Microstructural investigations on an abandoned 1935 concrete bridge

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INTRODUCTION

Petrography plays an essential role in the study of deteriorated concrete and is used since several tens of years [1-6]. The so-called concrete pathologies, as well as the petrographic nature of the aggregates, the nature of the binder, can be studied using a petrographic microscope, in most cases also using a scanning electron microscope (SEM) coupled with energy-dispersive spectroscopy (EDS) to perform semi-quantitative analysis. This method has been applied for real buildings such as bridges [7] or dams [8] for example and gave precise information on the deterioration mechanisms.

The present study deals with a bridge located in the center of France, built from June 1934 to August 1935; its inauguration took place on Sunday, October the 27th, 1935 (Figure 1a). It quickly showed some deterioration. During the 1960's, some limitations regarding the maximum weight of vehicles allowed to use the bridge were implemented. It has been definitely closed in 1980. Since then, it is left in an abandoned state (Figure 1b and c): cracking and steel reinforcement corrosion occurs in numerous places of the bridge.

The historical documents regarding the requirements for the building of the bridge (nature of aggregate, type of cement…) as well as original drawings, studied along with actual samples from the bridge, allow proposing an estimation of the concrete pathologies.

MATERIALS AND METHODS

The present study concerns only preliminary results on a few samples collected on the bridge in November 2016, April 2017 and May 2018. Exception made for the latest ones, preliminary samples were collected randomly, with no real knowledge of the damages affecting the bridge, in places where the concrete was crumbly enough to allow hand sampling.

Samples for thin sections or cross-sections have been impregnated in epoxy resin (H2020, Huntsman) under vacuum, colored with fluorescein in some cases ; thin sections were produced using regular practices [9] and polished using diamond abrasive pastes (6, 3, 1 and 0.25 micrometers). Optical microscopy has been carried out on a Leica DMRXP petrographic microscope and a Zeiss Axiozoom. Scanning Electron Microscopy has been carried out on a Hitachi S-4300SE/N coupled with a Thermoscentific ultradry EDS detector.

RESULTS

Petrography of aggregates

The region in which the bridge has been built belongs to one of the widest granitic massifs of France, namely the Guéret massif [10], the aggregates and sand used are of local source. Most of the aggregates consist on a dark granite (Figure 1d&g) in which plagioclase feldspar shows some evidence of sericitization (Figure 1d&e) transformation in fine-grained phyllosilicates, cordierite is generally not fresh and pinitized. Quartz generally display undulose extinction (Figure 1e). Some aggregates have revealed themselves to be rich in pyrite (Figure 1f), both inside the grains or at their surface. The precise source of the aggregate is unknown, several abandoned quarries being present in the vicinity.

The sand is coherent with a granitic origin, it consists on quartz and feldspar, mica flakes, or other minerals found in granite. Abandoned quarries of weathered granite in the vicinity might have provided this material.

Concrete sampled above the deck

The upper part of the deck is the part of the bridge showing the most extensive degradation (exception made of carbonation/reinforcement corrosion, which occurs almost everywhere, and will not be discussed here). Indeed, in many parts along the deck, concrete is totally crumbly and can be easily scraped with bare hands.

Ground slabs, compared under white and UV light, show well developed cracking occurring both in the cement paste and at the interface between aggregates and cement paste (Figure 1g&h).

Ettringite, actually an intermediate between ettringite and thaumasite (EDS analyses are not detailed in the present extended abstract), is abundant in concrete sampled from the upper part of the deck. Firstly, all porosities are totally filled by this fibrous phase (Figure 1i), generally forming radiating crystallizations. Then, many cracks, occurring along debonded aggregates, in the cement paste, or cutting aggregates, are filled by this fibrous phase; the elongation of the fibers is perpendicular to the cracks (Figure 1j). Calcite crystals, 20 micrometers in diameter (Figure 1k) occur locally within a cement paste mostly transformed in ettringite-thaumasite (Figure 1l).

Concrete sampled under the deck

Contrarily to the samples taken above the deck, the cement paste of the concrete from below the deck, at least on the place of sampling, is not grey, but orange-rose. Under the microscope, in thin sections, complementarily to unhydrated Portand clinker particles (Figure 1m), it shows abundance of orange particles of 50-100 micrometers in diameter (Figure 1n).

In thin section, their individual microstructure is difficult to decipher because they are very finely grained. Under the SEM, they show very poor contrast with their matrix (i.e. the cement paste) in BSE mode (Figure 1o). EDS results (not displayed here) indicate very impure calcium silicates and aluminates. Those latter forms an incipient interstitial phase between calcium silicates.

DISCUSSION

The microstructural study of randomly selected samples from the Charles Marlin bridge has revealed that the concrete with which it is made suffers from several pathologies, at least locally.

Although alkali-silica reaction has not (yet?) been formally identified, the presence of quartz showing undulose extinction might has led to this pathology. Furthermore, the bridge had been built some years before the formal description of alkali-silica reaction [11].

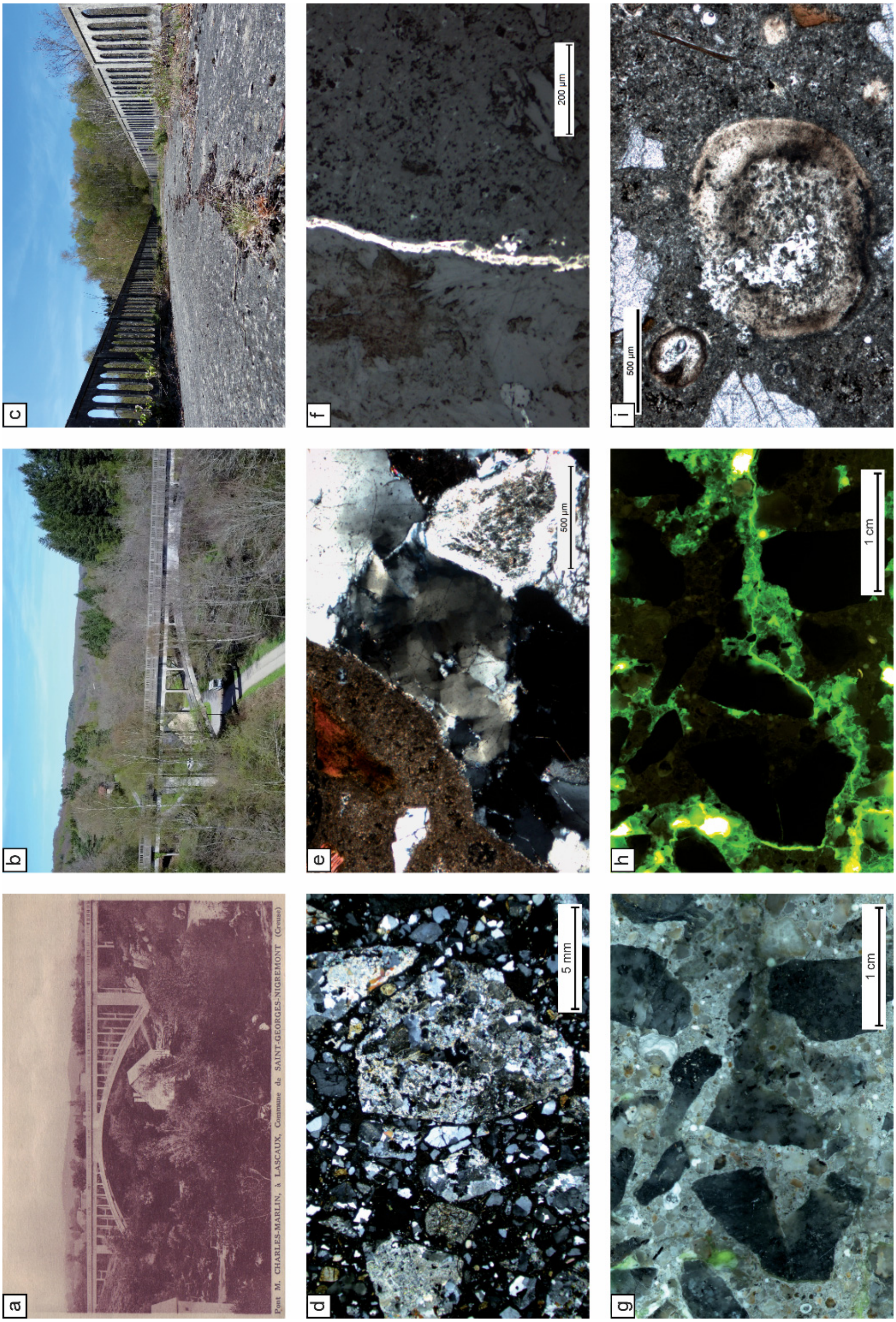
The orange particles observed in the cement paste of concrete from under the deck consist most probably on unburnt cement: they show a very poor development of phases, in which an incipient interstitial phase lies between poorly formed calcium silicates. This is coherent with a problem of burning of the cement, probably not burnt enough.

The abundance of ettringite-thaumasite in concrete from the upper part of the deck shows microstructural similarities with several concrete pathologies. Locally, ettringite-thaumasite is present as rims around the aggregates, but not all around as would be the case in delayed ettringite formation [12]. The cement paste is also completely cracked and locally partly replaced by ettringite-thaumasite. This shows some similarities with the thaumasite form of sulfate attack, especially concerning the fact that there is also calcite present as individual crystals within the damaged paste as in the case of “popcorn calcite deposition” [13]. The source of sulfur is to be found in the aggregates which are, in the present case, unusually rich in pyrite/pyrrhotite for granite. The use of such sulfide-rich aggregates is known to be deleterious for concrete [14]. Finally, in order to provide the same chronological comparison as for alkali-aggregate reaction (see above), it is worth noting that the first case of DEF in France has been described only in 1997 [15].

CONCLUSION AND PERSPECTIVES

The 1935 “Pont Charles Marlin” bridge has a rich history regarding concrete evolution and degradation and seems to have suffered from the coincidence of several factors: a potentially alkali-reactive, sulfide-rich aggregate; problems in the quality of cement, along with other problems related to the structure in itself or the pouring of the concrete.

In any case, it provides a good, as well as not usual, example of a concrete structure from the 1930’s, on which there has been no maintenance since at least 40 years, this displaying a “true” weathering, in an area where winter are tough and rain is frequent.


a
b
c
d
e
f
g
h
i
Pont M. CHARLES-MARLIN, à LASCAUX, Commune de SAINT-GEORGES-NIGREMONT (Creuse)
5 mm
500 µm
200 µm
1 cm
1 cm
500 µm

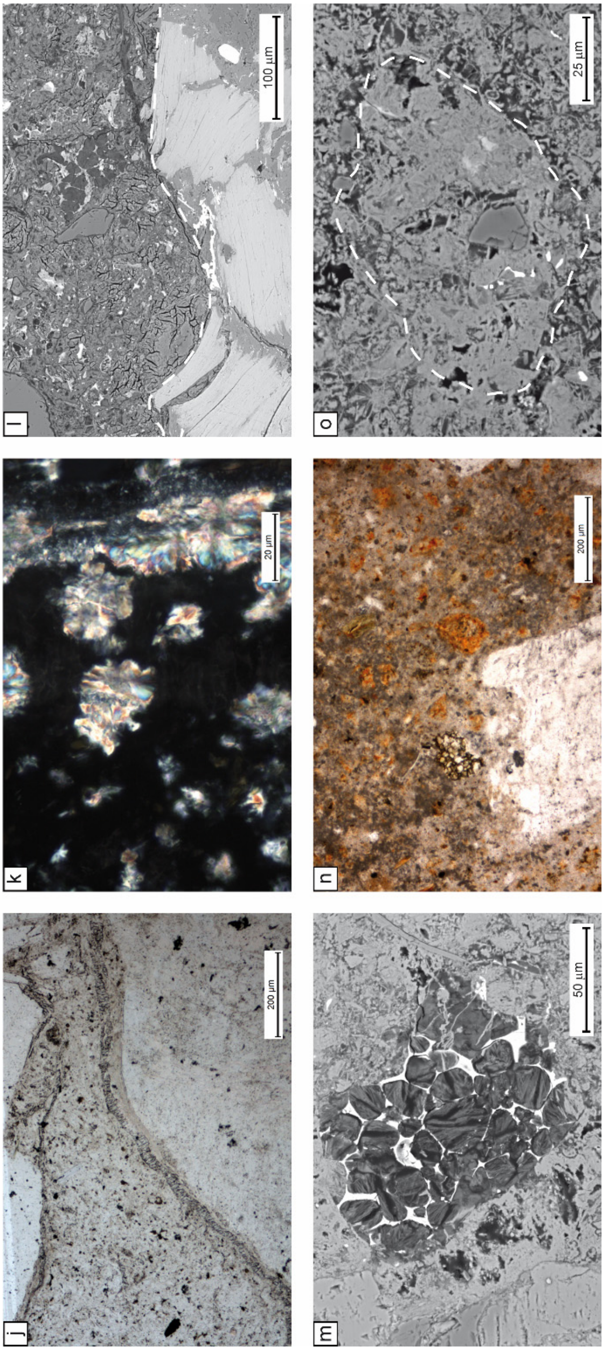


Figure 1. a-c : the bridge (a: postcard from 1936 or 1937, author's personal collection) and d-o: associated microstructures. See text for explanations.

ACKNOWLEDGEMENTS

The mayor of the city of Saint-Georges Nigremont for allowing access to the bridge and sampling, Frédéric Sion for filming the structure with a drone. Traveling to the bridge has been possible within the framework of the PAMGEE project funded by Unisciel.

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