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► **To cite this version:**

Véronique Bouteiller, Lucas Bourreau, Laurent Gaillet, Franck Schoefs, Benoit Thauvin, et al.. Presentation of the French Project DéCoF-Ré. 40th IABSE Symposium Tomorrow's Megastructures, Sep 2018, NANTES, France. 7 p. hal-02064237

HAL Id: hal-02064237

<https://hal.science/hal-02064237v1>

Submitted on 11 Mar 2019

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Presentation of the French Project DéCoF-Ré

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Abstract

A relevant knowledge of the state of the reinforced concrete is the basis for a successful management of the structures such as civil engineering bridges. To provide answers, IFSTTAR (coordinator), Cerema, Nantes University and Capacité SAS, SIXENSE-Concrete Company and the Département de la Charente-Maritime have contributed and funded a collaborative research project from 2015 to 2018. The French Project DéCoF-Ré meaning Decision Corrosion and Reliability of the ile de Ré Bridge has two main objectives. The first objective is to perform a reliable corrosion diagnosis of the piers of a bridge in a marine environment by means of non-destructive tests such as half-cell potential and resistivity. The second objective is to determine the durability of the concrete cover of the piers in terms of durability indicators. The aim of this paper is to present the Project DéCoF-Ré and to give some preliminary results.

Keywords: reinforced concrete, bridge, marine environment, corrosion diagnosis, concrete durability, chloride indicator

1 Introduction

Corrosion is considered as the main degradation of reinforced concrete structures ([1, 2]. In France, being designed for a lifespan of 50 years, the reinforced concrete bridge average is 35 years old. At the level of bridge's owners a plan is needed to prioritize the maintenance or rehabilitation or retirement. At the level of researchers, reliable tools to assess the state of the reinforced concrete structure based on the corrosion diagnosis of the steel reinforcement together with the concrete durability are to be provided in order to qualify the state of the structure, to predict its durability and to suggest further repair solutions (patch repair or electrochemical treatments).

The French Project DéCoF-Ré meaning Decision Corrosion and Reliability of the ile de Ré Bridge has two main objectives. The first objective is to perform a reliable corrosion diagnosis of the piers of the bridge which is located in a marine environment by means of non-destructive tests such as half-cell potential and resistivity. The second objective is to determine the durability of the concrete cover of the piers in terms of durability indicators [3].

The aim of this paper is to present the French Project DéCoF-Ré which is a collaborative research that started in 2015 involving six partners: IFSTTAR

(coordinator), Cerema, Nantes University and Capacité SAS, SIXENSE-Concrete Company and the Département de la Charente-Maritime (owner of the ile de Ré Bridge).

2 Presentation of the ile de Ré Bridge

The ile de Ré Bridge (Figure 1), located in the French Atlantic coast, was built in 1987-1988 to provide an access to the Ré Island from La Rochelle mainland. The bridge has a total length of 2928.5 meters, a width of 15 meters and a maximum height above the sea level of 30 meters (shipping channel). The bridge deck was constructed on 28 piers, from which 24 piers were founded in the sea (Figure 2).



Figure 1: Ile de Ré Bridge (V. Bouteiller, Ifsttar)

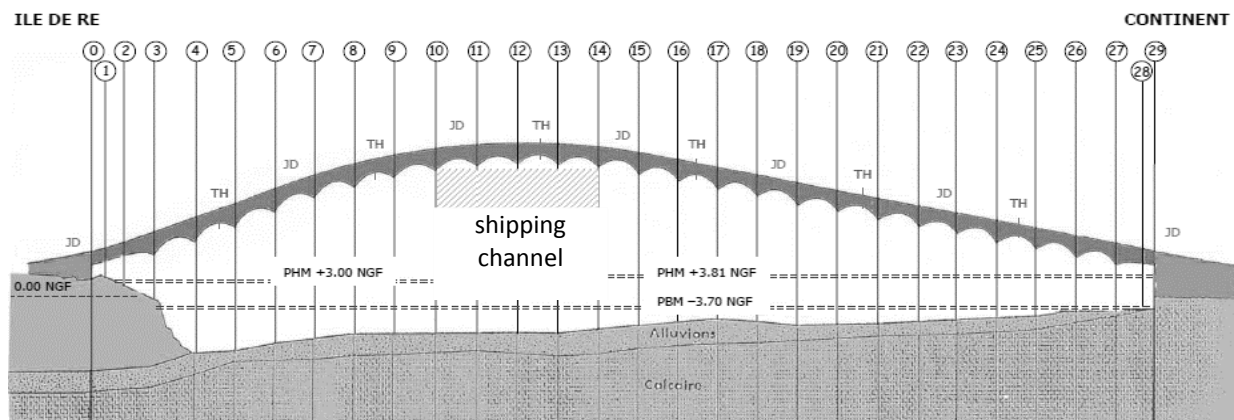


Figure 2. Ile de Ré Bridge - longitudinal scheme

Piers concrete composition was based on a CPJ 45 RPM cement that today would correspond to a CEM II/B cement (Table 1) and the water/cement ratio was equal to 0.5.

Table 1. Concrete mix composition (in kg/m³)

Cement	Water	Sand 0/3 mm	Gravel 6/20 mm	Additive Pozzolith 200N
370	185	830	1 200	0.74

The investigated area on a pier is described in Figure 3 and Figure 4.

Two faces (upon 8) of the piers were considered: face FC is the most exposed side with dominant winds (WSW for La Rochelle with 30 km/h mean speed), daily sunshine and strongest wetting/drying cycles and face FG is the opposite side which is more sheltered (Figure 3).

Because the investigations needed to be performed using a vessel and depended on the tide duration, three zones defined in a coordinate system XOY (face's wide 1.85m and height 1m) were studied corresponding to a total surface area of 5.55m² (Figure 4). These three zones includes atmospheric, splash and tidal exposures that can be related to the XS1 and XS3 exposure classes in marine environment according to the EN206 standard [4].

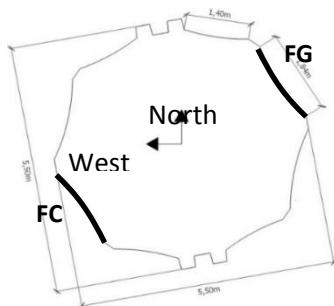


Figure 3. Top view of the pier with the investigated faces FC and FG

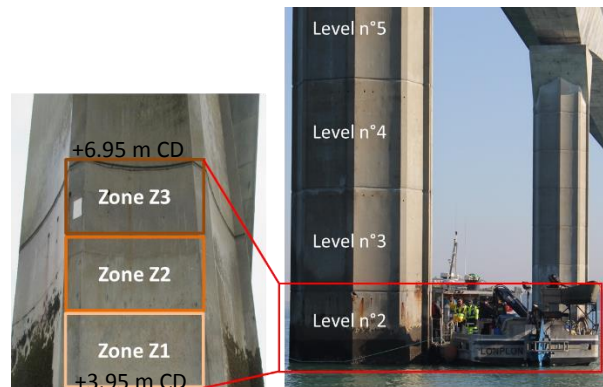


Figure 4. Investigated area with corresponding zones Z1, Z2 and Z3 and water heights (CD=Chart Datum)

3 Corrosion diagnosis

Corrosion diagnosis was performed on 15 piers of the ile de Ré Bridge (14 in seawater using a vessel and 1 on the beach).

Corrosion diagnosis methodology was divided in six steps. The first step consisted in finding the general bridge's information from the archives. The following steps, illustrated in Figure 5, were performed using a vessel. The second step consisted in a visual inspection of the piers (after cleaning) to assess the general degradation state (rust spots, leachings, cracks, etc.). The third step aimed at locating the steel reinforcements (horizontal and vertical rebars) using a ground penetrating radar (EasyScan® 1.6 GHz, GSSI). In the fourth step, concrete electrical resistivity was measured using a Wenner probe (Resipod® 5 cm, PROCEQ). The fifth and sixth steps were dedicated to the electrochemical measurements, respectively half-cell potentials (Canin+® (copper/saturated copper sulphate electrode (CSE, +318 mV vs NHE)), PROCEQ) and corrosion rates (GalvaPulse®, Germann Instrument).

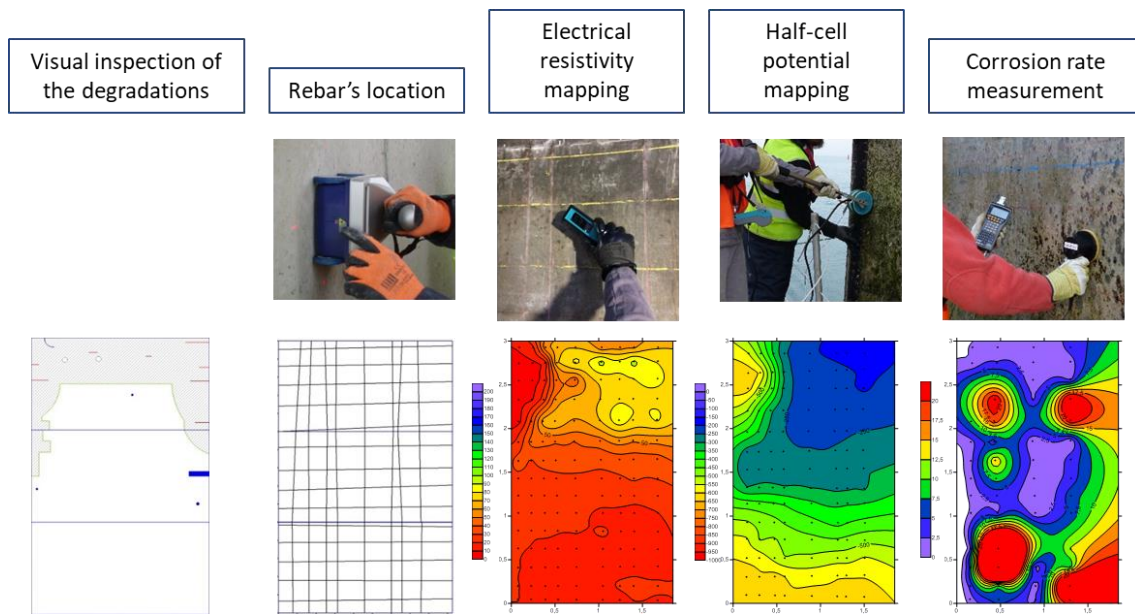


Figure 5. Methodology to assess the corrosion state of the steel reinforcement of the piers of the ile de Ré Bridge

4 Durability of concrete

After 29 years, the concrete durability of the piers of the ile de Ré Bridge was investigated on 11 piers (10 in seawater using a vessel and 1 on the beach). The durability of concrete is determined largely by its deterioration over time which is affected by the environment [3]. The study consisted, after drilling the cores from the structure, in determining the durability indicators (chloride migration tests, water porosity, gas permeability, capillary absorption and resistivity) and the penetration front of chlorides (X_d) as well as of carbonation (X_c).

5 Preliminary results

5.1 Corrosion reliability

The interpretation of measurement values according to different standards or literature recommendations [5-8] showed that the diagnosis can be erroneous because of the influence of the marine environment. In order to provide more reliable results, models of the influences of the

tide, the water height and the seasons were therefore studied [9, 10].

As an example for the half-cell measurement interpretation, Figure 6 (left) presents the potential mapping as measured on the pier PN face FG during summer, considering the ASTM analysis [6]. This mapping shows a gradual increase of potential from the bottom zone to the top zone. From the literature it appears that the gradient is not significant of a decrease of probability of corrosion but is rather due to a lack of oxygen (mainly in the bottom zone). A model was then developed considering the average values of half-cell potentials for the horizontal reinforcements. Figure 6 (middle) shows the heights and their corresponding half-cell potentials “reference profiles” for faces FC and FG. Finally, a reliable potential mapping was obtained considering the raw measurements and subtracting the reference profiles. The resulting mapping is illustrated on Figure 6 (right). The investigated area finally appears like a no-active-corrosion region.

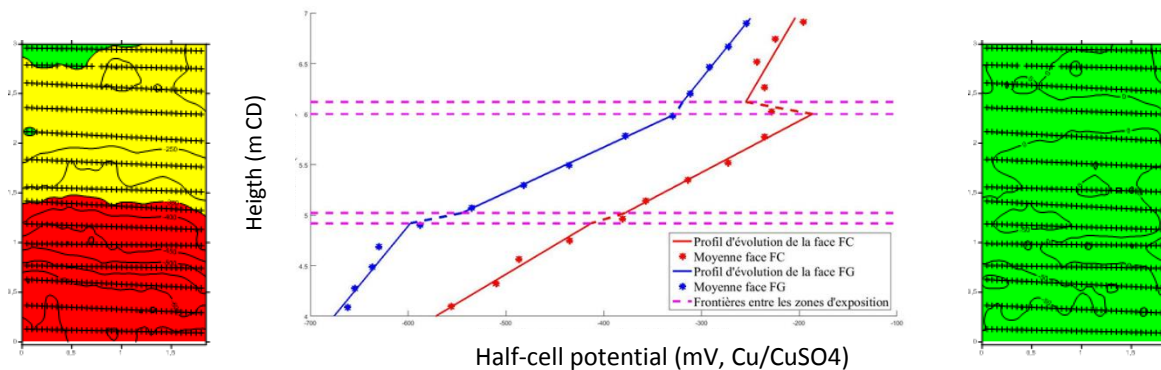


Figure 6. Potential mapping with ASTM C876 analysis (left), model of half-cell potential reference profiles (middle) and reliable potential mapping (right) for pile PN face FC

5.2 Concrete durability

In a marine environment, chloride ingress is one of the major causes of the premature deterioration of the reinforced concrete structures. From the durability point of view, when exceeding a certain amount of chloride at the rebar level, this latter can be depassivated and the corrosion initiating.

In the Project DéCoF-Ré, 51 cores were drilled from the structure to determine the chloride profiles depending on the pier, the face and the height. The penetration of chlorides was then compared to the concrete cover of the reinforcements.

As an example, Table 2 gathers the amount of free and total chlorides as determined by potentiometric titration for pier PN face FC for the three zones Z1, Z2 and Z3. The critical chloride content was considered equal to 0.4% weight of concrete as described in literature. The chloride content was higher than the critical chloride content for a concrete cover of 15-25mm (the values appear in red) or 45-55mm in the case of total chlorides for zone 1. The chloride penetration index, X_d , has been determined as the intersection of the chloride profiles and the critical chloride content and is also reported in Table 2. For the free chlorides X_d values are equal to 36, 33 and 42 mm respectively for zones Z1, Z2 and Z3. For the total chloride, X_d values become 59, 48 and 47mm.

From Figure 7 which illustrates the concrete cover of horizontal and vertical reinforcements of pier PN face FC as determined by radar and an image

analysis, the concrete cover values were in the range of 55 to 125mm.

For this pier, after 29 years, chlorides did not reach the reinforcement level and thus the corrosion is not alike to occur. This is in good agreement with the result from the reliable potential mapping (Figure 6 left).

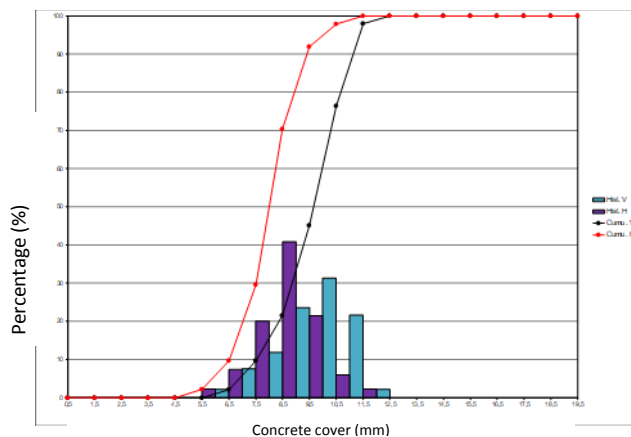


Figure 7. Concrete cover of horizontal and vertical reinforcements as determined by radar and image analysis for pier PN face FC

Table 2. Free and total chloride content versus depth and chloride front (X_c) ; Critical chloride content is equal to 0.67% (according to concrete formulation and density).

Free chlorides (g/100g of concrete)					
Depth (mm)	05-15	15-25	45-55	75-85	Xd free
PN-FC-Z3-X80cm-Y67cm	0,26	0,18	0,02	0,01	42
PN-FC-Z2-X110cm-Y66cm	0,17	0,09	0,02	0,00	33
PN-FC-Z1-X110cm-Y68cm	0,16	0,09	0,04	0,00	36
Total chlorides (g/100g of concrete)					
Depth (mm)	05-15	15-25	45-55	75-85	Xd total
PN-FC-Z3-X80cm-Y67cm	0,44	0,36	0,03	0,01	47
PN-FC-Z2-X110cm-Y66cm	0,35	0,20	0,05	0,01	48
PN-FC-Z1-X110cm-Y68cm	0,28	0,18	0,08	0,02	59

6 Conclusions

The results of the DéCoF-Ré Project have been gathered in two databases, one dealing with the corrosion diagnosis and a second one dealing with the durability of the concrete cover.

Corrosion results have been modelled in order to provide reliable mappings of half-cell potentials considering the influences of the tide, the height and the seasons.

The durability results have been analysed in terms of chloride profiles and compared to the concrete cover of the reinforcements.

More work is under progress and the state of the piers of the ile de Ré Bridge will be ascertained based on the complementary analysis of corrosion results and durability results. Furthermore, the autopsies performed on several locations will allow to validate the conclusions.

Acknowledgements

The authors would like to thank the team of the DéCoF-Ré Project: B. Godart, W. Traverst, P. Boujard, N. Coulaty-Chin, A. Orcesi, Y. El Rabbih, X. Derobert, M. Sissoko (IFSTTAR); R. Queguiner, S. Pasquie, P. Boulaire, M. Rebours, C. Naudat (Cerema Dter Ouest); F. Landrin and V. Queyrat (Cerema Dter Ile de France), J-F. Barthélémy (Cerema Dtec ITM); M. Roche, O. Amiri (Nantes University); M. Brouxel, S. Naar (SIXENSE-Concrete), A. Audouin-Dubreuil, F. Lavoute, M. Barbier (Département de la Charente-Maritime); F.

Gazet (Dekra). They also thank the team of the vessel for their help.

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