CORROSION PROTECTION AND MONITORING OF ELECTRICALLY ISOLATED POST-TENSIONING TENDONS

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The paper describes the experience and future trends in Switzerland and Italy with regard to durability and monitoring of post-tensioning tendons in prestressed concrete bridges and viaducts. Attention will be focused on the Italian high speed railways bridge under construction and on viaducts and fly-overs already built in Switzerland.

Two major tasks have been considered in the planning and design of these structures: durability and possibility of monitoring. In order to reach these goals in the frame of post-tensioning systems for prestressed concrete bridge decks, the thick-walled corrugated plastic ducts for bonded internal tendons have been applied and electrically isolated anchorages have been adopted, as first applications of these systems in Swiss and Italy.

Keywords: Post-tensioning; Durability; Plastic ducts; Electrically isolated tendons; Monitoring of post-tensioning Systems

1 Introduction

Post-tensioning tendons contribute decisively to the serviceability, safety and durability of prestressed concrete structures, especially of road and railway bridges. Optimum corrosion protection of post-tensioning tendons has been a priority since the beginning of this technology. The critical aspects of durability of post-tensioning tendons are summarized in a recent state-of-the-art report [1]: main problems are corrosion due to the ingress of chloride containing water and the lack of an established non-destructive technique that is able to obtain reliable information on the corrosion protection of the prestressing steel. Several national guidelines approved in the last years try to improve the situation. In Switzerland the SIA codes state that depending on the environmental conditions more stringent requirements may apply to achieve durability of post-tensioning tendons. The guideline “Measures to ensure the durability of post-tensioning tendons in bridges” published recently in English [2] thus explicitly requires the use of electrically isolated tendons with grouted plastic ducts for longitudinal tendons with low structural protection (concrete cover), high risk of chloride ingress and/or particular requirements for long-term monitoring. In Italy the new high-speed train lines have been planned and designed according to two major goals that are durability and possibility of monitoring [3].

Industry developed, manufactured and improved in the last years thick wall plastic duct systems including electrically isolated anchorage and couplers where the prestressing steel is protected on the whole tendon length. The requirements for these plastic ducts are defined in a fib technical report [7]. The electrical isolation protects against stray currents and, more important, allows to assess the degree of the corrosion protection of the prestressing steel both during construction (quality control) and during the service life of the structures (long term monitoring) by measuring the electrical impedance between the prestressing steel in the duct and the normal rebars in the structure [2,4,5].

All the results are further evaluated and compared to specific (independent of the length of the tendon) values of the capacitance, the electrical resistance and the loss factor from laboratory tests of grouted plastic ducts [4]. In addition, possible solutions for practical execution problems encountered are proposed.
2 Electrically isolated tendons

The design of an electrically isolated system for internal bonded post-tensioning differs from the normal one in order to a) guarantee the maximum degree of protection of cables against corrosion, and b) to allow at any time during the service life of the structure checking of the integrity of the protection with a rapid non-destructive method. The plastic duct fully encapsulates and isolates the strand bundle on the whole tendon length. Detailing is most important near the anchorages in order to guarantee complete encapsulation and electrical isolation [5]. Also the connection to the plastic trumpet, vents and drains need great care.

Another advantage of plastic ducts is the reduction of friction losses. The friction coefficient μ is 0.14 instead of 0.3 for steel ducts. The phenomenon of fretting fatigue is greatly reduced.

2.1 Anchorage

Between the steel anchor head (a in fig. 1) with the wedges that block the strands and the cast iron bearing plate (b), a mechanically resistant insulation plate (c) is placed in order to electrically isolate the tendon from the normal rebar network. Inside the anchorages a plastic trumpet (d) tightly connected to the duct (e) isolates the strands from the cast-iron bearing anchorage.

According to Swiss guideline [2], the anchor heads are protected by plastic caps (f) and fully grouted. Italian Railways asked for transparent caps in order to check visually the grouting execution of the caps. The guideline leaves to the designers the choice to cover the anchorage caps with concrete or not. The Italian Railways choice was to ask to all designers for head anchorages completely surrounded by non-shrinking reinforced concrete (g) as a mean of further protection.

The assembling of the ducts may be solved with plastic couplers produced by the prestressing companies, by thermal welding of the head faces with a special machine, before assembling, or by plastic collar and outer thermal shrinking sheath. Also the connection to the plastic trumpet of the anchorages must be carefully executed, with a watertight gasket and thermic shrinking sheath. The end of the grout inlets and vents should be carefully closed with a tight cap, otherwise an electrolytic pathway with preferential ingress of chloride containing water is formed. Leak test of the whole duct before grouting is important – a simple but efficient method was found to pull a lamp through the duct and observe (at night) any signs of light.

2.2 Duct

Ducts are usually made of high-density polyethylene or polypropylene: the fib Technical Report [7] specifies mechanical resistance and chemical requirements for the acceptance of a plastic duct. In particular, any new prestressing system with plastic ducts has to pass a System Approval Testing [7]. In Switzerland two systems are approved so far. The Italian Railways have recently started to apply System Approval Testing to every new system proposed by the construction companies. So far only one electrically isolated system has been approved and used on site.

![Figure 1: Electrically isolated tendon](image)

2.3 Measuring the impedance of the duct

The measurements of the electrical isolation between the strand and the rebars require a sound electrical connection (h in fig. 1) to each individual tendon (mostly mounted to one of the end anchorages) and another connection to the rebars. All the connection wires (area 1 mm² apart from the case of AC railway bridges where it is 6 mm²) are concentrated in a box easily accessible. Monitoring of the electrically isolated tendons was performed with AC impedance measurements at a frequency of 1 kHz with portable LCR meters. The instrument measures the impedance Z that includes (over the tendon length) the grout in the duct, the duct (with couplers, vents, pores and defects) and the concrete surrounding the duct. Grout and concrete are pure resistances, the intact polymer duct is a pure capacitance and “defects” are represented by ohmic resistances in parallel. The instrument calculates and displays the ohmic resistance R, the capacitance C and the loss factor D.

The capacitance C is constant for a specific tendon length, diameter and material, it increases proportionally to the length of the tendon. The ohmic resistance R for a given tendon decreases with its length. For a good electrical isolation the specific value ρ (Ωm) should be as high as possible, limiting values are given in [2]. ρ increases with time due to hydration and drying out.
The measurements of R, C and D allow to determine the degree of electrical isolation (and thus of the tightness of the duct on its whole length) at any time after grouting. This can be used both for quality control and for long-term monitoring of the corrosion protection of post-tensioned tendons.

3 Quality control

28 days after grouting the impedance measurements shall be performed for the first time [2]. The results can be used as a first quality control of the degree of electrical isolation. This quality control may be particularly useful when a great number of identical post-tensioned decks are produced in a pre-casting plant as it is the case for many railway bridges in Italy. The first application of this technology is the Piacenza Viaduct (figure 3 and 4), on the Milano-Bologna high speed line: 151 simply supported pre-cast prestressed concrete decks composed by a monolithic box girder with two cells, each spanning 33.1 m and weighing about 1000 tons. Other continuous prestressed concrete slab decks are under construction and the results of tests will soon be available.

So far, data have been collected from the first 38 decks of the Piacenza viaduct, each containing 9 cables with 12 wires, duct Ø 76 mm (in the lower slab) and 15 cables with 19 wires, duct Ø 100 mm (in the webs), both typologies of about 32.1 m length (figure 3).

A first control on the execution quality allow the values of the capacitance C: the mean value of the capacitance increases with the diameter of the duct, the specific capacitance (per meter length) is well below the limiting value specified in [2]. Thus the wall thickness of the duct is higher then required for electrical isolation and the execution is sufficiently well done.

<table>
<thead>
<tr>
<th>Type</th>
<th>C mean [µF]</th>
<th>Std dev [µF]</th>
<th>C spec. [µF/m]</th>
<th>C lim [µF/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø 76 mm</td>
<td>70.3</td>
<td>2.3</td>
<td>2.2</td>
<td>&lt; 3.05</td>
</tr>
<tr>
<td>Ø 100 mm</td>
<td>73.5</td>
<td>2.2</td>
<td>2.3</td>
<td>&lt; 3.35</td>
</tr>
</tbody>
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The statistical analysis of the measured resistance R is more complicated because the values do not show a gaussian distribution. The analysis is thus performed with the cumulative probability plot (figure 5). The plot shows that overall less then 1% of all the values are below 10 Ohm, thus cables with a short circuit (electrical contact) between the strand and the rebars. The limiting value R (300 kΩm / 32.1 m) is not reached by about 9% of the cables with the duct diameter of Ø 100 mm. Individual cables show even better performance (e.g. cable 11, 17). From figure 5 it can also be noted that for every cable nr. one or more segments were produced with a perfect isolation (reaching the theoretical value of a completely tight plastic duct).

4 Long term monitoring

The flyover “Prés du Mariage” [4, 5] is a simple, short construction with only one column in the middle. In each bridge girder three tendons were installed. The AC impedance of each of the six individual tendons
Tensioning system and to apply it in the future when durability of post-tensioning tendons has to be improved.

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References


5 Conclusions

The experience with the new electrically isolated post-tensioning system with plastic ducts are very encouraging both in Italy, and in Switzerland.

Measuring the electrical resistance 28 days after grouting has been shown to be an efficient way for quality control especially when a number of cables has to be checked in a large amount of simply supported spans.

Monitoring the electrical resistance of the tendons over time allows to identify the penetration of (chloride containing) water at defects of the duct – thus for the first time a simple, cost effective early warning system can be installed.

The large scale application of this technology in some high speed railway viaduct in Italy will allow the Italian Railways to reach enough confidence with this

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