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ANALYSIS OF BRITTLE FAILURE OF PRESTRESSED BRIDGE IN THE NORTH OF SLOVAKIA

Martin MORAVČÍK, Petra BUJŇÁKOVÁ
University of Žilina, Faculty of Civil Engineering, Žilina, Slovakia

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1. Introduction

This paper is focused on the primary causes of failures and collapse state of the concrete bridge superstructure which is located on the international route I/59 connecting Slovakia with Poland (bridge No. 59-090). Dangerous structural defects of brittle character were found in four girders of the bridge structure during the routine inspection in 2015. Subsequently, the object was declared as being in the emergency status and immediately closed for the traffic at the end of 2015. This bridge was built in 1956 as one of the first generation of the precast and prestressed structures in Czechoslovakia.

2. Basic facts about the first generation of precast bridges

Generally, the first precast girders were post-tensioned and additionally prestressed in the transverse direction to create the orthotropic load carrying system without using of any monolithic member. The gap between diaphragms was filled by the concrete. These girders were cast in one piece for the small bridge length or for longer spans in the three separated parts. Nowadays, many of those bridges are in insufficient condition and require extensive rehabilitation.

Several bridges were built in the northern part of Slovakia using post-tensioning technology. The mentioned type of bridge structure has been being in service for 60 years. The basic conception of the discussed prestressing technology is one of the most often cause of the bad technical state of such bridges due to the low level of knowledge and technical possibilities in that time. Especially, the insufficient grouting of ducts and corrosion of the anchorage zone of post-tensioning wires are the major reason of the emergency condition of those bridges.

Due to the strategic location of the bridge analysed in the work (on the international road between Slovak and Polish border) the temporary bridge was promptly assembled. The light temporary steel bridge was placed on the concrete panels fixed on the original abutments and central pier. It was assembled only for the light transport. This structure was installed without any additional loading of the original damaged superstructure (see Fig. 1). Consequently in two months, the heavy temporary railway bridge, type ŽM 60, was built near the damaged bridge for the heavy transport too. All traffic had to be controlled as one-way system with the traffic light during the rehabilitation process.

3. Description of the bridge

The discussed bridge is located near the village Podbiel in the northern part of Slovakia, crossing the river Studený Potok. It was built in 1956 as one of the first generation of the prestressed road bridges. The bridge consists of the two simple spans of 26.65 m. The total length of bridge is 63.90 m. The original bridge width was 11.80 m, and the original superstructure consisted of 10 post-tensioned girders with spacing of 1.14 m. In addition, the girders were transversely connected with crossbeams in spacing of 5.24 m. Finally, the girders were transversely post-tensioned through the top flange in spacing of 0.80 m and trough the diaphragms. The construction depth of the girder was 1.35 m, top flange was 1.10 m and the bottom flange was 0.47 m wide. The girders were post-tensioned with 22 tendons consisting of 12 patent wire strands in diameter ϕ P 4.5 mm. The layout scheme of the bridge is shown in Figs. 2 and 3.

Fig. 1. View on both temporary bridges.

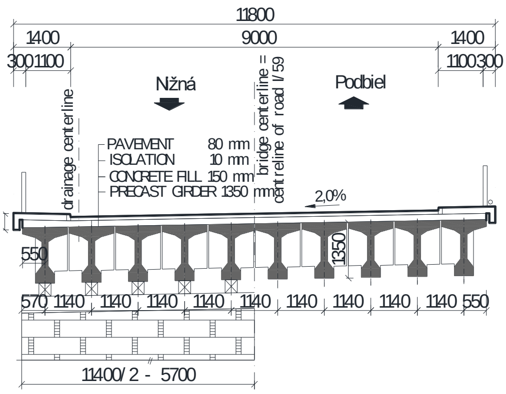

Fig. 2. Cross section of the original bridge.

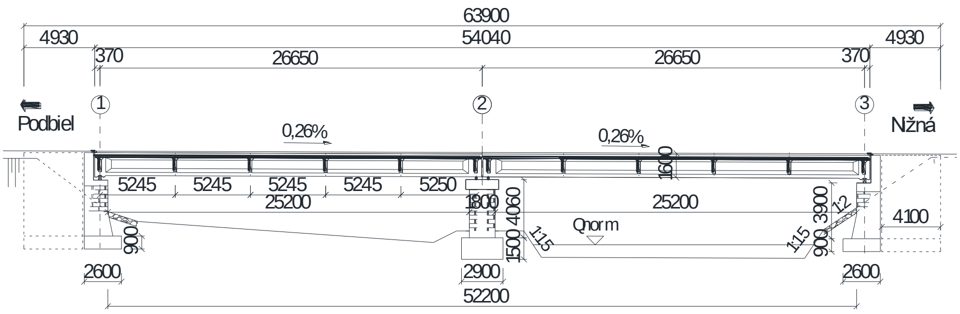

Fig. 3. Longitudinal section of the original bridge.

The superstructure was placed using the steel bearings on the abutments and steel fixed bearings on the central pier. The gravity abutments were made of plain concrete protected by the stone facing. The abutment length is 11.40 m, the height 4.80 m and the width of 1.65 m. The cross-section of pier is of the rectangular shape. The length of pier is 13.40 m, the width is 1.80 m and the height of 3.65 m.

The shape of the pier is modified to triangular shape on the upstream side and to circular shape on the downstream side. This shape corresponds to flow direction. The pier is protected by stone facing too. All foundation was designed on massive footing.

4. The crucial failures and their causes

The brittle failure had been raised at the right edge of the bridge in the second span. There was found out that 4 girders were totally broken. A critical crack in the middle section with several centimeters width was discovered. It had been formed almost in the entire cross-sectional height (see Fig. 4). Also the deformation of the right part of the bridge deck was visible, and that effect was accompanied by the excessive oscillation of the structure as the heavy trucks were passing through the bridge. The character of isolated wide crack in the middle cross-section was as a textbook example of brittle bending failure of concrete member. No other traditional distributed bending cracks were recorded. But at the same time, there were detected visible overloading and gradually developing cracks in the centre of span on remaining 6 girders. These beams were overloaded by the traffic and self-weight of the broken girders.

Fig. 4a. Brittle failure on the 4 edge girders.

Fig. 4b. Detail of the primary crack.

During the demolition work the main cause of the collapse was step by step detected. Many of the prestressing wires with parabolic course were corroded in the center of the span (see Fig. 5a) because water in the ducts was concentrated just in the middle cross-section due to the fact that some of them (around 50 %) have not been protected, and next ones have very poor concrete protection in the anchor zone (see Fig. 5b). Additionally, around 90% of the ducts were no grouted. There were the total number of 44 anchors, and 16 anchors were anchored on the top flange of the girder under the leveling concrete layer of the pavement. That fact greatly accelerated water flow to the middle cross-section and the corrosive action of the water in the ducts.

Beside loss of prestressing, there was the next negative moment of the brittle character of collapse. It was total absence of the standard reinforcement. Underestimation of conventional reinforcement was around 85 % comparing to the European standard requirements [1]. All those causes confirmed the assumption of the low ductility of the prestressed girders and the prediction of the brittle character of the collapse. However, the characteristic strength of the concrete achieved quite high values from 49 to 52 MPa, and it could be seemingly assessed visually as being in good condition. We can call this fact as a “time bomb” in the concrete structure.

Fig. 5a. Corroded wire pulled out from the duct.

Fig. 5b. Anchorage zone.

Fig. 5c. Falling down girder during demolition works.

The transverse prestressing consisted of 11 wires ϕ P 4.5 mm and was relatively functional and even partially grouted. That fact essentially ensured that no fatal event had been occurred to that time on the bridge. This was evidenced because, after cutting transverse wires, all damaged girders felt down (see Fig. 5c). They could not be able to carry their self-weight.

During the demolition works on the superstructure, the static load test was performed in situ. For that purpose, there was selected one girder in relatively good condition in comparison to the others which still acted on the abutments. Three sensors (s1-s3) were installed in the middle section to monitor the deflection during the test. As a load member the hydraulic jack with 100 tons (1000 kN) capacity was used. The total load 65 tons was reached. However, actual ultimate limit state occurred under load 60.5 tons. It represents a reduction of about 20 % compared to the assumed load capacity (around 75 tons, curve $P_{,mt}$, see Fig. 6). The first crack was discovered on a load level about 40 tons. It is apparent also from Fig. 6. The calculated value was estimated on the level around 48 tons, so it represents reduction around 17 %. It can be seen that the course of the theoretical and actual deflection begins to be different significantly after the first crack being formed. About 30 % lower level of prestressing was the reason of such load capacity and smaller ductility. It was derived by the reverse iterative calculation based on the girder stiffness according to Fig. 6. Assumed prestressing reduction, at the other girders in worse condition more than 50 %, can be considered.

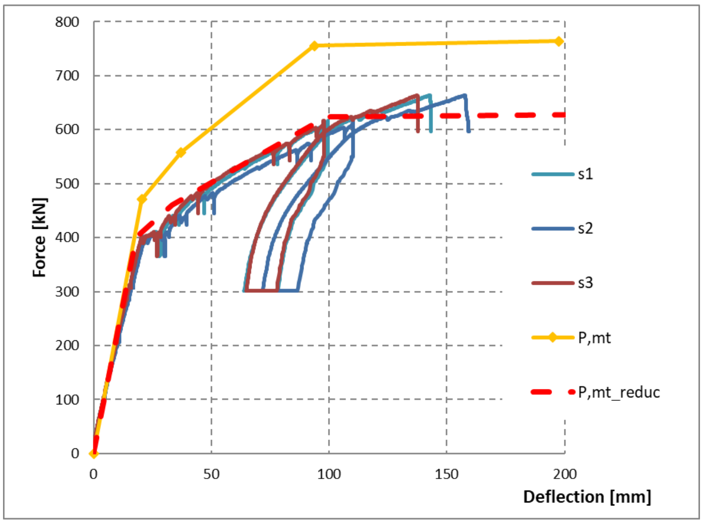

Fig. 6. Load vs. deflection diagram.

Besides to the primary defects of superstructure, other common failures in the supporting structure and bridge accessories were identified. They corresponded to the time of the bridge exploitation. The degradation of the concrete as well as the relatively large corrosion of the reinforcing concrete were marked on the head of both of abutments and the center pier. The expansion joints were damaged, and it resulted in extensive corrosion of steel bridge bearings.

5. Bridge rehabilitation

The diagnostic survey and structural analysis of the both abutments and the central pier had proved their relatively good technical condition and ability to next use. The substructure could be retained after the recommended intervention. The superstructure was demolished due to the significant failure of the girders.

The abutment caps as well as backwalls and pier cap had to be demolished and replaced with new ones, considering their bad conditions. The concrete of class C 35/45 was used to rebuild those elements. Footing of the pier was strengthened by reinforcing steel. The new footing extension was cast of the concrete C 30/37. Also the micropiles were installed through the existing foundation to increase the capacity of existing massive footing and to enhance the stability of the pier (see Fig. 7). The vertical and inclined micropiles were designed with 159 mm nominal diameter. Finally, the prestressing bars of 32 mm diameter were horizontally installed through the new footing extension and the waist of the original pier. The new riprap stone was constructed against scour around the pier area.

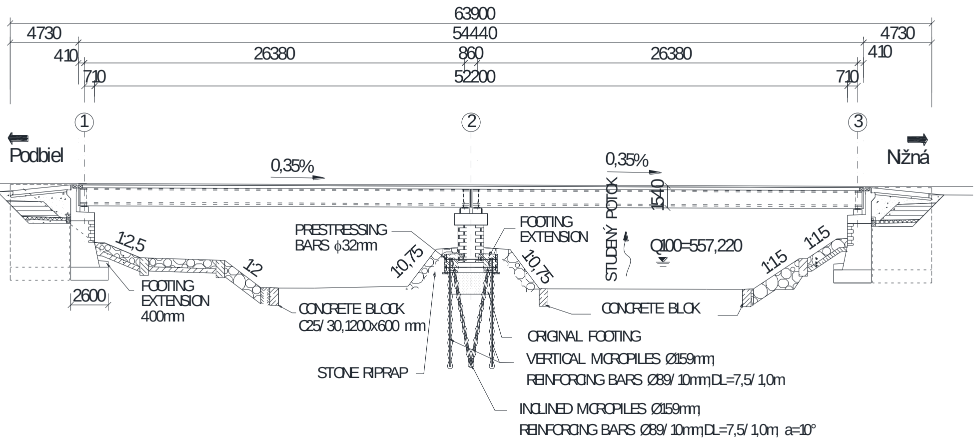

Fig. 7. Longitudinal section of the new bridge.

Due to the extreme traffic situation in the region, the new superstructure had to be built in a very short time. Therefore, the same type of precast superstructure was designed using the original substructure. The new bridge superstructure follows the same vertical layout and horizontal curve radius of the original road I/59. The bridge consists of two simple supported spans 26.38 m + 26.38 m long with composite continuous bridge deck. The width of the new bridge structure is 11.98 m. The transverse slope of the bridge is one-sided 2.5 %. The investor’s requirement was to extend the width of the roadway from the original dimension of 9.0 m to the standard one of 9.50 m. The one-side footpath is placed on the left side. The cross-section consists of 9 standard precast pretensioned girders “DPS VP I/10”, 27 m long and 1.5 m high. The girder spacing is 1.29 m and designed concrete class of girders is C 55/67. The thickness of concrete deck is min. 200 mm from concrete class C 35/45 (see Fig. 8).

Fig. 8a. View on the rehabilitated structure.

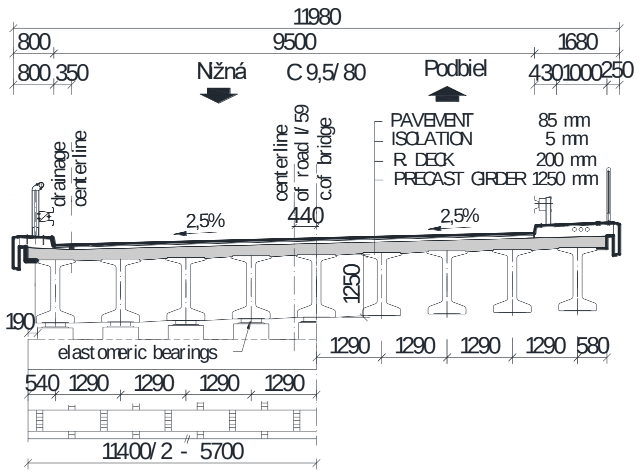

Fig. 8b. Cross section of the new superstructure.

6. Conclusion

As it is shown in the above-mentioned emergency case, it is necessary to know exactly how to deal with such prestressed structures that have more than half of its service life. Especially, the first-generation prestressed bridges, precast or monolithic ones, are beginning to exhibit increasingly frequent problems resulting both from the level of knowledge and technical capabilities of the then designers and contractors of such structures. The inspection made within the frame of this work confirmed that the main factor of the superstructure failure was the corrosion of the prestressing wires and the anchors those were installed without grouting. In combination with the absence of conventional reinforcement, the girders behaved actually almost as a plain concrete member with unbonded prestressing. In addition, prestressing was losing its capacity due to corrosion. Anchoring about 1/3 of the cables in the top flange of the girder and low or almost non protection of the anchors in the girders accelerated the corrosion processes. The low level of maintenance quality in combination with heavy traffic on the bridge was affiliated to that effect too. On the basis of the presented case, it can be stated that the main disadvantage in such diagnostic process is the question how to determine the real level of prestressing. Of course, indirect diagnostic methods can be helpful in practice which are based mainly on the observation of the values of deflections and deformations on existing concrete bridges, as well as in the presented case.

Early and accurate diagnostics intervention using detailed diagnostics and structural analysis is the most suitable approach how to prevent a similar emergency situation in the bridges – especially in the case of prestressed bridges where we suspect or even know some systematical deficiencies of the original technology. That is why there is a need even more thorough and more frequent inspection in the form of regular monitoring and possibly detailed diagnostics because the subsequent solution of the emergency situations with a sudden act of the traffic closing is often very complicated. It may result in serious problems from the social point of view and requires substantial financial costs for rapid rehabilitation.

Acknowledgements

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Summary

This paper is focused on the primary causes of failures and collapse state of the concrete bridge superstructure located in the north of Slovakia. It is situated on the international route I/59 connecting Slovakia with Poland and registered at No. 59-090. Dangerous structural defects of brittle character were found in four girders of the bridge structure during the routine inspection in 2015. Subsequently, it was declared as being in the emergency status and immediately closed for the traffic at the end of 2015. This bridge was built in 1956 as a bridge of the first generation of the precast and prestressed structures in Czechoslovakia.