Recent developments in the prevention and mitigation of AAR in concrete

B. Fournier, M.D.A. Thomas, K.J. Folliard, and M.A. Bérubé

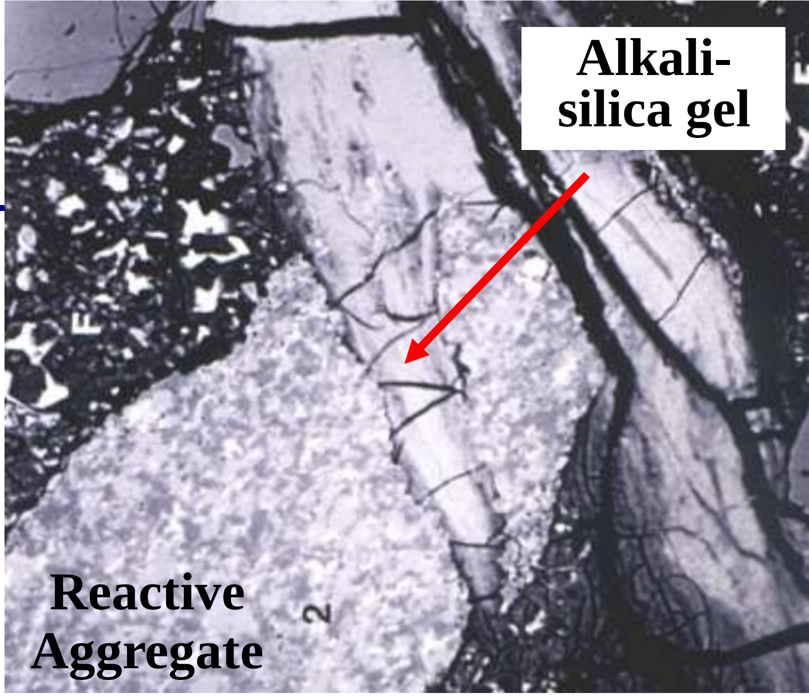
Seminário "A reação álcali-agregado - Causas, diagnóstico e soluções"
No 52º. CBC do IBRACON
October 15th, 2010, Fortaleza, Brazil

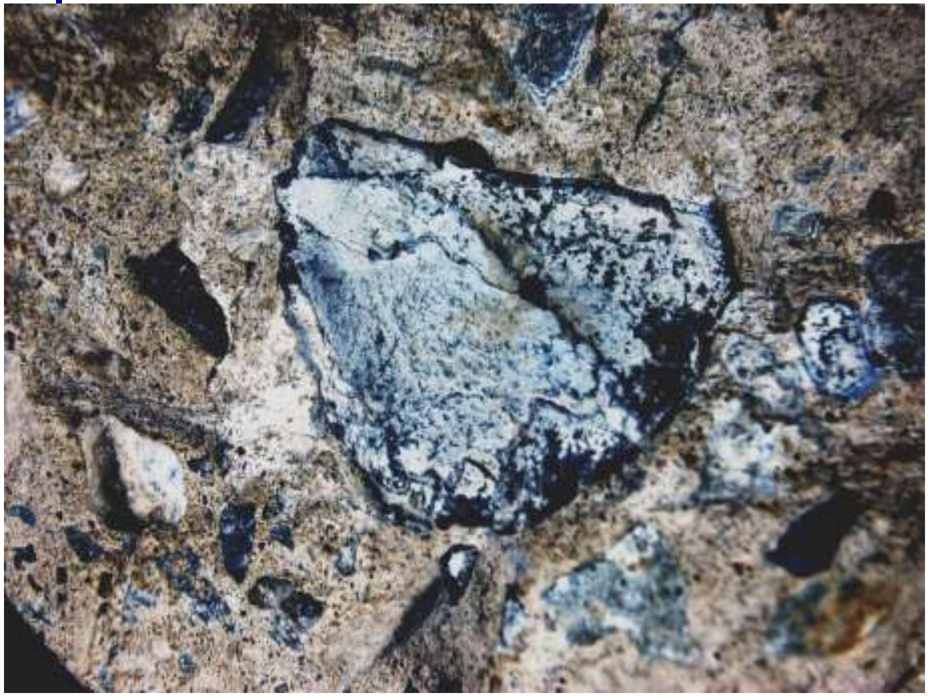
Outline of the Presentation

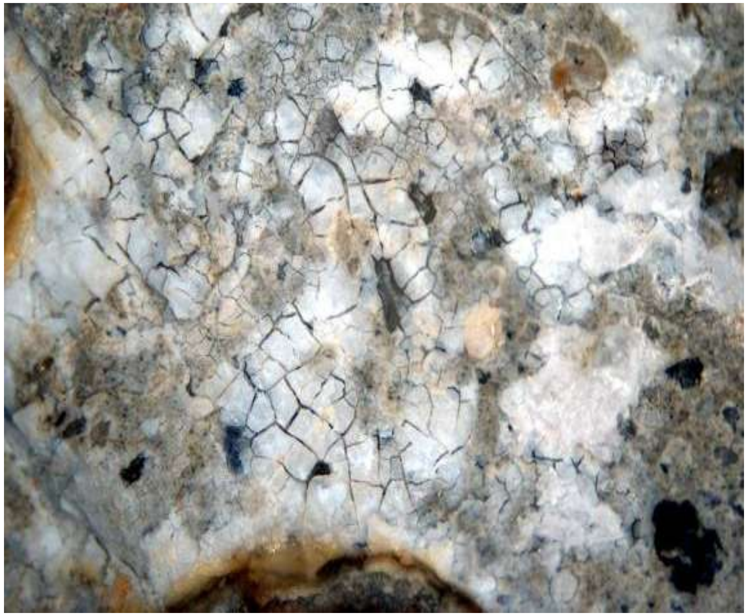
- **Alkali-silica versus alkali-carbonate reactions**
- **Review of recent developments in International Standard developing committees**
  - **ASTM (USA)**
  - **Canadian Standards**
  - **RILEM TC 191-ARP**
  - **ACI Committee 201**
- **FHWA – Protocol A -** ***Determining the reactivity of concrete 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 alkali-aggregate reaction (AAR) in transportation structures***

Alkali-Silica Reaction

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





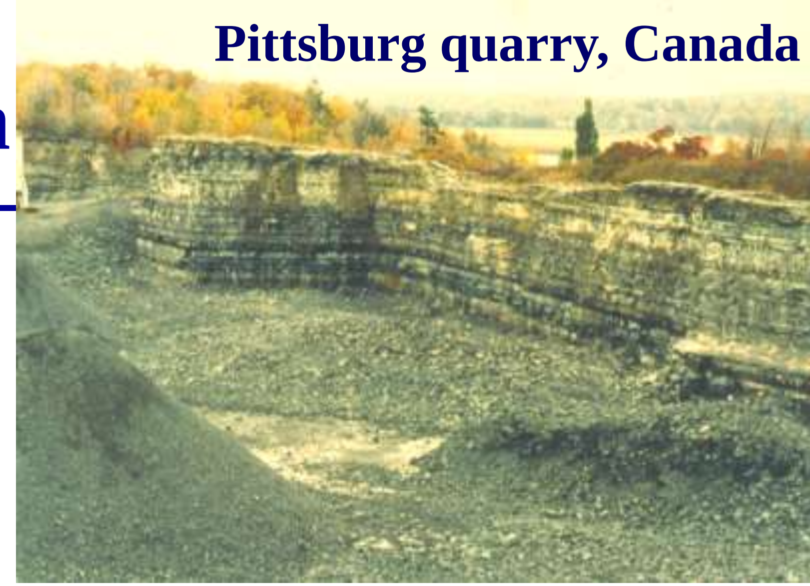


Alkali-Silica Reaction

- Internal expansion forces → cracking and distress of concrete

Alkali-Carbonate Reaction

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

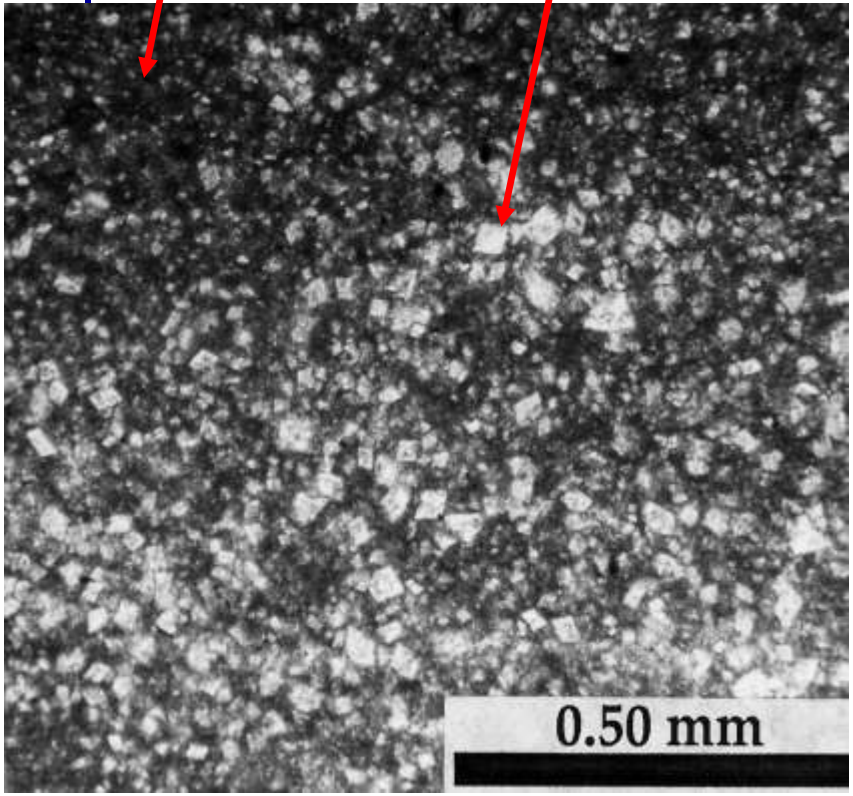


Pittsburg quarry, Canada

ACR

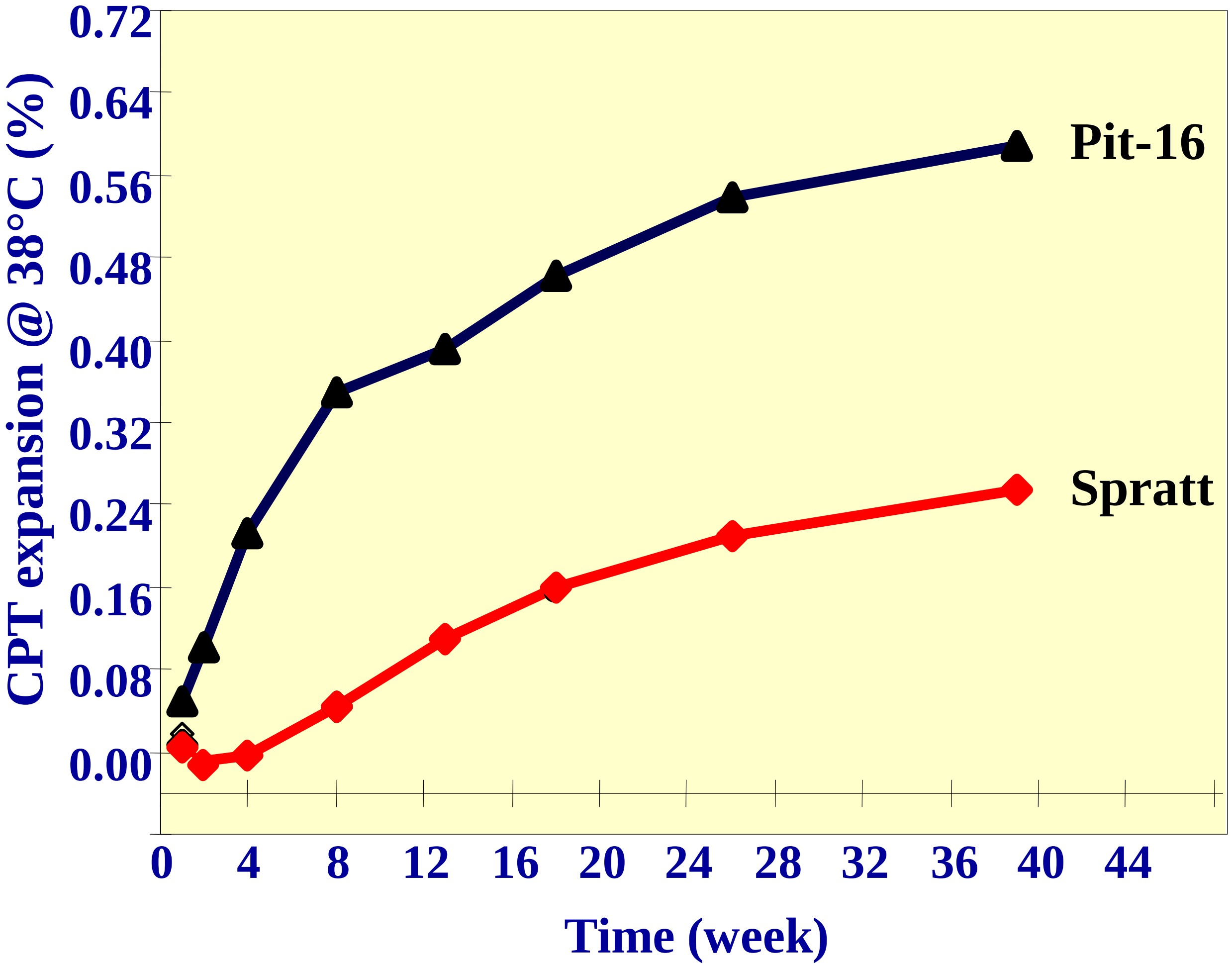
Fine-grained matrix

Dolomite crystals



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

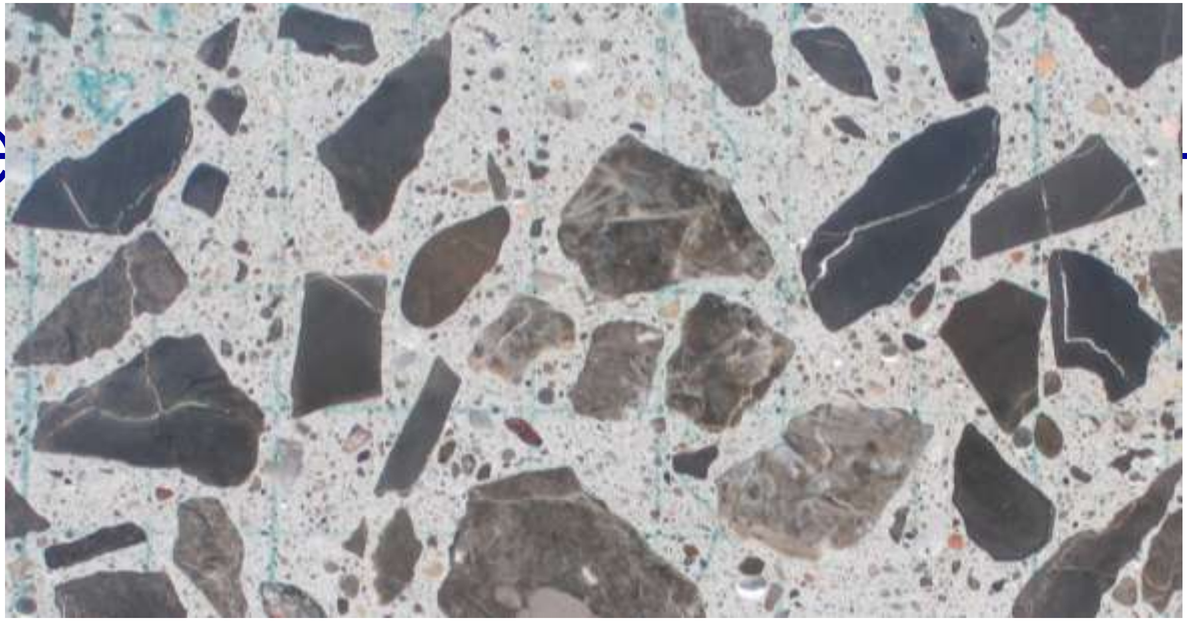
Expansion of Concrete Prisms @ 38ºC, R.H. > 95%



Kingston quarry

Spratt quarry

Concrete Prism Test

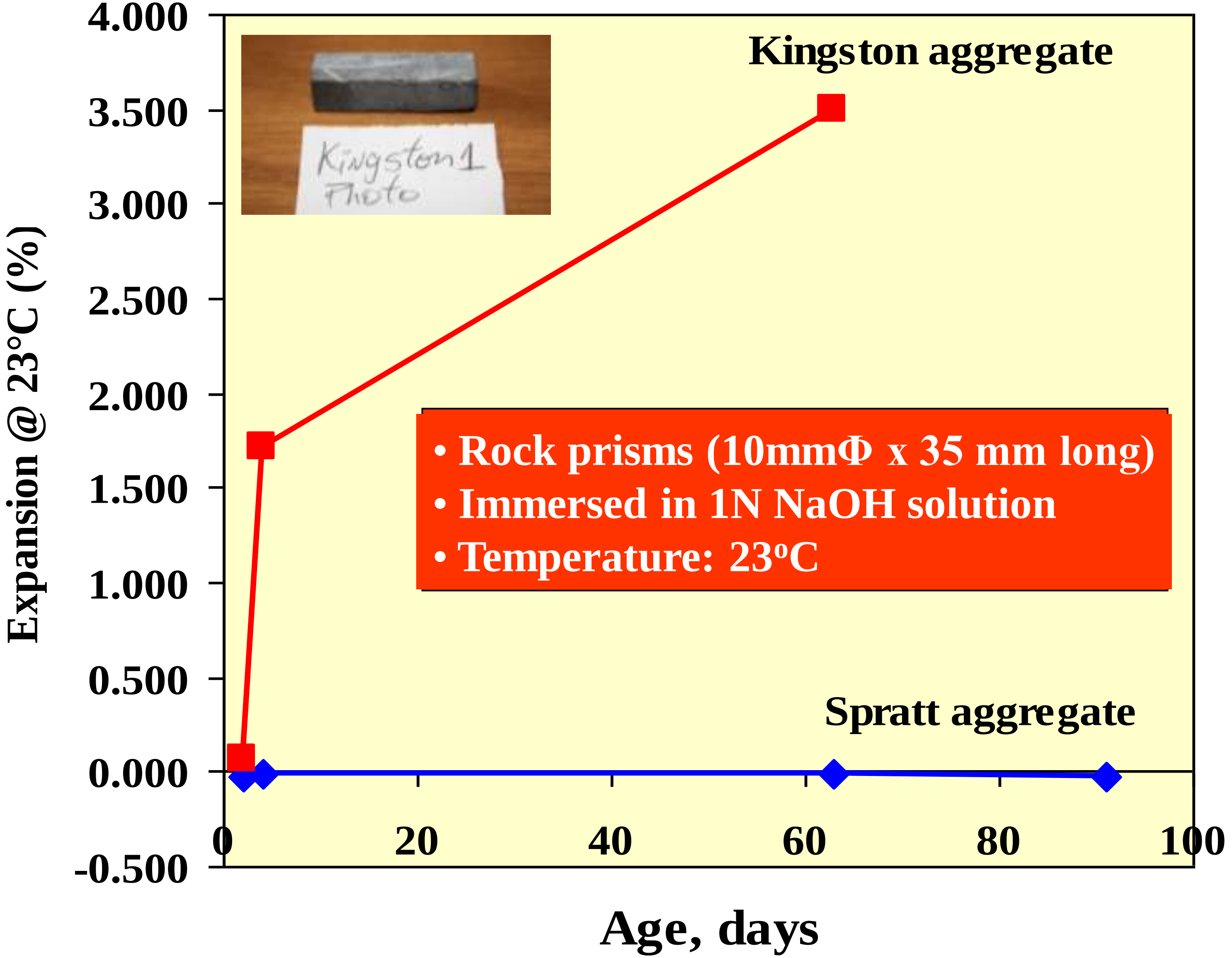


Spratt Limestone (Canada)

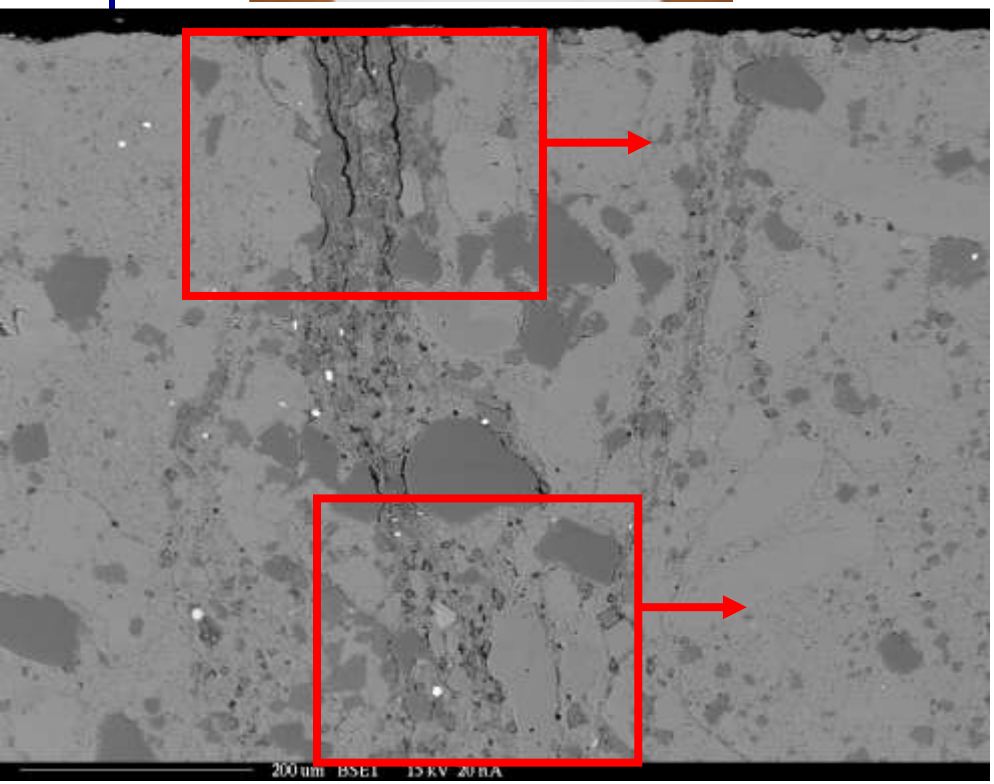
Kingston Limestone (Canada)

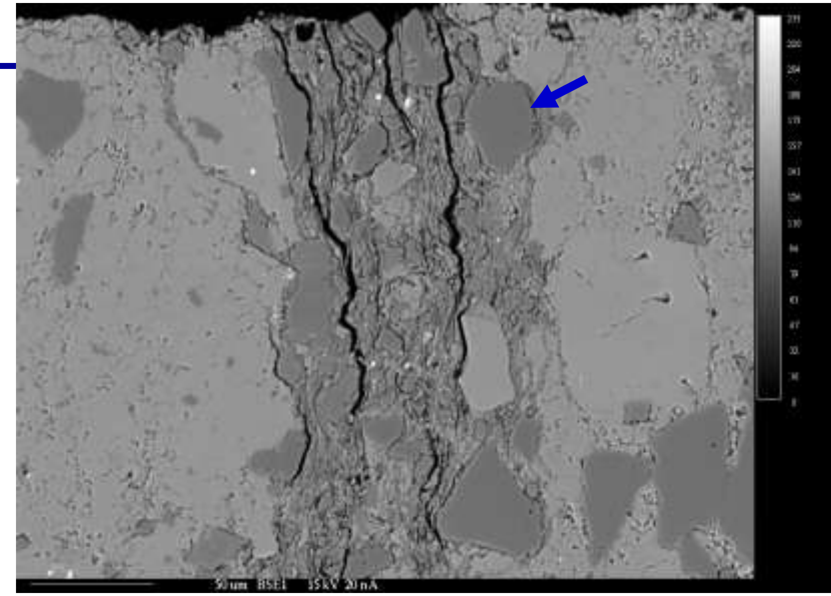
Expansion : ~ 0.20-0.25%

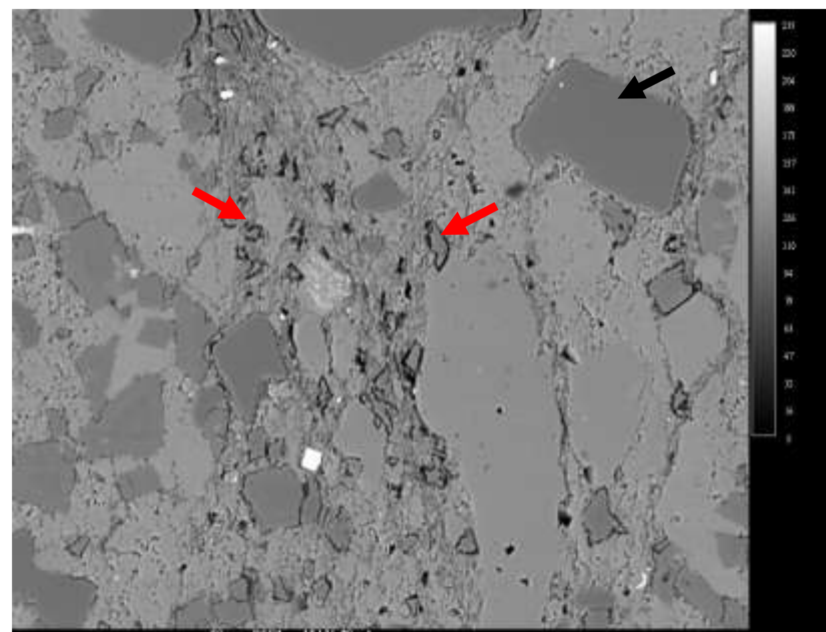
Rock Cylinder Test (ASTM C 586)



Alkali-carbonate reaction







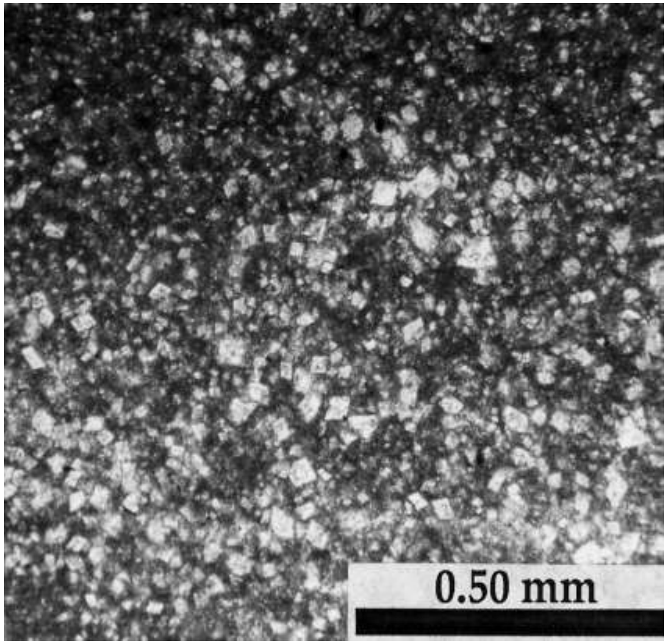
- **Dolomite grains experiencing dedolomitization**
- **K-feldpar grains**
- **Quartz grains**

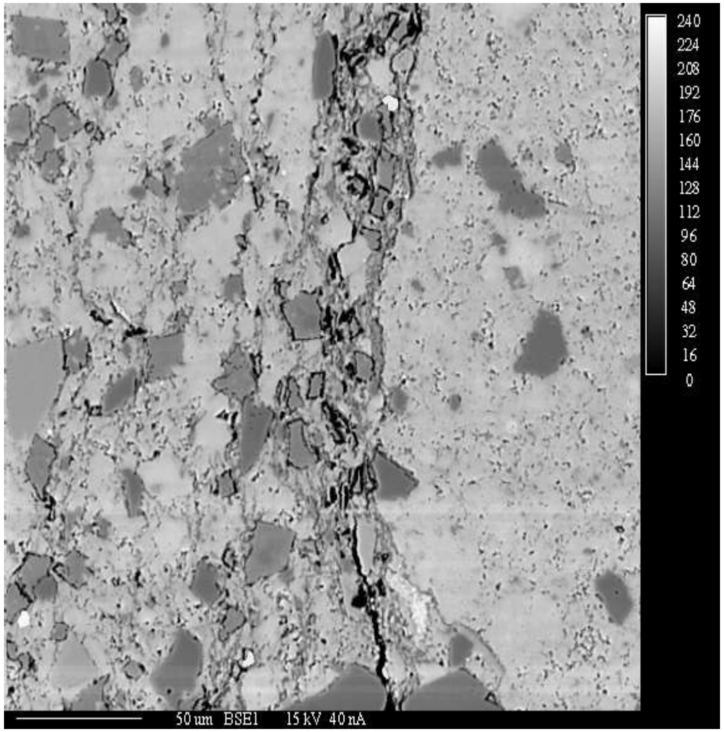
Alkali-carbonate reaction

Mechanisms still not well understood

- **Dedolomitization process:**

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



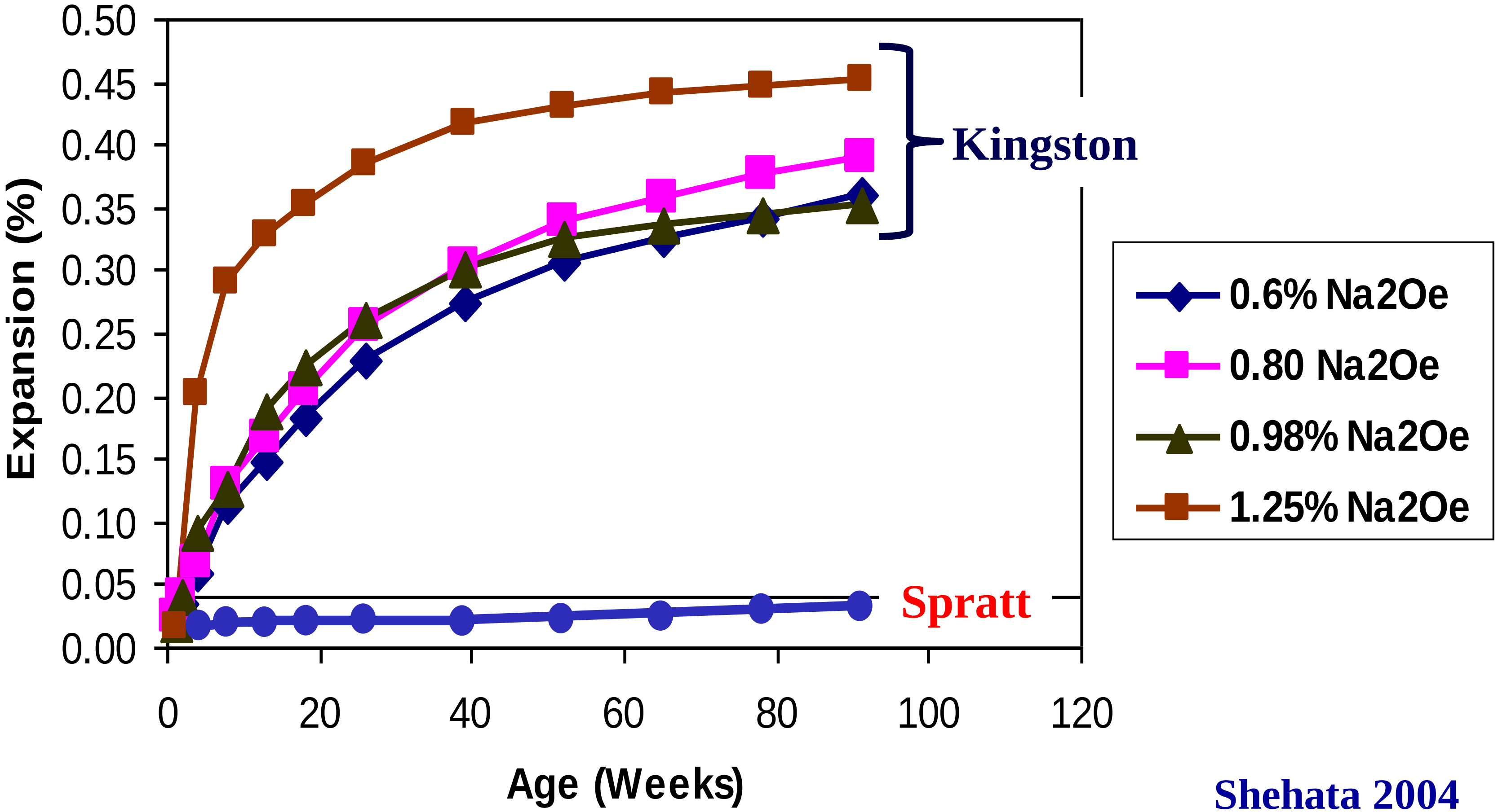


- **Recycling of alkalis**

$Na(K)_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2Na(K)OH$

Alkali-carbonate reaction

Expansion of concrete prisms vs concrete alkali content

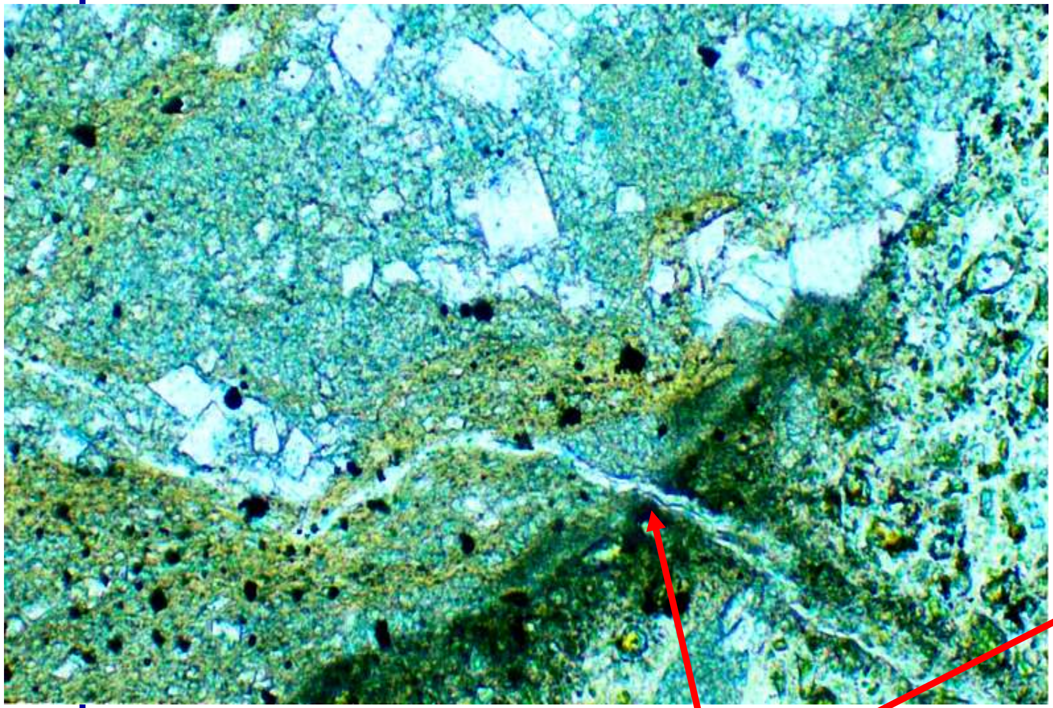


Shehata 2004

Alkali-carbonate reaction

Mechanisms still not well understood

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



Alkali-silica gel

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 alkali-aggregate reaction (AAR) in transportation structures***

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*".**

Test Method	Purpose		Type of test				Type of reaction	
			Other	Expansion				
	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	

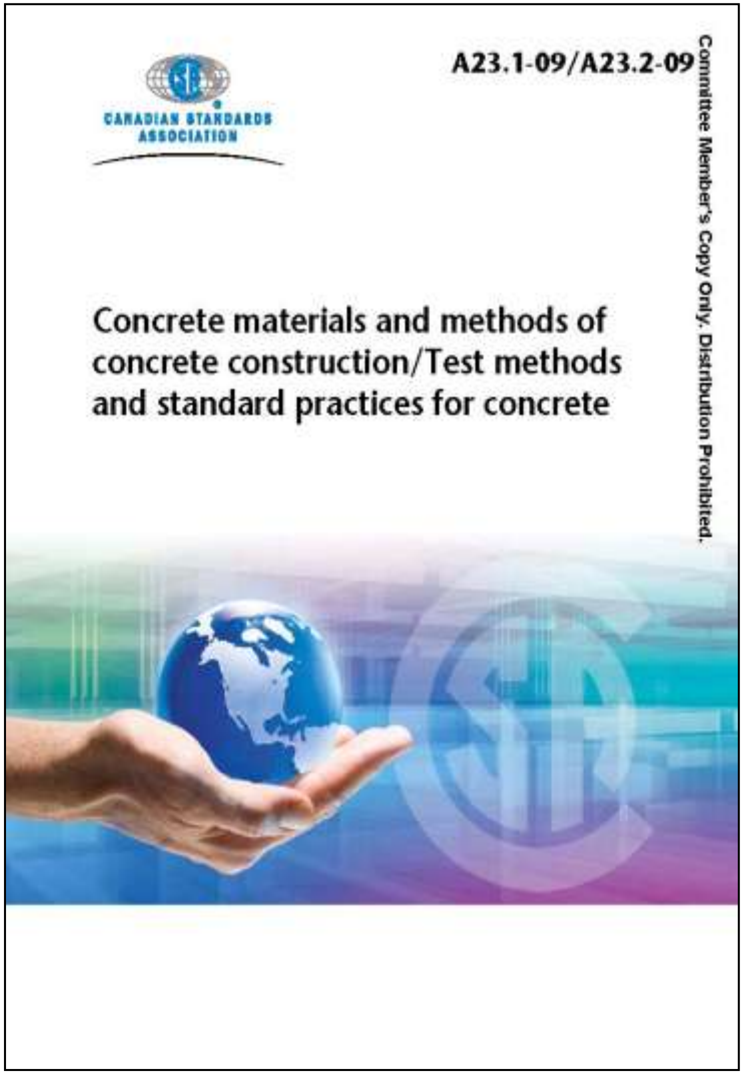
ASTM (USA)

- **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

© Canadian Standards Association — Concrete materials and methods of concrete construction

Annex B (informative)
Alkali-aggregate reaction

Note: *This Annex is not a mandatory part of this Standard.*

B.1 General

In several regions of Canada, concrete deterioration occurs due to a reaction between some minerals in certain rock types used as concrete aggregate and the soluble alkaline components in the concrete that are present mainly in the hydraulic cement. This phenomenon is known as alkali-aggregate reaction. For alkali-aggregate reactivity to occur, there must be reactive materials in the aggregates, sufficient alkali in the concrete, and sufficient moisture in the concrete to support the reaction process.

Alkali-aggregate reactivity can result in detrimental expansion of the concrete characterized by a well-defined crack pattern. The crack pattern is commonly identified as "map-cracking" or "pattern-cracking" (see Figure B.1). Other deterioration mechanisms can also cause pattern-cracking. Cracking in the concrete and the resultant deterioration is generally slow, although some extremely reactive aggregates can produce cracks within a few years. With time, alkali-aggregate reactivity can cause significant expansion, severe cracking, and differential movements in concrete components.

The risk of sudden structural failure in concrete components is almost nonexistent (Hasvik and Mielenz, 1991) and indeed, in Canada, much concrete made with reactive aggregate remains in service. Nevertheless, concrete affected by alkali-aggregate reactivity can pose serviceability problems, in some cases severe ones, which might result in high maintenance/rehabilitation costs or replacement of a component before the end of the anticipated service life. Cracking, regardless of origin, can allow rapid ingress of moisture or salts, or both, which might result in acceleration of deterioration due to other mechanisms.

Alkali-aggregate reaction problems in concrete should be avoided. This Annex provides general advice on strategies, test methods, and selection criteria for this objective. A useful general reference on alkali-aggregate reaction can be found in Fournier and Bérubé (2000). CSA A864 provides guidelines for the management of existing concrete structures already affected by alkali-aggregate reaction.

B.2 Types of alkali-aggregate reaction

B.2.1 General

Two types of alkali-aggregate reaction are encountered in Canada:
(a) alkali-silica reaction; and
(b) alkali-carbonate reaction.

Note: *The mechanisms of these expansive reactions are not clearly understood. The alkali-silica reaction is associated with the formation of expansive alkali silica gel in concrete (Diamond, 1989). Alkali-carbonate reaction is caused by the expansion of coarse aggregate particles (Gillott, 1978).*

B.2.2 Alkali-silica reaction

Aggregates exhibiting this type of reactivity contain various forms of reactive silica. For convenience, the alkali-silica reaction is divided into two categories according to the type of reactive silica involved (see Table B.1):
(a) the alkali-silica reaction that occurs with poorly crystalline or metastable silica minerals and volcanic or artificial glasses (see Category (a) in Table B.1):
(i) opal, tridymite, cristobalite, and beekite;
(ii) acid, intermediate, and basic volcanic glasses; and
(iii) artificial glasses.
Aggregates containing such materials might cause deterioration of concrete when the reactive

July 2009 — 141

Committee Member's Copy Only. Distribution Prohibited.

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*”**

Test Method	Purpose		Type of test				Type of reaction	
			Other	Expansion				
	Potential reactivity	Preventive measures	Chemical	Petro	Mortar	Concrete	ASR	ACR
15A	X			X			X	X
26A	X		X					X
25A	X	X			X		X	
14A	X	X				X	X	X

CSA Standard Practice A23.2-27A

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

© Canadian Standards Association — Test methods and standard practices for concrete

A23.2-27A

Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

1 Scope

1.1
This Standard Practice provides requirements for the determination of the degree of alkali-silica reactivity of aggregates, the risk level associated with structure size and environment, the level of prevention related to service life requirements, and the determination of the appropriate preventive measures.

1.2
This Standard Practice describes the determination of the potential for deleterious alkali-carbonate reaction and provides advice on appropriate preventive measures.

1.3
This Standard Practice applies to virgin aggregates and does not apply to recycled concrete used as aggregate for new concrete [see Clause E.6 of Annex E of CSA A23.1 for more information on the potential alkali-reactivity of reclaimed concrete aggregate (RCA)].

1.4
The levels of prevention determined following the procedure described in Clause 6 are applicable for concrete incorporating either portland cement or portland-limestone cement.

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

A23.2-14A-09
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

A23.2-15A-09
Petrographic examination of aggregates

A23.2-25A-09
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

A23.2-26A-09
Determination of potential alkali-carbonate reactivity of quarried carbonate rocks by chemical composition

July 2009 — 371

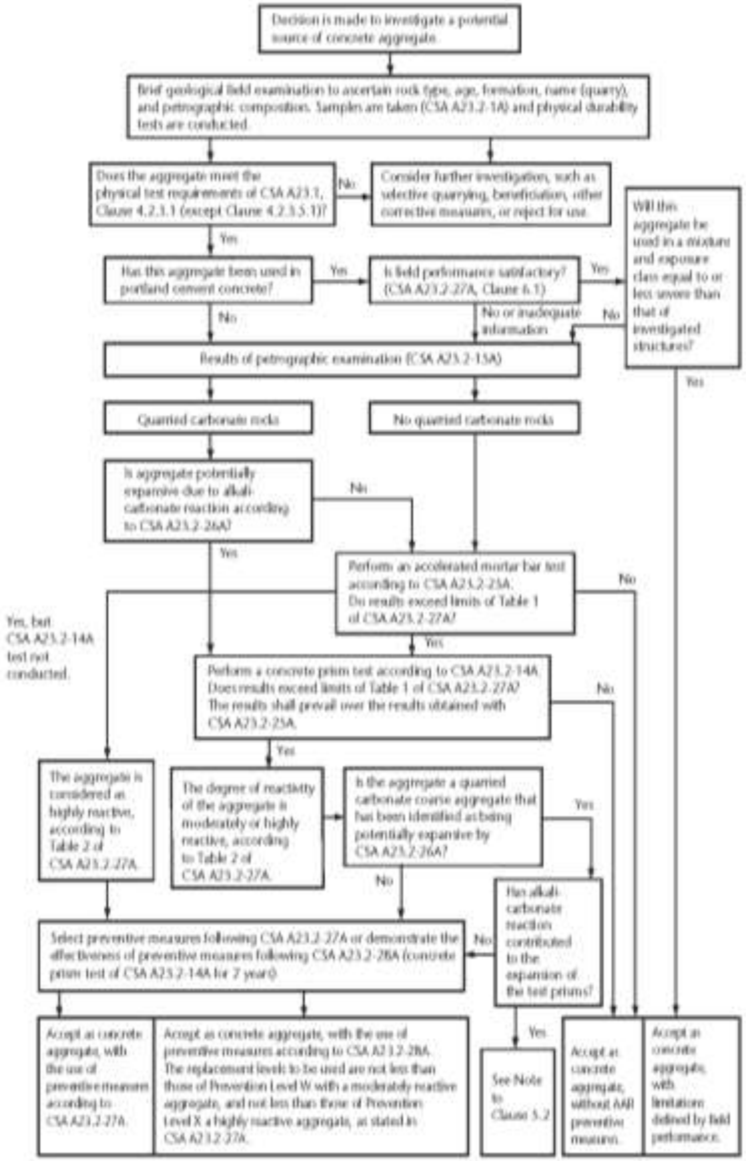
27A

Committee Member's Copy Only. Distribution Prohibited.

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**

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 cementing materials and lithium-based admixtures or combination thereof, in preventing excessive expansion caused by alkali-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

A23.2-14A-09
Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38 °C)

A23.2-25A-09
Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars

A23.2-27A-09
Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

A3001-08
Cementitious materials for use in concrete

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

ASTM International (American Society for Testing and Materials)

C 494/C 494M-04
Standard Specification for Chemical Admixtures for Concrete

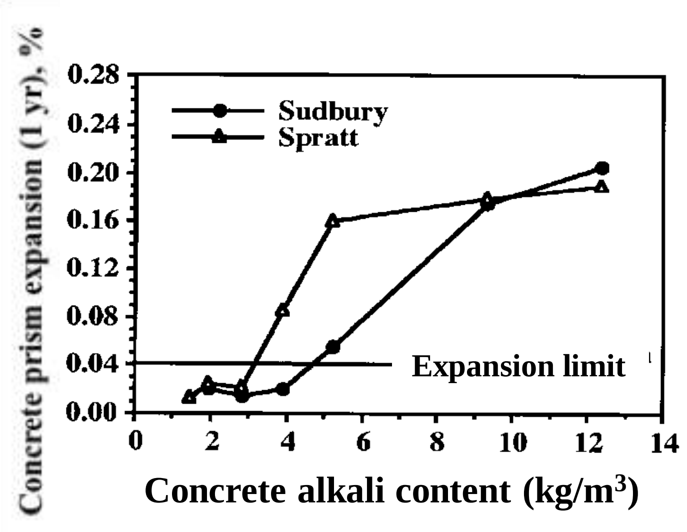
3 Definitions

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

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>);**

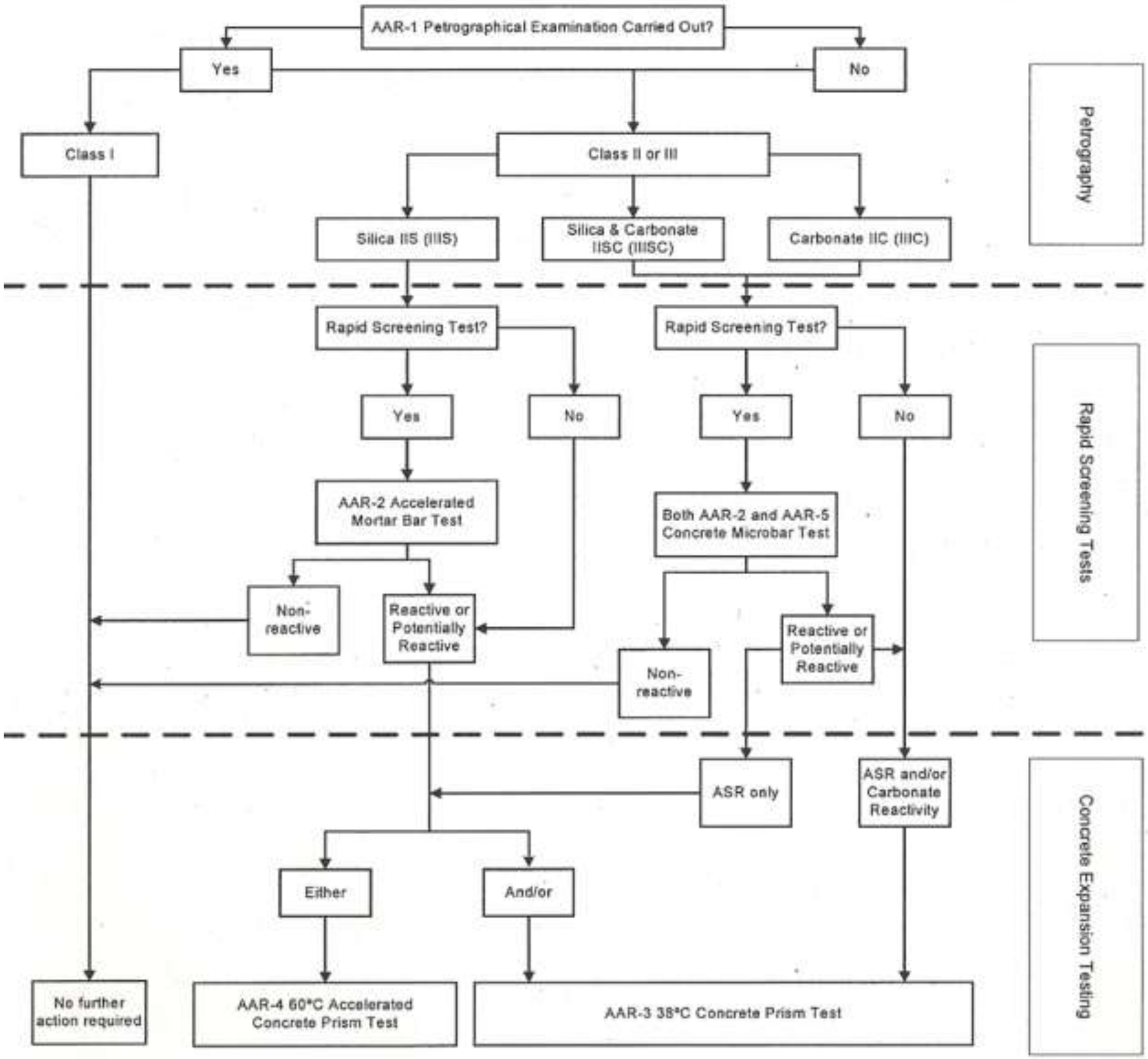


RILEM TC 191-ARP

Concentrates its activities on the assessment of the potential alkali-reactivity 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*

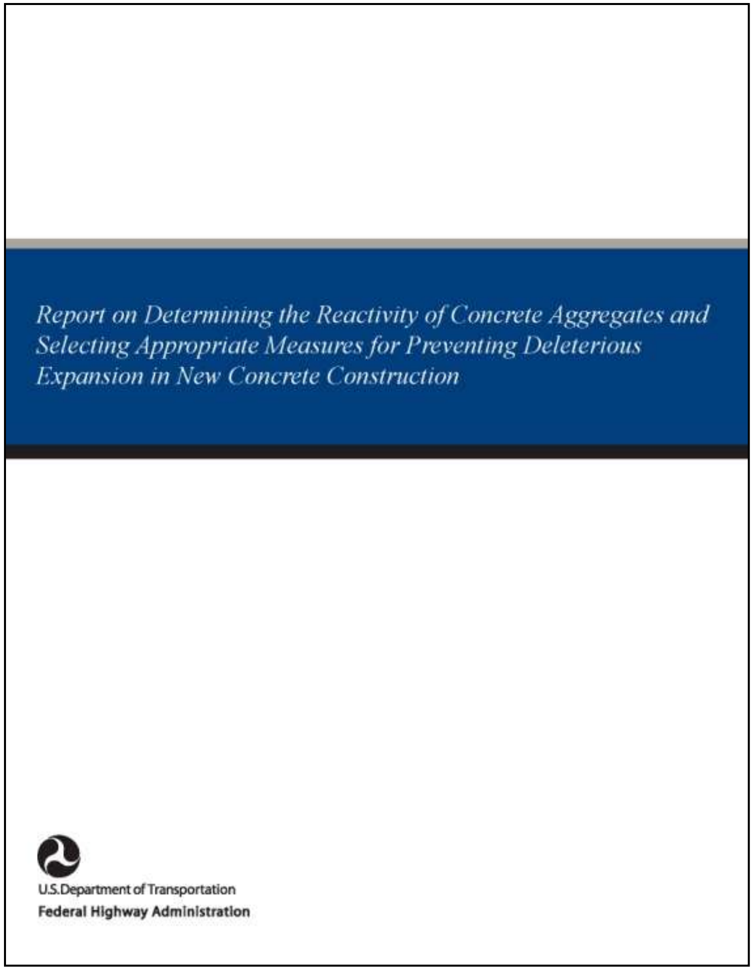
- ↑ technical information on:
  - ASR and ACR
  - AAR test methods & recommendations for use (or not !)
  - Preventive measures against ASR and laboratory test methods
  - Managing AAR-affected concrete structures

FHWA – Protocol for Preventing ASR

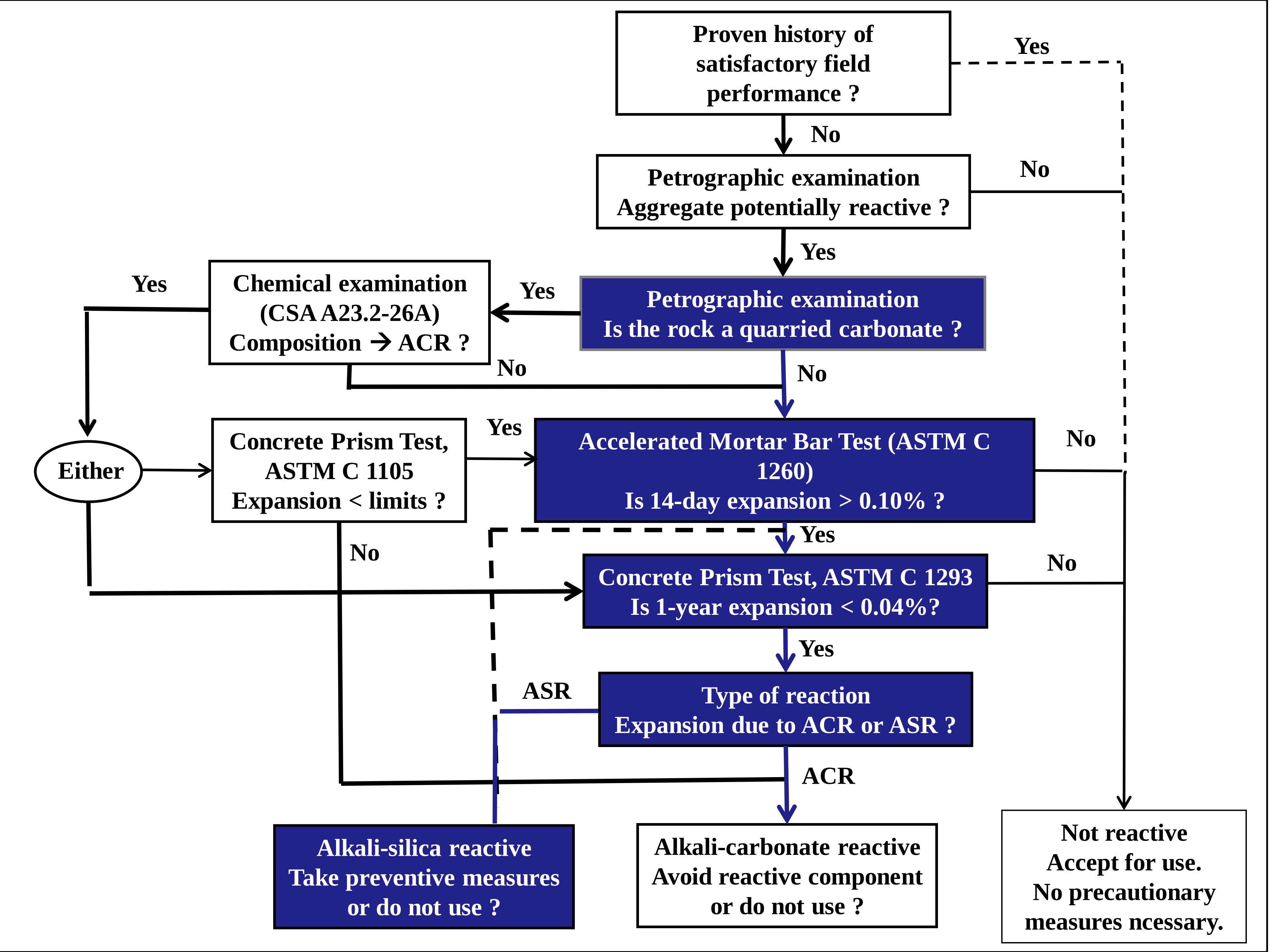
Thomas, Fournier & Folliard, 2008 → FHWA-HIF-09-001

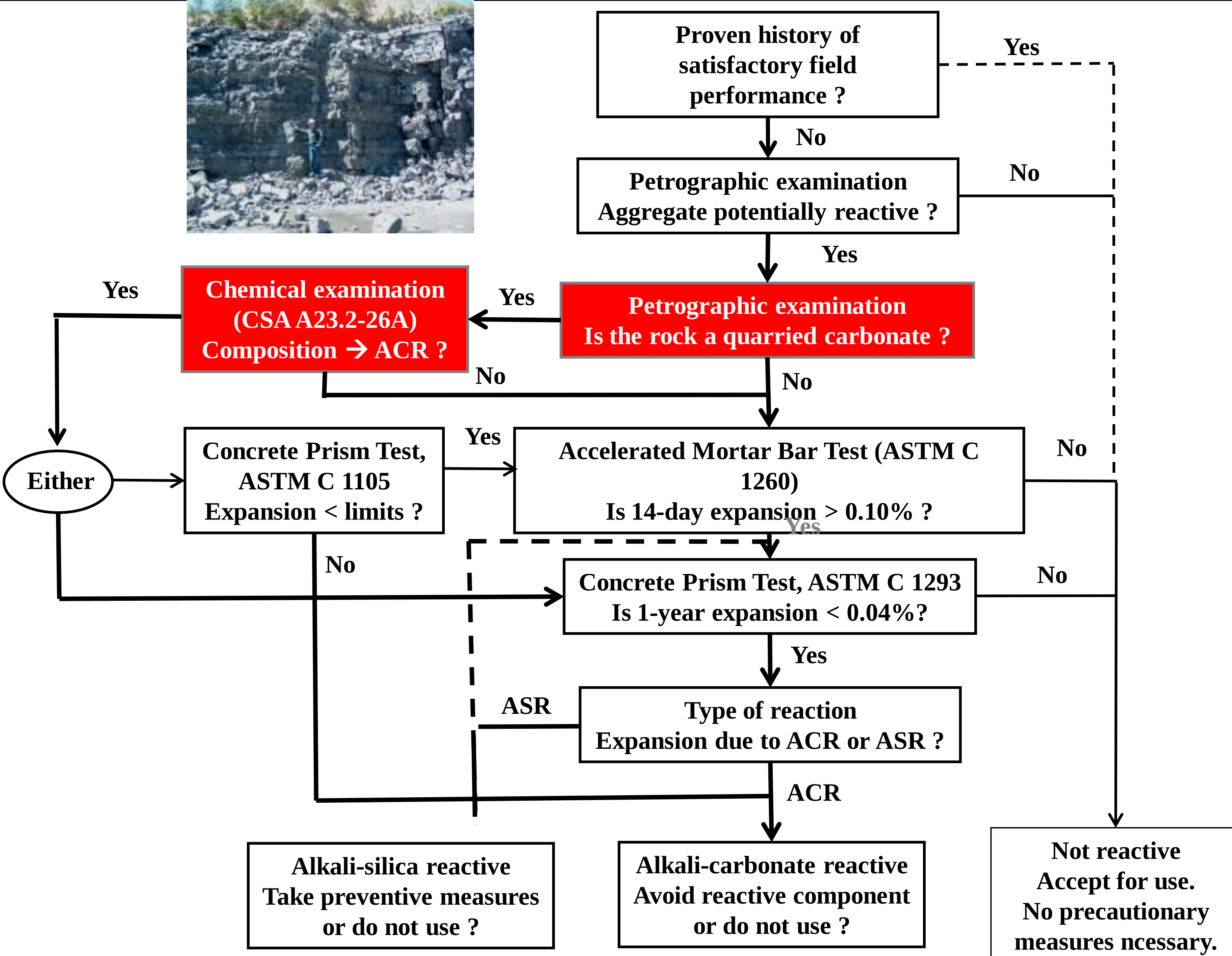
Document developed under the SAFETEA-LU legislation → develop and deploy techniques to prevent and mitigate ASR in concrete

AASHTO Designation PP65-10


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

U.S. Department of Transportation
Federal Highway Administration

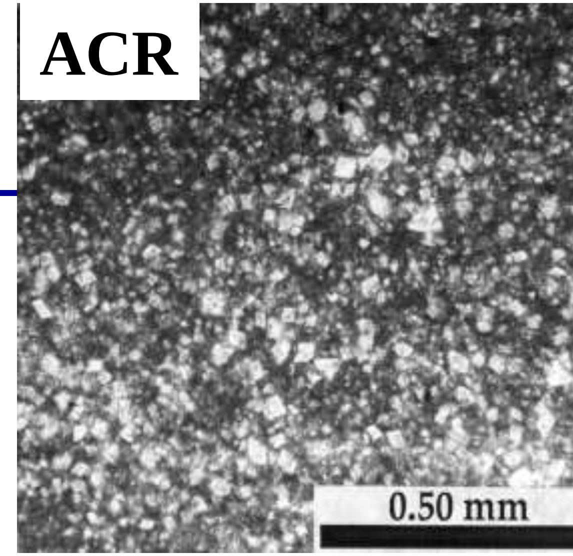

Proven history of satisfactory field performance ?
Yes
No
Petrographic examination Aggregate potentially reactive ?
No
Yes
Chemical examination (CSA A23.2-26A) Composition → ACR ?
Yes
Yes
Petrographic examination Is the rock a quarried carbonate ?
No
No
Either
Concrete Prism Test, ASTM C 1105 Expansion < limits ?
Yes
Accelerated Mortar Bar Test (ASTM C 1260) Is 14-day expansion > 0.10% ?
No
No
Yes
Concrete Prism Test, ASTM C 1293 Is 1-year expansion < 0.04%?
No
Yes
ASR
Type of reaction Expansion due to ACR or ASR ?
ACR
Alkali-silica reactive Take preventive measures or do not use ?
Alkali-carbonate reactive Avoid reactive component or do not use ?
Not reactive Accept for use. No precautionary measures ncessary.

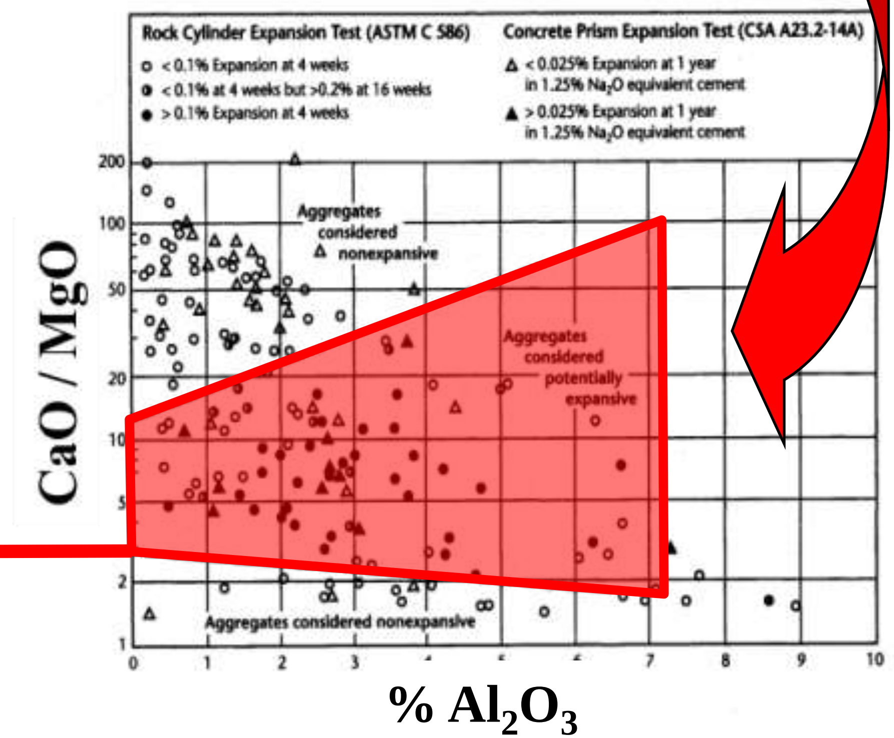


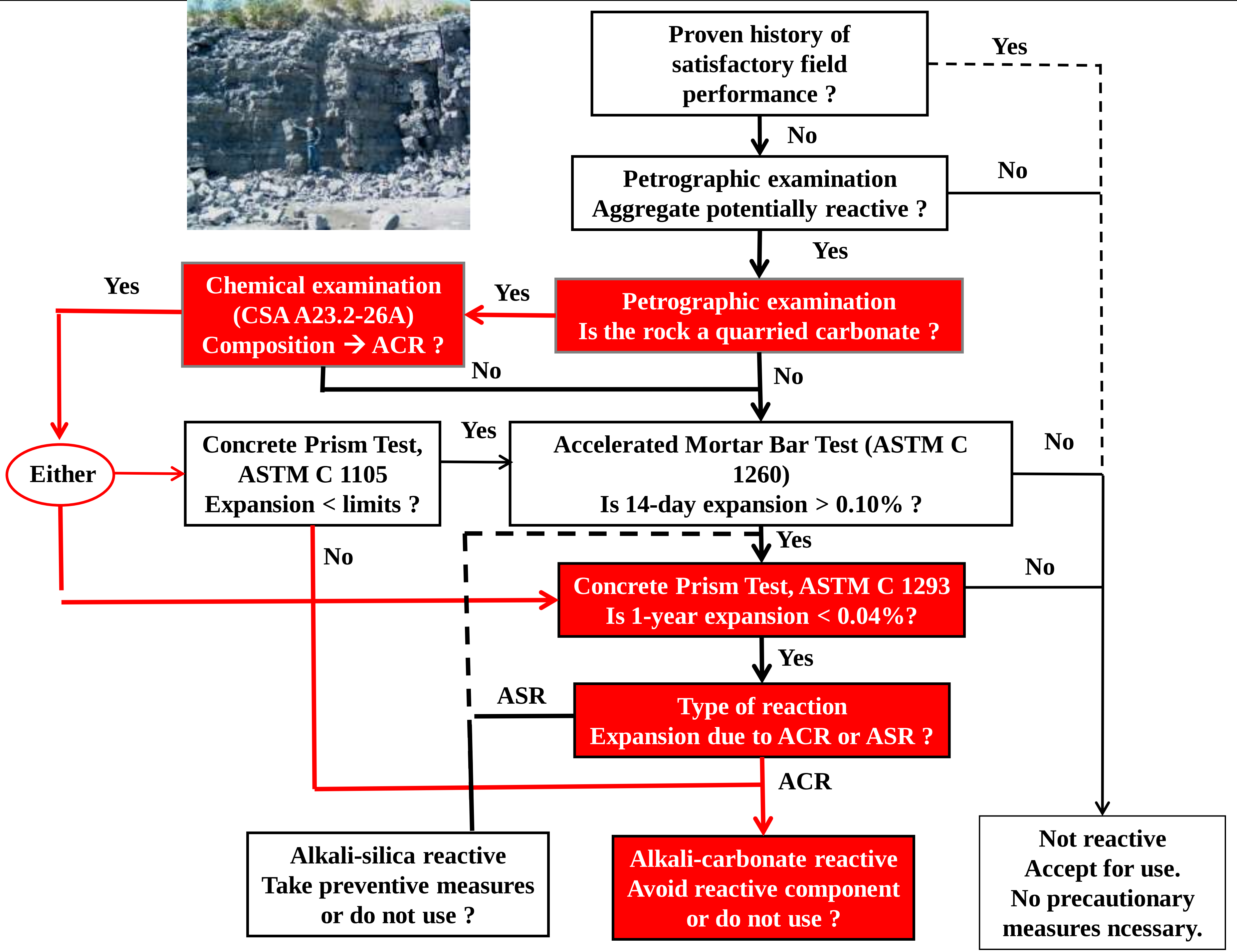
Proven history of satisfactory field performance ?
Yes
No
Petrographic examination
Aggregate potentially reactive ?
No
Yes
Petrographic examination
Is the rock a quarried carbonate ?
Yes
Chemical examination
(CSA A23.2-26A)
Composition → ACR ?
Yes
No
No
Either
Concrete Prism Test,
ASTM C 1105
Expansion < limits ?
Yes
Accelerated Mortar Bar Test (ASTM C 1260)
Is 14-day expansion > 0.10% ?
No
Yes
No
Concrete Prism Test, ASTM C 1293
Is 1-year expansion < 0.04%?
No
Yes
ASR
Type of reaction
Expansion due to ACR or ASR ?
ACR
Alkali-silica reactive
Take preventive measures
or do not use ?
Alkali-carbonate reactive
Avoid reactive component
or do not use ?
Not reactive
Accept for use.
No precautionary
measures ncessary.

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

- Screen test for quarried carbonate rocks
- Chemical analysis for Al_2O_3, MgO and CaO
- Zones for aggregates considered potentially expansives or non-expansives (ACR)
- Next step → Concrete Prism Test






Proven history of satisfactory field performance ?
Yes
No
Petrographic examination Aggregate potentially reactive ?
No
Yes
Chemical examination (CSA A23.2-26A) Composition → ACR ?
Yes
Yes
Petrographic examination Is the rock a quarried carbonate ?
No
No
Either
Concrete Prism Test, ASTM C 1105 Expansion < limits ?
Yes
Accelerated Mortar Bar Test (ASTM C 1260) Is 14-day expansion > 0.10% ?
No
No
Yes
Concrete Prism Test, ASTM C 1293 Is 1-year expansion < 0.04%?
No
Yes
ASR
Type of reaction Expansion due to ACR or ASR ?
ACR
Alkali-silica reactive Take preventive measures or do not use ?
Alkali-carbonate reactive Avoid reactive component or do not use ?
Not reactive Accept for use. No precautionary measures ncessary.

Alkali-Carbonate Reaction (ACR)

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**

A23.2-27A

Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete

1 Scope

RILEM TC ACS

AAR-7.1

RILEM TC ACS: Alkali-Aggregate Reactions in Concrete Structures

International Specification to Minimise Damage from Alkali Reactions in Concrete: Part 1 Alkali-Silica Reaction

SPECIFICATION TO COMBAT DAMAGE FROM ALKALI REACTIONS IN CARBONATE AGGREGATES: AAR-7.2

Proposals of RILEM TC ACS

AASHTO Standard Recommended Practice

Scope → This practice describes approaches for:

- **Selecting preventive measures against AAR**
  - **Performance approach**
  - **Prescriptive approach → 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 ≤ 0.30
R2	Highly reactive	0.120 – 0.240	0.30 > Exp ≤ 0.45
R3	Very highly reactive	> 0.240	> 0.45

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Step 2 – Determine Risk Level of ASR (1 → 6)

Size and exposure conditions	Aggregate-Reactivity Class			
	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

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Step 3 – Determine the Level of Prevention (V → ZZ)

Level of ASR Risk (Table 4)	Classification of Structure (Table 4)			
	S1	S2	S3	S4
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.

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Step 4 – Classify Structure → 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

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Step 4 – Classify Structure → 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

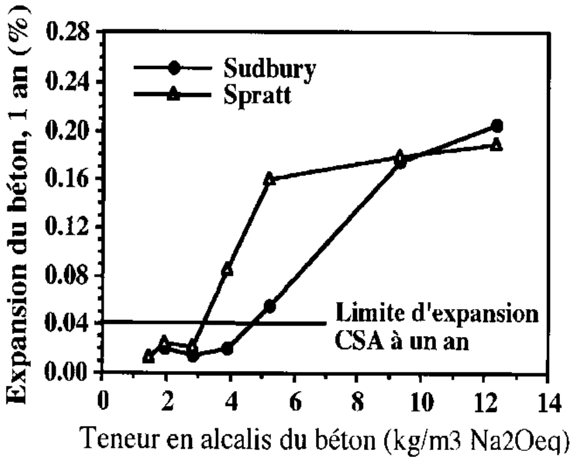
FHWA – Protocol for Preventing ASR – Prescriptive Approach

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

FHWA – Protocol for Preventing ASR – Prescriptive Approach

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

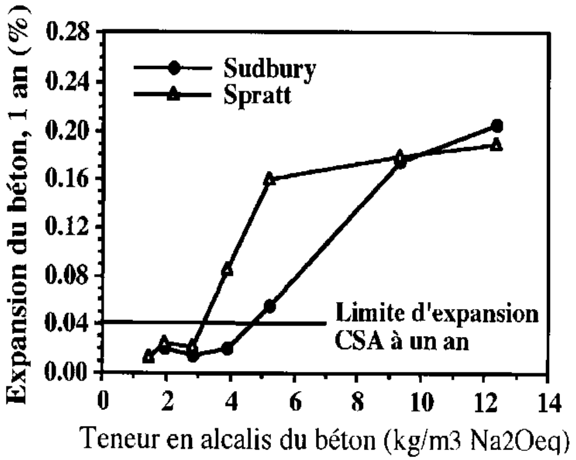
- **Limit Alkali Content of Concrete**



FHWA – Protocol for Preventing ASR – Prescriptive Approach

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

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



FHWA – Protocol for Preventing ASR – Prescriptive Approach

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

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

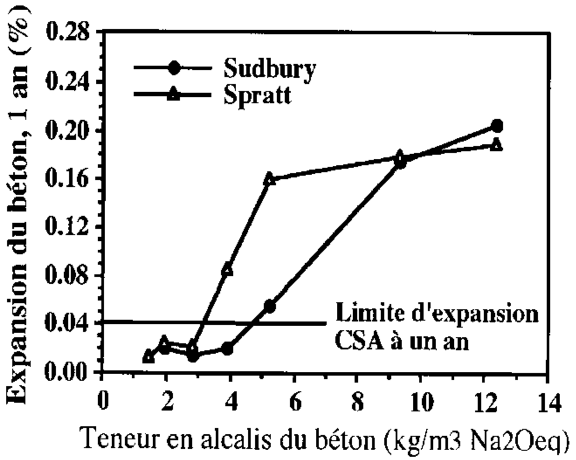


Table 5 Maximum Alkali Contents (from Portland Cement) to Provide Various Levels of Prevention

Prevention Level	Maximum alkali content of concrete (Na_2Oe), kg/m^3
V	No limit
W	3.0
X	2.4
Y	1.8
Z	Table 8
ZZ	

Concrete alkali content (kg/m^3, Na_2Oeq)

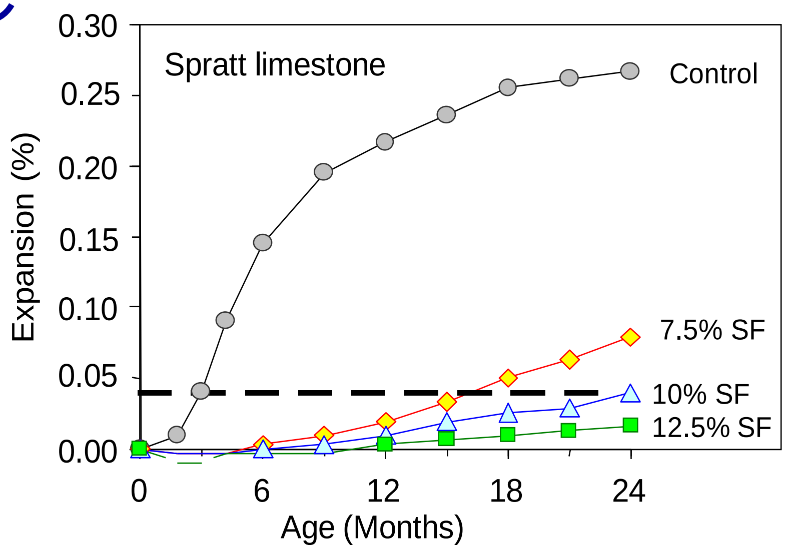
Prevention Level	Maximum alkali content of concrete (Na_2Oe), kg/m^3
V	No limit
W	3.0
X	2.4
Y	1.8
Z	Table 8
ZZ	

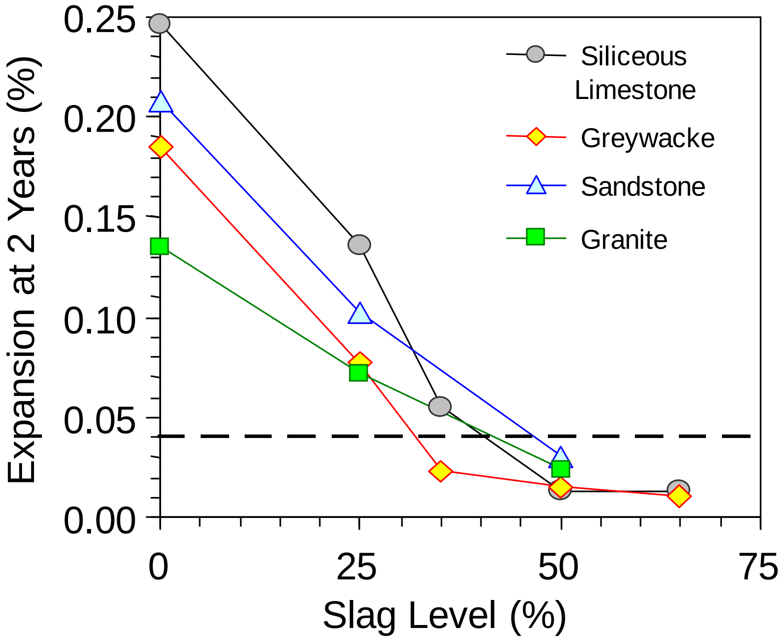
Cement content (kg/m^3)	Cement alkali content (% Na_2Oeq)						
	0.5	0.6	0.7	0.8	0.9	1.0	1.1
	Concrete alkali content (kg/m^3 Na_2Oeq)						
225	1.1	1.4	1.6	1.8	2.0	2.3	2.5
250	1.3	1.5	1.8	2.0	2.3	2.5	2.8
275	1.4	1.7	1.9	2.2	2.5	2.8	3.0
300	1.5	1.8	2.1	2.4	2.7	3.0	3.3
325	1.6	2.0	2.3	2.6	2.9	3.3	3.6
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

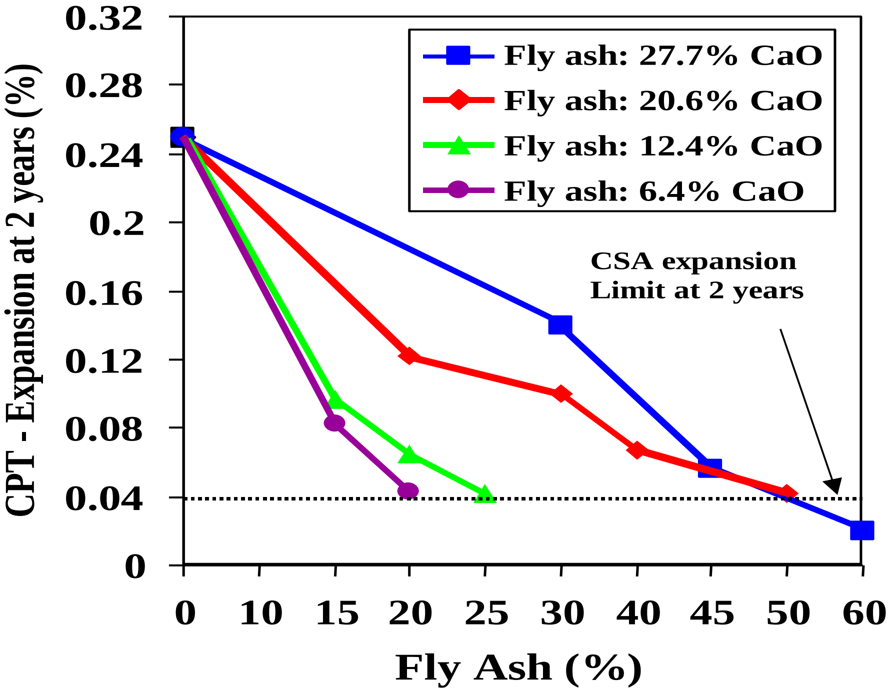
Table 6: Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash (CaO ≤ 18%)	< 3.0	15	20	25	35	Table 8
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† (SiO_2 > 85%)	< 1.0	2.0 x KGA	2.5 x KGA	3.0 x KGA	4.0 x KGA	

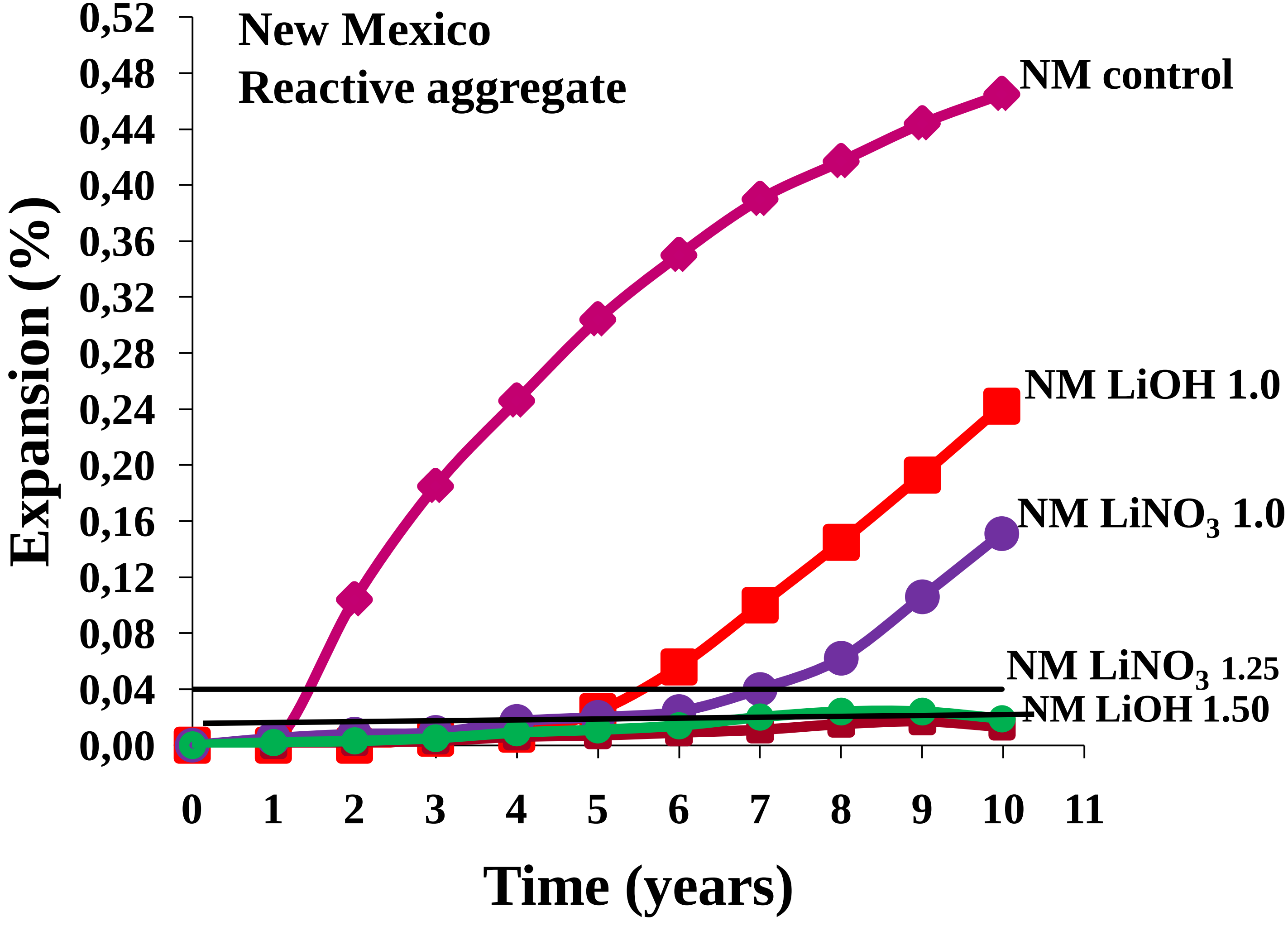
Laboratory testing

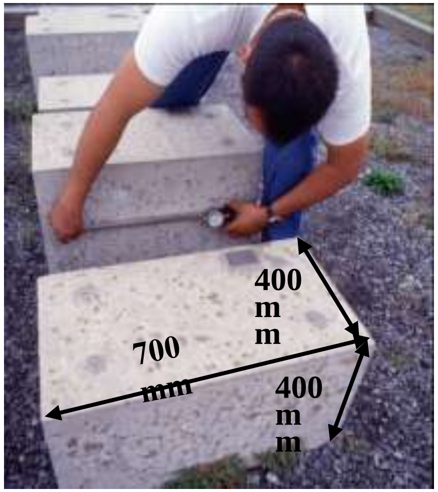






Exposure blocks





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 Provide Various Levels of Prevention

<table>
<tr><th rowspan="2">Type of SCM</th><th rowspan="2">Alkali level of SCM (% Na_2Oe)</th><th colspan="5">Minimum Replacement Level (% by mass)</th></tr>
<tr><th>Level W</th><th>Level X</th><th>Level Y</th><th>Level Z</th><th>Level ZZ</th></tr>
<tr><td rowspan="2">Fly ash (CaO ≤ 18%)</td><td>< 3.0</td><td>15</td><td>20</td><td>25</td><td>35</td><td rowspan="4">Table 8</td></tr>
<tr><td>3.0 – 4.5</td><td>20</td><td>25</td><td>30</td><td>40</td></tr>
<tr><td>Slag</td><td>< 1.0</td><td>25</td><td>35</td><td>50</td><td>65</td></tr>
<tr><td>Silica Fume† (SiO_2 > 85%)</td><td>< 1.0</td><td>2.0 x KGA</td><td>2.5 x KGA</td><td>3.0 x KGA</td><td>4.0 x KGA</td></tr>
</table>

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Using Combinations of SCM's

Table 6 indicates that either 30% fly ash or 50% slag or 10% silica fume is required → blend of A% fly ash + B% slag + C% silica fume:

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

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Using Combinations of SCM's

Table 6 indicates that either 30% fly ash or 50% slag or 10% silica fume is required → blend of A% fly ash + B% slag + C% silica fume:

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

20% Fly ash + 3.3% Silica Fume

30% Slag + 4% Silica Fume

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Table 7: Adjusting Minimum SCM Level Based on Cement Alkalis

Cement Alkalis (% Na_2Oe)	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

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Cement Alkalis (% Na_2Oe)	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

Table 6: Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ($CaO \leq 18\%$)	< 3.0	15	20	25	35	Table 8
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† ($SiO_2 > 85\%$)	< 1.0	2.0 x KGA	2.5 x KGA	3.0 x KGA	4.0 x KGA	

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Cement Alkalis (% Na_2Oe)	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

Table 6: Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ($CaO \leq 18\%$)	< 3.0	15	20	25	35	Table 8
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† ($SiO_2 > 85\%$)	< 1.0	2.0 x KGA	2.5 x KGA	3.0 x KGA	4.0 x KGA	

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Cement Alkalis (% Na_2Oe)	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

Table 6: Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ($CaO \leq 18\%$)	< 3.0	15	20	25	35	Table 8
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† ($SiO_2 > 85\%$)	< 1.0	2.0 x KGA	2.5 x KGA	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 Level	SCM as sole prevention	Limiting concrete alkali content plus SCM	
	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

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Selecting Preventive level Z

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ($CaO \leq 18\%$)	< 3.0	15	20	25	35	
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	

SCM only

SCM + alkali control

Prevention Level	Maximum alkali content of concrete (Na_2Oe)	
	lb/yd^3	kg/m^3
V	No limit	
W	5.0	3.0
X	4.0	2.4
Y	3.0	1.8
Z	Table 8	
ZZ		

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Selecting Preventive level ZZ

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ($CaO \leq 18\%$)	< 3.0	15	20	25	**35**	**No !**
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	

SCM only

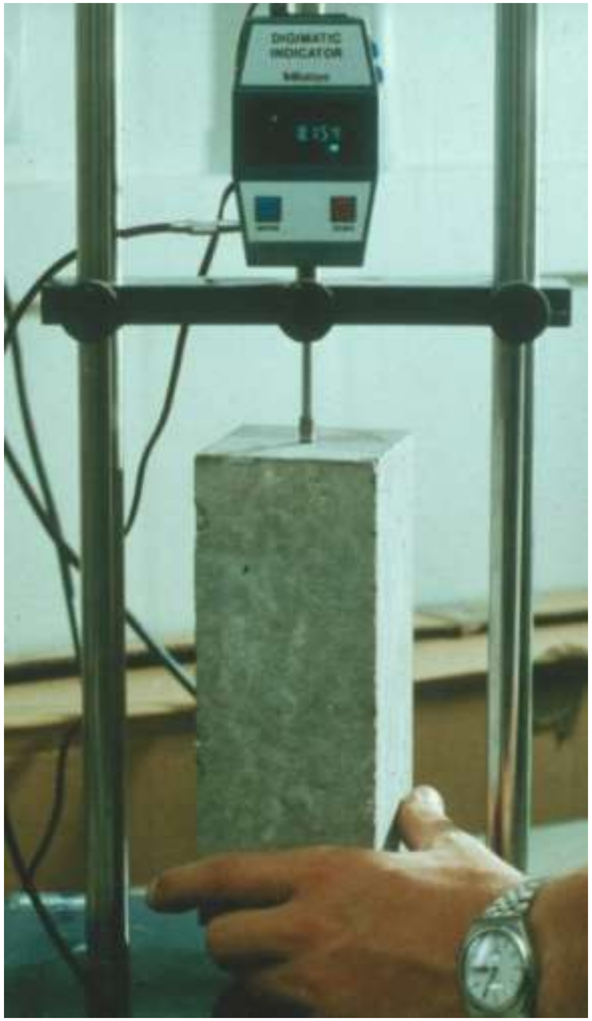
SCM + alkali control

Prevention Level	Maximum alkali content of concrete (Na_2Oe)	
	lb/yd^3	kg/m^3
V	No limit	
W	5.0	3.0
X	4.0	2.4
Y	3.0	**1.8**
Z	Table 8	
ZZ		

FHWA – Protocol for Preventing ASR – Performance Approach

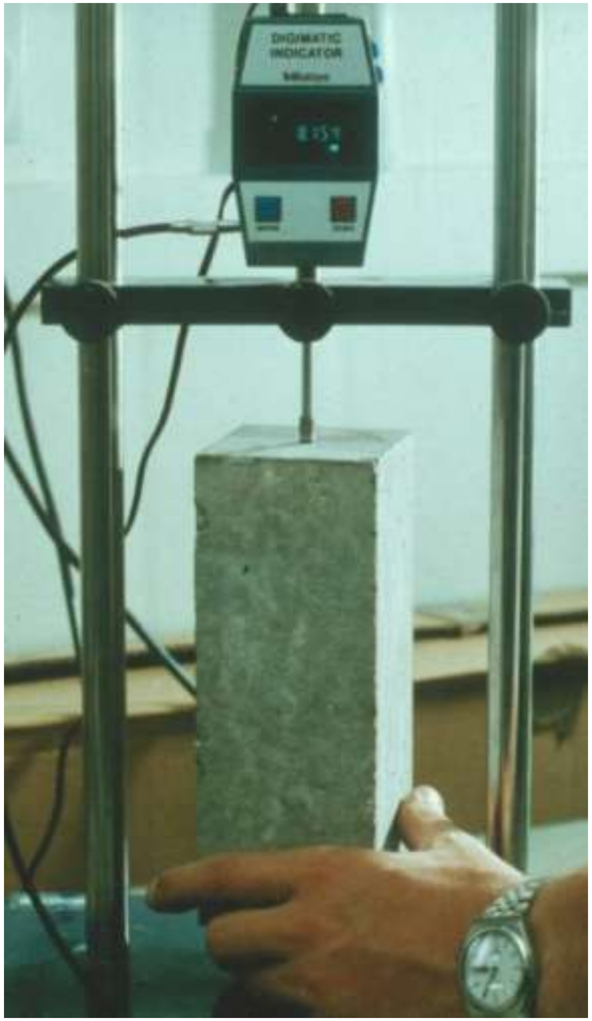
Evaluating SCMs using the CPT

1. Cementitious content = 420 kg/m^3
2. SCM's → partial replacement of PC
3. Alkalis raised to 1.25% Na_2Oe (cement portion)
4. W/CM = 0.42 to 0.45
   - Superplasticizer OK
   - Use VMA to ↓segregation
5. Expansion ≤ 0.04% at 2 years.



FHWA – Protocol for Preventing ASR – Performance Approach

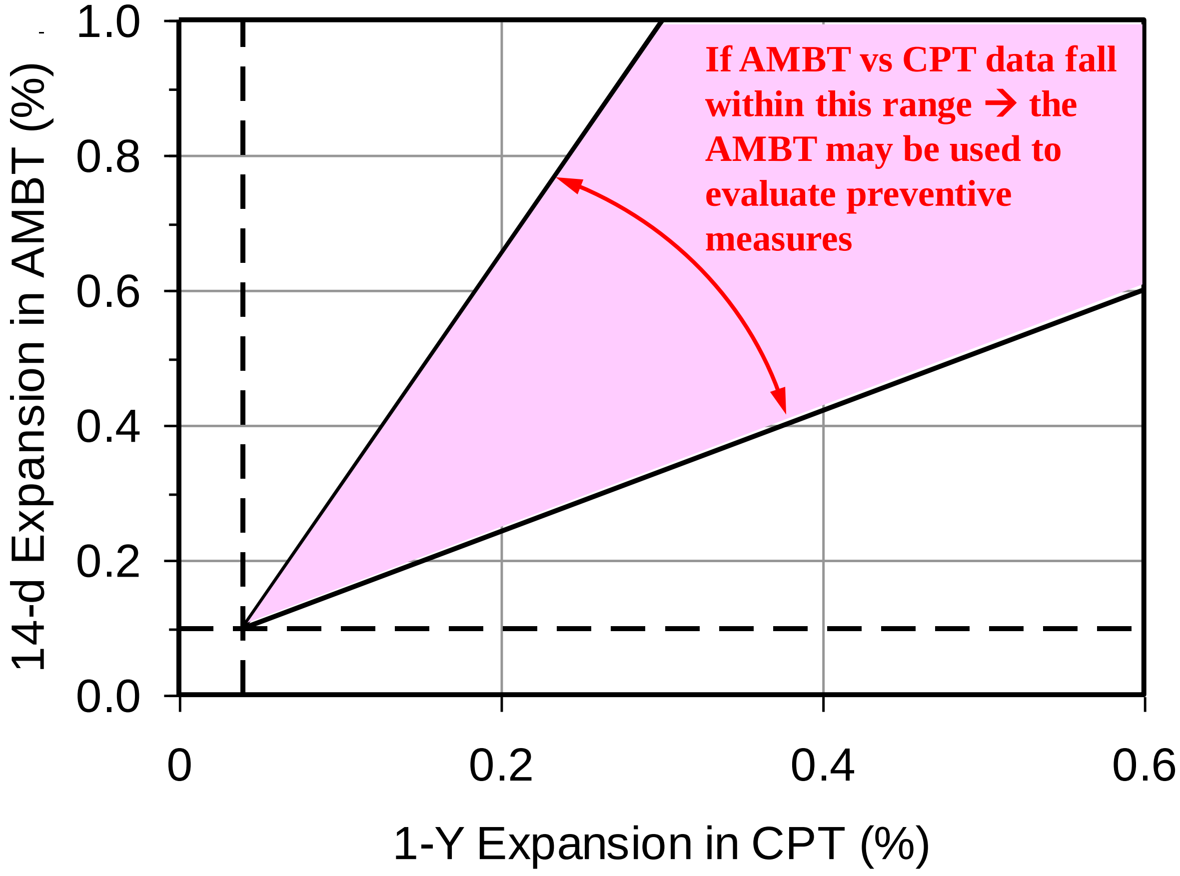
Evaluating $LiNO_3$ using the CPT



1. **Same mix proportions as for SCMs**
2. **$LiNO_3$ solution added to mix water at various levels**
3. **Expansion ≤ 0.04% at 2 years.**

Performance Testing using the AMBT

First establish correlation between AMBT & CPT for aggregate

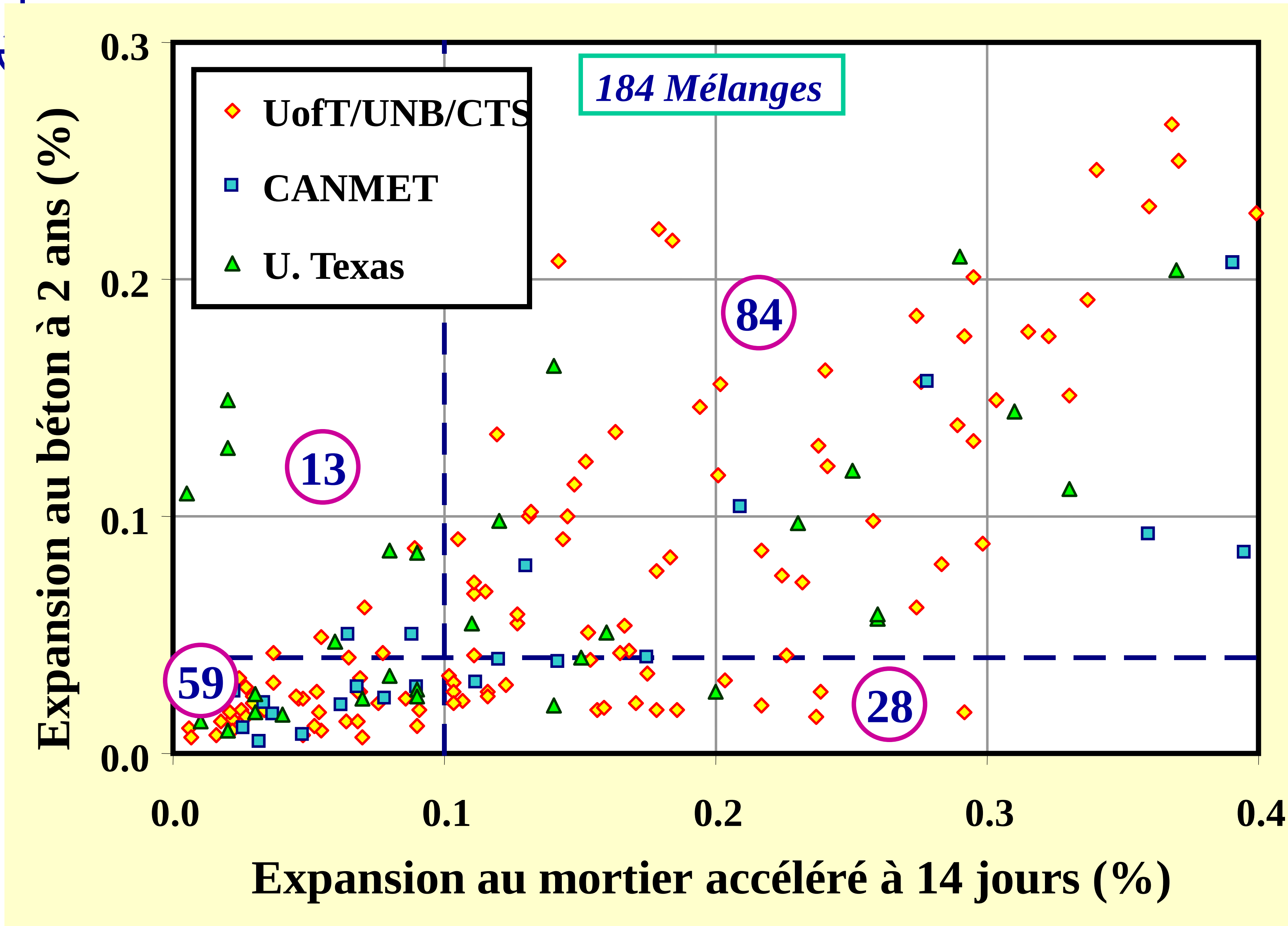


Performance Testing using the AMBT

Evaluating SCM's using the AMBT

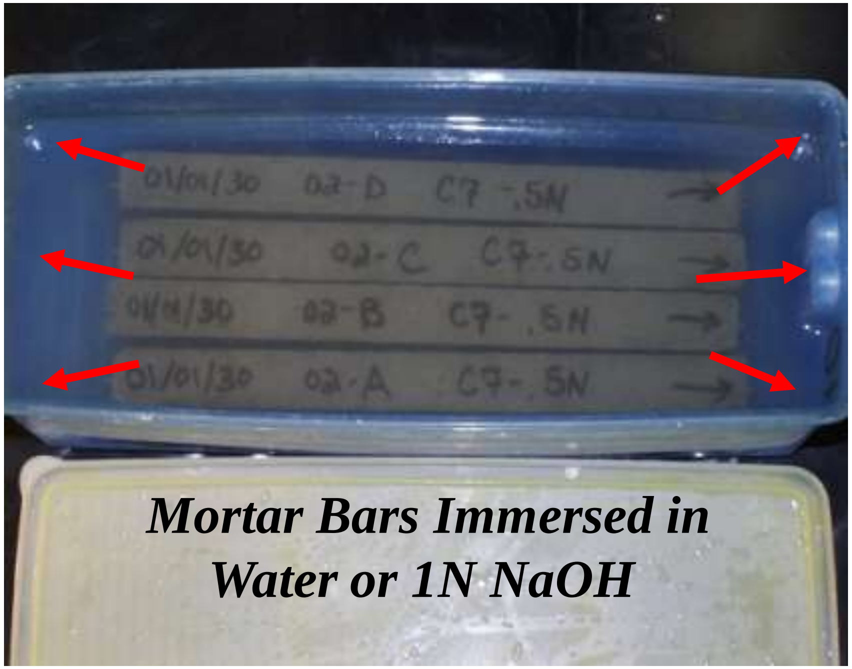
1. Use ASTM C 1567 except that the portland cement alkalis should be 0.90 ± 0.10% Na_2Oe
2. Do not use this test if fly ash alkalis > 4.5% Na_2Oe or alkali content of other SCM's > 1.0% Na_2Oe
3. Expansion < 0.10% at 14 days

14 jours mortier vs. 2 ans béton



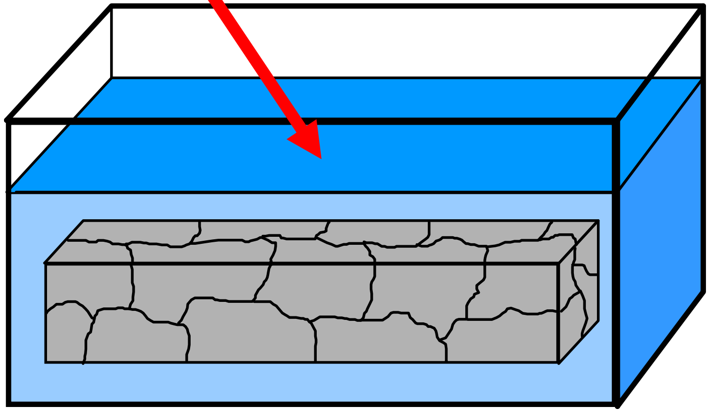
Accelerated testing for lithium dosage

- CPT is the preferred test → 2-year, 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)



Mortar Bars Immersed in Water or 1N NaOH

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



Performance Testing using the AMBT → $LiNO_3$

Begin by Testing the Aggregate with the following two mixtures:

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)

↓

Is the ((E2-E1)/E1) < 0.1

Yes

Use the following equation:
1.0 + 0.7 x ((E2-E1)/E1) = *Ratio*
The *Ratio* = [Li]/[Na+K] to use in concrete

No

Use concrete prisms test to evaluate the ratio to use

Tremblay et al. 2008

FHWA Protocol B

ASR Testing and Evaluation Protocols

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

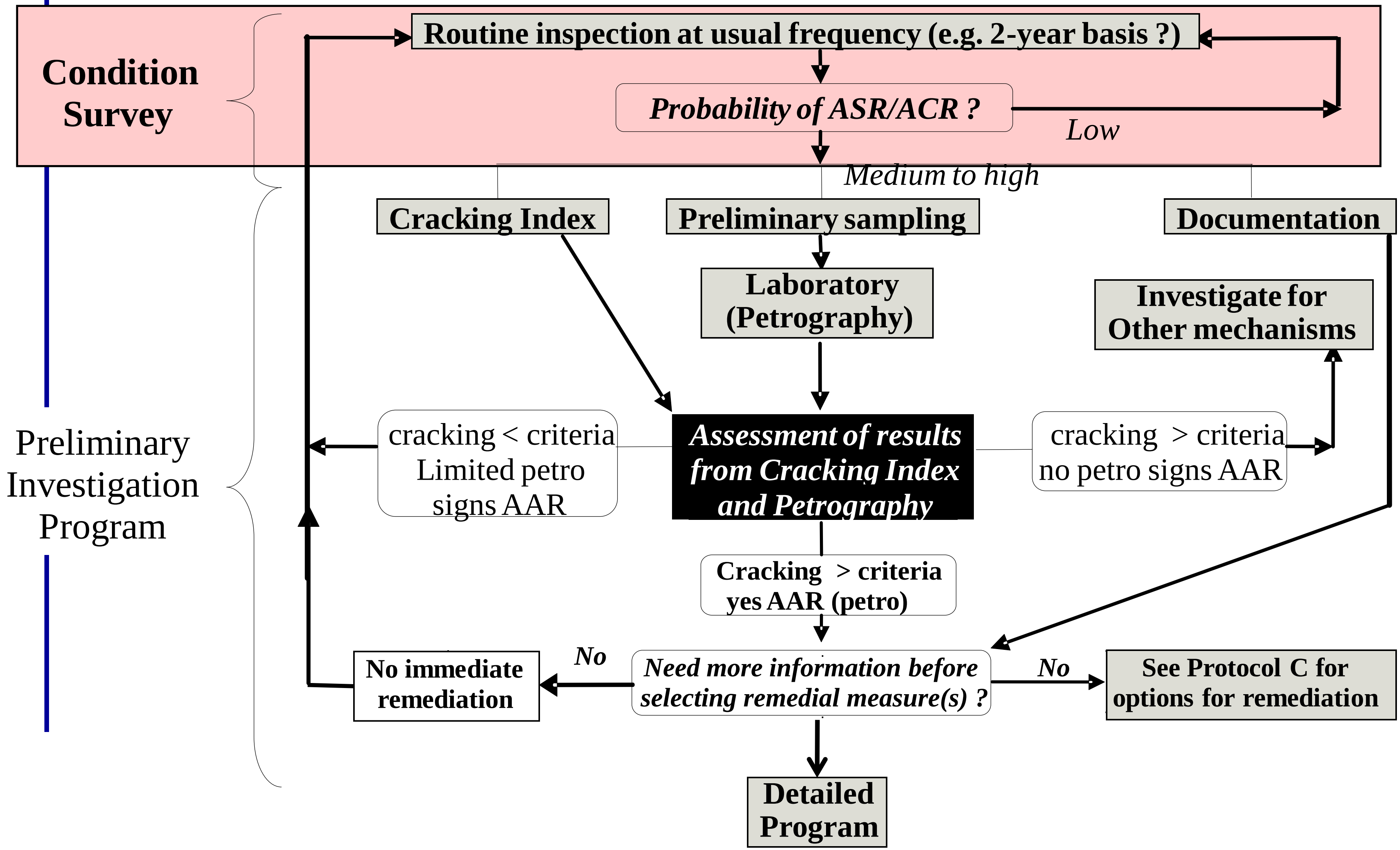
Benoit Fournier
Marc-André Bérubé
Michael Thomas
Kevin Folliard

The Transtec Group

THE TRANSTEC GROUP

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

Global Approach






Condition survey for AAR



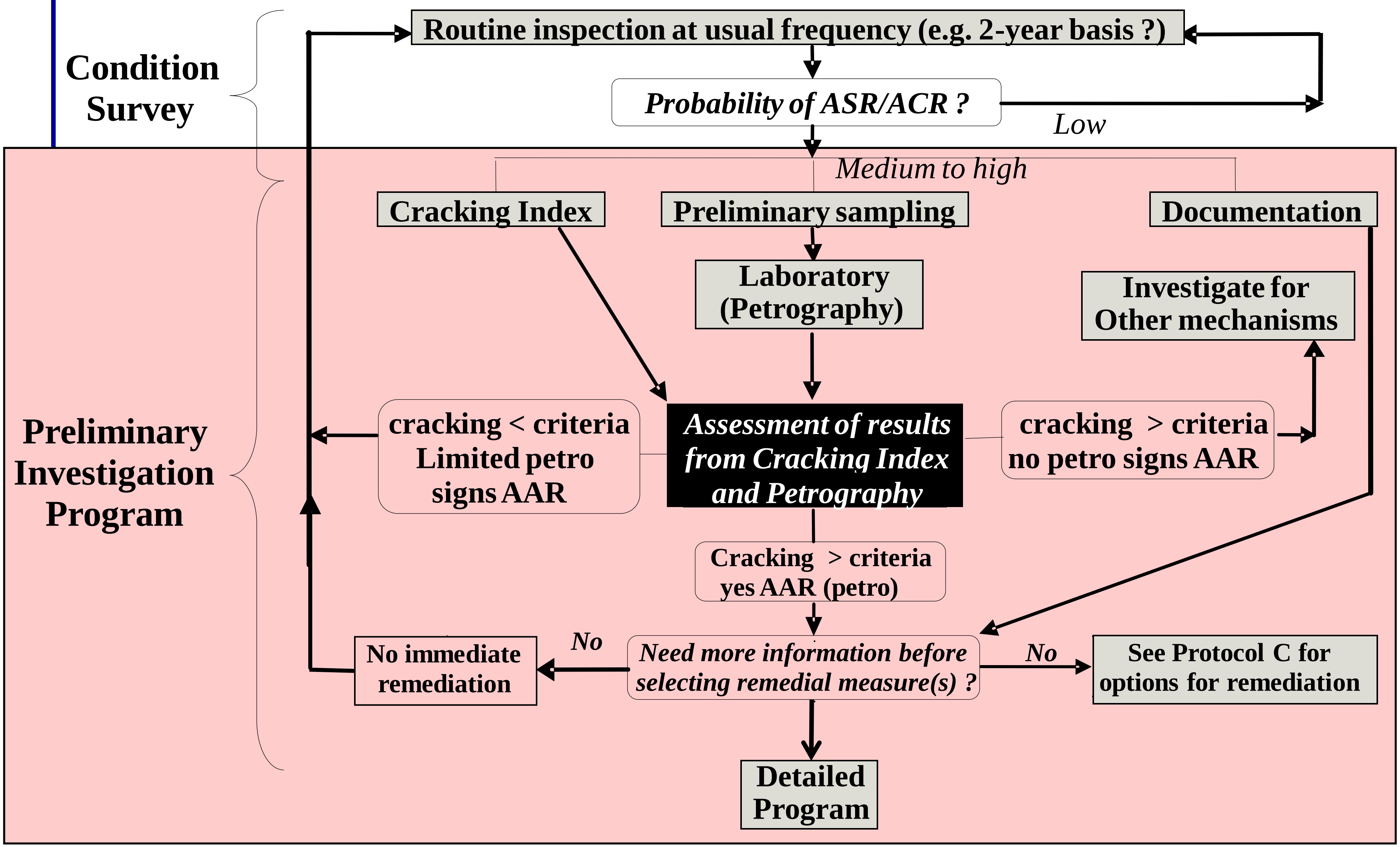



Classification System for the Condition Survey

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

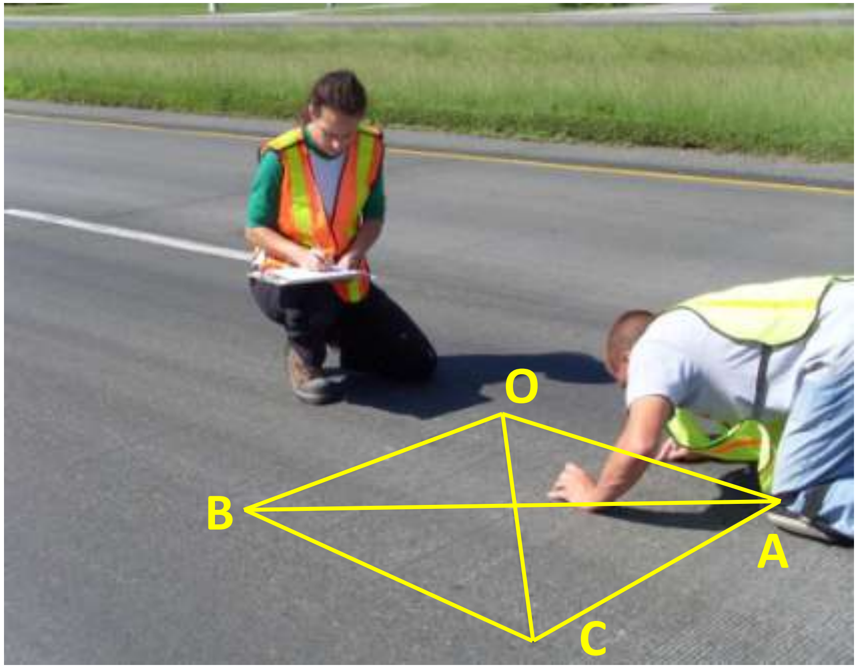
Probability of AAR ↑ with ↑ exposure to moisture

Global Approach

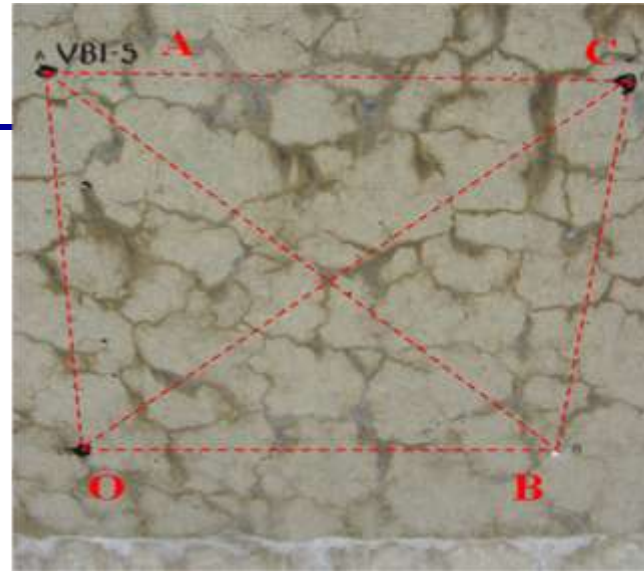


Cracking Index

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



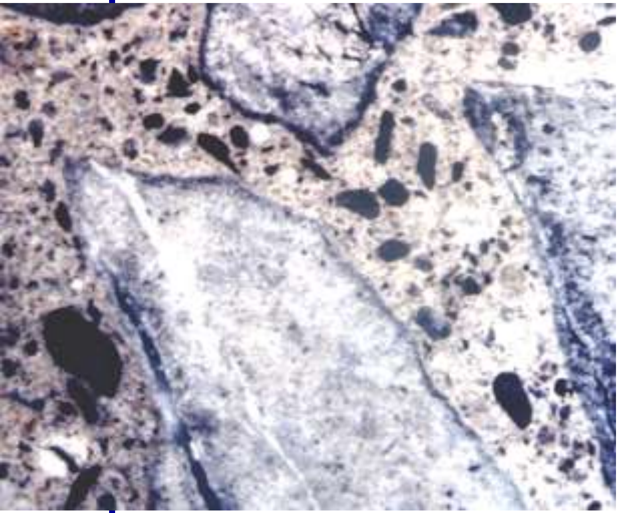
Cracking Index



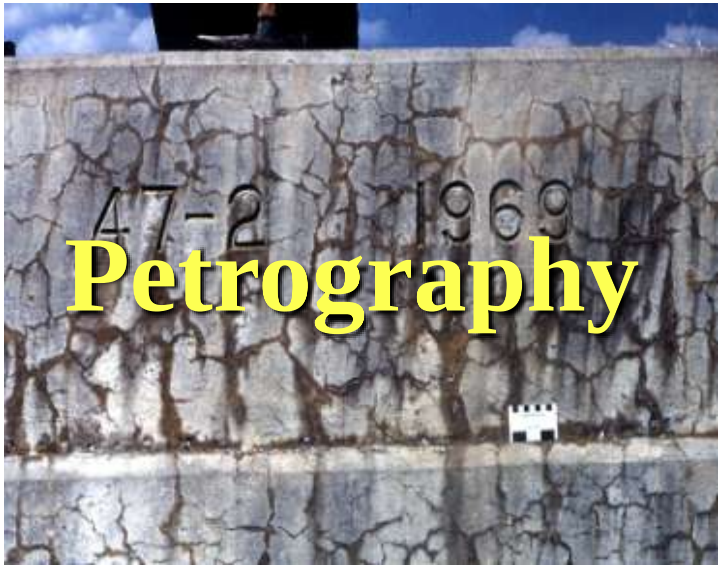
	1	2	3	4	5	Base Length (m)	# cracks	Crack opening (mm)			
Interval	6	7	8	9	10			Total sum	Avg. /crack	Avg. /m	C.I. mm/m
OA	0.1, 0.1	0.2	--	--	0.6	0.5	6	1.8	0.3	3.6	3.2
	0.4	--	--	0.4	--						
BC	0.1	0.4	--	0.1	0.1	0.5	7	1.4	0.2	2.8	
	--	0.3	0.2	0.2	--						
OB	--	--	0.3, 0.5	0.4	0.3	0.5	7	2.8	0.4	5.6	4.6
	0.4	0.3	--	--	0.6						
AC	0.5	0.2	--	--	0.3	0.5	8	1.6	0.2	3.6	
	0.05	0.05	0.1, 0.2	--	0.2						

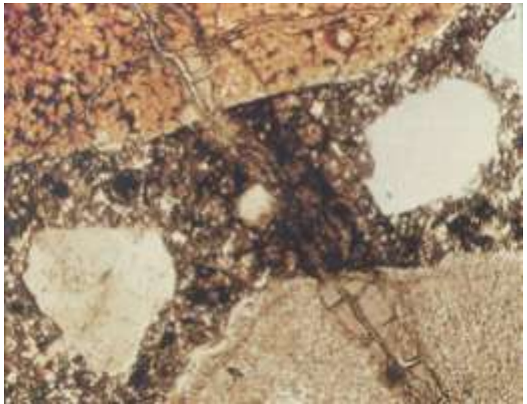
Preliminary Sampling Program

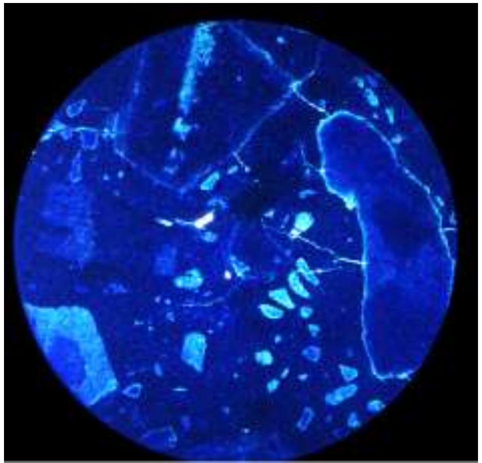
- Look for petrographic evidence of AAR
- Cores from components showing typical / more severe signs suggestive of AAR
- Cores from less deteriorated / exposed components



Petrography



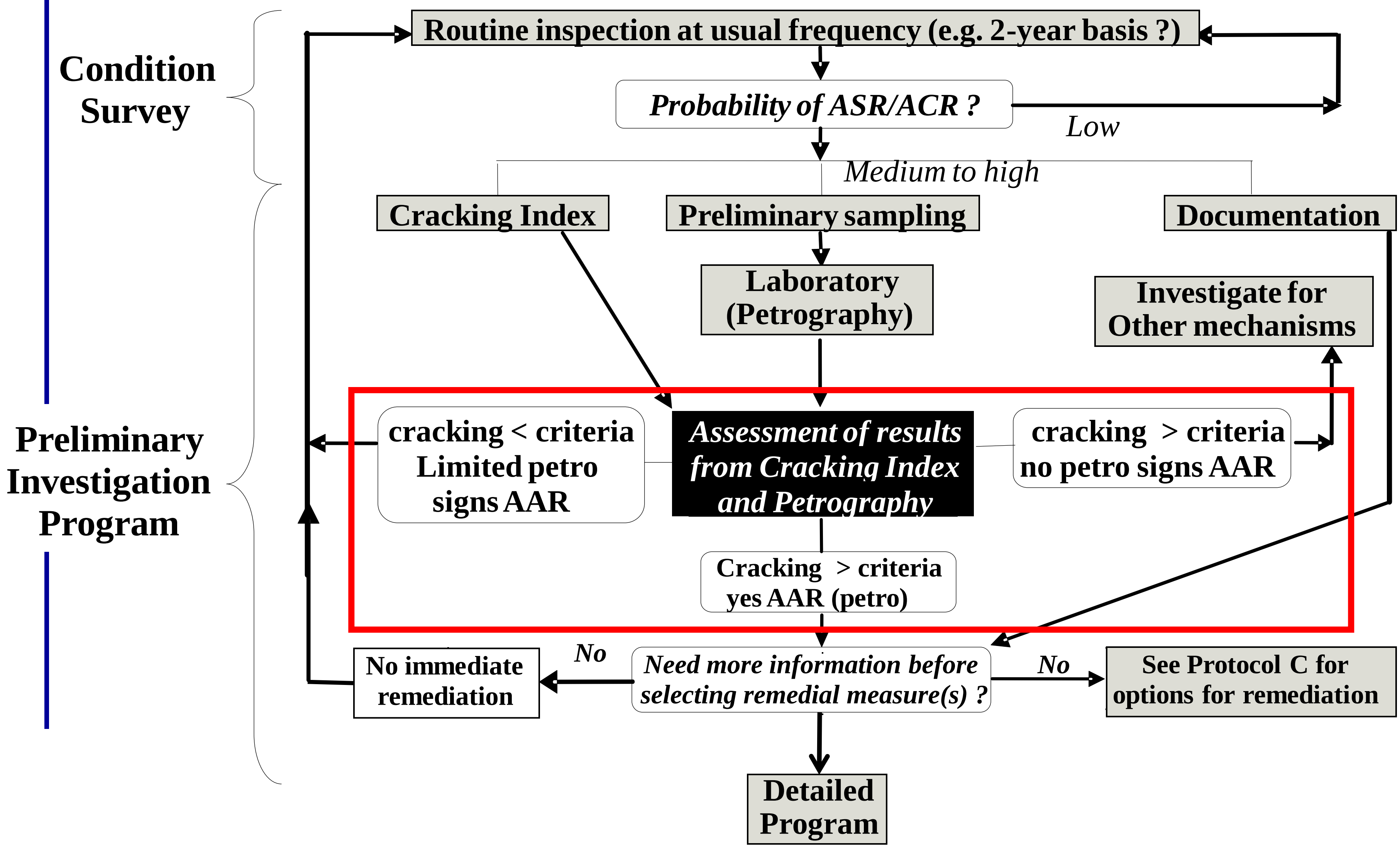




Interpretation of Results from Petrography

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

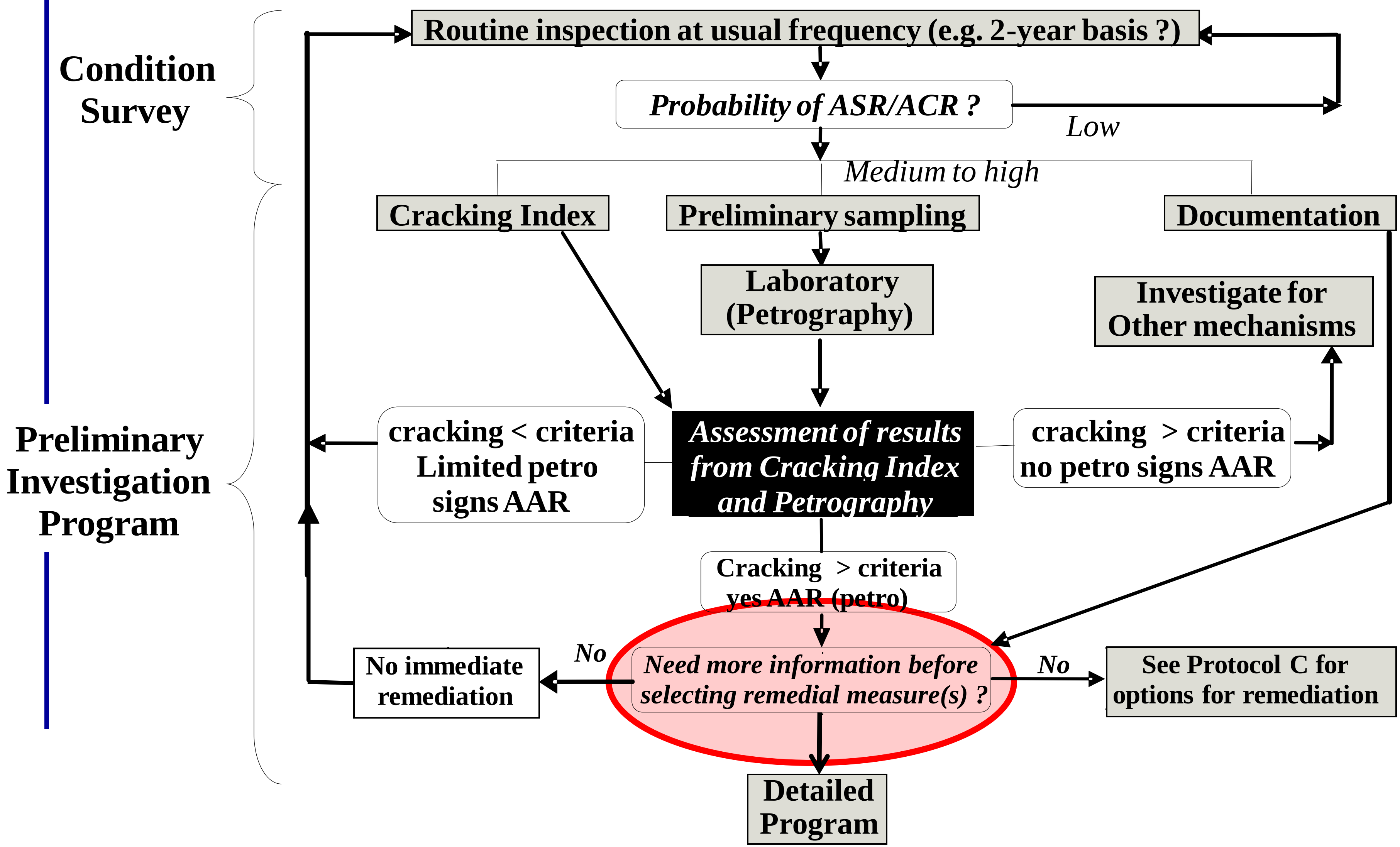
- *Cracking criteria* **proposed to identify an extent of cracking justifying more detailed investigations.**

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

Assessment from CI and Petrography

Criteria	Comments and Action
"Cracking" < criteria and Low 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 Medium to high 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. • Action: 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 Low 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). • Action: initiate further investigations for other mechanisms of deterioration, if required.
"Cracking" > criteria and Medium to high probability of AAR (from petrography)	• Presence of significant to extensive signs of ASR, both in-situ (cracking) and internally (petrography). • Action: 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



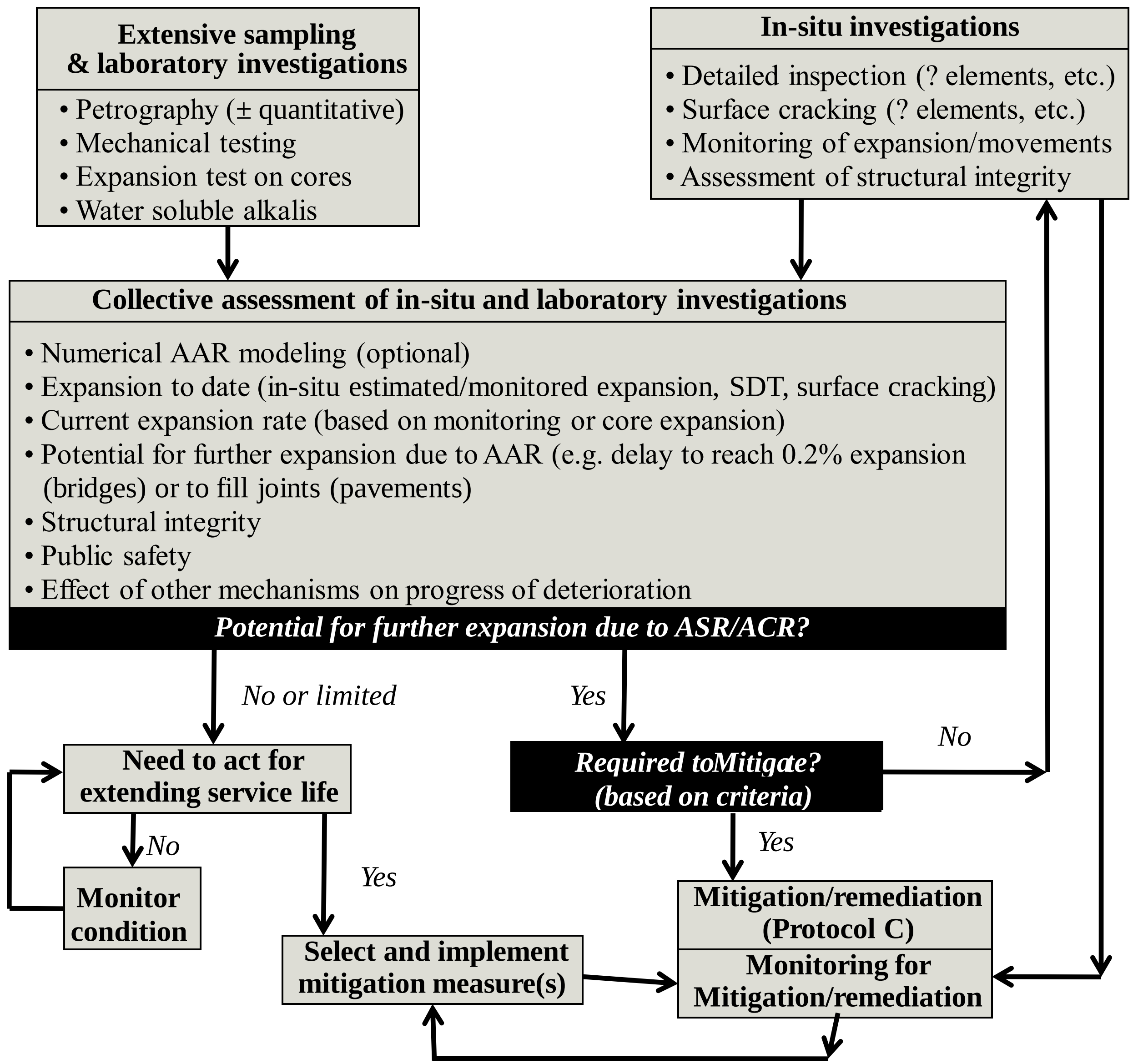
Structures Classification

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
S2	Some safety, economic or environmental consequences if major deterioration	Moderate risk of ASR is acceptable	▪ 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

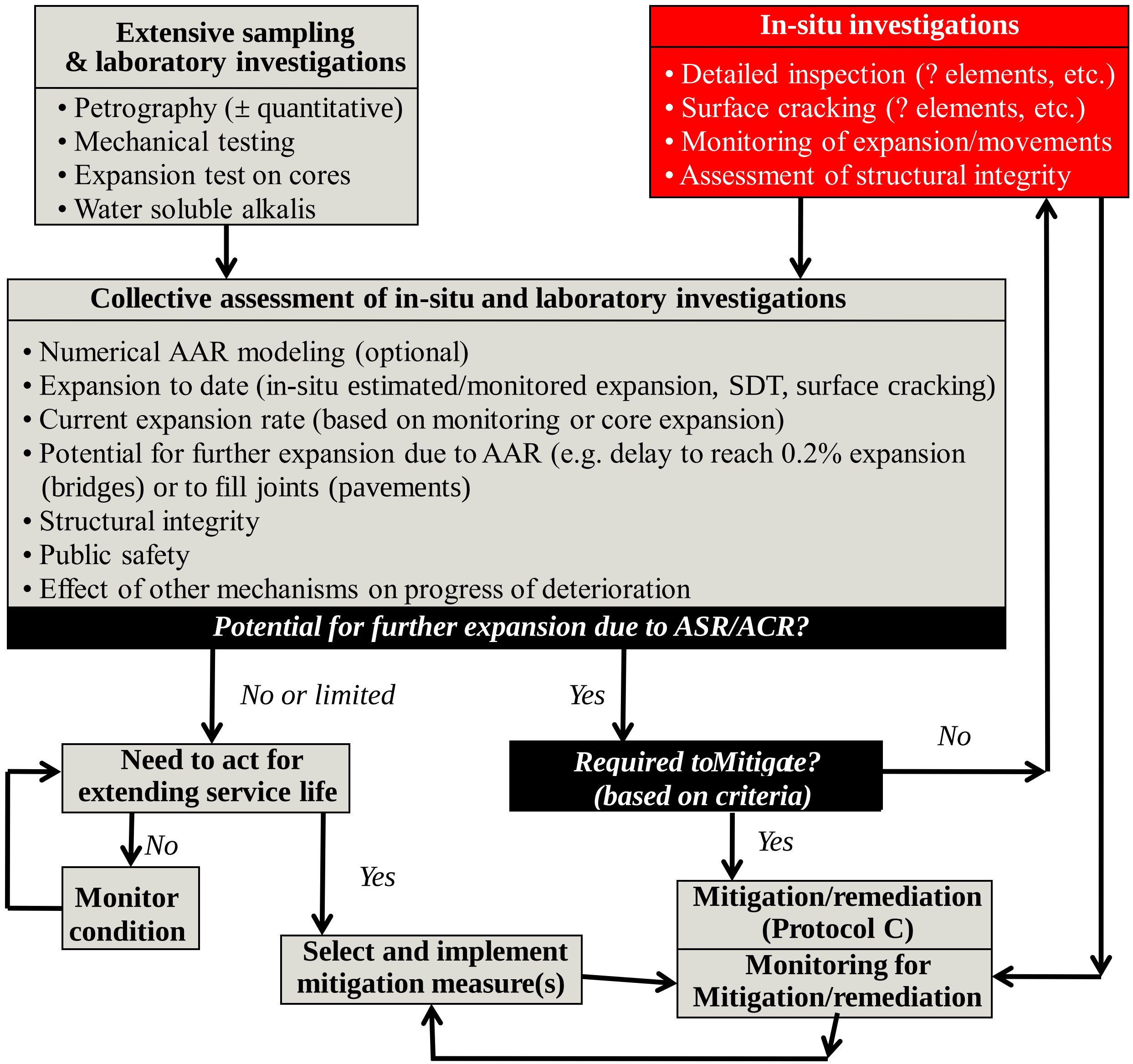
Necessity to Pursue Investigations

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).

Detailed Investigation Program



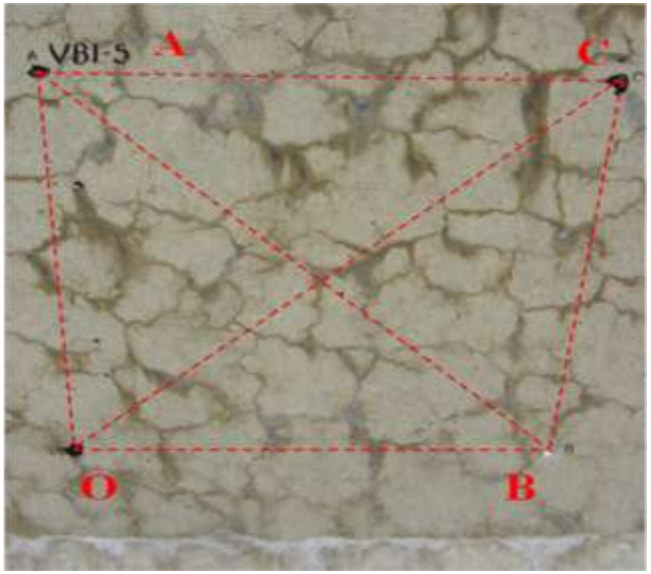
Detailed Investigation Program



Detailed Investigation Program

Information	In-situ testing
Expansion reached to date	• Preexisting monitoring • Crack widths on the affected concrete members
Current condition of the concrete	• Detailed visual inspection • Non-destructive testing • 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

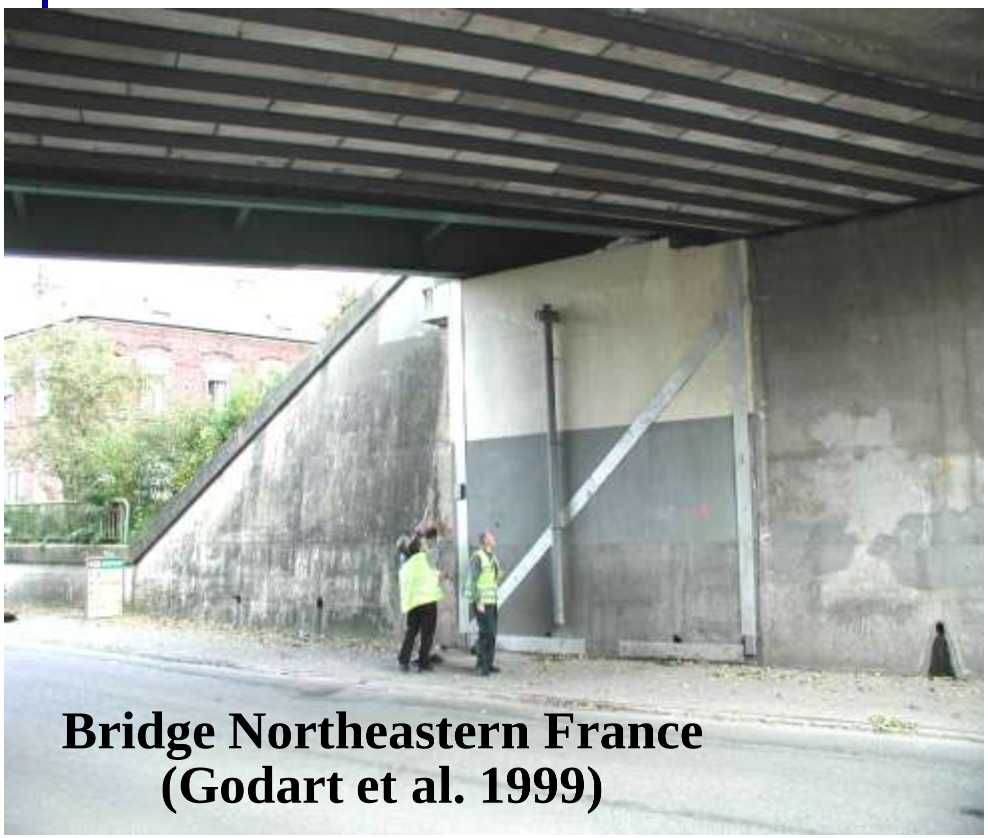
Deformation Measurements



Deformation Measurements

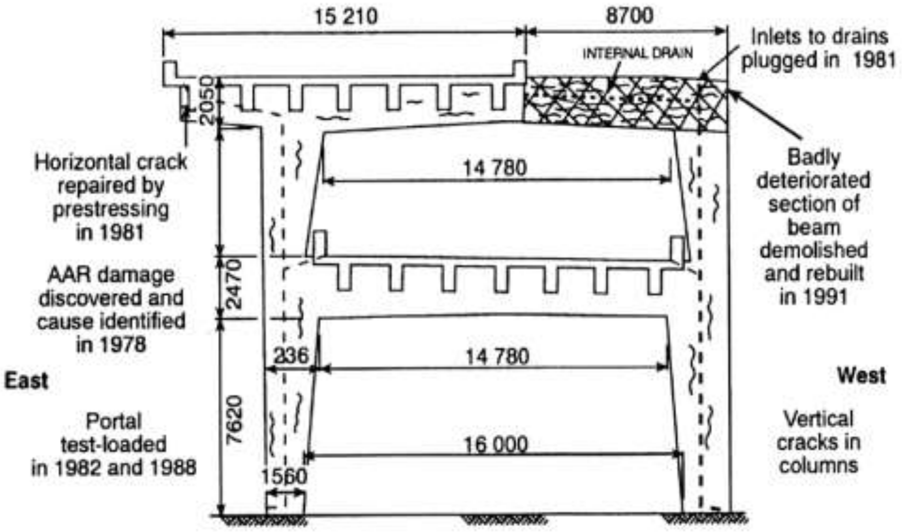
Deformation Measurements

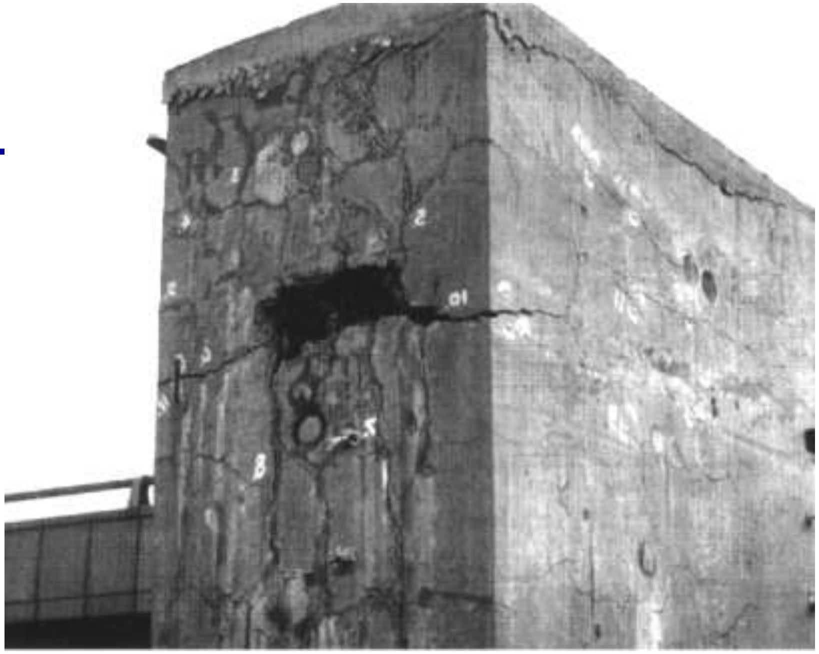
- **Infra-red "distancemeter"**



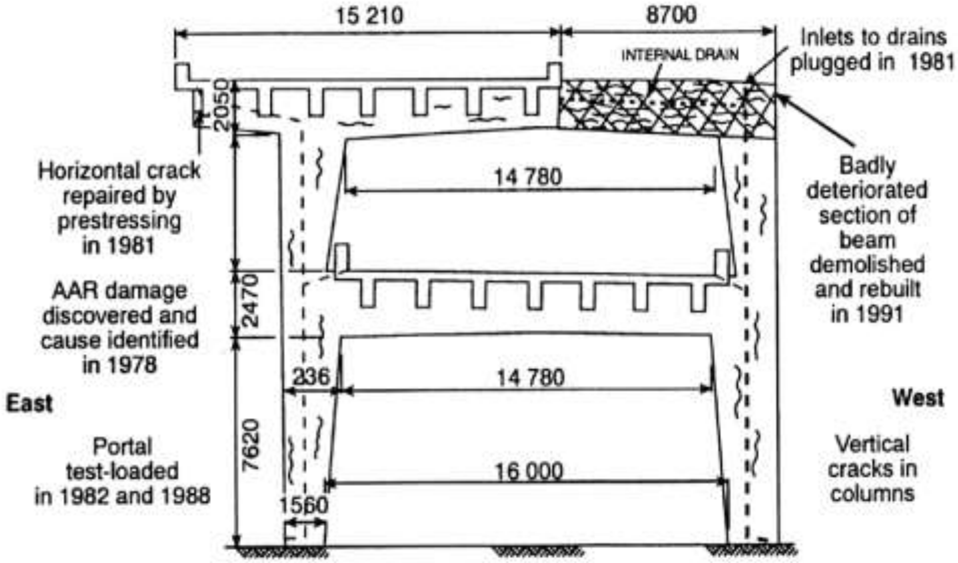
Bridge Northeastern France
(Godart et al. 1999)

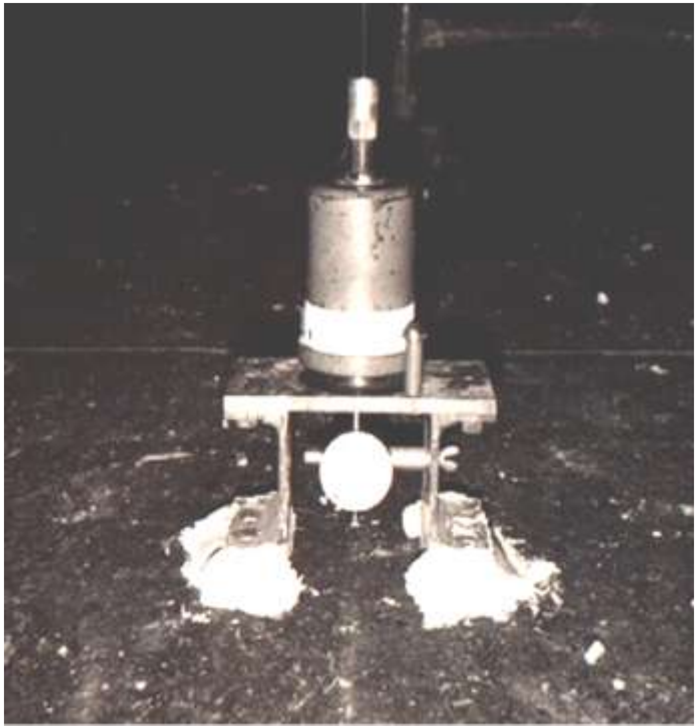
Stress Measurements



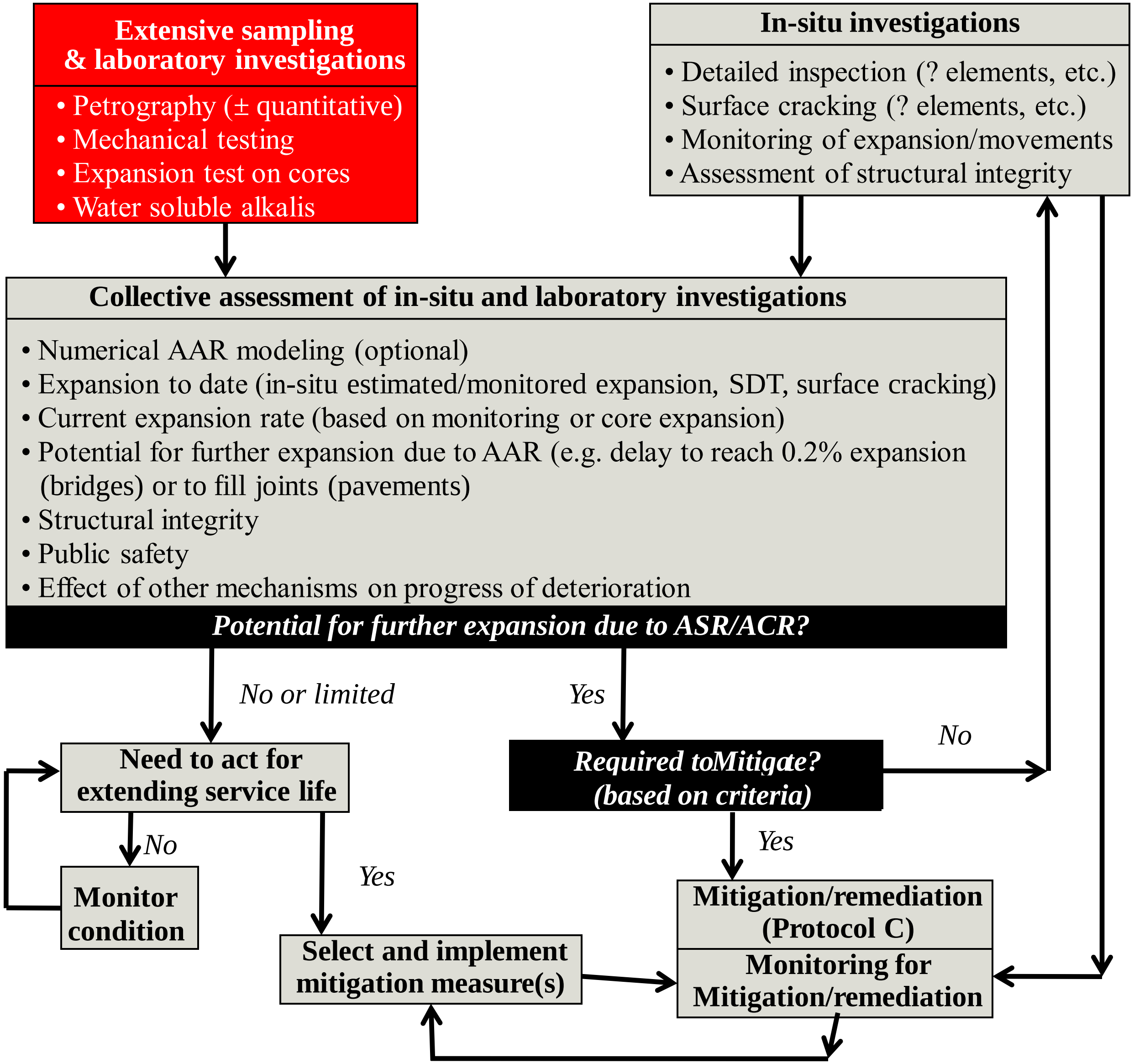


Structural Evaluation





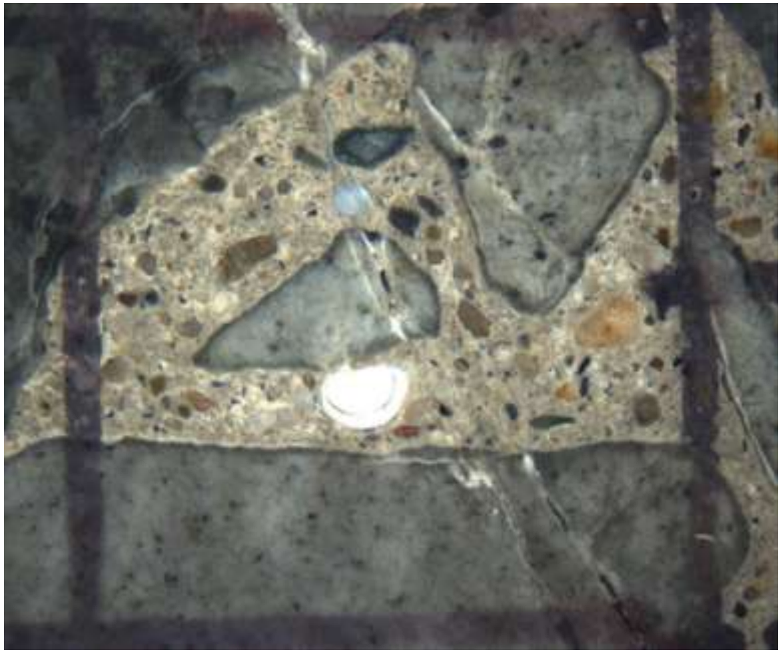
Detailed Investigation Program



Detailed Investigation Program

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)

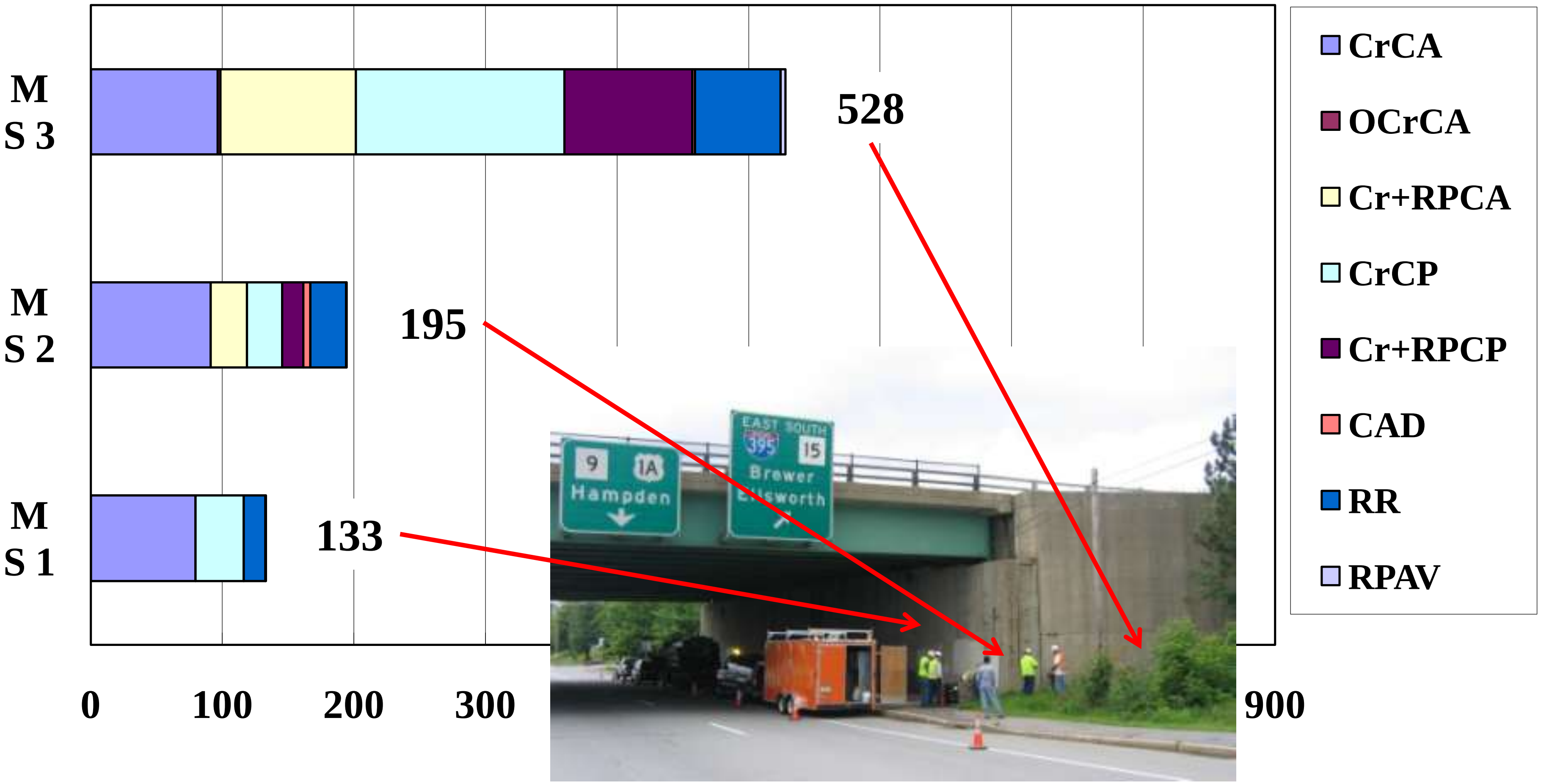


ASR Petrographic Features & Associated Factors

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	CP	2
Cement paste with crack and gel	CP+G	4
Gel in air void	V+G	0.5

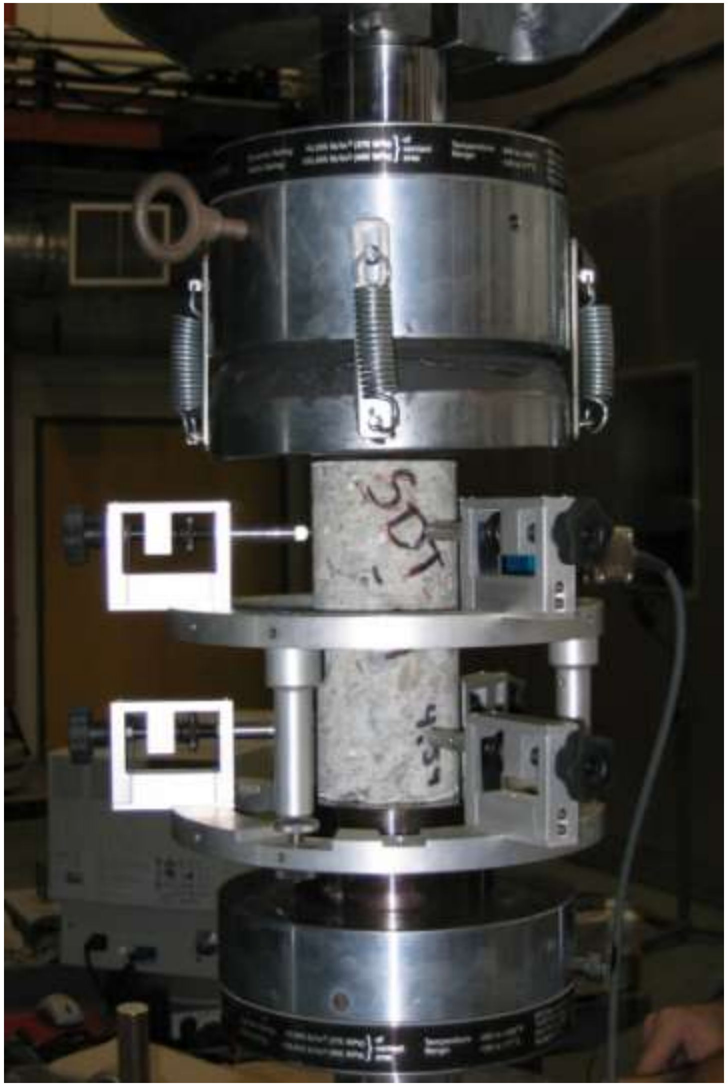
Grattan-Bellew and Danay (1992)

Damage Rating Index (DRI)

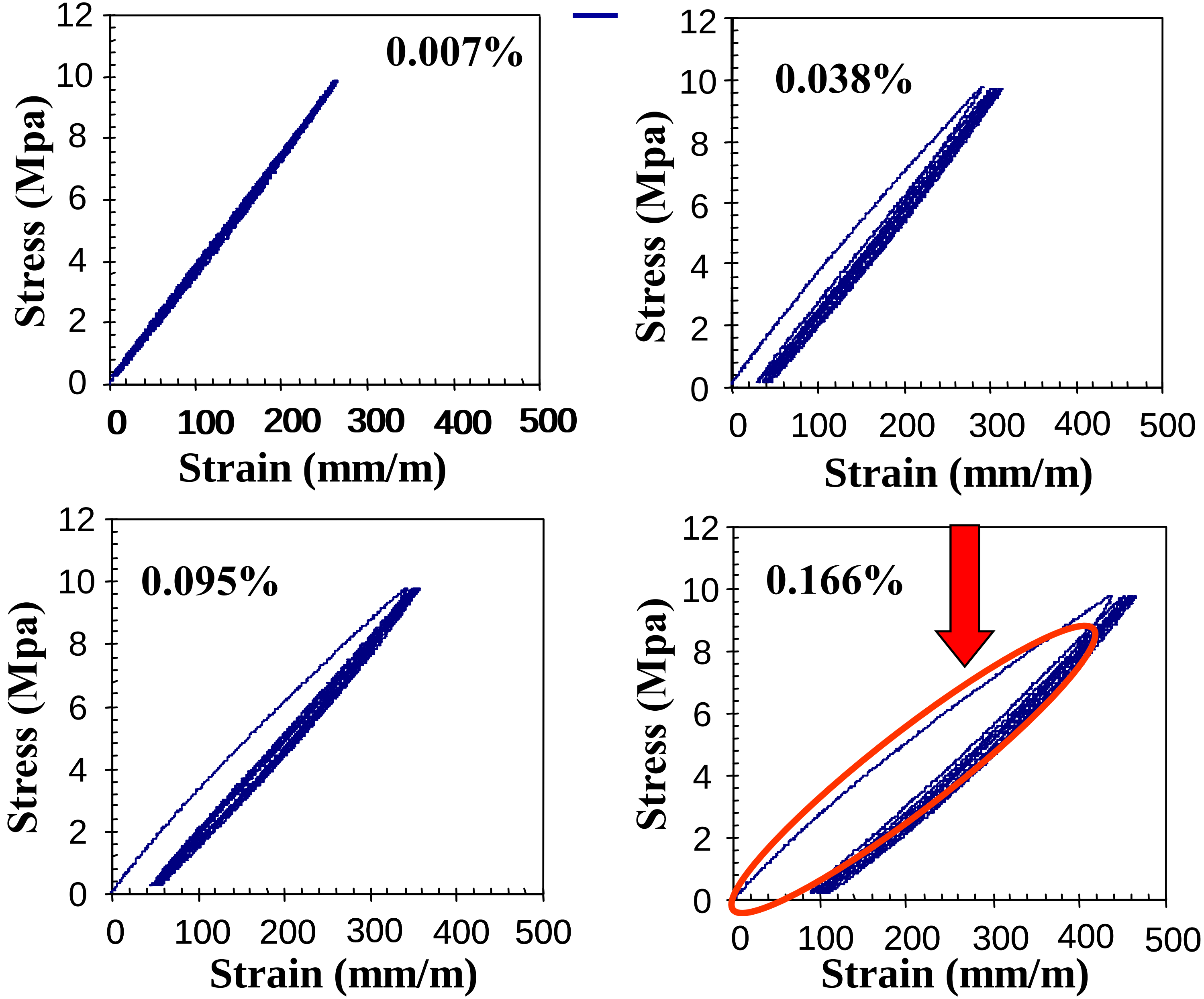


Stiffness Damage Test (SDT)

5 cycles of loading/unloading up to 10 MPa

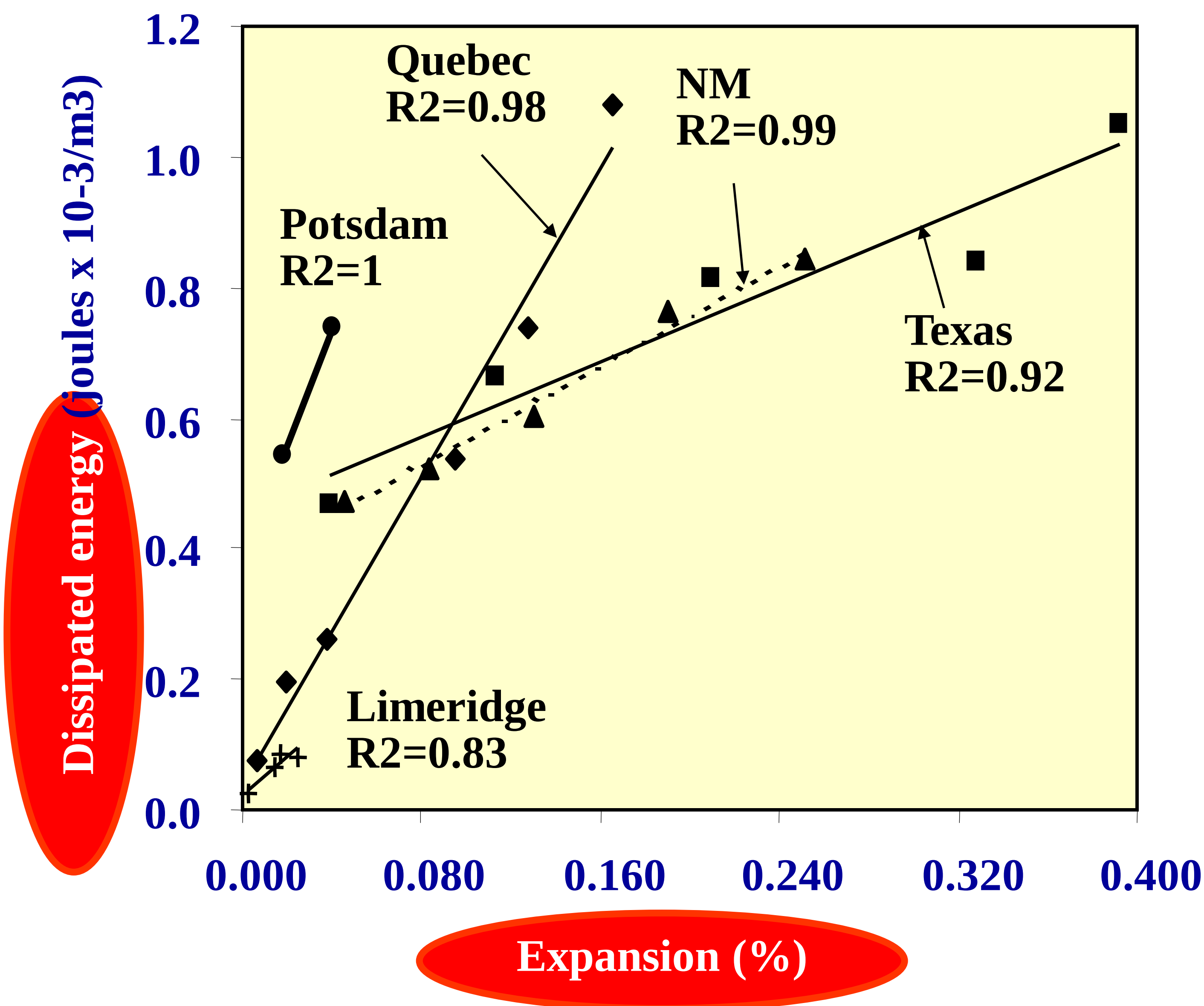


Stiffness Damage Test (SDT)



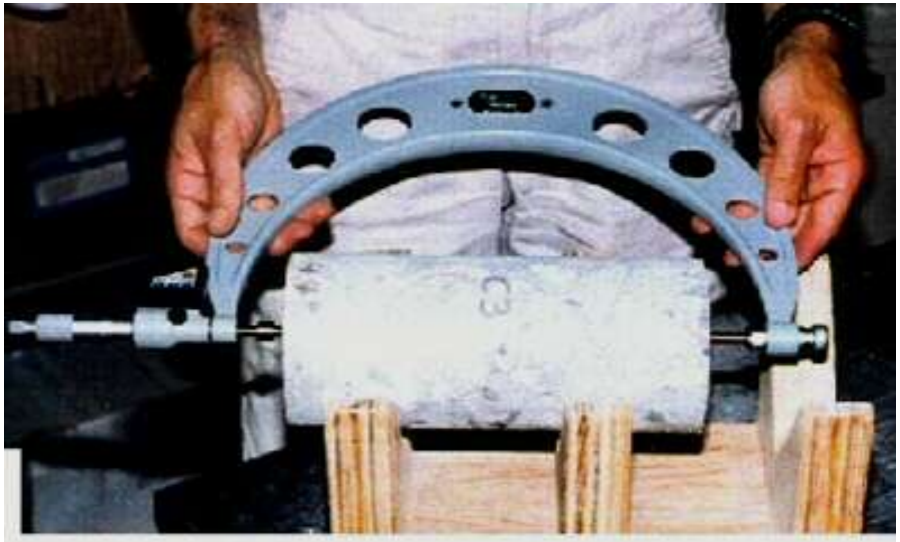
Stiffness Damage Test (SDT)

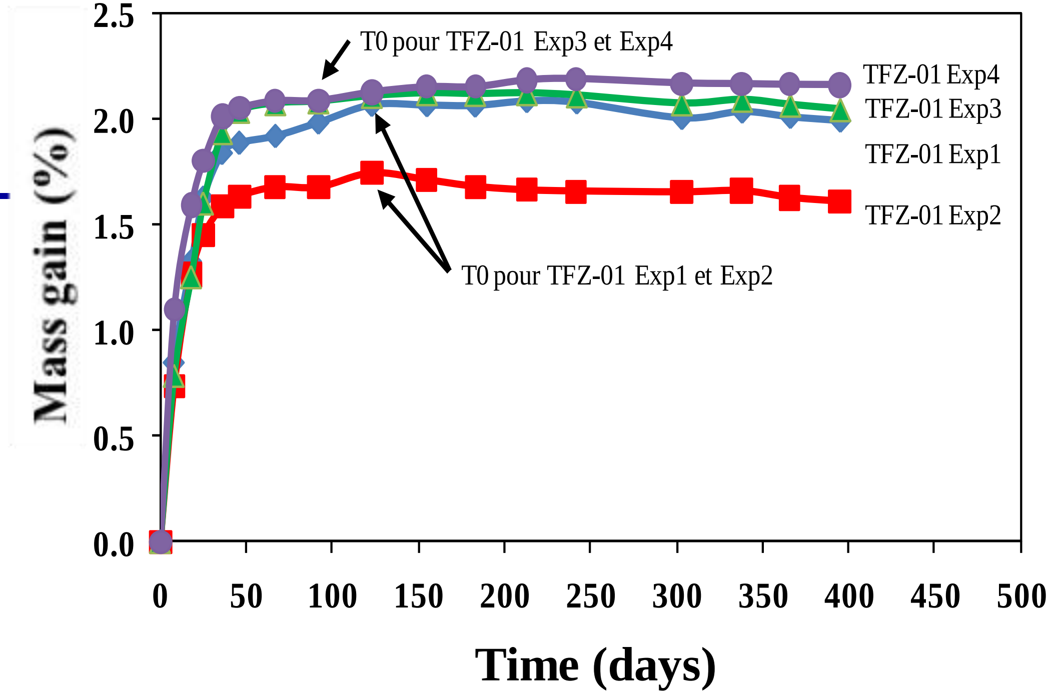
Samoui et al. (2003)



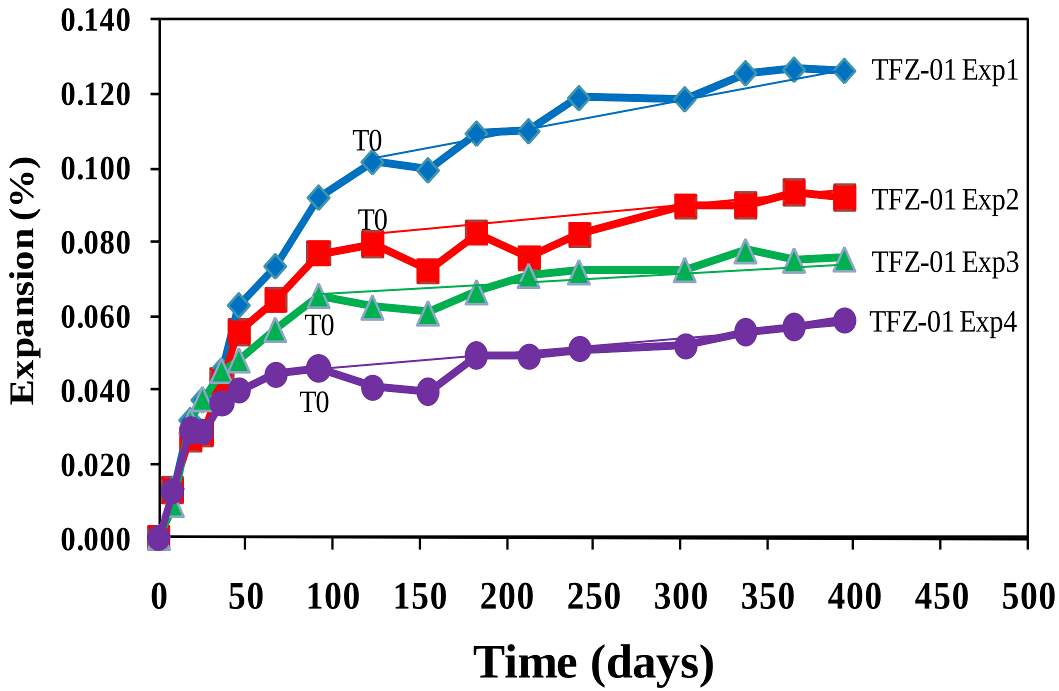
Expansion tests on cores

- 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)



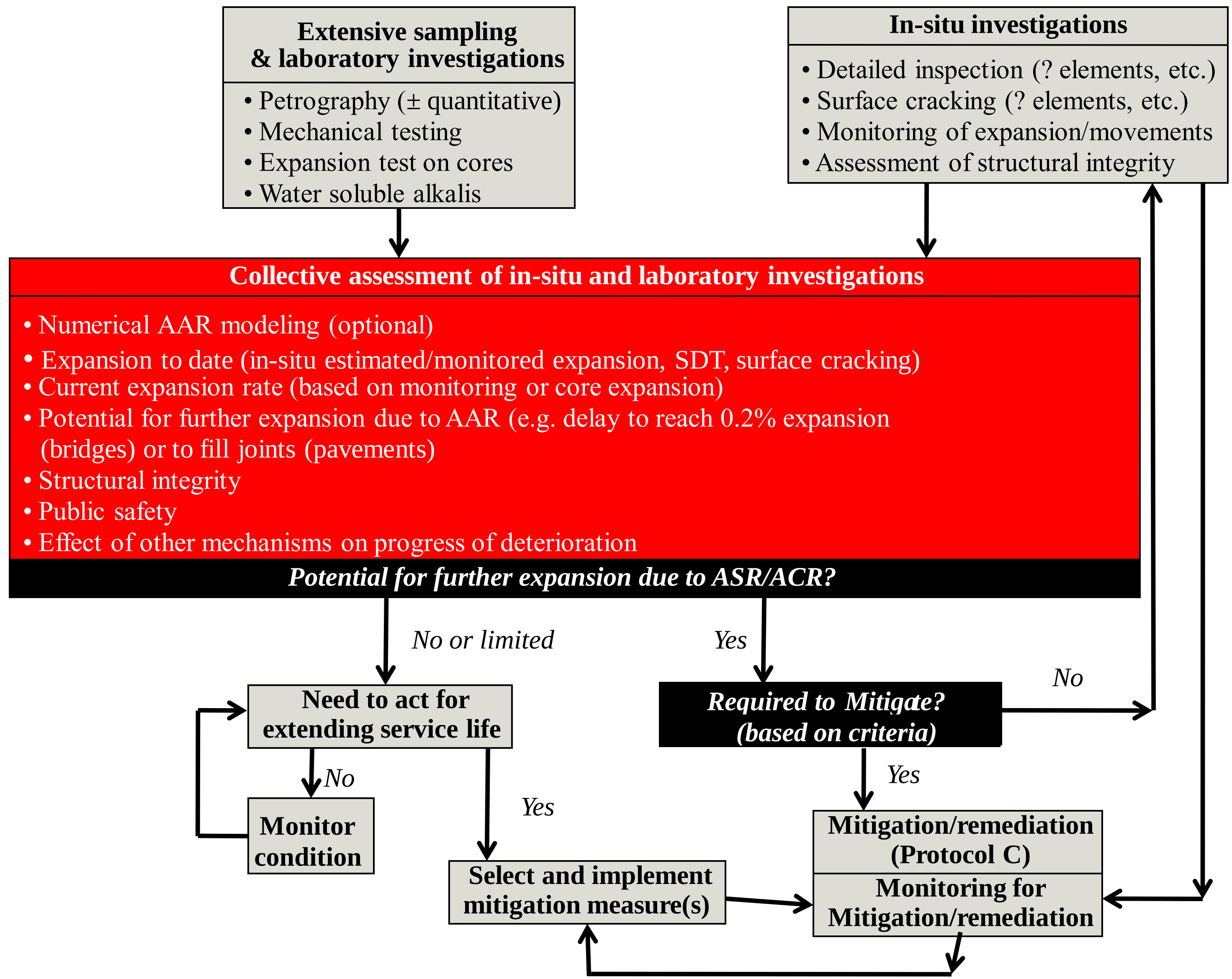


T0 pour TFZ-01 Exp3 et Exp4
TFZ-01 Exp4
TFZ-01 Exp3
TFZ-01 Exp1
TFZ-01 Exp2
T0 pour TFZ-01 Exp1 et Exp2
Mass gain (%)
Time (days)



TFZ-01 Exp1
TFZ-01 Exp2
TFZ-01 Exp3
TFZ-01 Exp4
T0
T0
T0
T0
Expansion (%)
Time (days)

Collective Assessment of Findings from Field and Laboratory Investigations



Potential for future expansion

- **Reinforced concrete members**
  - **Critical parameter → <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 → <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	TREAT THE SYMPTOM
Chemical Treatment/Injection • CO_2 • Lithium compounds ***Drying*** • Sealants • Cladding • Improved drainage	***Crack Filling*** • Aesthetics • Protection (e.g. from Cl^- ingress) ***Restraint*** • Prevent Expansion • Strengthen/Stabilize ***Relieve Stress*** • Saw Cutting/Slot Cutting (accommodate movement)

Conclusion

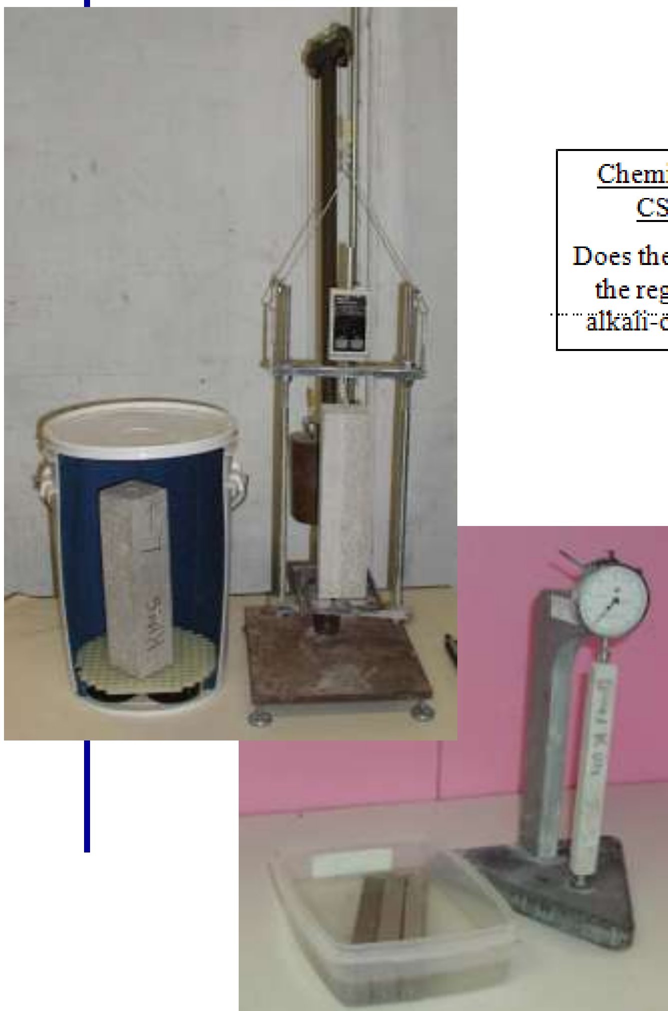
- **Alkali-aggregate reaction is still a subject of extensive work worldwide**
  - **Specifications to reduce the risk of AAR in new constructions**
  - **Determine the best approach for the management of AAR in existing concrete structures**

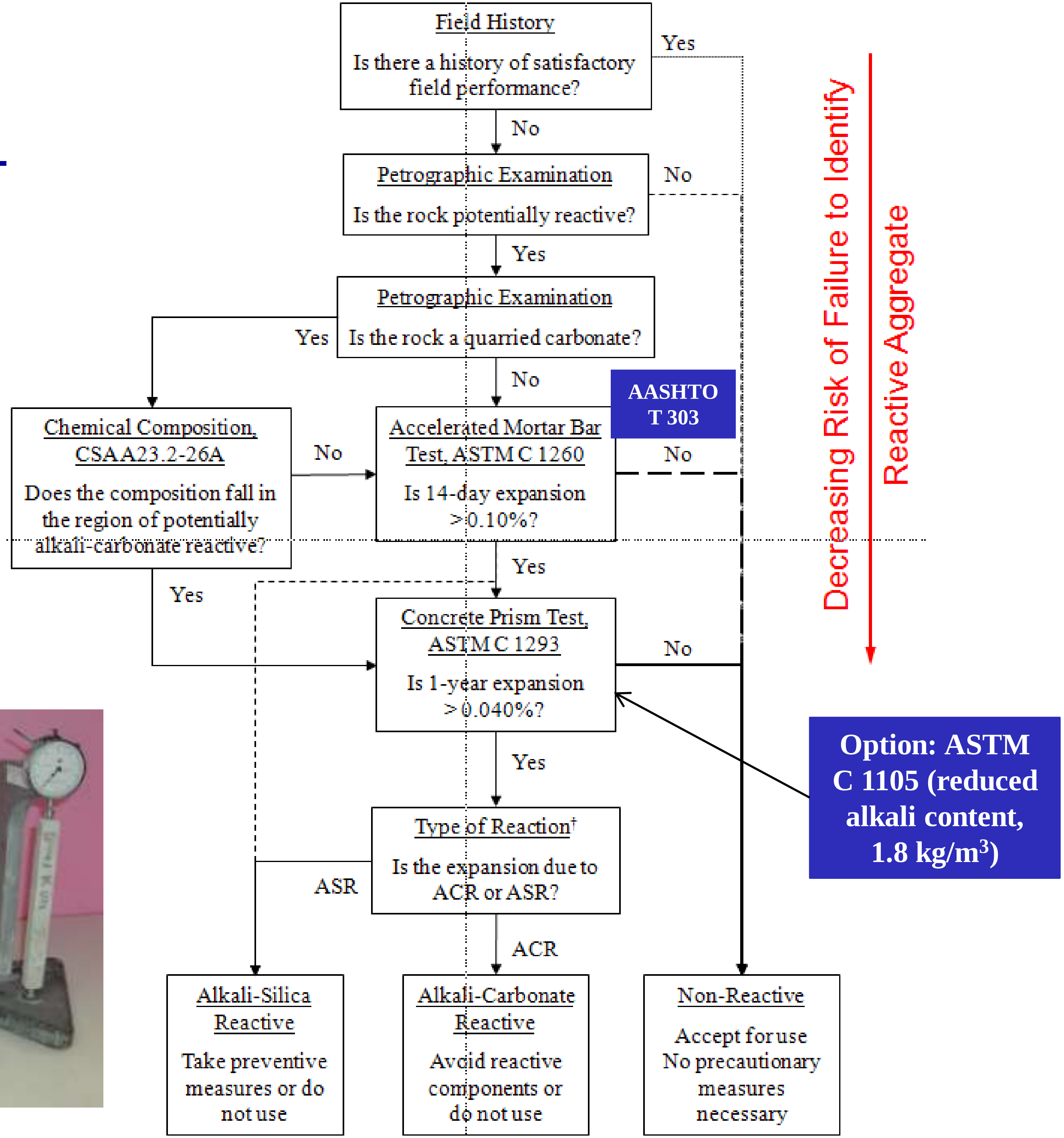
Conclusion

- **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**

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


Thank you very much
for your kind attention !!
Muito obrigado !!




Field History
Is there a history of satisfactory field performance?
Yes
No
Petrographic Examination
Is the rock potentially reactive?
No
Yes
Petrographic Examination
Is the rock a quarried carbonate?
Yes
No
AASHTO T 303
Chemical Composition, CSA A23.2-26A
Does the composition fall in the region of potentially alkali-carbonate reactive?
No
Accelerated Mortar Bar Test, ASTM C 1260
Is 14-day expansion > 0.10%?
No
Yes
Yes
Concrete Prism Test, ASTM C 1293
Is 1-year expansion > 0.040%?
No
Option: ASTM C 1105 (reduced alkali content, 1.8 kg/m³)
Yes
Type of Reaction†
Is the expansion due to ACR or ASR?
ASR
ACR
Alkali-Silica Reactive
Take preventive measures or do not use
Alkali-Carbonate Reactive
Avoid reactive components or do not use
Non-Reactive
Accept for use
No precautionary measures necessary
Decreasing Risk of Failure to Identify Reactive Aggregate

FHWA – Protocol for Preventing ASR – Prescriptive Approach

Step 5 – Select Preventive Measure

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

Prevention Level	SCM as sole prevention	Limiting concrete alkali content plus SCM	
	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