REPORT ON SOME LARGE SPAN STRUCTURES DAMAGED DURING THE “2016 KUMAMOTO EARTHQUAKE”

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ABSTRACT: The 2016 Kumamoto earthquake, that measured a maximum of seven on the JMA seismic intensity scale, occurred in Kyushu, Japan, in April, 2016. One of the two investigated buildings has a large membrane roof structure that normally has high earthquake resistance. It encloses a large space; nevertheless, it was not used as an evacuation center owing to the damage, not to the structural members, but to the non-structural components. Another building is a public hall that has a heavy ceiling for better acoustic performance. In this paper, the damage investigation of these two large-span structures in Kumamoto city is reported.

Key Words: Large-span structure, Evacuation center, Non-structural component, Ceiling, Earthquake, Hall, Membrane

INTRODUCTION

This paper reports the investigation of two large-span structures (**Table 1**) damaged by the Kumamoto earthquake and its foreshocks and aftershocks in April 2016. These two large-span structures are: a cultural facility that houses a public hall that has a heavy ceiling to ensure acoustic performance; and a large indoor athletic facility that has the important function of an evacuation center. These cultural and athletic facilities were investigated on May 5 and 12, 2016, respectively.

The 2016 Kumamoto earthquake was characterized by the occurrence of a series of strong earthquakes over a short period. The Japan Meteorological Agency (JMA) reports that the earthquakes, over 6-Lower on the JMA seismic intensity scale, struck the Kyushu region seven times from April 14 – 16, 2016. A maximum of 7 on the JMA scale was measured at the foreshock with a magnitude of 6.2 at a depth of approximately 11 km at 21:26 JST on April 14, 2016. The main shock was measured as magnitude 7.0 at a depth of approximately 12 km at 01:25 JST on April 16, 2016.

Table 1. Details of the investigated buildings

Institution classification	Completion	Building structure and scale	Damage overview
Public hall	Nov., 1967 Repaired in July, 2007	RC Four stories and one basement Total floor space of 9,197 m^2	Ceiling collapse and damage to the floor in the hall
Large indoor athletic facility	Mar., 1997	RC, S and double membrane air-supported structure Two stories and one basement Total floor space of 26,938 m^2	Falling of ceiling panels, damage to revolving doors, bearing failure of a truss frame and a canopy, etc.

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PUBLIC HALL

General information

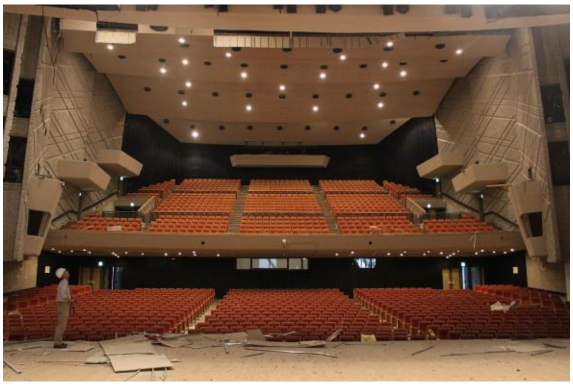
This facility is located in the Kumamoto city of Kumamoto prefecture, and consists of a hall with 1591 seats, conference rooms, a restaurant, and an exhibition lobby. The damage investigation of the facility was mainly conducted in this hall. An external view of the hall is shown in **Figure 1**. The facility was completed in 1967. The span of the hall is approximately 45 m and the frame is constructed of reinforced concrete (RC). The hall, which is surrounded by nine large RC walls, has a proscenium stage and the ceiling is arranged in tiers. An orchestra pit and duct space are installed in the basement

Figure 1. External view of the hall

(a) Before repair

(b) After repair

Figure 2. Comparison before and after repair of the hall



(a) From the stage side

(b) From the audience side

Figure 3. Internal view of the hall

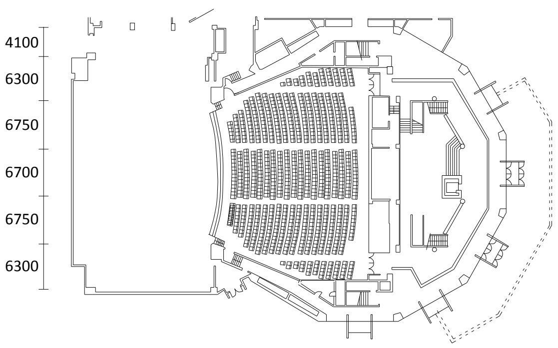


Figure 4. 1F Plan

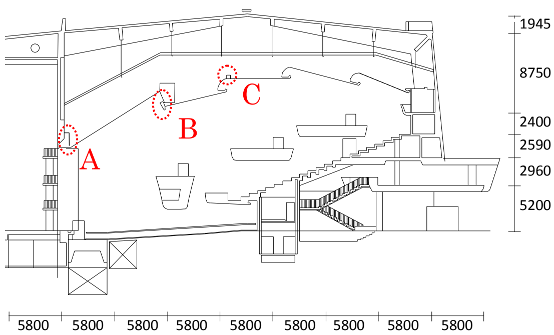


Figure 5. Section of the hall

Figure 6. Damage to the audience seats

Figure 7. Failure of the ceiling

Figure 8. Fallen lighting cover

Figure 9. Floor damage

of the hall. Although large-scale repair was conducted in 2006 – 2007, the internal view of the hall was not altered, as shown in **Figure 2**.

Details of the damage

The internal view is shown in **Figure 3**. **Figure 4** and **Figure 5** show the plan and section of the hall, respectively; the location where the ceiling fell from a height of 10 – 16 m is also shown in **Figure 5**. The observation was conducted from the floor in the hall without entering the space above the ceiling, owing to the danger of aftershocks. Therefore, the ceiling details were unfortunately unclear at this time. The suspended ceiling, mortar finish on 30 – 50 mm thick metal lath, installed on both sides of the stage and the 9.5 mm thick vertical gypsum boards installed in the center above the proscenium arch fell down. On both sides above the proscenium arch, shown at location A in **Figure 5**, the impact marks of the collision of the ceiling and the walls were observed. With regard to the vertical gypsum panels, the lighting equipment hanging in the front partially prevented the ceiling from falling. The ceiling installed directly under the ceiling room hung at location B in **Figure 5**, and the 6-mm thick calcium silicate ceiling fell down at location C in **Figure 5**. As mentioned, the ceiling materials differed according to location. The magnitude of the impact force caused by the fall of the ceiling is clear from **Figure 6**, especially in the case of the mortal finish on the metal lath. As shown in **Figure 7**, there was the danger of falling owing to aftershocks. Regarding further damage, the fall of the lighting covers (**Figure 8**) and the cracking of the floor above the duct space in the basement (**Figure 9**) were observed. It is considered that the crack occurred at the point of the floor overhanging the orchestra pit and the duct space, because of the vertical motion of the floor as a cantilever.

LARGE INDOOR ATHLETIC FACILITY

General information

The large indoor athletic facility was completed in March, 1997. It is a double-layer pneumatic dome enclosing a multi-purpose ground with 2,000 seats. It is approximately 48 m high with an area of 26,000 m^2. The double-layer pneumatic roof is installed inside a ring truss supported by assembled columns. The area within the ring truss is called the amorphous area, and a membrane roof is installed over this area by stretching it over the truss frame. The membrane material is polytetrafluoroethylene (PTFE) coated woven fiberglass. External and internal views are shown in **Figure 10** and **Figure 11**, respectively.

Details of the damage

Under the guidance of the facility's staff, the investigation was conducted both internally and externally. Unfortunately, when the field survey was conducted, this large indoor athletic facility was not functioning as an evacuation center. According to the staff, this is due to the falling of the glass

Figure 10. External view of the dome

Figure 11. Internal view of the dome

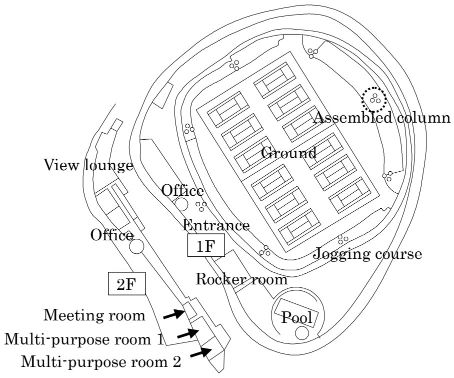


Figure 12. Plan

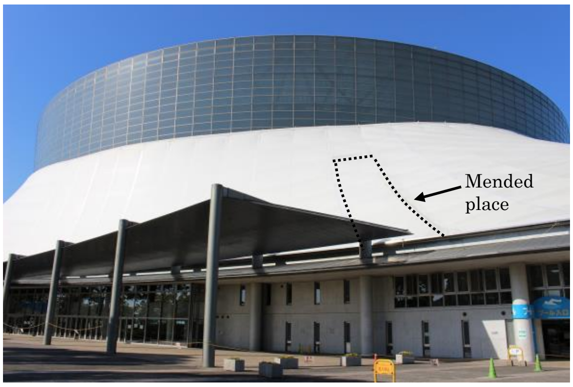


Figure 13. After repair of the membrane

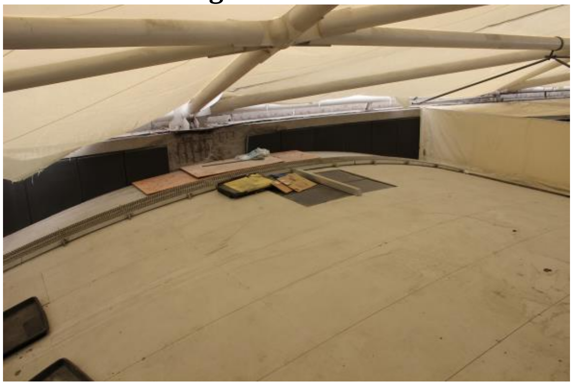


Figure 14. Damage to the bearing of the truss frame

Figure 15. Frayed strings of the membrane

Figure 16. Damage to the ceiling

Figure 17. Damage to the movable membrane ceiling

Figure 18. Ceiling failure

Figure 19. Safety net for ceiling collapse

Figure 20. Revolving door damage

wool panels installed at the ring truss for acoustic performance in the dome.

Figure 12 shows the plan of the facility. The damage in each area is summarized in the following section. According to the staff, although the welds of the membrane in the amorphous area fell off during the earthquake, the area was mended prior to the investigation (**Figure 13**). In addition, the connection of the canopy and the columns along the circumference of the amorphous area was damaged. In the multi-purpose ground, numerous glass wool panels of 50-mm thickness, which were installed at the ring truss for acoustic performance, fell off. Cracks and exfoliation of the concrete were observed in the bearing of the truss frame. The strings of the membrane under the truss frame in the amorphous area were frayed. The damage to the membrane caused rain to leak in on multi-purpose room 1, the meeting room etc. In the meeting room, the cracks in the walls occurred as a result of the leaking rain. Multi-purpose room 1 was used as the training room; however, all training machines were moved to other rooms because of the rain leaking in from the torn movable membrane ceiling. In multi-purpose room 2, glass wool boards were placed on the heavy ceiling made of expanded metal.

Both sides of the expanded metal ceiling were placed on the beams, but fell off as a result of the tremble from the earthquake. In the indoor swimming pool, the calcium silicate ceiling boards (thickness = 6.0 mm) fell down; the gutter cover came off; and the polyvinyl chloride board partition between the ground and the pool failed. Unfortunately, the safety net for accidental ceiling collapse was torn prior to the earthquakes; the reason for this is unknown. In terms of the other damage, the glass of the two revolving doors fractured and concrete exfoliation of the external walls was observed.

CONCLUSIONS

This report summarizes the investigation of two large-span structures, a public hall and a large indoor athletic facility, in Kumamoto city damaged by the 2016 Kumamoto earthquake.

For acoustic performance of halls:

1. Large ceilings are subject to large inertial forces
2. Several-tier ceilings are suspended by hanger bolts of different lengths.

For these reasons, acoustic ceilings exhibit complex movement during earthquakes. Therefore, it is necessary to take all appropriate measures against ceiling collapse as soon as possible. In addition, the hall in this report is characterized by different ceiling materials in each location. It is clear that the impact force of the falling ceiling, especially in the case of the mortal finished metal lath, is sufficiently large to inflict injuries on people. Therefore, a survey of halls with heavy ceilings and appropriate measures against ceiling collapse is required. As a countermeasure, ceiling members and their connections should be designed and constructed at the level of structural members. It is, however, difficult to apply this measure to existing buildings. In contrast, a safety net to guard against accidental collapse of heavy ceilings is proposed as a relatively inexpensive measure. However, this measure is not yet practical.

On the other hand, the facility staff at the large indoor athletic facility reported that the damage that occurred at the multi-purpose ground was limited to the falling of the glass wool panels. Since the damage risk to people by falling lightweight glass wool panels is quite low, it is unfortunate if this was the reason for not using this facility as an evacuation center. It is considered that the installation of the safety net relieves anxiety and mental stress of the evacuees, and the facilities can resume their function as evacuation centers.

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