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The road steel bridge over Bosut river in Serbia Part 1: The assessment of the bridge

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Abstract

Maintenance requirements for existing bridges outpace more and more available resources each day. Besides improved repair techniques, this situation emphasizes the need for a comprehensive approach to bridge management. An important activity in bridge maintenance is the inspection and assessment process, which includes determination of the general condition and structural safety of each bridge, as well as estimation of deterioration rates. Eventually, some idea of the structure repair can be determined. In this paper, the assessment of road steel bridge over Bosut river in Serbia was presented. During exploitation, numerous damages appeared on the bridge structural elements, mostly due to hundred years' old exploitation and inadequate maintenance of the bridge. In order to evaluate the real condition of the bridge structure and possibilities for further exploitation, the assessment of the bridge was carried out. The assessment included: detailed visual inspection of all accessible elements with registration of characteristic defects and damages, evaluation of incorporated materials quality, determination of the depth of cracks in the river piers and structural calculation according to current regulations for road bridges loads. Based on the results of both field and laboratory tests, it was concluded that the durability of bridge structure is significantly reduced, due to advanced corrosion process of steel material.

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1. Introduction

Bridges, including those on local roads, are integral elements of our highway systems. Despite their importance, however, they are often the most neglected components of the infrastructure. Demands on limited resources, especially competing roadway priorities for increased capacity and improved riding surfaces, too often result in deferred maintenance for bridges. The consequences are obvious - bridges are deteriorating far faster than they are being repaired. Without adequate attention, many require replacement or closure long before they are really obsolete, further adding to the demand for limited funds, impacting safety, and discouraging both users and transportation providers [1]. Thus, maintenance requirements for existing bridges outpace more and more available resources each day. Besides improved repair techniques, this situation emphasizes the need for a comprehensive approach to bridge management.

The paper presents the assessment of road steel bridge from the XIX century in Morovic, Serbia. The bridge was built in the first half of the twentieth century and it is used for road transport. The load bearing structure is made of steel, and the connections of the individual steel elements were made by rivets. The bridge has three fields, two massive river piers and two coastal supports. The appearance of the bridge is shown in Figure 1.

Fig. 1. Appearance of road steel bridge in Morovic

In the past period, numerous damages appeared on the steel structure of the bridge due to corrosion of steel material and macroscopic visual examination revealed damages in supporting zones. In order to check the possibilities for further exploitation of the bridge, and make eventual repair project, assessment of the load bearing steel structure of road bridge over the Bosut river in Morovic was carried out.

2. Basic data on the bridge

Steel road bridge over Bosut river in Morovic is designed for two-way road transport with the distance of 6.0 m between the main girders, pavement width of 4.5 m and two pedestrian paths width of 0.75 m. Bridge stands on four supports: two river pillars and two coastal pillars. The total length of the bridge is 119.10 m. Structure of the bridge was designed in a static system - gerber girders with the main truss girders with the span of 21.6 m + 56 m + 21.6 m, on whose endings main girders with width of 9.95 m are supported (joint connection) [2].

3. Detailed visual inspection of the bridge

As part of the assessment of the bridge, a detailed visual inspection of all accessible elements of the bridge structure was carried out.

3.1. Steel truss

Surface of the truss elements was coated with a protective anti-corrosive coating in a single layer. This coating is damaged and deteriorated on most of the elements, and restored in some parts of the individual elements. A detailed visual inspection of accessible elements of steel truss was observed and revealed the following types of damages:

- Surface spalling of protective layer,
- Spot corrosion,
- Surface corrosion;
- Delamination and spalling of steel due to corrosion, particularly in the joints of steel sheets,
- Swelling and expansion of steel profiles, especially in the lower parts of the elements due to water retention and a layer of moss between the steel sheets,
- The holes on the steel sheets due to corrosion, reduction of cross section of steel profiles,
- Vegetation.

The characteristic damages of the bridge structure are shown in Figures 2-7.

Fig. 2. Surface corrosion

Fig. 3. Delamination and spalling of steel due to corrosion, swelling and expansion of steel profiles

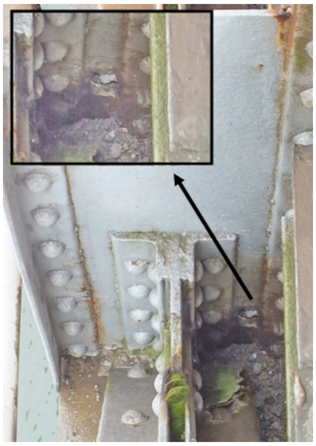

Fig. 4. Corrosion in the lower parts of the elements due to water retention and a layer of moss between the steel sheets, hole on the steel sheet

Fig. 5. Corrosion at the junction of main longitudinal and main transverse girder, reduction of cross section of steel profiles

Fig. 6. Appearance of transverze girder, corrosion in lower part of vertical steel sheet

Fig. 7. Appearance of the supporting zone, corrosion

3.2. River piers

River piers are built of brick and stone blocks. The dominant material for masonry is brick, while frontal parts, wreath below the supporting zone and the supporting zone of the upper structure of the bridge were made of stone blocks - cut stone. Visual examination of the pier showed following damages:

- Aslope cracks and horizontal crack (Figure 8),
- Rinsing of the mortar from the horizontal and vertical joints (Figure 8),
- Falling of brick parts (Figure 9),
- Salt crystallization (Figure 9),
- Biological corrosion – moss.

Fig. 8. River pier, cracks, mortar rinsing

Fig. 9. River pier, aslope crack, crushing and cracking of brick elements

In order to evaluate the quality of material that river piers were built of, core samples were taken out (Figs. 10 and 11). The mean value of apparent bulk density (bulk density of wet stone) amounts around 2070 kg/m^3, while mean value of stone compressive strength amounts 14.9 MPa. Based on obtained results, it was concluded that examined material is classified as medium heavy stone, according to bulk density, while, according to compressive strength, it is classified as stone with low compressive strength.

Fig. 10. Stone cylinders prepared for testing of compressive strength

Fig. 11. Brick's semi-cylinders prepared for testing the bulk density and water absorption

Water absorption was determined by using a gradually immersion method defined in SRPS B.B8.010. The mean value of ceramics' bulk density (bulk density of ceramics in the dry state) amounts around 1570 kg/m^3, while the mean value of its water absorption amounts around 22 %. Based on obtained results, it was concluded that examined bricks were made of terracotta - rough and porous ceramics.

4. The quality control of steel

Quality of steel, used for the bridge's upper structure was unknown. Therefore, subsequent determination of steel quality was performed, in order to conduct the control static and dynamic calculation and bridge condition evaluation in terms of its bearing capacity and stability. For this purpose, steel samples from individual steel structural elements were taken (Figures 12 and 13), and, later, examined in the laboratory.

Fig. 12. Extraction position of steel samples

Fig. 13. The appearance of cut steel samples

Macroscopic examination of steel samples showed that there are no severe corrosion or deformation of samples. Only surface rust was detected, as well as spot corrosion of local character. Mechanical properties of steel were determined on the standard specimens and results are given in Table 1.

Table 1. Mechanical properties of steel samples

Specimen	Modulus of elasticity E, GPa	Yield strength Re, MPa	Tensile strength Rm, MPa	Elongation A, %	Constriction Z, %
1S	204	272	350	35	69
2S	200	268	335	31	70
3S	201	283	324	34	59
4S	200	330	417	29	56
Average	201	288	356	32	63

Steel cut from the diagonal rod (sample 4S) suffered longitudinal crack propagation, occurred in the middle of the sample. Rest of the samples showed ductile fracture. Since the chemical composition was not determined, designation of structural steel can not be accurately given, but steel roughly corresponds to the S235 quality, according to its mechanical characteristics.

5. Evaluation of the condition of bridge structure

Based on analysis of data obtained by visual inspection of accessible elements of the steel road bridge structure, the results of field and laboratory tests, following was concluded:

- The durability of bridge structure is significantly reduced, due to advanced corrosion process of steel material, which in some segments of the construction is manifested by steel layering, rivets fallout, reducing the effective cross section of steel sheets, and even by complete "disappearance" of some sheets.
- This general condition of the bridge is the logical consequence of hundred years bridge exploitation, unfavorable shape of structural elements in terms of water influence and low temperatures and inadequate maintenance.
- Condition of bearings in the zones of coastal supports, cracks and crevices in one of the brick river piers, buckling of wing walls, followed by cracks and crevices and falling of its parts still does not directly threaten the bridge capacity and stability, but must be repaired to prevent further development of existing and appearance of additional damages.

It is necessary to immediately take appropriate measures, in order to bring the load bearing structure in a technically correct and functional condition, with satisfactory durability during future exploitation. Works on the rehabilitation and revitalization of the bridge structure include replacement of all parts of steel load bearing structure affected by severe corrosion processes, complete cleansing of the bridge structure from surface corrosion and protective coatings applications. Also, it is necessary to restore the function of bearings in the zones of coastal supports, to repair cracks formed in the river pier, and to eliminate cracked wing walls and to executed new ones.

6. FEM model of bridge structure

FEM modeling and numerical analysis of bridge's structure was performed by use of AxisVM® FEM software,. Mechanical properties of building materials were obtained by laboratory tests on proper specimens. FEM model comprehends:

- line beam FEs with 6 degrees of freedom (DOF) per joint for modeling of beams, columns and bars,
- surface shell FEs with 6 degrees of freedom (DOF) per joint for modeling of traffic slab and asphalt cover,
- special link FEs and support FEs with 6 degrees of freedom (DOF) per joint for modeling of interface and boundary conditions and
- steel material of "near to S235 quality" with modulus of elasticity of E_s=210 GPa, yield/failure limits f_y/f_u=235/360 MPa, density ρ_s=7850 kg/m^3 and asphalt concrete with E_a=5GPa and density ρ_a=2250 kg/m^3.

All joints and connections were treated as perfectly rigid and all supports and connections between segments of bridge were modelled as perfect cylindrical hinges. Between steel deck plate and asphalt cover was assumed a good bond. Numerical analysis and computation of bridge structure were performed for:

- self-weight (automatically defined) and permanent loads (defined by user) and
- traffic load according to our technical regulations (co-called V300 traffic scheme).

In the estimation of response of bridge's FEM model, following parameters were analyzed:

- stress state in the representative structural elements which are indicator of bearing capacity,
- dynamic characteristic as indicator of dynamic serviceability performance and
- displacements which could be influence on the serviceability state.

From the span/deflections ratio (Figure 14), it can be concluded that deflections are in the proper limits if spans are considered as distance from support zones. But if spans are treated as distance between discontinuities points of the deflections lines/areas, parts of the bridge which consist approach and cantilever structures don't satisfied requests of needed serviceability state.

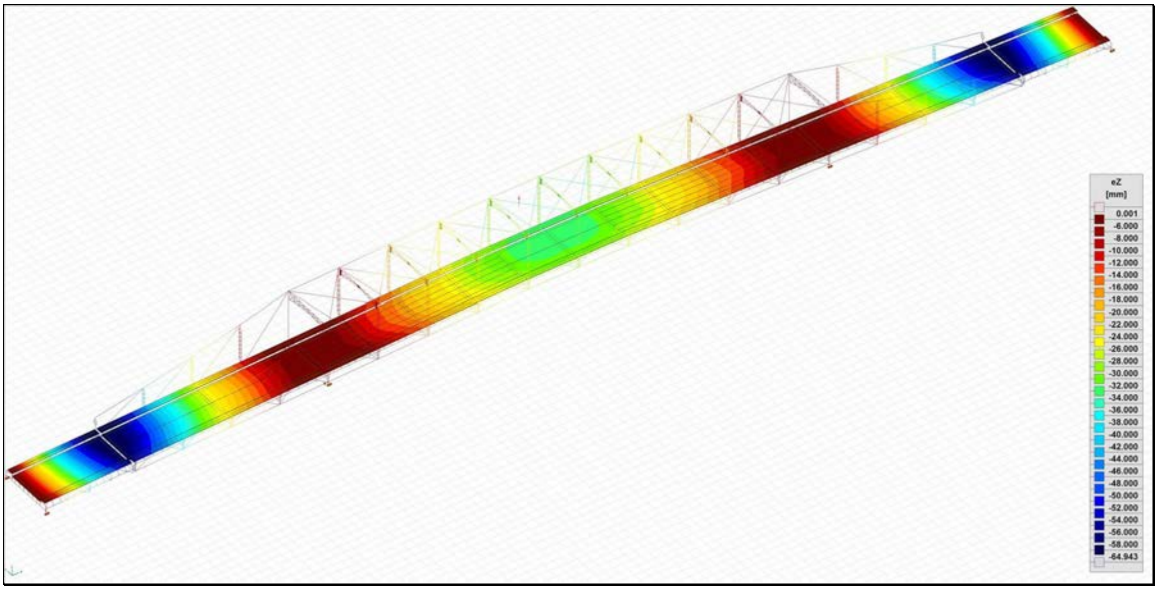

Fig. 14. Vertical displacements envelope (δ_{max}=-64.9mm)

Significant excess of stress limits as well as distribution of zones with these excess ($\sigma_{max/min}$ = -247.9 MPa+192.2 MPa) are indicative (Figure 15). These zones, between hinged joint of approach/cantilever connection and nearby column in the river, can be treated as critical according to criterion of need for rehabilitation or reconstruction. As this level of stress excess refers to permanent and traffic loads only (50 %), it is not necessary to check bearing capacity for other possible loads. In the next phase of project (rehabilitation and/or reconstruction) numerical analysis will be performed for these additional actions. Top and bottom chord members and web members (vertical and diagonal) of in the main span as well as deck plate had acceptable stress values.

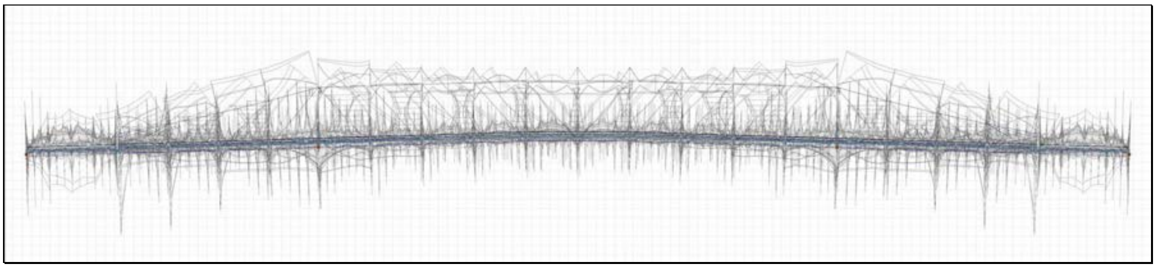

Fig. 15. Envelope of compression/tension axial stresses ($\sigma_{min/max}$=-247.9MPa/192.2MPa)

Range of frequency for the first six form of free vibrations (from 2.5 Hz to 5.5 Hz) designates to possibility of appearance of vibration beating which is unpleasant phenomenon for the fulfillment of a serviceability state especially in the case of pedestrian traffic (Figures 16-17).

Namely, hinged connection between approach and cantilever parts causes discontinuity in the angle of structural elements jointed in the hinge what could be cause of dynamical excitations (shock vibration) in the transition of heavy vehicles from the approach to cantilever. Also, this disagreeable phenomenon can be resolved by proper structural repair in the rehabilitation/reconstruction phase of this project.

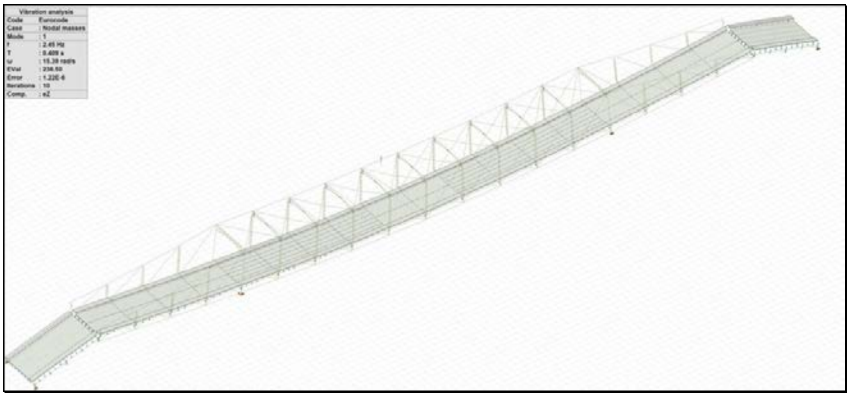

Fig. 16. First form of free vibrations (f_1=2.45Hz, T_1=0.41s)

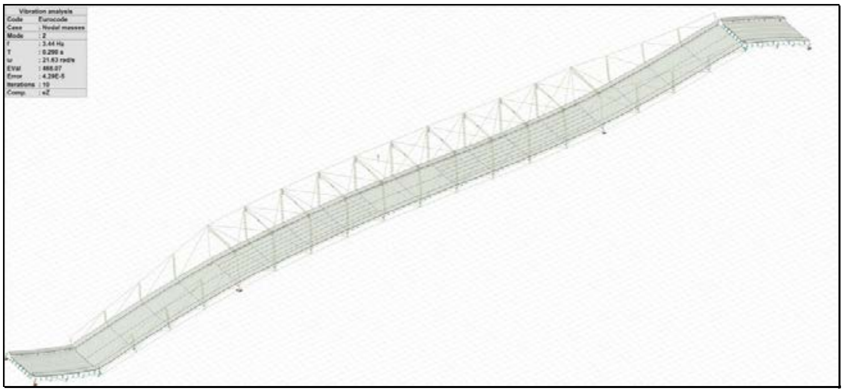

Fig. 17. Second form of free vibrations (f_1=3.44Hz, T_1=0.29s)

7. Conclusions

In order to bring the bridge bearing structure in a technically correct and functional state, with sufficient durability during future exploitation, it is necessary to urgently take the appropriate measures. These measures can be classified into two major groups of necessary works:

- Repair and revitalization of the bridge structure, which should include the replacement of all parts of the steel structures affected by severe corrosion processes, complete cleaning of the bridge structure from surface corrosion and protective coatings applications. Within this group of works, it is necessary to re-establish the function of rolling supports, to repair cracks formed on the river pier, to remove the cracked wing walls and build new, to remove dilapidated asphalt-concrete layer and brought a new driveway and to solve the problem of water drainage from the bridge.
- Strengthening of the bridge structure or changes of the structural static system, which would resolve the problem of exceeded stresses in some structural elements, as well as unfavorable dynamic characteristics of the bridge.

References

[1] Fundamentals of bridge maintenance and inspection, Office of Transportation Maintenance, New York (2008)
[2] V. Radonjanin, M. Malešev, Đ. Lađinović, D. Kovačević, R. Lekić, A. Rašeta, I. Lukić, S. (Vukoslavčević) Draganić, S. Šupić, Elaboration on the assessment of the load bearing structure of road steel bridge over river Bosut in Morovic, Department of Civil Engineering and Geodesy, Novi Sad (2015)