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# Pedestrian-level wind environment on outdoor platforms of a thousand-meter-scale megatall building: Sub-configuration experiment and wind comfort assessment

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ABSTRACT

A thousand-meter-scale megatall building is consisted of three peripheral elliptical towers and one central circular tower, together with 10 outdoor platforms along the height with an interval of 100 m to connect the four towers. As there is no shelter between every two adjacent platforms, pedestrians will feel uncomfortable or unsafe due to large approaching wind speed when strolling or walking across the platforms. Therefore, the pedestrian-level wind environment on outdoor platforms is studied via the combination of wind tunnel tests and CFD simulations. Firstly, wind environment experiment of a sub-configuration of the megatall building is carried out, and characteristics of the pedestrian-level wind environment are analyzed. Then, distributions of the pedestrian-level wind speeds of a full model of the megatall building are compared to that of the sub-configuration via CFD simulations, and an adjustment coefficient is introduced to establish the link of wind speeds between these two models. Lastly, based on the statistical meteorological data provided by the Dalian Meteorological Service Center and the aerodynamic information above, assessment of the pedestrian-level wind comfort and wind danger of the outdoor platforms is implemented using both the Lawson criterion and the NEN 8100 criterion. The results show that quality of the wind environment is very poor on most zones of the platforms, especially in the passageways of two adjacent towers due to the “funneling effects”, and some effective measures should be explored to improve it. This study contributes to further understanding of characteristics of the pedestrian-level wind environment of outdoor platforms high up on megatall buildings via sub-configuration experiment and full model simulations.



## 1. Introduction

As a result of extensive utility of new lightweight high-strength materials in construction, modern super-tall buildings went through a rapid development in the past decades, and the height of the tallest building in the world was constantly refurbished. At present, the tallest building is the Burj Khalifa in Dubai, with 163 storeys and a height of 828 m, while the Jeddah Tower with a design height of 1000 m is under construction in Saudi Arabia, and it will be completed in 2018. Besides, many countries, such as Japan, USA, AE, China, have the vision to construct an unprecedented megatall building. In order to satisfy the future development of the urbanization in China, and to provide strong technical reserves for designing a thousand-meter-scale megatall building, it is very necessary to study on the main technical difficulties related to its architectural and structural design.

A thousand-meter-scale megatall building, with a height of 1180 m, is proposed to be built in Dalian, China. The building, which is consisted of three equilateral-triangle-arranged elliptic towers and one central circular tower, has 10 outdoor platforms along its height with an interval of 100 m to connect the four towers. For each platform, its height is 15 m, and three pieces of wind shields with a height of 3 m are placed on its exterior edge. Above the top platform at level of 1000 m, there are four domes with a height of 180 m. Fig. 1 shows an effect drawing of this building.

Without any shelter between every two adjacent platforms, the approaching wind can pass through them directly, so there will be significant problems of the pedestrian-level wind environment for

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these outdoor platforms. Firstly, flow fields around the four towers are more complex than that around single tower, accompanying with the flow phenomena of separation, vortices, downwash, contraction, canalization, etc. [1,2]. The complex flows may lead to locally strong wind on the outdoor platforms, which will bring discomfort or even unsafety to pedestrians. Secondly, the approaching wind speed increases gradually with the height. According to the exposure category of B in "Load Code for the Design of Building Structures" (GB 50009-2012) in China (abbreviated as the "Chinese Load Code") [3], the approaching mean wind speed at the gradient wind height (or 350 m) is approximately 1.7 times of that at height of 10 m. Thirdly, there exists the "funneling effects" [4] when wind flows across the platforms, resulting in significant increment of local wind speed. Therefore, it is very necessary to study on the pedestrian-level wind environment, and to assess wind comfort and wind danger of these outdoor platforms.

Assessment of the pedestrian-level wind comfort and wind danger at a particular location requires the combination of statistical meteorological data, aerodynamic information and a comfort criterion [5]. Meteorological information comprises long-term wind statistics from the meteorological stations in the open terrain. Aerodynamic information is needed to transform the meteorological information from the meteorological stations to the building site where wind environment is to be assessed. Once this link is established providing us with the wind statistics at the location of interest, the comfort criterion is used to judge local pedestrian-level wind comfort and wind danger. Wind comfort criterion reflects the statistics of people's perception on different wind strength imposed on, distinguishing among various pedestrian activities, such as sitting, strolling, walking fast, etc. Since the 1970s, many scholars have proposed several criteria to assess the pedestrian-level wind environment, such as the Isyumov & Davenport criterion [6], the Melbourne criterion [7], the Shuzo Murakami criterion [8], and the Lawson criterion [9,10] etc. Furthermore, in 2006, a standard for wind comfort assessment (NEN 8100 [11–13]) was published in the Netherlands.

The aerodynamic information usually consists of two parts: the terrain-related contribution and the design-related contribution. The former takes into account differences of the terrain roughness between the meteorological stations and the building site, and the latter depends on the design of buildings and their surroundings, such as the building geometry, building orientation, the interactions between buildings, etc. And the design-related contribution can be determined via wind environment experiments or CFD simulations [14].

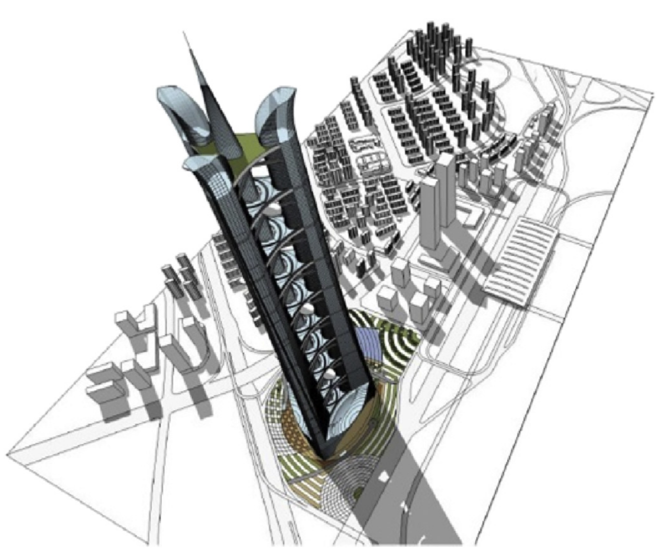

**Fig. 1.** Effect drawing of the thousand-meter-scale megatall building.

For the wind environment experiments, data of the design-related contribution can be the wind speeds of continuous surfaces or several individual points [15]. Measurement technologies of continuous surfaces include the scour techniques and the Particle Image Velocimetry (PIV) techniques. The former can only obtain qualitative results of flow fields around the building [16], and the latter can acquire quantitative results, but suffering from other drawbacks, such as laser sheet shielding, attenuation and reflections caused by the building or the ground [17]. Measurement technologies of individual points include the hot-wire anemometers and the pitot tubes, and they can provide quantitative data at any location. However, they will generate significant disturbance to the flow fields, and are usually time-consuming for data-measuring at a large number of locations. To solve the above problems, Irwin [18] invented the omni-direction pressure sensors in 1981. The Irwin sensors can synchronously measure pedestrian-level wind speeds of multiple points with much less disturbance to the flow fields, and their accuracy has been proven to be satisfactory for engineering applications in wind environment experiments [19,20].

Using the modified Irwin sensors, Tsang et al. [21] and Kuo et al. [22] studied the pedestrian-level wind environment in the street canyons around tall buildings, taking into account the effects of different building configurations, dimensions, spacing and podium. And the results showed that the wind speeds were significantly accelerated due to the "funneling effect" between the buildings. Besides, several experimental studies on the pedestrian-level wind conditions in complex urban environments were implemented [23–26], and the results showed that wind comfort and wind danger issues should be taken seriously.

In recent years, with the development of computer hardware, and the progress of computational methods, CFD simulations have been increasingly used to study on the pedestrian-level wind environment. Nearly all the CFD simulations were implemented using the steady Reynolds-averaged Navier–Stokes (RANS) approach [27–31], and the numerical results were often compared to the experimental data of the same building model for validation [28–31]. However, owing to restraint of the blockage ratio of wind tunnel, and the complexity of manufacturing a completely same urban model, wind tunnel test of a sub-configuration is conducted in a few studies to validate the CFD simulations [17,27]. This refers to performing validation for simpler generic building configurations that represent sub-configurations of the more complex urban configuration. For these generic configurations, wind environment experiments are generally available. The confidence extracted from this validation can be used to support the application of CFD simulations with similar computational parameters for the more complex urban configuration.

Due to the restraint of the blockage ratio of atmospheric boundary-layer (ABL) wind tunnel, together with the requirement of sufficient measuring points to acquire accurate wind environment results, a three-platform sectional model of the thousand-meter-scale megatall building (the sub-configuration) is employed as the experimental model in this paper. Characteristics of the pedestrian-level wind environment on outdoor platforms of the sub-configuration are analyzed, and the link of wind speeds between the sub-configuration and the full model is established by CFD simulations. Based on the results, the pedestrian-level wind comfort and wind danger of the most unfavorable platform of the megatall building are assessed by both the Lawson criterion and the NEN 8100 criterion. Section 2 is mainly concerned on the setup of wind environment experiment, and Section 3 presents the CFD