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Monitoring the structural effects of internal swelling reactions in Aguieira bridges

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Extended Abstract

A set of seven bridges located in the reservoir of Aguieira Dam, in the centre of Portugal, sharing the same structural solution and built between 1976 and 1979, was severely attacked by internal swelling reactions of concrete, which particularly affected bridge piers and foundations. Laboratory tests diagnosed both Alkali-Aggregate Reaction (AAR) and Internal Sulphate Reaction (ISR) due to Delayed Ettringite Formation (DEF) as the causes of those expansions.

The AAR was attributed to the use of alkali reactive aggregates, mainly quartzitic and granitic types. The aggregates will also have been an internal source of alkalis, since the measured levels of soluble alkalis in concrete samples extracted, expressed as Na_2O_{eq}, ranges between 0.93 to 8.13 (3.44 in average) kg/m^3 of concrete.

The ISR in these bridges was attributed to the high cement content employed, associated to the massive structural elements (foundations, piers and crossbeams). No information was obtained about the cement employed in these bridges, but the determinations of cement content in samples extracted confirms high dosages in some parts (higher than 400 kg/m^3), as well as high cement SO_3 contents (values between 1.48 and 4.44 %). These parameters, associated to the high alkalinity and presence of water, are crucial to trigger the ISR.

In face of this problem, different approaches were taken by the Portuguese road authorities to overcome the situation and to allow the continued use of the road network:

- One of the bridges, over the mouth of the Dão River, was replaced, due to the high cost of the rehabilitation works required.
- In three other bridges, it was decided to substitute the cylindrical piers by new annular cross section independent piers surrounding the old shaft, founded on micropiles executed through the existing footings.
- The rehabilitation of the three remaining bridges (Criz I, Criz II and São João das Areias) was based on the construction of six piles with a metallic casing around each pier and the corresponding pile cap which. Additionally, a concrete covering was applied in the upper part of the piers, above the pile cap.

This paper is focused on these last bridges, more specifically in Criz II Bridge and São João das Areias Bridge, whose structural behaviour has been monitored since its rehabilitation.

The superstructure of both bridges is a 15.20 m wide continuous prestressed reinforced concrete (RC) slab supported by four beams, 2,0–2,50 m high and 0,50–0,30 m wide. The slab has a variable thickness from 0,16 m to 0,25 m at the connection to the beams. Both decks have crossbeams in the support sections as well as at the third-span sections. The RC piers are composed of a single shaft, with a hollow cross-section, in the shape of a rhombus with sharp bevelled edges, inscribed in a 6,0 m × 3.0 m rectangle, with a wall thickness of 0,20 m. The bridges have direct foundations.

The Second Bridge over the river Criz, usually called Criz II Bridge, has a total length of 300 m with six intermediate spans of 40,0 m and two extreme spans of 30,0 m. The height of the piers varies between 27 m and 70 m. The piers P2 to P6 are founded inside the reservoir, with a maximum foundation depth of about 35 m.

The São João das Areias Bridge over the Mondego River has a total length of 260 m, with five intermediate spans of 40,0 m and two extreme spans of 30,0 m. The height of the bridge piers varies between 17,2 m and 50,6 m.

The rehabilitation works of the piers and foundations of these bridges took place in 2016 and 2017. As mentioned, it consisted in the execution of six piles around each pier, headed by a pre-stressed reinforced concrete pile cap, to ensure the load transfer to the new foundations when the stiffness of the immersed part of the pier decreases due to the swelling reactions. The piles built have 1,50 m diameter in Criz II Bridge (Figure 1) and 1,20 m diameter in São João da Madeira Bridge (Figure 2).

Figure 1: Criz II Bridge at the end of the rehabilitation works

Figure 2: São João das Areias Bridge at the end of the rehabilitation works

During these works an innovative Structural Health Monitoring (SHM) systems was installed in both bridges aiming to characterize the structural behaviour associated with the concrete expansion process, in particular the submerged part of the piers. In effect, since the development of the swelling reactions of the concrete will decrease, predictably, the stiffness of the concrete, leading to a load transfer from the original piers to the piles, the goal of the SHM is on the one hand to quantify the degradation process of the affected concrete, that is, the loss of column stiffness, and, on the other hand, to measure its evolution over time.

The SHM systems set-up in both bridges are identical, based in the installation of vibrating wire strain gauges in the piles of the piers P2 and P3 of both bridges. Complementary, some strains are also being measured at the surface of the original pier, as well as inside the additional concrete cover, besides the measurement of the rotation at the top of the piers, the movements of expansion joints and the ambient temperature.

In addition, in one section of São João das Areias Bridge resistivity sensors were installed along the thickness of two walls of the concrete casing, with different exposure conditions, in order to monitor the humidity inside the concrete. In the same section, three cores were extracted from the original concrete and instrumented in the laboratory with three pairs of graphite electrodes placed at different depths from the surface: 3 cm, 5 cm, and 10 cm. Then, the cores were placed again in its original hole and properly buffered, to avoid the water entry except by the outside surface. Since the temperature affects the resistivity, a PT100 sensor was installed together each core, in order to be clear the significance of the measured values of resistivity provide by the graphite electrodes.

In both bridges, a data acquisition system composed by a DT80G logger and two Datataker CEM20 channel expansion modules, were installed. Also, a router was installed in order to allow the remote communication, essential for the automatic feed of the database, and thus, for the data processing and storage.

This paper describes the structural health monitoring systems installed in both bridges and presents the preliminary results achieved. The slowness of swelling processes does not allow expecting drawing conclusions before a few years of monitoring. However, the initial results are fundamental for the characterization of the current situation and, therefore, for the detection of any changes resulting from the degradation of the concrete.

***Keywords**: concrete bridges; internal swelling reactions; structural health monitoring*

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