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Stress-Strain State of Reinforced Concrete Overpass under Load



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ABSTRACT

Beam spans are the most vulnerable elements of the bridge system, as they are exposed to direct effects of mobile load, environmental and climatic factors (temperature and humidity effects, including freezing and thawing, shrinkage, humidity, etc.). Appearance of defects of the structure is inevitable; therefore civil engineers face a topical problem of strengthening of damaged structures of bridges. The article discusses some results of calculated values and instrumental measurements of stress-strain state (SSS) of reinforced concrete beam span structures of railway overpass under operational load caused by different rolling stock units. The objective of this study is to control stress-strain state of railway overpass for identification and elimination of defects at early stages. The calculation results obtained, carried out by finite-element method (FEM) in the program ABAQUS/Standard correlate well with experimental data. These results can be used for monitoring the state of artificial structures on main lines of JSC NC KTZ.

Keywords: *railway, overpass, beam spans, stress-strain state.*

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A bridge bed is the main load-bearing element that transfers loads transversely to supports, such as a longitudinal beam, transverse beams and stringers. Since the reinforced concrete beams of the bridge are directly affected by the moving (transport) load, as well as the natural and climatic factors – freezing and thawing, shrinkage and humidity, they are one of the most vulnerable elements in bridges, where damage (defects), such as cracks, chips of the protective layer of concrete and corrosion of steel reinforcement most often occur. In addition, constant (real) loads from overloaded vehicles, which are often found on the main railway lines of Kazakhstan and Russia, lead to serious fatigue damage to load-bearing reinforced concrete beams. Due to such situations, the average life of reinforced concrete beam spans of railway bridges is sharply reduced, and the cost of maintaining and technical services of bridges is constantly increasing.

At the end of the last century, several countries, such as Germany, the USA, Canada, Japan and Korea realized that the service life of reinforced concrete beams is crucial for the entire bridge, and studies of the stress-strain state of beam spans of reinforced concrete bridges began. The appearance of defects (chips and cracks in concrete, corrosion of reinforcement) of bridge structures during operation is inevitable, therefore, for civil engineers, the issue of strengthening of damaged bridge structures is still relevant [1, pp. 1705–1708; 2, pp. 484–513; 3, pp. 35–49].

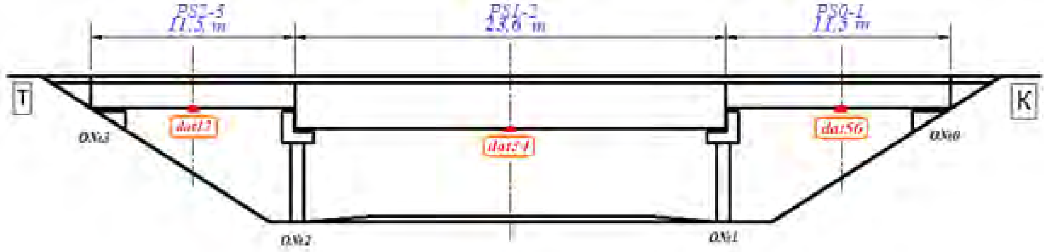
In a number of countries, it is customary to monitor artificial structures, timely eliminate defects (damage) in reinforced concrete beam span structures of bridges, and reinforce their structural elements with carbon fiber or composite materials [4, pp. 2769–780; 5, pp. 258–266; 6, pp. 302–310].

The following are the calculated and experimental results of determining the stress state of reinforced concrete beam spans of a railway overpass (Pic. 1) under the influence of known loads (a short train consisting of coupled TEM-18 locomotive and hopper-batcher car for crushed stone transportation, model 19–9870; triple-heading consisting of 3 diesel locomotives TEM-18), during static tests of the overpass.

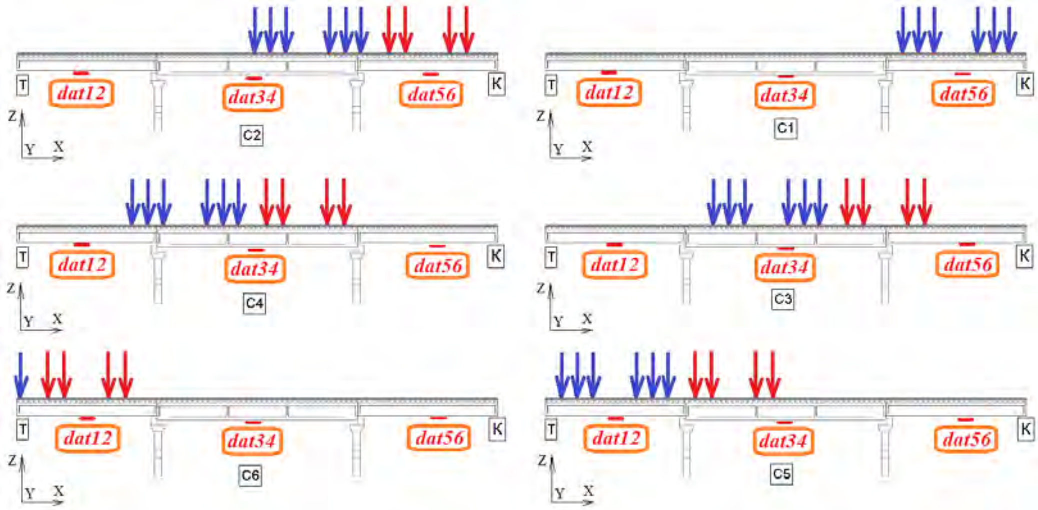
Static analysis results

The calculations of the stress state of the elements of the structure for given combinations of loads (design cases) were made [7, pp. 101–120].

In total, 12 design cases were considered: case 1 – P0. «Tension of reinforcement of blocks 23,6 m + dead weight»; case 2 – C1. «P0 + train (the middle of the locomotive is over the middle of PS0–1)»; case 3 – C2. «P0 + train (the middle of the car is above the middle of the PS0–1)»; case 4 – C3. «П0 + train (the middle of the car is above the support No. 1)»; case 5 – C4. «P0 + train (the middle of the train is over the middle of PS1–2)»; Case 6 – C5. «P0 + train (the middle of the train is above the support No. 2)»; case 7 – C6. «P0 + train (the middle of the car is above the middle of PS2–3)» (Pics. 2, 3); case 8 – L1. «P0 + triple-heading (the middle of the locomotive No. 1 is above the middle of PS2–3)»; case 9 – L2. «P0 + triple-heading (the middle of the locomotive No. 2 is above the support No. 2)»; case 10 – L3. «P0 + triple-heading (5th axis of the 2nd locomotive is above the middle of PS1–2)»; case 11 – L4. «P0 + triple-heading (2nd axis of the 3rd locomotive is above the middle of

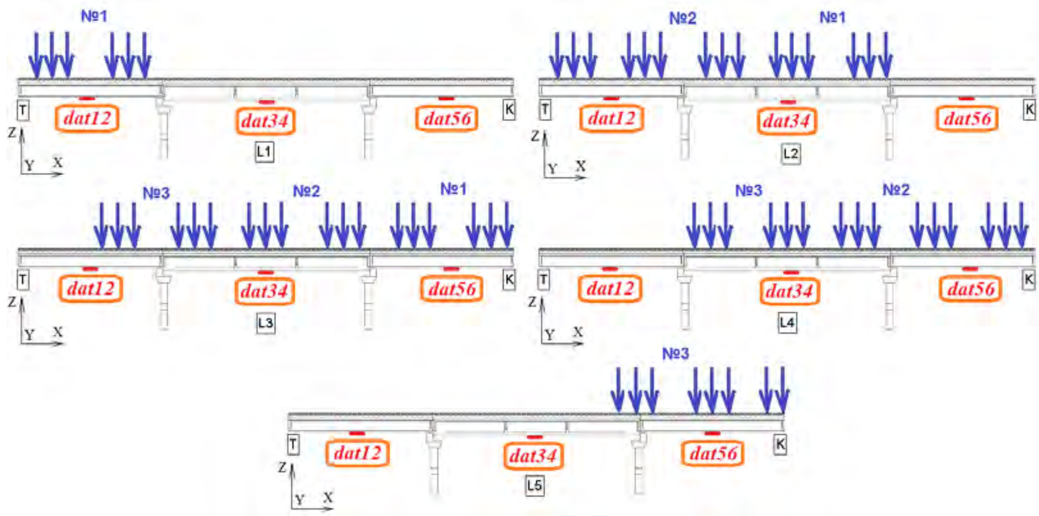


Pic. 1. Layout of resistance strain gages on span structures of railway reinforced concrete overpass, at 97 km PK5+20, PS0–1, PS1–2, PS2–3 – span structures of the overpass; dat 1, 2, 3, 4, 5, 6 – resistance strain gages FLM-60–11; O No. 1, O No. 2 – frame, two-rack intermediate supports; O No. 0, O No. 3 – foundations of talus type (authors' picture).



Pic. 2. Schemes of temporal loads from the train «locomotive–car» (C1–C6), dat 1, 2, 3, 4, 5, 6 – resistance strain gages installed on span structures of the overpass; K, T – stations before and after the overpass (authors' picture).

Pic. 3. Photo of installation of the train «locomotive–car» on a span structure 0–1 (load C1) (authors' photo).



Pic. 4. Schemes of temporal loads from the triple-heading (L1–L5), dat 1, 2, 3, 4, 5, 6 – tensile strain gages installed on span structures of the overpass; K, T – stations before and after the overpass (authors' picture).

Pic. 5. Authors' photo of installation of the triple-heading on a span structure 1–2 (load L4).

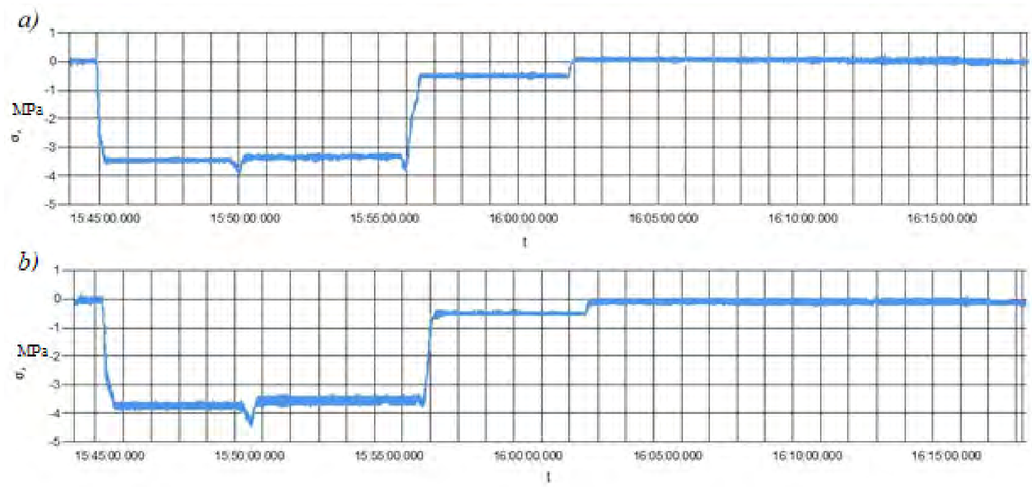
PS1–2)»; case 12 – L5. «P0 + triple-heading (2nd axis of the 3rd locomotive is above the middle of PS0–1)» (Pics. 4, 5).

The calculation model of the artificial structure under consideration is compiled in the program ABAQUS/Standard. The calculation results are presented in the form of strain values at control points obtained using virtual sensors (ductile rod elements with an initial length of 60 mm with linearly elastic properties of steel) mounted on concrete overpass structures. Control points were selected on the lower belt in the middle sections of the span structures of the structure:

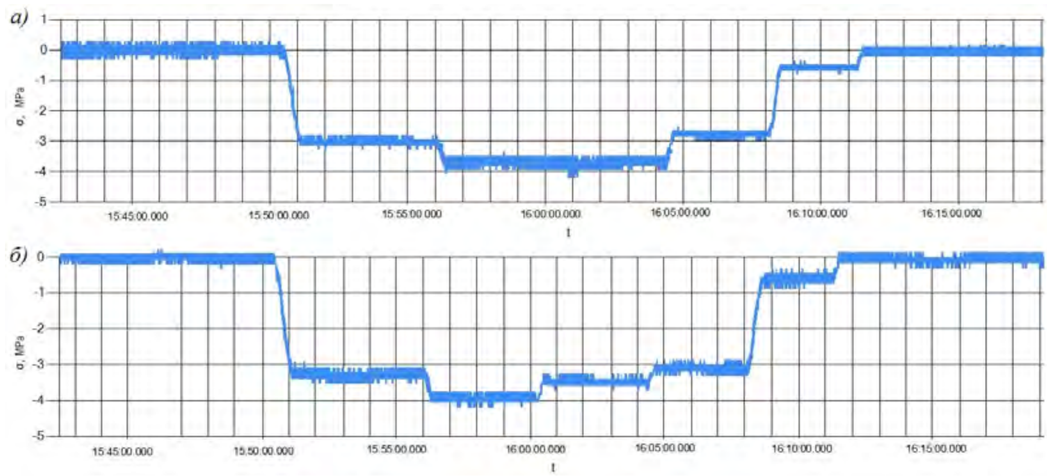
Table 1

Calculation values of tensions in the control points of span structures of the overpass

Calculation case	Tension, MPa			Increase of tension from the temporal loading, MPa		
	dat12	dat34	dat56	dat12	dat34	dat56
S_a	0,00	-22,88	0,00	–	–	–
P0	3,17	-17,98	3,14	–	–	–
Train of diesel locomotive TEM-18 and hopper-batcher car						
C1	3,17	-17,98	7,75	0,00	0,00	4,61
C2	3,17	-14,65	6,34	0,00	3,33	3,21
C3	3,17	-14,01	6,57	0,00	3,97	3,43
C4	4,54	-14,10	3,14	1,37	3,88	0,00
C5	8,59	-14,76	3,14	5,41	3,22	0,00
C6	8,56	-17,16	3,14	5,39	0,82	0,00
Triple-heading: locomotives TEM-18						
L1	6,40	-17,98	3,14	3,23	0,00	0,00
L2	3,17	-17,98	7,41	0,00	0,00	4,27
L3	3,17	-14,09	8,61	0,00	3,89	5,47
L4	8,53	-14,25	7,35	5,35	3,73	4,21
L5	6,27	-14,50	6,16	3,10	3,48	3,02



Pic. 6. Diagrams of fibre tensions of the stretched zone PS0–1 (dat 5, 6, load C1): a – in the right block; b – in the left block (authors' picture).



Pic. 7. Diagrams of fibre tensions of the stretched zone PS1–2 (dat 3, 4, load C4): c – in the right block; b – in the left block.

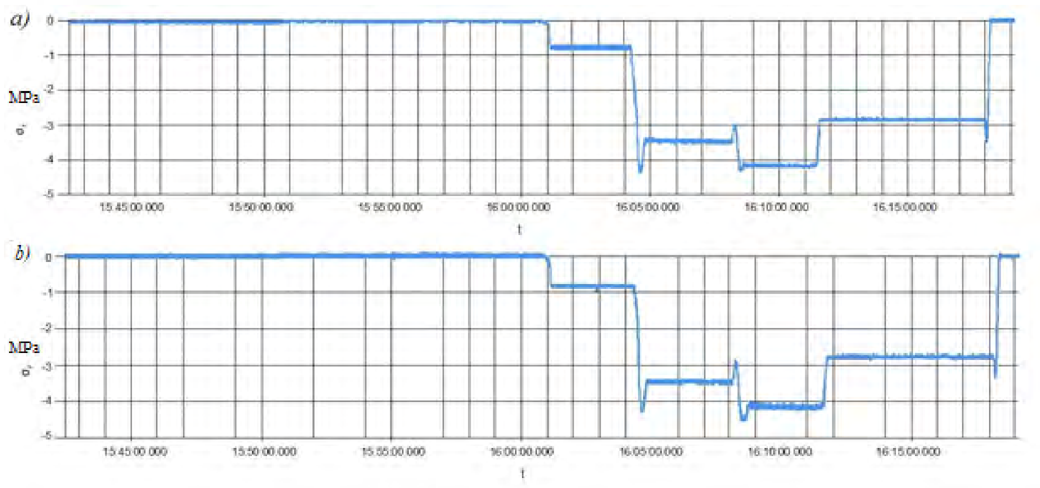
«dat 1, 2» – sensors in the middle of the span structure PS0–1; «dat 3, 4» – sensors in the middle of the span structure PS1–2; «dat 5, 6» – sensors in the middle of the span structure PS2–3 (where PS0–1 – span structure 11,5 m, from the side of the station K; PS1–2 – span structure 23,6 m; PS2–3 – span structure 11,5 m from the side of the station T).

The results of calculations of structural elements at given loads (C1–C6 and L1–L5) are presented in the form of stress distributions in the reinforcement and concrete of blocks of the span structures of the overpass for the design case P0 and in the form of voltage values at control points and virtual sensors for all considered design cases, S_a – tension of the reinforcement (Table 1). The data obtained by the calculation are consistent with those obtained experimentally by the authors [8, pp. 163–166; 6, pp. 64–67].

Results of the experimentally obtained data

Model tests of single-gauge railway overpass through a motorway in a productive zone, were conducted in spring of 2018, through a strain-gage hardware-software complex (TPAK) [10, pp. 43–47]. An overpass is built in 1988 according to the scheme: 11,5+23,6+11,5 m on 96th km of PK5–20 of railway line Kulsary–Tengiz, from collapsible reinforce-concrete constructions.

Resistance strain gages (dat 1, 2, 3, 4, 5, 6) are installed on every block of span in the middle part (odd number on right blocks, even on the left blocks), protecting of glued on



Pic. 8. Diagrams of fibre tensions of the stretched zone of PS2–3 (dat 1, 2, load C6): a – in the right block; b – in the left block.

resistance strain gages is similarly produced from external influences of environment with the purpose of further monitoring during 8–10.

As an example, the diagrams of the measured fibre stresses in the stretched zone (lower part of the edge) in the middle part of the reinforced concrete span structures of the railway overpass (Pics. 6–8), arising under the influence of temporary loads from the train «TEM-18 locomotive and hopper-batcher car» (Static tests, Table 2) are shown. A detailed description of the technical part (primary and secondary converters) and the software of the used

Table 2

Fibre tensions from temporal loads from the train «diesel locomotive TEM-18 and hopper-batcher car» and the «triple-heading consisting of 3 diesel locomotives TEM-18» (static tests)

Railway overpass 11,5+23,6+11,5 m on the 96th km of PK5–20						
Scheme of arrangement of temporal load	PS0–1		PS1–2		PS2–3	
	Right block dat 1	Left block dat 2	Right block dat 3	Left block dat 4	Right block dat 5	Left block dat 6
	σ, MPa	σ, MPa	σ, MPa	σ, MPa	σ, MPa	σ, MPa
Train of a diesel locomotive TEM-18 and hopper-batcher car						
C1	3,71	3,90	0	0	0	0
C2	3,.99	4,12	1,94	1,61	0	0
C3	1,54	1,59	3,37	2,97	0	0
C4	0	0	3,42	3,73	0,52	0,45
C5	0	0	1,63	1,75	3,70	3,46
C6	0	0	0	0	3,88	3,61
Triple-heading consisting of 3 diesel locomotives TEM-18						
L1	3,12	3,05	0,02	0,03	0,00	0,10
L2	0,07	0,08	0,03	0,04	3,02	3,06
L3	0,15	0,03	3,38	3,18	4,19	4,11
L4	4,12	4,15	3,26	3,19	3,99	3,96
L5	2,34	2,50	2,98	2,91	2,86	2,82

TENZO hardware-software complex is described in [11, pp. 275–279].

The calculated data are consistent with experimental data obtained at various facilities on the main lines of JSC NC KTZ, given in [12, pp. 163–166; 13, pp. 43–47; 14, pp. 38–57; 15, pp. 64–67; 16, pp. 275–279].

Conclusions

From a comparison of the stresses obtained by calculation using the finite element method and the stresses obtained during field tests of beam reinforced concrete spans of the overpass, it follows that the description of the stress-strain state of the spans of the railway overpass quite adequately reflects the effect of the load on the spans and the response of the structure to this impact. The obtained stresses in the beam reinforced concrete span structures of the overpass can be used in the calculations of similar (typical) beam span structures for seismic resistance and dynamic stability calculations with an increase in the operational load on the railway bridges.

In order to determine the actual technical state of structures and the most effective assessment of reliability of bridge structures and to establish correspondence between the design scheme and the actual operation of artificial structures, it is necessary to monitor changes in the stress-strain state of artificial structures under operational loads.

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