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Justification of the parameters of regulationof forces for steel-reinforced concrete span structures from project “43282 km” by TSNIIPSK

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Abstract. Steel-reinforced concrete spans in road bridges have been widely used since the late 1950s, in the configuration of large-span bridges built across significant water barriers. To date, the issue of the need to reconstruct such span structures, including those designed and built according to the project “43282 km” developed by TsNIIPSK, is becoming increasingly relevant. The authors analyze the stages of the production of works of a particular object, developed for the implementation of the entire complex of works on its reconstruction using the method of force regulation. The presented order of work was successfully implemented during construction of the bridge over Kabarga River in Primorsky Krai. This made it possible to preserve the existing structure of the span (main beams and braces), replacing the worn-out reinforced concrete slab with a new – metal orthotropic one, while ensuring that the conditions of strength and stability of the flexural-torsional shape of solid-walled beams are met, in the process of dismantling the existing roadway slab and constructing a new one. Considering that steel-reinforced concrete bridges are built across large water barriers and have a very significant cost due to their large length, reconstruction using existing supports can significantly reduce the cost of construction, so, the possibility of upgrading the existing steel-reinforced concrete span structure is, undoubtedly, relevant. Based on the structural and technological measures presented by the authors, it is possible to carry out and effectively implement work on the reconstruction of the existing steel-reinforced concrete bridges that do not fully meet modern requirements for load capacity and throughput.

Keywords: steel-reinforced concrete span structures, force regulation, flexural-torsional shape stability, jacking up, temporary supports

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Обоснование параметров регулирования усилий сталежелезобетонных пролетных строений разработки ЦНИИПСК «43282 км»

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Аннотация. Сталежелезобетонные пролетные строения в автодорожных мостах стали широко применяться с конца 1950-х гг. в компоновке схем большепролетных мостов, сооружаемых через значительные водные преграды. На сегодняшний день все большую актуальность обретает вопрос необходимости реконструкции отмеченных пролетных строений, в том числе запроектированных и построенных по проекту ЦНИИПСК «43282 км». В исследовании разобраны этапы производства работ конкретного объекта, разработанные для реализации всего комплекса работ по его реконструкции с применением метода регулирования усилий. Представленный порядок выполнения работ успешно реализован на строительстве моста через р. Кабаргу в Приморском крае, что позволило сохранить существующую структуру пролетного строения (главные балки и связи), заменив изношенную железобетонную плиту на новую – металлическую ортотропную, при обеспечении выполнения условий прочности и устойчивости изгибно-крутильной формы сплошностенчатых балок в процессе демонтажа существующей плиты проезжей части и устройства новой. Учитывая, что сталежелезобетонные мосты возводятся через большие водные преграды и в том числе из-за большой длины имеют значительную стоимость, а реконструкция с использованием существующих опор позволяет существенно сократить стоимость строительства, актуальность модернизации существующих сталежелезобетонных пролетных строений является, несомненно, актуальной. На основании предложенных конструктивно-технологических мероприятий возможно проведение и эффективная реализация работ по реконструкции действующих сталежелезобетонных мостов, не в полной мере удовлетворяющих современным требованиям по грузоподъемности и пропускной способности.

Ключевые слова: сталежелезобетонные пролетные строения, регулирование усилий, устойчивость изгибно-крутильной формы, поддомкрачивание, временные опоры

Introduction

Span structures developed by TsNIIPSK according to the project “43282 km” with an estimated span of 42.5 m are widely used in the construction of large and medium-sized bridges on the roads of the post-Soviet space. On the highways of the Far East, the total length of existing bridges, in the layout of which the spans of this project or similar are used, is 2325 meters. This fact emphasizes the need to work out the technology for the reconstruction of the designated spans for their restoration and modernization.

It is a well-known fact that the regulation of efforts in the construction of large-span steel-reinforced concrete bridges is an advantageous technique from a technical and economic point of view, because this makes it

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possible to reduce the consumption of steel and to use better the strength properties of the materials of the supporting elements of the span structures. The classification of these methods, the experience of their application in the construction of new bridges is also covered in [1–5].

Basic preconditions

The experience gained by the department "Bridges, Grounds and Foundations" (now the department "Automobile Roads") of PNU shows the possibility of successfully implementing the restoration of consumer properties of span structures of steel-reinforced concrete bridges with the extension of their service life using the option of regulating forces and creating on the basis of the existing structure a new span structure, which will meet the modern requirements for throughput and carrying capacity [6; 7].

Based on the above, the choice of the object of study is predetermined by the following:

1) the wide distribution of span structures according to the TsNIIPSK project "43282 km" which was issued in 1959;

2) real opportunities for their renovation in order to adapt to the loads A14, H14 in accordance with GOST 32960[1] (State Standard of Russian Federation) while providing the required dimensions in accordance with the requirements of CR 35.13330.2011[2] (Russian Code of Rules);

3) the embodiment of specific constructive and technological proposals implemented on the real objects of the existing transport infrastructure, according to the suggestions of the PNU [6; 7];

4) the prospect of integrating the proposed force regulating scheme with a low-cost and safe technology for performing work on replacing the passage slab on the spans of steel-reinforced concrete bridges.

The authors of [8] noted a characteristic detail of the projects for the reconstruction of steel-reinforced concrete bridges, presented in the developments of the department "Bridges, Grounds and Foundations" of the TOGU, in which the key condition is the installation of temporary supports [8] under the last assembly joints in the span structures developed by TsNIIPSK "43282 km" project. This position of temporary supports divides the span into three parts of almost equal length.

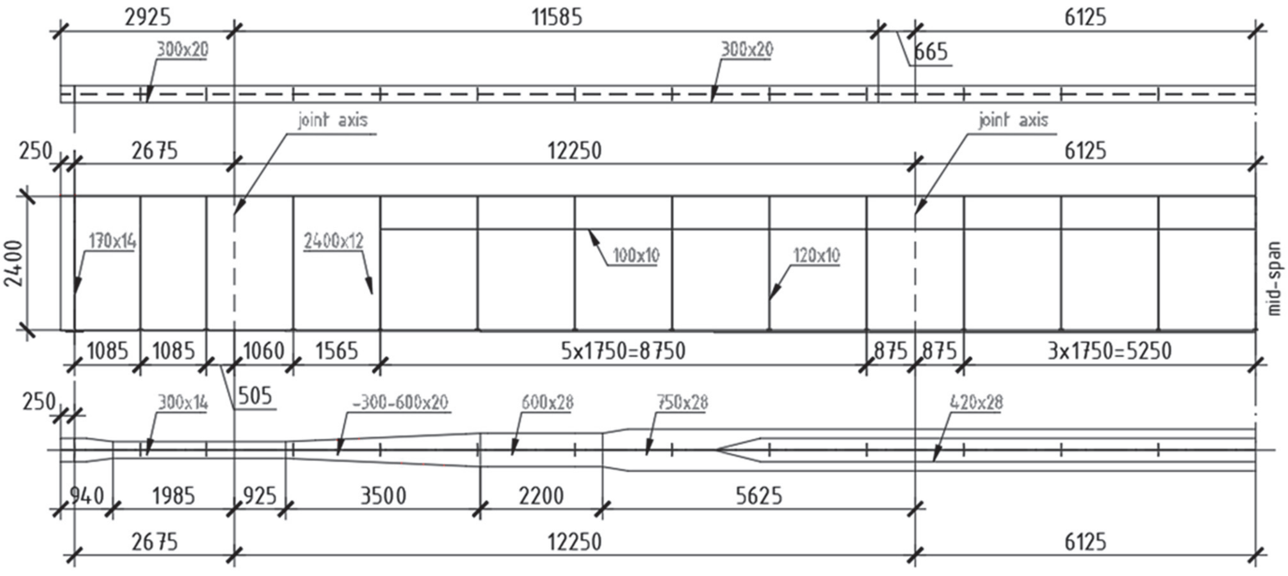


Figure 1. Plan of the upper and lower chords, and facade of the main beam

In each of the spans of the newly formed scheme (after the installation of temporary supports), the geometry of the cross sections of the beams ensures the fulfillment of the conditions for the strength and stability of the bending-torsional form of solid-walled beams. Thus, favorable conditions are created for the relative freedom of maneuver of load-lifting mechanisms and vehicles necessary for the disassembling of sidewalk blocks, rail-

[1] GOST 32960–2014. *Automobile roads of general use. Traffic load models, application of the load models*. Moscow: TSNIIS Publ.; 2014.

[2] SP 35.13330.2011. *Bridges and culverts*. Moscow: TSNIIS Publ.; 2011.

ings, dismantling and removal of bridge deck clothes, dismantling of concrete of monolithic “windows”, transverse and longitudinal seams of blocks of the passage slab and, accordingly, dismantling of existing road slab blocks. In connection with the peculiarity of the formation of the supporting structure of steel-reinforced concrete span structures, it is necessary to prevent the loss of stability of the bending-torsional form by solid-walled beams and to minimize the risks of this situation [8].

Stages of force regulation

Further, the operations of regulation of efforts are given on the example of the real construction object “Bridge across the Kabarga River” (Figure 2). These operations have been developed by the Department of Highways of the PNU and were subsequently implemented at the construction site. The order of work with the characteristics of technological operations and work of span structures, that satisfy the conditions of strength and stability of the flexural-torsional form and create the basis for regulating efforts in order to form a reserve of bearing capacity necessary to create a greater load capacity and a developed dimension of the carriageway and sidewalks, is presented. This, in turn, also makes the issue of developing a low-cost, efficient and safe technology for changing the passage slab on spans of steel-reinforced concrete bridges relevant [8].

a *b*

Figure 2. Side view of the span structure of the bridge across the Kabarga river:
a – before overhaul; *b* – after overhaul, 2020

For a substantive solution of the problem on the designated issue with reference to the stiffness characteristics of a particular span, the development of TsNIIPSK “43282 km” project was carried out (Figure 1). Within the framework of solving the problem, the assessment of the deformed state of the span structure from the loads accompanying the formation of the supporting structure of the span structure and reflecting, in the general case, the multi-stage nature of its operation was carried out. These loads determine the composition of the calculated section of the beam: its own steel section works on the action of loads from its own weight and the weight of a reinforced concrete slab; and the combined steel-reinforced concrete section works on the action of the weight of clothing and elements of the bridge deck.

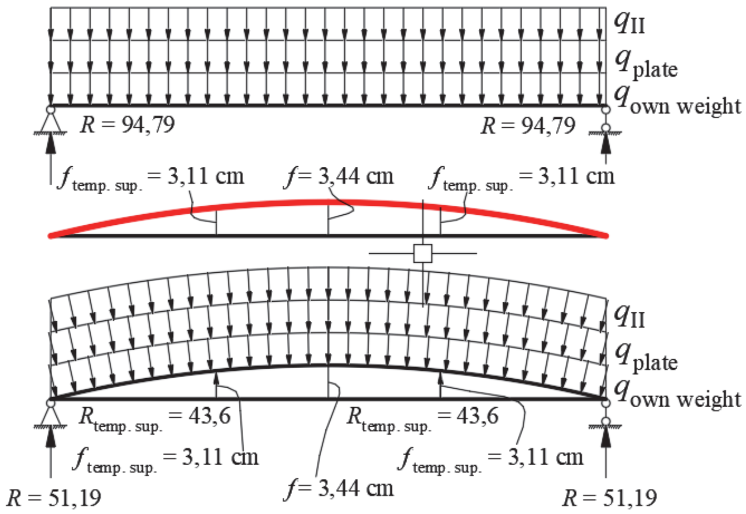
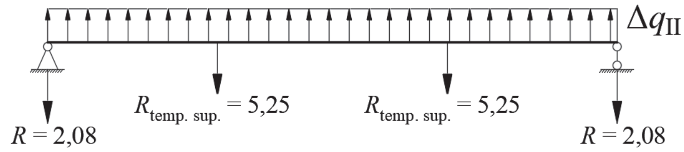
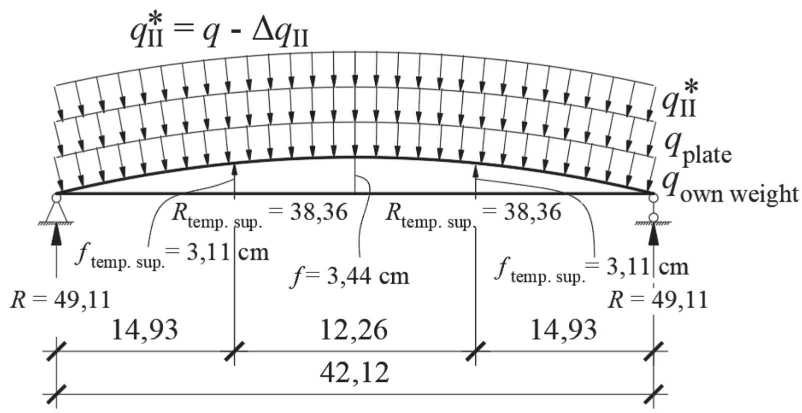
Thus, taking into account the scope of work carried out in the sequence accompanying the formation of the bearing structure of the steel-reinforced concrete span structure, the deflection of the beam with a span of l = 42.12 m was assessed under the action of: the weight of metal structures, the weight of the reinforced concrete slab [9]. The composition of the loads, indications of the nature of the work of the section of the span beam are given in Table 1.

In the technological part of the production of a complex of works aimed at dismantling the existing roadway slab and installing a new one, three main stages can be distinguished.

First stage. As part of the first stage, it is planned to jack out the span structure with a reference from the existing position to compensate for the action of the second part of the constant loads, which include: the weight of clothing, bridge deck elements; weight of barrier and railings. After the installation of temporary supports located in the extreme thirds of the span (at the location of the assembly joints), the span is jacked up on temporary supports by a value of 3.11 cm, counting from the existing high-rise position of the span. The section in the middle of the span will move in this case by 3.44 cm (Table 1).

Table 1

Name of work, scheme of the span's operation (the 1st stage)

Step	Description of works	Span's loading scheme, support reactions, displacements, cm
1	Jacking up the beams of the existing steel-reinforced concrete span structure to compensate for the load q_{II} from clothing and elements of the bridge deck	
2	Dismantling of barrier fences, railings, disassembling of the bridge deck over the transverse and longitudinal seams of the slab blocks	
The sum of support reactions and loads upon finishing the works of the 1st and 2nd steps of the first stage		

Notes:
– weight of steel structures $q_{own\ weight} = 0{,}694$ tf/m (normative), $q_{own\ weight} = 0{,}763$ tf/m (calculated);
– weight of reinforced concrete $q_{plate} = 2{,}171$ tf/m (normative), $q_{plate} = 2{,}388$ tf/m (calculated);
– weight of the bridge deck $q_{II} = 1{,}636$ tf/m (normative), $q_{II} = 2{,}188$ tf/m (calculated);
– in the second step of the first stage Δq_{II}, a decrease in the constant load is indicated as $\Delta q_{II} = 0{,}348$ tf/m (normative), $\Delta q_{II} = 0{,}411$ tf/m (calculated).

The vertical displacements (deflections) of the beam in the sections of setting temporary supports were found from loads indicated in the Table. 1. These displacements amounted to 3.11 cm. Thus, if efforts are applied on temporary supports, which are directed upwards, and the span structure on temporary supports is raised by a value of Δ = 3.11 cm, then the beams of the span structure are released from the action of loads, from which a deflection of 3.11 cm was found. So, the probability that solid-walled beams will lose of stability of the bending-torsional form will be minimized. The value of the support reaction on temporary supports was found from the solution of the inverse problem with the known bending stiffness of the beams and the given displacement value Δ = 3.11 cm.

Solutions for determining vertical displacements from the given loads and for the inverse problem which is determining forces (support reactions) for given displacements are made using the Mohr – Maxwell formula, taking into account the variable bending stiffness of beams along the length of the span (formulas 1, 2).

For a section in the middle of the span:

$$f_{0,5l} = 2\sum_{i=1}^{i=4}\int_{l_i-1}^{l_i}\frac{\bar{M}_1 M_q}{E_s I_i}dx. \quad (1)$$

In a section with a temporary support:

$$f_{\text{temp.sup}} = \sum_{i=1}^{i=3}\int_{l=0}^{l_3}\frac{\bar{M}_1 M_q}{E_s I_i}dx + \int_{l_3}^{a}\frac{\bar{M}_1 M_q}{E_s I_i}dx + \sum_{i=1}^{i=4}\int_{a}^{l_7}\frac{\bar{M}_1' M_q}{E_s I_i}dx. \quad (2)$$

A diagram reflecting the main steps of calculations which are necessary to determine the displacements of the span are shown in Figure 3.

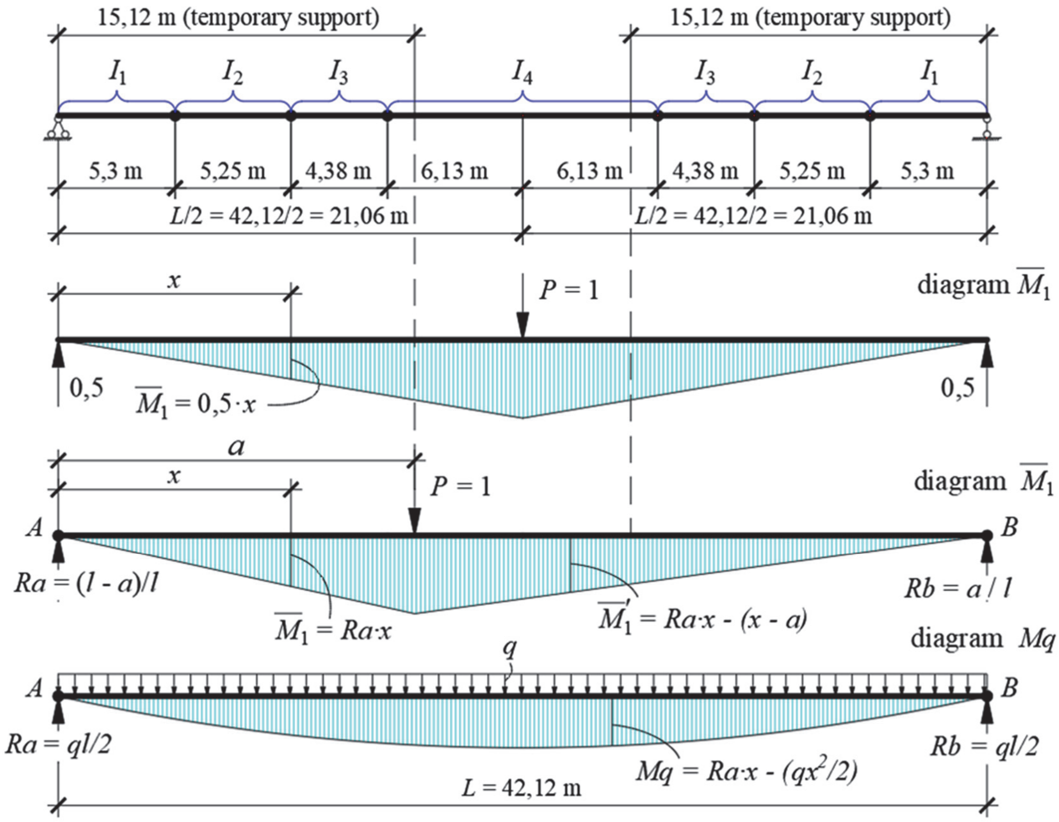


Figure 3. Scheme for determining bending moments from a distributed load and concentrated unit forces for implementation (1, 2)

The superstructure at this (first) stage step works with the reduced moment of inertia, while the concrete part is endowed with the value of the initial modulus of elasticity E_b, considering the assumption that during a relatively short time of jacking out, the unloading of concrete will most likely be accompanied by predominantly instantaneous deformations without development deformations of elastic consequences. Thus, the values of bending stiffnesses of steel-reinforced concrete sections, which have been taken for calculation without the effect of manifestation of concrete creep, predetermine a more unfavorable loading of temporary supports.

The following works are performed at the first stage as can be seen from Table 1:

– dismantling and removal of barrier and railing fences;

– disassembly and removal of the pavement clothing over the transverse and longitudinal seams between the blocks of the prefabricated slab of the roadway.

The total dismantling of the bridge deck clothing over the entire area of the road slab has not any fundamental importance if the regeneration of old asphalt concrete is not provided for and reduction the weight of the dismantled block of the road slab is not required because of the carrying capacity of cranes and vehicles involved in the process of dismantling and removal of the slabs.

After the removing the pavement clothing over the slab monolithic seams, the reaction to temporary supports can be ≈38.4 tf.

It is possible to carry out the work on disassembling the clothes of the bridge deck and dismantling the enclosing structures without jacking up the span structure. But application of jacking forces at this stage contributes to adaptation of the structure to the action of forces that are opposite in sign to the operational ones, this will eliminate the impulsive nature of the change in the composition of the cross sections in the future.

For efficient dismantling and removal of the slab from the spans, the second stage provides for the dismantling of the transverse and longitudinal seams of the slab blocks and the performance of technological operations that would exclude further dynamic impact on the span. The distribution of support reactions between the main supports and temporary supports is solved by considering a three-span beam under the action of unloading loads (Table 2).

The second stage included the following works:

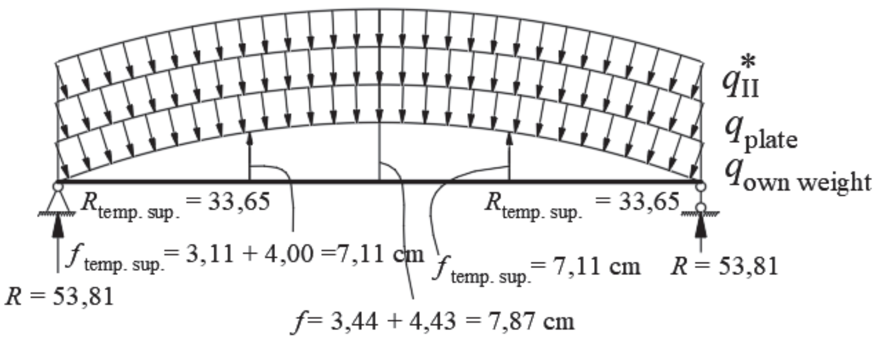
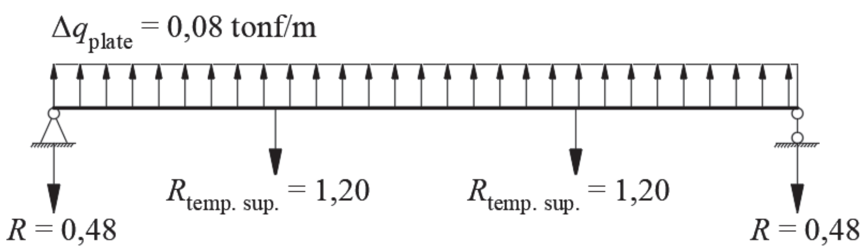
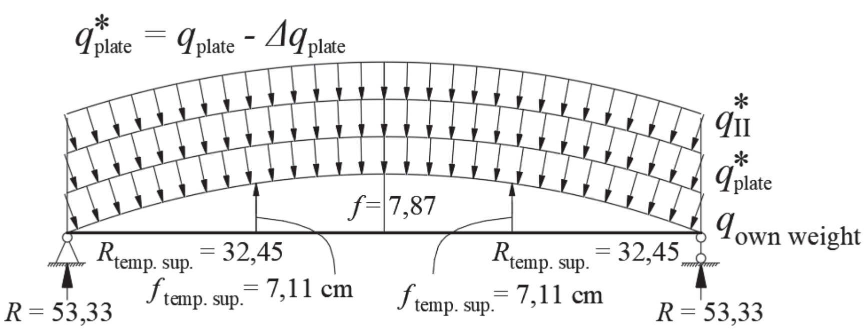
– jacking out of the superstructure on temporary supports by 4.00 cm, counting from the height position of the superstructure at the first stage (Table 2);

– the jacking value of 4.00 cm is derived from the determination of the deflection from the action of the load from the weight of concrete of the transverse joints of the blocks of the existing roadway slab;

– dismantling of concrete from the transverse seams of roadway slab blocks.

Table 2

Name of work, scheme of the span's operation (the second stage)

Step	Description of works	Span's loading scheme, support reactions, displacements, cm
1	Jacking out of the beams with a reference from the height position of the 1st step. The work of the beam is determined by the partial participation of the slab and is considered by the reduced moment of inertia for the section $I_{\text{is,red}} = k_{\text{red}} I_{\text{is}}$, with $k_{\text{red}} = 1{,}2$	
2	Disassembling of the transverse seams of the roadway slab blocks. Reducing the constant load by the value Δq_{plate} (normative – 0.080 tf/m; calculated – 0.088 tf/m)	
	The sum of the support reactions and loads upon completion of works of the 1st and 2nd steps of the second stage	

The value of the support reaction on the temporary support can be ≈ 33.7 tf immediately after jacking out, and it can be ≈ 32.5 tf after disassembly of the transverse seams upon completion of the stage.

When determining the deformation and force factors, it was accepted:

– in the area between the extreme stops of adjacent blocks, separated by a transverse seam, the plate is not involved in the work;

– the concrete of the slab in the area between the extreme "windows" in each of the blocks is partially included in the work; at the same time, it is understood that the decrease in the effect of joint work is due to the greater possibility of mutual displacements of the slab and the upper chord of the beam, which experiences deformations opposite in sign to the deformations corresponding to the arrangement of the passage slab;

– in the aggregate, the partial participation of the slab in joint work with the beam is taken into account by the reduced moment of its cross section $J_{is,red} = k_{red}J_{is}$ where $k_{red} = 1{,}2$;

– due to the transformation of the span structure's rigidity characteristics and redistribution of the forces of the 1st step, the support reactions at this stage, in accordance with the principle of independence of the action of forces, are determined from the total displacement of the 1st, 2nd steps and from loads corresponding to the end of the 1st step considering the dismantling of the concrete of the transverse seams at the end of this stage.

Third stage. In the calculation part of the third stage, when determining the support reactions, the following were accepted:

– loads corresponding to the completion of the 2nd step (Table 2);

– assumptions of the 1st stage regarding the value of bending stiffness and taking into account the total displacements of the 1st, 2nd, 3rd steps, which are equal to the following:

• on a temporary support $f_{\text{t.s.}} = 3{,}11 + 4{,}00 + 4{,}27 = 11{,}38$ cm;

• in the middle of the span $f = 3{,}44 + 4{,}43 + 4{,}71 = 12{,}58$ cm.

In the technological part, the third stage includes the following:

– jacking out (final move) of the span structure on temporary supports by 4.28 cm, counting from the height position of the span structures at the previous stage; at the same time, the reaction on temporary supports is approximately 53.85 tf, due to the fact that the reinforced concrete slab is completely switched off from joint work with the metal beams, and the support reactions are redistributed with their decrease on temporary supports (Table 3);

– dismantling of reinforced concrete slab blocks during crane operation according to the "retreating crane" scheme after dismantling the longitudinal seams of 2–3 rows of slab blocks and disassembling concrete of monolithic windows on them; direct removal of the block should exclude jerks and dynamic impact on the span and curvature of the upper chords of the main beam and auxiliary run.

The given values of jacking out (Table 3) unload the superstructure from work on the impact of the second part of the constant loads and the weight of the slab in the process of its dismantling, and they create preconditions for maintaining the strength and stability conditions of the metal structures.

The total displacement of the jacking out at the final stage is taken equal to the sum of the deflections from the second part of the constant load and the weight of the slab. Thus, after the completion of the dismantling works, the reaction of the temporary supports will become equal to zero, but at the same time, the contact of the support devices of the temporary supports with the span structure must be ensured so that such a mode of operation of the temporary supports endows them with the functions of tracking systems that monitor the height position of the beams of the span structures. This state can be taken as a control of the provision incorporated in the calculations that the own weight of the metal structures of the span structures (after the dismantling of the reinforced concrete slab) when working with a full span is perceived by the cross section of the steel beams.

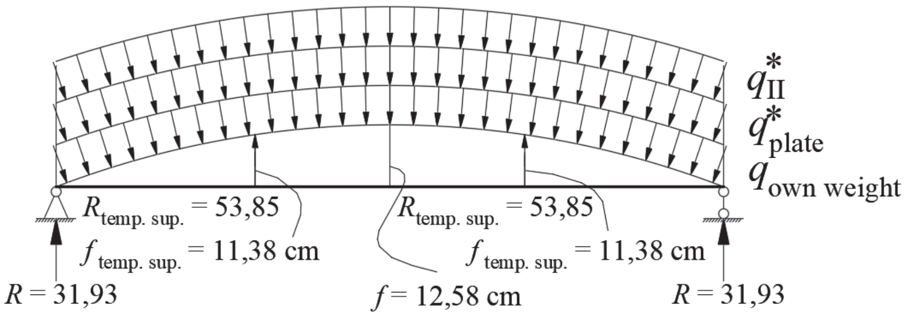
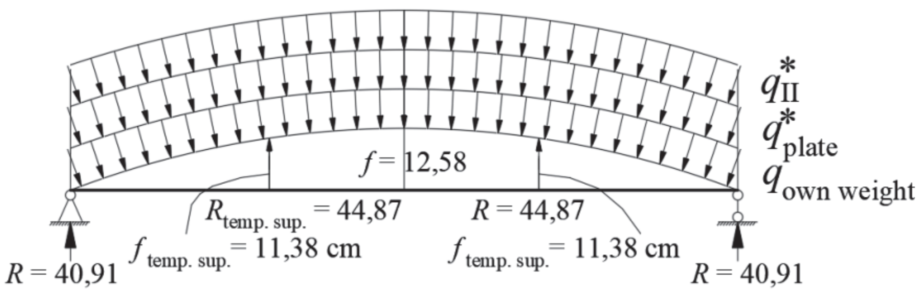
The accepted order to produce the works includes the phased jacking out of the span with the corresponding work on the dismantling of the existing (old) slab of the roadway and the clothing of the bridge deck. This procedure determines the following composition of cross sections and loads when determining the forces in the process and after the installation of a new orthotropic slab of the roadway, in during which the beams of superstructures perceive these loads:

– own weight when working with a calculated span $L = 42.12$ m;

– the weight of the orthotropic slab when the beam is operating in a continuous pattern (14.93 + 12.26 + 14.93 m), temporary supports and support reactions, arising from their side and directed upwardly, are necessary to unload the main beams of the span structures and provide the stability condition of a bending and twisted shape.

Table 3

Name of work, scheme of the span's operation (the third stage)

Step	Description of works	Span's loading scheme, support reactions, displacements, cm
1	Jacking out by 4.3 cm, which is the final move of the beams on temporary supports, counting from the height position of the 2nd stage	 The load composition corresponds to the end of the 2nd stage - $q_{own\ weight}$ (0,694; 0,763 tonf/m); - q^*_{plate} (2,091; 2,300 tonf/m); - q^*_{II} (1,288; 1,747 tonf/m).
	When the reinforced concrete slab of the passage is completely excluded from the joint work with steel beams while maintaining the height position, cm, the distribution of the support reactions is characterized by the following scheme	

In turn, the following loads act on the beams of spans after they were combined with an orthotropic plate:
– support reactions of temporary supports after their unloading;
– the weight of the pavement, the elements of the bridge deck and temporary load;
– the weight of the orthotropic road slab.

Conclusion

Taking into account the fact that steel-reinforced concrete bridges are built across large water barriers and, due to their large length, they are very expensive, then reconstruction with usage of the existing supports can reduce the cost of construction by an average of 60%, the modernization of existing steel-reinforced concrete superstructures is undoubtedly relevant. Based on the presented structural and technological measures, it is possible to carry out and effectively implement work on the reconstruction of existing steel-reinforced concrete bridges that do not fully meet modern requirements for carrying capacity and traffic capacity.

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