STRUCTURAL BEHAVIOR OF PRESTRESSED CONCRETE BRIDGE GIRDER WITH MONOLITHIC JOINT

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Resume
The paper presents the results of a test on a composite bridge girder of a length of 42.0 m, which was performed to assess its resistance, stiffness and crack resistance. Composite reinforced concrete beam with three blocks is joined by the two monolithic joints. When testing a beam with monolithic joint in terms of stiffness, crack resistance and strength, a load of 943.5 kN was achieved without cracking, which is 26.8% higher than the required one.

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1 Introduction

Composite prestressed concrete bridge beams are used when it is impossible or difficult to deliver solid beams to the construction site. In comparison to the whole transported ones, a number of requirements are imposed on the composite ones, associated with the manufacture of a stand for an even, practical ideal connection of beam blocks on the slipway

The nature of the shear at the interface between the high-strength precast concrete of a bridge beam and concrete used as a material for grouting bridge connections or as a repair material for the bridge decks was studied in the work [1]. The test results show that refurbishment concrete has excellent adhesion to precast concrete, which is higher than the guideline values.

The long-term behavior of joints of a prestressed concrete composite beam with precast and monolithic bridge decks is described in [2]. The results show that the normal stress of concrete in joints after pouring can develop over time from compressive stress to tensile stress and the effect of creep and shrinkage of assembled concrete decks over time can play a significant role.

Simulation of the glue lines showed that joints glued with plastic glue strongly depend on the shape of the cohesive zone models and that the trapezoidal shape is the best fit with experimental data [3]. On the other hand, when using the brittle adhesives, it is allowed to neglect the shape of the cohesive zone models.

2 Materials and methods

Control tests of a prototype of a composite bridge girder of a length of 42.0 m were carried out at the production base of the Almaty Plant of Bridge Structures (APBS).

The prototype composite along the length of the beam consists of three blocks - two outer and one middle, joined together by means of the two monolithic joints 0.2 m wide (Figure 1). Figures 2 and 3 show the formwork dimensions of the outer and middle beam blocks. The length of the outer block is 13.9 m, the length of the middle block is 13.8 m. The joints connecting the blocks are made of monolithic reinforced concrete 0.2 m wide.

The prototype of a composite beam with monolithic joints also consists of three blocks - two outer and

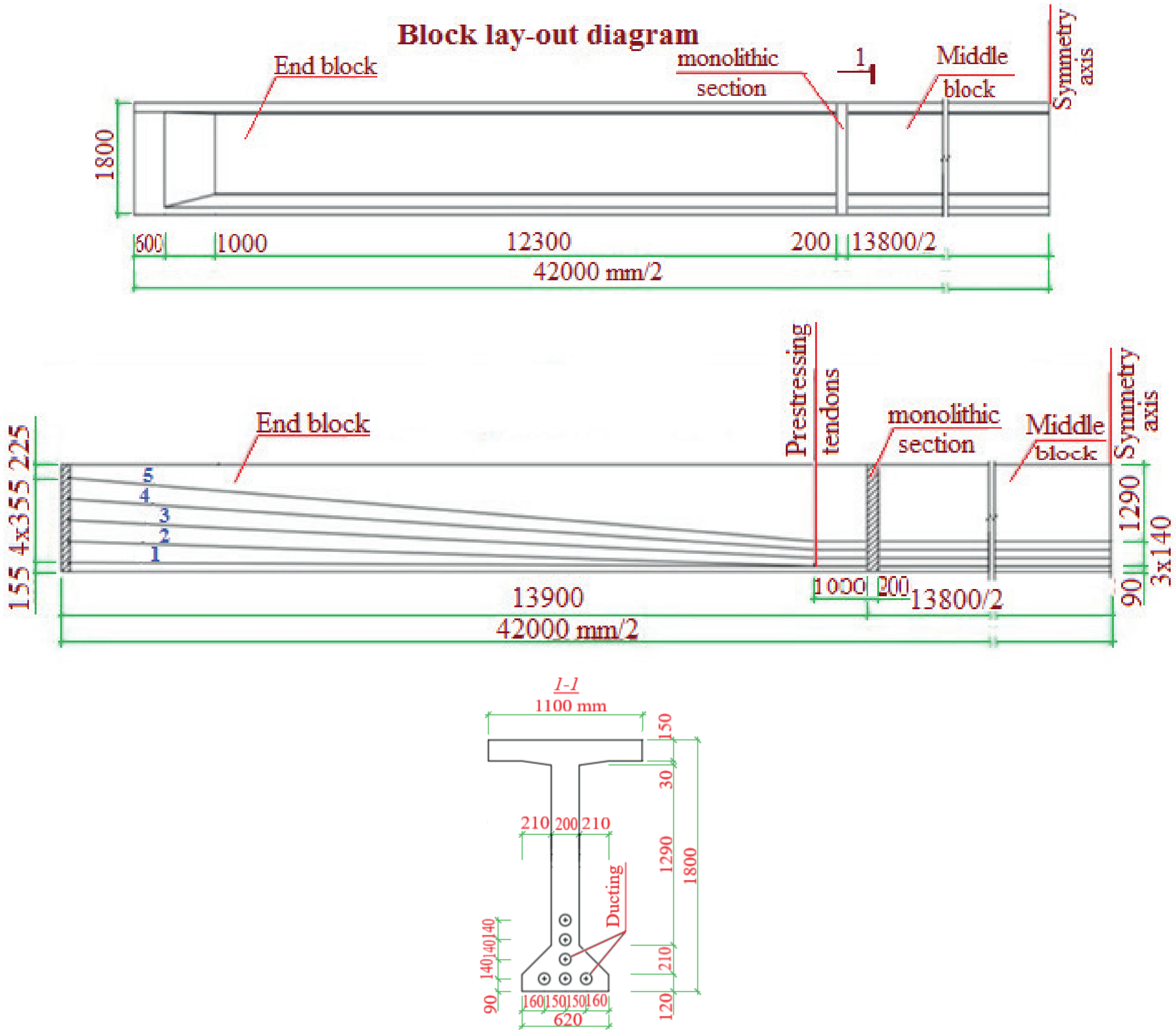

Figure 1 *General data, block layout diagram and the position of the prestressing tendons*

one middle (Figure 4). The length of the outer blocks is 14000 mm. The middle block has the shape of an inverted trapezoid - at the top the block has a length equal to 14010 mm, at the bottom - 14000 mm.

In the cross-section, the beam blocks have a T-section with an extended part at the bottom to accommodate beams prestressing steel.

The class of concrete for beam blocks is B40 according to [4].

When reinforcing a composite beam with prestressing steel, six tendons were designed, where each tendon consisted of seven strands K-7 of a diameter of 15 mm of Beloretsk Metallurgical Plant, having increased physical and mechanical characteristics in comparison to the characteristics given in the normative document "GOST 13840-68*. Reinforced steel ropes 1 × 7. Specifications". According to the document, for a single wire rope of a diameter of 15 mm, the force at the conditional yield strength is $P_{0.2} \geq$ 197 kN and the conditional yield strength is $\sigma_{0.2} \geq$ 1410 MPa. The controlled force in one prestressing tendon was taken equal to 1292 kN [5].

Figures 4 and 5 show the zones of monolithic joints No. 1 and No. 2 for combining the middle block with the two outer blocks. The class of concrete of a monolithic joint is taken equal to B40 with a strength range from 523.9 MPa to 589 MPa.

Before joining, the blocks of the composite beam were installed on the platform and the strands were pushed through the channeling blocks of the blocks. Figure 6 shows a general view of the end of the end block with the tendons laid in the assembly.

The joining of the blocks of the composite beam with each other in the staple was carried out by tensioning the beams of the prestressing tendons. The outer blocks are combined with the middle block using the two monolithic joints 0.2 m wide. Figure 7 shows the formwork of a monolithic joint.

After concreting the joints of the blocks and gaining their characteristic strength, the beams were gradually tensioned. The upper tendon was tensioned first, using a DN-7 hydraulic jack (Figure 8). The last were tensioned tendons in the lower row of the prestressing tendons. After tensioning each tendon was anchored. At the next stage of work, after prestressing the beams, cement

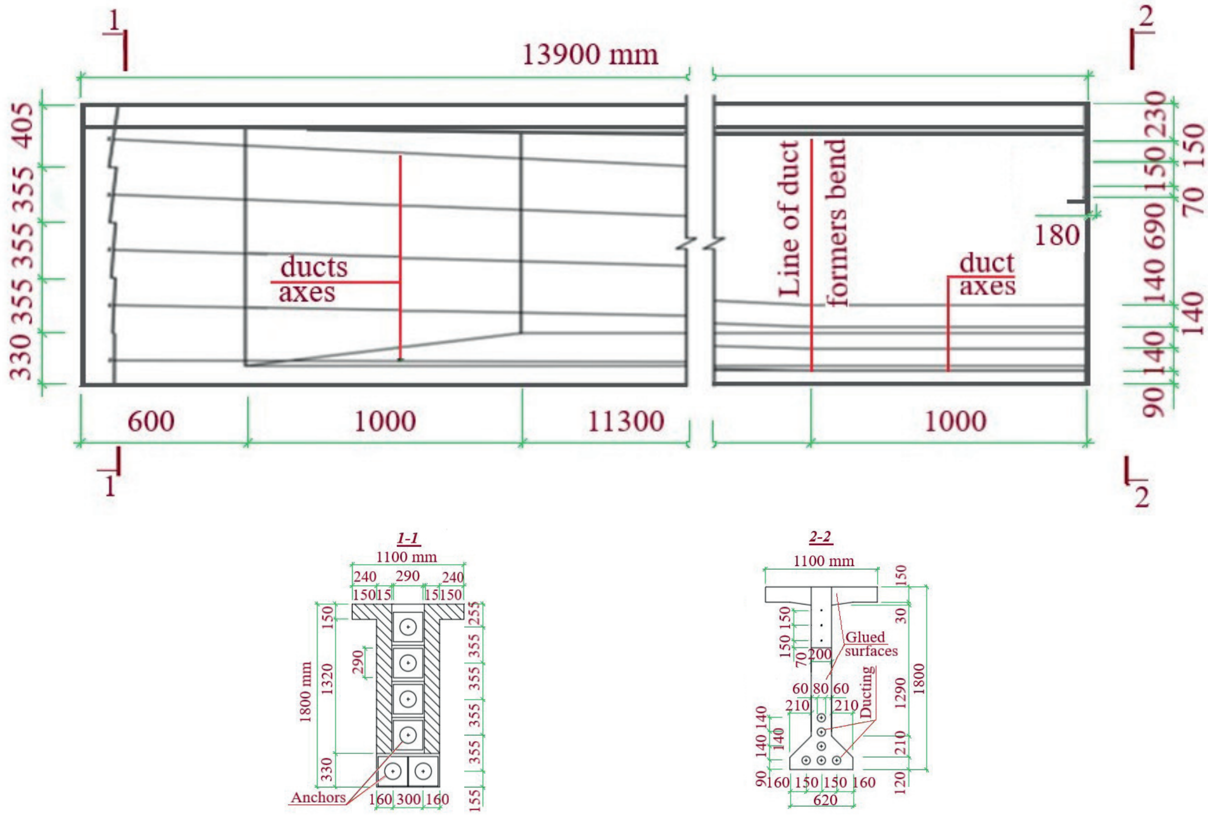

***Figure 2** Dimensions of formwork, front of the end block*

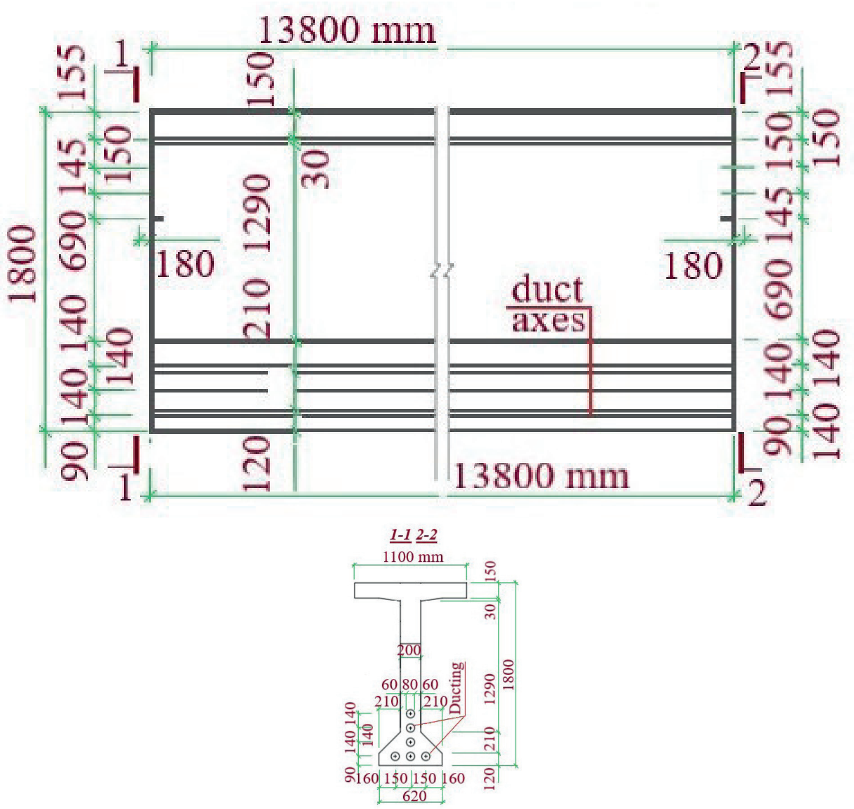

***Figure 3** Dimensions of formwork, middle block facade*

grout was injected into the ducts (Figure 9).

With the concrete age of the end blocks of 14 and 15 days and the middle block of 17 days, the actual concrete strength was tested. The strength of concrete was evaluated by the shock pulse method in accordance with State standard GOST 22690 "Concrete. Determination of the strength by mechanical methods of non-destructive testing "using an electronic meter of concrete strength IPS-MG4.03, developed by OOO "SKB" (Limited Liability Company "Construction Design Bureau") "Stroypribor" (Chelyabinsk, Russian Federation) was carried out.

The actual concrete strength of the outer blocks was B55 and B45 [4] and the middle block was B50. The strength of the concrete of the monolithic joints was B50.

To obtain the monolithic concrete of class B50,

Figure 4 *Joint zone No. 1 between the blocks before tensioning strands and concreting the joint (see Figure 1)*

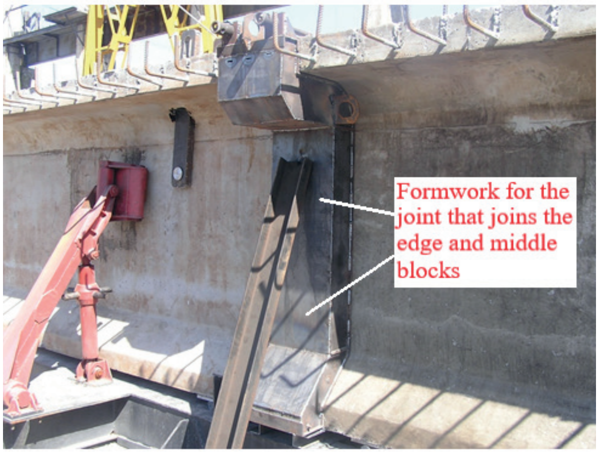

Figure 7 *Formwork for casting the joint*

Figure 5 *Joint zone No. 2 between the blocks before tensioning strands and concreting the joint (see Figure 1)*

Figure 8 *Tensioning of the upper tendon by a hydraulic jack DN-7*

Figure 6 *General view of the end block with tendons embedded in the ducts*

Figure 9 *Injection of cement grout into the second duct*

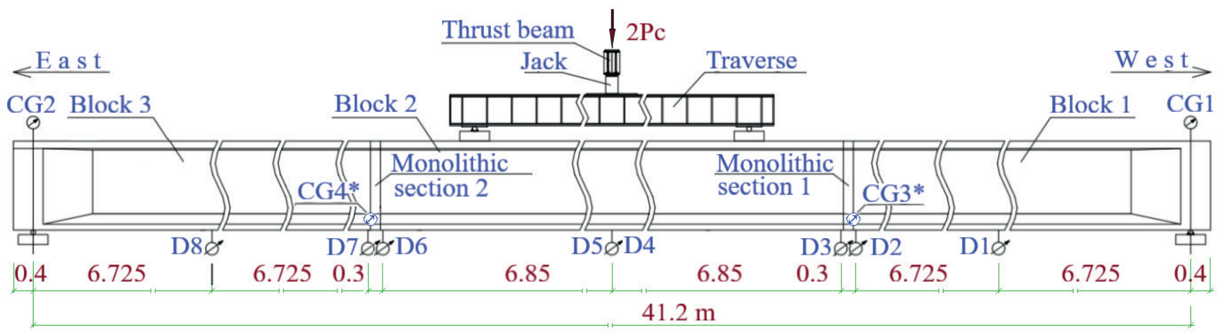

Figure 10 *Scheme of a composite beam of a length of L = 42.0 m with loading devices and mechanical indicators: - Deflection meters (D1 - D8); - Clock type gauge (CG1-CG2) with a division value of 0.01 mm; - Clock type gauge (CG3*-CG4*) with a division value of 0.001 mm*

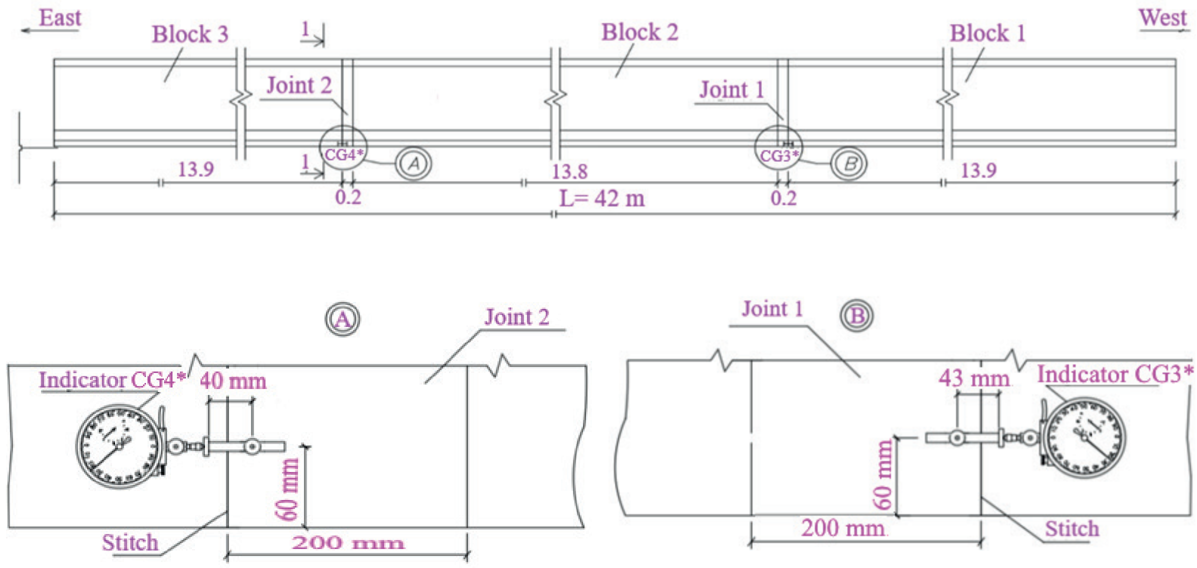

Figure 11 *Arrangement of dial gauges in the interface of joints 1 and 2 in a beam with a monolithic joints: CG3 * and CG4 * - with a graduation of 0.001 mm*

Portland cement of Topki plant (Russia) of grade M500 was used as a binder and as the main cladding additive - polycarboxylate hyper plasticizer Glenium 116, produced by BASF with a consumption of 1.2% by mass of cement.

The effect of chemical additives on the rheological properties of fresh concrete is given in [6]. The rheometric workability tests (RWT) on standard construction mortars were conducted. The results confirmed the effectiveness of the RWT for evaluation of modified concretes.

The effect of organo-mineral modifier for concrete of transport constructions is given in [7]. The introduction of the modified cement system reduced the porosity to 3-5%, depending on the composition of the concrete mixture. Tests of the repair layer of concrete with the modifier increased water resistance to W14 and frost resistance to grade F300.

Control measurements of the blocks showed that their geometric dimensions correspond to the design data.

Prior to testing, the bottom of the composite beam was surveyed using geodetic instruments to determine the camber of the beam. Instrumental survey was carried out using the tacheometer SOKKIA level of C3030 model and a geodetic rod.

Figure 10 shows a composite beam with a length of 42.0 m with loading devices and mechanical devices installed on the experimental structure. The mass of the loading devices was 49 kN. The effective length of the experimental beam, 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 outer blocks of the composite beam. In the middle part of the span, at a distance of 5.0 m from its centre, the test load was transferred in the form of two concentrated forces P (Figure 10).

To assess the stress-strain state of the monolithic joints No. 1 and No. 2 the middle block with the end ones and the possibility of fixing the opening of the joints in the process of loading, dial indicators were installed with a graduation rate of 0.001 and 0.01 mm (Figure 11 - at the joint zone).

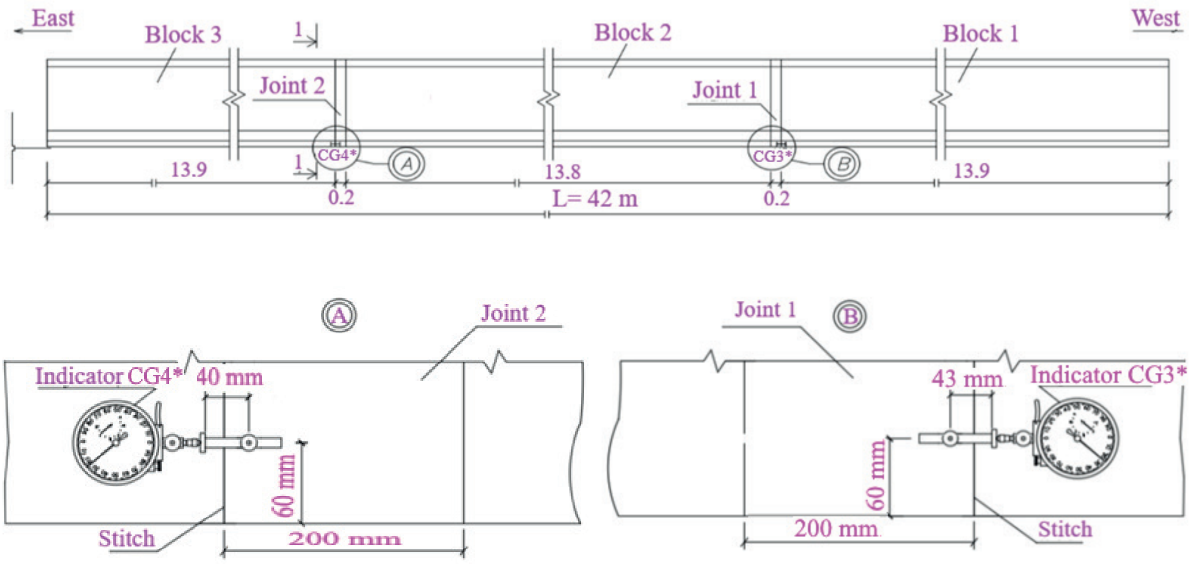

Figure 11 *Arrangement of dial gauges in the interface of joints 1 and 2 in a beam with a monolithic joints: CG3 * and CG4 * - with a graduation of 0.001 mm*

Figure 12 *Fragment of a composite beam 42.0 m long with installed strain gages and deflection meters in a beam with a monolithic joint*

Figure 12 shows the strain gauges glued to concrete beams to determine concrete strains along the height of the beam during the testing and mechanical devices installed on a composite beam to determine its deflections during the testing. The settlement of the supports was controlled using dial indicators with a graduation of 0.01 mm.

The results of experimental and numerical studies of the prefabricated bridge beam MDP for a span of 38 m with combined prestressing are given in [8]. The design of the beam is the result of a collaboration between the University of Zilina and a design company.

3 Results and discussion

3.1 Test results of a beam with a monolithic joints

In accordance with standard GOST 8829-94 “Reinforced concrete prefabricated concrete building products. Loading test methods. Rules for assessing, stiffness and crack resistance” [9] the values of control loads when testing a composite beam for stiffness, crack resistance and strength were adopted as follows:

1. When tested for stiffness:

- upon reaching the load $2P_c$ = 436 kN the deflection in the middle of the span a composite beam should not exceed a value equal to f_c = 83 mm.

2. When tested for fracture toughness:
   - upon reaching the load $2P_c$ = 534 kN the opening of cracks in concrete of a composite beam should not exceed the value a_{cr} = 0.15 mm.
3. When tested for strength:
   - upon reaching the load $2P_c$ = 744 kN the strength of the composite beam shall be ensured

Before the start of the tests, the lower edge of the 42.0 m long composite beam was leveled to determine the outline of its deformation. The deformation of the composite beam in the middle of the span, taking into account the preliminary rise of the middle block equal to 40 mm, was 103 mm.

To create and control the magnitude of the load when testing the composite beam, a power plant was used, which included a hydraulic jack DG100P230G with a lifting capacity of 1000 kN, a pressure cylinder, high-pressure tubes and a manual pumping station.

During the tests, the deflections of the beam were measured and recorded using the deflection meters. The possible opening of the joint at interface was recorded using dial indicators with a graduation rate of 0.001 mm. The settlement of the supports during the tests was controlled using the dial indicators with a graduation of 0.01 mm.

To control the moment of cracking, the side surfaces of the middle block of the composite beam were additionally covered with a thin layer of lime mortar. The crack width was determined using a Brinell microscope.

The load was applied to the composite beam in stages. After each stage of loading, readings were taken from the strain gauges, deflection meters and dial indicators.

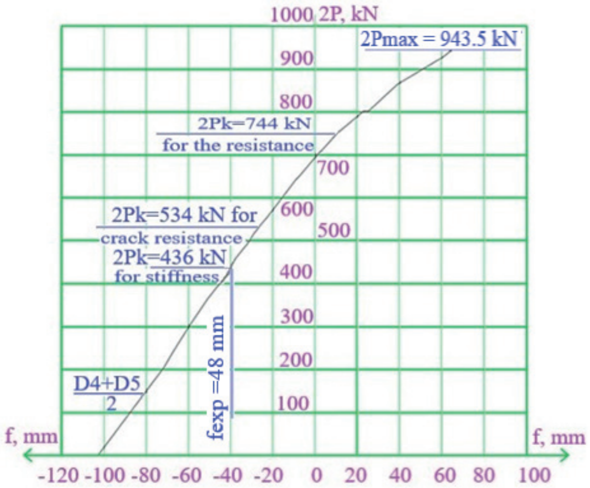

Figure 13 *- Load deflection graph of a composite beam in the middle of the span during its loading (D4 and D5 - deflection meters)*

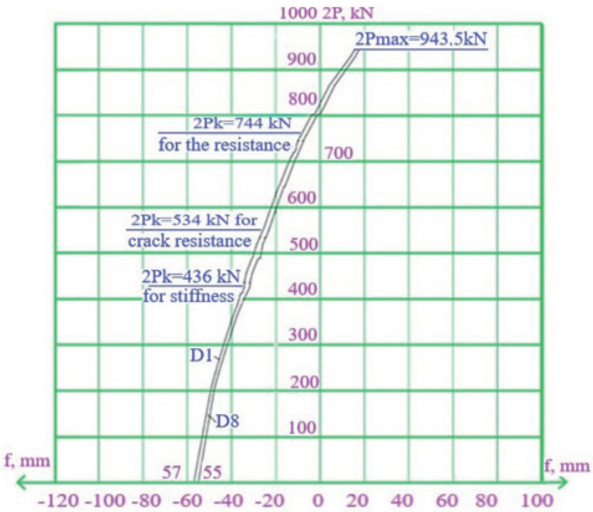

Figure 14 *Load deflection graph of a composite beam at a distance of 6.725 m from the axes of the supporting parts during its loading (D1 and D8 - deflection meters)*

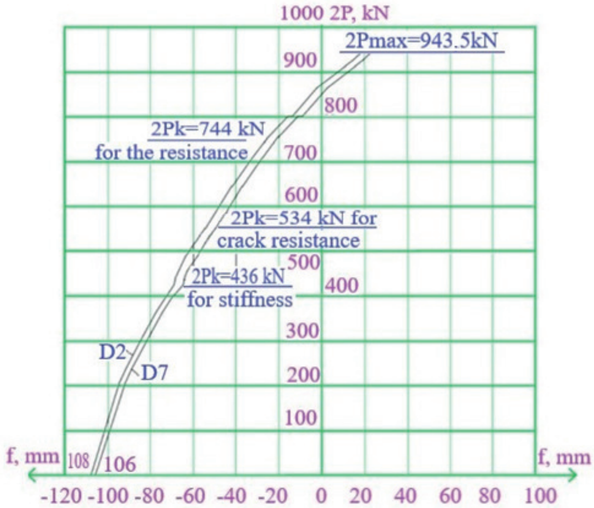

Figure 15 *Load deflection graph of a composite beam at a distance of 13.45 m from the axes of the supporting parts during its loading: in the joint zone 1 deflection meter D2, in the joint zone 2 deflection meter D7*

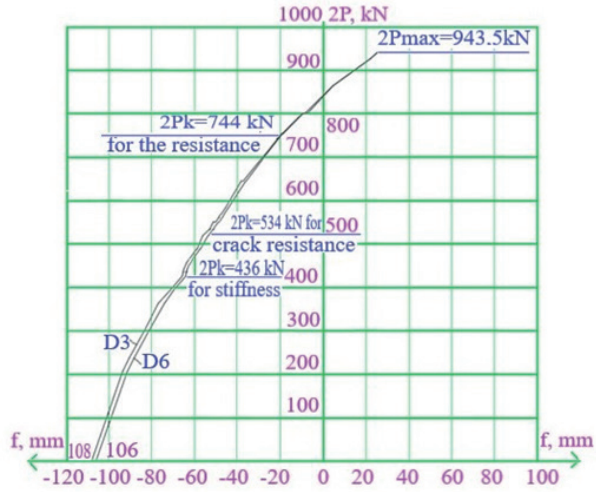

Figure 16 *The Load deflection graph of a composite beam at a distance of 13.75 m from the axes of the supporting parts during its loading: in the joint zone 1 deflector D3, in the joint zone 2 deflector D6*

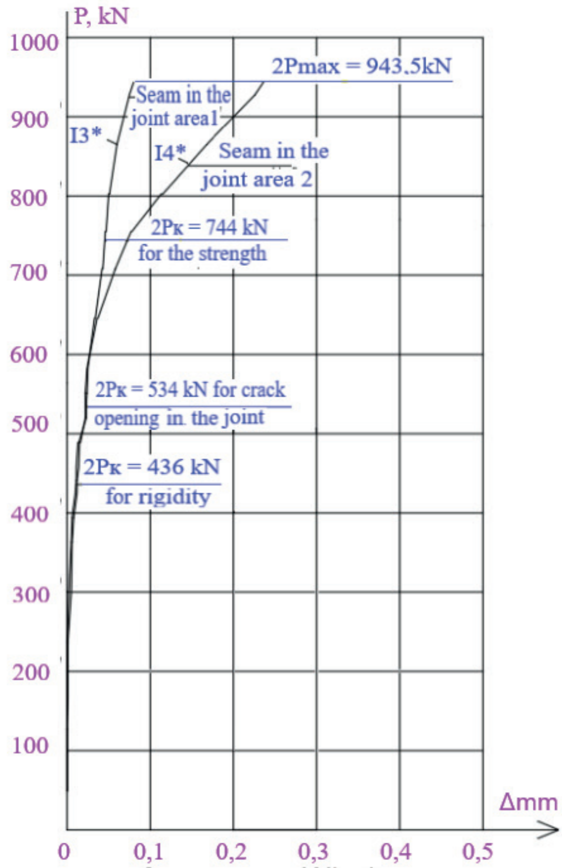

Figure 17 *Load-joint opening graph for the monolithic joints 1 and 2*

As an example, Figures 13 - 16 show the load-deflection graphs of a composite beam in the middle of the span during its loading.

Figure 17 shows a graph of the opening of the monolithic joint in the area of joints No. 1 and No. 2 of a composite beam during its loading, which were recorded by the dial indicators with a division value of 0.001 mm.

At the first stage of testing, the stiffness of the composite beam was evaluated. With a control load in terms of rigidity equal to $2P_c$ = 436 kN, the experimental deflection of a composite beam in the middle of the span should not exceed the control value of the deflection equal to f_c = 83 mm. Upon reaching the control load equal to $2P_c$ = 436 kN, the experimental deflection in the middle of the span of the composite beam had a value equal to f_{exp} = 48.0 mm, which was 57.9% of the permitted control deflection (see Figure 13).

In terms of rigidity, a composite beam with a length of 42.0 m meets the requirements of the bridge standards SNiP 2.05.03-84* [10] and GOST 8829-94.

At the second stage of testing, the crack resistance of the concrete of the composite beam itself was evaluated. Upon reaching the control load $2P_c$ = 534 kN, the crack opening width should not exceed the control value equal to a_{cr} = 0.15 mm

Upon reaching the control load equal to $2P_c$ = 534 kN in the concrete of the beam in the middle of the span, in the zone of maximum bending moments, there were no cracks.

At the same time, the possible opening of the joint at interface during the loading was monitored using dial indicators with a graduation rate of 0.001 mm. When the control load for the crack resistance was reached, equal to $2P_c$ = 534 kN, there was an opening of the joints No1 and No2. The size of the opening of the seams was 0.022 mm, which is lower than the value equal to a_{cr} = 0.15 mm.

In terms of the crack resistance, a beam 42.0m long meets the requirements of the bridge norms SNiP 2.05.03-84 * and GOST 8829-94.

At the last, the third stage of testing, the strength of the beam was tested. According to the design calculations, the control load when assessing the strength of the beam was $2P_c$ = 744 kN.

During the tests, an experimental load of $2P_c$ = 943.5 kN was achieved, which, when checking the strength of a composite beam, which exceeded the control load equal to $2P_c$ = 744 kN. The exceeded value of the experimental load achieved during the tests over the reference strength load was 26.8%.

The nature of the increase in the deflection curves in the composite beam (Figure 15) and the assessment of its stress-strain state indicated that the limiting state was not reached in it and the experimental structure still had reserves in bearing capacity [11-12].

In terms of strength, a composite beam of a length of 42.0 m meets the requirements of the bridge standards SNiP 2.05.03-84 * [10] and GOST 8829-94 [9].

During the tests, the possible displacement (pulling) of the prestressing steel, relative to the concrete of the composite beam, was monitored. At all the stages of loading a composite beam, no displacement (pulling) of the beams of prestressing steel relative to the concrete of the experimental structure was observed.

4 Conclusions

1. The control load, when checking a beam with a monolithic joint in terms of stiffness, was $2P_c$ = 436 kN. At a given load, the control deflection of the beam should not exceed a value equal to f_c = 83.0 mm. With a load of $2P_c$ = 436 kN, the experimental deflection of the beam in the middle of the span had a value equal to f_{exp} = 48.0 mm, which was 57.9 % of the permitted value for the control deflection.
   In terms of stiffness, the composite beam meets the requirements of the bridge standards SNiP 2.05.03-84 * and GOST 8829-94.
2. The control load, when checking a beam with monolithic joints for crack resistance, was equal to $2P_c$ = 534 kN. At a given load, the crack opening should not exceed a value equal to a_{cr} = 0.15 mm. Upon reaching the control load equal to $2P_c$ = 534 kN, no cracks were formed in the concrete of the beam in the zone of maximum moments.
   In terms of crack resistance, the beam meets the requirements of the bridge standard SNiP 2.05.03-84 * and GOST 8829-94.
3. The control load, when checking a beam with monolithic joints in terms of strength, was equal to 2 P_c = 744 kN. During the tests, an experimental load of 2 P_{max} = 943.5 kN was achieved, which, when checking the strength of a composite beam, exceeded the control load equal to 2 P_c = 744 kN. The assessment of the stress-strain state at the achieved experimental load equal to 2 P_{max} = 943.5 kN indicated that the limiting state was not reached in the beam and the prototype still had reserves for bearing capacity.
   In terms of strength, the composite beam meets the requirements of the bridge standard SNiP 2.05.03-84 * and GOST 8829-94.

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