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Research of aerodynamic properties of some building models

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Abstract. The paper provides a brief analysis of the history of urban development, depending on the consideration of natural and climatic conditions, in particular, the movement of air masses. The construction practice is taken into account when accounting wind conditions, which primarily involves the effective placement of industrial enterprises, sanitary break zones, residential development and public space. Theoretical studies of the aerodynamic properties of two models of buildings of simple shape, based on some experimental data, are presented. Comparing the flow directions calculated theoretically with the directions measured experimentally by different authors, it is confirmed that the proposed theoretical methods well reflect the actual picture of the flow around a rectangular profile by an air flow. For the considered models No. 1 and No. 2, according to the test results, it was determined that the pressure on the windward planes (walls) of different heights depends on the ratio between the thickness of the boundary layer and the height of the building, respectively, buildings of small height are almost entirely located in the boundary layer, i.e. in the layer of air, which, touching the surface of the earth, is slowed down due to the roughness of the underlying surface, as the speed of air movement decreases as it approaches the surface of the earth, and on the surface it is zero.

1. Introduction

Creating conditions that meet increasingly stringent requirements is the main idea of modern construction. Full and comprehensive consideration of natural, climatic and urban conditions means that design and construction works are as close as possible to the highest requirements of the modern construction industry.

In addition to the fact that buildings and structures, regardless of their purpose, bear the main technological load, they also serve as protection from external climatic influences. When designing in construction, it is necessary to make maximum use of useful environmental factors – solar radiation, air mass movement, geothermal heat, etc. At the same time, the emphasis in the construction of buildings, especially residential and public, should be aimed at creating the most comfortable microclimate.



The influence of climate in urban planning has been considered since ancient times. In the treatise “Politics”, Aristotle pointed out the importance of choosing the location of the city: “... cities facing east and towards the east winds are more suitable for sanitary conditions; they are followed by cities protected from the north winds - in such cities the cold season is easier to bear”. In the book “On air, water and terrain” Hippocrates describes the diseases that occur in the inhabitants, based on the analysis of natural and climatic conditions, especially noting the cities open to the east winds: “A city situated in this way is like spring in its moderation of heat and cold; even there are fewer diseases and they are weaker”.

The practice of modern construction has many examples of taking into account natural and climatic conditions, in particular wind loads. One of the most striking examples is the city of Chandigarh, which was laid out in 1953 and built entirely on a new site. [3] Initially, a detailed climate review was carried out, which was taken into account in the design by a group of architects under the leadership of Le Corbusier.

The practice of Soviet and Russian construction, taking into account wind conditions, primarily involves the placement of industrial enterprises, sanitary break zones, residential buildings and public space.

Inattention to wind conditions can lead to serious consequences. For example, in a number of cities of Kuzbass, despite the location of residential buildings taking into account the wind roses in winter in Kuzbass, an anticyclonic type of weather prevails with a large number of calms, and the terrain is determined by a large number of closed and poorly ventilated basins. At low wind speed, the situation is aggravated by the fact that the directions of the prevailing winds in complex terrain create a set of specific conditions that must be taken into account when building each specific enterprise and residential area [1, 8, 9].

2. Materials and methods

In the vast territory of Russia, there are various wind conditions, and when designing buildings and urban development, it is also necessary to take into account the deformation of the air flow, both in the direction and in the change in speed. The study of the impact of wind on buildings can be divided into two parts: the first – the formation of the microclimate of the space between buildings and the second – the formation of the microclimate inside buildings. Depending on the density of buildings, the shape of structures and the type of landscaping, the speed and direction of wind movement in the space between and above the projected buildings depend [1, 4, 5, 7].

To study the characteristics of air flow around buildings, experiments are usually carried out on models. But in this paper, the authors presented theoretical studies of the aerodynamic properties of buildings, based on some experimental data obtained by F.L. Serebrovsky, V.T. Samsonov, and others. Two models of buildings were considered: in the form of a rectangular parallelepiped (see Figure 1).

Models of individual buildings were considered in different positions relative to the direction of the air flow. For a more accurate description and analysis of the processes, the models were divided into levels. The pressures on the surface of the models and the velocity field in the space near the models were measured. The air flow is directed at an angle $\alpha = 90^\circ$ with respect to the longitudinal axis of the building.

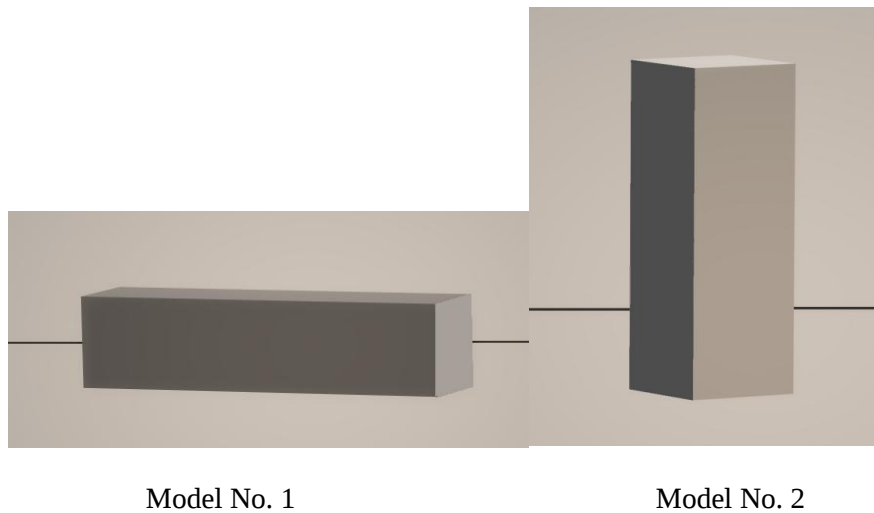


Figure 1. Models of buildings.

Model No. 1 “Flat parallelepiped with an elongated narrow face in the form of a base”, divided into five levels (see Figure 2).

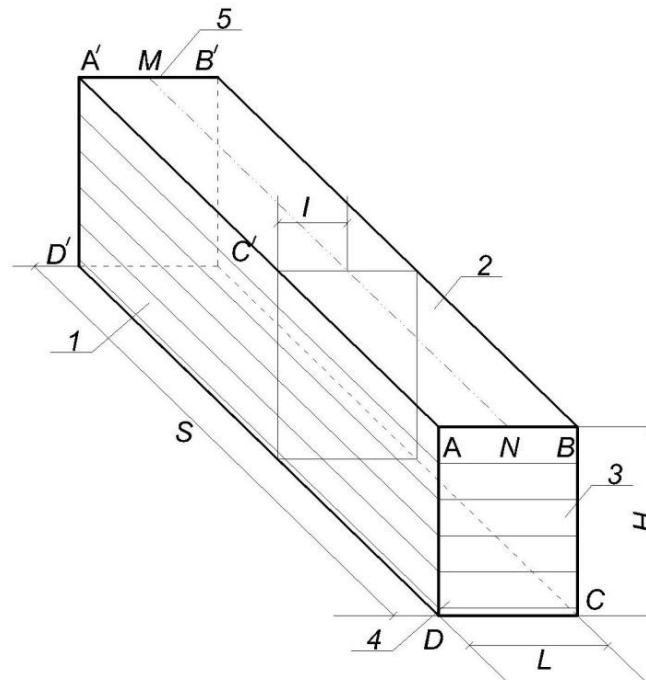


Figure 2. A flat parallelepiped with an elongated narrow face in the form of a base.

Model No. 2. “Parallelepiped with a square face in the form of a base”, divided into twelve levels.

The uniform distribution of the aerodynamic coefficients in height (with the exception of the first and second levels, where the influence of the boundary layer affects) is typical for the flow around a point-type building model (see Figure 3).

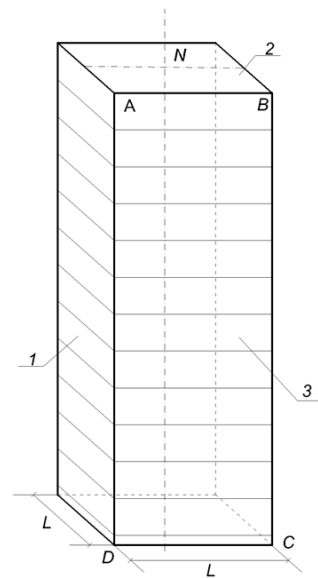


Figure 3. Parallelepiped with a square face in the form of a base.

3. Results and discussion

Surface 1 of the model 1. Windward wall of the building. When the wind direction is perpendicular to this surface, a positive pressure is observed: $k = +0.60 \div +0.90$. The highest pressure is in the middle section of the model, closer to the edges the pressure drops slightly. The greatest pressure in the cross-section is present at a height $4/5$ of the height of the building. At the second level, the pressure decreases and then increases slightly at the first level.

At the upper edge of the fifth level, the pressure is almost the same as at the fourth level, but at the front (frontal) part of the upper edge, it drops sharply to almost zero. In the absence of a special structure in the form of a cornice, the pressure in the upper part of the wall gradually decreases, reaching a minimum at its upper border.

Surface 2 of the model 1. The upper surface (roof) of the building always experiences the sucking effect of the wind. The aerodynamic coefficients are on average $k = -0.63$.

The value of the aerodynamic coefficients in this case can be calculated by the formula:

$$k_{90} = -[1,08 \exp(-2,7x^2) + 0,05] \quad (1)$$

where $x = \frac{l}{\sqrt{HS}}$ — dimensionless geometric Retter criterion;

l - the distance from the front edge AA' to the considered section MN ; H and S are the height and length of the building (see Fig. 2).

The greatest sucking effect of the wind is observed near the edge AA' .

Surface 3 of the model 1. The leeward wall of the building. The aerodynamic coefficients on this surface are negative and, consequently, the sucking effect of the wind is detected in this part. Aerodynamic coefficients $k = -0.4 \div -0.6$.

The aerodynamic coefficient for the leeward side of a building can be determined by the formula (1) if $l = L$.

In the upper edge of the fifth level, the aerodynamic coefficient is on average -0.35 . In the front part of the upper edge, it decreases to -0.70 .

Surface 4 and 5 of the model 1. The ends of the building. Negative pressure is also detected on these surfaces. The aerodynamic coefficient is on average $k = -0.60$, i.e. the suction at the ends is slightly greater than on the leeward wall. The same is observed on the upper edge of the fifth level, where the aerodynamic coefficient decreases from -0.35 to -0.45 .

The air flow, meeting an obstacle in its path, rises steeply enough at a distance of one height of the building; this was recorded when measuring the speeds in the space near the model of the building with the wind direction perpendicular to the longitudinal axis of the building. After passing over the roof of the building, the main stream passes at a height equal to two heights of the building, and then gradually approaches the ground. Behind the building, an elliptical vortex was found, the length of which is approximately four times the height of the building. At a distance of about five heights from the building, the vortex zone ends, and the air flow gets its main direction, gradually increasing the speed. Comparing the directions of the flows calculated theoretically with the directions measured experimentally by the authors V.T. Samsonov and F.L. Serebrovsky, it is possible to make sure that the proposed theoretical methods reflect the actual picture of the flow around a rectangular profile by an air flow well.

V.T. Samsonov, F.L. Serebrovsky noted the following phenomenon: vortices are not stable; they arise, move in a certain direction, and then disappear. This phenomenon was recorded by them in the flow channel, and the same scientists also noted that when measuring the directions and velocities of the air flow flowing around the model No. 1 for a long period of time (6 days), a clear, symmetrical picture of two strictly correct vortices was found. This is due to the averaged values of speed and direction over a certain period of time.

V.T. Samsonov and F.L. Serebrovsky described a positive pressure in front of model No. 1 at a distance of approximately three to four of its heights on the surface of the ground, which increased as they approached the model. Near the model No. 1, the pressure reached 0.7 velocity pressure.

A negative pressure (suction) zone was observed behind the model No. 1. The greatest suction was at a distance of about two model heights ($k = -0.6$). Then the value of the aerodynamic coefficient increased and reached zero at a distance of six heights of the model.

The air flow is directed along the model 1. ($\alpha=0^\circ$). The windward end wall is in almost the same conditions as surface 1 when the wind direction is perpendicular to the axis of the building. Aerodynamic coefficients at the end $k = +0.7 \div +1$.

The rest surfaces of the building experience more or less suction. This suction has the greatest value in the front zone of the longitudinal external surfaces (wall) and the upper surface (roof). As they move away from the windward surface (end face), the suction value decreases.

For sections lying in the area of $0.5 \leq y/H \leq 2.75$, where y is the distance of this section from the front end surface (wall) of the model, the formula is applicable

$$k_0 = -0,55 \frac{H}{y} \quad (2)$$

On the leeward surface (end face), the aerodynamic coefficients are equal to $k = -0,1 \div -0,3$.

Based on the analysis of the research conducted by V.T. Samsonov and F.L. Serebrovsky, the authors propose the following description of the flow around the building, in the form of a flat parallelepiped with an elongated narrow face in the form of a base located along the direction of the air flow: the front end of the building directs the air jets up and to the sides. Due to the interaction of these jets with the horizontal rectilinear air flow, vortices occur in the front zone of the building: two vortices near the longitudinal outer walls of the building and one above the roof. At some distance from the windward end, these vortices end, and the air flow moves parallel to the walls and roof of the building. Behind the building, a small vortex zone is formed with a length of about 1-1.5 meters of the building height.

Surface 1 of the model 2. The aerodynamic coefficients of the windward side of the building are $k = +0.7 \div +1$. On the leeward and side walls, there is a suction, aerodynamic coefficients $k = -0.58 \div -0.31$.

The vortex zone behind a point-type house does not depend on the height of the building — it is approximately twice the width of the building.

The study of these options was aimed at obtaining a profile of air flow velocities and its pressure depending on different buildings in height. Based on the results obtained [2,6], the authors draw the following general conclusions:

For the considered models No. 1 and No. 2, according to the test results [2,6], it was determined that the pressure on the windward planes (walls) of different heights depends on the ratio between the thickness of the boundary layer and the height of the building. Accordingly, buildings of small height are almost entirely located in the boundary layer, i.e. in the layer of air, which, touching the surface of the earth, is slowed down due to the roughness of the underlying surface, as the speed of air movement decreases as it approaches the surface of the earth and is zero on the surface (see Table 1,2).

Table 1. Experimental air pressure values for model 1.

Model 1			
Surface 1	Surface 2	Surface 3	Surface 4,5
+0.60 ÷ + 0.90	- 0.63	-0.4 ÷ -0.6	- 0.60

Table 2. Experimental air pressure values for model 2.

Model 2			
Surface 1	Surface 2	Surface 3,4	Surface 5
+0.7 ÷ + 1	-0.33	-0.58 ÷ -0.31	- 0.60

The results of studies of the numerical values of the aerodynamic coefficient for two models of buildings with the wind direction perpendicular to the windward wall of the building are shown in the diagram (see Figure 4).

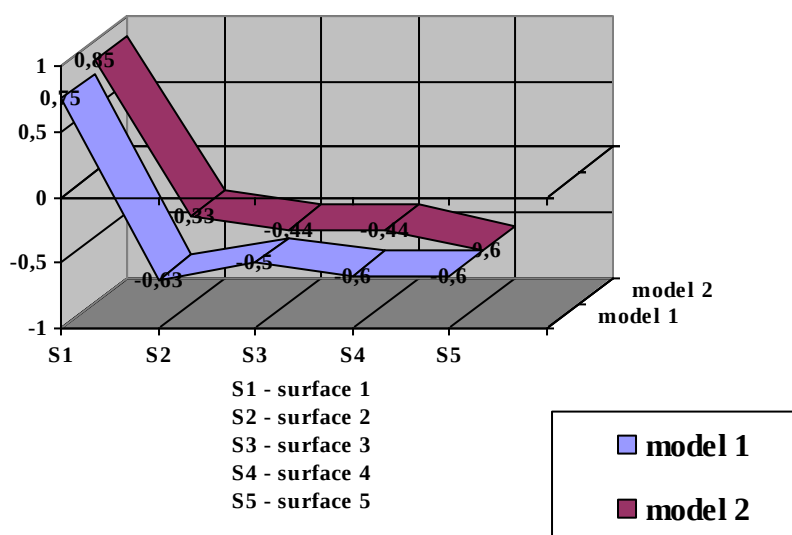


Figure 4. Values of the aerodynamic coefficient at $\alpha=90^\circ$.

4. Summary

1. Single-section houses have a different configuration in the plan. The influence of the shape of these buildings on their aerodynamic characteristics has not been sufficiently studied yet. Buildings that are round in plan and buildings in the form of an expanded book are of particular interest from an aerodynamic point of view.

2. Cylindrical buildings are better streamlined by air flows. Their resistance is therefore less. It follows that the heat loss of these buildings, resulting from the difference in pressure from the windward side and the suction from the opposite side, will be less.

3. The building in the form of an expanded book, like an airplane wing, will be provided with good ventilation conditions in any wind direction.

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