CALCULATION OF STRESS-STRAIN STATE OF OVERPASSES

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ABSTRACT

The article considers the results of the design analysis of supporting structures of overpasses with a single-track railway line. The obtained stress-strain states in the elements of reinforced concrete span structures and intermediate supports under given loads using spatial finite-element models allow us to compare them with the normalized load range and the level of real stability and reliability of bridge objects. In this case, the need arises to monitor such states to maintain viability of the structures in use.

Keywords: railway, overpass, beam span structures, calculation, finite element method, stress-strain state.

Background. *Creating a design model for the analysis of the stress-strain state of supporting structures of overpasses, it should be borne in mind that the regulatory rules differ in different countries.*

In the USA, the Cooper scheme, consisting of a five-axle steam locomotive, a four-axle tender and a uniformly distributed carload, is still used. The pressure from the axis on the rails in this scheme is taken in proportion to some constant coefficient K. In 1922, the bridges were designed for E10 loads, in 1935 – E72, and now they are designed for E80 loads.

Besides the United States, the Cooper model is used in the design of bridges in Mexico and Australia. Similar schemes of vertical regulatory loads of rolling stock, consisting of concentrated loads and evenly distributed rolling stock loads, were used in Belgium, France, Italy, Yugoslavia, Mozambique, Norway, Poland, Switzerland [1, pp. 117–120].

Objective. *The objective of the authors is to consider calculation of stress-strain state of overpasses.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, simulation.*

Results.

Description of design models

The design models for the analysis of the stress-strain state (SSS) of the structure are based on the data provided in the form of working documentation for an overpass on a single-track railway line. The overpass parameters are 16,5 + 23,6 + 16,5 m. A general view of the design model of the structure under consideration is presented in Pic. 1.

Models of reinforced concrete elements of supporting structures of the overpass take into account the joint work of reinforcing elements and concrete filling [2, pp. 222–224; 3, p. 53; 5, pp. 54–55]. The concrete filling of the span blocks of 16,5 m and 23,6 m, as well as the frames and pedestals of the intermediate supports of the overpass are given by volume elements. Reinforcing elements of span structures (frames, grids, wire bundles for prestressing concrete) and intermediate support structures are specified by core elements and take into account their spatial arrangement in concrete filling.

Track superstructure

Elastic mass characteristics of ballast and assembled rails and sleepers (rails, counter rails, sleepers) are taken into account in the computational models by directly specifying volumetric elements with the corresponding physical and mechanical properties of materials (Pic. 2). Section of wooden sleepers is of 180 × 250 mm (type IA).

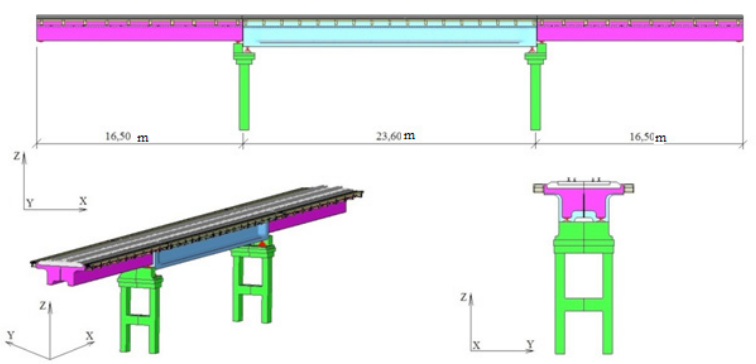
Side pavements

Elastic mass models of side pavements (metal consoles, reinforced concrete flooring) and railings are simplified (Pic. 3).

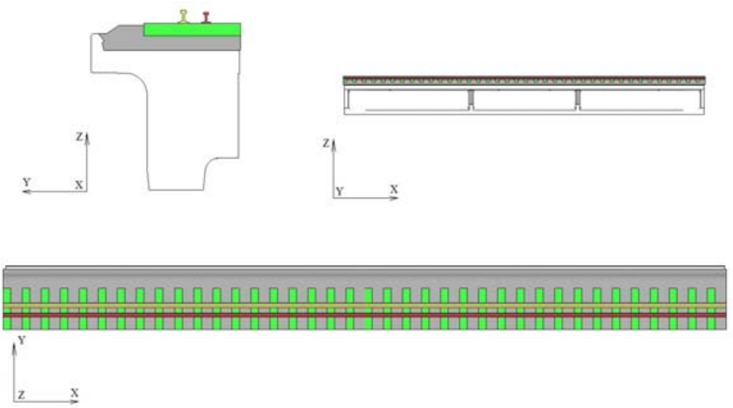
Supporting parts

Each supporting part of the span is presented in a simplified way – by combining a group of concrete nodes adjacent to the bordering box or supporting sheet into a single rigid body. The masses of the bearing parts are marked with point elements of the type MASS.

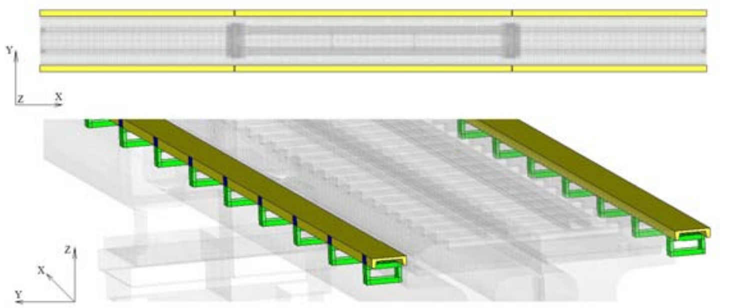
Between the rigid body of the intermediate support pedestal and the corresponding rigid body of the block of the span structure, kinematic links are given realizing the following types of support:



Pic. 1. Deformable finite element model of the overpass. General view.



Pic. 2. Track superstructure (span structures of 16,5 m and track superstructure on them are not shown).



Pic. 3. Side pavements and railing.

• in the places of installation of fixed support parts – «cylindrical joint»;

• in the places of installation of movable support parts – «roller» (cylindrical joint + translational degree of freedom along the local axis, initially parallel to the track axis).

23,6 m span structure block

The finite-element mesh of the concrete block takes into account the presence of holes for the drain pipes. Reinforcing elements are divided into groups according to the assigned classes:

• prestressing reinforcement (bundles of 24 Ø5 BII wires with installation in a concrete mass using frame-bar anchors);

• fittings of classes AI, AII.

For prestressed reinforced concrete blocks, the voltages in the reinforcing beams are set according to the working documentation:

• upper straight bunches of 7100 kgf/cm^2;

• polygonal bunches of 10500 kgf/cm^2;

• lower straight bunches of 10400 kgf/cm^2.

16,5 m span structure block

The finite-element grid of the concrete block takes into account the presence of holes for the drain pipes. The reinforcing elements are allocated in groups according to the designated classes AI, AII.

Concrete of the assembly joints of the blocks is allocated to a separate group of elements (Pic. 4).

Intermediate support

The model of intermediate support consists of a frame R-2 and a support bollard. The reinforcing elements are allocated in groups according to the designated classes AI, AII, AIII.

Fasteners

The ground level of the jumpers of the P-2 intermediate frames is about 1,0 m. For the nodes of the frame struts not higher than the specified level, the fasteners for any movements are set.

Due to the symmetry of the structure and the observed loads relative to the plane of track symmetry in the design models for the analysis of stress-strain states, symmetry conditions are provided (fasteners of the corresponding group of nodes from displacements along the transverse track axis).

For the calculated analysis of the forms and frequencies of natural oscillations of a structure, a model without symmetry conditions across the track axis is considered.

Loads

All values of loads are taken without taking into account the various coefficients of Russian SP [Construction Rules] [6, p. 33] and SNiP [Construction Standards and Rules] [7, p. 12] (working conditions, reliability regarding loads and strength responsibility, etc.).

The own weight of the structures is taken into account assuming inertial load – gravity [8–12].

Temporary loads are set according to the following types of effects:

• static load on the weight of the coupling according to the «locomotive–car» scheme;

• static load on the weight of a raft of three locomotives.

The impact of the weight of the locomotive is given in the form of a concentrated force of 202,7 kN/axis in the nodes of the rail track model in accordance with the distances:

• 16900 mm between axles of automatic couplings;

• 8800 mm between the pins of bogies (locomotive base);

• 1850 mm between bogie axles.

The impact of the weight of the car is given in the form of a concentrated force of 228,7 kN/axis in the nodes of the rail track model in accordance with the distances:

• 11520 mm between axles of automatic couplings;

• 7200 mm between the pins of bogies (car base);

• 1850 mm between bogie axles.

The considered schemes of temporary loads are presented in Pic. 5 and 6 (a total of six schemes for the «locomotive–car» connection and five schemes for the raft of «three locomotives»).

The results of the calculated static analysis

The calculations of the stress-strain state of the elements of the structure under given combinations of loads [13, pp. 101–120].

12 cases are considered:

• P0. «Tension of reinforcement of the blocks 23,6 m + own weight»;

• C1. «P0 + coupling (middle of the locomotive over middle of PS0–1)»;

• C2. «P0 + coupling (middle of the car over the middle of PS0–1)»;

• C3. «P0 + coupling (middle of the car above the support K)»;

• C4. «P0 + coupling (middle of the coupling over the middle of PS1–2)»;

• C5. «P0 + coupling (middle of the coupling over the support T)»;

• C6. «P0 + coupling (middle of the car over the middle of PS2–3)»;

• L1. «P0 + raft (middle of the locomotive No. 1 over the middle of PS0–1)»;

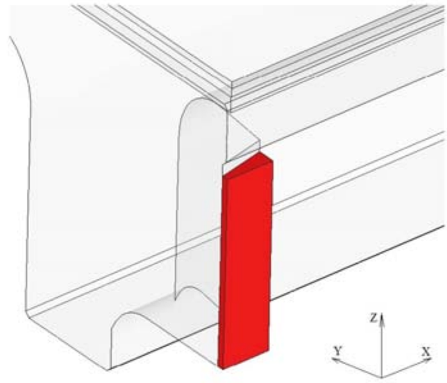
• L2. «P0 + raft (middle of the locomotive No. 2 above the support K)»;

• L3. «P0 + raft (5th axis of the 2nd locomotive over the middle of PS1–2)»;

• L4. «P0 + raft (2nd axis of the 3rd locomotive over the middle of PS1–2)»;

• L5. «P0 + raft (2nd axis of the 3rd locomotive over the middle of PS2–3)»,

where are marked: K, T – stations before and after the overpass; PS0–1 – span from the station K; PS1–2 – span of 23,6 m; PS2–3 – span from the station T.



Pic. 4. Deformable finite element model of the span of 16,5 m. Concrete of the assembly joints of the end diaphragms.

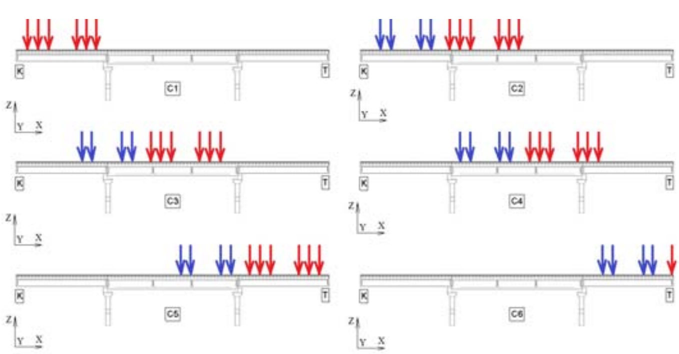
The results of the calculations are presented as displacement and deformation values at the control points obtained using virtual sensors (pliable core elements with an initial length of 60 mm with linear elastic properties of steel) installed on the concrete of the span of the overpass. Control points are selected on the lower belt in the middle sections of the span structures of the structure:

• «dat1,2» – sensors in the middle of the span PS0–1;

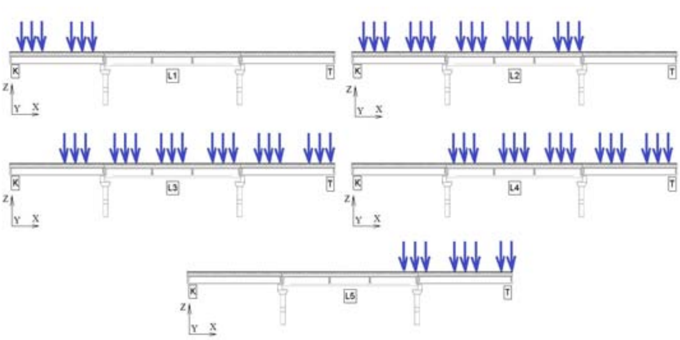
• «dat3,4» – sensors in the middle of the span PS1–2;

• «dat5,6» – sensors in the middle of the span PS2–3.

The results of calculations of elements of the structure under given loads are present in the form of distributions of displacements and stresses in reinforcement and concrete blocks of span structures of the overpass for the design case P0 and in the form of displacements, deformations and stresses at



Pic. 5. Schemes of temporary loads from the coupling «locomotive–car» (C1–C6).



Pic. 6. Schemes of temporary loads from the raft «three locomotives» (L1–L5).

Table 1

Calculated values of displacements, deformations and stresses at the control points of the span structures of the overpass

Design case	Displacement, mm			Displacement increment from temporary load, mm		
	PS0–1	PS1–2	PS2–3	PS0–1	PS1–2	PS2–3
S_a	0,00	24,63	0,00	–	–	–
P0	**-4,36**	**17,41**	**-4,36**	–	–	–
C1	-9,23	17,46	-4,36	4,87	0,05	0,00
C2	-8,92	13,55	-4,34	4,57	3,86	0,02
C3	-6,18	11,38	-4,30	1,82	6,03	0,06
C4	-4,29	11,52	-5,18	0,07	5,89	0,81
C5	-4,34	14,48	-9,14	0,02	2,93	4,78
C6	-4,36	17,44	-8,88	0,00	0,03	4,51
L1	-9,21	17,46	-4,36	4,86	0,05	0,00
L2	-9,62	11,69	-4,29	5,26	5,72	0,08
L3	-7,59	11,75	-9,01	3,23	5,66	4,65
L4	-4,28	11,70	-9,53	0,07	5,71	5,17
L5	-4,36	17,10	-8,93	0,00	0,31	4,57
Design case	Deformation, μm/m			Deformation increment from temporary load, μm/m		
	dat12	dat34	dat56	dat12	dat34	dat56
S_a	0	-666	0	–	–	–
P0	**146**	**-524**	**146**	–	–	–
C1	300	-524	146	154	0	0
C2	291	-443	146	145	81	0
C3	204	-408	146	58	115	0
C4	146	-410	169	0	113	24
C5	146	-466	299	0	57	153
C6	146	-524	290	0	0	144
L1	299	-524	146	153	0	0
L2	316	-410	146	171	113	0
L3	260	-411	301	114	113	155
L4	146	-410	317	0	113	172
L5	146	-519	313	0	5	168
Design case	Tension, MPa			Tension increment from temporary load, MPa		
	dat12	dat34	dat56	dat12	dat34	dat56
S_a	0,00	-22,87	0,00	–	–	–
P0	**4,50**	**-17,97**	**4,50**	–	–	–
C1	9,26	-17,97	4,50	4,76	0,00	0,00
C2	8,98	-15,20	4,50	4,48	2,77	0,00
C3	6,29	-14,01	4,50	1,79	3,96	0,00
C4	4,50	-14,08	5,23	0,00	3,89	0,73
C5	4,50	-16,00	9,24	0,00	1,97	4,74
C6	4,50	-17,97	8,96	0,00	0,00	4,46
L1	9,24	-17,97	4,50	4,74	0,00	0,00
L2	9,77	-14,08	4,50	5,27	3,89	0,00
L3	8,02	-14,10	9,30	3,52	3,87	4,80
L4	4,50	-14,08	9,80	0,00	3,89	5,30
L5	4,50	-17,81	9,68	0,00	0,16	5,18

control points and virtual sensors for all considered design cases, S_a – tensioning of the steel (Table 1). The calculated data are consistent with the data experimentally obtained by the authors [14, p. 165; 15, p. 45; 16, pp. 48–51; 17, p. 67; 18, p. 278].

Conclusions. *From the analysis of the calculated displacements, deformations and stresses of girder reinforced concrete span structures of the overpass it follows that for determining the stress-strain state of the span structures of the railway overpass for the purpose of comparison with the normalized range, the coupling (locomotive + car) and raft (three locomotive) were used.*

Data on displacement, deformation and tension of girder reinforced concrete span structures of the overpass can be used in calculations of similar structures for seismic resistance, as well as in dynamic calculations of stability with increasing operational load on railway bridges.

To determine the actual technical state of the bridge structures and the most effective assessment *of their reliability, to establish the correspondence between the design scheme and the actual operation of structures on the main lines of Kazakhstan and Russia, it is advisable to periodically monitor the stress-strain state of the bridge structures under operational loads.*

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