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DETERMINING FEATURES OF THE DEFORMED STATE OF REINFORCED CONCRETE BEAMS OF ROAD BRIDGES WHEN STRENGTHENING THE SPAN STRUCTURES

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The technology of repairing reinforced concrete bridges typically involves closing traffic on one half of the structure and performing work on it when it is possible to move vehicles on the second part of this structure. The main process of interest to practitioners in terms of hardening concrete, which occurs in the beams of a span structure during the passage of a temporary moving load, is deformation. By the time the cement of freshly laid concrete of the overhead reinforcement slab is hardened, it is necessary to create the necessary conditions for this (temperature, humidity, immobility over time, etc.). Before concrete acquires strength, movements arising in the span structure cause the destruction of cement stone at the formation stage. It is necessary to investigate the presence of deformations, as well as their impact on the impossibility of forming a homogeneous structure of concrete and its adhesion to reinforcing elements that combine the existing slab with the new one.

This study has established deformations induced by a temporary load from 1.61 to 5.83 mm, which have a negative impact on the process of solidification of concrete in the reinforcement slab for a span structure during the repair of a motorway bridge. The three-dimensional models were calculated by simulating a bridge of the M-04 highway. The results underlie the conclusions that the technology of repair work does not take into consideration the required conditions for high-quality concrete strength acquisition in an additional slab.

The study results established that operations on concreting an additional overhead reinforcement slab in the presence of vibrational effects exerted by the temporary load on the span structure cannot be performed because of the destruction of concrete at the hardening stage.

Given the above issue, several ways to address it have been devised and analyzed; the best of them is recommended

Keywords: repair of bridges, concrete road beams, reinforcement slab, deformation, concrete structure

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1. Introduction

Road load increases over time while bridges exposed to this load, which were designed according to earlier standards, are aged, demonstrating defects, and failing to meet the carrying capacity of modern carloads. There are about 12 % of bridges whose service life exceeds 80 years; the resource of those structures is close to exhaustion. A significant number of bridges on public roads were built before 1989, that is, 30 years ago; during operation, they are prone to defects. Thus, a significant share of them, 63.5 %, does not meet the requirements set by acting norms [1]. Therefore, there is a need to repair or reconstruct bridges while simultaneously increasing their carrying capacity. When executing such operations, important factors may be ignored needed for the qualitative achievement of the goal. Therefore, analyzing methods for improving the properties

of structures is necessary and always relevant, especially in a given area of high-class responsibility – bridge construction.

2. Literature review and problem statement

Work [2] states that the repair and restoration of the concrete coating are associated with significant material costs; in addition, they lead to reduced throughput and congestion. At the present stage, for restoring concrete structures, advanced methods for the reconstruction and repair of bridges are proposed [3], ensuring the durability of structures and increasing the carrying capacity of beams in span structures [4]. Most often, during the reconstruction of road bridges, in order to increase the carrying capacity of the bridge, the arrangement of an overhead slab for strengthening the motorway is implied. However, there remained unresolved issues related to the oc-

currence of deformations that are not taken into consideration for a high-quality acquisition of strength of fresh concrete mixture [5] when concreting the reinforcement slab.

The service life and reliability of monolithic reinforced concrete structures depend mainly on the influence of technology [2]. Mainly, the quality of concrete is associated with the composition of materials, their quality, and taking into consideration the criterion of compatibility of components [6]. In addition, the reliable structure of concrete depends on the processes during concreting and the conditions of primary hardening [7]. Work [8] shows the necessary conditions for the formation of high-quality concrete and analyzes the relationship of the main parameters of concreting technology. However, the moving load on the bridge during the implementation of concrete works contributes to the occurrence of deformations and affects the structure of non-hardened concrete. When performing operations on arranging an additional overhead strengthening slab [3], the newly laid concrete is affected by displacements unacceptable in the process of hardening concrete. In the case of work without complete removal of traffic from the span structure, the structure of freshly laid concrete could be destroyed; the adhesion between the fresh concrete with reinforcement and the old structure of the span slab would be disturbed [8]. Work on concreting an additional overhead reinforcement slab in the presence of vibrational effects induced by the temporary load on the span structure cannot be performed because of the destruction of concrete at the hardening stage. That is, when performing these construction operations, technological violations occur that adversely affect the condition of new concrete and the entire reinforcement of span structures [5]; this issue has not been investigated in detail. The above allows us to assert that it is expedient to conduct a study into the occurrence of deformations, their size, their impact on the process of hardening and the acquisition of strength by concrete of an additional reinforcement slab. It is predetermined by the urgent need to improve the resource and carrying capacity of road bridges operated on motorways. The prospect of such studies, based on unresolved issues in the analysis of problems, is that the method of reinforcement, which is considered in the current work, is the most appropriate, effective, and widespread.

3. The aim and objectives of the study

The purpose of this research is to identify deformations and confirm the impact of a temporary load on the violation of the technological process of hardening the concrete reinforcement slab using the software calculation of estimated models. This will make it possible to prove that an increase in the carrying capacity of span structures with the help of an overhead slab does not produce the desired effect, which makes the relevant research expedient.

To accomplish the aim, the following tasks have been set:

- to determine the amount of temporary load on the part of a bridge where construction work is carried out;
- to simulate the span structure according to a typical project, which was most often used on roads, determine the deformations in the cross-section of an additional slab, and analyze the impact of the detected deformations on the destruction of the structure of freshly laid concrete and violation of the adhesion of fresh concrete with reinforcement and the old structure of the span slab;

- to analyze possible ways to solve this problem and compare them.

4. The study materials and methods

A concrete mixture after pouring undergoes the physical and chemical processes that turn it into a solid basis for the construction structure. The strength indicator is the main characteristic of concrete as a structural material. One of its properties is the acquisition of strength by concrete over time. One makes a quality assessment only after complete hardening. As soon as water and cement come into interaction, the slurry gradually loses its mobility and changes its properties. A new structure forms over a certain time. The aging of concrete stone involves two stages in the solution evolution: the initial – concrete setting, and the final – concrete hardening. Their progress makes it possible to obtain the properties of strength corresponding to the concrete of a certain class and grade.

Concrete setting stage. During transportation to the place of concreting in a concrete mixer, the slurry remains movable due to its constant agitation and its thixotropic properties. Stopping the mechanical effect on a concrete slurry after pouring increases its viscosity; it begins to set. All detected defects in the slab formation should be removed at the beginning of the first stage of concrete stone aging: it starts immediately after pouring and does not last long.

The duration of the concrete setting depends on the ambient air temperature. A constant temperature of +20 °C is considered an ideal condition for the first stage of slurry solidification, which allows it to set in 3 hours. When changing this condition, the duration of the setting may vary towards a decrease or increase. This stage lasts the longest at ambient temperature values close to 0 degrees [9].

Laying concrete should be carried out in compliance with many conditions. One of the conditions concerns the restriction on the time of laying concrete. The end of laying the concrete slurry in the structure should take place no later than the start of cement setting. The onset of setting (OS) depends on the grade of cement, its activity, the presence or absence of admixtures – accelerators (inhibitors) of hardening, temperature, and other factors. OS is a characteristic of the cement grade; it is typically 3 to 6 hours.

Primary hydration of cement lasts from OS to the end of setting (ES); it occurs within 6–12 hours. This time involves the processes of cement stone formation, as well as the adhesion of cement stone to large and small aggregates and reinforcement [5]. During this period, concrete does not yet have the strength of single-axis compression, displacement, and stretching [6]. At the time of OS, concrete is a suspension of cement milk (slurry) and inert fillers. At the time of ES, concrete can be compared to sandy soils with a high content of gravel. Until the time of ES, concrete gains some shear strength, which is caused by the “stickiness” of cement slurry and can be compared to the characteristic of “adhesion” of sandy soils. A conditional plot of the concrete strength acquisition is shown in Fig. 1.

The equation describing the concrete hardening plot can be written as follows:

$$M = 31.3 \ln(T) - 2.38, \quad (1)$$

where M is the strength, %; T – time, day.

CONCRETE STRENGTH ACQUISITION PLOT

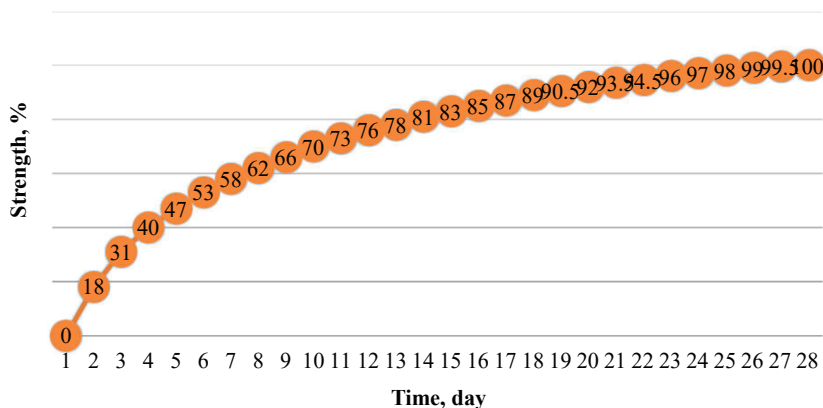


Fig. 1. Concrete strength acquisition plot

When arranging an overhead slab on the motorway of bridge structures, B35 class concrete should be used. The design strength of this class of concrete at the age of 28 days should be guaranteed to be at least 45 MPa (460 kg/cm²).

It should be noted that arranging an overhead slab for strengthening the motorway during the reconstruction and repair of bridges is implied for the repair of bridges whose span structures are made of prefabricated T-shaped or I-beam reinforced concrete beams. In this case, the beams can be combined either with monolithic parts of the motorway slab or with welds on the laid parts of the slab and diaphragm.

When repairing and reconstructing bridge structures, the idea to arrange an additional overhead slab is not bad, but controversial. The positive aspects include an increase in the compressed zone of the cross-section of the beams of the span structure. The result is an increase in the carrying capacity of the structure. Due to the increase in the height of the cross-section of the span, its carrying capacity and rigidity increase, therefore, deflections decrease while the comfort of movement improves [4].

Negative is an additional constant load on the span structure (+350 kg/m² with a slab thickness of 14 cm). In addition, with an increase in the rigidity of the span structure, the frequency of its natural oscillations changes. Typically, for reinforced concrete beam spans, the frequency of natural oscillations is 5÷12 Hz for the first shape of oscillations, and 18÷25 Hz for their second shape.

The technology of repairing reinforced concrete bridges, as a rule, involves closing traffic on one half of the structure and performing work on it (Fig. 2) while it allows for the further movement of vehicle load on the second part of the structure [3].

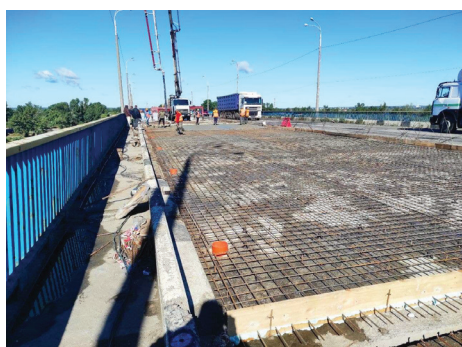


Fig. 2. Repairing a bridge on the road M-04, 233 km

The composition of maintenance work is typical:

1. Removal of asphalt.
2. Removal of the protective and leveling layer with waterproofing to the beam slab.
3. Installation of rows of anchors in increments of 1.0÷1.5 m (anchors Ø10÷12 mm, which are drilled to 100 mm).
Cleaning the surface of the slab.
4. Application to the entire surface of the slab of materials such as Sika to ensure further adhesion of new concrete to the slab.
5. Installation of reinforcing meshes on the entire area in one layer (reinforcement Ø10, step 150×150 mm).
6. Concreting the slab, taking into consideration the new requirements for transverse slopes (2.5 %).

Given that all the new layers in total should meet the previous marks, and the fact that the new thickness of asphalt is 110 mm, depending on the width of the bridge, the resulting thickness of the slab is 80 to 110 mm.

For our research, a software method of calculation is used – a finite-element method. 3D modeling is performed in Autodesk AutoCAD (USA) (Fig. 3) and the finished model is estimated using the ANSYS software (USA). To simplify the calculation, working fittings were combined into one volumetric rod and placed in the center of gravity of the reinforcement cross-section.

Before calculating the model using the ANSYS software (USA), it was divided into 261665 hexahedral finite elements (Fig. 4), which ensures sufficient accuracy of calculations.

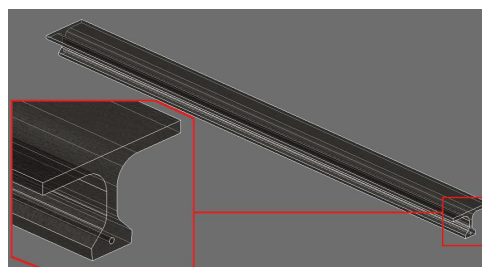


Fig. 3. 3D model prepared in Autodesk AutoCAD software (USA)

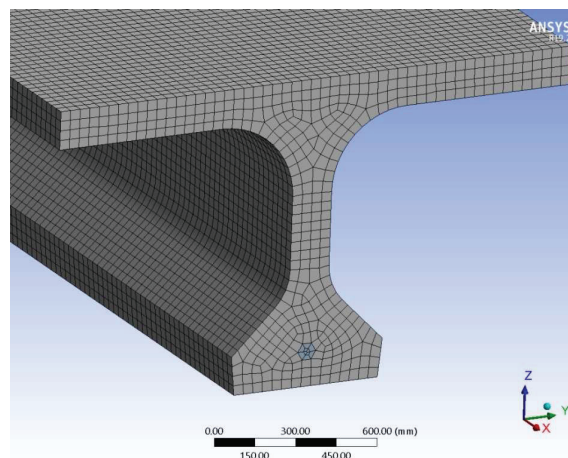


Fig. 4. The finite-element estimated model of a beam using the ANSYS software (USA)

The length of the beam model is equal to the estimated one of 24.0 m. The model was fixed according to the beam scheme on two supports. The specified characteristics of the materials correspond to concrete class B35 (C28/35) and strained reinforcement of class B-II (B1400).

5. Results of studying the deformed state of span structures in road bridges

5.1. Determining the amount of temporary load on the part of the bridge where construction work is carried out

The basic process of interest to practitioners when hardening concrete is deformations that occur in the beams of the span structure exposed to a temporary moving load. In this case, the internal efforts in the cross-sectional elements are secondary to us.

To carry out the required calculations, an actual bridge on the M-04 highway (Fig. 2) and model 1 of the carload according to the AK scheme were taken as examples [10]. On its basis, a similar cross-section of the span structure was projected using a beam 24.0 m long according to the typical project of the series 3.503.1-81, by Soyuzdorproekt, namely B2400.174.120-TV-5N (Fig. 5) [11]. In addition, to determine the magnitude of the force of influence induced by the temporary load acting on the span structure, we calculated the transverse impact factor.

The scheme of the cross-section of the span structure consists of nine beams arranged in increments of 2.1 m. With two lanes of traffic on the opposite part of the bridge,

the most unfavorable loading location is its maximum approximation to the concreting area (Fig. 6). The busiest beam on the concreting area of the reinforcement slab, in this case, is the B5 beam. For a given beam and a given scheme of loading the span structure, a line of influence of the coefficients of transverse arrangement (CTA) was built, which is shown in Fig. 6 [12].

The actual values of CTA under each wheel are given in Table 1.

Table 1

Coefficients of transverse arrangement depending on temporary load

Traffic line No.	CTA measurement site	CTA value
Lane 1	wheel 1	$y_{1,1}=0.068$
	wheel 2	$y_{1,2}=0.129$
Lane 2	wheel 1	$y_{2,1}=0.176$
	wheel 2	$y_{2,2}=0.237$

CTA mean value:

– for AK tandem:

$$\eta_p = \frac{0.068 + 0.129 + 0.176 + 0.237}{4} = 0.153; \tag{2}$$

– for distributed AK:

$$\eta_v = \frac{0.068 + 0.129 + 0.6 \cdot (0.176 + 0.237)}{4} = 0.111. \tag{3}$$

Sketch	Beam brand	Beam dimensions, mm		Concrete class	Costs of materials for the product							Weight, kg
		c	b		Concrete, m ³	B-II (B1400), kg	K-7, kg	A-I, kg	A-II, kg	A-III, kg	Steel rental, kg	
	B2400.174.120-TV.AIII-1H	700	2020	B35 (C28/35)	13,92	838,8	-	473,8	-	1258,4	72,6	34,8
	B2400.174.120-TV.AIII-2H				13,92	838,8	-	473,8	-	1276,3	310,6	34,8
	B2400.174.120-TV.AIII-3H				13,92	838,8	-	473,8	-	1272,6	262,6	34,8
	B2400.174.120-TV.AIII-4H				13,92	838,8	-	493,8	-	1385,3	148,2	34,8
	B2400.174.120-TV.AIII-5H				13,92	838,8	-	493,8	-	1381,6	100,2	34,8
	B2400.194.120-TV.AIII-1H				900	2220	14,64	838,8	-	488,1	-	1330,7
	B2400.194.120-TV.AIII-2H	14,64	838,8				-	488,1	-	1348,6	310,6	36,6
	B2400.194.120-TV.AIII-3H	14,64	838,8				-	488,1	-	1344,9	262,6	36,6
	B2400.194.120-TV.AIII-4H	14,64	838,8				-	508,1	-	1457,6	148,2	36,6
	B2400.194.120-TV.AIII-5H	14,64	838,8				-	508,1	-	1453,9	100,2	36,6

Fig. 5. Specifications for a typical beam of the span structure

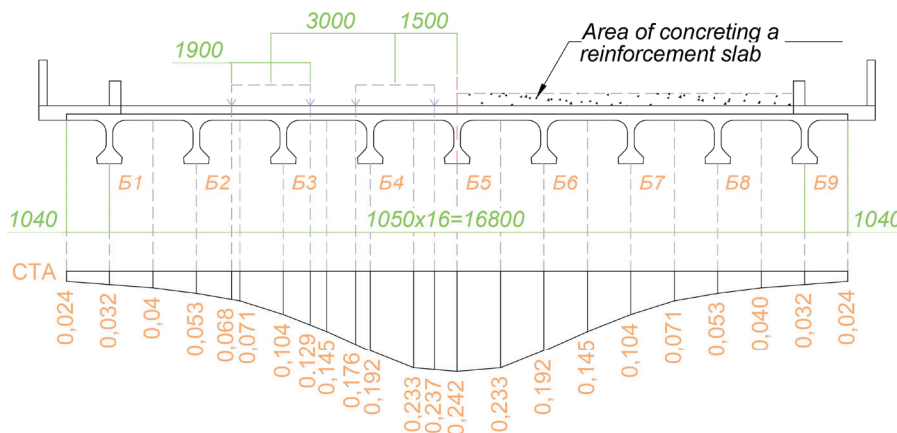


Fig. 6. Schematic showing the location of temporary load and the line of influence of the coefficients of transverse arrangement

Thus, the estimated temporary load is:

– depending on AK tandem:

$$P = 9.81 \cdot K \cdot n_c \cdot \eta_p \cdot \gamma_v \cdot (1 + \mu) = 9.81 \cdot 11 \cdot 2 \cdot 0.153 \cdot 1.5 \cdot 1.3 = 128.36 \text{ kN}; \tag{4}$$

– depending on distributed AK:

$$v = 0.98 \cdot K \cdot n_c \cdot \eta_v \cdot \gamma_v \cdot (1 + \mu) = 0.98 \cdot 11 \cdot 2 \cdot 0.111 \cdot 1.3 \cdot 1 = 6.23 \text{ kN/m}. \tag{5}$$

The obtained results of the intensity of loads from tandem and distributed pressure of cars, taking into consideration the transverse distribution coefficient, will later be used for software calculations of the volumetric model.

5. 2. Determining deformations by modeling the span structure of a typical project

Our calculations were carried out by a finite-element method for the spatial structure of the beam whose estimated model is shown in Fig. 7.

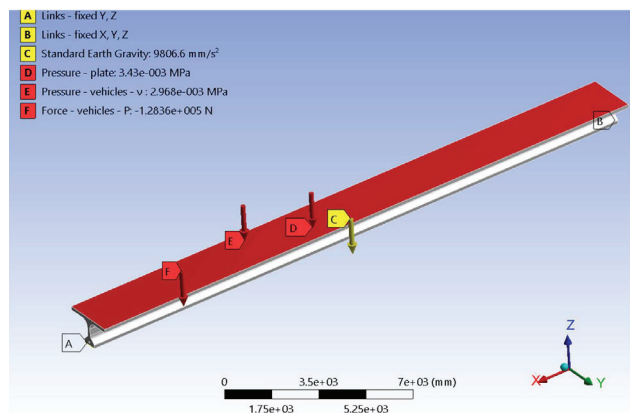


Fig. 7. Estimation model of the beam

Two calculations of the model with the following load options are carried out: the first in the case of taking into consideration the effect of only constant loads including the reinforcement slab, the second – constant loads (with a load of a new additional reinforcement slab) and an additional temporary load. The constant load from the reinforcement slab on the estimated model is 7.2 kN/m. The results of absolute movements of the lower fibers of the additional beam of slab reinforcement are shown in Fig. 8. The absolute values of horizontal movements of the lower fibers of the new beam slab for each variant are given in Table 2.

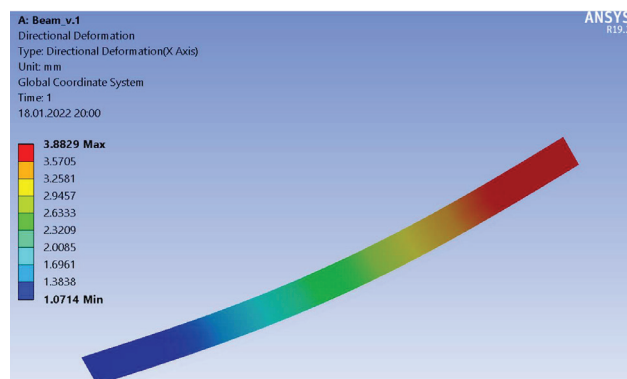
The relative, that is, the actual value of horizontal movement along the lower fibers of the new slab is determined from the following formula:

$$\Delta_x = (\Delta_{\max}^{p+v} - \Delta_{\min}^{p+v}) - (\Delta_{\max}^p - \Delta_{\min}^p). \tag{6}$$

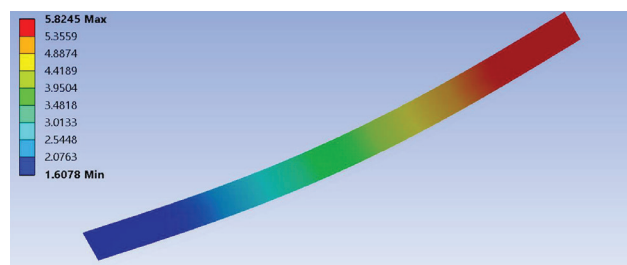
Our calculations of the model (Table 2) demonstrate that the difference in horizontal movements of the lower fiber of the new slab exceeds 1.5 times.

Consequently, the actual value of the relative horizontal movements of the lower fiber of the new slab depending on the effects of the temporary load is:

$$\Delta_x = (5.83 - 1.61) - (3.88 - 1.07) = 1.41 \text{ mm}. \tag{7}$$



a



b

Fig. 8. Results of absolute displacements of the lower fibers of the reinforcement slab: a – without taking into consideration the temporary load; b – under the influence of temporary load

Table 2

Results of absolute values of horizontal movements of lower fibers of the new beam slab

Calculation variant	Absolute displacements of the lower fibers of the reinforcement slab, mm	
	Excluding temporary traffic load	Minimal
Maximum		3.88
Under the influence of temporary traffic load	Minimal	1.61
	Maximum	5.83

According to regulatory documents [13], movement over concrete structures is allowed no earlier than concrete reaches a strength of 1.5 MPa. Practically, the movement is allowed at an air temperature of 15 °C after 2 days, at 10 °C – after 3 days, at 5 °C – after 4...5 days. The calculation results confirm the negative impact on the process of hardening concrete, namely the destruction of the structure of concrete at the beginning of its setting.

5. 3. Analyzing possible ways to solve this problem and comparing them

There are two possible solutions to this problem:

- 1) complete closure of traffic on the bridge;
- 2) division of the span structure by cutting the slab along the axis of the bridge into two parts: the first – on which repair work is carried out, the second – on which traffic is allowed [14].

Below are the advantages and disadvantages of each option in comparison with each other.

Option number 1.

Advantages:

1. Improved working conditions. The absence of a dangerous factor – traffic near the place of maintenance work.

2. Wide front of work for the contractor.
3. Simplified scheme of fencing the place of maintenance work (there is no need for reverse movement).
4. Reduction of terms of maintenance work by 30÷40 %.
5. Advanced technological processes when arranging deformation seams that do not require cutting with subsequent welding.
6. Reducing the cost of materials, the result being a reduced cost of construction work.

Disadvantages: availability or arrangement of a detour. When arranging a new detour on the near bypass, the cost of maintenance work increases. When arranging a detour on a long-distance bypass, the distance of the traffic increases.

Option number 2.

Advantages: preservation of traffic according to the existing scheme.

Disadvantages:

1. The presence of a dangerous factor near the place of maintenance work – traffic.
2. Additional costs for cutting the slab of the span structure along the entire structure. Increased cost.
3. Increasing the duration of maintenance work by 20÷30 % due to the need for operations in 3 stages – one stage for each direction and the stage of arranging the combined seam along the axis of the span structure.
4. Increased consumption of materials. The increased cost of maintenance work.
5. The need to close the traffic during concreting of the 3rd stage – arranging the joint seam for up to 7÷10 days (until concrete monoliths reach a strength of 70 %, Fig. 1).

By the number of advantages and disadvantages, the best way to solve the problem is option No. 1.

6. Discussion of results of studying the deformed state of reinforced concrete beams of road bridges with the strengthening of span structures

First, the issue of high-quality implementation of the technological process of concreting the slab for strengthening the beams of road bridges arose directly among builders; a new suggestion intended to investigate the deformations. For our study, a three-dimensional model of a typical bridge beam was built in the Autodesk AutoCAD software (USA); its calculation involved the ANSYS program (USA). It was established that horizontal deformations in the reinforcement slab, which arise from a temporary car load, have an effect on the freshly laid concrete of the additional slab.

Unlike studies [2, 5–8] where factors of high-quality concrete hardening did not take into consideration dynamic impacts, the result of displacements (1.41 mm) was determined taking into consideration the temporary load. Our results of emerging displacements (Fig. 8) from computer

calculations (Table 2) are of interest for laboratory tests, during which it is possible to determine in detail the level of dynamic influence on the behavior of the structure of solidifying concrete. The analytical study where deformations from a temporary load were established when concreting an additional slab fully explains the need to take these results into consideration (7). The identified features of the stressed-deformed state of reinforced concrete beams of road bridges confirmed the presence of deformations that destroy the structure of new concrete.

The proposed ways to solve the problem of the presence of temporary load during the implementation of technological works (chapter 5.3) take into consideration the material costs and provide for road traffic.

Our studies were limited by the presence and magnitude of the impact of movements, while the composition of the concrete and the presence of reinforcement in the additional slab were not taken into consideration. These restrictions can be eliminated through more detailed research, namely the behavior of individual types and the composition of concrete in interaction with reinforcement.

7. Conclusions

1. When moving a temporary load on one half of the bridge, the amount of the temporary load on the part of the bridge where construction work is carried out is, due to the AK tandem, 128.36 kN; due to the distributed AK load, 6.23 kN/m.

2. With the help of a model of the span structure based on the typical project by Soyuzdorproekt, series 3.503.1-81, with a beam length of 24 m, the method of finite elements for the spatial design of the beam was employed to determine deformations in the cross-section of the additional slab; without taking into consideration the temporary load, they are 3.88 mm; and under the influence of a temporary load, 5.83 mm. The difference in these movements in the absence and presence of a temporary load destroys the structure of hardening concrete. Our analysis of the effects of detected deformations reveals that there is a destruction of the structure of freshly laid concrete and a violation of the adhesion of fresh concrete with reinforcement and the old structure of the slab of span structure. The quality of concrete of the new slab does not allow for a long-term operation of the reinforced beam of the span structure, with a design period of 50–70 years of reinforced concrete structures.

3. Among the possible ways to solve this problem, when concrete works are performed to strengthen the span structures, complete closure of traffic is proposed. This technique is the most economical and fully provides conditions for the qualitative creation of the structure of concrete stone, which is necessary to increase the carrying capacity and durability of the structure.

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