Analysis of domestic and foreign regulatory and scientific and technical documents in the field of wind influence on buildings and structures that are part of hazardous production facilities

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Abstract. During the work more than 50 domestic and foreign normative and scientific and technical documents in the field of wind influence on buildings and structures that are part of hazardous production facilities were analyzed. Based on the results of the analysis it was revealed that the current domestic and foreign regulatory and technical documents consider only individual primitives, which forms a complex geometric construction of the structure, but it doesn’t provide information on the buildings of a complex spatial structure. It is established that for structures with an increased level of responsibility aerodynamic coefficients should be assigned according to recommendations based on the results of model tests in wind tunnels. It is determined that the analytical calculation by the methods given in domestic documents as well as in foreign ones gives only estimated value of wind load (usually with a large margin). Existing test methods almost do not involve permeable building structures, which are common in hazardous production facilities. It is determined that the analysis of numerical simulation experience of permeable building structures is revealed high labor intensity of this process, increased requirements on computing power, a considerable duration of work, which does not allow speaking on its effectiveness in this case. Based on the analysis of normative documents and scientific and technical literature, the necessity to develop a methodology for improving an increased level of responsibility buildings and structures safety that are a part of industrial enterprise, based on experimental research in wind tunnels, was identified.

1. Introduction
Permeable metal structures are widely distributed in various construction sectors. They can be found everywhere, from temporary assembly facilities at construction sites, to super high-power transmission lines and oil rigs. One of the designing bases for such objects is the calculation for wind load, regardless of the structure type and shape. Despite the fact that the engineers around the world are studying the wind loads for a long time, this issue is still relevant, especially in the Russian Federation, including in the arctic zone. This is due to the active enterprises development in the chemical, oil and gas industry (Figure 1), whose facilities often refer structures with an increased level of responsibility.
2. Results of literature analysis
Analytical methods for calculating building’s objects and structures for wind loads for simple typical buildings are described in one of the main normative documents in force on the Russian Federation’s territory - SP [1]. Paragraph 11.1.7 states that «for an increased level of responsibility structures , as well as in all cases not provided for in Annex D1 of Annex D (other forms of structures, taking into account, with proper justification for other directions of the wind flow or components of the total body resistance in other directions, the need accounting effects of nearby buildings and structures, etc.), aerodynamic coefficients should be taken based on the results of blowing structure models in wind tunnels or on the recommendations developed by the specialized organizations». Appendix V to SP «Loads and impacts. Updated SNiP version 2.01.07-85*» in clause B.1.14 «Lattice structures» presents formulas for determining the flat lattice structures and spatial trusses aerodynamic coefficient.

In fact, the SP [1] regulates the wind loads calculation for typical low-rise buildings; for buildings with complex architectural forms, high-altitude buildings with complex geometry, increased level of responsibility structures [1] recommends the wind loads determination by scale models physical testing in a special type wind tunnels, the procedure test itself, the requirements for tests or references to relevant regulatory documents are missing.

In addition to the SP [1], in Russian Federation, the wind loads calculation on permeable objects is governed by the «Manual for the Calculation of Buildings and Structures for Wind Effects» [2] and «A Handbook for the Design of Stand-alone Piers and Overpasses for Process Pipelines (to SniP 2.09.03-85)» [3].

In the «Manual on the calculation of buildings and structures for the effect of wind» [2] it is said that in permeable structures at certain wind speeds there may be oscillations across the flow associated with the phenomenon of aerodynamic instability of such bodies. Guidance on the calculation and measures to reduce the vibrations of such structures are established on the basis of aerodynamic test data. In this document, there is more detailed analysis of permeable structure’s separate elements of the indicated aerodynamic coefficients, in collision with a joint venture [1]. There are also examples of the wind load calculation on permeable structures.

In the «Manual for the design of stand-alone supports and trestles for process pipelines (for SniP 2.09.03-85)» [3] contains provisions for the exclusively stand-alone structures design. The standard wind load is determined in accordance with the requirements of SNIp 2.01.07-85, based on the standard head speed, and is composed of loads on the construction structure and pipelines. The action of the wind load is taken into account only in the direction across the pipeline route. There are no requirements for aerodynamic testing.
On the European Union countries territory, the calculation for wind loads is made according to Eurocode 1 «Effects on structures. Part 1-4. General effects. Wind loads» (Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions) [4]. These standards were adopted on the basis of the European standard adopted by CEN on June 4, 2004. Direct references to use the experimental data to study wind loads on buildings and structures not included in the field of application are not available, but it is said that aerodynamic tests can be used for loads and forces determination, approved and / or certified numerical methods with appropriate natural wind structure modeling. Refer to national applications, there are no methods, only the main requirements for aerodynamic testing carrying out.

The current Japan regulatory document «Air Recommendations for Loads on buildings. Chapter 6. Wind Loads. Architecture Institute of Japan» [5], indicates the necessity of the building study in wind tunnels, in the presence of adjacent building structures, the height which is equivalent to the height of the object under study. For other objects, a methodology is given for the analytical calculation of the wind loads on permeable structures. In many paragraphs of this document, small lattice structures standing on the surface of the earth are equated with impenetrable objects. Appendix A.6.6 provides formulas for calculating the wind loads on the lattice structure individual sections, taking into account permeability and vibration.

Analyzing and comparing the well-known normative documents and applications from different countries of the world, we can conclude that due to a lack of experimental material, inaccuracies in the existing analytical calculation methods and the test method’s absence in wind tunnels, the descriptions of wind effects on permeable building structures vary. This indicates that such a phenomenon as the wind load, needs further study.

Existing wind load studies carried out by authors from different countries are presented below.

In Southwestern Jiaotong University (China), the influence of horizontal and diagonal lattice structure ties on its main supporting vertical elements was investigated [6]. Tests of individual sections of the LEP support (Figure 2, 3) in the wind tunnel and their analytical calculation were carried out.

![Figure 2. Power line support sketch and selected sections schemes](image)
Comparison of experimental results in a wind tunnel and analytical calculation according to the relevant specifications in existing norms and standards (the authors refer to ASCE 74. Guidelines for Electrical Transmission Line Structural Loading. American Society of Civil Engineers, American; 2010 [7] and BS 8100-1. Lattice towers and masts-Part 1: Code of practice for loading. British Standards Institution, London; 1986 [8]) shows that the four-porous permeable structure experimental results are far from the values stipulated in the standards for permeable structures with diagonal and horizontal links. The discrepancy between these norms and standards for such facilities is patient. The authors don’t think that it’s possible to analytically take into account the mutual influence of structural elements, they indicate the necessity for wind tunnel testing. In this paper, a study of individual structural elements is presented, based on the results which the authors estimate the entire lattice construction [6].

In the laboratory of aerodynamics of the University of Louisiana, various options were tested for installing impermeable shields on a primitive symmetrical stack (Figure 4). When operating a different type of floor with hot pipelines or other equipment, a case of fire is possible. For the safe maintenance of equipment and the personnel evacuation, in this type of building structures they often share the bulk of the bookcase and stair flights with a fire screen. Such screens are impermeable, thereby creating a huge resistance to the wind flow and have a significant effect on a whole design.

In this paper, tests of partially permeable structures, often encountered in the hazardous industrial facilities structures, are considered [9]. The tests were carried out both in a laminar and a turbulent flow.

Figure 3. Power transmission tower sections models

Figure 4. Experimental model: a - installing screens scheme; b - a photo of the model; c - design sketch
Figure 5. Wind effect comparison on the structure in different configurations

In the course of the researches, the screen configurations were defined (Figure 4a), resulting in greater wind loads on the structure (Figure 5), but as the authors of the study themselves say, these results are not sufficient for use by their designers, since in reality there are other variables, such as the sizes of impermeable elements ratio to the permeable structure dimensions, the change in the shape of the object with height, the availability of equipment on the floors, the influence of surrounding objects, etc.

On the Russian Federation territory, similar studies are conducted on the basis of the Aerodynamic Test Laboratory of the Moscow State University of Civil Engineering. The article «The research of winds on buildings and structures with increased level of responsibility» [10] considers the features of permeable structures testing in a specialized wind tunnel. The authors of the paper described the physical and numerical modeling of wind effects on a spatial permeable model of complex shape (Figure 6) [10].

Figure 6. Scaled model of a complex shape permeable structure
Wind effects numerical modeling existing methods of building structures are ineffective for lattice objects [11, 12]. A large number of permeable structure’s elements require a significant increase in the number of computational grid cells. This increases the required cluster power which performs the calculations, and increases the execution time. According to normative documents, the results of calculations in specialized software complexes are recommended to verify with the results of experimental studies.

3. Conclusion
It has been established that in the domestic research course and foreign normative, scientific and technical documents in the field of an increased wind impact on buildings and structures liability level, today there are no unambiguous, theoretically substantiated analytical, experimental or numerical methods for studying wind impact on permeable or partially permeable buildings and structures of this kind. Based on the analysis of normative documents and scientific and technical literature, the necessity to develop a methodology for improving an increased level of responsibility buildings and structures safety that are a part of industrial enterprise, based on experimental research in wind tunnels, was identified.

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