Experimental determination of dynamic characteristics and analysis of acceleration of vibrations of pedestrian bridges

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Abstract. This article discusses the design of pedestrian bridges. When designing pedestrian bridges, engineers are guided mainly by the static characteristics of the types of spans under consideration. If you want to build a load-bearing beam structure of a large span, you cannot lose sight of their relatively large mass and low stiffness due to the length of the bridge. These factors lead to a low natural frequency close to the frequency of pedestrian load, in the form of people passing through this structure, which, in turn, act as recipients of vibrations. The structure is a metal span restructure with two I-beam main beams with a solid sloping wall, an orthotropic plate of the passer-by part below, a calculated width of 44.0 m, a total length of 44.6 m and a pedestrian dimension of 3.25 m. In the course of dynamic tests of the pedestrian bridge span, experimental values of the natural vertical vibration frequencies were determined, followed by the determination of the attenuation decrement. The natural oscillation frequency was 2.0 Hz, which corresponds to a period of 0.5 s oscillation.

Keywords: pedestrian bridges, dynamic characteristics, static characteristics, oscillations, metal span structure, building constructions.

1 Introduction

The object of study is a pedestrian bridge across the railways located in the city of Kazan.

The article is relevant to the present, because, according to Russian standards for objects of this type, mandatory dynamic tests are required with the application of real dynamic loads.

Such dynamic loads in accordance with the norms are created by a group of people moving at different speeds.

The main purpose of this work is to develop a method for experimental dynamic testing of a pedestrian bridge with the determination of its dynamic characteristics.

In this case, an important part is the experimental registration of possible resonant phenomena. Based on the results of dynamic tests, the actual dynamic characteristics of the pedestrian bridge are determined (natural frequency of vibrations, degree of attenuation, dynamic coefficient).

All these characteristics must be compared with the calculated parameters and regulatory documents. It is also important to get real information about the compliance of actual parameters with the calculated and normative ones.

The scientific significance consists in the development of an experimental technique and its implementation using group movements of people in order to obtain a different dynamic response of the bridge according to the required forms and frequencies of vibration.

The practical value lies in the use of data for the calculation and testing of transition bridges with high dynamic malleability.

When designing pedestrian bridges, engineers are guided mainly by the static characteristics of the types of spans under consideration. If you want to build a load-bearing beam structure of a large span, you cannot lose sight of their relatively large mass and low stiffness due to the length of the bridge[1-5]. These factors lead to a low natural frequency close to the frequency of pedestrian load, in the form of people passing through this structure, which, in turn, act as recipients of vibrations. For example, the frequency of a person's excitatory force when walking varies between 1.2 and 2.4 Hz [6-8].
Certain oscillations that the structure experiences can lead to a sense of anxiety for the inhabitants. To determine whether the impact of vibrations on a pedestrian is acceptable such criterion as the mean square acceleration averaged over a certain period of time is used [9-12].

2 Materials and methods
The structure consists of a metal span structure with two I-beam main beams with a solid inclined wall, an orthotropic plate of the passer - by part below, a calculated width of 44.0 m, a total length of 44.6 m and a pedestrian size of 3.25 m [13].

The general view of the span structure is shown in the figure (see Figure 1).

Materials of metal structures of the span structure – low-alloy steel 15HSND-2 according to GOST R 55374-2012, the calculated yield strength according to table 8.5 Ry = 295 MPa. Hardware is according to GOST R 52643-2006, made OF 40x "select" steel, strength class 10.9[14-15].

Figure 1. General view of the span structure.

Figure 2. General view of the pedestrian bridge.

Before conducting the tests, the equipment was installed according to the test program (see Figure 3).
In the course of dynamic tests of the pedestrian bridge spans, experimental values of the frequencies of proper vertical vibrations were determined, followed by the determination of the attenuation decrement [16-20].

In dynamic tests, the excitation of natural vibrations of structures was performed by swinging a group of 5 people, which was located in the middle of the span.

The group, at the direction of the head of experiment, worked for some time on the structures with vertical movements and after several vertical shocks, it stopped until the vibrations of the superstructure fell to zero, while recording was performed using vertical and horizontal vibration sensor "VEG " and the Ni SCXI-1000 docking station with the Ni 1317 module, installed in the middle of the span of the pedestrian bridge. The frequency of results removal is 50 Hz.

Figure 3. Scheme of installation of equipment for the experiment.

Figure 4. General view of vertical and horizontal vibration sensors.
3 Results
In the course of dynamic tests of the pedestrian bridge spans, experimental values of the frequencies of proper vertical vibrations were determined, followed by the determination of the attenuation decrement [16-20].

The span structure oscillation diagram for a vertical vibration sensor is shown in figure 6.

![Oscillation diagram in the span of a pedestrian bridge.](image)

The oscillation frequency is calculated from 10 vibrations using the formula:

\[ \vartheta = \frac{N}{t} = \frac{10}{5} = 2.36 \text{ Hz}, \]

where \( N \) is the number of vibrations equal to 10;

\( t \) is the time during which the superstructure makes \( N \) vibrations. From Figure 7 it is determined that 10 vibrations are performed in 4.24 s. Accordingly, the oscillation period is 0.424 s, which is not included in the range specified in clause 5.48 of SP 35.13330.2011 «Bridges and pipes. Updated version of SNiP 2.05.03-84* (with Change N 1)». 
Figure 7. Oscillation diagram for calculating the oscillation frequency.

The decrement of the oscillation attenuation \( \Delta \) is the ratio of two successive amplitudes:

\[
\Delta = \frac{A(t)}{A(t + T)} = \frac{0.717}{0.668} = 1.073,
\]

where \( A(t) \) is the amplitude of the n-th oscillation,
\( A(t + T) \) – is the amplitude of the n+1-th oscillation,
In this case the logarithmic decrement of oscillation attenuation is 0.071.

Figure 8. Oscillation diagram for the calculation of the decrement of oscillation attenuation.

When exposed to a group of people with a frequency close to the natural oscillation frequency of 2.0 GHz, a graph of changes in the amplitude of vibrations is obtained (see Figure 8), which shows an increase in the amplitude, which means that a resonance occurs. This phenomenon under certain conditions can lead to significant deformation of load bearing structures and glazing.
Discussions
In the course of dynamic tests of the pedestrian bridge span, experimental values of the frequencies of proper vertical oscillations were determined, followed by the determination of the attenuation decrement. The natural oscillation frequency was 2.0 GHz, which corresponds to the oscillation period of 0.5 s, which falls within the range specified in clause 5.48 of SP 35.13330.2011 " Bridges and pipes. Updated version of SNiP 2.05.03-84* (with Change N 1)" and 8 ISO 10137:2007(E) «International standard, Bases for design of structures — Serviceability of buildings and walkways against vibrations».

Also, during calculations and tests, a high dynamic malleability of the structure (the possibility of resonant phenomena) was revealed, which will be addressed in subsequent works.

Based on the results of these calculations and tests, it is possible to use this technique in the design of bridges of this type.

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