August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering
ICWE 16

Study of wind field for urban high-rise building based on Lidar measurement and wind tunnel test

Yi Yang [1], Haisheng Deng [2]

[1]*State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, China, ctyangyi@scut.edu.cn*
[2]*State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, China, ctyangyi@scut.edu.cn*

SUMMARY:
A one-month (September 8 to October 8, 2022) lidar field measurement and corresponding wind tunnel simulation tests for the boundary layer wind field of a 287.5m high-rise building were carried out, which is under built in the commercial district of Guangzhou, China. This paper reports the characteristics of the boundary layer wind field in a low-level jet of a sudden high wind event over a city captured by liar, and compares it with the average wind speed profile simulated by wind tunnel test. With the end of the low-level jet, the wind tunnel test results gradually approach the lidar measured results, and show that the wind profile index at the site of the building to be built is about 0.4-0.5.

Key words: Atmospheric boundary layer wind field, lidar, field measurement, wind tunnel test

1. BACKGROUND

The wind field characteristics of the boundary layer in the urban center are the key and premise to study the wind effects of the super high-rise buildings. Because it is impossible to measure the wind field in the urban center with dense high-rise buildings by using the traditional wind tower, the research on the measurement of the wind field in the urban center by employing the lidar, the "movable wind tower", has been developed in recent years. The urban boundary layer (UBL) of London was investigated by Drew et al.(2013) and Kent et al.(2018) . Kikumoto et al.(2017) performed measurement using Doppler lidars and ultrasonic anemometers in Tokyo, Japan, and evaluated the accuracy and limitations of the UBL wind field model using the power law in Tokyo. Yang et al (2023) measured the wind field data by the two lidars and to investigate the UBL wind field characteristics at the SEG Plaza were analyzed, then a new inversion method for constructing the atmospheric boundary layer wind field characteristics under built environment was established based on lidars and computational fluid dynamics (CFD) numerical simulation. The above achievements help us to deeply understand the characteristics of the real atmospheric boundary layer wind field in nature, and provide an important reference for the accurate assessment of the wind loads on building structures.

2. BRIEF INTRODUCTION OF THE PROJECT

The super high-rise building investigated in this paper is located in Guangzhou, China. The building height is 287.5m, which is under construction and shown in Figure 1(a). The aerial photo of the landform around the project is given in Figure 1(b).
The ESDU mathematical model is used to analyse the wind field roughness of the site around the building, and it can be categorised to be the Category C and Category B composite terrains in the Load Code for the Design of Building Structures (GB50009-2012) of China, as shown in Figure 2 (c).

(a) building effect map (b) surroundings around the measured buildings (c) site roughness analysis
Figure 1. Measured buildings and surroundings analysis

3. 3. FIELD MEASUREMENT STUDY

From September 8, 2022 to October 8, 2022, the field measurement of the boundary layer wind field was carried out at the building site using the WindMast PBL boundary layer wind profile lidar. The theoretical detection height ranges from 30m to 4000m, the wind speed measurement range is 0~75m/s, and the wind speed error is less than 0.1m/s. The wind direction error is less than 3 °. The vertical resolution is set to 15m, and the detection period is set to 1s. During the field measurement, the project is still in the foundation pit construction stage. The lidar is arranged in the southwest corner of the project plot, as shown in Figure 2.

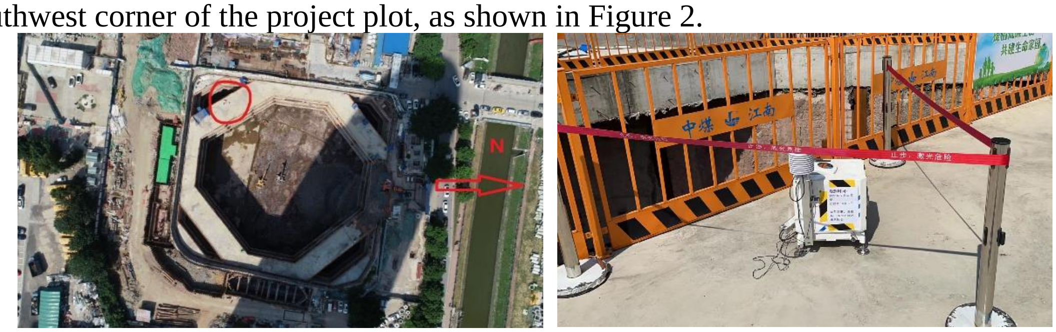


Figure 2. Layout of lidar field measurement

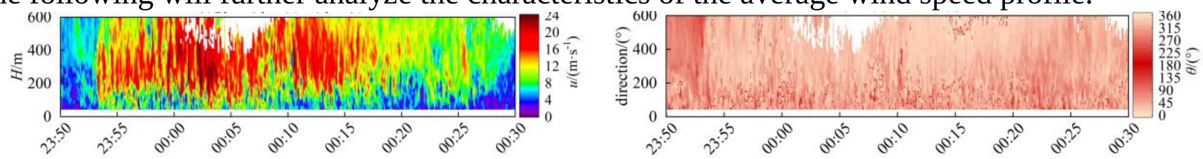
2.1 Field measurement research condition

During the one-month observation period, the lidar captured a sudden strong wind event from 23:50 on September 18, 2022 to 00:30 on September 19, 2022. This paper mainly studies the characteristics of the boundary layer wind field of this event.

2.2 Field measurement results

Analysing the characteristics of averaged wind speed, wind direction and wind profile based on the 10-minute interval data recorded by lidar; and the second interval data recorded by lidar is used to analyse the turbulence characteristics.
Figure 3 shows the wind speed and wind direction time history cloud chart of a complete gale event (between 23:53 on September 18 and 00:25 on September 19) measured over the studied

building. The measured results show that: 1) According to the mean wind speed time-history distribution nephogram, this gale event presents the characteristics of low-level jet, and the high wind speed bands are concentrated between 100m and 600m; 2) In low-altitude jet events, the wind speed in the first half of the event, from 00:00 to 00:10 on September 19, is the strongest. The maximum instantaneous wind speed recorded by the radar at high altitude (100-400m) reaches about 24.0m/s, and the 10-minute average wind speed at 42m in low altitude reaches 7.31m/s; 3) In this gale event, the wind direction is mainly between 0 °- 45 °and 315 °- 360 °. The following will further analyze the characteristics of the average wind speed profile.



(a) Wind speed time history (b) Wind direction time history

Figure 3. Cloud chart of wind speed and wind direction over the project site

4. WIND TUNNEL TEST

At the same time, according to the project's architectural design data, a rigid pressure measurement test model (the geometric scale of the model is 1:400) was made, and the wind tunnel test of the rigid model pressure measurement after the completion of the project was carried out in the Wind Tunnel Laboratory of South China University of Technology, as well as the wind profile test of the boundary layer wind field under current surroundings, so as to facilitate the comparison of the measured data of lidar.

The boundary layer wind tunnel test section is 24 m long, 5.4 m wide and 3 m high. The test model is installed on a 4-meter diameter turntable in the wind tunnel test section, as shown in Figure 4. The wind tunnel test simulated the Category C wind characteristics in the Load Code for the Design of Building Structures (GB50009-2012). In the wind profile test, the Cobra three-dimensional fluctuating anemometer was used.

In order to study the characteristics of the average wind speed profile, the complete 10-min average wind profile data recorded by the lidar with a height range of 450m were selected as samples for analysis. A total of 4 qualified wind profile samples were obtained, with the main wind direction of 325 °(± 5 °). Based on the field measurement results, the wind tunnel tests of the boundary layer wind field wind profile at 330 °, 325 °and 320 °were designed.

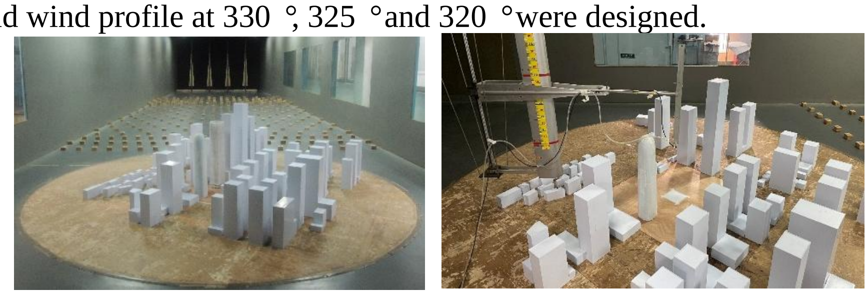


Figure 4. Pressure measurement test of rigid model and wind profile test of boundary layer wind field

5. COMPARISON OF WIND TUNNEL TEST AND FIELD MEASURED RESULTS

Figure 5 shows the comparison between the field measured results and the wind tunnel simulation results of the 10-min average wind speed profile for four consecutive periods in the sudden gale event. The height range is taken as 30-450m, and the wind speed at the top 450m is used to normalize the original data.

The wind profile results show that: 1) At the beginning of the gale event, the wind speed reached its maximum near the height of about 360m, and gradually decreased with the increase of height. Further analysis of the 10-min average wind profile data within the height range of 600m shows that the characteristics of low-level jet phenomenon are very obvious. In the vertical structure of the average wind speed, from the ground up, the wind speed gradually increases and then decreases, and the strong wind speed zone in the air within the range of 100-400m is obvious. 2) The low-level jet event over the measured location ends with the passage of time, and the average wind speed profile returns to the characteristics of the typical boundary layer wind field. The wind tunnel test results are then gradually close to the measured results, and the wind profile indexes fitted by the two methods are about 0.48 and 0.41, respectively.

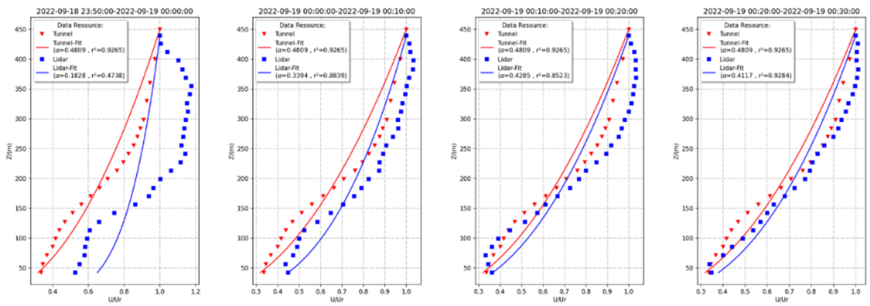


Figure 5. Average wind speed profile within 450m height range

6. CONCLUSIONS

In this paper, lidar field measurements and wind tunnel simulation tests are carried out on the boundary layer wind field at the site of a high-rise building under built, and the results of mean wind profiled are preliminarily compared. The results show that: 1) the sudden gale event captured by lidar shows obvious low-level jet characteristics. For this kind of special wind field, the conventional boundary layer physical wind tunnel can not accurately simulate; 2) With the end of the low-level jet, the wind tunnel test results gradually approach the lidar measured results, and show that the wind profile index at the site of the building to be built is about 0.4-0.5; 3) The impact of low-level jet on wind load of building structure needs further in-depth analysis.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial supports from the National Natural Science Foundation of China under Grant No. 52178480 and the GuangDong Basic and Applied Basic Research Foundation under Grant No. 2022A1515010350.

REFERENCES

Drew, D.R., J.F. Barlow and S.E. Lane, Observations of wind speed profiles over Greater London, UK, using a Doppler lidar. Journal of Wind Engineering and Industrial Aerodynamics, 2013. 121: p. 98-105.

Kent, C.W., et al., Assessing methods to extrapolate the vertical wind-speed profile from surface observations in a city centre during strong winds. Journal of Wind Engineering and Industrial Aerodynamics, 2018. 173: p. 100-111.

Kikumoto, H., et al., Observational study of power-law approximation of wind profiles within an urban boundary layer for various wind conditions. Journal of Wind Engineering and Industrial Aerodynamics, 2017. 164: p. 13-21.

Yi Yang, Fuxian Ma, Qingke Han, Reconstruction of Boundary Layer Wind Field at the SEG Plaza Based on Dual-Lidar Measurement and Numerical Simulation, Journal of Wind Engineering & Industrial Aerodynamics 233 (2023) 105298.