EXPERIENCES FROM STATIC PROOF-LOAD TESTS OF FIRST BRIDGES REINFORCED WITH GFRP REINFORCEMENT IN SLOVAKIA

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Abstract. *The proof-load tests are an integral part of verifying the actual behaviour of bridge objects. If a new bridge object is put into operation after construction, it is necessary to verify whether it will behave as it was supposed to when it was designed. In the case of existing bridge objects, it may happen that the bridge has malfunctions or behaves unconventionally due to failures - then there may be a need to reconstruct and strengthen the bridge object, and thus again there is a need to verify its behaviour using a proof-load test. The proof-load test can be static or dynamic. The aim of the paper is to point out the inevitability of the proof-load tests for the real and correct behaviour of bridge structures in ultimate limit state and maximum allowable deformations in serviceability limit states. It is necessary to point to the greatest consequences of resistance, reliability, durability and lifetime of the bridge structures. Using the proof-load tests for new bridges is prescribed by the Slovak standard STN 73 6209.*

Keywords

Proof-load test, bridge, GFRP reinforcement, real behaviour, deflection.

1. Introduction

Bridge objects are part of every transport route (roads or railways). Without bridge objects, these transport communications could not even exist, because they help to bridge various obstacles such as water courses (rivers, streams, etc.), other roads/railways, deep valleys, etc. [1,2]. By building up and putting the bridge into operation, the care about the bridge object does not end. Bridge administrator should perform the maintenance of the structure and, in addition, the supervision program. This means that the bridge administrator should perform regular inspections, detect possible defects and analyse their influence on reliability.

According to the standard STN 73 2031 [3], it follows that the tests serve for a one-time, or repeated verification of the quality parameters of selected properties of objects (including bridges), parts and structures based on the requirements of authorized state authorities. At the same time, this standard [3] defines that a construction, including a bridge object, is a complete, technically independent part of a construction serving a certain purpose. The bridge is used to transfer traffic on the bridge through the obstacle under the bridge. The construction is then divided according to purpose and materials.

The proof-load tests themselves are performed in accordance with the standard STN 73 6209 [4] - Loading tests of bridges, which implies the need to perform a proof-load test for new bridges. According to this standard, it follows that static proof-load tests should be performed either:

a) for permanent and long-term temporary bridge structures with a span greater than 18 m, or

b) for all bridge structures, as long as it was ordered by the designer or investor - so it also applies to shorter spans of less than 18 m.

The proof-load tests have to be carried out to detect defects prior to putting the bridge into operation [5-12]. Basically, it is an experimental verification of the real behaviour of a bridge structure in order to detect the visible and hidden defects that could limit or disable the operation of the bridge.

The paper deals with the proof-load test of two short bridge structures built in the city Senica. These are two footbridges for pedestrians and cyclists denoted as SO-02.1 and SO-02.2 on the cycling route “railway station –

Sotina". The spans of the footbridges are not greater than 18.0 m, but the main reinforcement in the transverse direction is GFRP bars (GFRP – Galss Fiber Reinforced Polymer), therefore the designer ordered a proof-load test to be carried out before using the footbridges in order to verify their behaviour.

2. Description of bridge objects

As already above mentioned, both bridge structures were built in the city Senica, Slovakia, on the newly built bicycle route "railway station - Sotina". These are slab bridges that are reinforced in the longitudinal direction with prestressing steel - cables. The use of GFRP reinforcement as the main reinforcement in the transverse direction is interesting. These are the first two bridge structures reinforced with GFRP reinforcement in Slovakia.

2.1. Bridge object SO-02.1

The footbridge is located on the local pedestrian road, in the city park. The footbridge bridges over the river Teplica. The route on the bridge is direct. The vertical alignment is max. 11% (average 6%) – in the height curve R = 62.95 m. The footbridge is located in the inner city of Senica. The area around the footbridge is mainly the river-basin of the river Teplica. The footbridge is perpendicular to the river.

The bridging is solved by a monolithic prestressed slab single-span bridge with a length span of 14.0 m in one expansion unit (simple span) - basic dimensions are shown in fig. 1. It is an additionally prestressed, monolithic, straight-strip construction, made using the technology of concreting on a fixed formwork. The cross-section of the bridge is slab with cantilevers, the maximum height of the cross-section is 0.45 m in the middle part. The transverse slope of the bridge is two-sided 2.0%. The side cantilevers of the bridge in the cross-section are narrowed to 80 mm (from 450 mm), which could be achieved by using GFRP reinforcement (with tensile strength 1000MPa) in this part of the structure using minimal concrete cover layer. The prestressing steel is designed from five 12-strand cables Ls 15.5/1800 - LSA with low relaxation.

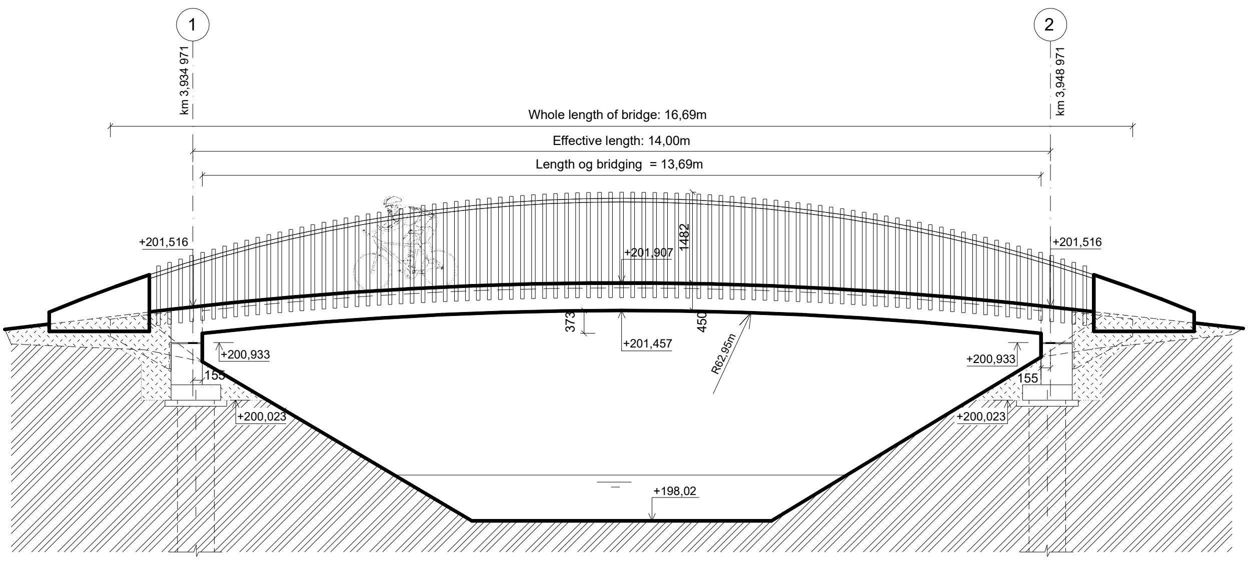
The substructure is made of reinforced concrete abutments - the side wings are part of the cross member of the superstructure. The embankment behind the support is solved with a reinforced embankment with a slope of 1:1. The requirement of minimum intervention in the flow profile of the river determined the position of the abutments and thus the length of the bridge. The supports of the bridge are based in construction pits on piles with a diameter of 600 mm.

2.2. Bridge object SO-02.2

The footbridge is located on the same local pedestrian road, but in a different part of the city. The footbridge is located on a local pedestrian road near the Tesco department store in the city of Senica. The footbridge bridges the Rovenský stream. The route on the bridge is direct. The elevation is max. 9% (average 5%) – in the height curve R = 62.95 m. The bridge is not perpendicular to the stream, the crossing angle is 73°.

The bridging is solved by a monolithic prestressed plate single-span bridge with a span of 11.0 m in one expansion unit (simple span). It means that this footbridge is shorter then footbridge SO-02.1. The shape of the cross-section and the other dimensions, including reinforcement (prestressing cables and GFRP transverse reinforcement), are identical to those of object SO-02.1.

The solution of the substructure is also identical (see fig. 2).



a)

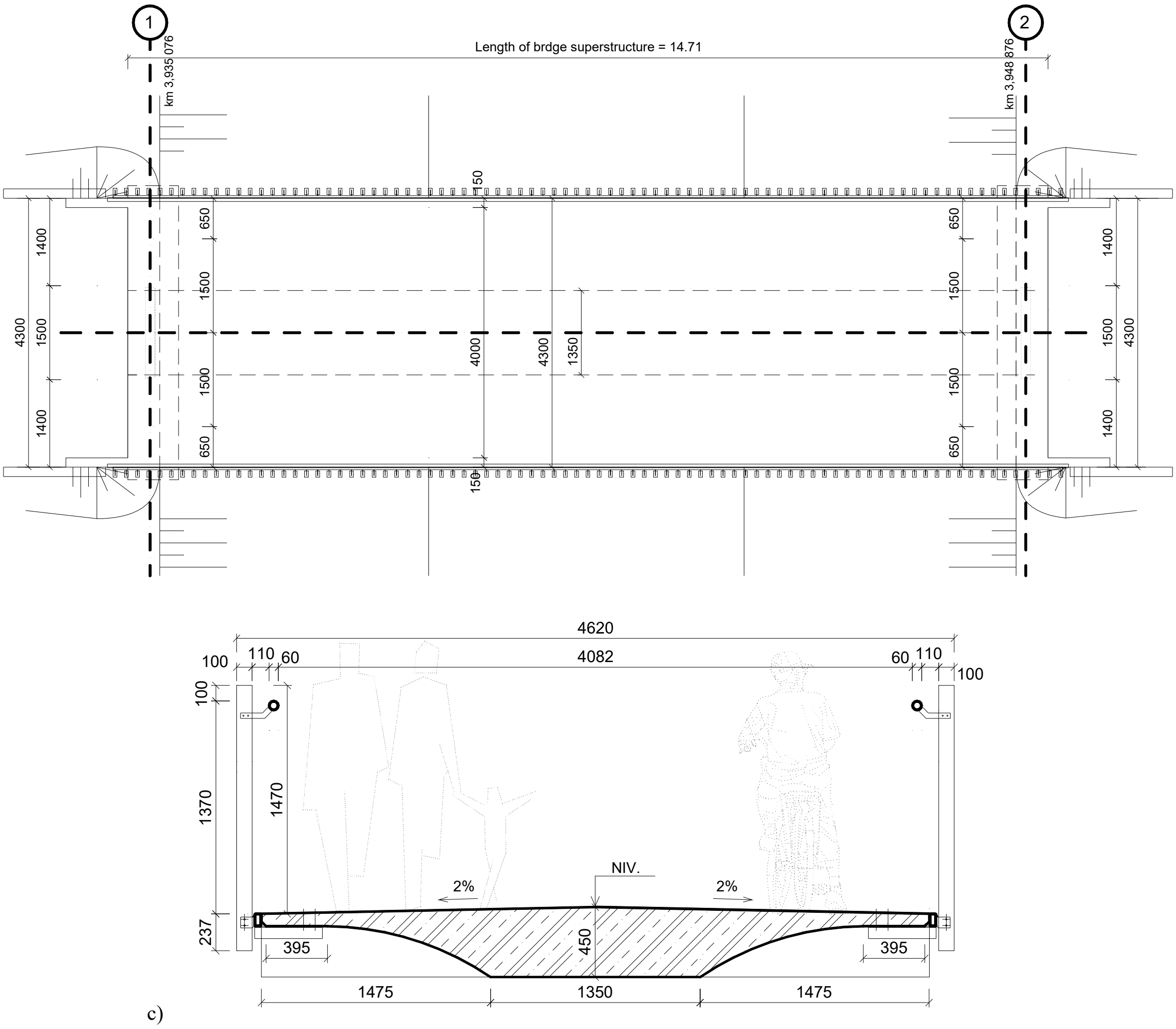
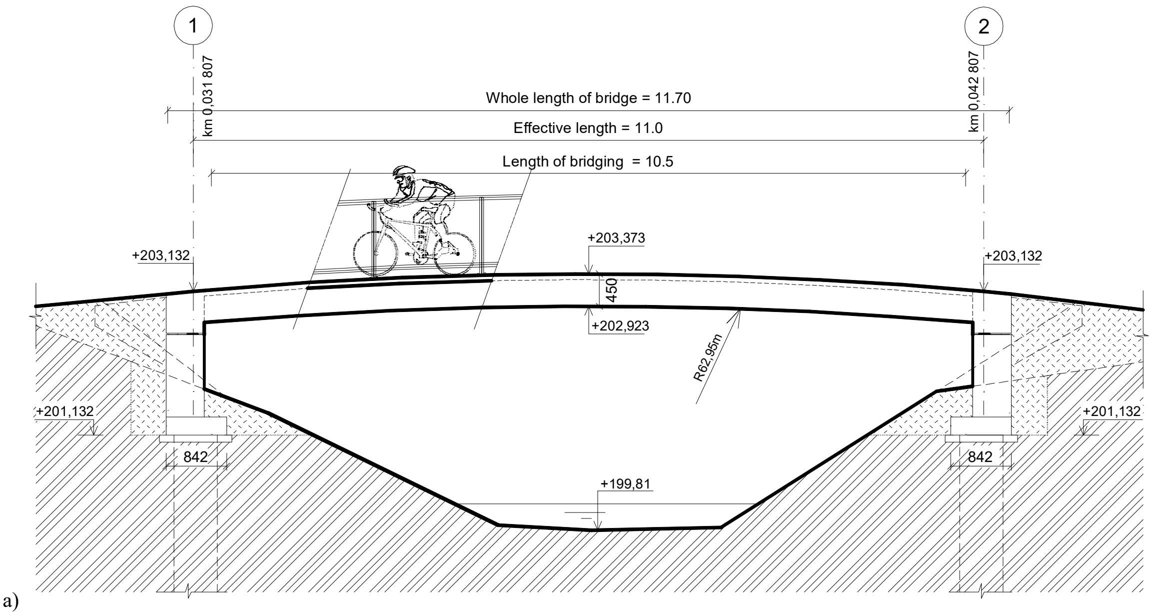


Fig. 1: Bridge object SO-02.1: (a) longitudinal view, (b) ground plan, (c) cross-section.



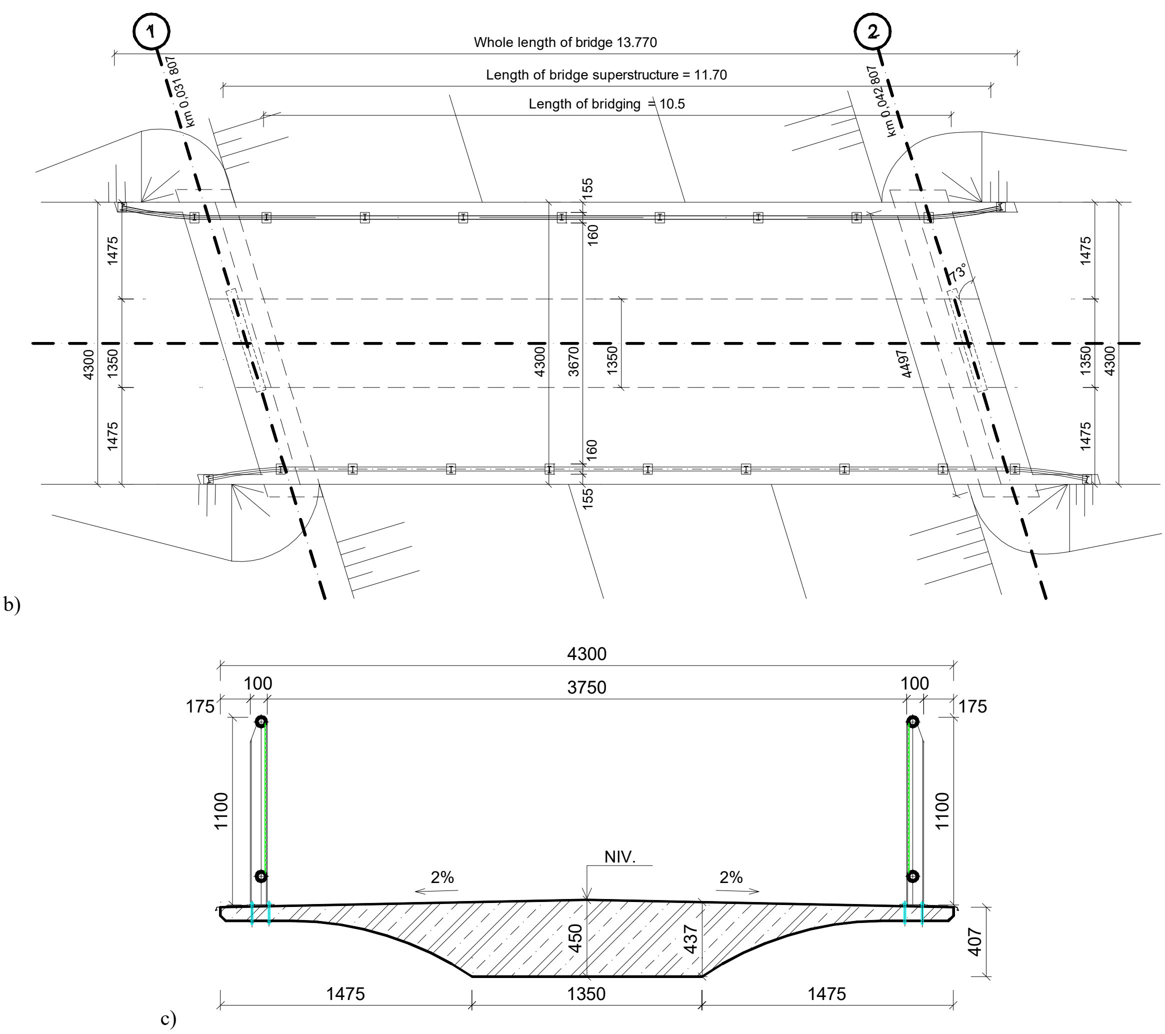


Fig. 2: Bridge object SO-02.2: (a) longitudinal view, (b) ground plan, (c) cross-section.

3. Proof-load tests of bridges

Standard STN 73 6209 [4] determines the design, safety and processing of the proof-load test in Slovakia, which is necessary for putting the bridge structure into operation. During the testing, a set of measurements are performed. The static proof-load tests are divided into basic, stricter and extraordinary. The static test load has negligible dynamic effects on the structure. It must accurately represent the real load of the bridge and move easily to allow a rapid change of load to complete unloading. Measuring devices were installed on the bridge, and sensors and long-term-monitoring devices are also used (if installed). Usually, the following measurements are normally performed:

– deformations/deflections of the superstructure;

– settlement and tilting of the abutments and piers;

– shifts and slew of the superstructure and substructure;

– width of the cracks.

Efficiency of the test load η is determined from the values of the vertical deformations in the mid-span, as well as from the bending moment values at those same points according to STN 73 6209 [4]. The numerical values of those test load efficiencies, for the most stressed sections in the mid-span of each field, should fulfil the following conditions:

$$\eta = \frac{f_{test}}{f_{cal}}, \quad (1a)$$

$$\eta_M = \frac{M_{test}}{M_{cal}}, \quad (1b)$$

$$0.5 < \eta < 1.0, \quad (2a)$$

$$0.8 < \eta_M < 1.0, \quad (2b)$$

where f_{test} is the vertical deformation in the mid-span measured during proof-load test; f_{cal} is the vertical deformation in the mid-span calculated from the theoretical model; M_{test} is the bending moment in the mid-span measured during proof-load test; M_{cal} is the bending moment in the mid-span calculated from the theoretical model.

4. Execution of proof-load tests

In this section, the basic parameters of proof-load tests will be described.

1) Numerical model

In both cases, a slab model was created for numerical calculation. The models took into account the change in thickness of the slab in the transverse direction - a gradual decrease in thickness from 0.45 m to 0.08 m (haunch). The superstructure was considered as a slab with a variable thickness in the transverse direction - the central part of the slab 1.35 m wide was modelled with a constant thickness of 0.45 m, the change in the cross-section in the haunches was modelled by two slabs with a change in thickness in the transverse direction (the "haunch" module was used) from the original hr. 0.45 m to 0.185 m in one slab 0.50 m wide and then from 0.185 m to 0.08 m in the second slab 0.55 m wide. The edge parts of the slab were again modelled in the transverse direction with a constant thickness of 0.08 m at a width of 0.425 m. The slab was considered in the model as a simple span in the longitudinal direction (one span) and was modelled as simply supported on supports. In the case of footbridge SO-02.1, the slab in ground view was modelled as perpendicular supporting (edges). But in the case of footbridge SO-02.2, the slab in ground view was modelled with skewness. The input data (geometry, cross-sectional and material characteristics) were taken from the provided projects documentations. The deformations of the described computational model of the supporting structure were calculated in the SCIA Engineering 2017 CAD system.

2) Variable load according to standard

The load model LM4 according to code STN EN 1991-2 [13] was applied for each field in that bridge structure. A maximum Uniformly Distributed Load (UDL) of $q_{ch} = 5.0$ kN/m^2 was located in footbridge between rails. The UDL was arranged for the maximum bending moment and maximum deflections in the centre of span. Only one loading state was performed during proof-load test on both footbridges.

3) Test load for proof-load test

The truck Mercedes-Benz Atego (1 piece on structure) was considered and modelled as forces of 1x52.00 kN for the front axle and 1x34.20 kN for the back axle. The load was modelled as a uniformly distributed load over the area 0.4 x 0.4 m under each wheel according to STN EN 1991-2 [13]. The positions of truck was placed in the most effective position to detect the maximum bending moments and deformations.

4) Organization and processing of proof-load test

The static tests were carried out in the same way for both footbridges. The geodetic measurements were used for measurement of the deflections on the edges of cross-section in the centre of the spans and the pushing of the bearings. The vehicle was arranged at the specified places. Once the measured deflections have stabilized, the final deformations have been recorded, after that the test load has left the bridge structure and deformations have been read again.

5. Results of proof-load tests

The proof-load test of object SO-02.1 was performed on 10.12.2021, and the proof-load test of object SO-02.2 was performed on 21.12.2021. Before starting the test, the measuring instruments were set for initial readings and baseline values were recorded. At the instruction of the test supervisor, the vehicle was lined up at the designated place in the middle of the bridge span according to the loading position. In a time interval of 15 min., the deformations of the observed cross-sections of the two edges of the bridge were read. After stabilization of the deformations, the test load left the tested field of the supporting structure and the permanent deformations of the supporting structure and bearings were read.

During the test, the supporting structure, its bearings and bridge abutments were monitored. No anomalies were detected in the behaviour of the bridge object under load. During the test, no cracks were recorded in the tested supporting structure.

5.1. Bridge object SO-02.1

The bridge supports (abutments) did not show any settlement during the proof-load test. Therefore, they did not affect the evaluation of vertical deformations.

The measured vertical deflections in the centre of the span and the values of the pushing the bearings together with the settlement of the abutments were processed in the Test Report, which was processed by the testing accredited laboratory of the Faculty of Civil Engineering of the University of Žilina. The results are shown in Tab. 1.

Tab. 1: Results of measurements SO-02.1 - comparison of theoretical and measured values.

Span	Edge of slab	Deflections due to pedestrian loads (mm)	Deflections due to test load (mm)	Efficiency of test load $\eta = f_{test}/f_{calc}$ [-]
Span 1 $L_1 = 14.0$ m	1	7.00	5.71	0.815
	2	7.00	5.71	0.815

5.2. Bridge object SO-02.2

Also in that case, the bridge supports (abutments) did not show any settlement during the proof-load test. Therefore, they did not affect the evaluation of vertical deformations.

The measured vertical deflections in the centre of the span parallel to the supports (due to oblique crossing - skewness) and the values of the pushing the bearings together with the settlement of the abutments were also processed by accredited laboratory of the Faculty of Civil Engineering of the University of Žilina. The results are shown in Tab. 2.

Tab. 2: Results of measurements SO-02.2 - comparison of theoretical and measured values.

Span	Edge of slab	Deflections due to pedestrian loads (mm)	Deflections due to test load (mm)	Efficiency of test load $\eta = f_{test}/f_{calc}$ [-]
Span 1 $L_1 = 11.0$ m	1	2.40	2.20	0.917
	2	2.50	2.15	0.60

6. Conclusions

The obtained results show that the results of numerical models were not much different from the real state. When the proof-load tests were correctly performed, the values were identical to the values from model. Thus, the bridge structures were reliable and are designed and usable for the operation throughout its planned lifetime. This means that the bridge objects (both footbridges) were reliable and can be put into operation.

The footbridges have been designed and built to perform the function of safely transmitting all components of permanent and variable loads over the lifetime. For comparison and verification of response and maximum load, the proof-load tests serve to detect all errors before putting bridge into operation. The task of proof-load tests is to verify the real behaviour of bridges for safe putting into operation. From that follows the requirement that the bridge objects have to fulfil certain parameters that, in their complexity, reflect their serviceability and service lifetime.

In this case, it was the first bridges in Slovakia reinforced in the transverse direction with GFRP reinforcement. The resistance of the objects and their usability in practice were verified, because during the proof-load test the footbridges behaved as expected.

Acknowledgements

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