DAMAGE TO NON-STRUCTURAL COMPONENTS IN LARGE ROOF BUILDINGS FAILED DURING AN EARTHQUAKE IN SURUGA-BAY ON 11 AUGUST 2009

Yoshiro OGI[1], Yasushi OBA[2] and Ken'ichi KAWAGUCHI[3]

ABSTRACT: This paper reports investigation results of large roof buildings whose non-structural components had failed during an earthquake in Suruga-Bay of Japan on August 11, 2009. While very little damage to building skeletons was reported, some failures of non-structural components, such as big louvers, ceiling panels, and lighting equipment, were observed. Such failures had occurred even in the area like Shizuoka where the occurrence of future major earthquakes had been expected for long, with high probability.

Key Words: *Earthquake, Large roof building, Non-structural component, Louver, Ceiling, Lighting equipment*

INTRODUCTION

This paper reports investigation results of large roof buildings whose non-structural components had failed during an earthquake in Suruga-Bay of Japan on August 11, 2009. While the fall of an expressway through Shizuoka Prefecture was widely reported, very little damage to building skeletons was observed. In several pubic large roof buildings, however, non-structural components had been failed.

EARTHQUAKE OVERVIEW AND INVESTIGATION METHOD

The earthquake occurred at 5:07 a.m., August 11, 2009 in Suruga-Bay (34.47 N, 138.30 E, focal depth 23 km) (Japan Meteorological Agency 2009) as illustrated in **Figure 1**. The magnitude of the main shock was 6.5 on a Japan Meteorological Agency (JMA) scale. The maximum seismic intensity of 6-Lower on the JMA scale was observed in several cities such as Izu, Yaizu, Makinohara, and Omaezaki, all of which are in Shizuoka Prefecture and approximately 20-40 km away from the focus.

Details of buildings reported in the successive sections are summarized in **Table 1**. They are located in Shizuoka city which is approximately 20-30 km away from the focus, and the seismic intensity was 5-Lower to 5-Upper. Time histories of observed accelerations near to investigated buildings and the fall point of the expressway, by K-NET (Kyoshin Network: strong-motion data published by the National Research Institute for Earth Science and Disaster Prevention, Japan), are shown in **Figures 2**.

The investigation was conducted by interviews, visual observations, size measurement, and photography.

[1] Research associate, Institute of Industrial Science, The University of Tokyo
[2] Graduate student, Graduate School of Creative Science and Engineering, Waseda University
[3] Professor, Institute of Industrial Science, The University of Tokyo

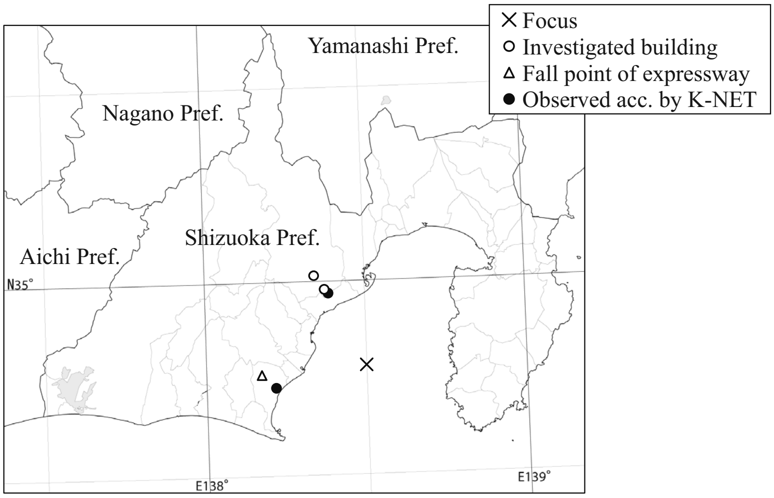
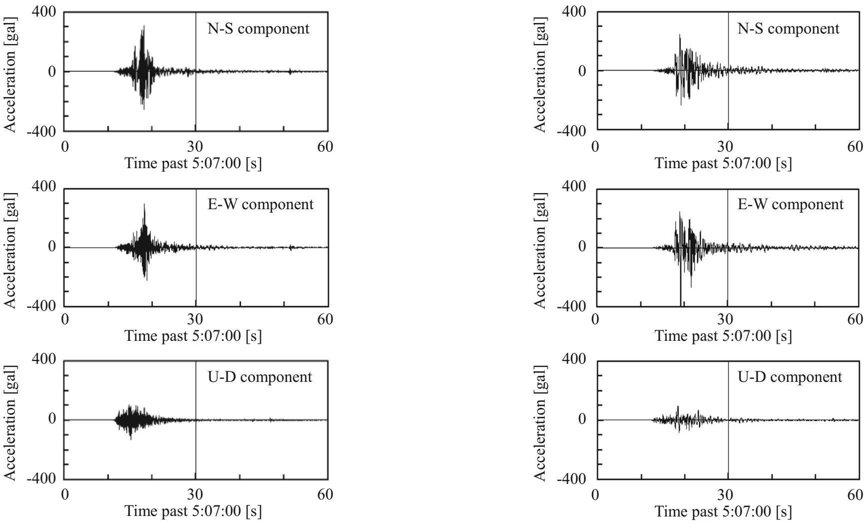


Figure 1. Shizuoka area



(a) Near to investigated buildings
(35.0 N, 138.4 E, 23 km away from the focus)

(b) Near to fall point of expressway
(34.7 N, 138.2 E, 26 km away from the focus)

Figure 2. Time histories of observed acceleration by K-NET

Table 1. Details of investigated buildings

(a) Public Pool-1

Building structure	RC (partially steel), 3 ground and 1 underground stories
Completion year	1990
Size of investigated space	*Arena:* 43.8 x 99.1 m, height to ceiling 13.0-18.5 m
Damaged components	*Arena:* louvers, ceiling panels *Foyer:* ceiling panels

(b) Public Pool-2

Building structure	RC, 2 stories
Completion year	1989
Size of investigated space	27.5 x 45.7 m, height to ceiling 7.5 m
Damaged components	Sliding walls, ceiling panels, H-bars

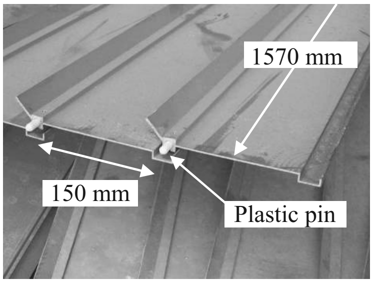
(c) Public Complex

Building structure	*Build.-1 (Gymnasium):* SRC, 2 stories *Build.-2 (Judo-kendo room, pool, meeting rooms):* steel, 3 stories
Completion year	*Build.-1 (Gymnasium):* 1971 (seismic retrofit in 2002) *Build.-2 (Judo-kendo room, pool, meeting room):* 2002
Size of investigated space	*Gymnasium:* 39.8 x 59.8 m, height to ceiling 14.3 m
Damaged components	*Gymnasium:* lighting equipment, ceiling panels, facing panels *Judo-kendo room:* sliding wall, lighting equipment, ceiling panel *Joint of two building:* facing panels

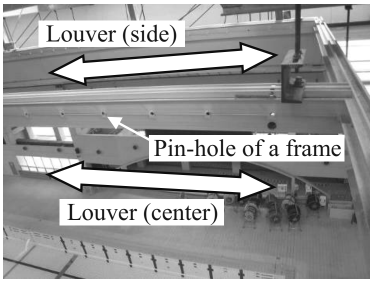
Figure 3. Public Pool-1 – hung louvers in the arena

PUBLIC POOL-1

As outstanding damage to non-structural components in this report, three big louvers each of which weighs 300 kg had hung down from the top of the ceiling at a public pool (**Figure 3**). The building was completed in 1990. Its skeleton is mainly reinforced-concrete (RC) and partially steel. There are three ground stories and one underground story. A 50-m swimming pool, a diving pool, and gallery seats are in an arena (width: 43.8 x 99.1 m, height to ceiling: 13.0-18.5 m). Damage to non-structural components had occurred in the arena and in a foyer, while the building skeleton, a pool tank, lighting equipment in every room, and a machine room seemed not to be damaged. According to an interview, the seismic intensity on the site was approximately 5.



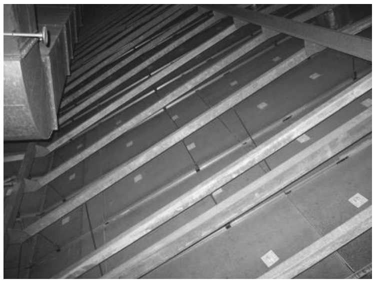
(a) Louvers



(b) Frame where louvers had been laid

Figure 4. Public Pool-1 – details of louver system in the arena

(a) Panel hung by an electric cable



(b) Furring under the roof

Figure 5. Public Pool-1 – failed ceiling panels in the arena

(a) Failure of panels

(b) Rusty screws and a staple

Figure 6. Public Pool-1 – failed ceiling panels in the foyer

Arena

Three movable louvers which had been laid horizontally in the skylight (5 x 56 m) at the top of the ceiling, hung down to the pool tank. The skylight was separated into three blocks (13-m-long, 19-m-long, and 13-m-long), and three louvers had been laid in each block. The hung louvers, each of which weighed approximately 300 kg, had been laid in the center 19-m-long block.

As shown in **Figure 4**, a piece of damaged louvers consisted of approximately 120 aluminum plates (1570-mm wide, 190-mm long, and 2-mm thick) arranged in a line. The plate is supported by two plastic pins (ϕ8 mm, 20-mm-long) at the both ends of width direction, inserted into a metal frame having 150-mm intervals. Therefore, as each plate can rotate around a connecting line between its pins, the louver can open and close, driven by a straight guide-member which connects to every plate and which can move back and forth using a motor. But the louvers were left to open during summer.

The reason of hanging was slip-off of the pins from the frame bending during the earthquake.

Several pins had also been cut off due to shear. In two 13-m-long blocks, louvers had not hang down, but slip-off of several pins had occurred.

As shown in **Figure 5**, failure of ceiling panels had occurred in the arena. The ceiling was grid-type, and its panel is a glass-wool board (1750 x 850 x 25 mm for example) with a waterproof membrane on the back side. One panel had fallen off and two panels had hung down. Hanger bolts of approximately 0.6-m length were arranged normal to the slope of the arch-shaped ceiling, which causes constant thrust of gravity inside the ceiling face.

Roof space in the arena had been ventilated at all hours to prevent bedewing.

Foyer

As shown in **Figure 6**, two ceiling panels (1600 x 900 mm and 1300 x 900 mm) in a foyer outside of the arena had fallen off. The height to the ceiling was not so high (1.4 m), but its space had often been used by athletes during swimming competitions. Failed ceiling panels were sets of a 9-mm-thick plaster board as a base layer and a 12-mm-thick rock-wool board as a finishing layer.

Several staples and 20-mm-long screws, both of which were in rust, had been scattering around. It may be considered that leak of water from eaves just above the fallen panels, or bedewing on panels caused the metal ones rusty. Mold could be observed on ceiling panels and walls.

PUBLIC POOL-2

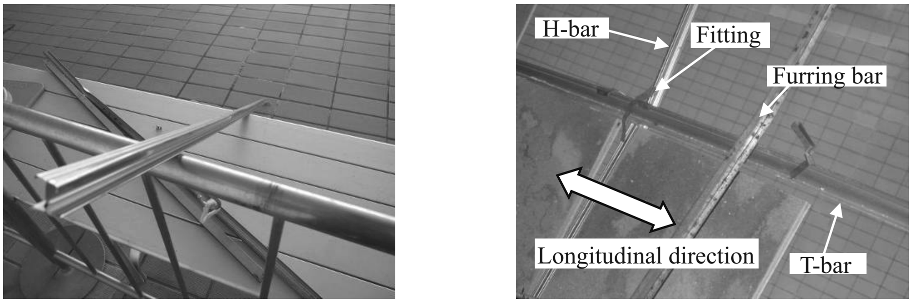
In another public pool as shown in **Figure 7**, damage to the line-type ceiling and sliding walls had occurred. The building was completed in 1989. Its skeleton is RC. There are two ground stories. A room (width: 27.5 x 45.7 m, height to ceiling: 7.5 m) where damage had occurred had a large swimming-pool and a small play-pool. According to an interview, fall of ceiling panels had not occurred until this earthquake while roof space had usually been bedewing.

Sliding wall

The eastern side of the room consisted of eighteen 2.6-m-wide sliding walls which could open and close. Each wall consisted of a quarter-cylinder metal frame and pieces of glass, and could move along a longitudinal direction of the room driven by a motor. The walls were closed when the earthquake had occurred. A lot of pieces of glass had got cracks but not fallen off.

(a) Internal view (b) External view (eastern side)

Figure 7. Public Pool-2 – internal and external view



(a) Fallen H-bar (b) Details of the ceiling

Figure 8. Public Pool-2 – line-type ceiling

(a) Furring under the roof (b) Failure of ceiling panels

Figure 9. Public Pool-2 – ceiling panels

Ceiling

As shown in **Figure 8**, the ceiling was line-type composed of 15-mm-thick rock-wool boards and metal H-bars, T-bars, and fittings. Panels, connected each other in a line by H-bars, were laid on two T-bars and kept by fittings. Several ceiling panels had fallen off with H-bars.

The suspending length of the ceiling panels was approximately 2.4 m (**Figure 9**). There were horizontal reinforcement-members on suspending bolts. But they were located 0.9-m above ceiling panels, and were not valid to suppress deformation of T-bars.

Failures were remarkable around the center of the ceiling. The main beams of the roof were laid along the longitudinal direction, to place sliding walls on the eastern side. It can be considered that, during the earthquake, the middle of the main beams had been moving laterally, which caused the damage to the panels under them.

PUBLIC COMPLEX

A public complex has a gymnasium, a judo-kendo (both of them are sports originated in Japan) room, a pool, and meeting rooms. They are in two buildings completed in different years. In 1971, the first building which has the gymnasium completed. In 2002, the second building which has other rooms described above completed, and the skeleton of the first building had been conducted seismic retrofit. As the complex has been a designated public shelter during disasters, it had been important to preserve its function. But damage to non-structural components had occurred.

(a) Interior view

(b) Failure of lighting equipment

(c) Lighting equipment under the roof

(d) Failure of ceiling panels

(e) Failure of vertical panels in roof space

Figure 10. Public Complex – Failure of non-structural components in the gymnasium

Gymnasium

Damage to non-structural components in a gymnasium (width: 39.8 x 59.8 m, height to ceiling: 14.3 m) in the first building had occurred as shown in **Figure 10**. Out of 51 pieces of lighting equipment, 1 whole piece and cover-glass and frames of 42 pieces had fallen off. A frame is attached to a piece of lighting equipment by three coil springs. The reason of the fall is elastic deformation of the spring during the earthquake.

The ceiling consisted of horizontal and inclined faces. Failures of ceiling panels had occurred on their boundary edges. The length of suspending bolts was approximately 60-150 mm.

A middle part in roof space is used for skylight with a louver. And its vertical faces are covered with facing panels. A few panels (plaster board) in a region had broken, and had been about to fall off. The vertical faces cross the roof skeleton. And the damaged region was located around the center of the roof, which can be considered that, during the earthquake, relative displacement of the damaged region and the roof skeleton was large.

(a) Failure of lighting equipment and ceiling panels around a steel column   (b) Failure of sliding walls and a ceiling panel

Figure 11. Public Complex – Failure of non-structural components in the judo-kendo room

Figure 12. Public Complex – Failure of facing panels in the joint of two buildings on the 2nd story

Judo-kendo room

The judo-kendo room on the 2nd story can be split into two rooms by sliding walls. As shown in **Figure 11**, sliding walls had deformed, lighting equipment which could lift by wire had hung down to height of a human's head, and ceiling panels had broken around a steel column and in several places.

Joint of two buildings

While two buildings completed in different years as described before, their skeletons are different as well: the first one is steel reinforced concrete and the second one is steel. In their joint on the 2nd story, there was space for skylight, and facing panels there had failed (**Figure 12**).

CONCLUSIONS

The region where this earthquake had been occurred had been expected to be suffered a future major earthquake, Tokai Earthquake. According to the investigation results in this report, various problems had been revealed. The authors had been pointing out risk of placing non-structural components at high in large roof enclosures (Kawaguchi et al. 2009). Even in the region, people had little understanding of the risk. Fortunately, the earthquake had occurred in the morning. But their improvements are urgently.

Public Pool-1 and Public Pool-2 are located far away from the focus. But their grounds may not be so firm because they are near to a river. These are typical examples that damage to non-structural components may occur even if buildings are far away from the focus.

Falling of louvers in Public Pool-1 was especially serious, because if the earthquake might have occurred at the time in service, it might have harmed people. We can point out that the problem is wrong design to place heavy equipment at high level without enough study.

Figure 13. Example of damage to line-type ceiling (The Niigataken Chuetsu-Oki Earthquake in 2007)

Line-type ceilings had frequently been damaged, as shown in the case of Public Pool-2. As another example, **Figure 13** depicts failed line-type ceiling during “The Niigataken Chuetsu-Oki Earthquake in 2007”. The problem is that panels are laid on T-bars with very narrow margin parts, which can fall apart easily during earthquakes.

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