RAPID STRENGTHENING METHODS OF REINFORCED CONCRETE BRIDGES AND OVERPASSES

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Annotation: Currently, most types of bridges on highways are reinforced concrete structures made with both conventional and prestressed reinforcement. Reinforced concrete bridges are affected by many negative factors that lead to degradation of material properties and loss of bearing capacity of superstructures. This requires rebuilding or strengthening bridges. Strengthening is a tool to extend the life cycle of building structures such as bridges. Existing studies focused on strengthening issues are aimed at maximizing this period, which is why the proposed solutions are long in time and difficult in terms of labor intensity. The purpose of this article is to propose and justify rapid methods for strengthening reinforced concrete bridges and overpasses as the most massive types of bridges. As a result, two main types of strengthening are proposed: rolling profile elements and bracing systems. And one and the second type are calculated justified, which is given in the article. In addition, the main schemes developed by the author are given. It has been determined that the proposed methods are very effective, and can be used in emergency situations or other cases that require minimizing the work time while increasing the load-bearing capacity.

Keywords: reinforced concrete bridge, technical condition, damages, strengthening, profile elements, bracing strengthening.

1. Introduction

One can find plenty of publications related to the problem of reinforced concrete bridges degradation and as consequences – the necessity of their strengthening [1-8]. This is the reality all over the world, but in particular – in Uzbekistan, Kazakhstan, Russia [1, 3, 7].

It is known [6, 7, 8] that simple beam reinforced concrete superstructures (made of conventional reinforced concrete and with prestressing reinforcement) are the most massive type used in roads bridges.

The author found that to date, the following standard projects have become the most widespread:

- Series 3.503-14 (Ribbed span structures without diaphragms made of ordinary reinforced concrete, 12, 15 and 18 m long) - about 35-40% of the total number of road bridges in operation;
- Project 3.503.1-81 (I-beam span structures with prestressed reinforcement, 12, 15, 18, 21, 24 and 33 m long) - about 45-48% of the total number of road bridges in operation.

In the course of their life cycle, such superstructures experience negative impacts of natural-climatic and man-made nature, leading to general degradation of the concrete of the beams, reduction of their strength and carrying capacity.

In the most significant way, the reduction of these and other parameters of the superstructure beam is influenced by various types of cracks and chips in the concrete of the stretched zone, as well as exposure, corrosion and breakage of the rods of the working reinforcement.

One of the ways to increase the bearing capacity of the operated beams and increase the level of their reliability is to strengthen the damaged elements [9]. In certain cases, existing reinforcement methods may not be feasible due to the duration of construction and installation work. This can be caused by natural disasters, military actions, or due to the high intensity of traffic in large cities. Therefore, the purpose of the article is to present rapid methods for performing reinforcement of defective structures in a short time.

2. Materials and Methods

In this article, it is proposed to group solutions by rapid strengthening into two types:

- strengthening of beams by rolling profile elements;

- bracing strengthening of superstructures.

As research methods, system analysis, scientific search, principles of structural mechanics and solid state mechanics are adopted.

At certain stages of the presentation and description of the proposed structures and design provisions (see section 3), justifying them, the author makes assumptions (restrictions) regarding the principles and conditions of work. These assumptions, on the one hand, simplify calculations, and on the other, lay down a certain margin factor, which significantly increases the reliability of the proposed methods.

3. Results

3.1. Beams strengthening by rolling profile elements

The structures of strengthened beams of reinforced concrete superstructures are known according to the author's certificates and patents [10, 11, 12]. These certificates indicate reinforced concrete beams of T-section and I-section and structures of their strengthening, consisting mainly of steel rolling elements and strips.

The disadvantages of these structures are mainly the complexity and high labor intensity of works performed in the bridge spans, including operations for drilling holes in the reinforced concrete slab and beam rib, installing strengthening elements, as well as attaching connecting rods to the slab and beam rib. In this case, the working reinforcement of the rib can be damaged, which will significantly reduce the reliability and carrying capacity of the beam and the strengthening itself.

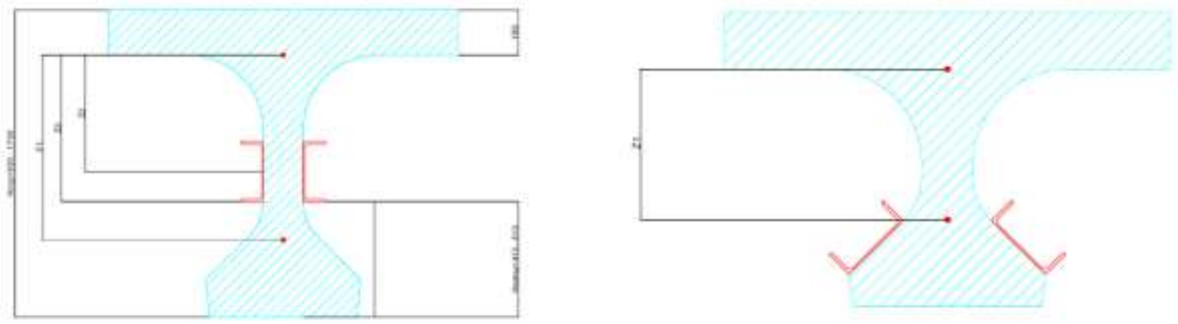
It is also widely known to strengthen single-span beams by sticking steel sheet in the form of side strip reinforcement [13, Fig. 2, e]. The sheets are glued to the rib of the beam, then attached to each other by means of studs installed in the drilled holes.

The disadvantage of such a solution is the low vertical stiffness of the strips which are bent together with the beam rib under the influence of movable loads (wheel and track equipment).

The use of shaped (rolling) profile elements (steel angles or channels), the mechanical characteristics of which are known to be higher, instead of steel strips, can significantly increase the strengthening efficiency.

Proposed solution consists in that design of reinforced concrete road bridge beam superstructures strengthening consists of two longitudinal angles or channels of equal length and range, at that rolling elements are located symmetrically on both sides of reinforced concrete rib of beam above zone of location of working reinforcement and tightly pressed to rib surfaces by threaded studs.

Here is a design justification for the strengthening using the example of an I-beam with prestressed reinforcement. The symbols used in the subsequent calculations and the principle diagram of the strengthening (on the example of channels) are shown in Figure 1.



(a) (b)

Figure 1. Principal strengthening scheme: (a) for beams 18-33 meter length; (b) for beams 12 and 15 meter length.

Obviously, the use of a channel or angle as a tensile stress sensing member is fundamentally different from high strength wire bundles. The moment of resistance increases significantly. However, this fact is not taken into account in the calculations (assumption No. 1), as being positive for the beam, i.e. leading to a margin in the calculations, and the possibility of not introducing additional stock factors or working conditions.

It is known that the area of the required reinforcement is determined by formula (1):

$$A_s = \frac{M_i}{R_s \cdot z}, \quad (1)$$

where M_i – estimated bending moment,

R_s – design resistance of metal,

z – forces couple arm.

Estimated bending moment $M_i = const$.

Average value of design resistance for prestressed reinforcement is $R_s^{арм}$=900 MPa.

Average value of design resistance for rolling profile made of steel types: Ст0, Ст1кп, Ст1пс, Ст1сп, Ст2кп, Ст2пс, Ст2сп, Ст3кп, Ст3пс, Ст3сп, Ст3Гпс, Ст3Гсп, Ст4кп, Ст4пс, Ст4сп, Ст5пс, Ст5сп, Ст5Гпс, Ст6пс, Ст6сппо ГОСТ 380 и ГОСТ 8240, is $R_s^{усил}$=350 MPa.

Forces couple arm z_1 tentatively can be found by the formula (2):

$$z_1 = h_{стр} - h_{пл} - \frac{2h_{пяты}}{3} \quad (2),$$

where $h_{стр}$ – beam structural height,

$h_{пл}$ – slab thickness,

$h_{пяты}$ – heel thickness.

Beam structural height is in the range of $h_{стр}$=930…1730 мм.

Sab thickness $h_{пл}$=180 мм.

Heel thickness defined as $h_{пяты}$=413…513 мм.

Then formula (2) transforms into:

$$z_1 = h_{стр} - 0{,}18 - \frac{2h_{пяты}}{3} \quad (3).$$

Forces couple arm z_2 determined by formula (4), taking into account the height of the reinforcement element $h_{усил}$:

$$z_2 = z_1 - \frac{h_{пяты}}{3} - \frac{h_{усил}}{2} \quad (4).$$

Previously, it is recommended to accept channels No. 18... 30, corners No. 160-250 (isosceles and unequal) as the most massive and effective elements of shaped (rolled) rolled products as reinforcement. However, depending on the structural height of the beam, it is possible that the strengthening elements do not fit due to the fact that the length of the vertical plane of the beam wall is insufficient. This applies to beams with a span of 12 and 15 m, where the strengthening elements will have to be located on the heel at an angle, and the maximum possible size of the channel will be 24 (see Figure 1b), and the corners - 250. In this case, the elements will be fixed not with studs through the wall, but with anchors.

As a reasonable assumption No. 2, we assume that the new arm of the pair of forces will be equal to z_3 (for beams with a length of 18 m and more, see Fig. 1a, for beams with a length of 12-15 m, see Fig. 1b), since in the vast majority of cases the upper part of the working reinforcement rods remains serviceable. As the center of action of the stretching component of the arm for beams with a length of 18 m or more, we accept the lower boundary of the attached strengthening t element, and for beams 12-15 m $z_1 = z_3$.

This also follows assumption No. 3, which consists in the fact that up to 50% of the initial number of rods (by area) remain valid, since otherwise the stability of the structure as a whole will not be ensured. This is confirmed by the adopted Rosavtodor assessment system [14], as well as studies in the field of reliability and load capacity of transport facilities [6, 8, 15]. In addition, the range of 15-50% is a rational area of use of the strengthening element tool [9, 16].

Then for beams of 18 m or more, the calculation is significantly simplified, and the formula for determining the new forces couple arm is converted into the form:

$$z_3 = z_1 - \frac{h_{пяты}}{3} \quad (5).$$

The area of the required strengthened elements will be:

$$A_s^{усил} = \frac{R_s^{арм}\cdot z_1\cdot A_s}{R_s^{усил}\cdot z_3} \Big/ 2 \tag{6}$$

Through transformations, expression (6) takes the form:

$$A_s^{усил} = \frac{900\cdot(h_{стр}-0,18-\frac{2h_{пяты}}{3})\cdot A_s}{350\cdot z_3} \Big/ 2 = 1,29A_s\,\frac{(h_{стр}-0,18-\frac{2h_{пяты}}{3})}{(h_{стр}-0,18-h_{пяты})} \tag{7}$$

For beams 12 and 15 m (7) will be simplified to:

$$A_s^{усил} = 1,29A_s \tag{8}$$

For various values of beam lengths, construction height and area of initial reinforcement, the required areas of channels, angles (isosceles and unequal) and their corresponding grades were calculated. The calculation results are summarized in Table 1.

Table 1.

Technical data and results of selection of the range of superstructures strengthening elements with prestressed reinforcement

Beam’s length, m	**12**	**15**	**18**	**21**	**24**	**33**	**33**
Beam structural height $h_{стр}$, m	0,93	0,93	1,23	1,23	1,23	1,53	1,73
Straight part of wall, m	0,037	0,037	0,287	0,287	0,287	0,537	0,737
Reinforcement area according to the design As, m^2	0,0043	0,0059	0,0051	0,0071	0,0041	0,0054	0,0045
Required area of strengthening elements $A_s^{усил}$, m^2	0,0055	0,0076	0,0056	0,0077	0,0045	0,0055	0,0041
The same, cm^2	55,2579	76,0481	55,8541	77,4199	44,6832	54,7513	41,2583
Area of one strengthened element, cm^2	27,6290	38,0240	27,9270	38,7100	22,3416	27,3756	20,6291
Channel Schedule	№18 …№24	№24	№18 …№27	№27	№18 …№27	№18 …№40	№16 …№40
Range of unequal corner	№160 …№250	№200 …№250	№160 …№250	№200 …№250	№140 …№250	№160 …№250	№140 …№250
Isosceles angle range	№125 …№250	№160 …№250	№125 …№250	№160 …№250	№100 …№250	№125 …№250	№100 …№250

Note that the unequal corners should be positioned short along the wall for more efficient operation.

By analogy, calculation was made for ribbed reinforced concrete beams with conventional reinforcement. The distinctive features in this case will be a different value of the design strength of the reinforcement and some changes in the geometric values of formulas (2) - (8).

The calculation results are summarized in Table 2.

Table 2.

Technical data and results of selection of the range of superstructures strengthening elements with conventional reinforcement

Beam's length, m	**12**	**15**	**18**
Beam structural height $h_{\text{стр}}$, m	0,9	0,9	1,05
Straight part of wall, m	166	265	325
Reinforcement area according to the design As, m^2	0,384	0,285	0,375
Required area of strengthening elements $A_s^{усил}$, m^2	0,0050	0,0082	0,0098
The same, cm^2	0,0024	0,0044	0,0052
Area of one strengthened element, cm^2	24,0376	43,5227	52,4011
Channel Schedule	№12…№32	№18…№27	№22…№24
Range of unequal corner	№100…№250	№125…№250	№160…№250
Isosceles angle range	№100…№250	№125…№250	№160…№250

The proposed structure is shown in Figures 2 and 3, where it is indicated: 1 - ribbed beam; pos. 2 - beam rib; pos. 3 - reinforcement (working) of the beam rib; pos. 4 - channel; pos. 5 - studs with washers and nuts; pos. 6 is a backing sheet; pos. a, b, c - distances between studs; L is the total length of the beam.

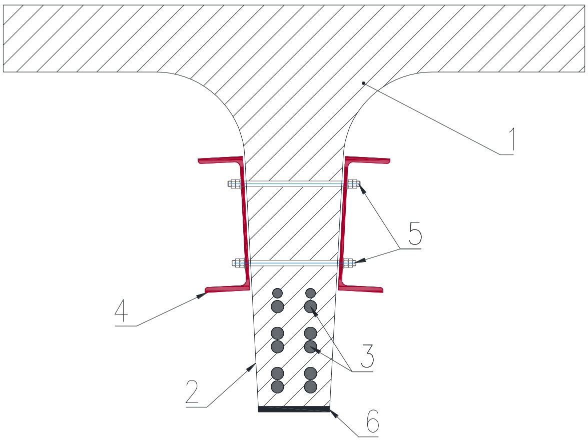


Figure 2. Beam's cross section

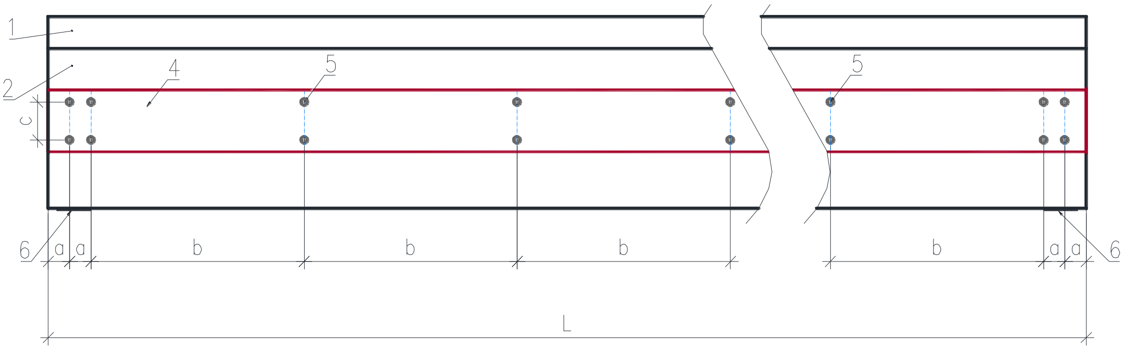


Figure 3. Beam with strengthening (superstructure facade)

3.2. Bracing strengthening of superstructures

Additional supports, braces and/or supporting systems are a well-known method of strengthening building structures [17, 18]. More widespread in the field of industrial and civil construction (buildings, ceilings, etc.). This is mainly due to the fact that the installation of additional supports for transport construction is associated with the laborious construction of an additional support under the bridge span beam: as a rule, this is the deepest place of the crossed water obstacle.

At the same time, these methods are also applicable for bridges - see materials [16, 19, 20]. In these sources, as effective methods of increasing the bearing capacity of reinforced concrete beams, options for changing their design schemes for calculating the installation of additional supports in the bridge spans are indicated.

The main drawback of the additional support is the fact that the middle of the span is located, as a rule, above the deepest place of the crossed watercourse, and the strengthening work due to the additional intermediate support is very time-consuming and expensive due to the need to arrange an additional foundation in the deepest place of the water obstacle, as well as reduce the subsurface dimensions in width (on navigable rivers).

A solution is known for strengthening single-span beams with braces (Fig. 25 in [20]), which are proposed to be used as additional reinforcing elements when reorganizing beam bridges into arched or frame ones.

The disadvantages of this solution are in the form of high labor intensity and time costs: it is necessary to perform many operations for the arrangement of longitudinal, transverse and vertical bearing elements (metal beams) in the bridge substructure space, fastening these beams to each other and with braces resting on foundations.

We offer a solution devoid of these shortcomings. The use of two struts resting on the existing foundations of supports adjacent to the span and converging in the middle of the lower belt of the reinforced defective beam can significantly increase the strengthening efficiency (primarily, reduce material consumption and labor costs).

The above technical problem is solved due to the fact that the design of the bracing strengthening of the reinforced concrete beam consists of two steel pipes of the same range and diameter, sections of channel and two angles, at that upper ends of pipes converge in the middle of lower chord of beam, where there is a channel section rigidly attached to the beam chord with anchor studs; lower ends of pipes rest on foundations of both bridge span piers through sections of steel angles rigidly connected with edges of foundations by stud anchors. Pipe ends are rigidly connected with channel and angles by welding.

The proposed design is shown in Figures 4-7, where pos. 1 - beam; pos. 2 - round steel pipe; pos. 3 - channel; pos. 4 - angle; pos. 5 - pier body; pos. 6 - foundation cap; pos. 7 - stud anchor with washers and nuts.

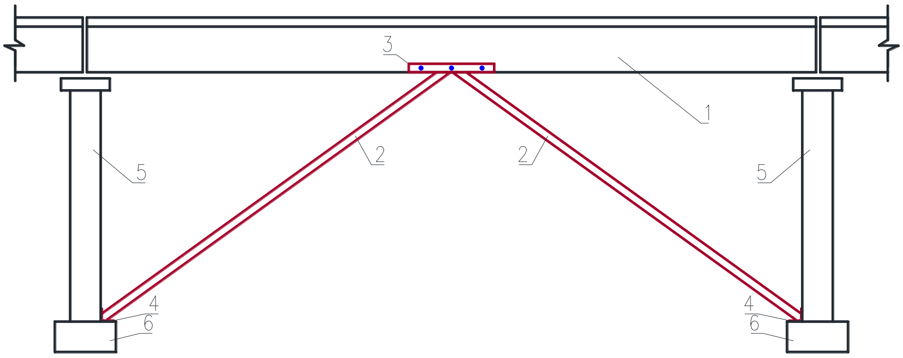


Figure 4. View of the bracing strengthening structure along the facade of the bridge

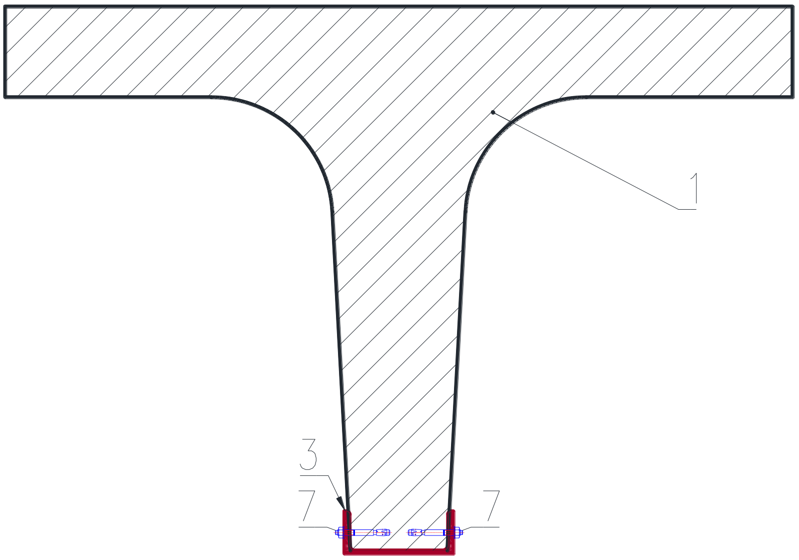


Figure 5. Beam's cross section

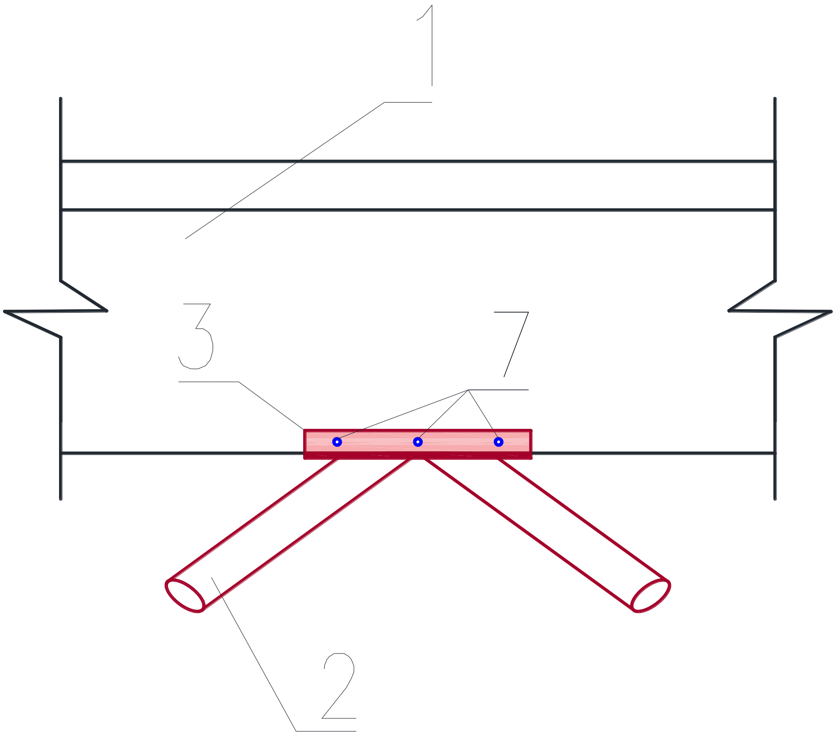


Figure 6. View of the connection of the strut pipes with the channel in the middle of the beam

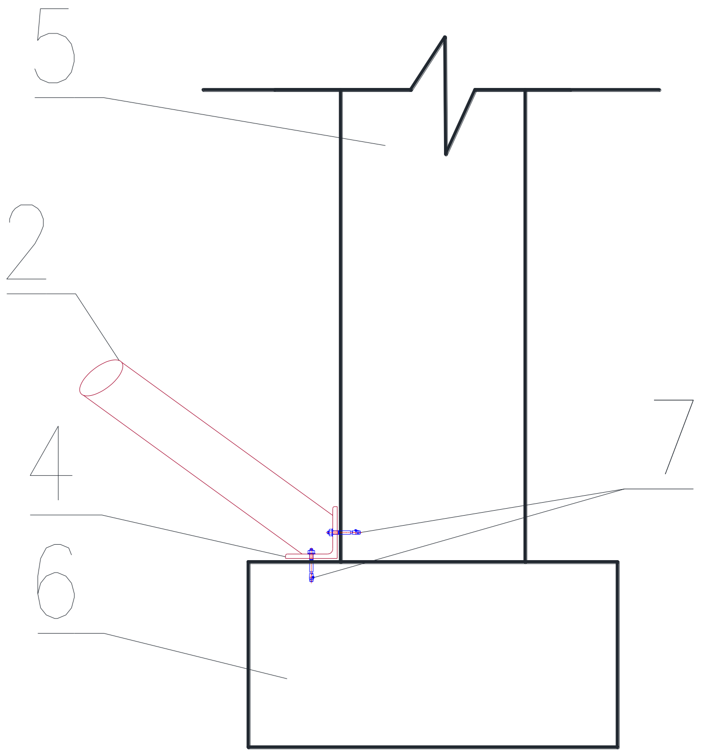


Figure 7. View of the unit for supporting the lower end of the pipe on the edge of the pier foundation

Installation works are performed in the following process sequence.

At the plant or in the workshops of the bridge building organization, the rolling channel of the design number is manufactured according to the drawings of pipe 2, channels 3 and angles 4 in the required quantities, as well as anchor studs 7 (Fig. 4-7).

At the same time, temporary scaffolds are mounted in the bridge spans (not shown in the figures).

The workers, being on the scaffolds, drill holes in the rib of the beam using channels 3 as a template (Fig. 4 and 6). Anchor pins (7) are inserted into drilled holes and nuts are tightened until both flanges of channels (3) are tightly pressed to surfaces of rib of beam (1) (Fig. 6).

In the area of mating of support pile cap (6) with its body (5), the workers attach angles (4) to anchor pins (7) (Fig. 4).

Thereafter, the actual distance between the middle of the channel 3 attached to the lower chord of the beam 1 to be strengthened and the angles 4 at the junction of the pile cap 6 and the body of the pier 5 for making a round-section pipe of the required length (pipe lengths may be different due to different depth of the foundations) is measured.

Then each pipe 2 is welded to channel 3 and angles 4.

Let's do a preliminary calculation confirming our proposals.

Let there be a road bridge. Its main beams of the span are loaded with a constant load of its own weight, the weight of sidewalks, railing fences and roadway pavement.

In the sketch calculation, we allow uniform distribution of the entire constant load between the main beams, we determine the standard constant load, kN/m:

Fig. 1. of own weight

$$p_1 = \frac{V \cdot \gamma_{жб}}{n \cdot l_n} \qquad (1).$$

Fig. 2. of road surface weight

$$p_2 = \frac{h_{покр} \cdot B \cdot \gamma_{покр}}{n} \qquad (2),$$

where
$V=50,6$ м^3 - volume of reinforced concrete
$l_п=18$ м – superstructure full length
$n=6$ – main beam number
$h_{покр}=0.18$м – average road surface thickness
$B=14,5$ м – bridge width
$\gamma_{жб}=24,5$кН/м3 — concrete specific gravity
$\gamma_{покр}=22.6$кН/м3 — asphalt concrete specific gravity
Then
$p_1 = 50,6*24,5/(6*18)=11,3$ кН
$p_2 = 0.18*14,5*22.6/6=9,8$ кН

Load safety factors γ_f for constant loads when calculating strength (stability) are accepted:

Fig. 3. for the dead weight of the structure $\gamma_{f_1} = 1{,}1(0{,}9)$

Fig. 4. for pavement weight $\gamma_{f_2} = 2{,}0(0{,}9)$

Standard time load on sidewalks is taken as uniformly distributed load with intensity of 2 kPa.

When calculating one of the main beams, it is necessary to determine the most unfavorable installation of load bands AK in the cross section of the span structure in order to obtain the largest value of the design forces. The share of the temporary load on the beam in question is determined by the transverse installation factor (TIF).

When calculating diaphragm-free span structures, the main beams are interconnected by a relatively flexible slab of the roadway, it is recommended to use an approximate method of determining the TIF using the "lever method." TIF is defined for the extreme and one of the middle main beams.

When calculating strength, two cases of AK load installation should be considered:

– placement of all lanes within the roadway excluding safety lanes
– placement of two lanes over the entire width of the roadbed, including safety lanes.

Load from one lane is taken with coefficient $s_1 = 1$; when the bridge is simultaneously loaded with several bands, the distributed load from the second and subsequent bands is taken with a factor of $s_1 = 0{,}6$.

TIF for the main beams is:
$\eta_{a1}=\eta_{\upsilon 1}=0.5y_1=0.5*0.76=0.38$
$\eta_{a3}=0.5(y_2+y_3+y_4)=0.5*(0.16+1+0.50)=0{,}83$
$\eta_{\upsilon 3}=0.5(y_2+y_3+0.6y_4)=0.5*(0.16+1+0.6*0.50)=0{,}73$
Design time load on the main beam is:
concentrated pressure from the uniaxial axis of the trolley –
$P_a=\gamma_{fa}(1+\mu)P_A\eta_a=1.4*1.3*137{,}34*0.83=163{,}0$кН
where
$P_A=137{,}34$ кН — axle pressure,
$\gamma_{fa}=1.4$ – load safety factor for trolley
$(1+\mu)=1.3$ – dynamic coefficient for trolley
distributed load –
$p_\nu=\gamma_{f\nu}(1+\mu)\nu\eta_\nu=1.15*1.0*13{,}75*0.73=9{,}0$ кН/м
where
$\nu=13{,}75$ кН/м – intensity of distributed load
$\gamma_{f\nu}=1.15$ - load safety factor for uniformly distributed load
$(1+\mu)=1.0$ – dynamic factor for evenly distributed load
concentrated pressure from the uniaxial axis of the trolley –
$P_{нк}=\gamma_{fнк}(1+\mu)P_{нк}\eta_{нк}=1.4*1.3*245*0.83=163{,}0$кН
where
$P_{нк}=245$ кН – axle pressure,

concentrated pressure from the uniaxial axis of the trolley –

$P_{нг}=\gamma_{fнк}(1+\mu)P_{нг}\eta_{нг}=1.4*1.3*196*0.83=163{,}0кН$

where

$P_{нк}=196$ кН – axle pressure,

The lines of influence of the forces are shown in Figure 8.

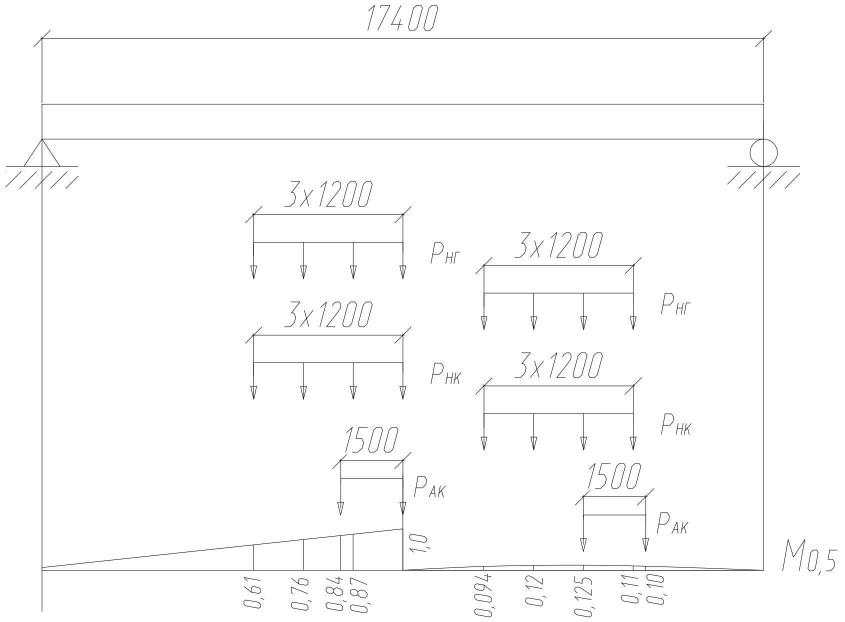


Figure 8. Lines of force influence for sketch calculation of brace strengthening

Full forces in beam sections:

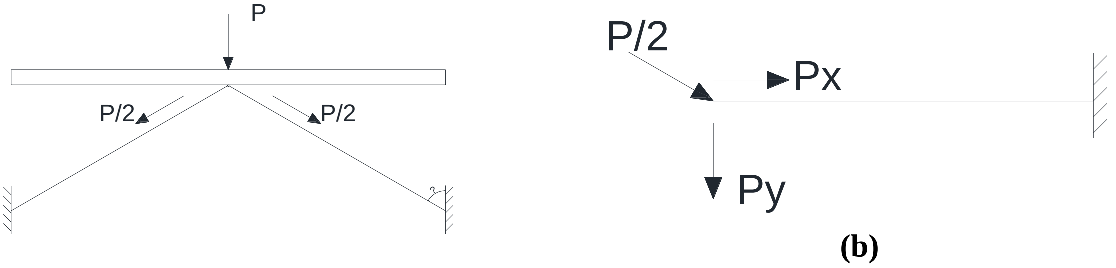
$Q_0=[\gamma_{f1}p_1+\gamma_{f2}p_2+p_{v3}]\omega_3+P_a(y_1+y_2+y_3+y_4)+P_{нк}(y_1+y_2+y_3+y_4)+P_{нг}(y_1+y_2+y_3+y_4)=(1.1*11{,}3+2*9{,}8+13{,}75)*5{,}481+137{,}34(1+0.84+0{,}125+0{,}1)+245(1+0{,}61+0{,}76+0{,}87+0{,}125+0{,}120+0{,}110+0{,}094)+196(1+0{,}61+0{,}76+0{,}87+0{,}125+0{,}120+0{,}110+0{,}094)=2157кН$

Here it is necessary to indicate several assumptions we have made.

The statistical analysis of small reinforced concrete bridges, performed by the author, allows us to conclude that the angle between the brace and the support post (denoted as α - see Fig. 9, a) is 60 ° (assumption 1).

The distribution of pressure coming to two braces of one beam shall be taken as equal, based on the uniform distribution of forces (assumption 2).

Static operation of one strut at further calculations shall be assumed as a cantilever with pinching in the place of attachment to the support (assumption 3). This allows you to enter a certain stock factor into calculations.



(b)

(a)

Figure 9. Diagrams for calculation of strut strength and stability: (a) for beams 18-33 meter length; (b) for beams 12 and 15 meter length.

Then when calculating strength:

$$P_y = \frac{P \cdot \cos\alpha}{2} = \frac{P}{4} \quad (3),$$

When calculating stability:

$$P_x = \frac{P \cdot \sin\alpha}{2} = \frac{\sqrt{3}P}{4} \quad (4),$$

Force for one strut for strength calculation P=Q/4=2157/4=539,25 кН.

Force for one stand for stability calculation P_y= 934 кН.

The cross-sectional area of the pipe with outer diameter 325 mm and wall thickness 9 mm is equal to 0,009м^2.

Design strength for steel grade C255 R=240 MPa.

When calculating stability, you enter a buckling factor that depends on the flexibility of the feature. Element flexibility is calculated λ_0 by formula: $\lambda_0 = \frac{l_0}{r}$,

where$l_0 = 10$ м–free length of the element;

r–radius of inertia of the element section relative to the axis perpendicular to the bending plane.

$$\lambda = \frac{l_0}{r} = \frac{10000}{111} = 90$$

At design resistance 240 MPa and with the flexibility of 90, the bending coefficient is φ =0,612.

Then, when calculating strength

σ=P/A=539.25/0.009= 60 МПа< R=240МПа.

When calculating stability

σ=1,8*P_y/A=934/0.009=104 МПа<φ R=0,612*240=147МПа.

4. Discussion

Despite the positive results shown in the above text, it should be noted that there are a number of points to be discussed.

Previous studies cited in this article and in the references were devoted to permanent and long-term work and the life of superstructures. In the present study, time is the most important criterion. Some solutions (such as placing strengthening elements not at the bottom of the beam, but on the wall) are not as technically effective. But integrally they are very effective, because they make it possible to quickly and easily amplify defective structures.

Future research on this topic should focus on developing accurate performance criteria and finding trade-offs between time, convenience and reliability.

5. Conclusions

This section is a mandatory.

Thus, the proposed strengthening design using rolling profiles provides an increase in strength, rigidity, reliability and carrying capacity of reinforced concrete beams of span structures of operated road bridges. It can also be used to strengthen reinforced concrete beams of the superstructure of road and railway overpasses, overpasses and transport interchanges. The strengthening method increases the service life of the reinforced concrete beams of the span structures, and, therefore, the entire bridge.

Thus, the bracing strengthening provides an increase in the strength, rigidity, reliability and carrying capacity of the reinforced concrete beam of the span structure of the operated road bridge. The solution can also be used to strengthen reinforced concrete beams of span structures of railway bridges.

At the same time, labor intensity and duration of work are reduced, as well as design reliability is increased in comparison with methods in which beams are converted into frame or arch schemes [19, 20] (both general and strengthened elements). Only span length and construction height are required as input data.

6. Patents

The proposed solutions of strengthening by rolling profile elements are patented by the author (co-authored) in accordance with the established procedure and are protected by copyright law in accordance with the legislation of the Russian Federation and EEU [21, 23].

The structural and technical solution of the brace strengthening was also patented by the author in the prescribed manner and is protected by copyright law in accordance with the legislation of the Russian Federation and EEU [22].

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