DAMAGE TO NON-STRUCTURAL COMPONENTS IN LARGE ROOMS BY THE JAPAN EARTHQUAKE, MARCH 11TH, 2011

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ABSTRACT: The author has kept warning the danger of the failure of non-structural components in large rooms since Kobe earthquake in 1995. The Japan earthquake in 2011 has brought about the damage to the non-structural components, especially to the suspended ceilings in large rooms, in a very wide scale. The examples of failure are reported and discussed.

Key Words: Large room, Non-structural component, Ceiling, Earthquake

INTRODUCTION

Large rooms are usually used for meetings, playrooms, shopping malls, stations, gymnasiums, event halls, auditoriums or exhibition halls, where many people gather for certain activities. They are often used for factories or warehouses with a very small population but the goods and machines inside are usually very important for the business. Therefore the preservation of the safety and the functions of the interior space of the large rooms is very important.

In 1995 in Japan, immediate after of the Kobe Earthquake, the author carried out a series of investigations of the damage to wide-roof buildings in Kobe area. The investigation revealed unexpected severe damage to many interior spaces of wide-roof buildings, of which structural damage was rather minor. Failure of nonstructural components suspended at a height, such as suspended ceilings, lightings, air-ducts or speakers spoiled the safety and the functions of the large rooms in the wide-roof buildings (**Figures 1 and 2**). It also blemished the important role of large public spaces to be converted into refuge stations for those who lost their houses. Since then the author has repetitively reported damage to non-structural components, especially in large public rooms, every time when we had major earthquakes in Japan.

The Japanese seismic code for structures has been improved and structural reinforcement for the existing weak buildings has been strongly promoted by the government. The structural performance of the buildings has been steadily improved and the structural damage by the earthquakes seems effectively reduced. In contrast with such progress of the seismic performance of structures, damage to non-structural components became to be more aware.

Since the northeast part of Japan is the region where they have major earthquakes most frequently the structures there have been well improved and prepared against the earthquakes. However almost nothing had been done for non-structural components. As the result, numerous buildings were suffered from the damage of their non-structural components by the Japan earthquake. The long duration of the earthquake seemed to make the damage to non-structural components even worse.

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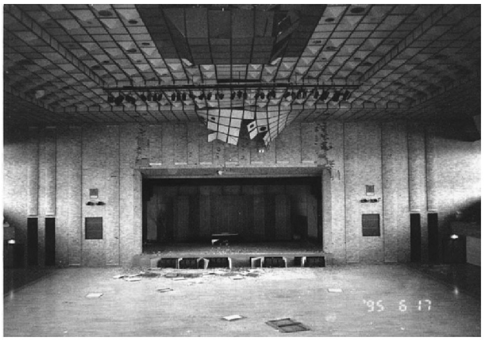
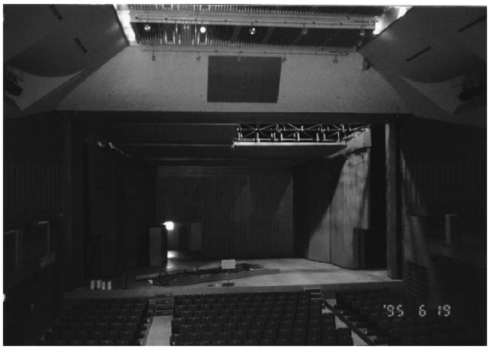


(a) Conventional type ceiling (b) Grid type ceiling

Figure 1. Suspended ceilings failed in the Kobe earthquake, 1995



(a) Collapse of an acoustic panel (b) A huge speaker cluster frame

Figure 2. Suspended facilities failed in the Kobe earthquake, 1995

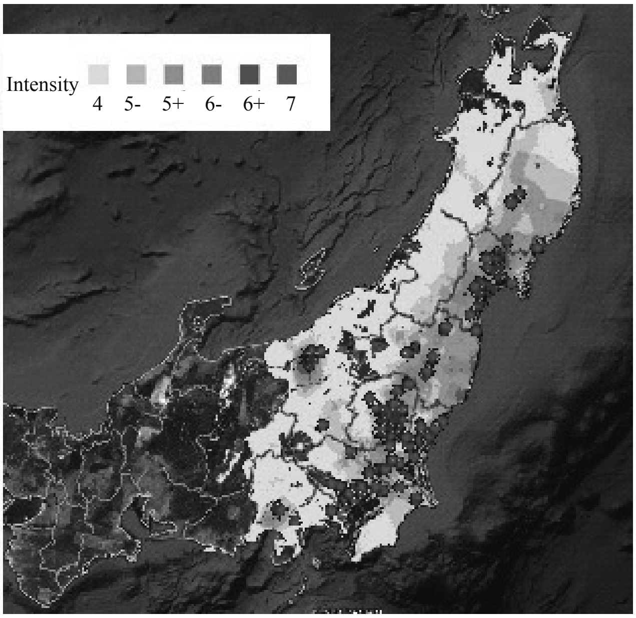


Figure 3. The area of intensity five or higher (colored in orange) and 186 buildings that had failure of suspended ceilings

DAMAGE BY THE JAPAN EARTHQUAKE

Generally, non-structural components are more vulnerable and fail easier than structural components in the shock of earthquakes. Therefore they fail more frequently and more widely than the structural components, in major earthquakes. According to our observations in the previous damage investigations, suspended ceilings start to fail when the buildings are hit by the earthquake of intensity five or higher. In **Figure 3** the area colored in orange shows the area hit by the shocks of intensity five or higher during the Japan earthquake or its after shocks. The red plots indicate the location of one hudred and eighty six buildings that had failure of suspended ceilings. The failure of ceilings spreads very wide area in the eastern part of Japan. In June 2011, the ministry of education of Japan has reported that more than one thousand and six hundred schools had collapse of ceilings and more than four hundred schools had failure of suspended facilities, such as lightings.

In the following sections some examples of failure of non-structural components, especially suspended ceilings, by the Japan earthquake are reported.

A school gymnasium in Tochigi prefecture

Most of the ceiling systems are developed and prepared for horizontal use. However in many cases in large rooms the ceilings are designed to be inclined or curved for many reasons. The gymnasium of a junior high school in Tochigi prefecture had inclined suspended ceilings finished with gypsum acoustic boards. Many of the ceiling boards fell by the failure at the heads of the nails, which fixed the board to the furring strips (**Figure 4**). Many covers of lightings also dislocated and fell. These failure injured many students who used the gymnasium at the moment when the main shock of the earthquake hit the area.

(a) Interior view of the gymnasium

(b) Gypsum boards failed at the nails' heads

Figure 4. Damage to the ceilings in a school gymnasium in Tochigi prefecture

Swimming pools

Swimming pools usually require large rooms and designed with wide windows. The structures are designed to have wide openings and they often become rather flexible to show comparatively large deformation during the earthquake. The rooms are naturally filled with moisture and the finishing easily gets condensation and grows molds, which deteriorate the strength of ceiling boards. Consequently swimming pools are frequently suffered from the failure of ceilings.

The large part of the curved ceiling of a swimming pool in Tochigi prefecture collapsed mainly because of the failure at the joints so-called “clips” (**Figure 5**). Clips have been developed for quick and easy construction and very commonly used for the conventional ceiling systems in Japan. However recently they became to be regarded as one of the most problematic parts, in the respect of earthquake resistance, in the ceiling systems. The steel frame of the building looked very sparse to allow lots of light from outside. The frame response was probably so strong that the clips could not keep their firmness.

Another swimming pool in Ibaragi prefecture was also suffered from collapse of suspended ceilings (**Figure 6**). Dislocation of the ceiling panels from “T-bar” type furring strips, failure at hanger-joints and clips can be observed.

(a) Interior view of the pool (b) Failed furring strips and clips

Figure 5. Damage to the curved ceilings of a swimming pool in Tochigi prefecture

(a) Interior view of the pool (b) Collapsed curved ceilings

Figure 6. Damage to the curved ceilings of a swimming pool in Ibaragi prefecture

Auditoriums

Auditoriums usually have ceilings of complexly curved surfaces for their functions and acoustic performance (**Figure 7**). Auditoriums often have very large space above the ceiling in order to form the curved ceilings and to house function rooms. Very long suspension length of the ceiling makes the ceiling system rather unstable and often causes the failure of the ceilings. Very heavy panels are usually used for the ceilings for their acoustics. These heavy ceilings also cause easy collapse of the ceiling systems.

Auditoriums also often have proscenium arches for the theater use. The proscenium arches often deforms largely during strong earthquakes and often fails.

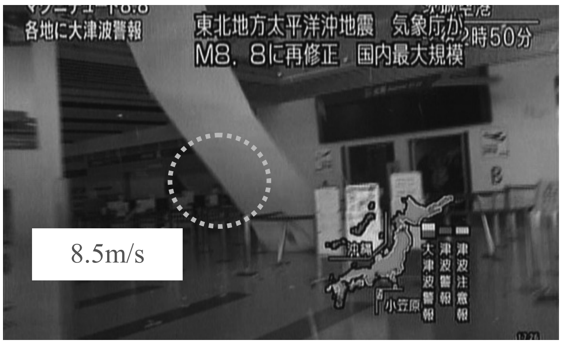
(a) An auditorium in Fukushima (b) An auditorium in Miyagi

Figure 7. Damage to the acoustic curved ceilings of auditoriums

The entrance hall of an airport

The ceilings at the entrance hall of an airport building, completed just a year ago, failed during the earthquake (**Figure 8**). There was no damage to the building structures. The height of the ceilings was so high but, luckily, nobody was injured. The important role of an airport in the emergency must not have allowed such easy collapse of non-structural components. The architectural design should have done more carefully. The instance of collapse of the ceiling was recorded by TV clue, which were there just by chance, and repetitively reported the failure with the video in the news program. The airport was reopened in a month by removing the remained ceilings of the entrance hall. The estimated impact load according to the results of dummy head experiment has been reported by the author's group in a report in Japanese.

(a) View of the entrance hall



(b) Estimated velocity of the ceiling during fall

(c) Estimation of the impact load in comparison to the dummy head experiment

Figure 8. Damage to the ceilings of entrance hall of an airport

The National Museum of Emerging Science and Innovation

The National Museum of Emerging Science and Innovation is standing at an artificial island in Tokyo (**Figure 9**). The ceilings of the entrance hall of the museum were failed during the main shock and the after shock. The evacuation guidance by the museum staff was so well organized that nobody was injured. The director of the museum considered the accident seriously and decided not to recover the ceilings in the same style as they were. He asked the author to supervise the recovery plan. The author recommended using the lightest and most flexible material, membrane, for the new ceiling. The director removed all the remained conventional ceilings of the entrance hall and renewed it with the membrane ceiling, which hardly fails again and never injure people.

The recovery work was quickly completed and the museum reopened on 11th June, 2011.

(a) View of the entrance hall before the quake

(b) The damage in the entrance hall

(c) New membrane ceilings

Figure 9. The National Museum of Emerging Science and Innovation

THE THREE CONDITIONS

Non-structural components, especially suspended ceilings in the large rooms can fail easily, and not only by earthquakes (**Figure 10**). The earthquake is just one of the causes that bring about the failure simultaneously in many places. Failure of non-structural components becomes extremely dangerous when they are put at the locations that satisfy the following three conditions.

1. The space is used for large public gatherings.
2. The nonstructural components are placed very high.
3. The space is very wide.

If these three conditions are satisfied, people using the space would possibly be endangered not only during earthquakes but also in ordinary time. Deterioration of the material, humidity, rainwater or non-earthquake vibrations can also cause the failure. Furthermore, as has already been mentioned earlier, wide-roof buildings provide space for refugee stations after disasters. One should therefore be very careful about the design of nonstructural components in large rooms.

(a) In a swimming pool in 2005 (b) n a swimming pool in 2008

Figure 10. Example of failure of suspended ceilings without any earthquake

CONCLUSIONS

This article reported the damage to non-structural components, especially to suspended ceilings, in large rooms, by the Japan earthquake. Probably because of the long duration of the earthquake, that could gradually weaken the most vulnerable part of the non-structural components, numerous buildings were suffered from the damage to non-structural components in their rooms. The damage spoiled the safety of the rooms. Some of the people were killed by the damage. The non-structural damage also spoiled the function of the rooms and brought about the huge damage to the business.

Generally, non-structural components fail easier than structural components in the shock of earthquakes. Therefore the failure occurs more frequently and more widely than that of structural components, in major earthquakes. Moreover the collapse of suspended ceilings often occurs in ordinary days when there are even no small earthquakes. The design of non-structural components should be done more carefully, not just in the respect of seismic performance but also in the respect of the selection of the appropriate material to be suspended high above the people to ensure the perfect safety.

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