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The Fire-Resistant Design of Tokyo Sky Tree

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Since receiving a Bachelor's and Master's of Engineering degree from Chiba University, he has been working for Nikken Sekkei Ltd. for more than 20 years. In 2006, he received a Doctorate of Engineering degree from Chiba University, based on a study of evaluation methods for the ultimate temperature of aluminum alloy structures exposed to fire. His previous works include a number of award-winning buildings, such as NIKKEI Tokyo Headquarters and Ishinomaki Red Cross Hospital.

As a critical asset for the city of Tokyo and its international reputation, the Tokyo Sky Tree was required to incorporate fire safety strategies that matched the importance of its superlative height and unique features. Two significant studies were conducted on Tokyo Sky Tree during the design phase to determine how to evacuate visitors in the event of a fire, as well as how to ensure that structural collapse does not occur. The two studies dealt with characteristic aspects of the building: the "Study of Urban Fires" and "Experimental Verification of the Glass Floor in the Sightseeing Section."

Introduction

Tokyo Sky Tree has an architectural height and height-to-tip of 634 meters, and serves primarily as a broadcasting and observation tower (see Figure 1). Under the provisions of the building standard law in Japan, the tower is classified as a "building within a structure" (see Figure 2), though it does not meet the CTBUH standard of qualifying as a "building," which must have 50% of its height or greater consisting of occupiable space. The tower is divided into two functional sections: a lower section that contains commercial establishments, and a tower section, which serves as an observation facility.

In the event of a fire in the building, the first priority is to ensure that all visitors are evacuated safely. A subsequent concern is that flashover – the near-simultaneous ignition of the directly exposed combustible material in an enclosed area – may lead to structural collapse, depending on the scale and location of the fire. The purpose of fire-resistant design is to prevent this type of collapse.

In fire-resistant design, it is crucial to accurately establish the properties of the fire that will occur at each location. Fires are generally classified according to whether they occur inside or outside the building. For fires inside the building, the design must assume flashover and other fire events. For fires outside the building, the design must anticipate fires that occur near the tower.

During the design of Tokyo Sky Tree, both internal and external fires were considered, and appropriate fire-resistant coverings and other means were provided to prevent structural instability.

Going Above and Beyond

The fire-resistant design of Tokyo Sky Tree is sufficiently safe for all assumed fires, as required by law. Due to the size and importance of the tower, however, assumptions above and beyond those required by law were used for the design, to enable the building to cope with unexpected fire scenarios.

One example of extensive fire safety design was the strategy undertaken to enable the building to cope with an urban fire that would engulf the area around the tower. The fire-resistant design adopted for Tokyo Sky Tree ensures that there would be no structural problems, even in such an extreme situation. A brief overview of this aspect will be presented in this paper.

Another unique feature of this building is the glass floor of the observation deck, which enables visitors to look down at the ground 300 meters below. If this glass floor should come loose and fall as the result of a fire, it could cause serious damage to the surrounding area, as well as fatalities. To ensure that this will not occur, a fire-resistance test was conducted by inserting a full-scale glass floor into a fire-resistance testing furnace, to verify that it can withstand the predicted fire. The results confirmed that no problems would arise. An overview of this test will also be presented.

> "The area within about 1,000 square meters surrounding the Sky Tree has a high fireproofing ratio of about 60%, the highest score in the 13.75-square-kilometer Sumida Ward."

Figure 1. Tokyo Sky Tree, Tokyo. © Orghi Dean

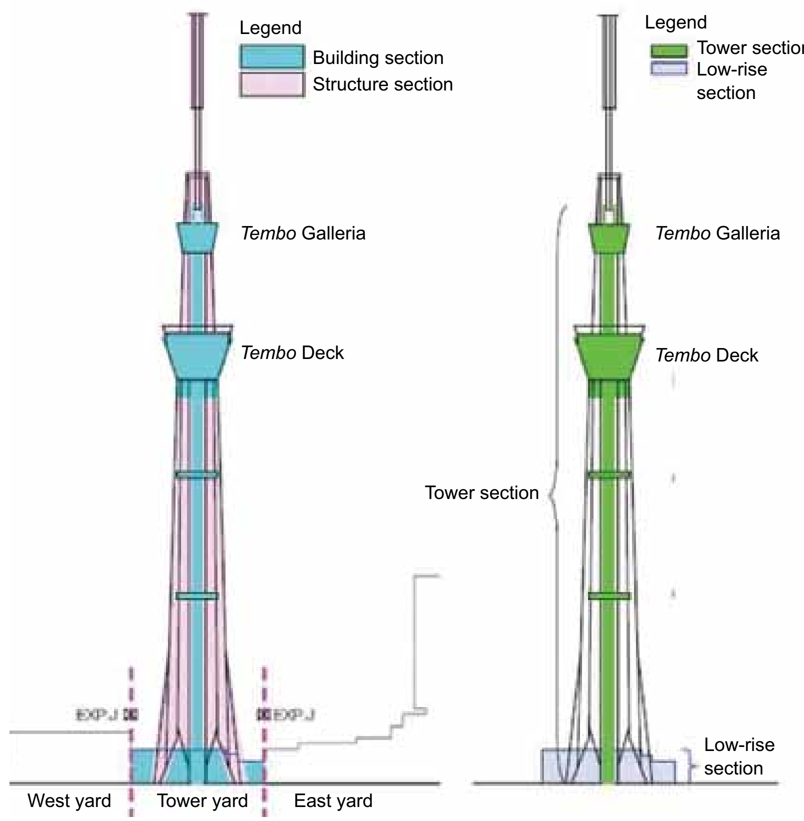

Figure 2. Distinction between Tokyo Sky Tree's building and structure sections, as well as its low-rise and tower sections.

Verification of the Tower's Integrity During an Urban Fire

An urban fire assessment begins by assuming the degree to which the buildings in the area have been fireproofed. There are many wooden residences in Japan, and major cities such as Tokyo are densely settled. For this reason, it is very important to conduct the assessment based on the location in question: whether it is an area packed with wooden structures that will burn easily, or an area with buildings that will not burn readily – in other words, to determine the degree to which the region has been fireproofed.

This area contains many sections that were subjected to aerial bombardment during the Second World War, and many buildings that would not burn readily were constructed in the reconstruction effort. The area within about 1,000 square meters surrounding the Sky Tree has a high fireproofing ratio of about 60%, the highest score in the 13.75-square-kilometer Sumida Ward.

The next step in the urban fire assessment is to assume where fires will occur near the site, based on the fireproofing ratio of the area. The final step is to assume the temperature of the heat received by the tower section from the heat source of the urban fire, and to study whether or not the framing is safe when exposed to such temperatures.

To calculate the temperature of the heat received by the tower section, it is necessary to calculate the maximum temperature distribution of the air currents produced from the fire source. Wind velocity has a particularly great effect on the maximum temperature distribution of air currents. Figure 3 shows the model used to calculate the maximum temperature of the air currents produced by the assumed fire. If the

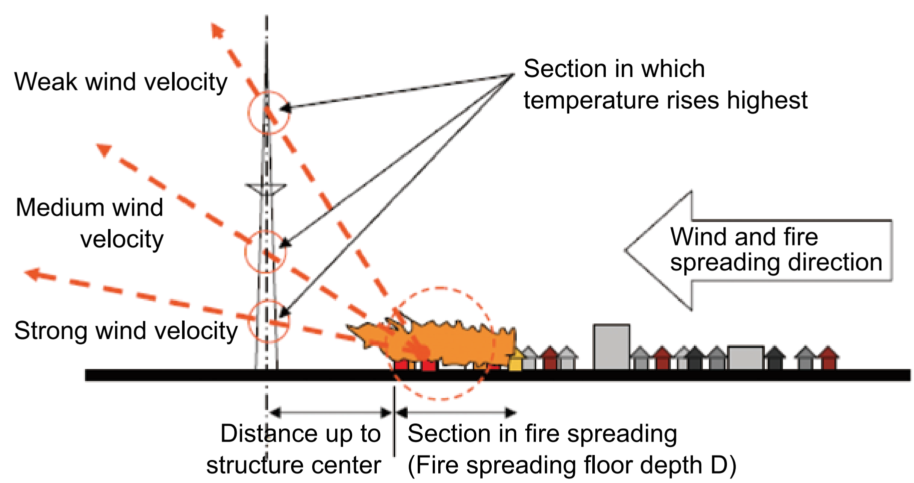

Figure 3. Model for calculating maximum air current temperature resulting from an assumed fire

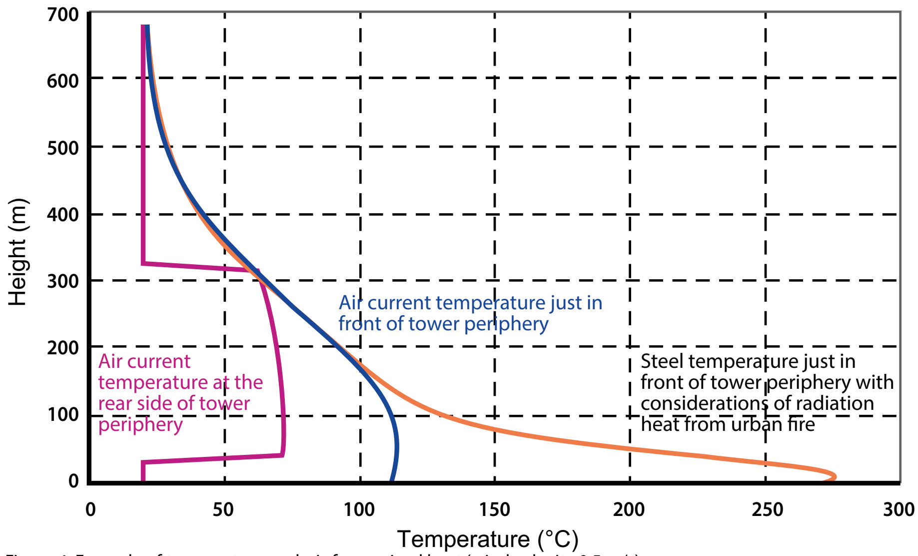

Figure 4. Example of temperature analysis for received heat (wind velocity 0.5 m/s)

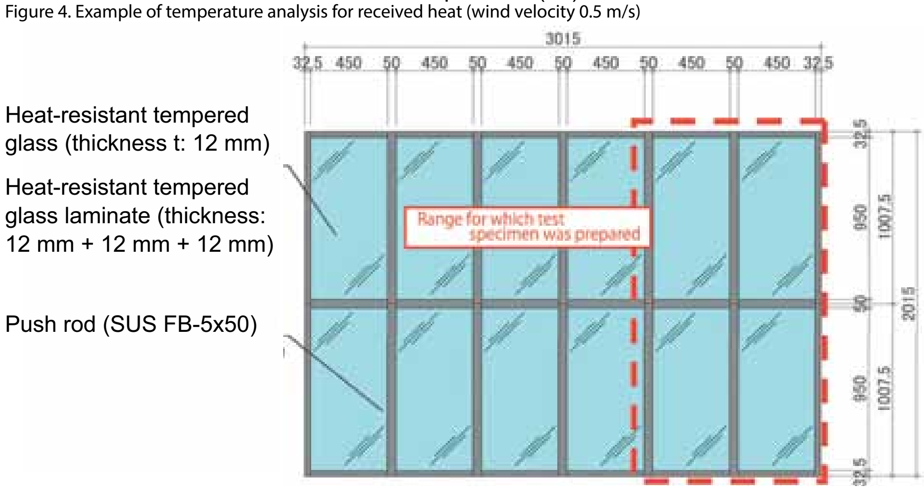

Figure 5. Location of sightseeing deck (Tembo Deck) used as test specimen.

Figure 6. Cross-section of the glass floor of the Tembo Deck used as a test specimen.

wind velocity is low, the maximum air current temperature will be produced at the top of the tower. If the wind velocity is high, the maximum air current temperature will be produced at the bottom of the tower. Figure 4 shows an example of the simulation results with different wind velocities.

Glass Floor Fire Resistance Test Overview

Figures 5 and 6 show the location and cross-section of the glass floor of the sightseeing deck (Tembo Deck). The glass floor is made up of two sections: an upper floor that people can actually touch, and a lower floor on the exterior that is capable of withstanding wind pressure. In the event of an internal fire, the upper floor on the interior is the glass floor that would be exposed directly to the fire, so a fire-resistance test was conducted for this section.

Due to the size restrictions of the fire-resistance test furnace, a section of the glass floor (see Figure 5) was used as the test specimen. The glass floor has a laminated structure that is made up of four layers of heat-resistant tempered glass (12 millimeters).

Figure 7 shows the test specimen after it had been inserted into the furnace. The test was a loaded heating test, in which the entire test specimen was inserted into the furnace and heated with a weight placed on top of the glass floor. Each 0.5- by 1.0- meter glass segment was compressed by a 65-kilogram

Figure 7. Test specimen.

> “Research has proven that the glass floor has a fire resistance equivalent to that of a concrete floor, and thus was allowed to be treated similarly in terms of fire code approvals.”

Figure 8. Test specimen after heating (two upper layers were removed to confirm no cracking in the third layer of the glass laminates).

Figure 9. Test specimen during heating (from observation window of test furnace).

weight. This is about twice the normal weight needed to pass the Japanese fire-resistance construction test, which is 65 kg/m^2. As only the glass side was heated, the surrounding walls supporting the glass floor were given thermal insulation treatment. The five white cylindrical members shown in Figure 7 are the fire-resistant coverings surrounding the measurement jigs that were provided to measure the amount of deformation due to the weight.

Figure 9 shows a photograph taken from the furnace observation window, showing the test specimen being heated. In the event that a fire should occur in the area with the glass floor, the duration of the fire was calculated to be about 40 minutes based on simulations using standard heating conversions. The simulation was carried out with the heating temperature curve of a standard heating test in ISO834 ($T = 345\log10(8t + 1) + 20$), in which T = average furnace temperature and t = test elapsed time. To confirm that the glass floor could withstand an interval longer than this duration, the test was conducted under standard heating for one hour. During the heating process, the glass did not break and the weight did not fall.

Figure 8 shows the test specimen after heating. Cracking occurred in only the top two of the four layers in the loaded heating test, which was conducted for a duration exceeding the assumed internal fire duration of 60 minutes. These results confirm that sufficient stability would be maintained in the event of a fire.

Conclusion

The glass floor of the Tokyo Sky Tree was proven to support the safety equivalent of a one-hour fireproofed structure. A glass floor would normally be treated as an “opening,” i.e., equivalent to a window in Japanese fire code, so the requirements for fireproofing the glass floor to a level equivalent to that of a piece of structure were steep. However, this research has proven that the glass floor has a fire resistance equivalent to that of a concrete floor, and thus was allowed to be treated similarly in terms of fire code approvals. This experience should prove useful in further applications of glass-bottomed observation decks, which are becoming more popular. ■

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