DAMAGE TO NON-STRUCTURAL COMPONENTS IN LARGE PUBLIC SPACES BY THE GREAT EAST JAPAN EARTHQUAKE

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ABSTRACT: This is an investigation report on damage to non-structural components in large public spaces by the "Great East Japan Earthquake." This paper mainly reports the field survey on damages to non-structural components in five large public spaces. Distribution of buildings which suffered ceiling damage during the "2011 off the Pacific Coast of Tohoku Earthquake" and its aftershocks is also shown by using data on web sites. The distribution clarifies that failure of ceilings occurred in the area of over 5-Lower intensity. Therefore, the distribution is likely to reach widely.

Key Words*: The Great East Japan Earthquake, Large public space, Suspended ceiling, Non-structural components, Distribution of ceiling damages*

INTRODUCTION

This is an investigation report on the failure of ceilings in large public spaces by the "2011 off the Pacific Coast of Tohoku Earthquake" on March 11, 2011 and its aftershocks. The magnitude of the main shock was 9.0 on a Japan Meteorological Agency (JMA) scale. Distribution of buildings which suffered ceiling damage during the "2011 off the Pacific Coast of Tohoku Earthquake" and its aftershocks is shown by using data on web sites. Authors also investigated damages to non-structural components during the "Southern Hyogo prefecture earthquake" in 1995. This paper mainly reports the ceiling damages in five large public spaces investigated through field survey (**Table 1**).

CEILING DAMAGE DISTRIBUTION

The distribution of buildings which suffered damage to ceilings during the "2011 off the Pacific Coast of Tohoku Earthquake" and its aftershocks (**Table 2**) is shown in **Figure 1**. This distribution is based on reports on web sites until May 20, 2011. Several estimated seismic intensity distributions are superimposed on the map. According to the distribution, most ceiling damages reported on web sites were in the area of over 5-Lower intensity. This is the same tendency confirmed by the authors in the "Mid Niigata Prefecture Earthquake" in October 2004. Since ceiling damages tend to occur on smaller seismic intensity than damages of building structure, the distribution is likely to reach widely.

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Table 1. Details of investigated buildings

Institution classification Location (Completion year)	Structure	Size		Details of damages
School gymnasium In Tochigi prefecture (1985~87)	Two stories RC (Steel roof)	(Arena)	Floor : 38m x 30m Ceiling height : 7~11m	Fall of ceiling panels (Porous plaster board t9.5), Fall of lighting covers
Public pool 1 In Tochigi prefecture (1997)	One story RC (Steel roof)	(Indoor pool)	Floor : 50m x 24m Ceiling height : 5~9m	Fall of ceiling panels (Calcium silicate board t8.0 + rock wool board t12.0), Fall of lighting equipments, Damage to glass curtain wall
Public pool 2 In Ibaraki prefecture (1997)	Two stories RC (Steel roof)	(Main pool) (Sub pool)	Floor : 99m x 60m Ceiling height : 14~19m Floor : 59m x 38m Ceiling height : 8~15m	Fall of ceiling panels (Aluminum nonwoven fabric glass wool board), Fall of ceiling panels (Aluminum nonwoven fabric glass wool board, plaster board t8.0 + rock wool board t12.0)
Cultural facilities 1 In Miyagi prefecture (1987)	Two stories RC (partically steel)	(Large hall)	Floor : 2800m^2 Ceiling height : 7~16m	Fall of ceiling panels (Plaster board t12.5 + rock wool board t9.0), Fall of hanger bolts
Cultural facilities 2 In Fukushima prefecture (2010)	Three stories RC (partically steel)	(Large hall) (Exhibit hall)	Floor : 1800m^2 Ceiling height : 3~16m Floor : 43m x 23m Ceiling height : 4.5m	Fall of ceiling panels (wooden board t12.0) Fall of ceiling panels, Fall of lighting equipments

Table 2. Earthquake history

Date	Maximum seismic intensity	Magnitude	Focus
March 11, 2011	7	9.0	Off the Sanriku caost
March 11, 2011	6-Upper	7.7	Off the coast of Ibaraki prefecture
March 12, 2011	6-Upper	6.7	Northern Nagano
March 15, 2011	6-Upper	6.4	Eastern Shizuoka

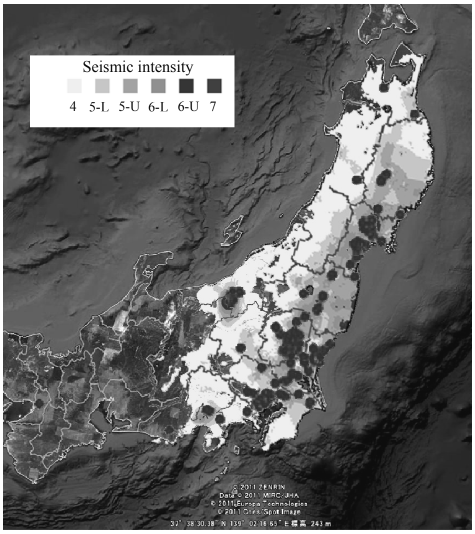


Figure 1. Distribution of buildings which suffered ceiling damage

FIELD SURVEY

School gymnasium

Falling of non-structural components such as ceiling panels and lighting equipments, occurred in the arena on the second floor of a school gymnasium during the “2011 off the Pacific Coast of Tohoku Earthquake” at 14:46 on March 11, 2011.

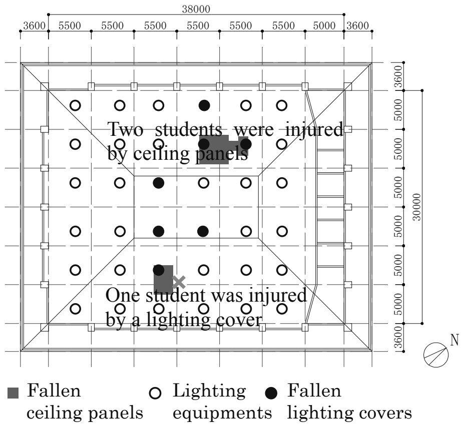
(1) Details of damage

The ceiling of the arena on the second floor of the gymnasium is a half-hipped type in accordance with the roof structure. Several ceiling panels, porous plaster boards of 9.0-mm thickness and 63.7 N/m^2 weight fell off because of slip out of screws. Lighting covers also fell off (**Figure 2(a)**, **(b)**). Fourteen panels in the northwestern area and six panels in the southeastern area fell from the ceiling of 7~11 m height. Falling of ceiling panels along the hip was also observed. According to observation of the northwestern area (**Figure 2(c)**), the hanger bolts near the main ridge were perpendicularly installed to the ceiling, and the hanger bolts near the edge of eaves were installed vertically. Float going up of a runner from the hanger attached to edge of the hanger bolt installed perpendicularly was also observed.

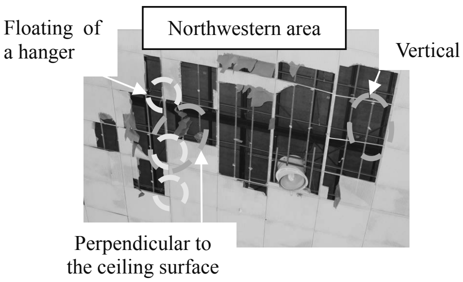
Lighting is fixed type, and its cover is detachable with four spring fittings for bulb’s replacement. The cover fell off during the earthquake (**Figure 2(d)**).

Porous plaster board fell off at the eaves of the northeastern side and the northwestern side.

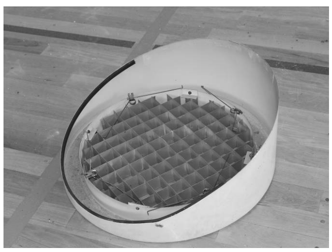
(a) Internal view



(b) Roof plan



(c) Failure of ceiling panels



(d) A lighting cover

Figure 2. School gymnasium

(2) Circumstances of accident

When the earthquake occurred, about 320 students were sitting to practice a graduation ceremony. Small tremble continued at first, and then one ceiling panel fell off at the stage side with the big tremble. Soon after that, ceiling panels, lighting covers, etc. fell off at once. Students escaped to the stage and under the gallery of both sides. However, some ceiling panels, a lighting cover, etc. hit students. The lighting cover (about 1 kg) installed about 9 m in height had fallen and hit to one student's glabella making bleeding. The ceiling panels installed about 7 ~ 9 m in height also hit a forehead and back of a head of two students making serious bruise. As a result, 20 students (11 men and 9 women) got a scratch and bruise on their shoulders and arms, and they were transported to a hospital.

(3) Details of ceiling

The ceiling system is suspended and constructed by a conventional method with metallic furring bars, clips, runners, and porous plaster boards of 9.0-mm thickness. Suspended lengths of hanger bolts are about 1 m. The pitch of runners and furring bars is about 900 mm and 300 mm, respectively.

(4) Estimation of the cause of the accident

According to interview with an office staff, falling of ceiling panels had occurred two or more times before the "2011 off the Pacific Coast of Tohoku Earthquake," and leak in the roof had also occurred in the gymnasium. It is estimated that the cause of falling is external force by the earthquake. The force caused the deformation of porous plaster boards which was already brittle due to the leak. The slip off of screws occurred in consequence.

Public pool 1

Falling of the non-structural components, ceiling panels, and lighting equipments, occurred in a pool during the "2011 off the Pacific Coast of Tohoku Earthquake" at 14:46 on March 11, 2011.

(1) Details of damage

Failure of the suspended ceilings occurred in an indoor pool (**Figure 3(a)**). Over two third of the ceiling panels which are installed in the longitudinal direction in shape of an arch and divided into four rows alternating with top light rows had fallen during the main shock, because of deformation of clips (**Figure 3(b)**). Falling of lighting equipments was also observed. Their attachments are simple ones without safety chain (**Figure 3(c)**). Moreover, a part of the glass curtain wall was damaged by collision of the fallen ceiling.

(2) Circumstances of accident

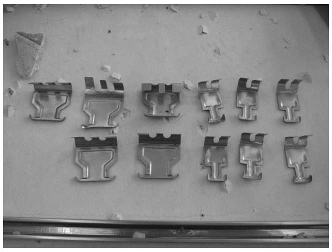
There were about 20 people when the earthquake occurred. Since refuge guidance was promptly performed by a staff in the pool who had been paid attention to the danger of ceiling's failure, no one was injured fortunately.

(3) Details of ceiling

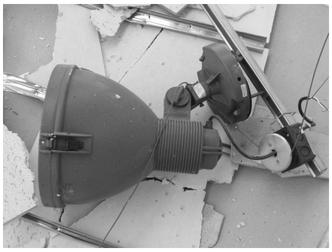
The ceiling is suspended and constructed by a conventional method with metallic furring bars, clips, runners, and ceiling boards which are sets of a 8.0-mm-thick plaster board as a base layer and a 12.0-mm-thick rock-wool board as a finishing layer (**Figure 3(d)**). Hanging lengths of hanger bolts are about 2 m, and it is hanging from the purlin in the perpendicular direction.

Runners were arranged in the longitudinal direction along the roof structure. The pitch of furring bars is 900 mm, and furring bars attached to runners by clips. Braces installed in the short direction were welded to light steel gage at separate points, but buckling of braces was observed. Anti-vibration bars were installed among hanger bolts. The ceiling panel is a set of a 8.0-mm-thick plaster board as a base layer and a 12.0-mm-thick rock-wool board as a finishing layer.

(a) Internal view



(b) Fallen clips



(c) Fallen lighting equipment

(d) Ceiling frame

Figure 3. Public pool 1

(4) Estimation of the cause of the accident

The shape of the ceiling is an arch, and thus both ends tend to separate each other. The earthquake fostered the separation, causing loose of clips.

The shape of the roof is an arch in the longitudinal direction, and three girders cross in the short direction. The column is SRC, and the girder is built-H (1200 mm×200 mm). It is considered that lateral flexural rigidity of the girder is low because of its short width. On the other hand, although the braces are installed in the roof side, it is discontinuous at the top light. Therefore, it is considered that the arch is flexible in the direction of roof plane.

Since calcium silicate boards as ceiling panels were bended when installed, they were always trying to recover to flat shape. On the other hand, hanger bolts were perpendicular to the arch, and the thrust force due to the self-weight of the ceiling pushed the arch outside. Therefore, it can be estimated that the force to induce clips' deformation always existed.

Public pool 2

Falling of the ceiling panels occurred in a main pool and a sub pool during the main shock of the “2011 off the Pacific Coast of Tohoku Earthquake” at 14:46 on March 11, 2011.

(1) Main pool

The ceiling is suspended. It is integrated ceiling composed of T-bar, H-bar, and ceiling boards which is a set of a glass-wool board for insulation and an aluminum unwoven fabric as a finishing layer. Ceiling panels fell off the T-bar (**Figure 4**).

(2) Sub pool

A top light is arranged in the center of the sub pool, and the ceiling is installed around it. The ceiling is symmetrical in the longitudinal direction, and its fallen distribution is also almost symmetrical. In the sub pool, the composition of two kinds of suspended ceilings is used. One is constructed by conventional method using a light steel gauge, which is used in the part of the pent ceiling which cut off a part of circle.

Hanger bolts are hanging from purlin of a steel frame, and the aluminum lip channel steel is hung in the short direction. Hanger bolts is further hung from lip channel steel, runner is similarly hung in the same direction, and furring is arranged in the longitudinal direction. The ceiling panel is a set of a 8.0-mm-thick plaster board as a base layer and a 12.0-mm-thick rock-wool board as a finishing layer, and its unit weight is 91 N/m^2. The length of the hanger bolt is about 1.5 ~ 5.0 m, and the pitch of anti-vibration bar is 1500 mm. Another ceiling is arranged in the longitudinal direction, and it is the same system as a main pool. The almost all ceilings constructed by conventional method had fallen and integrated ceilings had partially fallen (**Figure 5(a)**). According to an interviewwith staffs, the ceiling of the conventional method of construction arranged in the short direction of the pool fell from the center of an arch, and the side fell after that.

Although braces as reinforcement of vertical panels are arranged in the longitudinal direction, the deformation of the runner attached to the brace was observed.

Load might be locally applied to this portion, that portion might induce deformation of a clip, thereby fall may have started. Moreover, in the central part, it was confirmed that fall of the runner receptacle by deformation of a hanger (**Figure 5(b)**).

Figure 4. Internal view of Main pool

(a) Internal view (b) Ceiling frame

Figure 5. Sub pool

Cultural facility 1 (large hall)
Falling of ceiling panels occurred in a large hall twice during the main shock of the "2011 off the Pacific Coast of Tohoku Earthquake" at 14:46 on March 11 and its aftershock at 23:32 on April 7, 2011.

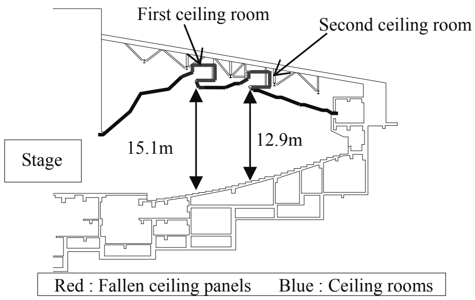
(1) Details of damage
The ceiling which is in tiers for acoustic composed of panels which are a sets of a plaster board and a rock-wool board at 12.9~15.5 m height fell off during the main shock (**Figure 6(a)**, **(b)**).

(2) Circumstances of accident
There were about 600 people during the earthquake, but the number of people to be injured was small.

(3) Details of ceiling
The ceiling system is the suspended ceiling constructed by a conventional method with metallic furring bars, clips, runners, and ceiling panels which are sets of a 12.5-mm-thick plaster board as a base layer and a 9.0-mm-thick rock-wool board as a finishing layer (**Figure 6(c)**). Suspended lengths of hanger bolts are about 3~5m.

(4) Estimation of the cause of the accident
Ceiling panels had fallen off from two ceiling rooms. Ceiling rooms were suspended by steel frame. It is estimated that the frame's movement during the earthquake is relatively small. However, the ceiling in front of the ceiling room was suspended from the roof with hanger bolt, and it is considered that the deformations of the ceiling room and the ceiling were different. Although there were braces between ceiling room and the ceiling, the buckling was observed (**Figure 6(d)**). While the ceiling under the ceiling room was suspended from the ceiling room, the other ceiling was suspended from the roof (**Figure 6(e)**). Therefore, it is considered that their hanging lengths are different causing the different earthquake responses.

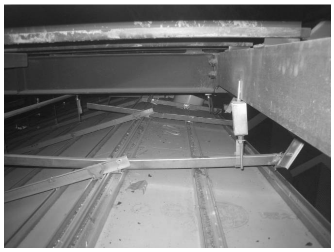
(a) Internal view



(b) Section

(c) Ceiling frame

(d) Buckling of braces



(e) Ceiling under ceiling room

Figure 6. Large hall

Cultural facility 2

Falling of non-structural components occurred during the “2011 off the Pacific Coast of Tohoku Earthquake” at 14:46 on March 11, 2011. As this facility is large, damage to non-structural components during the earthquake was observed in several places. In this paper, large hall and exhibition hall which are remarkable as for ceiling damages are reported.

(1) Large hall

Wooden curved surface ceiling panels had fallen partly in the large hall. Due to the main shock, the curved surface ceiling connecting the horizontal ceiling partially fell (**Figure 7(a)**). There was a difference in support method between the horizontal ceiling and curved surface ceiling. Five tiers of horizontal ceiling were composed of plywood and wooden furring (45 mm×45 mm). Furring is hanging on runners, and light gauge steel (25 mm×45 mm) arranged in 900 mm pitch support them. On the other hand, in the curved surface ceiling part, the curved surface ceiling was installed to connect the horizontal ceilings (**Figure 7(c)**). In this part, there is no hanger bolt; thereby the curved surface ceiling was installed by driving nails into the edge of horizontal ceiling. The cause of falling is considered that each horizontal ceiling forming tiers is moved differently, and deformation concentrated to this part. Therefore the curved surface ceiling fell because of easy connection.

(a) Internal view (b) Ceiling frame (c) Fallen curved surface ceiling

Figure 7. Large hall

(2) Exhibition hall

Failure and falling of the suspended ceiling occurred because of the collision between the ceiling and surrounding walls were observed. Hanger bolts also fell. The ceiling in the exhibition hall was composed of two tiers of ceilings. The upper tier was constructed by a conventional method with metallic furring bars, clips, runners, and ceiling panels which are sets of a 9.0-mm-thick plaster board (57 N/m^2). Suspended lengths of hanger bolts are about 1.9 m. The hanger bolts whose lengths are 0.3 m were welded to furring of the upper tier. The integrated ceiling composed of T-bar and H-bar was installed in the lower tier, and furthermore, the steel lattice frame (150 mm×150 mm) was placed below to prevent panels’ falling. Two tiers of ceiling act as ventilation. During to the main shock, ceiling panels at around surrounding walls failed (**Figure 8(a)**). Because the location of the failure and out-of-plane deformation of the ceiling is at around surrounding walls, it is considered that the cause of falling is collision between the ceiling and the wall.

At another place, the ceiling with runners fell because of deformation of hangers (**Figure 8(b)**, **(c)**). At this place, falling of hangers and hanger bolts due to loosening of nuts. It is considered that the nuts considered support the heavy ceiling.

(a) Internal view (b) Fallen ceiling (c) Deformation of a hanger

Figure 8. Exhibition hall

CONCLUSIONS

Distribution of ceiling damages during the "Great East Japan Earthquake" and field survey are reported in this paper. The acquired knowledge is shown below.

1. There is a tendency that most ceiling damages occur in the area of over 5-Lower intensity.
2. In many cases, ceilings in halls are constructed in tiers with heavy finishing materials for the purpose of sound effects. Furthermore, suspended lengths of hanger bolts are long, and lengths and installation methods are different according to places. This imposes forces on ceilings during earthquakes causing damage. The provision is urgently necessary.
3. Because small tremble continued for a long time at the early part of the earthquake, many people could afford to refuge.

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REFERENCES

Ishikawa, K., Kawaguchi, K., Tagawa, K., and Sakai, T. (1997). "Report on Gymnasium and Spatial Structures Damaged by Hyogoken-Nanbu Earthquake." *Architectural Institute of Japan Journal of Technology and Design*, Vol.5, 96-101.

Japan Meteorological Agency (2011). *Monthly Report on Earthquakes and Volcanoes in Japan March 2011*. (in Japanese: 平成 23 年 3 月地震・火山月報（防災編）)

Japan Meteorological Agency (2011). *Estimated-seismic-intensity distribution*, 2011.

Kawaguchi, K., Suzuki, Y., Ohya, S., and Hattori, M. (2005). "Safety of Interior Spaces of Large Enclosure Based on the Damage Investigation of Niigata-Chuetsu and Fukuoka-Seiho-Oki Earthquakes." *Report of Institute of Industrial Science, The University of Tokyo*, Vol. 57, No. 6, 39-41.