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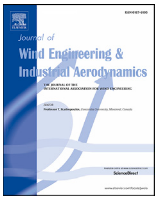

The environmental effects of aerodynamic interference between two closely positioned irregular high buildings

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ABSTRACT

The close proximity of high buildings in urban areas causes significant interference effects to occur between them. Commonly, it has an adverse effect upon wind conditions in such areas. Taking into account the increasingly dense arrangement of buildings in cities, this problem will most likely become more significant in future years. Aerodynamic interference has been analysed in many research papers; however, it usually focusses only on the influence of particular variables on the phenomenon. This paper provides a more comprehensive approach, taking into account a case study of irregularly shaped tall buildings. Aerodynamic interference is considered in three aspects: mean pressure distribution on external surfaces, aerodynamic global forces and pedestrian wind comfort. Measurement results clearly show that the orientation of the interfering building and its surroundings with respect to wind direction is crucial for the effects of aerodynamic interference. It is also concluded that the close proximity of two buildings causes high values of negative pressure on walls facing a gap. Nevertheless, at the same time, the shielding effect of the interfering building decreases with regard to the global wind action on the analysed building.

1. Introduction

High-rise structures in urban environments are significantly exposed to wind action due to their heights as well as to the aerodynamic interference with upwind and adjacent buildings. Wind loading codes do not consider the interference effect between buildings because of the complexity of the problem, taking into account only the case of the isolated building. Therefore, wind action calculated according to these standards does not correspond to reality. It omits beneficial shielding from other buildings in along-wind conditions and also the amplified wind action which is common in crosswind conditions. To estimate the wind field with respect to the interference effect between high buildings, proper simulation is recommended. Traditionally, it is conducted in boundary layer wind tunnels or with properly validated numerical models.

Complex wind flow patterns in urbanised areas depend on many different parameters: building shape, wind direction, terrain roughness, the vicinity of the building. Many research works concerning aerodynamic interference considered the influence of particular variables: arrangement of the buildings (Yu et al., 2015), terrain category (Mara et al., 2014), building height (Kim et al., 2011) or the building cross section (Hui et al., 2012). A grid-based approach for the various locations of interfering buildings is commonly applied in the analysis of the interference effect between two or three buildings (Xie and Gu, 2004). Moreover, particle image velocimetry tests are also conducted to create a visualisation of the wind flow pattern in the interference configuration (Hui et al., 2013).

It is widely known that aerodynamic interference causes changes to the wind action on buildings; however, it is worth pointing out that the specific arrangement of the buildings can adversely affect wind conditions at the pedestrian level. This problem must not be neglected because it can reduce the appeal of a given location and ultimately cause significant losses for the building owners. This issue has recently attracted increased attention with respect to wind comfort in urban areas (Blocken and Carmeliet, 2004; Koss, 2006). Taking into account the importance of the wind environment in the city, it is essential that it is predicted in the planning phase of designing a new structure. It is hard to obtain guidelines for urban planners which would help to avoid problems with aerodynamic interference because of the uniqueness of each case. However, in such situations, wind tunnel tests can be helpful in the assessment of wind conditions around the building under construction.

This paper is concerned with a case study of aerodynamic interference

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between two high-rise structures which will be built in the city centre of Katowice in Poland. The lower building was considered as the principal building A and the higher building as interfering building B because such an arrangement produces a stronger interference effect (Xie and Gu, 2007). The two buildings have slightly unusual shapes: they consist of two and three rectangular boxes, respectively, which are offset with respect to each other. Taking into account that aerodynamic forces largely depend on building shape (Kim et al., 2014), it is necessary to conduct the tests in the analysed case. The close arrangement of the investigated buildings causes a channelling effect and has a significant impact on wind action. In this study, aerodynamic interference is considered with respect to wind action on the building surfaces, aerodynamic global forces and pedestrian wind comfort. Wind tunnel tests were performed to identify the wind pressure distribution on the walls of the building models and mean wind velocities in the area between them. The buildings were set at fixed distances apart and different wind directions were considered. Two configurations of building arrangement were investigated in order to enable observing the effect of aerodynamic interference. In the first configuration, only principal building A was considered while during the second configuration, both of the buildings (A and B) were under investigation. The structure of the wind flow in urban terrain corresponding with the planned location of the designed objects was simulated. The comfort criteria proposed in (Flaga, 2008), which take into account the wind climate characteristic for Poland, were assumed in order to assess pedestrian wind conditions.

2. Material and methods

2.1. Description of the wind tunnel tests

Wind tunnel tests were carried out in the boundary layer wind tunnel in the Wind Engineering Laboratory at Cracow University of Technology. Measurements were conducted on models of two high-rise buildings which will be erected in Katowice, Poland, taking into account their nearest surroundings. The geometric scale was 1:300. Fig. 1 presents a computer visualisation of the turn table arrangement as well as the measuring position of the model. The objects of interest were the lower building (A – height 64.6 m) and the higher building (B – height 133.6 m). The investigated structures have slightly unusual shapes; they consist of two (building A) and three (building B) rectangular elements which are shifted with respect to each other. The space between the buildings is fixed and can be defined as dimensionless parameter: $\overline{b} = b/D = 0.25$, where: b – distance between building A and B, D – width of the cross section of building A (larger dimension).

Two phases of tests were performed. In the first phase, only building A was analysed; in the second phase, both buildings A and B were under investigation. In this manner, the effect of aerodynamic interference between these objects could be observed.

Both buildings were instrumented with 436 pressure taps distributed on their walls and roofs: 157 on building A and 279 on building B. A differential pressure measurement system of electronic scanners was used to measure the instantaneous pressure in each point. The scanner consisted of an array of pressure sensors enabling the taking of measurements at 64 points simultaneously. The sampling frequency was 200 Hz and the measurement time was 20 s. During pressure measurements, 24 angles of wind onflow were analysed at increments of 15° (Fig. 2).

Pedestrian wind comfort was assessed at 19 measurement points located in the space between buildings A and B. Investigations were carried out for 12 angles of wind onflow at 30° intervals (Fig. 2). A hot-wire anemometer system was used to obtain instantaneous wind velocity at a height of 0.55 cm which corresponds with pedestrian level at full scale (1.5–2 m). The measuring position for the pedestrian wind comfort investigations is presented in Fig. 1b.

2.2. Simulation of the boundary layer

The wind flow structure in the wind tunnel was simulated with use of appropriate turbulence elements such as barriers, spires and blocks. Measurements of instantaneous wind velocity were conducted at six points located at heights from 100 mm to 450 mm above the floor level of the wind tunnel working section. Hot-wire anemometers were used in these measurements; these were the basis for determining the mean wind velocity profile with using the following power-law form:

$$V(z) = V_{\mathrm{ref}}\left(z/z_{\mathrm{ref}}\right)^{\alpha} \tag{1}$$

where: $V_{\mathrm{ref}} = 12.55\,\frac{m}{s}$ – reference velocity, $z_{\mathrm{ref}} = 0.45m$ – reference height (height of building B), $\alpha = 0.3$ – exponent.

Both heights and velocities are expressed at the scale of the model.

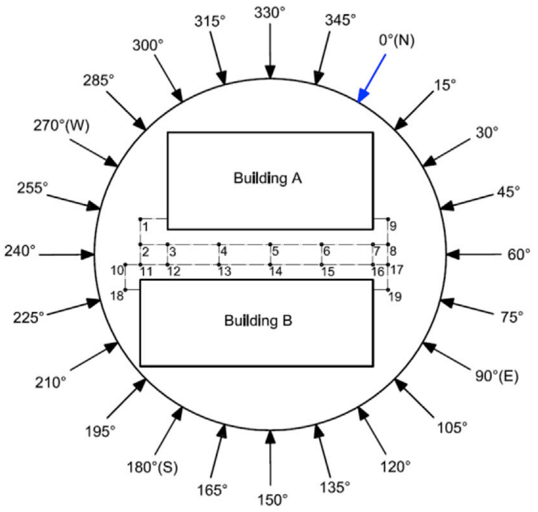

Fig. 2. Angles of wind onflow adopted during wind tunnel tests and measurement points in pedestrian wind comfort assessment.

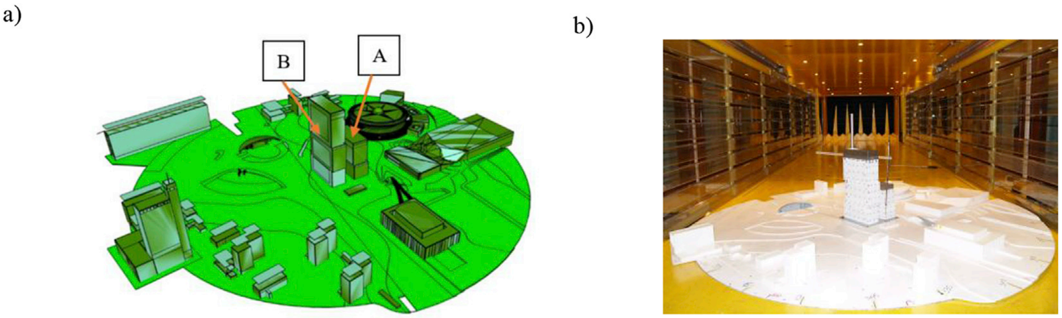

Fig. 1. Model of investigated buildings: computer visualisation (a), measuring position (b) (Research Report, 2017).

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