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Expansive behavior of thick concrete slabs affected by alkali-silica reaction (ASR)

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HIGHLIGHTS

- ASR caused heterogeneous expansion within the specimens.
- Expansion gradient caused by the reinforcement's confining effect.
- Stainless steel stud and fiber optics system generated similar results expansion results.
- Lithium nitrate proved to be a good mitigation method against the expansion caused by ASR.

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ABSTRACT

Some of the structures affected by ASR are bridges with thick concrete slabs without shear reinforcement. This implies that concrete is the only component resisting to shear forces, which might be a problem considering that ASR can progressively and significantly affect the mechanical properties of that material. A study was launched to gain a better understanding of the effects of ASR on the behaviour of thick concrete slabs without shear reinforcement. The methodology developed for this study, as well as the analyses of the deformations/expansions obtained from different surface measurements, are presented in this paper. It led to interesting observations about the heterogeneity of the deformations between slabs. The expansion was monitored extensively in the longitudinal, vertical and transversal orientation. The expansion was the greatest in the transversal orientation reaching up to 0.6–0.7%. The steel reinforcement at the base of the specimens locally limited the expansion of the slabs and as such created an expansion gradient which increased with the advancement of the alkali-silica reaction. Also, the use of lithium nitrate proved successful as a mitigation method against the development of expansion due to ASR.

1. Introduction

The Quebec Ministry of Transportation (*Ministère des Transports, de la Mobilité durable et de l'Électrification des Transport – MTMDET*) manages an infrastructure network which includes thick concrete slab bridges which were originally designed without shear reinforcement (stirrups). Considering that traffic volume and loads have increased considerably since their original design requirements, and since some of them are suffering from pathologies (such as corrosion, alkali-silica reaction (ASR) and freeze-thaw cycles), concerns were raised regarding their residual structural capacity that recently triggered strengthening work or, in some cases, their demolition.

The effect of ASR on the mechanical properties of concrete has been studied by multiple authors; however, few have conveyed investigations on the structural behavior of ASR affected structures. Traditionally, concrete's tensile strength may be neglected for designing structures solicited in flexion. However, tensile strength plays an important role regarding the adherence and anchorage of rebars, shear (and punching shear) behavior of elements without reinforcement, the design of prestressed concrete elements and the durability issues in regards with the initiation of cracks.

Even though highly/properly reinforced concrete can restrain the expansion caused by ASR, knowledge of the effects of ASR on the structural behavior is limited or often contradictory. Therefore, a study on the effects of ASR development and progression on the material and structural properties of thick concrete slabs without

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shear reinforcement was launched at Université Laval with the financial support of the MTMDET. This paper presents the study as a whole and particularly focuses on the analysis of the ASR induced deformations within the large-scale test specimens. As such, three different types of expansion assessment methods were used and their results are presented and analysed in details in order to determine the expansive behavior of ASR affected thick concrete slabs without shear reinforcement

1.1. Alkali-silica reaction (ASR)

Alkali-silica reaction induces premature deterioration in concrete elements when three conditions are met. The aggregate used in the concrete must contain reactive siliceous mineral phases. The concrete must have a high alkali concentration. Diamond [1] showed that the alkalis (Na,K) in the portland cement are largely responsible for the high pH of the concrete pore solution. The third condition is the presence of a high relative humidity. When all conditions are met the formation of a swelling secondary reaction product, an alkali-silica gel is triggered, thus inducing cracking and expansion/deformation within and between concrete elements [2]. The internal tensile stresses caused by the swelling of the reaction product create new cracks or may lead to the propagation of already existing cracks within the aggregate particles. These will eventually extend into the cement paste and connect with other existing cracks, thereby forming a network within the affected concrete element. The cracking network/pattern created by ASR is dependent upon the size of the reactive aggregate particle (coarse or fine) [3–5].

Cracks caused by ASR will develop differently according to the size and shape of concrete elements. As mentioned by Courtier [2], the surface layer of a concrete element will likely sustain alkali leaching and, as a consequence, will develop less expansion than the core of the specimen. Surface cracking will then occur because of the differential expansion between the surface and the heart of the concrete element. Moreover, sub-parallel microcracking will occur, as seen in Fig. 1. The surface layer of a concrete specimen may also develop cracks caused by environmental effects, such as shrinkage induced by concrete drying, freezing and thawing cycles, etc.

1.2. Effect of reinforcement on the expansion of ASR affected concrete

Expansion/deformation and cracking will develop differently in the case of a reinforced concrete element. Indeed, ASR expansion is reduced in the direction of the reinforcement [6], however, as presented in Fig. 2, the reductions in expansions may vary significantly for similar reinforcing levels. Indeed, for a compressive load or induced prestress of 1 MPa, ratios of restrained expansion over free expansion varying between 0.2 and 0.75 have been reported [7].

The presence and configuration of steel will also influence the orientation of cracking in ASR-affected reinforced concrete members [6]. The cracks will follow the path of least resistance and

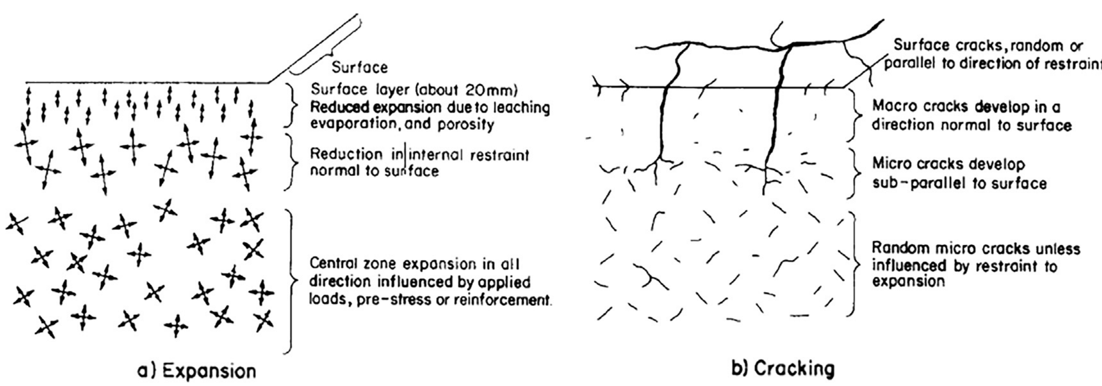

Fig. 1. (a) Development of expansion and (b) cracking linked to ASR [2].

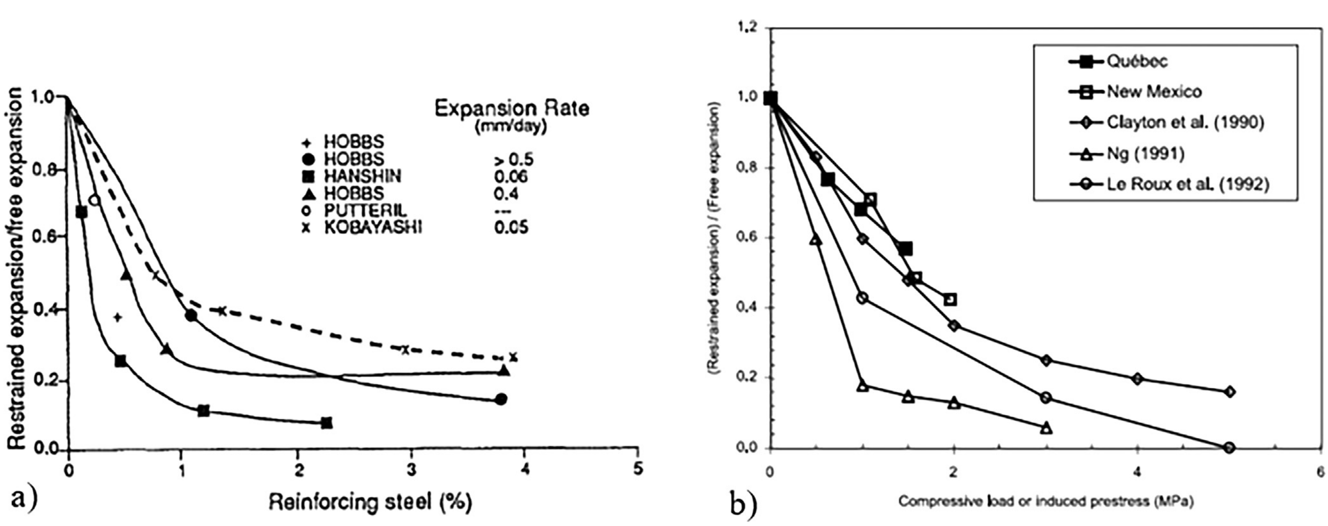

Fig. 2. (a) Effects of reinforcing steel on concrete's expansion [6] and (b) effects of confinement on the concrete's expansion [7].