Sixth International Conference on Durability of Concrete Structures **Paper Number RAM02**
18 - 20 July 2018
University of Leeds, Leeds, West Yorkshire, LS2 9JT, United Kingdom

Comparison data between hybrid and galvanic anode installation in the Arousa Island Bridge

J.A. Becerra-Mosquera
Neto Ingeniería, General manager, La Coruña, Spain

D. Carro-López
Universidade Da Coruña, Associate Professor, La Coruña, Spain

J.E. Pardo Landrove
Xunta de Galicia, Head of road safety and maintenance, Santiago de Compostela, Spain

J.M. Millán Pérez
Galaicontrol, Technical Manager, La Coruña, Spain

ABSTRACT

The Arousa Island Bridge, with its 1980 m is the only road access to the Arousa Island. Built in 1985, this single-cell box girder divided in 40 spans runs entirely on the sea. The deck is between 2 to 12 m above sea level, so after 25 years in a marine environment, the structure showed reinforcement corrosion, especially in piles and deck bottom. Attending to the corrosion damages, caused simply from a chloride attack, the local government decided to intervene with an ambitious repair project. This decision has been taken only after an exhaustive cost analysis to determine the feasibility of repairing the structure against the construction of a new one. In this project, the reparation was divided in three types of intervention: conventional reparation with patches, galvanic anode installation and hybrid anode installation. The objective of this division is the data collection for further repairs. The research will be explained in detail and the comparative results will be explained in depth, therefore examining the corrosion progresion and service life. Currently, after careful analysis of examining the last 6 years of data, the hybrid anode installation is the system with the better initial results. Though with the evolution of the years, the galvanic anode installation is just as effective.

Keywords: Cathodic Protection, structure repair, corrosion, chloride attack.

1.0 INTRODUCTION

The bridge of this research links the island of Arousa with the coast of Galicia in the NW of Spain. It is a reinforced concrete structure, planned and executed in the mid-eighties currently the twentieth century (year of commissioning: 1985).

The bridge is 1980 m long and it was designed in a circumference of 2.5 km radius. It consists of 40 spans, 38 of which are 50 m in span, whilst the other 2 ends with 40 m span. It includes joints only in the two brackets.

The deck consists of a single box girder, 2.3 m height, with two transversal projections. The total width of the roadway is 13.00 m, divided into two sidewalks of 1.50 m, two shoulders of 1.5 m and two lanes of 3.5 m.

The bridge was inspected and it was decided that a full intervention was required. The pathologies detected were: corrosion damage in deck and piles, shear cracks and compatibility in the deck, some gravel nests in piles and abutments, corrosion of the bearing plates, corrosion due to deficient surface drainage, deterioration of neoprene pot bearings, and damage in the lighting boxes.

The structural condition of the bridge was good however, there were some problems of durability. That was expectable considering the elapsed time from construction and the aggressiveness of the marine environment. This ambient saturated with chloride ions (Cl^-) produced corrosion of the reinforcement in some areas. Although this attack does not affect the structural safety, there are large areas visible damaged that affects the aesthetics of the bridge.

Within the field of concrete repair, the usual treatment is to apply localized repairs in the concrete. This technique was applied with satisfactory results. However, given to the aggressiveness of the ambient, it was decided to use also cathodic protection methods in conjunction with the localized patches repair (Leon-Gonzalez, 2011).

2.0 ECONOMICAL ISSUE AND PRESERVATION COST

Any type of action in matters of public investment must always be supported by an investment feasibility study. This type of study includes both the social and economic benefits of each action, in order to assess whether investment is viable or not

The main objective of an action of this type is after analysing the results, to lengthen the useful life of the structure, with the objective of postponing the final investment corresponding to the replacement of the infrastructure.

Therefore, it can be affirmed that the investment in repair of an existing structure, makes sense from the economic point of view if the estimated cost of repair is less than the cost of building a new structure.

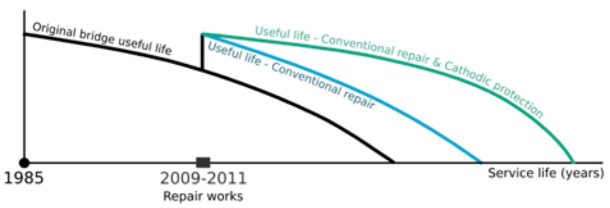

Fig. 1. Effect in Useful Life of three intervention decisions: no-intervention, conventional repair and conventional repair & cathodic protection

2.1 Cost comparison

To make a comparison of the costs associated with the replacement of the structure, an initial study was carried out that included only economic variables, without evaluating the beneficial effects that the investment may have on society.

The total replacement cost of the bridge, would be composed of the following items:

- Construction of a new concrete structure
- Preparation of access to the structure
- Endings on the structure: parapets, imposts, agglomerate.
- Demolition and waste management corresponding to the current bridge.

For the feasibility analysis, we proceeded to assess the first and major part of the budget factor, which is the construction of a new structure.

For the estimation of the cost we use the Guide for the construction of new bridge, and the base of reference prices, both published by the Spanish ministry of public works (Ministerio de Fomento. centro de publicaciones, 2000, 2016).

The amounts published in the Guide for the construction of new bridges and the prices published in the base of reference prices can be used to estimate the cost of construction of a new deck. Applying this information, the cost for the constriction of a new structure will be as given in Table 1.

Table 1. Cost of construction of a new structure

Item	Quantity estimation	Total	Price	Amount (€)
DECK CONSTRUCTION COST				
Active Steel	20 kg/m^2	475,200	3.06	1,454,112.00
Pasive Steel	110 kg/m^2	2,613,600	1.17	3,057,912.00
Concrete	0.68 m^3/m^2	16,156.80	118.17	1,909,249.06
Falsework	6.95 m^3/m^2	165,161.98	23.49	3,879,631.32
PILE CONSTRUCTION COST				
Pasive Steel	80 kg/m^3	197,851.20	1.17	231,485.90
Concrete	8.77 m^3/m	2,473.14	103.82	256,761.39
FOUNDATION CONSTRUCTION COST				
Pasive Steel	65 kg/m^3	83,947.5	1.17	98,218.58
Concrete	31.5 m^3/ud	1,291.5	96.51	124,642.67
TOTAL AMOUNT OF INVESTMENT (€)				**11,012,012.91**

The total amount of the investment for the reparation has been 5,065,841.80€, witch is divided as follows.

Table 2. Investment for the reparation

ITEM	AMOUNT (€)
Access platforms	316,467.50
Pile repair	2,960,048.13
Deck repair	1,680,008.73
Elastomeric supports replacement	109,317.44
TOTAL AMOUNT OF THE REPARATION (€)	**5,065,841.80**

Considering that the investment for the reparation has been less than half the investment necessary for the construction of a new structure, the investment in the repair instead of the construction of a new structure is justified.

3.0 CORROSION OF REINFORCED CONCRETE

3.1 Corrosion fundamentals

Corrosion is defined as the deterioration of a material under attack by an electrochemical environment (Gonzalez-Fernandez, 2007). More generally, it can be understood as the general tendency of material to find it's most stable or lower internal energy form. Provided that the corrosion is caused by an electrochemical reaction (oxidation), the rate at which occurs will depend to some extent on the temperature, the salinity of the fluid in contact with the metal and the properties of the metals in question (Cobo-Escamilla, 2001).

There are major differences between what is known as generalized corrosion and corrosion by chlorides. In the case of chloride corrosion, the chlorine acts as a catalyst for the reaction, causing it to accelerate at certain points producing what is named pit corrosion (Davison, 2006).Considering that the investment for the reparation has been less than half the investment necessary for the construction of a new structure, the investment in the repair instead of the construction of a new structure is justified.

3.2 Chloride attack in reinforced concrete: repairing methods

There are several repair systems that have traditionally been used with corroded reinforced concrete with chloride attack (Christodoulou, 2008). However, the technology has evolved with the experience and the monitoring of the evolution of the repaired structures:

Conventional reparation in patches
This is the most traditional repair system. It consists of the clean up of the affected areas, uncovering the rebar and applying new mortar to restore the affected area to its original state. This is the fastest and most economical repair option. In case of severe corrosion, this type of repair can produce new corrosion in the perimeter of the repaired area (Fig. 2). Also, there is a "radial expansion" over time. This phenomenon is known as incipient anode.

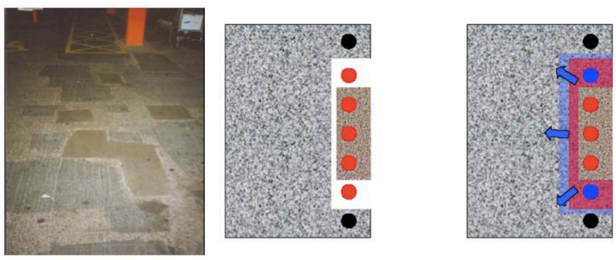

Fig. 2. Examples of patch repair and repair with mortar with corrosion inhibitors

Repair with mortar with corrosion inhibitors
A breakthrough to conventional patch repair is the use of hydraulic mortars modified including migratory corrosion inhibitors. These are polymeric products, which create a protective film around the steel; with this, there is a reduction of the possibility of corrosion by chemical attack. The fact that they are migratory products makes these able to penetrate into the concrete mass located on the perimeter of the patch. The distance that these products can penetrate in the concrete mass is based on Fick's law.

Cathodic protection with anodes of sacrifice
This method uses the knowledge of the scheme corrosion of steel in reinforced concrete, and in particular, the scheme of chloride attack. It applies sacrificial anodes in the perimeter of the repair; with this it prevents the creation of incipient anodes in the outside of the repair patch. Also, it is in compliance with the electrochemical scheme already established in the steel rebars. As stated previously, the corrosion of the sacrifice metal itself is at the same time, protecting the adjacent steel (Fig. 3). This is because the corrosion acidification leads to the re-alkalinization of the contiguous steel, protecting it thanks to the hydroxyl groups that migrate to these areas.

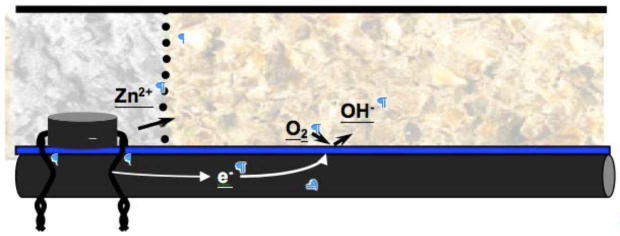

Fig. 3. Example of sacrificial anodes protection

This is the principle of cathodic protection, which allows for a controlled corrosion (in this case the anode, not the steel bars), and the re-alkalinization and protection of steel in the vicinity of the anode.

Cathodic protection with impressed current
Impressed current protection is another example of cathodic protection. The technique of impressed current is the use of an external power distributed by wiring to the entire structure and including a network of titanium anodes. With this, a distributed protection is achieved along the whole structure by means of the re-alkalization produced around the steel.

4.0 STRUCTURAL REPAIR OF THE BRIDGE OF ILLA DE AROUSA

The motivation of the repair project was to achieve the structural repairs that would allow the extension service life of the bridge. The intervention is divided into two parts: the deck repair and the reparation of piles. The division is made not only by the difference in the types of elements, but also by the different degrees of aggression that have the affected areas and treatments needed to be performed.

The sanitizing was carried out in the damaged areas performed with two methods, one manually by a chipping hammer and the other by hydro-demolition machine, which proved to be the most effective method. Both produced acceptable quality and cleanliness of the demoliation (Fig. 4).

Fig. 4. Techniques of demolition of damaged areas of the deck.

The repair system applied was the cathodic protection of the steel structure. This type of cathodic protection selected was sacrifice anodes of zinc. This metal, thanks to its lower galvanic potential draws to itself the aggressive agents (chlorides and oxygen). Furthermore, this metal presents another useful feature, when oxidized it does not suffer a significative increase in volume (this is the biggest problem of corrosion of reinforcing steel embedded in concrete, which increase about 6-10 times its volume when oxidized).

One of the decisions taken at the beginning of the repair, was that given the volume of work that had to be faced, was to use various products and patents on the market in time. This permitted to evaluate each of the products efficiency and applicability.

4.1 Repairs in the deck

The major structural repairs on the deck were of a greater magnitude in areas close to the supports of the piles, at the junction flange-web of the deck and the junctions between vertical sides and the bottom of the girder.

It was detected that many existing corrosion problems had been caused by defects in the concrete placement. In addition, with regards to the bridge it was established to use continuous plastic along the rebars. This type of spacer for reinforcing bars was a novelty at the time and it favoured substantially the entry of aggressive agents more directly and quickly (Fig. 5).

Fig. 5. Affected areas of the bottom of the concrete girder.

The repair was carried out on the deck which consisted of sanitizing each damaged area, replacement of steel in areas where the loss of section was excessive (Fig. 6). After this, placing discrete zinc anodes in the area of repair, next the application of thixotropic mortars. Finally, the entire surface of the deck (repaired and unrepaired areas) was painted with a special anti-chloride paint.

Fig. 6. Details of the repairing procedure (sacrifice anodes, application of mortar patches and final painting)

4.2 Repair of the bridge piles

The area of the tidal piles and splash zone and therefore suffered a much higher risk of corrosion. In the project it was indicated the need of cathodic protection as in the deck but with a different approach. After inspection, it was clearly observed that there was a need for a global repair instead of repair by batches as was performed in the deck.

The repair of the piles was structured and planned as follows:

<u>Conservation of one of the piles with conventional repair and without cathodic protection</u>
This will serve as reference and permit comparison for the deterioration of the bridge without cathodic protection.

<u>Conventional repair + cathodic protection jacket system (Fosroc)</u>
This system consists of placing some jackets of fiberglass mesh + zinc batteries. Filling the gap between the pile and the jacket with an special concrete that allows the current flowing between the mesh of zinc and the reinforcement (Fig. 7). This system was used in a limited group of piles because of the difficulties of the works in the areas hit by the sea. All circuits for the reinforcement and the zinc anodes was conducted to the deck and connected in electric boxes protected inside de girder box. This makes monitoring over time easy.

Fig. 7. Repair of the piles with the Fosroc jackets

<u>Conventional reparation + cathodic protection system with the hybrid system (CPT)</u>
The functioning of this technique stems from the introduction of sacrificial anodes in small holes in the structure and all embedded in a mortar of activation. The arrangement of sacrificial anodes was made based on a grid designed according to the detected damage and location relative to the different zones: tidal, splash, etc. These anodes are connected through titanium wire that closes the circuit against reinforcement steel bars, which in turn are connected in a connection box within the board for later supervision (Fig. 8).

The network of anodes and wiring permits the application of impressed current for a short period of time. This was performed initially after the repair works, however it can also be applied after a period of time since the intervention with a similar effect. The aim was to produce the re-alkalisation of the structure, with the consequent prevention of chloride attack. This delayed treatment would be possible simply by using external batteries and for a very short period of application, between 1 and 2 weeks. Thereafter the system is disconnected from the battery, starting its operation as conventional sacrificial anodes. The new electrochemical equilibrium starts from steel in a substantially improved situation from its initial point due to the process of re-alkalisation and previous chloride extraction technique.

Fig. 8. Repair of the piles with conventional technique and CPT cathodic protection

4.3 Control of corrosion evolution

As mentioned above, the repair performed included innovative solutions in many aspects, which include monitoring the cathodic protection. It is possible to measure the connections between the sacrifice anodes and the steel reinforcement, they are accessible in boxes for collecting data that allows the tracking of the installed systems (Fig. 9).

The monitor is designed to take data selectively from different areas of the bridge (north side, south side, splash zone, tidal zone). In this way, it is planned to carefully monitor the installed systems. It would permit to compare different electric consumption in the cathodic protection of the different zones depending on the aggressiveness of the areas.

Fig. 9. Detail of a connection box and the procedure of measurement of the voltage

5.0 RESULTS OF THE EVOLUTION OF THE CORROSION

The follow-up visits have produced extensive measurement campaign data. This enables to assess the correct behaviour of the cathodic protection. Whilst ensuring that they fulfil the criteria established by UNE 12696: (2001) and EN 12696 (2012): 2012. Also, it has been made, in first instance, corrosion potential measurements according to ASTM C876-09 (2009). In Fig. 10 are represented results of pile potential in different areas of the bridge repair.

In the displayed graphic is observable the different behaviours on different cathodic protection systems employed in the repair of the bridge. As we can see in the case of pile 1, a conventional repair was performed, the corrosion potentials were after two years of the repair, below -350 mV. With the predefined criterion of corrosion (less than -200mV), we would be in a case of highly probable corrosion (Te Liang *et al*., 2012).

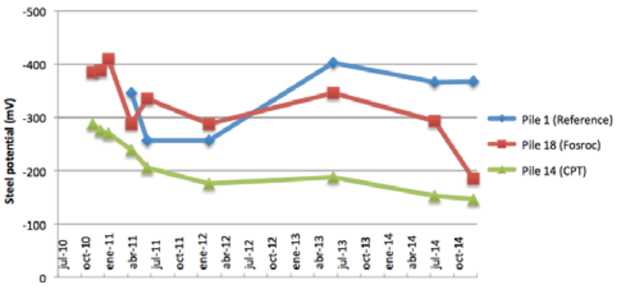

Fig. 10. Results of the evolution of the pile potential (V) in the period 2010 to 2014

In the case of the pile 14, in which it was used the system of discrete anodes with CPT hybrid cathodic protection, we see as a major change in the corrosion potentials, led by the first contribution impressed current applied at the initial time (Glass *et al*., 2001). We see potential are above -200 mv almost from the start, and the trend is almost horizontal with over the years.

The next case is the one of pile 18. In this pile it was used for galvanic protection the system of Fosroc GRP shirts that were covered with zinc anodes. In this case, the corrosion potentials have a different behaviour than the CPT system. As it can be seen, in this case the corrosion potentials increase rapidly after the repair work. With time, the protection system becomes more positive, slowly coming closer to the values given by the CPT system values. The fundamental difference is that this system does not give an initial contribution of impressed current, so that the potential of corrosion of steel are essentially the same as existed prior to the repair. Over time, the potential becomes increasingly positive; turning to over -200 mv positive values, which indicates almost certainly the passivity of steel in reinforced concrete.

6.0 CONCLUSIONS

In this paper we have analysed both the technical and economic feasibility of repairing an existing structure. It represents a preliminary study of the economic benefits of the repair and of the repair typology.

The structure has a size that allows the conclusions we draw from this project to be valid and applicable to new projects. In the economic part, the economic study we have seen has an impact that allows, at least, reduce investment by half (from 10 to 5 million € aprox). The validity of the economic data is greatly dependant on the life of the structure. Obtaining reliable data on the life of the structure after the repair will make this study much more accurate. Knowing the useful life of the repaired structure will be the key to closing the economic cycle, since when erecting a new structure we know that the useful life for which we will project it will be at least 50 years (or 100 years), however we do not know which will be the useful life of the structure after repair.

The objective that we propose in the future, is to take advantage of the information of this project to estimate the useful life of any structure that has been repaired in similar conditions.

In this project we used the major repair techniques:

- Conventional repair by patches.
- Corrosion inhibitors.
- Cathodic protection with sacrificial anodes.
- Hybrid Cathodic protection with impressed current.

Among the techniques used in the project of Repair of Bridge Illa de Arousa, it was used primarily cathodic protection with sacrificial anodes on the deck (using galvanic current), and in the piles it was chosen to perform a test with the different protection systems. In this case, one of the piles was repaired with the conventional repair, to serve as control of the evolution of the corrosion over time. The result after a few years of this repair indicates possibility of corrosion due to the values of electrochemical potential measured.

For the rest of systems analysed, we see the "CPT" hybrid system presented very favorable results from the beginning. The first phase of impressed current represents an advantage over other systems, the values of galvanic potential achieve high values (above -200mV) faster than the Fosroc system. In this system, although corrosion potentials take longer to get in than -200 mv values, (which is the barrier taken as synonym for passivity of steel in concrete) it does not mean that the system is not working. The trend of the potential indicates that the system is operating, and there are more forms of assessment and other measurement techniques to make these checks.

References

ASTM C876-09., 2009. Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete

Christodoulou, C., Glass, G.K., Webb, J., Ngala, V., Beamish, S., Gilbert, P., 2008. Evaluation of galvanic technologies available for bridge structures, in: Struct. Faults Repair, 12th Int. Conf., Edinburgh, UK, dspace.lboro.ac.uk/dspace-jspui/handle/2134/10972.

Cobo Escamilla, A., 2001. Corrosión de armaduras de estructuras de hormigón armado: causas y procedimientos de rehabilitación, Fundación Escuela de la Edificación, Madrid.

Glass, G.K., Hassanein, A.M., Buenfeld, N.R., 2001. Cathodic protection afforded by an intermittent current applied to reinforced concrete, Corros. Sci. 43 1111–1131. doi:10.1016/S0010-938X(00)00133-5.

González Fernández, J.A., 2007. Corrosión en las estructuras de hormigón armado: fundamentos, medida, diagnosis y prevención, Consejo Superior de Investigaciones Científicas, Madrid.

León González, J., Prieto Aguilera,F., 2011. Rehabilitación del puente de acceso a la isla de arosa, in: ACHE (Ed.), V Congr. ACHE, Barcelona. ache.com/modules/smartsection/item.php?itemid=126.

Ministerio de Fomento. Centro de publicaciones, 2000. Obras de paso de nueva construcción: conceptos generales. Dirección general de carreteras - Madrid.

Ministerio de Fomento. Centro de publicaciones, 2016. Orden circular 37/2016. Base de precios de referenciade la dirección general de carreteras Madrid.

N. Davison, N., Glass, G.K, Roberts, A.C, 2006. Inhibiting chloride induced reinforcement corrosion, National Association of Corrosion Engineers, Houston, Texas.

Perdix, C.A, Nuria, J., Ramos, N.R, Enrique, J., Landrove, P., millán, J., Ilarri,M.A., 2001. Supervisión de los sistemas de protección catódica instalados en la reparación de un puente

Te Liang, M., Chang, JJ., Yu, T.W., 2010. Studies of the effect of diffusion-induced chloride binding on chlorination life predictions for existing reinforced concrete bridges, J. Mar. Sci. Technol. 20 418–430. doi:10.6119/JMST-011-0318-2.

UNE EN 12696: 2001. Cathodic protection of steel in concrete (ISO 12696:2001).

UNE EN 12696: 2012. Cathodic protection of steel in concrete (ISO 12696:2012).

mediante técnicas electroquímicas de verificación de la protección catódica y potencial en off., in: ache (ed.), v congr. ache, barcelona, http://e-ache.com/modules/smartsection/item.php?itemid=360.