Building and Environment 130 (2018) 62–73

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Investigation on characteristics of thousand-meter height wind profiles at non-tropical cyclone prone areas based on field measurement

Zhao Liu[a,b], Chaorong Zheng[a,b,c,*], Yue Wu[a,b], Yu Song[d]

[a] Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin, 150090, China
[b] Key Lab of Smart Prevention and Mitigation of Civil Engineering Disasters of the Ministry of Industry and Information Technology, Harbin Institute of Technology, Harbin, 150090, China
[c] Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment (Beijing Jiaotong University), 100044, Beijing, China
[d] Dalian Meteorological Service Centre of Liaoning, 116001, Dalian, China

ARTICLE INFO

Keywords:
Synoptic wind
Mean wind profile
Atmospheric boundary layer
Clustering analysis
Wind profiler

ABSTRACT

Accurate representation of the atmospheric wind profiles is very important for the relevant research works on the environmental wind engineering and wind-resistance design of buildings. Recently, the characteristics of thousand-meter height wind field in the atmospheric boundary layer (ABL) are investigated based on the field measurement by a wind profiler, which was installed in a coastal area of China (121.75°E, 39.05°N). Specifically, mean wind velocity profiles and wind direction profiles measured during 16 strong windy days (synoptic wind) are analyzed in the present paper. It is found that based on the agglomerative clustering analysis, the mean wind velocity profiles can be divided into two categories, namely, I and R categories. For I category, the wind velocity increases with height monotonously. While for R category, the wind velocity reaches a maximum value at a height of 500–600 m, and then recedes with height. In most cases, I category wind velocity profile can envelope that of R category, and thus becomes the main consideration for the wind − resistance design of megatall buildings. Furthermore, for I category, the log − law can be used to describe the variation of wind velocities below the height of 360 m, while the power − law is valid up to 1000 m. With the increment of total twist angle and wind velocity, the variation of measured wind directions shows a better agreement with that implied by Ekman spiral. And the total wind twist angles can reach 5°–40° over the first 1000 m.

1. Introduction

The determination of accurate representation of wind profiles is the basis for some research works on environmental and structural wind engineering, including the assessment of wind comfort, modeling of air pollution dispersion and the wind-resistance design of buildings, etc. Because for these research works, the common feature is that the wind profiles should be properly set to be served as the inlet boundary conditions. In the case, an accurate wind profile is the precondition for drawing cogent conclusions and thus helpful for taking adequate measures. In most load codes (e.g. [1–3]), the wind profiles are described by the power-law or log-law with two assumptions: (1) A gradient height is specified (typically 200–650 m). And above the height, the wind velocities are taken as a constant or not given. (2) The wind directions along the height are taken as a constant. However, in some cases, these kinds of stipulations in the load codes need to be used carefully. For example, Tse et al. [4,5] investigated the pedestrian-level wind environment around buildings where the wind direction is no longer taken as a constant. It is found that the surrounding wind environment is considerably modified by the twisted wind profile. Besides, with the development of new lightweight, high-strength materials and advanced construction techniques, more and more magatall buildings have emerged. And the Jeddah Tower in Saudi Arabia (under construction) with a height of 1000 m even indicates that the height of modern megatall buildings is moving towards the thousand-meter scale (Council on Tall Buildings and Urban Habitat [6]). The heights of these megatall buildings exceed the gradient heights in the load codes excessively. For their wind environment assessments [7], the stipulations in the load codes will be inappropriate since they may underestimate the wind velocities in the upper levels and thus make the results unbelievable, especially for the assessment of high-altitude wind environment [8]. A similar embarrassing situation is also encountered for the wind-resistance design of megatall buildings. The wind loads cannot be calculated accurately based on the inappropriate wind profile, which may lead to the unnecessary wind-induced disasters. Thus, for the better research on environmental wind engineering and wind-resistance

* Corresponding author. Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin, 150090, China.
E-mail address: flyfluid@163.com (C. Zheng).

https://doi.org/10.1016/j.buildenv.2017.12.001
Received 16 September 2017; Received in revised form 14 November 2017; Accepted 2 December 2017
Available online 20 December 2017
0360-1323/

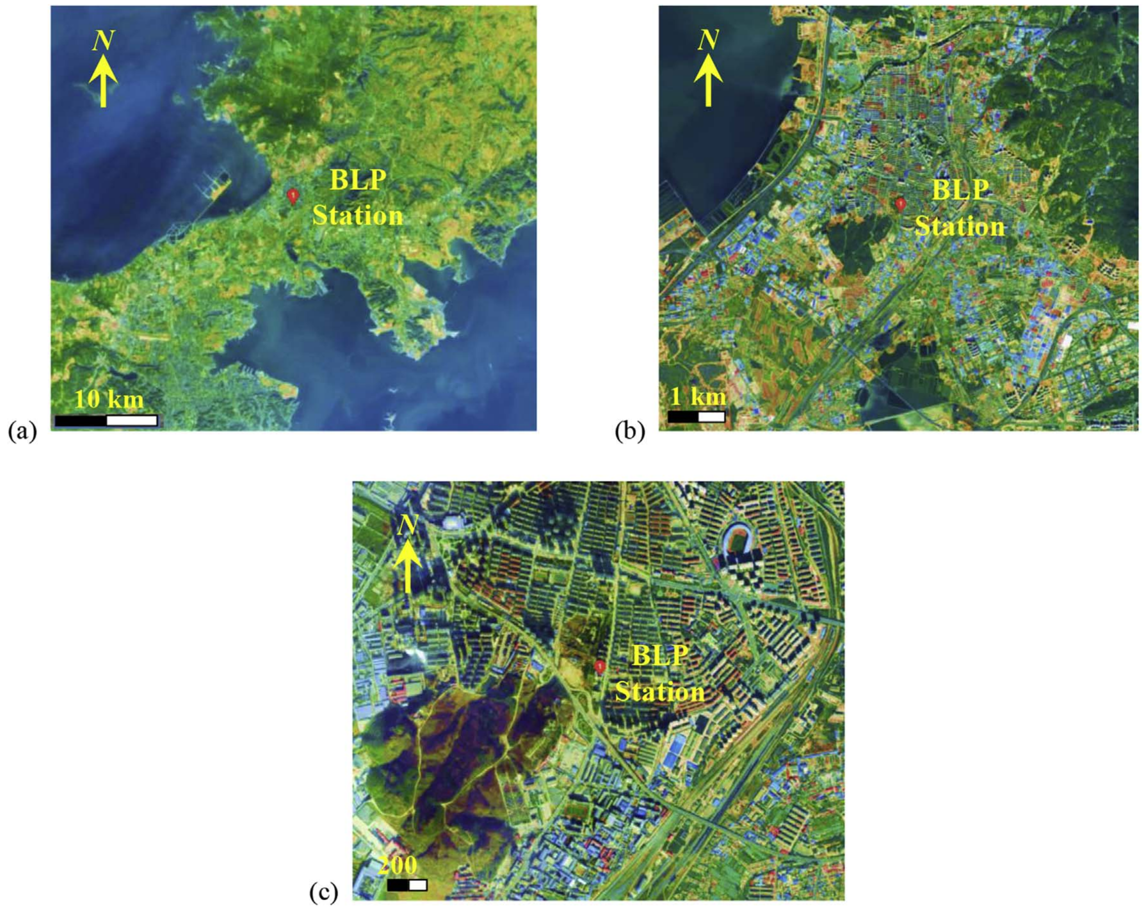

Fig. 1. Geographic location of the meteorological station in satellite maps.

design of megatall buildings [8–11], an accurate representation of the thousand-meter height wind profile is badly in need of determination.

Fortunately, based on the modern wind instruments, such as radiosondes and wind profilers, it has become possible to detect the wind field in the thousand-meter height. And in the past decades, numerous field measurements had been conducted to analyze the characteristics of the atmospheric wind. For example, Powell et al. [12] observed the wind profiles up to a height of 1.5 km during several tropical cyclones using GPS sonde. And it is found that, basically, the wind velocity increases first and then decreases with an increment of height. Giammanco et al. [13] observed the tropical cyclones based on GPS sondes and Doppler radars, and concluded that the variation of wind velocities along the height changes with decreasing radial distance toward the cyclone center. He et al. [14] analyzed both the wind velocity and wind direction profiles during 16 tropical cyclones at a coastal site using a Doppler wind profiler and an anemometer. The maximum height reaches 1.2 km. It seems that the pattern of wind velocity profile changes with the reference wind velocity and reference wind direction. Besides, the wind twist angle can reach 30° over a height of 1.2 km. Tse et al. [15] also made an effort to study the wind field in the thousand – meter height. And it was found that the low-level jet, which is commonly observed for the mean wind profile in the tropical cyclone system over the sea, was not found. He et al. [16] further analyzed the wind fields during 22 tropical cyclones which made landfall in Hong Kong. And the maximum height already reaches 5 km. The occurrence of low-level jets (near 0.33–1.6 km) and secondary maximum wind (near 3.0–3.5 km) were comprehensively investigated. There are also many other studies on the characteristics of atmospheric wind in the thousand-meter height [17]. Apparently, these studies can provide valuable insights into the characteristics of the atmospheric wind, and hence can also provide effective guidance for the assessment of wind environment and wind-resistance design of megatall buildings, etc.

However, it should be noted that the above-mentioned field measurements were all conducted during tropical cyclones, and the relevant results may not be referred securely for the non-tropical cyclone prone areas. Therefore, the characteristics of synoptic wind need to be investigated separately. Deaves and Harris [18] proposed a mathematical model (D-H model) for the structure of synoptic winds. After that, Deaves [19] further extended the applicability of the model to the heterogeneous terrain. The precision of the D-H model was evaluated through the field measurements conducted in Farnborough, Leipzig, Nantes, Rugby, Granfield and other cities. However, for these field measurements, the maximum heights just vary from 200 to 600 m. Using Doppler sodars and anemometers, Tamura et al. [20,21] and Li et al. [22] conducted field measurements in Japan and Beijing to detect wind velocity profiles during several storms. All of above studies can provide valuable data measured in the synoptic wind, however, the maximum heights in almost all these measurements are still no more than 500 m, and hence can not provide a guidance for the wind environmental assessment and wind-resistance design for megatall buildings, such as Burj Khalifa Tower (828 m) and Jeddah Tower (1000 m). Drew et al. [23] analyzed the wind velocity profiles measured over an eight-month period. This study put more emphasis on the application of morphological parameters which contribute to the accurate determination of wind velocity profiles when experiencing roughness changes. However, the wind velocities measured in that study are relatively small, and hence the characteristics of synoptic wind may need to be further investigated through the supplement data measured in larger wind magnitudes.