Aerodynamic Stability of Bridge Structures

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Abstract. Large-span bridges, which are flexible structures, are more susceptible to the wind influence. At the same time, it is necessary to take into account the effect of snow drift and automobile traffic on the stability of the superstructure. As the object of research a metal continuous beam bridge with two parallel independent span structures was chosen. The program of aerodynamic test at the wind-tunnel was given at the paper. The paper presents the test results for the most interesting angles of attack from the aerodynamic point of view. Based on the test results, it was established that it is impossible to speak unequivocally about the effect of snow deposits on the aerodynamic stability of the span. The presence of automobile traffic on the span under study excludes all possible phenomena of aerodynamic instability, for all the flow directions considered.

1. Introduction

At present, the design of bridges occupies one of the leading positions in the construction industry: unique structures are being built around the world with high speed, striking with technical solutions. It is important to emphasize that the infrastructure objects being built today surprise with the refinement of architectural thought, the scale and variety of the structures used, as well as the size of the overlapped spaces. A significant role in this issue is played by technological and scientific progress. It is thanks to the two jointly operating industries today that there are a number of opportunities that allow you to create unique objects from both aesthetic and technical points of view.

Designing large-span bridge structures is a multi-component task: when developing the documentation for such an object, it is necessary to foresee a number of factors of technogenic and natural origin. It should be noted that today special attention is paid to studying the effects of various natural influences, including the climate component. Large-scale bridge structures, which are flexible structures, are more susceptible to linear wind exposure. From the middle of the last century, a significant amount of occurrence of the phenomena of aerodynamic instability of bridge span structures was revealed. A large number of studies are devoted to this issue, both foreign [1-3] and domestic authors [4-8]. The methods of research data in various scientific centres are based on the same physical principles and laws. At the same time, there are some differences, one of which is the need to assess the impact of snow sediment and car traffic on the stability of the span.

2. Research method

The need for experimental studies of the aerodynamic stability of bridge structures is regulated at the legislative level both in the Russian Federation and abroad. The most significant examples of regulatory documents are:
1. At building code 35.13330.2011 “Bridges and pipes” it is indicated that hanging and cable-stayed [9], as well as steel beam bridges with spans of more than 100 m should be checked for aerodynamic stability and spatial rigidity. Also in this regulatory document it is noted that for structures with dynamic characteristics, studies should be conducted on models.

2. At Eurocode 1: Actions on structures. Part 1-4: General actions. (National Annex) [10] governed by the need for aerodynamic testing is regulated.

3. American Society of Civil Engineers. Minimum design loads for buildings and other structures. ANSI/ASCE 7-98 establishes the need for testing bridge structures in wind tunnels.

During the testing, an assessment is made of the stability of the structure and the possibility of the occurrence of aerodynamic instability phenomena (vortex resonance, galloping, buffering, flutter, divergence) in accordance with the requirements of paragraphs 5.48 and 6.24 of building code 35.13330.2011 “Bridges and Pipes”.

During the modelling the wind for large-span bridge structures, the main modelling criteria, that are taken into account as it follows.

• dynamic similarity between the model and the real object (the similarity of mass-inertial and frequency characteristics is observed);

• the similarity of the flow structure in a wind tunnel to real wind conditions on the construction site;

• As a rule, tests are conducted on sectional (cut-off) models of spans [], and only for some of the most unique and technically complex structures resort to full, dynamically similar models.

There are foreign regulatory documents, such as, for example, BD49 / 01 “Design rules for aerodynamic effects on bridge”, which set out in detail the requirements for the composition and conditions of aerodynamic testing of bridges (including the requirements for testing sectional models). Appendix C of the “Requirements for wind tunnel testing” to this document states that for sectional models it is necessary to accurately simulate the structure of the superstructure, roadway fences, and “possibly” road or train . About the need to simulate snow drifts on bridges, this document does not say a word.

Nevertheless, theoretically, snow drifts on barrier fences can lead to a significant change in the wind flow around the span and increase the area of active interaction between the bridge structure and the wind flow (figure 1), thereby changing the ratio B / H, where B is the width of the span , H is its height, which, as is well known, can significantly increase the likelihood of galloping [11].

![Figure 1. Snow drift on road bridge](image-url)
3. Object of study
A metal continuous beam bridge with two parallel independent span structures was chosen as the object of research, the length of the span under study is 150 m (figure 2).

The Eigen frequencies of the structure oscillations: frequency $F_1 = 0.6$ Hz for bending vibrations and $F_2 = 6.49$ Hz for torsional vibrations and the specified value of the logarithmic damping factor $\delta = 0.02$.

![Figure 2. Object of study](image)

4. Research program
During the research the following tasks were solved:

- experimental studies of span structures in the initial configuration;
- experimental studies of aerodynamic stability of spans with regard to snow deposits;
- experimental studies of aerodynamic stability of spans with regard to automobile traffic.

The unique scientific installation “Big Research Gradient Wind Tunnel” (BGWT) is used as an experimental installation for conducting aerodynamic experimental studies (The registration number of the BGWT is on the portal “Scientific and technological infrastructure of the Russian Federation. Centers for the collective use of scientific equipment and unique scientific installations”: 585332; Registration date: 04.05.2018).

BGWT MGSU is the first in the Russian Federation certified (Certificate No. 10/101/1171 dated August 15, 2018 issued by the State Scientific Metrological Institute "All-Russian Scientific Research Institute of Physico-Technical and Radio Engineering Measurements") designed for complex aerodynamic testing of building structures (high-rise and unique buildings and structures, bridge structures, objects of increased level of responsibility, etc.), in tons Included in gradient and turbulent flows.

The model of span structures of the bridge in scale of 1:70 was made. The deviation of the mass measured in the wind tunnel from the calculated one was 0.4%, which, together with the geometric similarity, suggests that the mass distribution corresponds to the natural object.

In the process of additional research, the model was installed on a specialized suspended spring stand. The tests were carried out for the windward and leeward span of the bridge under study in the following configurations:

A. Free span (figure 3);
B. Span structure taking into account snow deposits (permeability coefficients of barrier and railing barriers are equal to zero) (figure 4);
C. The superstructure, taking into account snow deposits and car traffic;
D. Span structure taking into account car traffic. The situation was simulated congestion of road vehicles in two directions of movement (traffic jam) (figure 5). In accordance with the average size of vehicles, when modeling the following dimensions were taken as the basis:
• trucks - 4x18x2.5 m;
• passenger vehicles – 1,5x4,2x1,7 m;
• distance between cars -1,5-2 m.

Experimental studies of the stability of the bridge span structures were carried out at flow directions equal to 0º, +3º, -3º, +5º, -5º.

Figure 3. Model of bridge span (Configuration A), view from above

Figure 4. Model of bridge span (Configuration B)
5. Results and discussions

Based on the climatic analysis, the calculated wind speed was calculated taking into account the safety factor of 1.4 - 23 m/s and the critical speed for assessing the bridge flutter - 34.5 m/s.

The research results are presented in graphical form as the dependence of the span displacement in full scale on the average wind speed, indicated also in full scale (Fig. 6-8). The article presents the test results for the most interesting angles of attack from the aerodynamic point of view - + 5°, + 3°, 0°.

Figure 6. Dependence of amplitude of oscillations of windward span of bridge on wind speed, flow direction $\alpha = + 5^\circ$
Figure 7. Dependence of amplitude of oscillations of windward span of bridge on wind speed, flow direction $\alpha = +3^\circ$

Figure 8. Dependence of amplitude of oscillations of windward span of bridge on wind speed, flow direction $\alpha = 0^\circ$
6. Conclusions
Based on the test results, it was established that it is impossible to speak unequivocally about the effect of snow deposits on the aerodynamic stability of the span. Although in general, the amplitudes of oscillations in the presence of snow drifts on barrier fences are lower than in their absence. With the flow direction $\alpha = 0^\circ$, in the configuration B a phenomenon of vortex resonance arose, which is not observed with other configurations of the span under study.

The presence of automobile traffic on the span under study excludes all possible phenomena of aerodynamic instability, for all the flow directions considered. Accordingly, the expediency of supplementing the classical program of testing bridge structures with research in the presence of automobile transport is absent, especially considering the variability of the location of various cars on the superstructure.

Studies of the effect of snow deposits on barrier fences should be carried out, if necessary, on the basis of a climatic analysis of the construction site (it is necessary to analyse the possibility of falling the required amount of snow precipitation), as well as analysing the operating conditions of the bridge crossing (regular snow cleaning during the winter period, etc.)

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