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ABOUT "LEGITIMIZATION" OF NUMERICAL MODELLING OF WIND IMPACTS ON BUILDINGS AND STRUCTURES IN DESIGN CODES

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Abstract: The distinctive paper is detoded to problem of "legitimization" of numerical modelling of wind loads and impacts on buildings and structures. General information about computational fluid dynamics (CFD) and its development prospects is presented. The main advantages and disadvantages of numerical simulation compared with tests in wind tunnels (wind tunnel tests) are considered. Besides, information about the second modification of corresponding Russian design codes (SP 20.13330.2016 "SNiP 2.01.07-85* Loads and effects") is provided. Prospects for the further development of numerical modelling and its applications for solution of problems of construction aerodynamics are given.

Keywords: numerical modelling, wind loads, wind impacts, wind tunnels, construction aerodynamics, computational fluid dynamics, design codes

О «ЛЕГИТИМИЗАЦИИ» В СТРОИТЕЛЬНЫХ НОРМАХ И ПРАВИЛАХ ЧИСЛЕННОГО МОДЕЛИРОВАНИЯ ВЕТРОВЫХ ВОЗДЕЙСТВИЙ НА ЗДАНИЯ И СООРУЖЕНИЯ

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Аннотация: Настоящая статья посвящена актуальным вопросам, связанным с «легитимизацией» численного моделирования ветровых нагрузок и воздействий. В работе приводятся некоторые общие сведения о развитии методов вычислительной аэродинамики и их приложений в строительной сфере. Рассмотрены основные преимущества и недостатки численного моделирования по сравнению с испытаниями в аэродинамических трубах. Кроме того, приведены сведения об изменении №2 свода правил (СП) 20.13330.2016 «СНиП 2.01.07-85* Нагрузки и воздействия». В заключение указаны перспективы дальнейшего развития численного моделирования для решения задач строительной аэродинамики.

Ключевые слова: численное моделирование, ветровые нагрузки, ветровые воздействия, аэродинамические трубы, строительная аэродинамика, вычислительная аэрогидродинамика, строительные нормы и правила

1. GENERAL INFORMATION

Analysis and design of unique buildings, structures and complexes is traditionally complicated, in particular, by the fact that the current design codes do not contain recommendations on the determination of values of aerodynamic coefficients for original in shape and large-sized construction objects (including majority of high-rise buildings) [1-8]. In addition to the substantially approximate nature of the corresponding engineering approaches, both Russian and a number of foreign design codes do not consider options for the location of such buildings and structures in buildings and the interference of buildings and structures. In other words, these approaches are suitable only for buildings and structures with a relatively simple shape, low and medium height, located in conditions of sparse development. For unique buildings, structures and complexes (especially located in conditions of relatively dense development) more accurate (refined, high-presicion) methods are needed. In such cases, in Russian and some foreign design codes it was proposed to use the results of tests of large-scale models in specialized wind tunnels, allowing reproducing the atmospheric boundary layer. At the same time, in accordance with numerous research works of Russian and foreign scientists published in recent years, it was noted that computational fluid dynamics (CFD) [1], which has been developing rapidly in recent decades, in the future can be considered as an effective alternative of tests in wind tunnels for solution of problems of determination of wind loads and impacts on buildings and structures, assessment of pedestrian comfort and analysis of air pollution. A certain confidence in such assessments was also given by the continuous rapid development of corresponding hardware and software.

Application of methods of computational aerodynamics methods (numerical modeling) allows researcher obtaining results with an accuracy equal to or greater than accuracy, provided by tests in wind tunnels, associated, as a rule, with the need to attract significant resources (including financial resources). Corresponding modern software is characterized by advanced user interface, powerful and convenient preprocessor and postprocessor, sophisticated tools for monitoring and analysis of results.

2. THE MAIN ADVANTAGES OF NUMERICAL SIMULATION IN COMPARISON WITH TESTS IN WIND TUNNELS

2.1. Automatic determination of computational parameters at specified subdomains of the computational domain.

As is known, when testing in a wind tunnel, it is necessary to place measuring equipment to determine the wind speed at a specific point. Application of methods of computational aerodynamics methods allows computing of velocity values within numerical modelling.

2.2. The relative simplicity of making changes to design solutions.

The software that implements the methods of computational aerodynamics allows efficient interaction with CAD applications; modifications of design solutions can be introduced as soon as possible. Obviously, within physical modelling, the same changes are associated with significantly larger time and labor costs, especially in situations when changes to design solutions are made after a considerable time and after the initial tests in wind tunnel or in conditions when the corresponding wind tunnel is busy in other projects.

2.3. Economic efficiency.

Application of method of computational aerodynamics is normally associated with significantly lower financial costs and time expenditures in comparison to conducting tests in wind tunnels.

2.4. Visual clarity of results.

Software that implements computational aerodynamics methods allows researcher simply and clearly visualize corresponding results. Photos of tests in wind tunnels, on the contrary, are not so informative.

2.5. Universality.
It is rather complicated to solve problems dealing with determination of the wind direction, the level of concentration of pollutants, radiation level, etc. by the tests in wind tunnels. Methods of computational aerodynamics are more flexible and therefore more convenient in this connection.

2.6. The disadvantages of wind tunnels.
As is known, testing in wind tunnels requires large-sized expensive equipment, which is produced by a relatively small number of multinational firms and foreign research and educational centers. Numerical modelling can be performed by a large number of firms, research and educational centers, which in many cases have deeper and more reliable values dealing with the meteorological situation in the construction area.

3. THE MAIN DISADVANTAGES OF NUMERICAL SIMULATION IN COMPARISON WITH TESTS IN WIND TUNNELS

3.1. Lack of standard approach status.
Numerical modelling is a relatively new, constantly improving approach to solving the problems of construction aerodynamics, which is currently used, first of all, by advanced scientific and educational centers equipped with sophisticated software.

3.2. Possible inaccuracy of the results.
According to the results of corresponding research works, it was found that the results of numerical modelling in some cases may be incorrect. However, problem areas of the application are quite well known, and the corresponding error of the results, as a rule, are small and uncritical, taking into account the hypotheses introduced on the safe side (it is quite typical for engineering approaches). In addition, multi-parameter verification analysis (accuracy assessments of numerical solutions in comparison with known solutions) and validation analysis (accuracy assessments of computer modelling in comparison with experimental data), including using the results of field measurements and / or wind tunnel tests.

3.3. High qualification requirements for research groups.
Numerous studies of recent years clearly show that the results of knowledge-based modelling carried out by different research groups can vary significantly, even if using the same software. Stages dealing with setting of initial data (in particular, defining parameters specifying the state of the atmosphere), boundary conditions, the choice of an approximation mesh and mathematical models (primarily turbulence models) are of paramount importance. In other words, the results of numerical modelling can be very sensitive with respect to some computational user-defined parameters of the corresponding software. In this regard, the task of development of appropriate methodological recommendations and descriptions of best practices for the application of computational aerodynamics methods in construction is particularly urgent. Besides, the practice of formal use of corresponding software (without deep knowledge of theoretical foundations of corresponding methods and algorithm, without any doubt about the correctness of the results obtained) is extremely dangerous.

3.4. Limitations on the complexity of objects of modelling.
The maximum dimension of the considering type of problems of numerical modelling depends on the productivity and available resources of the used hardware and software. A large wind tunnel is less limited in terms of size and complexity of models. Obviously, this drawback becomes less critical as the computer technology, universal and specialized software improve and develop.

3.5. Higher accuracy of results for less complex objects.

It should be noted that the accuracy of the results of tests in a wind tunnel does not depend on the complexity of the geometry of the considering object. High accuracy of results of numerical modelling, for complex objects requires significant time and computational costs. Moreover, for some approaches to modelling turbulence it is not at all currently achievable.

3.6. A significant amount of computational work associated with computing of pulsating component solutions.

The resulting distribution of the average components of wind loads can be used for a number of practical applications, including solution of problems of pedestrian comfort analysis and air pollution analysis (when the kinetic energy of turbulence is used to analyze wind gusts). The pulsating components of the loads are important for determining the most critical locations and times.

4. THE SECOND MODIFICATION OF CORRESPONDING RUSSIAN DESIGN CODES (SP 20.13330.2016 “SNIP 2.01.07-85 * LOADS AND EFFECTS”)

The second modification of corresponding Russian design codes (SP 20.13330.2016 “SNiP 2.01.07-85 * Loads and effects”) was approved by the order of the Ministry of Construction and Housing and Communal Services of the Russian Federation dated January 28, 2019 No. 49 / pr.

In accordance with the third paragraph of item 11.1.7 [8] of this document [9] we have the revised corresponding text version:

“For structures with increased level of responsibility, which are specified in [1, item 48.1, part 2] or in note 2, as well as in all cases not specified in B.1 (other shapes of structures, reasonable allowance for other directions of the wind flow or components of the total resistance of the body in other directions, the need to take into account the influence of nearby buildings and structures, terrain and similar cases), aerodynamic coefficients are specified in recommendations developed with allowance for item 4.7 and based on the results of

1) physical (experimental) modelling - tests in wind tunnels (appendices “G” and “I”);
2) mathematical (numerical) modelling of wind aerodynamics based on numerical schemes for solution of three-dimensional equations of motion of liquid and gas with adequate turbulence models implemented in modern advanced verified licensed software systems of computational fluid dynamics”.

It should be noted that the link [1] in the citation is the link [10] in this paper.

In accordance to [9], the last paragraph (before the note) of item 11.2 is formulated in the new edition:

“Aerodynamic coefficients and are computed on the basis of the results of model tests of structures in wind tunnels, numerical simulation or taking into account data published in the technical literature. For separate rectangular buildings in plan terms, the values of these coefficients are specified in B.1.17”.

These changes were the result of a corresponding initiative of the authors of the distinctive paper, due to the fact that recent years are associated with a fairly rapid development of computational aerohydrodynamics (computational fluid dynamics (CFD)), modification and refinement of computational technology and steadily increasing perfofmance of computers. Leading foreign research and design organizations have also increasingly begun to combine tests in wind tunnels and “numerical” experiments. In the future, the role of mathematical modelling, as experience in related fields (for example, aerospace engineering) and problems (structural mechanics) shows, will only increase.

5. PROSPECTS FOR THE FURTHER DEVELOPMENT OF NUMERICAL MODELLING FOR SOLUTION OF PROBLEMS OF CONSTRUCTION AERODYNAMICS

In accordance with the recommendations of Russian and foreign researchers, numerical modelling and tests in wind tunnels can be applied for solution of problems of construction aerodynamics. Besides, in the future, the role of numerical modelling, as shown by experience in related fields (for example, aerospace) and problems (structural mechanics)) will only increase. At the same time, high qualification of research team is a necessary condition for obtaining reliable results of numerical modelling.

It should be noted that currently researches in the field of analysis of errors in the results of numerical and physical modelling, sensitivity analysis of results, verification and validation are relevant.

It is necessary to continue the development and updating of design codes and methodological documents based on best practices in the application of methods of computational aerodynamics in the field of construction. It should be noted that such work has so far been done for steady RANS approaches to modelling turbulence based on Reynolds averaged unsteady Navier-Stokes equations, and to a much lesser extent for the large vortex modelling method (LES method). Corresponding research works will have highest priority in the future [11-49].

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