RESUME

L’étude porte sur un prototype de travée composite en béton tendu avec joint en époxy de longueur 42,0 m pour supports de pont destinés à la perception d’impact des véhicules motorisés de type A14, NK-120 et NK-180. La déformation expérimentale au milieu du pont avait une valeur égale à \( f_{\text{exp}} = 62.4 \text{ mm} \) à une charge de \( 2P = 436 \text{ kN} \), ce qui était à 75,2% de la déformation de contrôle.

Sous la base des résultats des tests, les joints de bloc de trave avec “dent” et “fente” sont trouvés être imparfaits.

L’objectif des tests a été atteint à une charge de \( 2P_{\text{MAX}} = 822.7 \text{ kN} \), qui a dépassé la charge de contrôle égale à \( 2P_{k} = 744 \text{ kN} \) en vérifiant la résistance et la charge de contrôle égale à \( 2P_{s} = 790 \text{ kN} \) en vérifiant la résistance du joint.

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1 Introduction

Le prototype d’une travée composite est composé de trois segments - deux extérieurs et un central (Figures 1, 2, 3). La longueur des blocs extérieurs est 14000 mm chacun. Le segment central a la forme d’un trapèze renversé - le bloc a une longueur de 14010 mm au sommet et 14000 mm à la base.

La travée composite a un T de profil avec une partie renforcée au sommet et au niveau des profils transversaux pour le passage des traverses.

La classe de résistance du béton des blocs est adoptée B40 conformément au projet.

Les câbles consiste de K-7 câbles à 7 fils de diamètre 15 mm de la Fonderie métallurgique de Beloretsk, augmentant les caractéristiques physiques et mécaniques par rapport aux spécifications du document normatif [1]. Les exigences techniques, ont été adoptées comme repose tension. Six câbles tendus ont été adoptés lors de la mise en place de la travée composite avec tendeurs en béton tendu, où chaque tendon consiste de sept K-7 câbles. La force contrôlée due à la tension a été assumée être égale à 1292 kN en accord avec le projet.
Figure 1 General data, segment layout scheme and the position of prestressing tendons

Figure 2 Dimensions of the girder and initial data of the outer segment

Figure 3 Dimensions of the girder and initial data of the middle segment
**Figure 4** No. 1 adhesive joint zone (the end segment on the left in the picture): a) there is a “tooth” and a “cutout” for the formation of a dowel in the middle part of the height of blocks; b) “cutouts” are placed in the upper zone of the blocks edges, to form a monolithic dowel.

**Figure 5** No. 2 adhesive joint zone (the middle segment on the left in the picture): there is a “tooth” and a “cutout” for the formation of a dowel in the middle part of the height of segments, b) “cutouts” are placed in the upper zone of the segment edges, to form a monolithic dowel.
The remaining four tendons have been further tensioned for the next day after the adhesive has been cured and the tension sequence was observed the same - the third tendon was tensioned first when counting from the top to bottom. The last tendons of the lower row of the prestressed reinforcement have been tensioned. Seven K-7 strands that are part of one tendon have been anchored after the tensioning of each prestressing tendons. (Figure 8).

to the joint surfaces of the blocks (No. 1 and No. 2 joints) before tensioning of the bundles of prestressed reinforcement [3-9].

The upper tendon has been tensioned using DN-7 hydraulic jack after applying the adhesive to the joint surfaces of the blocks (Figures 7 and 8). Then the second bundle has been tensioned when counting from the top to bottom according to the sequence adopted in the project.
At the next stage of work, after the tendon tensioning, the grout was injected into the ducts and then two monolithic dowels were concreted, one of which is shown in Figure 9. The grout has been injected into the ducts through the fittings installed at the end of the end segments (Figure 10).

Longitudinal and inclined cracks have been formed in the concrete of the middle and end segments in No. 1 and No. 2 joints zones during the tendon tensioning due to manufacturing of the blocks’ joint surfaces (Figures 11, 12). The cracks formed in the concrete of the middle and extreme blocks during the tensioning of the bundles of prestressed reinforcement revealed the deficiencies of the proposed structural concept of the joint.
bottom, including the weight of the loading devices. The outline has a shape of a curve close to a parabola [10].

A computational and analytical check was also performed. Table 1 shows the results of the calculation of the beam bending.

Table 1 Calculation results of beam bending

<table>
<thead>
<tr>
<th>Calculation of bending</th>
<th>Designation</th>
<th>Value</th>
<th>Measurement unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/ρв</td>
<td>6.57 ⋅10⁻⁷</td>
<td>mm⁻¹</td>
</tr>
<tr>
<td>2</td>
<td>fсв</td>
<td>74.9</td>
<td>mm</td>
</tr>
<tr>
<td>3</td>
<td>f2</td>
<td>64.5</td>
<td>mm</td>
</tr>
</tbody>
</table>

The actual strength of the girder concrete has been determined prior to testing of the beam. The concrete strength has been assessed by the shock pulse monitoring using IPS-MG4.03 electronic concrete strength meter, developed by “SKB Stroypribor” LLC (Chelyabinsk, Russia). The concrete strength has been assessed in accordance with [11] and [12] requirements.

Table 2 shows the processing results of the experimental values of concrete strength.

Table 2 Concrete strength data

<table>
<thead>
<tr>
<th>Structure name</th>
<th>Number of experimental unit values, n</th>
<th>Average value of concrete cube strength ṭ</th>
<th>Standard σ, MPa</th>
<th>Coefficient of variation, ν</th>
<th>Student's coefficient, t' ст</th>
<th>Experimental concrete class, B</th>
</tr>
</thead>
<tbody>
<tr>
<td>End segment block No. 1</td>
<td>22</td>
<td>57.59</td>
<td>8.72</td>
<td>0.151</td>
<td>1.72</td>
<td>42.58</td>
</tr>
<tr>
<td>Middle block No. 2</td>
<td>22</td>
<td>55.03</td>
<td>6.67</td>
<td>0.126</td>
<td>1.72</td>
<td>41.56</td>
</tr>
<tr>
<td>Extreme block No. 3</td>
<td>22</td>
<td>58.35</td>
<td>8.13</td>
<td>0.139</td>
<td>1.72</td>
<td>44.37</td>
</tr>
</tbody>
</table>
3.2 Beam tests

The purpose of the tests was to conduct control tests of 42.0 m-long composite beam. It was necessary to
conduct an experimental verification of the compliance of the actual strength and stress-strain properties of 42.0 m-long composite beam with the design data, according to the test program.

The failure load value during the load test (the ultimate limit state) and deflections values and the width of the cracks under imposed loads during the tests for stiffness and crack resistance (serviceability limit states) are determined according to the test results [14-18].

Figure 14 shows a general view of the 42.0 m long composite beam in the load bench during the testing.

Control tests of 42.0 m-long composite beam have been carried out according to the scheme provided for in the design documentation before the start of the mass production of these beams.

A power plant which included HJ200P300 hydraulic jack with a lifting capacity of 2000 kN, a load cell, high-pressure hoses and a manual pumping station have been used to create and control the vertical load value during the beam testing. The Appendix shows the calibration schedule of the hydraulic jack and the pressure gauge.

Figure 15 shows 42.0 m-long composite beam scheme with loading and mechanical devices installed on the experimental structure. The weight of the loading devices was 49.7 kN. The estimated length of the prototype adopted in the tests was 41.2 m, i.e. the axes of the supporting parts were located at a distance equal to 0.4 m from the ends of the end segments of the composite beam. The experimental load on the prototype was transmitted through the traverse beam in the form of two concentrated forces P in the middle part of the composite beam at a distance of 5.0 m from its midspan section or centre.

Mercer clock gauges with 0.001 and 0.01 mm readings have been installed in joints zone to assess the stress-strain state in the No. 1 and No. 2 adhesive joints and the possibility of fixing the opening of joints during loading of the beam (Figure 16). Table 3 presents data on the location of the mercer clock gauges of joints 1 and 2 of the composite beam L = 42 m.

![Figure 16 Scheme of dial indicators locations in the joint zones 1 and 2: mercer clock gauges CG3 and CG4 - with a graduation of 0.001 mm; CG3* and CG4* - with a graduation of 0.001 mm](image)

**Table 3** data on the location of the mercer clock gauges of joints 1 and 2 of the composite beam L = 42 m

<table>
<thead>
<tr>
<th>Distance</th>
<th>Mercer clock gauges base</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CG3*, mm</td>
</tr>
<tr>
<td>a</td>
<td>-45</td>
</tr>
<tr>
<td>b</td>
<td>-45</td>
</tr>
<tr>
<td>c</td>
<td>75</td>
</tr>
</tbody>
</table>
The settlement of supports was controlled using the mercer clock gauges with 0.01 mm readings.

The category of crack resistance requirements for the composite beam is - 2b, according to Table 39 *[19]*, which allows crack opening in the beam concrete up to 0.15 mm.

Values of the control loads have been determined when testing the composite beam for strength, crack resistance and stiffness in accordance with the project. The test loads of the girder strength test have subsequently been corrected. In the final form, the control loads when beam testing have been taken as follows:

1. When testing for strength:
   - the composite beam strength must be ensured when the load value \( 2P \) = 744 kN is reached;
   - No. 1 and No. 2 joints strength must be ensured when the load value \( 2P \) = 790 kN is reached.
2. When testing for the crack resistance:
   - there should be no cracks in No. 1 and No. 2 joints when the load value \( 2P \) = 536 kN is reached;
   - crack widths in the composite beam in the midspan should not exceed the value of \( \sigma_r = 0.15 \) mm, when the load value of \( 2P \) = 534 kN is reached.
3. When testing for stiffness:
   - the deflection in the composite beam midspan should not exceed the value equal to \( f_r = 83 \) mm when the load value \( 2P \) = 436 kN is reached.
   - The side surfaces of the middle block of the composite beam have been additionally covered with a thin layer of lime to control the moment of the crack formation. The crack width has been determined using a Brinell microscope.

The load has been applied to the composite beam in stages. Readings have been taken from deflectometers and mercer clock gauges after each stage of loading.

### 3.3 Test results of 42.0 m-long composite beam

#### 3.3.1 Deformability of beam

The stiffness can be assessed by comparing the actual deflection of the beam under the control load in the beam midspan with the control deflection value in accordance of [20].

The stiffness of the composite beam has been assessed at the first stage of the tests. The experimental deflection of the composite beam in the midspan should not exceed the control deflection value equal to \( f_r = 83 \) mm with a control load of stiffness equal to \( 2P \) = 436 kN. Figure 17 shows the deflection charts in the beam midspan, recorded by P7 and P8 deflectometers. The experimental deflection in the composite beam midspan had a value equal to \( f_{exp} = 62.4 \) mm, which was 75.2 % of the control deflection when the control load was reached equal to \( 2P \) = 436 kN.

The prototype beam meets the project requirements, [19] and [20] normative documents in terms of stiffness.

#### 3.2 Crack resistance of beam

The crack resistance of No. 1 and No. 2 joints and the crack resistance of the composite beam concrete have been assessed at the second stage of the tests.

Figures 18-22 show deflection charts in 42.0 m-long composite beam, recorded by deflectometers [21].

Cracks should not form in No. 1 and No. 2 joints with a control load of \( 2P_1 = 536 \) kN according to the project. Brittle cracking of adhesive composition and, accordingly, opening of No. 1 joint began at an experimental load equal to \( 2P = 143.7 \) kN. It should be noted that the cracking process of the epoxy based adhesive composition in No. 1 joint was perceived by ear. Due to the loose connection of the joined end surfaces of the middle and extreme blocks in No. 1 joint, the adhesive had a significant thickness, which was the reason for early crack formation in this joint [22-25].

When considering the charts presented in Figures 18-22 and 23 (CG3 indicator with 0.001 mm reading), it is clear that, slope of curves occurs at an experimental load of \( 2P = 143.7 \) kN, which also indicates the formation of a crack in No. 1 joint. There was a further opening of No. 1 joint during the subsequent loading of the composite beam.

Figure 24 shows opening chart of No. 2 joint during the loading of a composite beam with experimental load. From consideration of this chart it can be seen that opening of No. 2 joint began only with an experimental load of \( 2P = 582.7 \) kN, which was recorded by CG4 mercer clock gauge with 0.001 mm reading.

The crack resistance of the composite beam concrete has also been evaluated along with the crack resistance assessment of No. 1 and No. 2 joints. The first crack formation in the concrete of the composite beam middle block has been recorded at a load of \( 2P = 432.2 \) kN during the tests. It was speculated that the reason for the early crack formation in the concrete of the composite beam middle block was an imperfection of the structural concept for No. 1 and No. 2 joints [18, 26-27].

Additional cracks have been formed in the concrete of the composite beam during the further loading of the composite beam with an experimental load. The maximum crack opening measuring using a Brinell microscope did not exceed the value of \( \sigma_r = 0.1 \) mm at a load of \( 2P = 499.7 \) kN.

The crack opening width in No. 1 joint, fixed by the CG3 indicator, located on the composite beam side at a distance of 45 mm from its lower face, was \( \sigma_r = 0.7 \) mm at a load of \( 2P = 527.7 \) kN. And the fixed crack opening width, fixed by CG3* indicator, located on the same side face at a distance of 155 mm from its lower face was \( \sigma_r = 0.6 \) mm.

The fixed crack opening width in No. 2 joint, fixed by the CG4 indicator, located on the side face at a distance of 92 mm from the lower face of the composite beam, was \( \sigma_r = 0.003 \) mm at a load of \( 2P = 582.7 \) kN.
3.3.3 Strength of composite beam

The strength of the composite beam has been monitored at the last, third stage of the tests. The strength of No. 1 and No. 2 joints and the composite beam itself have been assessed during the tests in accordance with the project.

The control load when assessing the strength of the composite beam was $2P_k = 744$ kN and the control load when assessing the strength of No. 1 and No. 2 joints was $2P_k = 790$ kN according to the project.

The failure load of $2P_{\text{MAX}} = 822.7$ kN was achieved during tests which exceeded the control load equal to $2P_k = 744$ kN when checking the strength of the composite beam and the control load equal to $2P_k = 790$ kN when checking the strength of No. 1 and No. 2 joints.

The increase nature in deflection charts in composite beam (Figure 17) and assessment of its stress-strain state testified that it did not achieve the limit state and the pilot design had provisions for the bearing capacity [28].

The possible displacement of the prestressing tendons relative to the composite beam concrete has been monitored during the tests. No displacement (pulling) of the bundles of the stressed reinforcement relative to the pilot design concrete has been detected at all the stages of the composite beam loading.

4 Conclusions

1. The composite prestressed concrete bridge beam with a length of 42.0 m is manufactured at «AZMK» (Almaty, Kazakhstan) production base.

2. The control load when checking the composite beam for stiffness is $2P_k = 436$ kN. The control deflection of the composite beam should not exceed the value equal to $f_k = 83.0$ mm at this load. The experimental deflection of the beam in the midspan had a value equal to $f_{\text{exp}} = 62.4$ mm at a load of $2P_k = 436$ kN, which was 75.2% of the control deflection value. The composite beam meets the project requirements,[19] and [20] bridge standards in terms of stiffness.

3. The control loads when checking the composite beam joints and concrete for crack resistance had the following values:

   - The control load when assessing the strength of the composite beam was $2P_k = 744$ kN and the control load when assessing the strength of No. 1 and No. 2 joints was $2P_k = 790$ kN according to the project.

   - The failure load of $2P_{\text{MAX}} = 822.7$ kN was achieved during tests which exceeded the control load equal to $2P_k = 744$ kN when checking the strength of the composite beam and the control load equal to $2P_k = 790$ kN when checking the strength of No. 1 and No. 2 joints.

   - The increase nature in deflection charts in composite beam (Figure 17) and assessment of its stress-strain state testified that it did not achieve the limit state and the pilot design had provisions for the bearing capacity [28].

   - The possible displacement of the prestressing tendons relative to the composite beam concrete has been monitored during the tests. No displacement (pulling) of the bundles of the stressed reinforcement relative to the pilot design concrete has been detected at all the stages of the composite beam loading.

   - The composite prestressed concrete bridge beam with a length of 42.0 m is manufactured at «AZMK» (Almaty, Kazakhstan) production base.

   - The control load when checking the composite beam for stiffness is $2P_k = 436$ kN. The control deflection of the composite beam should not exceed the value equal to $f_k = 83.0$ mm at this load. The experimental deflection of the beam in the midspan had a value equal to $f_{\text{exp}} = 62.4$ mm at a load of $2P_k = 436$ kN, which was 75.2% of the control deflection value. The composite beam meets the project requirements,[19] and [20] bridge standards in terms of stiffness.
cracks should not form in the joints when the load value $2P_c = 536$ kN is reached;
- the crack opening in the composite beam concrete should not exceed the value of $a_c = 0.15$ mm when the load value $2P_c = 534$ kN is reached.

The early crack formation in No. 1 joint of the pilot design at a load of $2P = 143.7$ kN revealed shortcomings in the structural concept of the composite beam block joints. The results of the control tests when assessing the crack resistance of the prototype showed that the adopted structural concept for the composite beam block joints with the “tooth” and “cutout” was recognized as imperfect.

4. The control loads, when checking the composite beam for strength, had the following values:
- the composite beam flexural resistance shall be ensured when the load value $2P_c = 744$ kN is reached;
- No. 1 and No. 2 joints flexural resistance be ensured when the load value $2P_c = 790$ kN is reached.

The experimental load of $2P_{\text{MAX}} = 822.7$ kN was achieved during the tests which exceeded the control load equal to $2P_c = 744$ kN when checking the bending capacity of the composite beam and the control load equal to $2P_c = 790$ kN when checking the bending capacity of No. 1 and No. 2 joints.

The composite beam meets the project requirements, [19] and [20] bridge standards in terms of strength.
References


[15] SNIP 2.05.03-84*. Bridges and pipes.


