hz on the X, and 1.25 Hz on the Y direction, which is shown as Figure 6 (a). The response spectrum of the JMA-Kobe of 75% is nearly enveloped by the NTT standard spectrum.
In the high-rise building, the frequencies of the maximum amplitudes are 0.30 Hz on the X and 0.32 Hz on the Y direction (Main-shock 100%), 0.27 Hz on the X and Y direction (After-shock 330%), which is shown as Figure 6 (b). The frequencies of the maximum amplitudes are outside of the range of the NTT standard spectrum and the maximum amplitude of Y direction (After-shock 330%) is very large.



(a) Response acceleration spectrum

(b) Response velocity spectrum

Figure 6. Comparison of the response spectrum (P1FL h=3%)

4.2. Vibration Characteristics analysis

A white-noise loading with $50 cm/s^2$ in three directions was conducted before the test and after the all test in a day. Using the measured data of the white-noise loading, the frequency transfer function of server racks was calculated and the natural frequency was estimated. Figure 7 shows the change of the natural frequencies. Even though the design natural frequency of type D is 0.17 Hz, the clear natural frequency was not estimated from the frequency transfer function. Additionally the part of the clear natural frequencies of type A-2, A-3 was not estimated. In the high-rise building, there was little change of the natural frequencies between before test and after test. But, in the low-rise building, the natural frequencies changed into lower. It is estimated that a server rack and a raised floor were occurred a little looseness and damage.

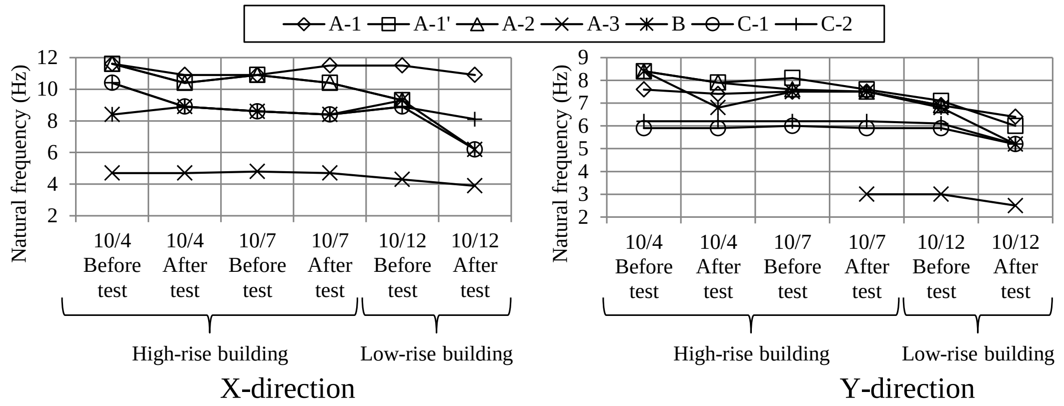


Figure 7. Change of the natural frequencies

4.3. Maximum response acceleration, damage and situation

The maximum response acceleration is shown in figure 8, 9. The damage situation of server rack and raised floor are shown in table 4. In the high-rise building, the maximum response acceleration was 174-263 cm/s^2 at the floor slab and 177-304 cm/s^2 at the top of rack (After-shock 330%), which is shown as Figure 8 (a). Because the After-shock has little short-period components, the maximum response acceleration is small and the increase of acceleration from floor slab to top of rack is little (1.33 times). But in case of type D, the seismic isolation table move to outside of allowed deformation (335 mm) and collided with a stopper. The colliding maximum response acceleration was 8034 cm/s^2, which is shown as Figure 8 (b). Even though the door was opened and the door hinge was damaged when the collision occurred, seismic isolation table and steel rack mount raised floor were no damage (Figure 10 (a), (b)). Additionally the server rack did not fall down, because the server rack and the seismic isolation table were anchoring using M12 bolts.

In the low-rise building, the maximum response acceleration was 1090-1115 cm/s^2 at the floor slab and 1739-3692 cm/s^2 at the top of the rack (JMA-Kobe 75%), which is shown as Figure 9 (a). The maximum response acceleration is very large and the increase of acceleration from floor slab to top of rack is 1.56-3.39 times. So large horizontal force and overturning moment occurred at the rack. In the type A-3, the crack occurred at the welded part of server rack’s frame and the residual deformation occurred (Figure 10 (c)). In the type C-2, flaking at five column bases occurred between paintwork and floor slab after test observation of raised normal floor (Figure 10 (d)). In the type C-3, rocking motion and move of server rack occurred. In the type E, Z-shape hardware was caused damage and rocking motion and move of server rack occurred (Figure 10 (e)). In the type D, the maximum response acceleration was 399-855 cm/s^2 at the floor slab and 247-628 cm/s^2 at the top of rack (JMA-Kobe 25, 50%), which is shown as Figure 9 (b). Because of the effect of seismic-isolation, the acceleration of the top of rack is 0.59-0.76 times smaller than floor slab. In case of JMA-Kobe of 75%, type C-3 collided with type D, so the acceleration of the top of rack is larger than floor slab.

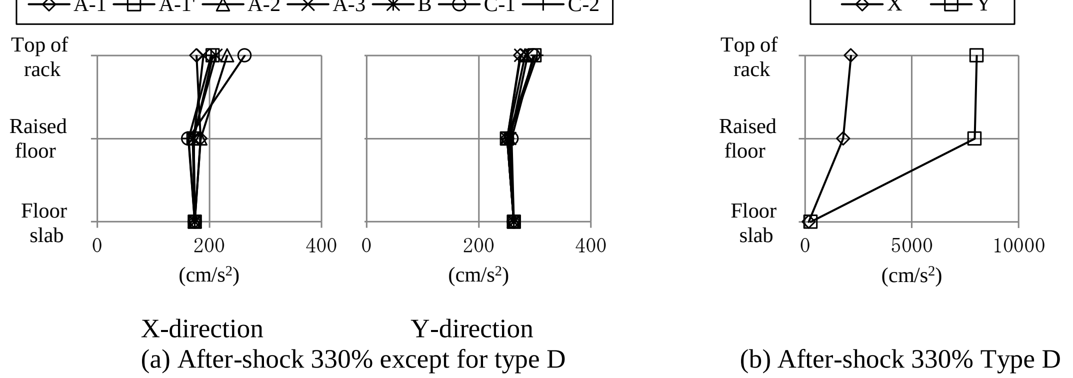
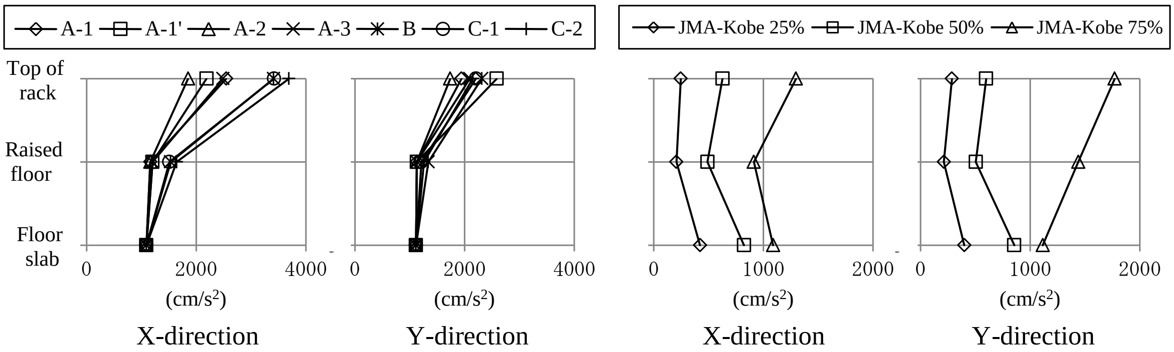


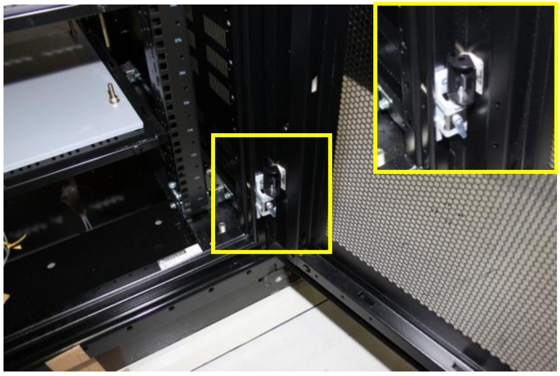
Figure 8. Maximum response acceleration in the high-rise building



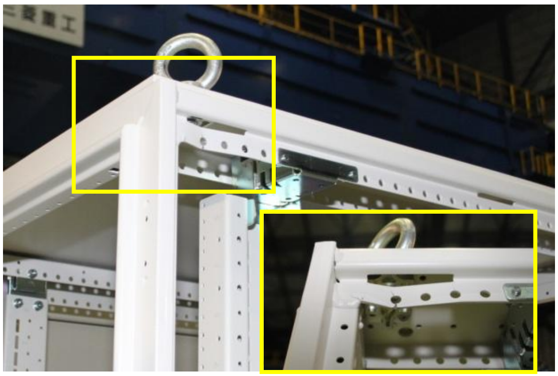
(a) JMA-Kobe 75% except for type D (b) JMA-Kobe 25, 50, 75% Type D

Figure 9. Maximum response acceleration in the low-rise building

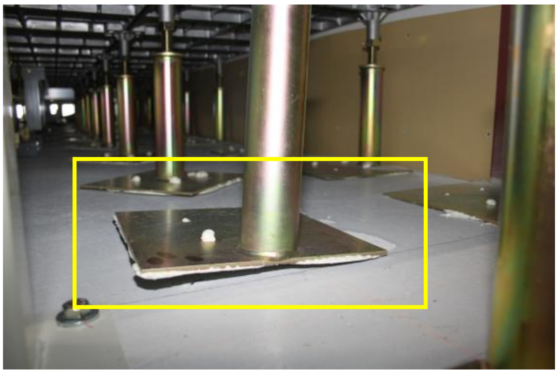
(a) Open of the door (After-shock 330%)



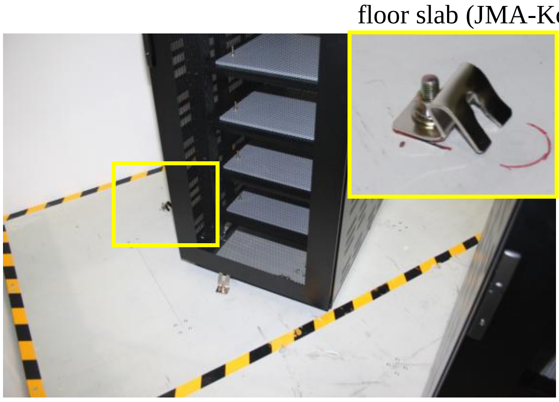
(b) Damage of the door hinge (After-shock 330%)



(c) Crack of welded part of rack (JMA-Kobe 75%)



(d) Flaking of column bases between paintwork and floor slab (JMA-Kobe 75%)



(e) Damage of Z-shape hardware and move of rack (JMA-Kobe 75%)

Figure 10. Various damage of telecommunications equipment

Table 4 Damage situation

Type	High-rise building	Low-rise building
A-1, A-1', B, C-1	No move and no damage of the server rack and the raised floor	
A-2	No move and no damage of the server rack and the raised floor No change of the pressure in the refrigerant pipe	
A-3	No move and no damage of the server rack and the raised floor	No damage of the raised floor Crack of the welded part of server rack's frame Residual deformation of the server rack
C-2	No move and no damage of the server rack and the raised floor	Flaking of the column bases between paintwork and floor slab
C-3	No move and no damage of the server rack and the raised floor	No damage of the raised floor Rocking motion and move of the server rack
D	Colliding with a stopper of the seismic isolation table outside of the allowed deformation Open of the door and damage of the door hinge No damage of the seismic isolation table and the raised floor	Reducing acceleration because of seismic-isolation effect (except for JMA-Kobe 75%)
E	No move and no damage of the server rack and the raised floor	Damage of the Z-shape hardware Rocking motion and moving of the server rack

5. CONCLUSION

In order to investigate the seismic loss of functionality of telecommunications equipment, a shaking table test was conducted. As existing seismic-resistant standards are mainly target at middle and low rise buildings, it is confirmed that another evaluation method is needed targeting at long-period buildings.
In the high-rise building, equipment which have long natural period, such as seismic isolation table, vibrated sympathetically with long-period ground motion, so it moved to outside of allowed deformation and collided with a stopper. It is considered that the seismic loss of functionality of telecommunications equipment is caused by the colliding large acceleration.
In the low-rise building, it is considered that telecommunications and power cables are damaged by the move of the server rack which is not enough anchored.
For the future, verifying a real damage, we study a quantitative evaluation of loss of functionality of telecommunications equipment.

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