Study of Wind Effects on Unique Buildings

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Abstract. The article deals with a numerical simulation of wind effects on the building of the Church of the Intercession of the Holy Virgin in the village Bulzi of the Chelyabinsk region. We presented a calculation algorithm and obtained pressure fields, velocity fields and the fields of kinetic energy of a wind stream, as well as streamlines. Computational fluid dynamic (CFD) evolved three decades ago at the interfaces of calculus mathematics and theoretical hydromechanics and has become a separate branch of science the subject of which is a numerical simulation of different fluid and gas flows as well as the solution of arising problems with the help of methods that involve computer systems.

This scientific field which is of a great practical value is intensively developing. The increase in CFD-calculation is caused by the improvement of computer technologies, creation of multipurpose easy-to-use CFD- packagers that are available to a wide group of researchers and cope with various tasks. Such programs are not only competitive in comparison with physical experiments but sometimes they provide the only opportunity to answer the research questions. The following advantages of computer simulation can be pointed out:

a) Reduction in time spent on design and development of a model in comparison with a real experiment (variation of boundary conditions).
b) Numerical experiment allows for the simulation of conditions that are not reproducible with environmental tests (use of ideal gas as environment).
c) Use of computational gas dynamics methods provides a researcher with a complete and ample information that is necessary to fully describe different processes of the experiment.
d) Economic efficiency of computer calculations is more attractive than an experiment.
e) Possibility to modify a computational model which ensures efficient timing (change of the sizes of wall layer cells in accordance with the chosen turbulence model).

The factor of wind effects becomes significant for buildings characterized by complex architectural forms and original design solutions. The safety case in design and use of such buildings is constrained by the current regulatory guidelines that lack recommendations for setting aerodynamic coefficients for buildings of complex forms and take no account of the influence of interference, terrain and changes in the spectrum of the incident flow. [1]

The information obtained by numerical simulation of the effects on buildings and structures helps to improve the quality and productivity of an engineer’s work, and also allows analyzing complex constructions that cannot be manually calculated. The idea to apply means of computer analysis is
accompanied by the task to make a competent and justified choice of numerical simulation tools and their parameters. [1-5]

In this article we expand on the computational procedure of evaluating wind effects that we used to investigate the bearing capacity of structural elements of particular objects of cultural heritage, that is, the Church of the Intercession of the Holy Virgin in the village of Bulzi, Chelyabinsk region (built in 1912) and the Church of the Nativity of Christ in the town of Yuryuzan, Chelyabinsk region (built in 1896). [6,7]

We propose to consider the application of the computational procedure by the example of calculating the wind effects on the Church of the Intercession of the Holy Virgin in the village of Bulzi. (Figure 1)

![Figure 1. Church of the Intercession of the Holy Virgin in the village of Bulzi.](image)

It is a brick one-dome temple with a rectangular apse. The building can be divided into 4 parts located on the longitudinal axis: a three-part altar; a temple topped with an octagonal drum; a rectangular refectory with aisles and a three-tier bell tower with service rooms attached on the north and south sides. [8,9]

When analyzing a building to calculate a wind load, we found that:
1 The building is characterized by an interpolation of complex forms, and it is not possible to collect its loads according to the building regulations “Loads and effects”. [10, 11, 12]
2 None of wind directions can be unequivocally characterized as the most dangerous.

Thus, we decided that it was rational to use the methods of numerical simulation to analyze wind loads on the building and set the following tasks:
- Develop a computing algorithm for the static part of the wind load.
- Validate the obtained results.

Algorithm for calculating wind effects on the building:
1. Preparation of the computational model. It includes:
   - Developing a geometric model that describes the computational domain (Figure 2). We determined the recommended sizes of the computational domain, they equal to at least 6-8 heights of the “main building” in all directions, but less space can be left in front of the
building (between the building and the point of inflow) than behind it (between the building and the point of outflow).

Figure 2. Three-dimensional model of the church: a) optimized for calculating wind effects; b) finite element model developed on the basis of a).

- Generating a grid model of air volume on the basis of the created geometry. To obtain the convergent solution, as well as to correctly simulate near-wall flows without using a supercomputer, the grid was finely meshed near the building walls. This procedure was implemented in the software package ANSYSICEMCFD as it allows obtaining the required quality of the grid model with simple tools and in reasonable time.
- Specifying boundary conditions and initial calculation conditions, choosing a physical calculation model (for example, a turbulence model, etc.) - preprocessing. It is noteworthy that the input flow rate was used as the input parameter that was determined using the Bernoulli formula and correction coefficients with respect to the pressure on the vertical wall according to the building regulations “Loads and effects” [11] and equaled 31.5 m/s. Openings with zero relative pressure are applied as output pressures. The condition of non-shear flow was imposed on the walls of the building, [5].

According to the procedure given in [1], the building is tested for 12 or more wind directions in the preliminary calculation, and then the most dangerous directions are calculated with greater accuracy in the steady state that allows obtaining time-averaged parameters or unsteady state calculation that allows a more accurate simulation of the entire process of origination and development of flows. In order to optimize the model, 8 directions of the wind flow were accepted, six of them were symmetrical because the building has the plane of symmetry. These factors allow reducing the required computational capability, without reducing the accuracy of calculations.

2. Start of the calculation task.
3. Revision and evaluation of calculation results – postprocessing. Usability of the proposed procedure consists in the possibility to obtain the complete information on the necessary parameters, such as the wind pressure on building walls, the rate of wind flow in any points and the aerodynamic coefficients.
4. Correction of the computational model (change of geometry, grid model or physical model) in case of unsatisfactory convergence of the solution. To improve the convergence, it is recommended to simplify the geometry, use a grid model of better quality and vary the parameters of the calculator. After that, calculations are repeated and changes are evaluated.

As indicated in point 1e of the presented algorithm, unsteady calculations have high accuracy and are justified in the case of construction projects, since a complex pattern of wind flow around buildings is characterized by an aerodynamically unsatisfactory construction shape (large relative
thickness of cross-sections, the sharp edges sharp, etc.), which leads to the detachment of the boundary layer, the formation of intense unsteady jet-vortex flows and recurrent vortex wakes.

Aerodynamic loads on building surfaces depend not only on the magnitude and direction of wind, but also on time. Shear and velocity pulsations of wind flow complicate the conditions, leading to additional unsteady effects especially on buildings of such a complex shape as a church.

The course of task solution comprises the following procedure: creation of a simplified volumetric model optimized for aerodynamic calculations. It is developed on the basis of a processed point cloud obtained by laser 3D scanning methods. Scanning was not the purpose of this work; therefore the materials of a 2013 diploma project were used to develop the model [6]. Then, it was imported into ANSYS. After that, a finite element grid model was created. The next step was to assign boundary conditions and turbulence models. Then, calculations were carried out and their results were analyzed (Figure 3).

When analyzing the results, the following parameters for the flow around the building can be found out: surface pressure, aerodynamic coefficients that can be used to calculate by standards, air stagnation zones, draughty areas, turbulence kinetic energy, wind current lines, loads on foundation and fields of wind velocities.

To carry out numerical simulation, software packages were selected:
- CAD system SolidWorks – to create and edit a geometric model.
- ANSYS Workbench-CFX package for numerical simulation of gas dynamics tasks was used to create a grid model, preprocess, solve and process the results.

Similar studies were conducted under the supervision of Professor V. Olenkov at the Department of Construction Mechanics of the South Ural State University; it is evidenced by published works of university staff members and students [4,6]. The present work, apart from the previously discussed issues, touched on the problems of obtaining a single algorithm, verifying the results obtained on the basis of the presented algorithm, and also the input data of wind effects in accordance with normative documents [10-12].

As the analysis of modern national and foreign documents has shown, the existing normative documents and guidelines fail to fully reflect the specifics of wind effects on unique buildings.

We developed a computational procedure of calculating standard parameters of wind effects and determining the aerodynamic coefficient for unique buildings on the basis of the numerical solution of steady and unsteady three-dimensional equations of hydrodynamics (Reynolds-averaged Navier-Stokes equations, RANS and DES turbulence models) that allow us to take into account such important factors as the direction of wind flows and the interference of parts of the building. [13-18].

To obtain the accurate value of the pulsating component of the wind load, it is recommended to perform the unsteady calculation using turbulence models DES or URANS. For further verification, we propose to carry out actual measurements of real wind effects. [5,7,9]

The modern concept of determining wind effects on the building under analysis was specified and provided with our developments: a) “preliminary” numerical simulation with determination of the most dangerous/typical wind directions; assessment of the need for testing in a wind tunnel; b) wind tunnel tests (if possible); c) refined multiparameter and multifactor numerical simulation including the comparison of characteristic parameters with test results.
Figure 3. Calculation results: a) wind current lines; b) field of wind velocities; c) field of pressures.

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