The 2016 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM16)
Jeju Island, Korea, August 28-September 1, 2016

Wind Tunnel Study on Reynolds Number Effects of Sectional Models for a Kilometer-Height Skyscraper

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ABSTRACT

Wind tunnel study was carried out on aerodynamic behavior of 2-D sectional models for various azimuth angles in the Reynolds number range between 6.1×10^4 and 5.7×10^5 for a kilometer-height skyscraper, and predicting wind loads at high Reynolds number by increasing surface roughness and flow turbulence. The study revealed that with smooth surface and in flow with low turbulence, the aerodynamic behavior has little change in the tested Reynolds number range. But in the case of increasing surface roughness or flow turbulence, the drag coefficient and Strouhal number show significant variations with Reynolds number, which proves the presence of Reynolds number effects on the kilometer-height skyscraper. Considering the actual flow turbulence and surface roughness, 3.0×10^5 can be supposed to be the critical Reynolds number of the kilometer-height skyscraper, and its aerodynamic behavior at high Reynolds number is less than that with smooth surface and smooth flow.

1. INTRODUCTION

For the building in real scale, the Reynolds number is usually in the range of 10^7~10^8, while due to the model size of wind tunnel test, the Reynolds number can only reach 10^5~10^6. Therefore the effect of Reynolds number is always the hot topic in the wind tunnel tests, especially for buildings with curve surface. Many researchers have carried out some works to investigate this effect. Zhang et al (2011) investigated the wind pressure distribution through wind tunnel test and CFD simulation, it was concluded that at the same Reynolds number the similar characteristics was obtained.

Larose(2012) studied the vortex shedding of super high building with circular section in the wind tunnel with section models to obtained higher Reynolds range. Chen(2010) investigated the effect of Reynolds number on the wind loading of rectangular super high-rise building, and compared the influence of turbulence and surface roughness on the Reynolds number effect. Based on the theses studies,

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Reynolds number could have different effects on high-rise buildings with different shapes. Regarding to different geometrical case, special researches should be carried out. In this paper, a kilometer-height skyscraper with curve surface is taken as the objective to be investigated. In order to increase the Reynolds number range in the wind tunnel, a sectional model is used for study, Reynolds number range between 6.1×10^4 and 5.7×10^5. By comparing the wind forces of sectional model in different turbulence flow and with different surface roughness, the sensitive of Reynolds number on wind forces is estimated, which could be helpful to decide the value for practical design.

2. WIND TUNNEL EXPERIMENTAL SETUP

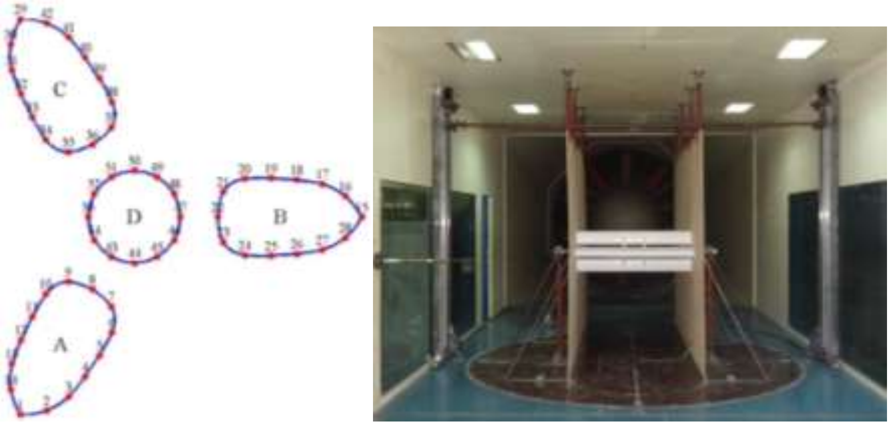
The kilometer-height skyscraper as shown in Fig.1 is composed of four building towers with curve surface, platforms at each 100m height connected all these four building towers. There are no walls between, wind can go through all the space. For this super high-rise building, wind loading becomes a domain loading during design. Therefore wind tunnel test is setup to help designers, while whether the wind tunnel data got from large scale models reliable is still unknown. In order to make a point of the effect of Reynolds number on wind pressure distributions, different model scales is suggested to use for measurement. The characteristics of wind pressure under different Reynolds number is investigated, and the effect of Reynolds number in wind tunnel is estimated.

Fig. 1 The sketch of the kilometer-height skyscraper

The experimental investigation was carried out in a closed-circuit-type wind tunnel with a working section 25 m long, 4 m wide and 3 m high, in Harbin Institute of Technology, China. The wind tunnel tests were conducted under approximately uniform flow conditions. Turbulent flow was generated by the grid with square meshes (bar width = 100 mm). The grid was mounted with three distances L_{grid} of 4, 6 and 10 m upstream from the test model. The objective profile of wind velocity and turbulence intensity followed the requirement of Chinese Code.

In order to extend the Reynolds number range in wind tunnel test, two model scales are used in the wind tunnel test, i.e. 1:450 and 1:600. Since except for some size change, the shape is nearly uniform along the height, the section of 500-600m is chosen to be the mainly 2-D sectional model, as shown in Fig.2. Total length of model is 1.3m, and length to diameter ratio is 4.5 and 6, which can keep flow through in 2-D character. Instantaneous wind pressures acting on the section were measured using a

DSM3400 pressure scanner system. A sampling frequency of 625 Hz was employed and the measurement duration was 100 s. The effect of the tube system, such as Helmholtz resonance on the measured pressure fluctuations, was eliminated by compensating the gain and phase shift using the transfer function obtained beforehand.



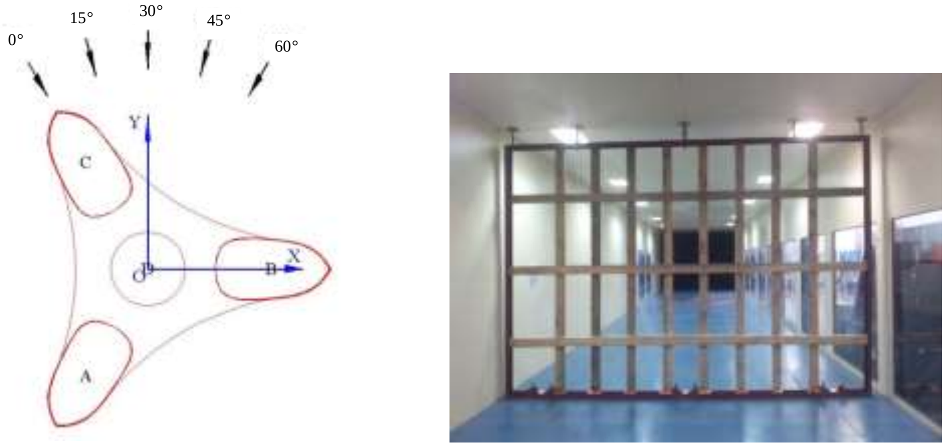
(a) Sectional tap arrangement（total 54 taps） (b) Picture of 2-D sectional model setup

Fig. 2 The graph of the 2D sectional model

In order to make sure the flow through the sectional model should be 2D, the sectional model is mounted at two plat plates with size of 3.4mx2.4m, as shown in Fig2b. The schematics of wind tunnel experimental setup and coordinates are shown in Fig. 3. In different grid distance cases, the normalized power spectra of longitudinal velocity fluctuations at several vertical positions are presented in Fig. 4.

3. WIND TUNNEL DATA ANALYSIS

The wind pressures used in this article are non-dimensionalized with respect to the kinetic pressure $0.5\rho_a U^2$, and the pressure coefficients are ensemble averages of 5 samples. Fig.5 shows the trend of drag coefficient C_d and lift coefficient C_l, here, C_d and C_l represent the dimensionless wind force in the streamwise direction and its perpendicular direction. As shown in Fig5, in the range of Re=$6.1\times10^4-5.7\times10^5$, drag force and lift are rarely change with Reynolds number. It is concluded that little Reynolds effect will be found for wind force coefficients, and from which we can't judge where is the transition region where the aerodynamic wind forces have greatly variation.



(a) Sketch of wind direction (b) Grid with square meshes to simulate Turbulent flow

Fig. 3 The sketch of wind direction and grid to simulate turbulent flow

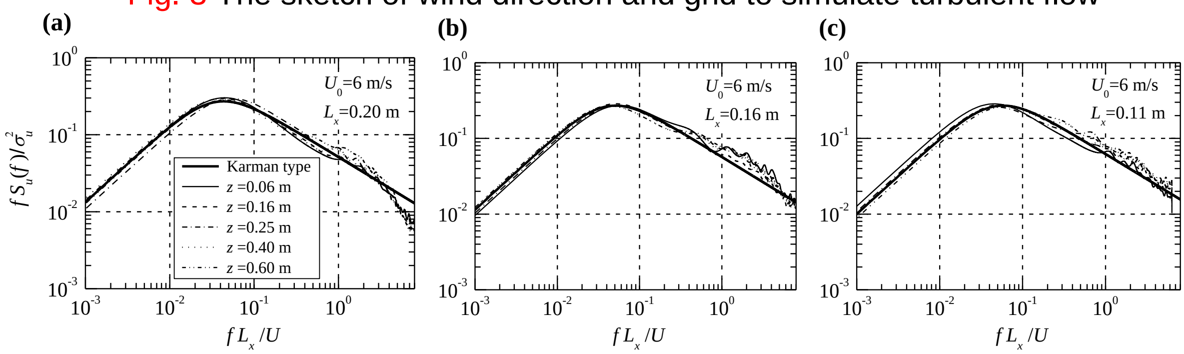
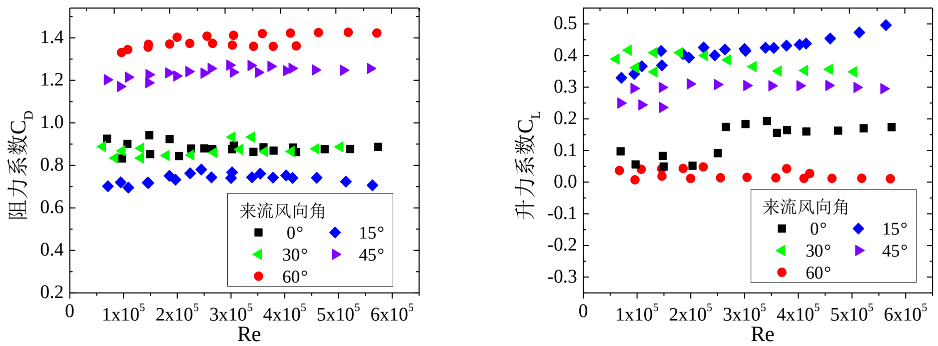


Fig. 4 Longitudinal velocity spectra compared with Karman spectra in different grid distance cases: (a) L_{grid} = 10 m, (b) L_{grid} = 6 m and (c) L_{grid} = 4 m.



(a) Drag force coefficient (b) Lift force coefficient

Fig. 5 Variations of force coefficients of sectional models with wind azimuths and Reynolds number in smooth flow

The transition region of Reynolds number for the super high-rise building is the basic information provided for the techniques who carry out the wind tunnel test, since we should avoid to do the test in the critical Reynolds number where great changes would happen. In order to locate the critical Reynolds number, further tests for model with roughness surface and in turbulent flow should be carried out.

4. CONCLUSIONS

Wind tunnel study was carried out on aerodynamic behavior of 2-D sectional models for various azimuth angles in the Reynolds number range between 6.1×10^4 and 5.7×10^5 for a kilometer-height skyscraper, and predicting wind loads at high Reynolds number by increasing surface roughness and flow turbulence. The study revealed that with smooth surface and in flow with low turbulence, the aerodynamic behavior has little change in the tested Reynolds number range.

REFERENCES

Chen Y(2010), “Investigation on Reynolds number effects of wind loads on rectangular super high-rise buildings by wind tunnel test”. Doctoral Dissertation of Wuhan University, Wuhan, 2010. (in Chinese)

Larose G L, Wall A, McAuliffe B R, et al. (2012), “Sectional model investigation at high Reynolds number for a super tall building”, J. Wind Eng. Ind. Aerodyn., 104(3): 49-55.

Nishimura H, Taniike Y. (2001), “Aerodynamic characteristics of fluctuating forces on a circular cylinder”, J. Wind Eng. Ind. Aerodyn., 89(7): 713-723.

Zhang D B, Liang S G, Chen Y, et al(2011), “Comparison of numerical simulation results with wind tunnel data for wind field of high-rise building”. Journal of WuhanUniversity of Technology, 33(4): 104-108. (in Chinese)