STUDY OF THE RESPONSE OF BEAM BRIDGES TO THE IMPACT OF A TRAIN

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ABSTRACT

The article presents the results of measurements of fluctuations of metal and reinforced concrete superstructures of railway bridges in the passage of the rolling stock with different speeds. The obtained data can be used to refine models of structures and to develop algorithms for damage detection.

Keywords: railway bridge, girder, amplitude and time dependence, vibration speed, vibration displacement, vibration acceleration, fast Fourier transform, frequency response.

Background. *In Europe, Asia and the United States numerous studies are conducted to evaluate technical condition and diagnostics of operated man-made structures by dynamic parameters. Especially remarkable breakthrough in this area occurred in the 90-ies of the last century, when powerful portable computers were created, and evaluation of vibration of the system by external forces has become affordable and accessible tool for practicing engineers.*

A monitoring system of bridges (Bridge Monitoring System «BRIMOS») [1], developed in Switzerland, is based on the fact that the condition of any structure can be estimated using parameters of the dynamic behavior. The so-called «dynamic autograph» (response) of the structure contains all information that is needed to conduct a detailed assessment of its condition. This technique is used widely to study the reaction of structures on such random effects, like wind, microseismic effects, transport movement on the bridge.

In Japan, the use of sophisticated monitoring systems is widespread, for which special hardware-software complexes of dynamic identification are developed and constantly improved. The dynamic identification of a system is determination of dynamic characteristics of a bridge or other engineering structure on information obtained during the registration of its oscillations. It should be noted that the number of publications on improving these techniques is not enough [2-6].

Simple and at the same time very effective method of selecting peak values of vibration spectra of bridge structures is based only on the analysis of spectra. In accordance with the requirements of the method own oscillation frequency is determined by peak values of averaged given power spectral density. For this case discrete Fourier transform of vibration displacement, vibration speed and vibration acceleration are used. The coherence function calculated for two simultaneously registered output signals, is similar to that of natural frequencies. This pattern helps also to find exactly those frequencies which can be considered as their own. This assumes that the dynamic response at resonance only refers to its own tone.

The method of selecting peak values does not require the use of complex algorithms for its implementation. In the framework of the method for building a graphical representation of the spectral density function, various modifications of fast Fourier transform are used, which are described in detail in the literature [7].

Objective. *The objective of the authors is to study interaction of bridge girders with rolling stock.*

Methods. *The authors use general scientific and engineering methods, simulation, evaluation approach.*

Results. *The objects of research outlined in this article are superstructures of bridge crossings across the canal Irtysh–Karaganda of a railway line Yereimentau-Ekibastuz (km. 257 PK 7+ 0) with metal beam (Pic. 1), (constructed in 1952) and with reinforced concrete beam (Pic. 3) (constructed in 1972), with respective superstructures' length of 27 m and 16 m.*

As a means of measurement a mobile vibration measurement complex was used, which includes a software package for data processing and visualization. Specifications, software, and signal processing methods are shown in detail in [8]. The studies were conducted in daytime, in summer, when rolling stock moved with velocities of 41-98 km/h.

Of particular interest were both amplitude and time dependence of vibration velocity, vibration displacement and vibration acceleration, as well as frequency response, determined by a corresponding graph of spectral density [9]. As an example, Pic. 5, 9, 13, show time dependence of vibration velocity, vibration displacement and vibration acceleration of a metal superstructure when a train of 10 cars moves at a speed of 98 km/h, and Pic. 7, 11, 15 – the same dependencies of a concrete span when a train of 8 cars moves at a speed of 61 km/h.

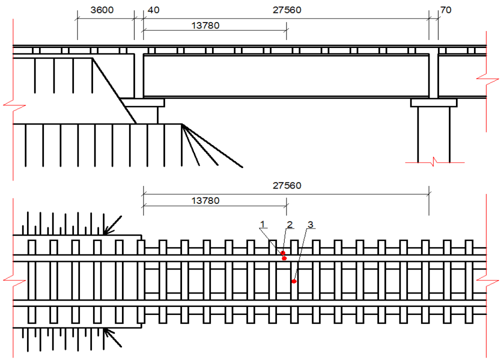
The corresponding graphs of spectral density are shown in Pic. 6, 8, 10, 12, 14, 16.

The analysis tests determined that the interaction of a metal girder superstructure with rolling stock is manifested mainly in disturbances, which frequencies are in the range of f = 5,34-7,27 Hz and reinforced concrete – in the range of f = 5,26-7,82 Hz. These disturbances determine, first of all, reaction of superstructures. The disturbances, which frequencies do not fall into these areas, as follows from the analysis of spectra do not play a special role in shaping the behavior of superstructures because their amplitudes are very small and the energy introduced in the system is negligible.

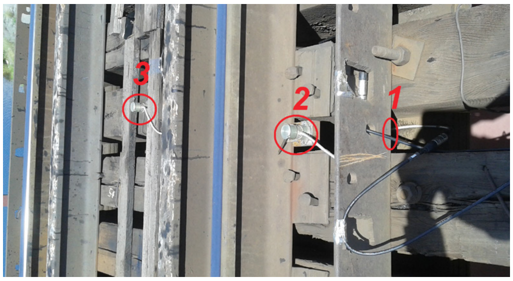
Analysis of experimental data characterizing the dynamic performance of bridges, allowed setting the parameters of free oscillations of unloaded spans.

According to the «tails» of experimental oscillogram, obtained after derailment (Pic. 17, 19) and spectra built on them (Pic. 18, 20), were determined frequencies of free oscillations of unloaded superstructures.

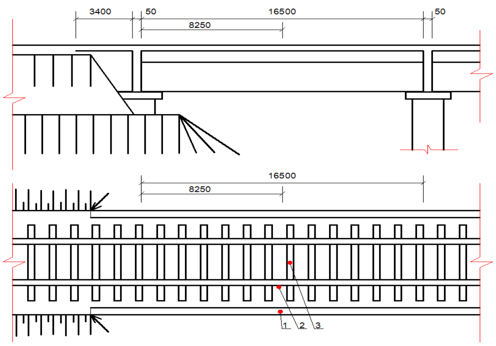
Kurbatsky, Evgeny N., Bondar, Ivan S., Kvashnin, Mikhail Ya. Study of the Response of Beam Bridges to the Impact of a Train



Pic. 1. Scheme of a metal superstructure with vibration sensors located on structural elements: 1 – middle of a beam span structure; 2 – rail base; 3 – middle of a sleeper.

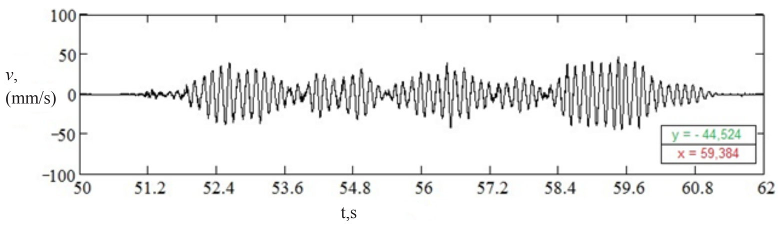


Pic. 2. General view of a metal superstructure with vibration sensors located on elements: 1 – middle of a beam span structure; 2 – rail base; 3 – middle of a sleeper.

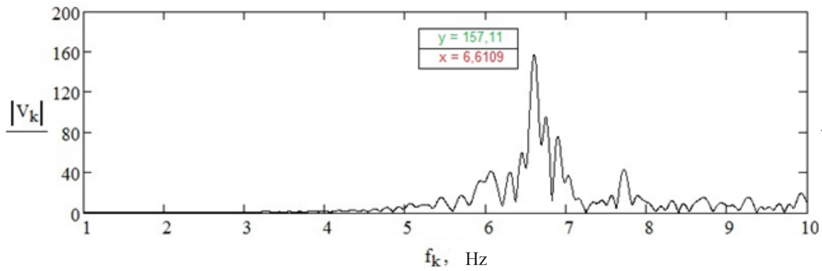


Pic. 3. Scheme of a reinforced concrete superstructure with vibration sensors located on structural elements: 1 – middle of a beam span structure; 2 – rail base; 3 – middle of a sleeper.

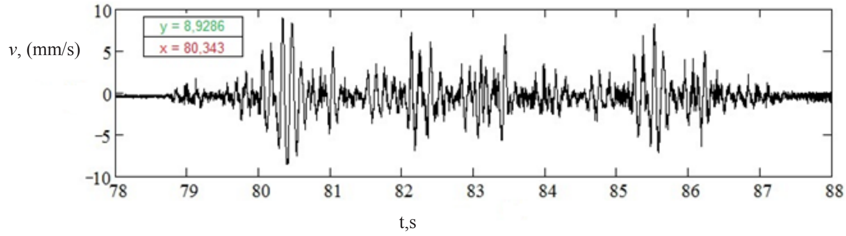
Pic. 4. General view of a concrete span with vibration sensors located on elements: 1 – middle of a beam span structure; 2 – rail base; 3 – middle of a sleeper.



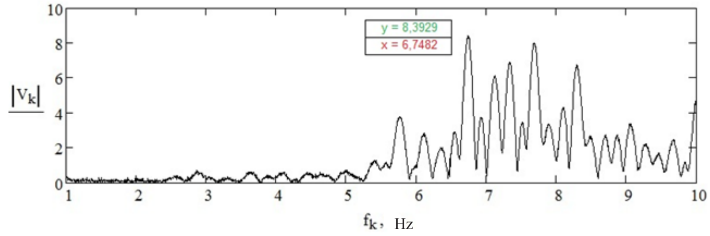
Pic. 5. Speed of vertical oscillations of a metal beam when a train of 10 cars moves at a speed of 98 km/h.



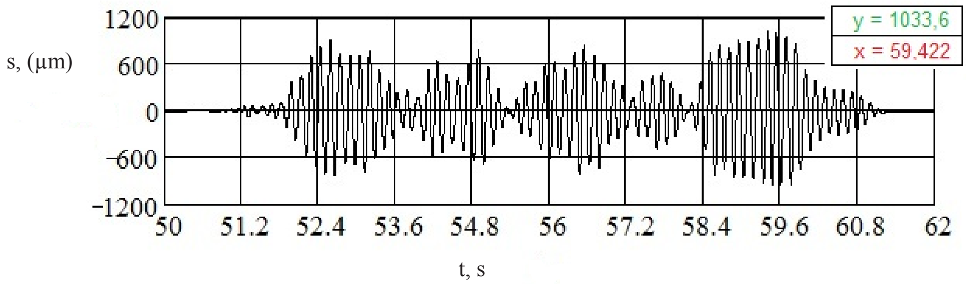
Pic. 6. The velocity spectrum of vertical oscillations of a metal beam.



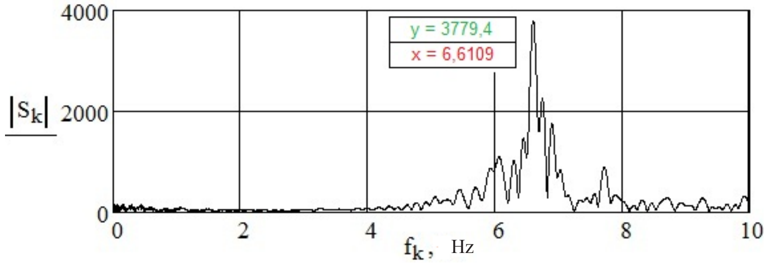
Pic. 7. Speed of vertical oscillations of a reinforced concrete beam when a train of 8 cars moves at a speed of 62 km/h.



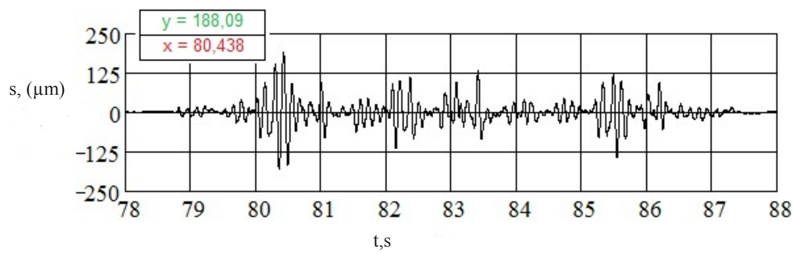
Pic. 8. The velocity spectrum of vertical oscillations of a reinforced concrete beam.



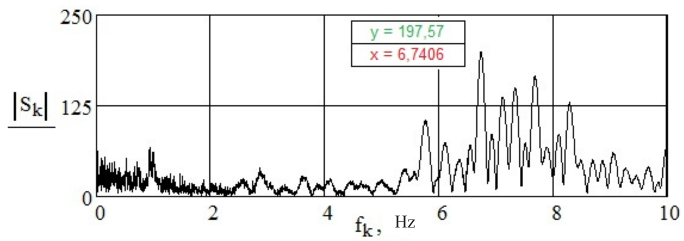
Pic. 9. Graph of vertical displacements of a metal beams when a train of 10 cars moves at a speed of 98 km/h.



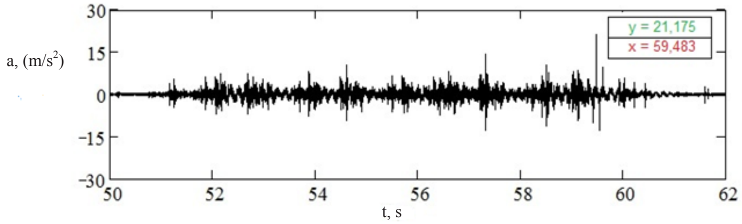
Pic. 10. The spectrum of vertical displacements of a metal beam.



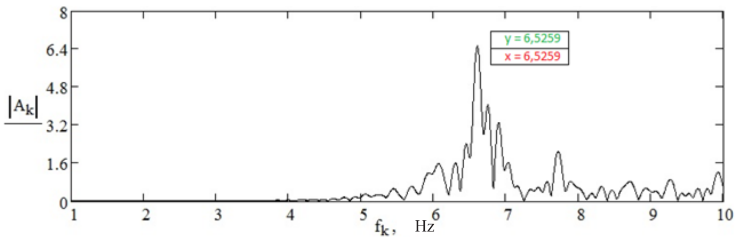
Pic. 11. Graph of vertical displacements of a reinforced concrete beam when a train of 8 cars moves at a speed of 62 km/h.



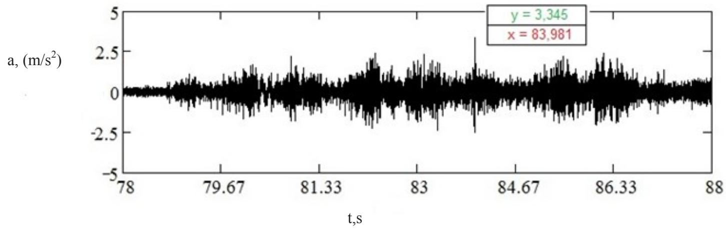
Pic. 12. The spectrum of vertical displacements of a reinforced concrete beam.



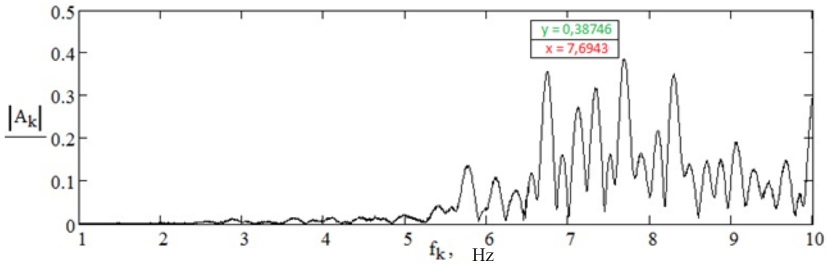
Pic. 13. Accelerogram of vertical oscillations of a metal beams when a train of 10 cars moves at a speed of 98 km/h.



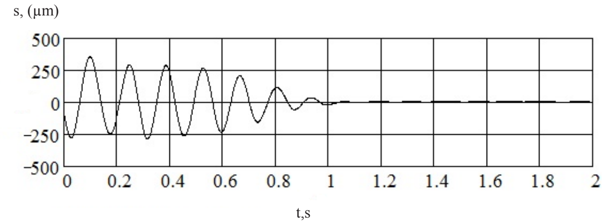
Pic. 14. The spectrum of acceleration of vertical oscillations of a metal beam.



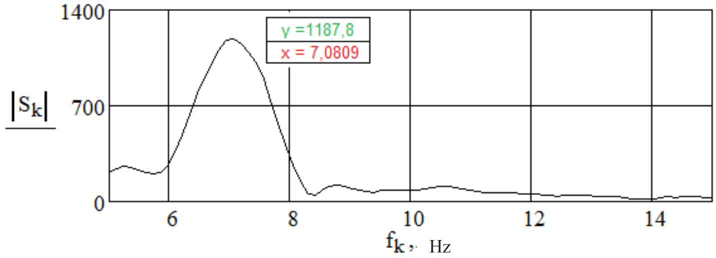
Pic. 15. Accelerogram of vertical oscillations of a reinforced concrete beam when a train of 8 cars moves at a speed of 62 km/h.



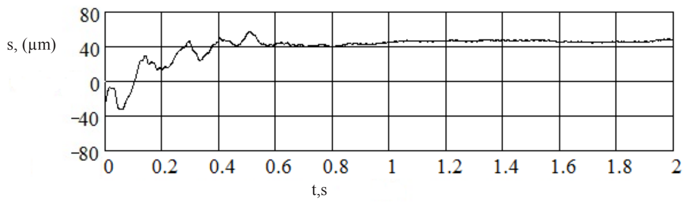
Pic. 16. The spectrum of acceleration of vertical vibrations of a reinforced concrete beam.



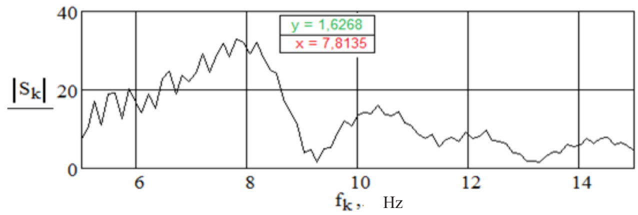
Pic. 17. Graph of free oscillations (displacement) of a metal beam after the disappearance of the load.



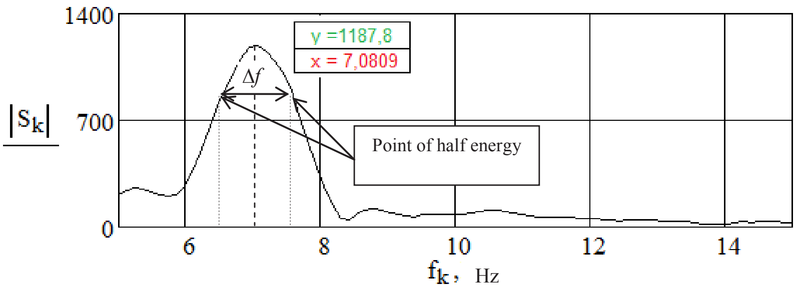
Pic. 18. The spectrum of free oscillations of a metal beam after the disappearance of the load.



Pic. 19. Graph of free oscillations (displacement) of a reinforced concrete beam.



Pic. 20. The spectrum of free oscillations of a reinforced concrete beam after the disappearance of the load.



Pic. 21. An example of the resonance curve indicating points of half energy

$$|S_k(f)| = \sqrt{1/2|S_k(f_0)|^2} = 0.707|S_k(f_0)|.$$

For metal and reinforced concrete beam spans, they are, respectively, f_m = 7,08 ± 0,35 Hz and $f_{r.c.}$ = 7,81 ± 0,39Hz.

Forms of spectral curves in the region of resonances can determine important characteristics under dynamic calculations – modal relative damping factor. Recall that the relative damping coefficient is equal to the ratio of actual damping to the critical. The relative damping factor, not the logarithmic decrement of oscillations, is regulated and used in the regulations on the calculation of structures on seismic effects.

The relative damping factor ξ in the performance of experimental work is determined on the width of spectral resonance curve at points of half energy (Pic. 21) according to the formula $\xi = \frac{\Delta f}{2 f_0}$. This parameter is the modal damping coefficient corresponding to frequency and form of natural vibrations. The frequency range between the points of half energy is often called a spectral width of the system.

The width of the spectrum at the points of half energy determines the property of the system to dissipate energy in vibrations. The increased width of the spectrum with vibrations of reinforced concrete structures indicates the presence of cracks in the concrete. For example, a relative factor for uncracked concrete beams is 3%, in the presence of cracks it is 5-7%.

In our research for metal beams, a wide range in the resonance frequency was obtained, which is equal to 7%, which means that energy dissipation occurs not only in the superstructure (in metal elements and compounds of the beam), but also in interaction with the upper structure and supports of a track: $\xi = \frac{\Delta f}{2 f_0} = \frac{1.05}{2 \cdot 7.08} = 0.07$. Typically, the relative damping coefficient at fluctuations of steel beams does not exceed 3%.

To assess the state of superstructures on the width of spectra in the resonance region it is necessary to know what part of energy is dissipated in the superstructure and what part – in the upper structure of the track or in supporting parts.

Conclusions. *From the analysis of field measurements of oscillation processes of beam spans it follows that the spectrum of these oscillations in the interaction of elements of the bridge with a moving train is multimodal. The frequency of individual components depends essentially on the speed of a train, and the bulk of energy of fluctuations accounts for harmonics corresponding to the frequencies of natural oscillations of the system «superstructure –railway track–rolling stock».*

To assess the state of superstructures it is possible to use the width of spectra at the points of half energy of the spectral curve in the resonance region. Comparing the width of the obtained spectrum with spectra of new undamaged spans, we can estimate the degree of wear and extent of damage to structural elements.

The resulting vibration characteristics of the system «superstructure – railway track–rolling stock» can serve as baseline data in calibration of a construction model and preparation of algorithms to detect damage.

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