Experimental study of the aerodynamic effects on the monument

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Abstract. Chapter 1 of this article discusses the need for aerodynamic research for sculptural structures, and also presents the purpose of these studies. Chapter 2 provides a description of the methods used to study the effects of wind on construction projects carried out on the basis of the National Research Moscow State University of Civil Engineering. Chapter 3 presents a direct study of the wind impact on the monument, as well as the results of tests and numerical simulations. Chapter 4 contains conclusions that were formulated on the basis of the work done.

1. Introduction

Recent adjustments to regulatory documents in force in the Russian Federation have significantly tightened the requirements for determining the wind load on building structures with an increased level of responsibility [1, 2]. If earlier the aerodynamic coefficients necessary for calculating the wind load could be obtained from analytical recommendations issued by an authorized specialized organization, now two methods for their determination are clearly regulated: experimental modeling in wind tunnels and numerical modeling in licensed verified software systems. Moreover, a number of requirements are imposed on experimental modeling, such as the use of certified specialized wind tunnels of the architectural and construction type, mandatory modeling of the surface atmospheric boundary layer, etc. [1]. At the same time, there are no requirements for numerical modeling, it only talks about the need to use “adequate” turbulence models, while any criteria for “adequacy” are not considered. In accordance with the foregoing, the use of pure numerical modeling to determine wind loads on the most unique and critical objects does not allow us to unequivocally confirm the reliability and adequacy of the results, and it is recommended that comprehensive computational and experimental studies be performed [3, 4, 5].

One of the most unique, responsible and socially significant types of building structures are architectural monuments and sculptures. Each of these construction sites is unique, usually geometrically complex, and therefore requires increased attention when assigning loads. Questions regarding the wind effect on sculptures have been studied in our country since the seventies of the last century. For example, TsAGI experts conducted research in the wind tunnel of such large-scale monuments as the Mother Motherland monument on Mamaev Kurgan, the Victory monument on Poklonnaya Hill, the Worker and Collective Farm Girl monument, etc [6-11]. It is important to emphasize that, thanks to the results of the research, the ability to avoid the negative impact of wind on structures by identifying problem areas and upgrading them.
Thus, it is possible to formulate the objectives of studies of the wind effect on sculptural structures: to ensure the reliability of the construction of monuments and the safety of the adjacent territory, it is necessary to determine the average and peak values of the aerodynamic coefficients, which can be obtained by performing design and experimental studies. Knowing these parameters allows you to make adjustments to the structure, strengthening or, conversely, lightening its parts.

2. Research methods
Currently, research in the field of aerodynamics of building structures is being carried out by specialists from the Educational Research and Production Laboratory for Aerodynamic and Aero-Acoustic Testing of Building Structures of the National Research Moscow State University of Civil Engineering (UNPL AAAISK NRU MGSU). On the basis of the UAPL AAAISK NRU MGSU, calculations are carried out in the ANSYS CFX software package. Aerodynamic tests are carried out on the basis of a certified Unique scientific facility - the Large Research Gradient Wind Tunnel (BIGAT NIU MGSU) using a high-precision complex of measuring equipment. The characteristics of the installation provide research on large models at a modern level.

Specialists of the NRU MGSU developed a methodology for experimental studies of wind effects on construction sites. This technique is fundamental to the study of various kinds of building structures [2, 12].

Based on the requirements of the theory of similarity, the technique is the following algorithm:
1. Development of a three-dimensional geometric model of the object;
2. Analysis of weather and topographic data in the area of development and the appointment of wind characteristics;
3. Designing and creating a model on a reduced scale;
4. Tests in the wind tunnel of a scale model of an object. Determination of average and peak values of aerodynamic pressure coefficients $C_p$ at control points on the surface of the object under study.
5. Creating a computer model based on the constructed geometry;
6. A series of calculations on a representative set of wind directions for the characteristics of the overlying wind assigned by the JV “Loads and Impacts” for the relevant weather and topographic data for the construction area.

When performing research, the following attorneys and calibrated measuring instruments are used:
7. The pressure pitot tube is designed to measure the volumetric flow rate of liquid and gas at one point in the cross section of the channel with an equivalent diameter of at least 300 mm.
8. Digital differential pressure gauge DMC-01M with data processing.
9. Pressure sensors - MPXV7002DP.

3. Research progress and results
3.1 Property Description
This article discusses the implementation of a study of the wind effect on a monument planned in the Murmansk region.

The designed object is an unheated mast structure with half-timbered structures attached to it, to which, in turn, bronze sheets are attached.

| Name                        | Value (m) |
|-----------------------------|-----------|
| total height of the monument| 28        |
| figure height               | 23        |
| figure width                | 18        |
| figure depth                | 8         |
| pedestal height             | 5         |
| pedestal width              | 10        |
| pedestal depth              | 14        |
3.2 Analysis of weather and topographic data in the area of development and the appointment of wind characteristics

The projected construction site is located in the Murmansk region. The initial data on wind speeds, directions, and frequencies were transmitted by the nearest hydrometeorological station. Working with the materials obtained made it possible to compose a wind rose, and also to determine the maximum wind speed of 10-minute averaging - 34 m/s and the maximum gust of wind - 40 m/s.

![Figure 2. Rose of Wind.](image)

Based on the available data, the terrain type ("A") was determined, and the profile of the change in the wind flow velocity in height was determined:

\[ U_m(Z) = 34.5 \cdot \left( \frac{K_m \cdot Z}{10} \right)^{0.15} \]

3.3 Development of a three-dimensional geometric model of an object; design and creation of a model on a reduced scale

For experimental studies, a model of the object under study was developed and manufactured. Considering the dimensions of the working part of the wind tunnel, the maximum scale scale of 1:28 was chosen from the conditions of blocking the flow. The investigated model was installed on an automated rotary table located in the working area of the wind tunnel.
Figure 3. Model of the studied object.

The model is made using 3D printing technology and has pressure collection points on the surface. From each hole, pressure is transmitted through copper and then through silicone tubes to differential pressure sensors.

3.4. Drainage test results
During a series of physical tests on a reduced model of the monument, average and peak values of the Cp coefficient were obtained at control points on the surface of the model. The results are shown in Fig. 4.
3.5. Results of numerical simulation

A three-dimensional computer model of the object under study is surrounded by a turbulent flow of an incompressible air medium having an average velocity distribution over the height of the computational domain in accordance with the experimental velocity profile and turbulent ripple intensity, defined as the ratio of the rms velocity pulsation to the average flow velocity at a given point.

In the course of the work, an unsteady flow pattern and the corresponding distribution of the dimensionless pressure coefficient $C_p$ on the facades along the perimeter of the horizontal section of the object and along its height were calculated. The results are shown in Fig. 5.

Figure 4. Graph of the distribution of the aerodynamic pressure coefficient for all studied directions of air flow for one point.

Figure 5. Distribution of the average aerodynamic pressure coefficient over the facades of the object under study for the $0^\circ$ direction.

4. Conclusions

Calculation of the wind load on large-scale monuments and sculptures can be carried out only on the basis of the results of computational and experimental modeling. This is due to the unique and inimitable form of these objects, with the requirements set forth in the current regulatory documents, as well as with the cultural value of these structures.
The construction of the monument is a metal frame, sheathed with elements of bronze. At the same time, the wind load is one of the main parameters necessary for calculating strength and stability. The results will indicate to designers and constructors the most vulnerable elements and structural units in terms of wind load - in this case, these elements are a sword and a chapel, and it is recommended to pay special attention to the cloak of the figure.

Competent design and experimental studies, in accordance with the methods developed on the basis of NRU MGSU, in combination with experience in the design of unique structures, will ensure the safe operation of the monument throughout the entire calculation period when exposed to the maximum wind speeds characteristic of the construction area.

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