Investigation of the influence of wind flow over the grandstand with a canopy

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Abstract. The article deals with the investigation of the influence of wind flow over the grandstand with a canopy. Temporary stands with canopies are widely used for various entertainment events. The wind load is dominant for the structures of the stands with the canopy. The SP "Loads and impacts" presents the aerodynamic coefficients only for an open canopy. In the case of stands the nature of wind flow around the structure changes and the wind effect on the canopy structure changes accordingly. In this regard, it is necessary to clarify the wind load on structures of this type. The prototype object is a grandstand with a canopy. The study is performed in the ANSYS CFX software package using variations in wind flow speeds, canopy tilt, and the presence or absence of walls and other obstacles. During the study it was found that the grandstand and obstacles affect the wind pressure on the canopy. Also, quantitative comparison and analysis of the results show that peak pressures have a maximum deviation of the values of aerodynamic coefficients of 43 %.

Keywords: Structures, Wind load, Particle Image Velocimetry, Computational Fluid Dynamics, Grandstand, Wind-induced pressure.

1 Introduction

Temporary stands with canopies are widely used for various entertainment events [1-2]. Since the wind for such buildings and structures is one of the main loads, the study of this theme is of interest [3-5]. In most cases permeable elements are used as the part of the grandstand with a canopy [6-7]. Both Russian and foreign regulatory documents for the study of wind impact are usually proposed to use the results of tests of large-scale models in specialized wind tunnels, allowing to reproduce the atmospheric boundary layer [8-11]. Unfortunately, such tests are very time-consuming, and for the most large-scale models they have to be performed in special laboratories [12-15].

In modern construction it is increasingly necessary to design buildings and structures of complex geometric configuration with more advanced enclosing materials that require more accurate determination of aerodynamic coefficients for further application of wind loading [16-17]. Recently, computational hydro-gas dynamics (CFD) has been rapidly developing, and technologies for calculating wind impacts on buildings and structures are being improved with the steadily increasing power of computers. The applied methods of mathematical modeling and computational experiment, as well as software tools that implement it, provide acceptable practical accuracy, and significantly reduce the time resources for performing calculations of wind impacts (the average component of loads on load-bearing structures, peak pressures on facade structures) on buildings [18-23]. In computational hydro-gas dynamics, the most popular programs are the ones of the ANSYS complex (in particular, FLUENT and CFX parts of this complex), largely due to the ability to simulate accurately wind impacts and the visibility of the numerical simulation process.

ANSYS CFX is a powerful tool for optimizing the development process and technological training in the field of computational fluid dynamics. The results obtained using the developed methodology can be used for verification of similar calculation technologies and specialized software systems, as

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well as for “tuning” newly commissioned wind tunnels, to improve efficiency, reduce test times and optimize sensor placement.

2 Materials and methods

2.1 Object of research

The study of air flow influence is carried out on the example of suspended structures and temporary structures of stands, due to the predominance of wind forces on these structures.

The object (see Figure 1) is a temporary structure installed specifically for the "High diving" competition in the framework of the XVI world aquatics Championships 2015. The structure of the stands with canopies was located on the bank of the Kazanka River to accommodate spectators.

A cross section of the supporting frame of the stands is shown with a distance between the supporting columns of the stands of 33.184 m, the tribune part is 20 m wide and 15 m high along the length of the stands, the supporting structures and the back wall were made of monotonous rod elements of scaffolding. The supporting frame along the inner perimeter of the "horseshoe" was made in the form of three frames. The columns of both frames were made latticed in the form of separate sections of different lengths with simple junctions. All sections were made of pipes of various cross-sections according to GOST 8732-78 made of steel 09G2S and ST20.

2.2 Meshing

The calculation area is divided into final elements in the meshing block of the ANSYS PC (see Figure 2). The calculated area is divided into tetrahedral finite elements with edge sizes up to 500 mm. The function of grinding the calculated grid in areas with a large pressure gradient is applied. The number of finite elements in different calculation models reaches 3 million.
3 Results and discussion
At the initial stage, the study and calculation of free-standing canopies without solid-wall vertical enclosing structures is carried out. The results of experimental studies of distributed aerodynamic characteristics of canopy models are presented.

3.1 Investigation of the influence of wind speed on the canopy
The numerical experiment was performed in the Ansys PC at wind flow speeds of 10 m/s, 20 m/s, and 40 m/s. For visualization of the results obtained, (see Figure 3) you can see the flow pattern of the wind flow, the flow rate and the distributed pressure on the canopy surface for one of the speeds for the canopy at an angle of 10°.

Figure 3. Wind flow pattern, flow velocity and distributed pressure over the canopy surface at 10 m/s for a canopy at an angle of 10°.

The results of modeling are presented as an epure of the aerodynamic coefficients $c_e$ on the canopy at wind flow speeds of 10 m/s, 20 m/s and 40 m/s (see Figure 4). We compare the same aerodynamic coefficients given for the design in the SP 20.13330.2011 "Loads and impacts" appendix D. 1. 10 "Canopies" (see Figure 5).

Figure 4. Aerodynamic coefficients $c_e$ for a canopy with a slope of 10° according to the SP "Loads and impacts"

Figure 5. Aerodynamic coefficients $c_e$ for a canopy with a slope of 10° according to the SP "Loads and impacts"
The SP document "Loads and impacts" currently being the normative document on the territory of the Russian Federation does not provide any guidance for the application of appropriate aerodynamic coefficients at different wind speeds.

However, checking the work of one and the same canopy located at an angle of 10° to the horizon we get the result that when the wind flow speed changes, the nature of flow of the wind flow is changes as well, the acceleration zone and deceleration change locations and may even disappear, and new places of disruption and interruption that leads to resistance of fluent, the flow and transfer of the wind flow mass and the pressure. In connection with all of the above, the pressure distribution over the top of the canopy changes its qualitative and quantitative character. This is not very similar to the results that were taken for the SP.

3.2 Investigation of the wind flow influence on the canopy at different angles of structure inclination

Based on the simulation results, pressure distribution epures are created in the form of aerodynamic coefficients $CE$ for canopies with a canopy tilt of 10°, 20° and 30° (see Figure 6).

![Figure 6. Aerodynamic coefficients $c_e$ for a canopy with a slope of 10°, 20° and 30° at a wind speed of 20 m/s.](image)

Below, to compare the results obtained, are the aerodynamic coefficients for canopies according to SP 20.13330.2011 "Loads and impacts" Appendix D. 1. 10 "Canopies" (see Figure 7).

![Figure 7. Aerodynamic coefficients $c_e$ for a canopy with slopes of 10°, 20°, 30° according to the SP "Loads and impacts".](image)

Numerical simulation allowed us to compare the aerodynamic coefficients given in the SP "Loads and impacts" with the results obtained in ANSYS CFX. The character of wind flow is almost similar to the data taken from the SP "Loads and impacts", but still not identical with it. Quantitative comparison and analysis of the results show that peak pressures have a maximum deviation of 43 % of the aerodynamic coefficients. Also, the integrated pressure on the canopy surface in the case of numerical simulations and data from the SP "Loads and impacts" show almost identical results and have a maximum discrepancy of up to 30 %. According to the distribution of aerodynamic pressure on the surface of the canopy, we can say that according to the results of numerical modeling, the canopy has more "moment", and will perceive more twisting forces than the canopy taken from the SP.
3.3 Results of numerical simulation of the work of canopies with stands under wind influence

The study of the influence of air flow is carried out on the example of suspended structures and temporary structures of the grandstands. The calculation and design of the canopy in such conditions are not regulated by the SP "Loads and impacts", that’s why there is an interest in the study of this design. At the first stage of the study of the canopy with stands, the structures of the stands and the canopy with an open back wall between these structures were adopted. At the second stage, the structures of the stands and the canopy with a closed back wall were adopted, respectively.

The first stage of the study. Numerical experiments of wind effects on the design of stand with canopy at angles of 10°, 20° and 30° to horizon in the "frontal" (the angle of the canopy is positive) and backward (the angle of the canopy is negative) location in relation to flood loading of a solid wind flow with a wind speed of 20 m/s. Results of numerical investigation of wind influence on the stands with a canopy, the open space between the designs of the stands and canopy. Pressure distribution epures are created in the form of aerodynamic coefficients on the surface of canopies when the canopy is tilted 10°, 20° and 30° (see Figure 8).

![Figure 8. Aerodynamic coefficients $c_e$ for a canopy with a slope of 10°, 20° and 30° at a wind speed of 20 m/s](image)

Numerical modeling has shown that in the presence of stands, there is an increase in wind load on the structure of the canopy, where the maximum pressure differs compared to the SP: when the canopy is tilted 10° – by 51.2%; at 20° – 72.7%; at 30° – by 156.1%. After integrating the pressure on the surface of the canopy and a similar comparison with the SP data, the differences in aerodynamic coefficients are slightly leveled, but still remain with large exceedances of norms.

Pressure distribution plots are constructed in the form of aerodynamic coefficients on the surface of canopies when the canopy is tilted -10°, -20° and -30° (see Figure 9).

![Figure 9. Aerodynamic coefficients $c_e$ for a canopy with a slope of -10°, -20° and -30° at a wind speed of 20 m/s](image)

The second stage of the study. Numerical experiments of wind effects on the design of stand with canopy at angles of 10°, 20° and 30° to the horizon when the "frontal" (the angle of the canopy is positive) and backward (the angle of the canopy is negative) location in relation to flood loading of a solid wind flow with a wind speed of 20 m/s are carried out. The gap between the platform and the canopy is closed by a wall, impervious to the wind. Results of a numerical study of the wind impact on the stands with a canopy, between the structures of the stands and the canopy there is a solid back wall. Pressure distribution plots are created in the form of aerodynamic coefficients on the surface of canopies when the canopy is tilted 10°, 20° and 30° (see Figure 10).
Figure 10. Aerodynamic coefficients $c_e$ for a canopy with a slope of 10°, 20° and 30° at a wind speed of 20 m/s

Numerical simulations have shown that in the presence of stands and the back wall, there is an increase in wind load on the structure of the canopy, where the maximum pressure differs compared to the SP: when the canopy is tilted 10° – 2.2 times; at 20° – 2.6 times; at 30° – 1.9 times. Excess pressure from the standard is excessively high.

Results of a numerical study of the wind impact on the stands with a canopy, between the structures of the stands and the canopy there is a solid back wall. Pressure distribution plots are constructed in the form of aerodynamic coefficients on the surface of canopies when the canopy is tilted 10°, 20° and 30° (see Figure 11).

Figure 11. Aerodynamic coefficients $c_e$ for a canopy with a slope of -10°, -20° and -30° at a wind speed of 20 m/s.

Numerical modeling has shown that in the presence of stands and the back wall, there is a decrease in wind load on the structure of the canopy, since the main flow of air mass takes over the structure of the back wall and the stands. Pressure on the surface of the canopy, compared with SP, with the canopy inclination of 10° is almost identical with the normative distribution with only a small excess at the end of the departure canopy of the flow present disruption when tilted 20° pressure on the canopy from the wind flow is minimal, in connection with the change in the "true" slope of the canopy relative to the wind flow, and is only 35 % of the normative values of the pressure at 30° the nature of the flow of the wind flow is not similar to the inherent nature without stand. Due to the presence of a strong suction factor the pressure is directed in the opposite direction.

3.4 Study of the terrain impact on the canopy with a grandstand

A numerical simulation of the wind impact on the structure of the canopy with stand and an angle of inclination of 10°, with the adjacent terrain in the form of a developed inclined ground is presented. The slope angle of the terrain is 10°, located on the windward side of the structure of the canopy and stands.

Results of a numerical study of the wind impact on the stands with a canopy, taking into account the adjacent terrain are the following. Pressure distribution plots are constructed in the form of aerodynamic coefficients on the surface of canopies at a tilt of the canopy of 10° and a wind flow speed of 20 m/s.

Figure 12. Aerodynamic coefficients $c_e$ for a canopy with a slope of 10° at a wind speed of 20 m/s
Conclusion

Based on the above results obtained in the course of numerical research, we can draw the following conclusions:

1. The ANSYS CFX PC is used for solving the set tasks of hydro gas dynamics.
2. Numerical tests of free-standing canopies, as well as canopies with stands under them, were performed in the ANSYS CFX PC.
3. The results of numerical simulation are obtained in the form of distributed pressures on the surfaces of structures of the canopy and stands, “streamlines” of the wind flow, which further allows us to determine the nature of wind flow and aerodynamic coefficients on the surface of structures.
4. After investigating the operation of a free-standing canopy at different speeds of the wind flow, located at an angle of 10° to the horizon, we get the pressure distribution over the surface of the canopy, which changes its qualitative and quantitative character. That is not taken into account according to data from the SP.
5. Having studied the operation of a free-standing canopy at different angles of inclination, it was determined that the flow pattern of the wind flow is almost similar to the data from the SP. Quantitative comparison and analysis of the results show that peak pressures have a maximum deviation of 43 % of the aerodynamic coefficients.
6. Numerical modeling of the canopy with stands determined that the structure of the stands interacts with the incoming wind flow and changes the flow pattern of the structure, the nature of the pressure distribution and aerodynamic coefficients do not coincide when compared with the data of the joint venture. The presence of stands significantly affects the wind impact. The pressure on the canopy surface increases. In this regard, when designing structures of this type, it is necessary to take into account the presence of the stand part and take aerodynamic coefficients based on the results of purging models of structures in the aerodynamic tube, or the results of numerical studies.
7. When purging the structure of the canopy with stand with an open back wall, the pressure on the canopy is less than in the version with a closed wall. This indicates that the structures are less loaded if there is a free passage of wind flow between the canopy and the stands. However, when the wall is open, the wind flow passes through the stands at a high speed, which violates the condition for a comfortable stay of the audience.
8. When purging the structure of the canopy with stands with the reverse direction of the wind flow, it turns out that the canopy is loaded less and the suction pressure prevails more.
9. The terrain of the surrounding area affects the structure of the canopy, changing the direction of the incoming flow. In this regard, it should be taken into account that the actual slope of the canopy in relation to the wind flow changes, with an increase or decrease, depending on the given terrain.

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