Alkali-Silica Reactivity in the State of Montana

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Funded By: MDT & MCA

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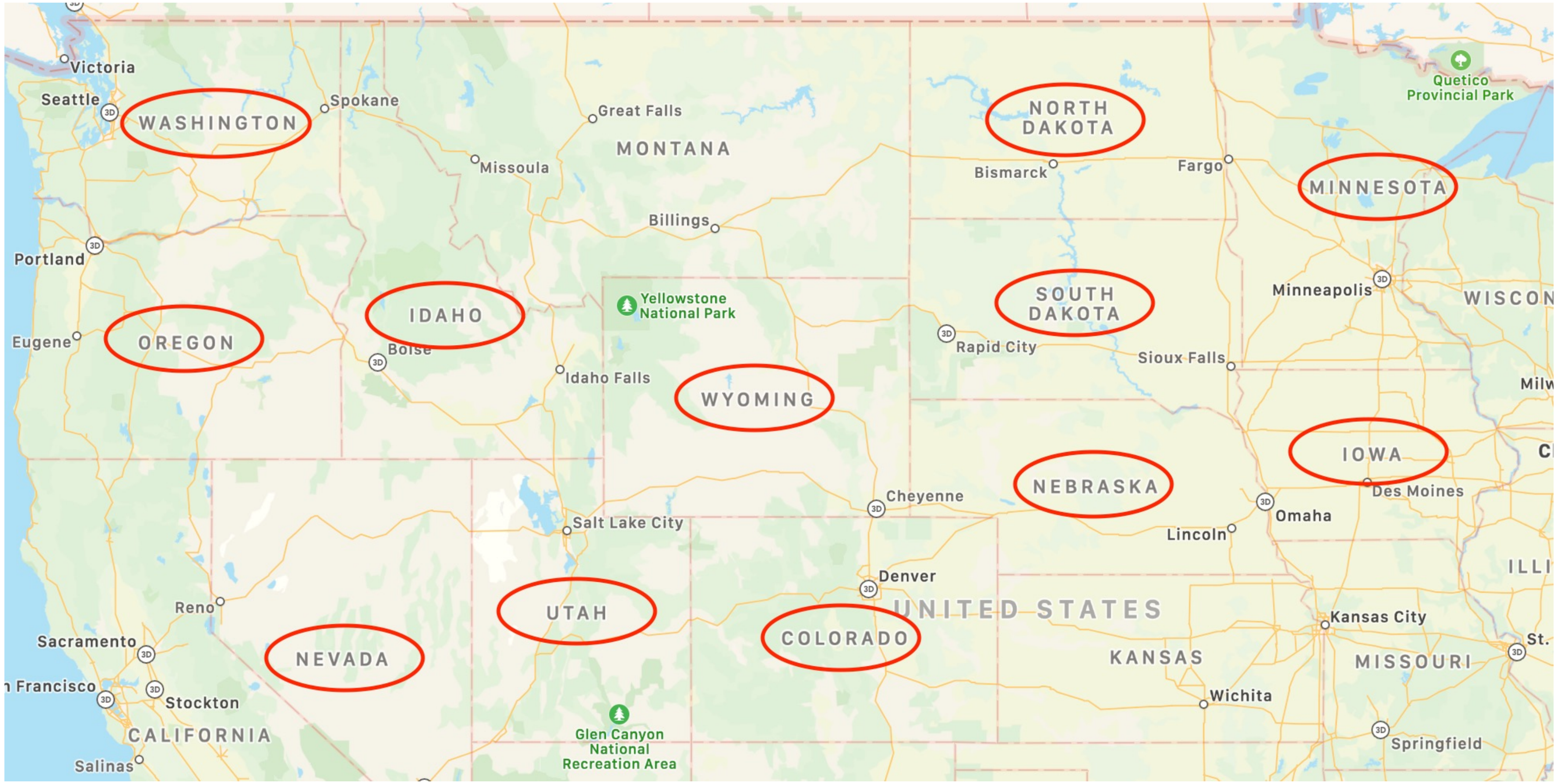
Overview

- Research Objective
- Background
- State of Practice
  - Regional ASR Practices
  - Federal ASR Practices
  - Current Aggregate Testing Methods
  - Newly Developed Aggregate Testing Methods
  - Identifying/Quantifying ASR Damage in Concrete
- Cases of ASR Damage in Montana
- Montana Aggregate Testing
- Summary and Conclusion

Background

- What is ASR?
  - Alkalis – cement / SCM's
  - Silicas – aggregate
  - Water
- Damage
  - Reduced lifespan
  - Expensive repairs
  - Replacement of concrete

Regional ASR Practices



Regional ASR Practices

- Material Specifications
  - All regional states, except North Dakota
  - Alberta and British Columbia
  - Minnesota & Washington State DOTs maintain aggregate databases
- Research
  - All regional states, except Colorado and North Dakota

Federal ASR Practices

Federal ASR Practices

- Federal Highway Administration (FHWA)
  - No requirements for ASR testing
  - Allow individual state DOTs to establish requirements
  - The FHWA sponsors ASR research
- Federal Aviation Administration (FAA)
  - Required aggregates testing per ASTM C1260 & ASTM C1567 – (28-day testing)
  - 28-day expansions in excess of 0.10% require mix modification and re-testing
  - FAA handbook

Currently Accepted Aggregate Testing Methods

- Accelerated Mortar Bar Method – ASTM C1260/C1567 – AASHTO T303
  - 14-day testing period
  - Overly conservative results
- Concrete Prism Test – ASTM C1293
  - 1–2 years testing period
  - Reliable results, good correlation to field performance
- Petrographic Evaluation – ASTM C295
  - Identify and quantify reactive aggregate constituents
- Aggregate Reactivity & Mitigation Measures – ASTM C1778 – AASHTO R80

Newly Developed Aggregate Testing Methods

- Miniature Concrete Prism Test – AASHTO T380
  - 56-day testing period
  - Hybrid methodology
  - Good correlation to ASTM C1293
- Chinese Accelerated Mortar Bar Test
- Rapid Chemical Method for Determining Alkali-Silica Reactivity
- Autoclave Tests for Determining Potential Alkali-Silica Reactivity of Concrete Aggregates

Methods for Identifying and Quantifying ASR Damage in Existing Concrete

- Los Alamos Staining Method
- Petrographic Analysis
  - ASTM C856
  - ASTM C1723
  - Damage Rating Index

Cases of ASR Damage in Montana

- Memo
- Billings Logan International Airport
- Willow Creek Dam Spillway
- Belt Creek Bridge

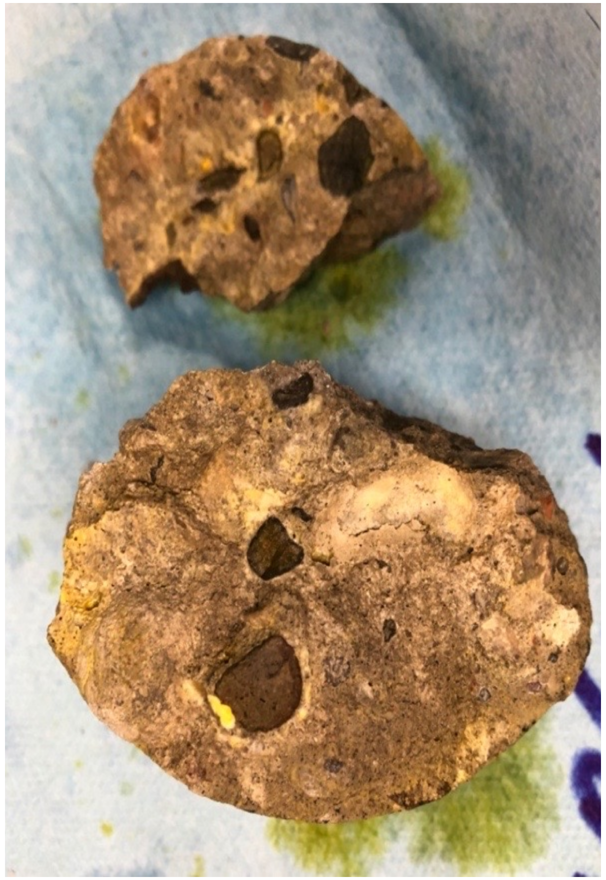
Billings Logan International Airport

Billings Logan International Airport – Site 1

- Original construction – 40 years ago
- Paste comprised solely of hydrated portland cement
- Aggregate – crushed siliceous gravel – (1 in.)
  - Rhyolite, granite rocks, quartzite and chert
  - Trace amounts of andesite and basalt
- Located near terminal
- Approximate dimensions
  - 4″ Diameter
  - 6 ¼″ - 8″ Length

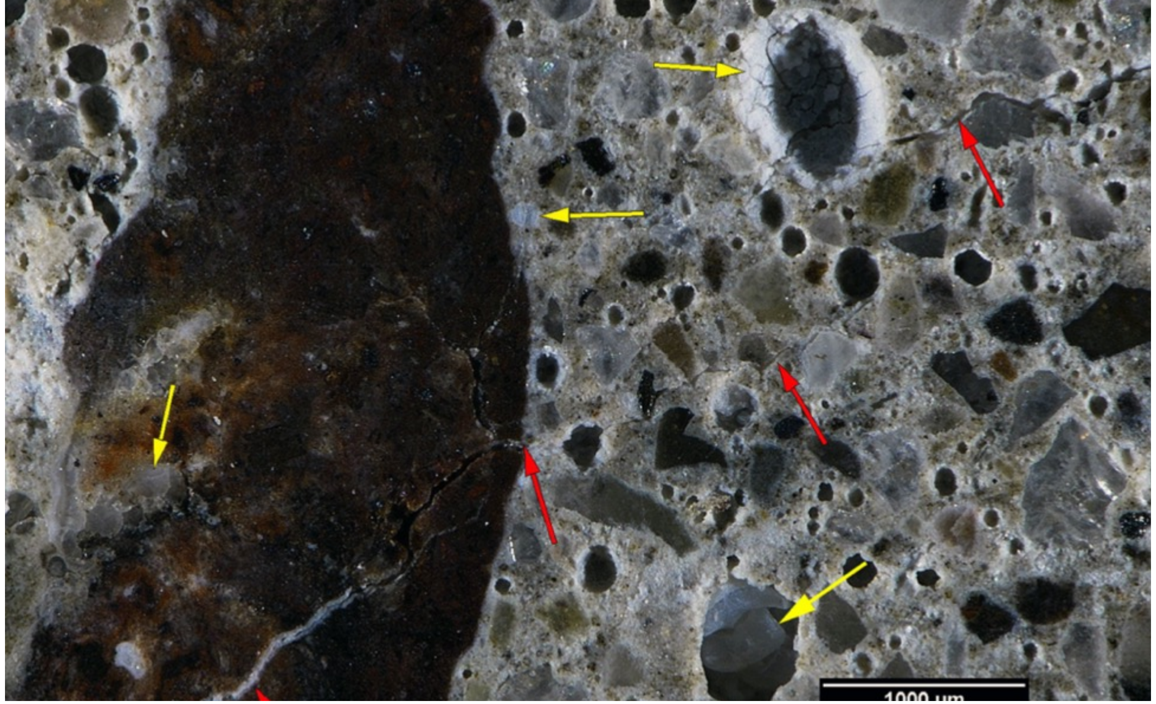
Los Alamos Staining Method – Site 1

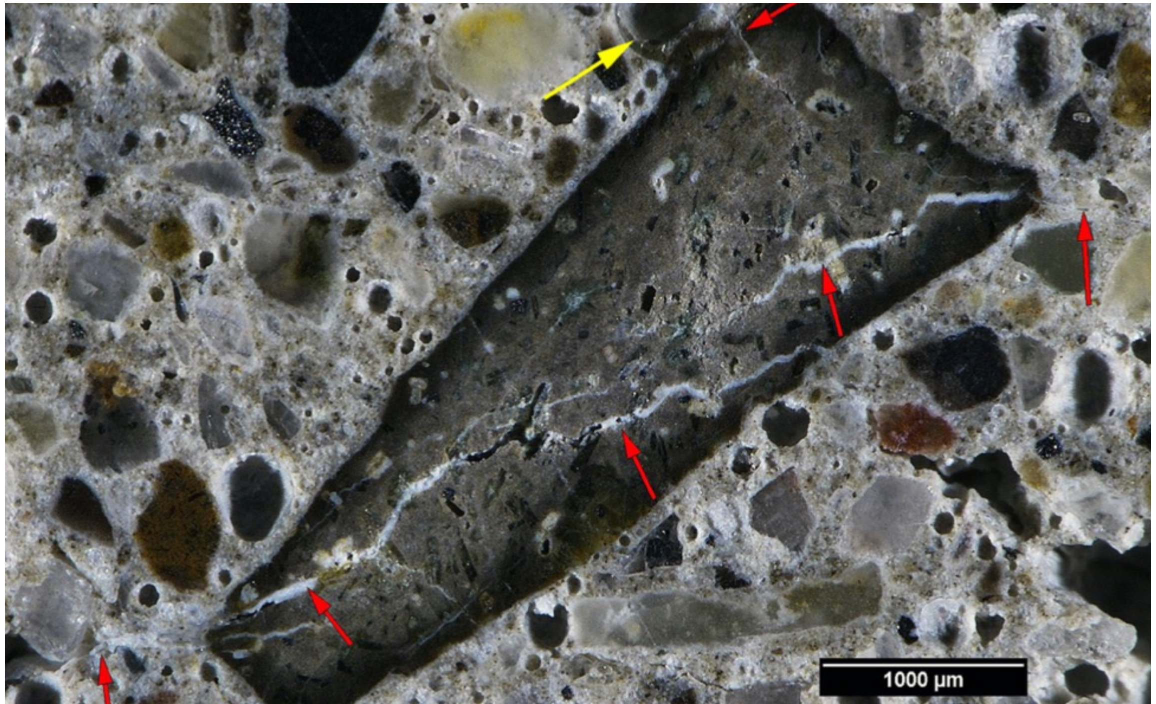
- Procedure
  - Apply distilled water to freshly broken surface
  - Apply yellow reagent to test surface
  - Wash off reagent with distilled water spray
  - Dry surface and examine for presence of ASR gel
  - Repeat process using red reagent
- Highly subjective results



Petrographic Analysis – Site 1

- Petrographic analysis per ASTM C856
- Concrete composition
  - No slag cement, fly ash or other supplementary cementitious materials
  - Coarse and fine aggregate were of similar reactive constitution
- Failure mechanisms
  - Early age shrinkage cracking
  - Sub-horizontal cracking
  - Cracking and microcracking due to ASR
- ASR classified as "Severe / Type V"





Billings Logan International Airport – Site 2

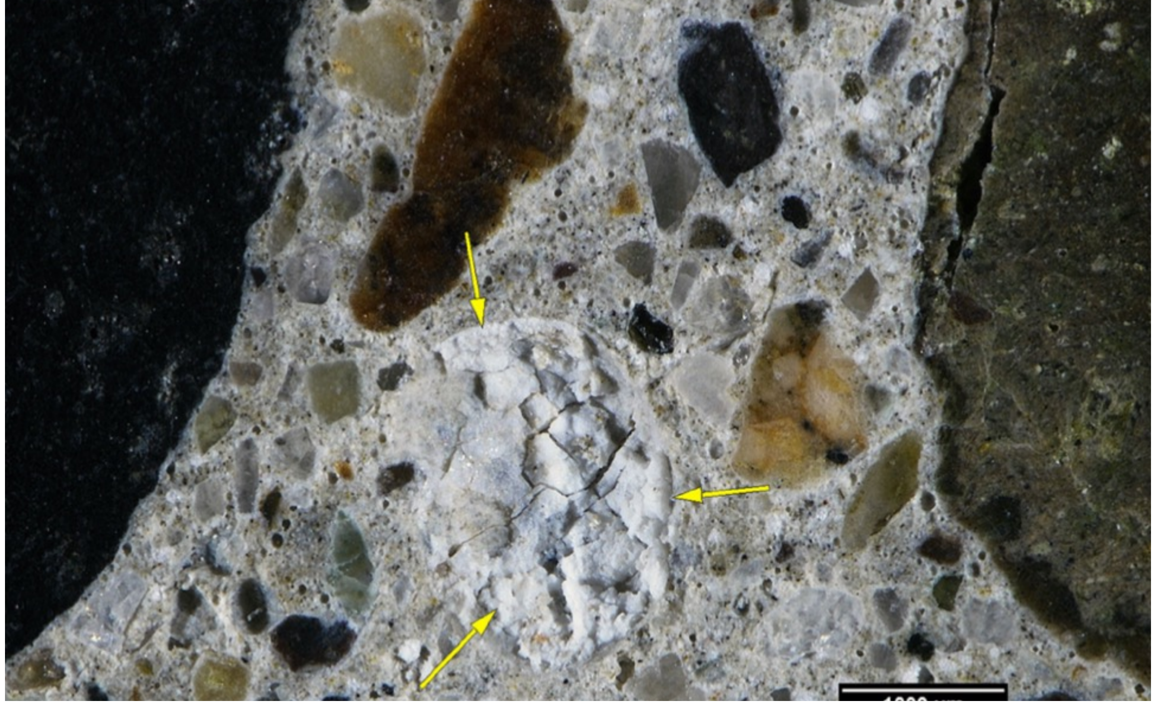
- Original construction – 20 years ago
- Paste comprised of hydrated portland cement & fly ash
- Aggregate – crushed siliceous gravel – (3/4 in.)
  - Rhyolite, granite rocks, quartzite and chert
  - Trace amounts of andesite and basalt
- Located near drain
- Approximate dimensions
  - 4″ Diameter
  - 6 ¼″ - 8″ Length

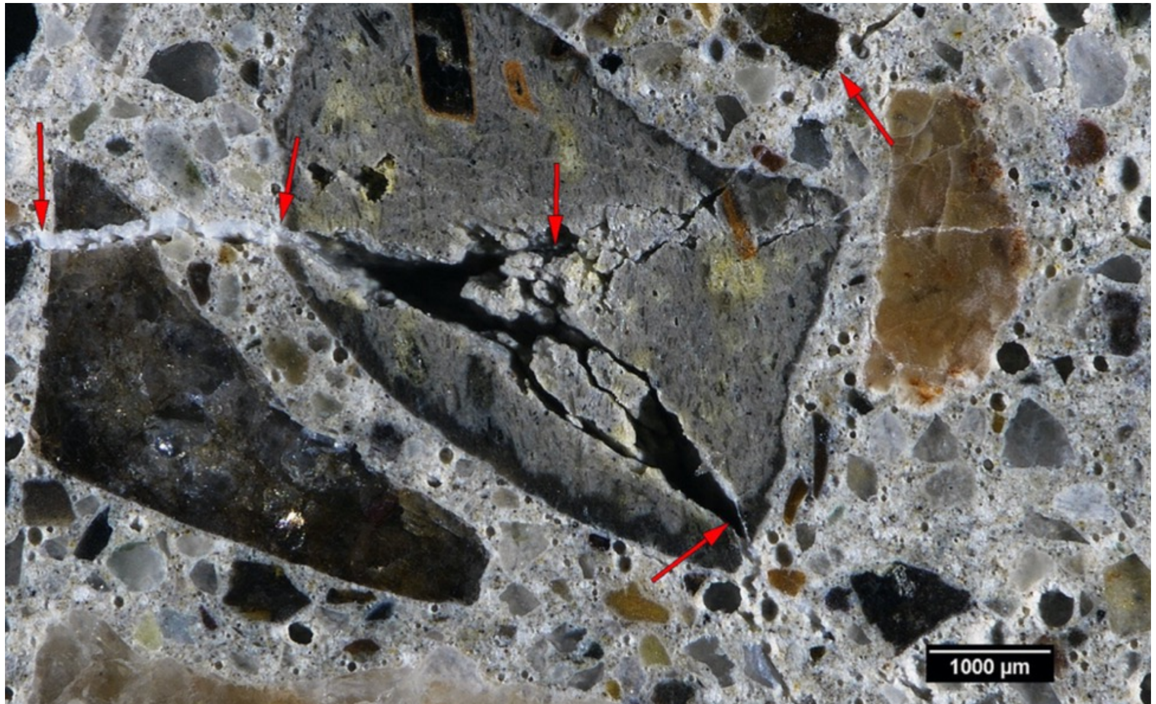
Los Alamos Staining Method – Site 2

- Procedure
  - Apply distilled water to freshly broken surface
  - Apply yellow reagent to test surface
  - Wash off reagent with distilled water spray
  - Dry surface and examine for presence of ASR gel
  - Repeat process using red reagent
- Highly subjective results

Petrographic Analysis – Site 2

- Petrographic analysis per ASTM C856
- Concrete composition
  - No slag cement or other supplementary cementitious materials
  - Coarse and fine aggregate were of similar reactive constitution
- Failure mechanisms
  - Early age shrinkage cracking
  - Sub-horizontal cracking
  - Cracking and microcracking due to ASR
- ASR classified as “Severe / Type V”





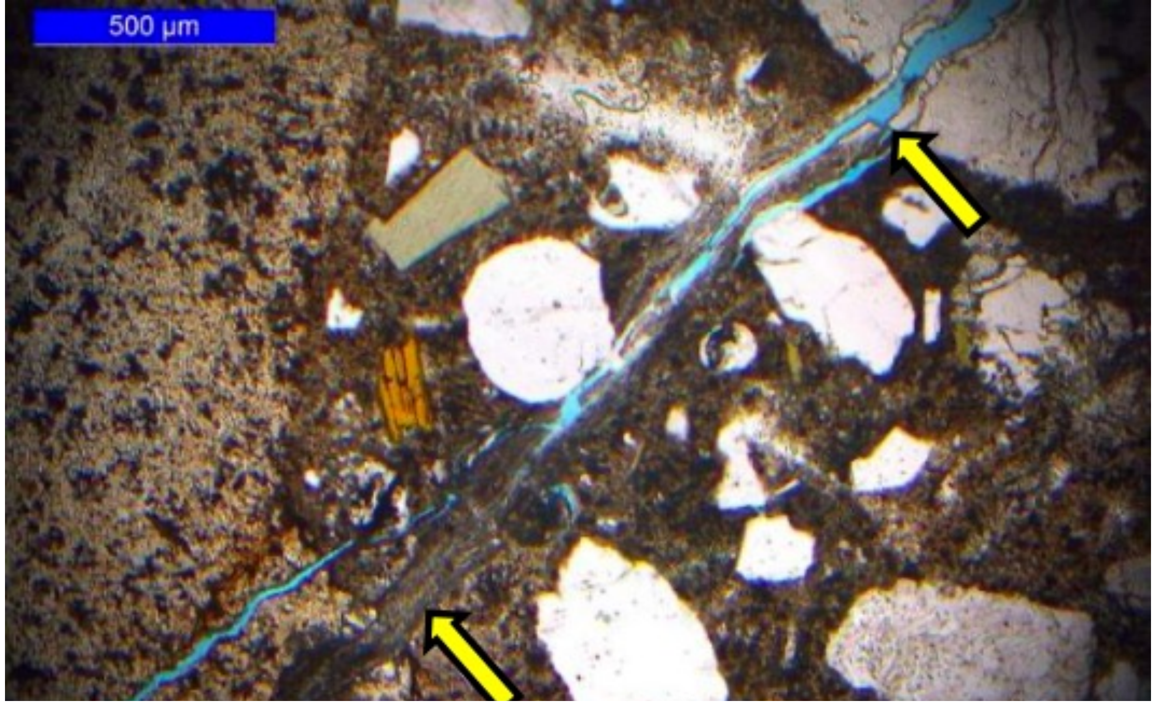
Willow Creek Dam Spillway

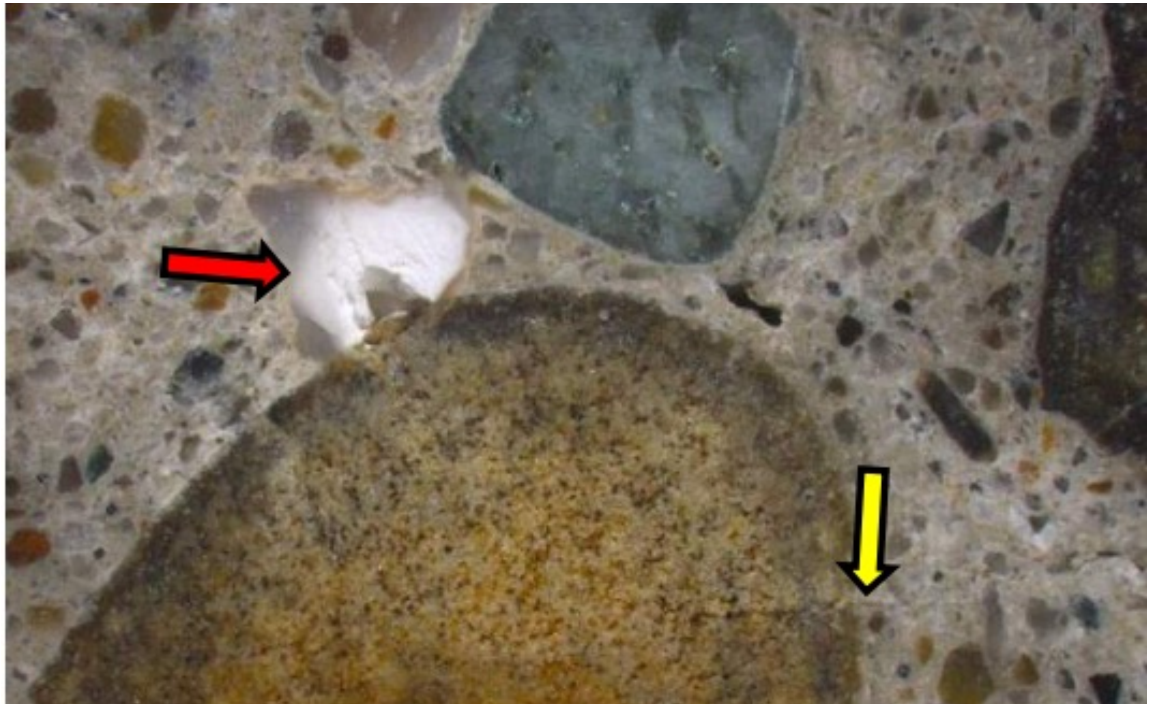
Willow Creek Dam Spillway

- Original construction – 75 years ago
- Consists of:
  - Side walls, chute, flip bucket, ogee
- Minor repairs and sealant work completed
- WJE retained by DNRC to assess condition
- Paste comprised of portland cement
- Aggregate – natural siliceous gravel – (1 in.)
  - Felsic igneous and metamorphic rocks, quartzite, chert and sandstone
  - Trace amounts of carbonate.

Petrographic Analysis – Willow Creek Dam Spillway

- Petrographic analysis per ASTM C856
- Failure mechanisms
  - Transverse and longitudinal cracking
  - Patterned cracking
  - Freeze thaw distress
  - Alkali-silica reaction
- Advanced ASR was detected in the ogee
- Other areas of the slab exhibited ASR-related distress to a lesser extent.





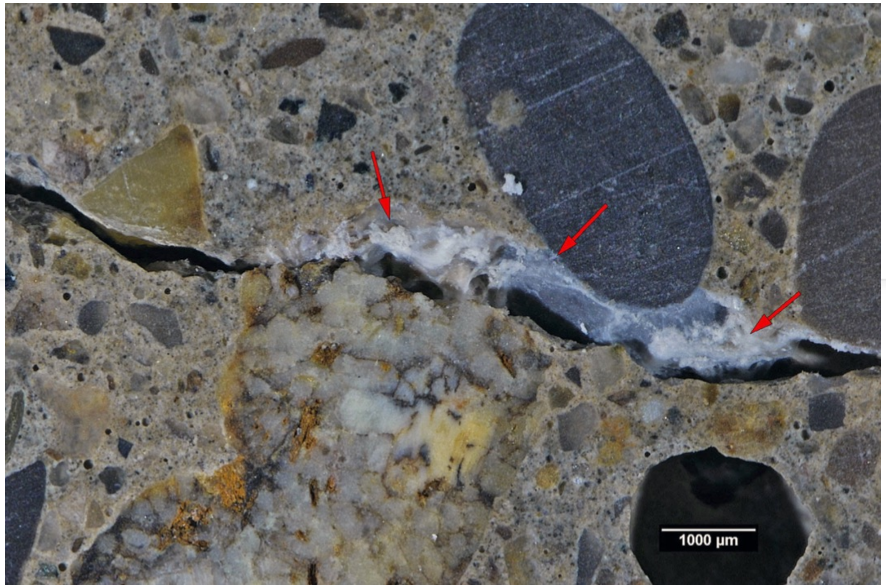
US-87/US-89/MT 200 Bridge over Belt Creek

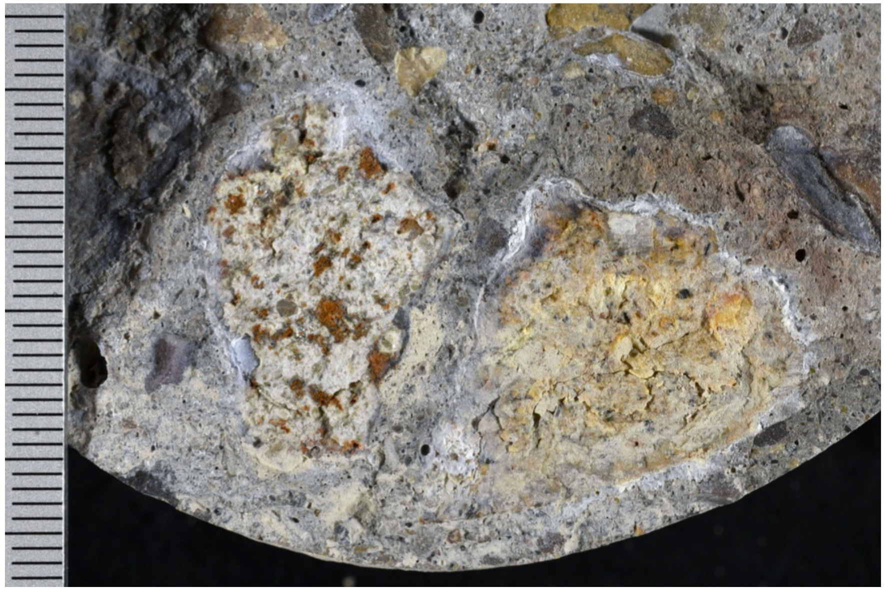
Bridge over Belt Creek

- Original construction – 1954
- Significant cracking/efflorescence observed on backwall
- 3 cores were extracted and sent to DRP for petrographic analysis
- Paste contains portland cement, no fly ash
- Aggregate – natural siliceous and carbonate rock
    - limestone, siliceous limestone, quartzite, chert, and siliceous volcanic rocks

Petrographic Analysis – Bridge over Belt Creek

- Petrographic analysis per ASTM C856
- Concrete composition
  - No slag cement or other supplementary cementitious materials
  - Coarse and fine aggregate were of similar reactive constitution
- Moderate to severe damage from ASR DRP Scale
- ASR classified as “Stage IV” Katayama Scale





Montana
Aggregate Testing

- Eight aggregates
- ASTM C1260
- AASHTO T380

Materials

- Eight aggregates
  - Helena
  - Billings - duplicate
  - Missoula
- Graded Ottawa test sand / limestone
- Type I/II portland cement – ASTM C150
- Deionized water
- Technical grade sodium hydroxide

Preparation – ASTM C1260

- Physical property tests per ASTM
  - Oven-dried specific gravity
  - Absorption
- Crush, sieve and recombine
- Mix proportions

Sieve Size		Mass, %
Passing	Retained on	
4.75 mm (No. 4)	2.36 mm (No. 8)	10
2.36 mm (No. 8)	1.18 mm (No. 16)	25
1.18 mm (No. 16)	600 μm (No. 30)	25
600 μm (No. 30)	300 μm (No. 50)	25
300 μm (No. 50)	150 μm (No. 100)	15

Variable	Amount
w/c ratio	0.47
Reagent water	206.8 g
Portland cement	440 g
Aggregate - coarse/fine	990 g

Mixing – ASTM C1260

- Mixing per ASTM C305
- Three specimens per mix design
- Molds
  - 1 in. x 1 in. x 11.25 in. (25 mm x 25 mm x 285 mm)
  - Metal gauge studs
- Curing
  - Moist room – 24 hours
  - Demolded & initial reading
  - Water bath 80°C (176°F) – 24 hours

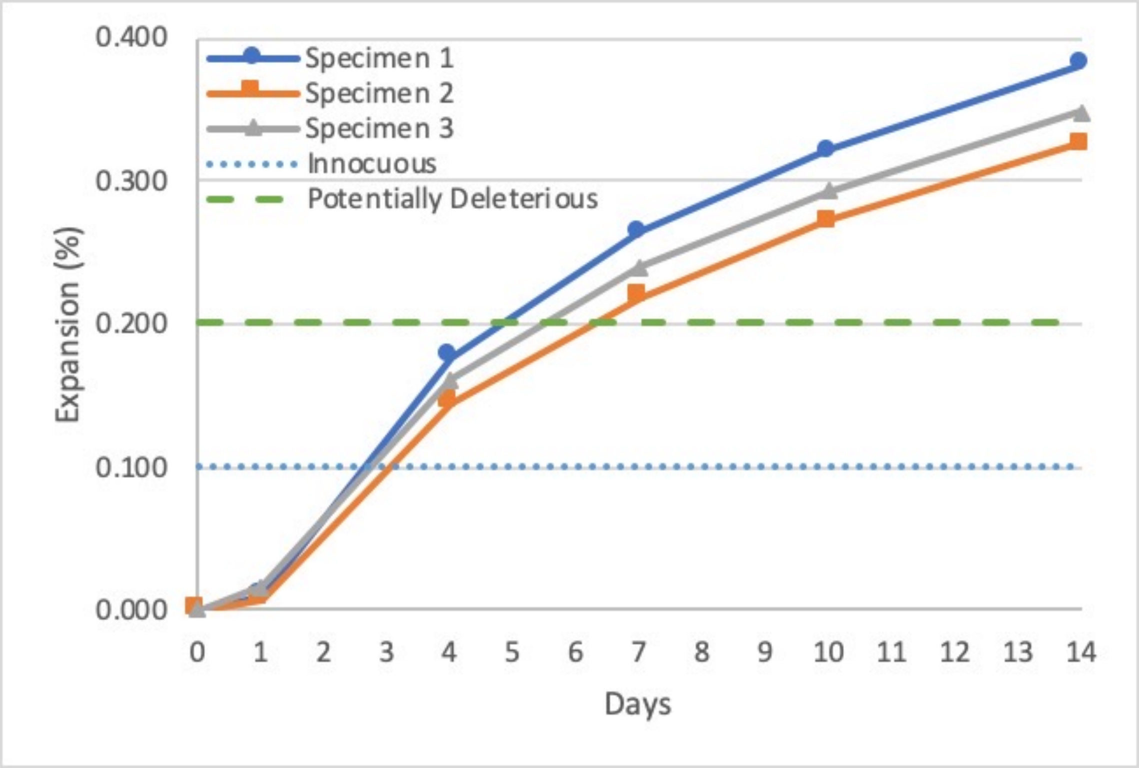
Testing – ASTM C1260

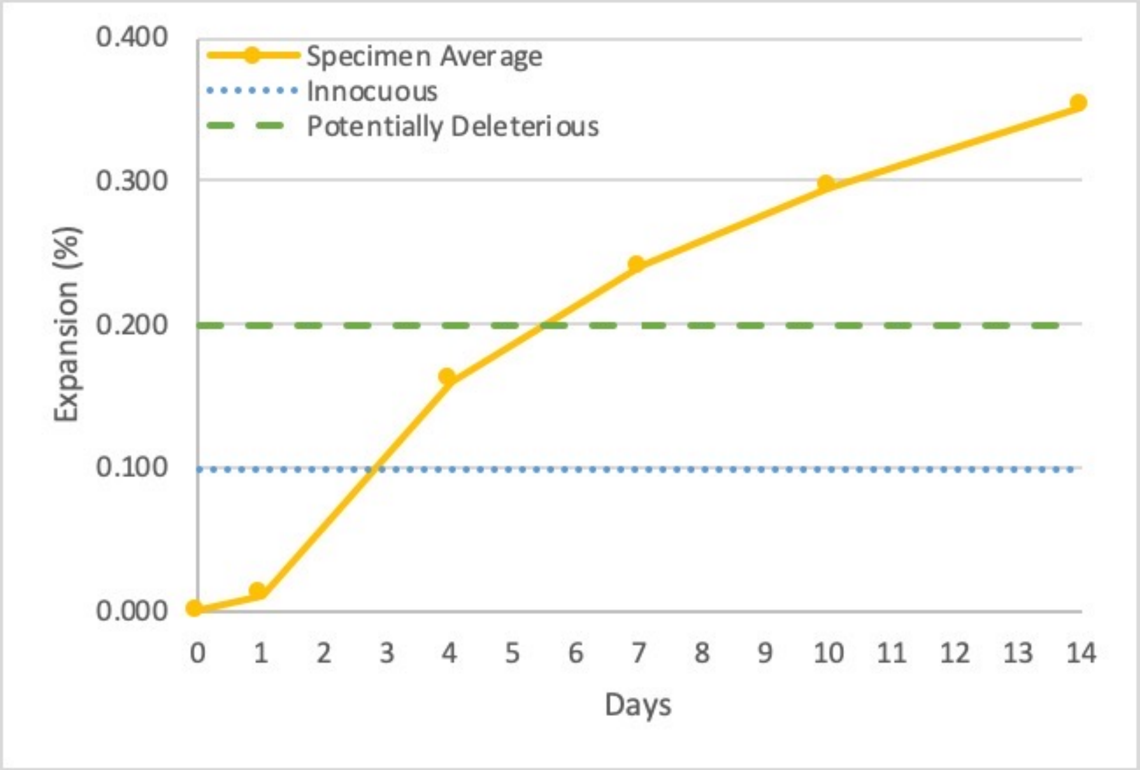
- Storage
  - Approved Humboldt container
  - 1N NaOH solution at 80°C (176°F)
- Testing apparatus
  - Length comparator
  - Reference bar
- Testing period
  - Initial reading after demolding
  - Zero reading after water bath
  - 1, 3, 7, 10 and 14 days

ASTM C1260 Expansion Limits

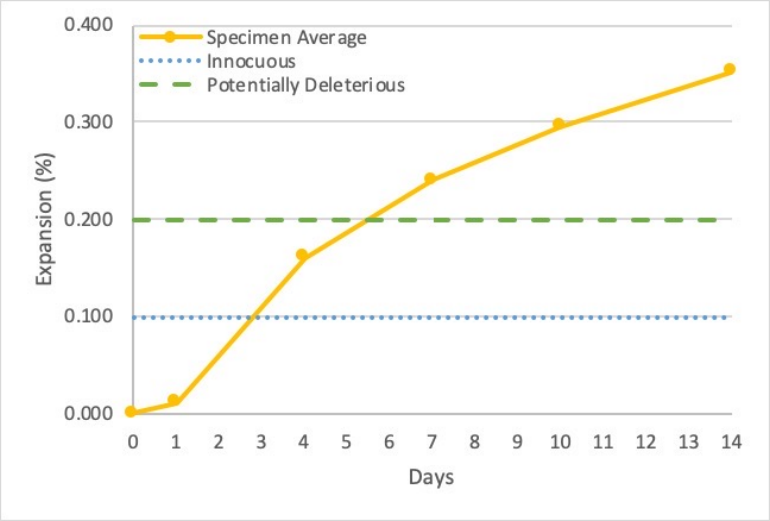
Degree of Reactivity	Expansion (%)
Innocuous	< 0.10
Potentially Deleterious	0.10-0.20
Reactive	> 0.20

ASTM C1260 Results





ASTM C1260 Fine Aggregate Results



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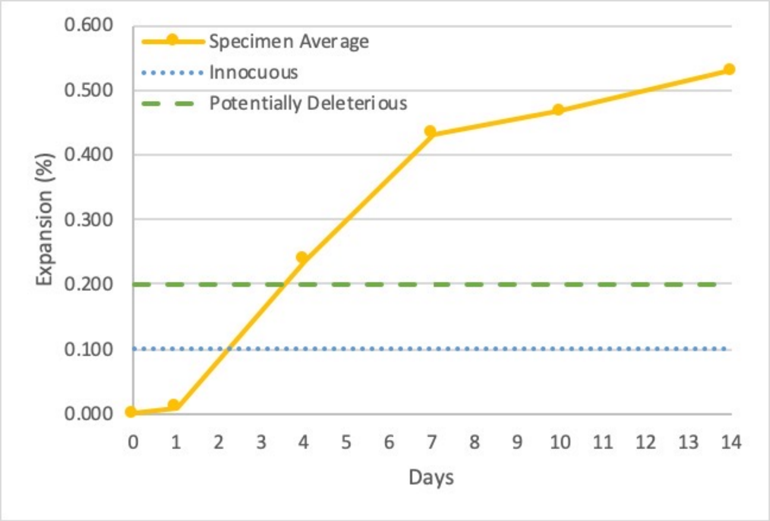

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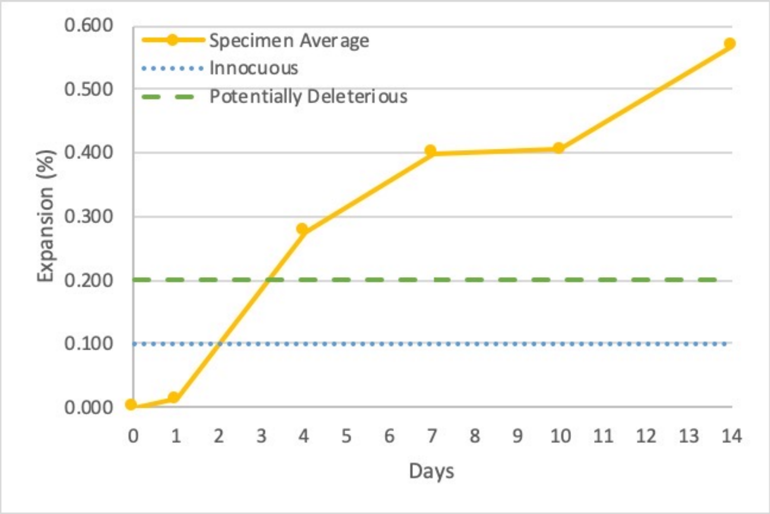

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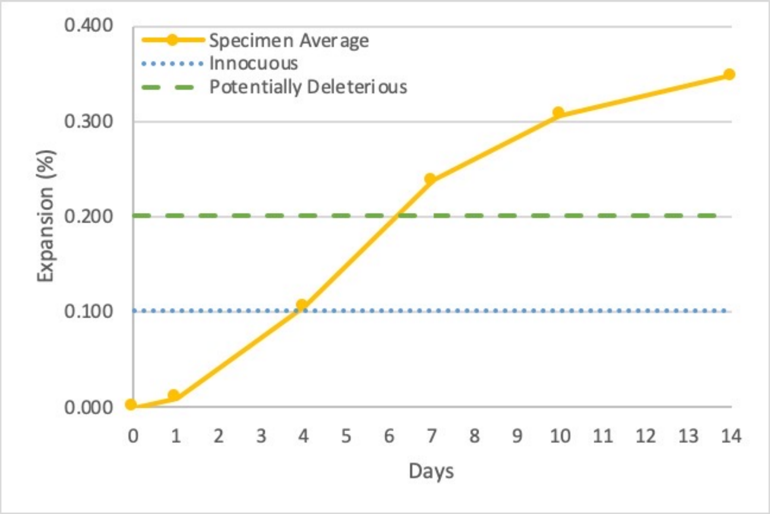

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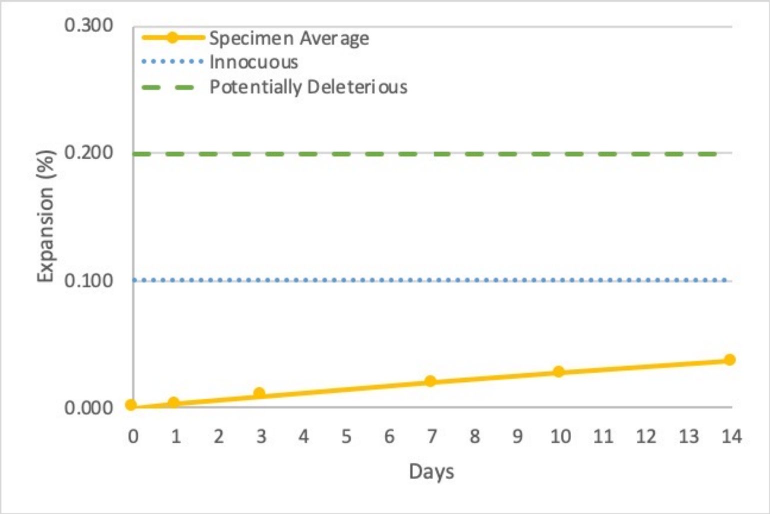
ASTM C1260 Coarse Aggregate Results



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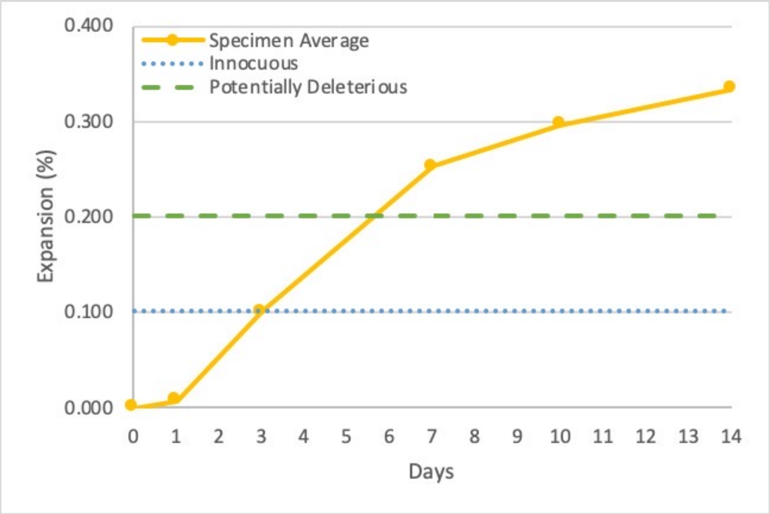

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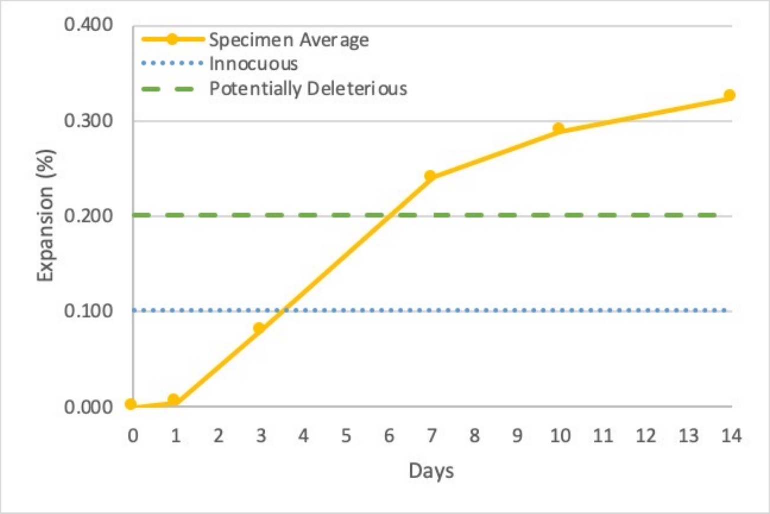

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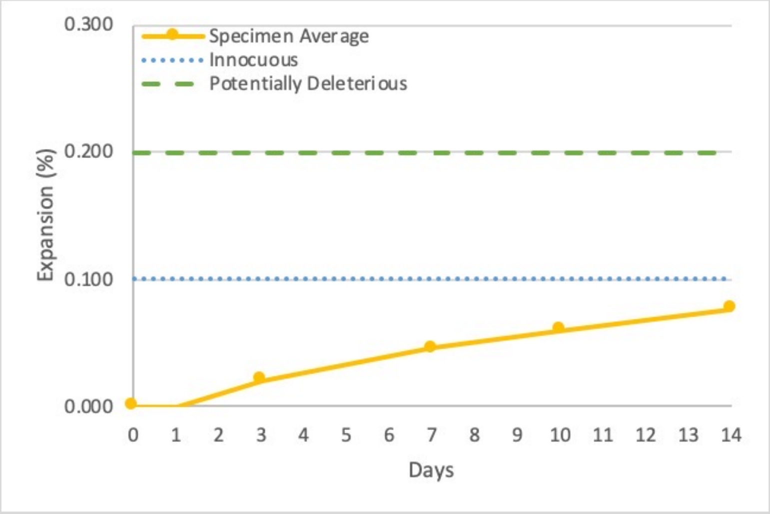


C-4

Preparation – AASHTO T380

- Physical property tests per ASTM
  - Dry-rodded unit weight

- Crush, sieve and recombine

Sieve Size		Mass, %
Passing	Retained on	
12.5 mm (1/2 in.)	9.5 mm (3/8 in.)	57.5
9.5 mm (3/8 in.)	4.75 mm (No. 4)	42.5

Mix Design – AASHTO T380

- ACI's Absolute Volume Method
  - Coarse aggregate volume fraction – 0.65
  - Cement content – 708 lb./yd^3
- Reactive w/ non-reactive
- Sodium hydroxide addition
  - Increase alkali content of the concrete to 1.25% by mass of cement

Mix ID	w/c Ratio	Reagent Water (lb)	Portland Cement (lb)	NaOH Admixture (lb)	Coarse Aggregate (lb)	Fine Aggregate (lb)
F-1	0.45	14.80	26.22	0.099	67.24	67.24
F-2	0.45	14.25	26.22	0.099	67.24	67.24
F-3	0.45	14.28	26.22	0.099	67.24	67.24
F-4	0.45	14.37	26.22	0.099	67.24	67.24
C-1	0.45	13.96	26.22	0.099	65.32	65.32
C-2	0.45	13.41	26.22	0.099	66.96	66.96
C-3	0.45	13.33	26.22	0.099	67.08	67.08
C-4	0.45	13.35	26.22	0.099	66.54	66.54

Mixing – AASHTO T380

- Mixing per ASTM C192
- Three specimens per mix design
- Slump test
- Molds
  - 2 in. x 2 in. x 11.25 in. (50 mm x 50 mm x 285 mm)
  - Metal gauge studs
- Curing
  - Moist room – 24 hours
  - Demolded & initial reading
  - Water bath 60°C (140°F) – 24 hours

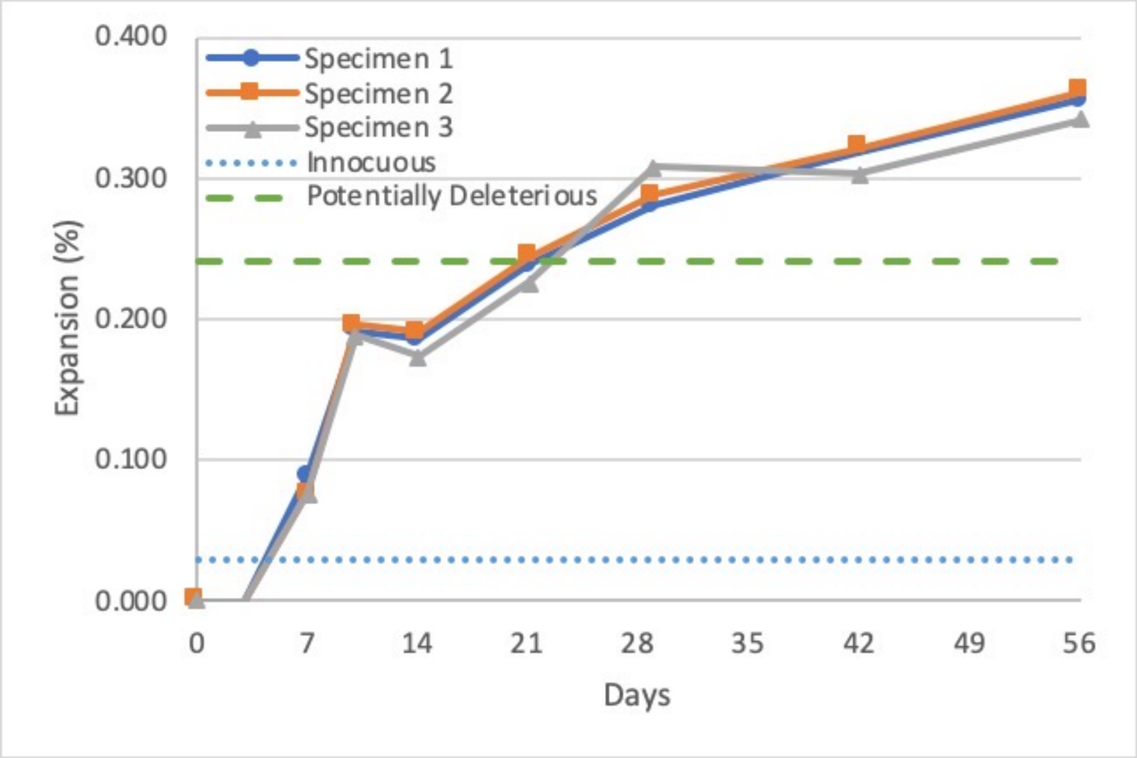
Testing – AASHTO T380

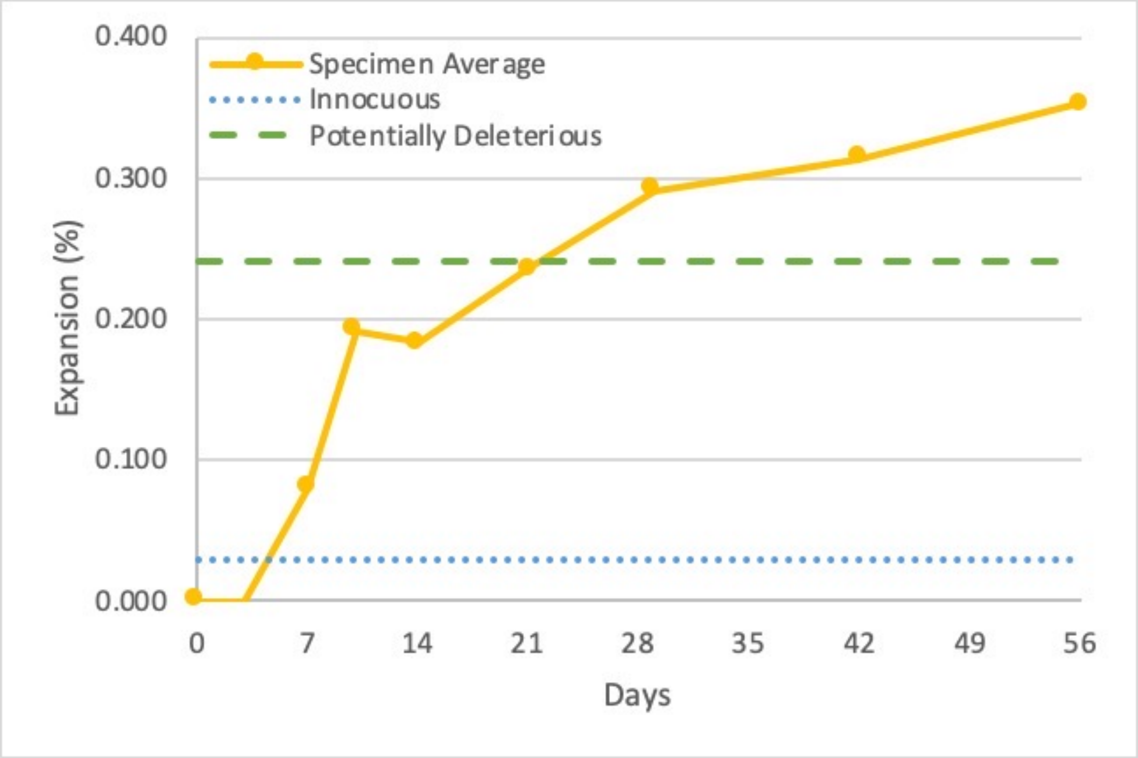
- Storage
  - Approved Humboldt container
  - 1N NaOH solution at 60°C (140°F)
- Testing apparatus
  - Length comparator
  - Reference bar
- Testing period
  - Initial reading after demolding
  - Zero reading after water bath
  - 1, 3, 7, 10, 14, 21, 28, 42 and 56 days

AASHTO T380 Expansion Limits

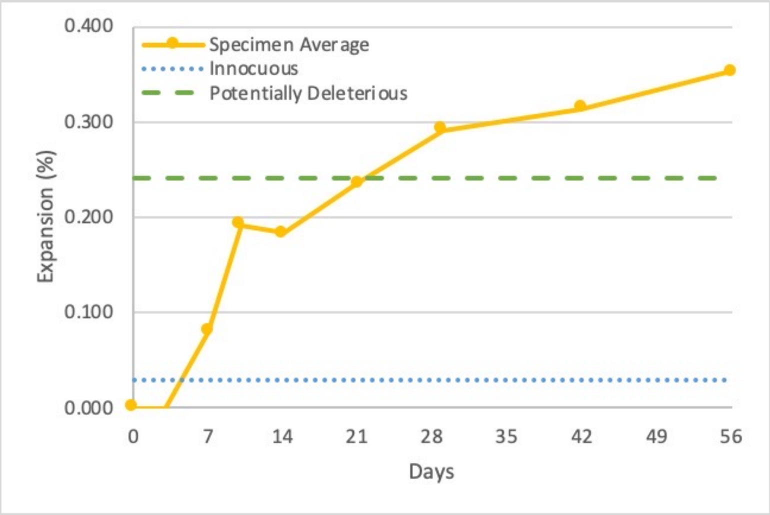
Degree of Reactivity	% Expansion at 56 Days (8 Weeks)	Average Rate of Expansion from (8-12 Weeks)
Non-Reactive	<= 0.030	N/A
Non-Reactive	0.031-0.040	<= 0.010 per two weeks
Low/Slow Reactive	0.031-0.040	> 0.010 per two weeks
Moderate Reactive	0.040-0.120	N/A
Highly Reactive	0.121-0.240	N/A
Very Highly Reactive	> 0.240	N/A

AASHTO T380 Results





AASHTO T380 Fine Aggregate Results



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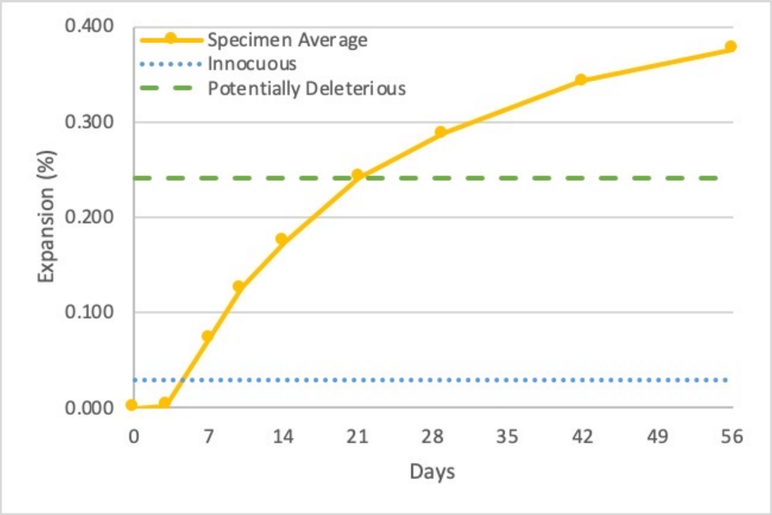

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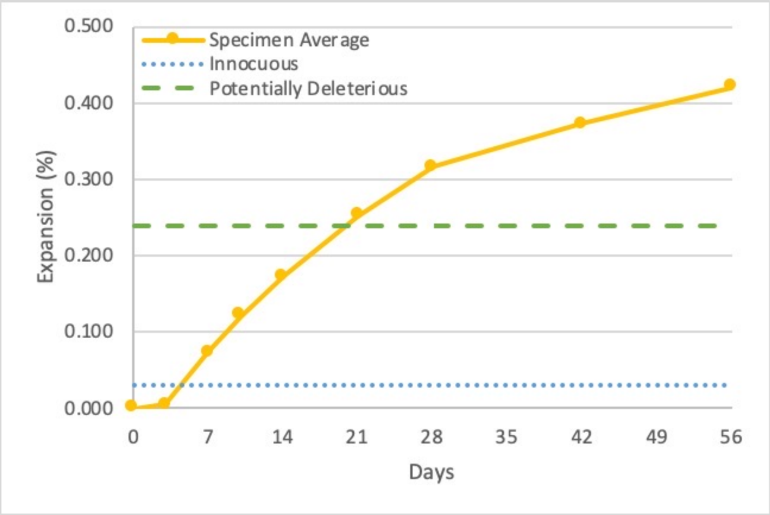

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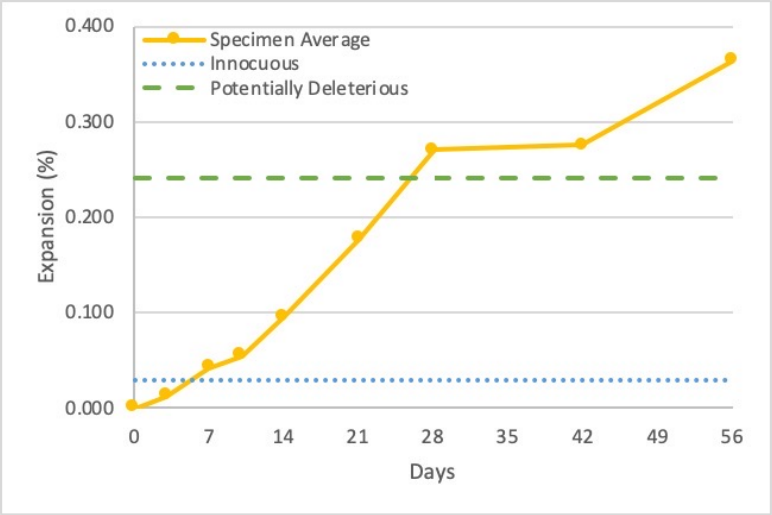

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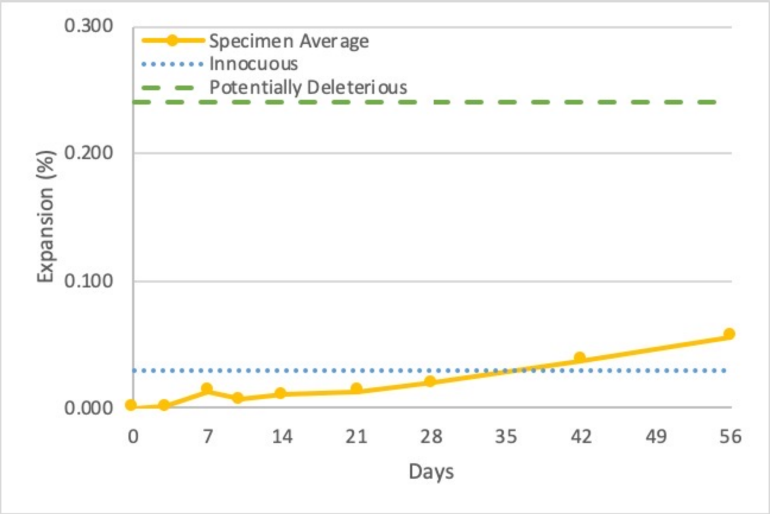
AASHTO T380 Coarse Aggregate Results



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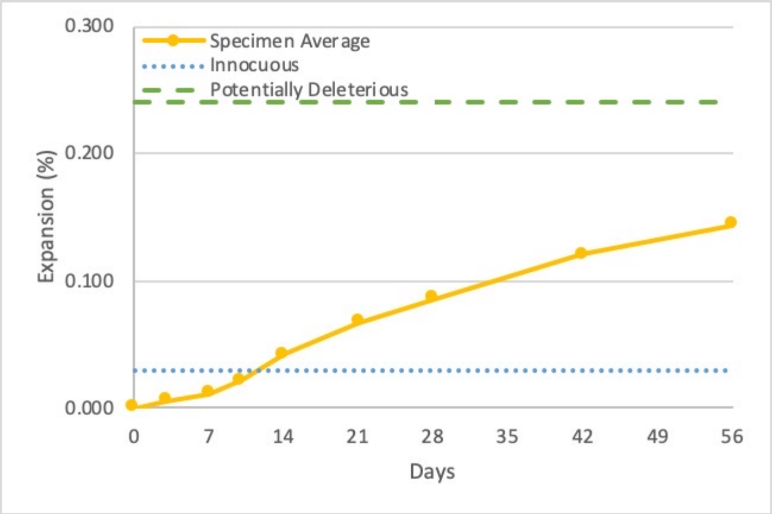

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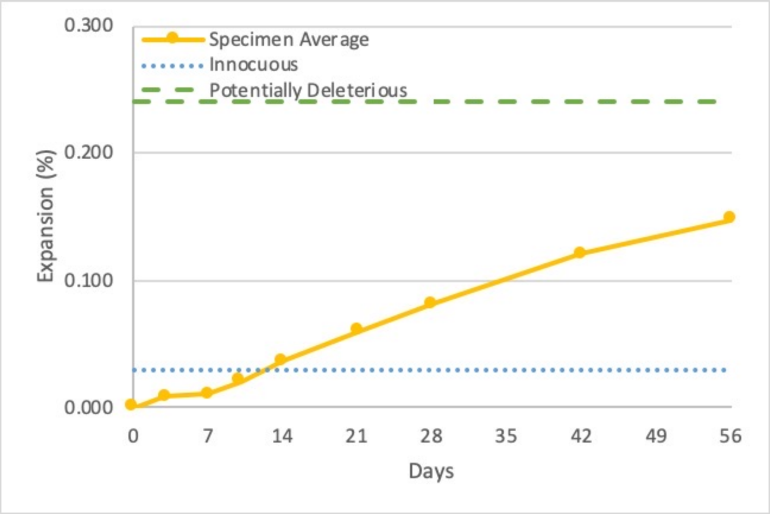

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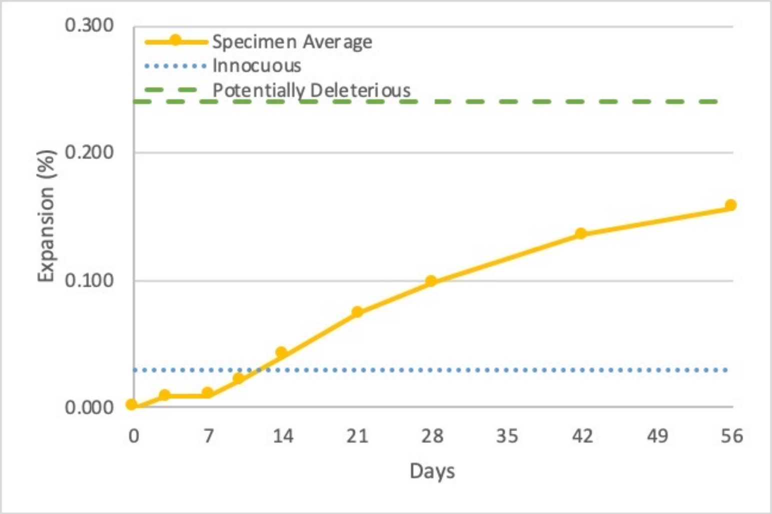
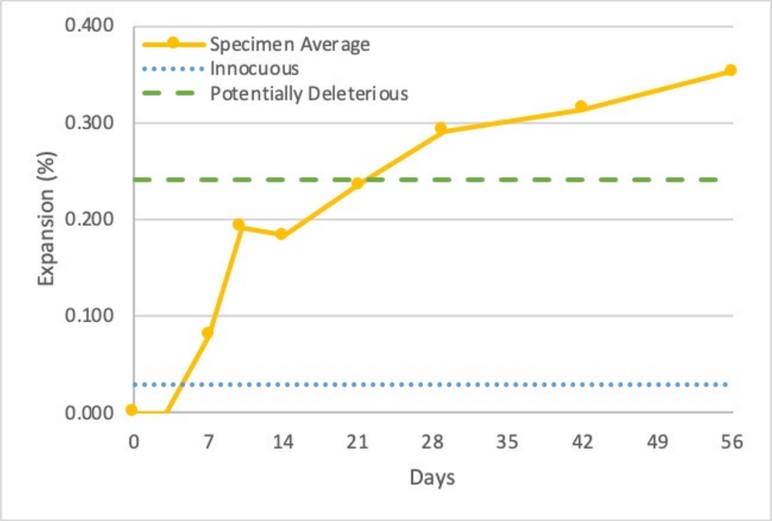


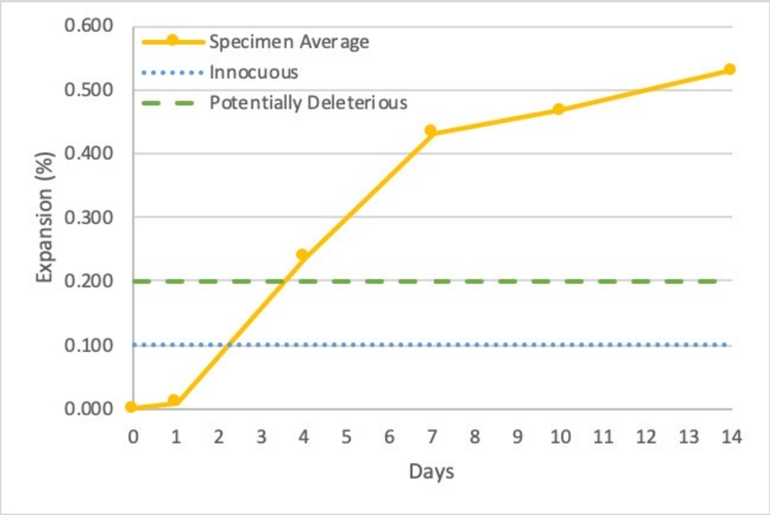
C-4

ASTM C1260 vs. AASHTO T380 Fine Aggregate Results

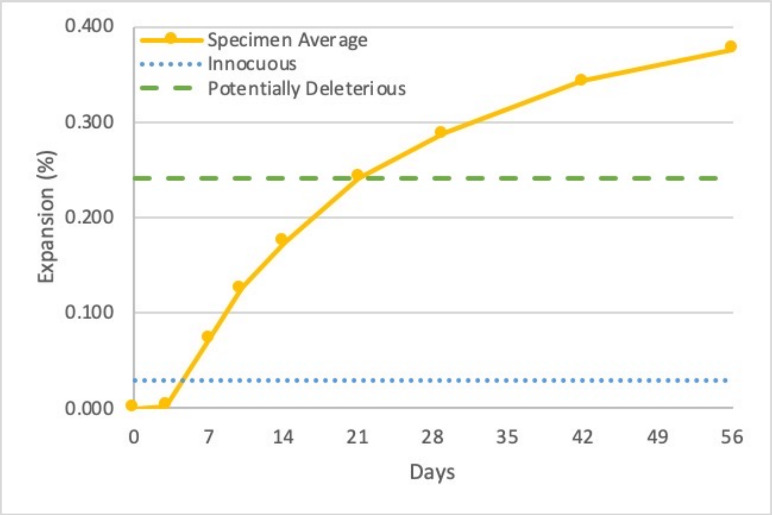
F-1 - ASTM



F-1 – AASHTO

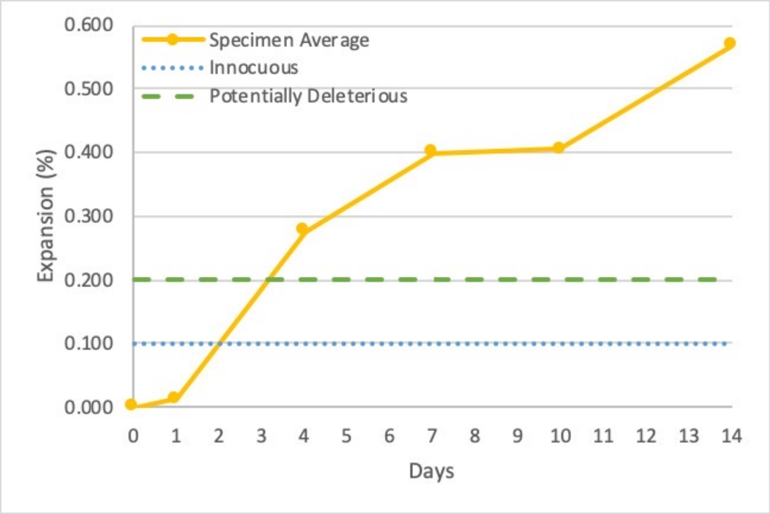


F-2 - ASTM

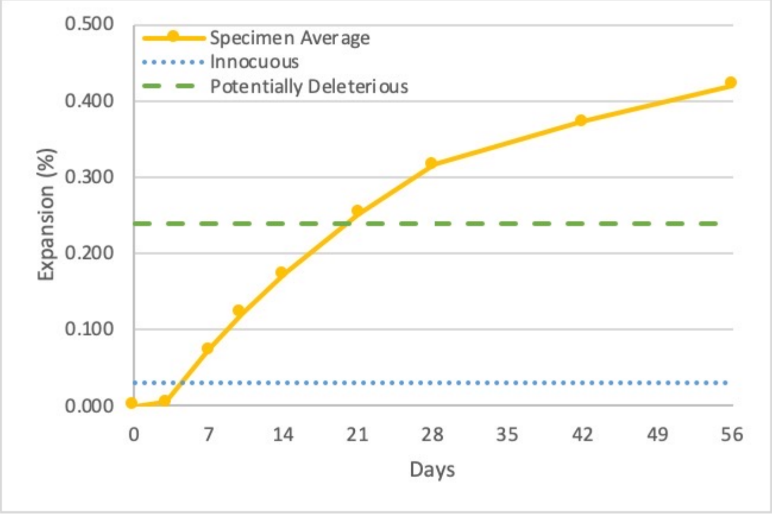


F-2 - AASHTO

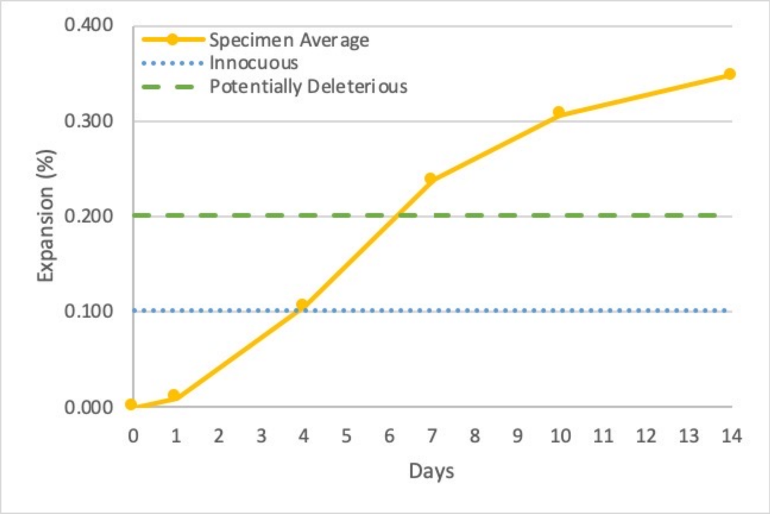
ASTM C1260 vs. AASHTO T380 Fine Aggregate Results



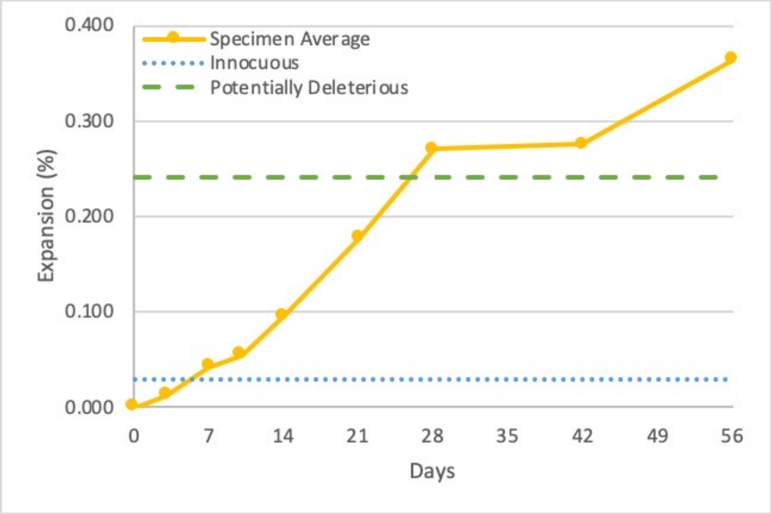
F-3 - ASTM



F-3 – AASHTO

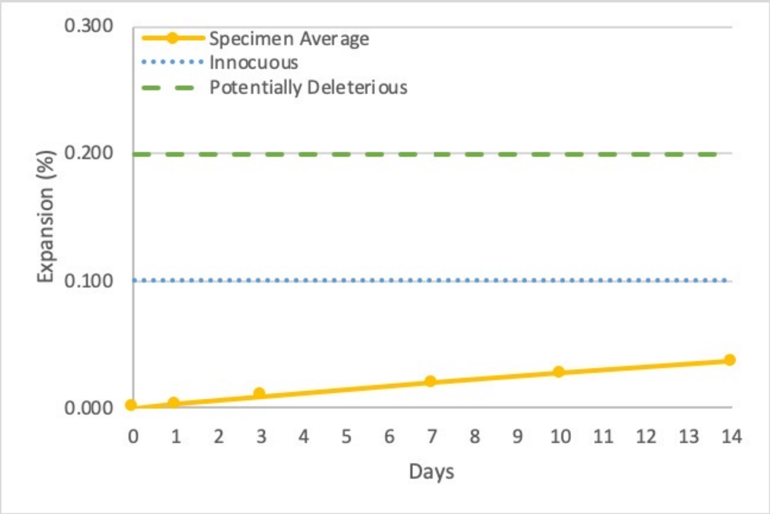


F-4 - ASTM

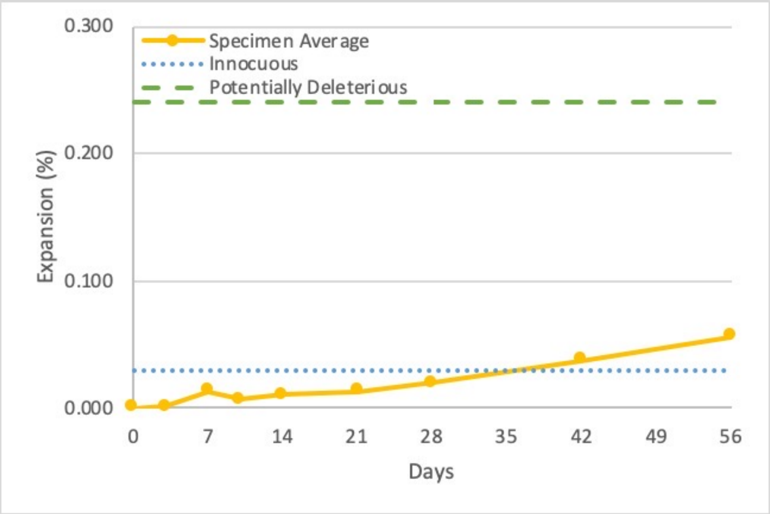


F-4 – AASHTO

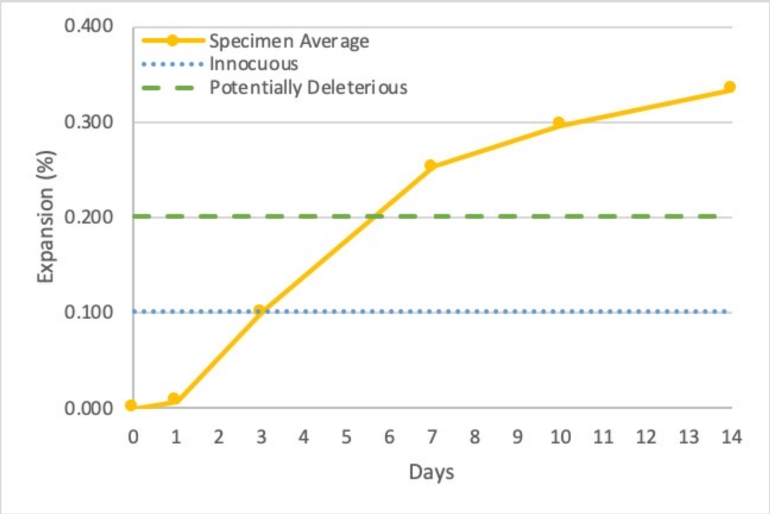
ASTM C1260 vs. AASHTO T380 Coarse Aggregate Results



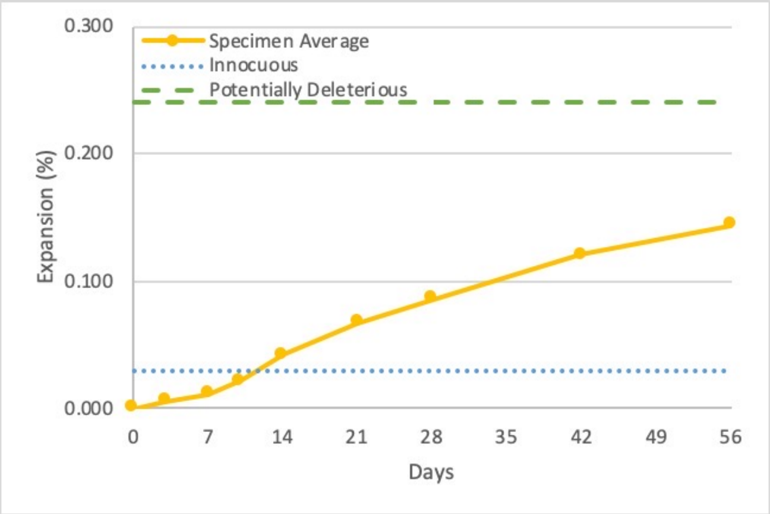
C-1 - ASTM



C-1 – AASHTO



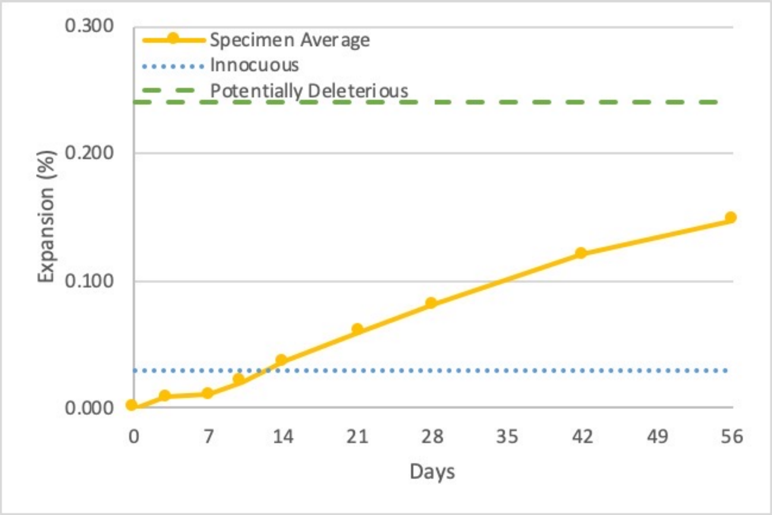
C-2 - ASTM



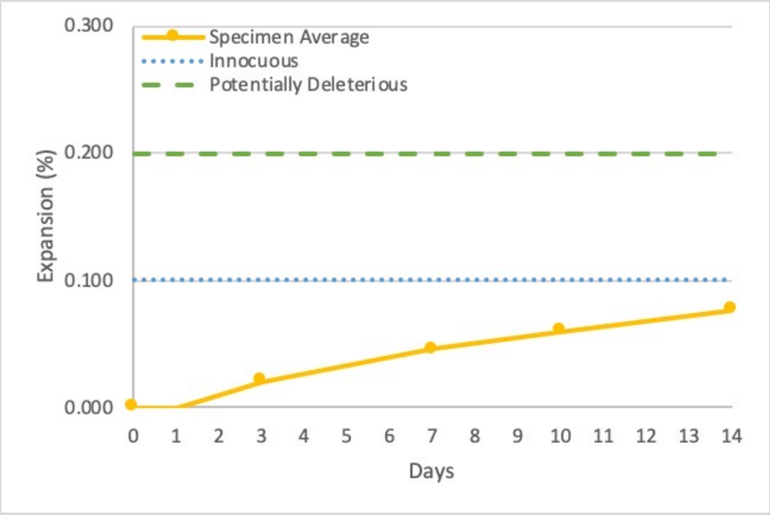
C-2 – AASHTO

ASTM C1260 vs. AASHTO T380 Coarse Aggregate Results

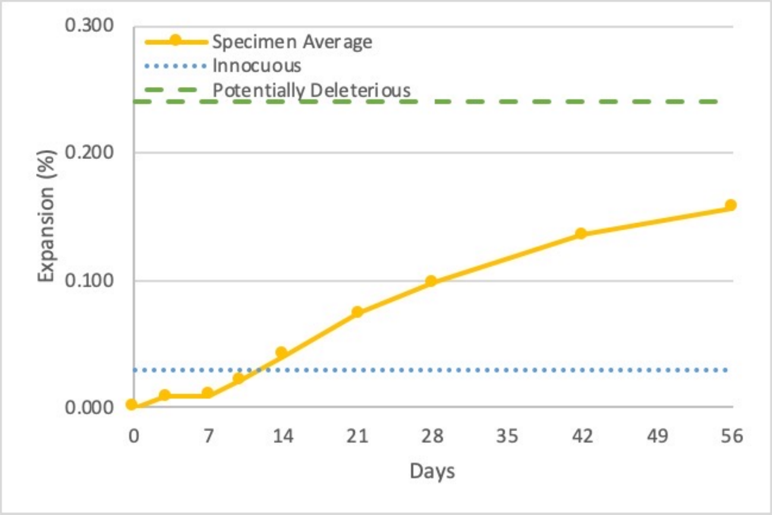
C-3 - ASTM



C-3 – AASHTO



C-4 - ASTM



C-4 – AASHTO

Summary of Results – Fine Aggregates

Mix ID	Location	ASTM C1260, 14 Days		AASHTO T380, 56 Days	
		% Expansion	Degree of Reactivity	% Expansion	Degree of Reactivity
F-1	Helena Sand & Gravel - Lake Helena Drive Pit	0.351	Reactive	0.352	Very Highly Reactive
F-2	Knife River Billings - Sindelar Pit	0.529	Reactive	0.376	Very Highly Reactive
F-3	Knife River Billings - Sindelar Pit	0.568	Reactive	0.419	Very Highly Reactive
F-4	Knife River Missoula - Allen Pit	0.347	Reactive	0.364	Very Highly Reactive

Summary of Results – Coarse Aggregates

Mix ID	Location	ASTM C1260, 14 Days		AASHTO T380, 56 Days	
		% Expansion	Degree of Reactivity	% Expansion	Degree of Reactivity
C-1	Helena Sand & Gravel - Lake Helena Drive Pit	0.036	Innocuous	0.056	Moderate Reactive
C-2	Knife River Billings - Sindelar Pit	0.333	Reactive	0.143	Highly Reactive
C-3	Knife River Billings - Sindelar Pit	0.324	Reactive	0.147	Highly Reactive
C-4	Knife River Missoula - Allen Pit	0.076	Innocuous	0.157	Highly Reactive

Summary and Conclusions

- Literature Review
  - All of the states and provinces investigated in this research (except North Dakota), addressed ASR in their material specifications to varying degrees
  - The FHWA defers to individual states to determine ASR practices
  - The FAA has more stringent ASR-related requirements
  - Examined the advantages and shortcomings of new and existing aggregate testing methodologies
  - Miniature Concrete Prism Test most promising

Summary and Conclusions Cont.

- Billings Logan International Airport
  - The Los Alamos Staining results positive for ASR
  - ASR classified as severe/Type V in both sites
- Willow Creek Dam Spillway
  - Advanced ASR was detected in the ogee
- Belt Creek Bridge
  - Moderate to Severe/Stage IV ASR damage

- Demonstrated that cases of ASR in Montana do exist, and that the infrastructure in the state is susceptible to ASR

Summary and Conclusions Cont.

- ASTM C1260
  - All the fine aggregates were classified as reactive
  - Two innocuous and two reactive coarse aggregates
  - The blind duplicate aggregates from the Knife River Billings – Sindelar Pit and were classified as reactive
- AASHTO T380
  - All the fine aggregates were classified as very highly reactive
  - All the coarse aggregates were reactive to varying degrees
- This and previous studies have demonstrated that Montana aggregates are reactive

Recommendations

- MDT should consider using AASHTO T380 (Miniature Concrete Prism Test) as apposed to ASTM C1260 when testing the reactivity of aggregates
  - Research has shown this method to be more accurate and less conservative than ASTM C1260, with results quicker than ASTM C 1293
  - Less preparation, aggregate gradations are closer to natural state
  - Very similar implementation as ASTM C1260

- Los Alamos staining method should not be used to determine potential ASR Damage

Recommendations (cont)

- Research clearly demonstrates the potential for ASR in Montana and the occurrence of it, but damage from ASR was not determined to be a wide-spread issue.
- Current practice in Montana (limiting alkalis in cement) seems appropriate for mitigating ASR in Montana and should be continued.
  - Limited alkali loading is similar to limits prescribed by AASHTO R80 (Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction)
- However, several upcoming changes may affect this approach, at which point this policy should be revisited.
  - Low alkali cements may be on the way out due to increased production of limestone cements, and the increased availability of cheaper cements from newer/neighboring cement plants.
  - The decreased availability of Class F fly ash also may exasperate the issue
  - At this point MDT could look to adopting AASHTO R80 for ASR mitigation or at least some aspects of this policy (e.g., prescriptive alkali loading limits).

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