Alkali-Silica Reaction in Transportation

An Online Continuing Education Course for Engineers

Course Number: C-6011

Credit: 6 Hours / 6 PDH / 6 CPD

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Premature Deterioration of Concrete Structures Due to Alkali-Silica Reaction (ASR)

1.0 Introduction

Alkali-aggregate reaction (AAR) is only one of the many factors that might be fully or partly responsible for the deterioration and premature loss in serviceability of concrete infrastructure. Two types of AAR reaction are currently recognized depending on the nature of the reactive mineral; alkali-silica reaction (ASR) involves various types of reactive silica (SiO_2) minerals and alkali-carbonate reaction (ACR) involves certain types of dolomitic rocks ($CaMg(CO_3)_2$). Both types of reaction can result in expansion and cracking of concrete elements, leading to a reduction in the service life of concrete structures (ACI 221.1R-98).

In many cases, several deleterious mechanisms will act simultaneously or consecutively, thus contributing to the damage observed; this is particularly the case in northern regions where freezing and thawing cycles will definitely contribute at increasing damage in concrete affected by other deleterious mechanisms such as AAR, sulfate attack, or others. It is consequently crucial, when assessing the cause of damage affecting a concrete structure, that every mechanism that may have contributed to the deterioration observed be considered. One should remember that an incorrect diagnosis may lead to the implementation of inappropriate/ineffective remedial actions.

Generally, it is only after a fairly extensive program of field and laboratory investigations that AAR can be confirmed as the main cause or a contributor to the deterioration observed. Such detailed investigations will likely include one or several of the following steps: 1) the survey of the presence/distribution and severity of the various defects affecting the concrete structure (especially those features diagnostic of AAR), 2) in-situ monitoring of deterioration (especially signs of expansion and deformation), and 3) a range of laboratory tests (including petrography, chemical, physical, and mechanical tests) on samples collected from one or several components of the affected concrete structure.

Visual symptoms on concrete structures affected by ASR and ACR are generally similar; i.e., evidences of expansion, relative movements between structural members showing different expansion rates, cracking. Petrographic examination generally allows differentiating ASR from ACR as deleterious expansion and cracking due to ASR relies on the formation of a secondary reaction product called *alkali-silica gel* that can generally be observed in concrete members affected by this mechanism. Since cases of ACR are generally limited and considering that the large majority if not all investigations to date related to the management of AAR-affected concrete structures have been carried out on structures affected by ASR, this course will focus only on ASR.

2.0 General Approach

The global approach proposed for the diagnosis and prognosis of ASR in transportation structures is illustrated in the flow chart in Figure 1 and briefly described hereafter; Table 1 lists and provides an appreciation of the value of the various investigation tools/activities commonly performed in the field and in the laboratory for the diagnosis and prognosis of ASR in concrete structures. The global investigation program can be divided into three levels, as described hereafter.

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2.1. ASR Investigation Program Level 1: Condition Survey

Signs of premature deterioration in concrete pavement and bridge structures that could be related to ASR can generally be detected during routine site inspections (*condition survey*) that are performed regularly by trained personnel of the State Highway Authorities (Van Dam et al. 2002). Visual symptoms of deterioration are noted and compared to those commonly observed on structures affected by ASR. If no visual signs suggestive of ASR are noted during the routine inspection program, further work is postponed until the next inspection. However, when the visual signs of deterioration observed on the structure(s) examined are such that AAR is a possibility, a "preliminary" investigation program (Level 2) is recommended to confirm the first diagnostic obtained from the visual survey.

2.2. ASR Investigation Program Level 2: Preliminary Studies for the Diagnosis of ASR

First, any documents relating to the structure and the materials used for the construction (e.g., construction files including results of AAR tests performed, reports from previous surveys/investigations on the structure, etc.), and reports on cases of ASR in the region (if any), should be gathered and reviewed. This "review of documentation" step could also be carried out in preparation for the condition survey (Investigation Level 1); as such information may assist in the appraisal of the structure.

Field activities at this *Level 2* consist in: 1) a measurement of the extent of cracking (*Cracking Index (CI) method*) on the most severely exposed/cracked sections of concrete; and 2) a "preliminary" sampling program on a selected number of elements from the concrete structure(s) examined. The quantitative assessment of the extent of cracking through the *Cracking Index*, along with the *Petrographic Examination* of the cores taken from the same affected element, is used as tools for the early detection of ASR in the concrete.

Cores are generally collected in concrete members showing visual signs of deterioration subjective of ASR and are then subjected to *petrographic examination* in the laboratory. If petrography does not confirm the presence of ASR in the concrete member examined, further investigations for other mechanisms of deterioration could be initiated, if necessary. On the other hand, when petrographic evidence of ASR is confirmed, a decision on the further steps to follow is then taken on the basis of the severity/extent of the cracking observed as follows:

- If the extent of cracking is limited (i.e., cracking index < criteria selected) and only
- limited to mild petrographic evidences of ASR are observed in the concrete, no immediate action is required; progress in deterioration will be monitored through cracking index measurements to be carried out as part of the next routine inspection survey.
- If the extent of cracking is considered "important" (i.e., the CI is > selected criteria) and definite petrographic signs of ASR are noticed, additional work may be required (i.e., ASR Investigation Program Level 3) and/or immediate remedial actions can be applied.

The decision regarding the nature and the magnitude of further actions to be taken at this stage will likely depend on factors such as the "criticality" of the structure and the extent of the damage observed. In some cases, it may be decided to limit further "technical" investigations and proceed immediately with some remedial actions such as the application of sealers and/or lithium-based products, corrections to drainage systems, etc. More details on "early-stage" remedial actions are discussed in Section 6.0. However, in the case of "critical" structures (e.g., large size highway bridges, Interstate/State concrete

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highway pavements) or when the extent of deterioration is judged significant enough to warrant further investigations, a detailed laboratory and/or in-situ investigation program may be necessary before selecting the best remedial measure to apply (ASR Investigation Program Level 3).

2.3. ASR Investigation Program Level 3: Detailed Studies for the Diagnosis/Prognosis of ASR

The ASR Investigation Program Level 3 deals with the assessment of the current condition, i.e., determination of the degree of expansion/damage reached to date, and of the trend for future deterioration of the concrete undergoing ASR expansion. Such investigations will provide critical information for the selection of the appropriate remedial actions to implement in ASR- affected concrete members/structures.

An in-situ investigation program which includes monitoring of expansion and deformation generally provides the most reliable "prognostic" for ASR-affected structural members. Considering the seasonal variations in climatic conditions that affect the progress of ASR and the differences in the reactivity levels of aggregates and other mix designs considerations (alkali contents, etc.), it is generally considered that a minimum of 2 years and ideally 3 years are required for reliable decisions on the implementation of remedial actions to be drawn from in-situ monitoring programs. A reasonable estimate of the potential for further expansion/deterioration can also be obtained through a detailed laboratory testing program. Such a program involves a series of tests on cores extracted from the concrete member / structure investigated, as listed in Table 1. In most severe cases of deterioration, an assessment of structural integrity may be required. The above investigations will provide further critical information in the selection of repair and/or mitigation strategies.

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Figure 1. Global flow chart for the evaluation and management of concrete structures for ASR.

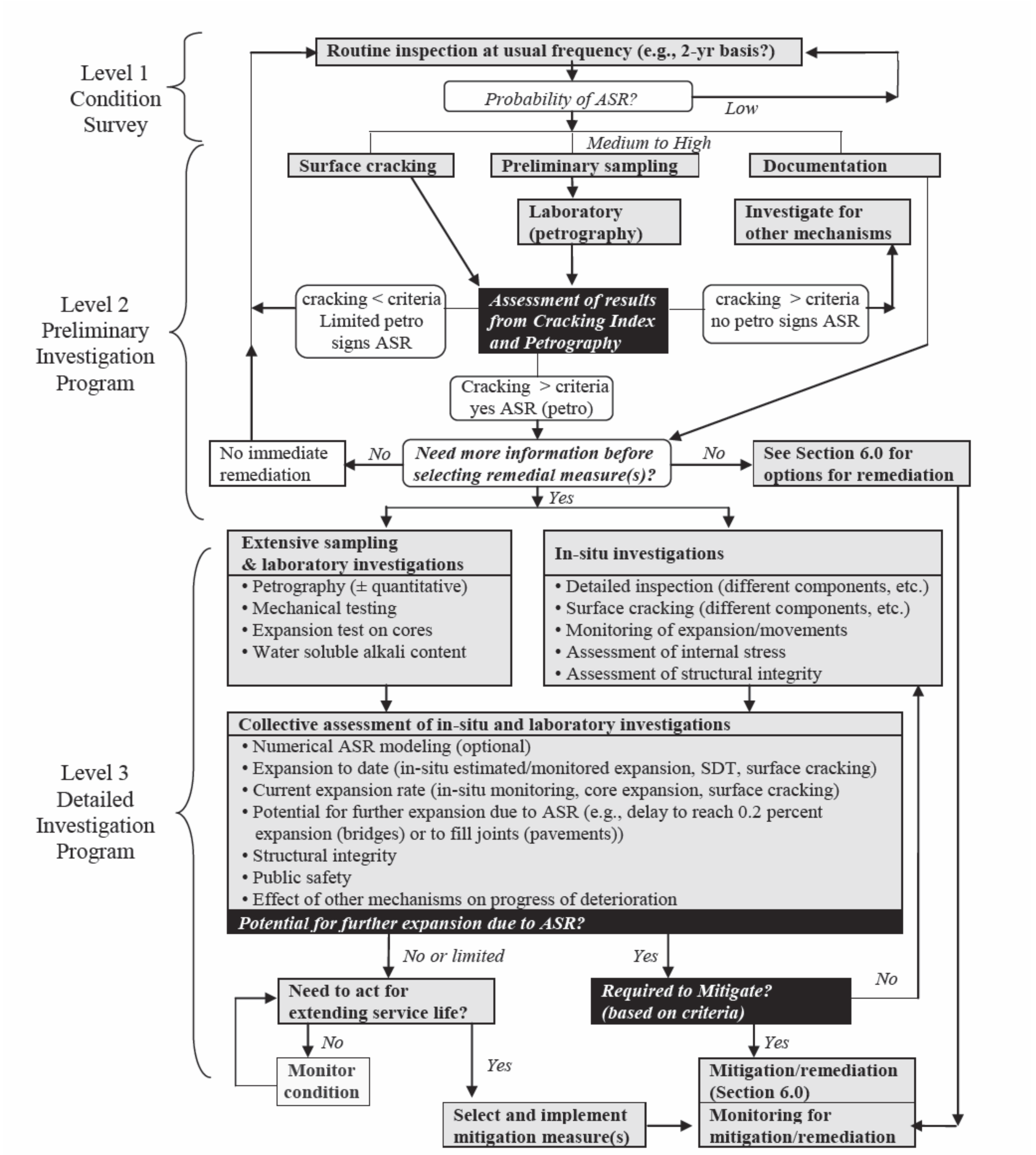

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Table 1. Investigation tools for the diagnosis and prognosis of ASR in concrete structures (Fournier et al. 2004, adapted from BCA 1992).

Test / investigation	Main Objective	Diagnosis	Prognosis
Site investigation (condition survey)	• Assess the nature and extent of distresses and deterioration, and the risks relative to structural integrity and public safety • Assess the exposure conditions • Select sites for sampling and cracking measurements	XXX	X
Documentary evidence on concrete structures investigated	Collect and review available documents relating to the design, construction, survey and mai nance of the structure(s)	XXX	X
Initial and periodic measurement of cracks (Cracking In	•	XXX	XX
Petrographic examinati			
• Macroscopic descript	es	XXX	X
• Microscopic examinat polished slabs, thin sec (impregnated or not), b pieces of concrete (pos uranyl acetate treatmen	n	XXX	X
• Quantitative petrograph analysis on polished slal		XX	X
Mechanical testing			
• Compression and splittin tensile testing		XX	
• Direct tensile strength, fl strength, and Young mod		XX	
• Stiffness Damage Test	reached to date	XXX	
Expansion test on concrete c			
• Cores at 38°C, R.H. > 95 percent	• Confirmation of deleterious expansion • Assess current rate of expansion • Assess potential for future expansion	XX	XXX
• Cores in 1N NaOH at 38°C	• Identification of reactive aggregates • Assess residual reactivity of aggregates • Assess potential for future expansion	X	XX
Determination of the water soluble alkali content of concrete	• Assess potential sources of alkalis • Assess potential for future expansion	XX	XX
Monitoring of expansion and movements	• Confirmation of deleterious expansion • Assess current rate of expansion • Assess potential for future expansion	XX	XXX
In-situ assessment of internal stresses and structural integrity	• Stresses in concrete and reinforcements • Assessment of structural damage and integrity	XX	
Numerical AAR modeling	• Confirmation of deleterious expansion • Assessment of structural damage and integrity • Forecasting future expansion and stability • Predict structural responses to remedial actions	XX	XX

X: Results could be useful if test can be done; XX: Do when possible; XXX: Important test

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