Protocol for Selecting Alkali-Silica Reaction (ASR)-Affected Structures for Lithium Treatment

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Foreword

This document describes a protocol for evaluating damaged structures to determine whether they are suitable candidates for lithium treatment to address alkali-silica reaction (ASR). A major part of this report deals with the approach/tools that can be used to determine whether ASR is the principal cause or only a contributing factor to the observed deterioration (diagnosis), determine the extent of deterioration due to ASR in the structure, and evaluate the potential for future expansion due to ASR (prognosis). Finally, the report lists items to be included in the proposal that will be submitted for the selection of structures for lithium treatment.

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Notice

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16. Abstract
This document describes a protocol for evaluating damaged structures to determine whether they are suitable candidates for lithium treatment to address alkali-silica reaction (ASR). A major part of this report deals with the approach/tools that can be used to determine whether ASR is the principal cause or only a contributing factor to the observed deterioration (diagnosis), determine the extent of deterioration due to ASR in the structure, and evaluate the potential for future expansion due to ASR (prognosis). Finally, the report lists items to be included in the proposal that will be submitted for the selection of structures for lithium treatment.

Guidelines on evaluating and managing structures affected by ASR have been published by the Canadian Standards Association (CSA).[1] Pictures of field symptoms and petrographic features of ASR can be found in the documents from CSA, the British Cement Association, the American Concrete Institute, Stark, and Farny and Kosmatka. (See references 1, 2, 3, 4, and 5.) More recently, Folliard and Kurtis summarized such features as part of the Federal Highway Administration (FHWA) workshop material "Guidelines for the Use of Lithium to Mitigate or Prevent ASR in Concrete."[6,7]

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Table of Contents

List of Tables

1. INTRODUCTION

Three conditions are necessary to initiate and sustain alkali-silica reaction (ASR) in concrete: (1) reactive siliceous phase(s) must be present in the aggregate; (2) the concentration of alkali hydroxides ([Na^+, K^+, -OH^-]) in the concrete pore fluid must be high (which is generally a function of the alkali content of the cement used); and (3) sufficient moisture must be present. Concrete elements affected by ASR respond quite differently from one another, reflecting wide variations in the above conditions, especially in the type and degree of reactivity of the aggregates used, the mixture characteristics (e.g., type and composition of cement, concrete alkali content, water/cement ratio (w/c), and use of supplementary cementing materials (SCM)), the temperature and humidity exposure conditions, and mechanical restraints.

To reliably evaluate the efficacy of lithium in treating ASR-damaged concrete structures, the structures selected for field trials must meet the following general criteria:

- ASR must be firmly established as the primary cause of deterioration. The symptoms of ASR, such as cracking and differential movement, may be caused by other processes, including freeze-thaw action, internal or external sulfate attack, corrosion of embedded steel, and even drying shrinkage. Consequently, ASR frequently has been misdiagnosed as the cause of deterioration in structures exhibiting such symptoms. Clearly, treating concrete with lithium will have little or no impact on other mechanisms of deterioration.
- Even where ASR is confirmed as the primary cause of deterioration, the action of other deterioration processes may render treatment ineffective. For example, ASR may make concrete more susceptible to freeze-thaw deterioration by producing a network of cracks that are readily filled with water and become sites of expansion when this water freezes, and through the partial filling of air voids with alkali-silica gel. Treatment with lithium may prevent or suppress further reaction of the aggregate, but will not mitigate future freeze-thaw cycles. In cases where ASR has initiated or exacerbated other deterioration processes, the action of these processes also must be addressed in the repair strategy. For example, where deicing salts are used on reinforced concrete structures, the symptoms of ASR are likely to increase the likelihood of chloride-induced corrosion of the embedded steel. If the corrosion problems are not addressed, lithium treatment of ASR will not impact the life of the structure significantly. Thus, it is necessary to determine the presence and extent of other deterioration processes and include strategies for mitigating these procedures in the overall repair procedure. If the other processes of deterioration cannot be addressed, the structure is not likely to be a suitable candidate for lithium treatment.
- Deterioration due to ASR should have reached a certain level/severity displayed by noticeable surface cracking, so that lithium penetration, at least in the case of topical treatment and vacuum impregnation, will be adequate, at least.

- There must be potential for further expansion and damage due to ASR to occur if the structure is untreated. Eventually, the reactants required for ASR, (i.e., available alkalis and reactive silica), will be depleted and the process of ASR will cease (unless there is an external source of alkalis). If there is little further potential for ASR, treatment with lithium may not be a viable or economic option. Furthermore, evaluating lithium treatment in the field requires reference to a control (untreated) section of the structure to establish the impact of the treatment. If ASR has run its course, it will not be possible to determine the effect of lithium.

2. DOCUMENTARY EVIDENCE

The first phase in the evaluation procedure is to review all documents relating to the structure. Information that may assist in the appraisal of the structure includes:

- The type and location of the structure and, hence, its likely exposure conditions due to its nature of operation and geography.
- Age of the structure and the details and dates of any modifications or repairs. ASR may take from 3 to more than 25 years to develop significantly in concrete structures, depending on the nature of the aggregates used, the moisture and temperature conditions, and the concrete alkali content.
- Plans, drawings, and specifications.
- Details of the approved concrete mixes used, particularly mix proportions, sources of cementitious materials and aggregates, and details of any analyses or tests conducted on concrete materials. The availability of samples of these materials should also be checked; some agencies store samples of cements and aggregates used in major projects.
- Previous inspection/testing reports, especially the dates when deterioration was first observed.
- Information from other structures in the area that may have been constructed with similar materials, especially if these structures are exhibiting signs of deterioration typical of ASR.

Details regarding the concrete materials, especially the composition and proportion of the cement and the type of aggregate used, are most useful when assessing the likelihood of ASR at this stage. Information of this nature often is not available or lacks specific detail in the case of many structures; however, it is important to collect whatever data is available.

3. DIAGNOSIS

The evidence from field and laboratory investigations should be compared to establish a causal link between signs of reaction in laboratory examinations and the damage observed onsite.

Site Investigation

Field inspection is a critical part of the diagnosis of ASR in concrete structures. Each major component of the structure should be examined separately, and observations of the type, extent (relative severity from one component to another and even within one component as a function of the exposure condition), and location of the defects should be recorded consistently. Examples of damage should be documented using color photographs that include an indication of scale. In addition, a sketch of the structure indicating the location of each component examined should be made. Particular attention should be paid to the following features:

- **Environmental conditions**. ASR typically develops or sustains in concrete elements with internal relative humidity greater than 80–85 percent. Expansion and cracking due to ASR is generally most severe in concrete elements or parts of structures subjected to an external supply of moisture. Surfaces of concrete elements affected by ASR and exposed to sun, moisture (wetting and drying cycles), and frost action usually show more extensive cracking and deterioration.

- **Nature and extent of cracking** (e.g., pattern cracking, preferred orientation). The pattern of cracking due to ASR is influenced by the geometry of the concrete element, the environmental conditions, the presence and the arrangement of reinforcement, and the load or stress fields applied to the concrete. Cracking usually is developed most strongly in areas of structures where the concrete has a constantly renewable supply of moisture, such as close to the waterline in piers, from the ground behind retaining walls, beneath pavements slabs, or by wick action in piers or columns.

  Map cracking often is associated with, but not exclusive to, ASR; it develops when internal expansive forces occur in concrete components that are free of stress or restraint. In pavement and slabs on grade, cracking from expansive ASR often begins near free edges and joints where moisture is abundant. The ASR cracks are usually perpendicular to transverse joints and parallel to free edges along the roadside and against asphalt pavements, where there is less restraint. These cracks often progress to a map pattern. In reinforced concrete members or under stress and loading conditions, the ASR cracking pattern generally will reflect the arrangement of the underlying steel, or travel in the direction of the major stress fields. Longitudinal cracking is often observed in reinforced concrete columns and beams affected by ASR. Surface macrocracking due to ASR rarely penetrates more than 25 to 50 millimeters (mm) of the exposed surface (in rare cases, reaching depths of more than 100 mm), where they convert into microcracks. The width of surface macrocracks generally varies from 0.1 mm to 10 mm in extreme cases.

- **Popouts**. Alkali-silica reactive aggregates that are expanding near the concrete surface may induce the detachment of a conical portion of the surface leaving the reactive aggregate in the bottom. Locating gel at the popout is a strong indication of ASR. The presence of ASR-induced popouts does not necessarily indicate that the concrete structure will expand and have map cracking or other signs of ASR distress. Popout also can be caused by freezing and thawing (e.g., clayey/argillaceous aggregates), or by low-density porous aggregates at or near the concrete surface, such as expansion of porous chert aggregate. The number, size, and location of popouts provide valuable information about the quality of aggregates in concrete.

- **Movements, displacements and deformations** (e.g., closing of joints, misalignment of adjacent components). The extent of the reaction and expansion processes due to ASR often varies throughout the volume of the concrete or within the various concrete elements or parts of the affected structure. The overall, uneven, or differential concrete swelling due to ASR may cause distresses such as relative movements, misalignment, distortion, excessive deflection, or separation of adjacent concrete members or structural units. The closure of joints, causing extrusion of jointing and sealing materials and, ultimately, spalling of concrete at expansion or construction joints is a common feature of ASR in concrete pavements.

- **Surface discoloration**. Cracks caused by ASR often are bordered by a broad brown zone, which appears to be permanently damp.

- **Surface deposits** (gel exudation versus efflorescence). Although surface gel exudation is a common and characteristic feature of ASR, the presence of surface deposits is not necessarily as indicative of ASR as are other mechanisms (such as frost action). Water that is transmitted through cracked concrete components also can cause efflorescence without the presence of ASR gel. It is good investigative practice during a site survey, however, to record the extent and location of surface deposits along with their color, texture, dampness, and hardness. A chemical analysis can help determine if ASR gel is present in the deposit.

The site investigation report should include a description of the presence, distribution, and extent (severity) of the above features on the various components of the structures, with appropriate sketches and picture records. As mentioned previously, special attention should be given to the potential correlation between the development of the above features and the specific exposure conditions affecting the different components (such as the availability of moisture, exposure to sun, wind, etc.). Canadian Standards Association (CSA) A864 classifies the occurrence of the above features obtained from the field survey of concrete structures as indications of low, medium, and high ASR probability (see table 1).[1]

Table 1. Classification System for Field Inspection[(1)]

Feature	Probability of ASR		
	Low	**Medium**	**High**
Expansion and/or displacement of elements	None	Some	Structure shows symptoms of increase in concrete volume leading to concrete spalling, displacement, and misalignment of elements
Cracking and crack pattern	None	Some cracking–pattern typical of ASR (i.e., map cracking or cracks aligned with major reinforcement or stress)	Extensive map cracking or cracking aligned with major reinforcement
Surface discoloration	None	Slight surface discoloration associated with some cracks	Line or cracks having dark discoloration with an adjacent zone of light-colored concrete
Exudations	None	White exudations around some cracks	Colorless, jelly-like exudations readily identifiable as ASR gel associated with some cracks
Environment	Dry and sheltered	Outdoor exposure but sheltered from wetting	Parts of components frequently exposed to moisture such as rain, groundwater, or water due to natural function of the structure (e.g., hydraulic dam or bridge)

Sampling

For the purposes of selecting candidate structures (and appropriate components of structures) for lithium treatment, a full, detailed investigation of the structure is required. Samples, typically 100-mm diameter cores (although other sizes may be required where large aggregate or closely spaced reinforcement requires cutting larger or smaller cores, respectively), are to be taken from the major components of the structure and/or those showing the most typical signs of deterioration. In addition, parts of a single component subjected to different exposure conditions and exhibiting different degrees of damage should be sampled. Cores should be as long as possible to provide a profile of the concrete from the surface to the interior of the element. If the original documentation or subsequent reports show that different concrete mixtures were used, then the sampling program should ensure that each mix type is adequately represented.

Laboratory Investigations

The main objectives of the laboratory investigation are:

- Diagnosis—to confirm the presence of ASR and to determine whether the apparent damage to the structure can reasonably be attributed to ASR.
- Prognosis—to predict the potential for further deterioration due to ASR.

Petrographic Examination

The cores should be examined and photographed in "as-received" condition. The following macroscopic features may assist in the diagnostic process, and their presence should be noted:

- Cracking location (i.e., at surface, around, or through aggregate particles), associated gel exudation, width, depth, etc.
- Presence of gel in voids/pores, cracks, around aggregate particles, or exuding from the core.
- Damp patches on the concrete surface.
- Reaction rims around aggregate particles.

Certain features may be highlighted by rewetting the core surfaces and making observations as the core dries. The visual examination of cores should include observations normally made on core samples, such as size and distribution of aggregate, compaction, void content, and presence and condition of reinforcement.

Polished surfaces and thin sections should be prepared from samples taken at various depths (including the surface) within the structure. When the core is taken from an area showing surface distress, the section for microscopic examination should be taken from a region of the core exhibiting damage. At depths below the original concrete surface, visible signs of deterioration may not be obvious, and suitable areas for examination may have to be chosen on the evidence of damp patches, reaction rims around aggregates, or the presence of gel on the surface of the core.

Examining polished surfaces with the naked eye and low-powered (stereo-binocular) microscopy are efficient methods for studying large areas of concrete and determining the intensity of certain macroscopical features. However, examining thin sections often is necessary to positively identify diagnostic features of ASR; these sections must be used to confirm the existence of features identified on polished surfaces.

Using polished surface and thin-section microscopy together, the information listed below may be obtained. Record the presence of these features and estimate their frequency of occurrence.

- Petrographic nature of the aggregates.
- General characterization of microcracking, including intensity, size range of cracks, apparent association with particular aggregate type, cracking in or around aggregate particles, and presence of gel or any other deposits in cracks.
- Presence of reaction and/or alteration rims around aggregate particles (note that not all reaction rims are symptomatic of deleterious ASR).
- Presence of gel or other deposits in voids.
- Sites of expansive reaction—occurrences of features that provide evidence of reaction and emanation of expansive forces, i.e., reactive aggregate particles showing cracking internally

or at the cement/aggregate interface with cracks propagating into the surrounding matrix, and cracks filled or partially filled with gel.

- Air-void parameters (determined in accordance with American Society for Testing and Materials (ASTM) C 457).
- Presence of other features that are diagnostic of other deterioration processes. Examples include the presence and distribution of sulfate phases, and gaps around aggregate particles. The presence of ettringite in cracks and voids in concrete is not unusual and does not necessarily indicate that either internal or external sulfate attack has occurred.

The uranyl-acetate treatment is a method that helps detect alkali-silica gel on polished and broken surfaces of concrete specimens; it also has been used to detect ASR gel in field structures.[4,8] By applying a uranyl-acetate solution to a surface containing the gel, the uranyl ion substitutes for alkali in the gel, thereby imparting a characteristic yellowish-green glow when viewed in the dark using short wavelength ultraviolet light. ASR gel fluoresces much brighter than cement paste due to the greater concentration of alkali and, subsequently, uranyl ion in the gel.

The uranyl-acetate treatment procedure requires experienced technicians for correct interpretation. The test does not differentiate between a harmless presence of gel or reactivity and one that is detrimental. Not all florescence indicates ASR gel. For example, some aggregates fluoresce naturally. In addition, uranyl ions can be absorbed on cement hydration products and appear as broad, faint areas of fluorescence. Neither of these conditions is an indication of ASR gel. Furthermore, positively identifying gel by this technique does not necessarily means that destructive ASR has occurred. The test is ancillary to more definitive petrographic examinations and physical tests to determine concrete expansion. The uranyl-acetate treatment procedure must not be used alone to diagnose ASR. Because of the potentially hazardous nature of the product, preparing, using, and handling the uranyl-acetate solution should be done cautiously, following appropriate health and safety procedures.

Petrographic examination of polished and thin sections is the most powerful tool in establishing whether ASR has occurred and whether the extent of the reaction is sufficient to cause the level of concrete deterioration observed onsite. If signs of damaging reaction cannot be found by such an examination, it may be reasonable to assume that ASR is not the main cause of damage, and other mechanisms should be sought. The petrographic examination must be conducted by a qualified petrographer who is experienced in examining concrete affected by ASR.

The laboratory investigation report should include a description, for the cores sampled, of the presence, distribution, and extent of the features listed previously in this document, with appropriate picture record. CSA A864 classifies the occurrence of features obtained from petrographic examination to give an overall assessment of the probability of ASR (see table 2).[1]

Table 2. Classification System for Laboratory Findings (Petrographic Examination)[1]

Probability of ASR	Nature and Extent of Features
Low	No gel present, no sites of expansive reaction, presence of other indicative features rarely found
Medium	Presence of some or all features generally consistent with ASR, such as: • Cracking and microcracking (associated with known reactive particles). • Presence of potentially reactive aggregates. • Internal fracturing of known reactive aggregate particles. • Darkening of cement paste around reactive aggregate particles, cracks or voids (“gelification”). • Presence of reaction rims around the internal periphery of reactive particles. • Presence of damp patches on core surfaces.
High	Evidence of site of expansion reaction, i.e., locations within the concrete where evidence or reaction and emanation of swelling pressure can be positively identified, and/or presence of gel in cracks and voids associated with reactive particles and readily visible to the unaided eye or under low magnification

Mechanical Testing

In addition to petrographic examination, some mechanical testing of cores can be performed; however, selecting the appropriate test methods is critical because ASR does not alter the engineering properties of concrete equally. The compressive strength generally is not sensitive to ASR until excessive expansions/cracking are reached; losses in tensile strength of 40 to 80 percent were reported, depending on the test method used and the expansion level. The tensile-to-compressive strength was found to be a good indicator of internal concrete damage due to ASR; this ratio typically varies from 0.07 to 0.11 for sound concrete, while values less than 0.06 would indicate internal damage due to ASR.[9] ASR deleteriously affects the elastic modulus of concrete, even at a low level of expansion or when compressive strength is still increasing.

Interpretation of Findings (Diagnosis)

The interpretation of the data collected from the investigation outlined here should be conducted by a professional concrete specialist with experience in evaluating concrete structures affected by ASR. CSA A864 analyzes the findings from both the site and laboratory investigations to determine the likely contribution of ASR to the overall observed deterioration (see table 3).[1]

Table 3. Diagnosis from Site and Laboratory Observations(1)

Evidence of ASR		Interpretation
Site	**Laboratory**	
Low	Low	If neither the site nor laboratory investigations produce significant evidence of ASR, the reaction can be positively eliminated as a possible cause of damage, and alternative mechanisms must be sought. The presence of considerable displacement, movement, or cracking of the structure is not sufficient to suggest ASR if neither the type of damage observed onsite nor the results of laboratory examinations are consistent with ASR.
Low	High	If the evidence from the site indicates a low probability of ASR but a high incidence of reaction observed in the laboratory, it is not possible to establish a causal link between the deterioration onsite and ASR. The most likely explanation for this result is that ASR has occurred, but the operation of other mechanisms has prevented typical manifestations of ASR in the structure. Other possible mechanisms must be sought and eliminated before ASR is implicated as the main or sole cause of damage.
High	Low	If the evidence from the site indicates a high probability of ASR, but no evidence of reaction was observed in the laboratory examination, three possibilities exist: • The sampling program excluded locations where significant reaction had occurred. • The features observed onsite, although consistent with ASR, are a result of another mechanism. • The reaction is not sufficiently advanced to reach a conclusion. A judgment must be made whether to carry out further sampling, seek the presence of alternative mechanisms, or both.
Medium	Medium	If the evidence from both the site and laboratory investigations indicates a medium probability of ASR, then it may be concluded that ASR has occurred and may be a contributory cause of damage; however, it is likely that other mechanisms exist and have contributed to the overall deterioration of the structure.
High	High	If the evidence from the site and laboratory investigations implies a medium-to-high probability of ASR, it may be concluded that ASR is at least a significant contributing cause of the damage to the structure. In the absence of any other mechanism, it may be reasonable to assume that ASR is the principal or sole cause of damage.

4. PROGNOSIS

Ideal candidate structures for lithium treatment are those for which laboratory testing or in situ monitoring indicate that potential for further expansion and damage due to ASR is significant if the structure is left untreated.

In Situ Evaluation

The most reliable method for determining the likelihood of further reaction and expansion is to instrument the structure and monitor its behavior for a period of time; the period of time required is usually at least 2 years to account for seasonal variations in measurements. This may not be practical (or desirable) in cases when a decision regarding lithium treatment must be made in a shorter timeframe.

There are several ways to monitor the rate of expansion. For example, the long-term change of length between reference points mounted on the concrete surface can be measured. The method most suitable for monitoring the expansion must be considered in each specific case. However, such observation should cover entire structural units. Crack mapping is an interesting visual tool for evaluating the progress of the expansion/deterioration. The measurements and summations of individual crack widths in concrete structures are too uncertain for this purpose, because shrinkage of the concrete between the cracks will contribute to the opening of the cracks. Measurements of crack widths may therefore give a false indication of the expansion in the concrete. Likewise, gathering sufficient data to be able to correct for the effects of variations in ambient temperature and humidity is important. Because these variations are often seasonal or more frequent, at least several years of measurements normally are necessary before definite conclusions can be reached about the rate of ASR-induced expansion in the structure.

Humidity and temperature measurements at different depths within the concrete elements can provide information that can help when interpreting seasonal fluctuations in the in situ expansion measurements.

Laboratory Evaluation

Expansion tests (usually carried out at 38 ^{o}C) on cores often are used to provide an indication of the potential for further expansion of the concrete. However, the initial volume and mass changes observed when the specimen is placed at high humidity (and temperature) may indicate the extent of ASR already in the concrete. This initial behavior should be interpreted with great caution, because it depends on factors other than ASR (e.g., moisture sensitivity of aggregates). A further complication arises from the leaching of alkalis from relatively small specimens stored at 100 percent relative humidity. This can lead to underestimating the residual potential for ASR. Indeed, cores taken from structures that clearly exhibit symptoms of continuing ASR often show little potential for further expansion in the laboratory.

It is possible to get an indication of the quantity of reactants (reactive silica and soluble alkali) remaining in the concrete separately. Expansions tests on cores immersed in alkali solution (1M NaOH at 38 ^{o}C or 80 ^{o}C has been used) can provide an indication of the amount of reactive aggregate remaining in the system. The water-soluble alkali content, on the other hand, can provide a measure of the alkalis that are still available for reaction. It is possible to combine these measurements to determine the potential for further ASR. A procedure for predicting the future risk of expansion of structures based on such measurements has been developed by Bérubé et al.[(10)]

5. SELECTION OF STRUCTURES FOR LITHIUM TREATMENT

The objective of the lithium implementation program is to evaluate the potential efficacy of lithium treatment for different types of concrete structures/elements affected by ASR in different environments (i.e., various regions across the United States), and of using various methods such as electrochemical extraction, vacuum impregnation, and topical treatment. Although specific requirements may be identified depending on the method of treatment to be used for particular affected components, ideal structures for lithium treatment will be those for which, in general:

- It has been confirmed that the structure is suffering from ASR and that the reaction is the principal cause of deterioration.
- ASR deterioration has reached a certain severity displayed by noticeable surface cracking.
- In situ or laboratory investigations indicate that there is significant potential for further expansion and damage due to ASR if the structure is left untreated.
- The nature or geometry of, or access to the affected concrete member make lithium treatment possible.
- The owner is committed to keeping the treated structure inservice for a period time to ensure and allow access to monitor the effectiveness of the treatment adequately.
- An interesting opportunity exists to evaluate the effectiveness of lithium treatment versus, or in combination with, other types of treatments.

For the purpose of selecting structures for this Federal Highway Administration-sponsored study, proponents are asked to prepare submission files reporting findings from site inspection and laboratory investigations of the proposed concrete structures in accordance with the recommendations described in this protocol. In summary, the proposal will include the following information on the candidate structure (see previous sections for detailed information):

- Basic information on the structure from existing records, including:
  - Location, construction period, type of structure, configuration, and size.
  - Exposure conditions (humidity, temperature, and other conditions (e.g., typical wind conditions, exposure to sun as a function of the components)).
  - Plans, drawings, and specifications.
  - Details and dates of any modifications or repairs.
  - Concrete mixes used (mix proportions, source of cement and aggregates, test results on the concrete materials).
  - Previous inspection/testing reports.
  - Available information from other structures in the area.
- Observations from the field survey (diagnosis):
  - Nature, distribution, and severity of deterioration/distress affecting the different components of the candidate structure(s).
  - Exposure conditions of the components examined.
- Results available from laboratory investigations (diagnosis):
  - Petrographic examination of cores (logging of cores, examination of polished slabs, broken samples, thin sections).
  - Other tests (e.g., mechanical).

- Results available from the evaluation for potential future expansion (prognosis) (if available):
  - In situ monitoring.
  - Laboratory testing on cores (e.g., expansion tests on cores, water-soluble alkalis).

Assistance can be provided to the State departments of transportation in developing the proposal, especially in the analysis of the field evidence of the ASR, the evaluation of the petrographic features of the ASR, and the mechanical testing of samples taken from candidate structures.

For additional information, contact Fred Faridazar at fred.faridazar@fhwa.dot.gov.

REFERENCES

1. Canadian Standards Association, 2000, "Guide to the Evaluation and Management of Concrete Structures Affected by Alkali-Aggregate Reaction," CSA A864-00, Canadian Standards Association, Rexdale, Ontario, Canada.

2. British Cement Association, 1992, "The Diagnosis of Alkali-Silica Reaction," (ISBN 0 7210 1369 4, British Cement Association, Telford Avenue, Crowthorne, Berks, RG11 6YS) 44 pp.

3. American Concrete Institute, 1998, "State-of-the-Art Report on Alkali-Aggregate Reactivity," ACI 221.1R-98, P.O. Box 9094, Farmington Hills, MI 48333.

4. Stark, D., 1991, "Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures," Strategic Highway Research Program, SHRP-C315-91-101, National Research Council, Washington DC, 49 pp. (Revised 2002—revised version available at http://leadstates.tamu.edu/asr/library/C315/.)

5. Farny, J.A. and Kosmatka, S.H., 1997, "Diagnosis and Control of Alkali-Aggregate Reactions in Concrete," Portland Cement Association, PCA Research and Development Serial No. 2071, Skokie, IL 60077, 24 pp.

6. Folliard, K., Thomas, M.D.A., and Kurtis, K., 2003, "Guidelines for the Use of Lithium to Mitigate or Prevent ASR in Concrete," workshop material. (Participant workshop materials available to the workshop participants.)

7. Folliard, K., Thomas, M.D.A., and Kurtis, K., 2003, "Guidelines for the Use of Lithium to Mitigate or Prevent ASR in Concrete," Federal Highway Administration, Publication No. FHWA-RD-03-047, Washington, DC, July 2003, (http://www.tfhrc.gov/pavement/pccp/pubs/03047).

8. AASHTO T299-93, 1993, "Standard Method of Test for Rapid Identification of Alkali-Silica Reaction Products in Concrete," American Association of State Highway and Transportation Officials, AASHTO T 299, 444 North Capitol Street NW, Suite 249, Washington, DC 20001.

9. Nixon, P. and Bollinghaus, R., 1985, "The Effect of Alkali-Aggregate Reaction on the Tensile and Compressive Strength of Concrete," *Durability of Building Materials*, Vol. 2, pp. 243-248.

10. Bérubé, M.A., Padneault, A., Frenette, J. and Rivest, M., 1995, "Laboratory Assessment of Potential for Future Expansion and Deterioration of Concrete Affected by Alkali-Silica Reactivity," *Proceedings CANMET/ACI International, Workshop on Alkali-Aggregate Reactions in Concrete,* Dartmouth, Nova Scotia, October 1995, pp. 267-291.

BIBLIOGRAPHY

The following references provide further information that may be useful in evaluating a concrete structure for the purposes of determining the presence and extent of ASR.

Federal Highway Administration, 2002, "Guidelines for Detection, Analysis, and Treatment of Materials-Related Distress in Concrete Pavements"

- FHWA-RD-01-163, Volume 1: Final Report.
- FHWA-RD-01-164, Volume 2: Guidelines Description and Use.
- FHWA-RD-01-165, Volume 3: Case Studies Using the Guidelines.

(Available online at http://www.tfhrc.gov/pavement/pccp/pubs/01163ab.htm.)

Federal Highway Administration, 1997, "Petrographic Methods of Examining Hardened Concrete: A Petrographic Manual," FHWA-RD-97-146 (available online at http://www.tfhrc.gov/pavement/pccp/petro.htm).

Guthrie, G.G. Jr. and Carey, J.W., 1997, "A Simple, Environmentally Friendly, and Chemically Specific Method for the Identification and Evaluation of the Alkali-Silica Reaction," *Cement and Concrete Research*, Vol. 27, No. 9, pp. 1407-1417.

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