Advances in Computer Science Research (ACSR), volume 72
IV International Research Conference "Information Technologies in Science, Management, Social Sphere and Medicine" (ITSMSSM 2017)

Physical simulation of wind pressure on building models at various arrangement and airflow conditions

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Abstract—**The paper presents the results of physical modeling of the wind pressure. Systematic data are obtained for the pressure coefficient distribution over the sides of the different-size building models under the airflow conditions. These conditions are provided by an obstacle situated in front of the building model. The obstacle has the same geometrical parameters as the building and is longitudinally and transversely displaced relative to the airflow direction.**

Keywords—aerodynamics of buildings; physical modeling; static-pressure field; pressure coefficient; building model

I. Introduction

In the last few years there has been a growing interest in the construction of high-rise buildings in Russia. This has made it possible to arrange living and working areas more compactly within the city. At the same time, the density of block building increases. Of greater interest is the wind pressure on buildings situated in inner-bloc spaces. The modern calculation techniques allow to fully determine the pressure on bearing and wall structures of buildings. To the authors' knowledge, the aerodynamics of buildings under restrained urban conditions has been scarcely investigated that creates errors in the analysis of bearing structures under the airflow conditions. This is especially relevant in terms of studying the wind pressure on wall structures of tandem-arranged buildings located at a short distance.

Different bodies located around a building change its aerodynamic behavior and the distribution of pressure coefficients.

The results of field studies provide a comprehensive idea on the architectural aerodynamics of buildings. However, due to the expensiveness and difficulties in conducting field studies, they can be used in exceptional cases.

For the past decade, the amount of structural analyses provided by the application software packages has been considerably increased. This trend is being currently developed. Thus, a certain progress is achieved in the field of the experimental and numerical calculations for relatively simple blunt bodies, such as a cube in a boundary layer, a long square prism, and some others [1–11]. Still, little is known at present about the interaction between few buildings and their arrangement effect on the airflow interference. A complex three-dimensional behavior of separation flows and their interference during the airflow around the obstacle system, significantly lower the capability of numerical modeling of aerodynamics.

Thus, the experimental research carried out on installations which create real wind pressure conditions is the main tool of studying aerodynamic parameters of buildings affected by the airflow.

Investigation results obtained in this work is the integral part of complex experimental research carried out into aeromechanics and heat exchange between building models having various shape and arrangement.

The main purpose of this work is to study the change in the pressure coefficient on the side surfaces of the building model affected by vortex flows. The latter are generated by an obstacle having geometrical parameters similar to that of the building model and longitudinally and transversely displaced relative to the airflow direction [12–14].

II. Task Descriptopn. Prototype Unit and Measuring Technique

Buildings are actually blunt bodies of different shape, however, often represent square prisms. In this connection, building models with 3 and 6 height/width (H/a) ratios were selected for this experiment. The cross-section of this prism is $a = 50$ mm. The section shape and size selected for the building models allow the experimental data on the wind pressure to be used not only for a wide range of buildings but also for other structures of the similar shape.

These experiments are presented with the physical modeling of a group of building models using the theory of similarity.

The main concern of the paper is to study the model transverse displacement equaling 25 mm relative to the long axis of the working chamber channel. The accepted transverse displacement range $L2/a$ is 0.5, 1, 1.5 and 2. Fig. 1 shows respectively longitudinal ($L1$) and transverse ($L2$) displacements of building models.

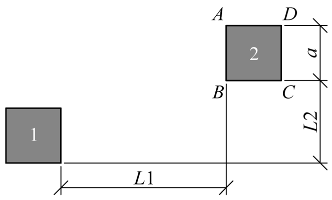

Fig. 1. Schematic arrangement of building models at longitudinal ($L1$) and transverse ($L2$) displacements: *1* – obstacle in front of the model; *2* – building model.

The building model consists of two square prisms (building + obstacle) having 50×50×150 and 50×50×300 mm is size (H/a = 3 and 6, respectively). The selected airflow rate matches the Reynolds number $Re = 4.25\times10^4$. The airflow angle of attack is 0 degrees. The distance between the models in the turbulent wake suits to the accepted longitudinal displacement range $L1/a$ = 1.5, 3 and 6.

All the experiments were conducted on an aerodynamic test bench at the Construction Engineering Technology Department of Tomsk State University of Architecture and Building. The full view of this test bench is illustrated in Fig. 2.

Fig. 2. Full view of aerodynamic test bench.

Aerodynamic tests are carried out in the open-type wind channel operating in suction mode. The wind channel has 0.4×0.4 m cross-section and 1.2 m long working section. Blocking of the wind channel depends on the model height and ranges within 1.5÷9.3%. The speed profile in the airflow middle is uniform, while the thickness of the boundary layer on the model placement is ~20 mm.

The models are made of organic glass 5 mm thick and mounted to the base also made of this material. Holes with 0.8 mm in diameter are made in one of the sides of Model 2 positioned behind Model 1. The holes are made vertically and horizontally at 10 and 7.5 mm distance, respectively. They serve as air inlets to determine the wind pressure for 21 models 150 mm high and 42 models 300 mm high (Fig. 3). Model 2 is connected to a tilting multichannel micromanometer which is used for data readout.

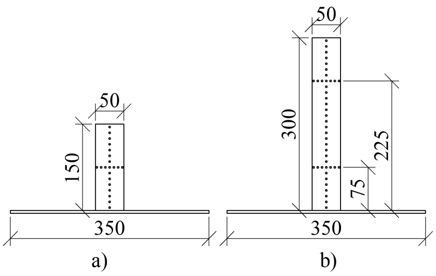

Fig. 3. Schematic view of square Model 2 installed on the base at different heights: *a* – 150 mm; *b* – 300 mm. Dots indicate air inlet locations.

The schematic view of horizontal and vertical sections of Model 2 with the relative height H/a = 3 and 6 is shown in Fig. 4.

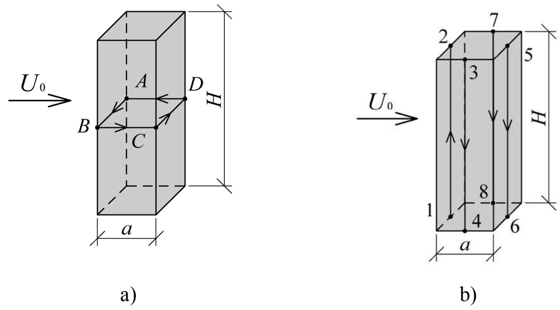

Fig. 4. Schematic view of Model 2 with the relative height H/a = 3 and 6: *a* – horizontal section (ABCD); *b* – vertical section (1–6).

The main value to be studied in terms of the static-pressure field, is the pressure (aerodynamic) coefficient C_p which can be obtained from

$$Cp = \frac{p - p_o}{\frac{1}{2}\left(\rho U_o^2\right)}, \quad (1)$$

where p and p_0 is the static pressure respectively in the considered surface point and the environment, *i.e.* the wall of the wind channel in the model placement; ρ is the airflow density (kg/m^3); U_0 is the airflow speed (m/s).

A tilting multichannel micromanometer with 1 mm w.g. scale interval was used for measurements of the pressure difference. A reading was made by a digital camera and then digitalized with GetData Graph Digitizer. The static pressure in the undisturbed flow channel was considered as abutment pressure.

Calculations results obtained for the pressure coefficient C_p were used for the value grouping and plotting the respective diagrams.

III. Results and Discussion

Fig. 5–7 contain the plots of the mean pressure coefficient affecting the sides of Model 2 depending on $L2/a$ and $L1/a$ ratios at the maximum constant speed of the airflow.

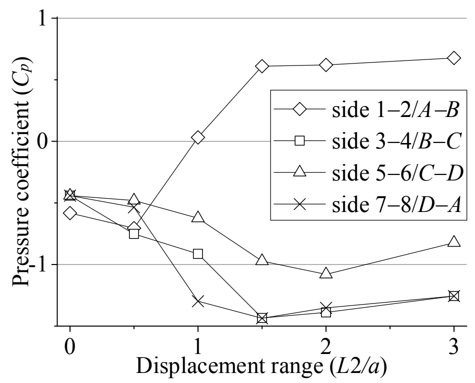

Fig. 5. Mean pressure coefficient affecting the sides of Model 2 depending on displacement range: *L2/a* at Re = 4.25×10^4 and *L1/a* = 1.5.

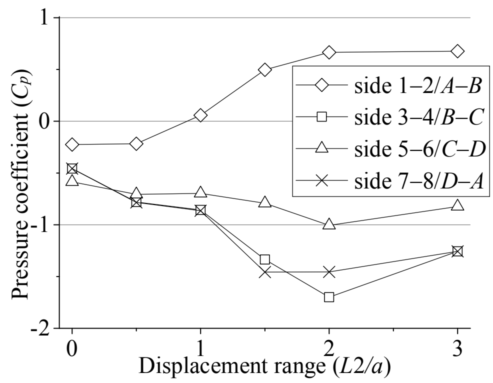

Fig. 6. Mean pressure coefficient affecting the sides of Model 2 depending on displacement range: *L2/a* at Re = 4.25×10^4 and *L1/a* = 3.

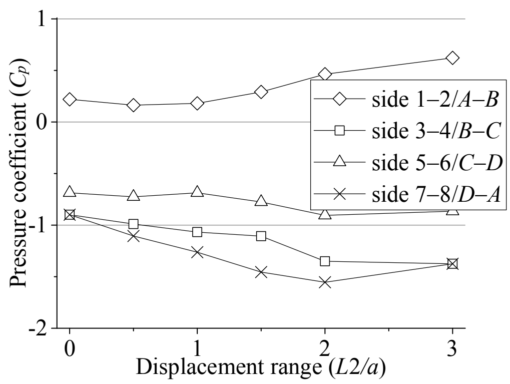

Fig. 7. Mean pressure coefficient affecting the sides of Model 2 depending on displacement range: *L2/a* at Re = 4.25×10^4 and *L1/a* = 6.

The analysis of these plots shows that at *L*2/*a* = 0.5, the negative pressure in the lateral side *D–A* is 3% higher than on the lateral side *B–C*. At *L*2/*a* = 1 and 1.5 it is respectively 8% and 12% higher. However, the increase in the transverse displacement range *L*2/*a* = 2 significantly increases the negative pressure on the side *B–C* which exceeds that on the side *D–A* by 22%. In other words, the pressure difference on the opposite sides results in the formation of transverse pressure which changes its direction at different *L*2/*a* ratios.

This phenomenon is characterized by the increase in the negative pressure due to the separation flow. Nearby Model 1 the airflow separates and accelerates so that some air impacts the front side *A–B* of the Model 2 positioned behind, thereby forming another separation flow nearby the side *D–A*. And some air involves the side *B–C* in the turbulent wake around Model 1.

When *L*2/*a* = 2, the interference of two separation flows of Models 1 and 2 results in the increase in the airflow speed passing between the models and, as a consequence, the increase in the negative pressure on the lateral side *B–C*.

When *L*1/*a* = 1.5 and *L*2/*a* ranges from 0.5 to 1.5, the intensive pressure growth is observed on the windward side *A–B* (Fig. 5). The pressure coefficient C_p ranges from –0.7 to 0.6.

According to Fig. 6, Model 2 is subjected to the pressure ranging from –0.2 to 0.6 at *L*1/*a* = 3, while at *L*1/*a* = 6 (Fig. 7) the pressure ranges between 0.2–0.6.

According to Fig. 5, at each *L*1/*a* value, the wind pressure acts normally to the airflow direction at the pressure difference observed on the lateral sides. With the increasing longitudinal displacement *L*1, the wind pressure acquires the constant direction that can be observed at *L*1/*a* = 6 in Fig. 7.

The greatest changes are observed at *L*1/*a* = 3 as shown in Figs 8–9. This is because the vortex structures form owing to the specific configuration of the models, their geometry and the airflow speed.

This is typical for the models with prismatic configuration and the height/width ratio *H*/*a* = 2 and higher. In particular, this is proved by the experiments with 50×50×300 mm models, their upper part being beyond the boundary layer of the channel.

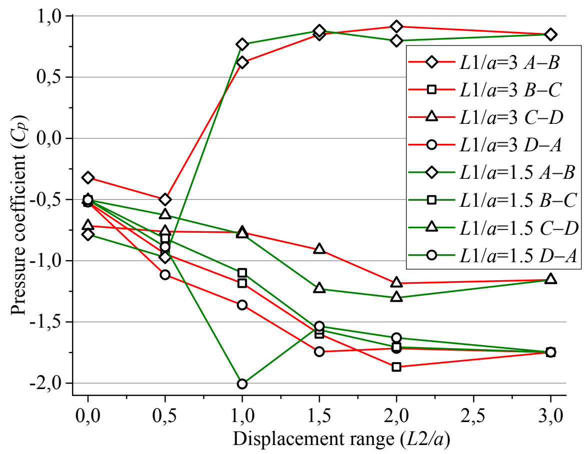

Fig. 8. Maxima and minima of pressure coefficient for Model 2 depending on *L*1/*a* and *L*2/*a* of Model 1 at 150 mm height of square prisms (*H*/*a* = 3).

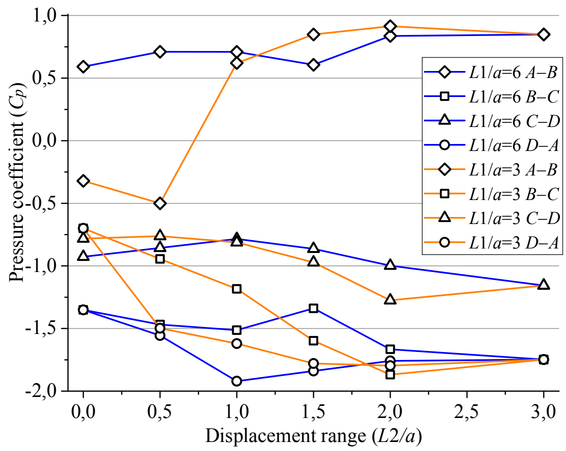

Fig. 9. Maxima and minima of pressure coefficient for Model 2 depending on $L1/a$ and $L2/a$ of Model 1 at 300 mm height of square prisms (H/a = 6).

Experimental results show that at the displacement range $L1/a$ = 2, the primary and the secondary separation flows of Model 1 and Model 2 respectively, have an effect on the lateral sides *D–A* and *B–C*, *i.e.* the difference in the negative pressure on these sides is 0.5 and tends toward the side *D–A*.

When Model 2 leaves the turbulent wake of Model 1, the pressure difference occurs on the lateral sides of Model 2. Due to the separation flow generated by Model 1, the longitudinal pressure increases in comparison to a separately positioned model. This phenomenon is observed at $L1/a$ = 1.5, 3 and 6. The obtained results indicate that the obstacle in front of the building model does not only decrease the wind pressure but also leads to the formation of additional longitudinal and transverse wind pressures.

IV. Conclusions

The findings of our research are quite convincing, and thus the following conclusions can be drawn:

1. The interaction between the building models was identified in the airflow conditions.
2. The minimum wind pressure was determined for Model 2 positioned behind.
3. The effect of the primary and the secondary separation flows on the negative pressure on the sides of Model 2 was identified depending on the initial distance between models.
4. It was found that when windward Model 2 left the turbulent wake of Model 1, the pressure coefficient grew on the front side of Model 2.
5. It was also found that when windward Model 2 left the turbulent wake of Model 1 at $L1/a$ = 6, the formation of additional longitudinal and transverse pressures occurred. So the change in the airflow direction had a significant oscillating effect on windward Model 2.

The obtained results are important for attaining new knowledge on the aerodynamics of high-rise buildings in restrained urban conditions. These results can be also useful for the strength analysis of bearing and wall structures of buildings in complex aerodynamic conditions.

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