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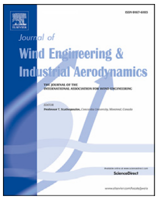

Short communication

Aerodynamic treatments for reduction of wind loads on high-rise buildings

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ABSTRACT

For investigation of the effects of building corner modifications on reduction of wind loads on high-rise buildings, a benchmark square model and three corner modified models including recessed, chamfered and rounded are tested by pressure measurements in a boundary layer wind tunnel. Based on the experimental results, mean wind pressure coefficients, base moment coefficients, local wind force coefficients, power spectral densities and vertical correlation coefficients of the three corner modified models are discussed and compared with those of the square model to provide comprehensive evaluations of the effects of the aerodynamic treatments on reductions of the wind loads. This paper aims to provide useful information for the wind-resistant design of high-rise buildings.

1. Introduction

Due to occurrence of flow separation and reattachment around bluff bodies, wind effects on high-rise buildings are very sensitive to their external shapes. Therefore, appropriate aerodynamic treatments for external shapes of tall buildings can reduce the wind loads fundamentally and lead to a significant economic benefit. The aerodynamic treatments can be divided into two categories including horizontal and vertical aerodynamic treatments. Horizontal treatments refer to corner modification of building plane such as chamfer, recession, roundness and so on; while vertical treatments usually mean changing section along building height, including tapering, setback, twisting and opening. Although vertical aerodynamic treatments have been reported to be effective in reducing across-wind loads and responses of tall buildings (Dutton and Isyumov, 1990; Kim and Kanda, 2010; Xie, 2014), minor modifications on horizontal shape of tall buildings are generally more convenient or feasible than vertical aerodynamic treatments for structural designers and especially more easily accepted by building owners. In fact, horizontal corner modifications of building shapes have been proved to be useful for reduction of wind effects on tall buildings (Miyashita et al., 1993; Kawai, 1998; Choi and Kwon, 1999; Tamura and Miyagi, 1999; Mandal and Faruk, 2010; Tanaka et al., 2012; Carassale et al., 2014).

Despite there have been some research works conducted on the horizontal aerodynamic treatments for reduction of wind effects on tall buildings, quantitative assessments of the influence of different corner modifications on the reduction of wind loads on typical high-rise buildings are still lacking. Since square section has been widely used for design of high-rise buildings due to its simple and good appearance, a square section model is chosen as a benchmark in this study and other three square-based models modified by recessed, chamfered and rounded with corner cut rate of 10% are considered for investigating the effects of corner modifications for the reduction of wind loads on square sectional high-rise buildings through a detailed wind tunnel experiment.

2. Wind tunnel test

Wind tunnel test was carried out in a boundary layer wind tunnel at Hunan University of Science and Technology, China. The cross-section of the wind tunnel is 4.0 m wide by 3.0 m high. Spires and roughness elements were used to simulate a boundary layer wind flow field specified in the Loads Standard Code of China (GB50009-2012, 2012) as exposure category C. This urban terrain type specifies a mean wind speed profile with a power law exponent of $\alpha = 0.22$ and a gradient height of 450 m. The profiles of mean wind speed and turbulence intensity at various heights over the turntable in the wind tunnel are shown in Fig. 1. It can be found that the simulated profiles agree well with those stipulated in the design code. The integral length scale of the approaching wind is 0.46 m, which is equivalent to 230 m in prototype, while the geometric scale of the wind tunnel test is 1/500. The longitudinal wind velocity spectrum at reference height of 0.8 m above the turntable is in good agreement with the von Karman spectrum, as shown in Fig. 2.

As introduced previously, a square model was selected as the

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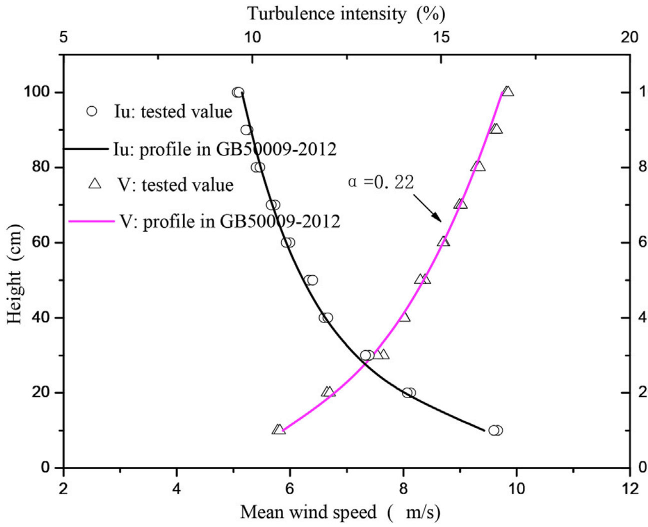

Fig. 1. Mean wind speed and turbulence intensity profiles.

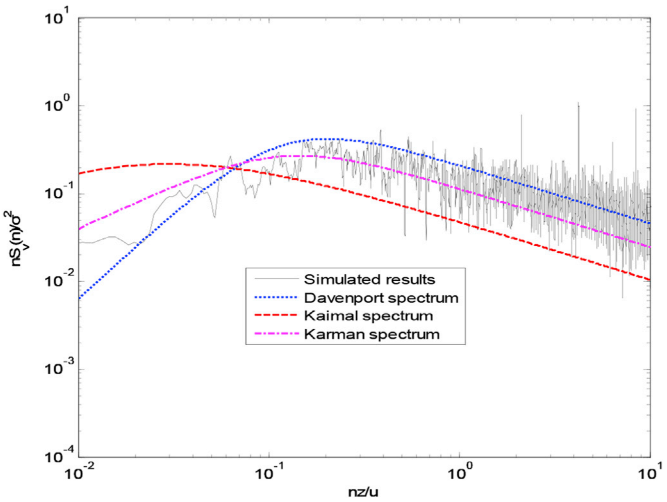

Fig. 2. Longitudinal wind velocity spectra at the reference height.

benchmark in this study. Width B of the square model is 0.1 m and height H is 0.8 m, giving an aspect ratio H/B of 8.0. Three square-based models with different horizontal aerodynamic treatments including recessed, chamfered and rounded modifications are used in this study to examine the differences of the wind loads on these three models and the square model. Since the optimum size of corner cut did not exist throughout all the cases of wind attack angles and damping ratios (Kawai, 1998; Choi and Kwon, 1999), only 10% rate of corner modification is adopted in this study for investigating the reduction of wind effects on tall buildings. The blockage ratio of each model at attack wind angle of 0° was 0.67% which is acceptable in wind tunnel tests so that no correction for the blockage effect was made to the pressure measurements in this study. Measurement layers, pressure tap distributions and wind forces definition of each model are illustrated in Fig. 3. Mean wind speed at the top of the models U_H was set at 9.3 m/s. The Reynolds number calculated in terms of U_H and the width of models is $R_e = 6.15 \times 10^4$. Pressure measurements on the models were conducted for wind direction from 0° to 90° at an interval of 5°. The data sampling frequency was set to be 333 Hz and the sampling length was 30 s for pressure measurement under each wind direction.

3. Results and discussions

Time series of wind forces at each measurement layer on building models can be obtained by integrating simultaneously measured wind pressures from pressure taps and associated area on that layer. Non-dimensional coefficients of wind forces are defined as follows:

$$C_D(z_i) = \frac{\overline{F_D}(z_i)}{L_i B q_H} \quad C_D^*(z_i) = \frac{\sigma_D(z_i)}{L_i B q_H} \tag{1}$$

$$C_L(z_i) = \frac{\overline{F_L}(z_i)}{L_i B q_H} \quad C_L^*(z_i) = \frac{\sigma_L(z_i)}{L_i B q_H} \tag{2}$$

$$C_T(z_i) = \frac{\overline{F_T}(z_i)}{L_i B^2 q_H} \quad C_T^*(z_i) = \frac{\sigma_T(z_i)}{L_i B^2 q_H} \tag{3}$$

$$C_{MD}(z_i) = \frac{\overline{F_{MD}}(z_i)}{B H^2 q_H} \quad C_{MD}^*(z_i) = \frac{\sigma_{MD}(z_i)}{B H^2 q_H} \tag{4}$$

$$C_{ML}(z_i) = \frac{\overline{F_{ML}}(z_i)}{B H^2 q_H} \quad C_{ML}^*(z_i) = \frac{\sigma_{ML}(z_i)}{B H^2 q_H} \tag{5}$$

$$C_{MT}(z_i) = \frac{\overline{F_{MT}}(z_i)}{B^2 H q_H} \quad C_{MT}^*(z_i) = \frac{\sigma_{MT}(z_i)}{B^2 H q_H} \tag{6}$$

in which, $C_D(z_i)$, $C_L(z_i)$ and $C_T(z_i)$ are mean local wind force coefficients of the i-th layer in along-wind, across-wind directions and mean torque, respectively; $C_{MD}(z_i)$,$C_{ML}(z_i)$ and $C_{MT}(z_i)$ are mean base moment coefficients, respectively;$C_D^*(z_i)$, $C_L^*(z_i)$, $C_T^*(z_i)$, $C_{MD}^*(z_i)$, $C_{ML}^*(z_i)$ and $C_{MT}^*(z_i)$ are corresponding RMS coefficients. $\overline{F_D}(z_i)$, $\overline{F_L}(z_i)$ and $\overline{F_T}(z_i)$ are mean wind forces and torque while $\overline{F_{MD}}(z_i)$, $\overline{F_{ML}}(z_i)$ and $\overline{F_{MT}}(z_i)$ are mean base moments; $\sigma_D(z_i)$, $\sigma_L(z_i)$, $\sigma_T(z_i)$, $\sigma_{MD}(z_i)$, $\sigma_{ML}(z_i)$ and $\sigma_{MT}(z_i)$ are RMS of local wind forces or torque and base moments. L_i represents the occupied height of the i-th layer; H is model height; B is model width; $q_H = 0.5\rho U_H^2$ stands for the reference wind dynamic pressure, ρ is air mass density, generally is $1.25 kg/m^3$,U_H is mean wind speed at the top of the model.

3.1. Mean wind pressure coefficients distributions

Fig. 4 presents the mean wind pressure coefficient distributions on the four models at wind direction of 0°. The mean wind pressure coefficients on the windward of the square model show the maximum at 0.8 H with a positive value of 0.8 and decrease near the peripheral edges. However, the maximum positive pressure coefficients have been decreased from 0.8 to 0.6 for the three corner modified models and their locations have been dropped down to about 0.7 H. Due to the speed-up separation caused by the corner modifications, larger negative wind pressure coefficients emerge at the leading edge on the side wall when compared to the square model. The negative wind pressure coefficients change sharply from the leading edge to trailing edge, especially for recessed and chamfered models. The absolute values of the negative wind pressure coefficients can even reach to 1.2 or more, which should be paid special attention in wind-resistant design of claddings on high-rise buildings with similar corner configurations. For the leeward, the corner modifications reduce the negative wind pressure coefficients from −0.6 to −0.4, which result in the reduction of the along-wind forces.

3.2. Base moment coefficients

3.2.1. Mean base moment coefficients

Since the mean base moment coefficients are very small in the across-wind and torsional directions for the tested models, hereby only the variation of mean along-wind base moment coefficients is shown in Fig. 5. The trends that the mean along-wind base moment coefficients of the square, recessed and chamfered models varied with wind direction