STAGE PROTECTION AGAINST DEGRADATION DUE TO THE USE OF DEICING SALTS OF A STRUCTURE IN ANDORRA

ALBELDA CUADRA, RAÚL
Construction Projects, Globalvía, Spain
ralbelda@globalvia.com
RODRÍGUEZ, JOAN LLUIS; TRIAS PATOUT, CHRISTOPHE
Túnel d'Envalira Concesion, Andorra
jlrodriguez@tenvalira.ad; ctrias@tenvalira.ad
GARCÍA GUILLOT, MARTA
Durability Advisor; Codyatec, Spain
martagarciagui@gmail.com
ARIAS HOFMAN, GONZALO
Maintenance Engineering Department, INES Ingenieros, Spain
gah@inesingenieros.com

SUMMARY

In the current economic context, the managers of the roads discussed in detail their budgets in search of efficiencies and optimizations. In particular, the amounts allocated to ordinary and extraordinary maintenance of the structures are also the subject of this review, even in severe weather environments such as Envalira Tunnel in Andorra.

Under the premise of this conference "The winter maintenance in times of crisis" is an example of how to address a stage repair into a bridge located in Pas de la Casa (Andorra), to avoid the problems of corrosion and degradation of concrete due to the massive and continuous use of deicing salts, prioritizing actions based on the time of year that can carry out repairs and resources available each year.

Keywords: deicing salts, structure, corrosion, degradation, tests, rehabilitation; efficiency

1. INTRODUCTION

The Envalira Tunnel Concession is located in the north of the Principality of Andorra, in the parish of Encamp. This Concession, comprised mostly of a long tunnel, crosses the Ariège River at the east exit through a precast viaduct that connects with Route Nationale No. 22 in France.

Following the results of routine inspections conducted by the Envalira Tunnel Concession under its own Quality and Environmental Management System, in October 2012 was performed, as recommended in the routine inspection report, a special inspection and a study of the structure to evaluate the current status of each of the elements thereof and the expected breakthrough of contaminants through non destructive testing (NDT). This analysis was developed by INES Ingenieros, with extensive experience in the analysis of similar pathologies, and in it were established phased intervention guidelines. After this study, the guidelines for the stages intervention were established, defining the areas and elements that could be most affected and the most appropriate methodology for possible repair, taking into account the durability requirements in such an aggressive environment.

With the pathologies found at the piers, it was decided to perform some actions adapted to the timeframe available, anticipating certain actions before the degradation process forward and have consequences that would require some repairs of significant economic value. It has been tried to optimize available resources, posing a stage implementation of the proposed actions. The recommended actions initially try to avoid the presence of water as a trigger for the degradation processes identified, addressing in a second phase the repairs of the most exposed and degraded elements, that also have a great influence on road safety. Finally, it has been proposed the proceedings relating to the protection of other elements against degradation processes, increasing the durability of them.

This article is intended to illustrate a bridge rehabilitation example that has adapted to the socioeconomic situation of the moment, which is required to continue maintaining and protecting the structures. This, in general, requires a deep and detailed knowledge of the actual state of the structure, which requires going beyond the mere visual inspection and testing using specialized techniques. The global analysis of all information enables a particularized performance design for each element of the structure, using more complex and expensive solutions exclusively in the areas necessary, and defining perfectly the level and type of activity for each area and item.

The storyline of this work has been the popular assumption that in the medium to long term, it is more efficient to invest in the study and design of actions, so as to optimize the amount and term intervention, without prejudice to the required safety an infrastructure of the importance of the viaduct.

2. DESCRIPTION OF THE STRUCTURE AND DIAGNOSIS

2.1. Description of the structure

It is a curved viaduct, about 225 m long with 7 spans of the same length (31.7 m). The structure was built in 2002.

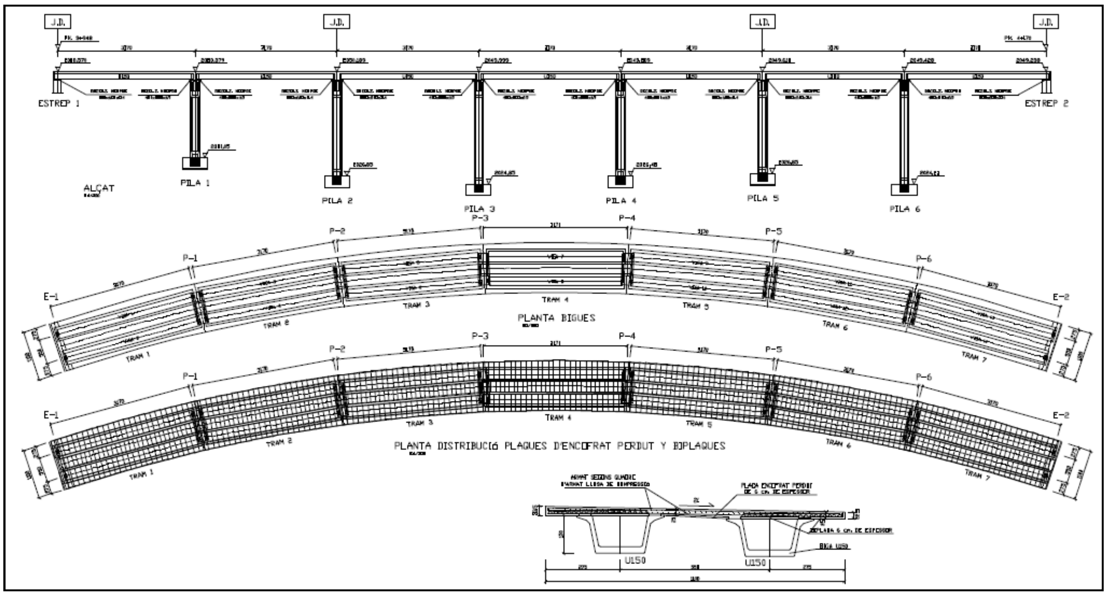

Figure nº 1. General drawing of the structure

 

Figures nº 2 and nº 3. View of the viaduct to abutment nº 1 (left) and abutment nº 2 (right)

The deck, 11.00 m in overall width, is constituted by two prestressed precast beams (1.50 m height and 3.24 m wide), with a 5.50 m interaxis. The slab of reinforced concrete has a variable height between 22.5 and 33.5 cm, to get a cross slope of 2% (with fall toward the south side of the viaduct). The concrete of the beams is HP-45/F/20/IV + F, while the concrete of the slab is HA-30/F/20/IV + F. The deck is finished laterally by cor-ten steel elements.

Piers consist of a single shaft rectangular hollow section (3.00x2.50 [m]) of variable height, finished at the top by a pier cap. The shaft, will "punch" through bars to the foundation. All elements are of reinforced concrete. The concrete of all elements of the piers is HA-35/F/25/IIa. The pier cap has two parallel knives with a slab at the top and two side slabs that match the sides of the pier shaft. At piers No. 1, No. 4 and No. 5, the terrain is a mixture of gravel and decomposed products, taking deep foundation with micropiles, while other piers take direct foundation.

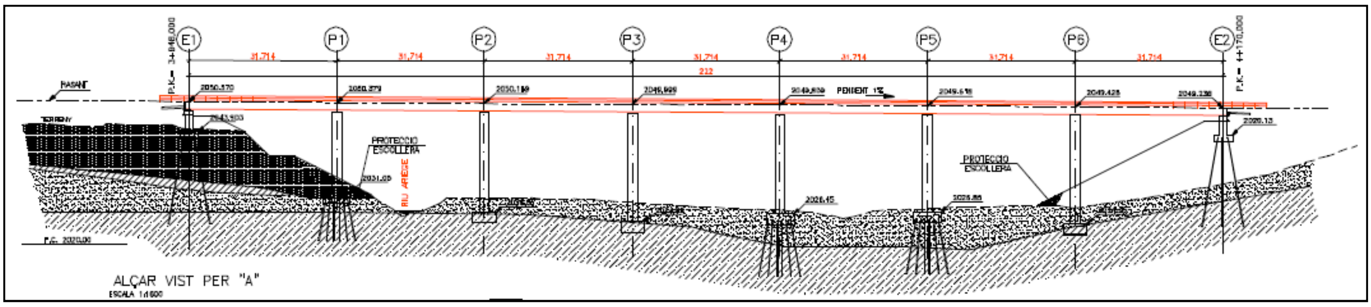

Figure nº 4. Foundation drawing

The abutments consist on a concrete surface foundation. The pile cap consists of a deep foundation based micropiles. Both abutments have flippers back and only the abutment No. 2 has a front wall containing the land in behind. The concrete of all the elements of the abutments is HA-30/B/30/IIa + H.

The bridge has an expansion joint cross-filed on both abutments and in piers No. 2 and No. 5, of armed elastomeric (as classified in "Highway Bridges Joints", AIPCR Spanish Local Committee; 2003). Bearings are elastomeric (according to UNE-EN 1337 Part 3; the definition given in the document in question, it is a "Support comprising a vulcanized elastomeric block can be reinforced with one or more steel plates"). Each beam is supported trough single elastomeric at each end, giving a total of 28 bearings.

 

Figures nº 5 and nº 6. Left beam bearing at No. 1 abutment (left) and right beam bearing at pier No. 2 (right)

The platform consists of a single carriageway with one lane in each direction and shoulders, with an asphalt pavement.

Figure nº 7. Top view of the viaduct, from No. 1 abutment

 

Figures nº 8 and nº 9. Drainage tube at No. 4 span (left) and sink at No. 2 span (right)

The safety barrier system is a metal guardrail (safety level H3, according to UNE 1317) anchored to the slab of the deck. The concrete longitudinal beam to which it is anchored forms a sort of lateral sidewalk. The drainage system consists of sinks topped protected and newly implemented inferior drain tubes (originally there was a longitudinal manifold whose anchors still be seen under the right overhang the deck, which suffered numerous breakdowns as a result of the weight of the iced water remained housed inside).

2.2. Pathologies observed

The most relevant pathologies are outlined below:

1. **Corrosion of reinforcement and concrete alteration**. As a result of freeze-thaw cycles and water with salts from the platform (around sinks, among shuttering slabs and beams, through the expansion joints and at the end of the cantilever) is an alteration of the concrete surfaces of the beams, piers and abutments. Alteration starts with the loss of the protective paint of the beams, continues with the presence of small cracks as a result of the reinforcement corrosion and the appearance of spalling in concrete, which then allow the view of the reinforcement at the affected elements.

   The hardest hit walls in piers are those located on the south side of the structure, since the deck lateral slope causes the water to fall to this side. On the other hand, the prevailing winds are from south to north on the valley under the viaduct, so that the water affects the south-facing paraments. Because water with chlorides filtration (from the molten salts composed primarily of sodium chloride), corrosion processes are triggered very active in the reinforcement, which affect areas with the highest incidence of moisture (facing south); within these are particularly evident in the areas of lower coating thickness. This shortage of coating was recorded especially in the corners of some of the pier shafts; it has been detected on a detailed visual inspection that this covering failure had tried to be alleviated by successive layers of repair mortar. It was found that these layers are undergoing degradation, being one of the most affected areas

   In general coating thicknesses are quite variable, even though in some areas are rare (less than 1 mm), the remainder exceed 25 mm and, occasionally, even 50 mm.

   In many paraments of the structure shows the degradation of concrete mass, starting altering cementitious mass itself that becomes micro-cracking and spalling, leaving the aggregates in sight, which then come off, resulting in loss of material. This effect is due to the combined and synergistic action of freeze-thaw and salt crystallization. Both effects are mainly active in the most exposed areas in which water with salts drains. This effect is observed in a particularly intense in the base of the safety barrier system, mainly on the left side, where large areas are totally deteriorated (responsible for maintenance of the Concession reported about recent timely repairs on this element). This has also been observed in concrete abutments.

 

Figures nº 10 and nº 11. Concrete beams surface alteration with the presence of punctual reinforcements in sight

 

Figures nº 12 and nº 13. Degradation of concrete abutment No. 2 (left) and surface alteration of concrete base for safety barrier (right)

2. **Efflorescence and stains** in beams and cantilever on deck, especially in the right side (due to the steepness of the deck, the water has a greater tendency to come out of this area). The cause of these efflorescences, somehow anticipating previous deterioration, is motivated by a precarious deck waterproofing. On bridges is very common the water passing through the expansion joints, at the edge of the deck or around water seeping sinks, but is less common to happen through the concrete slab (as seen in the stains and surface alteration between formwork slabs and beams), which can occur if there are defects in the waterproofing of the concrete slab. It should be highlighted that even though stains, virtually no reinforcement bars are exposed except in localized points. The conclusion is that if indeed the current drainage system makes the water not slipping by concrete walls with the intensity with which he did from the construction of the viaduct, the alteration of the concrete elements will be much slower or nonexistent at the points where improvement has occurred (around sinks and of the joints).

 

Figures nº 14 and nº 15. Detail views of spalling, stains and alteration of concrete surface at bottom of pier No. 2 (top left) and detail view of the pier cap (top right)

3. STUDT METHODOLOGY

Once a detailed inspection with appropriate access arrangements to approach the higher altitudes and lower side of the deck (a summary of damages stated in the previous section) has made a study of durability which is summarized then to analyze the degree of involvement of the elements by the presence of deicing salts and other aggressive.

In order to assess the durability of the structure, it is necessary to take into account the environment in which it is located, determining the possible causes of attack that may be experiencing. The viaduct is located in an area of high mountains (above 2,000 in elevation above sea level). Under these conditions, temperatures below 0 °C are common and permanent for long periods. This favors the formation of ice and forces the use of molten salts on the pavement to facilitate road traffic. A priori, and without making a detailed study of the specific climatic conditions of the viaduct, it is expected that major attacks occur as a result of freeze-thaw cycles, as well as by the presence of the molten salts used to facilitate winter maintenance. As noted in the detailed inspection of the structure, the various elements constituting the viaduct show damage resulting from the impact of the aggressive environment in which it is located, with damage all related to the presence of water.

3.1. Aggressive characterization

In order to assess the status of the structure has made a determination of potential aggressive agents which can affect the durability, from the point of view of corrosion of reinforcement (chlorides and carbonation). Chloride determination has been performed in the laboratory on samples previously taken in the field, while the carbonation was made in-situ, in recent fracture (punctual tastings).

- Determination of the carbonation front advance. Determining the progress of carbonation front or carbonation depth was achieved by adding phenolphthalein, following the UNE 112011:2011. Once the indicator has taken the appropriate color (colorless for pH less than 8, turning a red-purple color as the pH rises), the thickness of the carbonate is measured. The carbonation reaction is caused by carbon dioxide from the air that penetrates through the pore network of concrete, with the alkaline constituents of the cement. These results in a significant drop in pH, which causes a loss of passivity of the reinforcement embedded in the concrete.

The highest advances of the carbonation front occur with humidities between 50 and 80%. In the case of areas of high humidity such as the environment in which is located on the viaduct over Ariége river, the pores are saturated, which impedes the diffusion of CO_2. In dry areas, the limited amount of water in the pores prevents dissolution of CO_2 and thus the carbonation reaction.

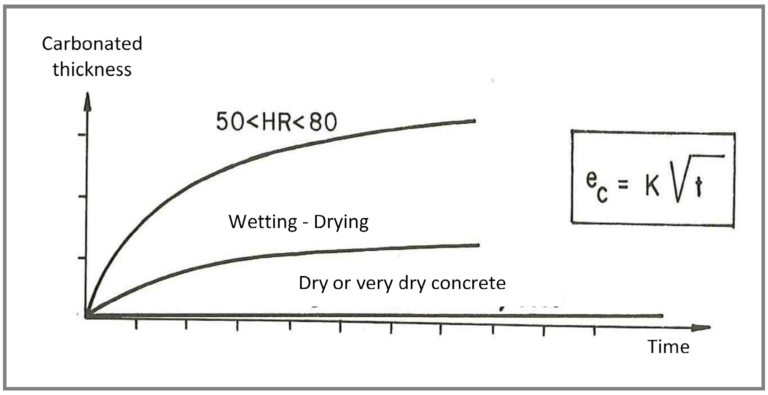

Figure nº 16. Advance of carbonation front versus time

The data obtained indicate that the carbonation is negligible in all sides of the shafts, so this data extrapolated to the rest of the structure, is considered that <u>the carbonation is not the trigger of corrosion processes</u> logged.

The following Figures show the front carbonated revealed some of the determinations made.

Figures nº 17 and nº 18. Advance of carbonation front in piers No. 2 and No. 3 respectively

- <u>Determination of chlorides</u>. In order to characterize corrosion processes and also to establish appropriate recommendations for intervention, it is necessary to know if there are chlorides above permissible limits, though high contents are harmful to reinforced concrete and can trigger active corrosion processes of reinforcement, even in the case of non-carbonated concrete. Chloride attack produces a local breakdown of the passive layer that protects the reinforcement, having morphology of localized corrosion or pitting. Chlorides can come from the outside or be in the concrete mass itself having been added in the concrete (as setting regulator or as a contaminant in one of the components, water or aggregates). The chloride content determination was carried out following the UNE 112010:2011, the percentages being calculated on the weight of concrete. Chloride determination was made at 5 points located in all the piers (4 in the shafts and 1 in the pier cap). The sampling design was made so as to be representative of the current state of the structure, taking points apparently damaged and healthy. Furthermore, in the most affected areas, the samples were taken covering a profile depth of about 10 cm from the surface in order to identify the level of penetration of chloride attack. This allows identifying more precisely the level of cleanliness or chopped to be applied in different areas, depending on the actual situation of the concrete elements. Sampling was done by core drilling with different diameters, collecting the sample in powder form, distinctly as depth intervals. Thus, the samples called "exterior" relate to a mean value of chlorides corresponding to a thickness between 0 and 5 cm from the concrete surface. Samples called "interior" correspond to coating depths between 5 and 10 cm from the concrete surface. Table No. 1 shows the samples taken and the results obtained.

Table nº 1. Chlorides determination

SAMPLIG	CHLORIDES	
	INTERIOR	EXTERIOR
P1 S shaft	0,04	0,74
P1 N shaft	---	<0,01
P2 S shaft	0,02	0,78
P2 N shaft	---	<0,01
P2 S pier cap	0,07	0,13

The maximum limit of chlorides currently prescribed in EHE Regulation for concrete is 0.4% relative to the weight of cement (half in the case of prestressed concrete). If it is a good concrete (350-380 kg of cement per cubic meter of concrete), this limit will be approximately 0.05-0.10% by weight relative to the concrete, so has been taken this value as the maximum permissible limit. Figure No. 19 shows the chloride concentration determined for each sample. As can be seen, the chloride content of samples taken on the south side is clearly significant (above 0.1%), dropping to negligible levels inside (samples "interior"). However, none of the samples taken on the north side are contaminated by this aggressive ([Cl-] <0.01%). Furthermore, the distribution indicates that this aggressive chlorides derived from the molten salts used, not having been added during casting (or setting regulator contaminating any component). In Figure No. 20, these data are represented in the form of profile.

In order to estimate the depth of the concrete shafts repairing, pier caps and abutments, it is necessary to clean up at least 5 cm with stains or areas that indicate water runoff, so as to eliminate the contaminated concrete. These areas are basically:

- South facing paraments in the shafts of all piers
- Pier caps No. 1, No. 2 and No. 5, in the south paraments and east and west half paraments
- Full abutment No. 2

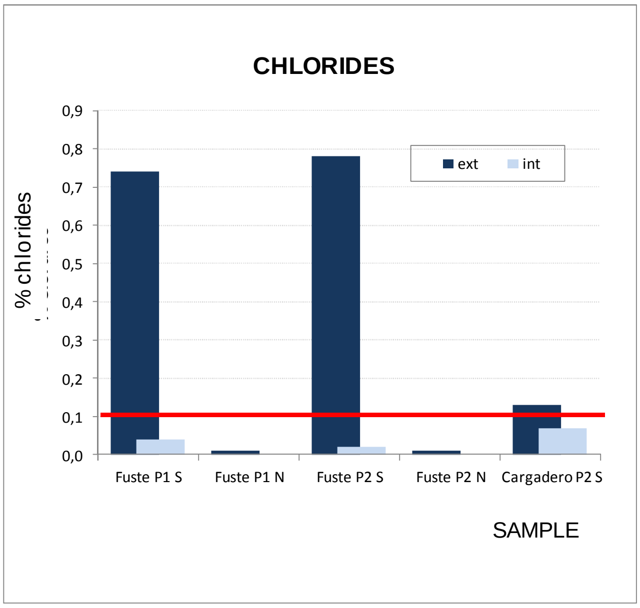

Figure nº 19. Chlorides concentration data in concrete samples

The paraments of the beams are affected much more superficially, and would be enough with a surface cleaning and protection in all areas matching sinks (beams right, next to the piers) and in other specific areas of contact between shuttering slabs and beams.

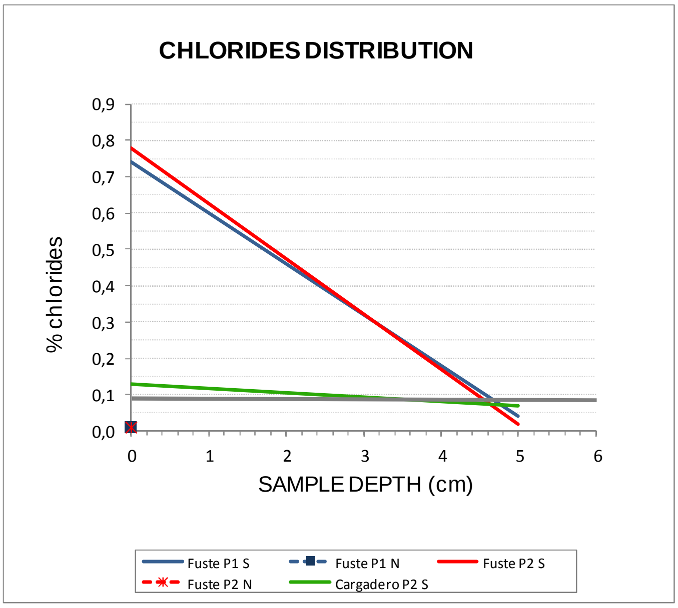

Figure nº 20. Chloride distribution in samples

3.2. Determination of reinforcement corrosion parameters

In order to characterize the state of reinforcement corrosion, the durability study is complemented by recording the characteristic corrosion parameters. Those parameters, interpreted in conjunction with other tests make possible the determination of the conditions of the structure. The parameters recorded were the corrosion potential of the reinforcement and the electrical resistivity of concrete, employing CANIN+ (PROCEQ). The potential measurements were performed following the UNE 112083:2010 "Measurement of free corrosion potential in concrete structures" and provide qualitative information on the risk of reinforcement corrosion. The potential variation along the structure may identify the presence of areas with and without corrosion. Reference limits established by Spanish and international regulations are outlined in terms of the reference electrode used (see Table No. 2).

Table nº 2. Corrosion potential criteria

ELECTRODE	E_{corr} LIMIT VALUES FOR RISK OF CORROSION		
	< 10 %	**≅ 50 %**	**> 90 %**
$Cu/CuSO_4$ saturated	> -275 mV	-275mV < E_{corr} < -425mV	< -425 mV
Calomel (ESC)	> -200 mV	-200mV < E_{corr} < -350mV	< -350mV

In this case measures have been carried out with a device electrode wheel with saturated copper ($Cu/CuSO_4$ saturated), thus adopting the values shown in the first row of the previous table. Such as the table shows, values more negative than -425 mV Cu/Cu_2 indicate a probability greater than 90% of being produced an active process of corrosion, values more positive than -275 mV Cu/Cu_2 indicates a 90 % non corrosion, remaining uncertain the probability of corrosion in the case of values between -275 and -425 mV. The potential determinations made were performed on the south side and north of the shafts of the piers No. 1 (moderate corrosion damage), No. 2 (coinciding with an expansion joint on the deck, with significant corrosion damage) and No. 3 (low corrosion damage), trying to characterize the different situations occurring in the structure. The location of the records is as follows:

Pier No. 1:	South parament	North parament
Pier No. 2:	South parament	North parament
Pier No. 3:	South parament	North parament

Below a number of Figures show the six potential maps collected, which comprise about 600 total corrosion potential readings. The results are clearly determinants:

- Searches conducted on the northern paraments indicate passivity of reinforcement (more positive E_{corr} -275 mV), which is consistent with the absence of aggressive (chlorides and carbonation negligible) to begin the process of corrosion
- Searches conducted on the southern paraments clearly indicate active corrosion visually affected areas, consistent with the high content of chlorides obtained in these area, triggers the oxidation process

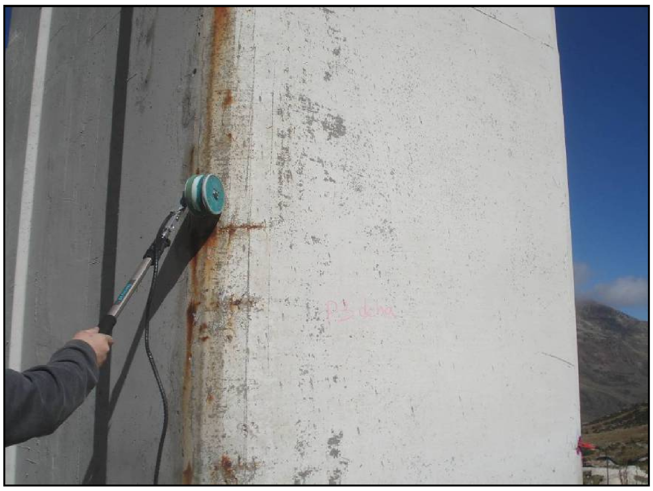

Figure nº 21. Corrosion potential record in south parament at pier No. 3

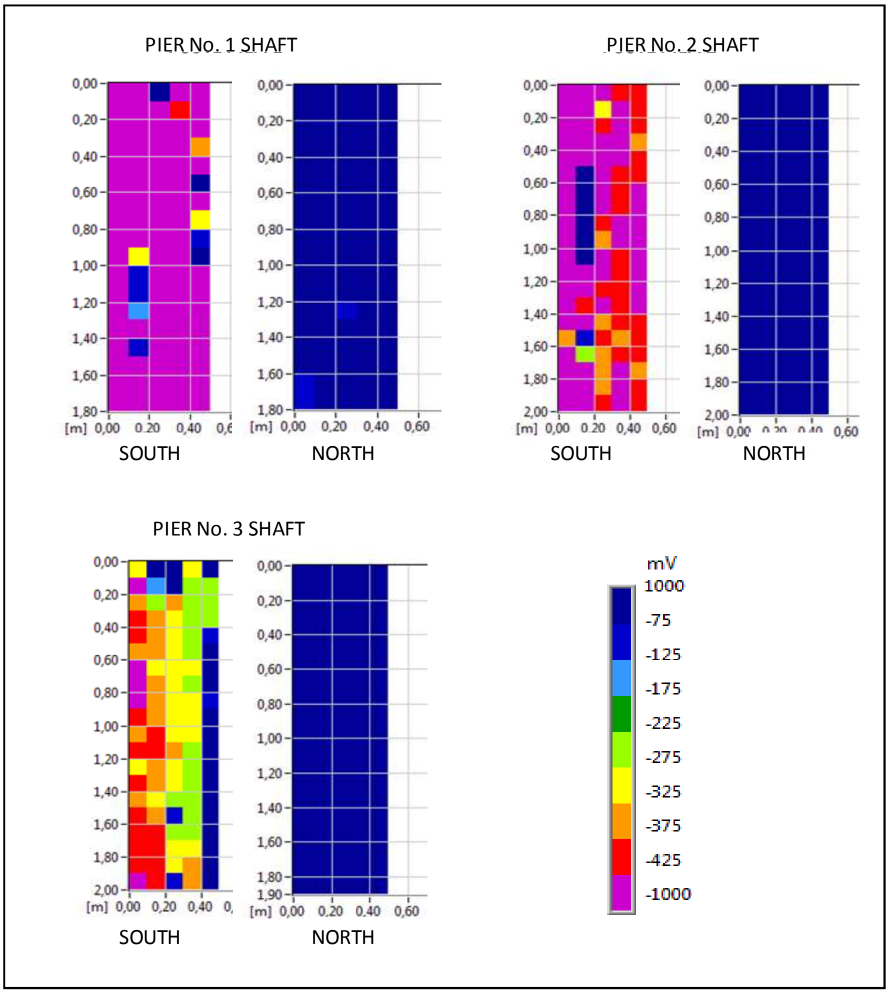

Figure nº 22. Potential maps on north and south paraments at piers No. 1, No. 2 and No. 3

The results of electrical resistivity recorded, following the criteria of the Manual CONTECVET, are consistent with the rest of the data, ranging from 50-100 Kohm·cm on the north side and are under 50 Kohm·cm in the face south. In Table No. 3 are outlined the criteria.

Table nº 3. Resistivity criteria

RESISTIVITY (Kohm x cm)	RISK OF CORROSION
>100-200	Negligible corrosion
50-100	Low
10-50	Moderate to high

Regarding this parameter, there are no regulations for in situ measurements, having been employed as a reference UNE 83988-2:2008 "Determination of electrical resistivity. Part 2: Method of the four corners or Wenner ", although it does not include reference limits.

4. STAGE PROTECTION PROPOSED

Since in the climatic environment in which the bridge is, the working periods for repair of structures are very limited, the actions proposed have been focused in stages over several years, and also the available resources are optimized each year:

i. First is to avoid the presence of water (triggering factor detected for degradation processes)
ii. Next actions are the repairs of the most exposed and degraded elements, with influence on road safety
iii. Finally, the activities relating to the protection of the rest of the elements from degradation processes must be undertaken, with the intention of increasing the durability of them

In the design of these interventions, it is assumed as a condition that the bridge will be in permanent contact with contaminated water and snow melting salts.

4.1. Performances in first stage: water control

In this first phase arise all those performances to control of the water, trying to minimize the contact between the water (inevitably contaminated by the salts used in winter maintenance) and the elements of the bridge. After analyzing the critical points where water drains, the actions to achieve the stated objective have been taken.

In the short term it is proposed placing a waterproof membrane under all expansion joints (currently placed under the right road). Current joints can be kept still in service, even though the elastomeric coating is scratched. It should replace the anchors of the drain tubes beams, since they are not galvanized, and its durability is reduced. Finally, it has been proposed placing a drip at the lower ends of the two cantilevers, to prevent the water which may drain from the platform by sliding the two cantilevers and reach even the beams. In the future it is recommended, but without the urgency of the above measures, the application of a high quality waterproofing system on the upper face of the concrete slab (thermoplastic, double diaphragm type or polyurea) with sinks properly sealed and protected. It is important to extend the detail of high quality waterproofing system all trough the base of the safety barrier system.

4.2. Performances in second stage: repairing the most exposed elements

As a second stage, to those elements in permanent contact with the water and the snow (mainly concrete bases of safety barrier system), it is recommended to clean up and demolish the concrete, always coming to the reinforcement, cleaning up and passivating it) and reconstruction with mortar (type R2, UNE EN 1504). Prior to concreting, it is recommended that once the reinforcements are clean, they are protected with a product with corrosion inhibitor (active protection for reinforcement, due to Principle 11 11.1, method UNE-EN 1504-9:2011). That product can also act as a union bridge with the mortar.

It is advisable also to apply a corrosion inhibitor to the concrete mass, in order to establish a multilayer protection system. This migration will be of type inhibitor when applied to existing concrete, and aggregated to the concrete that is used in the reconstruction. In this concrete base, once repaired, it is recommended to apply also highly waterproof system (Principle 2, method 2.2 UNE-EN 1504-9:2011).

4.3. Performances in third stage: repairing all the other elements

In those elements on which the water is not going to have a contact as permanent and harmful, it is proposed the sanitizing and reconstruction of damaged concrete paraments, restoring lost materials and reinforcements coatings, to thicknesses according to durable conditions as shown in the EHE-08, considering the characteristics and aggressive environment of the structure. In the piers, more damaged than the other elements, it is proposed to demolish to find sound concrete (due to the tests performed, it is recommended to demolish at least 12 cm, always coming to the reinforcement and removing degraded concrete layers and passivate the reinforcement) and reconstruction with mortar (type R4, UNE EN 1504). Prior to concreting, it is recommended that once the reinforcements bars are clean, they are protected with a product with corrosion inhibitor (active protection reinforcements Principle 11 11.1 method UNE-EN 1504-9:2011), that can also act as a union bridge. It is advisable also to apply a corrosion inhibitor to the concrete mass, in order to establish a multilayer protection system. This migration will be of type inhibitor when applied to existing concrete and aggregating to the new concrete to be used in the reconstruction. In the repaired paraments is recommended to apply a highly waterproof system (Principle 2, method 2.2 UNE-EN 1504-9:2011).

For the beams of the deck, sandblasting of the paraments affected is recommend (in case of reinforcement in sight, it is necessary to discover itching around to clean them up and proceed to pasivante, adding reconstruction mortar type R4, DIN EN 1504). In the repaired paraments is recommended to apply a protective coating with repellent feature, in order to allow evaporation and elimination of possible leakage sites (Principle 2, method 2.1 UNE-EN 1504-9:2011). In abutments, it is recommended in the abutment No. 2 a deep sanitizing, which would be recommended to remove at least 10 cm thick coating, applying reconstruction mortar (type R4, UNE EN 1504) and the use of protective reinforcement and concrete with corrosion inhibitor (follow requirements offered for piers). In the repaired paraments is recommended to apply a protective coating with repellent feature, in order to allow evaporation and elimination of possible leakage sites (Principle 2, method 2.1 UNE-EN 1504-9:2011).

5. CONCLUSIONS

1. From the work carried out and the data analyzed, the following conclusions can be drawn:

    a. Management System and Environmental Quality Award of Globalvía Envalira Tunnel Concession has allowed early detection and implement the necessary mechanisms to analyze and assess the conservation status of this viaduct, that was put into service in September 2002
    b. The problem of degradation of concrete located in certain parts of the viaduct has been analyzed, mainly as a result of corrosion of reinforcement and cementitious mass destruction of the concrete
    c. Initial diagnosis has defined degradative processes as triggers, first, the action of the salt water coming from the sinks of the deck during the winter and, secondly, the freeze-thaw cycles that occur on a frequent basis to throughout the year
    d. Concrete degradation in piers has been due to the drain sinks and downpipes were placed in design precisely over the piers. The direct

drainage water deck on their own piers has accelerated the degradation phenomenon of these elements

e. The results of chloride content, maps of potential and concrete resistivity allow identifying hardest hit bridge areas, matching the most visible damage. With respect to chloride content, note that the profiles obtained (between the interior and exterior of the concrete mass) confirm that the origin of those are external contributions and not the mixing into the water in construction

2. The most affected elements are those to who water comes to (or has arrived for most of its life), which during the winter period downs from the platform mixed with salts as a result of winter maintenance work required. The elements affected are: beams, abutments, piers and the base of the safety barrier system

3. Within each element, the damages are localized in singular areas (at the ends of the beams, on the piers in which there is expansion joints and in the abutments, at the outlet of the sink and at certain points which the original longitudinal tube collector has ruptured over the piers, in the south facing sides in all shafts and in some pier caps, in the loading and side paraments of the abutments, and in the base of the safety barrier system)

From the identification of the damage, its causes and the extension on the different elements, there has been a proposal for staged actions, to optimize the resources available for the years 2013-2015, according to the following schedule:

a. Elimination, as far as possible, the presence of water on the different elements of the bridge (work already initiated in 2013)
b. Protection and repair of the most exposed elements: concrete base of safety barrier system (work planned between 2013 and 2014)
c. Repair and protection from the elements with less exposure (deck, abutments, piers), although at the time of the completion of the inspection and study were the elements whose conservation status was more striking (work planned to run in 2015)

In July 2013 Tunel d'Envalira had already begun the work to prevent the action of salt water on the affected elements, undertaking repairs the first performances on the deck and pier caps in accordance with that described in section 4.1 (First stage performances).

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