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Research Paper

Numerical modeling of condition of the bridge structure based on the results of national surveys

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Abstract

The possibilities of calculating the bearing capacity of hydraulic structures with the use of modern software products are based on the example of a bridge structure in the Krasnodar region. This bridge construction across the river Bezymyannaya is located near the city of Gelendzhik. In the process of inspection some defects were indentified that affect the bearing capacity of the construction: the destruction of the protective layer of concrete by separate segments; corrosion of reinforcemnt in load-bearing elements with loss of cross-section up to 16,6%; corroison of concrete in load-bearing elements of type I and II; cracks in the crossbar with a width of opening up to 0,5 mm, which indicates the overstrain of the structure.

Keywords: *Hydrotechnical Constructions; Inspection of Technical Condition; Mathematical Modeling; Numerical Calculation.*

1. Introduction

The bridge construction across the river Bezymyannaya is located in the Krasnodar Region near the city of Gelendzhik. Operating conditions are characterized by the following parameters: wind zone - V; snow area - II, seismicity of the construction site on the map OCP-2015 B - 9 points; the landscape of the area is pre-mountaneous.
Geometrical characteristics of the structure are shown in sectional drawing Figure 1.

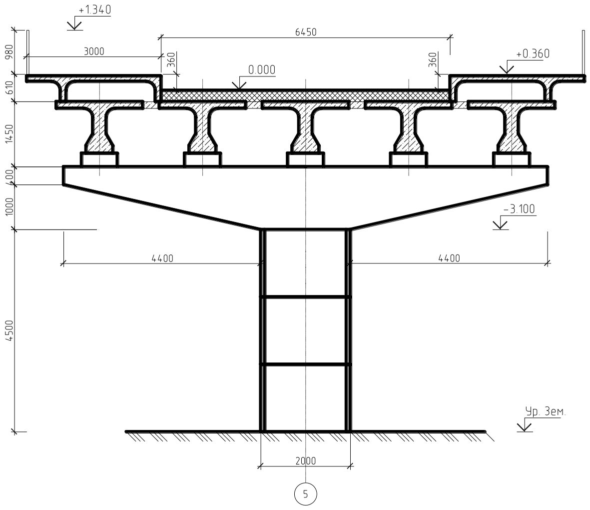


Fig. 1: Geometrical Charachteristics of the Structure in Sectional Drawing.

2. Materials and methods

As a result of visual inspection of the structure, the following defects were detected:
Defect 1 - local destruction of the protective layer of concrete (Figure 2).

Fig. 2: Local Destruction of the Protective Layer of Concrete.

The presence of this defect affects the duration of the operational period of the structure, due to the loss of the cross-section of the reinforcement from corrosion.
Defect 2 – Corrosion of reinforced concrete elements (Figure 3).

Fig. 3: Corrosion of Reinforced Concrete Elements.

The development process of this defect reduces the strength characteristics of the concrete stone, which directly affects the strength of the monolithic sections of the structure.
Defect 3 – Cracks in reinforced concrete structuresre (Figure 4).

Fig. 4: A Crack in A Reinforced Concrete Structure.

The presence of this defect leads to a decrease in the life of the structural elements, since the further spread of cracks contributes to the development of corrosion of reinforcement in reinforced concrete elements.
The next stage of the survey of the structure was an instrumental survey, which begins with geodetic measurements. In the process of performing geodetic work, a bridge plan, transverse and longitudinal profiles were compiled, and the deflections of the beams of the span part of the bridge were measured. The measurements were made using the level of optical CST / Berger SAL 32 ND. As shown by measurements, deflections do not exceed 18% of the normative value.
Determination of the strength characteristics of concrete is carried out by the method of nondestructive testing using the instruments ONYX-OS and UKS-MG4S. The results of measurements are used in calculating the bearing capacity of structures.
To measure the width of the crack opening, the MPB-2 microscope (Figure 5) and the metal measuring tape FISCO were used.

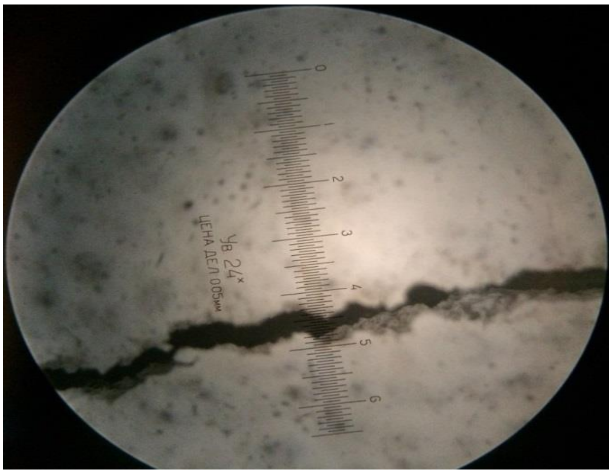


Fig. 5: Crack in A Reinforced Concrete Structure Under A Microscope.

At the examination, the presence of cracks with an opening width of 0,5 mm was recorded, which exceeds the allowed value for prolonged crack opening (0,3 mm).
Further, the degree of corrosion of concrete and reinforcement was determined.
As a result of the survey, the presence of corrosion of concrete type I (dissolution of concrete stone components in aqueous solution) and type II (removal of products of chemical reaction between cement stone and filtration flow solution).
Measurement of the diameters of the cross-section of reinforcing bars, susceptible to corrosion, was carried out at the points of opening of reinforcing frames by a caliper. The loss of cross-section of the reinforcement from corrosion in the span structures of the bridge (monolithic sections and prefabricated structures of pedestrian areas) is up to 16, 6%.
Verification calculation of structures' bearing capacity
The calculation was carried out using a multifunctional software package for calculating, researching and designing structures for various purposes «Stark ES», version 2018. The design model describes in detail the structural design of the structure. This calculation is carried out in accordance with the requirements of the following regulatory documents: SR 20.13330.2011 «Loads and impacts»; SR 35.13330.2011 «Bridges and pipes»; SR 63.13330.2012 «Concrete and reinforced concrete structures».
Initial calculation data. Normative wind pressure is accepted – 0, 38 kN/m^2; estimated snow pressure – 1, 2 kN/m^2; seismicity of the construction site – 9 points.
Collecting loads. Constant and long-term load is comprised from the weight of structures themselves, pavement and metal fencing.
The temporary load is represented by the load from a biaxial trolley with an axial load of 10K, HK18 in the form of a four-axle trolley, and evenly distributed from the normative load from vehicles, taking into account the dynamic coefficient.
Volumetric-planning and constructive solutions. The structural solution of the surveyed bridge structure is shown in Figure 1.
Estimated part.
The computational model is prepared in the position preprocessor of the software complex «Stark ES», version 2018. Model of the final element method (FEM) is shown in Figure 6.
To obtain the most accurate calculation of the structure and a complete mathematical analysis of the operation of the structures, a computational model is compiled with a detailed study of all its design features.

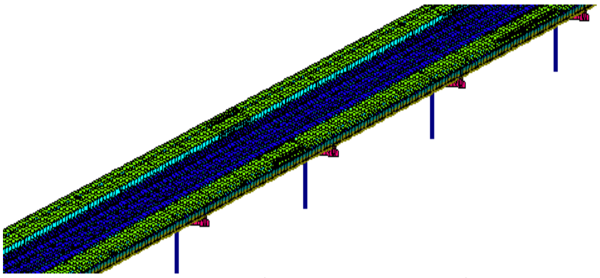


Fig. 6: Calculated Model of Final Elements (FE) of the Structure

Materials of the project FE (3D-rods) are presented in Table 1.

Table 1: Materials of 3D-Rods

No	A [м^2]	As [м^2]	At [м^2]	Ir [м^4]	Is [м^4]	It [м^4]	E [кН/м^2]	G [кН/м^2]	Rho [т/м^3]
1	0.00614	0.00	0.00	1.2e-006	5.86e-006	3.55e-007	2.06e+008	7.92e+007	8.24
2	2.9400	0.00	0.00	1.16	0.529	0.98	3e+007	1.25e+007	2.75

A – the cross-sectional area; Ir – moment of inertia rel. OR;
As – shift area in destination to OS; Is – moment of inertia rel. OS;
At – shift area in destination to. OT; It – momeht of inertia rel. OT;
E – modulus of elasticity; G – shift modulus; Rho – the density of the material.
Materials of FE project are presented in table 2.

Table 2: Isotropic Materials

No.	d [m]	E [kN/m^2]	Mue	Rho [t/m^3]
3	0.12	2.75e+007	0.2	2.75
4	0.13	2.75e+007	0.2	2.75
5	0.15	2.75e+007	0.2	2.75
6	0.15	3.25e+007	0.2	2.75
7	0.325	3e+007	0.2	2.75
8	0.41	3.25e+007	0.2	2.75
9	1.25	3e+007	0.2	2.75
10	1.5	3e+007	0.2	2.75

D – thickness; Rho – density of the material; E – modulus of elasticity; Mue – Poisson ratio.

To determine the stress-strain state (SSS) of building structures, the task of loads for static calculation has been performed.
In the Stark ES PC, the weight of the structures is taken into account automatically and is loaded into the load 1. We carry out the task of the 1st load.
Figure 7 shows a uniformly distributed load corresponding to load 1.

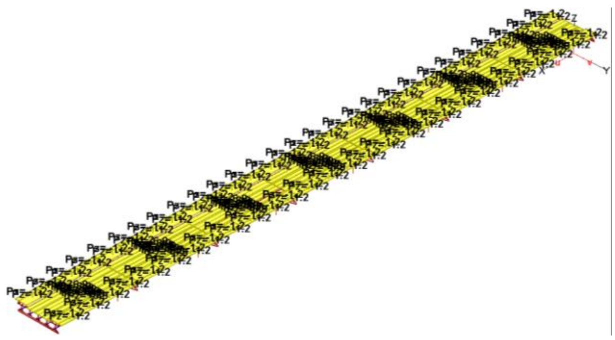


Fig. 7: Linear Loads Corresponding to Loading 1.

Static calculation is performed based on the generated FE model of the bridge. The calculation was carried out in accordance with the combinations of loads presented in Table 3.

Table 3: Combinations of Loads

Номер	НГ-1	НГ-2	НГ-3	НГ-4	НГ-5	НГ-6	НГ-7	НГ-8	НГ-9
К-1	1	1	1	0	0	0	0	1	1
К-2	1	1	0	1	0	0	0	1	1
К-3	1	1	0	0	1	0	0	1	1
К-4	1	1	0	0	0	1	0	1	1
К-5	1	1	0	0	0	0	1	1	1

Based on the results of the static calculation, the efforts in the constructions were obtained. The maximum force values are fixed in a combination of 4:

- Membrane stress Ss = –58607,1 kN/m^2;
- Transverse force at the site Qs = –4036,07 kN/m;
- Bending moment Ms = 1796,74 kNm/m.

With the purpose of analyzing the SSS of span structures, the strength analysis of the fragment part shown in Figure 8 was carried out. The calculation was carried out for specified cross-section parameters, reinforcement and material characteristics of the reinforced concrete element.

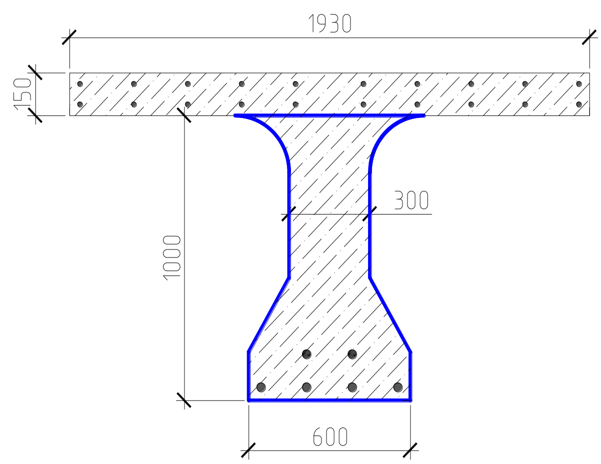


Fig. 8: Cross-Section of the Element of the Span Structure.

The initial data for calculating the strength evaluation of the elements of bridge span structures are shown in Figure 9. The characteristics of concrete, as well as the reinforcement of structures, are determined by field trials.

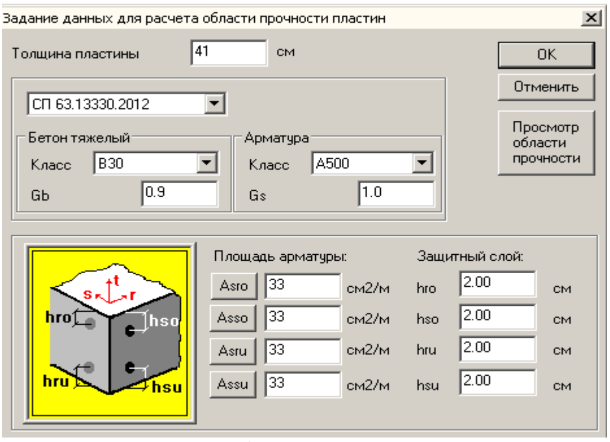


Fig. 9: Baseline Data for Calculating Strength Evaluation.

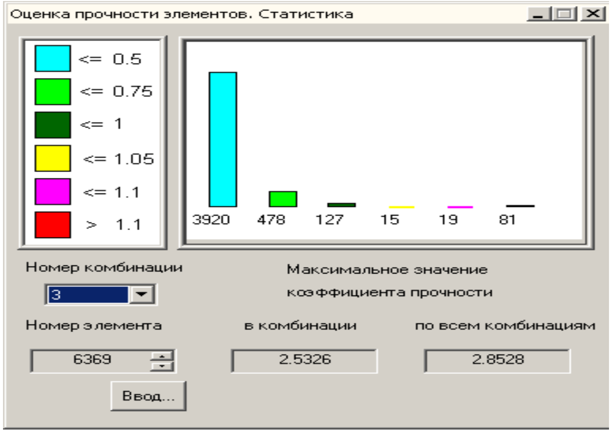
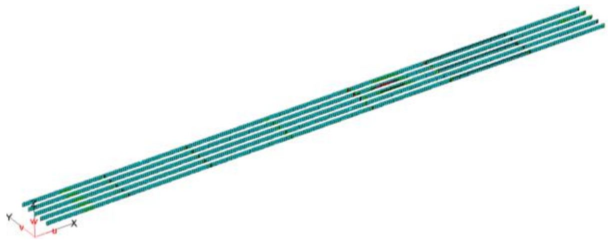


Fig. 10: Strength Evaluation by Combination 3.

As an example, Figure 10 shows the results of calculating the strength of bridge spanning structures, according to combination 3.



Proceeding from the presented, it can be concluded that local overvoltage can be seen in overflights, which indicates the boundary condition of the SSS. The load cannot be increased.

For similar combinations of loads, the calculation of the structural elements on the deflection was carried out. The results of the calculation are shown in Figure 11.

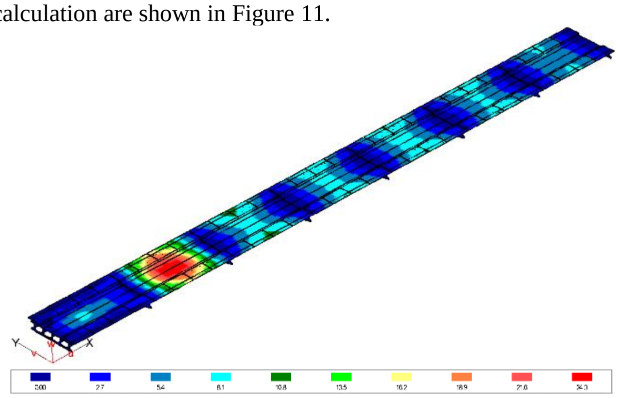


Fig. 11: Flexure of Structural Elements.

Max shift = 24, 3427 mm at node 18830.

It can be seen from Figure 11 that the maximum design flexure is 24,34 mm, which is 44,4% of the standard value (52,5 mm).

The types of defects detected during the survey are presented in Table 4.

Table 4: Types of Defects Identified

Defect type number	Descpription of the defect	Causes of defect
1	Local destruction of the protective layer of concrete	• Violation of construction technology; • Aggressive impact of water during the high season; • Periodic freezing-thawing
2	Corrosion of reinforced concrete elements	• Violation of construction technology; • Soaking of structures; • Aggressive environment
3	Crecks in reinforced concrete structures	• Uneven sediment of the structure; • Excessive stress in the structure
4	Cracks in the roadway	• Violation in construction technology; • Violation of the material production technology; • Aggressive environment; • Uneven sediment
5	Clogging of the drainage funnel	• No timely service takes place

Defects are assigned to categories shown in Table 5.

Table 5: Defect Categories

Defect type	Alpha indexes	Digital indexes of categories of defects for safety, durability and carrying capacity				
		0	1	2	3	4
1	S	–	+	–	–	–
	C	–	–	+	–	–
	R	–	–	+	–	–
2	S	–	+	–	–	–
	C	–	–	+	–	–
	R	–	–	+	–	–

	S	–	+	–	–	+
3	C	–	–	+	–	+
	R	–	–	+	–	+
	S	–	–	+	–	–
4	C	–	–	+	–	–
	R	–	–	+	–	–
	S	–	–	+	–	–
5	C	+	–	–	–	–
	R	–	+	–	–	–

0 – non-essential defects;
1 – minor defects;
2 – significant defects;
3 – dangerous defects;
4 – critical defects.

S – on the traffic safety;
C – on the carrying capacity;
R – on the remaining resource.

Table 6 shows the classification of defects for maintainability.

Table 6: Repairability of Defects

Defect type	Digital defect index for maintainability P1	P2	P3	P4
1	–	+	–	–
2	–	–	+	–
3	–	–	+	–
4	–	+	–	–
5	+	–	–	–

P1 – easily removable defects, usually associated with deficiencies in the current content;
P2 − defects, the elimination of which does not require a special design study;
P3 − defects, the elimination of which is difficult. Elimination of such defects requires preliminary design work and is carried out during repair or major repairs;
P4 − irreparable defects, that is, such defects, the elimination of which is technically impossible or economically impractical.

3. Conclusions

In the process of inspection some defects were indentified that affect the bearing capacity of the construction: the destruction of the protective layer of concrete by separate segments; corrosion of reinforcemnt in load-bearing elements
with loss of cross-section up to 16,6%; corroison of concrete in load-bearing elements of type I and II; cracks in the crossbar with a width of opening up to 0,5 mm, which indicates the overstrain of the structure.
As a result of the carried out verification calculation, it is established that there is an overvoltage in the supporting part of the supporting span structures. In the designs, there are forces that lead to the formation of plastic hinges (cracks), which is confirmed by the results of visual inspection of structures. Consequently, an increase in the load on the bridge structure is impossible.
On the basis of full-scale surveys and numerical modeling of the state of the bridge structure, the following maximum load-carrying capacity of the structures is established:

- From a biaxial trolley with an axial load – 273 kN;
- From the evenly distributed load from vehicles – 9,66 kN/m2;
- From HK18 in the form of a four-axle trolley – 388, 08 kN.

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