# Alkali Aggregate Reactions
## Harmonization with ASTM

Colin Lobo

National Ready Mixed Concrete Association

# FHWA – Protocol for Preventing AAR

**Federal Highways Administration,**

**FHWA-HIF-09-001**

Thomas, Fournier & Folliard, 2008

***Determining The Reactivity Of Concrete Aggregates And Selecting Appropriate Measures For Preventing Deleterious Expansion In New Concrete Construction***

# Standards

**AASHTO PP-65-10 – Provisional Standard Practice (TS 3c)**

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

**AASHTO R 80-17 – Approved Standard Practice (release April 2017)**

**ASTM C1778-14 – Standard Guide (Subcommittee C09.50)**

***Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete***

**Current version – C1778-16**

**Based on CSA A23.2-27A (Canadian Standards)**

# AASHTO R 80 and ASTM C1778

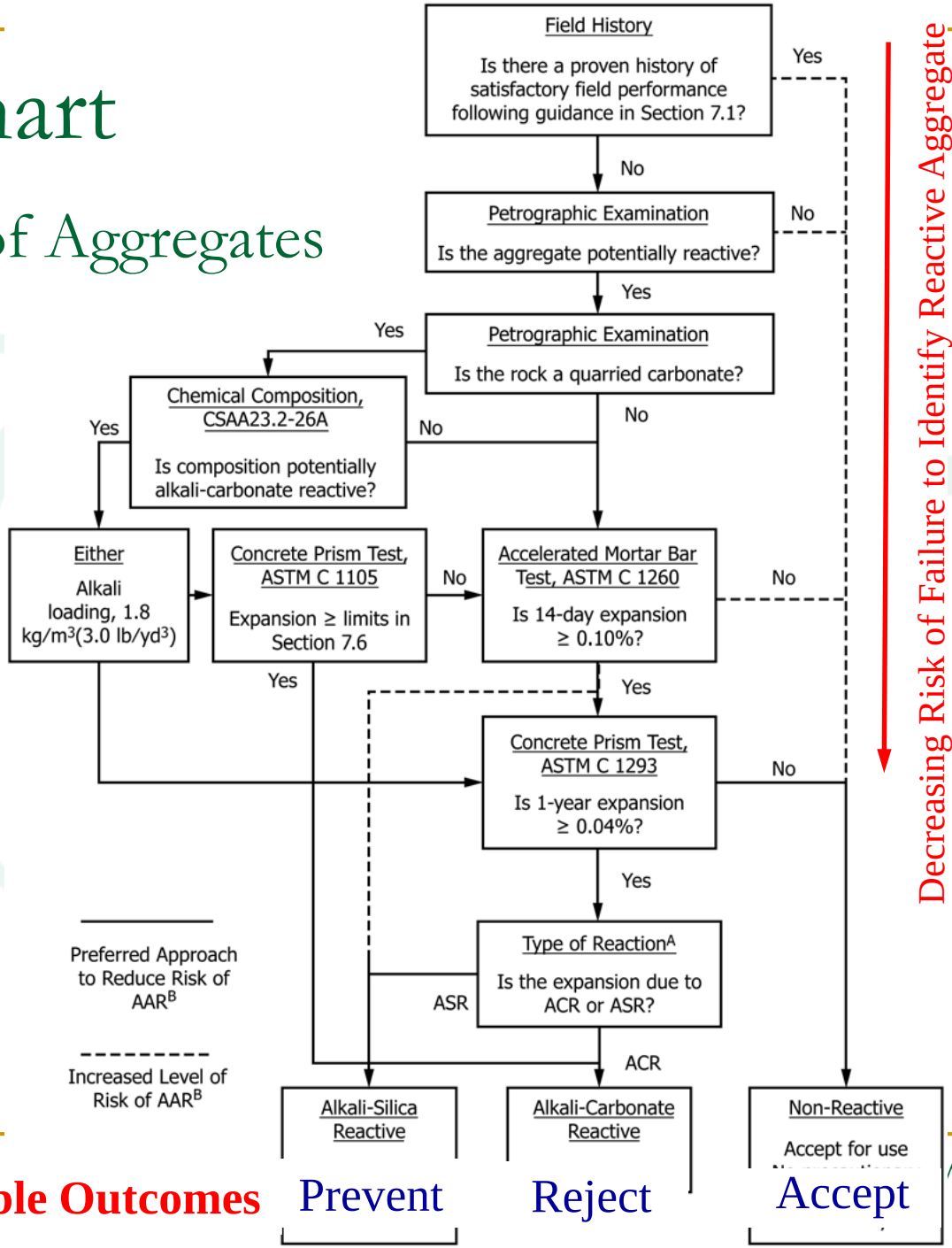
- Testing for aggregate reactivity – sets reactivity levels
- Prescriptive & performance alternatives
- Allows the use of reactive aggregates with the following preventive measures:
  - Limiting the alkali content of the concrete
  - Use of fly ash
  - Use of slag
  - Use of silica fume
  - Use of ternary blends
- The actual level of prevention varies with “risk” as defined by:
  - Reactivity of the aggregate
  - Nature of the structure (includes. design life)
  - Exposure condition

# AASHTO R 80 and ASTM C1778

- There are some differences
- Should lead to the same solution in both
- R 80 has an Appendix for additional guidance
  - Examples
- Lithium admixtures
  - Not covered in C1778
  - Some guidance in R 80
  - More detail covered in FHWA-HIF-09-001

# Flow Chart

## Evaluation of Aggregates




**3 Possible Outcomes** Prevent Reject Accept

# AASHTO R 80 and ASTM C1778

## Step 1 – Determine Aggregate Reactivity

- Field Performance History (to deem non reactive)
  - Age of structure > 10 yrs
  - Cement and alkali content
  - Use of SCMs
  - Exposure
  - Presence of distress
- Petrography – ASTM C295
  - Mineralogy indicates reactivity – still need to test
  - Alkali carbonate reactive rocks – composition – CSA A23.2-26A
    - Evaluate further – ASTM C1293 or C1105

Some differences between R 80 and C1778

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 1 – Determine Aggregate Reactivity

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

More reactive aggregate establishes level of prevention

(R 80) - No data – Assume R3

# ASTM C1260 / AASHTO T303

- AASHTO R 80
  - If the expansion < 0.10 percent, the aggregate is considered nondeleteriously reactive and can be accepted for use
- ASTM C1778
  - …the aggregate is considered to be innocuous in most cases.

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 2 – Determine Risk of ASR

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.)

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 3 – Determine the Level of Prevention

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.

# AASHTO R 80 – Prescriptive Approach

## Step 4 – Classify Structure

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

# ASTM C1778 – Prescriptive Approach

## Step 4 – Classify Structure

**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 |

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

**Step 5 – Select Preventive Measure**

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 ZZ

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

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 5 – Select Preventive Measure – 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/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 | | |

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 5 – Select Preventive Measure – 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 | < 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/yd$^3$ (LBA in Table 6) or kg/m$^3$ (KGA in Table 6).

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 5 – Select Preventive Measure – Option 2

- No guidance – use performance testing
  - Fly ash – CaO > 18% OR $Na_2O_e$ > 4.5% (4.0%)
  - Slag and silica fume - $Na_2O_e$ > 1.0%
  - Natural pozzolans

**Step 5 – Select Preventive Measure - Option 2**

## Using Combinations of SCM's

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:

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

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 5 – Select Preventive Measure - 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 | Increase the minimum amount of SCM given in Table 6 by one prevention level |
| > 1.25 | No guidance is given |

# AASHTO R 80 and ASTM C1778 – Prescriptive Approach

## Step 5 – Select Preventive Measure – Higher Level of Prevention

**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 |

# AASHTO R 80 and ASTM C1778 – Performance Approach

- What doesn't matter:
  - Reactivity of aggregate
  - ASR Risk Level
  - Classification of structure
  - Alkali level of portland cement
  - Prevention Levels

  No distinction on performance criteria (at this time)

# AASHTO R 80 and ASTM C1778 – Performance Approach

## Option 1

**Determine effective quantity of SCM's using the CPT – ASTM C1293**

- Alkali content of portland cement component raised to 1.25% $Na_2Oe$
- Expansion ≤ 0.04% at 2 years.

## Option 2

**Determine effective quantity of SCM's using the AMBT – C1260, T303**

- Portland cement alkalis should be 0.90 ± 0.10% Na2Oe
- Not applicable for
  - Fly ash $Na_2O_e$ > 4.5% or
  - Other SCM $Na_2O_e$ > 1.0%
- Expansion < 0.10% at 14 days

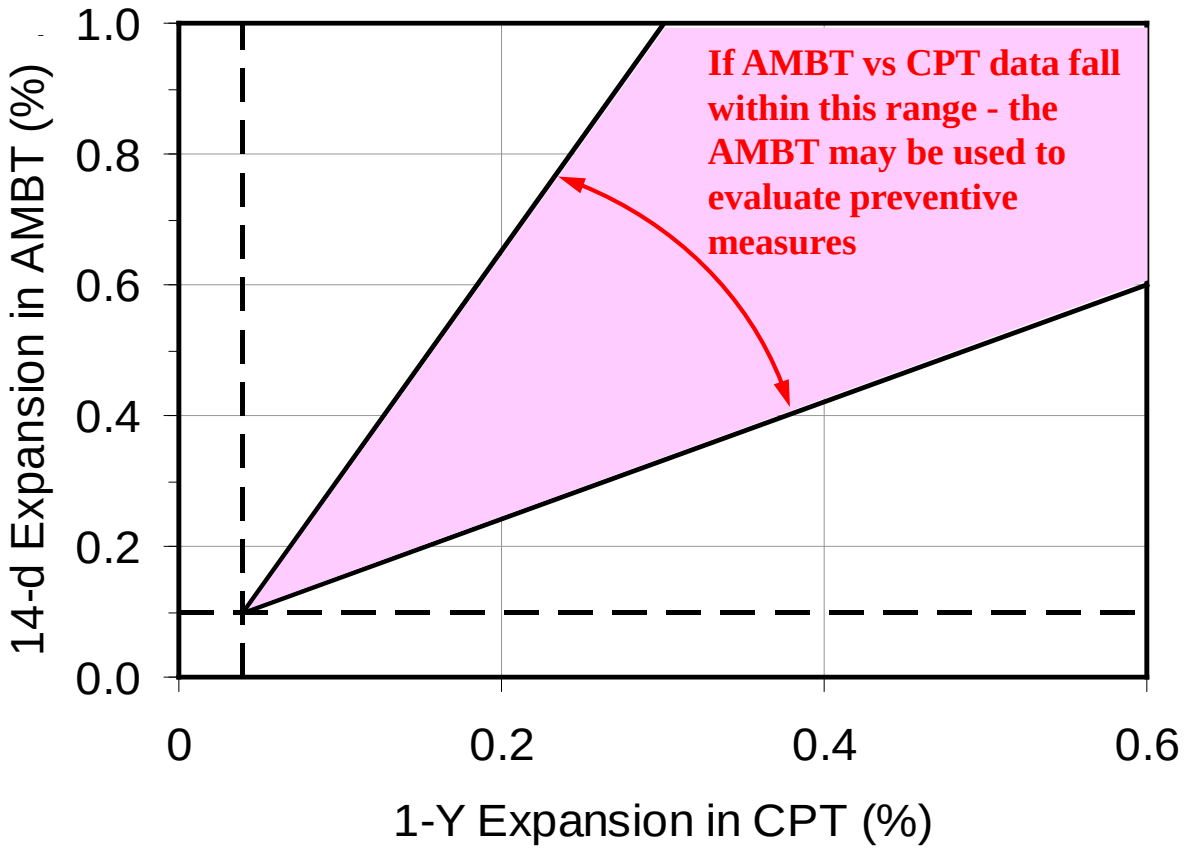
# FHWA – Protocol for Preventing ASR – Performance Approach

- CPT (C1293) cannot be used to
  - determine the safe alkali level for a particular aggregate
  - evaluate a combination of low-alkali cement and SCM
  - PC alkalis to increased to 1.25% $Na_2O_e$ to compensate for leaching

- AMBT (C1567) cannot be used to
  - determine the safe alkali level for a particular aggregate
  - evaluate a combination of low-alkali cement and SCM

# Performance Testing using the AMBT

First establish correlation between AMBT & CPT for aggregate



# Performance Testing using the AMBT

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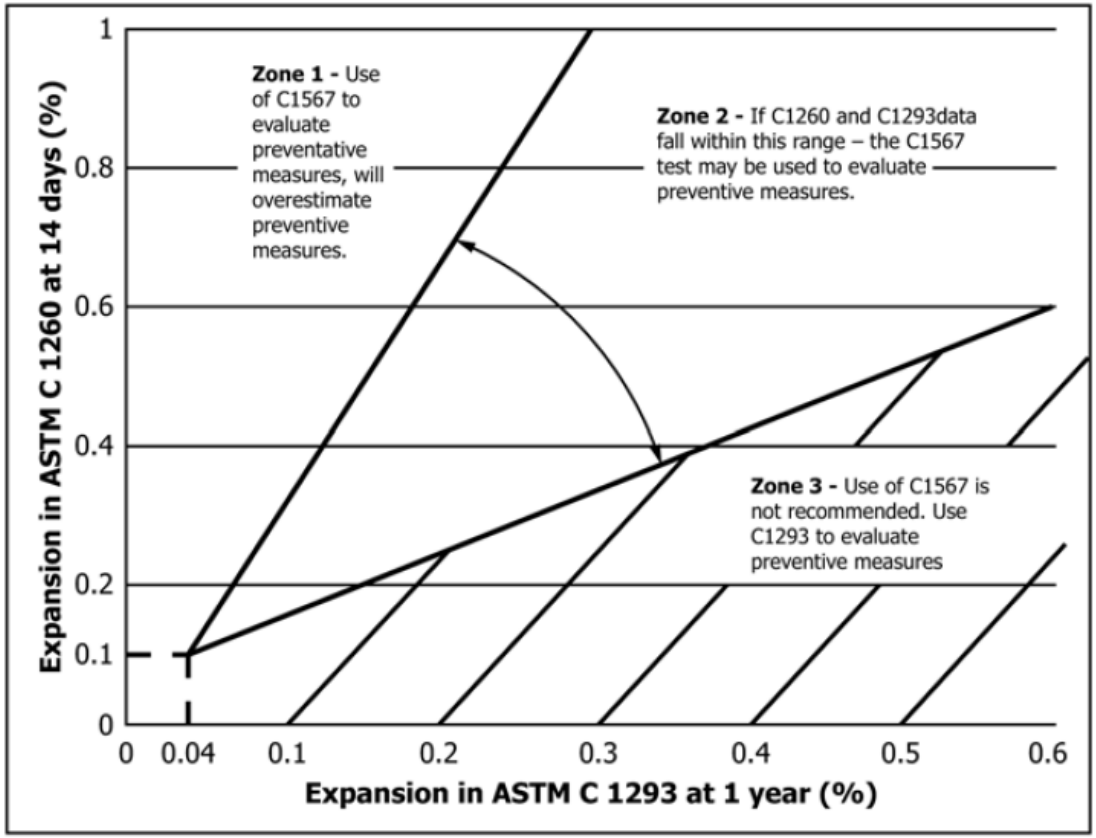
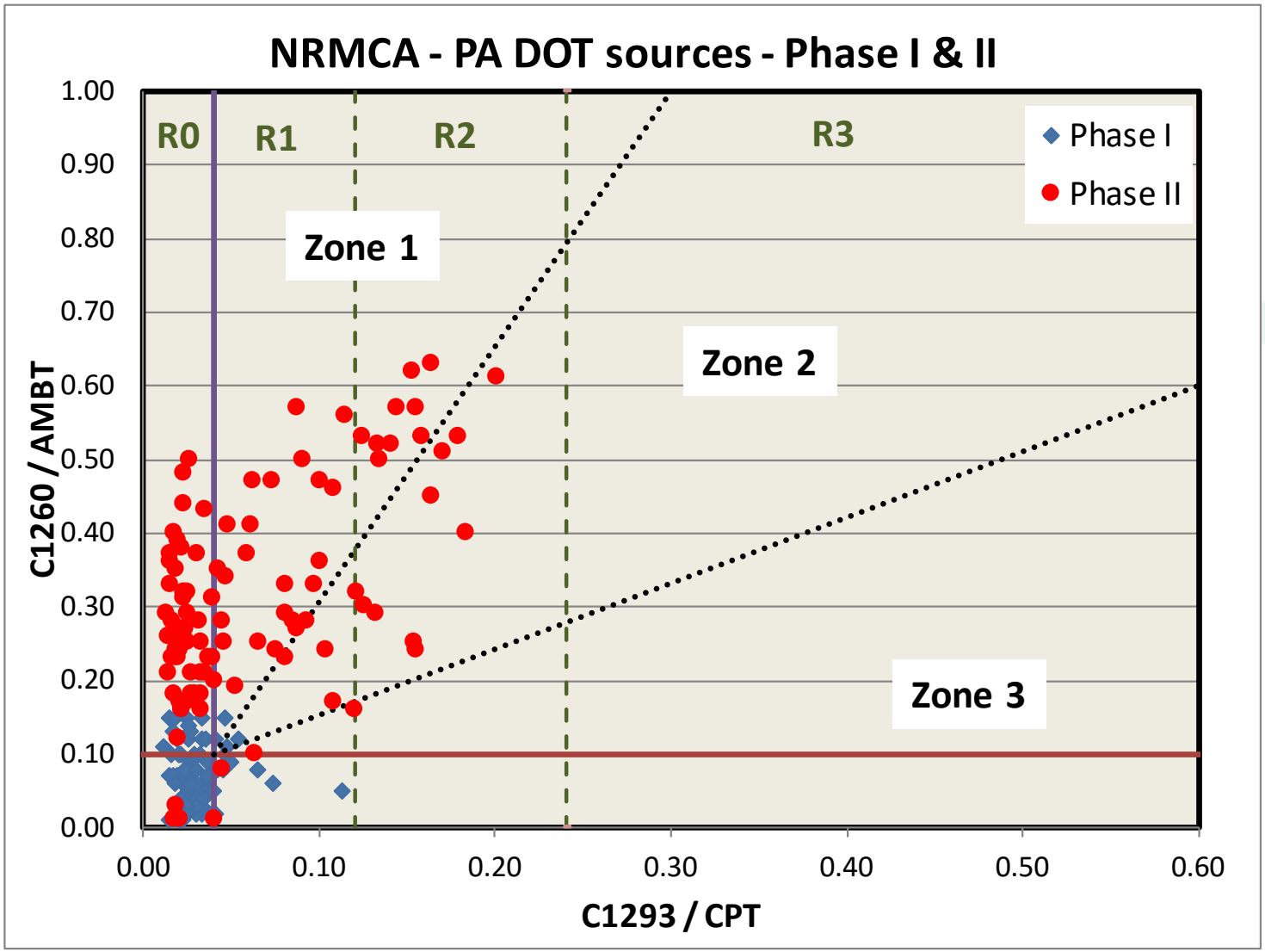


# R 80 / C1778– Performance Approach (PA Aggregates)




Total = 179

Reactive
C1260 63%
C1293 36%

Reactivity
R0 64%
R1 25%
R2 11%
R3 0%

Zone 1 86%
Zone 2 9%
Zone 3 5%

# AASHTO R 80 - Example

Concrete for a bridge deck on interstate in North Dakota

ASTM C 1260

Fine Aggregate = 0.101 % at 14 days

Coarse Aggregate = 0.502% at 14 days

ASTM C 1293

Fine Aggregate = 0.031 % at 1 year

Coarse Aggregate = 0.191% at 1 year

How much Fly Ash (5.5% CaO, 2.1% $Na_2Oe$)

# AASHTO R 80 - Example

***Step 1 – Determine* Aggregate *Reactivity***

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 | Fine |
| R1 | Moderately reactive | 0.040 – 0.120 | > 0.10, ≤ 0.30 | Fine |
| R2 | Highly reactive | 0.120 – 0.240 | > 0.30, ≤ 0.45 | Coarse |
| R3 | Very highly reactive | > 0.240 | > 0.45 | Coarse |

**Reactivity = R2**

# AASHTO R 80 - Example

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 |

**Risk of ASR = Level 5**

# AASHTO R 80 - Example

***Step 3 – Classify Structure***

| 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<br>▪ Temporary structures (e.g. < 5 years) |
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# AASHTO R 80 - Example

***Step 4 – Determine the Level of Prevention***

Table 3 Determining the Level of Prevention

| 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 | †† |

# AASHTO R 80 - Example

***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 | |
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| | 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** |

# AASHTO R 80 - Example

***Step 5 – Select Preventive Measure***

**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) | | | | |
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| 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/yd$^3$ (LBA in Table 6) or kg/m$^3$ (KGA in Table 6).

# AASHTO R 80 - Example

**Prescriptive Solution**

Use 35% Fly Ash

**AND**

Limit alkalis from portland cement to 1.8 kg/m$^3$ (3 lb/yd$^3$) $Na_2Oe$

**Performance Solution**

AMBT or CPT at range of fly ash replacement levels

Establish minimum needed to meet expansion limits

# Alkali Aggregate Reactions
## Harmonization with ASTM

Thank You