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Load testing of the Hercegovina bridge

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Abstract: The paper presents static and dynamic load testing of the Hercegovina bridge over the Neretva River. In addition to presenting the basic structural elements of the bridge, the paper briefly describes the testing method, and provides the basic characteristics of the equipment used for testing. The conducted tests included measurements of vertical displacements, strains and accelerations. Given the excessiveness of the testing, the paper presents the most important results, along with an analysis and comparison of the measured parameters. These procedures determined the static and dynamic characteristics of the constructed structure with the aim of assessing the quality of construction.

Key words: bridges, load testing, oscillation frequencies, displacements, strains, stresses

Ispitivanje probnim opterećenjem mosta Hercegovina

Sažetak: Članak prikazuje statičko i dinamičko ispitivanje probnim opterećenjem mosta Hercegovina preko rijeke Neretve. Uz prikaz osnovnih konstruktivnih elemenata mosta, u članku je ukratko opisan način ispitivanja te su date osnovne karakteristike primijenjene opreme korištene za ispitivanje. Provedena ispitivanja uključivala su mjerenje vertikalnih pomaka, deformacija i ubrzanja. Zbog obimnosti ispitivanja prikazani su najvažniji rezultati provedenog ispitivanja uz analizu i usporedbu izmjerenih parametara. Ovim postupcima određene su statičke i dinamičke karakteristike izvedene konstrukcije u cilju ocjene kvalitete izvedbe.

Ključne riječi: mostovi, ispitivanje probnim opterećenjem, frekvencije osciliranja, pomaci, deformacije, naprezanja

1. INTRODUCTION

The subject of this paper is a presentation of the results obtained from the load testing of the Hercegovina bridge. The bridge is located on Corridor Vc in the Počitelj-Bijača section (Figure 1). It crosses the Neretva river valley, the M17 highway and the railway line (Figure 2). The bridge was constructed by a consortium consisting of Azvirt Limited Liability Company (Azerbaijan), Sinohydro Corporation Limited (China) and Powerchina Roadbridge Group Co. Ltd. (China), while the subcontractor that carried out most of the works was Hering d.d. Široki Brijeg, Bosnia and Herzegovina [1].

According to the standard designated as U.M1.046 from 1984, derived from the JUS standard [2] which is applicable in Bosnia and Herzegovina, road bridges are subject to testing under static and dynamic loads. The effect of the test load must, to a certain extent, correspond to the effect of the moving load applied in the static analysis, in accordance with the specified standard.

Figure 1. - Bridge location on Corridor Vc

Figure 2. - Hercegovina bridge

In accordance with the applicable regulations, load testing of bridges is one of the requirements for technical inspection and issuance of an operating permit, and it applies to road bridges with spans greater than 15 meters and railway bridges with spans greater than 10 meters. The load testing of the Hercegovina bridge was carried out by staff of the Faculty of Civil Engineering, Architecture and Geodesy, University of Mostar. The testing determines the response of the structure to specific static and dynamic loads, as specified in the design [3].

2. DESCRIPTION OF THE BRIDGE STRUCTURE

The description of the bridge structure is based on the Technical Report for the bridge design, prepared by the company IPSA INSTITUT d.o.o. Sarajevo.

The bridge is classified as a prestressed concrete frame structure with 7 spans with a total length of 105.00 + (5 x 147.00) + 105.00 = 945.00 m. It was constructed using the free cantilever construction technology with in-situ concreting, employing a form traveler.

The heights of the piers are as follows: S1 = 92.00 m, S2 = 97.00 m, S3 = 92.00 m, S4 = 91.00 m, S5 = 88.00 m, S6 = 66.00 m (Figure 3). All piers are monolithically connected to the superstructure and are designed in the same way, from the top of the pier downward, with the highest constructed pier being S2 and the others shortened while retaining the same cross sections. The piers have a variable octagonal cross section in which the outer and inner haunches retain their height dimensions, while the intermediate parts vary. Pier S2 has the largest cross section at the bottom with external dimensions of 9.0 x 7.6 m, while pier S6 has the smallest, measuring 8.36 x 5.65 m. The pier walls are 0.6 m thick, except for the wall on the inside of the curve which is 0.8 m. Through the top four segments, the piers transition into a rectangular cross section that corresponds to the diaphragms and webs in the superstructure.

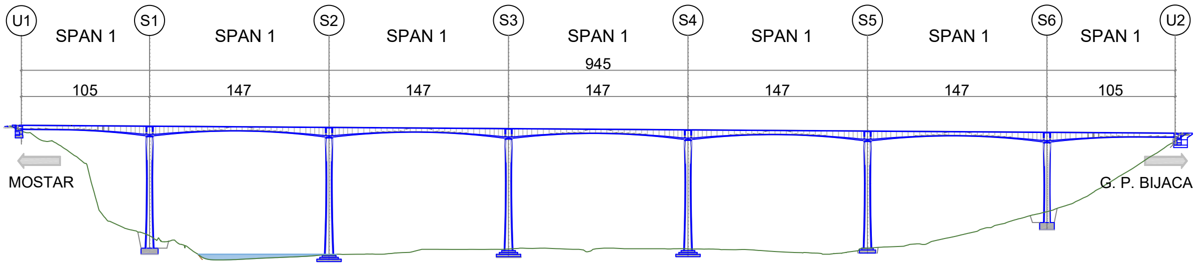

Figure 3. – Longitudinal section of the Hercegovina bridge

The superstructure is common to both highway directions and has a box cross section of variable height, which is 8.0 m over the piers and 3.6 m in midspan and in the continuous section near the abutment. The top slab is 21.92 m wide and has a variable thickness (0.25 m at the edge of the cantilever, 0.6 m at the connection with the web and 0.3 m in the middle of the slab). The webs are inclined and have a variable thickness, being the thickest at the pier at 0.8 m and tapering to 0.5 m. The bottom slab has a variable thickness, being the thickest at the pier at 1.2 m and tapering to 0.25 m, or 0.55 m in the haunches located at the webs. Since the webs are inclined, the bottom slab has a variable width. It is narrowest at the contact with the piers, measuring 7.0 m, and widest in midspan, measuring 10.0 m (Figure 4).

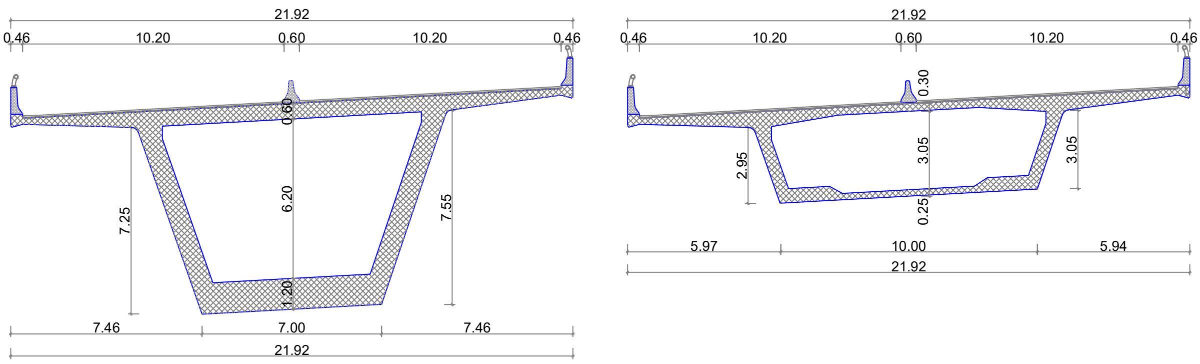

Figure 4. - Cross-section of the Hercegovina bridge (left at the pier, right in the span)

The structure is longitudinally and transversely prestressed with tendons made up of Y1860 steel strands. There are 86 prestressed tendons above each pier that are used for the construction phases (43 above each web). Continuity tendons are located in each span and are prestressed after the structure is connected. Spans 1 and 7 have 34, spans 2 and 6 have 44, and spans 3, 4, and 5 have 40 continuity tendons each (this also includes the tendons in the top slab that are prestressed after the connecting segment is completed). There are a total of 276 longitudinal prestressed continuity tendons. A total of 792 longitudinal prestressing tendons are installed in the bridge.

The middle piers are monolithically connected to the superstructure, while the superstructure is supported by bearings on the abutments. The superstructure is made of C45/55 concrete, the piers are made of C40/50 concrete (except for the initial segments which are made of C50/60 concrete), while the foundations are made of C30/37 concrete.

The bridge was designed using the DIN FB 101 and 102 regulations [5], as well as EN 1998 [6]. The calculations were performed using the SOFiSTiK computer program [7].

3. TESTING PROGRAM

The behavior of the structure under static and dynamic traffic loads, the conformity of construction quality with the design requirements, and the ability of the structure to bear the designed loads are verified by load testing of the bridges.

In accordance with the specified rules and standards, the effect of the test load must correspond to a certain extent to the effect of the moving load applied in the static analysis. Since the static analysis uses the standard loads given in the relevant standards for the calculation of road bridges, and heavy trucks are used for load testing, the number and mass of the trucks must be determined to obtain adequate internal forces.

According to the Testing Program, which was prepared and subsequently approved by the supervisory authority and the designer, the load testing was conducted using 10 heavy trucks, each with a mass of approximately 400 kN, positioned to induce maximum stresses in all spans (Phase I). For the load test above piers S2 and S3 (Phase II), the loading was carried out with 12 heavy trucks (Figure 5).

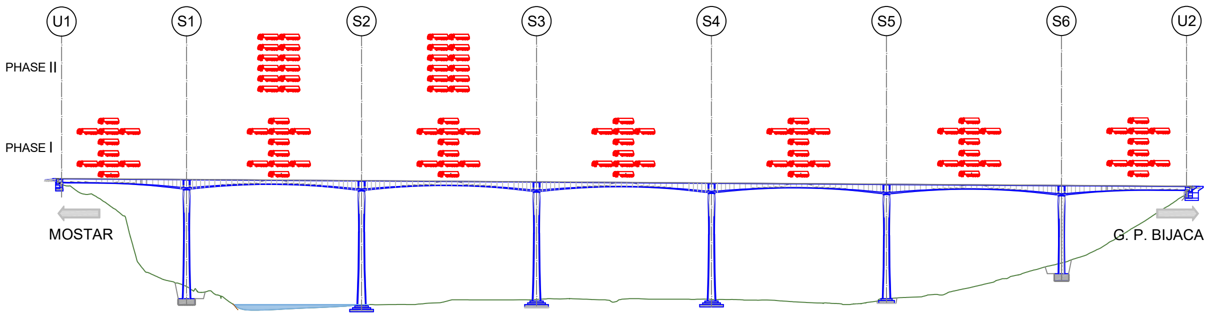

Figure 5. - Loading phases of the Hercegovina bridge

According to the rules and standards used, the efficiency coefficient is the ratio of the effect of the design load to the effect of the actual test load applied by heavy trucks, and it must be between 0.5 and 1.0, which is satisfied for the Hercegovina bridge according to the adopted Testing Program. Specifically, the efficiency coefficients were between 0.73 and 0.80, depending on the span, for measuring the effect in the bridge spans, while the efficiency coefficient for measuring the effect on the piers was 0.5.

4. LOCATIONS OF MEASUREMENT POINTS AND EQUIPMENT USED

4.1 Locations of measurement points

In accordance with the previously briefly described Testing Program, a load testing was conducted where vertical displacements were geodetically measured in all bridge spans (Figure 6) at three points across the width of the roadway (Figure 7).

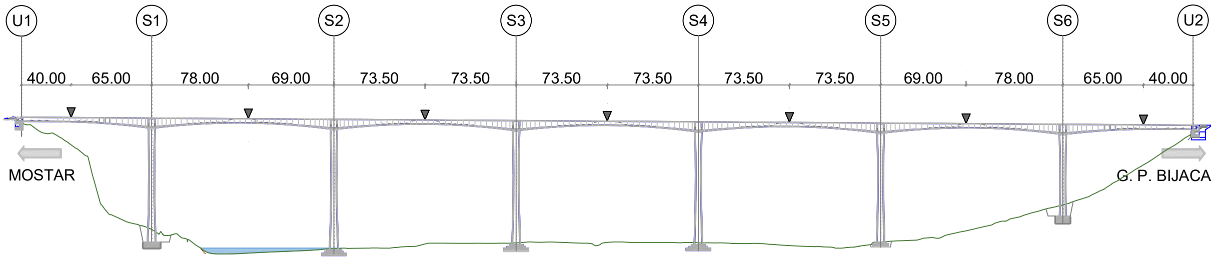

Figure 6. - Measurement points for measuring vertical displacements - longitudinal section

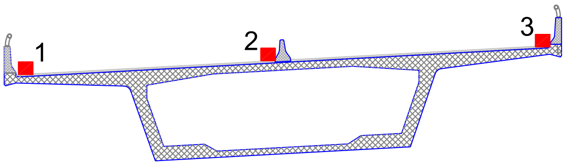

Figure 7. - Measurement points for measuring vertical displacements - cross section

In addition to vertical displacements measured in all bridge spans, strains were also measured using concrete and steel strain gauges in critical sections for spans 2, 3, and 4 and at piers S2 and S3 (Figure 8). Since the midspans are the critical points on the bridge, the vertical displacements were measured at these points except in the end spans where the critical points are slightly closer to the abutments. In the cross section, the arrangement of measurement points is dictated by the geometry of the cross section itself and the width of the bridge structure.

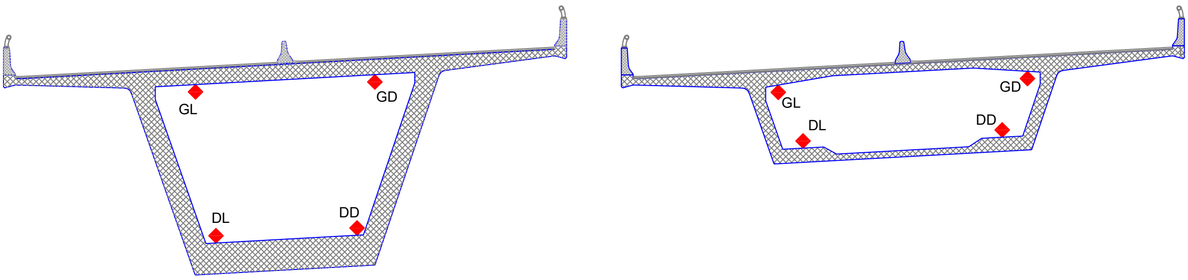

Figure 8. - Measurement points for measuring strains (left at the pier, right in the span)

4.2 Measurement equipment used

A total of 20 measurement locations were observed on the Hercegovina bridge, where strain gauges were installed on the concrete structure inside the bridge (Figure 9).

Figure 9. - Measurement equipment at the test site

For measuring strains, strain gauges manufactured by HBM, type K-LY411-15-120-0, were used (Figure 10).

Figure 10. - Strain gauges for concrete

Acceleration was measured using an acceleration transducer, specifically an HBM uniaxial accelerometer, type B12/500 (Figure 11a). The measured values were collected by the *MGC plus* system (Figure 11b) and were processed in the Catman AP software package.

a) Acceleration transducer

b) "MGC plus" device

Figure 11. - Measurement equipment used

5. RESULTS OF STATIC TESTS AND COMPARISON WITH CALCULATION

Static tests (Figure 12) were carried out according to the loading schemes presented in Chapter 3. The test results for vertical displacements and strains will be presented in the following text.

Figure 12. - Placing the load in position for static testing

5.1 Vertical displacements of the Hercegovina bridge

Vertical displacements were measured using geodetic instruments at three points in the bridge cross section, as shown in Chapter 4, with measurements taken before, during and after the application of the test load. The maximum values for the middle point are presented below (Figure 13).

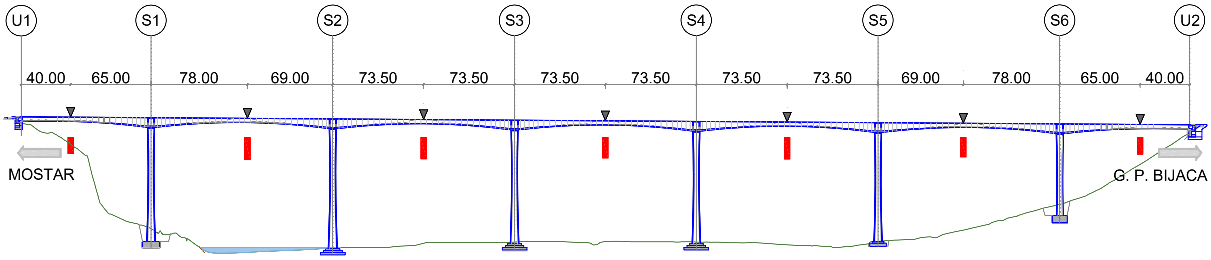

Figure 13. - Maximum vertical displacements in the middle of the roadway (mm)

The results obtained from the load testing (Table 1) were compared with the vertical displacements calculated using the SOFiSTiK software package (Figure 14).

Table 1. - Comparison of measured and calculated vertical displacements

		SPAN						
		1	**2**	**3**	4	**5**	**6**	**7**
MEASURED DISPLACEMENTS (mm)	1.	29.7	38.1	35.2	**38.2**	36.5	33.4	28.2
	2.	28.5	39.8	38.5	**36.8**	38.7	34.9	3.0
	3.	25.4	38.5	37.8	**34.5**	34.9	37.9	33.2
CALCULATED DISPLACEMENTS (mm)	1.	37.06	46.76	47.42	**47.09**	46.70	44.94	36.16
	2.	37.06	46.76	47.42	**47.09**	46.70	44.94	36.16
	3.	37.06	46.76	47.42	**47.09**	46.70	44.94	36.16

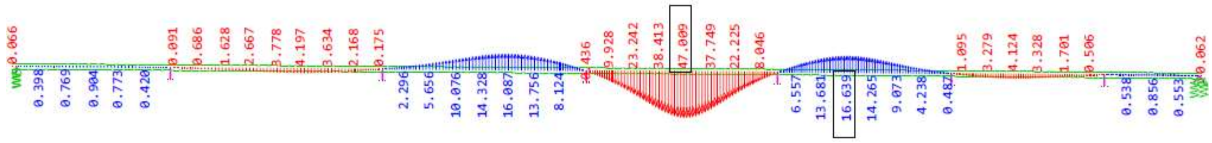

Figure 14. - Calculated displacements for span 4

By analyzing the results, it can be concluded that the measured values of vertical displacements are lower than the calculated values, which is a basic prerequisite for the structure to be in good technical condition.

5.2 Hercegovina bridge strains

The load test results are presented in tables and in diagrams obtained by processing the measured values in the Catman AP software package.

Given that the measured strains in concrete are within the linear-elastic range of concrete behavior, based on the known secant modulus of elasticity obtained from the Report on Control Tests of the Designed Concrete, the equivalent stresses in concrete were calculated using the following expression:

- Stress for concrete (C50/60): $\sigma=\varepsilon(‰)\cdot 37000(MPa)$

The strains in spans 2, 3, and 4 (Figures 15, 17, and 19), as well as the strains at piers S2 and S3 (Figures 21 and 23), were measured at four measurement points according to the scheme presented in Chapter 4. The labels used for the measurement points are: GL - top left, GD - top right, DL - bottom left, DD - bottom right. After analyzing the measured results, a comparison was made of the obtained stress values with the computational model developed in the SOFiSTiK software package for spans 2, 3, and 4 (Figures 16, 18, and 20) and for piers S2 and S3 (Figures 22 and 24).

5.2.1 Strains for span 2

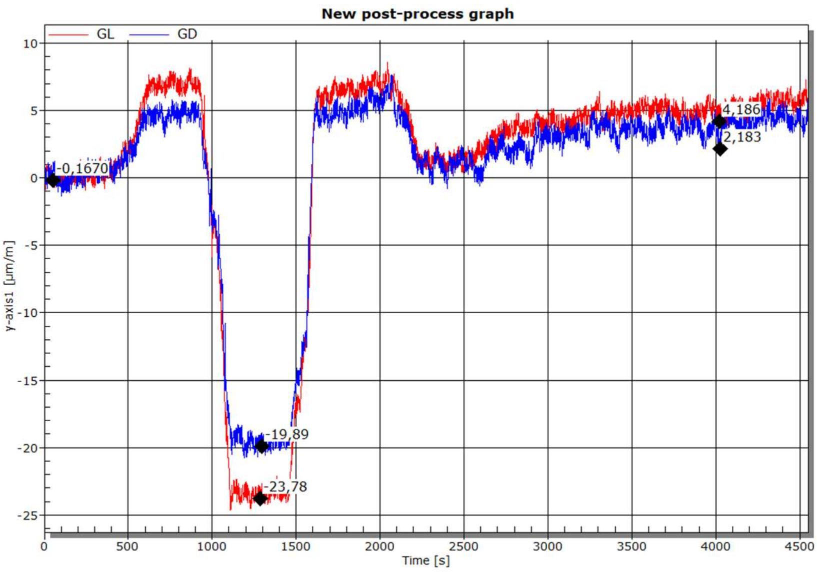

Figure 15. - Time history of strains for span 2

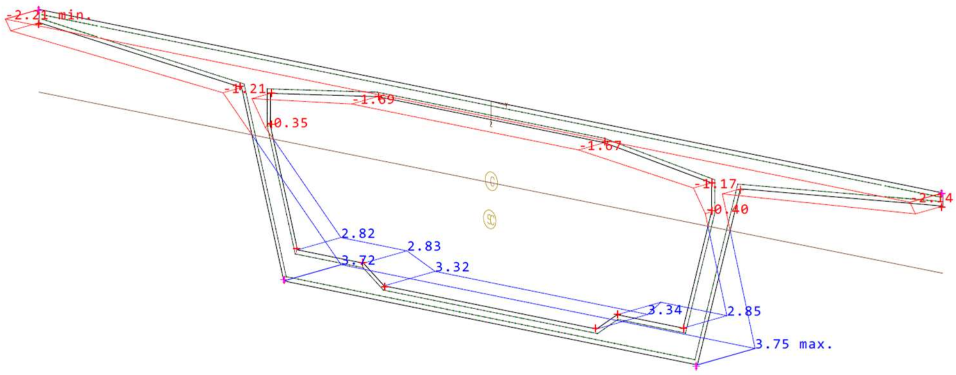

Figure 16. - Calculated stresses for span 2

Table 2. - Comparison of stresses for span 2

	GL	GD	DL	DD
Calculated stress (MPa)	-1.21	-1.17	+2.83	+2.85
Measured stress (MPa)	-0.73	-0.87	/	/

Due to damage to the strain gauges at points DL and DD, values for these measurement points could not be measured.

5.2.2 Strains for span 3

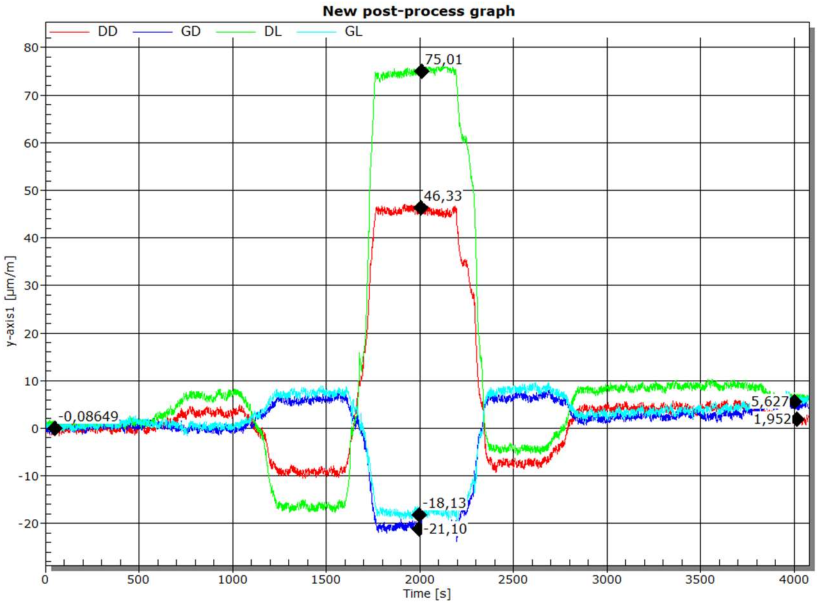

Figure 17. - Time history of strains for span 3

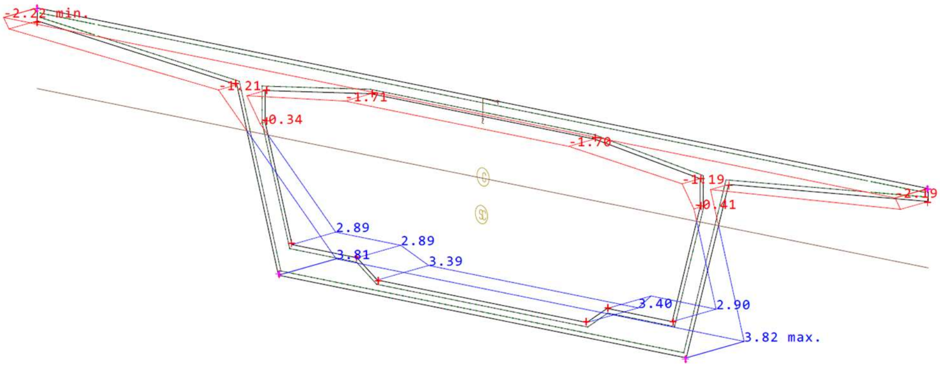

Figure 18. - Calculated stresses for span 3

Table 3. - Comparison of stresses for span 3

	GL	GD	DL	DD
Calculated stress (MPa)	-1.21	-1.19	+2.89	+2.90
Measured stress (MPa)	-0.66	-0.77	+2.77	+1.71

5.2.3 Strains for span 4

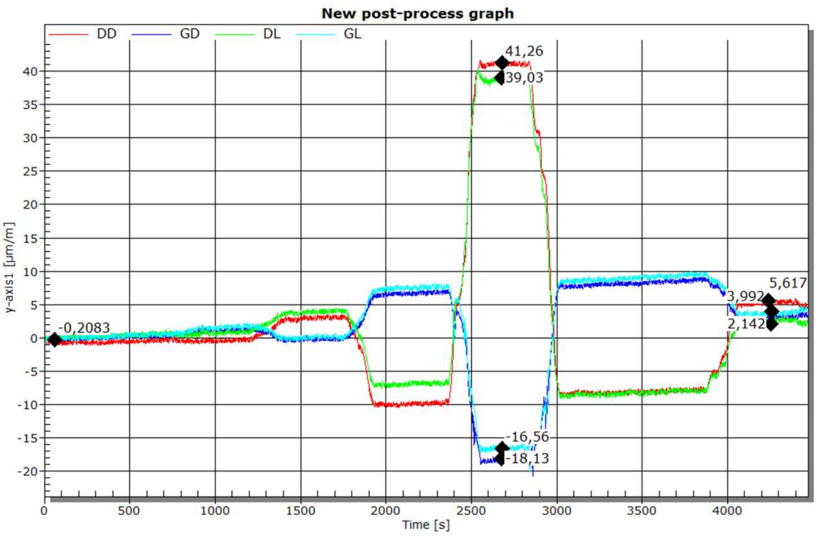

Figure 19. - Time history of strains for span 4

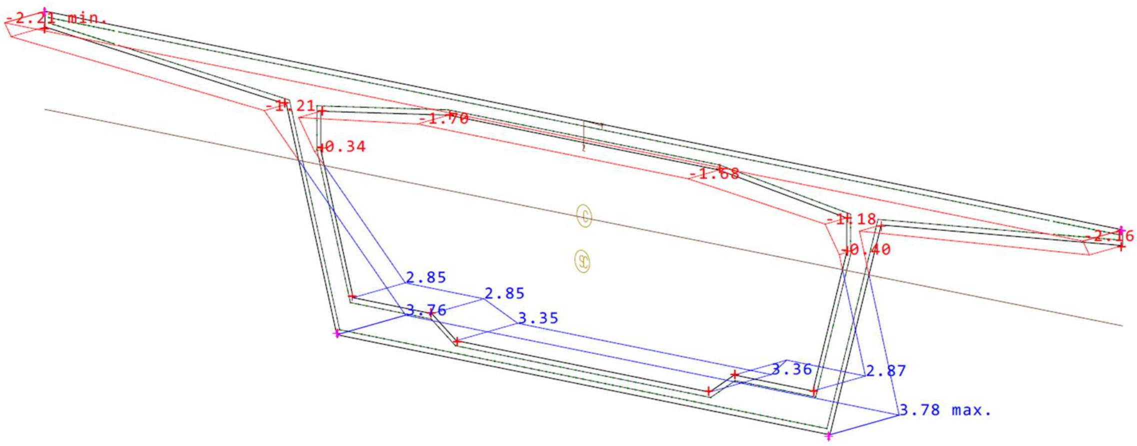

Figure 20. - Calculated stresses for span 4

Table 4. - Comparison of stresses for span 4

	GL	GD	DL	DD
Calculated stress (MPa)	-1.21	-1.18	+2.85	+2.87
Measured stress (MPa)	-0.60	-0.66	+1.36	+1.53

5.2.4 Strains at pier S2

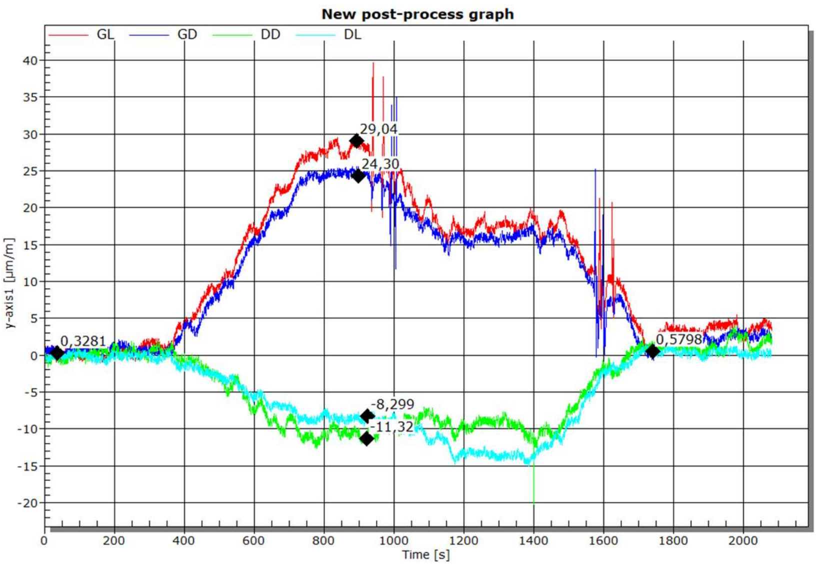

Figure 21. - Time history of strains at pier S2

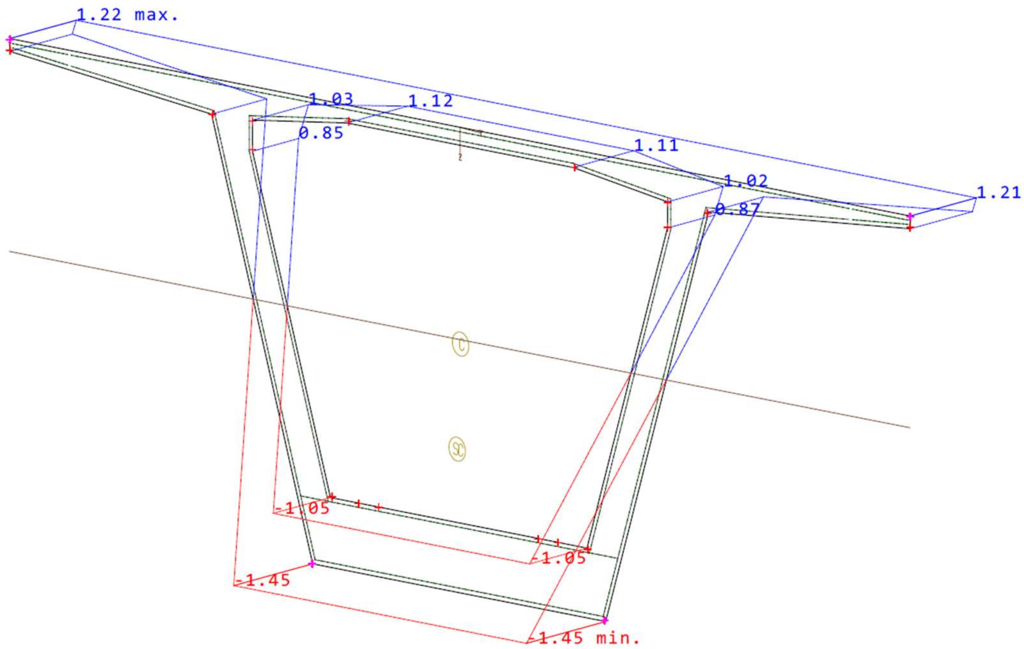

Figure 22. - Calculated stresses at pier S2

Table 5. - Comparison of stresses at pier S2

	GL	GD	DL	DD
Calculated stress (MPa)	+1.12	+1.11	-1.05	-1.05
Measured stress (MPa)	+1.06	+0.88	-0.31	-0.43

5.2.5 Strains at pier S3

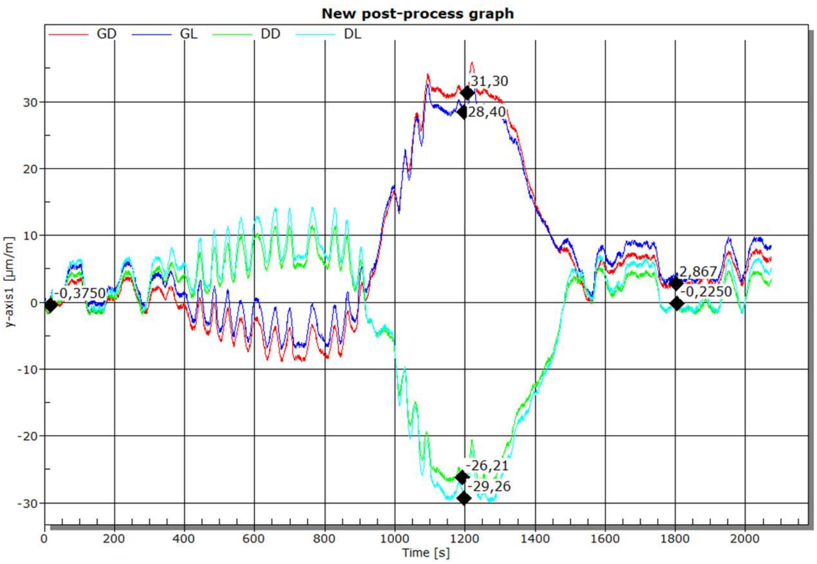

Figure 23. - Time history of strains at pier S3

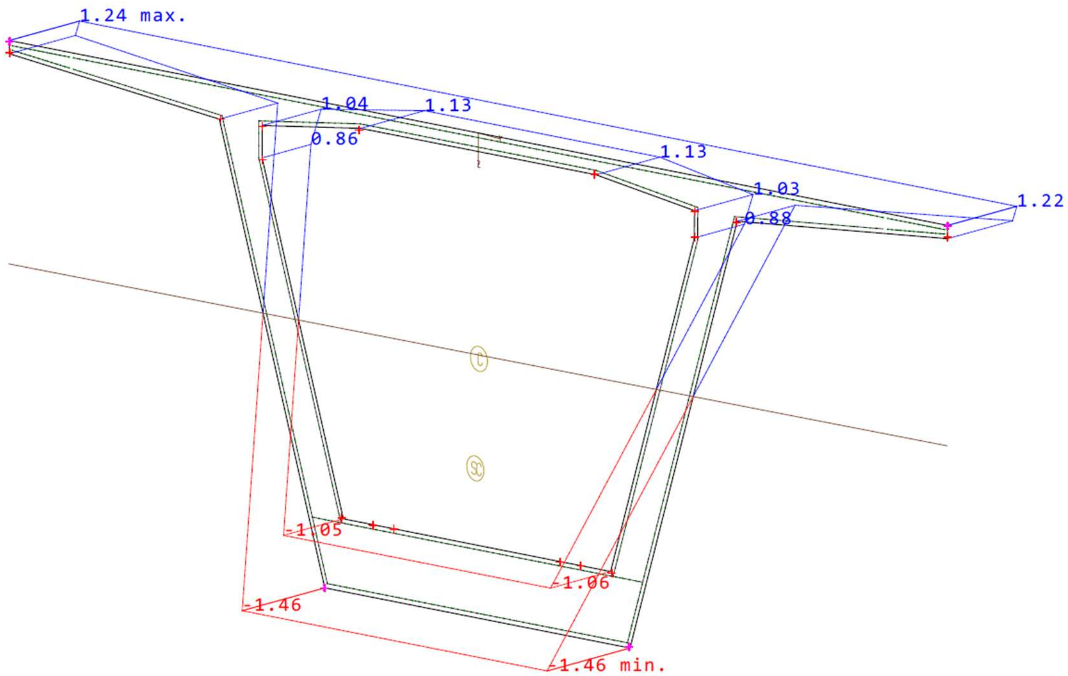

Figure 24. - Calculated stresses at pier S3

Table 6. - Comparison of stresses at pier S3

	GL	GD	DL	DD
Calculated stress (MPa)	+1.13	+1.13	-1.05	-1.06
Measured stress (MPa)	+1.06	+1.17	-0.95	-1.06

By analyzing the results, it can be concluded that the measured stress values for selected cross sections are lower than the calculated values, which also indicates that the structure is in good technical condition.

Figure 25. - Conducting load testing

6. RESULTS OF DYNAMIC TESTS AND COMPARISON WITH CALCULATION

The best indicators of the actual condition of the structure are dynamic parameters (i.e., the natural frequencies, damping and modal shapes) which are functions of global stiffness and any significant change will therefore result in a change in the values of dynamic parameters [8].

In the dynamic testing of the bridge, vertical accelerations induced by excitation with a vehicle traveling at approximately 30 km/h over a 5 cm thick wooden plank in span 4 were measured. This excitation was registered using an accelerometer, as shown in the attached diagram (Figure 26), and after processing the results, a diagram of the bridge oscillation frequencies was obtained (Figure 27).

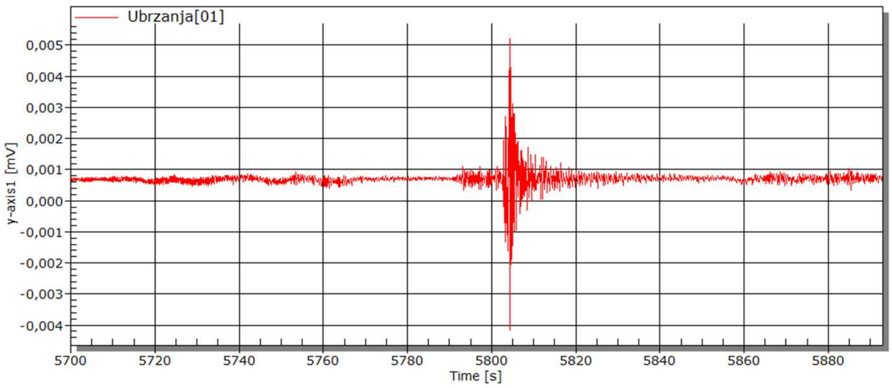

Figure 26. - Acceleration record obtained by the accelerometer

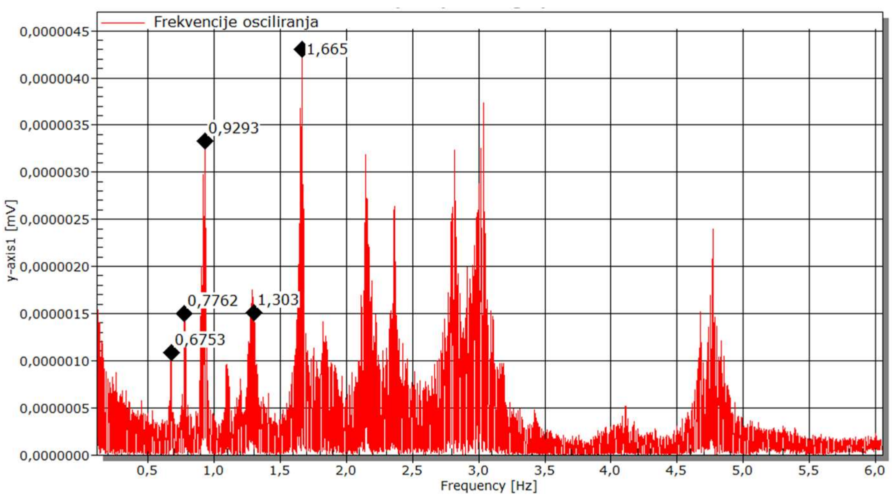

Figure 27. - Oscillation frequencies

Modal shapes of oscillation were determined using the computational model, also developed in SOFiSTiK (Figure 28). Based on the processing of the measured results, the oscillation frequencies of the bridge were determined and compared with the calculated values (Table 7).

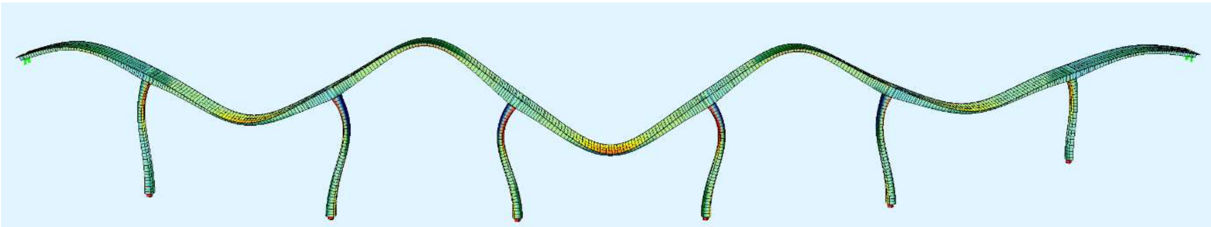

Figure 28. - First calculated modal shape of oscillation (T= 0.60 Hz)

Table 7. - Comparison of oscillation frequencies

Frequency /Hz/	Value 1	Value 2	Value 3	Value 4	Value 5
Calculated	0.60	0.72	0.87	1.19	1.79
Measured	0.67	0.77	0.92	1.30	1.66

By analyzing the obtained results, it can be concluded that the measured oscillation frequencies of the bridge are comparable to the calculated frequencies, and we can conclude that under these conditions the bridge behaves as a structure in proper technical condition.

7. CONCLUSION

To analyze the behavior of the Hercegovina bridge structure under static and dynamic traffic loads, load testing was performed. Load testing is conducted to verify compliance with the design, conformity of construction quality with the project requirements, and to assess the structure's ability to withstand the designed load. During the static and dynamic tests, the relevant static and dynamic parameters (displacements, strains, and natural frequencies) were experimentally determined and compared with the corresponding calculated values. The conducted analysis of the obtained parameters, both measured and calculated, established a high level of agreement for static and dynamic effects. This suggests that the bridge performs consistently with the design during its service state. With this procedure, the performance of the structure was verified, which is a prerequisite for the Hercegovina bridge to be put into operation.

8. REFERENCES

1. https://www.jpautoceste.ba/
2. JUS U.M1.046:1984 Pravilnik za ispitivanje mostova probnim opterećenjem, Sl.list 60/84
3. Rak, M.; Krolo, J.; Bartolac, M.: Ispitivanje i analiza parametara velikih lučnih mostova, Građevinar 62, pp. 913-920, Zagreb, 2010.
4. Biondić, H.: Probno opterećenje mostova, Ekscentar, No. 14, pp. 80-83, Zagreb, 2011.
5. DIN-Fachbericht 101:2009-03, Actions on bridges, Germany, 2009
6. EN 1998-1:2004 Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]
7. www.sofistik.com
8. Damjanović, D.; Herceg, Lj.; Duvnjak, I.: Dinamička ispitivanja zavješenih i visećih mostova, Građevinar 62 (2010) 10, 905-912