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Design of temporary, conditional, and highly influential buildings for severe local storms including tornadoes

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SUMMARY:
This paper examines the design principles for buildings and structures and discusses the crucial differences among building performances against tropical cyclones (TCs) and severe local storms (SLSs) such as tornadoes and downbursts. The design load level of claddings/components and that of main frames are discussed, and the importance of cladding/component performance is emphasized. It also discusses design load levels for temporary buildings including scaffoldings and construction offices and for conditional buildings and structures (CBSs) including cranes, movable roofs and so on. Finally, design issues of tornado effects on highly important and highly influential buildings such as nuclear power plants (NPPs) are discussed. Then, the following facts are recognized. Buildings are more vulnerable to them than to TCs because of lack of an efficient warning system for SLSs. CBSs should be carefully operated following operation manuals and signs of weather and sky, especially for SLSs. The design load level of buildings and structures should not simply be decided based on the lifetime or the period of individual use.

Keywords: tornado; severe local storm; temporary building; conditional building; highly influential building

1. CRUCIAL DIFFERENCE BETWEEN TROPICAL CYCLONES AND SEVERE LOCAL STORMS

According to the Building Standard Law of Japan (BSLJ), the basic design wind speed in Tokyo is 34m/s, which is a 50-year-recurrence 10min-mean wind speed 10m above the ground in open flat country. The 10min-mean value, 34m/s, can be converted to 3s-gust speed, 56m/s, by being factored by 1.66 (Harper et al., 2008). This value can be converted to the 500-year-recurrence value of 70m/s based on the BSLJ. The wind speeds of 56m/s and 70m/s are in the ranges of F2, EF2 - 3, and JEF2 - 3 (Tamura et al., 2022). The majority of tornadoes in Japan are of F0 and F1; F2 and F3 tornadoes are very rare. This suggests that buildings designed based on the BSLJ can resist the majority of tornadoes. However, there is a crucial difference between tropical cyclones (TCs) and severe local storms (SLSs) including tornadoes. We have effective warning systems for TCs, and the information can be opened to the public in various ways including TV broadcasts. Thus, we can appropriately prepare for them, such as by closing storm shutters, protecting or reinforcing windows and doors, cancelling outdoor events and outings, and so on. However, no effective warning systems are available for tornadoes or downbursts. In Japan, we have a tornado warning system, where the Japan Meteorological Agency (JMA) predicts the development and movement of supercells and dispatches a 'tornado warning' based on meteorological observation data and analyses. However, its accuracy and reliability are limited, and the lead time is insufficient for some buildings and structures. Therefore, they basically encounter tornadoes or downburst without sufficient preparation.

2. CONDITIONAL BUILDINGS AND STRUCTURES (CBS)

There are many types of buildings and structures designed under the assumption that they will be controlled or maintained in strong wind events, such as movable roofs, freight handling facilities, scaffoldings, cranes, and various net/sheet supporting structures, which are defined as 'conditional buildings and structures (CBSs)' in this paper. For strong winds, special treatments and cures are necessary as follows: movable roofs should be closed; nets and sheets should be removed or tied; crane operation should be suspended; mobile facilities should be stopped and locked; and so on. These structures are vulnerable to winds. For safe operation and usage of CBSs, well designed operation manuals should be prepared and strictly observed to guarantee design assumptions. As an efficient warning system is not available for SLSs, damage and collapse of scaffoldings, cranes, and net supporting structures have often occurred. Responsible persons for operation, management and maintenance of CBSs should pay careful attention to daily meteorological conditions, and safer and earlier decisions should be made.

3. DESIGN LOAD LEVELS FOR MAIN FRAMES AND CLADDING/COMPONENTS

The BSLJ requires main frames to be designed based on a 50-year-recurrence wind load and a 500-year-recurrence wind load, while it requires claddings/components to be design based on a 50-year-recurrence wind load only. There seems to be an implicit consensus that the design load level for claddings/components can be lower than that for main frames. However, in main frame design, the same external wind pressure/force coefficients are generally used for both 50-year-recurrence and 500-year-recurrence wind load levels. This suggests that the original building configurations should be maintained even for the ultimate state corresponding to the 500-year-recurrence wind load level, and claddings and components should not be broken or torn off. Some people say that claddings and components are replaced at certain predetermined intervals. Thus, they advocate that the lifetimes of claddings and components may be generally shorter than those of main frames, so their design wind load levels can be lower. However, it should be noted that they are replaced with identical cladding elements and members, so they always exist and are never permanently removed as long as the building exists. Therefore, the short replacement intervals of specific cladding elements cannot be a reason for reducing the load level. Theoretically, there is no reason to accept a lower level of wind load for cladding/components than for main frames (Tamura et al., 2018). Therefore, the design load level for claddings/components should be the same as for main frames, or the progressive change of aerodynamic characteristics of buildings due to cladding/components damage should be taken into account in mainframe design.

4. DESIGN LOAD LEVELS FOR TEMPORARY BUILDINGS INCLUDING CONSTRUCTION OFFICES AND SCAFFOLDINGS

For temporary buildings including construction offices, the BSLJ specifies reduced design loads and less strict construction methods. Other codes and standards such as AIJ-RDKTB (2013), ASCE 37-14 (2019), and AS/NZS 1170.2 (2021) also allow reduction of design wind speeds for temporary buildings and structures. Thus, there is a common consensus that design load levels for temporary buildings can be lower than those for general buildings, so construction offices are basically more vulnerable to wind and seismic excitations. However, Tamura et al. (2018) pointed out the contradictions of this theoretical background. Similarly, design loads for scaffoldings are much lower than those for general buildings. For example, SCEAJ-TRSSW (1999) specifies design wind loads for scaffoldings based on 1-year-recurrence wind speed. The British Standard requires design wind loads based on 2-year-recurrence wind speeds (BS EN 12812, 2008), and Chinese Codes/Standards require design wind loads based on 10-year-recurrence wind speeds (GB 50009, 2012, GB 51210, 2016, JGJ130, 2011, JGJ/T 128, 2019). However, Tamura et al. (2018) also pointed out the irrationality of this preconception. The average existence period of a specific scaffold at an individual site is short, but it moves to other locations and continues to exist. The construction sites are moving, but the number of construction sites remains almost constant. Tamura et al. (2018) also proved that there is no relation between design load level and length of individual use or life-time, raising examples of average rental period of rental cars and periodic replacements of parts of airplanes. Anyway, when we discuss the design load level of so called 'temporary buildings', we should reconsider the real meaning of the individual life-time of each building. Then, the design principle focusing on a group or an assemblage of unspecified buildings rather than an individual specific building might be necessary.

5. DESIGN PRINCIPLE FOR HIGHLY IMPORTANT AND INFLUENTIAL BUILDINGS AND STRUCTURES

Owing to their importance and social impacts, sufficient attention should be paid to the design load levels of highly important and influential buildings and structures under strong winds, especially SLSs. Like railways, power transmission cables and towers comprise line-like structures extending over land, and have a much higher possibility of encountering tornadoes than individual buildings. Thus, tornado effects should be considered in disaster management of these facilities. One highly influential and important facility is the nuclear power plant (NPP). Temporary shutdowns of NPPs were made in the US due to tornadoes at Dominion Virginia Power, Surry, VA and Browns Ferry Nuclear Plant, Athens, AL, on April 16 and 27 in 2011, respectively (Prevatt et al., 2015). Incidentally, these shutdowns happened almost one month after the Fukushima Daiichi NPP accident due to the Great East Japan Earthquake-induced tsunami. The reason for the shutdowns of NPPs in the US were collapses of external power lines due to tornadoes. Back-up generators immediately kicked in at those two NPPs, so no serious accidents happened. The scenario up to activation of back-up generators was the same for the Fukushima Daiichi NPP. However, in the Fukushima case, the back-up generators were also destroyed around 50min later by the big tsunami. As is well-known, multiple tornadoes can happen, and there is a possibility of damage to back-up generators due to consequent tornadoes. Thus, fail-safe counterplans should also be prepared for back-up generators. There are several design guides and regulations for tornado effects on NPPs, e.g. ANSI/ANS-2.3 (1983) and RG 1.76 (2007) in the US and JNES-TPU (2011) and NRA Guide (2013) in Japan. The US guidelines adopt an annual exceedance probability of 10^{-7} to determine the design tornado following Markee et al. (1974), and JNES-TPU (2011) also proposed a design tornado model based on an annual exceedance probability 10^{-7}. The impacts of failure of NPPs cannot be limited to the nation in which it is constructed, because the effects of failure could immediately propagate to many other countries. Therefore, they should be treated as a worldwide issue, and a worldwide consensus should be obtained, and cooperative studies on the design load levels of NPPs are necessary. In addition to electric facilities, the buildings and structures, including liquefied natural gas (LNG) storage tanks, super-tall buildings, local government offices, fire stations, hospitals, evacuation facilities, disaster prevention centers, data/computer centers and so on, are highly important for society, and special consideration should also be given to them.

6. CONCLUSIONS

This paper discussed wind-induced damage to buildings/structures and design principles, with special focus on the difference between SLSs and TCs, temporal and CBSs, and highly important and influential buildings.

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