Wind loads on buildings in tandem arrangement

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Abstract. The paper presents the research results of the distribution of the local and integral pressure coefficients over the sides of the square prisms arranged in tandem and experiencing the airflow. The correlation is shown between the obtained airflow patterns and the pressure coefficient distribution; the dependences are obtained between the building arrangement and the distribution of the pressure coefficients; the phenomena caused by the airflow interaction are described in this paper.

1. Introduction

The issues of the building aerodynamics have always been considered very important and in some cases, determinative when designing ventilation system, airflow calculation inside buildings, air filtration in selecting building envelopes, and assessing the building influence on aerodynamics of the adjacent territory. On the other hand, aerodynamics of buildings involves a study of the wind loading, hazardous substance dissipation in the atmosphere, pedestrian path system, snow drifts, etc.

In recent years, the role of aerodynamics of buildings has significantly increased due to the advances in tall building design, a search for opportunities of natural ventilation, air flow optimization inside buildings, wind-driven power plants built in the building envelope for energy supply.

The important data on wind loading are widely used in modern energy-efficient multilayered facade systems with insufficient strength properties [1].

Currently, the most interesting is the interaction between buildings in urban environment. Regulatory documentation does not fully allow for the presence of other structures near the planned building.

Aerodynamic or pressure coefficient is a degree of the load transmission from the wind flow to the building envelope and then on its bearing elements.

A very wide range of foreign works was devoted to aerodynamics of various types of structures and buildings on the whole. Research was carried out both for a single building model of various configuration [2–6], buildings in tandem arrangement, and groups of buildings [7–23].

The aim of this work is to study the wind loads affecting the square prisms arranged in tandem.
2. Experimental setup and measurements

Our experiments are focused on the investigation of the local and integral pressure coefficients distributed over the sides of the square prisms arranged in tandem, as illustrated schematically in figure 1. These experiments continue our previous research [24−25].

Let us consider the influence of the distance between the prisms in the longitudinal direction \( L_1/a \) on the distribution of local and integral pressure coefficients along the sides of the prism with relative height \( H/a = 3 \) (where \( a = 50 \) mm and is the cross-section of the prism), which is located behind an obstacle. The prisms are made of 5 mm plexiglass. In these experiments, the distance \( L_1/a \) between the prisms is selected as 0, 0.5, 1, 1.5, 3, 4.5 and 6, and the airflow angles of attack \( \varphi \) are 0 and 45 degrees.

Measurements of the static pressure fields and a study of the air motion are performed on a purpose-made aerodynamic test bench [25]. The Reynolds number (Re) varies between \( 3.13 \times 10^4 \) and \( 4.25 \times 10^4 \) over the prism side.

3. Results and discussion

At the first stage, we obtain information on the separated flow structure using the oil flow visualization on the wind tunnel wall. The results of this visualization are illustrated in figure 2. The oil flow visualization is used to detect the correlation between the obtained visible flow patterns and the distribution of the pressure coefficients as well as to evaluate the hydrodynamic structure of separated flows, their size and behavior.

![Figure 1](image1.png)

**Figure 1.** Schematic view of building models arranged on one axis: \( a - \varphi = 0^\circ; b - \varphi = 45^\circ; \)

\( 1 - \) obstruction model; \( 2 - \) model of interest.

![Figure 2](image2.png)

**Figure 2.** Oil flow visualization on the tunnel surface in measuring distance between two tandem-arranged models at \( \text{Re} = 4.25 \times 10^4 \): \( a, b - \varphi = 0^\circ; \)

\( c, d - \varphi = 45^\circ; a, c - L_1/a = 1.5; b, d - L_1/a = 6.0. \)
According to figure 2a, the horseshoe vortex field which forms behind Model 1 increases at an angle of attack of $\varphi = 0^\circ$ and the distance between the models of $L1/a < 4.0$. When $L1/a > 4.0$, Model 2 is less affected by the vortex field and goes out from the upstream building wake. According to figure 2b, the vortex contours appear in front of Model 2 at $L1/a = 6$, where separated flow joins the vortex at the upper side. Recirculation zones on the lateral sides $B$–$C$ and $D$–$A$ of Model 2 reduce with increasing distance between the prisms and disappear at $L1/a \rightarrow 6$.

The same is also observed at an angle of attack $\varphi = 45^\circ$ in figure 2c. When $L1/a = 1.5$, the horseshoe vortex field which forms behind Model 1 increases and then shifts to the lateral sides $B$ and $D$ of Model 2. The horseshoe vortex propagates not only over the front but also on the lateral sides of this Model. As shown in figure 2d, with the increase in the distance $L1/a$ between the prisms up to 6, the horseshoe vortex field behind both Model 1 and Model 2 reduces to that of a freestanding prism.

As can be expected, the upstream prism has a greater effect on the front side of the downstream prism. This is proven by the analysis of figure 3, which shows the wind pressure distribution in horizontal sections of both prisms. The wind pressure on the front side $E$–$F$ (see figure 1) is replaced by the negative pressure that indicates the formation of a stagnant wake between the prisms, which remains even at large distances between them.

The formation of separated flows can be most clearly seen in figure 4, which gives the distribution of integral pressure coefficients on the different sides of the tandem-arranged prisms, depending on the longitudinal pitch between them. These data are obtained by integrating the pressure distribution both in vertical and horizontal directions of each side.
Integral pressure coefficient

At an axial airflow (see figure 2a), the pressure on the front side $A-B$ and lateral side $B-C$ of the upstream prism does not depend on the prism in the wake. At the same time, the negative pressure drastically increases on the back side of the prism and then gradually stabilizes. This behaviour is caused by the formation of the cellular vortices between the prisms, which are stable at longer distances. As can be seen from figure 4, the intense vortex between the prisms substantially affects the negative pressure on the front side $E-F$ of the second prism. At small distances $L_1/a < 1.0$, $C-D$ and $E-F$ sides are in the same conditions, but with decreasing aerodynamic interference, the pressure on the front side of the second prism starts to grow and approaches that of a freestanding prism.

At an angle of attack of 45 degrees (see figure 2b), the behavior of the pressure fields is identical, the difference being that the influence of the upstream prism is lower than at a zero angle of attack.

Conclusions

The findings of our research are quite convincing and are as follows:
1. The airflow pattern and the distribution of the pressure coefficients around the square prisms in tandem arrangement. The recirculation zone at a 45-degree angle of attack is not as long as at a zero angle. This fact is confirmed by the influence of the upstream model at the maximum longitudinal pitch $L_1/a$ and the total wind pressure.
2. The lower wind load on the downstream model varies between 1.5 and 3 of the longitudinal pitch $L_1/a$, both at zero- and 45-degree angles of attack. Supposedly, the wind load at a zero pressure could occur at the $L_1/a$ value varying from 2 to 2.2.
3. The upper points of the 150 mm high model ($H/a = 3$) are constantly affected by the separated flow from the front side of the upstream model within the whole range of the $L_1/a$ value to a zero distance between the models.
4. The use of the pressure coefficients will assist in analyzing the extreme values of the pressure on the sides of the models depending on numerous factors, including their arrangement.

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