Numerical study and calculation of the structures of the stands with canopies on the wind impact, taking into account the terrain

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Abstract. Operation of stands with canopies is possible under different landscape conditions, including conditions in areas with a slope or in areas with various obstacles that change the profile of the wind flow and, accordingly, affect the distribution of wind pressure acting on the surface of the canopy. Determination of the actual wind loads on the stands with a canopy is an important task due to the lack of appropriate schemes in the SP 20.13330.2016 "Loads and impacts". The relevance of this problem is associated with the complexity of tests in specialized wind tunnels, as well as with the rapid development of computational fluid dynamics. In this regard, a numerical study of the aerodynamics of these structures was made in the software package ANSYS Fluent for the analysis of flows of liquids and gases. The article presents a comparison of the results with the schemes of wind pressure for awnings from SP 20.13330.2016 "Loads and effects" and Eurocode "Wind effects". The obtained results were used for verification of similar calculation technologies and specialized software systems, addition of regulatory documents and for “adjustment” of newly commissioned wind tunnels (in order to optimize and improve the efficiency of tests).

1. Introduction
Currently, the stands with a canopy are often used as temporary entertainment facilities. Wind is one of the main loads for them, so it is the actual wind loads on the stands with a canopy that are the subject of the study. According to the norms of SP "Loads and impacts" it is expected to use the results of large-scale model tests in special wind tunnels that are able to simulate the boundary layer of the atmosphere. However, such tests are extremely difficult, and for the largest models they need to be carried out abroad. In addition, the method of experimental modeling of wind flows and the impact on the facilities has its own errors and limitations [1], [2].

Recently, there has been a rapid development of computational fluid dynamics (CFD), improving the technological processes of calculations of wind impacts on buildings and structures, constantly growing computing power of personal computers [3], [4]. Leading foreign scientific research and design companies often combine testing and "numerical" experiments [5], [6], [7], [8]. In the future,
the role of mathematical modeling, as shown by experience in neighboring industries (such as aerospace) and tasks (construction mechanics), will only increase [3], [7], [9].

From the programs of computational fluid dynamics to perform the necessary calculations, the ANSYS Fluent complex was used. In many ways, the choice is connected both with the possibility of relatively accurate modeling of wind effects, and with the visual process of numerical modeling.

2. Numerical experiment with a calculation model without an obstacle

2.1. Formation of the calculation model
As a prototype object, a temporary structure was taken, installed specifically for the so called "high diving" competitions of the XVI World Aquatics Championships in 2015. The structure of the stands with canopies was located on the banks of the Kazanka river to accommodate spectators. Variable parameters in the calculation model of the stand with canopy are only three – the angle of inclination of the canopy ($\alpha$) – the base value – 10 degrees, the slope angle ($\beta$) – the base value of 15 degrees, the length of the horizontal projection of the slope ($h$) – the base value – 1h, that is equal to the height of the stand with the canopy (figure 1). $C_1$ and $C_2$ – aerodynamic coefficients of wind pressure on the canopy. In the calculations for the basic schemes without obstacles the following values were used: the values of the angle of the canopy ($\alpha$) of 10, 20 and 30 degrees, the angle of the slope ($\beta$) of 0, 15, 30, 45 degrees, length of the horizontal projection of the slope ($h$) – h, 10h and 20h. Since the length values are taken not in absolute values, but relative to the height of the stand with a canopy, the results of the calculations will be applicable for stands with canopies of different sizes.

![Figure 1. Calculation model of the stand with a canopy.](image)

2.1.1. Basic schemes. The calculations were carried out according to four main schemes, which differed in the direction of the wind (runs in front or behind the stand), as well as the presence or absence of a "wall" between the main part of the stand and the canopy. Scheme 1 – the wind runs in front of the stand, the wall is missing. Scheme 2 – wind runs in front of the stand, the wall is present. Scheme 3 – wind runs behind the stand, the wall is missing. Scheme 4 – wind runs behind the stand, the wall is present.

2.1.2. The distribution of wind pressure. As a result of the calculation in the ANSYS Fluent software package, it is possible to obtain a calculation model with a realistic curvilinear distribution of wind pressure on the canopy. For ease of use in further calculations, the distribution of wind pressure is transformed to a rectangular trapezoid from the condition of equality of the module and the arm of the reduced force. $S_{gen}$ or $C_f$ – the average value of the distributed load factor in this case will be equal for both the calculated and transformed models.
2.2. Selection of comparative values

Review of literature showed that in SP "Loads and impacts" there are diagrams of buildings, open on one side and ones with fully open canopies. At the same time Eurocode "Wind effects" produces examination of stand-alone canopies with barriers, where $\phi$ is the barrier degree. To compare the results of numerical modeling with the normative literature, the average pieces of data, most approximate to our models, from each of the sources were taken.

2.3. Results of calculation

The results illustrating figures were constructed as follows. The first line corresponds to the change of the canopy angle parameter ($\alpha$), the second – to the change of the slope angle parameter ($\beta$), and the third – to the change of the length parameter of the horizontal projection of the slope ($h$). The number in the upper left corner of each segment of the figure is equal to the corresponding value of the parameter to be changed. The numbers on the edges of the diagrams correspond to the boundary values of the aerodynamic coefficients for the corresponding schemes. According to the results, as the angle $\alpha$ increases, the values of $C_1$ and $C_2$ begin to increase, while the angle $\beta$ increases, the values of $C_1$ and $C_2$ decrease (figure 2). For the design scheme 4, due to the location of the wind flow behind the podium and the presence of the wall, the $C_f$ values are extremely small, compared to the other three schemes (figure 3).

![Figure 2. Results of the design scheme 1.](image)

![Figure 3. Results of the design scheme 4.](image)
2.4. Comparison of results with normative documents

For each of the considered cases, the average $C_f$ values were calculated, graphs were plotted to allow a visual comparison with the normative documents. For the change of the angle $\alpha$ values of SP "Loads and impacts" almost coincide with the calculated ones. At zero slope angle $\beta$, the calculated value is in absolute value greater than the value in SP "Loads and impacts" (figure 4). This is the only such case in all the calculations. For scheme 2, the calculated values are always less than SP "Loads and impacts" and Eurocode "Wind effects". In the case of scheme 3, in some cases, the calculated values of aerodynamic coefficients are greater than in Eurocode "Wind effects" (figure 5). For the calculation scheme 4, as for the calculation scheme 2, the calculated values are always less than the values from the normative documents.

![Figure 4](image.png)

**Figure 4.** Graphs comparing the results of the calculation scheme 1 for changing the angle of inclination of the canopy (left) and the angle of slope (right).

![Figure 5](image.png)

**Figure 5.** Graphs comparing the results of the calculation scheme 3 for changing the angle of inclination of the canopy (left), the angle of slope (center) and the length of the horizontal projection of the slope (right).

3. Numerical experiment with a calculation model with an obstacle

3.1. Formation of the calculation model

A rectangle with variable values of the sides was chosen as a computational model of a conditional obstacle in the wind path. The second part of the calculation model was again a rostrum with a canopy, similar to the temporary structure at the competitions in "high diving" XVI world Championships in water sports in 2015 (figure 6). Variable parameters in the calculation model of the podium with the
presence of obstacles are also three – the height of the obstacle (H), the width of the obstacle (b), the distance between the obstacle and the stand (d). The basic value of the parameters – 1h, that is equal to the height of the stand with a canopy. In the calculations for the scheme with an obstacle the values were the following ones: the obstacle height (H) – 0.5 h, h, 2h, the obstacle width (b) – h, 2h, 5h, the distance between the obstacle and the stand (d) – h, 2h, 5h, 10h. Since the values of the dimensions of the obstacle and the distance between the obstacle and the stand are taken not in absolute terms, but relative to the height of the stand with a canopy, the results of the calculations will be applicable for stands with canopies of different sizes.

![Figure 6. Calculation model of the stand with an obstacle.](image)

3.1.1. *The distribution of wind pressure.* As for the previous numerical experiment, for ease of use in further calculations, the distribution of wind pressure is transformed to a rectangular trapezoid from the condition of equality of the module and the arm of the reduced force. $C_{gen}$ or $C_f$ – the average value of the distributed load factor in this case will be equal for the calculated and transformed models.

3.2. *Results of calculation*

The figure illustrating the results was constructed as follows. The first line corresponds to the change in the height of the obstacle (H), the second to the change in the width of the obstacle (b), and the third to the change in the distance between the obstacle and the podium (d). The number in the upper left corner of each segment of the figure is equal to the corresponding value of the parameter to be changed. The numbers on the edges of the plots correspond to the boundary values of the aerodynamic coefficients for the corresponding schemes. It can be seen that with increasing of the angle $\alpha$ the values of $C_1$ and $C_2$ start to increase too, and with the increase of the angle $\beta$ the values of $C_1$ and $C_2$ decrease. For the design scheme 4, due to the location of the wind flow behind the stand and the presence of the wall, the $C_f$ values are extremely small, compared to the other three schemes. The analysis of the results showed that the calculation scheme with the presence of an obstacle is characterized by a sharp decrease in $C_f$ – in comparison with earlier calculations without obstacles, and with the normative documents SP "Loads and impacts" and Eurocode "Wind effects" (figure 7).
4. Conclusion
A numerical study of the distribution of wind pressure on the stand with a canopy was done depending on: the angle of inclination of the canopy, the angle of inclination and the length of the horizontal projection of the slope. The results were compared with the values specified in the normative documents SP "Loads and impacts" and Eurocode "Wind effects". Changes in the terrain and the angle of the canopy affect the distribution of wind pressure, but the results are less than the values specified in the SP "Loads and impacts". It is established that with wind influence behind a stand with a canopy the loading is more when the tribune is open whereas with wind influence in front of a stand with a canopy the loading in some cases can be more when the stand is closed with wall. This is important to consider when installing and dismantling a temporary structure. A numerical study of the influence of obstacles on the distribution of wind pressure on the stand with a canopy was done, depending namely on its height, width and distance between the stand with a canopy and an obstacle. It is established that the presence of an obstacle leads to a sharp decrease in aerodynamic coefficients in comparison with both normative documents and calculations without obstacles.

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