The influence of the structural vibrations’ logarithmic decrement on its stability in the event of vortex excitation

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Abstract. The article considers the influence of the structural vibrations’ logarithmic decrement on its stability in the event of vortex excitation. The relevance of the topic is due to the widespread problem of vortex excitation in the construction and operation of large-span bridge structures. The introduction presents the characteristic features of vortex excitation as a phenomenon of aerodynamic instability. In the second section, the research method is given, the research object is described, and the considered variants of the logarithmic decrement of the beam span’s investigated construction vibrations are given. The third section presents the experimental studies’ results at the Unique Scientific Installation, Big Research Gradient Wind Tunnel, NRU MGSU in graphical form. The conclusions about increasing the structural stability with increasing values of the vibrations’ logarithmic decrement are drawn.

1. Introduction
Vortex excitation is the most widespread phenomenon of aerodynamic instability of building structures. This phenomenon is observed when the natural vibrations frequency of the structure coincides with the Karman vortex disruption frequency, and can occur at relatively low wind flow velocities, which significantly increases its danger to strength and stability [1-5]. The most famous case of this phenomenon in our country is the fluctuations of the Volgograd bridge in 2010 (Figure 1) [6]. Despite a fairly good study of this phenomenon, bridges continue to fluctuate under the wind influence - on May 5 this year, the Humen sea bridge in China was closed. According to the official information, the bridge could lose stability due to the emergency barriers installed on it during the repair. Barriers could make changes to the structure of the wind flow around the bridge, due to which, when a certain wind speed is reached, the vortex excitation phenomenon occurred.
One of the features of this phenomenon is the sharp occurrence of oscillations upon reaching a certain value of the wind flow velocity (critical velocity) and their disappearance when this velocity is exceeded or decreased [1,7,8]. Accordingly, the vortex excitation occurrence does not lead to the building structure’s guaranteed destruction, such as flexural-torsional flutter or galloping [9-11], but the designer needs to evaluate such parameters as the amplitude of vibration and oscillation acceleration, compare them with the maximum allowable values included in the calculation model and accept the decision on the need to make certain project’s adjustments.

2. Research method
Despite a significant breakthrough in the computer technology and software systems’ development, the most reliable way to determine these parameters is experimental modeling in wind tunnels. The key criterion for the simulation results’ adequacy is the dynamic similarity of the experimental model and the object under study.

The experimental model should correspond to the real object in the following parameters:
- complete geometric similarity;
- correspondence of the model’s natural vibration frequency to the calculated value of the natural vibration frequency of a real object (as a rule, the first bending and the first torsional vibration modes are modeled);
- level of structural damping (depends on the material and design features of the studied object).

The studies were carried out in a specialized test desk for dynamic testing of the building structures at the Unique Scientific Installation, Big Research Gradient Wind Tunnel, NRU MGSU (Figure 2). The research methodology is described in sufficient detail in the articles of domestic and foreign authors [12-14].
The object under study is a continuous metal span with four main beams. The cross section is shown in Figure 3. The choice of the study object is due to the revealed phenomenon of vortex resonance at wind flow velocities close to the calculated ones with dangerous oscillations amplitudes (150-350 mm, at different angles of attack) with a minimum value of the design oscillations’ logarithmic decrement.

Using special damping elements, the model’s structural damping value (logarithmic decrement of oscillations) in a specialized stand was changed within the values considered in regulatory documents: d=0.02 (metal span with welded joints), d=0.03 (metal span with high-strength bolted joints), d=0.06 (metal span with bolted joints) and d=0.15 (value for the steel structures in accordance with the Building Code “Loads and Impacts”) [15].

3. The results of the study
The study results of the TS stability at various levels of damping are presented as a graph of the TS movement in full scale, depending on the average wind speed, also in full scale. The article presents two characteristic angles of the wind flow attack - along the horizontal axis (0º) (Figure 4), as well as the upward flow (−5º) (Figure 5).
Figure 4. Dependence of the bridge span amplitude on the wind speed, flow direction $\alpha = 0^\circ$ at various values of the logarithmic attenuation decrement

Figure 5. Dependence of the bridge span amplitude on the wind speed, flow direction $\alpha = -5^\circ$ at various values of the logarithmic attenuation decrement

Table 1. Dependence of the vibrations’ amplitude on the structural damping value

| $\alpha = 0^\circ$ | $\alpha = -5^\circ$ |
|------------------|-------------------|
| d    | Amplitude of oscillations, mm | d    | Amplitude of oscillations, mm |
| 0.02 | 155               | 0.02 | 350               |
| 0.03 | 135               | 0.03 | 255               |
| 0.06 | 93                | 0.06 | 99                |
| 0.15 | 29                | 0.15 | 19                |

4. Summary
The conducted studies with the structural damping level (logarithmic decrement of vibrations) $d=0.03$ and $d=0.06$ for upstream ($\alpha = -5^\circ$), showed the best stability of the bridge structure. At $d=0.06$ the oscillation amplitude decreased to 100 mm (more than 3 times).

It should be noted that the decrease in the amplitude of oscillations on the model is not proportional to the decrease in the value of structural damping, which indicates the need to refine the results of experimental modeling by conducting the tests in various configurations.

In general, increasing structural damping of the structure is an effective measure to increase the stability of the structure in the wind flow, which should be considered along with the use of aerodynamic fairings and mechanical dampers.

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References
[1] Kazakevich M I 2019 Fundamentals of design calculations for wind effects (Moscow, MGSU).
[2] Diana G, Fiammenghi G, Belloli M, & Rocchi D 2013 Wind tunnel tests and numerical approach for long span bridges: The Messina bridge Journal of Wind Engineering and Industrial Aerodynamics 122 38-49
[3] Diana G, Resta F, Belloli M, & Rocchi D 2006 On the vortex shedding forcing on suspension bridge deck Journal of Wind Engineering and Industrial Aerodynamics 94 (5) 341-363
[4] Zakora A L 2005 Damping of vibrations of bridge structures Science and transport progress. Bulletin of the Dnipropetrovsk National University of Railway Transport 6.
[5] Naumova G A, & Ponomarenko S A 2017 Evaluation of the aerodynamic stability of continuous beam bridges in foreign and domestic regulatory documents Vestnik Volgogradskogo Gosudarstvennogo Arhitekturno-Stroitelnogo Universiteta. Seriya: Stroitelstvo i Arhitektura 47 (66).
[6] Ovchinnikov I I, Ovchinnikov I G & Filippova V O 2015. Dancing bridge in Volgograd: reasons, analogies, events. Part 1. Reasons Bulletin of Eurasian Science 7 (6) (31).
[7] Churin P, & Fedosova A 2019. Aerodynamic Stability of Bridge Structures IOP Conference Series: Materials Science and Engineering 661 012050.
[8] Naumova G A, Samanov V V, & Ponomarenko S A 2012 Effective solution to the problem of ensuring the stability of beam bridges.
[9] Gu M, Chang C C, Wu W, & Xiang H F 1998 Increase of critical flutter wind speed of long-span bridges using tuned mass dampers Journal of Wind Engineering and Industrial Aerodynamics 73 (2) 111-123.
[10] Walther J H, Christensen D S, Malthue M G, Roenne M, Spietz H J, Larsen A, & Larsen S V 2017 The collapse of Tacoma Narrows Bridge: a piece to the puzzle APS Division of Fluid Dynamics Meeting Abstracts.
[11] Chen X, Matsumoto M, & Kareem A 2000 Aerodynamic coupling effects on flutter and buffetting of bridges Journal of Engineering Mechanics 126 (1) 17-26.
[12] Ricciardelli F, de Grenet E T, & Hangan H 2002 Pressure distribution, aerodynamic forces and dynamic response of box bridge sections Journal of wind engineering and industrial aerodynamics 90 (10) 1135-1150.
[13] Poddaeva O, Churin P, Fedosova A, & Truhanov S 2018 Investigation of the stability of a two-span bridge with the use of a high-precision laser displacement sensors *IOP Conference Series: Materials Science and Engineering* 317 012020.

[14] Bienkiewicz B 1987 Wind-tunnel study of effects of geometry modification on aerodynamics of a cable-stayed bridge deck *Journal of Wind Engineering and Industrial Aerodynamics* 26 (3) 325-339.

[15] Jeary A P 1997 Damping in structures *Journal of wind engineering and industrial aerodynamics* 72 345-355.