MEASUREMENT OF DEFORMATIONS OF BEAM SPANS OF BRIDGES

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ABSTRACT

The necessity of application of mobile measuring and computing systems for diagnosing bridges is shown, as well as an analysis of the results of measurements of flexural deformations and natural vibration frequencies of a beam reinforced concrete spanning structure of a railway bridge during the movement of a train is provided.

Keywords: bridge, span structure, deformation, diagnostics, monitoring.

Background. *Artificial structures of the transport industry in terms of strength, reliability, stability, economy of service and service life must meet the current technical requirements and ensure handling of existing and future loads with the established speeds.*

Numerous cases of deformation of artificial structures with increasing axial loads and speeds of movement pose the task of timely revealing the nature and causes of defects in the elements of the structure. This is due to the fact that the destruction and accidents that occur due to deformation processes cause huge economic, social and environmental damage incomparable with the means spent on protective measures.

The conditions for carrying train loads along bridges are established by comparing the classes of elements of span structures specified in the guidelines for determining the load capacity of bridges [1–3], with the classes of handled rolling stock given in [4]. The span structures in determining their load capacity are tested in accordance with SNiP [5], if it is necessary to clarify the actual stress state of the elements, as well as in the presence of defects and damages, the effect of which on load-carrying capacity is difficult to take into account theoretically.

Objective. *The objective of the author is to consider deformations of beam spans of bridges and its measurements.*

Methods. *The author uses general scientific and engineering methods, mathematical calculation, graph construction.*

Results. *In 2013 in Kazakh Academy of Transport and Communications was created a research laboratory «Trials of tracks and artificial structures (IPiIS)». The need for its creation is caused by the acute need of the structural units of JSC NC KTZH, responsible for maintenance of the infrastructure.*

Two years later the laboratory was accredited in the accreditation system of the Republic of Kazakhstan for compliance with the requirements of ST RK ISO / IEC17025–2007 «General requirements for the competence of testing and calibration laboratories» (certificate No. KZ.I.02.1656 dated 27.10.2015).

At present the laboratory is equipped with modern instruments and equipment. The main activities for it are:

– inspection and testing of bridge structures, culverts and other artificial structures on railways and highways, assessing the technical condition and determining the conditions for carrying the train load, developing recommendations for eliminating malfunctions and extending the safe operation period of the structure;

– training, specialization and internship of bridge specialists;

– field and laboratory studies of grounds of foundation bases of existing and projected buildings and structures;

– improvement and introduction of precision (high-precision) methods of measuring deformations and vibrations;

– realization of quality control of construction and reconstruction of artificial structures and subgrade;

– vibrodiagnostics and monitoring of the railway track and artificial structures in transport.

The existing equipment provides a high degree of fault tolerance and noise immunity of the measuring instruments and communication lines used, the possibility of expanding the configuration of the connected measuring devices (sensors), their application in the monitoring system, automatic recognition and diagnostics of objects.

With the help of laboratory equipment it is possible to produce:

– measurement of stresses and relative deformations in the elements of span structures of bridges under the influence of rolling stock simultaneously in 16 sections with the length of the measuring path up to 500 m;

– measurement of the dynamic characteristics of bridges under the action of rolling stock simultaneously in 8 sections with the length of the measuring path up to 250 m;

– plotting of deflection curves and determination of the maximum dynamic coefficients of span structures of bridges under the influence of rolling stock;

– determination of the periods (frequencies) of own (free) oscillations of the span structures of bridges;

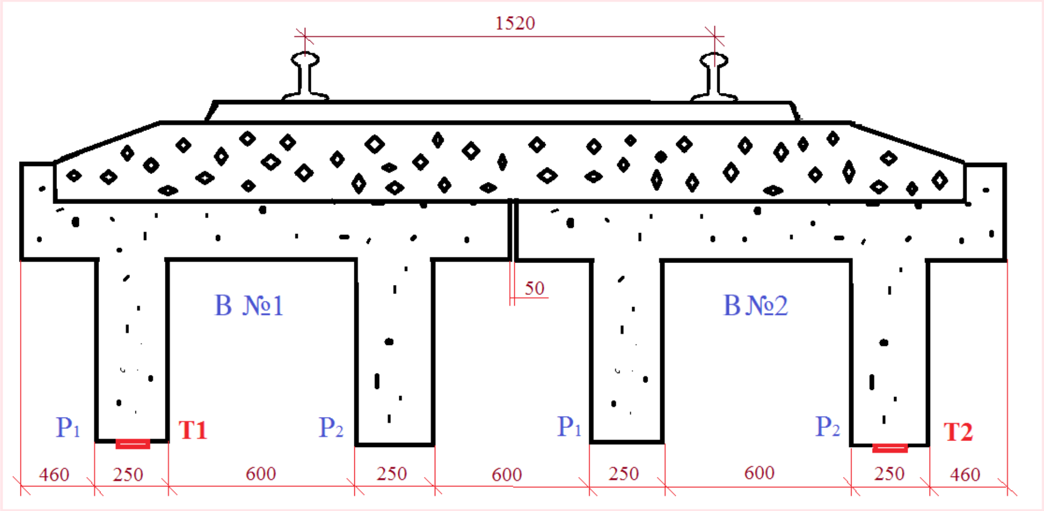
– determination of the amplitude-frequency characteristics of span structures of bridges in vertical, horizontal-transverse and horizontal-longitudinal directions;

– assessment of the impact of rolling stock on approaching embankments and roadbed.

Identification and analysis of the conditions under which the dynamic deformations and displacements in the «bridge-train» system have the most unfavorable character in operation, was consider by professor N. G. Bondar as a paramount task to be studied within the framework of the problem of interaction of bridges and rolling stock [7].

Since the load from the rolling stock is concentrated at the locations of the axles of bogies, the deflections of the span structure at each moment of time will correspond to flexural deformations and it is always possible to find its two positions giving the greatest and the least static deflections of the span structure.

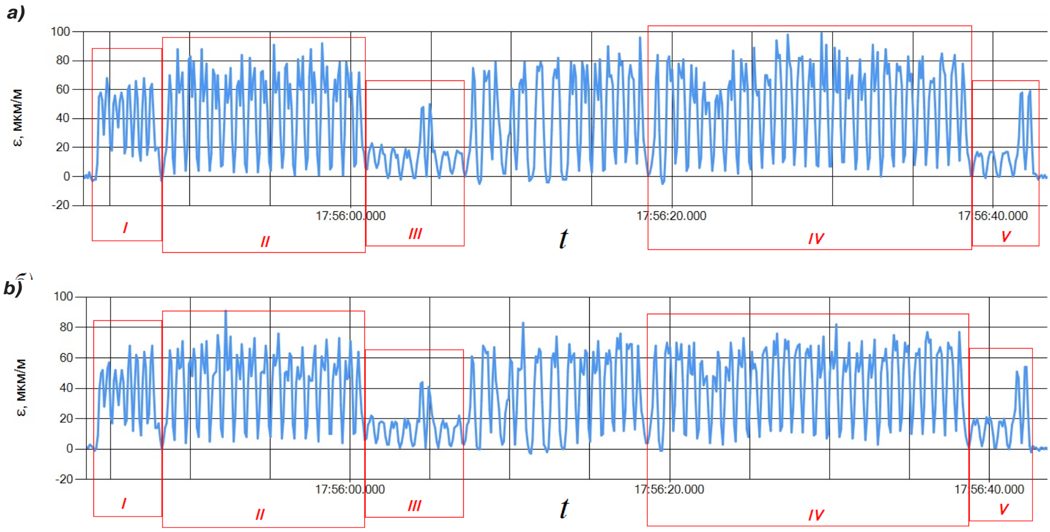
From measured values of flexural deformations, knowing the concrete class and the design modulus



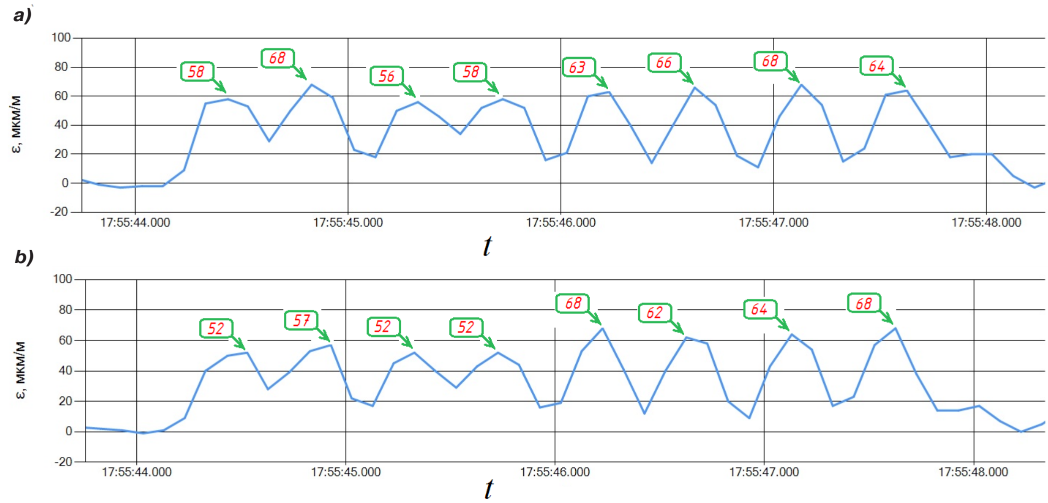
Pic. 1. Cross section of the span structure with the layout of the measuring instruments: B № 1 and B № 2 – a ribbed beam of the span structure of the bridge; P_1 and P_2 – edges of the beam; T1, T2, – strain gauges.

Pic. 2. Strain gages FLM-60–11 with a protective coating from climatic influences on the lower edges of the edges of the plates.

Pic. 3. General view of the mobile complex for tensometric measurements: 1 – measuring modules; 2 – rechargeable battery; 3 – sinusoidal inverter; 4 – a semi-industrial computer.



Pic. 4. Diagram of flexural deformations in the passage of the modular freight train (2-section electric locomotive VL-80 c + KZ-8A, gondola cars, tanks, platforms, etc.): a – on the first edge of beam № 1; b – on the second edge of beam № 2.



Pic. 5. Diagram of bending deformations in the passage of the modular freight train (fragment I – 2-section electric locomotive VL-80^c + KZ-8A): a – on the first edge of the beam № 1; b – on the second edge of beam № 2.

of the structural material, according to Hooke's law, one can make a transition to the actual stresses in the bridge design.

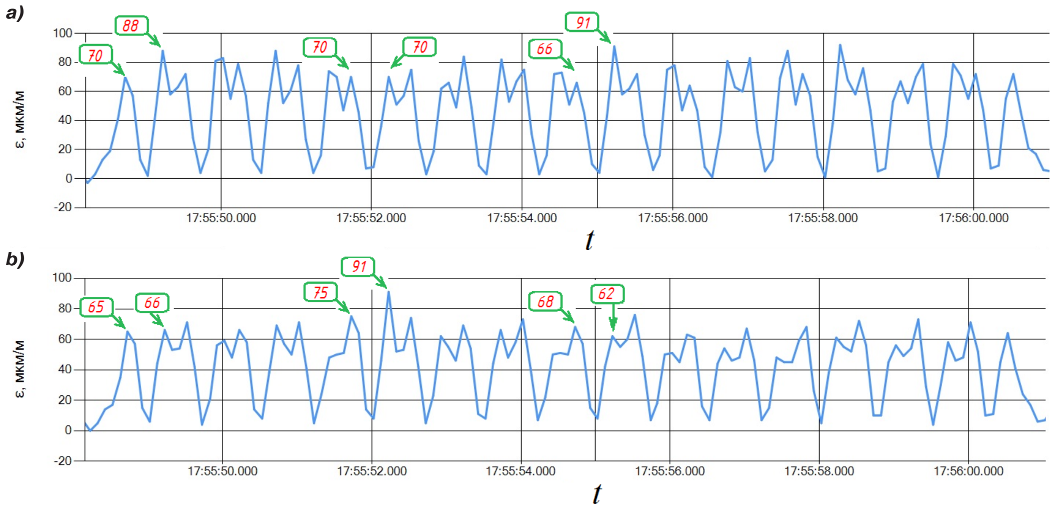
As an illustration of the capabilities of the mobile complex for tensometry, some results of measurements of relative flexural deformations of the ferroconcrete flight structure of the railway bridge located on the 118th km of the PK-6 line Astana–Pavlodar are shown below when passing a train consisting of mobile units of various types (the so-called «assembly»). The train passed with a decrease in speed from 70 km / h at the entrance to the bridge to 61 km / h when leaving the bridge and consisted of loaded and empty cars, gondola cars, cisterns, platforms, bunkers in the amount of 74 units. The towing force was electric locomotives VL-80^c and KZ-8A.

The span structure consists of two ribbed plates 6 m long. Pic. 1 shows the cross section of the structure with an indication of the locations of the strain gages on the structural elements.

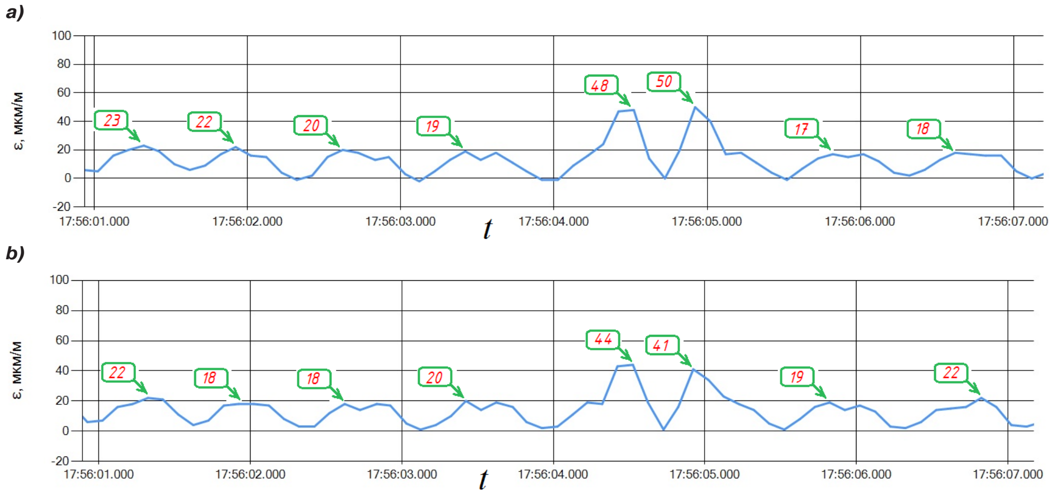
To further determine the change in the stress-strain state of the structure from the effects of climate factors (alternating freezing and thawing) and the rolling stock operated on this site, the FLM-60–11 tensometric sensors installed on the structure are protected from external environmental influences (Pic. 2).

Periodic measurement of the deformations of the structure of the span structure within 2–3 years will make it possible to predict the change in its state in time and determine the remaining life by bearing capacity and carrying capacity.

Pic. 4 shows a complete record of the flexural deformation diagram of the stretched zone in the middle part of the span at the passage of the «assembly», and Pic. 5–9 highlighted in Roman



Pic. 6. Diagram of bending deformations in the passage of the modular freight train (fragment II – loaded gondola cars and bunkers): a – on the first edge of the beam № 1; b – on the second edge of beam № 2.



Pic. 7. Diagram of bending deformations in the passage of the modular freight train (fragment III – platform and gondola car): a– on the first edge of the beam № 1; b –on the second edge of beam № 2.

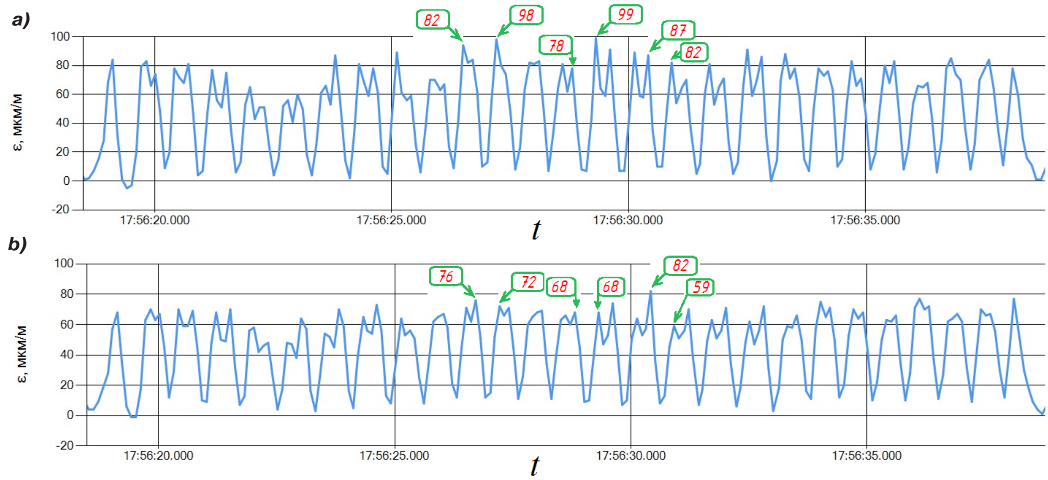
numerals in Pic. 4 fragments of this record, in more detail and visually illustrating the nature of deformations under the influence of mobile units of various types.

From Pic. 4 it follows that the deformations from the impact of laden gondola cars (fragment IV) are 1,5–1,6 times higher than the deformations from the action of locomotives (fragment I). This circumstance is due primarily to the difference in the bases of bogies and axle loads of locomotives and cars and, as a consequence, by the different nature of their influence on the structure. The base of the bogie of four-axle gondola cars is 1,85 m, and the base of electric locomotives KZ-8A and VL-80^c is 2,6 m and 3,0 m respectively.

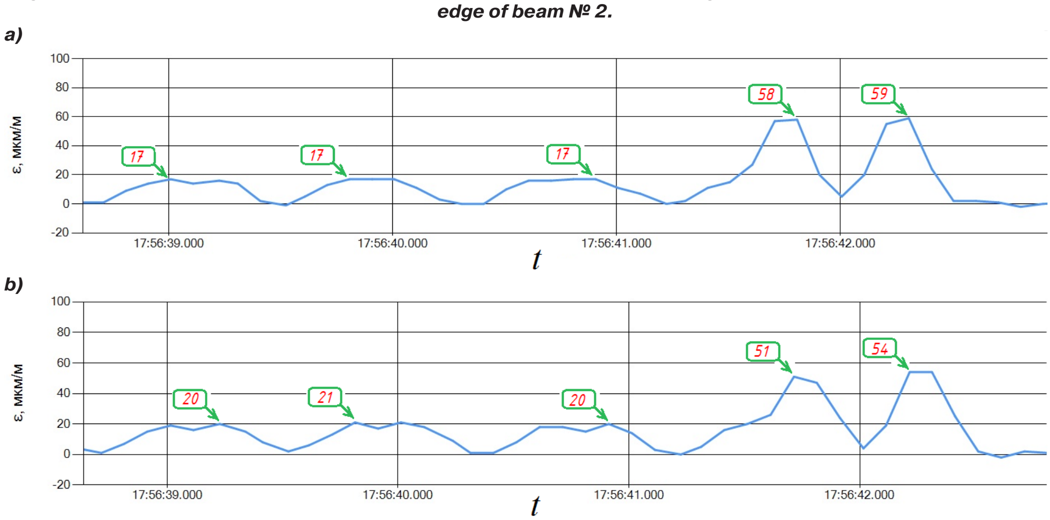
In Pic. 5 (fragment I in Pic. 4) the passage of 2-section electric locomotives VL-80^c and KZ-8A over the span structure is shown in more detail with demonstration of quantitative values of deformations. It can be seen from the diagram that the difference between the deformations caused by the force action of the locomotives reaches 16–20 %, with the difference between the loads on the axis of the locomotives KZ-8A (25 tf) and VL-80^c (24 tf) in only 4 %.

This circumstance is also explained by the difference in the distances between the axes of the wheel sets (base) of the biaxial bogie and the location of the load on the span structure–for the bogie of the electric locomotive KZ-8A this distance, as already mentioned, is 2,6 m, and for the VL-80^c – 3,0 m.

And the greatest deformations are observed when the overlying section of the middle section of the biaxial bogie of electric locomotives is located above the measured section (axial load is located symmetrically relative to the middle part of the span), while the smallest ones are located at the middle parts of their sections (middle of the base) and the coupling between them. Since the base of the section of the VL-80^c electric locomotive (7,5 m) is smaller than the base of the section KZ-8A (8,5 m), the quantitative values of the smallest deformations at the location of its section centers



Pic. 8. Diagram of flexural deformations in the passage of the modular freight train (fragment IV – loaded gondola cars, bunkers, tanks in the middle of the train): a – on the first edge of beam № 1; b –on the second edge of beam № 2.



Pic. 9. Diagram of bending deformations in the passage of a modular freight train (fragment V – empty platforms and loaded gondola car): a – on the first edge of the beam № 1; b – on the second edge of beam № 2.

above the section exceed the smallest deformations at the location above the cross-section of section centers of KZ-8A.

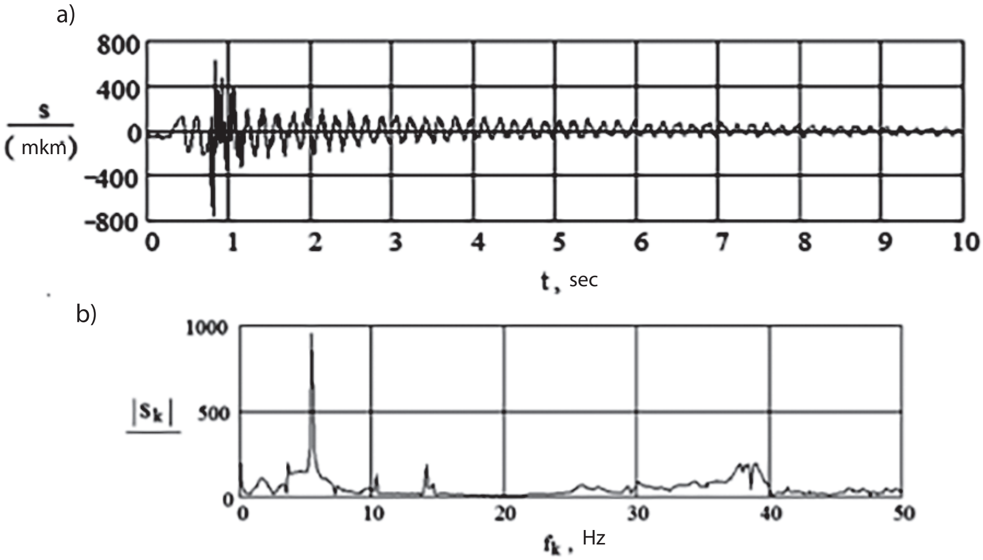
Pic. 6 (fragment II in Pic. 4) shows in more detail the passage of loaded gondola cars and bunkers located in the head of the train. One can clearly define the number of mobile units (in this case, 14 gondola cars and 2 bunkers), and deformation of the span structure caused by the action of each individual bogie. It can be seen that bending deformations qualitatively and quantitatively differ from deformations in the passage of locomotives and have a slightly different character.

Firstly, the smallest deformations at the location above the cross-section of the middle part of gondola cars are much less in size than the analogous effects from locomotives, since the base of gondola cars is 8,65 m, and here the factor of the speed of the train has the greatest influence.

Secondly (and this is clearly demonstrated by the quantitative parameters of the greatest deformations from the impact of the bogies of the 1st, 5th and 9th gondola cars shown on the diagram), it is different as the effect of the bogies of these gondola cars on the fins symmetrically located relative to bridge axis of U-shaped ribbed plates in the cross section of the bridge, and the front and rear bogies of each gondola car separately.

Here, in addition to the change in acceleration during the movement of the train, the displacement of the center of mass caused by the oscillations of the supersorbing part of the carriage across («hunting» and «lateral rolling») and along («galloping») the axle of the bridge, as well as the uneven loading of gondola cars and bunkers, can be affected.

Pic. 7 (fragment III in Pic. 4) shows that empty platforms cause relatively small deformations of the span structure (3–4 times less than loaded gondola cars), and the gondola car is loaded by 60–70 %. The smallest deformations reach zero values, that is, a process of cyclic loading and complete unloading of the structure takes place. It should be noted that the deformations from the gondola cars are different in the longitudinal and transverse directions.



Pic. 10. Oscillogram and its spectrum from human jump (maximum spectral emission at a frequency of 5,47 Hz).

The diagram shown in Pic. 8 (fragment IV in Pic. 4), is even more complex, since it is a record of the effect of mobile units of various types.

Pic. 9 (fragment V in Pic. 4) shows the process of deformation of the span structure at the exit of the train. It is seen that the smallest deformations are not instantaneous, that is, there is complete unloading of the structure over a certain period of time.

The base of the platform (8,72 m) slightly exceeds the base of the gondola car (8,65 m), and here, in addition to the rigidity of the structure, the influence of the speed and load factors on the axis in the time aspect of the interaction of the bridge with the rolling stock (for comparison, see Pic. 7 – fragment III in Pic. 4).

The calculated values of such controlled parameters as the stresses in the main beams in the middle of the span can be determined both by engineering methods and by means of specialized computational software that implements finite element methods (MIDAS Civil, APM Civil Engineering, APM Structure3D module, Cosmos M). The advantage of using finite element models is the ability to simulate various malfunctions in a design, adapting the calculation results to actual operating conditions. By deviating the actual stresses from the calculated values, it is possible to judge about the degree of damage to the structures of the span structure of the bridge.

Periodic measurement of the deformations of the structure of the span structure within 2–3 years will make it possible to predict the change in its state in time and determine the remaining life by bearing capacity and carrying capacity.

*Norms of design [6, paragraph 1.48 *] regulate the periods (frequencies) of natural oscillations for beam cross-section metal and steel-fiber span structures of railway bridges, as well as pedestrian and city bridges at the stages of calculation and erection.*

The natural frequencies of the oscillations of the span structure recorded under the passing load will differ significantly from the design frequencies due to the presence at that time of the design of a significant variable mass of the rolling stock. Taking into account that the linear mass of metal span structures of old design standards lies in the range 0,5–1,0 tf / m, and the distributed load from the currently rolling stock can exceed 10 tf / m, fix the true natural vibration frequencies of the structures under the moving train is not possible. Therefore, the natural vibration frequencies of the structures are determined either by the «tails» of the experimental oscillograms after the departure of the load from the span structure, or during rapid diagnostics for the excitation of the process of structural oscillations, a pulsed action of a concentrated low-mass cargo in the middle of the span structure (the method of small impulse actions – «jump of the person»).

As an example, Pic. 10 shows the amplitude-time (a) and amplitude-frequency (b) dependence of the oscillations of the beam metal span structure of the railway bridge across the river Sarybulak railway line Ainabulak–Almaty span 27 m, obtained by the impact of a man's jump weighing 80–90 kg.

The methods for determining the natural frequencies of oscillations of beam span structures along the «tails» of the experimental vibrations and small impulse actions have been tested and widely used, for example, in the practice of diagnosing road and railway bridges by specialists of TsNIIS [8], MADI [9] and SGUPS [10].

Vibrograms of natural oscillations are recorded with the help of special highly sensitive seismometers that are part of a measuring and computing complex for dynamic testing of structures installed in the middle of a span on the upper (or lower) belt of one of the metal beams. Reduction of the natural frequencies of oscillations can serve as an indicator of the technical state of the structure.

The results of measurements made with the use of complexes can be visualized in the form of graphs of changes in deformations and stresses (in the case of the known actual elasticity modulus of the material), deflection patterns, amplitude-time and amplitude-frequency dependences of *displacements, velocities, and accelerations of the oscillatory process. The obtained characteristics can serve as initial data that increase the accuracy of calculation in the development of the model of the structure and the formation of algorithms for damage detection.*

Some results of full-scale experimental scientific research of laboratory staff were published in publications included in the Russian Scientific Citation Index (RINC) and collections of materials of international scientific and practical conferences (in which the laboratory staff participated and made presentations) published in the Republic of Kazakhstan and abroad [11–16].

Conclusions. *For the most effective assessment of the reliability of bridge structures and the correspondence between the design scheme and the actual operation of the structures, it is necessary to periodically monitor the stress-strain state of the structures under operational loads.*

Conducting periodic monitoring and vibro-diagnostics in the long term will allow:

1. To ensure the safety of the railway transport infrastructure in accordance with the requirements of the technical regulations of the Customs Union TR TS01/01/2012, 002/2011 and 003/2011.

2. Substantiate the possibility of increasing the speed of movement of the rolling stock and the load up to 27 tons / axis on the busiest lines.

3. Increase the service life and reduce costs for the current maintenance of the track and artificial structures.

4. To adopt the most optimal design solutions for the design and reconstruction of track and artificial structures.

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