Recent developments in the prevention and mitigation of AAR in concrete

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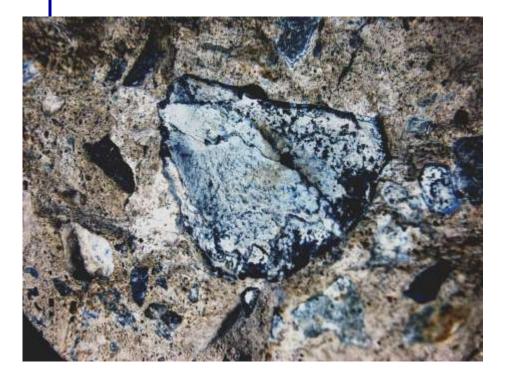


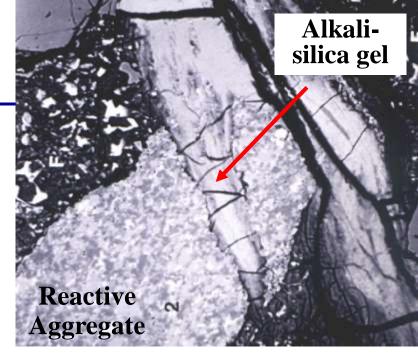
Outline of the Presentation

- Alkali-silica versus alkali-carbonate reactions
- Review of recent developments in International Standard developing committees
 - ASTM (USA)
 - Canadian Standards
 - RILEM TC 191-ARP
 - ACI Committee 201
- FHWA Protocol A Determining the reactivity of concrete Aggregates and selecting appropriate measures for preventing deleterious expansion in new concrete construction → AASHTO Designation: PP 65-10
- FHWA Protocol B Diagnosis and prognosis of alkaliaggregate reaction (AAR) in transportation structures

Alkali-Silica Reaction

- Most common form of AAR
- Reaction between concrete pore fluid and <u>siliceous phases</u> from aggregates → alkali-silica gel







Alkali-Silica Reaction

• Internal expansion forces → cracking and distress of concrete





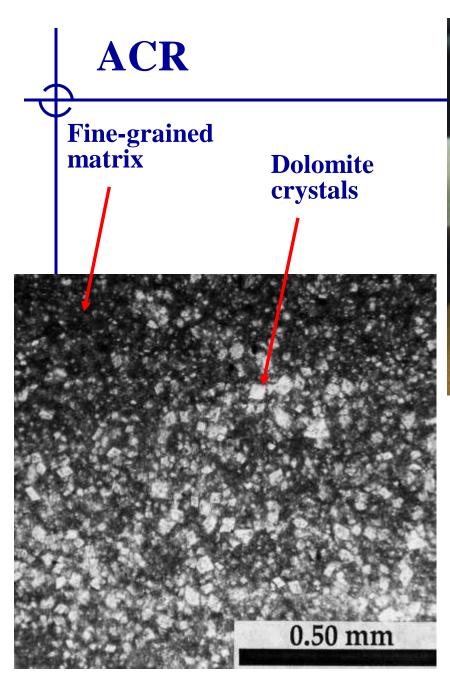


- <u>Limited</u> cases from Canada, USA, China, Austria
- "Classical" ACR in Canada: argillaceous dolomitic limestone



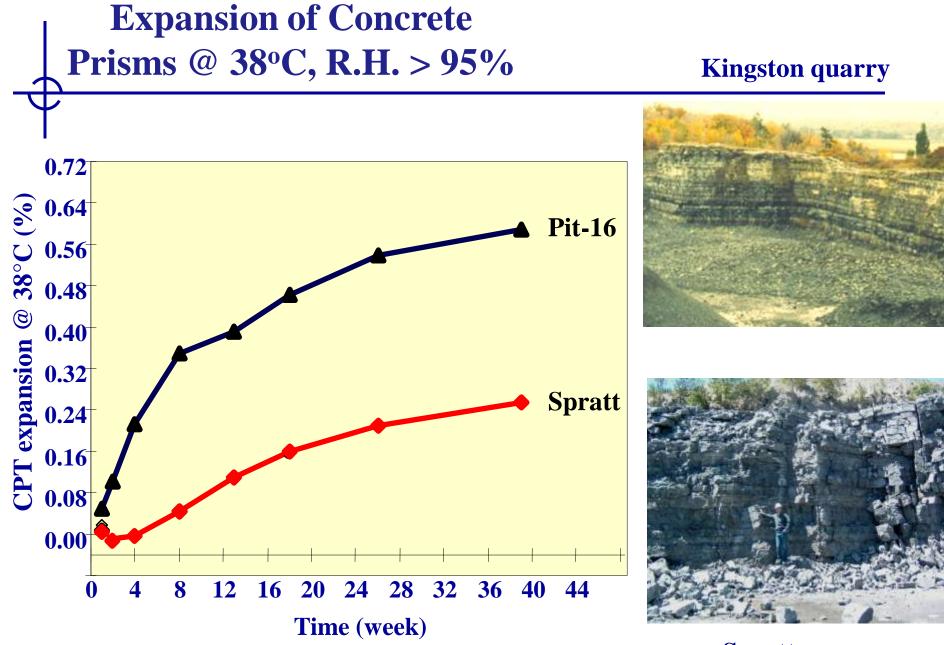




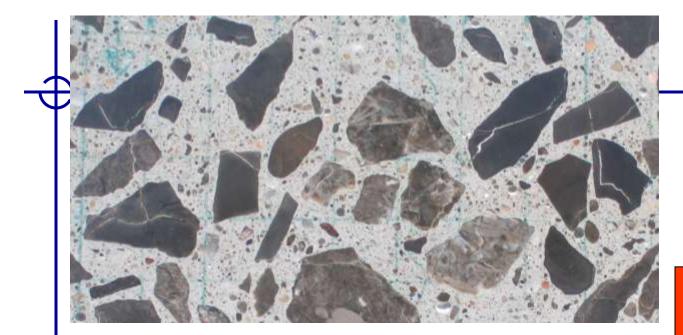




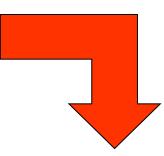
Typical petrographic texture: dolomite crystals (10-50 μm) disseminated in a fine-grained matrix of calcite and clay minerals



Spratt quarry



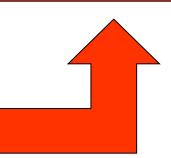
Concrete Prism Test



Expansion : ~ 0.20-0.25%

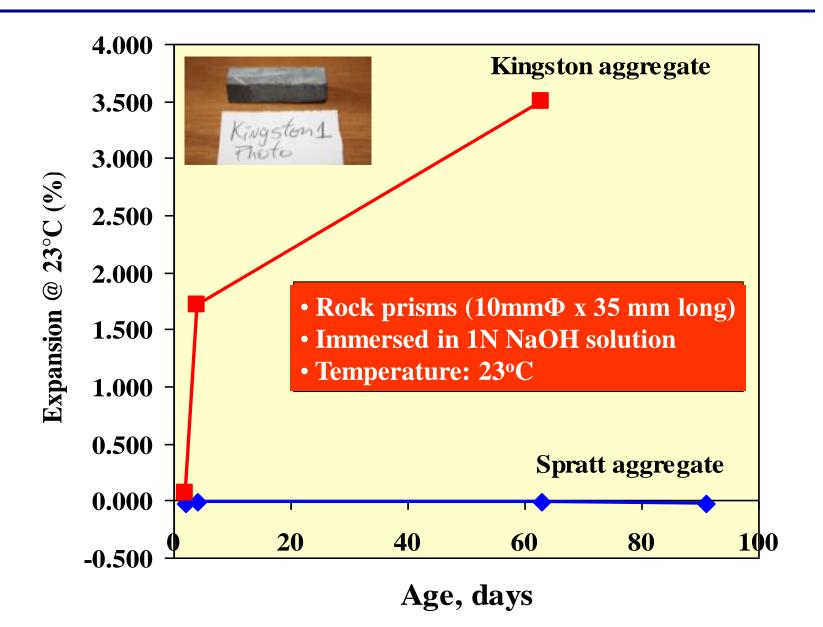
Spratt Limestone (Canada)

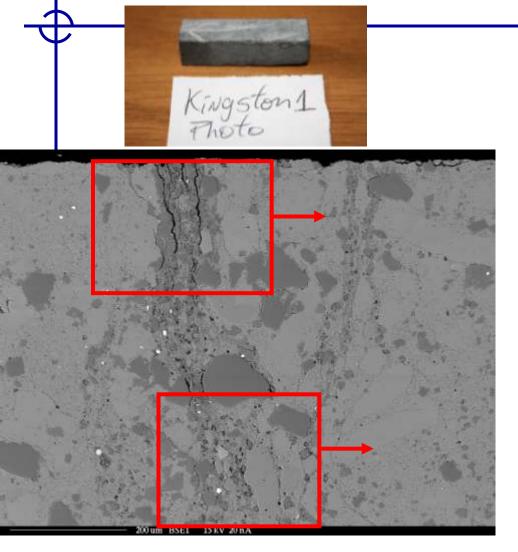




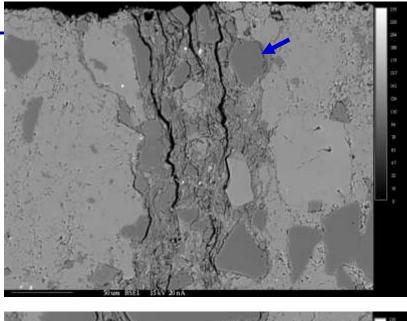
Kingston Limestone (Canada)

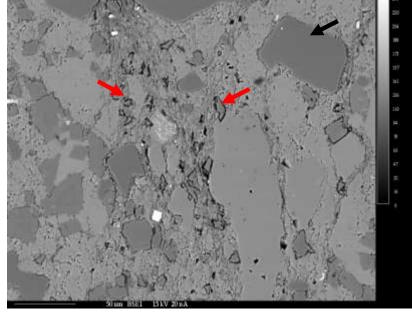
Rock Cylinder Test (ASTM C 586)





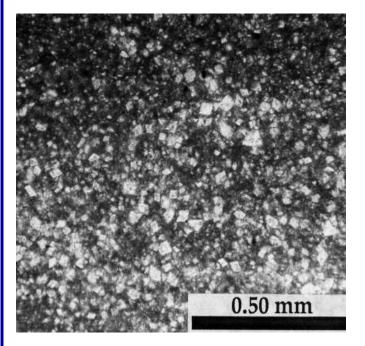
- Dolomite grains experiencing dedolomitizationK-feldpar grains
- **Quartz grains**

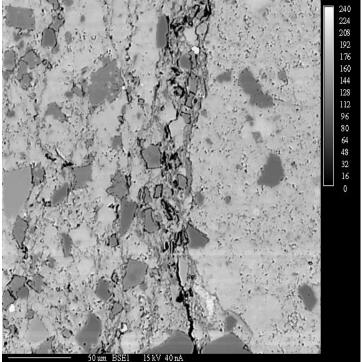




Mechanisms still not well understood

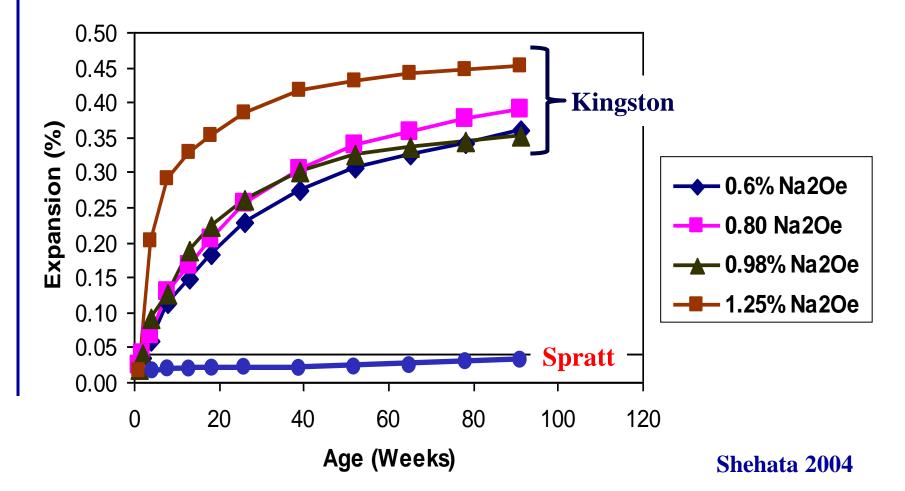
- Dedolomitization process:
 - $CaMg (CO_3)_2 + 2Na(K)OH \rightarrow Mg(OH)_2 + CaCO_3 + Na(K)_2CO_3$





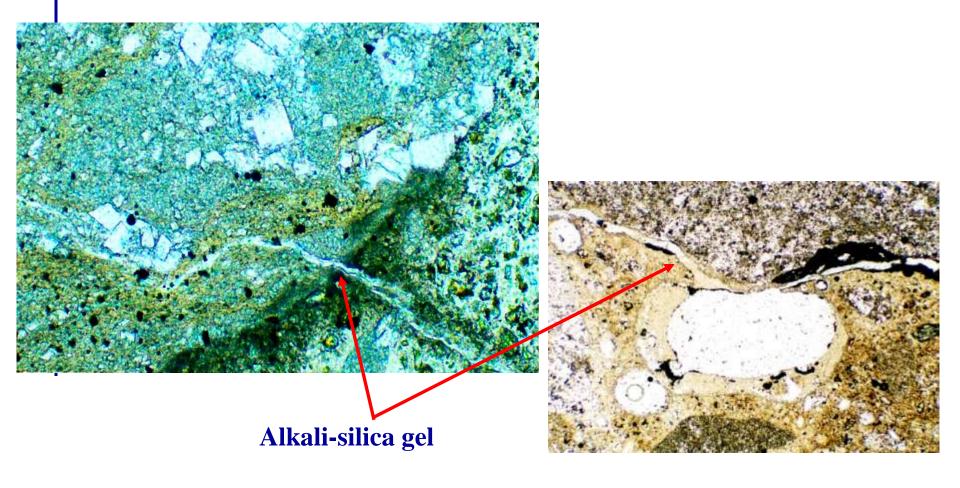
• Recycling of alkalis $Na(K)_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2Na(K) OH$

Expansion of concrete prisms vs concrete alkali content



Mechanisms still not well understood

• Katayama (2000's) : ACR is a form of ASR !!



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ASTM (USA)

• ASTM C 33 → "Concrete aggregates ... shall not contain any materials that are deleteriously reactive with the alkalis in the cement in an amount sufficient to cause excessive expansion of mortar or concrete".

	Purpose		Type of test				Type of reaction	
Test			Other Expansion					
Method	Potential reactivity	Preventive measures	Chemical	Rock	Mortar	Concrete	ASR	ACR
C 289	X		X				X	
C 586	X			X				X
C 227	X				X		X	
C 1260	X				X		X	
C 1105	X					X		X
C 1293	X					X	X	X
C 441		X			X		X	
C 1567		X			X		X	

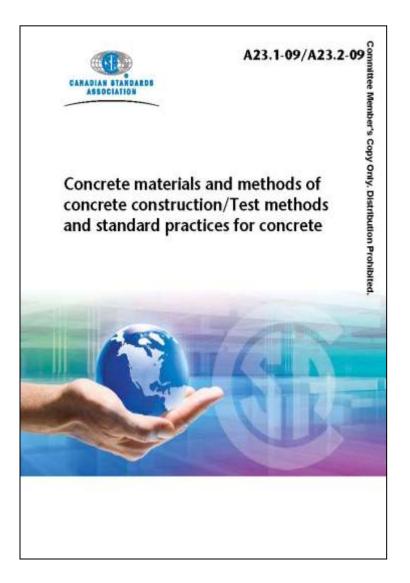
ASTM (USA)

- June 2010 → Joint C09/C01 technical subcommittee (C01/C09-50) was formed to develop new global requirements for the *Risk Management of Alkali-Aggregate Reactions*.
- This new subcommittee will start its activities in 2010.

CSA A 23.1 & A23.2 on AAR (Canada)

AAR-related specifications

- CSA A23.1 → general specifications for concrete materials
- CSA A23.2 → Four test methods and two standard practices to detect and prevent AAR



A23.1 – Appendix B (Informative)

- General
- Types of AAR
- Test methods for evaluating potential reactivity of aggregates
- Potentially-reactive aggregates across Canada
- Measures to prevent AAR in concrete
- Reactivity of reclaimed concrete for use as recycled aggregate
- Summary

5 Canadian Standard Association	Concrete materials and without of concrete construction
Annex B (informative)	
Alkali-aggregate read	ction
Aikan-aggregate read	ction -
Note: This Annor is not a manufatory part of this 5	tenderi
B.1 General	
setain rock types and a concrete agregation and present marking in the hydrautic senset. For alkali-aggregate reactivity to occur, then the concrete, and adhibition maisture in the well-defend crack pattern. The reack pattern of pattern-occurring (rein Figure 12.1). Other of Dataking in the concrete and the resultant of eventre aggregater can produce tacks with one of the second second second second second Dataking in the concrete and the resultant of the second second second second second second Dataking and the second second second second the second second second second second second the second second second second second the second second second second second second second second second second second in the second second second second second is to target section can be leaded of the second in 56 second second second second second second second second second second second	ionation occurs due to a reaction between some minerals in ward the iolohies alkaline components in the concrete that. This phenomenon is known as alkal-aggregate reaction, erman the reactive materials in the aggregate, sufficient alkali e comments to support the concrete characterized by a in commonly identified of "many cracking" or eterioration in generally slow, although nome externely in a leveryeast. With time, skalar aggregate reactions, to eterioration mechanisms can also cause pattern-cracking, territoritori in generally slow, although nome externely in a leveryeast. With time, skalar aggregate reaction is an ever etericoration mechanisms components. eter conservation is almost nonexistent (Hawki and Meleriz, terite components almost nonexistent (Hawki and Meleriz, terite components is almost nonexistent (Hawki and Meleriz, terite components almost nonexistent (Hawki and Meleriz, terite components almost nonexistent (Hawki and Meleriz, terite about the acceleration of determentation that to other crite should be avoided. This Annes provides general adhres ment for this objective. A useful general adhress non- tion almost adhress to almost components.
не панафилали и велику солония поло	ина алексу алестно оу акан-адрукула текстол.
B.2 Types of alkali-aggre	gate reaction
8.2.1 General	
fwo types of alkal-appropriate reaction are e	rezuntereil in Canada:
 alkal-slica reactor; and alkal-carbonate reaction; 	
Note: The mechanisms of these opportable random	n are not clearly understand. The allost sitica maction is analogical with to (Disamond, 1989). Alloali carbonate reaction is called by the Fig.
8.2.2 Alkali-silica reaction	
skal-slica reaction is divided into two catego	contain various forms of reactive silica. For conversience, the pories according to the type of reactive silica involved (see
tir artificial glasses (see Category (x) in	
 tipal, tridymlin, tristabelite, and b acid, intermediate, and basic volca 	
 (A) accel internetione, and pace voice (A) artificial glazami. 	ent gannet and
	sals might cause deterioration of concrete when the reactive

CSA A23.2 Test Methods

• Clause 4.2.3.5.1 (AAR) states that : "Aggregate for use in concrete shall not react with alkalis contained within the concrete to an extent that results in excessive expansion or cracking, or both, of the concrete. When potentially reactive aggregates are to be considered for use, preventive measures acceptable to the owner shall be applied"

	Purpose		Type of test				Type of		
	lest thod	est		Other	Expansion			reaction	
IVIE	Method Potential reactivity	Preventive measures	Chemical	Petro	Mortar	Concrete	ASR	ACR	
1	5A	Χ			X			X	X
2	6A	Х		X					X
2	5A	X	X			X		X	
1	4 A	Х	X				X	X	X

CSA Standard Practice A23.2-27A

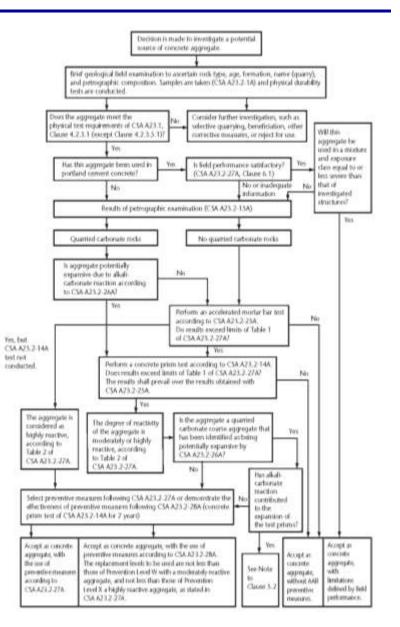
- Backbone of CSA specifications on AAR
- Step-by-step procedure for:
 - 1) determining potential alkalireactivity of aggregates, and
 - 2) selecting preventive measures against ASR using a risk analysis → prescriptive approach

0 Canadae Manilesh Associative	Test methods and standard practices for converse
A23.2-27A	
measures to avoid del	identify degree of gregates and to identify leterious expansion in
concrete	
1 Scope	
	or the determination of the degree of aliasi-silica reactivity cture size and environment, the level of provention related tion of the appropriate preventive measures.
1.2 This Standard Practice describes the determinal eaction and provides advice on appropriate pr	tun of the potential for deleterious alkal-carbonate eventive measures.
	ites and does not apply to recycled concrete used as Novax 8 of CSA A21.1 for more information on the apgregate (RCA)).
1.4 The leasts of prevention determined following is concrete incorporating effect portland cement	the procedure described in Circuit 6 are applicable for or portained kinestone content.
2 Reference publications	
CSA (Canadian Standards Association) A23.1-09 Concrete materials and methods of concrete cons	nuclion
A23.2-1A-00 Geographics aggregate for ane in concrete	
AZI 2-14A-09 Potential expansivity of aggregates (procedure fo prime at 18 °C)	length shange due to alkal-aggingate reaction in concrete
823.2-158-09 Netrographic examination of aggregates	
A23.2-254-09 Test method for detection of alkali-alica mactive s	sgargate by accelerated expansion of mortar bars
A23.2-264-09 Determination of potential alkal-carbonate react	why of quartiesf conformate rocks by chemical composition
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CSA Standard Practice A23.2-27A

Flow chart

Process for determining potential alkali-aggregate reactivity of concrete aggregates and use of preventive measures



CSA Standard Practice A23.2-28A

 Laboratory testing to demonstrate the effectiveness of SCMs and chemical admixtures to prevent ASR in concrete





© Canadian Standards Association

Test methods and standard practices for concrete

A23.2-28A

Standard practice for laboratory testing to demonstrate the effectiveness of supplementary cementing materials and lithium-based admixtures to prevent alkali-silica reaction in concrete

1 Scope

This Standard Practice describes the procedures to be followed to demonstrate the effectiveness of supplementary concerning materials and Effium-based administrates or combination thereof, in preventing excessive experision caused by aikali-silica reaction. The supplementary cementing materials are as defined in CSA A3001.

2 Reference publications

CSA (Canadian Standards Association) A23.1-09 Concrete materials and methods of concrete construction

A23.2-1A-09 Sampling aggregate for use in concrete

A21.2744.09 Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete primum at 3^{+} C)

A23.2-25A-09 Text method for detection of alkali-alica reactive aggregate by accelerated expansion of montar bars

A23.2-2274-09 Standard practice to identify degree of alkali-seachivity of aggregates and to identify measures to avoid deleterisus expansion in concrete

A3001-08 Cementitious materials for use in concrete

A3004-08 Test methods for cementitious materials for use in concrete and maponry

ASTM International (American Society for Testing and Materials) C 494/C 494M-04 Standard Specification for Chemical Admintunes for Concrete

3 Definitions

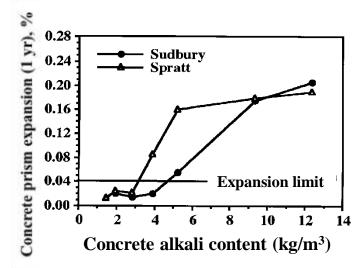
In addition to the definitions in Clause 3 of CSA A23.1, the definitions of CSA A3001 apply in this Standard Practice.

549 2009

RILEM TC 191-ARP

Activities → assessment of the potential alkali-reactivity of aggregates and of particular mixture combinations

- Petrographic Examination (AAR-1) → ACR & ASR
- Accelerated Mortar Bar Test (AAR-2) → ASR
- Concrete Prism Test (38°C test procedure)(AAR-3) → ACR & ASR
 - 3.1: Evaluation of the reactivity of an aggregate combination;
 - 3.2: Determination of the alkali threshold of a particular aggregate combination (<u>applicability under review</u>);



RILEM TC 191-ARP

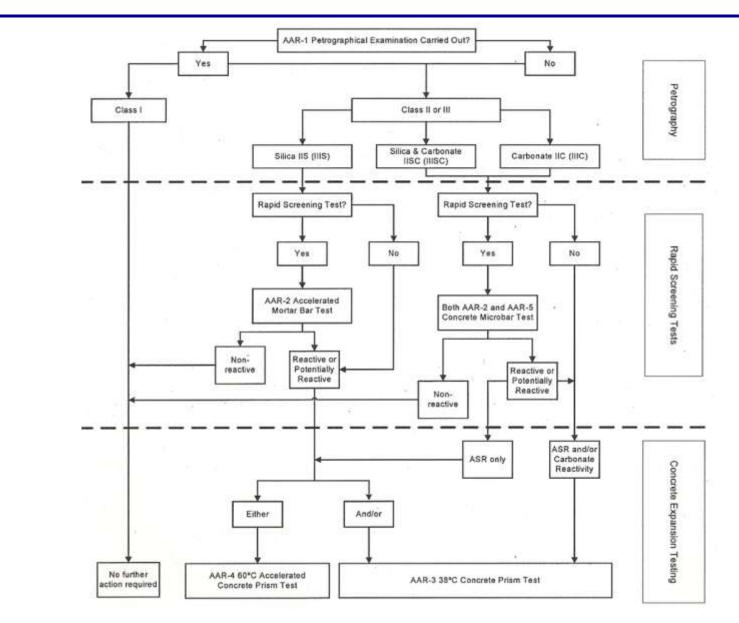
Concentrates its activities on the assessment of the potential alkalireactivity of aggregates and of particular mixture combinations

- Accelerated CPT (60°C)(<u>applications under development</u>);
 - 4.1: Rapid evaluation of reactivity of aggregate combination;
 - 4.2: Performance test for particular concrete mixtures;
- Carbonate Aggregate Testing (AAR-5) → accelerated screening test for aggregates incorporating <u>carbonate</u> material.





RILEM → Global approach AAR-0



RILEM TC 191-ARP

Guidance & specifications on other AAR-related topics:

- AAR-6.1: Diagnosis and appraisal of AAR damage to concrete in structures
- AAR-6.2: Appraisal and repair of AAR-affected structures
- Minimise damage from ASR (AAR-7.1) and from alkali reactions in carbonate aggregates (AAR 7.2)
- AAR-8: Releasable alkali content of aggregates

ACI Committee 201

Revising ACI 201.2R-08 - *Guide to Durable Concrete*

- technical information on:
 - ASR and ACR
 - AAR test methods & recommendations for use (or not !)
 - Preventive measures against ASR and laboratory test methods
 - Managing AAR-affected concrete structures

FHWA – Protocol for Preventing ASR

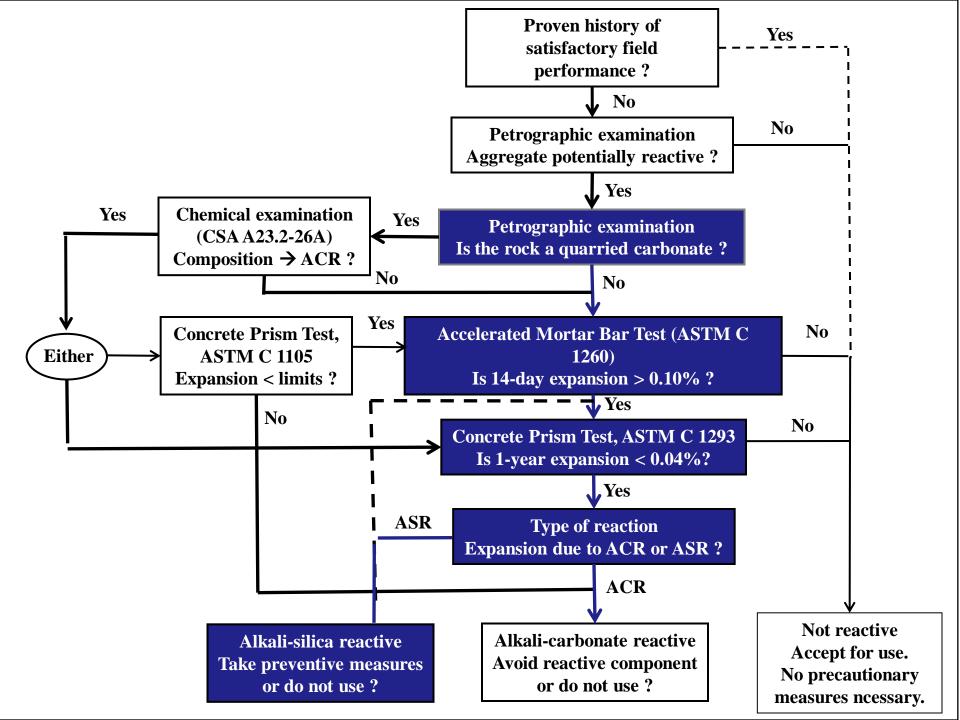
Thomas, Fournier & Folliard, 2008 → FHWA-HIF-09-001

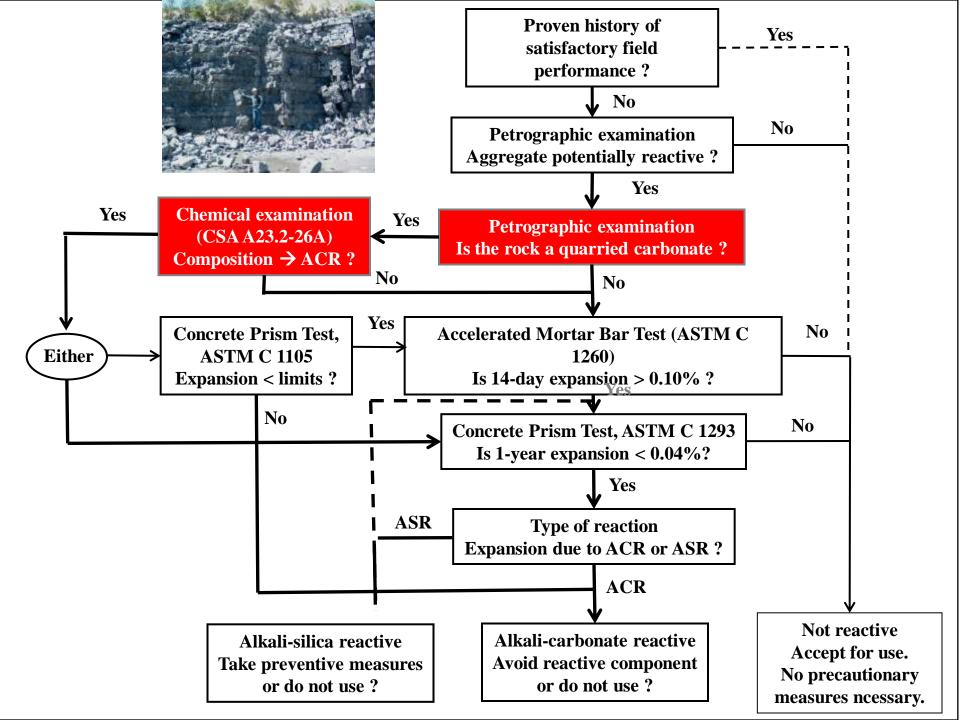
Document developed under the SAFETEA-LU legislation → develop and deploy techniques to prevent and mitigate ASR in concrete

AASHTO Designation PP65-10

Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

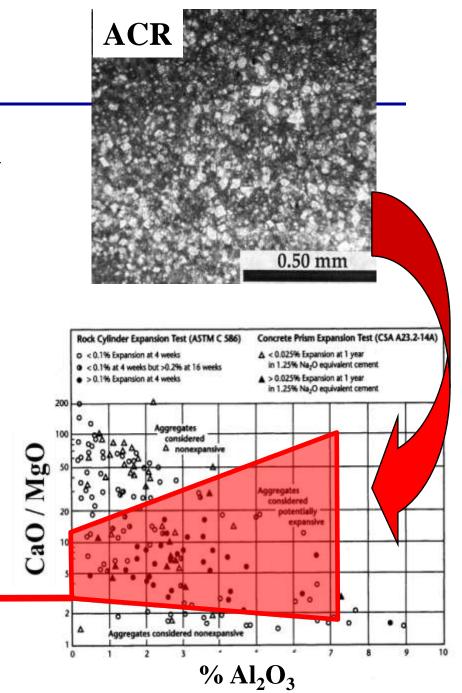


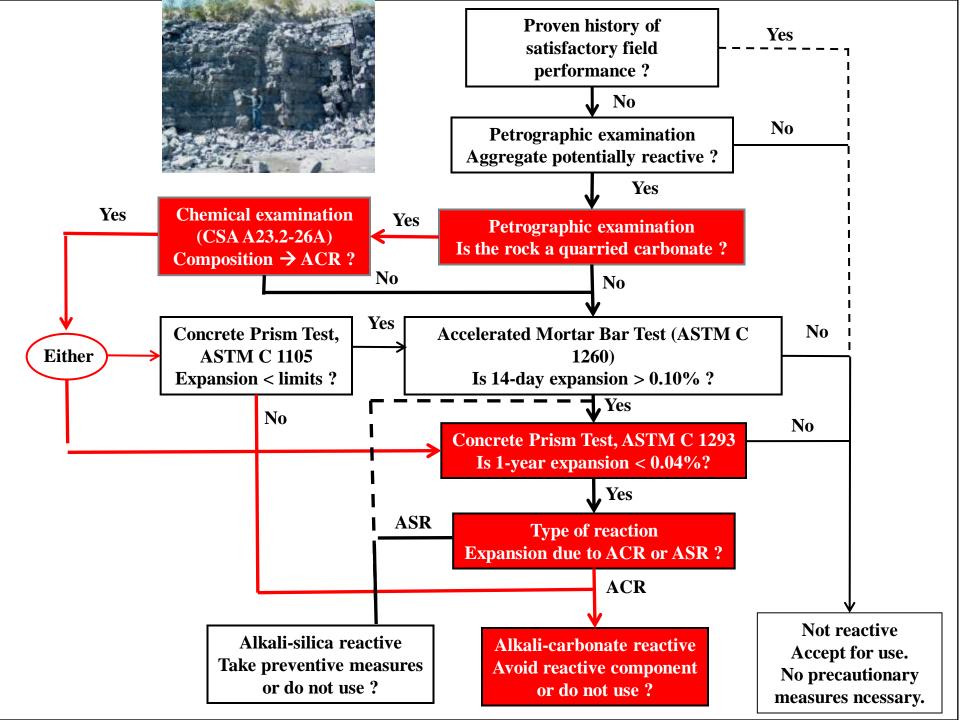




Chemical Method for ACR (A23.2-26A)

- Screen test for quarried carbonate rocks
- Chemical analysis for Al₂O₃, MgO and CaO
- Zones for aggregates considered potentially expansives or non-expansives (ACR)
- Next step → <u>Concrete</u> <u>Prism Test</u>





Alkali-Carbonate Reaction (ACR)

Slab 3 50 and

75% slag

Ontario Ministry of tranportation site (25 years)

FHWA – Protocol for Preventing ASR

Similar documents

- CSA A23.2-27A
- RILEM TC-219 ACS -International Specification to minimise damage from alkali reactions in concrete
 - 7.1 ASR
 - 7.2 AAR in carbonate aggregates

	A South Provinsi Australia Statement Provinsi Australia Specific Provinsi P				
	A21.2-27A				
	Standard practice to identify degree of				
	alkali-reactivity of aggregates and to identify				
	measures to avoid deleterious expansion in				
	concrete				
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AASHTO Standard Recommended Practice

Scope → This practice describes approaches for:

- Selecting preventive measures against AAR
 - Performance approach
 - Prescriptive approach \rightarrow risk analysis
 - Reactivity of the aggregate
 - Nature of the structure (includes. design life)
 - Exposure conditions

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Step 1 – Determine Aggregate Reactivity

Aggregate- Reactivity Class	Description of aggregate reactivity	One-Year Expansion in CPT (%)	14-day Expansion in AMBT (%)
R0	Non-reactive	< 0.040	≤ 0.10
R1	Moderately reactive	0.040 - 0.120	$0.10 > Exp \le 0.30$
R2	Highly reactive	0.120 - 0.240	$0.30 > Exp \le 0.45$
R3	Very highly reactive	> 0.240	> 0.45

Step 2 – Determine Risk Level of ASR $(1 \rightarrow 6)$

Size and ownegung conditions	Aggregate-Reactivity Class							
Size and exposure conditions	R0 R1		R2	R3				
Non-massive concrete in a dry environment	Level 1	Level 1	Level 2	Level 3				
Massive elements in a dry environment	Level 1	Level 2	Level 3	Level 4				
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5				
All concrete exposed to alkalis in service	Level 1	Level 4	Level 5	Level 6				

Step 3 – Determine the Level of Prevention ($V \rightarrow ZZ$)

Level of ASR	Classification of Structure (Table 4)						
Risk (Table 4)	S1 S2		S 3	S 4			
Risk Level 1	V	V	V	V			
Risk Level 2	V	V	W	X			
Risk Level 3	V	W	X	Y			
Risk Level 4	W	X	Y	Z			
Risk Level 5	X	Y	Z	ZZ			
Risk Level 6	Y	Z	ZZ	††			

^{††} It is not permitted to construct a Class S4 structure (see Table 1) when the risk of ASR is level 6. Measures must be taken to reduce the level of risk in these circumstances.

Step 4 – Classify Structure \rightarrow based on the severity of the consequences should ASR occur

Class	Consequences of ASR	Acceptability of ASR	Examples ^{††}
S1	Safety, economic or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	 Non-load-bearing elements inside buildings Temporary structures (e.g. < 5 years)
S2	Some safety, economic or environmental consequences if major deterioration	Moderate risk of ASR is acceptable	 Sidewalks, curbs and gutters Service-life < 40 years

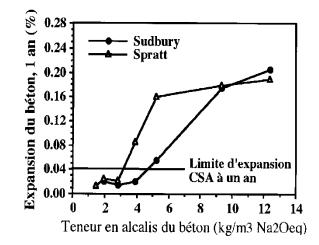
Step 4 – Classify Structure \rightarrow based on the severity of the consequences should ASR occur

Class	Consequences of ASR	Acceptability of ASR	Examples ^{††}
S3	Significant safety, economic or environmental consequences if minor damage	Minor risk of ASR acceptable	 Pavements Culverts Highway barriers Rural, low-volume bridges Large numbers of precast elements where economic costs of replacement are severe Service life normally 40 to 75 years
S4	Serious safety, economic or environmental consequences if minor damage	ASR cannot be tolerated	 Major bridges Tunnels Critical elements that are very difficult to inspect or repair Service life normally > 75 years

Step 5 – Select Preventive Measure → <u>always 3 options</u>

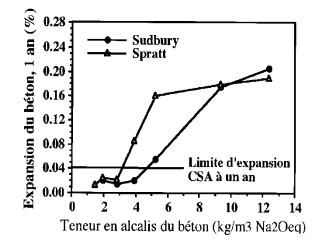
Step 5 – Select Preventive Measure → <u>always 3 options</u>

Limit Alkali Content of Concrete



Step 5 – Select Preventive Measure $\rightarrow always 3 options$

- Limit Alkali Content of Concrete
- Use Supplementary Cementing Material (SCM) or lithium-based admixtures





Step 5 – Select Preventive Measure $\rightarrow always 3 options$

- Limit Alkali Content of Concrete
- Use Supplementary Cementing Material (SCM) or lithium-based admixtures
- Reject the aggregate

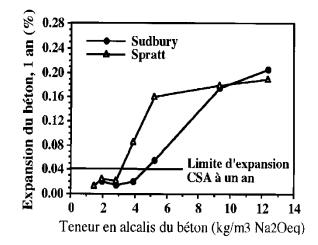






Table 5 Maximum Alkali Contents (from PortlandCement) to Provide Various Levels of Prevention

Prevention Level	Maximum alkali content of concrete (Na ₂ Oe), kg/m ³
V	No limit
W	3.0
X	2.4
Y	1.8
Ζ	Table 9
ZZ	Table 8

Concrete alkali content (kg/m³, Na₂Oeq)

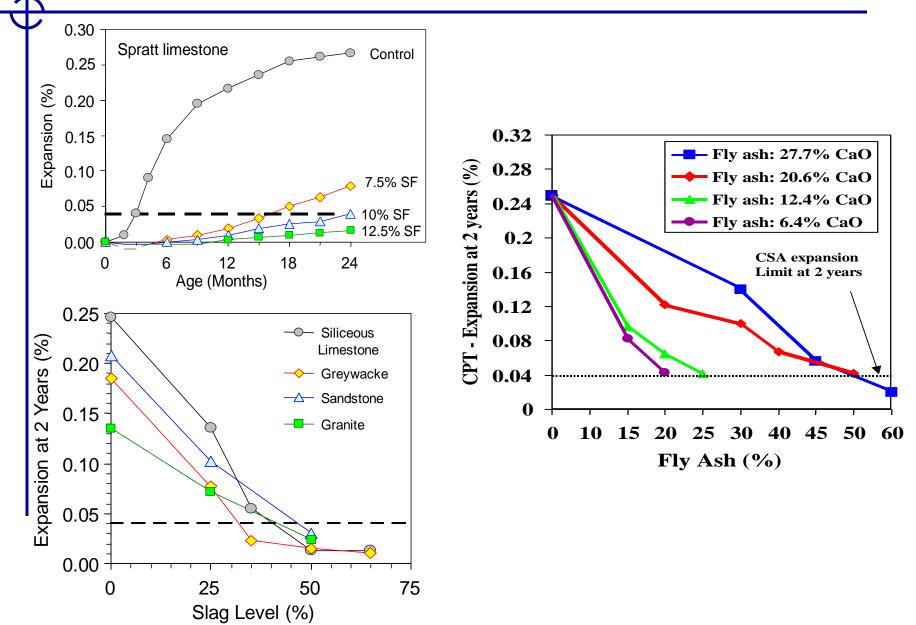
Prevention Level	Maximum alkali content of concrete (Na ₂ Oe), kg/m ³
V	No limit
W	3.0
X	2.4
Y	1.8
Z	Table 8
ZZ	Table 8

Cement	Cement alkali content (% Na ₂ Oeq)									
content (kg/m ³)	0.5	0.6	0.7	0.8	0.9	1.0	1.1			
(8,)		Concrete alkali content (kg/m ³ Na ₂ Oeq)								
225	1.1	1.4	1.6	1.8	2.0	2.3	2.5			
250	1.3	1.5	1.8	2.0	2.3	2.5	2.8			
275	1.4	1.7	1.9	2.2	2.5	2.8	3.0			
300	1.5	1.8	2.1	2.4	2.7	3.0	3.3			
325	1.6	2.0	2.3	2.6	2.9	3.3	3.6			
350	1.8	2.1	2.5	2.8	3.2	3.5	3.9			
375	1.9	2.3	2.6	3.0	3.4	3.8	4.1			
400	2.0	2.4	2.8	3.2	3.6	4.0	4.4			

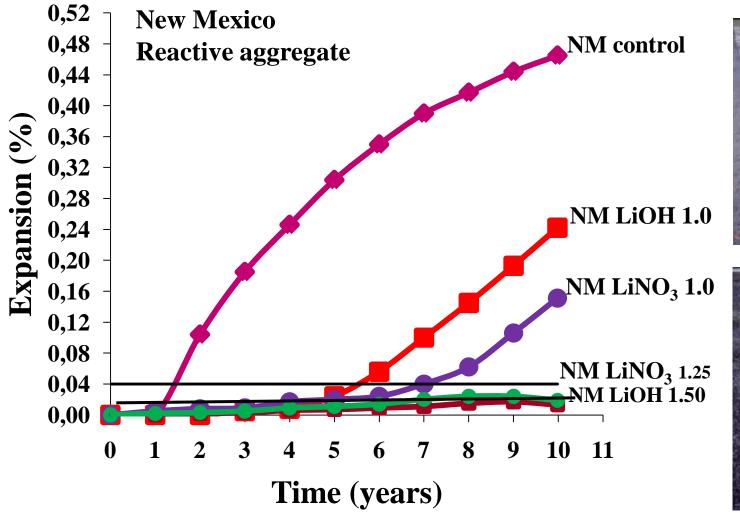
Table 6: Minimum Levels of SCM to ProvideVarious Levels of Prevention

	Alkali level of	Willing Replacement Level (70 by mass)						
Type of SCM		Level W	Level X	Level Y	Level Z	Level ZZ		
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	< 3.0	15	20	25	35			
	3.0 – 4.5	20	25	30	40			
Slag	< 1.0	25	35	50	65	Table 8		
Silica Fume [†] (SiO ₂ > 85%)	< 1.0	2.0 x KGA	2.5 x KGA	3.0 x KGA	4.0 x KGA			

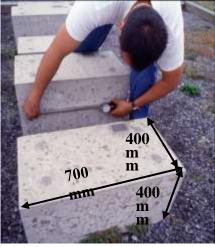
Laboratory testing



Exposure blocks







Field performance of concrete structures

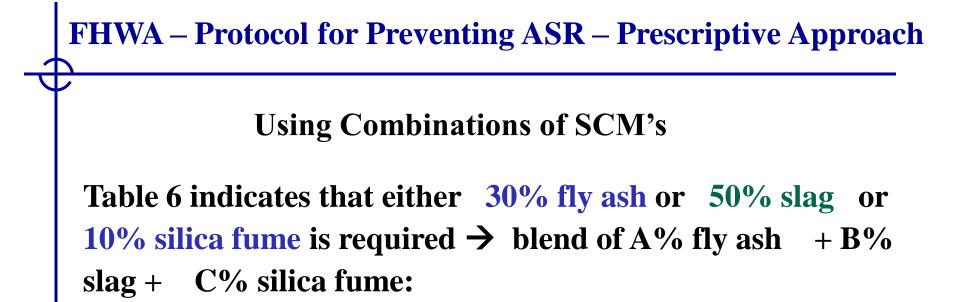
• Lower Notch dam (Northern Ontario, Canada)



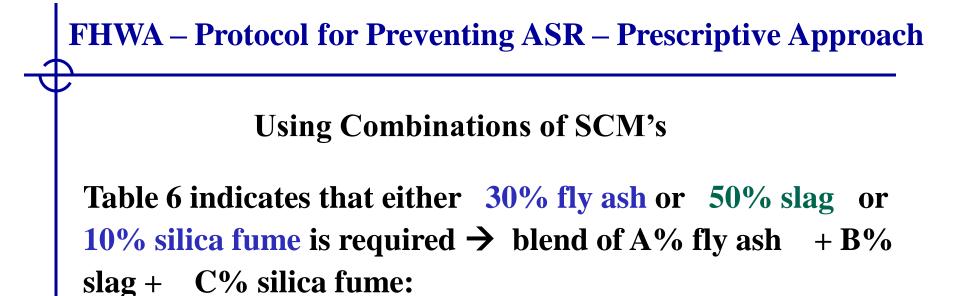
High-alkali cement + 30% Class F FA

Table 6: Minimum Levels of SCM to ProvideVarious Levels of Prevention

	Alkali level of	Willing Replacement Level (70 by mass)						
Type of SCM		Level W	Level X	Level Y	Level Z	Level ZZ		
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	< 3.0	15	20	25	35			
	3.0 – 4.5	20	25	30	40			
Slag	< 1.0	25	35	50	65	Table 8		
Silica Fume [†] (SiO ₂ > 85%)	< 1.0	2.0 x KGA	2.5 x KGA	3.0 x KGA	4.0 x KGA			



$$\frac{A}{30} + \frac{B}{50} + \frac{C}{10} \ge 1$$



 $\frac{A}{30} + \frac{B}{50} + \frac{C}{10} \ge 1$

 Table 7: Adjusting Minimum SCM Level Based on Cement Alkalis

Cement Alkalis (% Na ₂ Oe)	Level of SCM
< 0.70	Reduce the minimum amount of SCM given in Table 6 by one prevention level
0.70 to 1.00	Use minimum SCM levels in Table 6
> 1.00	Increase the minimum amount of SCM given in Table 6 by one prevention level
> 1.25	No guidance is given

ASR – Pres	ASR – Prescriptive Approach				Cement Alkalis (% Na ₂ Oe)		Level of SCM		
				<	< 0.70	-	duce the minim CM given in Ta preventior	ble 6 by one	
Table 6: Min	nimum Lev	vels		0.7	0 to 1.00	Use r	ninimum SCM	levels in Table	
of SCM to Provide Various Levels of Prevention							Increase the minimum amount o SCM given in Table 6 by one prevention level		
				>	> 1.25		No guidance	is given	
	Alkali level of	Mir	nimum 1	n Replacement Level (% by mass)				ass)	
Type of SCM	SCM (% Na ₂ Oe)	Level W	el W Level X		Level	Y	Level Z	Level ZZ	
Fly ash	< 3.0	15	20		25		35		
$(CaO \le 18\%)$ 3.0 – 4		20	25		30		40		
Slag	< 1.0	25	35 2.5 x KGA		50 3.0 x KGA		65	Table 8	
Silica Fume [†] (SiO ₂ > 85%)	< 1.0	2.0 x KGA					4.0 x KGA		

ASR – Pres	SR – Prescriptive Approach				Cement Alkalis (% Na ₂ Oe)		Level of SCM		
				<	< 0.70		educe the minim SCM given in Ta prevention	ble 6 by one	
Table 6: Minimum Levelsof SCM to Provide VariousLevels of Prevention				0.7	0 to 1.00	Use	minimum SCM	levels in Table	
				> 1.00		Increase the minimum amount of SCM given in Table 6 by one prevention level			
				>	> 1.25		No guidance	is given	
	Alkali level of	Min	imum	Repla	acement	Lev	vel (% by m	nass)	
Type of SCM	$\frac{SCM}{(\%)}$ Na ₂ Oe)	Level W	Level X		Level	Y	Level Z	Level Z	
Fly ash	< 3.0	15	20		25		35		
(CaO $\leq 18\%$) 3.0 – 4.5		20	25		30		40		
Slag	< 1.0	25	35		50		65	Table 8	
Silica Fume [†] (SiO ₂ > 85%)	< 1.0	2.0 x KGA	2.5	x 3.0 x A KGA			4.0 x KGA		

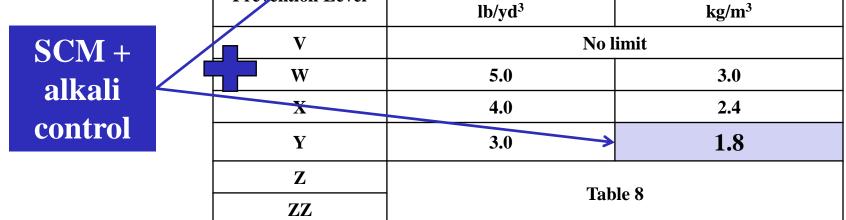
ASR – Prescriptive Approach				Cement Alkalis (% Na ₂ Oe)			Level of SCM	
					< 0.70	-	duce the minim CM given in Ta preventior	ble 6 by one
Table 6: Minimum Levelsof SCM to Provide VariousLevels of Prevention				0.7	0.70 to 1.00 Use		Jse minimum SCM levels in Table 6	
				:	> 1.00Increase the minimum amo SCM given in Table 6 by prevention level		ble 6 by one	
				2	> 1.25		No guidance	is given
	Alkali level of	Mir	imum 1	m Replacement Level (% by mass)				nass)
Type of SCM	$\frac{SCM}{(\%)}$ Na ₂ Oe)	Level W	Leve		Level	Y	Level Z	Level ZZ
Fly ash	< 3.0	15	20		25		35	
(CaO ≤ 18%)	3.0 – 4.5	20	25		30		40	
Slag	< 1.0	25	35		50		65	Table 8
Silica Fume [†] (SiO ₂ > 85%)	< 1.0	2.0 x KGA	2.5 KG		3.0 x KGA		4.0 x KGA	

Table 8: Using SCM and Limiting the Alkali Content of the
Concrete to Provide Exceptional Levels of Prevention

Prevention	SCM as sole prevention	Limiting concrete alkali content <u>plus</u> SCM				
Level	Minimum SCM level					
Z	SCM level shown for Level Z in Table 6	1.8	SCM level shown for Level Y in Table 6			
ZZ	Not permitted	1.8	SCM level shown for Level Z in Table 6			

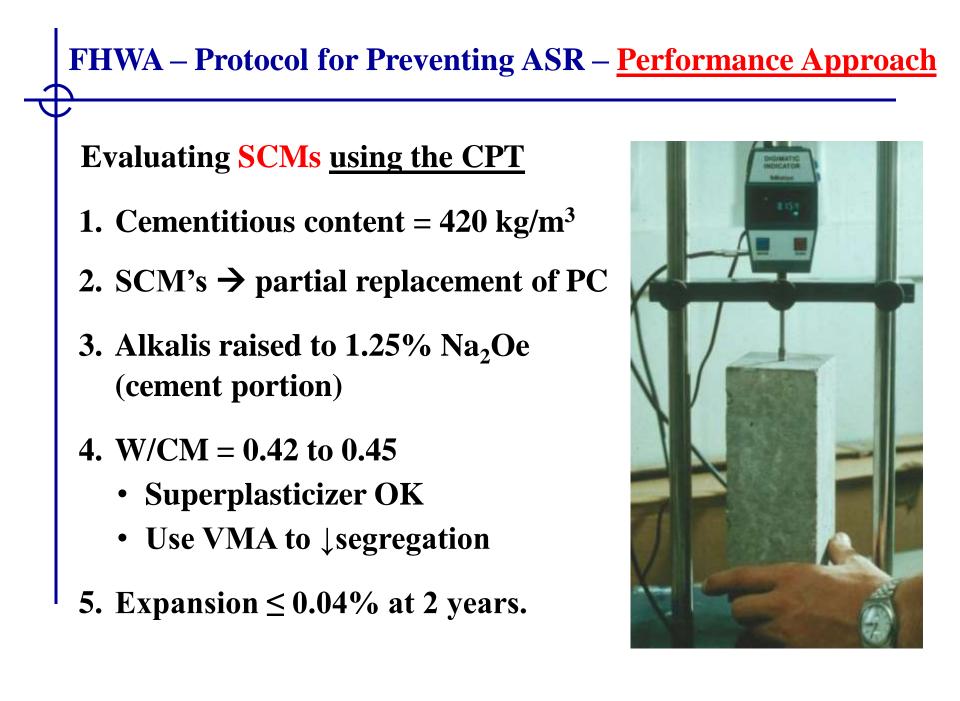
Selecting Preventive level Z

	Alkali	Minimum Replacement Level (% by mass)						
Type of SCM	level of SCM (% Na ₂ Oe)	Level W	Level X	Level Y	Level Z	Level ZZ		
Fly ash	< 3.0	15	20	25	35	R.		
(CaO ≤ 18%)	3.0 – 4.5	20	25	30	40	SCM		
Slag	< 1.0	25	35	50	65	only		
	Drow	rention Level	Maxim	um alkali cont	ent of concrete			
Preve		ention Level		/vd ³	ka	/m ³		



Selecting Preventive level ZZ

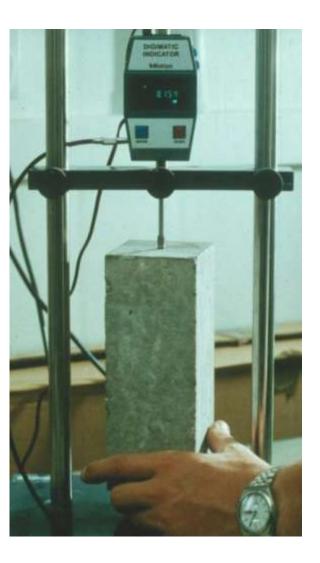
	Type of SCM Alkali SCM (% Na ₂ Oe)		Minimum Replacement Level (% by mass)					
Type of SCM			Level W	Level X	Level Y	Level Z	Level ZZ	
Fly ash	< 3.0 3.0 - 4.5		15	20	25	35	No !	
$(CaO \le 18\%)$			20	25	30	40		
Slag	< 1.0		25	35	50	65	SCM	
		r					only	
		D		Maximum alkali content of concrete (Na ₂ Oe)				
		Prev	vention Level	lb/yd ³		kg/m ³		
SCM +		V		No limit				
alkali			W	5.0		3.0		
		X			4.0		2.4	
control			Y	3.0		1.8		
			Z		Table 9			
		ZZ		Table 8				

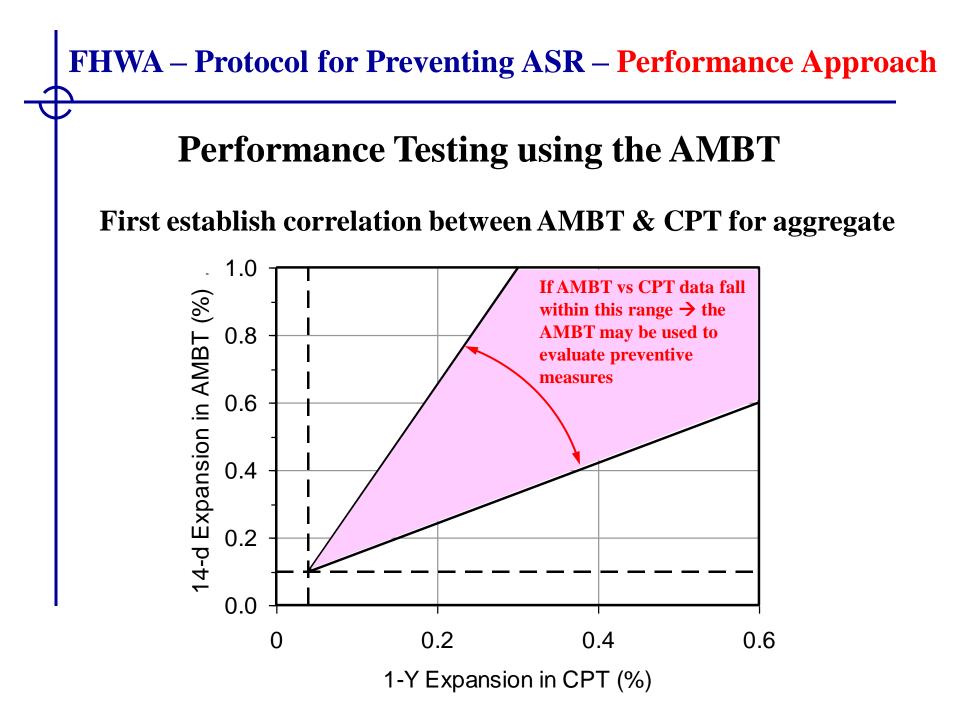


FHWA – Protocol for Preventing ASR – <u>Performance Approach</u>

Evaluating LiNO₃ using the CPT

- **1. Same mix proportions as for SCMs**
- 2. LiNO₃ solution added to mix water at various levels
- 3. Expansion $\leq 0.04\%$ at 2 years.





FHWA – Protocol for Preventing ASR – Performance Approach

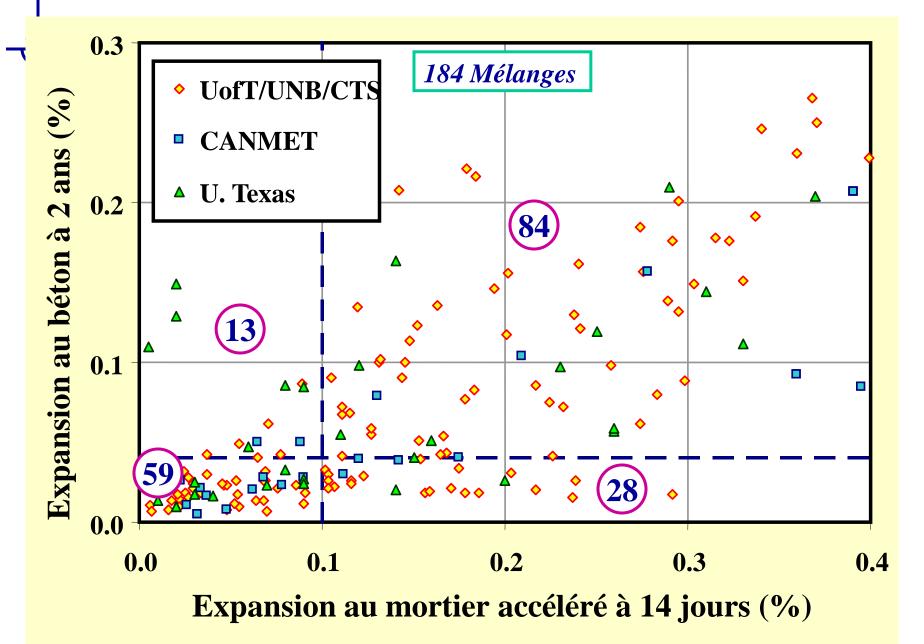
Performance Testing using the AMBT

Evaluating <u>SCM's</u> using the AMBT

- 1. Use ASTM C 1567 except that the portland cement alkalis should be $0.90 \pm 0.10\%$ Na₂Oe
- 2. Do not use this test if fly ash alkalis > 4.5% Na₂Oe or alkali content of other SCM's > 1.0% Na₂Oe
- **3. Expansion < 0.10% at 14 days**



14 jours mortier vs. 2 ans béton

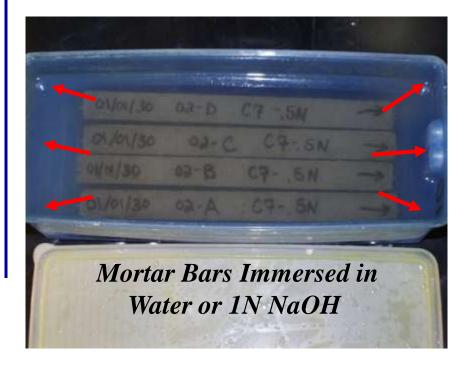


Accelerated testing for lithium dosage

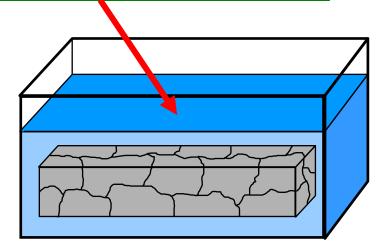
CPT is the preferred test \rightarrow <u>2-year</u>, 0.04% exp limit)

Modified version of AMBT

- Lithium to be added in the bar and the soak solution
- Expansion limit ?? (~ 0.10% @ 28 days)

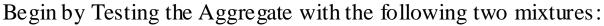


To control leaching, ASTM C 1260 is modified by adding Li to the soak solution

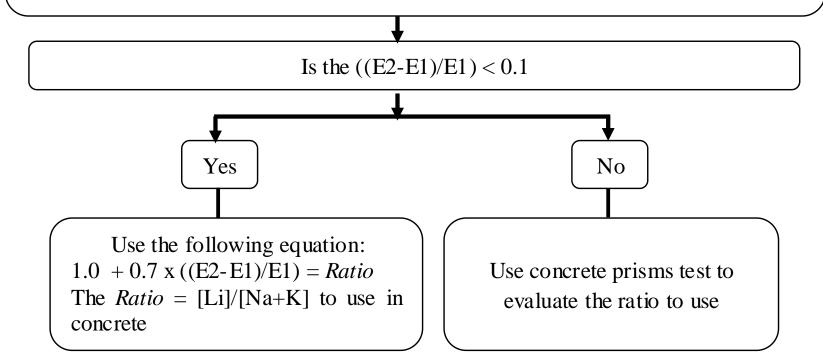


FHWA – Protocol for Preventing ASR – Performance Approach

Performance Testing using the AMBT \rightarrow LiNO₃



- **1.** Control mixture (Expansion at 28 days = E1)
- 2. Mixture with lithium: [Li]/[Na+K] = 0.74 in bar and [Li]/[Na]=0.148 in soak solution (Expansion at 28 days = E2)



Tremblay et al. 2008

FHWA Protocol B

ASR Testing and Evaluation Protocols

Diagnosis and Prognosis of Alkali-Aggregate Reaction (AAR) in Transportation Structures

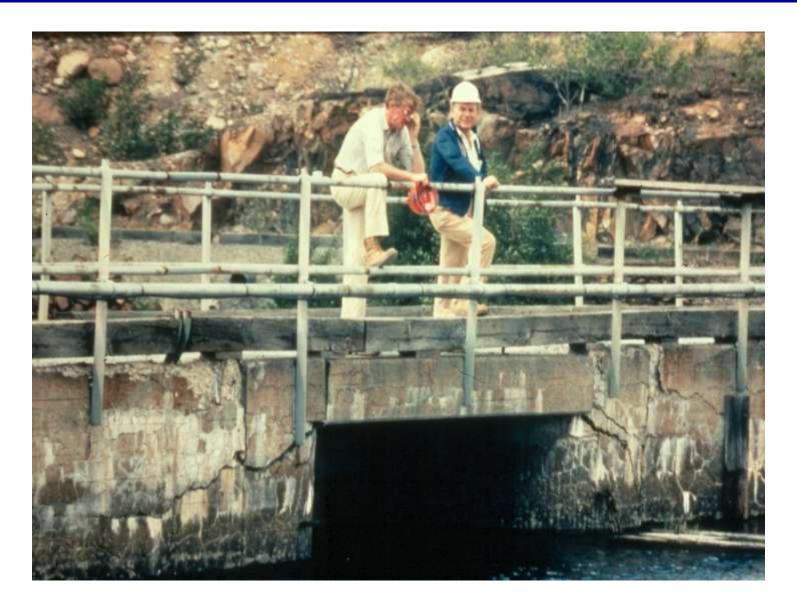
> Benoit Fournier Marc-André Bérubé Michael Thomas Kevin Folliard

The Transtec Group

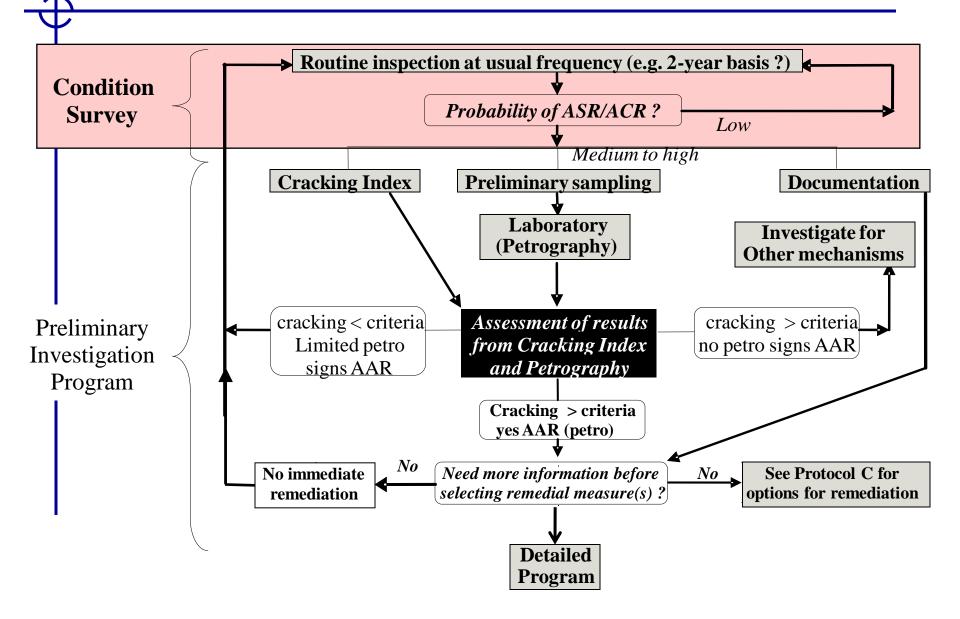




How and When to Repair AAR-affected Concrete Structure???



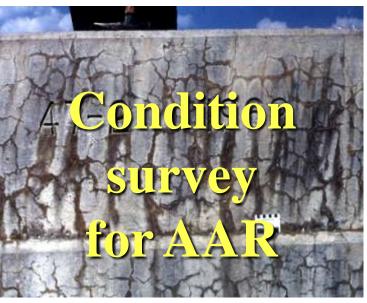
Global Approach

















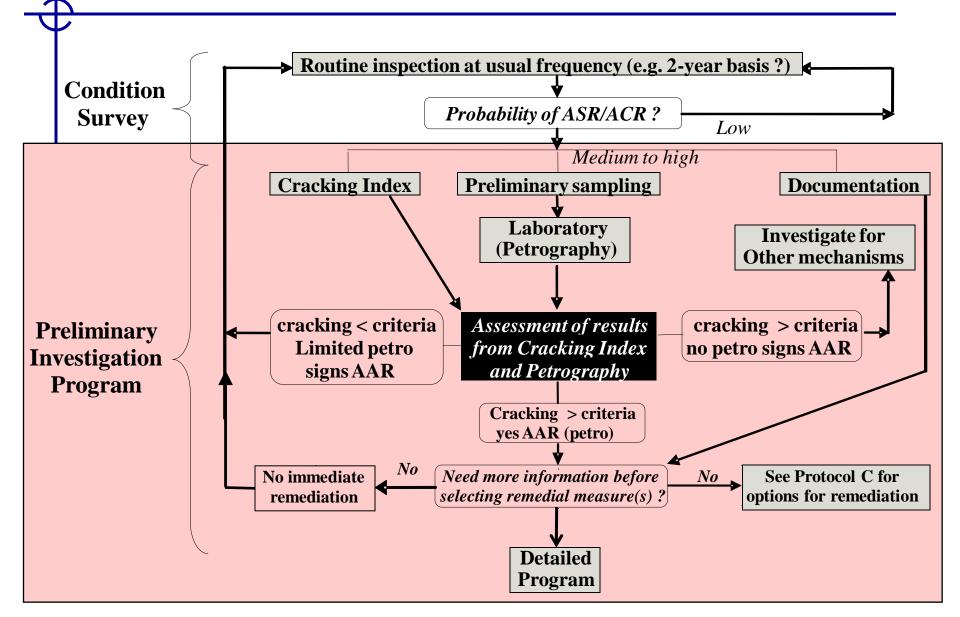


Classification System for the Condition Survey

Feature		Probability	of AAR
	Low	Medium	High
Expansion and/or displacement of elements	None	Some evidence (e.g. closure of joints in pavements, jersey barriers, spalls, misalignments between structural members)	Fair to extensive signs of volume increase leading to spalling at joints, displacement and/or misalignment of structural elements
Cracking and crack pattern	None	Some cracking pattern typical of AAR (e.g. map cracking or cracks aligned with major reinforcement or stress)	Extensive map cracking or cracking aligned with major stress or reinforcement
Surface discoloration	None	Slight surface discoloration associated with some cracks	Many cracks with dark discoloration and adjacent zone of light colored concrete
Exudations	None	White exudations around some cracks; possibility of colorless, jelly-like exudations	Colorless, jelly-like exudations readily identifiable as ASR gel associated with several cracks

Probability of AAR \(\circ) with \(\circ) exposure to moisture \)

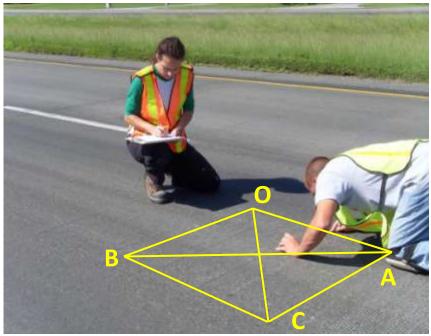
Global Approach

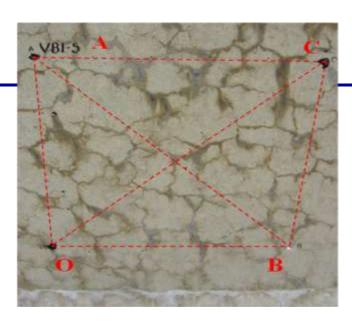


Cracking Index

- Measurement and summation of crack widths along a set of lines
- Lines on the most severely cracked structural components (moisture and severe conditions)









Cracking Index

	1	2	3	4	5	Base	#	C	brack ope	ning (mr	n)
						Length (m)	cracks				
Interval	6	7	8	9	10			Total	Avg.	Avg.	C.I.
								sum	/crack	/m	mm/m
OA	0.1, 0.1	0.2			0.6	0.5	6	1.8	0.3	3.6	
0A	0.4			0.4		0.5	0	1.0	0.5	5.0	3.2
BC	0.1	0.4		0.1	0.1	0.5	7	1.4	0.2	2.8	
DC		0.3	0.2	0.2		0.5	7	1.7	0.2	2.0	
			0.3, 0.5	0.4	0.3						
OB	0.4	0.3			0.6	0.5	7	2.8	0.4	5.6	
	0.5	0.2			0.3						4.6
AC	0.05	0.05	0.1, 0.2		0.2	0.5	8	1.6	0.2	3.6	

Preliminary Sampling Program

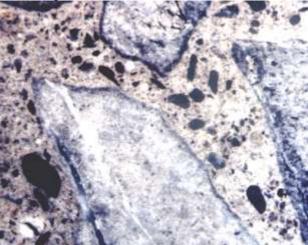
- Look for petrographic evidence of AAR
- Cores from components showing typical / more severe signs suggestive of AAR
- Cores from less deteriorated / exposed components



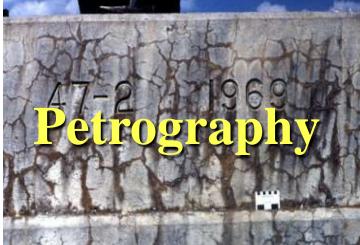






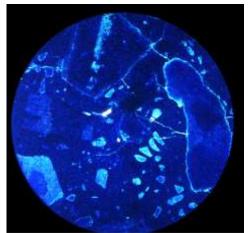








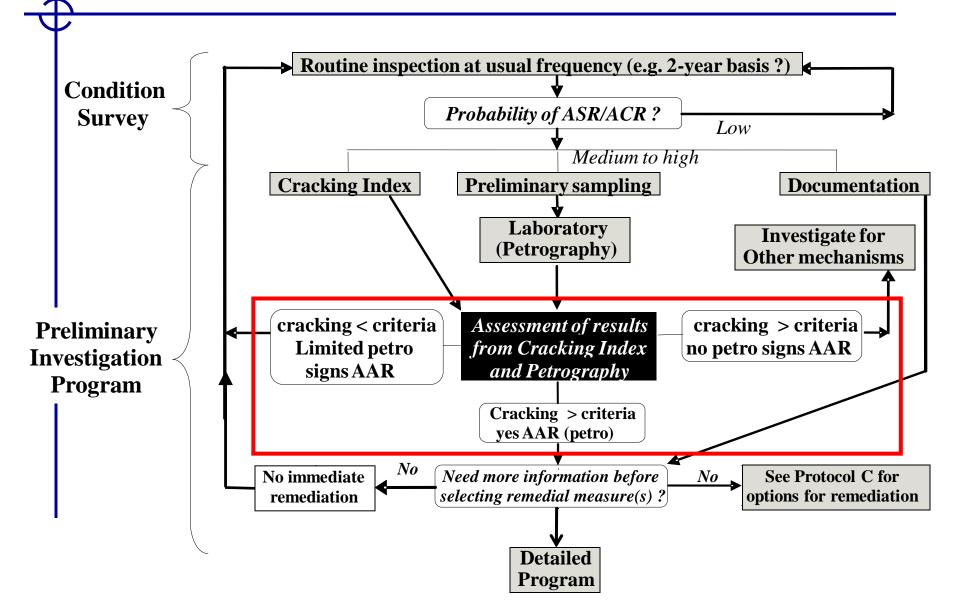




Interpretation of Results from Petrography

Probability of AAR	Nature and Extent of Features
Low	 no potentially reactive rock types (from petrographic examination of thin sections); no alkali-silica gel present (or only in a very few air voids), no (or very few) reaction rims, no (or very few) sites of expansive reaction, very limited cracking within the aggregate particles that extends, or not, in the cement paste; presence of other indicative features rarely found (see Annex C); no (or very few) dedolomitization rims surrounding coarse limestone aggregate particles (signs of ACR).
Medium	 Presence of some or all features generally consistent with AAR: damp patches on core surfaces presence of potentially reactive rock types (from petrographic examination of thin sections); cracking/microcracking within a fair number of aggregate particles; some of the cracks may extend in the cement paste; alkali-silica gel observed in cracks within a fair number of aggregate particles and/or cracks within the cement paste and/or air voids; darkening of cement paste around reactive aggregate particles, cracks or voids ("gelification"); reaction rims around the internal periphery of a fair number of reactive particles; dedolomitization rims surrounding a fair number of coarse limestone aggregate particles (signs of ACR); advanced microscopic examination under the SEM reveals the presence of brucite surrounding some "reacted" coarse limestone aggregate particles.
High	 presence of extensive signs of AAR (as described in the previous section but observed in larger frequency); 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 several reactive particles and readily visible to the unaided eye or under low magnification.

Global Approach



Cracking Index

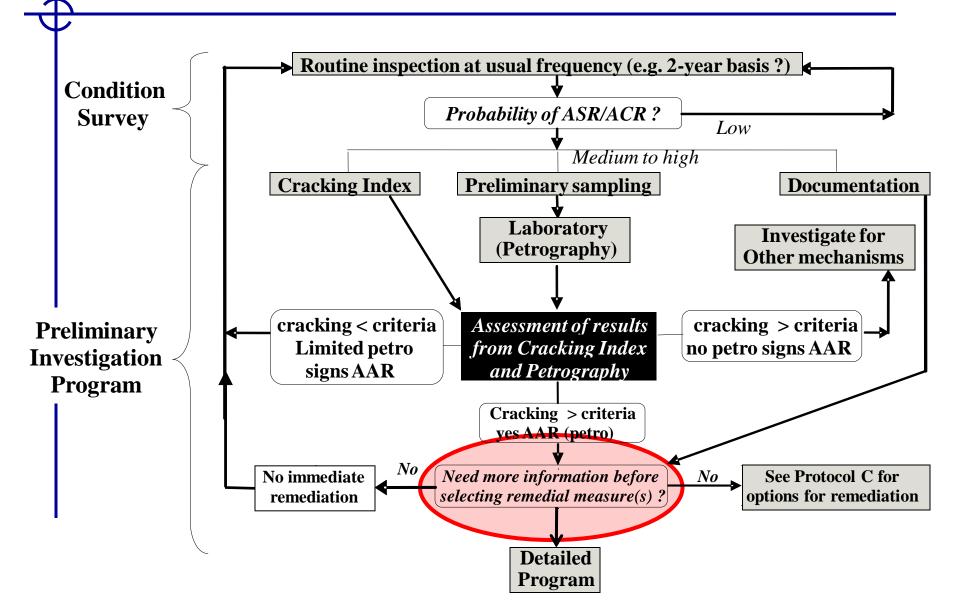
• *Cracking criteria* proposed to identify an extent of cracking justifying more detailed investigations.

CI > 0.5 mm/m, and/or Cracks of width > 0.15mm

Assessment from CI and Petrography

Criteria	Comments and Action
"Cracking" < criteria and <u>Low</u> probability of AAR (from petrography)	 Although cracking is noted in the element examined, the extent of cracking is still limited; there is no conclusive evidence of AAR in the concrete (based on petrography). Action: monitor the progress in cracking by repeating the crack mapping process as part of the next routine inspection survey. If evidence of progress in cracking is noted, further coring and petrographic examination is recommended to evaluate the progress in internal distress due to AAR.
"Cracking" < criteria and <u>Medium to high</u> probability of AAR (from petrography) (situation not in flow chart)	 This a fairly unlikely situation as AAR, when present to a significant extent in concrete, generally leads to noticeable cracking at the surface of at least on the most severely exposed affected elements. It may however correspond to a relatively early stage of AAR. Also, some signs of ASR may be observed in the case of some reactive aggregates such as opal-bearing or cherty that may react close to the surface (thus producing pop outs) or that may dissolve in the concrete without necessarily inducing significant cracking in the concrete element as a whole. <u>Action</u>: initiate further investigations on other members of the structure (e.g. assess effect of exposure conditions, look for signs of expansion, coring of other members for petrography).
"Cracking" > criteria and <u>Low</u> probability of AAR (from petrography)	 Significant cracking is affecting the element investigated. On the other hand, there is no conclusive evidence of AAR in the concrete (based on petrography). <u>Action</u>: initiate further investigations for other mechanisms of deterioration, if required.
"Cracking" > criteria and <u>Medium to high</u> probability of AAR (from petrography)	 Presence of significant to extensive signs of ASR, both in-situ (cracking) and internally (petrography). <u>Action</u>: additional investigations may be required to establish the expansion reached to date and the potential for further expansion, leading to the selection of the most appropriate remedial action. Some immediate remedial actions (e.g. application of sealers) may already be a possibility at this stage (i.e. without any further investigations).

Global Approach

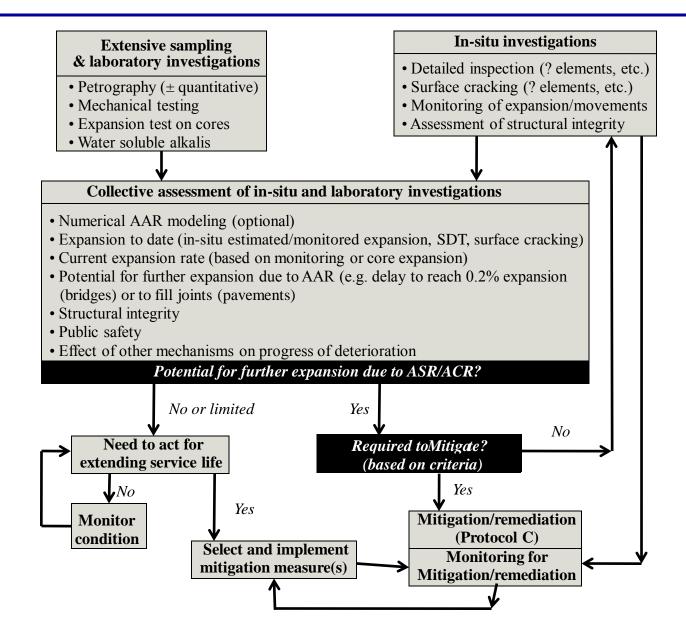


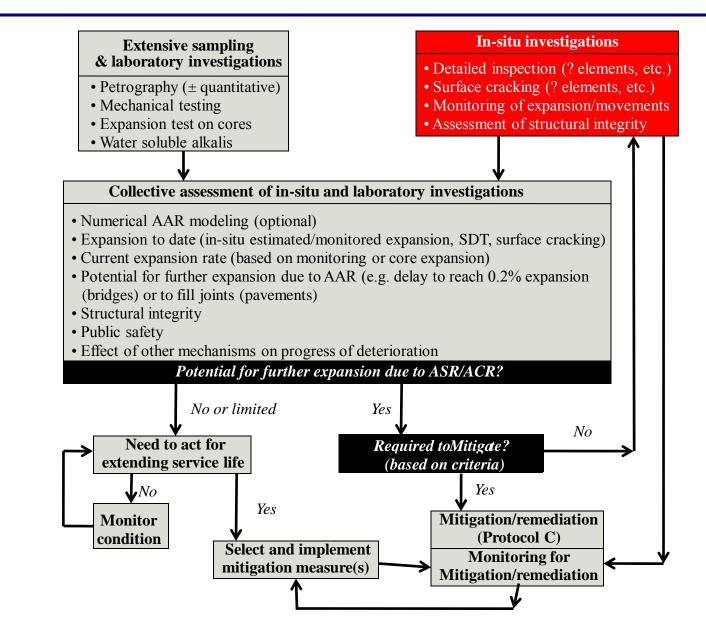
Structures Classification

Class	Consequences of ASR	Acceptability of ASR	Examples
S1	Safety, economic or environmental consequences small or negligible	Some deterioration from ASR is acceptable	 Non-load-bearing elements inside buildings Temporary structures (e.g. < 5 years) Small numbers of easily replaced elements Most low-rise domestic structures
82	Some safety, economic orModerate riskenvironmentalof ASR isconsequences ifacceptablemajor deterioration		 Most building and civil engineering structures Sidewalks, curbs and gutters Highway barriers Culverts Service-life < 40 years
S3	Significant safety, economic or environmental consequences if minor damage	Minor risk of ASR acceptable	 Pavements Rural, low-volume bridges Large numbers of precast elements where economic costs of replacement are severe Service life normally 40 to 75 years
S4	Serious safety, economic or environmental consequences if minor damage	ASR cannot be tolerated	 Major bridges Dams Tunnels Nuclear installations Structures retaining hazardous materials Critical elements that are very difficult to inspect or repair Service life normally > 75 years

Necessity to Pursue Investigations

Type of Structure (Table 6)	Damage	Signs of AAR	Rationale for Implementing Immediate Remedial Action
S1 and S2	Mild to moderate	Mild to moderate	 No requirement for detailed studies (limited deterioration/AAR, type of structures) To prevent or slow down further damage Stability and safety issues Note: some monitoring of repair needed (especially S2)
S1	Severe	Mild to moderate	 No requirement for detailed studies (type of structures) Prevent further damage Stability and safety issues
S3 and S4	Mild to moderate	Mild to moderate	 Correct some obvious issues identified during condition survey (e.g. modify drainage system to control moisture) Some ~ inexpensive early-action measures (e.g. application of sealers) Note: need further investigations to select remedial actions (long-term).

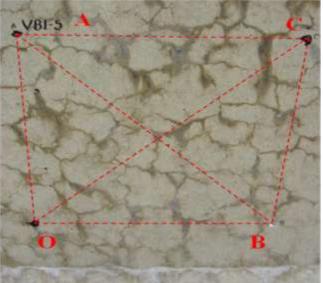




Information	In-situ testing			
Expansion reached to	Preexisting monitoring			
date	Crack widths on the affected concrete members			
	Detailed visual inspection			
Current	Non-destructive testing			
condition of the concrete	• Stress conditions (overcoring, strain gages on reinforcements which are cut)			
	Measurements of temperature and humidity			
Current expansion rate	• Instrumentation and monitoring of expansion (minimum 3 years)			
Potential for future expansion	• Determination from monitoring of expansion			

Deformation Measurements









Deformation Measurements



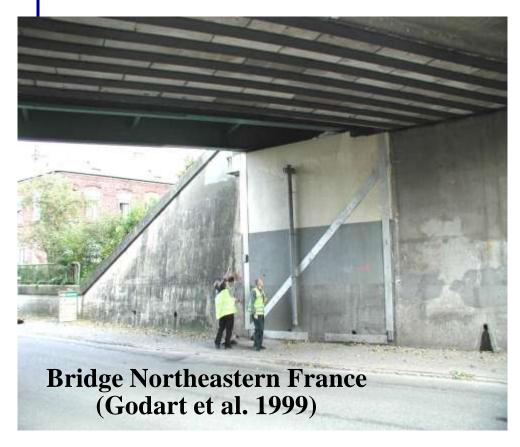






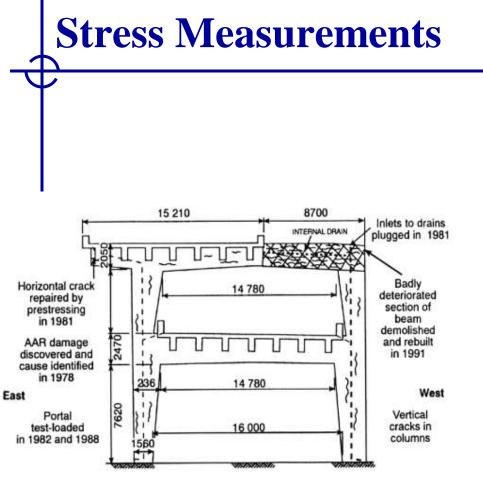
Deformation Measurements

• Infra-red "distancemeter"





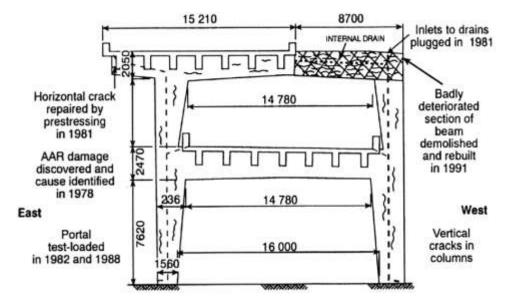




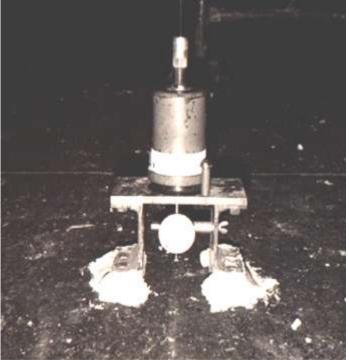


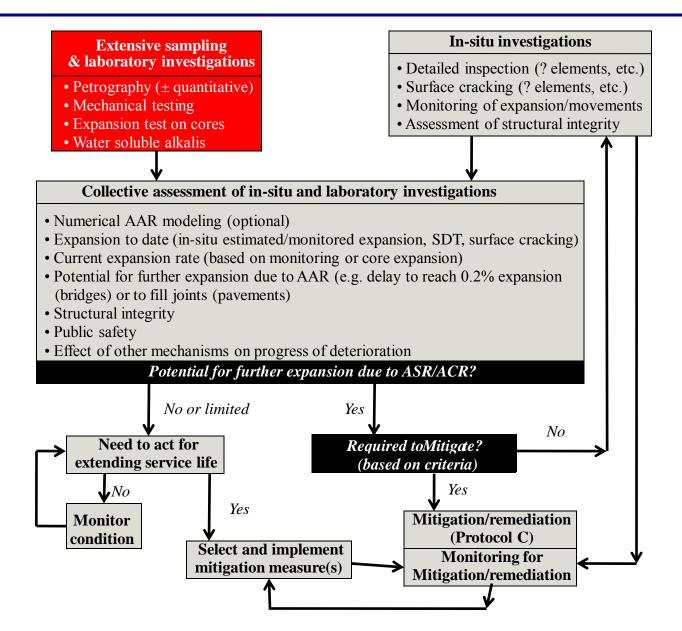


Structural Evaluation





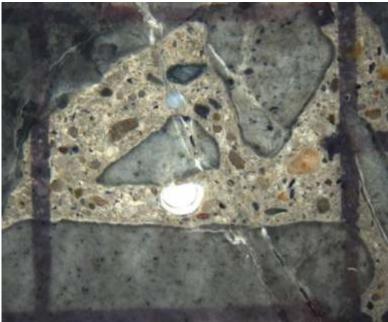


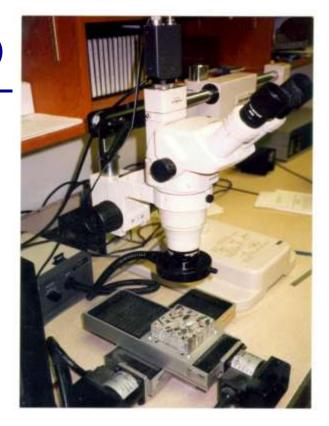


Information	Laboratory investigations		
Expansion reached to date	Modified Stiffness Damage Test performed on concrete cores		
Current condition of the concrete	 Petrographic examination Mechanical testing (compressive and direct tensile strengths, direct tensile-to-compressive strength ratio, modulus of elasticity) 		
Current expansion rate	 Expansion test on cores (1 yr) Measurement of water-soluble alkalis in the concrete 		
Potential for future expansion	• Estimation from expansion test on cores (1 yr), measurement of water soluble alkalis in the concrete and some field considerations (humidity, temperature, and stress conditions)		

Damage Rating Index (DRI)







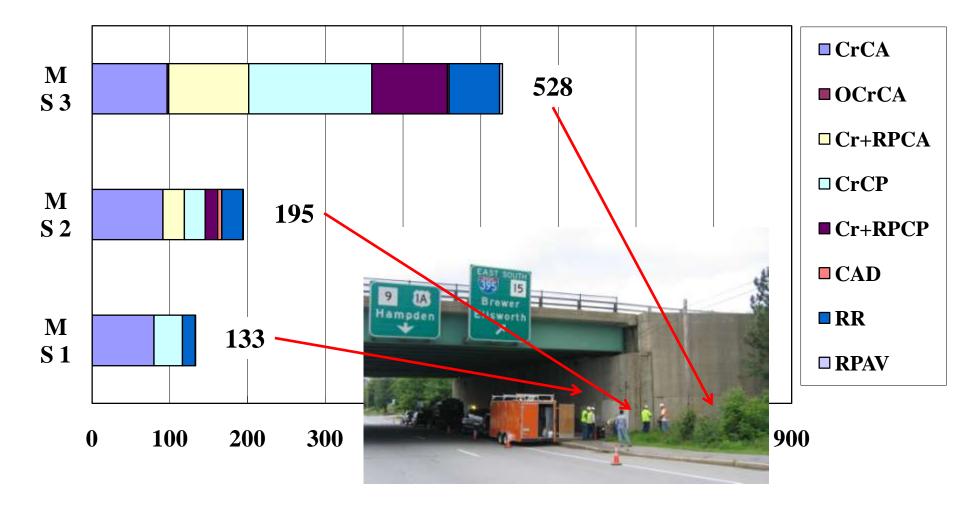


ASR Petrographic Features & Associated Factors

Petrographic feature	Abbreviation	Factor
Coarse aggregate with crack	CA	0.25
Open crack in coarse aggregate	OCA	4
Coarse aggregate with crack and gel	CA+G	2
Debonding coarse aggregate	DCA	3
Reaction rim	RR	0.5
Cement paste with crack	СР	2
Cement paste with crack and gel	CP+G	4
Gel in air void	V+G	0.5

Grattan-Bellew and Danay (1992)

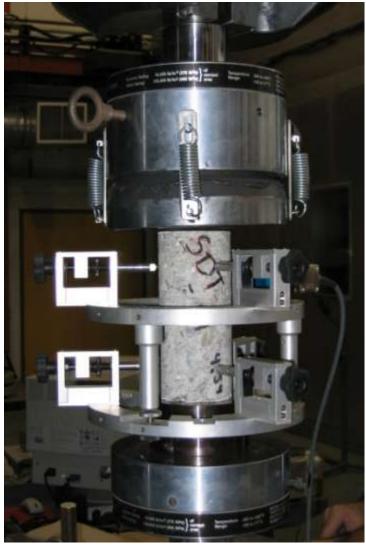
Damage Rating Index (DRI)



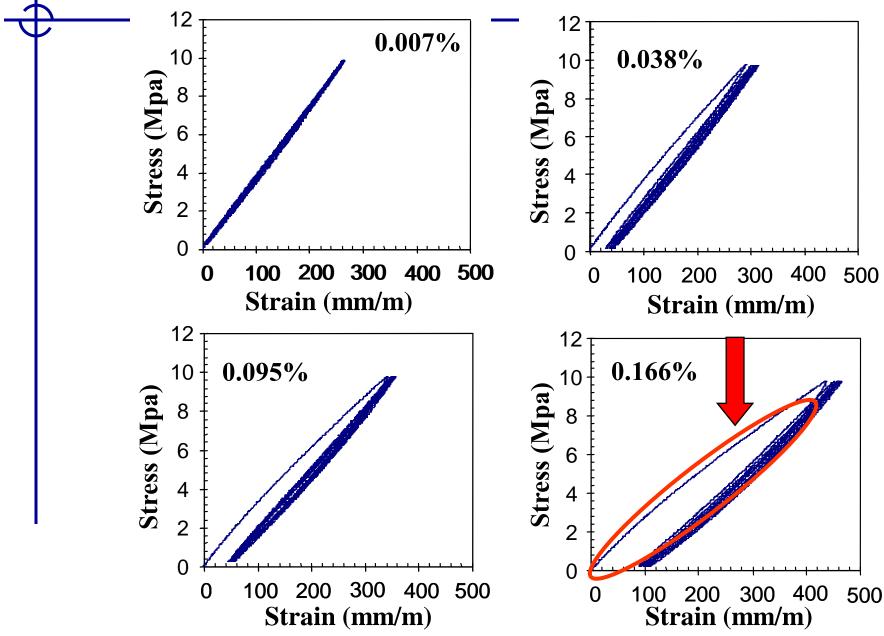
Stiffness Damage Test (SDT)

5 cycles of loading/unloading up to 10 MPa



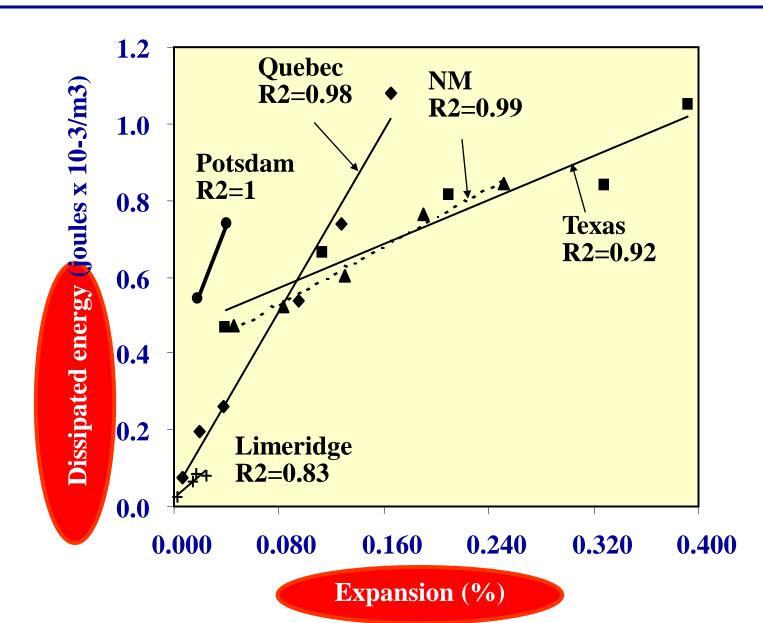


Stiffness Damage Test (SDT)



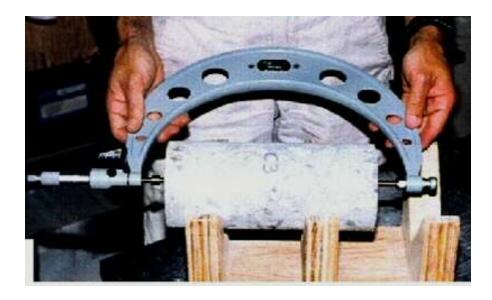
Stiffness Damage Test (SDT)

Samoui et al. (2003)



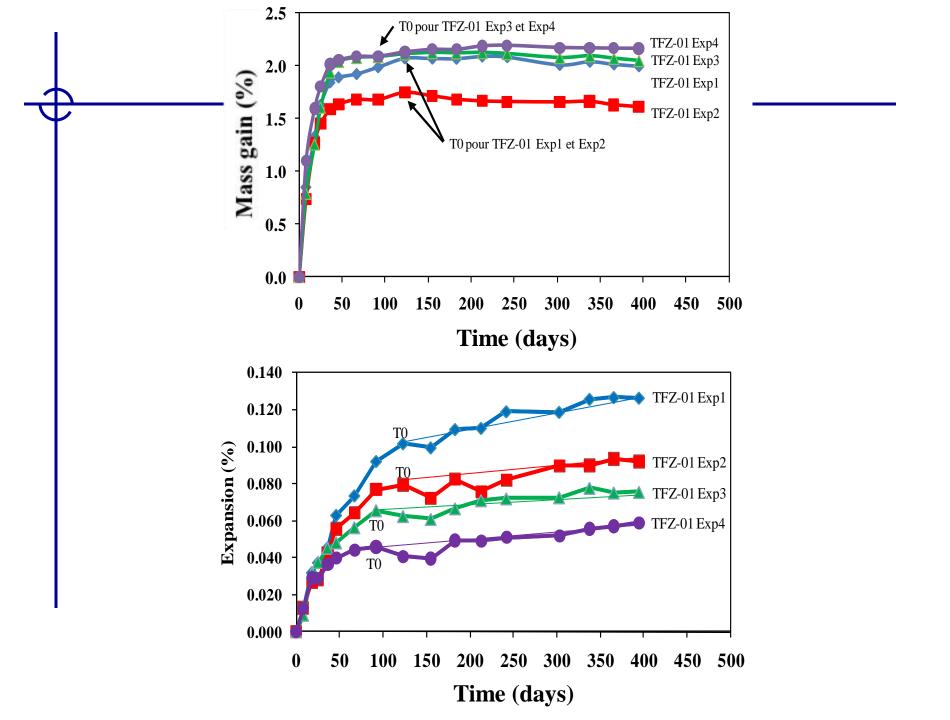
Expansion tests on cores

- Install demec points on the cores
- Test a minimum of two cores (minimum 4 inches in Φ)
- Larger cores are recommended (reduce effect of leaching)

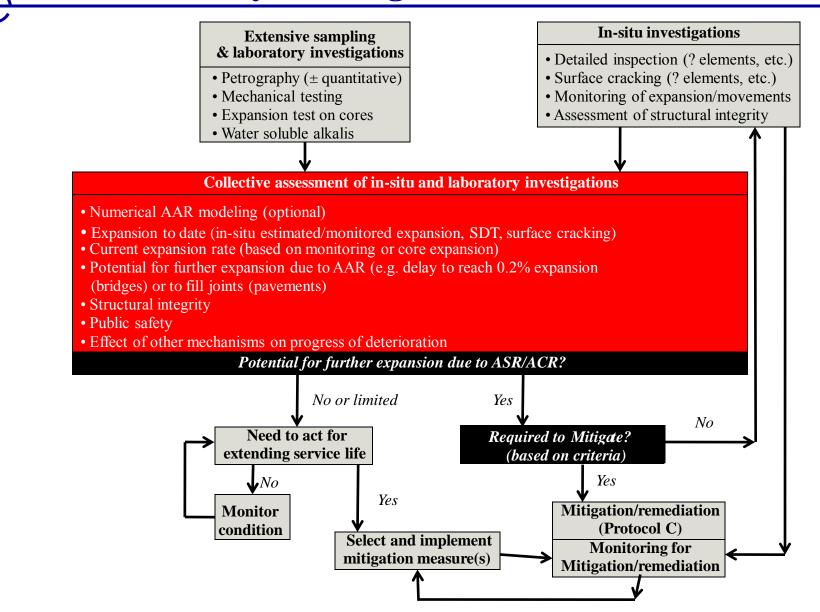








Collective Assessment of Findings from Field and Laboratory Investigations



Potential for future expansion

- Reinforced concrete members
 - Critical parameter \rightarrow <u>expansion reached to date</u>
 - Determine number of years before the reinforcing steel could exceed its elasticity limit → expansion of 0.20%
 - Urgency to implement remedial actions → function of the time left before steel yielding
 - If < 5 years → detailed structural investigation needed

Decision Criteria for Additional Investigation or Immediate Application of Mitigation/Remediation Measures

Decision criterion	Based on following investigations	Immediate action(s) recommended
Risk of steel yielding (expansion > 0.2%) in 5 years or less (reinforced members of bridges)	 Expansion to date (preexisting monitoring, modified SDT or Cracking Index) Current rate of expansion (monitoring or expansion tests on cores) Stress conditions (in-situ measurements in concrete and reinforcing steel) 	 Implement monitoring for better assessing the current rate of expansion (minimum of 3 yrs), if not done; measure the stress conditions, if not done Apply appropriate measures of mitigation/remediation (see Protocol C)

Potential for future expansion

- Concrete Pavement
 - Critical parameter \rightarrow <u>current expansion rate</u>
 - Need to determine the number of years before closure at joints → spalling
 - Urgency to implement remedial actions → function of the time left before closure of joints
 - If time is < 5 years → detailed structural investigations needed

Decision Criteria for Additional Investigation or Immediate Application of Mitigation/Remediation Measures

Decision criterion	Based on following investigations	Immediate action(s) recommended
Risk of closure at joints by 5 years or less (unreinforced members of bridges, pavements)	 Current widths of joints (maximum opening in summer) Current rate of expansion (monitoring or expansion tests on cores) 	 Implement monitoring for better assessing the current rate of expansion, if not done Apply appropriate measures of mitigation/remediation (see Protocol C)

Mitigation Measures for ASR-Affected Structures

TREAT THE CAUSE

Chemical Treatment/Injection

- CO₂
- Lithium compounds

Drying

- Sealants
- Cladding
- Improved drainage

TREAT THE SYMPTOM

Crack Filling

- Aesthetics
- Protection (e.g. from Clingress)

Restraint

- Prevent Expansion
- Strengthen/Stabilize

Relieve Stress

• Saw Cutting/Slot Cutting (accommodate movement)

Conclusion

- Alkali-aggregate reaction is still a subject of extensive work worldwide
 - Specifications to reduce the risk of AAR in new constructions
 - Determine the best approach for the management of AAR in existing concrete structures

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 - Determine the best approach for the management of AAR in existing concrete structures

Increasing interest in Brazil → host 15th International Conference on AAR in 2016 ????

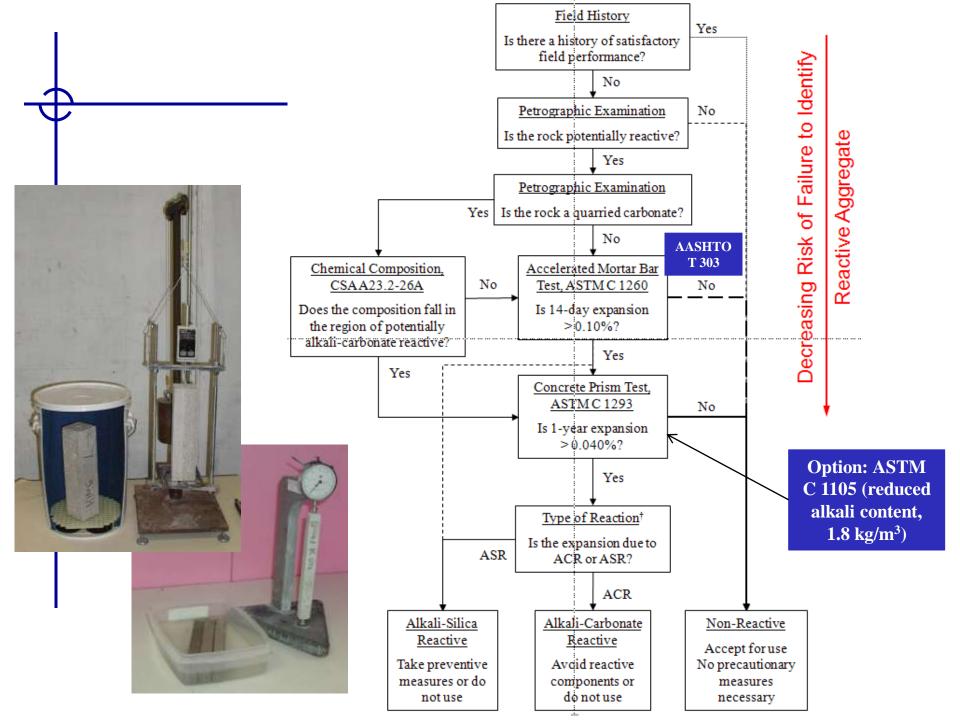
Thank you very much

for your kind attention !! Muito obrigado !!









FHWA – Protocol for Preventing ASR – Prescriptive Approach

Step 5 – Select Preventive Measure

Table 8: Using SCM and Limiting the Alkali Content of the Concrete toProvide Exceptional Levels of Prevention

Prevention	SCM as sole prevention	Limiting concrete alkali content <u>plus</u> SCM		
Level	Minimum SCM level	Maximum alkali content, kg/m ³	Minimum SCM level	
Z	SCM level shown for Level Z in Table 6	1.8	SCM level shown for Level Y in Table 6	
ZZ	Not permitted	1.8	SCM level shown for Level Z in Table 6	