Computation of dynamic wind-induced interferencein a row of tall buildings

K.M. Lam, M.Y.H. Leung, J.G. Zhao

Department of Civil Engineering, The University of Hong Kong,

Pokfulam Road, Hong Kong, China. kmlam@hku.hk

Abstract: Large-eddy simulation is applied to compute the dynamic wind loads on three tall buildings arranged closely in a row. The computed values and spectra of along-wind and across-wind forces on the buildings reproduces reasonably the dynamic interference effects observed in the wind tunnel, despites the use of a simple model of turbulence characteristics of the incident wind flow.

1. Introduction

When two or more buildings are placed in close proximity, flow interference occurs and wind loads on each building are modified from its isolated single building situation. Interference effects on two tall buildings in proximity have been reported extensively in the literature [1] but there are few studied on interference in a group of closely-spaced tall buildings. The authors' group has been investigating wind-induced interference in a group of tall buildings placed in close proximity under a number of arrangement patterns [2-4]. Wind tunnel measurements made on five closely spaced square-plan buildings arranged in a row identified the following wind interference mechanisms unique to closely spaced tall buildings [2]:

1) Upwind interference by which an upwind building experiences increased wind loads (than the isolated single building case) when wind blows at a slight oblique angle to the row;
2) Negative drag forces by which the inner buildings in the row experience very small drag forces (negative in the extreme case) when the row is at normal or oblique wind incidence;
3) Large modifications on the fluctuating wind loads, with the disappearance of the sharp spectral peak of vortex excitation in the across-wind load spectra of buildings being in a row.

For the first two interference phenomena on the mean wind loads, we carried out wind pressure measurements on the surface of the building models and found the explanations and mechanisms for the observed interference effects. The main culprit is the channeled wind through the gaps between adjacent buildings which leads to large suctions (negative pressures) on the relevant building faces. We also performed computation fluid dynamics (CFD) study using the Reynolds-averaged Navier-Stokes (RANS) approach and reproduced the measured wind pressure distributions [2,5]. The computed mean flow fields around the building group with the k-ε model helped to explain the generation of those pressure patterns.

For the third interference effect on the dynamic wind loading, we have not been able to provide solid evidence on the destruction of vortex shedding for the tall buildings while placed in a row. The RANS computation could not provide the fluctuating flow fields. In this paper, we attempt to apply large-eddy simulation (LES) to capture the time-varying wind flow patterns around the row of tall buildings. Our main target is to find whether the modifications of the fluctuating wind loads and the load spectra can be modeled with a commercial code using a simple model of the turbulence characteristics of the incident wind flow.

2. Building and computation models

The computation is targeted on the previous series of experiments carried out on a row of five tall buildings [2]. The experiments were made in the boundary layer wind tunnel of the Department of Civil Engineering in The University of Hong Kong. The test section was 3.0 m wide and 1.8 m high and the geometrical scale of the wind tunnel tests was 1:300. All square-section tall building models had breadth B = 0.1 m and height H = 0.5 m (30 m width and 150 m height, in full scale). The notation of building members and wind load components are reproduced in Fig. 1. The main set of tests were carried out in an open land terrain type where the profiles of mean wind speed and turbulence intensity follow approximately the power law with exponents 0.16 and –0.32, respectively.

The flow computation was carried using the finite volume code FLUENT (Fluent, Inc.). The computational domain, corresponding to a section of the wind tunnel, was 6 m long, 3 m wide and 1.8 m tall. As the focus is on the interference effects on the edge and inner buildings in a row, a row of three buildings instead of five were used in the computation model in order to reduce the computation demand. Same as the wind tunnel models, the square tall buildings had size B = 0.1 m and H = 0.5 m. Computation was made at a clear spacing between buildings at $S = B/4$ where typical interference phenomena were observed in the wind tunnel tests [2]. The centre of the building row was placed at 1.5 m from the inlet of the computational domain.

The flow domain was discretized into a structured grid of hexagonal elements for efficient solution process and subsequent analysis. Each building wall was modeled by 40×20 meshes and there were 10 nodes across each building gap (Fig. 2). Coarser meshes were used outside a volume enclosing the buildings with margins of 3B, 1B and 0.5H in the x, y and z directions, respectively, from the outmost building walls or roofs. This paper reports the CFD results for wind incidence along the building row ($\theta = 0^o$). The mesh size was 6.1×10^5. A reference case of an isolated single tall building (building S) was also computed and the mesh size of that computation was 2.6×10^5.

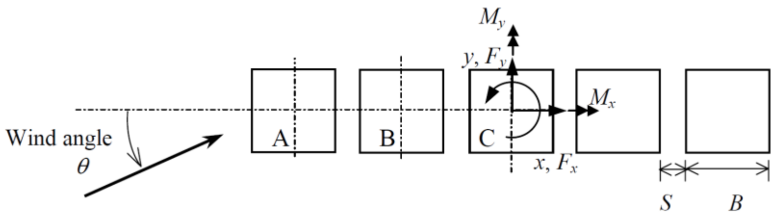

Fig. 1. Row of 5 tall buildings in wind tunnel experiments.

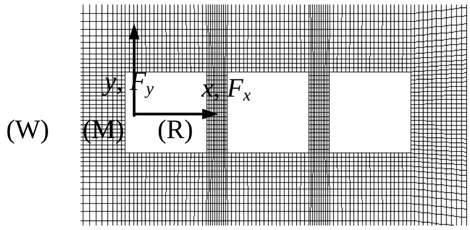

Fig. 2. CFD model of 3 tall buildings in a row at S/B = 0.25. Building names: (W) for windward building; (M) for middle building; (R) for rear building.

For the boundary conditions, the ground and all building walls were modeled as solid walls. The side and top faces of the computational domain were given the symmetry boundary condition. At the inlet face, the following power law profiles of mean velocity and turbulence intensity were inputted to the flow domain while all flow was made to exit at the outlet face:

$$U(z) = 6.0\ \mathrm{m/s} \times \left(\frac{z}{z_{ref}}\right)^{0.16},\ I_u(z) = 0.0544 \times \left(\frac{z}{z_{ref}}\right)^{-0.32},\ z < z_{ref} = 1.5\ \mathrm{m} \qquad (1)$$

The Reynolds number was $U_H B/\nu = 3.3\times10^4$.

Reported LES works on computational wind engineering suggested that correct representation of the turbulence characteristics of the incident wind flow is crucial to the accurate modeling of wind loads on buildings [6-7]. However, the main aim of this study is on the interference effects of neighboring tall buildings. Thus, the simple turbulence model standard in the FLUENT code was used. This model of spectral synthesizer constructs the fluctuating velocities from the given vertical profiles of k and ε. These profiles were calculated from the profiles in Eq.(1) [8]. The Smagorinsky-Lilly subgrid model was used without a dynamic stress option.

3. Results and discussion

The mean interference phenomenon of upwind interference has been modeled by the RANS computation previously [2,5]. Computed mean flow patterns at $\quad = 30^{o}$ show strong channeling of wind flow through the building gaps as a result of the close proximity of buildings. This leads to highly negative pressures on building walls facing a gap. For the upwind edge building in the row, this much higher suction on its leeward wall leads to increase in F_x. The second mean interference effect of negative drag force was also indirectly demonstrated by the RANS computation. In the present LES computation, the mean wind load coefficients and root-mean-square values of load fluctuations computed for the three buildings in a row are listed in Table 1. A negative value of mean force coefficient is indeed computed for F_x on the second building M. The value agrees closely with the wind tunnel value on building B.

For the isolated single building, the mean along-wind force coefficient is measured in the wind tunnel is C_{Fx} = 1.04. The CFD value from the present LES (and also from the previous RANS k-ε model [2,5]) is higher at 1.26. Force fluctuations are available from the LES results and the computed RMS along-wind force coefficient is 0.08 which is only about 60% of the wind tunnel value. This is believed to be caused by the inadequacy of the simple model for the incident flow turbulence. The across-wind force has a mean zero value at normal wind incidence and a large RMS force coefficient is expected from across-wind vortex excitation. Strong vortex shedding is captured in the LES results and the RMS force coefficient is C'_{Fy} = 0.35. This value is 1/3 times higher than the wind tunnel value. This may also be due to the lower levels of turbulence modeled for the incoming wind in the present LES which produces a smoother incident flow on the building to enhance vortex shedding.

Table 1. Comparison of force coefficients from LES and wind tunnel

Building:	W	M	R	A	B	C	S (LES)	isolated
Mean C_{Fx}	1.28	–0.30	–0.19	0.98	–0.24	0.03	1.26	1.04
Mean C_{Fy}	0.00	0.00	0.00	–0.20	0.16	0.12	0.00	0.00
RMS C_{Fx}	0.03	0.08	0.09	0.15	0.11	0.06	0.08	0.14
RMS C_{Fy}	0.05	0.09	0.14	0.20	0.18	0.12	0.35	0.26

The main focus of this paper is on the numerical modeling of the third interference effect of dynamic interference, especially the marked reduction of vortex excitation for tall buildings placed in a row. This is evidently observed in Table 1 on the much lower LES values of C'_{Fy} computed for buildings W, M, R as compared to S. Fig. 3 shows the computed moment spectra of the three building models. A very sharp vortex excitation peak is computed at reduced frequency $nB/U_H \approx 0.1$ in the across-wind moment spectrum of M_y on the single isolated building S. The present LES evidently reproduces vortex shedding from the tall building in more regular and enhanced manner than in the wind tunnel. This also produces in the along-wind moment spectrum a small spectral peak at twice the vortex excitation frequency ($nB/U_H \approx 0.2$) which is not as clearly observed in the wind tunnel spectrum. For buildings in a row, the disappearance of the vortex excitation peak is well modeled quantitatively in the LES computation. The LES also reproduces the increased load fluctuations at the high frequency end of all three moment spectra.

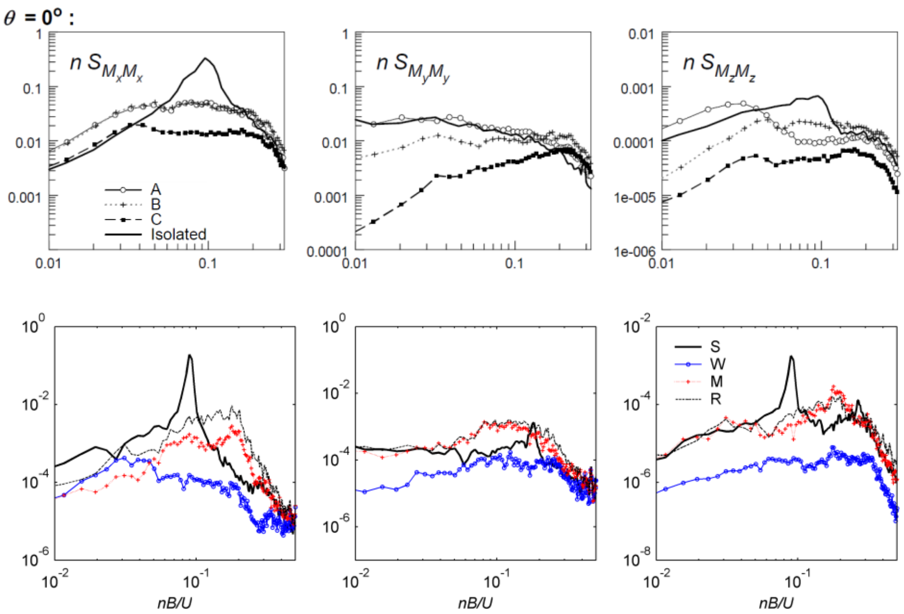

Fig. 3. Moment spectra on single isolated tall building and buildings in a row. Upper row: wind tunnel results; lower row: LES computation.

4. Concluding remark

A LES computation is attempted to reproduce the major interference phenomena previously observed in the wind tunnel on a row of square-section tall buildings. The computation satisfactorily models the interference phenomena on mean wind loads including upwind interference and negative drag force. The dynamic interference effects, in particular the destruction of across-wind vortex excitation, are only quantitatively captured by the present LES employing a simple standard model of turbulence characteristics of the incident wind flow.

5. Acknowledgement

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