

Internal post-tensioning tendons : many problems and sometimes solutions

Ir Pierre GILLES, Ingénieur des Ponts et Chaussées, Direction de l'Expertise des Ouvrages, Service Public de Wallonie, Belgium

1 INTRODUCTION

When internal post-tensioned bridges are inspected, numerous defects can be observed or suspected. Generally these defaults are related to water with de-icing salt percolation through vents, anchorages, and concrete itself.

This paper will review three case histories encountered in Belgium with old (about 40 years) bridges using wires or monostrands.

Identify and quantify these defects is difficult and non destructive techniques are mainly inefficient. We have techniques to locate tendons as high frequency radar or gammagraphy. To detect void into the duct, often metallic sheet, there are not yet field techniques. Some methods seem to give good results in laboratory (impact-echo, ...) but it will take several years to use these methods on the field. To detect corrosion, it is generally impossible due to the presence of the reinforcement and/or the metallic sheet duct.

Most of the time, the main investigation method is to perform an opening (window) into the concrete, up to the tendon. It allows injection quality evaluation (void, moisture,...), wires or strand corrosion observation, grout sampling for chloride analyse, ...

Nevertheless, even after investigation, the main question remains often without precise answer : what is the remaining load capacity of the bridge considering the defaults ?

2 BRIDGE A : MULTI SPAN BEAM BRIDGE

2.1 Bridge structure

Bridge A is a beam bridge 600 length with a double deck. Beams were built on site and post-tensioned. Several tendon anchorages are present in the upper face of the deck slab (figure 1). At the construction time (middle 60's), it was a kind of challenge to design the beam with a very low reinforcement versus post-tensioning ratio.

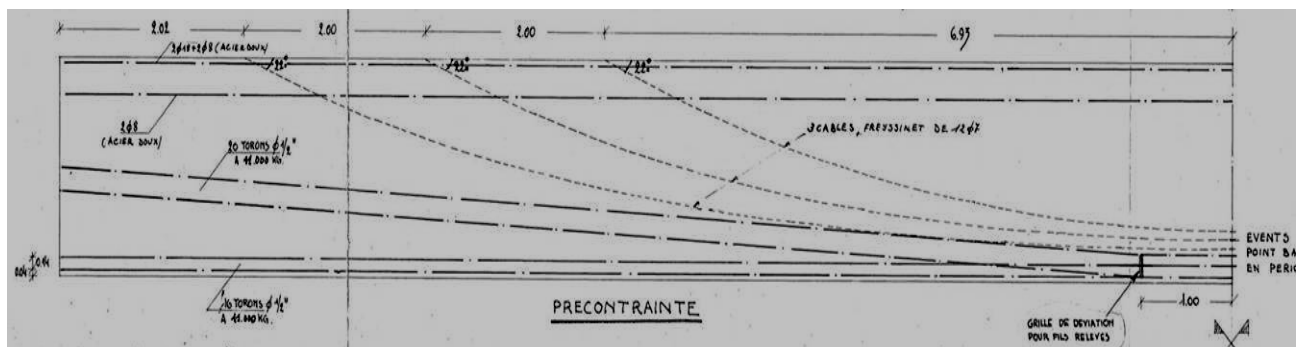


Figure 1 : Post-tensioned beam : half longitudinal cross section

The deck is composed with these beams and with prefabricated transversal beams (figure 2), assembled by post-tensioning tendons (1/m in the slab and 1/transversal beam in the lower part).

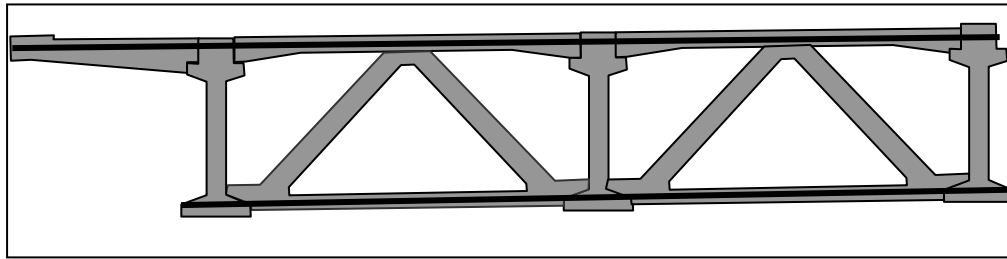


Figure 2 : Bridge deck : half transversal cross section

2.2 Bridge Inspection

The inspection procedure was not applied normally for this bridge. That is the reason why defaults have been observed when the degradation was already very important.

Due to leakage in the waterproofing system, water went into deck anchorages, followed duct with many voids and induced severe corrosion with complete tendons rupture (figures 3 and 4).



Figure 3 : Concrete spalling along tendons



Figure 4 : Corroded tendons after removing of concrete spalling

Due to tendon corrosion, concrete delamination and spalling occurred on both side of the web beam. After removing the spalled concrete, easily done due to the light reinforcement, a hole appeared through the web (figure 5).



Figure 5 : Corroded tendon and hole in the web

These defaults concern only the edge beams located under the gutter. A total of 26 beams have to be replaced for a total of 42 edge beams.

In the slab, water goes also through the concrete up to transversal tendons. Many wires are broken and 20 % of the transversal tendons are considered ruptured (figure 6).



Figure 6 : Corroded slab transversal tendon

2.3 Bridge rehabilitation

Edge beams and concrete slab have to be replaced. Doing that, a stability problem will occur due to the fact that the transversal post-tensioning in the lower part of the transversal beam will not be compensated by the transversal post-tensioning in the slab. A temporary consolidation would be necessary.

Considering these technical problems combined with time life and economical analysis, it has been decided to replace all the deck, including slab and beams.

It is a very expensive solution, considering the minor defaults as voids in the duct, the waterproofing leakage and bad inspection.

3 BRIDGE B : CANTILEVER BRIDGE

3.1 Bridge structure

Bridge B is a cantilever box girder bridge built in 1951 (figure 7). The external post-tensioning was renewed in 1991 with wax sheathed monostrands. In the transversal beam, at the cantilever girder hinge, post-tensioning became internal up to the anchorage (figure 8). Strands are placed in a plastic duct with wax injection.



Figure 7 : Bridge B

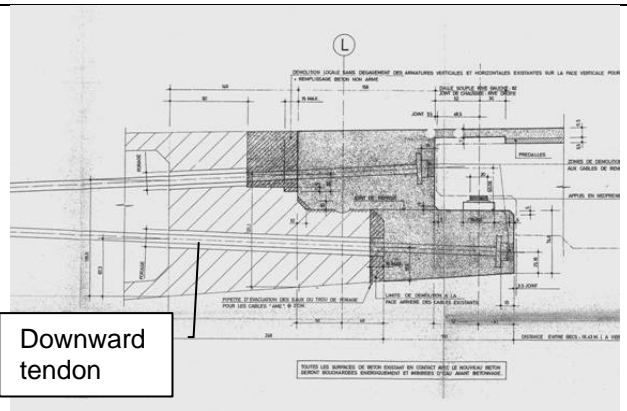


Figure 8 : Tendon anchorage at cantilever hinge. The dark part was added in 1991.

3.2 Bridge inspection

In 2005 sheathed strand ruptures have been observed in the box (figure 9). Rapidly, inspection turned to the anchorages in the cantilever hinge. It appeared that in the downward tendons, a small volume (several litres) of water was locked in the anchorage head. The injected wax floated over the water (figure 12).

This stuffy environment allowed development of stress corrosion cracking (figure 11) [1] of the strand just behind the anchorage head (figure 10). At this place, the monostrand HDPE sheath was still removed. High steel resistance ($>1920 \text{ N/mm}^2$) and high level working rate (80 %) are factors facilitating stress corrosion cracking development. Indeed, stress corrosion cracking may appear if wire stress is higher than 1200 N/mm^2 .



Figure 9 : Ruptured tendon in the box girder

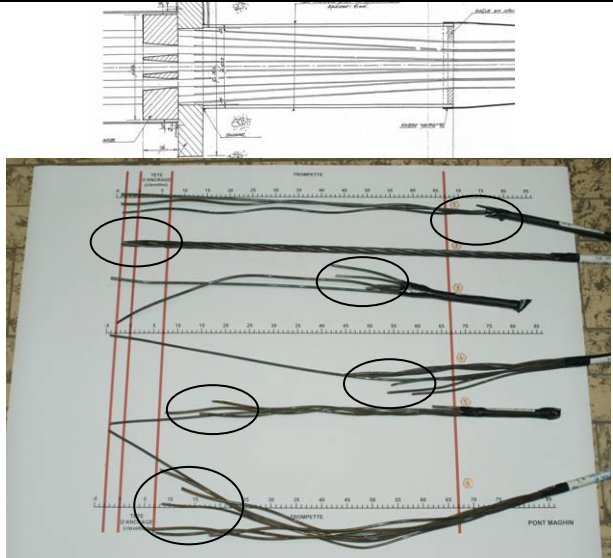


Figure 10 : Anchorage : rupture localisation



Figure 11 : Strand wire rupture



Figure 12 : Anchorage cap. Lower part was full water and wax floated over it.

3.3 Bridge rehabilitation

In regards of rupture increasing risk, it was decided to replace all downward (relatively to position at hinge area) tendons which represent half of bridge post-tensioning.

Wax sheathed monostrands are often considered as the actual best solution. It appears that it is not sufficient to guarantee the post-tensioning durability. During the design and the construction, the attention brought to details remains essential. High stress level makes also the strands sensitive to stress corrosion cracking.

4 BRIDGE C : BOX GIRDER BRIDGE

4.1 Bridge structure

Bridge C, built in 1973, is a continuous box girder bridge of 240 m with 4 spans.

Tendons are placed from one end to mid length. At that time, it was difficult to manage full length (240 m) tendons.

Near the mid pier, anchorages are positioned in the upper face of the deck. Half of the 44 deck anchorages are placed just under the gutter (figure 13).

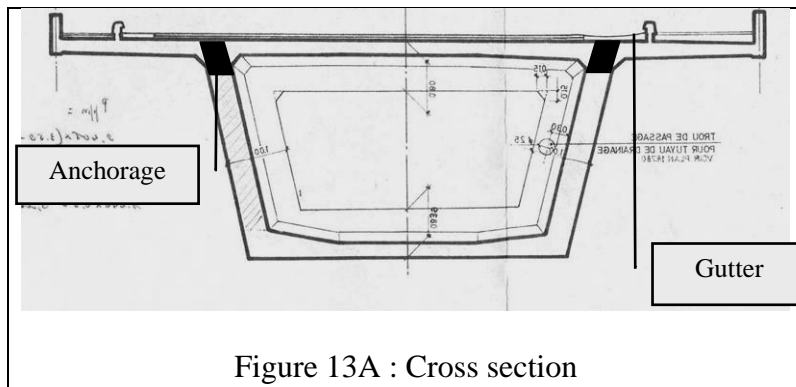




Figure 14 : Tendon opening : very moderate corrosion



Figure 15 : Opening after 3 months. Calcium carbonate deposit in the upper part. Active corrosion.

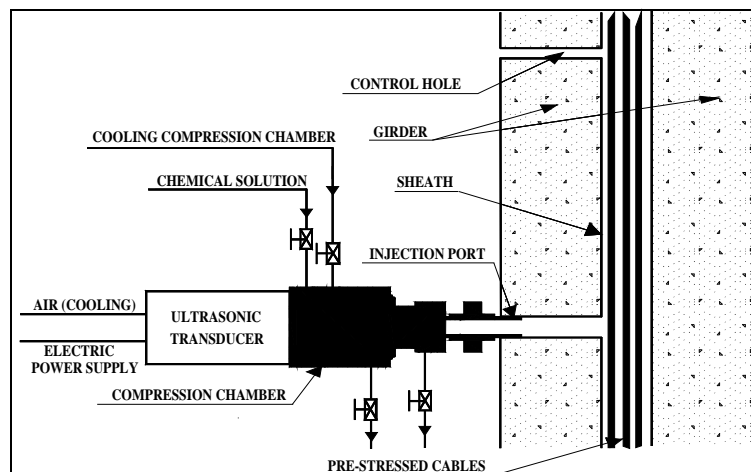
4.3 Bridge rehabilitation

Corrosion was moderate but without any action; ruptures may appear due to chloride pollution. It was decided to inject an inhibitor solution in the grout. This is possible using the patented PMD/ATEAV process[©] based on power ultrasonic technology. The calcium nitrite has been selected due to his well known effect against chloride induced corrosion [5].

4.3.1 PMD/ATEAV Process[©]

Holes are drilled at regular intervals along the cable path through the concrete and the duct (figure 16). A tube is tightly sealed inside each hole to permit the fitting of a reciprocating pump. The pump's compression chamber is then filled with the inhibitor solution.

The high frequency compression and depression created by the reciprocating pump forces the liquid to penetrate the grout within the duct.



Control holes on both sides of the injection hole permit the technician to monitor the movement of the inhibitor solution inside the duct. When the liquid overflows through both control holes, the pump is moved to the next injection hole.

Figure 16

The heart of the high frequency reciprocating pump developed for this application consists of a power ultrasonic transducer with a sonotrode confined in a compression chamber. The expansions and retractions of the sonotrode create overpressures and underpressures at ultra high frequency speed.

The inhibitor injection may not be stopped in a chloride polluted area. All the polluted parts must be treated.

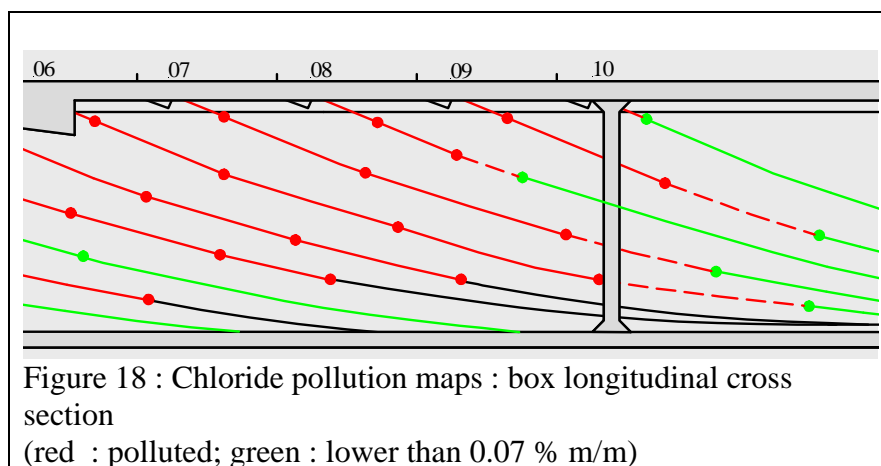
Considering the inverse relationship between injection travel times and the lack of grout (porosity and/or voids), this diagram constitutes a precise map of the quality of the protective cement grout filling.

Figure 17 : Injection time map

4.3.2 Application to Bridge C

On Bridge C, this following procedure is applied, system based on chloride content measurements prior to injection. In this case, chlorides only penetrate through the anchorages. For economical reasons, the chloride content is determined to treat only the polluted zones. These measurements are performed on the field. If chloride content is higher then 0.07 % (m/m grout, acid extraction), inhibitor (calcium nitrite) solution injection is performed. If it is lower then 0.07 %, injection may be stopped. As a safety precaution, the injection is however continued 1 m farther. The 0.07 % threshold is based on a cement content of 70 % and a chloride content of 0.1 % relative to cement mass. About 315 chloride measurements were performed and gave a precise chloride pollution map (figure 18).

This methodology is completely new.



Looking to all the results, it appeared that :

- Chloride contents may reach 0.6 % (m/m grout, acid extraction)
- Chlorides may progress in well injected duct more than 30 meter from the anchorage

5 CONCLUSIONS

Post-tensioned concrete bridges are good structures but very sensitive to tendon degradation generally related to water ingress into ducts.

Post-tensioned tendons inspection is very difficult and often it gives only partial answer to our questions.

Rehabilitation is always difficult and expensive. In many cases, the reduced load capacity cannot be estimated considering tendons degradation. In those cases, tendons have to be replaced and because of their location inside the box or beam webs, rebuilding the bridge is often the unique solution.

When corrosion is not too severe, but grout has been polluted by chlorides, it is possible to treat the tendons by inhibitor solution injection using power ultrasonic technology. The patented PMD/ATEAV process[®] is applied since 1994 in Belgium and Luxembourg with satisfaction.

The three case histories exposed here must also be analysed by new bridge designer considering following aspects :

- Using wax sheathed monostrands is not a full durability guarantee.
- Putting tendons internally in the concrete web or slab stop any replacement of degraded strand.
- Avoid putting anchorages in the upper face of deck slab.
- Regarding stress corrosion, it will be good to maintain tendon stress lower than 1200 N/mm².
- Waterproofing system efficiency is guaranteed if details are well designed and well realised.

6 REFERENCES

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