Some lessons of more than 20 years of inspection, maintenance and rehabilitation of bridges in Spain

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ABSTRACT: Spain has implemented a Management System for bridges belonging to the national road network since 1998. Since 1999, IDEAM has carried out for the Spanish public administrations more than 8000 principal inspections; 150 specialized inspections; 200 structural damage evaluation reports; 200 repair and strengthening projects and 150 drafts of maintenance plans for structures.
In most cases, the pathologies detected derive from construction failures or deficiencies in the conception of some details that could have been easily remedied or even anticipated, namely: drainage and waterproofing; duct grouting in post-tensioned concrete girders; internal corrosion of weathering steel box girder bridges; corbels; bearings; corrosion of tendons of stays belonging to the first cable-stayed bridges generation; problems arising from fatigue in steel bridges under increasing heavy traffic forces, etc.
This lecture focus on the description of some relevant practical case studies related to the aforementioned topics

1 INTRODUCTION

Spain, like most developed countries, has implemented a Management System for bridges belonging to the national road network since 1998. The regional network is currently being implemented in some autonomous communities.

The Management System comprises the following concepts:

- Structures inventory
- Periodic inspections
- General Maintenance actions, mostly preventive.

Inspections are rated depending on the intensity, technical specialization and frequency. As in most Management Systems, three inspection types may be distinguished:

- General or regular inspections. They are generally conducted on an annual basis, coinciding with general maintenance actions. General inspections, consisting of a visual verification of the structure and its main components, are performed by non-specialized staff and don’t require specific auxiliary equipment.
- Primary inspections. They are conducted every 5 years -except for special situations- by specialized engineers using auxiliary means for them to be able to visually inspect all bridge elements, characterize and assess damages.
- Special inspections. They are specific of each structure and provide an individual rating of pathologies diagnosis. Generally, they are complemented by surveys, safety and functionality structural analysis, damage identification maps and, depending on the case, the structure repair or strengthening.

IDEAM has performed many primary inspections of bridges for the Spanish public administrations since 1999. We have inspected more than 8000 structures over all these years and are a key collaborator with the Ministry of Public Works in the development of the 'Guide for Bridge Inspections’ and the ‘Guide for drafting Maintenance Plans of Bridges’.

Since 2002, we have also carried out more than:

- 150 specialized inspections;
- 200 structural damage evaluation reports;
- 200 repair and strengthening projects;
- 150 drafts of maintenance plans for structures.

In very few cases, the pathologies detected were the consequence of failures in structural analysis or the design and dimensioning of a certain element. In contrast, they mostly derive from construction failures or deficiencies in the conception of some details that could have been easily remedied or even anticipated, namely:

- drainage and waterproofing;
- duct grouting in post-tensioned concrete girders;
- internal corrosion of weathering steel box girder bridges;
- corbels;
- bearings.

Particular attention should be paid to other cases, like the replacement of stays belonging to the first cable-stayed bridges generation or problems arising from fatigue in steel bridges under increasing heavy traffic forces.

Due to space constraints, pathologies deriving from foundation scouring issues of piers and abutments located in riverbeds do not fall within the scope of this article. Nonetheless, scouring is one of the most important elements to be considered during inspection (often very complex) and old bridge maintenance due to the potential risk of brittle fracture.

Figure 1. Scouring of foundations.

Figure 2. Scouring of foundations.

The cases described below, most of them regarding to bridges that were designed and built less than 25 or 30 years ago, aim to draw attention and focus the concerns of engineers involved in the design and construction phases on the upgrade of conservation and maintenance conditions of this type of structures. As they are an important part of the heritage value of developed countries' infrastructures, they require continuous investments in conservation, which are hardly sustainable if bridge designs aren't upgraded from the maintenance perspective (in Spain, there are around 18000 km of conventional railway lines, approximately. 4500 km of high-speed lines, around 170000 km of roads and highways containing a total of approximately 40000 structures and is therefore estimated that the order of magnitude of the structural heritage is above 18000-20000 million euros).

2 DRAINAGE AND WATERPROOFING

Based on our extensive experience of more than 20 years in bridge inspection, water is certainly the main cause of pathologies and needs for bridge strengthening and repair.

What's striking to us is that this is broadly acknowledged by engineers and authorities involved, and yet, no substantial improvement is being made in bridges constructed in the last 10 or 15 years. On the contrary, errors in the design of drainage, discharge and waterproofing details, as well as their associated pathologies are continuously repeated.

Additionally, it is important to stress that risks associated to water don't affect steel bridges only. Indeed, reinforced or prestressed concrete bridges are risk-sensitive and, in many cases, repair processes of those pathologies are more costly and complex.

The origin of those pathologies is mainly the following:

- water tightness failures under expansion joints in abutments or, mostly, between isostatic spans;
- drainage system failures and rainwater discharge on the platform sides;
- water tightness failure or deficient design of downspouts and sumps sewers;
- waterproofing design or placement failures, or frequently, damages in the waterproofing system during subsequent pavement replacement or strengthening operations.

Figure 3. Water leakage through expansion joints.

Figure 4. Missing elements in drains.

Figure 5. Water filtrations under the platform's side bars.

Water circulation through the structure may cause:

- concrete carbonation processes, including PH loss, that may accelerate corrosion of reinforcements in permeable concrete due to low compactness;
- surface concrete deterioration with cracking and spalling due to expansion processes deriving from reinforcement corrosion;
- chloride, sulphate or other salts corrosion processes due to the concrete contamination through fissures, joints between concrete layers, etc. (these processes are very intense when de-icing salts are used);
- intense development of alkali-aggregate reaction expansion processes with the presence of aggregates susceptible to such chemical attack;
- corrosion processes under the active reinforcements pressure, referred to further on.

Figure 6. General corrosion due to concrete carbonation.

Serious pathologies recently detected on an overpass spanning one of the main thoroughfares into Madrid with an ADT of approximately 8000 vehicles per day are described below. The severity of the damages made it necessary to completely demolish the deck and replace it for a new precast deck, which will have a significant impact on the accesses to Madrid for nearly 9 months.

The structure inspection was undertaken when significant deviations from the deformed alignment with respect to the theoretical elevation were detected. Such inspection revealed serious alkali-aggregate reaction issues, having as a consequence an important reduction of up to 60% of the deformation modulus of concrete and intense expansion processes associated to general longitudinal cracking processes at the deck.

Figure 7a. Serious alterations at the alignment of the overpass located at Colmenar & M40 junction (Madrid).

Figure 7b. Serious alterations at the alignment of the overpass located at Colmenar & M40 junction (Madrid).

When the pavement layer was lifted, it was detected that the subsequent replacement processes of the road surface had virtually removed the waterproofing layer, meaning that the platform water entered directly through the cracks due to alkali-aggregate processes, intensively polluting the concrete core. The lack of an efficient drainage system stressed the runoff rainwater of the structure's lateral surfaces, showing significant concrete degradations and intense corrosion processes.

Figure 8a. Cracking and general longitudinal fissures due to alkali-aggregate reaction expansion processes.

Figure 8b. Cracking and general longitudinal fissures due to alkali-aggregate reaction expansion processes.

Figure 9. Systematic fractures of the transversal reinforcement due to expansion and corrosion processes under de-icing salts and runoff rainwater.

Finally, the frequent use of de-icing salts in winter and general failures in duct-grouting processes had dramatically emphasized the damages. As a result, systematic fractures of the cross-sectional reinforcement were found under the platform's longitudinal cracks, as well as an advanced corrosion under stress in post-tensioning cables, mostly unprotected due to inadequate grouting and corrocted own ducts.

Figure 10. Bottom of deck deterioration due to rainwater drainage failure.

Figure 11. Corrosion of ducts and post-tensioning cables under the action of de-icing salts and a deficient duct injection.

Figure 12. Photograph of the interior of the duct showing the incomplete filling by the grouting.

All this inevitably led to an immediate decommissioning of the structure and a subsequent deck demolition and replacement.

3 DUCTS GROUTING IN POST-TENSIONED CONCRETE GIRDERS

The accidents that took place during the construction of steel box girder in developed countries like Germany, Austria, Wales and Australia in the 70s had a big impact on the analysis and design criteria of structures and steel box girder bridges, as well as on construction controls of this type of structures. This translated into delays in the construction of steel bridges and set the ground for the creation of the Merrison Committee, which completely transformed analysis and stability control theories (buckling) of compressed thin plates as it now appears in the modern standards (AASHTO, Eurocodes, etc.)

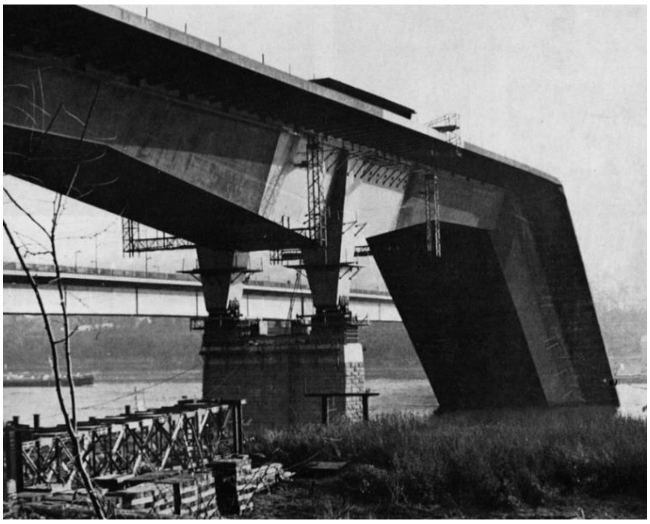

Figure 13. Accident during the cantilever erection of the Koblenz bridge (Germany) 1970

Similarly, several accidents affecting concrete bridges took place in the second half of the 80s. The Ynys-y-Gwas Bridge collapsed in 1985 in England as a consequence of the fracture and sudden collapse of a post-tensioned concrete deck due to corrosion of tensioned tendons. De-icing salts were present and ducts had been inadequately grouted, which led to a delay of this type of decks by The Department of Transport of the UK in 1992, a thorough special inspection campaign and the drafting of new specifications for duct grouting, stability of the grouting and control in most of the European and North American Administrations (SETRA, FIB, etc.).

More than 160 bridges were inspected in a campaign conducted jointly by the British Highways Agency and the French LNPC, where serious grouting problems were detected in nearly 15% of bridges. Similar campaigns were performed with similar results in USA over the 2000s.

Figures 11 and 12, corresponding to the demolished overpass at the highway in Madrid, show how the series of failures in the grouting system of ducts, together with the described water filtration issues with salts triggered the collapse by corrosion under stress of an undetermined number of corroded prestressing tendons, which obliged the immediate demolition of a crucial structure for the accesses into Madrid.

Figure 14. Lack of corrosion protection due to a not-conforming grouting of ducts.

Figure 15. Lack of corrosion protection due to a not-conforming grouting of ducts.

As a consequence, the Spanish Ministry of Public Works has started an inspection campaign on the condition of ducts and post-tensioning cables of a number of structures built throughout the 90s, mainly those with waterproofing issues and, specifically, those subject to de-icing salts in winter.

The results of these inspections, similarly to the aforementioned French and English campaigns, show a significant number of failures within the duct-grouting systems, leading to the need for a precise monitoring of affected structures and, in some cases, to the implementation of repair measures contributing to prevent the development of corrosion processes in cables or to arrange external reinforcing post-tensioning cables.

The figures below show some images illustrating the importance of these pathologies, both in road bridges (figures 14 and 15) and railway bridges (figures 16 and 17) built less than 30 years ago.

Figure 16. Water leakage through anchor caps of upper cables over piers on a box girder launched railway viaduct.

Figure 17. Continuous water flow when loosen some screws of anchors caps.

4 INTERNAL CORROSION OF WEATHERING STEEL BOX GIRDER BRIDGES

Weathering steel has been largely used in Spain since the 40s due to its excellent results and unquestionable cost and maintenance advantages in comparison to conventional painted carbon steel.

Our country's weather conditions, characterized by frequent damp and dry cycles are suitable for this type of steel to develop its own self-protection surface layers against corrosion processes.

The only exceptions provided in national and European standards (Eurocodes) for the use of this type of steel are the areas affected by industrial environments or sites near the sea.

On the inner surfaces of box girders, depending on the degree of atmospheric aggressiveness and inner accessibility, standards establish different internal protection requirements by means of paint, special sealing measures or damp control in certain inaccessibility cases.

However, maybe due to a tendency to rely excessively on the anticorrosive properties of this type of steel, in many cases, aspects such as the inner accessibility, facilitating periodic inspections, and the design of inner stiffening details avoiding water build-up and ensuring the inspections' regularity are often disregarded.

Our extensive experience in the inspection of this type of structures, quite common in Spain, indicates that the inner state of conservation of box girder composite bridges built less than 30 years ago is far below from the expected if the required design and maintenance precautions had been followed.

The failure of the waterproofing system, often inexistent due to the aforementioned road surface replacement processes, is systematically the origin of most of pathologies.

Additionally, concrete slabs of composite bridge (tensioned under a negative flexure and slightly compressed at the mid-span due to the frequent construction processes with no formwork) are subject to present passing fissures in their thickness unless special care is taken to minimize shrinkage during hardening. Such passing fissures are an easy ingress way fort water into the box girders.

The advanced deterioration condition of the bridge of Mengibar, over the Guadalquivir river, can be observed on figures 18 and 19. An overall failure of the deck waterproofing system led to a water leaking that was accumulated due to the blockade of the steel stiffeners. This water built up between the bottom steel plate and the deck webs, producing an accelerated corrosion process with a net steel depth loss higher than the 5-10%.

The poor ventilation in box girders, together with the high humidity coming from the riverbed, caused frequent condensations inside the box girder, preventing the development of a self-protection layer that required frequent damp and dry cycles that never took place.

Figure 18. General corrosion at the bottom plates of the Mengibar bridge box girder.

Figure 19a and b. Oxide thickness surface release due to the lack of weathering steels' own self-protection layer.

5 CORBELS

It is important to emphasize the importance of sharing the vast amount of information that may be extracted from the results of hundreds of bridge inspections in the Management Systems already implemented in many countries. It should enable to avoid design failures of certain details that, systematically, are subject to suffer pathologies and accidents, i.e., corbels.

This type of bearings was greatly developed since the 50s in the design of precast concrete bridges, as it enabled to increase main spans by more than 60%, implementing isostatic solutions (Gerber beams) without increasing the dimensions and transport and assembly elements of conventional precast elements.

By locating corbels at quarters or fifths of span, almost coincident with the points of inflection of continuous solutions, precast isostatic schemes of a similar strength efficiency were achieved. Corbels were also applied to steel bridges.

Problems deriving from the design of this types of details are well-known:

- the non-ductility and weak character of its strength behavior;
- its permanent exposure to leaked water through common water tightness issues of expansion joints;
- in concrete bridges, its high sensitivity to cracking due to failures and execution tolerances, specifically of the corner reinforcement;
- in concrete bridges, the almost inevitable development of concrete degradation processes and the corresponding reinforcement corrosion in an area constantly subject to moisture and water leakage;
- in steel bridges, the high sensitivity to corrosion and fatigue of the corner section, where there is a high stress concentration;
- its exposure to dynamic traffic impacts in joints;
- the difficulty/inability of a design providing access for a proper inspection, maintenance and strengthening.

Figure 20. Concrete degradation of spalled corbels with general corrosion at reinforcements

Figure 21. Concrete degradation of spalled corbels with general corrosion at reinforcements

Figure 22. Corbel failure in a concrete bridge.

In Spain, this type of details is clearly obsolete and many of them are rejected by Public Administrations. Since the 90s, the precast technology of road and railway bridges has undergone an important technological development and Gerber solutions were replaced by permanent precast ones where the continuity between segments was achieved by means of passing bars and pre-tensioning cables.

Figure 23. Precast, varying depth continuous viaduct at the M50 to M501 connection in Madrid.

Notwithstanding the above, precast solutions with corbels at quarters or fifths of span are still largely used in many emerging countries despite their cost of maintenance and frequent pathologies which, in many cases, have caused serious accidents with fragile breaking, such as the Chicago (steel) and Montreal (concrete) bridges, involving 5 fatalities in 2006.

Figure 24. Failure by fatigue of a corbel in a steel bridge, Chicago.

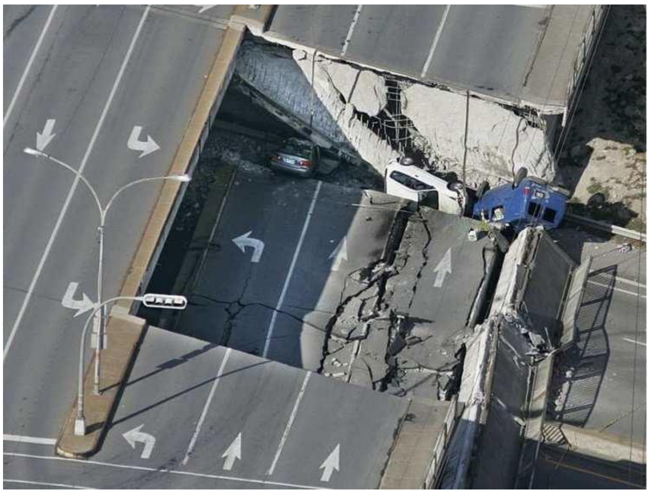

Figure 25. Concorde Overpass accident in Montreal due to the concrete corbel failure.

Figure 26. Detail of damages at the Montreal corbel before collapse.

6 BEARINGS

Bearing devices are one of the most susceptible elements to damages and pathologies leading to the replacement before the bridge life in service is over. Generally, such damages don't involve relevant structural safety risks, which could explain the relative lack of attention that is often given to the design of details and placements.

However, we needn't downplay the increasing influence of these factors on the structures' proper operation. A clear example of this are the high-speed railway lines where the demanding alignment conditions increasingly lead to construct long viaducts, in some cases with high piers, where the proper operation of the different bearings is crucial to guarantee the safety of railway traffic and the proper operation of expansion joints, which sometimes accommodate movements of up to 1000 mm.

The proper adjustment and dimensioning of long sliding plates and uni-or multidirectional ends, as well as the planning of suitable details to facilitate access for inspection, maintenance and eventual replacement of bearing devices are key conditions in order to avoid dramatic affectations to communication routes that are more and more important in developed countries.

Figure 27. Archidona viaduct (Spanish HSRL). 3150 meters between expansion joints at abutments.

Figure 28. Arroyo de las Piedras viaduct (Spanish HSRL). 1210 meters between expansion joints at abutments and piers of up to 95 meters height.

Going into details of the multiple pathologies of bearing systems systematically encountered in the multiple inspections carried out does not fall within the scope of this article. For the past few years and given the economic and operational effects that they may generate, damages in bearing devices are a priority in congresses, technical notes and design and placement guidelines by Administrations and Concession companies managing road and railway communication networks.

Figure 29. TPFE sheet removal of a POT-bearing.

Figure 30. TPFE sheet removal of a POT-bearing.

Figure 31. Excessive distortion at elastomeric bearings due to errors in the estimation of imposed deformation.

However, if we aim to highlight how complex and costly the replacement of bearing devices out of service due to a deficient design and placement may be, as it was often the case. Until now, as has often been the case, the projects have not always considered the structure jacking system in the design of pier caps and bearing diaphragms, as it had occurred in the Viaduct spanning the Contreras reservoir in the highway Madrid-Valencia. The viaduct, with a traffic of around 1000 vehicles/day had to be taken out of service for several months in order to replace the named bearing devices.

Figure 32. Contreras viaduct, 170-meter span composite truss.

Figure 33. Contreras viaduct: bearing devices under out-of-service conditions.

Figure 34. Contreras viaduct: cable lifting from the carriageway in order to facilitate the bearing replacement, as it had not been planned from pier caps (2014).

7 FATIGUE PROBLEMS IN ROAD BRIDGES: VIADUCT OVER THE CONTRERAS RESERVOIR LOCATED AT THE MADRID-VALENCIA HIGHWAY

Until recently, fatigue was mainly associated to structures under intense vibration phenomena: industrial, aeronautical, off-shore and railway bridges. Road bridge, except for some special cases, weren't regarded as susceptible to suffer fatigue problems that could affect their safety.

Spanish standards, as the SIA in Switzerland, provided a fatigue control under the action of a heavy vehicle of 480 kN and a number of cycles depending on the road ADT that, generally, provided satisfactory results.

Due to a series of accidents occurred in Asia and North America (Ontario, 2003; Minneapolis, 2007) with a huge media impact and the confirmation that the intensity of heavy vehicles in large highways and European industrial areas exceeded by far the references that had served as a basis for traditional fatigue controls, between the years 80 and 90 it was recommended to conduct several campaigns including heavy vehicle traffic studies in different roads of French (near Lyon) and German industrial areas. Those studies evidenced the noticeable lack of current controls and need for a new regulatory approach on fatigue, both for actions (EC1 for actions on bridges), exceeding up to 3 times the precedent references (EC3-1.9 for steel structures), and construction controls (EN 1990).

In 2013, during a routine inspection, a complete rupture of the welding connecting sections at the bottom chord of a composite truss in the lateral span of a viaduct located over the Contreras reservoir (with a main span of 170 meters), at the Highway A3 connecting Madrid-Valencia (Mediterranean coast), was detected.

Figure 35. Welding rupture at the truss traction chord.

Figure 36. Replacement of the damaged element.

The event, that could have had catastrophic consequences given the strategic location of the highway carrying high traffic intensities (approximately 10000 vehicles per day and traffic direction and a percentage of heavy vehicles carrying an average load of 420 kN, both in the order of magnitude already detected in the aforementioned European campaigns), obliged to immediately close the traffic of the A3 highway and start an intensive inspection, survey and repair program that lasted for nearly 2 years and a half and was performed under the direction of the signatories to this paper, including the following actions:

- preliminary full visual inspection of all truss nodes, located under each highway's carriageway in order to provisionally reopen the viaduct for a limited and light traffic while the detailed inspection program continued;
- a subsequent detailed ultrasonic inspection and survey campaign from the exterior of all trusses welds, together with an accurate data collection, geometric discontinuities, etc. that enables to identify and select the most susceptible welds to develop fatigue cracks;
- opening closed sections in areas in which ultrasonic tests detected a damage degree that obliged a direct internal visual inspection, especially in the root area and backing plates in order to determine the necessary cleaning, repairing or strengthening operations.

Figures 37a and b. Sections opening for internal inspection and repair (root and backing plate areas).

The laboratory inspection of the damaged welding identified the fatigue crack very clearly. The fissure started and developed due to the absence of backing plate, the deficient preparation of welding edges and inappropriate control of fit up between elements borders before starting welding.

Figures 38a and b. Fatigue fracture from a notch due to lack of backing

In another node open for inspection, a new fatigue cracking process in similar conditions to the damaged welding was detected.

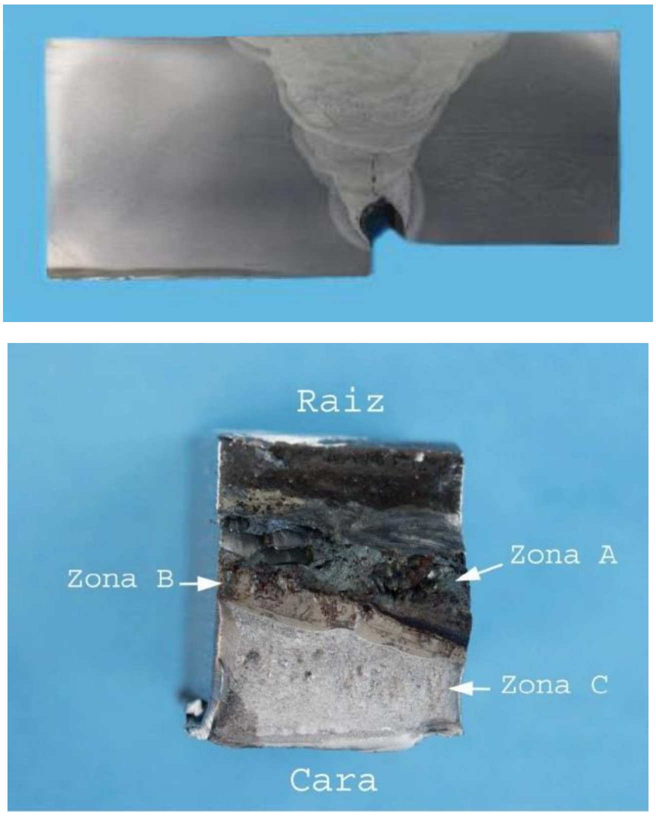

Figure 39. Fatigue crack initiation coming from a notch due to lack of backing

In both cases, there was an absence of a backing plate in the inner face, necessary to ensure the procedure of the non-accessible root area of V-weldings performed from the outside. Presumably, misalignment problems between adjacent elements hampered their fitting, and the lack of technical experts specialized in fatigue on site during construction did not allow for the identification of risks derived from this malpractice.

The complexity and high cost of the repair process and the confirmation of a potential accident with catastrophic consequences set the path for the Administration to undertake an urgent awareness and training campaign within Spanish engineering professionals in the framework of the design and construction of steel structures with a fatigue risk, as well as to intensify teaching on this issues at Engineering Universities.

IDEAM was also commissioned by the Spanish Ministry to draft a ‘Guide for the fatigue design of steel and composite bridge’ under Eurocodes and following similar initiatives by SETRA, ECCS, etc.

Figure 40. Fatigue design guides (SETRA, ECCS, Spanish Ministry)

8 STAY CABLES CORROSION IN 1ST GENERATION CABLE-STAYED BRIDGES: CENTENARY BRIDGE IN SEVILLE

Modern cable-stayed bridges date back to more than 60 years: Stromsund in Sweden (1953) and Nordbrucke in Dusseldorf (1958). In Spain, the Rande bridge (Galicia) and Castejón (over the Ebro river) were constructed during the 70s.

Steel cable protections in the first cable stayed bridges, until the 90s, were scarce: double barrier (PHD external duct and internal mortar grout). Since the early days, there was a technical consensus between experts on the necessity to improve the weakest element of this typology, as the mortar cracking under dead loads and live loads reduced the protection of tendons and caused dangerous damages due to friction.

Figure 41. Observed damages in stay-cables with PHD ducts and mortar slurry

Figure 42. Observed damages in stay-cables with PHD ducts and mortar slurry

Current technology is based on the use of multiple protection barriers (3 to 5):

- triple barrier protection:
  - external PHD duct (1)
  - strands with individual duct (2) and self-protected (grease or wax) (3) or
  - galvanized/galfanized strands (2) and air humidity control inside the duct (3)
- up to 4/5 barriers protection:
  - external PHD duct (1)
  - galvanized/galfanized strands (2), individually self-protected with duct and grease (3 and 4)
  - external PHD duct (1)
  - possible internal filling of the duct with wax or grease grouting between strands (perhaps excessive) (5)

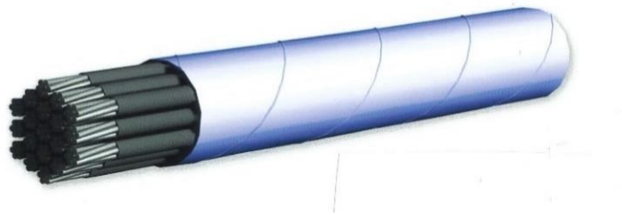

Figure 43. Multiple-barrier current technology for stay-cables protection.

The most recent technological developments focused on the following:

- strand insulation, avoiding contact with each other in order to protect them from:
  - corrosion under tension;
  - fatigue due to friction between strands;
  - corrosion due to friction between strands;
- pay extra attention to the cables' most vulnerable areas: anchors, temporary cables, saddles, etc.;
- reducing aerodynamic vibrations: ducts composed by spirals anti-wind/rain effects, deflectors, anchor dampers, etc.;
- continuous monitoring of stay cables and possibility to inspect and replace tendon by tendon.

In 2018, the unfortunate accident of the Polcevera viaduct in Genoa intensified the media pressure on public administrations for safety in this type of structures. Inspection campaigns on stay cables of the first-generation cable-stayed bridges, built before the end of last century, evidenced the need to tackle the replacement of such bridges' stay cables for other with technologies ensuring an increased durability.

In 2016, the sudden failure of one stay cable at the 132-meter main span Alcoy bridge, put in service in 1987, led to a complete replacement of its stay-cable system.

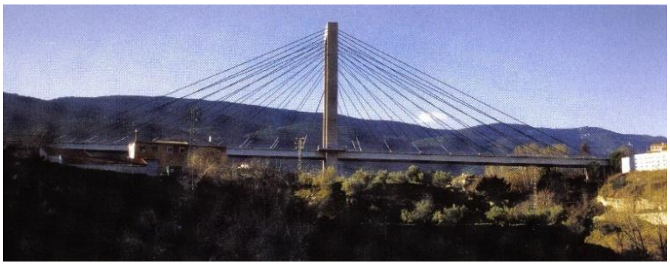

Figure 44. Alcoy stay-cable bridge (1987).

Figure 45. Generalized corrosion at the Alcoy bridge's broken cables (2016).

Subsequently, the condition of the Centenary Bridge's stay cables was inspected. The bridge, inaugurated in 1992 in Seville on the occasion of the Universal Exhibition, over the Guadalquivir river and has a main span of 264 meters. The inspection detected the start of the corrosion processes development at stay cables. Although this process did not affect the structural safety yet, it was recommended to draft an urgent replacement project of the stay cables, which was completed in 2019, allowing works to start in the second half of 2020. The project and future construction support services has been developed by IDEAM, author of the original project that dates back 30 years, in JV with FHECOR.

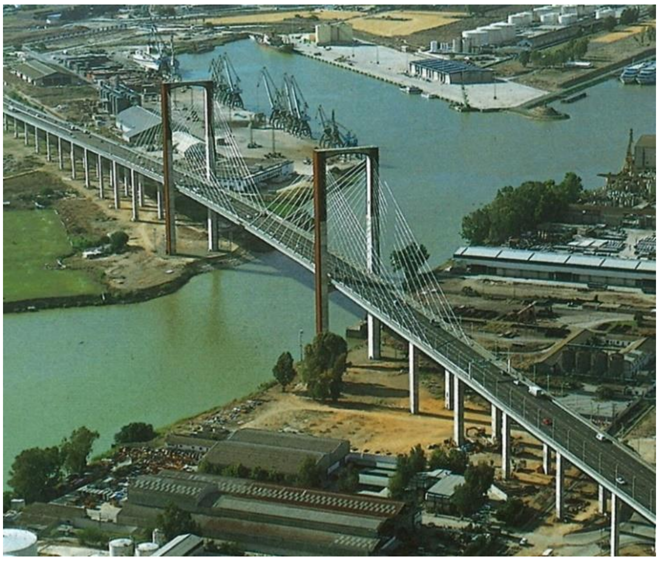

Figure 46. Centenary cable-stayed bridge in Seville, 1992.

Figure 47. Corrosion detected at some tendons of the Centenary Bridge, 2018

As the Centenary bridge is a main infrastructure in the city of Seville (with an ADT of approximately 100000 vehicles/day), the process of replacing stay cables cannot be carried out with traffic closures, as it was the case at the Alcoy bridge. This obliged to develop a complex project that would enable to tackle such replacement without posing any risk for users and minimally affecting the traffic capacity of the roadway.

Figure 48. Traffic-jammed Centenary bridge (100000 vehicles/day).

Simultaneously, given the serious traffic capacity problems of the bridge, carrying 5 continuously jammed lanes, a design to allow the widening of the current roadway to 6 lanes was developed, for this purpose, both cable-stayed planes were displaced sideways, as well as their respective anchors at pylons and precast deck by means of transversal steel beams.

Additionally, this proposal was designed in a way that it is compatible with a subsequent lateral expansion of the platform, encompassing two closed steel sections external to the pylon on both sides of the deck, which will allow for a future capacity of 10 lanes.

In our view, it is an extremely complex and high-tech innovative action, and, to our knowledge, there aren't any similar precedents with similar circumstances requiring not to affect intense traffic flows like this particular case.

The original transversal section and the expanded sections after the replacement of the stay-cables are included in the figures 49, 50 and 51.

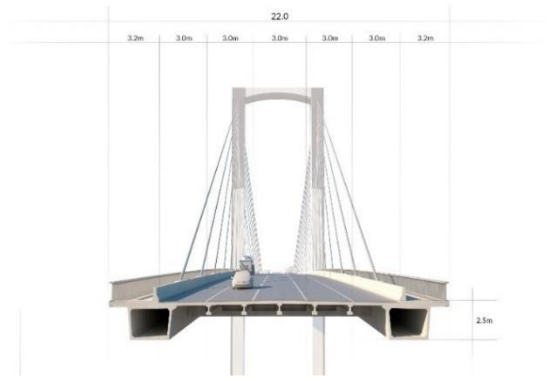

Figure 49. Current cross-section (5 lanes).

Figure 50. Cross-section after the replacement of the stay-cables (6 lanes)

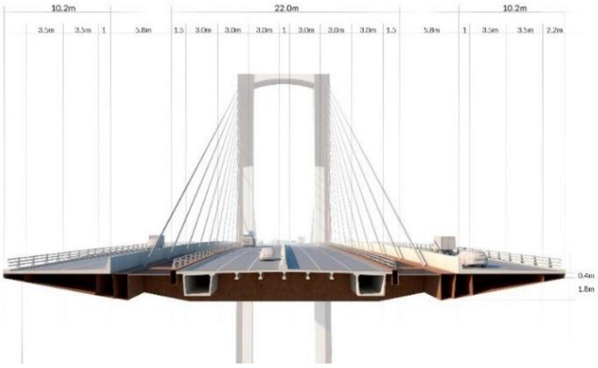

Figure 51. Cross-section of the future projected widening (10 lanes).