27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#100**, pp. 245–248, doi: 10.21495/51-2-245

AERODYNAMIC INTERFERENCE FORCES ACTING ON TWO SQUARE PRISMS IN A MODEL ATMOSPHERIC BOUNDARY LAYER

Macháček M.[*], Lo Y. L.[**], Máca J.[***]

Abstract: *The presented experimental analysis focuses on the definition of interference factors for aerodynamic forces acting on two square prisms depending on their relative position. Both prisms used had the same dimensions and a height to width ratio of 6; this ratio is relatively common in high-rise buildings. The experiment was performed in a wind tunnel with a model atmospheric boundary layer, which represented a dense urban area. The forces acting at the base of one of the buildings were measured, and by moving the other building it was possible to measure 204 mutual configurations, i.e., 204 interference positions. In all positions, the windward facades of the small-area model were placed perpendicular to the direction of the incoming flow. This created a detailed map of the interference effect on a wind-loaded pair of buildings. The results show a significant effect of the relative position of buildings on wind loads. A significant increase in load occurred due to the proximity of buildings. Due to the interference effect, wind load fluctuations can increase by up to 28% and average values by up to 36%.*

Keywords: Interference effect, Two square prisms, Wind tunnel experiments, Turbulent boundary layer.

1. Introduction

The wind loading on two tall buildings close to each other can be very different from loading on an isolated tall building. This phenomenon is called the interference effect; it can cause an increase in wind loading and change its behaviour. There are significant changes in local pressures on the surfaces of buildings: changes in the aerodynamic drag forces of structures and changes in the aeroelastic response. This phenomenon occurs not only in isolated groups of nearby buildings but also, e.g., in dense urban areas. Cases of interference effect leading to significant failure or even destruction of structures were also reported in a group of power plants cooling towers or chimneys built in one or more rows.

The aerodynamic interference effect between bluff bodies has already been examined by many authors and is not a new topic in the field of wind engineering. One of the first studies on this issue was published as early as 1934. Harris (1934) focused on defining the influence of surrounding buildings on the increase in wind pressure load on the Empire State Building. His article states that shielding may produce a variation in the twisting moment about a vertical axis at different levels. The mutual proximity of buildings can cause a wind load that would not occur on a free-standing building. Sakamoto and Haniu (1988) published one of the fundamental papers that focus on two prism bodies in the atmospheric boundary. The authors focused on investigating the interference change of the frequency spectrum of wind loads as well as the interference effect on the magnitude of the fluctuation wind loads and also the average values of aerodynamic coefficients in bodies in many mutual assemblies. The presented study expands their paper on the larger interference area in different turbulent boundary layer conditions. Taniike (1991) describes the effect of turbulence of incoming wind flow on interference effects. He reports a significant decrease in interference effects with increasing turbulence intensity. The effect of interference becomes negligible if the turbulence intensity is higher than 17-18%. It is also important to take into account the surface roughness of the bodies. Machacek et al. (2020) report on the behaviour of three cylindrical bodies with high surface roughness

[*] Ing. Michael Macháček, Ph.D.: Institute of Theoretical and Applied Mechanics of the CAS; Prosecká 76, 19000 Prague; CZ, machacek@itam.cas.cz

[**] Assoc. Prof. Yuan-Lung Lo, Ph.D.: Department of Civil Engineering at National Taipei University of Technology; num. 1 section 3, Zhongxiao East Road, Taipei City; TW, yllo@ntut.edu.tw

[***] Prof. Ing. Jiří Máca, CSc.: Faculty of civil engineering in Prague, Czech technical university in Prague; Thákurova 7/2077, 166 29 Prague; CZ, maca@fsv.cvut.cz

placed in one row. One of the contributions focused on the interference effect in real construction practice is that by Yan and Li (2016), where the authors describe the interference wind load on a pair of high-rise buildings in the Hong Kong financial center in terms of aerodynamic forces and local pressures on the building facade.

2. Methods

Experimental laboratory tests were performed in a boundary layer wind tunnel located at the Wind Engineering Research Center at Tamkang University in Taiwan. The wind tunnel is of the open type and the cross section of the aerodynamic part, where the models were located, is 2.2 m (width) and 2 m (height). The turbulent incoming flow was modelled with an atmospheric boundary layer adapted to urban topography IV, terrain category according to (EN 1991-1-4, 2020), reduced to a simulation length scale factor of 1: 300.

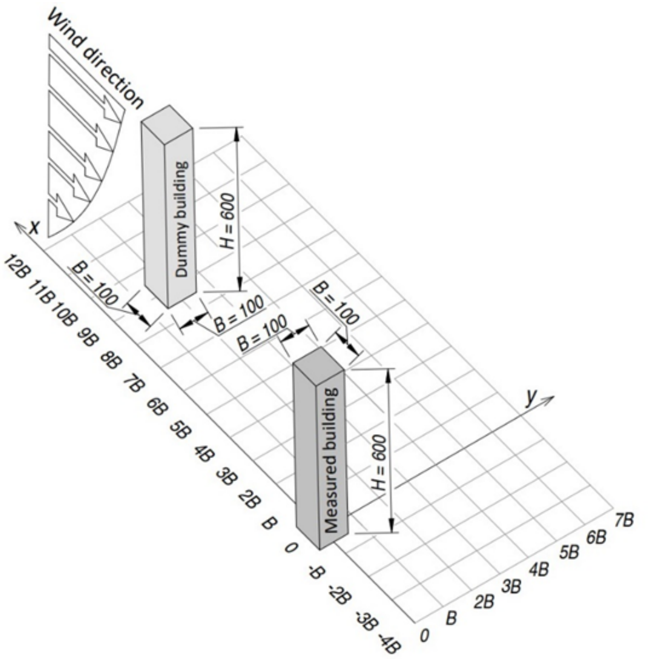

Fig. 1: Sketch of the designed wind tunnel experiment with a dimension of buildings and range of interfered positions.

Experimental measurement was focused on defining the wind interference effect on prism rectangular buildings. The range of interfered positions and the size of the model downscale buildings are shown in Fig. 1. The measured building was fixed to a multi-axis force-torque sensor (Model 45E15A4 100N, JR3, California, USA) at the bottom of the model. The sampling frequency of measurement was 1000Hz with 180s long records. The mean wind velocity of the incoming flow at the height of the top of models was chosen at 9,2 m/s so the Reynolds number was $6{\cdot}10^4$. The ratio between the height and width of buildings was chosen as six, which is relatively common in high-rise buildings. The dummy building was able to be fixed to the wind tunnel floor in many interference positions. The fixing positions were placed at a distance from the measured building, starting at twelve times the width of the building in the windward direction and ending at the four times of the building width in the leeward direction. The position of the dummy building in a crosswind direction was available from zero to seven times the building width. The interference effect in this article is presented by a ratio called the interference factor (IF), where the IF is the ratio between the wind loading on measured building with the dummy building present and the load on the free-standing measured building; the latter measurement is used as a reference value. Symbolically, the IF is shown in schematic equation (1).

$$IF = \frac{Wind\ loading\ on\ measured\ interfered\ building}{Wind\ loading\ on\ alone\ building} \tag{1}$$

$$C_L = \frac{2 \cdot F_L}{\rho_{air} \cdot B \cdot H \cdot V_{mean}^2} \tag{2}$$

Aerodynamic forces perpendicular to the mean wind speed will be represented by lift coefficient C_L in Eq. (2), where F_L is the aerodynamic force perpendicular to the wind direction, V_{mean} is the mean wind velocity at the high tip of model, ρ_{air} the air density and B, H are dimensions of the model as is shown in Fig 1.

3. Results

The interference factor of the average aerodynamic drag force in the wind direction is shown in Fig. 2. All measured positions of the dummy building are highlighted by the crosses and the black rectangle symbolizes the measured principal building. The bright rectangle around the measured building is a blind spot where it was not possible to place the dummy building. The incoming wind flow is from the left side, so if the dummy building has x coordinate negative, it is located on the leeward side of the measured building and if the dummy building has positive x coordinate, the measured building is located in the wake of the dummy building. The interference positions of the dummy building placed inside the white border have IF values greater than 1. The increase in the aerodynamic drag forces is relatively small, up to 5%. A significant reduction in aerodynamic drag occurs when the measured principal building is directly behind the dummy building. When the dummy building is placed at coordinates [1,5 ; 0], it shields completely the measured building and the drag forces on the measured building act against the wind directions.

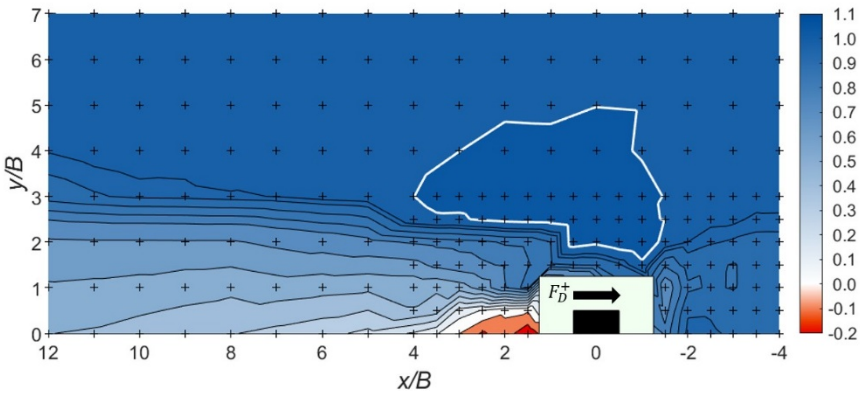

Fig. 2: Interference factor of mean drag forces.

The case of the free-standing measured building is symmetrical, so the mean lift forces are equal to zero, but the interference effect disrupts the symmetry of the flow and aerodynamic lift forces on the measured building are becoming noticeable. The average aerodynamic lift coefficient does not reach high values, but high increases are evident in certain areas, as can be seen in Fig. 3. The lift force increases the most when the dummy building is placed at coordinates [-1; 1.5] and reaches values $C_L = -0.86$. The total aerodynamic force, which was obtained as the sum of the drag and lift force on the measured building, showed a 36% increase in wind force with respect to the free-standing building. The lift coefficients in areas around coordinates [4; 1] and [-1.5; 1.5] are not too large, but the rapid change in sign can lead to aeroelastic instabilities such as the interference galloping. The area around coordinates [4; 1] is very typical for the occurrence of the interference galloping, especially when a row of bodies is slightly deviated from the wind direction. The most susceptible configuration to galloping is that where the direction of the row deviates from the wind direction by about 10 degrees.

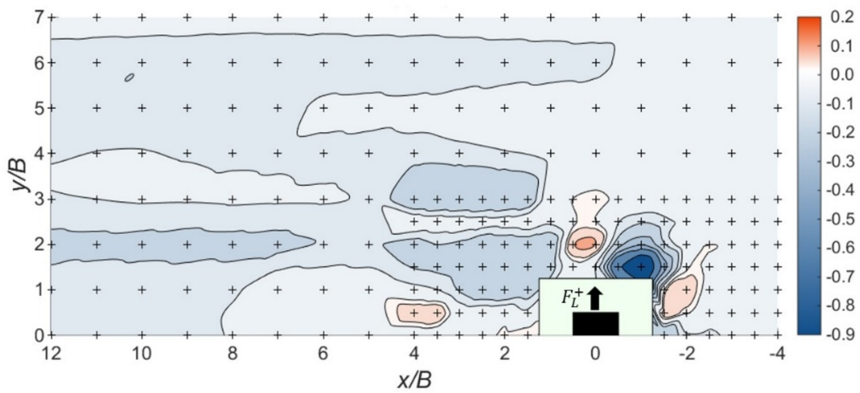

Fig. 3: Coefficient of mean lift forces.

The aerodynamic interference causes also a very substantial increase in the load fluctuation component in the direction perpendicular to the wind, as is shown in Fig. 4, which shows the spatial distribution of the IF being defined by the ratio of standard deviations of lift forces. Areas with the IF value greater than one are red and areas with values less than one are marked in blue colour. The maximum increase of the fluctuation component is observed at coordinates [4; 2], where the increase reaches 28%. A significant reduction in the fluctuation component can be observed in cases where the buildings are in close proximity to each other. The increase of fluctuation forces is caused by the vortices that are generated behind the dummy building when placed against the flow.

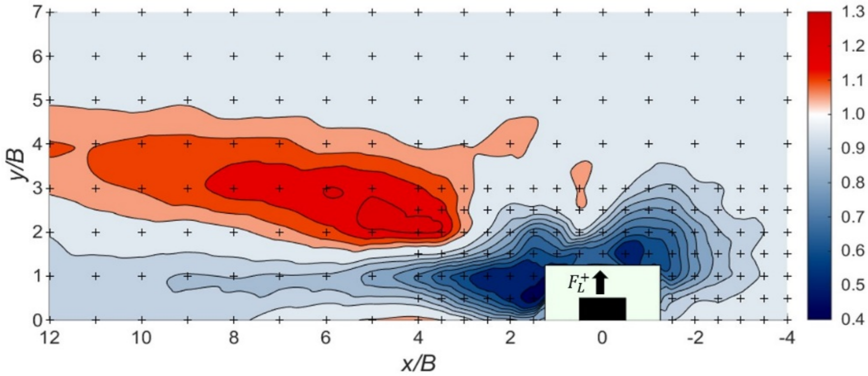

Fig. 4: Interference factor of standard deviations of lift forces.

4. Conclusions

The wind tunnel experimental tests defined the interference effect of wind loads on two buildings with a square cross-section. Close mutual proximity can cause a significant increase in aerodynamic load compared to a stand-alone structure. The greatest increase in mean total wind force is when the dummy building is placed at coordinates [-1; 1.5]. Considerable lift forces were found in the case of close proximity of the buildings, while for a free-standing building the mean lift value equals zero. The lift force significantly changes its direction even with small changes in the position of the dummy building. This phenomenon can lead to a loss of aeroelastic stability, the so-called interference galloping. The increase in fluctuations of the aerodynamic lift force can reach up to 28% when the axial distance of the buildings corresponds to four times the width of the buildings and the wind exposure is deviated by about 10° from the connecting line of the buildings.

Acknowledgement

The kind support of Czech Academy of Sciences projects no. VAJVA-19-20 and RVO 68378297 institutional support are gratefully acknowledged.

References

EN 1991-1-4 (2010) *Eurocode 1 – Actions on structures – Part 1-4: General actions – Wind actions*. CEN/TC 250, Brussels, Belgium

Harris, C. L. (1934) Influence of neighboring structures on the wind pressure on tall buildings. *Journal of Research-National Bureau of Standards,* Vol 12, pp. 103-118 .

Machacek, M., Urushadze, S., Pospíšil, S., Trush, A. and Pirner, M. (2020) Aerodynamic interference of wind flow around three cylindrical bodies with surface roughness, MATEC Web Conf. 313 0005.

Sakamoto, H. and Haniu, H. (1988) Aerodynamic forces acting on two square prisms placed vertically in a turbulent boundary layer, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 31, No 1, pp 41-66.

Taniike, Y. (1991) Turbulence effect on mutual interference of tall buildings, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 117, pp. 443-456.

Yan, B. and Li, Q. S. (2016) Wind tunnel study of interference effects between twin super-tall buildings with aerodynamic modifications, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 156, pp. 129-145.