Wind Engineering Joint Usage/Research Center
FY2016 Research Result Report

Research Field: Wind disaster and wind resistant design
Research Period: FY2016 Apr. ～ FY2017 Mar.
Research Number: 162001
Research Theme: Aero-elastic behavior of high-rise buildings under downstream interference effects
Representative Researcher: Yuan-Lung Lo
Budget [FY2016]: 450,000Yen

1. Research Aim

This research investigates the effect of the single and multiple aerodynamic modification mechanisms on the dynamic behavior of the principal building when it is interfered by a very closely located building. During the study, aeroelastic vibration tests and high-frequency force balance tests are conducted to compare responses and wind forces in a well-simulated turbulent boundary layer flow. The principal building is manufactured with three different building configurations to represent the single and multiple aerodynamic modification treatments; the neighboring building which produces interference effects is made as a square prism model. Results show that the multiple modification treatment is efficient in reducing wind forces in all interference location series. However, it is also found that in some critical conditions, such treatment is sensitive to reduced velocity and may amplify the interference effect and result in larger displacements.

2. Research Method

Both the aeroelastic vibration test and the high-frequency balance test are conducted in the 18 × 1.8 × 2.2 m boundary layer wind tunnel of Wind Engineering Research Center at Tokyo Polytechnic University. A 1/400 scale turbulent flow over a sub-urban terrain with a power law index exponent for mean velocity profile of 0.19 is simulated with properly equipped spires, saw barriers, and roughness blocks. For the aeroelastic vibration test, three rigid base-pivoted aero-elastic models are manufactured for the role of the principal building. The square prism model is 0.07 m in both width (B) and depth (D) and 0.56 m in height (H), which make the aspect ratio (H/B) 8. The tapered model is 0.04 m in width on the roof-top and 0.10 m in width on the bottom. The height is the same as the square one and the aspect ratio (height to the averaged width) is also 8. The helical tapered model has the same geometrical appearance as the tapered model but has a helical twisting angle of 180° from the bottom to the top. All the three principal models are manufactured with the same volume in order to have a basic comparison level. Both the tapered and the helical tapered models have been proven to efficiently reduce the projected wind force when they are considered in an isolated condition (Kim et al., 2014, 2015, 2016). The tapered model and the helical tapered model in this study are also referred to Model IV and X by Kim et al. (2016). The reason to choose the tapered and the helical tapered models in this study is that the buildings with tapered shape and twisting features are becoming more and more attractive in the modern skyscraper designs; however, the associated discussions have not been widely made for such two features. It is also the authors' interest to investigate the consequences with the consideration of interference effects. Fundamental modal information of the three principal models is listed in Table 1. The fundamental frequencies in along-wind (longitudinal) and across-wind (lateral) directions are tuned to 6.5 Hz based on free vibration tests. The damping ratios are kept under or equal to 1% in both directions for three models and the generalized masses are about 0.11 kg. The corresponding mass-damping parameter is determined by

$$\delta = \frac{M\xi}{\rho B^2 H} \tag{1}$$

where ρ is the air density. M is the generalized mass. ξ is the damping ratio. For the rigid base-pivoted aeroelastic model in this study, the mass-damping parameters for three models are in the range of 0.23 to 0.33, which is slightly lower than the range of typical full scale high-rise buildings (0.4 – 0.6) and can be converted to Scruton numbers of 0.7 to 1.0 based on the linear mode shape assumption of its rigid elastic feature. Generally speaking, in this range of lower Scruton numbers, the across-wind response of an isolated square prism model will increase significantly when the reduced velocity rises to values larger than 9 or 10. Furthermore, from Table 1, the parameters in these three models are intentionally made the same or similar in order to reduce the possible differences in reducing wind forces or dynamic response not by the shape changes. In real situations, the tapers building may be stiffer than the square buildings. The displacement signals of both directions are recorded by two laser sensors at the sampling rate of 550 Hz. The sampling length is 16,384 for one sample record and the ensemble size is 10 in order to obtain a statistical result. For the high-frequency force balance test, the three principal models are fixed and un-flexible to the balancer for both horizontal forces measuring under the same sampling conditions. Instantaneous wind velocity is recorded at the model height for further normalizations.

The interfering building model is made of acrylic and has the identical size as the square prism model; unlike the principal building models, however, this interfering model is made rigid and un-flexible providing only the disturbed flow coming from upstream or downstream. The interference locations of interest are focused on those considered significant in the surrounding area (Fig. 1). Both the principal and interfering models are orientated with one face normal to the wind when both tests are carried out. Five location series including the upwind series, the oblique-upwind series, the side series, the oblique-downwind series and the downwind series are selected for observing different interference mechanisms.

Table 1 Fundamental information of three principal models

Principal model	Square (SQ)	Tapper (TA)	Helical tapper (TH)

Height (H)	0.56	0.56	0.56
Depth (D)	0.07	0.10 (bottom) 0.04 (top)	0.10 (bottom) 0.04 (top)
Width (B)	0.07	0.10 (bottom) 0.04 (top)	0.10 (bottom) 0.04 (top)
H/B_{ave}	8	8	8
Helical angle	0º	0º	180º
$f_{n,x}$ (Hz)	6.5	6.5	6.5
$f_{n,y}$ (Hz)	6.5	6.5	6.5
ξ_x (%)	0.8	0.7	1.0
ξ_y (%)	0.9	0.8	1.0
M^* (g)	107	111	111
δ_x	0.25	0.23	0.32
δ_y	0.30	0.27	0.33

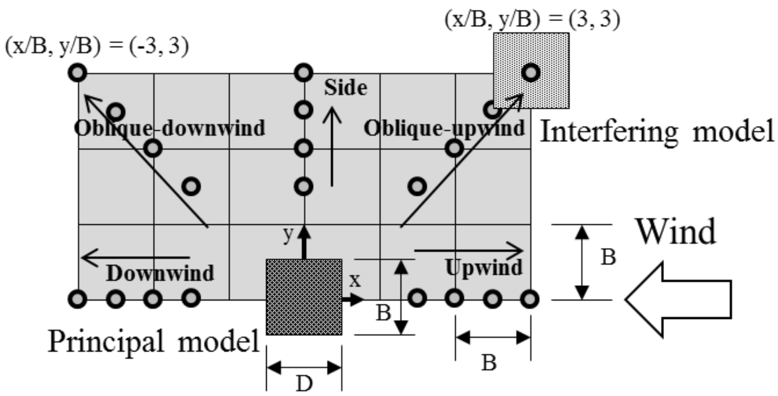

Fig. 1 Diagram of interference location series

3. Research Results

Interference effects on high-rise buildings with three different configurations have been examined in this study. Both the single and the multiple aerodynamic modifications were performed by the tapered model and the helical tapered model. Their treatment efficiencies were evaluated in details. Several findings have been concluded as follows:

(1) Aerodynamic modifications by changing the appearance of the building shape were confirmed through the comparisons in wind forces and responses without interference effects. However, it was found that at lower reduced velocities near 5.2 – 6.8, the aerodynamic modification provided by the tapered model may slightly amplify the across-wind response, which was unable to be discovered by the high-frequency force balance test in previous works.

(2) The aerodynamic modification by the TA model was proven to be sensitive to the reduced velocity and the interference location. With the existence of a neighboring building, such modification cannot guarantee the reduction efficiency but may sometimes amplify the across-wind vibration severely, especially at locations which are considered having critical interference effects.

(3) The modification provided by the TH model was proven to efficiently reduce both the wind force and the responses in general. The interference effect generated by the interfering model could amplify the response at certain location series. However, if compared to the isolated SQ model, the amplified response is still much smaller than no modification at all.

4. Published Paper etc.

Lo, Y.L., Kim, Y.C., Yoshida, A., Effects of Aerodynamic Modification Mechanisms on Interference from Neighboring Buildings. European African Conference on Wind Engineering 2017, Liege, Belgium. (Oral presentation accepted)

Lo, Y.L., Kim, Y.C., Yoshida, A., Effects of Aerodynamic Modification Mechanisms on Interference from Neighboring Buildings. J. Wind Eng. Ind. Aerodyn. (Under-reviewing)

5. Research Organization

1. Representative Researcher

   Yuan-Lung Lo/ Assistant Professor, Dept. Civil Eng., Tamkang Univ., Taiwan (ROC)

2. Collaborate Researchers

   Yong Chul Kim/ Associate Professor, Dept. Architecture, Tokyo Polytechnic Univ., Japan