The numerous cases of deformation of technogenic objects in the transport industry under increasing axial loads and speeds of motion aggravate the need to solve the problems of early recognition of the nature and causes of deformations of structural elements. The need for this is due to the fact that destructions and accidents, resulting from deformation processes, cause enormous economic, social and environmental damage, incomparable with the funds spent on protective measures.

The object of the study in the article is a railway trestle, consisting of two spans of a ribbed reinforced concrete beam. Determination of the residual resource in terms of bearing capacity and load-carrying capacity of the railway trestle is the main task. The authors have obtained bending deformations (stresses), frequencies of natural vibrations and operating modes of structures of railway trestle spans. The damage degree of the railway overpass spans structures may also be judged by the deviation of the calculated values of the amplitude-phase-frequency characteristics (AFFR) from the standard values. The peculiarity of this research is the fact, that the natural frequencies of railway overpass vibrations are determined either by «tails» of experimental vibrograms (oscillograms) after the load release from the span structure. During the express-diagnostics of railway overpasses, the relative deformations (stresses) of girder spans in the middle of the span, the first frequency (period) of natural vibrations of girder reinforced concrete spans of railway overpasses are used as parameters characterizing the technical condition of the spans. The results of tests and examinations of overpasses to ensure their safe operation have been given

Keywords: traffic safety, roadway, bending deformation, natural frequencies, vibration forms, vibrodiagnostics

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DEVELOPMENT OF SAFETY METHODS ON ARTIFICIAL STRUCTURES OF RAILWAY LINES

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1. Introduction

The development of the transport industry depends on logistical analysis and safe railroad traffic, which is aimed at improving the level of development of the infrastructure of the transport system [1].

An important task of transport and communications infrastructure is to ensure the availability and quality of transport services and the creation of «infrastructure centers» in remote regions of the country with insufficient population density [2].

The transport industry man-made facilities in terms of strength, reliability, stability, cost-effectiveness of maintenance and lifecycle should meet the latest modern technical requirements and be capable for the passage of nowadays established loads at set speeds. It is carried out at arraigning and performing work on their current maintenance and overhaul of them.

Artificial structures are repeatedly exposed to extreme influences as a result of climatic factors.

A significant number of artificial structures need a comprehensive assessment of their safety and operational reliability in connection with an increase in axial loads and speeds of rolling stock.

In world practice, there are many cases where due to improper maintenance and operation of artificial structures, particularly bridges, their poor repair or repair with deviations from construction standards and regulations, there were their destruction, collapse, sometimes with human casualties.

The on bridges passing train loads conditions are set through comparing the superstructure elements classes determined according acting Guidelines for determining the carrying capacity of bridges [3–5] with the classes of rolling equipment to be passed through, given in [6]. These Guidelines are used in the maintenance and operation of railroad bridges on railroad lines. Spans, when determining their load capacity, are tested in accordance with the need to clarify the actual stress state of the elements, as well as in the presence of defects and damages, the impact of which on the load capacity is difficult to consider theoretically, it is necessary to test and inspection of these artificial structures [7].

These studies are necessary for all transportation facilities because in the process of operation of each artificial structure is deformed, new defects appear, and therefore the dynamic passport of the object must be changed.

2. Literature review and problem statement

In [1] four reinforced concrete (RC) beam models undamaged, damaged by notches and strengthened by external bonded (EB) glass fiber reinforced polymer (GFRP) strips have been experimentally studied. The paper aims to assess the availability of strengthening with EB GFRP strips in RC beams having a deep localized damage. The behavior of RC beams has been analyzed under bending loading until failure. Furthermore, the assessment of RC beam models foresaw nondestructive control of damaged and strengthened models by free vibration tests to obtain frequency values at different damage degree. Damage, artificially obtained by notches with different width, on the midspan section and on the lateral location of beams, has been analyzed. The envelope of frequency response functions (FRFs) obtained by dynamic tests was elaborated and changes of natural frequency values are then correlated to damage both to non-strengthened beam with notches and to strengthened beam models. Results of static tests on RC beams strengthened with filled mortar in the notched sections and EB GFRP strips have allowed to validate the strengthening of RC elements with composite material characterized by relatively low elastic modulus; further, it has been assessed maintenance of bond between concrete surface and GFRP strips until failure under bending loading.

In [2], the presence of a transverse crack in the beam bending node is considered, which leads to a decrease in the modal frequency of bending. In this study, the modal behavior of a beam with a transverse crack at the bend node was examined and it was found that this assumption is not met, especially for a deep crack at the high-frequency bend node. The validity of the proposed frequency equation was demonstrated by comparing quantitative results with finite element analysis and experimental data.

The paper presents the level of safety on the railway transport affects the system of safety on the railroad transport, which is a complex of technical means and administrative measures. Current and previous accidents show the need to address these issues [3].

This article [4] shows the possibility of using the devices and equipment of the laboratory during inspections and tests of bridges and diagnostics of railway embankment earthwork in order to ensure their safe operation. Instruments and equipment of the laboratory were used when developing methods for vibrodiagnostics of track superstructure, girder spans of railway bridges and approach embankments to bridges, high railway embankments and embankments on weak bases. As an example, some results of measurements of bending deformations of a reinforced concrete bridge superstructure during a train movement are given with an analysis of the influence of the rolling stock on its stress-strain state. The result of using the methods is the assessment of the technical condition of the beam spans of railway bridges, determined by two types of condition – defect-free (when the beam span does not have defects that reduce its carrying capacity, i. e. operable) and defective (when, according to the results of the assessment of the survey and testing, the measured values: natural frequencies (periods), relative damping coefficient and relative deformations (stresses), performed in accordance with the requirements of regulatory documents, it is possible to diagnose the presence of a defect). The assessment of the technical condition is carried out by comparing the values of the first natural frequency and relative damping coefficient, obtained from the results of full-scale tests of the oscillation parameters of beam span structures of the bridge, with the values of the first natural frequency (period) and coefficient of relative damping, obtained by calculation on models of defect-free beam superstructures.

The stress-strain state in the structural elements of reinforced concrete spans of railway overpasses under the action of its own weight and temporary loading based on experimental and numerical methods is investigated in this work [5].

The paper presents the methodology of express diagnostics of girder spans.

The technique of express diagnostics of the girder spans, which allows determining the technical state of the girder spans of the railway bridges. The technique is based on the analysis of the structure response to a small impulse action – «man-jump». The application of this technique will increase the service life and reduce the cost of the current maintenance of railway bridges [6, 7].

This [8] contribution deals with the dynamic behavior of railway bridges for high-speed traffic and investigates the impact of changes to the structural system on the dynamic response due to crossing trains. Multi-span simply supported beams represent the most unfavourable system for high-speed trains, structurally as well as aesthetically. Therefore, alternative structural systems were analyzed to find out whether the dynamic characteristics of railway bridges can be adjusted in the design stage. Because of the strong interaction between the crossing train and the bridge structure the impact of changes to the structure is very difficult to estimate a priori. The internal forces in continuous beams with lengths exceeding 30 m are generally smaller than those in single-span beams with the same cross section and the speeds at which they can be crossed are significantly higher. By adding haunches to the beams those eigenfrequencies whose eigenmodes exhibit curvatures at the supports can be increased. Shortening the end spans leads to an increase in all eigenfrequencies and hence in resonance speeds. Using the findings from this article the dynamic stability of high-speed railway bridges can be improved at the preliminary design stage.

The article considers the issues of safe operation of artificial structures of transport infrastructure are of paramount importance for the transportation of goods and passengers. A significant number of artificial structures needs a comprehensive assessment of their operational reliability due to the increase in transport loads and speeds [9].

This study investigated the effect of maintenance work on the lifetime traffic load and structural safety of long-span bridges [10].

Bridges are often key factors in transport, allowing to get across landscapes efficiently. If a bridge fails, the results can be catastrophic for human life, for economies and societies and for the environment. This is why bridges are monitored as they age, to estimate whether they can still safely bear expected traffic. But the processes that civil engineers use to do that on long-span bridges are limited. This could result in bridges being closed due to safety concerns. Have been using cameras to augment the data it is possible to collect about traffic weights and patterns on long-span bridges. They have developed a first-of-its-kind method to quantify the traffic loading on some of the world's biggest bridges – structures with clear spans of up to 2 kilometres. This means that engineers can now provide a more realistic measurement of bridge safety, thereby protecting human lives. The UCD-developed method should also help to prevent the unnecessary closure of economically important bridges, thus saving money and reducing disruptions to economies and societies and to the environment.

The purpose of this article is to provide a comprehensive review of the literature on the problem associated with evaluating the safety of train traffic on bridges. The first step summarizes existing normative criteria from various regions of the world pertaining to this topic. The article gives a brief description of the available models of interaction between the train and the bridge, necessary for unambiguous assessment of traffic stability, and then presents the traffic safety indicators used to assess the risk of derailment [11].

Experimental tests [12] in the repair of reinforced concrete columns with different levels of preliminary damage. The test results showed that the determination of bearing capacity, axial displacement, stiffness and plasticity of the repaired columns have a significant impact on the restorability of the confinement. It is observed that increasing the volumetric limiting factor can restore both strength and ductility of repaired reinforced concrete columns up to 171 % and 172 % at the same level of preliminary damage. A study of the effect of the level of preliminary damage on the efficiency of concrete repair using an external retaining device.

In [13] dynamic analysis of complex systems usually simplified models are used. In case of floor vibration, an SDOF model is used to calculate the acceleration of the structure, in the seismic design of structures lumped parameter models are recommended to include the effect of the soil-structure interaction (SSI) in the analysis. Nonetheless, for rib stiffened floors, and for finite depth soil layers under the structure these models can be very inaccurate. In these cases (infinitely) long constrained bars (or beams) are recommended as simplified models. In this article an infinitely long, axially constrained bar connected parallelly to a mass-spring system is analyzed. An analytical solution is derived, and the impedance functions are determined, which are significantly different from those of simple lumped parameter models. It is shown that this simple model, which depends only on three parameters, is an excellent tool for determining the response of structures excited by horizontal harmonic or earthquake loads, where SSI plays an important role.

The [14] quantitative design of fabricated joint is a key issue to realize the effective mechanized assembly of tunnel steel set. However, there is no reported research on the failure mechanism and quantitative design method of fabricated joint for underground support structures. Taking a type of fabricated joint used for concrete-filled steel tubular (CFST) set as research object, the refined finite element model is constructed in this paper considering the complex nonlinear characteristics of joints. The simulation scheme is verified and validated based on four-point flexural and eccentric compression experiments. Failure modes and bearing mechanism of fabricated joint are obtained through above methods. Research results prove that there are two primary failure modes: the destruction of joint components and the tearing fracture at joint-CFST junction, the latter of which might lead to overall brittle failure of tunnel support structures. Parametric studies of joint specimen are carried out accordingly to establish an analytical model for fabricated joint design. The research results could provide basis for the design and application of mechanized assembly construction in tunnel excavation.

This [15] study demonstrates the development of bivariate fragility curves for a fire-exposed simple-span overpass bridge prototype with composite steel plate girders. The fire and resulting heat transfer to the girders are modeled using the computationally efficient Modified Discretized Solid Flame (MDSF) model, developed previously by the authors. Several input parameters to model the thermo-structural response of the girders (particularly the material strength and applied loading) are stochastically selected for Monte Carlo Simulation via Latin Hypercube Sampling. The thermo-structural response of the composite steel girders is calculated using uncoupled, reduced-form finite element analyses. The structural-fire response of the prototype bridge girder is iteratively calculated for a large suite (~1,00 iterations) of fire scenarios and then categorized into escalating damage levels based on the maximum deflection reached during the fire event. The damage from each fire scenario is correlated to two measures of fire hazard intensity: the peak heat release rate, and the total thermal energy imparted along the girder span. Bivariate fragility curves that correlate the two intensity measures to each damage level via a cumulative normal distribution function are obtained for the prototype bridge with span length varying from 12.2 to 42.7 m. An illustrative example uses these fragility curves to assess fire-induced damage for the two overpass spans in the MacArthur Maze interchange in Oakland, CA that collapsed due to a 2007 tanker truck fire.

In [16], the effect of rotation speed, bending-torsional coupling and damping on the natural frequencies of beams was investigated. The superposition principle is used and expressions for the dynamic characteristics of beams under various harmonic loads are obtained. The presented solution procedure for Timoshenko beams can be degenerated to solve Rayleigh and Euler beams by setting values of shear stiffness and rotational inertia.

The paper [17] presents an improvement of methods that are commonly used to analyze and evaluate the safety of automatic devices in controlled transportation systems. Artificial intelligence techniques include the development of several approaches and tools to assist in modeling, storing and evaluating security knowledge. Software tools have two main purposes: first, to record and store experience related to security analysis, and second, to assist those involved in system design and evaluation in the complex task of evaluating security studies. These tools are in the layout stage, but initial testing by security experts has shown interest in the proposed approaches. This study is aimed at completing and improving the model for representing accident scenarios, taking into account the human factor.

Dynamic behavior is essential in the analysis of railway bridges and trains namely on high speed tracks [18]. The action of railway traffic on bridges is performed by two different methodologies: in the first the train is considered as a set of moving masses, being the effects of the moving forces and masses implied; in the second both the structural behavior of the train and the interaction with the bridge are involved. Based on a real case, the effect of some parameters are analyzed in this paper: characteristics of stiffness and mass of the bridge, stiffness of the train, bridge span and track irregularities. The main aim is to evidence the importance of these parameters in order to investigate the structural behavior of the bridge and the comfort at the train.

3. The aim and objectives of the study

The aim of the study is to determine the residual life of the bearing capacity and load capacity of railway overpasses.

To achieve this aim, the following objectives are accomplished:

– to calculate the stresses deformations in the structures of railway overpasses;

– to determine the forms of vibration of girder spans of railroad overpasses.

4. Materials and methods of research

Modern measurement and computing complexes (Fig. 1, 2), the world's leading manufacturers, provide high mobility, the range of information transfer and easy installation of measuring equipment, a high degree of fault tolerance and noise immunity, and the ability to use the monitoring system, automatic identification and diagnosis of connected devices.

Fig. 1. Strain measuring and computing complex for measuring relative deformations and stresses in structures

Fig. 2. Measuring and computing complex for man-made facilities structures dynamic testing

Deformations are recalculated into stresses, knowing the physical and mechanical characteristics of the structural elements of the bridge.

Fig. 3 shows a cross-section of the span with the locations of the strain gauges on the structural elements.

Fig. 4 shows a general view of the mobile complex for resistive strain gage measurements installed at the site.

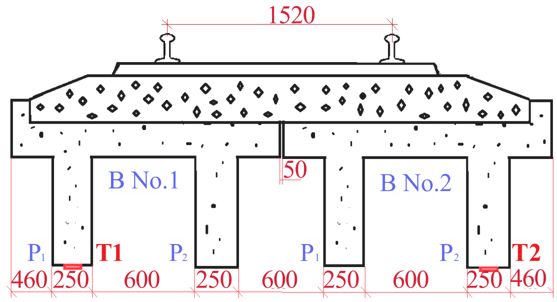

Fig. 3. Superstructure Cross-section with the layout of the measuring instruments: *B* No.1 and *B* No.2 – ribbed beam of the bridge span; P_1, P_2 – beam ribs; *T*1, *T*2 – resistive strain gage

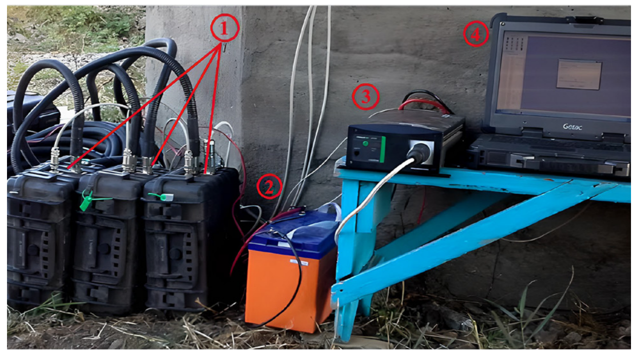

Fig. 4. Mobile complex general view for strain gauge measurements: 1 – measuring modules; 2 – storage battery; 3 – sine inverter; 4 – semi-industrial computer

This paper presents the modal analysis results of a reinforced concrete railway overpass according to the scheme 16.50+23.60+16.50 m (Fig. 5).

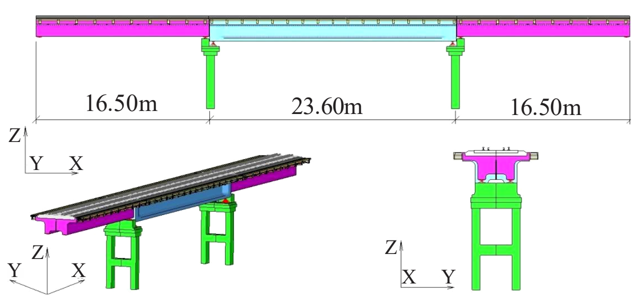

Fig. 5. General form finite element model of the overpass

The following design case is considered: «23.6 m blocks tension reinforcement + sole weight».

Forms and frequencies calculations of structure natural vibrations were carried out under preloading with constant loads «Blocks Reinforcement Tension of 23.6 m + sole weight».

The damage degree of the railway bridge superstructures can also be judged by the calculated values deviation amplitude – phase – frequency characteristics (AFC) from the standard values [10, 11].

Power spectral density (PSD) Graphical structure of the for signals obtained by seismometers determines the power distribution over frequencies having the dimensionality (mkm / sec^2)^2/Hz or mkm^2/sec^3 – accelerating, mkm^2/sec^2 – speed, mkm^2/sec – removement [3].

To determine the natural frequencies of the girder span, let's use the differential equation:

$$\frac{\partial^2}{\partial x^2}\left(EJ\frac{\partial^2 y}{\partial x^2}\right)+m\frac{\partial^2 y}{\partial t^2}=0.$$

Natural flexural vibrations frequencies:

$$f_n=\frac{\lambda_n^2}{2\pi l^2}\sqrt{\frac{EJ}{m}},\quad n=1,\ 2,3\ldots,$$

where λ_n is determined by the vibration mode number and the boundary conditions; l is the beam superstructure length; E is the material elasticity modulus; J – inertia moment; m is the beam linear mass. The main issue associated with modeling the interaction of the superstructure with damage and the rolling equipment passing through it is the numerical description of the damage.

The natural frequency f, in addition to the rigidity of the superstructure itself, is influenced by the mass of the structure m, which changes due to a change in the thickness of the layer of the laid ballast under the sleeper h_b.

On spans of railway bridges, for the same span, the thickness of the ballast layer can vary significantly.

The controlled parameters computed values, such as main beams stresses in the middle of the superstructure, could be determined by both engineering methods and using specialized computational software packages that implement finite element methods (ABAQUS/Standard, MIDAS Civil, APM Civi Engineering, APM Structure3D Module, Cosmos M). The privilege of using finite element models is the skill to simulate various malfunctions in the structure, adapting the calculation results to genuine operating conditions. By the deviation of the calculated values real stresses, one can judge the damage degree to the bridge superstructures [12].

The program for calculation by the finite element method ABAQUS/Standard was used. Fig. 5 shows the design model of a bridge consisting of 3 spans (16.5×23.6×16.5 m).

Modal analysis is shown below in Fig. 8–12.

5. Results of the study of the impact of the deformed state of the overpass on operational safety

5. 1. Determination of deformations in structures

Fig. 5 illustrates a complete record of flexural strain diagrams of the tensile zone in the middle part of the superstructure during the passage of the «assembly», and respectively Fig. 6–10 include fragments of the same composition highlighted in Roman numerals [9].

The assessment of the technical condition is carried out by comparing the values of the first natural frequency obtained from the results of field tests of the vibration parameters of girder spans of railway overpasses with the values of the first natural frequency (period) obtained by calculation on the models of defect-free girder spans.

The periodic measurements deformations of the of the superstructure within 2–3 years will make it possible to predict changes in its state over time and determine the residual life in terms of bearing capacity and carrying capacity.

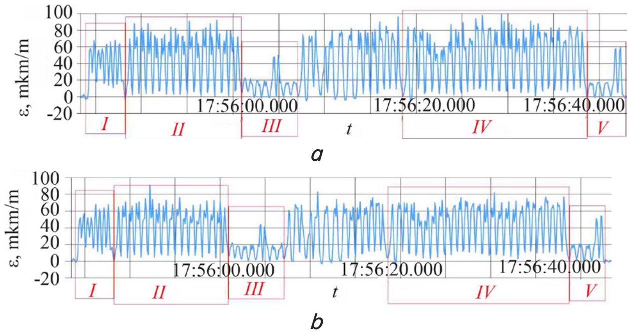

Fig. 6. Flexural deformation diagram when passing precast freight train (2 sectional, low-sided cars, tank cars, platform, etc.): *a* — the first edge beams No. 1; *b* — the second edge of the beam No. 2

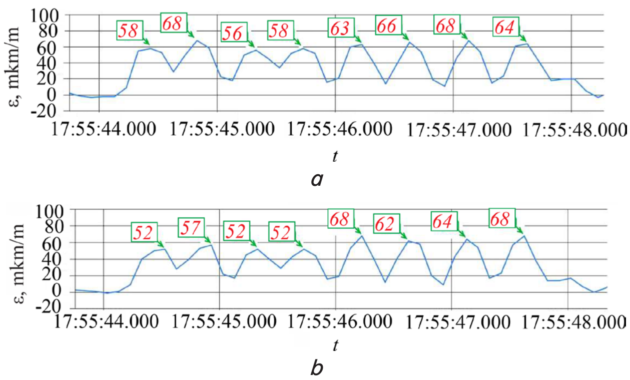

Fig. 7. Diagram of flexural deformations in the process the freight train passage (Fragment I — 2-section electric locomotive): *a* — on the first edge of No. 1 beam; *b* — on the second edge of No. 2 beam

5. 2. Determination of amplitude-phase-frequency characteristics of structures

The data obtained at this calculating the superstructure beam of the railway overpass by the shapes (modes) and frequencies of natural vibrations are summarized in Table 1.

Table 1

Forms and frequencies of construction blocks natural vibrations

Superstructure 23.60 m					
Form (fashion)	1st	2nd	3rd	4th	5th
Frequency Hz	4.56	6.00	7.67	7.92	9.15

The modal analysis results of the overpass are presented in Fig. 8–12:

– form 1. The first transverse flexural form (with one «bundle» in the plane of the path). «Bundle» is the section of the standing wave, the oscillations have the largest amplitude of oscillations, the frequency is 4.56 Hz (Fig. 8);

– form 2. The first vertical flexural form (for a of 23.6 m with one «bundle» in the vertical plane), frequency 6.00 Hz (Fig. 9);

– form 3. The second transverse oscillations flexural form (with two « bundles» in the track plane), frequency 7.67 Hz (Fig. 10);

– form 4. The second vertical flexural form similar in appearance to Form 1. The differences only in the direction of inclination of the support frames with the same shape of the 23.6 superstructure bend m «bundle» upwards, the frequency is 7.92 Hz (Fig. 11);

– form 5. The oscillations complex form – the 23.6 m superstructure twists around some longitudinal axis, thus on a top view one «bundle» from the bend in the track plane is distinguishable – torsional, frequency 9.15 Hz (Fig. 12).

Thus, the calculated vibration frequencies do not fall within the prohibited interval of less than 0.67 Hz [13, 14].

Experimental data concerning the frequencies and modes of natural vibrations obtained on the girder concrete slab spans of railway bridges correlate well with the results of the calculations outlined in this paper.

The design standards [15] regulate the periods (frequencies) of natural vibrations for girder spans of metal and steel reinforced concrete spans of railway bridges, as well as pedestrian and city bridges at the stages of calculation and installation.

The oscillations natural frequencies of the span, recorded below the passing load, will differ considerably the design frequencies due to the presence at this moment on the structure of a significant variable mass of the rolling stock. Taking into account that linear mass of metal spans of the elderly design norms lies within the range of 0.5–1.0 tf/m, and the distributed load the rolling stock circulating at the moment can exceed ten tf/m, it's impossible to register true structures vibrations natural frequencies of below the emotional train. That's why the natural frequencies of the structures vibrations are determined either by the «tails» of the experimental vibrograms (oscillograms) after the load has left the span structure or, if it's required to carry out express-diagnostics, to excite the process of the structures vibrations a concentrated mass pulse effect is applied in the center of the span structure (the method of tiny pulse effects – «human jump» Fig. 13) [16].

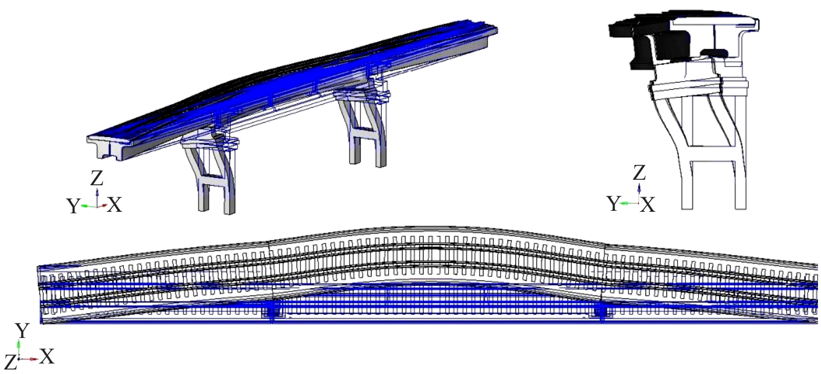

Fig. 8. Modal analysis 1st natural mode of vibration (frequency 4.56 Hz)

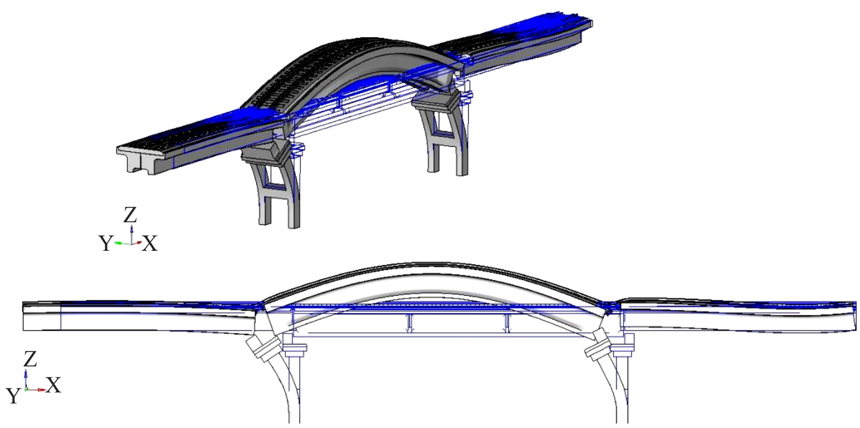

Fig. 9. Modal analysis 2nd natural mode of vibration (frequency 6.00 Hz)

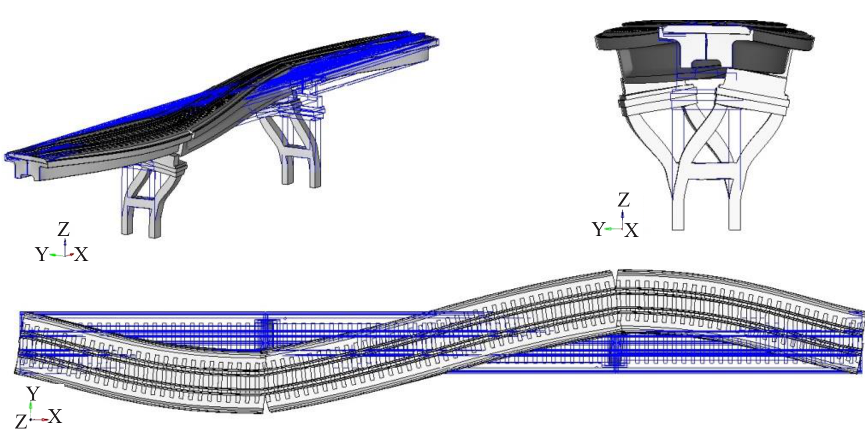

Fig. 10. Modal analysis 3rd natural mode of vibration (frequency 7.67 Hz)

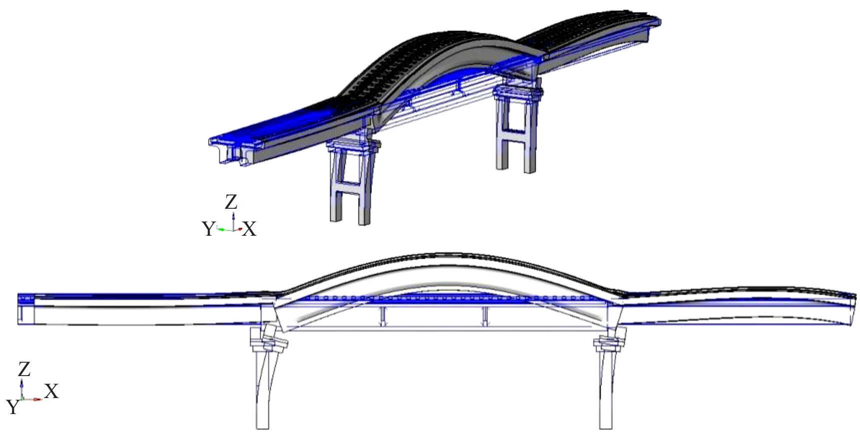

Fig. 11. Modal analysis 4th natural mode of vibration (frequency 7.92 Hz)

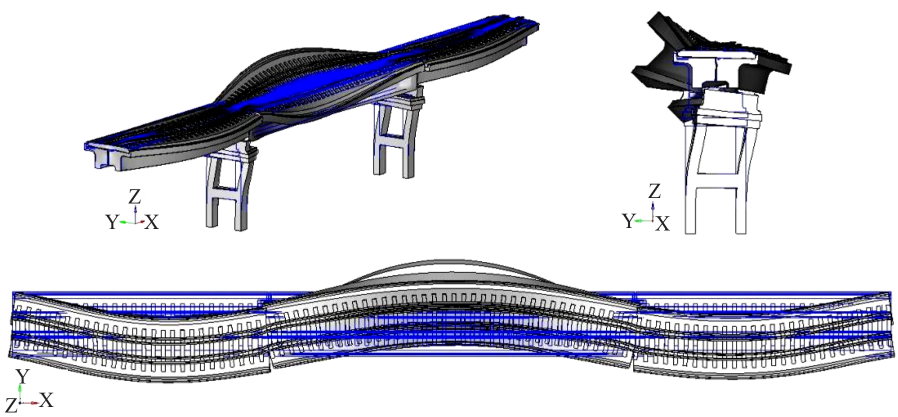

Fig. 12. Modal analysis 5th natural mode of vibration (frequency 9.15 Hz)

Vibrograms of natural vibrations are recorded with the help of special highly sensitive seismometers, which are part of the measuring-computer system for dynamic tests of structures (Fig. 13), installed in the middle of the span on the upper (or lower) belt of one of the metal beams. The decrease of natural frequencies can serve as an indicator of the technical condition of the structure. As an example, Fig. 13 shows the amplitude-time (*a*) and amplitude-frequency (*b*) vibration dependence of the girder metal span of a railway bridge span of 27 m, obtained under the influence of a jump of a man weighing 80–90 kg [15]. The measurements results with the of the over complexes can be presented in the form of graphs of strain and stress changes (in case of the known real modulus of elasticity of the material), deflection diagrams, amplitude-time and amplitude-frequency dependences of movements, speeds and accelerations of the vibration process, as well as stored in digital form in the [5].

Consequently, there is an opportunity of periodic monitoring of span structures with the assessment of the dynamics of its change. Naturally for elderly structures there is number data on the initial state, but on the newly built structures and structures after major repairs or reconstruction it's already possible to carry out comprehensive monitoring. In the future, a continuous automated monitoring system can be deployed on large and off-grade structures, particularly in case of unsatisfactory or emergency condition.

Table 2 shows the calculated values of natural vibration frequencies for reinforced concrete spans from 6 m to 16.6 m, defect-free and having defects.

Cracks shall be modeled by attaching an additional point mass to the beam, leads to a decrease in the natural frequency, the same as when a crack appears.

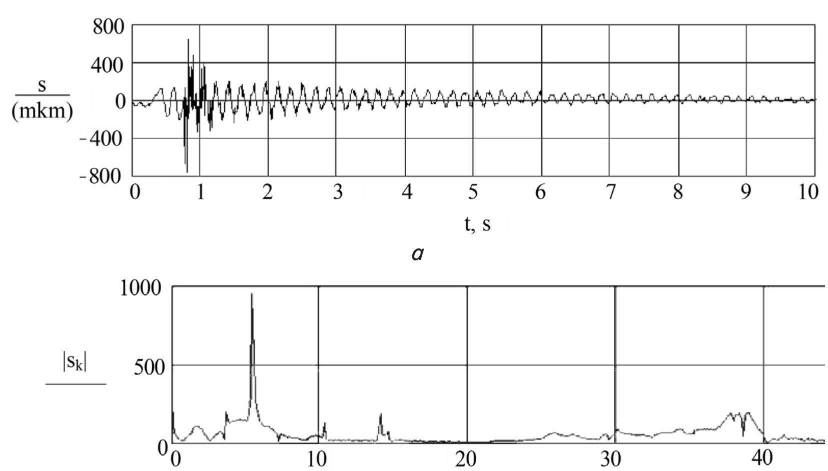

Fig. 13. Oscillogram and its spectrum from a human jump (maximum spectral emission at a frequency of 5.47 Hz): *a* — amplitude-time dependence; *b* — amplitude-frequency dependence

Table 2

Calculated values of reinforced concrete beam superstructures natural frequencies

Span, m	Frequencies, Hz			
	hb=0.25 m	hb=0.35 m	hb=0.50 m	hb=0.65 m
16.6	Defect-free superstructure			
	6.76	6.08	5.70	5.08
	Transverse and oblique cracks in superstructure concrete			
	5.18	4.76	4.21	3.85

The frequencies are defined at the thickness values of the ballast layer under the tie h_b=0.25÷0.65 m. Intermediate values of the frequency at the corresponding thickness of the ballast layer under the tie h_bs can be determined by linear interpolation.

Tables 3–5 show the design characteristics of reinforced concrete and metal girder spans with and without defects.

Table 3

Comparison of defect-free and defective reinforced concrete girder spans design characteristics

Description	Defect-free superstructure	Lack of a protective layer of concrete and corrosion of the working reinforcement of the superstructure
Reinforced concrete beam 16.6 m		
Tension in the upper belt, MPa	–2.901	–4.024
Tension in the lower belt, MPa	2.728	4.162
First natural frequency, Hz/Period, s	6.76/0.148	5.08/0.197

Table 4

Frequencies of natural oscillations of beam reinforced concrete superstructures obtained experimentally

Estimated span, m	16.6	
Ballast thickness, m	0.25	0.65
PS weight, kN	2130	3080
Frequency, Hz	6.20	4.98

Table 5

Comparison of experimental data of reinforced concrete beams

Characteristic	Defect-free superstructure	Span structure with an increased layer of ballast under the sleepers
Reinforced concrete beam 16.6 m		
Stress in the upper belt, MPa	–5.47	–7.11
Stress in the lower belt, MPa	6.84	7.89
First natural frequency, Hz/Period, s	6.20/0.161	4.98/0.201

Ulcerous corrosion, corrosion damage of main superstructure span beams, disorder or absence of rivets and high-strength bolts, fatigue cracks or piercing cracks are also modeled by attaching additional point mass to the beam resulting in a decrease in natural frequency, and the greater the point mass, the more significant the defect.

6. Discussion of the results of the study of the stress-strain state of the overpass

Fig. 6 shows that the deformations from the impact of loaded low-sided cars (fragment IV) are 1.5–1.6 times higher than the deformations from the impact of locomotives (fragment I). This case is explained, first of all, by the difference in wheelbases and axle loads of locomotives and cars and, as a result, by the different nature of their influence on the structure. The wheelbase of the four-axle low-sided cars is 1.85 m and wheelbase of the electric locomotives is 2.6 m and 3.0 m, respectively [4].

Fig. 7 (I fragment in Fig. 6) represents the passage of 2-section electric locomotives along the superstructure is shown in more detail with the quantitative values of deformations. From the above diagram, it can be seen that the difference between the deformations caused by the force action of these locomotives reaches 16–20 %, with the difference between the axle loads of the (25 tf) and (24 tf) locomotives, only in 4 % [11]. This case is also explained by the distances variety between the wheelsets (base) axles the of the biaxial low-sided cars and the location of the load on the superstructure – for the electric locomotive bogies, this distance, as already noted above, is 2.6 m, and for the bogies – 3.0 m [13].

Along with this, the greatest deformations are surveyed when the middle part of the electric locomotives biaxial bogie are placed above the superstructure measured section (the axial load is located symmetrically relative to the middle part of the span), and the smallest when the middle parts of their sections (the middle of the base) and the coupling between them are located. As the section base of the electric locomotive (7.5 m) is less than the base of the section (8.5 m), the smallest deformations quantitative values when its middle sections are located above the section exceed the smallest deformations when the middle of the sections are located above the section [15].

Modification analisys in natural frequencies leads to the following conclusions:

– in case if natural frequency dropped, then a dangerous section appeared;

– if for the 2nd frequency there is a small drop, and for the 3rd – a large one, then the dangerous section is in the middle of the beam;

– if the drop of the 3rd frequency is small and the 4th frequency is large at the same time, then the dangerous section is at a distance of 1/3 from one of the supports;

– if the drop of all frequencies is large at the same time, then the dangerous section is located near the supports.

The railway bridges operating experience proves that in the areas where the track adjoins the bridges in front of the abutments, so-called «bridge pits» are formed, i. e., there is a progressive accumulation of residual deformations in the ballast layer and earthwork. An accumulation of residual deformations has significant role in the in the ballast layer and earthwork by the fact that the drainages behind the cupboard walls of the abutments, as a rule, are not cleaned from the moment the facility is built, and the water behind the abutments abundantly wets the earthwork main area, that contributes to the sediment appearance directly behind the basements. These deformations consequence are «hanging» cross sleepers, under which free movement (gaps) up to 5–10 mm are formed, causing shock effects during the passage of trains, especially at high speeds. One of the main reasons for bridge superstructures damage can be deemed the increased dynamics of the rolling equipment impact that occurs due to the sharp impacts of the locomotive and cars at the entrance to the bridge [16].

The problem of transition sites is now so significant that many countries are trying to address it in a variety of ways.

The disadvantages include the lack of joint work with the main load-bearing structures of the bridge deck and track superstructure elements, which affects the accuracy of solving the problem of determining the natural frequencies and stresses occurring in the structural elements of the railway overpass. The solution to this problem was proposed to the operating service to eliminate on the track poor fixing of the intermediate bracing, sagging sleepers before full-scale tests.

Analysis of the calculated value of the first natural frequency allows to conclude that it is possible to use the first natural purity to determine the presence or absence of a defect in the span structure [17, 18].

Comparison of measured and calculated values of natural frequencies allows to determine the presence of damage in the girder spans and can serve as a basis for the methodology of rapid assessment of the technical condition of girder spans of the operated railway overpasses.

7. Conclusions

1. Relative deformations (stresses) on the first rib are 78–99 μm, on the second rib 59–82 μm (23000*59==1357000–1886000) of the ribbed girder span structure of the railway bridge in the middle of the span 16,6 m long.

2. The first frequency (period) of natural oscillations of beam reinforced concrete superstructures with a length of 6.0–16.6 m is in the range of 18.95 Hz (period 0.150) of railway bridge.

The assessment of the technical condition is carried out by comparing the values of the first natural frequency obtained from the results of full-scale tests of the oscillation parameters of beam spans of railway overpasses with the values of the first natural frequency (period) obtained by calculation on models of defect-free beam spans.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has data included as electronic supplementary material.

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