SOME CASES OF PATHOLOGIES IN PRESTRESSED CONCRETE BRIDGES IN SPAIN. DIAGNOSIS, ANALYSIS, AND DECISION MAKING

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ABSTRACT: During the last years, several problems and pathologies derived from flaws in the prestressing grouting system have been detected in Spain, which has led to costly repairing operations, and even to the demolition of viaducts placed, in many cases, in main arterial communication lines.
As it is well known, these problems had already occurred in Europe and the US during the 80´s, the 90´s and the beginning of the 00´s. They have been detected in Spain recently, with the logic time-lag considering the different infrastructure level of development between the mentioned countries.
This paper provides an overview of the main problems that have been encountered, frequently associated with alkali-aggregate reaction, failure of drainage and water-proofing systems, and the usage of deicing salts, which, together with inadequate grout injection, have led to severe corrosion problems in prestressing cables.
Some relevant cases detected in Spain are shown. Detected pathologies are described, and management, technical and administrative decisions that were taken are analyzed.
Among the mentioned cases, different structures from the main ring road in Madrid, the highway M-40, are included. Additionally, several bridges placed in the highway A-6 (North-West of Spain), with different age and prestressing systems, are shown, including the viaducts of “El Castro”, a precast segmental structure with external prestressing.

1 BRIEF HISTORICAL BACKGROUND

Prestressing of concrete dates back to the early 1900s, when several engineers experimented with the technique, but it was Eugène Freyssinet (1879-1962) who first applied for a patent in 1928. Freyssinet is reported to have built an experimental arch in 1908 which incorporated prestressing tendons, and in 1930 he used prestressing during the construction of the Plougastel Bridge in France. Freyssinet is considered the father of modern-day prestressing.

It was after the Second World War when the prestressed concrete became popular as a bridge construction material and it was about 1960s when the development of motorways helped to prestressing concrete become very popular for, solving complex structural problems and it also meant the beginning of the precast system for fast construction.

In this period, the technique of placing the post-tensioned tendon externally to the concrete was developed. However, the different corrosion protections were ineffective, and the external tendons showed corrosion pathologies. In the UK problems with durability tendons resulted in the ban of using external tendons inside the cross section for several years.

In 1992, a few years after the collapse of the Ynys-y-Gwas Bridge in Wales, the UK, due to corroded tendons, banned internal tendons and all UK designs, at that time, had to use external tendons.

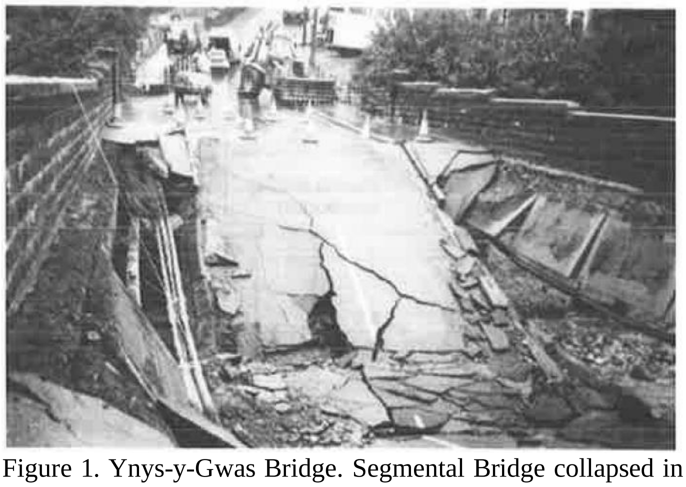

Figure 1. Ynys-y-Gwas Bridge. Segmental Bridge collapsed in Wales. Source: Woodward, R.J. 1989. Collapse of a Segmental Post-Tensioned Concrete Bridge

A few years later, this ban was partially lifted in 1996, when internal tendons were allowed again, except for precast segmental constructions, due to the usage of good detailing and construction practice. External tendons were again the posttension system allowed in the UK. The report TR47 “Durable Bonded Post-Tensioned Concrete Bridges” was the publication which regulated the new design and execution standards.

More cases of this type of pathologies appeared at that time, like the partial collapse of the Berlin Congress Hall in 1980; Mandovi bridge collapse in Indian in 1986; and the collapse over river Malle in Belgium in 1992.

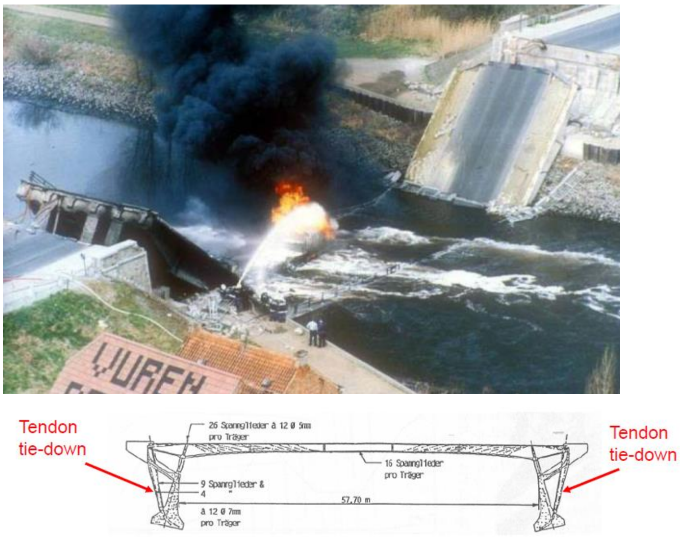

Figure 2. Bridge over river Malle in Belguim, were the failure of the tendon tie-down caused the bridge collapse in 1992. Source: *Durable Post-Tensioned Concrete Structures. Concrete Bridge Development Group July 2011*

In 1996, the French technical institution SETRA developed a test to verify the quality and the stability of the grouted tendons. This test was later the basis of the norm EN 445 Grout for Prestressing Tendons. Test Methods.

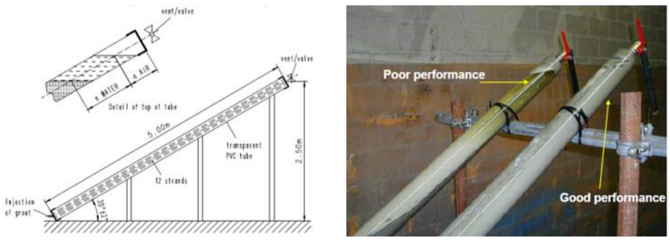

Figure 3. Outline of the stability grout test and and photo example of the test. Source: *SETRA and VSL Brochure.*

In 1999 the book “Post-tensioned concrete bridges/Ponts en béton précontraint par post-tension” was published. This publication was developed by the UK and France Roads agencies, and it collected the studies and analysis developed in 163 bridges in these countries. More than 12% showed tendon grout problems.

In 2000 several failures in tendons were detected in the Mid-Bay bridge in Florida, USA, a precast segmental bridge of 5,8 km of length and 41,45 m typical spans. In this case, the official report showed the bad grout quality and a fill tendons’ failure as the source of the pathology.


Figure 4. Mid-Bay Bridge general overview. Source: https://www.mid-bay.com/about-us-2/mid-bay-bridge/


Figure 5. Detailed view of an anchor plate tendon and of a damaged tendon. In both cases, corrosion and grouted problems were detected. Source: Mid-Bay Bridge Post-Tensioning Evaluation

At this time, a few more cases were detected around the world, and specially in the USA and in Europe.

Later, in 2002 no. 20 fib bulletin “Grouting of Tendons in Prestressed Concrete” was published. This guide described typical and historical problems and it proposed a new methodology and frequencies of control for the tendons grout.

Three years later, in 2005 no. 33 fib bulletin “Durability of Post-Tensioning Tendons” was published and it established the different corrosion protections of the prestresing tendons depending on their environment and the possibility of water aggressivity usage (deicing salt, waste waters, etc).

Despite new guidelines and studies, in 2010 a few problems with a new pathology concept, the “soft grout” were detected. It consists in the deficient hydration of the cement, which produces a soft and a porous grout. It’s a phenomenon very localized and this aggressive corrosion starts within grout matrix at the interface between soft and good grout (without external factors). The first cases were observed in bridges in Italy and Switzerland.

Along all these last years, some cases were detected and published like:

– Varina-Enon bridge, in Virginia, USA.
– I’île de Ré, in France.
– Roosevelt Bridge, in Florida, USA

2 THREE SPANISH CASES

Infrastructure’s development in Spain took place a few years later than in Europe and the USA because of the civil war and the dictatorship suffered until 1976, but it was with the adhesion to the EU in 1986 when the infrastructures construction rose. This peculiarity means that a large part of the bridges in Spain are less than 40 years and that a lot of experience and pathologies suffered abroad could be implemented. However, some cases and failures in prestressing systems have been detected in recent years, part of which are discussed below.

2.1 *Ruitelán access viaduct*

Ruitelán Viaduct is an important bridge located in the A-6 highway that connects the Galizian region with the central part of the country. The bridge is divided in three different sections. The central main viaduct is a balanced cantilever bridge. The north approach consists of 3 medium length spans of prestressed precast concrete beams. The beams had an unusual V-shape geometry and, as we could know later, they had one old posttensioning system, from the 70s. The tendons were in located in the middle of the web beams.

Figure 6. Ruitelán (down) general overview. At the left, north approach viaduct.

Figure 7. Ruitelán detailed view of north access viaduct.

Almost all the V-shape beams showed atypical cracks, all of them with the same pattern, beginning in the corbel bearing and going to the bottom section in the middle span. In addition, some cracks had evidence of water circulation, a fact that was very strange and suspicious.

Figure 8. Detailed view of the cracks of the V-Shape beams. Evidence of water circulation and white carbonates spots.

A detailed inspection of the prestressing system was delivered with NDT and by opening some ducts testing to introduce the boroscope to make the interior voids duct inspection.

The inspection result was very conclusive: several ducts had corrosion wires, and a few of them showed a severe corrosion stage. The presstressing damage was estimated about 40%. Strengthening solutions were studied and analysed, but due to the important damage percentage, and as the new code design carries a very complex solution, the final decision was the access span substitution.

The orography of the environment was very irregular, with more than 35% of average slope, and there was not an easy underbridge access. The three-span substitution was studied with cranes and a heavy-lifting system, but it was finally executed with a launching girder. This system was used for the deconstruction of the existing bridge. This operation was more complex and delicate than the typical construction due to the additional weight of the beam-slab section.

Figure 9. Ruitelán first deconstruction V-shape beam with a launching girder.

2.2 *M-607 overpass highway M-40 viaduct*

This viaduct connects two high density highways in the surroundings of Madrid, with more than 550 m of total length. The viaduct was a continuous lightening prestressing slab, with a very irregular span distribution which made it hard to save the different obstacles of the environment (roads, electric towers, water conductions, etc). The maximum length was 55 m over the M-40 highway. The prestressing system was bonded and internal to the section.

Figure 10. General plan overview of the viaduct and the environment.

In this case, the bridge suffered from a well known Alkali-Silica Reactivity (ASR) and manifested several cracks and deformations, mainly in the main span. These problems had been studied for a long time.

Previous months after the intervention, an accelerated deformation was detected in the main span and this was the signal for the intervention. An invasive special inspection was carried out to have more information about the concrete mechanical and chemical properties, the steel reinforcement and, mainly, about the prestressing system of the bridge. In this sense, all the pavement was retired to be able to inspect the top slab, and to access the top points of the ducts prestressing.


Figure 11. Up to 60 cm deflection in main span. Perfectly visible along the bridge.

After retiring the pavement, several cracks, some of which were very big, were discovered on the top slab, in the contiguous main span. The depth of these cracks was of many centimetres and the reinforcement bars were broken/cut where the cracks were bigger. Chemical and mechanical tests showed that the failure of the mechanism had begun with the non-controlled concrete cracking, which had been generated by the ASR, where the water with de-icing salts had accumulated and produced the total corrosion of the rebars until their local disappearance.


Figure 12. On the left picture, general cracking of the top slab bridge. On the right one, reinforcement bars sectioned along the bigger cracks.

The prestressing inspections focused on pier sections, coinciding with the top points of the prestressing elevation. Couplers sections were also investigated but their depth made that investigation very complex and difficult. The inspection was carried out hydrodemoliting the concrete to access the top ducts points over piers and with a boroscope in case there were voids or grouting failures. Several ducts with grouting problems were detected and corrosion prestressing wires appeared too. In some cases, the wires corrosion was so several, that some of them were completely broken.


Figure 13. Grouting voids with severe corrosion and broken wires and strands.

After considering all the detected pathologies and the uncertainties about the real integrity of the bridge, the global analysis resistance of the structure was alleged to be very unfavourable and critical to ensure a minimum resistance to permit the strengthening of the viaduct, so finally, the decision was to replace the bridge.

Again, the deconstruction of the existing viaduct was a critical operation by the uncertainty about the residual mechanical resistance of the bridge. For the main span, a hanging beam was used to ensure the stability of the bridge. The span was cut off in pieces about 2000 kN and lowered with cranes. This operation was developed along one full weekend to ensure the traffic security and the operation viability itself.

Figure 14. Deconstruction general view.

2.3 *Castro viaducts*

Castro viaducts are formed by 3 different bridges with the same typhlology and typical span of 45 m. The longest one has 13 spans and a total length of 585m, the second one has 7 spans and a length of 315 m and the shortest one has 2 spans only and 90 m of length. The total viaduct's length is around 1000 m. Span type is isostatic and consists of a segmental pre-cast concrete bridge with external (inside the section) prestressing system. The slope road is around 4,5 %.

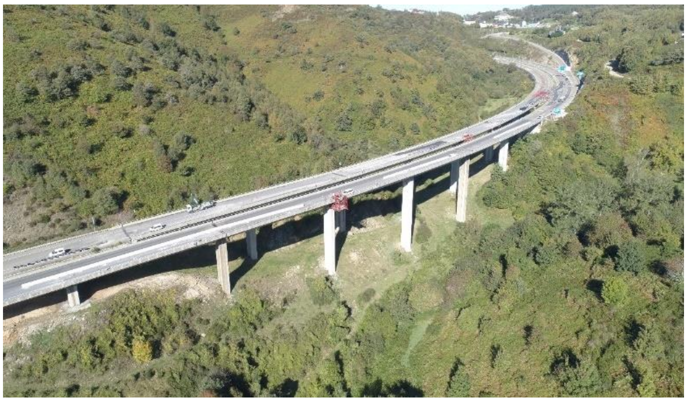

Figure 15. Castro viaducts general overview.

The prestressing system is formed by 8 tendons, 4 near the top slab, 2 on the corners of top webs part, and 2 more over the bottom slab.

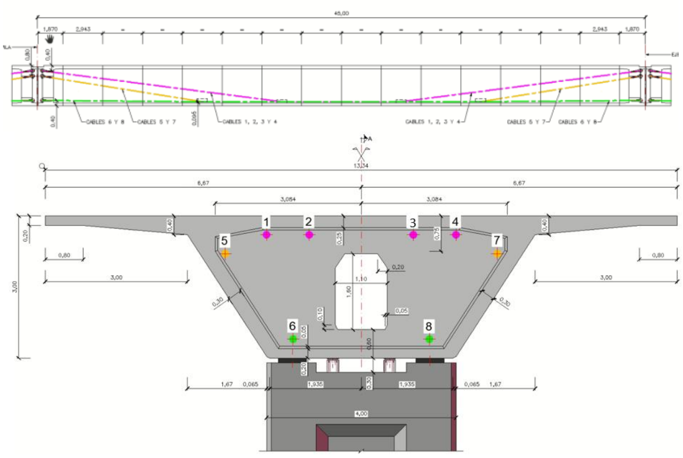

Figure 16. Span general elevation and cross section with the prestressing anchorages position.

These viaducts are located in a very cold and snowy area in winter in Spain, near Piedrafita do Cebreiro mountain pass, where de-icing salts are used very frequently.

An inside inspection of the box girders detected water circulation along the protection mortar prestressing blocks, which caused a lot of white carbonates spots. This pathology appeared in almost every anchor protection blocks. In addition, one complete failure tendon was detected and water circulation evidence inside the HDPE ducts was also found.

Figure 17. On the left picture, detailed protection anchorages blocks with water circulation. On the right one, evidence of water circulation along the interior prestressing duct.

Considering the critical failure of the bridge, traffic restrictions were established, and a reduction of the pavement thickness was carried out too.

Special inspection was developed with urgency and 100% tendons and anchor blocks were inspected in detail. These works consisted in:

- Mortar protections blocks demolition and capot withdrawal.
- Visual inspection of anchor blocks.
- Correct ducts grouting.
- Borescope internal ducts with grout voids.
- Vibration tendons test.

The inspections' results showed that a very important number of tendons had serious corrosion pathologies. They had a double origin. On the one hand, there were problems and defects of the grouting ducts, specially inside the upper anchors, helped, probably, by the longitudinal slope. And on the other hand, there was water circulation with de-icing salts along the dilatation joints of the bridge and consequently, along the mortar protection blocks. The damages were classified into inside defects, when they had taken place in the interior of the anchorage block and could be detected only by drilling and borescope, and outside defects, when they were perfectly visible without any special issue.

Figure 18. Interior anchorage block inspection by borescope. Significative grout voids detected with strand corrosion. Source: Freyssinet.

Figure 19. Exterior aspect anchorage block after mortar withdrawal. Different corrosion levels were discovered.

The vibration test wires provided a good tension result in almost all tendons compared with the theoretical values. As that test doesn't include information about the durability and longtime response of the bridge, this information was decisive to design the strategy of the intervention with structural security.

In the first phase, 2 additional tendons were implemented. This strengthening gave an additional security margin and allowed the replacement of the tendons with total security and without resistance uncertainties in the second phase.

The tendons replacement wasn't an easy operation. The free space between end-beams spans was very reduced, around 70 cm, and made the solution and the performance very difficult. This space was totally insufficient to use a multi-strand jack, so a reduced mono strand jack of 30 cm and 45 mm of stroke was designed. In any case, the limited space forced to stress the strands in more than 10 steps.

Figure 20. On the left hand, mono strand jack of reduced dimensions. On the right hand, free space between anchors block. Detail while the stressing operation.

The new strands have the maximum durability standards: individually greased and sheathed strands involved in a global grouted HDPE duct. Grouting and anchors blocks were specially designed and controlled during its execution. Finally, an extra waterproofing protection was designed to prevent the water access and circulation along the protection blocks.

Obviously other durability and improvement details were implemented, specially all the ones that have relationship with rainwater and de-icing salts: waterproofing of all the platform, restauration and improvement of the continuity slabs, installation of new expansion joints with a waterproofing membrane, etc.

3 CONCLUSIONS

This paper remember some known problems about the prestressing systems along the time and around the world, and exposes three recent cases in Spain.

In addition of the lessons learned about the importance execute an excellent grout of the ducts and of waterproofing of the external blocks, the example of the Castro viaduct showed how external tendons is easier to inspect, evaluate and to repair/replace preserving the original structure.

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