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Assessing alkali-silica reaction damage to concrete with non-destructive methods: From the lab to the field

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ABSTRACT

The effectiveness of any non-destructive (ND) procedure for evaluating the damage to concrete depends on the relation between physical and mechanical properties. With this attempt, this paper deals with the application of three ND methods (ultrasonic wave velocities, dynamic Young modulus measured with resonant frequency and electrical resistivity) for the evaluation of concrete cores drilled from a large hydraulic structure affected by alkali-silica reaction (ASR). In parallel, the concrete was tested for its mechanical properties and petrographic examinations were also performed. ND results were compared with those obtained from concrete specimens made in the lab and showing various levels of deterioration associated with ASR.

Results from all methods (except electrical resistivity) showed that the overall condition of the concrete remains of good quality, in spite of the significant expansion rates measured on the structure. On the one hand, damage is mainly located within the first two meters from the surface. On the other hand, concrete deterioration at the bottom of the structure was very low.

The electrical resistivity did not appear to be appropriate for evaluating the damage level related to ASR. Dynamic Young modulus and ultrasonic pulse velocity yielded better results. The best correlation was obtained between the *P*-wave velocities and the static Young modulus. This study emphasizes that laboratory results cannot be directly extrapolated to field results.

1. Introduction

The development of innovative and efficient procedures for ASR assessment becomes an urgent need owing to the ageing condition of concrete structures and the excessive costs associated with their replacement, rehabilitation or repair requirements. Such procedures will firstly assist in estimating the current condition of the structures but also their future performance.

In many field cases, involving deterioration due to alkali-silica reaction (ASR), only a limited range of investigation techniques are used and their effectiveness has not always been demonstrated. For instance, visual inspection can provide an overall estimate of the amount of damage but it remains highly qualitative, superficial, time-consuming, and moreover it strongly depends on the skill and experience of the inspectors. Semi-quantitative methods have been proposed to assess surface cracking associated with ASR. These methods are based on the measurement of the crack width intersecting lines drawn on the structure surface [1,2]. However, it was reported that these same methods have failed to evaluate the expansion with appropriate accuracy [3].

Management of ASR-affected structures remains largely based on periodic inspections, and on monitoring the displacements of different members using a more or less efficient system with regard to the importance of the structure. For instance, papers by Fournier and Bérubé [4], and Godart [5] provided relevant overviews of the management of ASR-affected structures, which are mainly based on visual inspections, surface cracking investigations, mechanical testings and residual expansion tests performed on drilled cores. However, the authors did not really consider non-destructive (ND) methods in their approach to the problem.

Hence, the effectiveness of any ND procedure for evaluating the damage depends on the relation between physical and mechanical properties. For instance, measuring a compression wave velocity of 4000 m/s does not appear as a relevant parameter for engineers responsible for determining whether the concrete is worthy of repair.

With this attempt, this paper deals with the application of three ND methods (ultrasonic wave velocities, dynamic Young modulus measured with resonant frequency, and electrical resistivity) for evaluating the concrete condition on laboratory specimens and on cores drilled from a large hydraulic structure suffering from ASR. In parallel, mechanical properties and petrographic examinations were performed on concrete cores.

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The main goal of this study was to test all methods in order to highlight the most efficient ones, in lab and on site. In this view, whether the results commonly found in laboratory are suitable for in situ assessment must be discussed. The results derived from this work could be valuable for designing systematic concrete damage monitoring program based on a non-destructive approach.

2. Alkali-silica damage

ASR is a complex reaction between reactive silica phases in aggregates and hydroxyl ions in the concrete pore solution. It produces a gel (silica gel) that swells in the presence of moisture. The expansion of concrete generates two main types of problem: (1) the deformation of the structure that impairs the serviceability and, (2) the development of crack network through the structure. Both problems, however, do not arise at the same level within the structure. ASR expansion is heterogeneous and varies from an element to another with respect to several parameters: temperature, moisture level, reinforcement and external stress, exposition to sun/rain, etc. Furthermore, it is recognized that ASR has a greater effect on the surface concrete [4]. This would be attributed to a slower expansion at the surface – mainly due to the decrease of the pH pore solution caused by alkali leaching and carbonation – that generates tensile stress (and therefore cracking), and also to environmental agents, such as frost action or wetting/drying cycles that are only active in the surface zone. Regarding the inner damage, it appears that the effect of confinement by the surrounding concrete body – as well as the protection against environmental agents – limit the damage.

Fig. 1 shows a polished section impregnated with colored resin prepared from a core collected deeply from a dam built in the 30s in Eastern Canada. It can be seen that cracks are relatively thin, and like in most non-reinforced mass, followed an isotropic network. This kind of damage may reduce the effectiveness of some methods to assess ASR damage as it will be later discussed in this paper.

ASR does not uniformly alter the engineering properties of concrete. The compressive strength does not appear to be a relevant criterion (virtually no loss at low to medium expansion levels) but the static Young modulus and the tensile strength would give better results, at least on laboratory concrete [4,6]. A stiffness test, based on the analysis of the concrete behaviour after 5 cycles of loading, would also be valuable for assessing ASR damage [3,7].

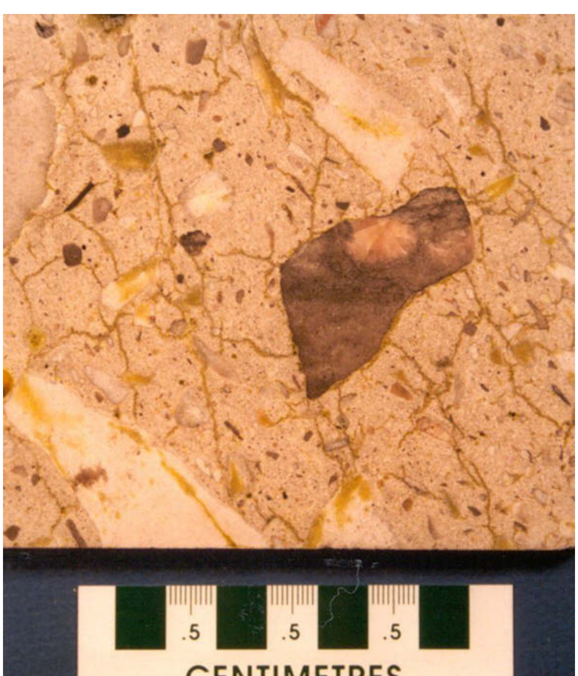

Fig. 1. Thin and isotropic cracks in ASR-affected dam concrete as highlighted with epoxy impregnation.

The ND testing that was used the most to assess ASR effects is the ultrasonic pulse velocity (UPV) method, although the conclusions drawn have not always been consistent. Several papers dealing with laboratory concrete specimens reported that UPV decreases with expansion [6,8–10]. However, some others reported that UPV is slightly affected by ASR, except at very high expansion levels [11–13].

The resonant frequency technique has mostly been applied for assessing concrete damage, particularly due to frost action, and the results found are relevant [14–16].

Only one reference dealing with the influence of ASR on the electrical resistivity was found [17]. The study was performed on several laboratory mortars specimens. An increase of the resistivity was observed for all specimens, but it was much higher for the reactive mortar.

3. Experimental work

3.1. Laboratory concrete

Two concrete mixtures were made with a W/C of 0.5 (Table 1). The reactive mixture was batched with a reactive limestone as coarse aggregate (Spratt limestone). The total alkali content of both mixtures was boosted to 7.0 kg/m^3 Na_2O_{eq} by adding reagent grade NaOH pellets to mixing water.

Three concrete prisms (75 × 75 × 300 mm) of each mixture were cast with stainless steel reference studs fixed at both ends for length measurements and electrical resistivity monitoring. Other ND measurements were performed on cylinders (100 × 200 mm).

After 24 h in a curing room, specimens were taken out of the molds and placed over water in hermetic plastic pails to provide the humidity condition required for ASR development. There was no direct contact between the water and the concrete since the specimens rest on a perforated plastic rack placed at about 2 cm above water that fills the bottom of pails. The pails were stored at 38 °C to accelerate the reaction. The prism expansiveness was monitored regularly in compliance with the CSA A23.2-14A Canadian standard, which considered an aggregate to be reactive when the prism expansion exceeds 0.04% after 52 weeks.

3.2. Field study

The investigated site is an hydraulic structure located in Southern Quebec (Canada). The concrete is 50-years old and is affected by ASR, which was detected about 20 years after the construction. ASR is due to a reactive siliceous limestone used as coarse aggregate in the concrete. Several recurrent operating problems have been reported over the past years. The current horizontal expansion rate is estimated to be about 1.6 mm/year.

Table 1
Concrete mixture proportions

Mixtures	Non-Reactive	Reactive
W/C	0.50	0.50
Coarse aggregates	Limeridge limestone	Spratt limestone
Cement (kg/m^3)	400	400
Water (kg/m^3)	200	200
Aggregates (kg/m^3)	1074	1074
Sand (kg/m^3)	792	792
Na_2O_{eq} (kg/m^3)	7.0	7.0