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VERIFICATION OF PRECAST CONCRETE GIRDER BRIDGE UNDER STATIC LOAD

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Abstract

Large-scale construction of transport infrastructure inevitably includes the construction of new bridges. During the design process, many assumptions and simplifications are taken into account. Therefore, the verification of the structural response of new bridges is necessary. One of the possible tests of structural response is a proof-load test which can detect certain problems of investigated structures. The paper introduces numerical and experimental analysis of the new bridge, which is located on Slovak Highway D1, section Hricovske Podhradie – Lietavska Lucka. The verified bridge is a four-span continuous structure with a total length of 129.4 m. The bridge is a representative of typical precast girder bridges adopted for construction of Slovak highways. The superstructure consists of eight post-tensioned precast I-beams. During a load test, predicted structural response was verified to check for any unusual behaviour. Finally, recorded data was summarised and report was distributed to all subcontractors and bridge owner. This information may help in further bridge management program.

Keywords:

Proof-load test;
Structural response;
Static load;
Assessment;
Bridge.

1 Introduction

Girder bridges built with precast concrete beams and a cast in-situ deck are a good alternative to cast in-situ bridges. The bridge structure with spans from 15.0 to 50.0 m is usually composed of several prestressed concrete beams. Small and medium spans are assembled from typical precast pre-tensioned or post-tensioned beams. During the developing process, prestressed beams became gradually higher and increased from 30 m to 50 m. Different beam section has been gradually developed in most countries in Europe. In France, the first document about precast bridges was published in 1973 by SETRA (French national design agency for roads and motorways). Precast prestressed beams have also been used for the construction of the rail bridge deck [1]. In Slovakia, typical beams of I or T-shaped sections are used for new highway bridges [2].

Higher quality and mechanized concreting in the precast factory represent the main advantages. Faster assembly and minimization of the wet process are other pros. The deck is concreted on the construction site. The bridge structure in the longitudinal direction can be composed of simply supported spans with a continuous slab or form of a continuous system, Fig. 1. In the first system, each beam at the ends is supported by a separate bearing [3]. Transmission of vertical loads acts as a statically determinate structure. However, horizontal actions are transferred as in a continuous structural system. To reduce maintenance, the number of bearings is minimalized. Today, continuous bridges are preferred. Precast beams are first placed on the precast or cast-in-place crossbeam and act as simply supported beams. After concreting their ends and reinforcement deck

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slab, the bridge behaves as a continuous structural system, Fig. 1. Therefore, it changes its static system during construction. The central row is usually accommodated two or more bearings.



Fig. 1: Detail over the pier: simply supported spans with continuous slab (left), full continuity (right).

The need for new bridges results in long procedures which include design, construction process, and subsequent service. Nowadays, designers have a lot of possible software for linear or even non-linear analysis [4, 5]. These programs are a useful tool for quick and effective analysis of the structures. However, their application requires the assumption of, for example, material and geometric properties which can differ from reality [6] where also the complex nature of concrete mechanics may play an essential role [7]. Therefore, the testing of the new structure is a very important part of the above-mentioned process which should be added between construction and service [8, 9].

1.1 General consideration of bridge load testing

Historically, both new and existing bridges have been verified by load tests. New bridges are verified using a proof load test. Load-carrying capacity is the main goal of all proof load tests [10]. Diagnostic load test is used to update an analytical model. Moreover, this type of test can be also performed in cases of structures that are in service for a certain time, but some problems were noticed by the administrator. The requirements for proof-load tests vary in different countries. Safety is crucial importance during a load test. In general, the applied static (or dynamic) load should sufficiently simulate the expected traffic on the investigated bridge. Experience from proof-load tests suggests that inadequate short-term behaviour under static load tests can lead to abnormal long-term performance, such as cracking or sagging [11, 12]. The measurements need to verify that no irreversible damage takes place. Criteria depend on construction type, material, and expected structural behaviour. The resistance after a successful proof load test is larger than the load effect caused by the applied load as shown in Fig. 2.

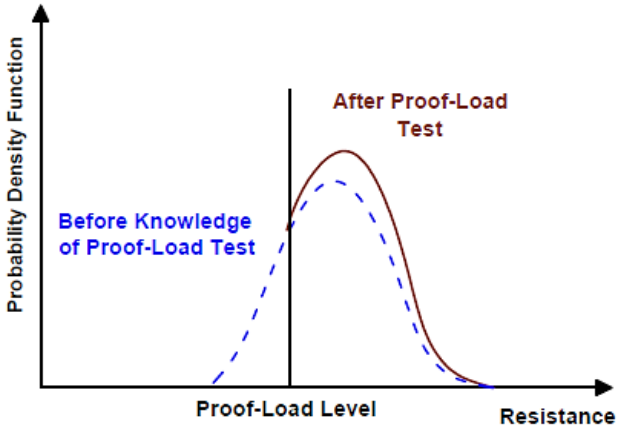


Fig. 2: Resistance after proof load test (Nowak and Tharmabala, 1998).

In France, quality control of a structure including load tests for all new bridges is required. Structural response to the calculations and model is verified. For bridges of less than 10 m (e.g. reinforced frame bridges), simplified load tests can be carried out. Contract with several bridges with a similar bridge type, same material, and bridge spans, at least 10 % of these structures, obviously at

least one has to be tested [1]. For bridges with a span length of more than 40 m special requirements are in place. Specific bridges with span lengths exceeding 200 m, cable-stayed or suspension bridges, and footbridges must undergo a test. When it is necessary to monitor all responses, the deflections, settlements of the supports, horizontal displacements at the supports, flexural rotations, strains, curvatures, and tension forces in hangers are measured. The applied load during a test is 75 % of the live load model. Different type of load is used for heavy convoys.

In Poland, the minimum span length for obligatory load testing according to Polish standards and technical standards is 20 m [13]. Bridges are tested under static and dynamic loads. Static load test includes measurement of deflection, support settlements, and compression of the bearings. In practice, stress or strain measurements are obligatory for large or untypical construction [14]. No nonlinear behaviour is permitted during the test. Residual deformations are verified. These are limited to 20 % of maximum deformation for reinforced concrete and 10 % for prestressed concrete bridges.

Slovak standard [15] requires that all bridges with lengths over 18.0 m should be subjected to a static proof-load test and bridges with a span over 45.0 m also to a dynamic proof-load test. Three acceptance criteria are based on the relationship between total S_{tot}, the permanent $S_{r,}$ and the elastic S_e deformation as follows (1):

$$S_{tot} = S_e + S_r. \tag{1}$$

For the choice of applied load, the so-called efficiency factor η is very important. The efficiency factor represents the ratio between the experimental value of observed elastic deformation S_e and the value which corresponds to the standards load model S_{cal}. The η - factor should be in the interval between 0.80 and 1.05 for prestressed bridges. Then, the first acceptance criterion for a load test is the condition of elastic deformation, for prestressed bridges is given as:

$$0.8 < \frac{Se}{S_{cal}} \leq 1.05. \tag{2}$$

The second acceptance criterion for the condition of permanent deformation for prestressed bridges is:

$$\frac{Sr}{S_{tot}} \leq 0.2, \tag{3}$$

where:
S_e - elastic deformation,
S_r - residual deformation,
S_{cal} - calculated deformation considering the appropriate load model,
S_{tot} – total deformation.

The third acceptance criterion is related to maximum crack width. For fully prestressed bridges, any crack can discover. Partially prestressed post-tensioned bridges allow a value of 0.1 mm.

When loading the bridge, the individual load cases are divided into stages (e.g. 25 - 50 - 75 - 100 % of the test load). The individual sub-stages serve to monitor the behaviour of the structure. Thus, no problems are not expected when the bridge is immediately fully loaded. Full load (or later unloading) must act on the concrete structure for at least 1 hour, or until the increment of the measured value during at least 5 minutes is less than 15 % of the last increment. Prior to and during the test, the appearance of cracks on the bridge structure is monitored. Cracks must not appear on prestressed structures. Proof-load tests belong to the group of so-called Structural response methods. These methods are based on the application of known external load to structure and subsequent observations of its response.

2 Bridge description

The tested bridge located on Slovak Highway D1, section Hričovské Podhradie – Lietavská Lúčka consists of two parallel bridges – left (LB) and right (RB), [15]. The structure of each of the bridges was designed as one dilatation part, from the static point of view representing a continuous system consisting of four spans with continuity between adjacent spans, see Fig. 3. Bridge spans measured in the bridge axis are the same 22.0 + 32.0 + 42.0 + 32.0 m (total length of 129.40 m), see Fig. 4.



Fig. 3: View on analysed precast girder bridge.

The structure consists of eight precast I-beams type DSP I/10 in the spacing of 1.78 m and height of 2.0 m and a deck slab with a minimum height of 0.22 m. Post-tensioned beams are made of concrete class C45/55 and connected to a reinforced concrete slab made of concrete class C30/37. Material properties are listed in Table 1.

The prestressing of the beams is provided by post-tensioned tendons, a type of ϕ 15.7 mm/1860. The total number of used tendons varies according to the length of the beams. The length of beams is 40.9 m; 31.7 m and 30.9 m, and they are composed of three individual elements which were delivered to a construction site individually. The width of the structure is 13.75 m (LB) and 13.6 m (RB). The plan of the bridge is arc-shaped with a radius of R = 1750.0 m. The bridge cross-section is shown in Fig. 5. Ideal cross-sectional parameters of precast beams (composite cross-section in the final stage) are listed in Table 2. The precast prestressed beams are placed on the cross beam on a pair of pot bearings. The substructure of the bridges consists of abutments and piers. The deep foundation was designed to take large uplift and lateral loads.

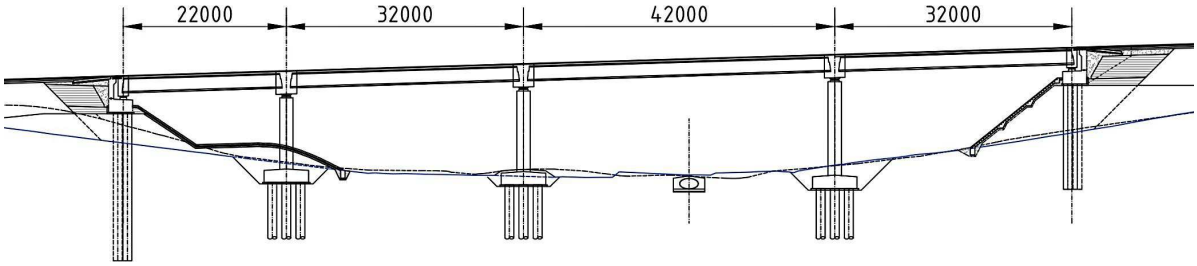


Fig. 4: Longitudinal section of the bridge [mm].

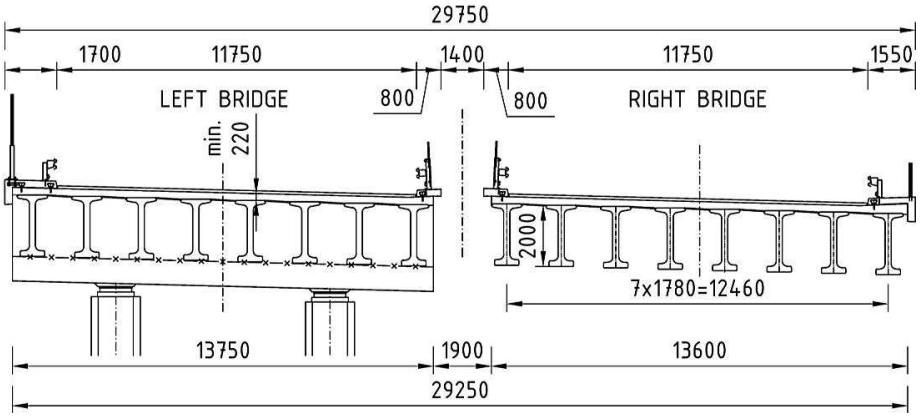


Fig. 5: Cross-section of the bridge [mm].

3 Experimental investigation

The static load test was performed by the Department of Structures and Bridges (University of Žilina) in collaboration with the Accredited Laboratory of Civil Engineering at the University of Žilina.

Experimental investigation of the right bridge consisted of numerical analysis and subsequent experimental measurement during the test. Finally, an evaluation of recorded data was done.

3.1 Numerical analysis

The numerical analysis was performed in software midas Civil. The structure of the right bridge was modelled in a straight line, but the elevation of the structure was neglected. The finite element model (FEM) of the bridge was created from 1D elements – beams set in axial distances of 7.0 x 1.78 m. The mutual interaction of the beams has been achieved by creating a grid, connecting the beams with 1D elements in the transversal direction. The cross-section consisted of eight atypical precast beams DSP I/10, 2.0 m high. The top flange is 920 mm wide and the bottom flange is 800 mm wide. The web is 200 mm. Ideal cross-sectional properties for the composite section are listed in Table 2. The beams were labelled from B1 to B8. They were numbered in ascending order from the outer edge of the structure towards the gap between bridges on the right side of the bridge. Fixed bearings were considered above support No. 3. Cross beams at the abutments were modelled as 1D elements with the following cross-section dimensions: width of 1.40 m; the height of 2.62 m. The cross beams above the piers were assigned these dimensions: a width of 2.80 m, and a height of 3.02 m. Material parameters of individual elements were considered according to requirements from the design of the structure. The numerical model is shown in Fig. 6.

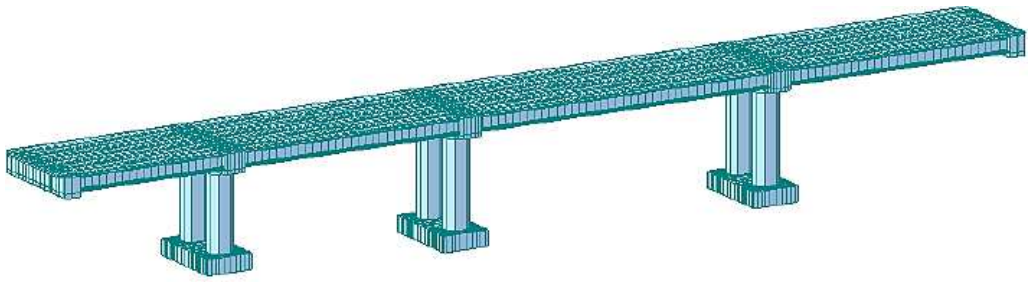


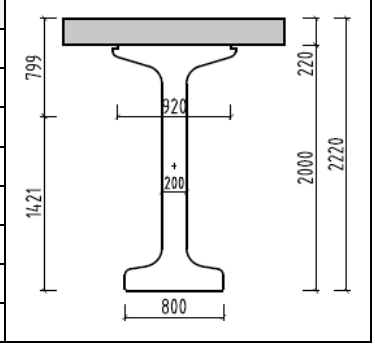
Fig. 6: FEM model of the bridge.

Table 1: Material parameters of I-beams and composite deck slab.

Material parameter of concrete		**I-beams (C45/55)**	**Deck slab (C30/37)**
Characteristic cylinder compressive strength	f_{ck} [MPa]	45.0	30.0
Characteristic cube compressive strength	$f_{ck,cube}$ [MPa]	55.0	37.0
Mean cylinder compressive strength	f_{cm} [MPa]	53.0	38.0
Mean tensile strength	f_{ctm} [MPa]	3.8	2.9
Elastic modulus	E_{cm} [GPa]	36.0	33.0

Table 2: Ideal cross-sectional parameters (composite cross-section).

Parameter		**Unit**	**Value**
Area	A	[m^2]	1.022
Shear area in principal direction “y”	A_{sy}	[m^2]	0.547
Shear area in principal direction “z”	A_{sz}	[m^2]	0.427
Position of neutral axis from top fibers	z (+)	[m]	0.799
Position of neutral axis from bottom fibers	z (-)	[m]	1.421
Second moment of inertia with respect to “x”	I_{xx}	[m^4]	0.026
Second moment of inertia with respect to “y”	I_{yy}	[m^4]	0.628
Moment of inertia with respect to “z”	I_{zz}	[m^4]	0.122



The numerical analysis provided expected values of deflections resulting from the standard load model and also test load in each investigated bridge span, see Fig. 7.

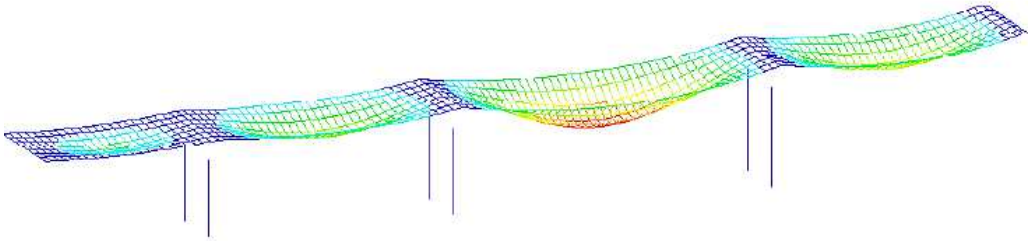


Fig. 7: Deflections due to the Test load in span No. 3.

3.2 Experimental program and discussion

The experimental measurement consisted of the measurement of deflections, settlement of the supports and temperature.

The measurement of beams' deflections in the mid-span of individual bridge spans was recorded using TR 50 linear displacement transducers owned by the department. The impact of the bearings' settlement was also measured using the same type of sensor. The setting of the supports was measured using Geodetic Surveying at the height of the horizon of the levelling device. In order to exclude the influence of the measured values by the settlement of the surroundings, measuring points were placed directly on the supports. During the proof-load test, the temperature of the bridge structure as well as the ambient temperature was recorded for proper evaluation of the measurement. In the case of the investigated bridge, all four spans were experimentally tested. Several options are available to apply the load. Load testing is mostly done by loading vehicles. Depending on the span length, three, four or six vehicles of 42.0 tons were required. The measurement of deflections was performed on beams B1; B4 and B8 in the mid-span area of each span of the bridge, see Fig. 8. The measurement points were installed at one line of the beam in the centre and at the edge. The transverse loading position which causes a maximum deflection in the central beam was placed on the axis of the structure in span no. 1 and span No. 4. The transverse loading position in span No. 2 and span No. 3 was applied to an off-axis to investigate the behaviour of the edge beam. The scheme of vehicles' layout during the proof-load test is presented in Fig. 9 and the view on the testing span No. 4 can be seen in Fig. 10.

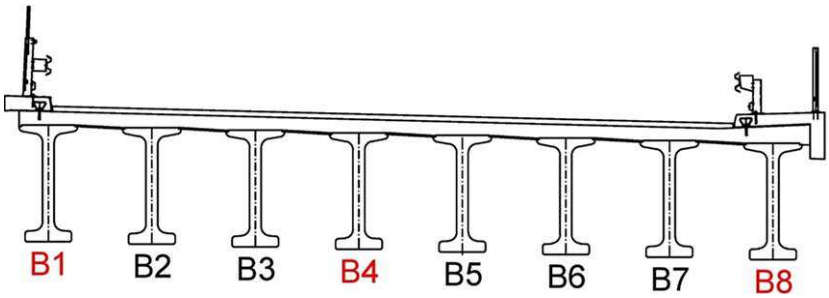
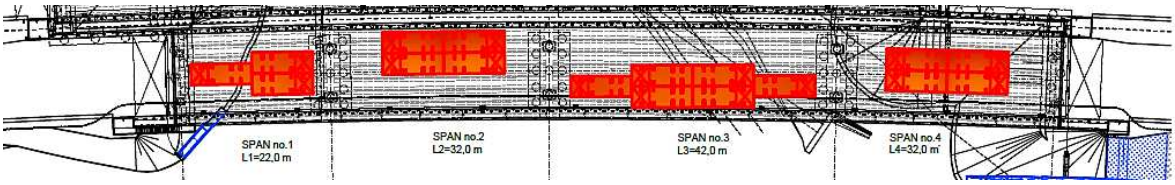


Fig. 8: Cross-section: Position of deflection measurements.



Span no.1 – 3 vehicles, Span no. 2 – 4 vehicles, Span no.3 – 6 vehicles, Span no.4 – 4 vehicles.

Fig. 9: Scheme of vehicles' layout.



Fig. 10: Proof-load test in Span No. 4.

The final step was the data gathering and evaluation of performed proof-load test based on the comparison of the experimentally obtained response and numerical analysis and updating the analytical model. The comparisons of vertical deflections are presented in Fig. 11. The bridge can carry predefined loads. The test confirmed assumptions regarding to the expected structural response determined prior to the test according to the acceptance criteria described in chapter 1. In all cases, the efficiency factor was higher than 0.8 and permanent deformation was less than the value of 0.2. No cracks were observed on the structure during the testing.

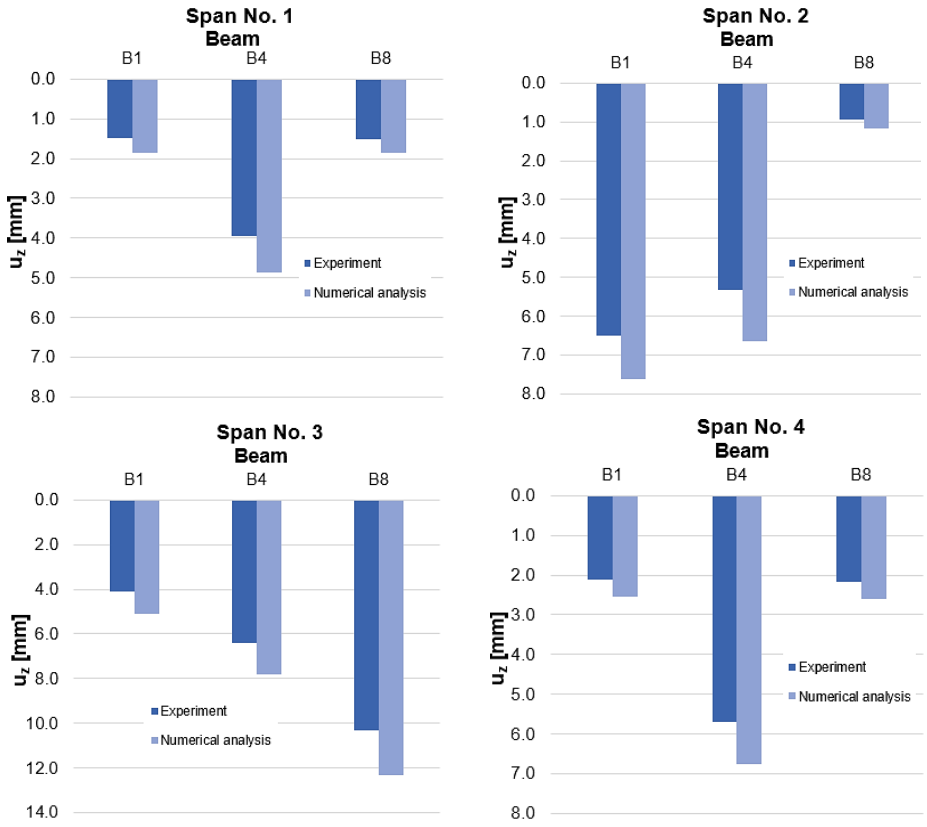


Fig. 11: Comparison of experiment and numerical analysis.

4 Conclusions

The structural behaviour of the new post-tensioned precast concrete bridge was verified under short-term loading during the proof-load test. This testing procedure was carefully arranged in advance. Very important was the choice of the type of response that was observed and the location of monitoring points in longitudinal, but also the transversal direction of the investigated structure. A static load test performed on the Slovak precast girder bridge fulfilled all acceptance criteria required

by standards for the load test of bridges. Neither cracking nor other signs of unusual effects were observed during testing.

Evaluation of new and existing structures is becoming a very important tool for further improvement in the design process, maintenance, and structural assessment. If some criteria are uncertain then additional inspection using non-destructive (NDT) methods or long-term monitoring of the bridge structure is needed. Many countries are currently working on revisions and updates of practice for load testing of bridges, both diagnostic and proof load tests. Examples and information from this and other real bridge testing and evaluation should be very beneficial and helpful for developing new guidelines.

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References

[1] Bridge testing guide. SETRA. Road Bridges and Footbridges, 2006, p. 164.
[2] BUJŇÁKOVÁ, P. – STRIEŠKA, M.: Development of precast concrete bridges during the last 50 years in Slovakia. Procedia Engineering, Vol. 192, 2017, pp. 75-79, https://doi.org/10.1016/j. proeng.2017. 06.013.
[3] Fib Bulletin No. 99: Conceptual Design of Precast Concrete Bridge Superstructures, technical Report. Fédération Internationale du Béton, 2021, 126 p.
[4] BUJŇÁK, J. – BUJŇÁKOVÁ, P. – JEDRASZAK, B.: Modelling and verification of bridge behaviour. MATEC Web of Conferences, Vol. 174, 2018, 10 p., https://doi.org/10.1051/matecconf/20181740 3002.
[5] BOUCHAIR, A. – BUJNAK, J. – DURATNA, P. – LACHAL, A.: Modeling of the Steel-Concrete Push-Out Test. Procedia Engineering, Vol. 40, 2012, pp. 102–107.
[6] KRAĽOVANEC, J. – MORAVČÍK, M. – JOŠT, J.: Analysis of Prestressing in Precast Prestressed Concrete Beams. Civil and Environmental Engineering, Vol. 17, Iss. 1, 2021, pp. 184-191, https://doi.org/10.2478/cee-2021-0019.
[7] PERKOWSKI, Z. – TATARA, K.: The Use of Dijkstra's Algorithm in Assessing the Correctness of Imaging Brittle Damage in Concrete Beams by Means of Ultrasonic Transmission Tomography. Materials, Vol. 13, Iss. 3, 2020, 37 p., https://doi.org/10.3390/ma13030551.
[8] VIČAN, J. – GOCÁL, J. – ODROBIŇÁK, J. – KOTEŠ, P.: Existing steel bridges evaluation. Civil and Environmental Engineering, Vol. 12, Iss. 2, 2016, pp. 103-110, https://doi.org/10.1515/cee-2016-0014.
[9] SŁOMKA-SŁUPIK, B. – PODWÓRNY, J. – GRYNKIEWICZ-BYLINA, B. – SALAMAK, M. – BARTOSZEK, B. – DRZYZGA, W. – MAKSARA, M.: Concrete Examination of 100-Year-Old Bridge Structure above the Kłodnica River Flowing through the Agglomeration of Upper Silesia in Gliwice: A Case Study. Materials, Vol. 14, Iss. 4, 2021, 32 p., https://doi.org/10.3390/ma14040981.
[10] VIČAN, J. – ODROBIŇÁK, J. – GOCÁL, J.: Determination of Road Bridge Load-Carrying Capacity. Civil and Environmental Engineering, Vol. 17, Iss. 1, 2021, pp. 286-297, DOI: 10.2478/ cee-2021-0030.
[11] LANTSOGHT, E. O. L. – VAN DER VEEN, C. – HODIJK, D. A. – DE BOER, A.: State/of/the art on load testing of concrete bridges. Engineering Structures, Vol. 150, 2017, pp. 231-241.
[12] SCHMIDT, J. W. – HALDING, P. S. – JENSEN, T. W – ENGELUND, S.: High magnitude loading of concrete bridges. Chapter SP-323-9 in Evaluation of concrete bridge behaviour through load testing - International perspectives. American Concrete Institute, 2018, pp. 9.1-9.20.
[13] PN–S–10040:1999 Bridge structures. Reinforced concrete and prestressed concrete structures. Requirements and tests (in Polish).
[14] FILAR, L. – KALUZA, J. – WAZOWSKI, M.: Bridge load test in Poland today and tomorrow: The standard and new ways in measuring and research to ensure transport safety. Procedia Engineering, Vol. 192, 2017, pp. 183-188.
[15] STN 73 6209/a: Loading test of Bridges. Praha, 1990.
[16] BUJŇÁK, J. – BUJŇÁKOVÁ, P.: Load test on Highway bridge at the highway construction D1 Hričovské Podhradie – Lietavská Lúčka. Technical Report. University of Žilina, 2018.