Monitoring of “Zarzuela Racecourse” structure by means of no-destructive techniques for durability assessment

A. Castillo, C.Andrade, I Martínez, N. Rebolledo
Instituto de Ciencias de la Construcción Eduardo Torroja (CSIC). Madrid, Spain
L. Fernández Troyano, G. Ayuso, J. Cuervo
Carlos Fernández Casado, S.L., Madrid, Spain.
J. Junquera, C. Santana
Estudio Jerónimo Junquera, S.L., Madrid, Spain

ABSTRACT: Present paper describes some aspects of the restoration project recently undertaken in La Zarzuela Racecourse, designed by E. Torroja and Dominguez in 1934. Despite the good mechanical work of steel, it has started a deterioration process which has caused the corrosion of reinforcement by carbonation. It has been detected corrosion attack in some places due the breaking of the upper waterproofing membrane of the shell which enabled the water to remain long periods in the roof and therefore promoted corrosion of reinforcement. For the repair first an assessment of the degree of corrosion was made. The restoration project finally consisted in the injection of all the cracks in order to assure the joint work of the shell and the patching of the deteriorated zones. Profiting these works it was installed a monitoring system of corrosion sensors. Results of the recording are given in the paper.

1. INTRODUCTION

The Zarzuela Racecourse in Madrid was projected by the Engineer Eduardo Torroja and architects Arniches and Domínguez in 1934. Due to the Spanish Civil war, it was not inaugurated until 1941, and the stands were declared National Heritage in 1980. There have been horse races steadily until 1996, year in which activity ceased. In 2003 Spanish National Heritage found a consortium for the Zarzuela race course exploitation, and in 2005, after nine years closed, the Racecourse is re-opened. The restoration process described in this paper was undertaken in 2008.

The three decks of the structure are considered an art in terms of engineering. It is formed by thin concrete sheets of a hyperboloid shape with variable thickness between 65 cm in the area of pillars and 6 cm at the edges, supported up by a single pillar as cantilever to 13 m high; Zarzuela Racecourse-Construction Reports, (1962). That is possible thanks to intelligent intertwined armed design and installation of steel bracing liabilities (Figure 1).

Figure 1. Panoramic photograph of the decks and construction scheme.

2. STUDY OF THE DECKS DETERIORATION

During the hole service life of these structures no important maintenance works were undertaken. For this reason, and despite the good mechanical work of steel, it was started physic and physical-chemical deterioration processes due to its long period of exposure to the atmosphere, which has caused the corrosion of reinforcement by carbonation.

This Concrete carbonation has been studied and quantified on site, measuring a carbonation front (by the application of alcoholic phenolphthalein solution) higher than 60 mm in some points (Figure 2), reaching completely the shell thickness in some areas. In this way, it can be said that almost all the structure was affected by generalized corrosion, but no pitting or important localized lost of section in the rebars was detected.

Figure 2. Measurement of the carbonation front in the shell.

The corrosion attack has been accelerated in some places due the loss of the upper waterproofing foil of the shell which (Figure 3).

Considering the importance of this building, the authorities decided to undertake a restoration project where it is contemplated the installation of a continuous monitoring system.

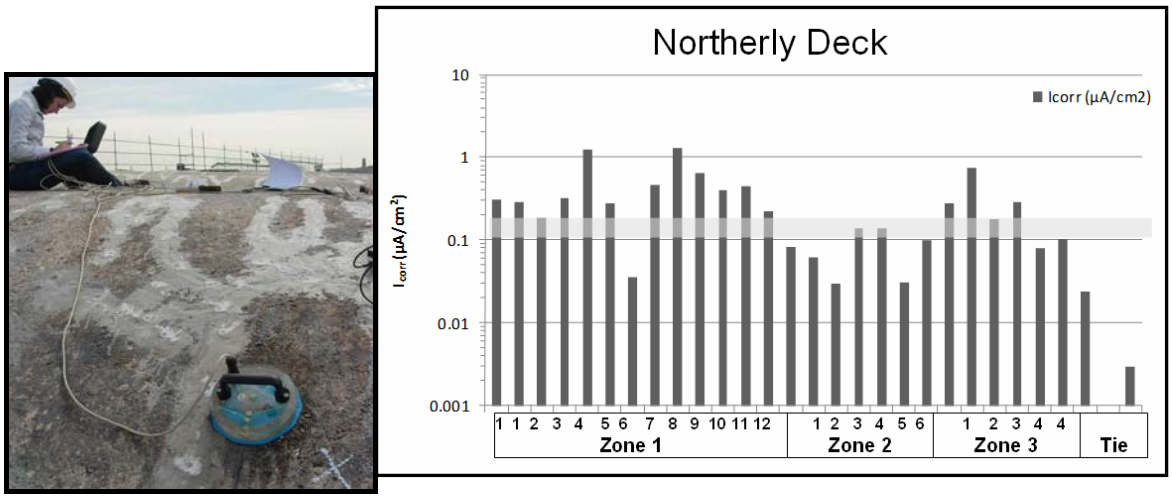
Figure 3. Deterioration observed before the restoration: Left: Lower part of one deck. Right: loss of upper waterproofing foil

3. CORROSION ASSESSMENT AND RESTORATION WORKS.

After removing all the paint in the lower part and the waterproofing in the upper part of the decks by water under pressure, an assessment of the extent of corrosion was required. It was possible to measure the carbonation front (Figure 2), and to apply a non-destructive electrochemical method based on the polarization resistance technique to verify the corrosion rate (0a).

The corrosion rate (evaluated by the modulated confinement method by means of the corrosion rate meter Gecor 08) was quantified in different areas of the three decks (Figure 5). The results indicate that almost all the structure is corroding due to the concrete carbonation. The majority of the values registered are in the range of moderate corrosion rates (between 0.5 and 1 $\mu A/cm^2$), as is shown in the example of 04b (Feliú et al. 1990).

Other corrosion indicators, as are the corrosion potential and the resistivity, were also evaluated. E_{corr} was measured with a $Cu/CuSO_4$ reference electrode. The majority of the values measured were in the range between -250 and -350 mV, what means an intermediate corrosion risk. Talking about concrete resistivity, very high values (higher than 200 KΩ.cm) were measured. These high values are due to the delaminations and voids present in the concrete, which do not allow a properly electrolytic contact for the measurement. For this reason, they do not correspond with the real concrete cover resistivity.



(a) **(b)**

Figure 4. Left: Sensor and device used for the corrosion rate measurements. Right: I_{corr} values registered in the northerly deck.

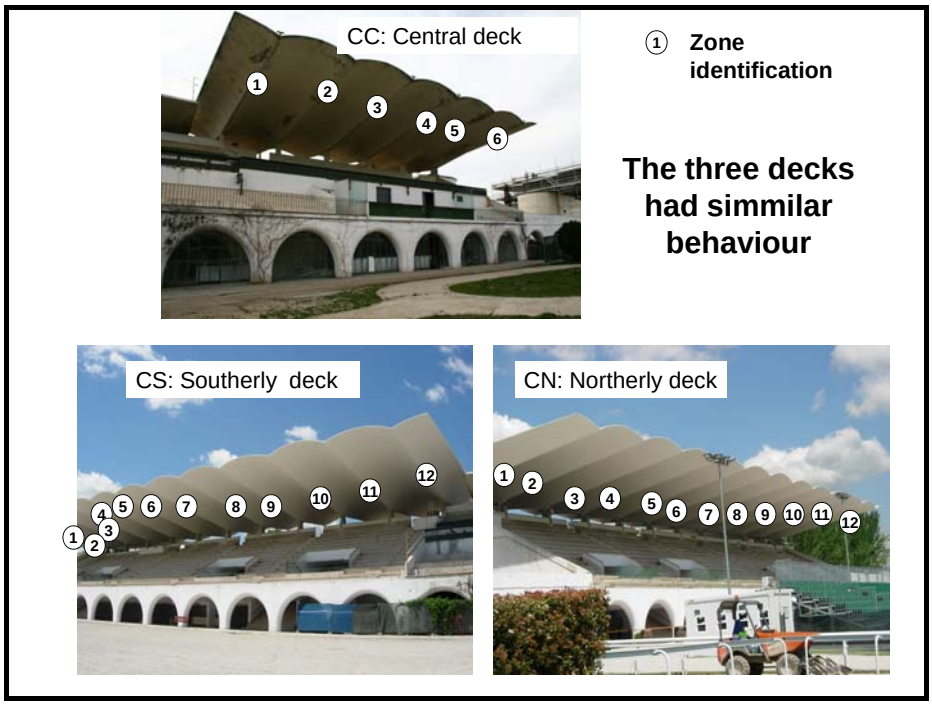


Figure 5. Different zones evaluated in the three decks.

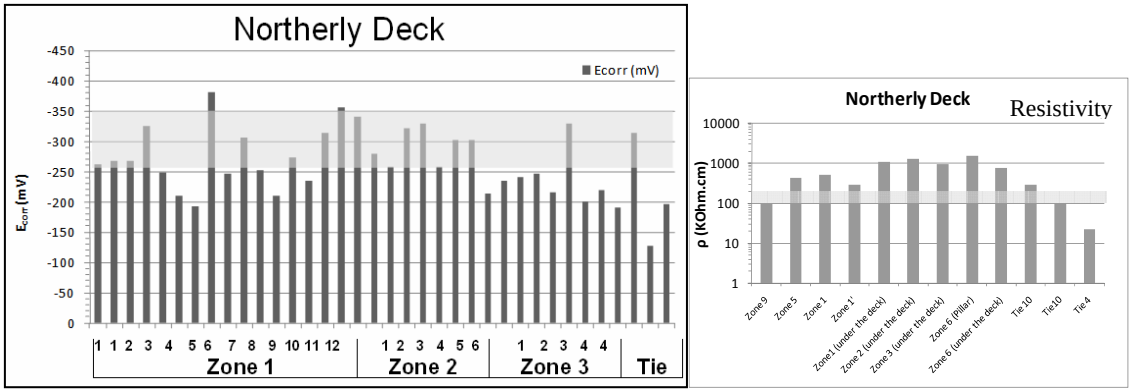


Figure 6. E_{corr} and resistivity results obtained in the northerly deck.

After the corrosion assessment, the concrete detached areas were removed and the rebars were cleaned and passivated. All the area was repaired with specific cement based mortar, and cracks were filled injecting resin and then sealed (Figure 7).

In this phase, the ties were also repaired. The ties are composed by three non corrugated steel bars (placed asymmetrically) embedded in cement mortar and waterproofed by a fibro-cement cover (Figure 8). Even when the waterproofing system seemed to be not the most suitable, the carbonation in these elements was very low, and the loss of section in the steels was not important.

Figure 7. Restoration process

Figure 8. Ties restoration.

Electrochemical sensors able to indicate the risk of corrosion of reinforcement were installed in the decks and in the ties. These sensors enable the monitoring of the water content and the corrosion potential, in order to predict the need of maintenance interventions, Martínez & Andrade (2009). As an example a photograph of the sensors installed and some of the first results obtained are presented in Figure 9 and Figure 10.

The E_{corr} tend to less negative values with time what means that the steel is being passivated. In the case of water content sensors, the response is measured in mV (difference of potential between two metals embedded in the sensor). Values around 0mV means no liquid water, so, the new waterproofing system is working properly

All the temperature sensors have the same behavior and the correlation of the temperature with the electrochemical parameters is now under study.

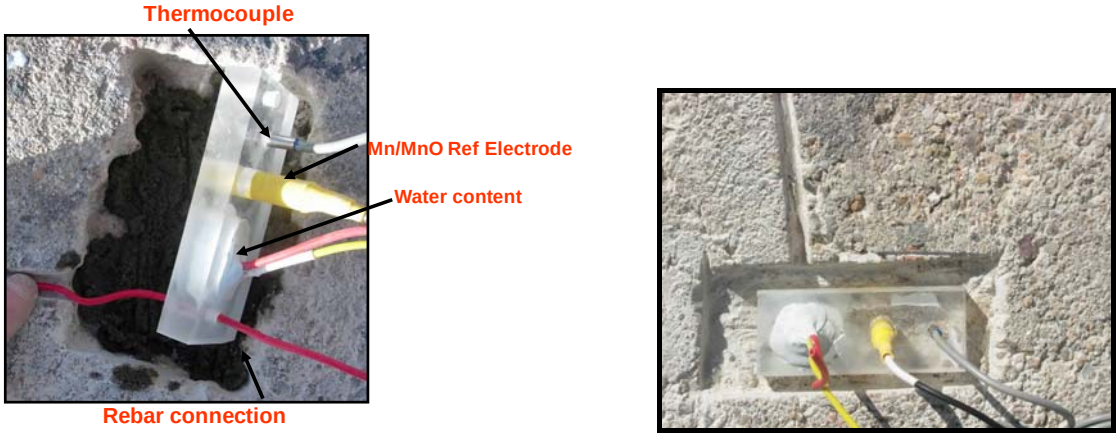
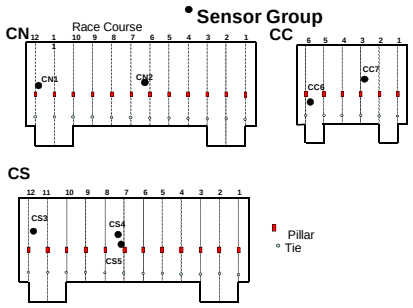


Figure 9. Permanent sensors installed



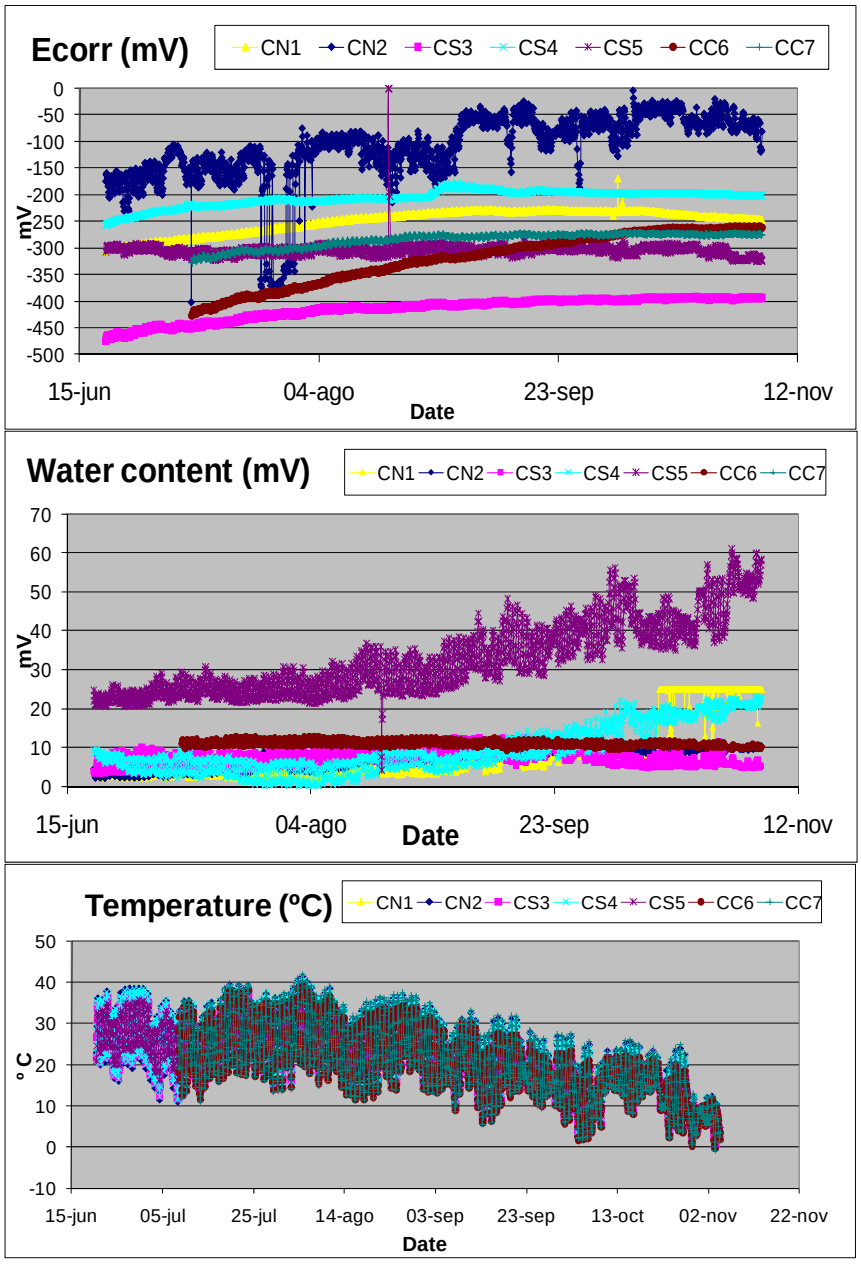


Figure 10. Some of the results obtained from the embedded sensors

4. CONCLUSIONS

- Before the restoration, the decks presented a high carbonation degree. Even when the loss of section in the rebars was not very high, generalized corrosion was quantified by ND electrochemical techniques.
- The ties presented a moderate deterioration process with a low carbonation degree, even when the original fibro-cement waterproofing mechanism of the three bars that compose the tie looks to be not the most appropriate.
- Permanent sensors show that the new decks water proofing is working properly now. The corrosion indicators go to no corrosion risk values.
- It is important to remark the new tendencies here shown about the corrosion monitoring in deteriorated/repaired structures. It allows to check the structure state and to prevent for future deteriorations.
- Performance has been remarkably good comparatively to other structures of the same age.

5. ACKNOWLEDGEMENT

Authors thank the collaboration of the Zarzuela racecourse owners and also the collaboration of the company DRAGADOS, who undertook the repair work.

6. REFERENCES

- Feliú, S., González, J.A., Feliú, S.Jr., and Andrade, C., "Confinement of the electrical signal or in-situ measurement of Polarization Resistance in Reinforced concrete," *ACI Mater. J.*, **87**, pp 457. (1990).
- Martínez, I., Andrade, C., Examples of Reinforcement Corrosion Monitoring by EmbeddedSensors in Concrete Structures, Cement & Concrete Composites (2009), doi: 10.1016/j.cemconcomp.2009.05.007
- Zarzuela Racecourse. Construction Reports, 1962