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Inspection and Monitoring of post-tensioned bridges – advantages of electrically isolated tendons (EIT)

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Abstract

Problems in existing post-tensioning structures with metallic ducts occur mainly related to corrosion of the tendons due to chloride ingress at "weak points" in the structure. Despite this PT technology overall can be considered as proven and successful, sometimes severe damages and collapses without warning are reported. As none of the existing inspection and monitoring methods allows a complete and meaningful evaluation of post-tensioning tendons in existing structures, owners and engineers face uncertainty regarding safety and durability of existing post-tensioned structures with metallic ducts.

The situation changed with the introduction of corrugated polymer ducts and electrically isolated anchorages (EIT) in civil engineering practice about 25 years ago. Polymer ducts prevent the ingress of aggressive substances into the tendons and the electrical isolation allows monitoring of the tendons with simple, hand-held instrumentation over the whole service life. Based on many results from laboratory and field It is concluded that EIT tendons can be considered a smart structure not necessitating additional sensors. For the first time the most important structural elements, the tendons, can be easily monitored over time and initiation of damage can be detected early.

Keywords

Durability, non-destructive testing, polymer ducts, electrically isolated tendons, long-term monitoring

1 Introduction

Most of road and railway bridges are built with prestressed concrete. Post-tensioning with high-strength steel and bonded by grouting is a construction method that generally performed well, but corrosion of the prestressing steel is a great danger for the serviceability and load-bearing capacity of PT bridges. Sometimes even collapses occurred without signs of warning [1], the most recent tragic event was the collapse of the Polcevera viaduct in Genoa, Italy, in 2018 [2].

The development and increasing worldwide application of tendons with polymer ducts and electrically isolated anchorages (Figure 1) opened a new area in prestressed concrete construction. Initially developed, tested and applied in Switzerland [3, 4, 5], the EIT technology now is used world-wide. The Swiss guideline [6] was at the root of the fib recommendation for EIT [7]. The Italian Railways massively used EIT in the prefabricated segments of the Piacenza viaduct [8]. Further results can be found in ref. [9, 10]. Recently also the US FWHA is exploring the experience in Europe [11] and working on the adaption of EIT to US construction practice, e.g. the use in conjunction with epoxy coated reinforcement [12]. EIT technology is recognized to greatly improve corrosion protection of the high-strength steel in the ducts, the main advantage however is the easy way to measure and control during the whole service life the degree of protection and encapsulation of the structurally most important elements, the post-tensioned tendons.

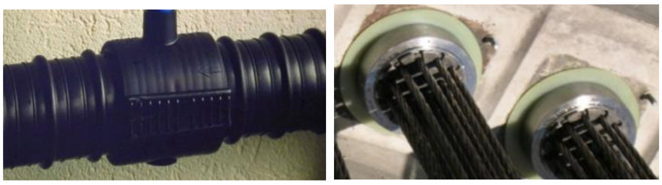

Figure 1: The EIT system: thick corrugated polymer duct with grout vent coupler designed and produced to fit perfectly tight on the duct in order to guarantee a fully leak tight duct system (a), electrically isolated anchorage plate requires a high-strength, isolating polymer disc put between anchor bearing plate and anchor head (b).

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2 Measuring degree of protection

Given the electrical isolation of the strands in the grouted polymer duct from the reinforcement cage, the degree of protection of the encapsulation can be measured. The measuring path (Figure 2) is steel strands – grout – polymer duct – concrete – reinforcement, the polymer duct being an electrical isolating material has a very high resistance. The measurements are performed with a simple hand-held LCR instrument with a frequency of 1 kHz [4 – 7]. The measured AC impedance (here simply termed "resistance") is a direct measure of the quality of the encapsulation, the associated capacity C is given by the material, thickness and diameter of the polymer duct.

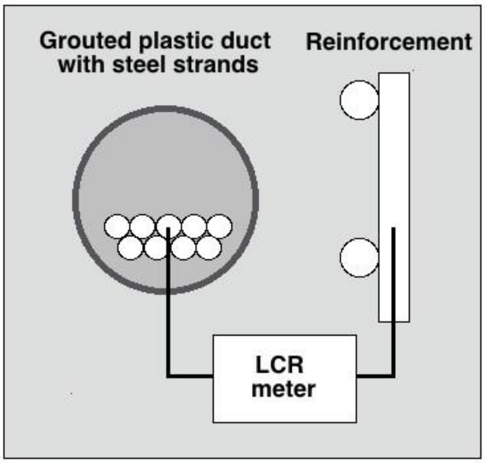

Figure 2: Measuring principle: system of steel strands in grouted polymer duct vs reinforcement in concrete

In order to study the effect of defects in the duct, laboratory measurements were performed [5, 6]. The results showed a marked decrease in the measured resistance from intact ducts (values of ca. 2 MΩm) due to the presence of an *electrolytic leakage* at the point of the defect, where grout is in direct contact with concrete (2 mm hole in the duct, R < 0.1 MΩm).

The recommended limiting values for electrically isolated tendons according to the main reason for their use of the Swiss guideline [6] are given in Table 1. Measurements shall be performed 28 days after grouting.

Table 1 Limiting values for EIT Tendons according to Swiss guideline

criteria	Resistance R (1 kHz)
Avoid fretting	R > 20 Ω
Long-term monitoring	R > 50 kΩm
Avoid stray current	R > 150 kΩm

Note that even if the limiting values for long term monitoring are not reached, the degree of corrosion protection of the tendons can still be followed over time.

3 Long-term monitoring of structures

Post-tensioning structures with electrically isolated tendons (EIT system) can easily be monitored over time, no additional sensor is needed. The electrical resistance between the steel strand in the polymer duct and the normal reinforcement in concrete allows to check at any time during service life the degree of corrosion protection. The electrical resistance of both grout and concrete increase over time (similar as the compressive strength of concrete) with a square root law [5]. In the log-log plot as Figure 3 this corresponds to a slope of the trend line of 0.5. An example of this continuous increase are the six tendons of the flyover Prés du Mariage (Switzerland), constructed in 1993. The small fluctuations are due to changes in temperature at the time of measurement.

Another bridge with four tendons shows a similar increase of the electrical resistance over time (Figure 3b). However, one of the four tendons after about 1 year of service showed a continuous decrease of the resistance – a clear sign of ingress of water at a defect present in the duct.

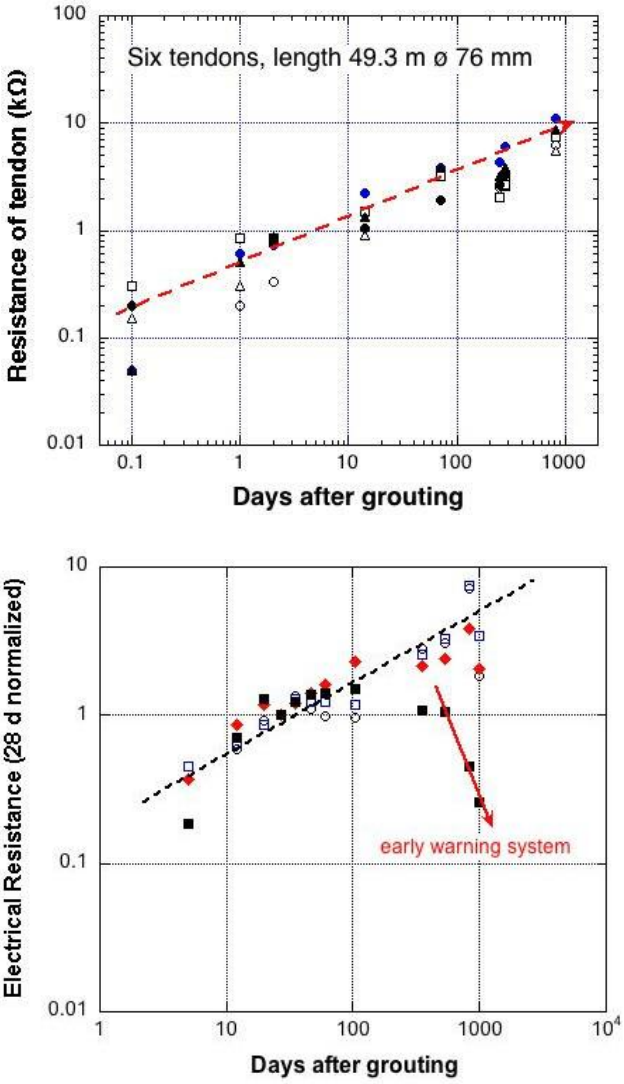

Figure 3: Examples of long-term monitoring of the electrical resistance of tendons in bridge girders, resistance plotted in a log R vs log t graph. Prés du Mariage, pilot object with six tendons, continuous increase (upper), bridge where one tendon shows a clearly decreasing resistance after 300 days, indicating ingress of water (lower).

4 Conclusions

Electrically isolated tendons (EIT) are a proven system to enhance the durability of prestressed structures. Results from structures in Switzerland and a large scale application in the Piacenza viaduct of the Italian high-speed train network document the successful application in practice.

As stated in a recent report of US Federal Highway Administration [12] “Establishing electrical isolation of tendons permits long-term non-destructive monitoring of the tendons in service. Changes in electrical measurements made over time can be used to identify developing breaches in the protective systems or detect ingress of moisture or chlorides through defects in the encapsulation. Early detection of these changes can warn of an elevated corrosion risk and perhaps trigger a more in-depth evaluation of the PT tendon before significant corrosion damage has occurred.”

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