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IN SITU VERIFICATION OF TENDONS OF FIRST SEGMENTAL POST-TENSIONED ROAD BRIDGES

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Abstract

Prestressed concrete bridges represent a massive part of our infrastructure. The state of the prestressing is crucial for the load-bearing capacity and remaining service life of these structures. Harmful factors, for instance, corrosion negatively affect the prestressing steel and consequently the level of prestressing. The risk of corrosion is higher if the ducts are not injected (or partially injected) by cement grout. Therefore, the detection of the state of the prestressing steel is an important part of the diagnostic survey which should be performed on existing prestressed concrete structures. This paper describes the outcomes of a diagnostic survey performed on four segmental post-tensioned road bridges built in the 1970s. Specifically, one single-span bridge, one three-span bridge, and two two-span bridges are pivotal objects of this study. These bridges' prestressing has been assessed and the outcomes have been evaluated with final recommendations for the administrator. To sum up, the prestressing of assessed bridges was in relatively good condition with none or only local corrosion. Consequently, the overall prestressing level should not be hugely affected, but certain actions from the administrator are required to repair detected failures and extend service life.

Keywords:

Assessment;
Bridges;
Segmental structures;
Prestressing;
Destructive testing;
Corrosion.

1 Introduction

The first applications of prestressed concrete in former Czechoslovakia were performed in the late 1940s. In 1947, a short-span bridge was built in Bohemia [1]. Since then, prestressed concrete structures have become important parts of our transport infrastructure. This fact is even more important in the case of road infrastructure. Early prestressed concrete bridges have a lot of conceptual errors. Moreover, this negative feature is highlighted by the neglected maintenance. Consequently, these structures are deteriorating, and their reliability is inevitably decreasing [2]. Mass replacement of the structures is not possible from economic and ecological points of view. Therefore, inspections and diagnostic surveys are crucial parts of the administration. For the right decision-making, the classification of assessed structures is needed. Based on the obtained data, the administrators can subsequently prepare actions that will extend the service life of the early prestressed concrete bridges [3].

In Slovakia, road bridges are classified into seven possible condition classes (from I. to VII.). The purpose of the Slovak methodology is to guide the management of bridges and to introduce a unified system of records, supervision, preparation of maintenance, repairs and reconstruction of bridges and their implementation [4]. Generally, condition classes I. to III. illustrate the structural state which is good and without significant risk in the near future. Condition class IV. characterizes possible dangers relating to their condition in the near future. Nonetheless, condition classes from V. to VIII. describe a state with the required repair or even immediate closure of the bridge for traffic [5].

Figures 1 and 2 describe the development structural state of Slovak road bridges in the period from year 2000 to 2022 [6-7]. Overall number of bridges in problematic condition classes from V. to VII.

highly increased since the year 2010. In 2022, almost one-third of road bridges (31.4 %) belonged to these classes. This information is frightening and requires immediate interest. In such cases, the reliability of the bridges is in danger, and demountable temporary bridges must be mounted. Moreover, climate change results in geohazards that influence the safety of our infrastructure [8-10]. Consequently, this certainly leads to additional costs for the administrators [11-13].

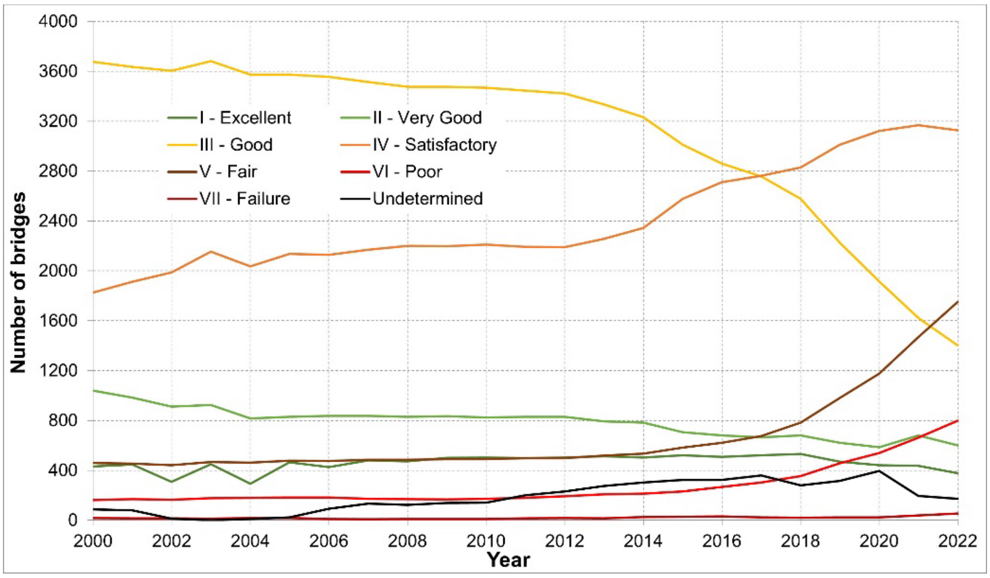


Fig. 1: The classification of Slovak road bridges according to their structural state [7].

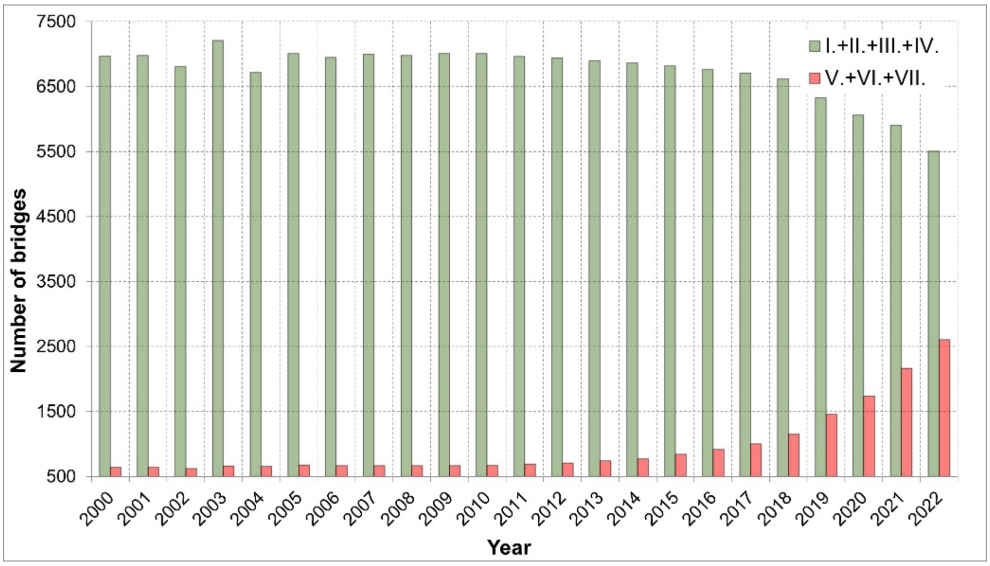
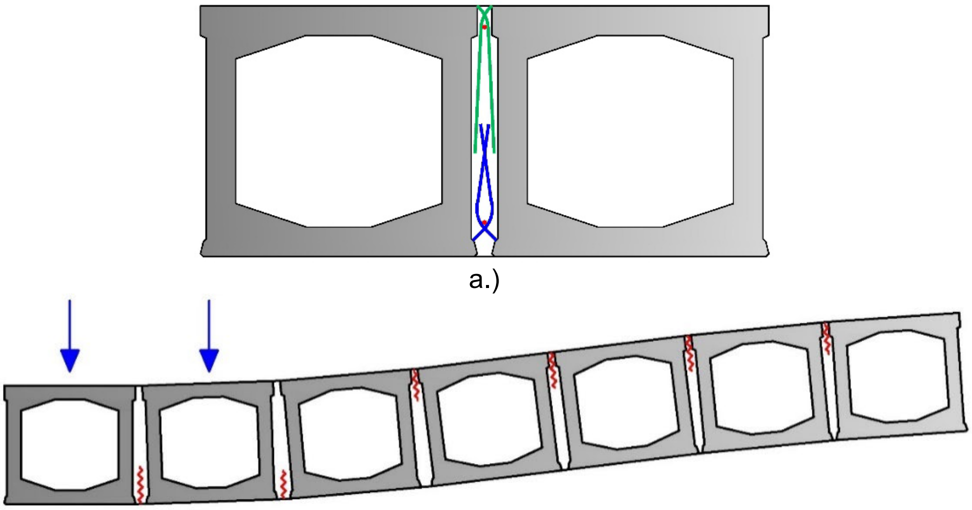


Fig. 2: Detail on the structural state of Slovak road bridges [7].

The problems with precast girder bridges in Slovakia are alarming. In recent years, several bridges of this type have failed. All these structures belonged to the group of early post-tensioned bridges built in former Czechoslovakia. A huge factor influencing the structural state of these bridges was the corrosion of prestressing wires resulting from insufficient cement grout and protection of anchorages [14-15]. Therefore, the diagnostic survey is very important in the case of existing prestressed bridges regarding the verification of the state of tendons. Consequently, the aim of this study was to prepare a detailed analysis of the prestressing in the four bridges and summarize the recommendations for the administrator. Other detected failures of the bridges are not the object of this paper and have been summarized for the administrator in the final report. In the presented paper, two types of prestressed girder bridges were subjected to the diagnostic survey. Specifically, two two-span bridges were built from KA box girders, and single-span and three-span bridges consisting of I-girders "Sefcik". All mentioned bridges were built in the 1970s as segmental structures. Longitudinal prestressing ensures the contact between individual segments and creates the complete length of the girder. The history of both studied types of prestressed girder bridges was described in Vitek, 2016 [1].

1.1 History of box girders "KA"

In the 1950s, Czechoslovak civil engineers started to develop box girders consisting of several segments connected by prestressing. Thus, the girder reaches its overall length. The gaps between the segments were filled with cement grout. At the beginning of the development, the girders were prestressed transversally too. However, such a connection was problematic in the case of skew bridges. The reason was that the holes for transversal prestressing limited the skewness as the holes had to fit one another. Therefore, the engineers proposed a new transversal connection which consisted of cement grout in the gaps between the girders with modified stirrups and several longitudinal bars. This construction was called "hinge connection". However, such a connection is not absolutely a "hinge connection". The connection is rigid at the beginning and as the load increases the cracks are initiated in the gaps. Thus, the rotation is enabled, see Figure 3. Consequently, the engineers used the term "semi-rigid slab". Using this solution, the construction process was easier, and the possibility of errors on site was lower as well as the cost of the bridge construction. The design manuals were prepared for the girder lengths of 9, 12, 15 and 18 m [1].



a.)

b.)

Fig. 3: KA box girder – a.) detail on the gap; b.) transversal deformation [1].

1.2 History of I-girders "Sefcik"

At the beginning of the 1960s, in Slovakia (at that time part of Czechoslovakia), an I-girder for the spans between 21 to 30 m was developed, see Figure 4. This girder type was named after his founder Sefcik. Similarly, as in the case of the KA girder, the connection between individual girders was provided only in the contact of the top and bottom flange of the I-beam. This connection was created by the transversal reinforcement (stirrups) overhanging the flanges. Additionally, longitudinal bars were put through the overhanging stirrups. Concreting the gap between the bottom flanges was very complicated, especially for short-span girders as their heights as well as the space between the top and bottom flanges were much smaller. The design manuals were prepared for the girder lengths of 21, 24, 27 and 30 m [1].

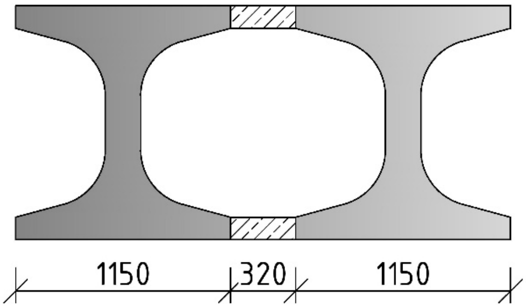


Fig. 4: I-girder “Sefcik”.

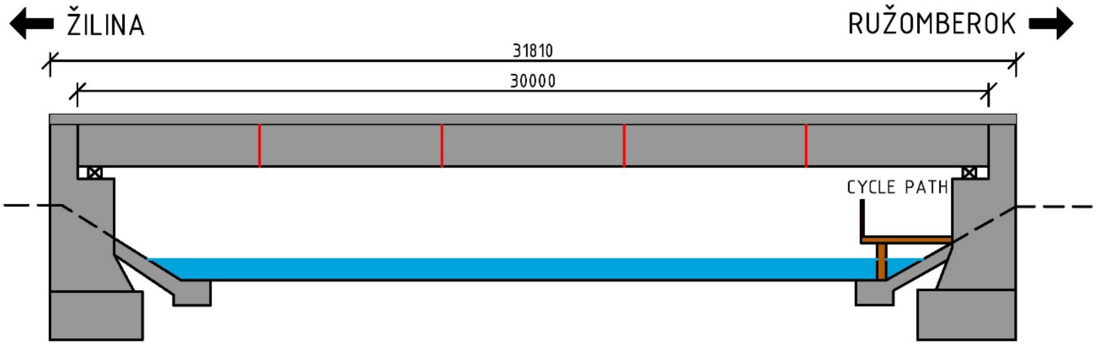
2 Description of Diagnosed Bridges

Overall, four segmental post-tensioned bridges have been subjected to detailed prestressing diagnostics. Three of them are situated in northern parts of Slovakia and one bridge is on the south. In this section, a short description of each bridge is listed. In the case of all verified brides, prestressing steel was in the form of patented wires. The studied bridges belong to the group of first segmental bridges built in Czechoslovakia. Their gaps between segments were filled with cement mortar.

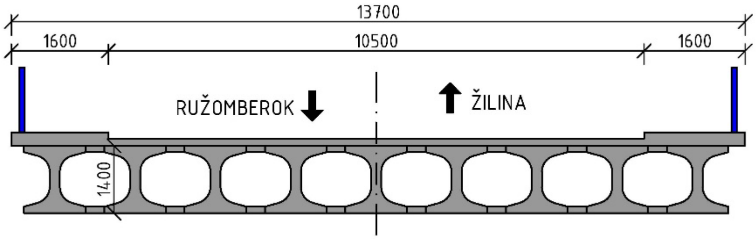
2.1 Bridge “A” (Martin)

The bridge has been designed as a single-span girder bridge, see Figure 5. The superstructure of the bridge consists of nine precast prestressed girders I-67 “Sefcik” with a height of 1.40 m, which are placed on steel bearings. The girders consist of five individual segments. The overall length of the girders created by five individual segments is 30 m. The substructure of the bridge contains massive abutments with parallel wing walls. The bridge deck is formed by an asphalt pavement with a width of 10.50 m between curbs and sidewalk ledges with a total width of 1.60 m. The sidewalks are 1.20 m wide. According to the information from the administrator, the bridge was built in 1970. The drawings of Bridge “A” can be seen in Figure 6.

Fig. 5: Sideview on the Bridge “A” in Martin.



a.)

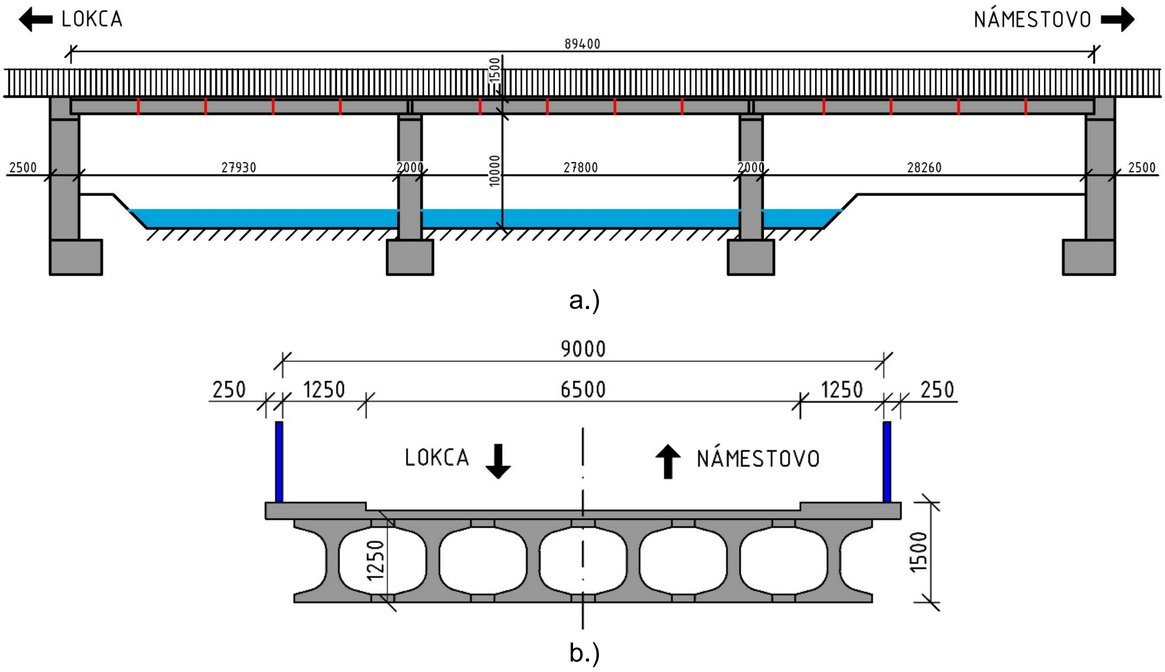


b.)
Fig. 6: Bridge “A” in Martin: a.) Longitudinal section; b.) Cross-section.

2.2 Bridge “B” (Oravska Jasenica)

The bridge has been designed as a three-span girder bridge with massive abutments with parallel wing walls and two pillars placed in the course of the Biela Orava River, see Figure 7. The superstructure of the bridge consists of six precast prestressed girders I-67 “Sefcik” with a height of 1.25 m, which are placed on steel bearings on abutments and pillars. The girders consist of five individual segments. The bridge deck is formed by an asphalt pavement with a width of 6.50 m between raised curbs and sidewalk ledges with a total width of 2 x 1.50 m. The sidewalks are 1.25 m wide. According to the information from the administrator, the bridge was built in 1971. Consequently, the age of Bridge “B” is almost the same as in the case of Bridge “A”. The drawings of Bridge “B” are shown in Figure 8.

Fig. 7: Sideview on the Bridge “B” in Oravska Jasenica.



a.)

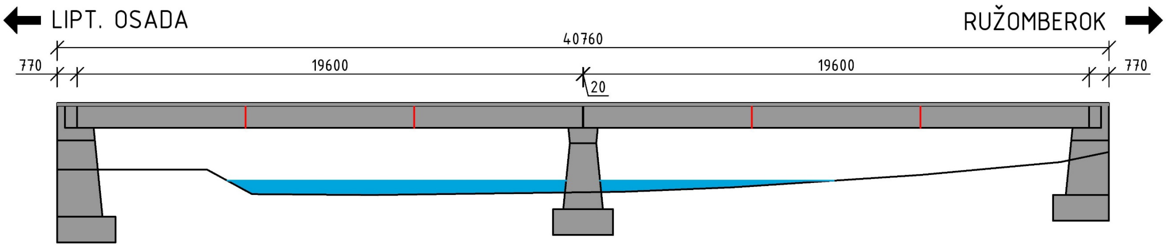
b.)

Fig. 8: Bridge “B” in Oravska Jasenica: a.) Longitudinal section; b.) Cross-section.

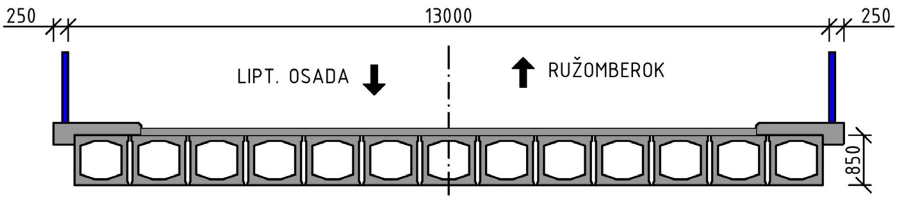
2.3 Bridge "C" (Ruzomberok)

The bridge has been designed as a two-span bridge, see Figure 9. The girders are simply supported on massive abutments with parallel wing walls and a central pillar. The superstructure of the bridge consists of thirteen precast prestressed box girders KA with a height of 0.85 m. The girders consist of three individual segments. The supports are in the form of asphalt bands. The bridge deck consists of an asphalt road with a width of 10.50 m between the raised curbs of the sidewalks and sidewalk ledges with a total width of 1.50 m. The sidewalk clearance is 1.25 m wide. According to the bridge documentation, the bridge was built in 1973. The simplified scheme of Bridge "C" is depicted in Figure 10.

Fig. 9: View on the Bridge "C" in Ruzomberok.



a.)



b.)

Fig. 10: Bridge "C" Ruzomberok: a.) Longitudinal section; b.) Cross-section.

2.4 Bridge "D" (Rimavska Sobota)

The bridge was designed as a two-span bridge with two simply supported girders on massive abutments with parallel wing walls and a central pillar, see Figure 11. The superstructure of the bridge consists of thirteen precast prestressed KA box girders with a height of 0.85 m. The girders consist of three individual segments. The superstructure was supported by asphalt bands. The bridge deck is formed by an asphalt road with a width of 10.50 m between raised curbs and two-sided sidewalks with a total width of 1.50 m. The sidewalk clearance is 1.25 m wide. According to the bridge documentation, the bridge was built in 1971. The drawings of Bridge "D" can be seen in Figure 12.

Fig. 11: Sideview on the Bridge “D” in Rimavska Sobota.

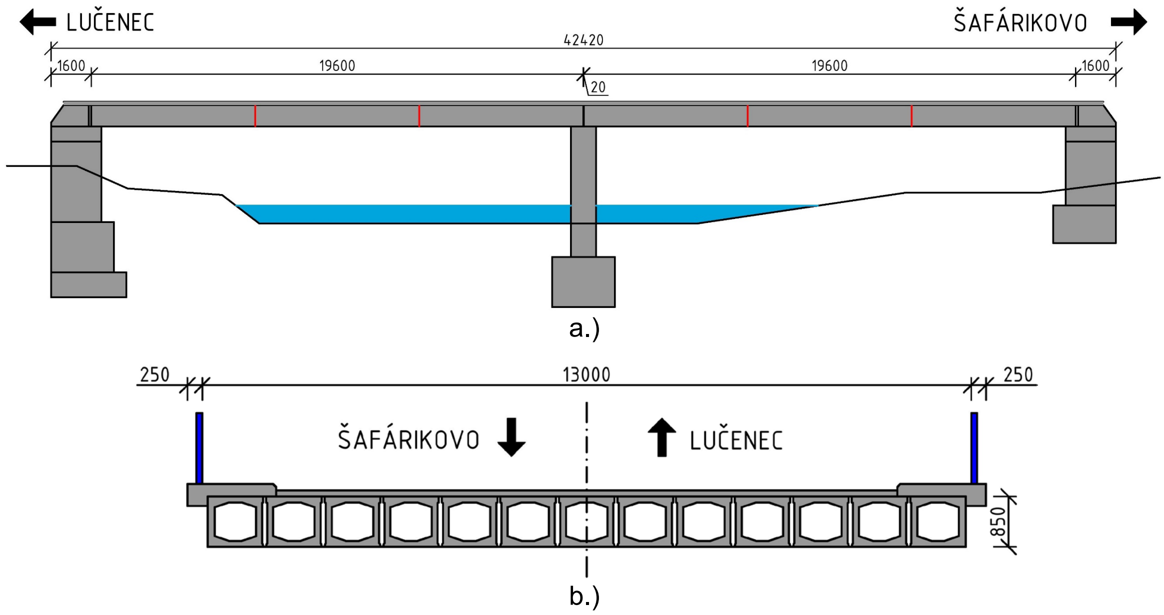


Fig. 12: Bridge “D” Rimavska Sobota: a.) Longitudinal section; b.) Cross-section.

3 Diagnostic Survey Results

The verification of the state of the prestressing steel was performed destructively. Specifically, the tendons were revealed by drilling. The individual tendons in the girders were indicated by the Hilti 1000 Pro Reinforcement Scanner. In the verification, several indicators were monitored. These indicators describe the state of the prestressing steel. The procedure of the diagnostic is displayed in Figure 13. Individual indicators were evaluated according to scales listed in Table 1.

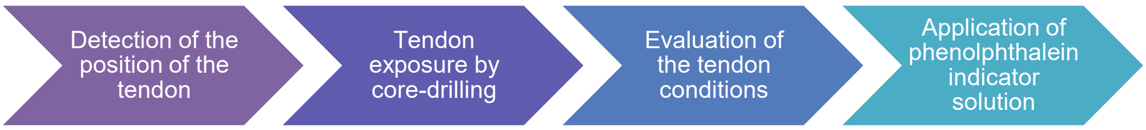


Fig. 13: The procedure of the diagnostic survey.

The monitored indicators can be summarized as follows:

1. State of the cable duct;
2. Injection (cement grout) of the cable duct;
3. pH of cement grout;
4. Moisture of cement grout;
5. State of prestressing steel (wires).

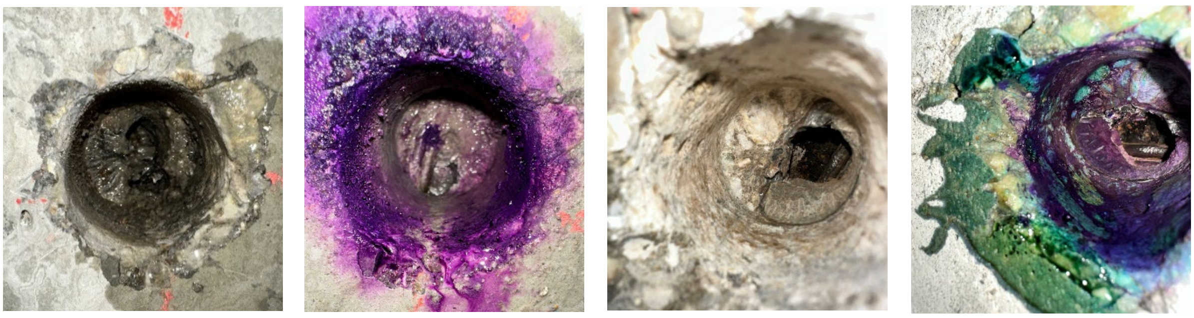
Table 1: Evaluation of the indicators.

<table>
<tr><th>Indicator</th><th colspan="12">Scales</th></tr>
<tr><td>1.</td><td colspan="3">No corrosion</td><td colspan="3">Mild corrosion</td><td colspan="3">Corrosive</td><td colspan="3">Corroded</td></tr>
<tr><td>2.</td><td colspan="4">Injected</td><td colspan="4">Partially injected</td><td colspan="4">Not injected</td></tr>
<tr><td>3.</td><td colspan="6">≥ 11</td><td colspan="6">< 11</td></tr>
<tr><td>4.</td><td colspan="4">Dry</td><td colspan="4">Moist</td><td colspan="4">Water is present</td></tr>
<tr><td>5.</td><td colspan="4">No corrosion</td><td colspan="4">Mild surface corrosion</td><td colspan="4">Corroded</td></tr>
</table>

3.1 Evaluation

The diagnostic survey was conducted on individual bridge spans with the aim of performing at least five cores in each span. Figure 14 displays the overall number of cores in individual bridges. The examples of the revealed ducts can be seen in Figure 15. Specifically, Figure 15a presents a duct with the presence of water. Interestingly, the prestressing wires were not corroded. It can be attributed to the fact, that the water was present in only one duct and could leak during recent pavement reconstruction. Photographs on the right side represent the cores after application of phenolphthalein indicator solution. All performed cores were in alkaline environments. In Figure 15c and Figure 15e, partially injected ducts are displayed. Moreover, corroded wires in not injected duct can be seen in Figure 15g. In the investigation, the state of tendons in the area adjacent to gaps between the individual segments was studied too. This is important because this location can be prone to water voids which could result in corrosion which could spread along the insufficiently injected tendon.

Fig. 14: Amount of performed core drilling in individual bridges.



a.) b.) c.) d.)

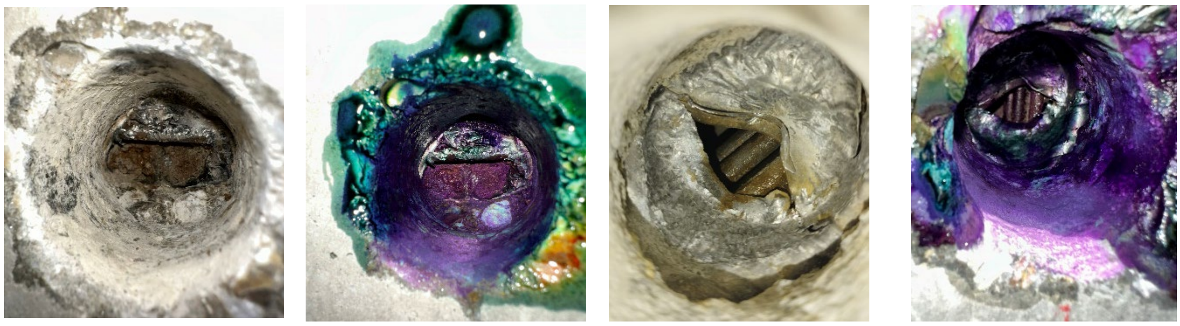


Fig. 15: Examples of revealed prestressing steel: a.) presence of water (Bridge "B"); c.) partially injected duct (Bridge "D"); e.) partially injected duct (Bridge "D"); g.) corroded wires (Bridge "B"); b.; d.; f.; h.) cores after application of indicator solution.

3.1.1 Bridge "A" (Martin)

Figure 16 displays the evaluation of performed cores in Bridge "A". Overall, nine cores were drilled in the single-span bridge. All cores were in a good state – the presence of injection and no signs of corrosion. Consequently, the prestressing of this bridge was in good condition. The alkalinity of the concrete met the required criteria in all cases.

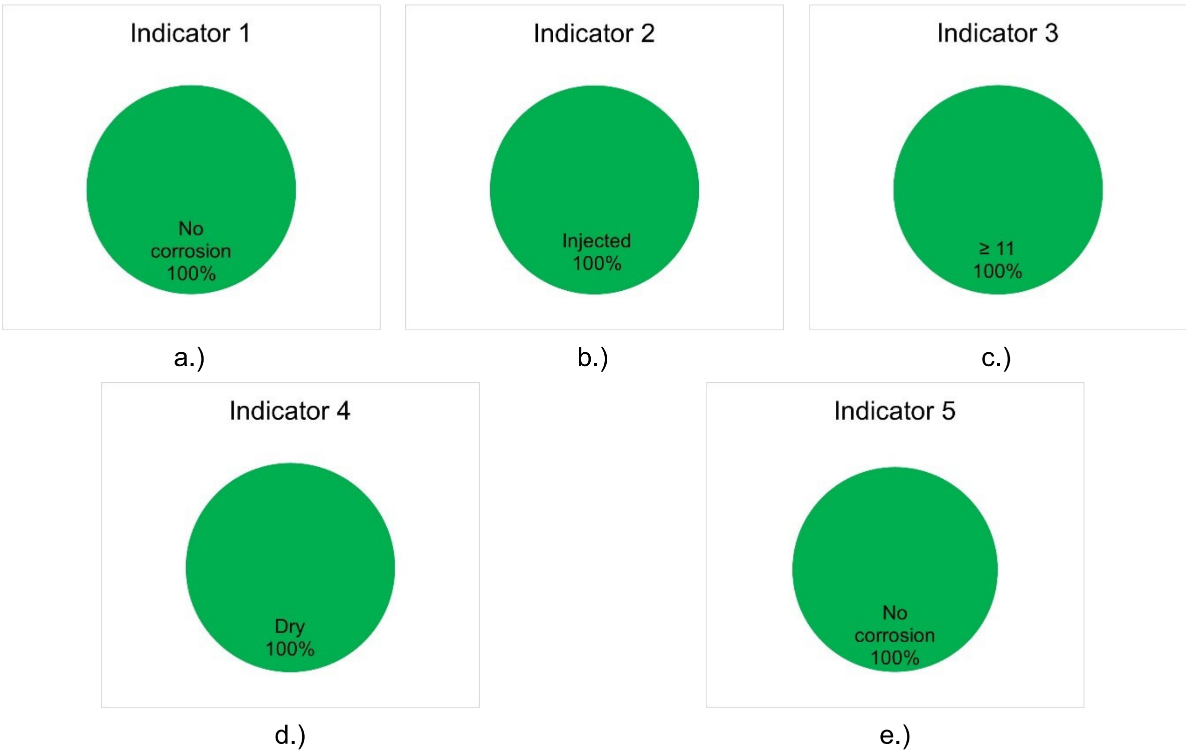


Fig. 16: Bridge "A" – evaluation: a.) Indicator 1; b.) Indicator 2; c.) Indicator 3; d.) Indicator 4; e.) Indicator 5.

3.1.2 Bridge "B" (Oravska Jasenica)

Figure 17 presents the results from the exposure of tendons in Bridge "B". Overall, seventeen cores were drilled in the three-span bridge. Specifically, five cores in 1st span, six cores in 2nd span, and six cores in 3rd span. The majority of the revealed tendons were in a good state. However, in one tendon in 3rd span, the water was present. Probably because of recent pavement reconstruction and the longitudinal slope of the bridge that enabled water to accumulate in lower parts. This tendon was anchored in the top flange of the I-girder right under the pavement. Almost 90 % of revealed tendons were fully injected. Additionally, circa 30 % of the diagnosed tendons contained wires with signs of corrosion. To sum up, the prestressing of this bridge was in sufficient condition without affecting the overall performance of the structure. However, attention is required regarding the possible presence of the water in not-injected tendons. The alkalinity of the concrete was sufficient in all drilled cores.

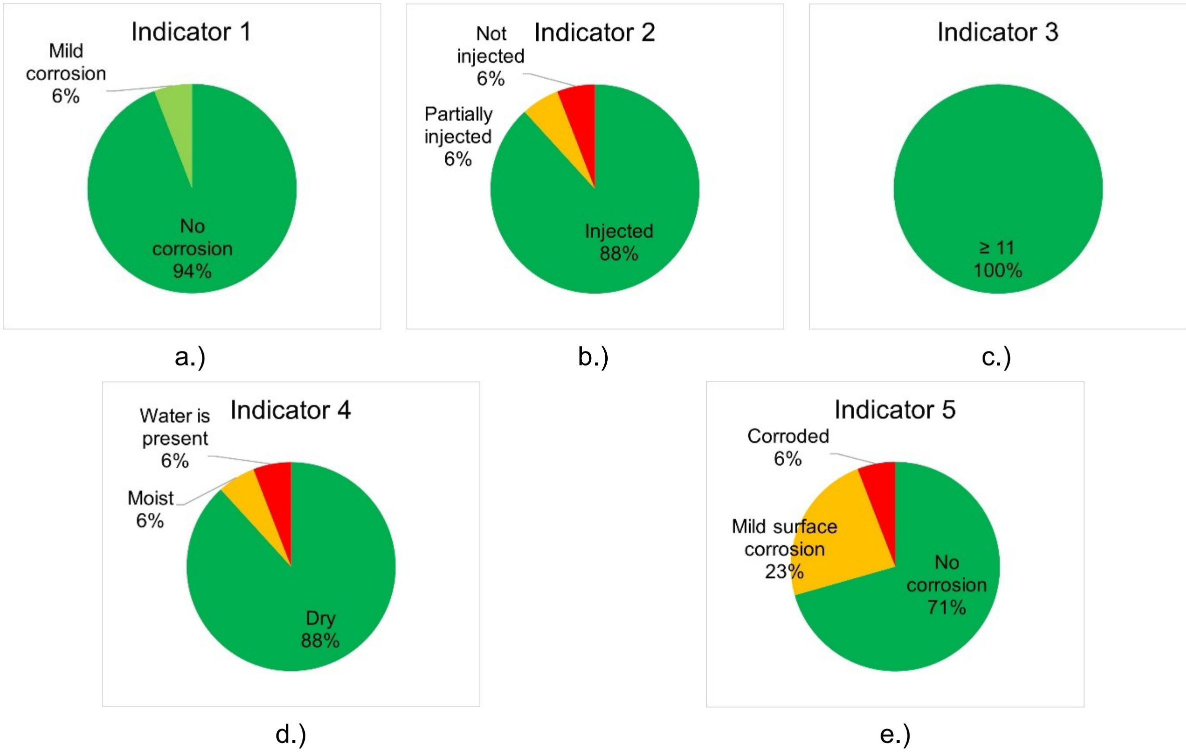
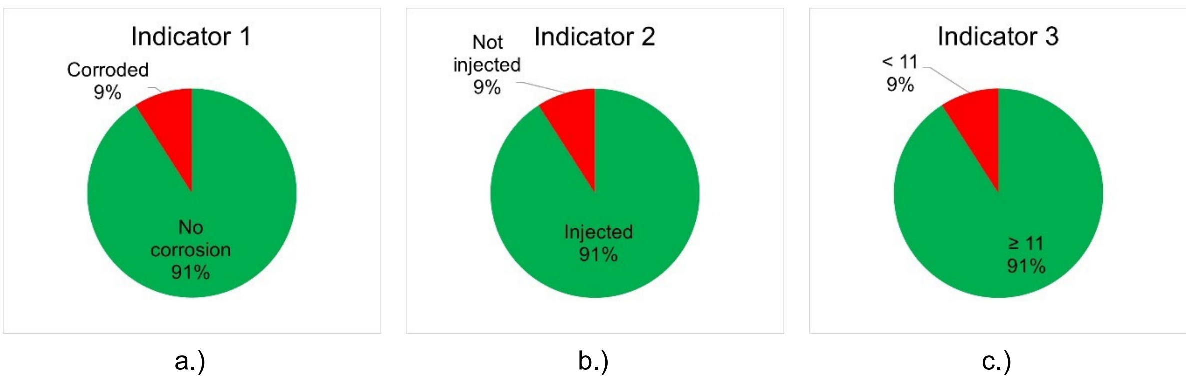
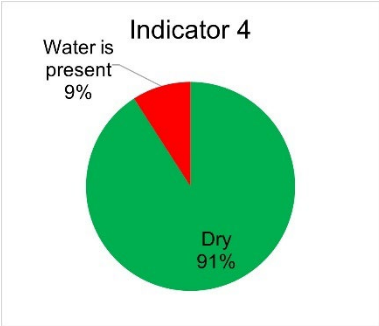


Fig. 17: Bridge "B" – evaluation: a.) Indicator 1; b.) Indicator 2; c.) Indicator 3; d.) Indicator 4; e.) Indicator 5.

3.1.3 Bridge "C" (Ruzomberok)

The evaluation of data collected in Bridge "C" is summarised in Figure 18. To sum up, two-span Bridge "C" was subjected to overall eleven prestressing steel exposures. In particular, in 1st span five exposures were performed and in 2nd span six exposures respectively. In 2nd span, tendons of edge girders were visible without any intervention - a detached concrete cover. Except for this tendon, all other diagnosed tendons were in good condition with the present injection. To sum up, a damaged edge girder requires action to avoid spreading corrosion to other girders. The problematic edge girder can be seen in Figure 19. The alkalinity of the concrete did not meet the required criteria only in the case of edge girder.





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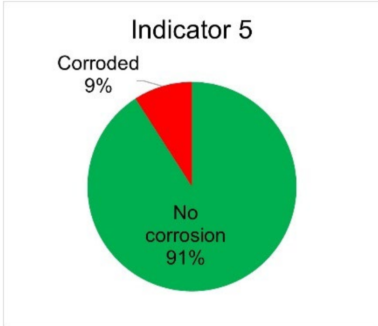


e.)

Fig. 18: Bridge “C” – evaluation: a.) Indicator 1; b.) Indicator 2; c.) Indicator 3; d.) Indicator 4; e.) Indicator 5.

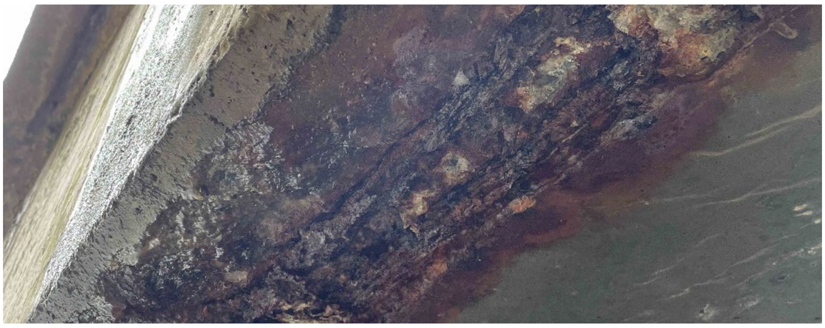
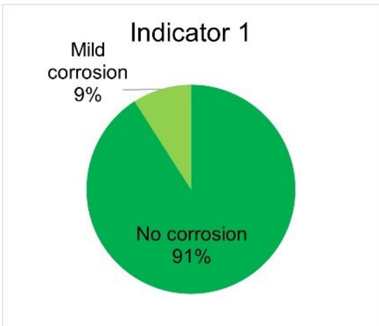


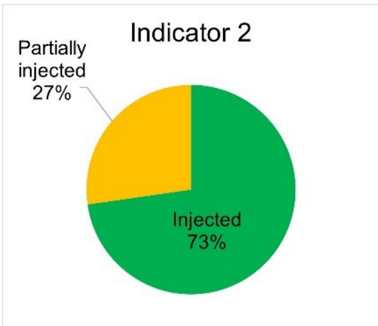
Fig. 19: Bridge “C” – edge girder with visible corroded tendons.

3.1.4 Bridge “D” (Rimavska Sobota)

Figure 20 summarises the results of the Bridge “D” prestressing diagnostics. In the case of this two-span bridge overall eleven drilled cores were performed – five in 1st span and six in 2nd span respectively. More than two-thirds of the revealed tendons were fully injected. The rest of them were only partially injected. Almost 30 % of diagnosed tendons consisted of corroded wires or wires with mild surface corrosion. Importantly, water was not detected in the tendons. Finally, the overall prestressing of the bridge should not be significantly affected. The alkalinity of the concrete was sufficient in all cases.



a.)



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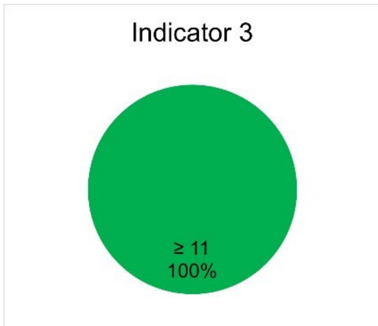
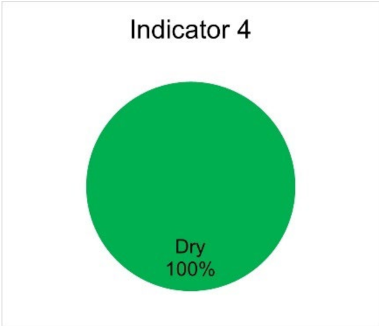


c.)



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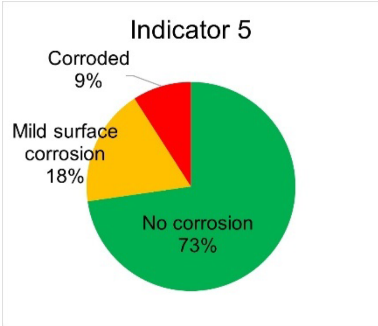

e.)

Fig. 20: Bridge “D” – evaluation: a.) Indicator 1; b.) Indicator 2; c.) Indicator 3; d.) Indicator 4; e.) Indicator 5.

4 Conclusions

The conclusions from the performed diagnostic survey and subsequent evaluation of four prestressed segmental bridges built in the 1970s can be summarized as follows:

- The majority of performed core drills did not suggest any problems with prestressing steel.
- Problematic tendons regarding corrosion of wires were found in the edge girders on which higher loads act. These girders are subjected to a more aggressive environment (de-icing substances) that negatively affects the protection of prestressing steel in the form of concrete cover.
- Higher attention should be paid to tendons which have anchorages in the top flange of the I-beams as they can be damaged during, for instance, pavement reconstruction.
- Diagnosed prestressed I-girders as well as box girders did not suggest any severe problems after more than 50 years of service and sufficient rehabilitation can extend their service life. Detected problems were mainly connected to water voids and corrosion of, for example, steel railings.
- The tendons in the gaps between individual segments were in general adequately protected.
- In this study, the number of spans or number of the girders in the cross-section of the bridge did not affect the state of prestressing. However, the state of the individual spans can differ and is related to the longitudinal slope of the bridge. Water can therefore accumulate in the lower parts of the bridge.
- A diagnostic survey aimed at the exact verification of the actual state of prestressing steel is very important as the prestressing level is directly affected by possible corrosion. Consequently, a decrease in residual prestressing results in a reduction in the load-bearing capacity of these structures.

Acknowledgements

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