CFD study of dynamic wind actions on faces of a tall building

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Abstract: This paper computes and investigates the fluctuating wind forces on different building faces of a 6:1:1 square-section tall building with LES. Time histories of aerodynamic forces on building faces are computed from which power spectra and cross correlation analysis are made. The computation results are compared to past wind tunnel data from base balance and wind pressure measurements. Most results show qualitative agreement.

1. Introduction

In metropolitan cities, such as Hong Kong, there is increasing popularity of high rise residential buildings. Wind-induced dynamic response is one of the important parameters in designing of tall building in terms of serviceability and safety limit. In recent decades, computational fluid dynamics (CFD) using large eddy simulation (LES) are increasingly used in wind engineering applications. LES can simulate complex unsteady turbulent flows around a bluff body, which is associated with wind-induced dynamic responses of buildings and structures (e.g. Swaddiwudhipong and Khan [1]; Huang et al. [2]; Braun and Awruch [3]). Murakami [4] also commented that the LES with a dynamic subgrid-scale (SGS) model can better predict the flow field around a bluff body comparing with other turbulence models.

The main objective of the present study is to simulate the dynamic wind effects on a tall building using LES technique with the parallelized CFD software FLUENT. Time histories of forces and moments, moment spectra as well as force correlations on the building faces are computed and compared with previous wind tunnel data. The relationship between wind actions on the side faces of building towards the production of across-wind forces is also discussed.

2. Experimental setup and numerical simulation model

The wind tunnel data for comparison were obtained in the boundary layer wind tunnel of the Department of Civil Engineering at the University of Hong Kong. The details were described in Wong and Lam [5], Wong et al. [6]. The experiments were conducted at the working section of the tunnel with 12 m long, 3.0 m wide and 1.8 m tall. The square building model of sizes 6:1:1 (height: width: breadth) was tested under the sub-urban roughness terrain where the mean wind speed varied with height following the power law with an exponent 0.2. Both high-frequency force-balance (HFFB) and wind pressure measurements were performed. In the experiments, the wind speed at the roof level of the building, U_H, was between 6.4 to 11.4 m/s and the Reynolds number based on the building breadth was $Re \approx 3.5\times10^4$ to 6.1×10^4.

In the CFD simulations, the flow domain corresponding to the section of the wind tunnel was generated by unstructured hexahedral elements. The computational domain was 60*B* in the streamwise (*x*-) direction, 30*B* in the cross-stream (*y*-) direction and 3*H* in vertical (*z*-) direction, where *B* and *H* are breadth and height of the building respectively. A square building model of size with 6:1:1 was located at 1 m downstream of the inlet plane of the computational domain in CFD. The entire computational domain is illustrated in Fig. 1. Refined meshing with size of 1/120 *H* was employed around the building and the meshes became less dense away from the building. The number of computation elements was about 5 millions in this study. The wall boundary condition was set for the ground and all building faces.

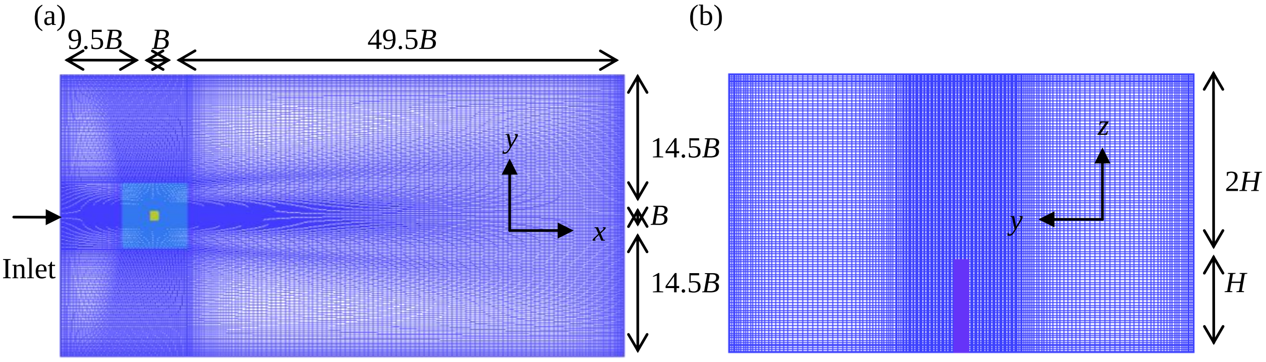

Fig. 1. (a) Grid distributions on *x*-*y* plane; (b) grid distributions on *y*-*z* plane.

At the inlet of computational domain, the incident wind boundary layer profile was modeled under the same terrain type as the wind tunnel experiment:

$$\frac{u}{U_{ref}} = \left(\frac{z}{z_{ref}}\right)^{0.2} \tag{1}$$

where U_{ref} = 9.57 m/s and z_{ref} = 0.8 m. The mean wind velocity components in *v* and *w* direction were set to be zero. SIMPLEC was adopted for pressure-velocity coupling. Dynamic Smagorinsky-Lilly model was used for the subgrid turbulence model. LES was used to simulate unsteady flow at time steps of 1 ms interval and 2000 total time steps.

3. Results and discussion

From the LES computation results, time histories of wind pressure at all computational grid points on the building faces are obtained. Time histories of wind forces on individual building faces as well as the entire building can then be obtained from integration of wind pressures at the computational grid points and the face areas of the grid points. Mean and root-mean-square (RMS) force and moment coefficients are defined as:

$$\overline{C}_M = \frac{\overline{M}}{\frac{1}{2}\rho\overline{U}_H^2 BH^2}, \text{ and } \qquad C'_F = \frac{F'}{\frac{1}{2}\rho\overline{U}_H^2 BH} \qquad (2)$$

At this normal wind incidence, the building has the highest along wind force and moment and the computed values are $\overline{C}_{F_x}$ = 1.18 and $\overline{C}_{M_y}$ = 0.64. These are slightly higher than the wind tunnel data. The RMS values of these computed along-wind load fluctuations at C'_{F_x} = 0.09 and C'_{M_y} = 0.04 are, however, only about half of the wind tunnel values. The building has zero mean across-wind loads but large across-wind load fluctuations. This is well modeled in the LES computation. The computed RMS coefficients are C'_{F_y} = 0.33 and C'_{M_x} = 0.18 which are about 15% to 20% higher than the wind tunnel results.

Figure 2 shows the across-wind moment and along-wind moment spectra for comparison. The vortex excitation spectral peak is well modeled in the computed across-wind moment spectrum at $nB/U \approx 0.1$. The overall spectral distributions and levels also agree reasonably well with the wind tunnel spectra. However, the computed along-wind moment spectrum has much lower levels than the wind tunnel spectra.

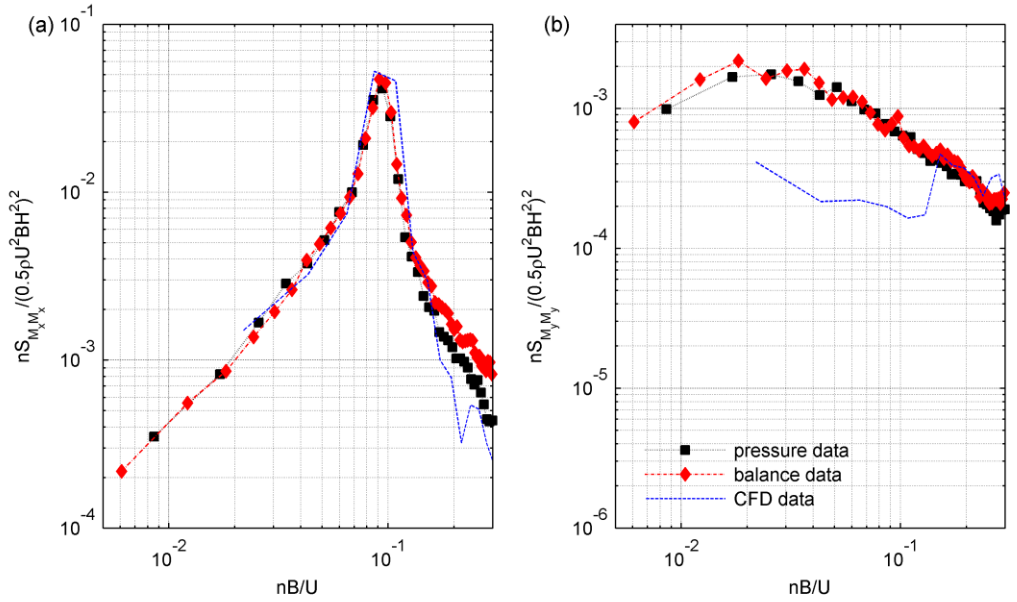

Fig. 2. (a) Across-wind moment spectra and (b) along-wind moment spectra.

The across-wind actions on the building are caused by wind loads on the two side building faces. Figure 3 shows the cross correlation between wind forces on the two side faces from LES and pressure measurement. The curve of cross correlation coefficients $R(\tau)$ in both pressure model and CFD model show the clear quasi-periodicity of across-wind vortex excitation and the almost perfect in-phase relationship of the y-component wind forces from the two side faces. Both of them have peak correlation value about 0.4 near zero time lag.

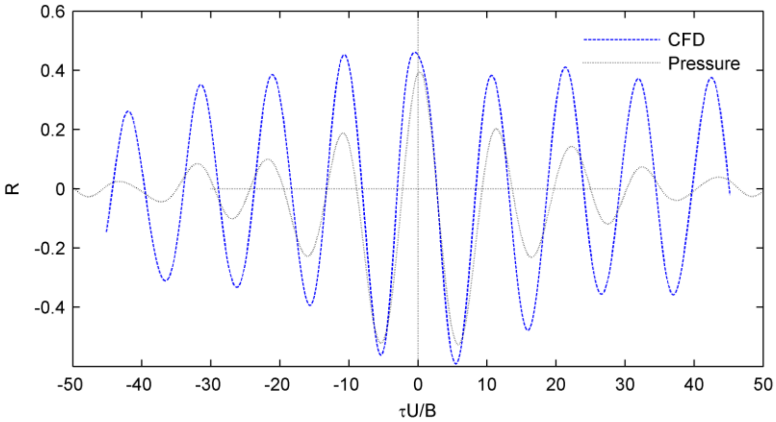

Fig. 3. Cross correlation curves between *y*-force contributions from side faces of building.

Cross power spectral densities are computed to investigate the relationship of coherence and phase between across-wind excitation forces on the two opposite building side faces. The magnitudes and phases of these cross power spectra between the across-wind force (F_y) are shown in Fig 4. For pressure model, the spectra of the square building exhibit the spectral peak of vortex excitation at $nB/U_H \approx 0.1$. This shows that the across-wind forces from the two building side faces are well correlated at the vortex shedding frequency. In the CFD model, the variations of spectral value with frequencies are smaller but a clear peak is also found at $nB/U_H \approx 0.1$. It has higher spectral value than that of pressure measurement data. Both sets of results have near-zero phases at frequencies between $nB/U_H = 0.03$ and 0.12.

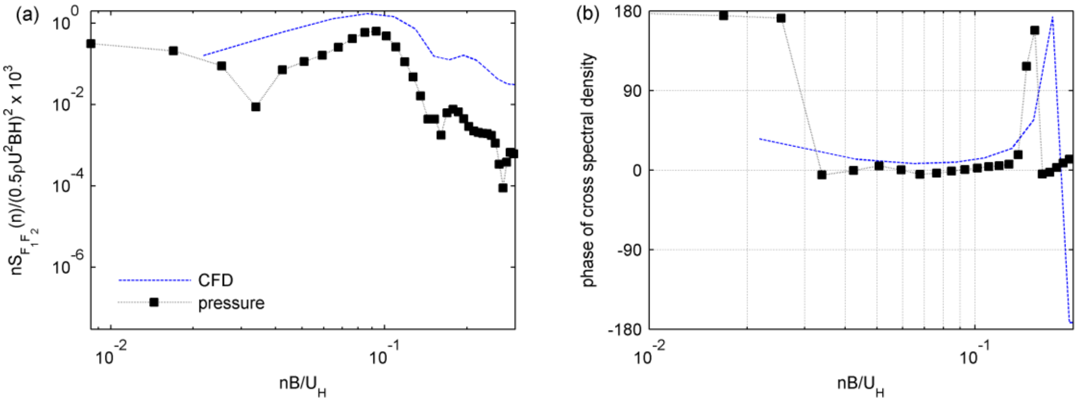

Fig. 4. Cross power spectral density (a) in magnitude; (b) in phase angles between across-wind force contributions by building side faces.

4. Conclusion

This paper investigates the characteristics of fluctuating wind loads on different faces of a tall building using LES simulation. The CFD results are in qualitative agreement, as well as reasonably good quantitative agreement in regard to the important across-wind excitation, with previous wind tunnel results. Coherent wind forces on opposite side building faces act together to provide large and periodic dynamic actions in the across-wind direction.

5. Acknowledgement

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