

Anchorage length of patented wire cables in prestressed bridge girders

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This paper briefly describes the methodology, performance and the obtained results of unique experiments performed on original I-73 precast bridge girders. The main objective of the experiments was to determine the actual anchorage length of corroded-through fully grouted prestressing reinforcement (prestressing wires), which is important for determination of the residual load-bearing capacity of prestressed structures. Observation probes leading all the way to the prestressing wires were drilled on selected sections of the girders along the length of the prestressing reinforcement. Optical image acquisition devices were then installed at these probes. Subsequently, controlled breakage of the patented wires (corrosion failure simulation) and observation of the changes that occurred in the prestressing wires after relief of stress were carried out. Evaluation of the experiments was then performed by analyzing the images obtained before and after the prestressing reinforcement failure.

INTRODUCTION

As of 2020, about 2600 bridges with prestressed precast girders of the KA and I type (most commonly KA-67 and I-73) could be found within the road network in the Czech Republic. These bridges were built between 1960 and 1990. It is estimated that dozens to hundreds more bridges of these types are owned and managed by cities and municipalities.

For the purpose of scientific research, an original 27-meter-long prestressed precast bridge girder of the I-73 type was obtained during bridge demolition near Pasohlávky (Fig. 1). In a cross-section, this girder, together with 7 other pre-stressed precast girders (with longitudinal joints 0.43 m wide), constituted the structure of the bridge ev. no. 52-059 “Most přes přelivný objekt za obcí Pasohlávky” (Bridge over the overflow structure behind the village of Pasohlávky) since 1979. In the longitudinal direction, the bridge consisted of 4 spans, all of which included 27-meter-long prestressed I-73 girders – the examined girder came from the first span in the direction from Mikulov, and in a cross section, it was the right outer girder. The outermost girder was selected

for the proposed experiments, because with regard to the transverse slope of the road, the outermost girders are usually the ones affected the most by leaking and other related degradation processes.

The main objective of the performed experiments was to provide a qualified answer to a frequent question that has not been addressed so far, namely “What is the actual anchorage length of the corroded-through fully grouted prestressing reinforcement and to what extent can reliable anchorage of prestressing reinforcement damaged in this way be considered in static calculations?”.



Fig. 1. A complete view of the 27-meter-long I-73 girder during performance of the experiments

Prestressed precast girders of the I-73 type

Precast girder bridges are characterized by prestressing systems made of patented wire cables, most often marked Pz ϕ 4.5 mm. The entire prestressing system consists of continuous cables, which are anchored in girder faces, and non-continuous cables, which are anchored in anchorage areas prepared on the top surface of the precasts. The prestressing system was designed according to the principles of load balancing, and, by using a number of curved cables, it reduced the shear stresses on the girders to such an extent that the reinforcement of the girders against shear and torsion was practically only secondary. [1]

The cables are supposed to be protected by the alkaline environment of the grouting mortar, usually filled through a single anchor at the end of the girder through the cable duct to the opposite cable anchor. The relatively large number of prestressing cable failures which has been diagnosed in the last ten to twenty years in the anchoring areas represents evidence of substandard workmanship during construction and they also cause frequent statements about removal of such bridges and replacement with new structures, even though these structures are 50 to 60 years old and far short of the previously estimated service life of 100 years.

METHODOLOGY AND PERFORMANCE OF EXPERIMENTAL MEASUREMENTS

In cases in which diagnostics detects corrosion of the cables in the end locations of the girders (near the anchors), while in other parts of the bridge the cables are properly grouted, a question arises as to what is the actual degree of weakening of the girders. Since the early days of prestressed concrete, it has been assumed that in addition to its protective function, the grouting of the cables is also supposed to ensure full cohesion of the cables with the concrete of the girders to the extent that they can be taken into account in the determination of the load-bearing capacity and to provide for additional anchorage of the cables in cases in which the anchorage of the cables in the original anchors fails during the service life of the structure.

It is therefore advisable to investigate the actual additional anchorage length of the original prestressing cables, from which the proposed anchorage length can then be derived for the additional evaluation of girders or bridges damaged in this way (using a safety factor or statistical methods with a sufficiently large number of tests). In doing so, it is also necessary to determine the quality of the original grouting and at least one basic mechanical characteristic - the strength of the grouting mortar.

Researchers from the Faculty of Civil Engineering of Brno University of Technology have proposed a methodology for an in-situ experiment that uses optical devices to monitor the measured variable, i.e. the slip of the cable wires in the grouting mortar by taking images during a controlled breakage of the prestressing reinforcement (the simulation of a full-scale corrosion of the reinforcement) at predefined locations along the length of the cable. The experiment is then evaluated on the basis of image analysis.

In the preparatory phase of the measurement, it was necessary to define the locations along the length of the cable at which the reading of the prestressing reinforcement slip would be carried out. These locations were evenly distributed along the length of the expected an-

chorage length, which was determined according to the methodology listed in EN 1992-1-1[2] (analogically to the calculation of the anchorage length for prestressed elements in which the prestressing reinforcement is anchored only by cohesion).

It was necessary to drill semi-destructive probes to the prestressing reinforcement at the measurement reading points so as to expose the individual cable wires, and, at the same time, to avoid any large impairment of cohesion between the individual cable wires and the grouting mortar which would affect the measurement result. In the probes, the protector was removed and approximately 40 mm of the outermost wires of the cable was exposed. The size of the probes was selected on the basis of the measuring technology (digital cameras) used to perform the measurements.

Experimental measurement of the anchorage length of the prestressing cable in an existing construction has been realized neither in the Czech Republic nor anywhere else in the world so far. Before the implementation, the authors performed a theoretical calculation of the anchorage length corresponding to the standard assumptions, but the actual anchorage length had to be verified experimentally. That is why relatively small distances between semi-destructive probes were selected as well as the frequency of the probes, so that the measured data could be used to compile a slip function with sufficient accuracy.

There is no method of measuring the cable slip along its length in an existing prestressed structure other than to uncover it at several locations, and by doing so, to locally damage the cohesion of the cable with the grouting. This means that at the probe locations, the outermost wires were exposed (approximately 30-40% of the cable wires) and the rest of the wires were not affected. Exposing the outermost wires introduces a measurement error into the measured values – the measured slip values are overestimated compared to the reality in which the fully grouted cable is corroded-through. The authors of the experiment are aware of this measurement error, but the



Fig. 2. A measuring set of digital cameras at the open semi-destructive probes during the experimental measurement of the anchorage length of a straight prestressing cable (EXP1)

anchorage length measured in this way, which is then used in the structural calculations of the structure, can be considered safe and relevant for the above reason.

For the actual measurements, digital cameras were used. These were installed on tripods at the semi-destructive probes along the length of the measured cable (Fig. 2). Observance of constant lighting conditions and distances between the lens and the measured wires of the prestressing cable was a prerequisite for successful measurements using optical devices. In addition, auxiliary gauges were glued into the probe area and used to calibrate the measured slip distances during the evaluation.

The measurement methodology was based on a capture of image of the prestressing wires using digital cameras in open probes before and after controlled breakage of the prestressing cable using an angle grinder as well as on a comparison of images – image analysis (Fig. 3). During the image processing, common features for each pair of images (before and after the breakage) were found at the pixel level. This allowed us to evaluate the change of conditions captured in the probe (wire slip). The photographs were calibrated using external measures for the purpose of measuring of the magnitude of the slip.

A total of 3 experimental measurements of the anchorage length of the prestressing reinforcement with the following denotation was designed and performed:

EXP1 Measurement of the anchorage length of a continuous straight cable of the I-73 girder (cable No.1, according to [1]), which leads through the bottom flange of the girder (Fig. 4). The experiment was prepared at a distance of 2.2-3.315 m from

the anchorage area of the girder on the side in the direction towards Brno. The wire slip was measured at 6 locations at the distances of 150, 300, 500, 700, 900 and 1150 mm from the breakage point.

EXP2 Anchorage length measurements of the same continuous straight I-73 girder cable as in case of EXP1, but the experiment was prepared near the anchorage area on the side from Mikulov, again at a distance of 2.2-3.315 m from the edge of the girder. The experiment was designed symmetrically to the EXP1 experiment with the axis of symmetry drawn in the middle of the girder span. The wire slip was measured at 6 locations at the distances of 150, 300, 500, 650, 900 and 1150 mm from the breakage point.

EXP3 Measurement of the anchorage length of a continuous curved cable of the I-73 girder (cable No.8, according to [1]), which is anchored in the girder web (Fig. 5), through which it traverses longitudinally in a curved trajectory consisting of a straight section and an arc of $R = 10$ m, and at a distance of 4.86 m from the girder edge, it transitions from the arc to a straight section led in the bottom flange of the girder. The experimental measurement was performed close to the anchorage area at a distance of 0.8-1.7 m. The wire slip was measured at 5 locations at the distances of 150, 300, 500, 700 and 900 mm from the breakage point.

A schematic representation of the experiments is shown in the following figures.

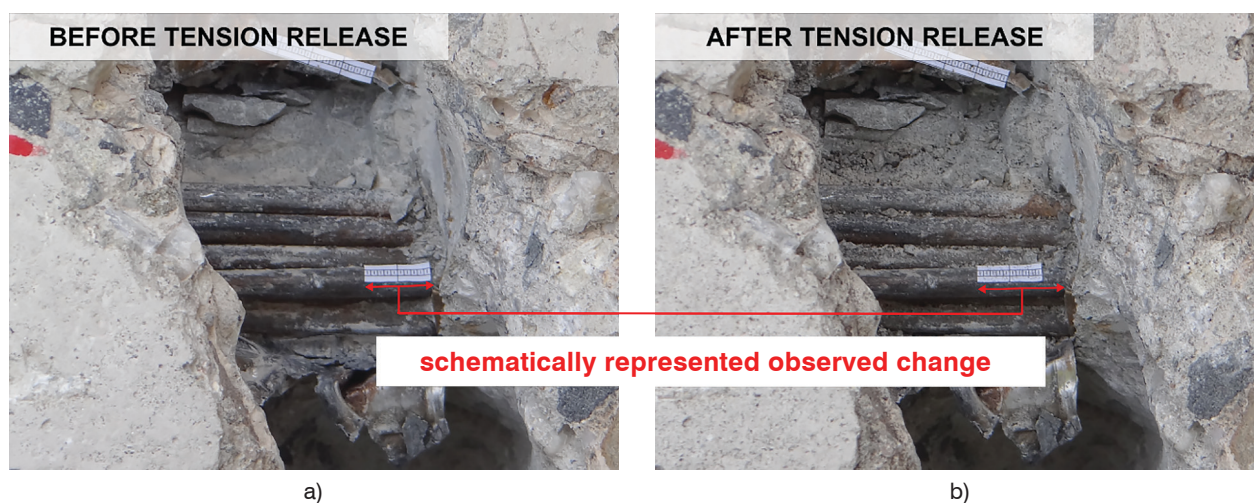


Fig. 3. A sample of images from the measuring of the slip of the I-73 girder prestressing reinforcement. The left image shows the condition before tension release, the right image shows the condition after tension release (after the performed slip)

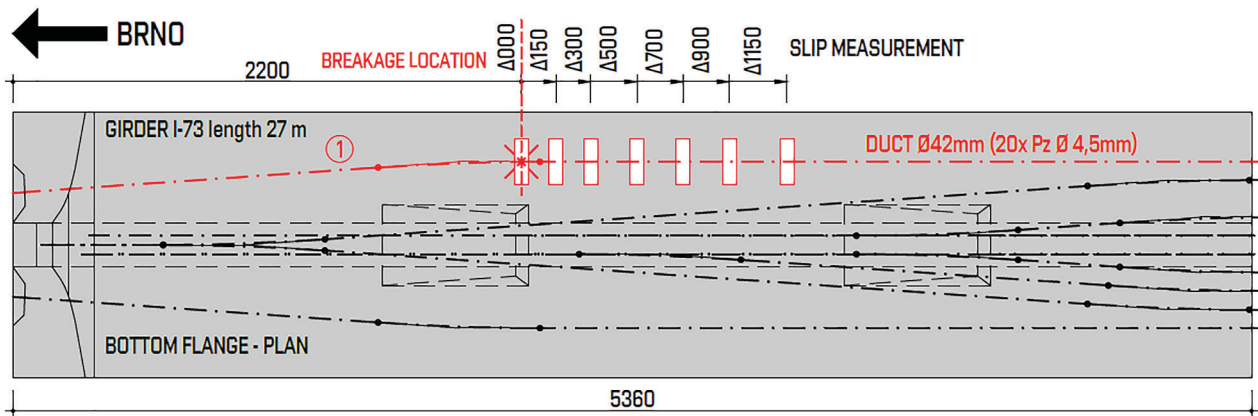


Fig. 4. Schematic illustration of the experimental measurement of the straight cable anchorage length (denoted EXP1) In the case of EXP2, the measurements were made symmetrically to EXP1 with the axis of symmetry drawn in the middle of the girder span

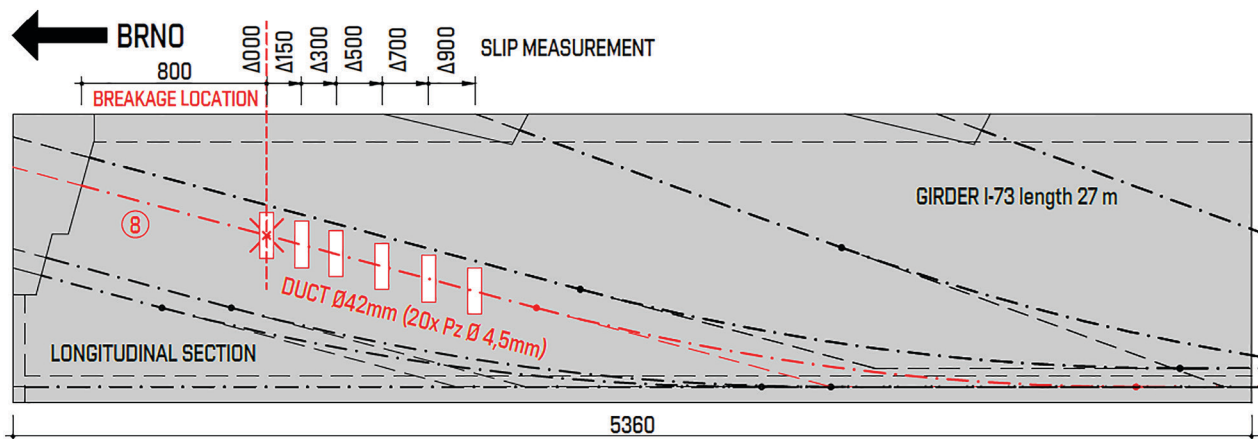


Fig. 5. Schematic illustration of the experimental measurement of the curved cable anchorage length (denoted EXP3)

OBTAINED MEASUREMENT RESULTS

Using the above mentioned image analysis methodology, the following results of the slips of individual wires in the open probes on the straight cables and on the curved cable were obtained. On the basis of these results, the anchorage length of the prestressing reinforcement (zero slip location) can be determined experimentally.

The resulting graph of the measured slips of the 4 wires of the straight cable is shown in Figure 6 (experiments denoted EXP1, EXP2). By mathematically interposing the measured values with a second degree curve, it is possible to determine the anchorage length of the straight cable, which, according to the measured values, reaches a length of about 1.9 m.

The resulting graph of the measured slips of the 4 wires of the curved cable is shown in Figure 7 (experiment denoted EXP3). By interposing the measured values, the anchorage length of the curved cable was determined to approximately 1.2 m. This experimentally determined anchorage length of the curved cables is significantly

shorter than in the case of straight cables – the effect of the curved cable trajectory, which contributes to their “docking”, has manifested itself.

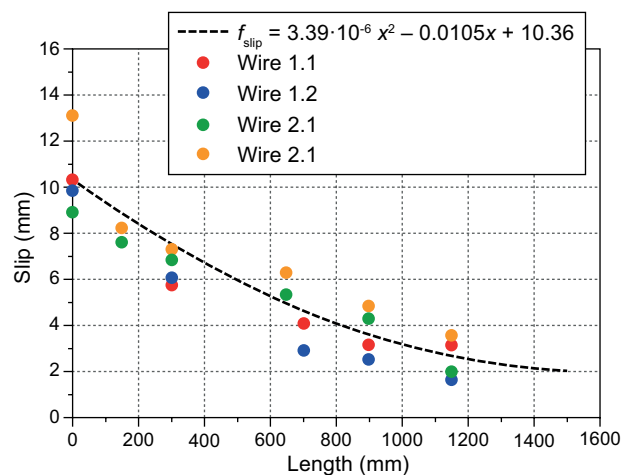


Fig. 6. The resulting anchorage length measurement graph for the straight cables of the I-73 girder (EXP1 and EXP2)

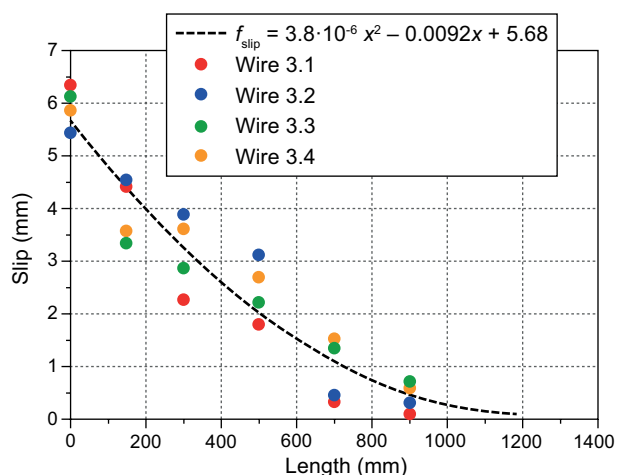


Fig. 7. The resulting anchorage length measurement graph for the curved cable of the I-73 girder (EXP3)

CONCLUSION

The performed experimental measurements of anchorage lengths and their results have demonstrated the applicability of the proposed methodology for investigation of the actual anchorage length of the prestressing reinforcement of precast prestressed girders built between 1960 and 1990. The performed experiments also be used to confirm the hypothesis regarding “over-anchorage” of the prestressing reinforcement and the capture of the prestressing force by the grouting mortar, which forms the basic assumption for the determination of the load-bearing capacity of prestressed precast girders.

Anchorage lengths of the interrupted fully grouted straight cable and the curved cable of the prestressed precast girder of the I-73 type from 1979 were determined

in the experimental measurements. In the case of the straight cable, using mathematical interposing of the measured values, the anchorage length was determined to be approximately 1.9 m, and in the case of the curved cable, it was determined to be approximately 1.2 m. The investigation will continue with static analyses (including the safety coefficients) to answer the question as to what degree does the interrupted over-anchored prestressing reinforcement affect the load-bearing capacity of the entire element.

In the next steps of the research, experiments of this type will continue so that the set of the measured values was more extensive, and, at the same time, the problem will be investigated numerically using the FEM method, in which the mechanical parameters of the grouting mixtures which affect the cohesion of the prestressing reinforcement with the grouting will be used.

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REFERENCES

1. Konštrukce cestných a diaľničných mostov z prefabrikátov I-73 dĺžky 21-30 m, Typový podklad, Dopravoprojekt, Bratislava 1973.
2. EN 1992-1-1 Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings, European Committee for Standardization, Brussels 2004.