

Refinement of transport's transverse installation coefficient for composite bridge structures

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Abstract. In article calculates the coefficients of transport transverse installation for steel-reinforced concrete bridge structure with the use of off-center compression methodology. Two design models of beam continuous span structure of bridge central part were simulated in the Lira-SAPR software package. Based on the numerical data obtained the coefficients of transport transverse installation (TIC) were determined and the nature of transport temporary mobile load's distribution between main beams of the bridge was revealed. As a result of research a comparative analysis of transport transverse installation coefficients was accomplished, obtained by theoretical and numerical methods. The research established in contrast to the engineering analysis methodology using the eccentric compression method the most loaded is the middle main beam B4 when four traffic lanes are located across the span. Analysis of main beam using engineering methodology assumes that the bridge deck is loaded with three traffic lanes. Based on results of the spatial model analysis in the LIRA-SAPR software were constructed lines of pressure influence on the outermost (B1) and middle (B4) main beams and for each of them were calculated TICs. In course of comparative analysis it was determined the TIC from the temporary moving load AK-15 for the main outer beam B1, determined using the engineering method of eccentric compression, is on average overestimated by 38.7% compared to TIC determined by the numerical method. The coefficient of performance coefficient from the temporary moving load AK-15 for the main middle beam B4, determined using the engineering method of eccentric compression, is on average underestimated by 11.96% compared to TIC determined by the numerical method.

1 Introduction

In the instant case the bridge span which is a spatial structure formed by the main beams, bracings and reinforced concrete slab of the roadway is considered. Due to the significant complexity of taking into account the actual operating conditions as a spatial structure,

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approximate methods for taking into account the distribution of vertical transport load between the longitudinal main beams are widely used in practice [1, 2].

The coefficient of transport transverse installation (TIC) shows what part of the design temporary moving load installed in the transverse direction of the bridge span is transferred to the main beam regarded [3,4]. Currently, there are several methods for determining the TIC coefficients, considered in the works of I.G. Kozlov, V.V. Rakitin, M.E. Gibshman, A.A. Mironov, and others [5-8]. The lever and the eccentric compression methods are the easiest to apply, which allow us to estimate the ordinates of the support pressure influence line on the element under consideration quickly [9,10]. The cross sections of all other beams are assumed to be of the same structure. However, a modest accuracy design distribution of the temporary moving load across the span may lead to overconsumption of materials or underestimation of structural capability [11-13].

1.1 The research object description

The object of research is an artificial transportation structure (bridge) across the Kalmius River on Ilyicha Avenue in Donetsk (Figure 1), located on a highway of national importance, designed for the passage of cars, buses, trolleybuses and pedestrians. The bridge was put into service in 1951 [1, 8].



Fig. 1. Bridge over the river Kalmius in Donetsk city

The supports are reinforced concrete massive. The bridge spans are covered by three-span continuous steel-reinforced concrete beams.

The static circuit of the span structure is a three-span continuous beam construction organized by a system:

$(15,68+16,0+17,06)+(33,84+37,6+33,84)+(17,06+16,00+15,68)$ m, separated by two functional joints.

The length of the bridge (along the rear faces of the foundations) - 206,0m.

The bridge dimension - Г-14 + 2x3,0 (m).

The underbridge clearance - 3,0m.

The bridge aperture - 192,0m.

The type of bridge deck - curb.

The bridge dimension - G-14 + 2x3,0 (m), the number of traffic lanes - 2.

The bridge spans are covered by three-span continuous steel-reinforced concrete spans of two types:

– in the coastal spans (0-1-2-3 и 6-7-8-9) according to a scheme $15,68 + 16,0 + 17,06$ (m);

–in the central spans (3-4-5-6) according to a scheme $33,84 + 37,6 + 33,84$ (m) – see figure 2.

The height of the beam's web is 1120 mm for the coastal spans and 1420 mm for the central span. The cross-section is variable along the span length, the change is achieved by placing additional flange plates in the zones of the highest bending moments. The results of the bridge examination show that by the mechanical characteristics and chemical composition the metal of the span beams constructure is the closest to the bridge steel M16C according to GOST 6713-53 and St3 according to GOST 380-53 [1, 8]. Mounting joints of the main beams are made on rivets with connection of beam elements by flange plates and double-sided plates on the webs.

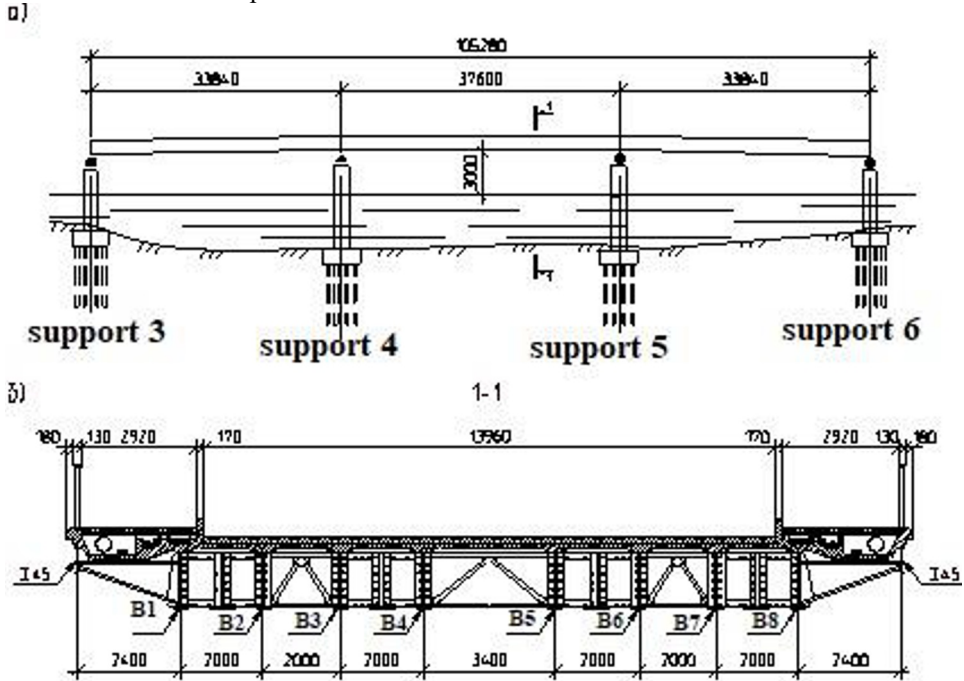


Fig. 2. Scheme of span's central part of bridge structure (a); layout of the main beams in bridge cross section (b)

There are eight main beams with a spacing 2000 mm and 3400 mm (only between B4 and B5) in the cross section of each bridge span constructure. Longitudinal and transverse rigidity, stability of geometrical shape and spatial operation of the span structure are achieved by installing:

- a system of longitudinal braces along the lower chords of the main beams and transverse braces between the main beams made of angles;
- a reinforced concrete slab of the roadway forming a horizontal rigid brace disk.

The beams are connected in pairs by the longitudinal braces: B1-B2, B3-B4, B5-B6 and B7-B8, the same beams are connected above the supports by jacking beams or reinforced cross braces (for coastal spans on the outermost supports).

The thickness of the reinforced concrete monolithic slab is 160 mm (between the beams in the span). The slab of the roadway and the main beams are connected into monolithic steel-reinforced concrete section by the rigid connectors made of steel angles $L 150 \times 100 \times 10$ attached to the upper chords of the main beams by four single-shear rivets of 22 mm diameter. The spacing of the rigid connectors varies from 750 mm to 850 mm in the coastal spans and from 850 mm to 900 mm in the central span.

The sidewalk sections of the monolithic roadway slab have a polygonal contour and form communication niches under the sidewalks. Along the facade edges the cantilever sections of the sidewalk slab are supported by longitudinal beams made of I-beam №45 which are supported on the ends of steel brackets made of angle bars.

2 Materials and methods

The study considers the central three-span structure of a 105,28m long continuous beam system. The width of spans 3-4 and 5-6 is 33,8 m, the width of span 4-5 is 37,6 m. The material of the sidewalk and roadway slab is made of B15 concrete. Cross sections of the span section's main beams are shown in Figure 3.

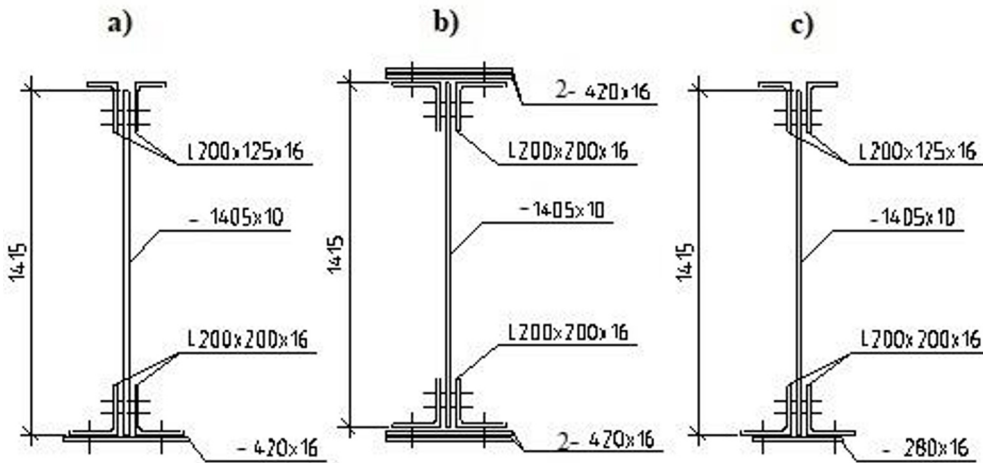


Fig. 3. Scheme of the cross section for existing main beams: a) section in the central part of spans 3-4 and 5-6; b) section on support area 4 (5); c) section in the central part of span 4-5.

The forces from constant and temporary moving loads have been determined by the calculation method [14, 15]. The constant loads are determined accounting the actual thickness and materials of bridge road deck layers according to the survey results. Static calculation of the span section's main beams is made by method of eccentric compression according to the methods of structural mechanics [1, 16-18, 22] to determine TIC of vehicles A-15, NK-100 and pedestrian load for the outermost beam B1 and central beam B4 of the span structure in the cross-section of the bridge.

The ordinates of the pressure influence line on the main beams of the span structure are determined according to [1, 8] by formula (1):

$$\eta_{1,2} = \frac{1}{n} \pm \frac{a_1^2}{2 \cdot \sum_{i=1}^n a_i^2} \quad (1),$$

where n – the number of main beams in the cross-section of the bridge;

a_i – the distance between the centers of gravity of symmetrical beams relative to the longitudinal axis of the bridge;

$\sum_{i=1}^n a_i^2$ – the sum of squares of distances between the centers of gravity of symmetrical

beams relative to the longitudinal axis of the bridge. The results are shown in Table 1.

3 Results and discussions

3.1 Analysis of the central part of bridge for main beams according to the I and II groups of limit states

Table 1. Results of ordinates analysis of pressure influence lines on main beams using the eccentric compression method [8]

Beams	n	a ₁	$\sum_{i=1}^n a_i^2$	η_1	η_2
B1	8	15,4	433,44	0,399	-0,149
B4		3,4		0,138	-0,112

Influence lines for determining the TIC of AK-15 and NK-100 are shown in Figures 4, 5.

The transverse installation coefficients for the outermost beam B1 according to Figure 4 are:

–for two-axle bogie AK-15:

$$TIC = S_1 \cdot (\eta_1 + \eta_2 + \eta_3 + \eta_4) + S_2 \cdot (\eta_5 + \eta_6) = 1 \cdot (0,3549 + 0,2873 + 0,2481 + 0,1805) + 0,75 \cdot (0,1414 + 0,0738) = 1,2322;$$

– for NK-100 load:

$$TIC = \eta_1 + \eta_2 = 0,3602 + 0,2641 = 0,6243;$$

–from the weight of the crowd of pedestrians on the left sidewalk combined with the A-15 load:

$$TIC = \frac{1}{2} \cdot (\eta_1 + \eta_2) \cdot l_{mp} = \frac{1}{2} \cdot (0,4844 + 0,3805) \cdot 2,92 = 1,2628,$$

where η_i – ordinate of the support pressure influence line for the most loaded outermost main beam of the span; S_1 and S_2 – coefficients taking into account simultaneous loading of several traffic lanes with A-15 load [2]; l_{mp} – width of the loaded sidewalk.

The transverse installation coefficients for the central beam according to Figure 5 are:

– for two-axle bogie AK-15:

$$TIC = S_1 \cdot (\eta_1 + \eta_2 + \eta_3 + \eta_4) = 1 \cdot (0,4684 + 0,3366 + 0,2604 + 0,1286) = 1,194;$$

– for NK-100 load:

$$TIC = \eta_1 + \eta_2 = 0,4788 + 0,2916 = 0,7704;$$

–from the weight of the crowd of pedestrians on the left sidewalk combined with the A-15 load:

$$TIC = \frac{1}{2} \cdot (\eta_1 + \eta_2) \cdot l_{mp} = \frac{1}{2} \cdot (0,7208 + 0,5183) \cdot 2,92 = 1,809.$$

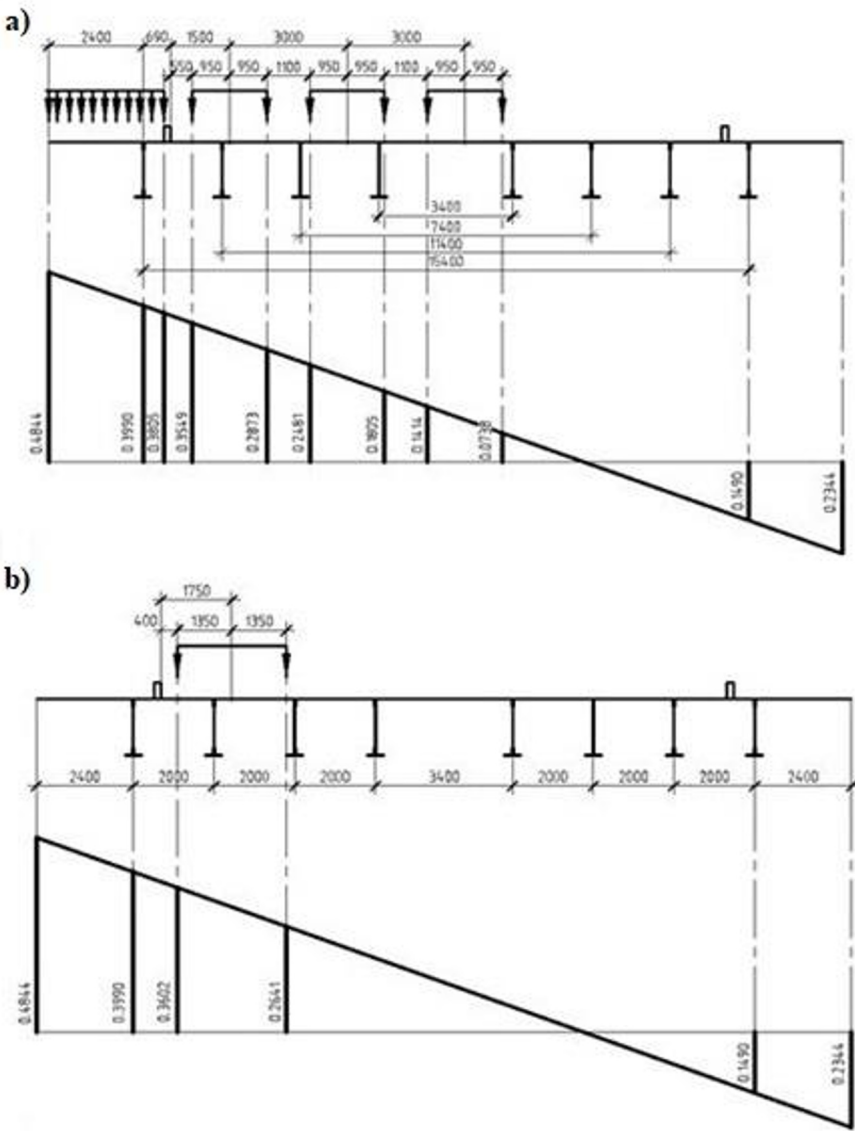


Fig. 4. Pressure influence line on the outer beam B1 for temporary moving load AK-15 and weight of crowd of pedestrians (a) and NK-100 (b), constructed using the eccentric compression method [8].

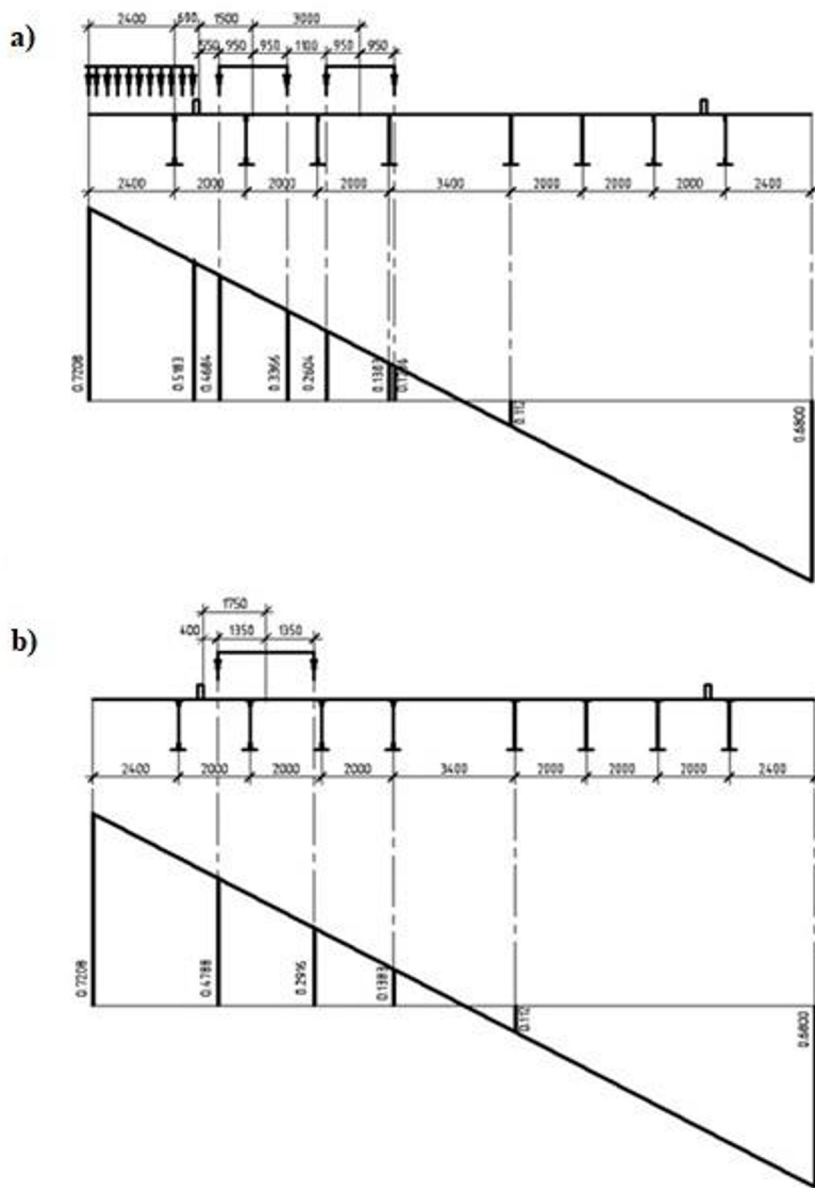


Fig. 5. Pressure influence line on the outer beam B4 for temporary moving load AK-15 and weight of crowd of pedestrians (a) and NK-100 (b), constructed using the eccentric compression method [8].

Having analyzed the pressure influence lines on the main beams it becomes clear that according to the method of eccentric compression the outermost beams B1 (B8) are the most loaded ones. Therefore the main longitudinal beams B1 (B8) are the design ones and the other beams are assumed to be of the same cross-section. When calculating the main beam for the second group of limit states it is considered that the load AK-15 is combined with the weight of a crowd of pedestrians on one sidewalk. In characteristic cross-sections of the outermost beam B1 the influence lines of bending moments and transverse forces are constructed in the LIRA-SAPR software (Figure 6). The transportation arrangement is performed according to the requirements stated in research work [19-21].

The main beam B1 precieves the following loads: $q = 59,55 \text{ kN/m}$ – constant load; $P = 150,27 \text{ kN}$ – design pressure on the main beam from one wheel of the bogie A-15; $v_p = 11,34 \text{ kN/m}$ – design strip load on one track A-15; $P_m = 2,49 \text{ kN/m}$ – design moving load from the weight of a crowd of pedestrians.

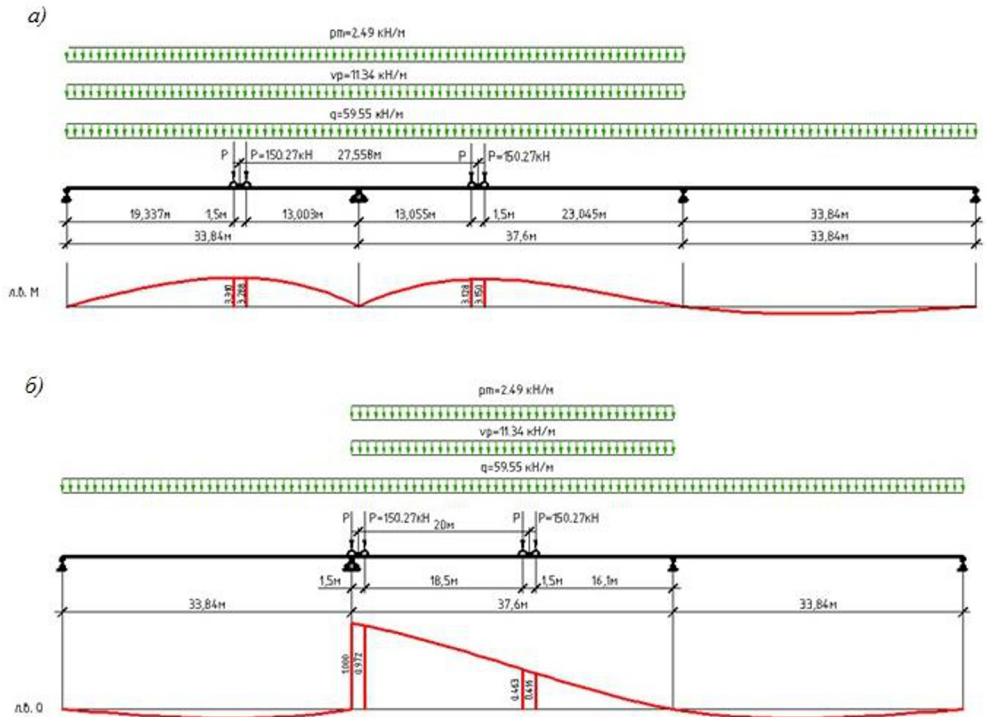


Fig. 6. Bending moments influence line (a) and shear force (b) for the section above support 4 of beam B1. Lines of forces influence for other characteristic points are constructed similarly

After analysis of the beam’s B1 bar model using « LIRA-SAPR 2013 » software the forces in the beam B1 from each of the temporary load combination of are determined. The engineering analysis of the B1 beam’s cross-sections for the first and second group of limit states was performed. The calculation results are summarized in Table 2.

Table 2. Analysis results of rod model for main beam B1

Location of design section B1	M^I , $\text{kN}\cdot\text{m}$	M^{II} , $\text{kN}\cdot\text{m}$	Q^I , kN	Q^{II} , kN	$\sigma_{\max}$, MPa	$R_y \cdot m$, MPa	Δ , %
In the middle of span 3-4	2280	6387	-	-	276,9	213,6	-22,86
On support 4	3877	8433	587	1207	320,1	213,6	-33,27
In the middle of span 4-5	965	4309	-	-	183	213,6	14,3

M^I – bending moment from loads corresponding to the installation stage;
 M^{II} – bending moment from loads corresponding to the operational stage;
 Q^I – shear force from loads corresponding to the installation stage;
 Q^{II} – shear force from loads corresponding to the operational stage;
 $\sigma_{\max}$ – total normal stresses in design sections;
 $R_y \cdot m$ – design resistance of material taking into account the operating conditions coefficient m;
 $\Delta = \frac{R_y \cdot m - \sigma_{\max}}{R_y \cdot m} \cdot 100\%$ – cross-section using factor
(«-» – overstrain, «+» – lowerstrain)

It is obvious that the highest normal stresses in the lower chords of the main beams exceed the maximum permissible values. In this case a selection of new sections (Figure 7) which satisfy the requirements for the first and second group of limit states when the bridge is passing the moving load AK-15 and NK-100 is made.

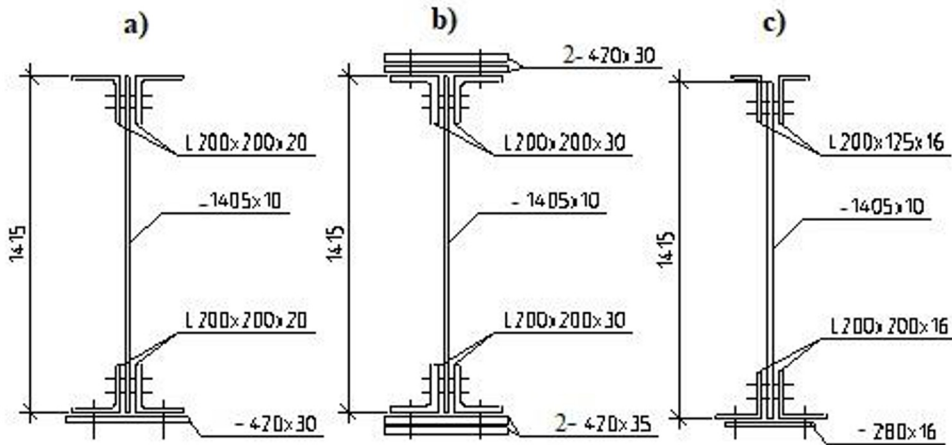


Fig. 7. Scheme of the adopted main beams' cross section: a) section in the central part of span 3-4 (5-6); b) section on support 4 (5); c) section in the central part of span 4-5.

3.2 Numerical researches of spatial models for main beams of span

Two models of the central span structure accounting the bending stiffness of the selected sections were built in « LIRA-SAPR » software. In model №1 (Figure 8) the main beams are made of rods (FE 10) on rigid inserts, which simulate the displacement of the centers of gravity of the slab and the main beam. In model №2 (Figure 9) the main beams are represented as shell FEs (FE 44). For the convenience of modeling accepted beam sections with the chords consisting of angles and plates are replaced by equivalent ones consisting of plates. In the first and in the second model the reinforced concrete slab of sidewalks and roadway is made of FE shell (FE 44). The actual stiffness of the slab based on the results of the bridge survey is assigned on the model №1, while the stiffness of main beam's upper chord on the model №2 is reduced to the equivalent reinforced concrete slab thickness in terms of bending stiffness. The unit load $P = 1$ kN is moving in the cross-section of the bridge to calculate the ordinates of pressure influence line on the main beam in the middle of the span 3 – 4.

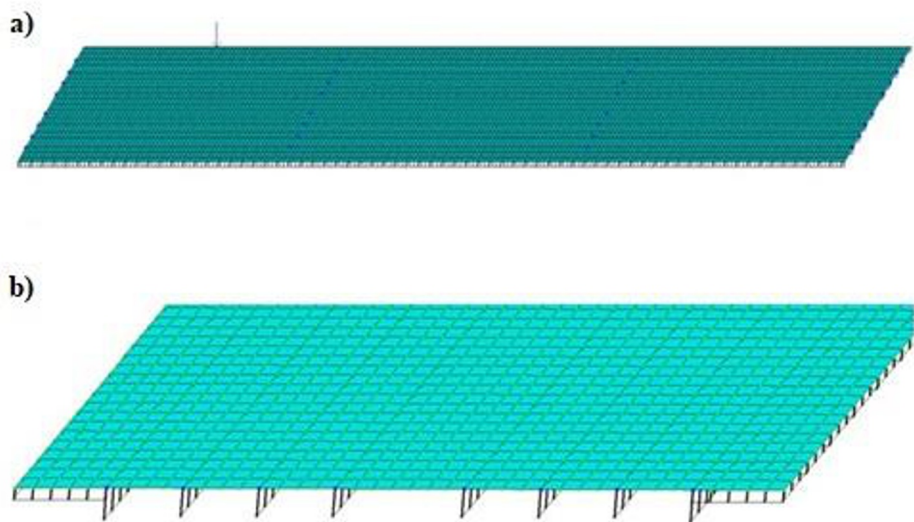


Fig. 8. Design model №1 of bridge span with rigid inserts (a). The number of nodes in model is 8904, the number of elements is 11471. Fragment of design model №1 with rigid inserts in the cross section of bridge span (b)

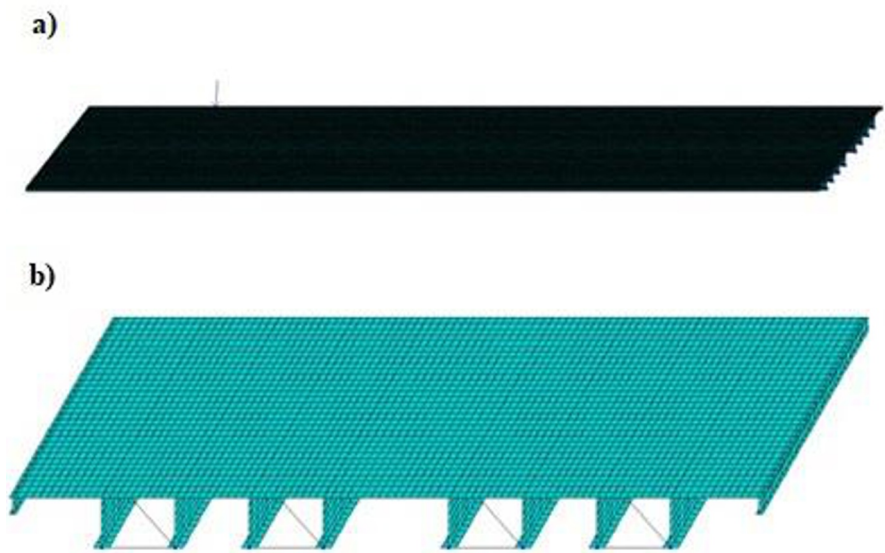


Fig. 9. Design model №2 of bridge span. The number of nodes in model is 87850, the number of elements is 87246. Fragment of design model № 2 in the cross section of bridge span (b)

Design model №1 is used to determine the TIC of support reactions, design model №2 to determine the TIC of bending moments. Figures 10 and 11 show the influence lines for identifying the TIC in beam B1 and B2 plotted by the results of model calculation in « LIRA-SAPR 2013 » software. The results of determining the TIC from the temporary moving load are given in Table 3.

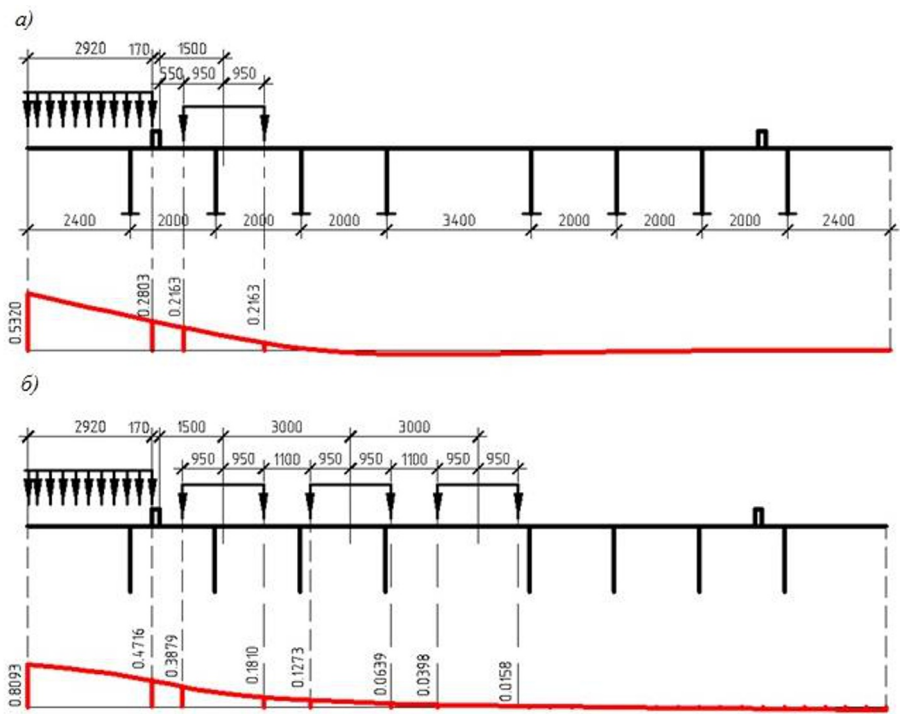


Fig. 10. The influence line for determining the TIC from the temporary moving load AK - 15 and weight of the crowd of pedestrians for the outer beam B1, built according to the results of design model №1 (a) and model №2 (b) in the LIRA SAPR software

Table 3. Results of determining the control factor from temporary moving load AK-15

Beams	TIC, engineering methodology	TIC, numerical method			
		Design model №1	Δ, %	Design model №2	Δ, %
B1	1,2322	0,7085	42,5	0,8018	34,9
B4	1,194	1,4316	16,6	1,2884	7,32

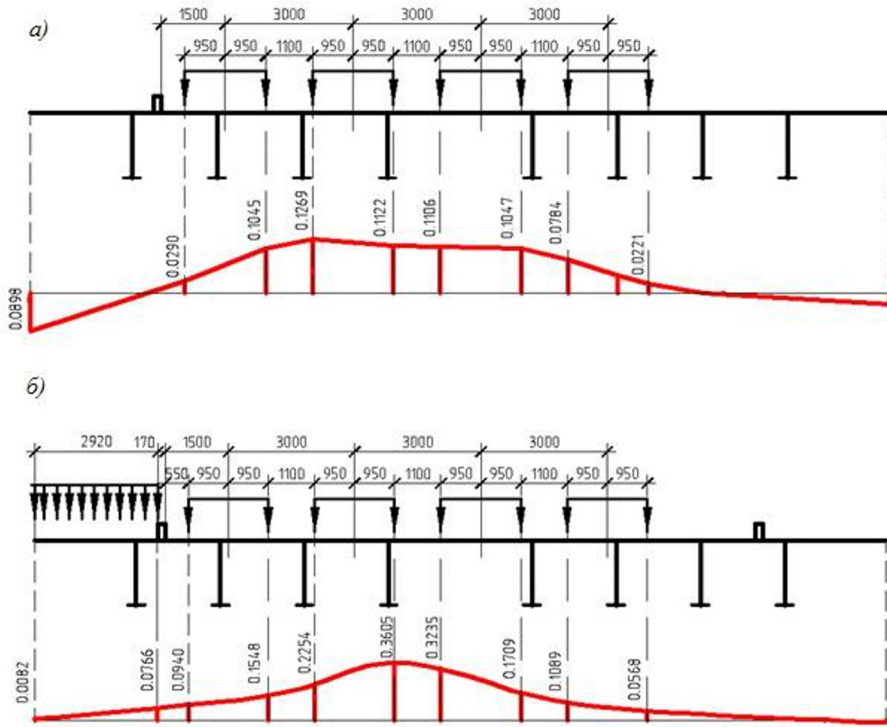


Fig. 11. The influence line for determining the TIC from the temporary moving load AK - 15 and weight of the crowd of pedestrians for the middle beam B4, built according to the results of design model №1 (a) and model №2 (b) in the LIRA SAPR software

4 Conclusions

1) Based on results of the spatial model analysis in the LIRA-SAPR software were constructed lines of pressure influence on the outermost (B1) and middle (B4) main beams and for each of them were calculated TICs.

2) The research established in contrast to the engineering analysis methodology using the eccentric compression method the most loaded is the middle main beam B4 when four traffic lanes are located across the span. Analysis of main beam using engineering methodology assumes that the bridge deck is loaded with three traffic lanes.

3) In course of comparative analysis it was determined the TIC from the temporary moving load AW-15 for the main outer beam B1, determined using the engineering method of eccentric compression, is on average overestimated by 38.7% compared to TIC determined by the numerical method.

4) The coefficient of performance coefficient from the temporary moving load AW-15 for the main middle beam B4, determined using the engineering method of eccentric compression, is on average underestimated by 11.96% compared to TIC determined by the numerical method.

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