# Towards an Improved National Approach to Preventing Alkali-Aggregate Reactions (ASTM C1778/AASHTO R80)

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## Outline of Presentation

1. What is Alkali-Aggregate Reaction?
2. Development of ASTM C1778/AASHTO R80: Background and History
3. Lessons Learned and Knowledge Gained
4. Towards Improved National Guidance (Prescriptive and Performance-Based) in Preventing Alkali-Aggregate Reaction in New Concrete Construction

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## Alkali-Aggregate Reaction

**Alkali-Aggregate Reaction (AAR):** chemical reaction in either mortar or concrete between alkalies (sodium and potassium) from portland cement or other sources and certain constituents of some aggregates.

**Alkali-Silica Reaction (ASR):** the reaction between the alkalies (sodium and potassium) in portland cement and certain siliceous rocks or minerals, such as opaline chert, strained quartz, and acidic volcanic glass, present in some aggregates.

**Alkali-Carbonate Reaction (ACR):** the reaction between the alkalies (sodium and potassium) in portland cement and certain carbonate rocks, particularly calcitic dolomite and dolomitic limestones, present in some aggregates.

This presentation will focus primarily on ASR, which is much more prevalent than ACR.

*(ACI CT-13, 2013)*

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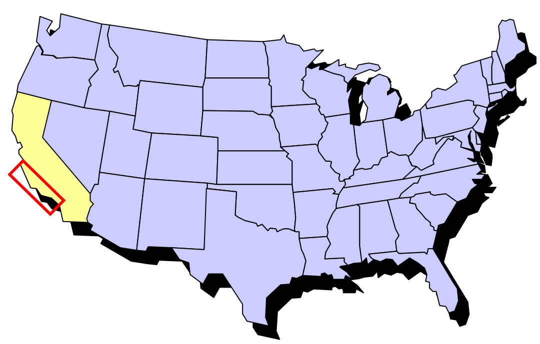
## History of ASR



- First discovered in the late 1930s
- In Monterey County and Los Angeles County
- Thomas Stanton of California State Division of Highways

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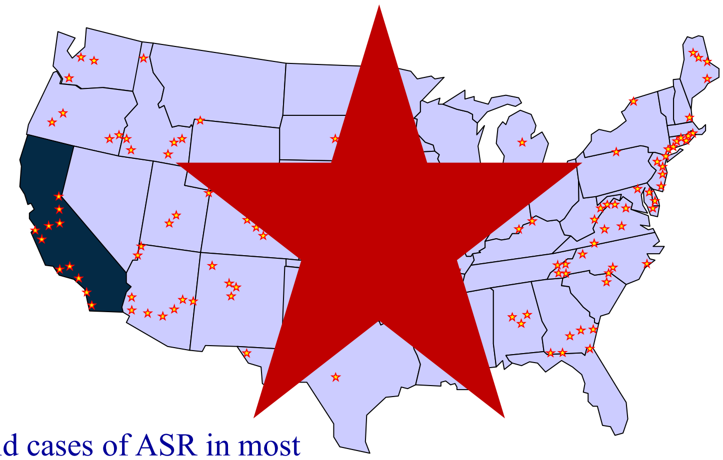
## Occurrences of ASR in U.S.A.



- Field cases of ASR in most (if not all) states of USA.

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## ASR in Transportation Infrastructure


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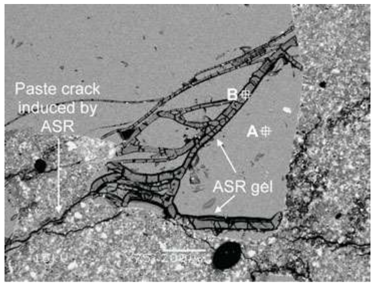
## ASR in nuclear plant (Seabrook, NH)

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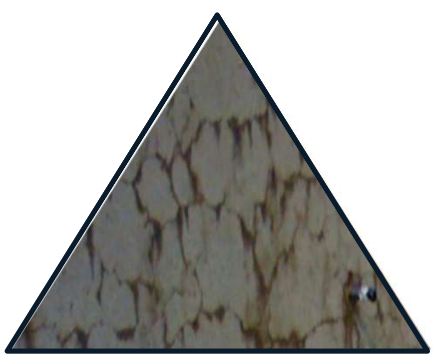
## The Three Necessities for ASR

Sufficient
alkalies



Reactive
silica

Available
moisture

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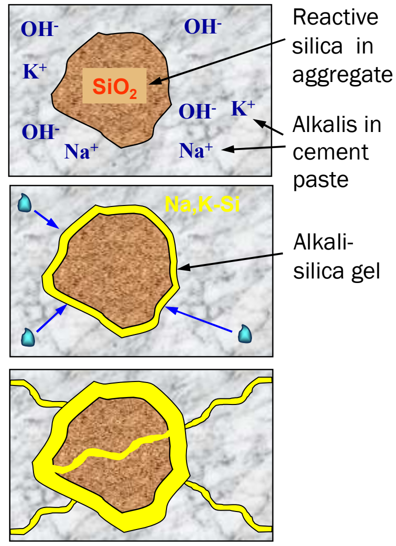
## Mechanisms of ASR

Reaction between the cement (Na, K & $OH^-$) and unstable silica, $SiO_2$, in some types of aggregate.

The reaction produces an alkali-silica gel, which absorbs water from the surrounding paste …

… and expands.

The internal expansion eventually leads to cracking of the surrounding concrete.

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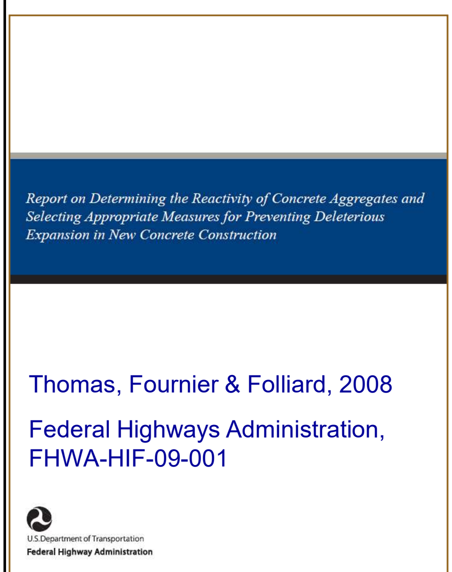
## It all started with…


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

Thomas, Fournier & Folliard, 2008

Federal Highways Administration, FHWA-HIF-09-001

U.S. Department of Transportation
Federal Highway Administration

- Deals with AAR – in other words ASR & ACR
- Based on CSA approach (with significant revisions)
- Prescriptive & performance alternatives
- Allows the use of (alkali-silica) reactive aggregates with the following preventive measures:
  - Limiting the alkali content of the concrete
  - Use of SCM including (ternary blends)
  - Use of lithium
- The actual level of prevention varies with "risk" as defined by:
  - Reactivity of the aggregate
  - Nature of the structure (design life & consequences of ASR)
  - Exposure condition

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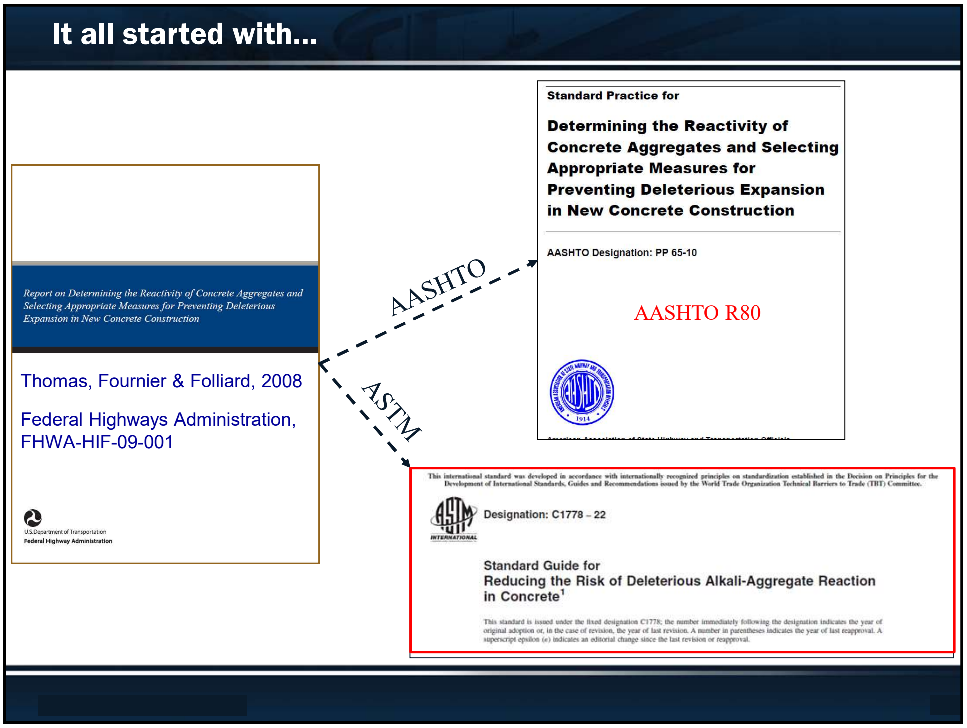
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U.S. Department of Transportation
Federal Highway Administration
AASHTO
ASTM
Standard Practice for
Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction
AASHTO Designation: PP 65-10
AASHTO R80
Designation: C1778 – 22
Standard Guide for
Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete

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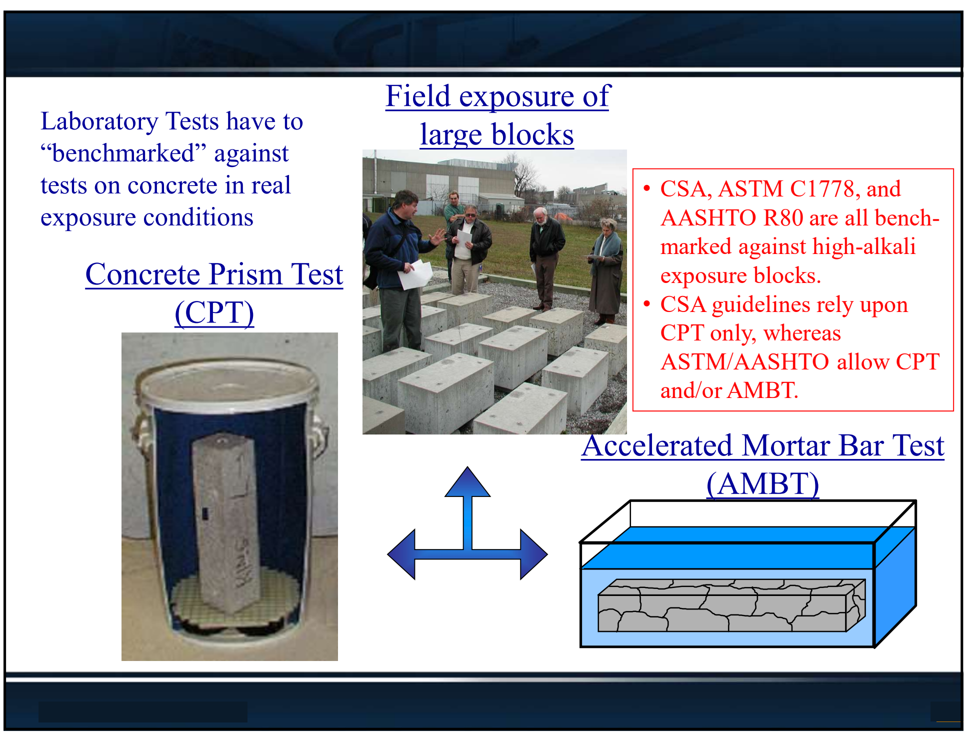
Laboratory Tests have to "benchmarked" against tests on concrete in real exposure conditions
Field exposure of large blocks
Concrete Prism Test (CPT)
• CSA, ASTM C1778, and AASHTO R80 are all bench-marked against high-alkali exposure blocks.
• CSA guidelines rely upon CPT only, whereas ASTM/AASHTO allow CPT and/or AMBT.
Accelerated Mortar Bar Test (AMBT)

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## Concrete Prism Test (CPT) – ASTM C1293

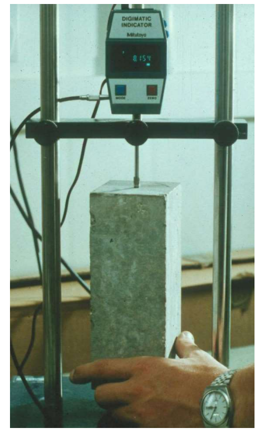
708 lb/yd$^3$ (420 kg/m$^3$)
cementitious material

NaOH added to yield 1.25% $Na_2O_e$ by mass of Portland cement

0.42 ≤ W/CM ≤ 0.45

Concrete prisms
3 x 3 x 10 (min.) inch
(75 x 75 x 250 mm)

Stored over water at 100°F (38°C)
(and nominally 100% RH)
for 1 year to test aggregates or 2 years to test preventive measures



for 2 years to evaluate preventive measures

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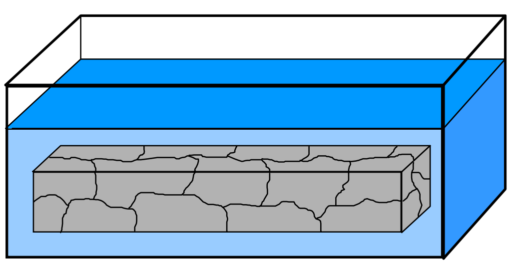
## Accelerated Mortar Bar Test (AMBT) – ASTM C1260/ASTM C1567

Aggregate/cementitious material = 2.25

W/CM = 0.47

Portland cement = 0.8 to 1.0% $Na_2O_e$

Mortar bars, 3 x 3 x 10 (min.) inch (25 x 25 x 250 mm),
stored in 1M NaOH at 176°F (80°C) for **14 days** (or 28 days)



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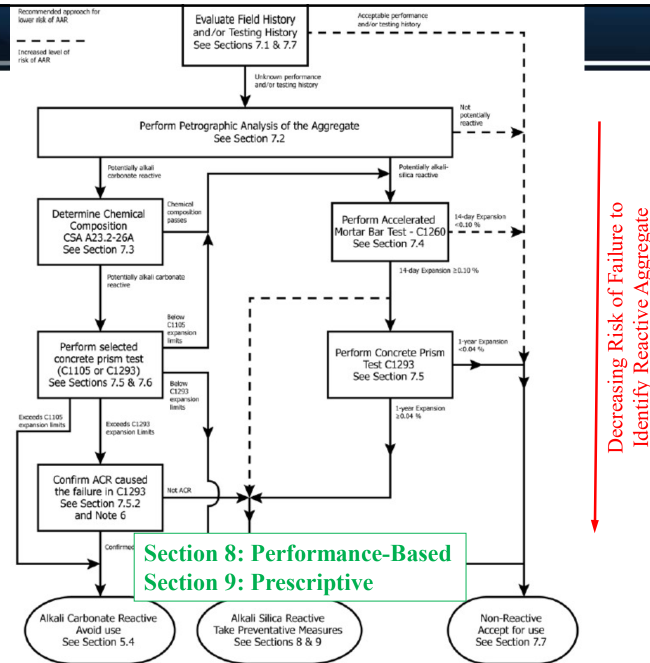
## Flow Chart




**Evaluating Aggregate**
**3 Possible Outcomes**

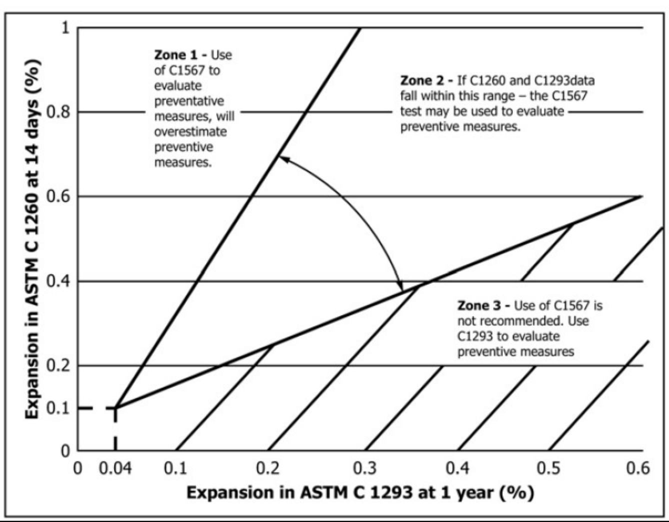
**Reject** **Prevent** **Accept**



## Performance Testing

**Performance Testing using the AMBT**

First establish correlation between AMBT & CPT for aggregate



## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → Step 3 Determine Level of Prevention → Step 4 Determine classification of structure → Step 5 Select preventive measure(s)

Table 1 Classification of 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, ≤ 0.30 |
| R2 | Highly reactive | 0.120 – 0.240 | > 0.30, ≤ 0.45 |
| R3 | Very highly reactive | > 0.240 | > 0.45 |

CPT ASTM C1293;
AMBT ASTM C1260; AASHTO T 303

If CPT and AMBT results are available – CPT results govern



## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → Step 3 Determine Level of Prevention → Step 4 Determine classification of structure → Step 5 Select preventive measure(s)

Table 2 Determining the Level of ASR Risk

| Size and exposure conditions | Aggregate-Reactivity Class | | | |
|---|---|---|---|---|
| | R0 | R1 | R2 | R3 |
| Non-massive[1] concrete in a dry[2] environment | Level 1 | Level 1 | Level 2 | Level 3 |
| Massive[1] elements in a dry[2] 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[3] | Level 1 | Level 4 | Level 5 | Level 6 |

[1]A massive element has a least dimension > 3 ft (0.9 m)
[2]A dry environment corresponds to an average ambient relative humidity lower than 60%, normally only found in buildings
[3]Examples of structures exposed to alkalis in service include marine structures exposed to seawater and highway structures exposed to deicing salts (e.g. NaCl) or anti-icing salts (e.g. potassium acetate, sodium formate, etc.)

## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → **Step 3 Determine Level of Prevention** → Step 4 Determine classification of structure → Step 5 Select preventive measure(s)

Table 3 Determining the Level of Prevention

| Level of ASR Risk (Table 2) | 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.



## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → Step 3 Determine Level of Prevention → **Step 4 Determine classification of structure** → Step 5 Select preventive measure(s)

TABLE 3 Structures Classified on Basis of the Severity of Consequences Should ASR[A] Occur (Modified for Highway Structures from RILEM TC 191-ARP)

| Class | Consequence of ASR | Acceptability of ASR | Examples[B] |
|---|---|---|---|
| Class SC1 | Safety, economic, or environmental consequences small or negligible | Some deterioration from ASR may be tolerated | Non-load-bearing elements inside buildings<br>Concrete elements not exposed to moisture<br>Temporary structures (service life < 5 years) |
| Class SC2 | Some safety, economic, or environmental consequences if major deterioration | Moderate risk of ASR is acceptable | Sidewalks, curbs, and gutters<br>Elements with service life < 40 years |
| Class SC3 | Significant safety, economic, or environmental consequences if minor damage | Minor risk of ASR may be acceptable | Pavements<br>Foundations elements<br>Retaining walls<br>Culverts<br>Highway barriers<br>Rural, low-volume roads<br>Precast elements in which economic costs of replacement are severe<br>Service life normally 40 to 74 years |
| Class SC4 | Serious safety, economic, or environmental consequences if minor damage | ASR cannot be tolerated | Major bridges<br>Power plants<br>Dams<br>Nuclear facilities<br>Water treatment facilities<br>Waste water treatment facilities<br>Tunnels<br>Critical elements that are very difficult to inspect or repair<br>Service life normally ≥75 years |

## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → Step 3 Determine Level of Prevention → Step 4 Determine classification of structure → **Step 5 Select preventive measure(s)**

Option 1

Table 5 – Limit Alkali Content of Concrete

Option 2

Table 6 – Use Supplementary Cementing Material (SCM) or Blended Cement

Table 7 – Adjust Level of SCM Based on Cement Alkalis

Higher level of prevention – Level Z and ZZ

Table 8 – Limit Alkali Content of Concrete **and** Use SCM



## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → Step 3 Determine Level of Prevention → Step 4 Determine classification of structure → **Step 5 Select preventive measure(s)**

Option 1

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

| Prevention Level | Maximum alkali content of concrete ($Na_2Oe$) | |
|---|---|---|
| | lb/yd³ | kg/m³ |
| V | No limit | |
| W | 5.0 | 3.0 |
| X | 4.0 | 2.4 |
| Y | 3.0 | 1.8 |
| Z | Table 8 | |
| ZZ | | |

## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → Step 3 Determine Level of Prevention → Step 4 Determine classification of structure → **Step 5 Select preventive measure(s)**

Option 2

**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 Cement | < 1.0 | 25 | 35 | 50 | 65 | |
| Silica Fume† ($SiO_2$ > 85%) | < 1.0 | 1.2 x LBA or 2.0 x KGA | 1.5 x LBA or 2.5 x KGA | 1.8 x LBA or 3.0 x KGA | 2.4 x LBA or 4.0 x KGA | |

† The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali ($Na_2Oe$) content of the concrete contributed by the portland cement and expressed in either units of lb/yd³ (LBA in Table 6) or kg/m³ (KGA in Table 6).



## Prescriptive Approach

Step 1 Determine aggregate reactivity → Step 2 Determine Risk of ASR → Step 3 Determine Level of Prevention → Step 4 Determine classification of structure → **Step 5 Select preventive measure(s)**

### Using Combinations of SCM's

Option 2

When two or more SCM's are used together to control ASR, the minimum replacement levels given in Table 6 for the individual SCM's may be reduced provided that the sum of the parts of each SCM is greater than or equal to one

For example: If Table 6 indicates that either 30% fly ash or 50% slag or 10% silica fume is required – it is permissible to use a blend of A% fly ash + B% slag + C% silica fume provided:

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

## Prescriptive Approach

| Step 1 | Step 2 | Step 3 | Step 4 | Step 5 |
|---|---|---|---|---|
| Determine aggregate reactivity | Determine Risk of ASR | Determine Level of Prevention | Determine classification of structure | Select preventive measure(s) |

Option 2

**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 to 1.25 | Increase the minimum amount of SCM given in Table 6 by one prevention level |
| > 1.25 | No guidance is given |



## Prescriptive Approach

| Step 1 | Step 2 | Step 3 | Step 4 | Step 5 |
|---|---|---|---|---|
| Determine aggregate reactivity | Determine Risk of ASR | Determine Level of Prevention | Determine classification of structure | Select preventive measure(s) |

Higher level of prevention – Level Z and ZZ

**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, lb/yd$^3$ (kg/m$^3$) | Minimum SCM level |
| Z | SCM level shown for Level Z in Table 6 | 3.0 (1.8) | SCM level shown for Level Y in Table 6 |
| ZZ | Not permitted | 3.0 (1.8) | SCM level shown for Level Z in Table 6 |

## Lessons Learned Since Development of ASTM C1778/AASHTO R80

1. The concrete prism test has been found to be very reliable in assessing aggregate reactivity (1-yr, 0.04% expansion).
2. The 2-year concrete prism test has been found to underestimate the dosage of SCM (or lithium nitrate) needed to control ASR-induced expansion, based on correlation with high-alkali exposure blocks.
3. Based on the preliminary findings from NCHRP 10-103, revisions are recommended to ASTM C1778/AASHTO R80, as described next.



## NCHRP 10-103

Project aimed specifically at filling in the gap in field exposure block data for lower alkali, more realistic concrete mixtures.

| Location | Average Low Temperature (ºF) | Average High Temperature (ºF) | Average Precipitation (in.) |
|---|---|---|---|
| Austin, TX | 59.0 | 79.8 | 34.3 |
| Port Aransas, TX | 72.5 | 77.9 | 34.8 |
| Corvallis, OR | 41.9 | 63.4 | 42.8 |
| Newport, OR | 44.1 | 58.5 | 69.6 |
| Fredericton, NB (CA) | 30.9 | 51.9 | 43.3 |
| Treat Island, ME | 35.3 | 52.6 | 44.9 |
| Honolulu, HI | 70.7 | 84.5 | 17.1 |
| Lawrence, MA | 50.2 | 59.8 | 51.6 |

450 low-alkali exposure blocks were cast and stored on eight different exposure sites during the 3-year project. Only 4 blocks have expanded to date, as expected.

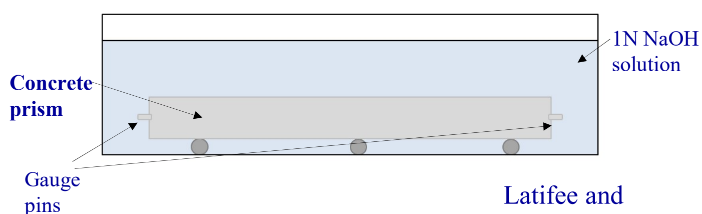
## NCHRP 10-103

Several new and revised test methods were included:

- AASHTO T380 (miniature concrete prism test)
- UNBCCT (University of New Brunswick Concrete Prism Tes)
- T-Fast
- Variations of ASTM C1293, including wrapping of prisms (to reduce leaching)



## AASHTO T380 – Miniature Concrete Prism Test




Latifee and Rangaraju, 2015

- Miniature concrete prism test
- 2 x 2 x 11.25 in. bar
- 140 F (60 C) exposure
- 1 N NaOH (current standard)
- Matched pore solution soak (modification)
- 56 or 84 day duration

## NCHRP 10-103 – PRELIMINARY FINDINGS

1. ASTM C1293 is still recommended for evaluating aggregate reactivity but NOT to evaluate preventive measures.
2. AASHTO T380 is recommended to evaluate aggregate reactivity or preventive measures (56 and 84 day expansion limits, respectively).
3. ASTM C1567, once properly benchmarked against ASTM C1293 or AASHTO T380 for a given aggregate, can be used to determine SCM dosage using a 28-day expansion limit of 0.10 percent.
4. Natural pozzolans should be included both in the performance and prescriptive-based approaches.
5. The SCM dosages previously recommended should be increased to better correlate with exposure blocks.
6. A combination of SCMs and cement alkali loading limits are recommended for critical structures.
7. All of these recommendations may change as the data from the 450 exposure blocks emerges.



## Other continuing research

Under funding from Airfield Pavement Technology Program (APTP):

- Additional materials, including reclaimed or blended fly ashes, ground bottom ash, and chemical admixtures (e.g., calcium nitrite, magnesium acetate) are being evaluated.
- New test methods are being evaluated, including:
  - Alkali release tests (from SCMs or aggregates)
  - Pozzolanic reactivity testing (R3)
  - Other rapid tests