

Reconstruction of the suspended pedestrian bridge through the River Bug to border island

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Abstract. The results of the technical examination of the pedestrian bridge over the Western Bug River on the territory of the Brest Fortress are presented. A new constructive solution of the bridge, the results of its numerical modeling and the features of installation are presented. The full-scale tests of the bridge with a movable test load confirmed the design decisions made by the authors. The resulting efforts in the ropes did not exceed the calculated values.

1 Results of technical expertise

At the beginning of the last century, a pedestrian bridge (from Brest to the Pogranichny Island across the Bug River) was built and reconstructed several times in the area of the border sign No. 1265. Structurally, the bridge is made as a single-span suspended bridge with a span of 143.25 m and a distance between the axes of paired ropes - 4.6 m. The height of the bridge pylons was 10.6 m. The supports for the pylons are made of monolithic reinforced concrete: the left bank in the plan is rectangular, and the right bank is in the form of a hexagon, while the top of the left bank support is 1.15 m higher than the ground surface. The stops for fastening cable systems are also made of monolithic reinforced concrete and have a rectangular shape with dimensions of 7.1 × 6.0 m. The top of the stops is at the same level as the ground surface, and the depth of the thrust is – 2.8 m. The bridge is made of wood, made of planks along the beams resting on steel corners attached to the suspension of the bridge. A general view of the bridge before reconstruction is shown in Figure 1.

As it was noted above, the main load-bearing elements of the bridge are four flexible curved threads (cables of the cable-stayed system), passed over the top of the steel pylons and anchored in the tensioners of the coastal reinforced concrete stops. Steel flexible hangers are attached to the ropes of the cable system to hold the bearing elements of the roadway in the design position. There are two ropes on each pair of pylons. At the stage of technical expertise, according to the results of testing the wires selected from the strands of the ropes, it was established that the structure of the bridge used double lay ropes with an organic core (TLK-O type) with a diameter of 50 mm in accordance with GOST 3079 [6]. The pylons of the suspension bridge are made in the form of a spatial rod pyramidal tetrahedral truss. The height of the pylon is 10 m, which is 1/14 of the span. The lower base

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of the pyramid is rectangular in plan with dimensions in the axes of 2270 x 1078 mm, the upper one is 760 x 566 mm. In accordance with GOST 8240 the pylon posts have a box section and they are made of two hot-rolled steel channels No. 30. In accordance with GOST 8509 Bracing and posts are made of equal angles 140x12. Rollers with a diameter of 100 mm in the supporting part and the place of support of the ropes are installed on the head of the pylons (two channels) and they have a diameter of 160 mm in the middle part [1, 5]. A general view of the pylon head is shown in Figure 2.



Fig. 1. General view of the bridge before reconstruction.



Fig. 2. General view of the head of the pylons and moving support wheels.

In order to determine the geometry of the sagging of the ropes, a tachymetric survey of the bridge was carried out. The boom of the sagging of the ropes at the time of the survey was 10.495 m. So, taking into account the length of the suspensions in the middle part of the bridge, made it possible to draw a conclusion about the "sagging" of the roadbed of the bridge in relation to the horizon by about 2 meters. It should be noted that by the time of the survey, part of the suspension brackets was "torn off" from the roadbed, and the roadway structures (girders and flooring) were partially destroyed.

2 Constructive solution

When performing design work on the reconstruction of the existing suspension bridge, it was decided to preserve the geometric parameters of the bridge and to partially use the existing supporting structures (pylons, supports for pylons, cable-stayed cable system and its support part with tensioners) as elements of a new design solution for the bridge taking into account the requirements for functional loads according to EN1990.

For the designed bridge in order to perceive the acting loads, it was decided to change its structural scheme, namely, in accordance with [10], to design the bridge in the form of a combined system. The span structure of the bridge is customarily made in the form of a three-span continuous spatial arched truss with the value of the extreme (coastal) spans 29.93 m long and the central (channel) span - 79.5 m, resting on the existing bank supports and new channel spans and supported by the existing cable-stayed cable system using new flexible hangers. The use of a three-span continuous spatial arched truss as the main supporting structure is due to the insufficient load-bearing capacity of the cable-ropes for the perception of loads, for which at the design stage it was decided to limit the calculated longitudinal force in the cable-cable to 400 kN based on the maximum design tensile force at acting loads, which is

$$N_{dn} = \frac{N_{un}}{\gamma_m} \cdot m \cdot m_1 = \frac{1060}{1,6} \cdot 0,8 \cdot 1,0 = 530 \text{ kH}, \quad (1)$$

γ_m – is the material safety factor for steel ropes, $\gamma_m = 1,6$ [7, 10];

m – is the coefficient of the working conditions of the steel rope, taken according to item 58 [10], $m = 0,8$;

m_1 – is the coefficient of the operating conditions of the ropes in the bend zone, $m_1 = 1,0$ [10].

A general view of the bridge is shown in Figure 3.



Fig. 3. General view of the bridge during construction.

The main elements of the spatial steel arch truss are two (2) flat steel arches with a height along the axes of the chords of 2.0 m. The length of the upper chord panel along the axes of the nodes is 4958 mm. The width of the superstructure along the axes of the pylons is 4.28 m. Because of the conditions of transportation and installation the arched truss is divided into 7 spatial dispatch blocks.

The truss belts are made in the form of a welded box made of sheet steel (in accordance with GOST 19903), class C345 (in accordance with GOST 27772). Height and width are 200 mm. The thickness of the sheets of the welded box is variable and was taken depending on the diagram of bending moments on the supports and in the span, and the corresponding value of the longitudinal force in the chords of the truss.

The use of a welded box in the chords is due to the insufficient bearing capacity of bent-welded closed sections according to GOST 30245. Strength calculations at the stage of the architectural design made it possible to establish that the use of hot-rolled sections as chords increases metal consumption by (30...35) %. The technology for the design and manufacture of such sections was used and proved itself in the design and construction of

the wa-ter sports palace in Brest and made it possible to ensure the overall stability of the flat shape of the bending of the upper belt in the sections between the runs (in accordance with the re-quirements of TCP EN 1993-1-1 [9]).

The lattice of the space truss is triangular, made of steel bent closed welded square pipes in accordance with GOST 30245: □ 120x7, □ 100x5, □ 80x4 from steel S345 in accordance with GOST 27772.

Along the upper chord, in the truss nodes, there are transverse beams made of hot-rolled steel I-beams 20B1 according to GOST 26020. In the middle of the span of the trans-verse beams there is a 20P channel according to GOST 8240, which is used as an intermediate support for the bridge deck beams.

The central (channel) span of the spatial arch is supported by hangers made of pipes □ 60x5mm, which are attached to the existing cable-ropes with controlled tension.

The spatial rigidity of the combined bridge structure is ensured by means of flat vertical trusses, cross beams, horizontal cross braces and a two-layer timber deck structure. In order to increase the rigidity of the bridge in the plane of operation of the structures (vertical), as well as excessive vibrations, the existing cable-ropes were pre-tensioned and rigidly connected to the spatial truss in the middle of the span (Figure 4) [2].

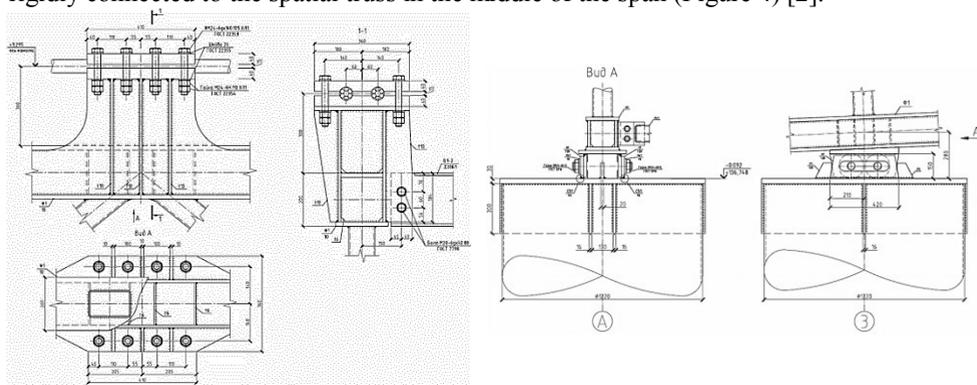


Fig. 4. Central node for attaching the ropes to the upper chord.

Intermediate (channel) supports (along axes 3 and 4) were made in the form of steel-reinforced concrete bored piles. Electric-welded pipe Ø1220x10 in accordance with GOST 10704 made of steel C245 in accordance with GOST 27772, which is filled using concrete of class C20 / 25, W6, F200 with self-tension grade Sp0.6, was adopted as a casing pipe. Work-ing reinforcement in the frame is represented by 8 rods Ø20 S500, distribution rods Ø8 S500.

To exclude the transfer of the thrust to the supports from temperature changes and to reduce the sensitivity of the bridge to the settlements of the supports, a special support struc-ture has been developed. The support reaction from the dead weight of the bridge and the temporary load is transmitted to the steel-reinforced concrete columns through two cylindrical rollers, to the foundation of the pylons - through one roller. Moving support wheels are made of hot-rolled round rolled Ø150 mm in accordance with GOST 2590 from alloy structural steel 40X in accordance with GOST 4543. The design solution and general view of the inter-mediate support are shown in Figure 4.

3 Numerical modeling

The static calculation of the coating was carried out using the PC "LIRA" and was controlled according to the methods set forth in the normative docu-ments. This software

package is based on the finite element method implemented in the form of a displacement method.

The static calculation was carried out in a geometrically nonlinear formulation. When calculating geometrically nonlinear systems, it is assumed that Hooke's law is observed and at each step for bar elements when constructing the stiffness matrix, the longitudinal force is taken into account.

The ropes were modeled by a geometrically nonlinear universal spatial rod element (thread) - FE 310. To take into account the geometric nonlinearity, it is assumed that at each step Hooke's law is fulfilled ($\sigma_x = E \cdot \epsilon_x$), and the deformation included in this expression has the following form:

$$\epsilon_x = \frac{du}{dx} + \frac{1}{2} \left[\left(\frac{du}{dx} \right)^2 + \left(\frac{dv}{dx} \right)^2 + \left(\frac{dw}{dx} \right)^2 \right] - z \frac{d^2w}{dx^2} - y \frac{d^2w}{dx^2} \quad (2)$$

The pretensioning of the ropes was created by a special rod end element of pretensioning - FE 308. The first loading of this element in the design scheme ensures the appearance of a given force in it. For subsequent loadings, FE 308 works like a thread (FE 310) [2, 3].

The finite element model of the bridge is shown in Figure 5.

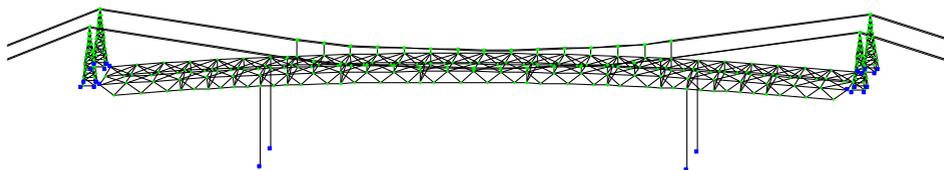


Fig. 5. Finite element model of the bridge.

The calculation was made for the following types of loads:

- pre-tensioning of the ropes;
- load from its own weight (weight of the bridge leaf, wooden flooring, lighting and fencing);
- live load (standard value 4 kPa), applied according to various loading schemes;
- moving load 30 kN.

4 Mounting

The construction of the pedestrian bridge was carried out in a complex flow and covered the following types of work:

- engineering preparation of the territory;
- dismantling of the remains of the bridge roadbed structures;
- dismantling of steel hangers;
- partial backfilling of the channel with a parallel arrangement of an artificial embankment for the installation of erection cranes;
- hammering of metal casing pipes;
- excavation and installation of reinforcing cages in the pipe and their subsequent concreting;
- tensioning of steel ropes to reduce boom sagging;
- installation of the bridge deck with spatial blocks;
- tension of the ropes by lowering the superstructure of the bridge to the design marks;
- installation of wooden purlins and flooring;
- antiseptic and anti-corrosion treatment of bridge structures.

The backfilling of the assembly sites was carried out from both sides of the river to the intermediate supports in axes 3 and 4, which were later reinforced with road slabs. The installation of the bridge deck was carried out in spatial blocks. On each bank, two sections, 40 m long, were erected, which rest on the foundations for pylons and intermediate supports. The outer cables from the side of the installation of the cranes were lowered into the water, and from the other side of the bridge they were pulled away from the structure being mounted. The central span of the bridge 60 m long, consisting of three sections, was assembled on the right bank of the river at a special assembly site, and then, with the help of blocks and winch-es, was pulled onto the pontoon bridge. The section was lifted by two DEK-251 cranes (Fig-ure 6). The boom length was 30 m, the outreach was 15 m. The lifting capacity of the cranes at the indicated outreach was 12 tons. The weight of the lifted section of the bridge, according to the construction metallic drawings, did not exceed 22 tons.



Fig. 6. Installation of the central span of 60 m long bridge by two cranes DEK-251.

The raised section was connected with the previously mounted ones using an equal-strength butt welded joint, which was also developed by specialists of the Department of Building Structures of the BrSTU. Preliminary calculations of the average span of the bridge for loads from its own weight showed the presence of a reserve of bearing capacity, which made it possible to install a structure with a length of 60 m (Figure 6).

The pre-tension of the ropes was created by the weight of the metal structures of bridge. For these purposes, the span structure of the bridge was installed on temporary sup-ports at an amount 700 mm higher than the design level. After the rigid connection of the ropes at the central nodes of the trusses (Figure 3), the bridge bed with a length of about 140 m using hydraulic jacks was lowered to the level of the design marks of the main supports. As a result of this mounting technology, a force of 71.1 kN was created in each rope.

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