



# BEHAVIOR OF NONSTRUCTURAL COMPONENT SUPPORTED BY HANGER BOLTS UNDER SEISMIC EXCITATIONS BY SHAKING TABLE TEST

HAEYOUNG KIM<sup>1</sup>, KUNIO MIZUTANI<sup>2</sup>, and SYOJIRO MOTOYUI<sup>3</sup>

<sup>1</sup>*Dept of Civil Engineering, Yokohama National University, Yokohama, Japan*

<sup>2</sup>*Dept of Architectural Engineering, Tokyo Polytechnic University, Atsugi, Japan*

<sup>3</sup>*Dept of Architectural Engineering, Tokyo Institute of Technology, Yokohama, Japan*

During the Great East Japan Earthquake of March 2011, nonstructural components, such as pipe systems, ducts, cable racks and ceilings were severely damaged while main structural members in the building were not damaged seriously. Pipes, cable racks, apparatus and ducts' hanger bolts were ruptured causing the equipment to fall down. Because of these damages, buildings cannot be used for a long period of time and one person was killed by pipe's falling in Japan. In this study, the behaviors of nonstructural components are investigated by conducting shaking table tests to verify the cause of damage. More specifically, damage to hanger bolts is investigated by simulating its rupturing mechanism through shaking table test. To simulate the real installation condition of nonstructural components, apparatus-duct-pipe system supported by hanger bolts is selected as specimen. Roof floor response wave at the actual 5-story steel building under the Great East Japan Earthquake and sweep wave are used for the input waves. The maximum response acceleration was about 4 G in X direction under response wave 75% and the damage occurred at the metal fitting which is the connection part between braces and hanger bolt. And without installing braces, the upper hanger bolts at the fixed supporting part were ruptured easily since the natural frequency of the specimen closed to those of target building during excitations and the response became huge.

*Keywords:* Great East Japan earthquake, Apparatus-duct-pipe system, Rupturing mechanism.

## 1 INTRODUCTION

Under the Great East Japan Earthquake of March 2011, the damage on the nonstructural components was seen in many buildings as shown in Figure 1 summarized from Mizutani and Kim (2012, 2013). By the Japan Building Mechanical and Electrical Engineers Association (JBMEE) and the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE), the questionnaire from members and company of these associations was performed about the nonstructural components damage caused by this earthquake disaster. We analyzed the data from questionnaire. The rate of nonstructural components damage factor is shown in Figure 2(a). The damage report by shaking is as the highest as 87%, and the damage report according the damage caused by ground subsidence and liquefaction to 6% and tsunami has become only 1%. In addition, the damage case, which is hit by tsunami to the whole building, is not included in this questionnaire. The damaged equipment is classified into the air conditioning equipment,

plumbing equipment, electric equipment, fire protection equipment, and elevators, and the rate is shown in Figure 2(b). For the characteristics of damage, the rupture of the hanger bolt, which supported the facilities or duct or plumbing from a slab floor, many were seen. Therefore, in this study, the damage to hanger bolts is investigated by simulating its rupturing mechanism through shaking table test.

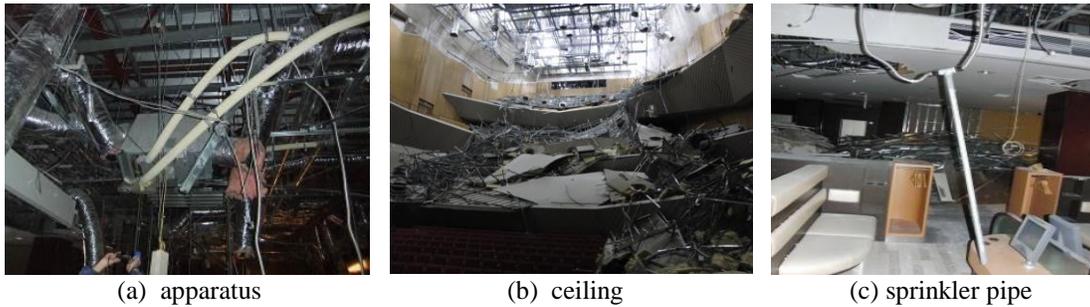


Figure 1. Damages on the nonstructural components.

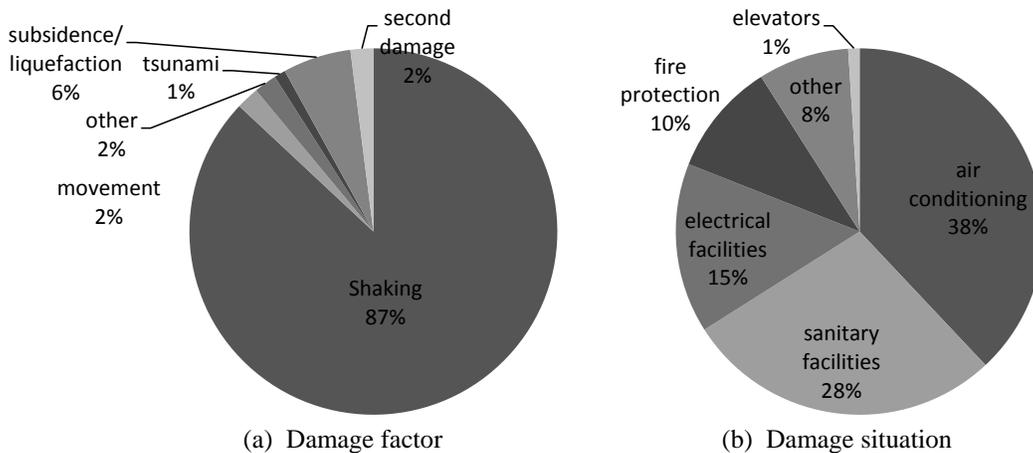


Figure 2. Damage situation.

## 2 SHAKING TABLE TEST

### 2.1 Experiment Outline

To simulate the real installation condition of nonstructural components, apparatus-duct-pipe system supported by hanger bolts is selected as specimen as shown in Figure 3. The shaking table and the installed apparatus-duct-pipe system are shown in Figure 4 (a) and (b), respectively. The braces installed in each side of the apparatus's hanger bolt with X-shape shown in Figure 4 (c). Table 1 shows the outline of each specimen.

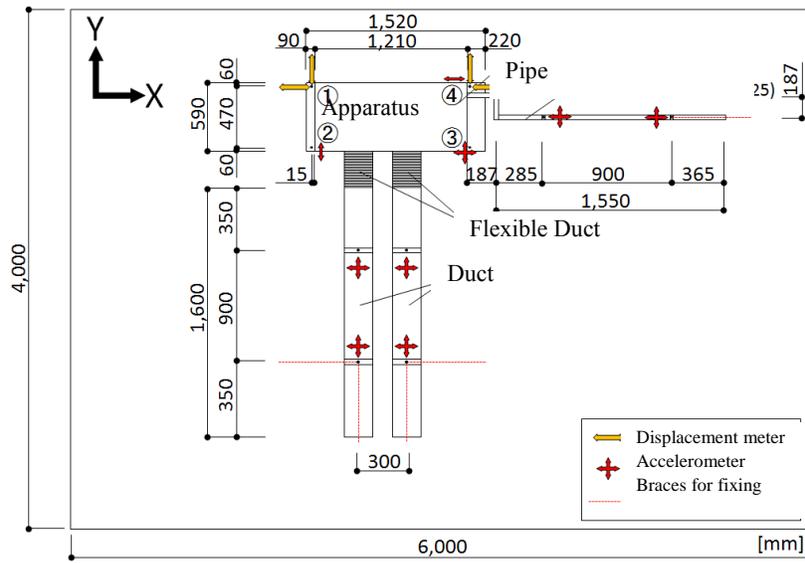


Figure 3. Plan view of specimen (apparatus-duct-pipe system).



Figure 4. View of shaking table.

Table 1. Outline of each specimen.

Specimen	Hanging length	Weight	No. of hanger bolt	Size of hanger bolt
Apparatus	600 mm	57.5 kg	4	W3/8
Duct	360 mm	4.5 kg	2	W3/8
Pipe	400 mm	1.5 kg	2	W3/8

## 2.2 Experiment Method

The target building was selected as the low-rise steel frame building which was seen many damages of ceiling and apparatus during the Great East Japan earthquake. It is the fifth stories steel frame building located in Hitachi City, Ibaraki Prefecture. The response of the roof floor of the target building as shown in Figure 5, obtained by the earthquake response analysis is used as the input wave. Figure 6 shows the response spectrum of the input wave and it contains two peak frequencies which are the 1<sup>st</sup> and 2<sup>nd</sup> frequencies of the target building. Those are 1.1 Hz and 3.57 Hz. Input waves are shown in Table 2. After exciting every response wave, the sweep wave is used for investigating the natural frequency of specimen. Table 3 shows the changes of the natural frequency of specimen. It was changed from 2.807 Hz to 2.624 Hz because of weakened stiffness of hanger bolts after exciting the response waves.

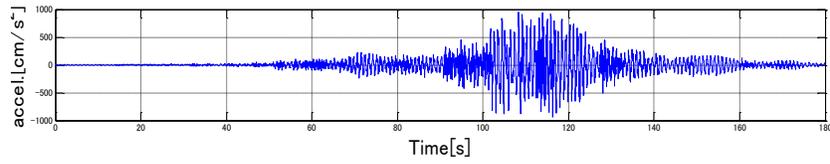


Figure 5. Response wave.

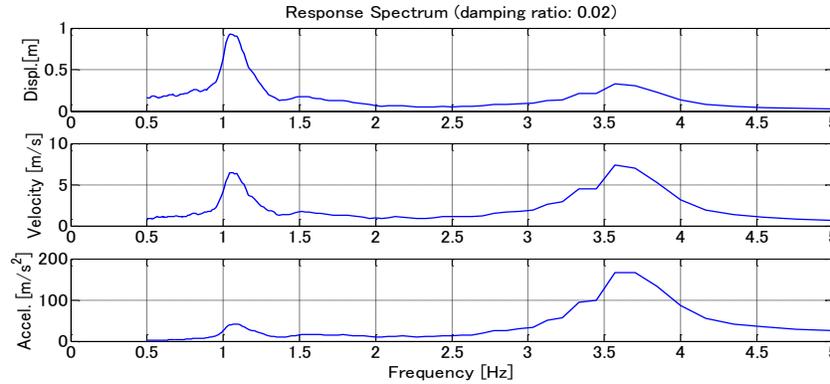


Figure 6. Response spectrum of the response wave.

Table 2. Input waves.

No.	Name	Input wave	Remarks
1	sweep1	sweep wave 1	0.2Hz~2.5Hz, 30 gal
2	RW25	response Wave 25%	Max. 0.3 G
3	sweep2	sweep wave 2	0.2Hz~2.5Hz, 30 gal
4	RW50	response Wave 50%	Max. 0.6 G
5	sweep3	sweep wave 3	0.2Hz~2.5Hz, 30 gal
6	RW75	response Wave 75%	Max, 1.2 G
7	sweep4	sweep wave 4	0.2Hz~2.5Hz, 30 gal

Table 3. Changes of the natural frequency of the apparatus.

Input wave	Natural frequency	Natural period	Remarks
sweep1	2.807 Hz	0.356 s	initial condition
sweep2	2.807 Hz	0.356 s	after exciting the RW25
sweep3	2.750 Hz	0.364 s	after exciting the RW50
sweep4	2.624 Hz	0.381 s	after exciting the RW75

### 3 EXPERIMENT RESULTS

#### 3.1 The Responses under the Response Waves

The maximum responses of specimen are shown in Table 4. There is a gap between the apparatus and the hanger bolt and it is about 15 mm as shown in Figure 7. If the response displacement is larger than this gap, the apparatus impacts the hanger bolt. Under response wave 25%, the response displacement was about 20 mm and the impacting occurred 25 times. The maximum

response acceleration was about 1.5 G and the maximum restoring force on hanger bolts was about 1.2 kN. After exciting RW25, there were no released bolts and the natural frequency was same as one in the initial condition. Under response wave 50%, the impacting between the apparatus and the hanger bolt was occurred 70 times. The maximum response acceleration was about 3 G and the maximum restoring force on hanger bolts was about 2 kN. After exciting RW50, some released bolts were seen in the connection part of brace and hanger bolt. And the natural frequency became low from 2.807 Hz to 2.750 Hz. Next, under response wave 75%, the maximum response displacement was about 27 mm and the impacting between the apparatus and hanger bolts was occurred about 116 times. The maximum response acceleration was about 4 G in X direction and about 1 G in Y direction. The relationship between restoring force and relative response displacement at each hanger bolt is shown in Figure 8. The impacting at the hanger bolt 1 was occurred severely and the restoring force reached 1.5 kN at the hanger bolt 1. The apparatus is connected with the pipe and ducts. It caused the apparatus vibrated in torsional motion and the hanger bolt 1 was loaded severely. As shown in Figure 8, the stiffness of the apparatus became very high after impacting and it caused the hanger bolt was loaded to the horizontal direction excessively. After exciting RW75, there were released bolts in the connection part of brace and the metal fittings were stretched. The natural frequency became 2.624 Hz.

Table 4. Maximum responses under RW25 and RW50.

Input	Input level	Max. accel.	Max. restoring force	Numbers of impacting
RW25	0.3 G	1.5 G	1.2 kN	25
RW50	0.6 G	3 G	2 kN	70
RW75	1.2 G	4 G	3 kN	116

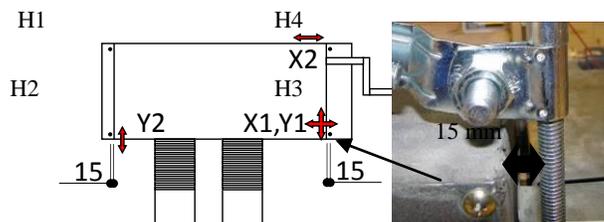


Figure 7. Gap between apparatus and hanger bolt.

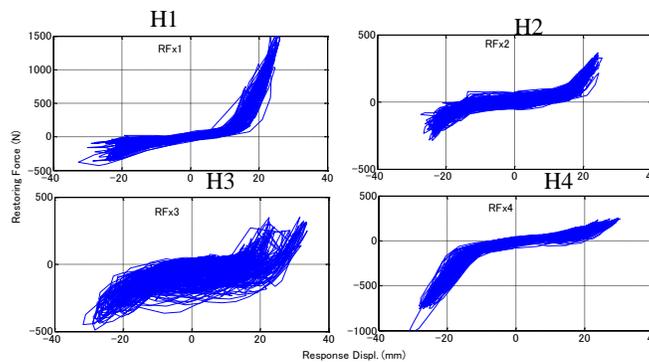


Figure 8. Relation between restoring force and displacement at each hanger bolt under RW75.

### 3.2 The Responses under the Sine Wave

After exciting the response wave 75%, the bolts and nuts were released on the connection parts of braces and hanger bolts and metal fittings were stretched. We considered the braces didn't work out any more. Therefore, we took the all braces off. And the natural frequency of the apparatus became 1.75 Hz. To investigate the failure of specimen, the sine wave, which contains 1.75 Hz was used as input wave. As a result, the hanger bolt 1 at the apparatus was ruptured on the upper fixed part after only 10 seconds. Figure 9 shows the response acceleration. The pipe was put out of joint and the flexible ducts were ruptured. This situation of failure was seen many in the apparatus-pipe-duct system under the Great East Japan Earthquake.

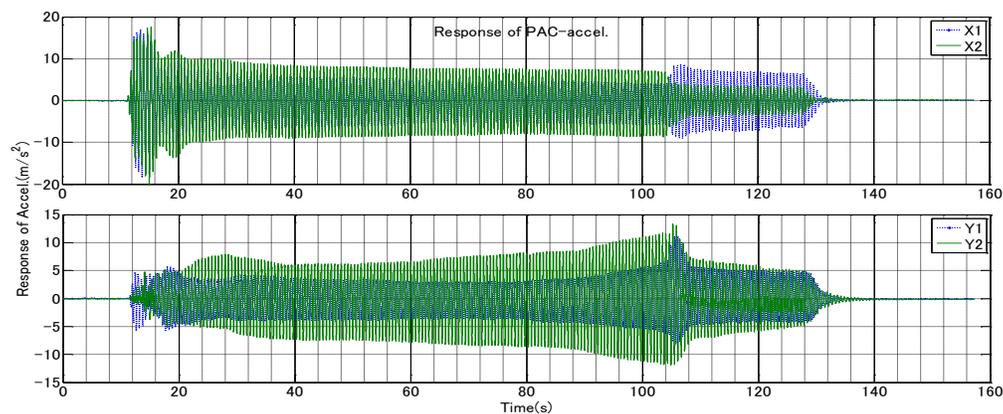


Figure 9. Response acceleration of apparatus w/o braces under sine wave.

## 4 CONCLUSIONS

In this study, the behaviors of nonstructural components are investigated by conducting shaking table tests to verify the cause of damage. To simulate the real installation condition of nonstructural components, apparatus-duct-pipe system supported by hanger bolts is selected as specimen. We found that the damage occurred at the metal fitting which is the connection part between braces and hanger bolt. And without installing braces, the upper hanger bolts at the fixed supporting part were ruptured easily because the natural frequency of the specimen closed to those of the target building during excitations, and the response became huge.

### Acknowledgments

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### References

- Mizutani, K. and Kim, H., *The Damage of the Building Equipment under The 2011 Tohoku Pacific Earthquake*, 9th International Conference on Urban Earthquake Engineering, 6-8, March, 2012.
- Mizutani, K. and Kim, H., *Behavior of Building Equipment Under Seismic Excitations*, 10th International Conference on Urban Earthquake Engineering, 1-2, March, 2013.