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Access Viaducts to the Drawbridge of Leixões Harbour - Diagnosis of Concrete Deteriorations

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ABSTRACT

The two access viaducts to the drawbridge of Leixões harbour are connected with the metallic structure of the drawbridge and allow the passage between the two towns, Leça da Palmeira and Matosinhos. The viaducts are concrete structures, composed of wall-columns and abutments, in reinforced concrete, supporting longitudinal beams placed side by side and braced by transversal beams, all of prestressed concrete. The slab is also in reinforced concrete.

The viaducts built between 1957 and 1960, were repaired between 1991 and 1993. As the drawbridge was inadequate for both the road and the harbour traffic, it was replaced and some of the spans of the viaducts were demolished and all the concrete was repaired between 2006 and 2008.

The aim of this work was, before this last rehabilitation, to make a diagnosis of the deterioration of the concrete viaducts. After collecting and analyzing all the information about the characteristics of the different materials used in concrete and its composition and properties, a visual inspection of the structure was made, and all relevant evidence of deterioration was recorded and photographed. Some samples of apparently non-deteriorated concrete and visually deteriorated concrete were extracted for analysis. The carbonation and the chloride ingress were determined in samples of apparently non-deteriorated concrete. All samples were observed and analyzed by scanning electronic microscopy (SEM) and energy dispersive spectrometry (EDS).

KEYWORDS

Concrete, durability, petrography, pathology.

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1 INTRODUCTION

The two access viaducts are located 500m from the sea at Leixões harbour, the biggest port infrastructure in the north of Portugal (‘Fig.1’). The viaducts are concrete structures, composed of wall-columns and abutments, in reinforced concrete, supporting longitudinal beams placed side by side and braced by transversal beams, all of prestressed concrete. The slab is in reinforced concrete.

Figure 1. Aerial view of Leixões harbour.

The viaducts, built between 1957 and 1960, were repaired between 1991 and 1993. The repair work in the concrete consisted of a reconstruction of the concrete in the support zone, filling cracks in the beams and the application of grout repair and painting of beams, wall-columns and abutments. As the drawbridge was inadequate for both the road and the harbour traffic, it was replaced and some of the spans of the viaducts were demolished and all the concrete was repaired between 2006 and 2008 (‘Fig.2’).

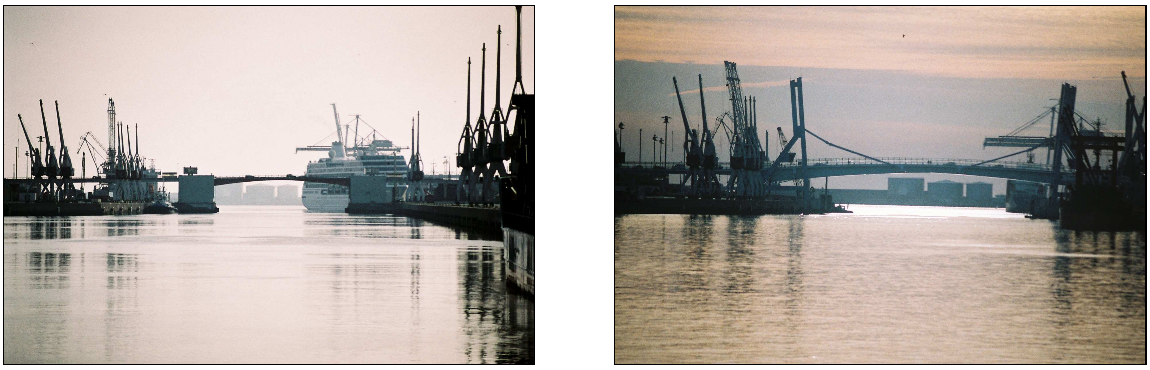


Figure 2. Access viaducts and drawbridge before and after the repair work in 2006.

In this work, a diagnosis of the deterioration of the concrete viaducts, before this last rehabilitation, was done [Mota-Miranda 2006].

The engineering design, the construction and any subsequent repairs on the viaducts were studied by collecting and analyzing the information kept in the archives of the Leixões harbour. The composition of the concretes of all structural elements was identified (‘Fig. 3’), as well as the origin and properties of the materials used. A visual inspection of the structures was made and the most relevant deteriorations were recorded and photographed. Some samples of apparently non-deteriorated concrete and visually deteriorated concrete, as well as some stains and efflorescence were extracted for analysis. The carbonation and chloride ingress were determined in samples of concrete apparently non-deteriorated. All samples were observed and analyzed by scanning electronic microscopy (SEM) and energy dispersive spectrometry (EDS) to study their mineralogy and chemical composition.

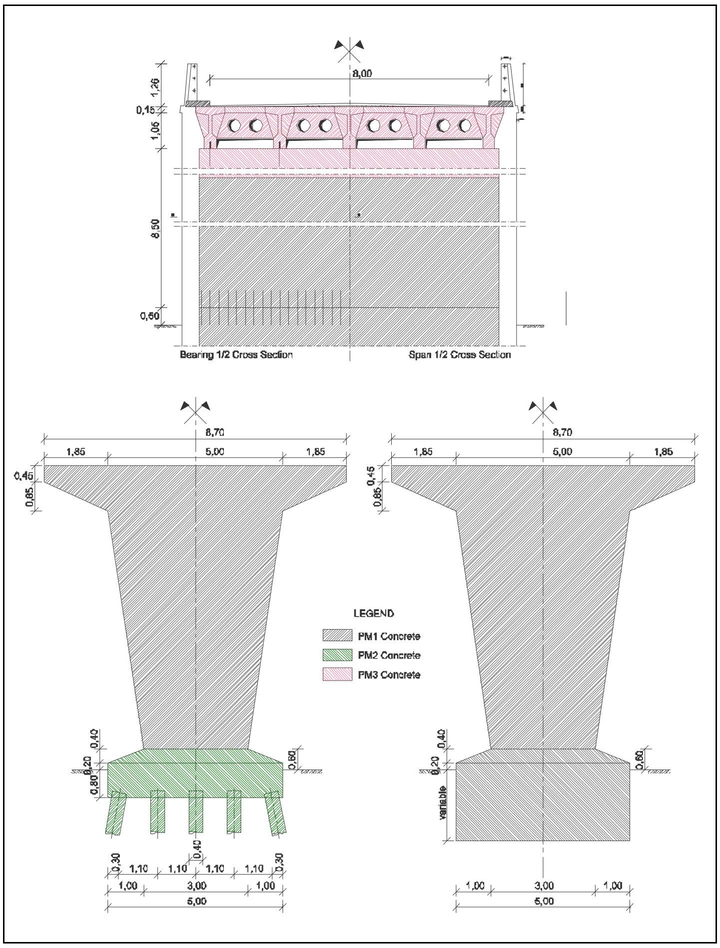


Figure 3. Concrete identification.

2 EXPERIMENTAL STUDY AND DISCUSSION

2.1 Tests

Several tests to characterize the concrete of the viaducts physically, mechanically and chemically were performed [Mota-Miranda 2006]. Only the results of the progression of carbonation and chloride ingress tests, closely associated with the deterioration process of the concrete are shown. The two tests had been carried out in two cores extracted at the same location.

The carbonation depth was determined from the cores from a wall-column of the viaduct with an alcoholic solution of phenolphthalein of 1% [RILEM 1988]. The carbonation depth was 5mm.

Measurements of chloride ingress were made according to specification E 253 [LNEC 1971]. Initially, the chloride content in the concrete was determined at a depth of 5 mm. The determination of the actual chloride content in the cement was done by taking into consideration the concrete composition. The chloride content was 0.02% in the concrete and 0.16% in the cement. Carbonation depth and chloride content were very small.

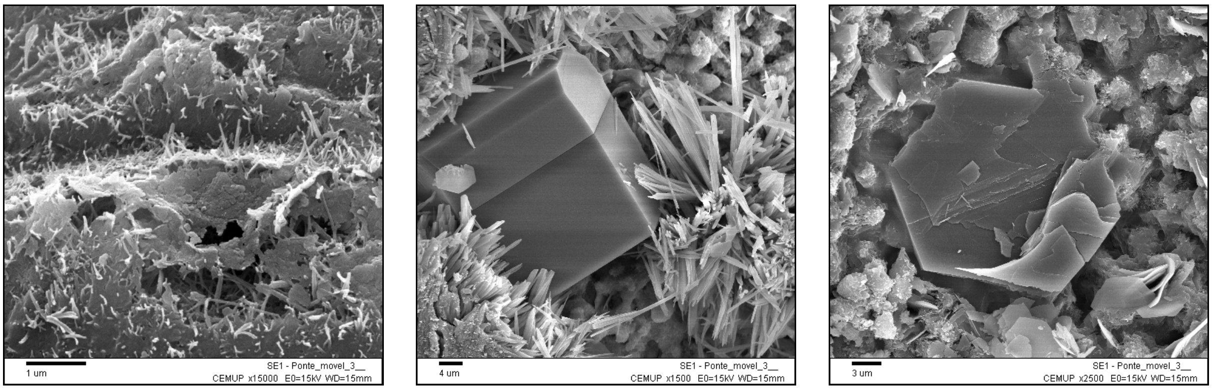
2.2 The Petrographic Study of the Concrete

Samples of non-deteriorated concrete and visibly deteriorated concrete, as well as samples of all the relevant deterioration (brownish stains and white and dark efflorescence) were observed and analyzed by SEM/EDS [St John et al. 1998].

The visibly deteriorated concrete was obtained from locations near non-structural cracking at the base of one wall-column, at beams (along the reinforcement) and under stains and efflorescence (‘Fig. 4’).

Figure 4. Visually deteriorated concrete, stains and efflorescence.

The observations and analysis of apparently non-deteriorated concrete of the two access viaducts showed good quality concrete, compact and with a well hydrated cement paste, showing hydrated calcium silicates and portlandite, calcium hydroxide, ($Ca(OH)_2$) (‘Fig. 5’). The neoformation products found were calcite, calcium carbonate (CO_3Ca), sylvite, potassium chloride (KCl), ettringite, calcium sulfo-aluminate hydrated ($3CaO.Al_2O_3.3CaSO_4.32H_2O$) and gypsum, calcium sulphate bi-hydrated ($CaSO_4$. $2H_2O$) (‘Fig. 6’). Large quantities of calcite were found even at 5mm depth, very small quantities at 8mm and at 100mm depth no neoformation calcite was identified. This concrete also showed potassium chloride crystals next to the surface. Beyond 5mm the concrete showed an incipient sulphate attack with the development of ettringite and gypsum.



Calcium silicates | Portlandite Crystal | Portlandite Crystal

Figure 5. Calcium silicates and crystals of portlandite.

The cement paste showed hydrated calcium silicates, which are mainly responsible for the resistance and binding properties of cement paste, and portlandite crystals, responsible for long-term stability of the silicates. The observations of calcite are coherent with the carbonation test. The sylvite crystals next to the surface are probably due to the contamination of the repair mortar that had chloride in its’ composition [Mota-Miranda 2006]. The sulphate attack with formation of gypsum and ettringite is an external attack due to the water from the “Leça” river. Analysis of this water showed a very high sulphate content [Mota-Miranda 2006].

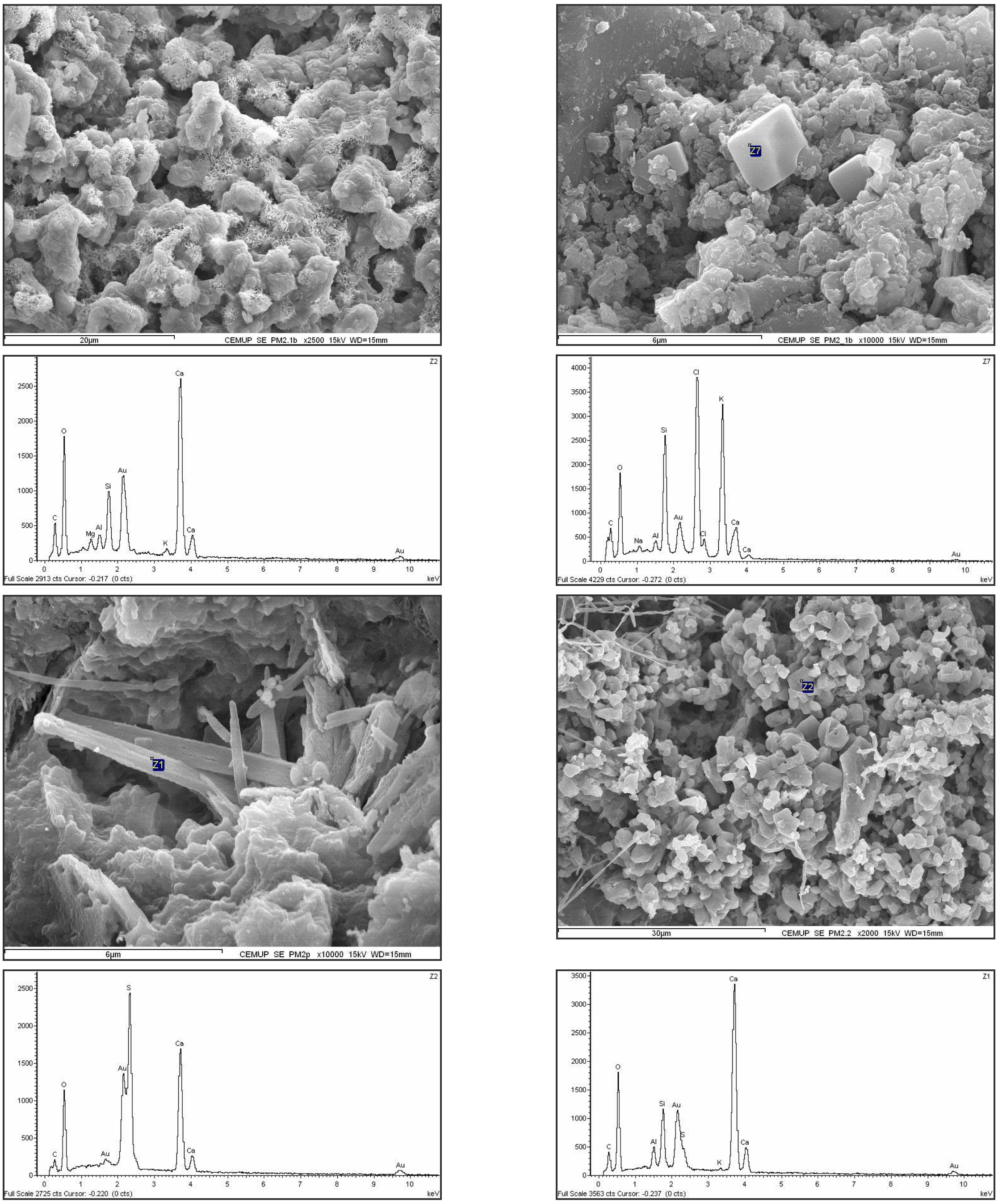


Figure 6. Calcite (dissolution forms), sylvite, ettringite and gypsum images and spectra.

The concrete of the base of one wall-column with a non-structural crack, showed calcium silicates and aluminates, along with large quantities of calcium carbonate and halite, sodium chloride, (NaCl) (‘Fig.7’).

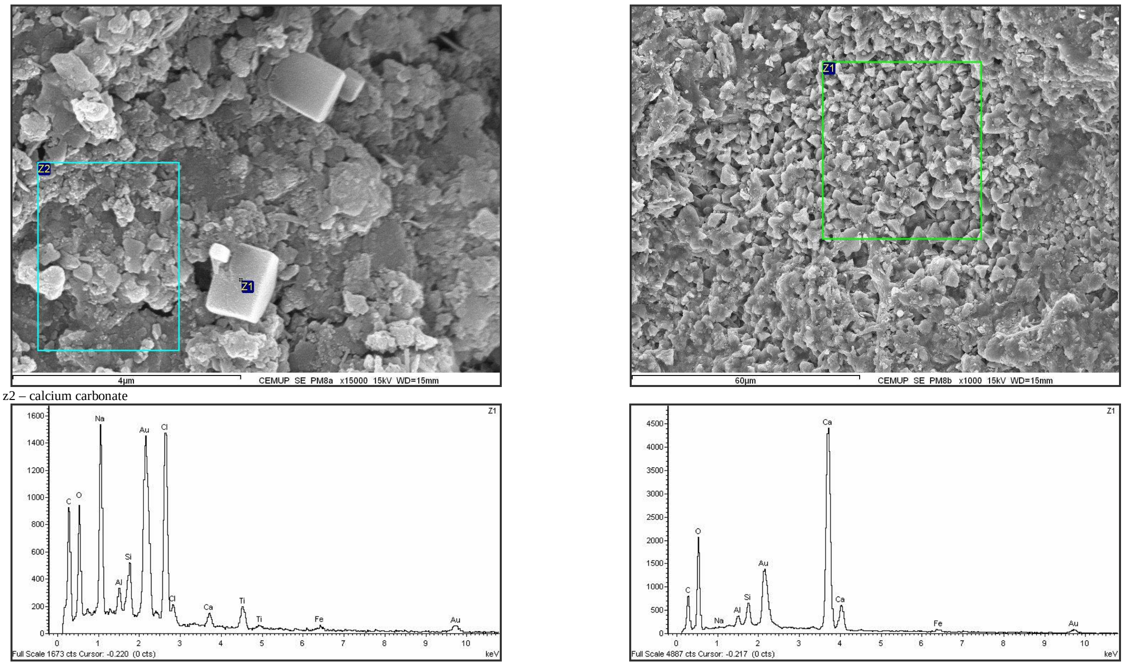


Figure 7. Images and spectra of sodium chloride and calcium carbonate.

The concrete facing south showed many crystals of calcium carbonate and of sodium chloride. This is the original concrete, without treatment, so, the origin of chloride is associated with environmental contamination; it rapidly develops in areas exposed to rainwater. Calcite is due to the penetration of carbonation which is easier when you have crack openings.

The observations and analysis of the concretes that are partially detached from the structures, near non-structural cracking along the reinforcement, showed that these concretes are very rich in calcite. The brownish stains found, on these concretes, were all of iron oxides ('Fig.8').

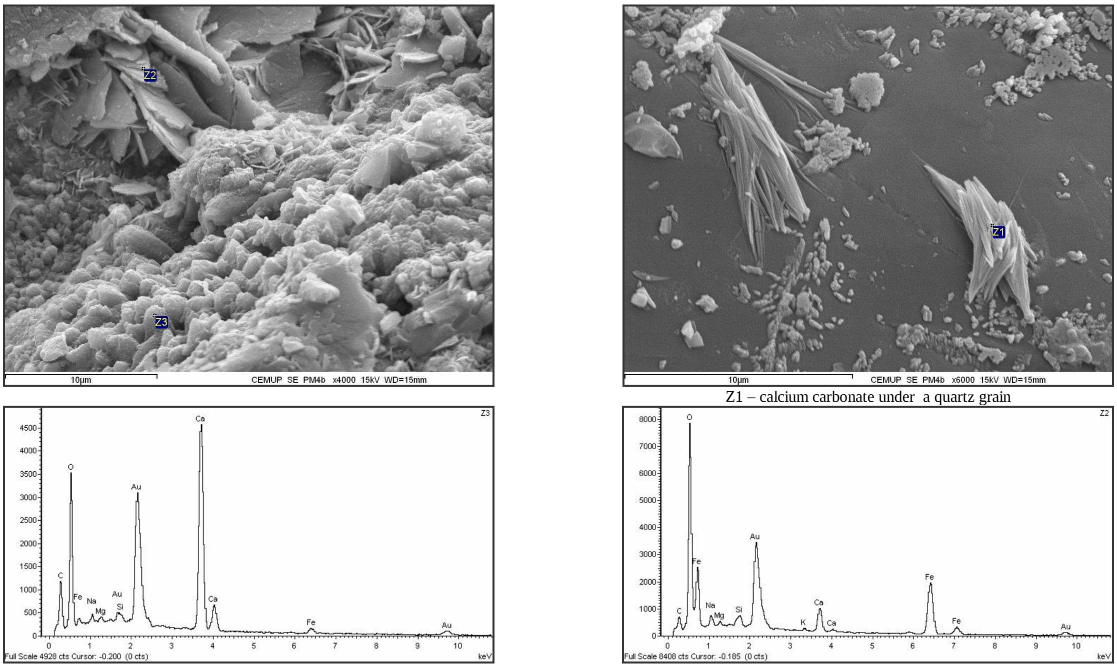


Figure 8. Calcite and iron oxides images and spectra.

These concretes show corrosion due to carbonation. The results of the chloride content analysis show that the corrosion of the reinforcement are caused by carbonation and not by high chloride content. The stains on these concretes consisted totally of iron oxides, and are caused by steel corrosion. The non-structural cracking along the reinforcement and the concrete spalling or delamination are due to the formation of expansive products of steel corrosion.

White and dark efflorescence were also analyzed. The white efflorescence consisted essentially of calcium carbonate (‘Fig. 9’). The black efflorescence was organic substances (‘Fig. 10’).

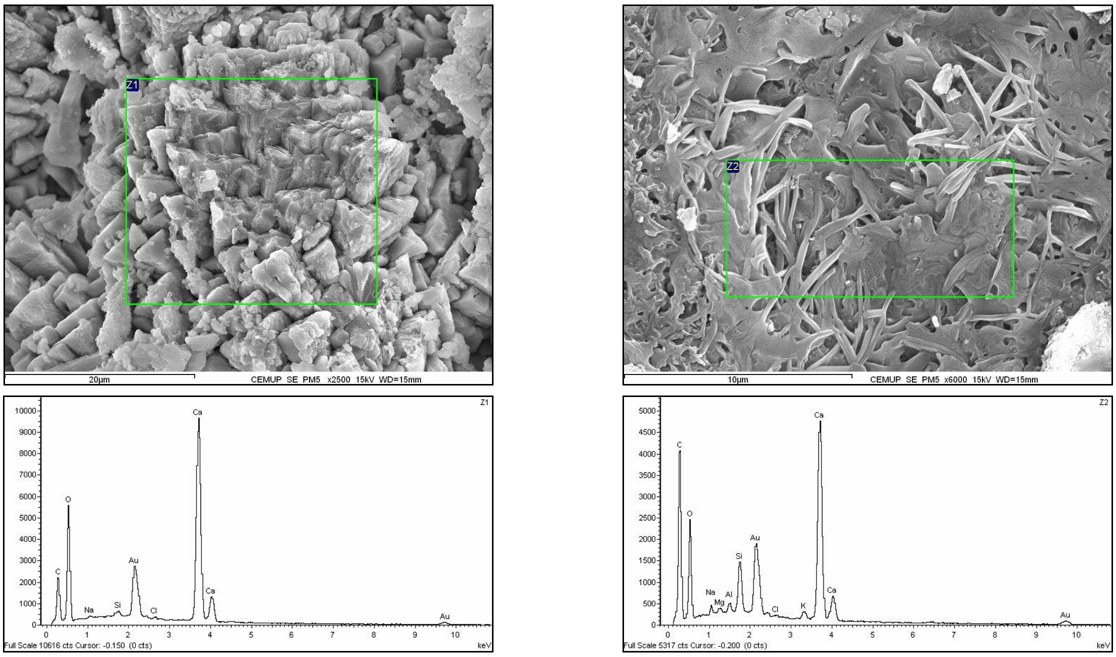


Figure 9. White efflorescence images and spectrum.

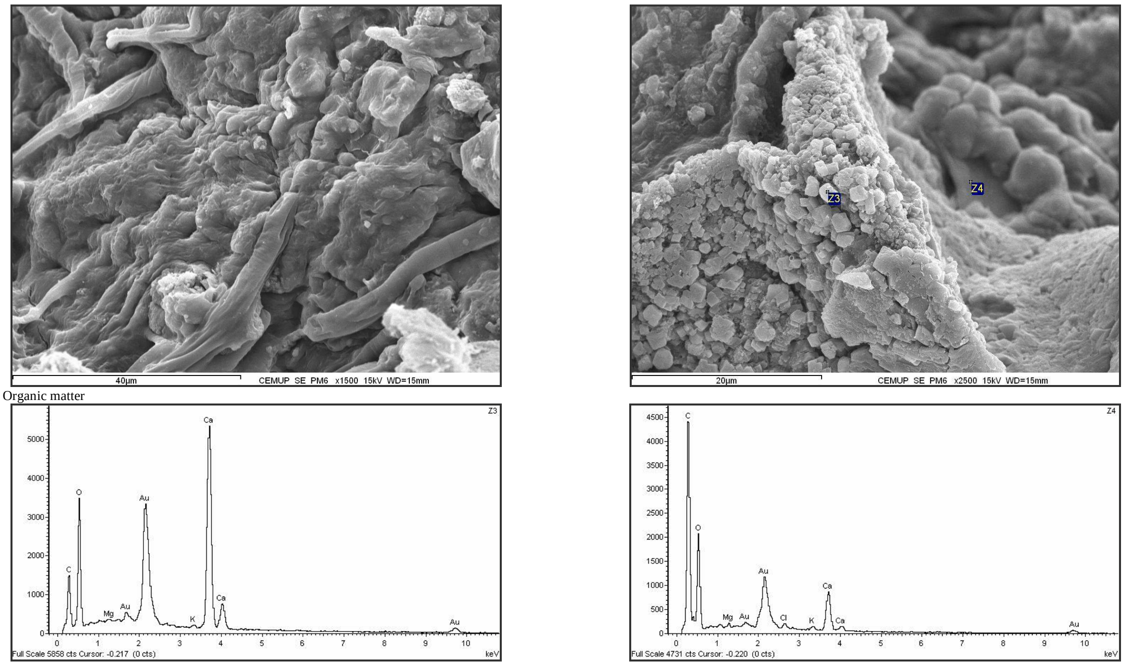


Figure 10. Black efflorescence images and spectra.

The white efflorescence has its genesis in the leaching of lime compounds in the concrete and its carbonation at the surface. The dark efflorescence is an organic substance caused by moisture.

3 CONCLUSIONS

From the evaluation of the results, we can conclude that:
The carbonation depth in concrete was very small, much less than the coating thickness, which in the worst case was 20 mm.

The chloride content results at a depth of 5 mm showed that the risk of corrosion is negligible or low. For this reason it was not necessary to take measurements at greater depths. The chloride content, showed smaller values than those allowed by the European legislation for chlorides in concrete mix of construction located in proximity to marine environment, (total chlorides for each concrete component).

Given these results, it may seem strange that the structures essentially show corrosion by carbonation. However, problems occurred during the repair work done between 1991 and 1993 [Mota-Miranda 2006] that resulted in a repair which did not eliminate all sources of corrosion.

The SEM/EDS observations and analysis of apparently non-deteriorated concrete showed well hydrated cement paste with hydrated calcium silicates, which are mainly responsible for the resistance and binding properties of the cement paste, and portlandite, is responsible for long-term stability of the silicates. This concrete showed four main products of neoformation: calcite, sylvite, ettringite and gypsum. The calcite is due to carbonation and the observations are coherent with the results obtained from the carbonation test. The sylvite is probably due to the contamination of the repair mortar that had chloride in its composition. This shows the importance of controlling the repair mortar composition, since this mortar was rich in chlorine, an element clearly aggressive for corrosion of reinforced and pre-stressed concrete. The ettringite and gypsum result from a sulphate attack due to external sulphates from the water of the Leça river. This attack is until now incipient with no visible manifestations.

The SEM/EDS observations and analysis of visibly deteriorated concrete and of brownish stains confirm that the concrete detachments spalling or delamination has their origin in corrosion of the concrete reinforcement.

The SEM/EDS observations and analysis of white and dark efflorescence prove that the white efflorescence are due to the leaching of lime compounds and the dark efflorescence are caused by moisture.

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