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CATHODIC PROTECTION ON AN ICONIC BUILDING OF THE MODERN MOVEMENT ARCHITECTURE

Xavier Hallopeau, Arnaud Meillier, Olivier Lesieutre
Freyssinet International & Cie
280 Ave Napoléon Bonaparte
Rueil Malmaison, 92506
France

Elisabeth Marie-Victoire, Myriam Bouichou
Laboratoire de Recherche des Monuments Historiques
29, rue de Paris
Champs-sur-Marne, 77420
France

ABSTRACT

The repair of a French building classified as an historic monument must meet specific requirements, in particular very precise rules within the framework of the scientific and technical control exercised by the services of the French Ministry of Culture. Repair work must not alter the general appearance of the building or the nature of the materials. In this context, this paper discusses the various operations carried out on an iconic building of the Modernist Architectural Movement situated on the seaside, Villa E-1027 located in Roquebrune-Cap-Martin (06), French Riviera involving: investigation, diagnosis, identification of reinforcing steel corrosion root cause, implementation of a repair strategy, pilot test, installation of cathodic protection by impressed current and results.

Key words: reinforced concrete, cathodic protection, preservation.

INTRODUCTION

In France, among the 850 historic monuments made of concrete, 26% are suffering from chloride pollution and most of them are affected by carbonation.¹ Villa E-1027 is one of those monuments. Carbonation induced corrosion and chloride induced corrosion were extensively studied as separate mechanisms.^{1,2,3,4,5} Research on the combined effect of carbonation and chloride contamination, which is often encountered in the field of historic concrete, is rare.⁶ Some of the results of a previous project⁷, are presented in this paper as a basis to support the selection of the chosen repair solution, the use of cathodic protection by impressed current (ICCP).

CONTEXT

Built between 1926 and 1929 by Eileen Gray and Jean Badovici in Roquebrune-Cap-Martin near Nice, Villa E-1027 faces the Mediterranean Sea, Figure 1 and 2. Its structural elements and floors are made of concrete, while the non-structural components are more heterogeneous (bricks...). It was partially rendered and totally covered with a lime wash.



Figure 1: Back facade



Figure 2: Front facade

The structure built on the shore of Cape Martin is exposed to the sea spray, and from a more general point of view it is considered to be in a marine atmosphere, therefore aggressive from an electrochemical point of view with regard to steel reinforcement in concrete. After being abandoned for a long time, in 2000, the villa was showing evidence of decay from water infiltration, ground movement and reinforcing steel corrosion. The restoration works conducted between 2000 and 2006 comprising standard concrete repair patching in combination with a migrating corrosion inhibitor, had shown limited effectiveness at reducing rebar corrosion, as the durability achieved was less than 10 years. In 2000, the first investigation determined the concrete design to be a mix of CEM I cement (300kg/m^3) and calcareous aggregates with siliceous sand. The durability performance of this concrete was assessed to be quite low with an open porosity of 17% and compressive strengths ranging between 9.6MPa (patio beam) and 13.3MPa (patio pillar). In terms of deterioration mechanism, where carbonation was determined to have exceeded the depth of reinforcing steel which was in most of the areas examined moderate external sulfate and chloride pollution was also encountered which had resulted in the formation of Friedel Salts and Ettringite in the cement matrix.

A second stage of investigations was carried out in 2016, showing significant chloride contamination (0.05 up to 2.14% by weight of cement) and alkali pollution (1.19 up to $22.5 \text{ eqNa}_2\text{O kg/m}^3$) on both the patio and the balconies of the villa, and a moderate sulfate pollution (1.18% up to 5.36% by weight of cement). Carbonation had also progressed (20 to 70mm), and corrosion was still active as confirmed by instant electrochemical measurements performed.

Considering this problematic state of preservation of the Villa, prior to the final choice of restoration strategy and taking into account that complementary maintenance work had just been performed to eradicate some infiltration problems on the balconies that had also an impact on the concrete of the patio, a last phase of investigation was scheduled with the aim of evaluating the residual corrosion activity on the balconies and the patio, after this maintenance. Two types of analysis were considered: instant electrochemical measurements and permanent monitoring over one year.

The results of this diagnosis evidenced a quite active level of corrosion induced by a combination of carbonation and chloride pollution with maximum potential gradients recorded (with a Gecor10[®] with a Cu/CuSO₄ reference electrode) ranging from 95mV to 160mV and corrosion currents up to 1.55 $\mu\text{A}/\text{cm}^2$ (measured with a Gecor10[®]), despite a low yearly average relative humidity in the concrete. Relative humidity for the beam monitored (embedded Vaisala[®] probes) averaged 68% with a maximum of 78%. The resistivity of the concrete was variable, with significant gradients found and values ranging from 9 to 176 kohm.cm. As a consequence of the result of these investigations the possible durable restoration strategies were considered to be limited to only one option: cathodic protection (CP).

For more than 20 years, this technique, CP has been implemented on projects in the UK and the USA to mitigate steel frame corrosion in historic structures.^{8,9,10} As this technique can be quite invasive and in addition difficult to implement in historic concrete due to an erratic and often discontinuous reinforcing steel network, a pilot impressed current cathodic protection (ICCP) system was installed on a beam, a pillar and 1m² of the southern balcony soffit. The intention of the pilot was to explore how to limit the slots, cuts and holes necessary to install an ICCP system in order to respect the conservation principle of historic monuments and to allow assessment of the efficiency of such a treatment in a quite dry concrete, over a 6 month period before proceeding with installation of the full-scale system on the whole patio.

PILOT TEST

The objectives of the pilot test were to validate:

- the use of ICCP on such a dry concrete,
- the choice of the anodic system,
- the ability to meet the historic concrete conservation requirements, ie. make the system as aesthetically invisible as possible and reproduce the wood formwork prints finish on the repaired concrete surfaces.

The pilot test performed in 2019 concerned the following elements of the villa structural concrete framework:

- Zone 1: Column exposed to sea spray and being partly repaired and partly still in its original state,
- Zone 2: Most exposed beam,
- Zone 3: Slab soffit.