Assessing peculiarities of condition and behaviour of low-level bridges

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Abstract. The article considers peculiarities of operation and monitoring of low-level bridges which are found on highways of regional, intermunicipal, and local significance. The vibrations of the bridge superstructure are considered in detail taking into account its interaction with other elements of the structure and the environment. It is proposed to use the natural frequency of vibration as a characteristic, the change of which takes into account the change in the condition of the bridge structure.

1 Introduction

It is impossible to imagine modern transport communications without man-made structures, the peculiarities of construction and operation of which make a significant contribution at all stages of the life cycle of the route.

Most often such structures are of temporary category, but at the same time there are examples of very long operation of such bridges and their presence on federal highways (the Crimean bridge, the bridge over the Amur Bay in Vladivostok, etc.).

In general, it can be noted that low-level bridge crossings are built without taking into account the possibility of ice drift, high water, and water traffic passing.

2 Research methods

Let us consider in detail the vibrations of the bridge superstructure, taking into account its interaction with other elements of the structure and the environment (ground, water). It is proposed to use the natural frequency of oscillations as a characteristic, the change of which takes into account the change in the condition of the bridge structure [1-3]. Separately, the absence of description in the normative literature of peculiarities of monitoring of low-level bridges, which in these documents practically do not differ from ordinary bridge crossings, can be observed, but the experience of real operation of such artificial structures shows the presence of multiple differences [4, 5].

The following scheme is used as the basic design of the bridge crossing to be modelled. The bridge superstructure, which consists of the roadway and load bearing parts, is supported by rigid bank bearings. The upper structure (railway) absorbs the load from passing traffic and transmits the pressure from it to the span (bearing part), which then transmits the load to

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the transom beam, through it to the pile posts and further to the foundation ground [6-8]. To simulate the dynamic effects of transport and the dynamic behaviour of individual elements and the structure as a whole, viscoelastic elements of Kelvin-Feugt type are supposed to be used, which, as shown by studies of domestic and foreign researchers, best describe the changes in time of the state parameters of the materials, structural solutions, components and the environment under the action of external dynamic load [9, 10, 11].

Traditional methods of determining the stress-strain state of bridge crossing elements [12-15] mainly assume consideration of static loading with determination of the bending moment and transverse force in the cross-sections of the span by the well-known formulas:

\[
M \left( x = \frac{1}{2} \right) = \gamma_f p_{nc} \omega_m + \gamma_f k_p \left( 1 + \mu_p \right) \omega_m + \gamma_f p_n \left( 1 + \mu_p \right) (y_1 + y_2) \eta_s \quad (1)
\]

\[
Q \left( x = 0 \right) = \gamma_f p_{nc} \omega_0 + \gamma_f k_p \left( 1 + \mu_p \right) \omega_0 + \gamma_f p_n (y_3 + y_4) \eta_s, \quad (2)
\]

where \( \gamma_f \) - load factor; \( p_{nc} \) - intensity of uniformly distributed load from the dead load of the span structure; \( k_p \) - the intensity of the evenly distributed load from the dead weight of the road superstructure (carriageway); \( \omega_m \) and \( \omega_0 \) - the area of the bending moment and shear force influence line section, respectively at a given cross-section; \( p_n \) - the wheel axle load determined by the type of vehicle load; \( \mu_p \) - coefficient of influence of transverse deformation of the span structure; \( y_1, y_2 \) and \( y_3, y_4 \) - bending moment and shear force line ordinates for a two-axle vehicle at the external force application points; \( \eta_s \) - factor related to the symmetry of the load application in relation to the longitudinal axis of the bridge.

To check the strength of the span, the highest normal (mid-span) and shear stress (at the support) are calculated:

\[
\sigma = \frac{M \left( x = \frac{1}{2} \right)}{v_1 w_{nt}} \leq R_y \cdot m_n, \quad (3)
\]

\[
\tau = \frac{Q \cdot b_r \cdot t_w}{v_2 / b_r \cdot t_w} \leq R_s, \quad (4)
\]

where \( m_n, v_1, v_2 \) - safety factors; \( R_y \) - calculated bending resistance of the span material; \( R_s \) - design resistance of the span material to shearing; \( W_{nt} \) - moment of resistance of the cross-section of the net span; \( t_w \) - girder wall thickness; \( J_{br} \) - moment of inertia of the gross cross-section of the span; \( S_{br} \) - Static moment of part of the cross-sectional area \( S_{br} = 0.5 \cdot F_{br} \cdot y_{wt} \); \( F_{br} \) - gross sectional area of the span; \( y_{wt} \) - the ordinate of the centre of gravity of the half-section of the span.

If girder elements are used as load-bearing structures of the span, the overall stability of the girder in the compressed area must be calculated against bulging in the horizontal plane, using the following expression:

\[
\sigma = \frac{M \left( x = \frac{1}{2} \right)}{W_{br} \cdot \varphi_{pr}} \leq R_y \cdot m_n, \quad (5)
\]

where \( W_{br} \) - moment of resistance of the compressed chord of the gross girder; \( W_{br} = \frac{t_r b_r^2}{6}, \)

\( b_r \) and \( t_r \) - width and thickness of the girder chord, respectively, \( \varphi_{pr} \) - bending coefficient, determined according to the recommendations BC 35.13330.2010.

When using a span structure with stiffening support ribs, the stability of the girder wall and support ribs must be checked using the formula:
\[ \sigma = \frac{R_{op}}{A_{br} \phi_i} \leq R_y, \]  

(6)

where \( R_{op} \) – Supporting reaction at the girder span support of the girder support; \( A_{pr} \) – the reduced working area of the stiffener, usually defined as \( A_{pr} = 30t_w \cdot t_w + 2b_p \cdot \delta_p \); \( \delta_p \) – stiffener thickness; \( b_p = h_{st}/30 + 40 \), \( h_{st} \) – wall height, measured in mm.

The choice of the frequency of natural vibrations of the span as one of the main parameters for monitoring the technical condition of the bridge crossing is explained by the fact that this characteristic is reflected in the normative-legal documentation on the design and operation of artificial structures [16, 17, 18]. When designing bridge crossings with girder spans, it is necessary that the first natural frequency of vertical oscillations satisfies the conditions:

\[ f_{1,\text{min}} \leq f_1 \leq f_{1,\text{max}}, \quad 1.2f_1 \leq f_{1,t}, \]  

(7)

where \( f_1 \) - first natural frequency of the vertical vibrations; \( f_{1,t} \) – natural frequency according to the first torsion form; \( f_{1,\text{max}} \) – the upper limit of the first natural frequency, associated with excitation frequencies arising from uneven road surfaces and abnormal deformation of vehicle wheelsets; \( f_{1,\text{min}} \) - the lower limit of natural frequency, related to the possible resonance of the superstructure due to the movement of the vehicle wheelsets and essentially depending on the length of the superstructure.

Condition (7) was developed by the International Union of Railways and is largely advisory in Russia. Chinese railways have alternative criteria for limiting the lower limit of natural vibration frequencies, depending on the speed of the crews and the span length of the split girder scheme, such criterion is in the range of \( 100/L \) till \( 150/L \) [19-21].

Graphically, the conditions-restrictions described can be represented as two curves, between which is the area of permissible values for the first natural frequency of the span (Fig. 1), the curve for \( f_{1,\text{max}} \) is represented by a solid line, for \( f_{1,\text{min}} \) - dotted line.

Fig. 1. Limitations of natural frequency of vibration according to the first form for the sectional girder span design scheme
As shown by studies by domestic and foreign scientists, these graphical limiting conditions are well suited for speeds between 100 and 450 km/h, with the higher the speed value in this interval, the more the calculated curve for natural frequency is located closer to the upper limit [22-25].

3 Conclusion

Periodic monitoring of the same bridge crossings using the approaches considered will detect the presence of defects in the superstructure itself, associated with cracking, spalling, reduction of the working areas of significant elements, etc., as the presence of such defects changes the estimated frequencies and this can signal necessary repairs or impose restrictions on vehicle axle load, total crew weight, distance between crews and speed when they are travelling.

References