Assessment of bridges on the "Demir Kapija-Smokvica" motorway section on Pan-European Corridor X using loading test

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Key words: *assessment; prestressed bridges; loading test; static test; dynamic test*

ABSTRACT

This paper presents the results obtained by the loading test performed on 12 new bridges along the "Demir Kapija-Smokvica" motorway section on Pan-European Corridor X. Four (2x2) of them are simply supported post tensioned beams bridges and the other eight (4x2) are balanced cantilever. Static loading test was performed with a certain number of identical trucks applied in pre-defined positions. For the dynamic loading test, one truck, moving with different velocities, was used. The purpose of the loading test was to assess the quality of the newly built bridges by comparing the real behavior of the structures with the theoretical assumptions in the structural design.

Deflections as well as strains were measured at several measurement points of specific cross sections of the decks. The measurement was performed by deflect meters, however for the sections over the rivers a proper survey equipment was used. Strains were measured with strain gauges for concrete and data acquisition units DATALOG8. Acceleration time histories were recorded in a single cross section of the smallest span. Accelerometers of the type Digitexx D110-T with portable compatible data acquisition system were used. Estimation of the dynamic amplification factor was the main purpose of the dynamic loading test.

Prior the testing, structural finite element analysis of the bridges, using the actual loading test schemes, geometry and material data, was performed. This analysis defines the intensity of the gross-weight of the vehicles in order to obtain threshold values of internal forces and deflections within limits of 50 to 100% from the designed values. Analysis of the results shows good agreement between measured performance and numerically calculated values.

I. INTRODUCTION

Proof loading test on bridges intend to verify resistant capacity of a structure for major loads, demonstrate the possibility of an eventual load increase per truck axle or present structure capacity to resist loads on service conditions (Chahud et al., 2018). Worldwide, this type of loading test of bridges is not unified. In some countries, like Switzerland (Moses et al., 1994) and Italy (Veneziano et al., 1984), such tests are still required prior to opening (Lantsoght et al., 2017). However, in other countries these tests are not required, but there are many differences between the codes and guidelines provided in this field in each country. For example in Germany there is a guideline, Load test on concrete structures (DAfStb, 2000) while in the USA, ACI 437.2M-13 (ACI Committee 437, 2013).

The loading test of new bridges is a common practice in Republic of North Macedonia. According to the standard MKS U.M1.046 (which in meantime is replaced with MKS 1019:2018) road bridges with span larger than 15m must be tested with proof loading test. This loading test is obligatory not only for the newly built bridges, but also for the repaired and strengthened one.

In this paper emphasis is given on the loading test on 2 selected new bridges, one representing 4 simply supported post tensioned and the other 8 balanced cantilever bridges, built along the "Demir Kapija-Smokvica" motorway section on Pan-European Corridor X. Static and dynamic loading tests were performed in order to assess the quality of the newly built bridges by comparing the real behavior of the structures with the theoretical assumptions in the structural design. Structural finite element analysis of the bridges, using the actual loading test schemes, geometry and material data, was performed prior the testing. This analysis defines the intensity of the gross-weight and the numbers of the vehicles in order to obtain threshold values of internal forces and deflections within limits of 50 to 100% from the designed values.

The loading test of the bridges was organized and performed by the University “Ss. Cyril and Methodius”, Faculty of Civil Engineering – Skopje, Chair of concrete structures. The main design, as well as the structural analysis needed for the assessment of the bridges was done by “TTA S.A. Athens”, Greece with the finite element software SOFISTIK. The testing was made for the needs of the Client “AKTOR ADT GREECE-Subsidiary Skopje”, as a contractor of the bridges.

II. SELECTED BRIDGES

For the static loading test of the two selected bridges, four “MAN” trucks were used as trial traffic load, each of them by single gross-weight of 300.4kN. The loading test was done for four positions of the trial traffic load (load phases): half and full load asymmetrical and half and full load symmetrical. During the loading test, trucks were set in the most critical symmetrical and asymmetrical position of each span, shown in Fig. 2 and Fig. 8.

The measurements of the deflections were done in $1/4^{th}$, L_{crit} (or 1/2) and $3/4^{th}$ of each span, as well as at the beginning (L_0) and the end (L_1) of the span with two deflection meters type “STOPANI” (accuracy of 1/100mm). For the sections where these measurements were not possible, survey measurements with “Trimble Dini 03” (accuracy of 1/100mm) were performed by the company “Topometria dooel-Skopje”.

Strain gauges type Kyowa with a length of 120mm and accuracy of 1/1000mm were used for strain measurements for both bridges.

The dynamic loading test was performed with one truck moving through the smallest span of the bridges with four different truck velocities: V=10 / 20 / 30 / 40 [km/h]. Accelerometers of type Digitexx D110-T with portable compatible data acquisition system were used for the dynamic loading test.

Disposition of the measurement points for deflections and strains is presented in cross and longitudinal section in Fig. 1 and Fig.7, respectively.

A. *Balanced cantilever bridge B3 (right branch)*

1) General description: Bridge B3 at km.5+278.668 – km.5+753.668 (right branch) was designed as balanced cantilever five-span continuous bridge (64.59+3x114.27+64.59=471.99m) with segmental construction. The total width of the bridge is B=12.22m.

The superstructure of the bridge consists of box prestressed concrete girder with variable geometry along the bridge. The depth of the girder is 3.20m (3.96m in the outermost spans) in the middle of the span and increases to 7.20m at the supports. The thickness of the top slab of the box girder is 0.65m adjacent to the supports (piers) and 0.30m in the middle of the span. The bottom slab has 1m thickness near the supports approaching a value of 0.30m in the middle of the span. The girder webs have a thickness of 0.80m near the supports and 0.50m in the middle of the span. Characteristic cross-sections and longitudinal section of the bridge are shown in Fig. 1.

The substructure of the bridge consists of two abutments and four piers.

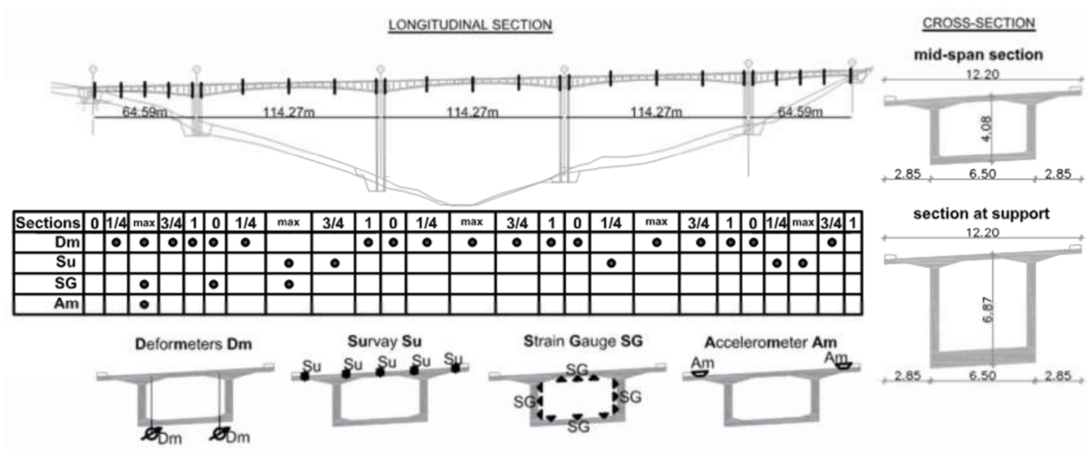
The abutments were designed as spill through abutments with parallel wing walls. The foundation type is pad foundation.

The piers are constructed as reinforced concrete separate columns with rectangular box cross-section. The foundation type is caisson (shafts).

According to the main design for the structural elements the following concrete classes were used:

- for bridge deck – C35/45
- for pier columns – C30/37
- for abutments – C20/25
- for caisson head – C30/37
- for caisson stem – C20/25.

For prestressing of the main girders steel with quality of σ_{02}/σ_m=1670/1860 MPa was used and S500 reinforcement was used in the girders, abutments, wing walls and foundations.



Sections	0	1/4	max	3/4	1	0	1/4	max	3/4	1	0	1/4	max	3/4	1	0	1/4	max	3/4	1	0	1/4	max	3/4	1
Dm		●	●	●	●	●	●			●	●	●	●	●	●	●		●	●	●	●			●	
Su								●	●								●					●	●		
SG			●			●		●																	
Am			●																						

Figure 1. Longitudinal and cross sections and disposition of measuring instruments

2) Specifics regarding the loading test: The measurements of the strains in concrete for this bridge were performed by 36 strain gauges, 12 of them set in the critical section of the first span, 12 at the support and 12 in the middle of the second span.

3) Selected results: In this paper only selected results for some cross sections are presented. For the static loading test, the deflections are presented for the critical section of the second span, where they were obtained by survey measurements. The deflections in the above-mentioned cross section are presented in Fig. 2, while longitudinally they are presented in Fig. 3.

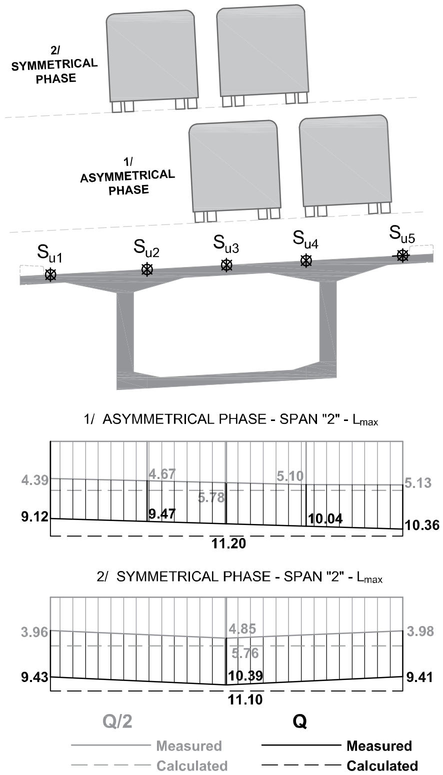


Figure 2. Measured vs. calculated deflections for the critical section of the 2nd span

Maximum deflection of 10.39 mm was measured for the symmetrical load phase in the middle of the box girder.

The strain distributions for the cross section at support (above first pier) are presented in Fig. 4.

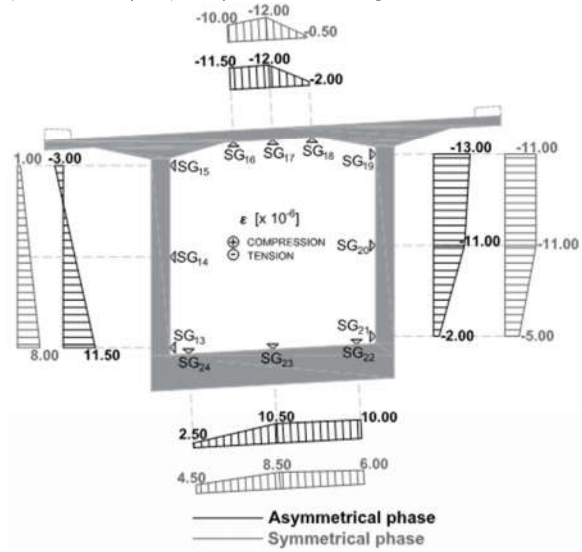


Figure 4. Measured strains for the critical section at support (above first pier)

Table 1 presents the comparison between measured and calculated stresses in the middle of the top and bottom slab, as well as in the webs of the box girder.

Table 1. Measured vs. calculated stresses

Section at support				
Meas. point	**Phase**	**strains ε [μs]**	**stresses σ_c [Mpa]**	
		Meas.	Meas.	Calc.
SG17	**Asym.**	-12.00	-0.408	-0.415
	Sym.	-12.00	-0.408	-0.415
SG23	**Asym.**	10.50	0.357	0.448
	Sym.	8.50	0.289	0.448
SG20	**Asym.**	-11.00	-0.374	/
	Sym.	-11.00	-0.374	/

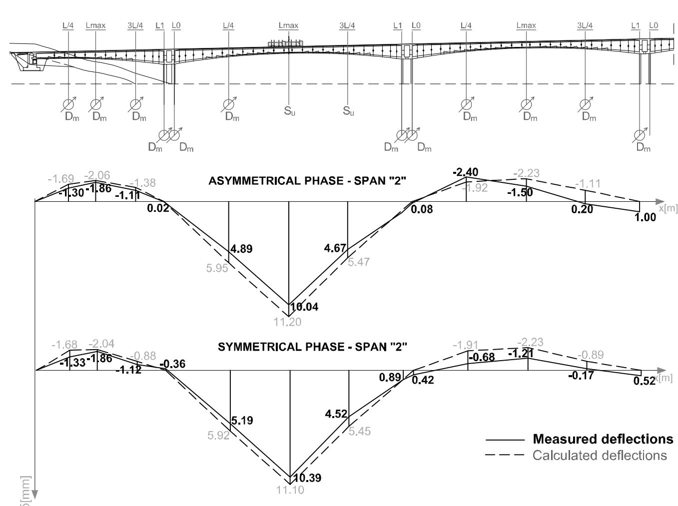


Figure 3. Measured vs. calculated deflections when live load is in 2nd span

Acceleration responses of the bridge structure were recorded for unloaded and loaded scenarios with triaxial acceleration sensors placed at two measurement locations (Am) per bridge (Fig.1).

The Dynamic Amplification Factor (DAF) was estimated as the ratio of the maximal dynamic response and maximal quasi-static response obtained by filtering the dynamic response (Fig.5). Towards this end, the recorded vertical acceleration time histories, corresponding to the four loaded cases (10 km/h to 40 km/h), were filtered with a low-pass digital filter.

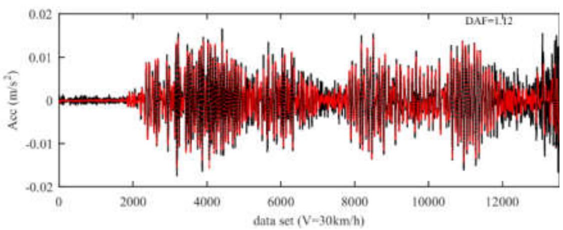


Figure 5. Dynamic (black) and static (red) response data for DAF estimation

The filter parameters are chosen as to "smooth-out" the dynamic components of the signal, hence the filter stop band frequency is selected in reference to the identified range of the first natural frequency.

The maximum experimentally obtained DAF for this bridge was 1.12, estimated for 30km/h velocity. Part of the measuring equipment is presented in Fig. 6.

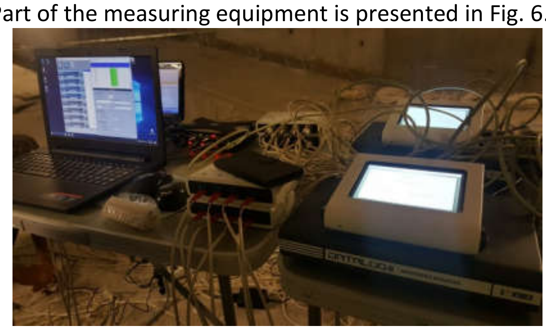


Figure 6. Part of the measuring equipment

B. *Post tensioned simple supported bridge B1 (Left branch)*

General description: The bridge at km.0+927.465 – km.1+058.339 (Left Branch) was designed and constructed as semi-prefabricated prestressed concrete structure with four spans (32.20+2x33.25+32.20=130.90m), system simple supported beam. The total width of the bridge is B=12.20m.

The superstructure of the bridge consists of 5 prefabricated prestressed concrete girders with „T" shape cross section (1.78m height) mounted on distance between them of 2.36m. Cast in place slab was placed above them with a depth of 0.25m. Longitudinal and characteristic cross-section of the bridge are shown in Fig. 7.

The substructure of the bridge consists of two abutments and three piers. The abutments were designed as spill through abutments with parallel wing walls and pad foundation. The piers are constructed as reinforced concrete separate columns with circular cross-section. The pier foundation type is piles.

According to the main design project for the structural elements, the following concrete classes were used:

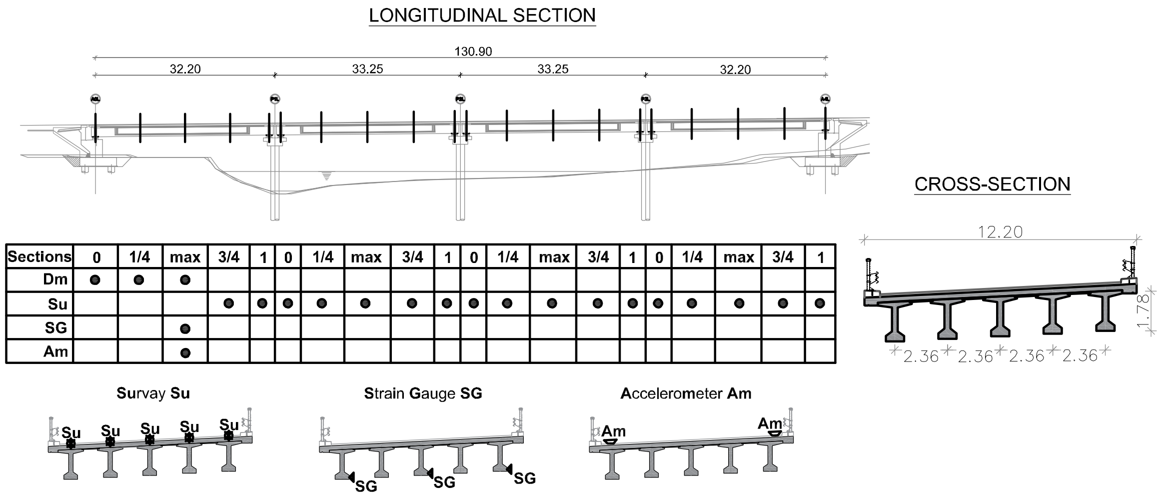
- for main prestressed girders – C35/45
- for bridge deck slab – C30/37
- for piers and pier head – C30/37
- for abutments – C25/30

For prestressing of the main girders, steel with quality of σ_{02}/σ_{m}=1670/1860 MPa was used and S500 reinforcement in the girders, cross girders, deck slab, cap beams, abutments, wing walls and the foundations.

2) Specifics regarding the loading test: The measurements of the strains in concrete were performed by 3 strain gauges set on the most left, middle and most right girder of the first span.

3) Selected results: For the static loading test, the deflections are presented only for the critical section of the first span, where they were measured with deflection meters due to the accessibility of the terrain. The measured deflections in the above-mentioned cross section for all four load phases are presented in Fig. 7 along with the calculated results. Fig.8 presents the comparison between measured and calculated deflections in each quarter of the considered span for the asymmetrical and symmetrical phase with full load intensity. Maximum deflection of 5.98 mm was measured in the asymmetrical load phase for the most right girder.

In each measuring point of each section, the calculated deflections are higher than the measured ones.



Sections	0	1/4	max	3/4	1	0	1/4	max	3/4	1	0	1/4	max	3/4	1	0	1/4	max	3/4	1
Dm	●	●	●																	
Su				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
SG			●																	
Am			●																	

Figure 7. Longitudinal and cross section and disposition of measuring instruments

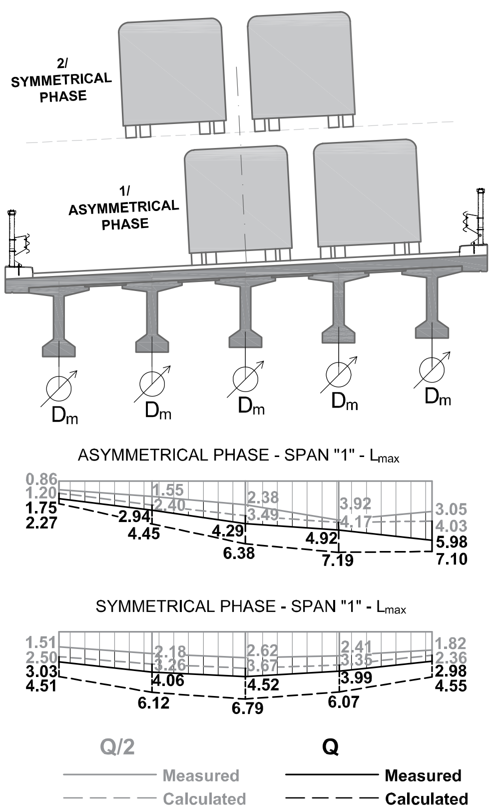


Figure 8. Measured vs. calculated deflections for the critical section of the 1st span

Table 2 presents the comparison between measured and calculated stresses in the most left (SG1), middle (SG2) and most right girder (SG3) in the first span of the bridge.

Maximum stress of 2.86 MPa in concrete was measured in the most right exterior girder for the asymmetrical position of the trucks. All measured stresses are less than the calculated ones.

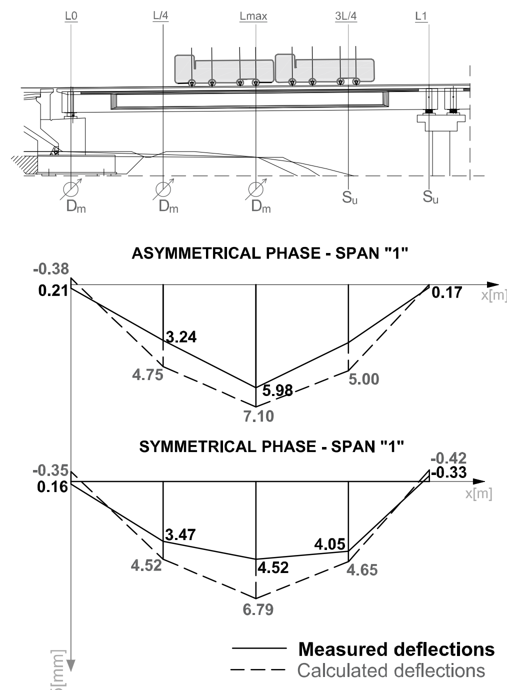


Figure 9. Measured vs. calculated deflections in each quarter of the 1st span

For each span and each load phase, residual plastic deflections and strains were less than 20% of the maximum measured one, which is the prescribed limit for residual deformation in the current standard for testing of prestressed concrete bridges.

Table 2. Measured vs. calculated stresses

Mid-span section				
Meas. point	**Phase**	**strains ε [μs]**	**stresses σ_c [Mpa]**	
		Meas.	Meas.	Calc.
SG1	**Asym.**	12	0.41	0.89
	Sym.	24	0.82	1.91
SG2	**Asym.**	74	2.52	2.91
	Sym.	60	2.04	3.17
SG3	**Asym.**	**84**	**2.86**	**3.07**
	Sym.	22.5	0.77	1.88

Acceleration responses of the bridge structure were recorded with triaxial acceleration sensors placed at two measurement locations (Am) as shown in Fig.7.

Vertical acceleration time histories were recorded for the four load cases (10km/h to 40km/h).

Dynamic (black) and static (red) response data used for estimation of the DAF are presented in Fig.10.

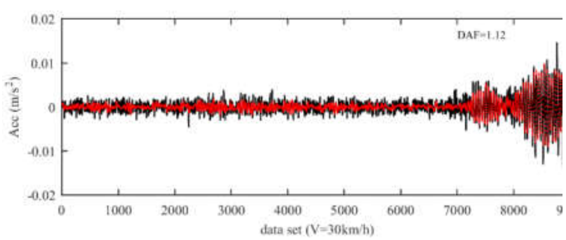


Figure 10. Dynamic (black) and static (red) response data for DAF estimation

The maximum experimentally obtained DAF for this bridge was 1.12 estimated for 30km/h velocity.

The estimated DAFs for each vehicle velocity are in good agreement with the calculated dynamic coefficient Φ used in the Main design.

The trucks used as live load for testing of bridge B1 are shown in Fig. 11.

Figure 11. Live load used for testing of bridge B1

III. CONCLUSION

Proof loading test of two groups of bridges, balanced cantilever and post-tensioned prestressed, with different topology along Demir Kapija – Smokvica motorway section is presented. From the very large collection of obtained data from many sections, in this paper only selected results are presented. For both presented bridges, the following can be addressed:

- Measured deflections, as well as stresses in concrete in the critical sections of each span for all four load phases are less than the calculated ones, which is required by the standard.
- Residual deflections and strains after unloading are less than 20% of the maximum measured, a value prescribed in the current standard for testing of prestressed concrete bridges.
- Estimated dynamic amplification factors from the dynamic test for all four velocities are in good agreement with the calculated dynamic amplification factor used in the Main design.

Analysis of the results show a good agreement between measured performance and numerically calculated values. Differences between them might be a consequence of:

- Imperfection in the methods considering the distribution of the loads in orthogonal direction,
- Imperfection in the calculation methods of the internal forces and deflections, based on the approximation in the structural system,
- Changing of the mechanical characteristics of the inbuilt materials with time.

Based on the results from the performed proof loading test and the theoretical results from the analysis of the 12 Bridges on Pan-European Corridor X, Demir Kapija – Smokvica motorway section, it can be concluded that the bridges are constructed with good quality which fulfilled safety and bearing design capacity criteria.

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