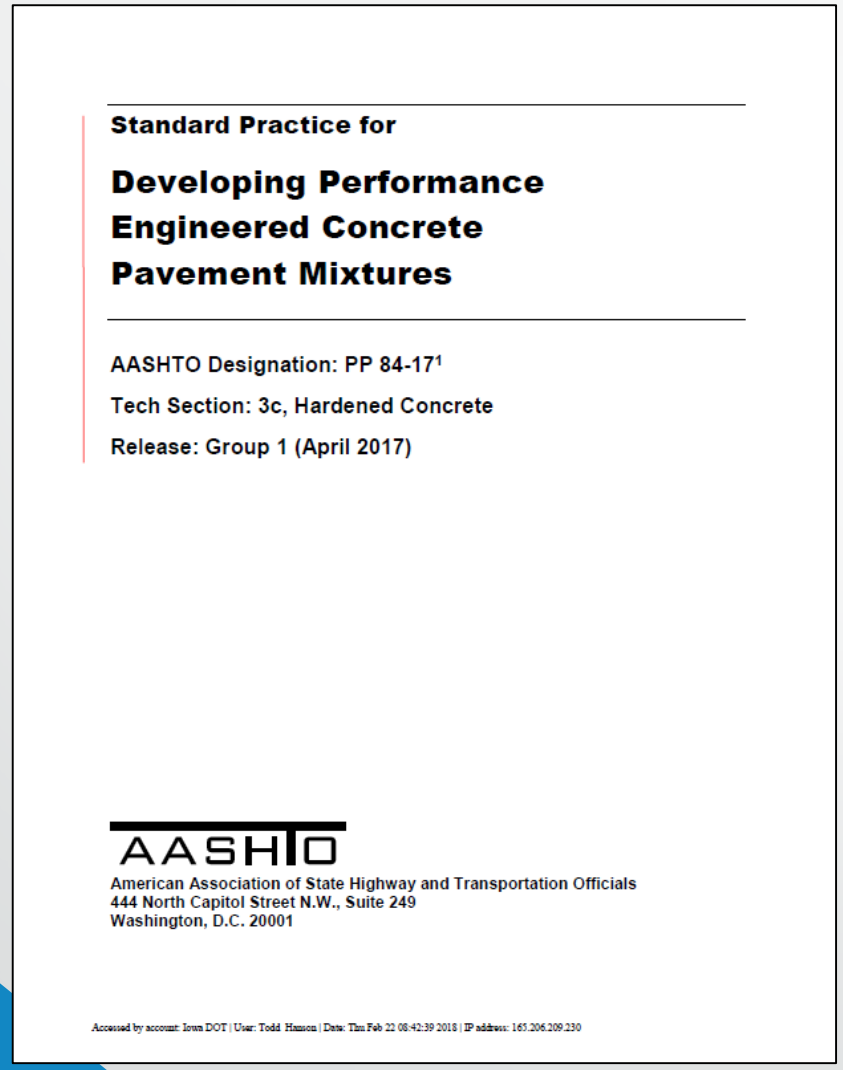
PEM Implementation Data in Iowa

2019 Mid-Continent Transportation Research Symposium
August 22, 2019 Ames, Iowa

Todd Hanson, PE Concrete Materials Engineer
Peter Taylor, PhD, Director CP Tech Center

What is PEM ?



Standard Practice for

Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: PP 84-17[1]

Tech Section: 3c, Hardened Concrete

Release: Group 1 (April 2017)

AASHTO

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

- AASHTO Provisional Standard PP84
- Performance Engineered Mixtures (PEM)
- Identify critical mix properties for long term durability in environment
- Measure these properties– New Tests
- Develop specifications and limits
- Pooled Fund Research Project
  - 18 states, FHWA, Industry

PEM – Critical Parameters

- Cold weather resistance (cold locations)
  - SAM Air Meter, LTDSC- Salt Resistance
- Transport properties/permeability (everywhere)
  - Resistivity/Formation Factor
- Aggregate stability (everywhere)
  - ASR/D-Cracking
- Workability (everywhere)
  - Box Test/V-Kelly
- Strength (everywhere)
  - Flexural or Compressive
- Shrinkage (dry locations)
  - Ring Test

PEM Pooled Fund Research Project

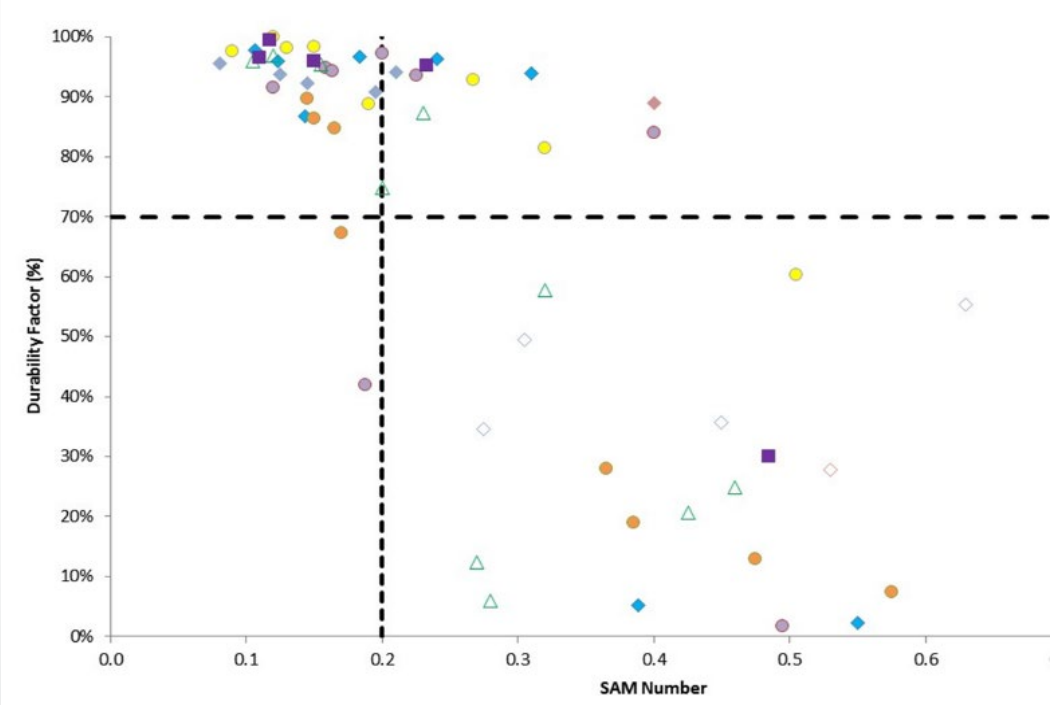
- Shadow projects
- Investigate ruggedness of test methods
- Develop specification limits
- Collect data for modelling
- Contractor QC Testing

Iowa PEM Shadow Project

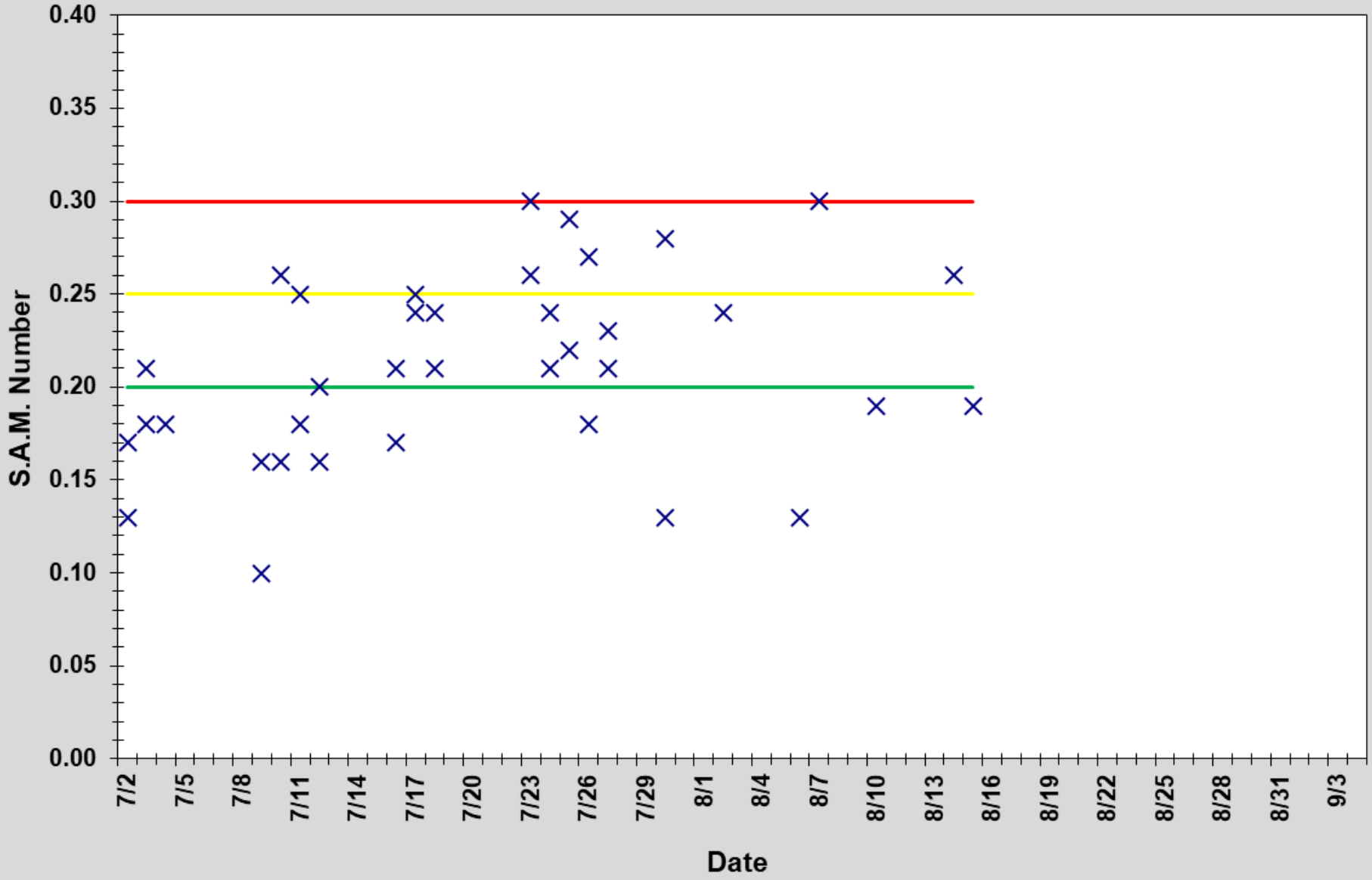
- US 20 Woodbury Co.
- Contractor Comprehensive QC Plan
  - Control Charts
  - Air PWL
  - SAM Test
  - Box Test
  - Resistivity/Formation Factor
  - Calcium Oxy Chloride Potential
  - Trial batch mix design reduced cement

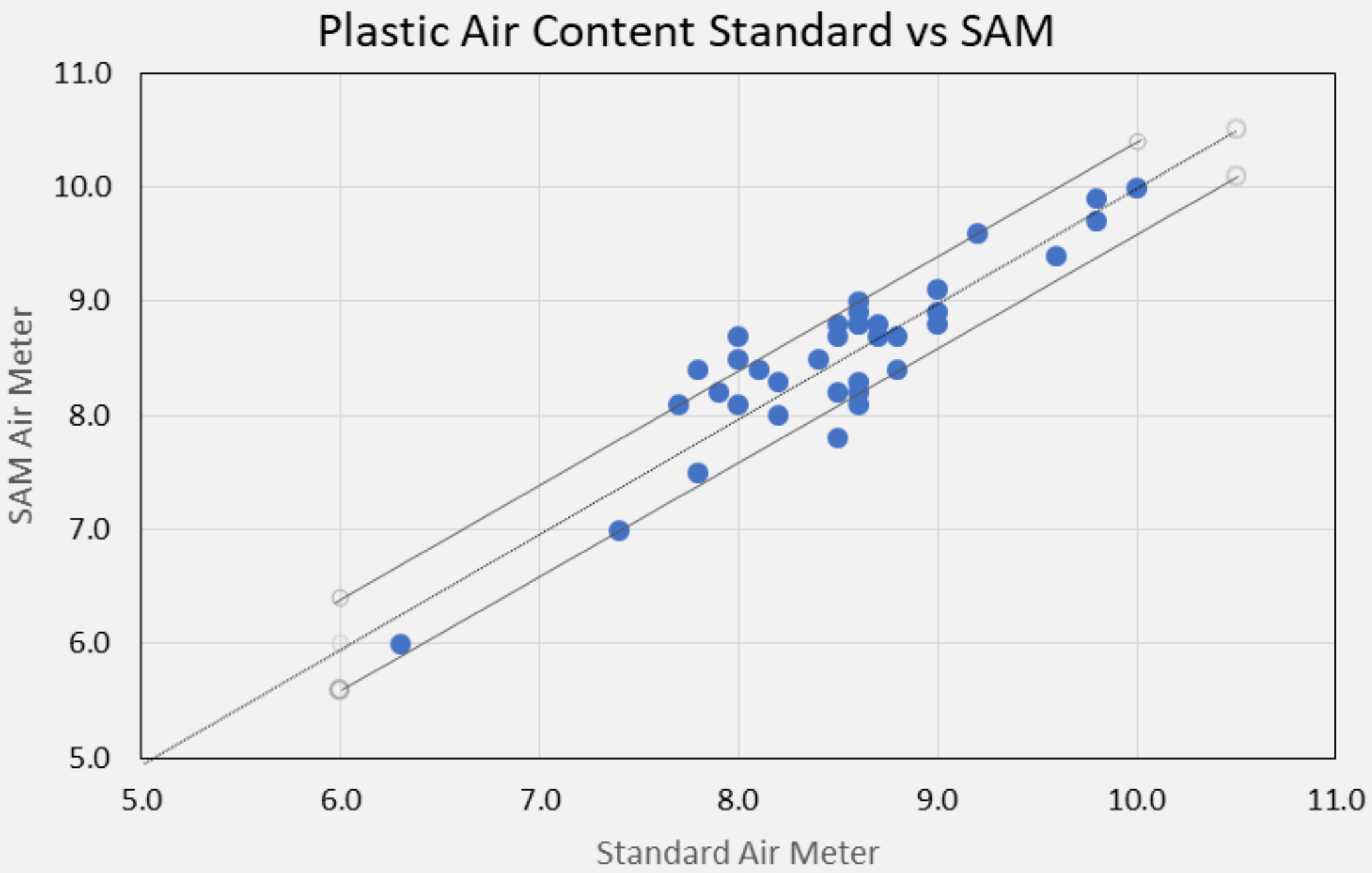
Super Air Meter

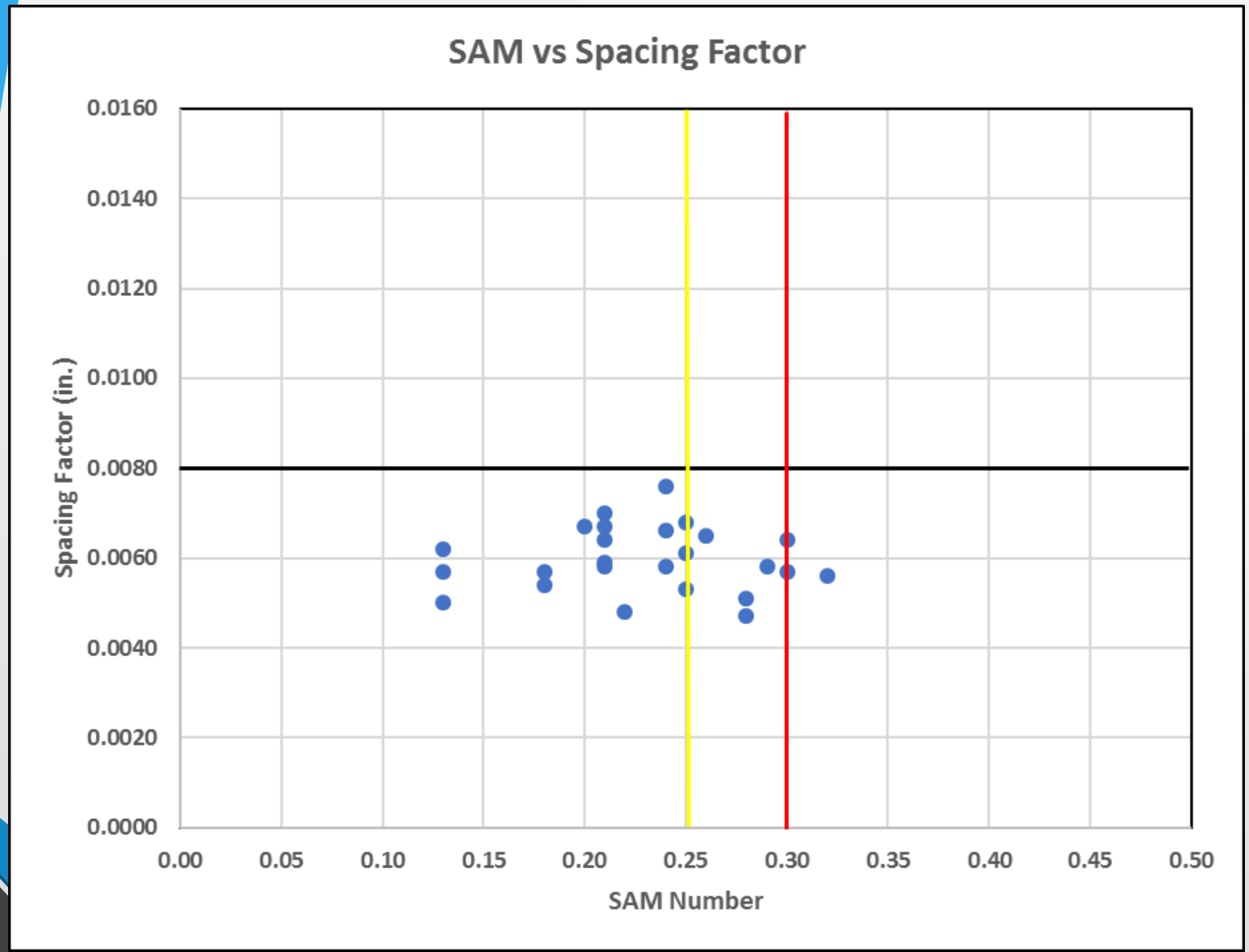
- Test at 14.5, 30 & 45 psi
  - Release and repeat
- Report air content and SAM number (Spacing Factor)
- SAM number correlates with freeze thaw testing



Before Paver

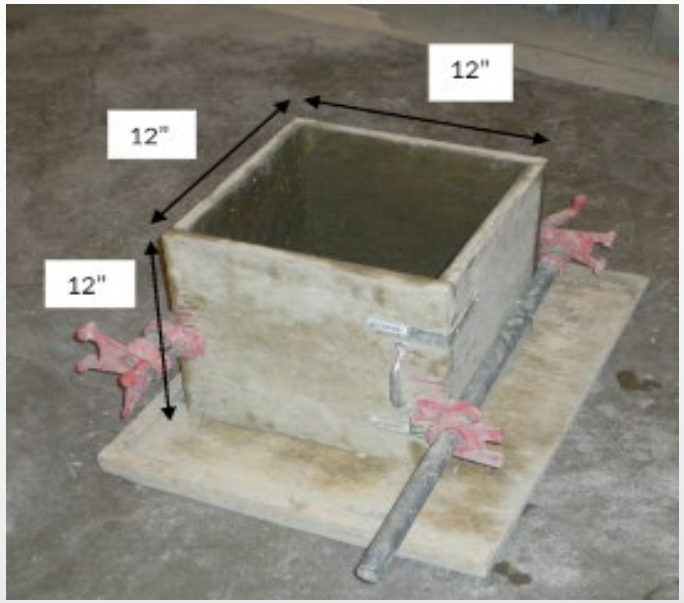



Plastic Air Content Standard vs SAM
11.0
10.0
9.0
8.0
7.0
6.0
5.0
SAM Air Meter
5.0
6.0
7.0
8.0
9.0
10.0
11.0
Standard Air Meter


SAM vs Spacing Factor
Spacing Factor (in.)
0.0160
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
SAM Number

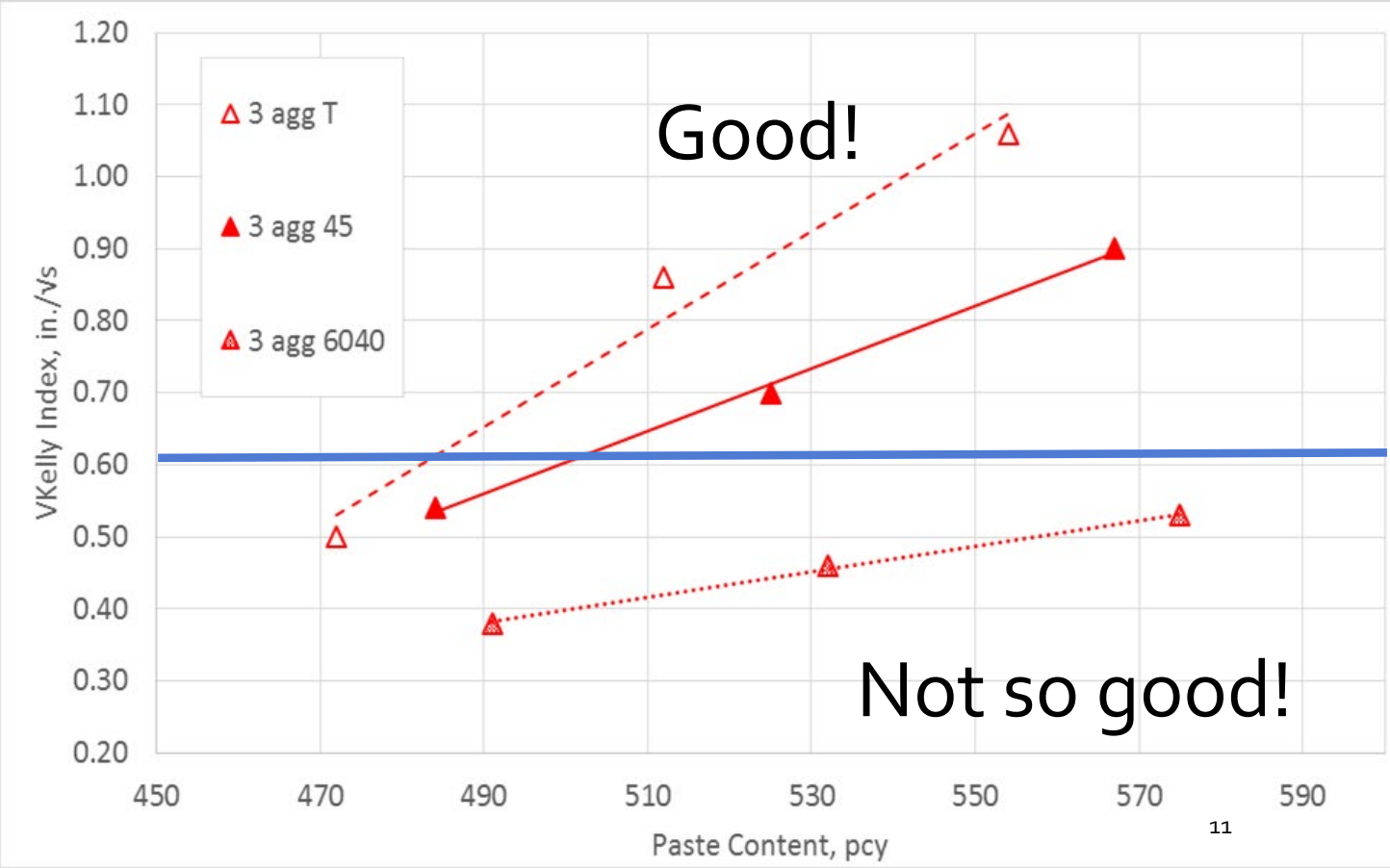
Workability

- Slump Test
  - Uniformity Test
  - Nothing about response to vibration
- Box Test & V-Kelly Test
  - Gives Info on Response to Vibration
- Factors in Workability
  - Aggregate Gradation
  - Paste Content
  - Admixtures



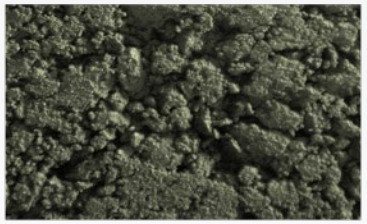
Workability - VKelly

- Fill Container
- Ball weight only to depth
- Ball vibration
  - Record Depth every 6 seconds
- Remix and repeat twice
- Avg. depth vs. sq. root of time
- Effect of Aggregate system



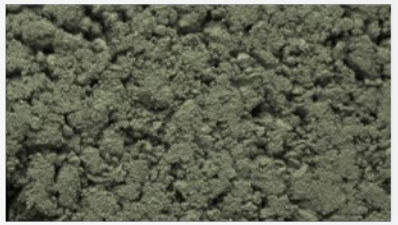
Workability - Box Test

- Fill box to 9.5 inches
- Insert vibrator 12,500 vpms
  - 3 seconds to bottom
  - 3 seconds out
- The edges of the box are then removed and inspected for honeycombing and edge slump



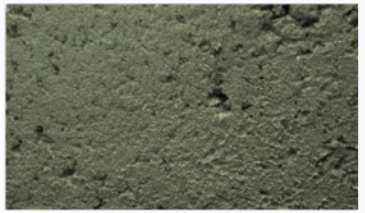
4

Over 50% overall surface voids.



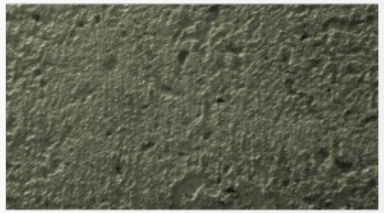
3

30-50% overall surface voids.



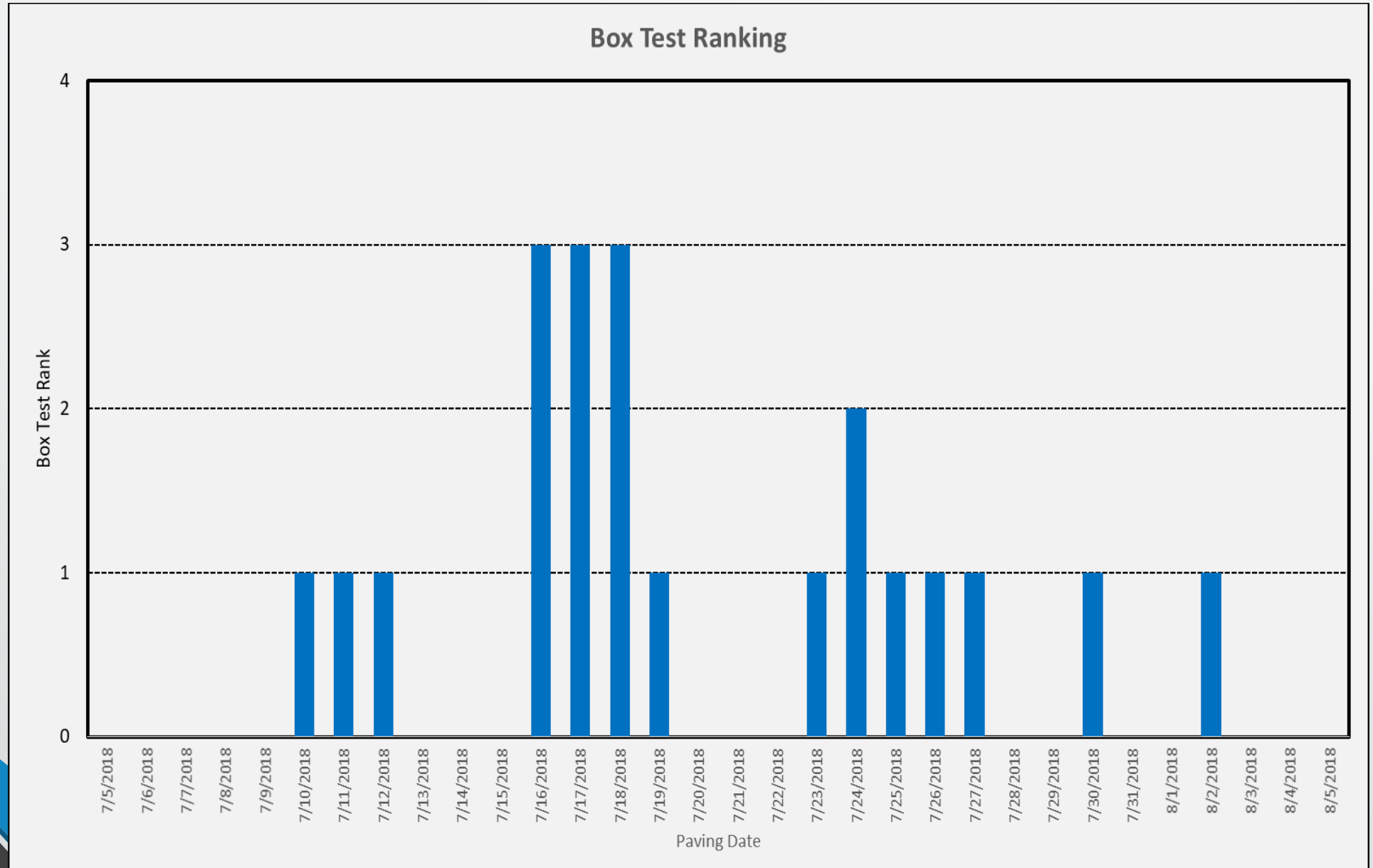
2

10-30% overall surface voids.

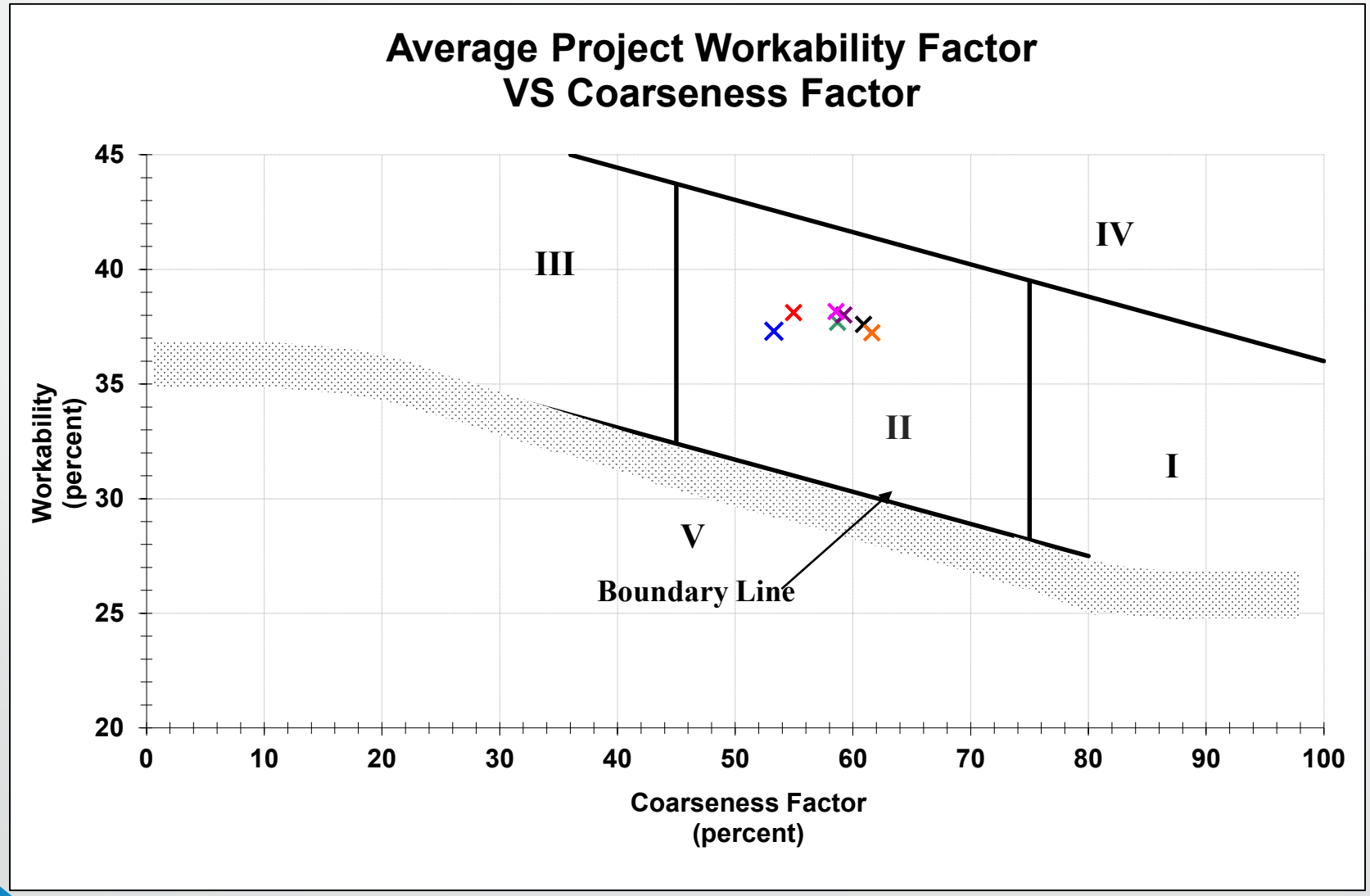


1

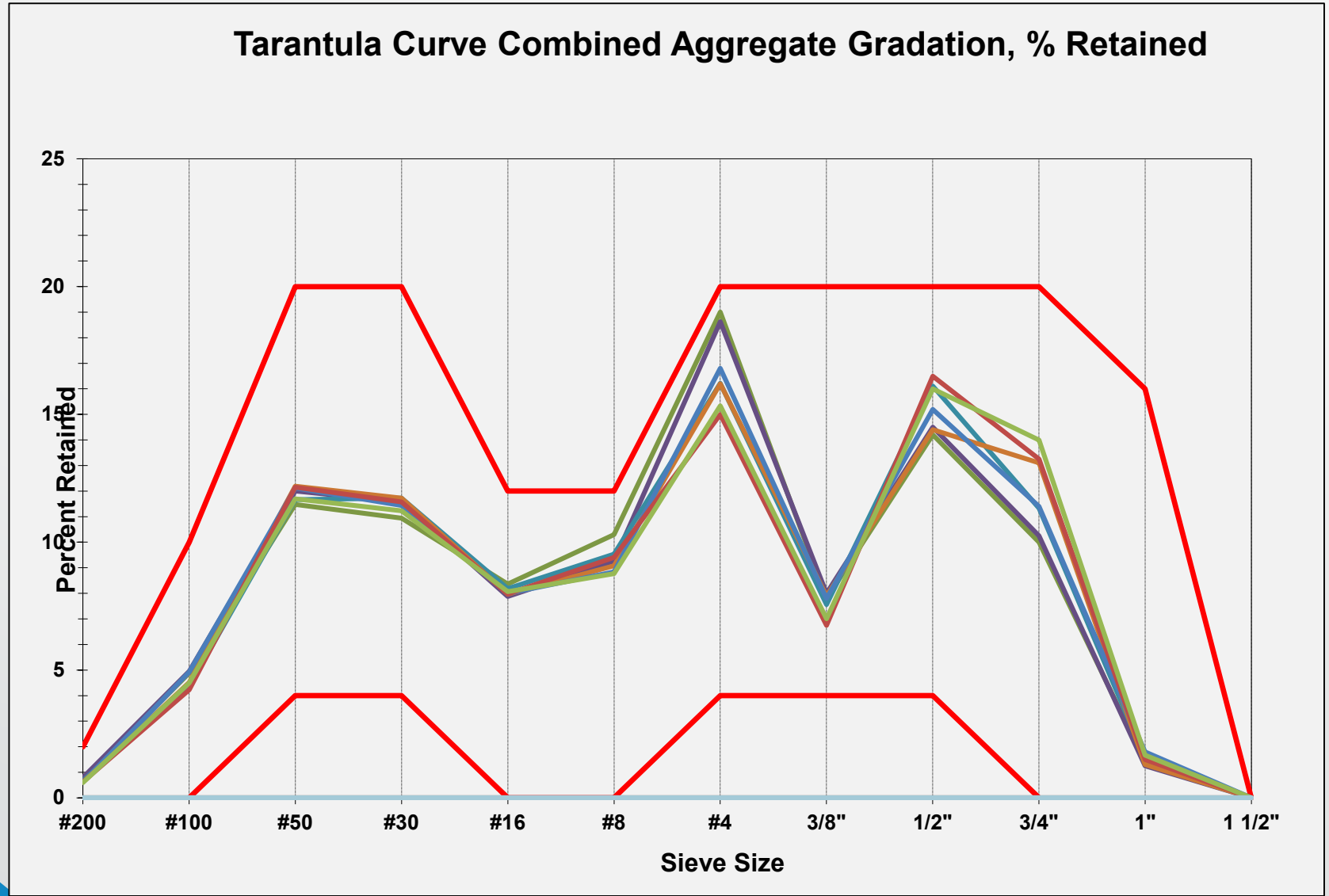
Less than 10% overall surface voids.


Box Test Ranking
Box Test Rank
4
3
2
1
0
7/5/2018
7/6/2018
7/7/2018
7/8/2018
7/9/2018
7/10/2018
7/11/2018
7/12/2018
7/13/2018
7/14/2018
7/15/2018
7/16/2018
7/17/2018
7/18/2018
7/19/2018
7/20/2018
7/21/2018
7/22/2018
7/23/2018
7/24/2018
7/25/2018
7/26/2018
7/27/2018
7/28/2018
7/29/2018
7/30/2018
7/31/2018
8/1/2018
8/2/2018
8/3/2018
8/4/2018
8/5/2018
Paving Date

Combined Aggregate Gradation



Combined Aggregate Gradation



Transport Properties - Resistivity

- Cast Two Cylinders
- Place in bucket with (Ca, Na, K) hydroxide solution
- Test Resistivity at 3, 7, 28, 56 and 91 days

Transport Properties – Formation Factor

US 20 Test Results

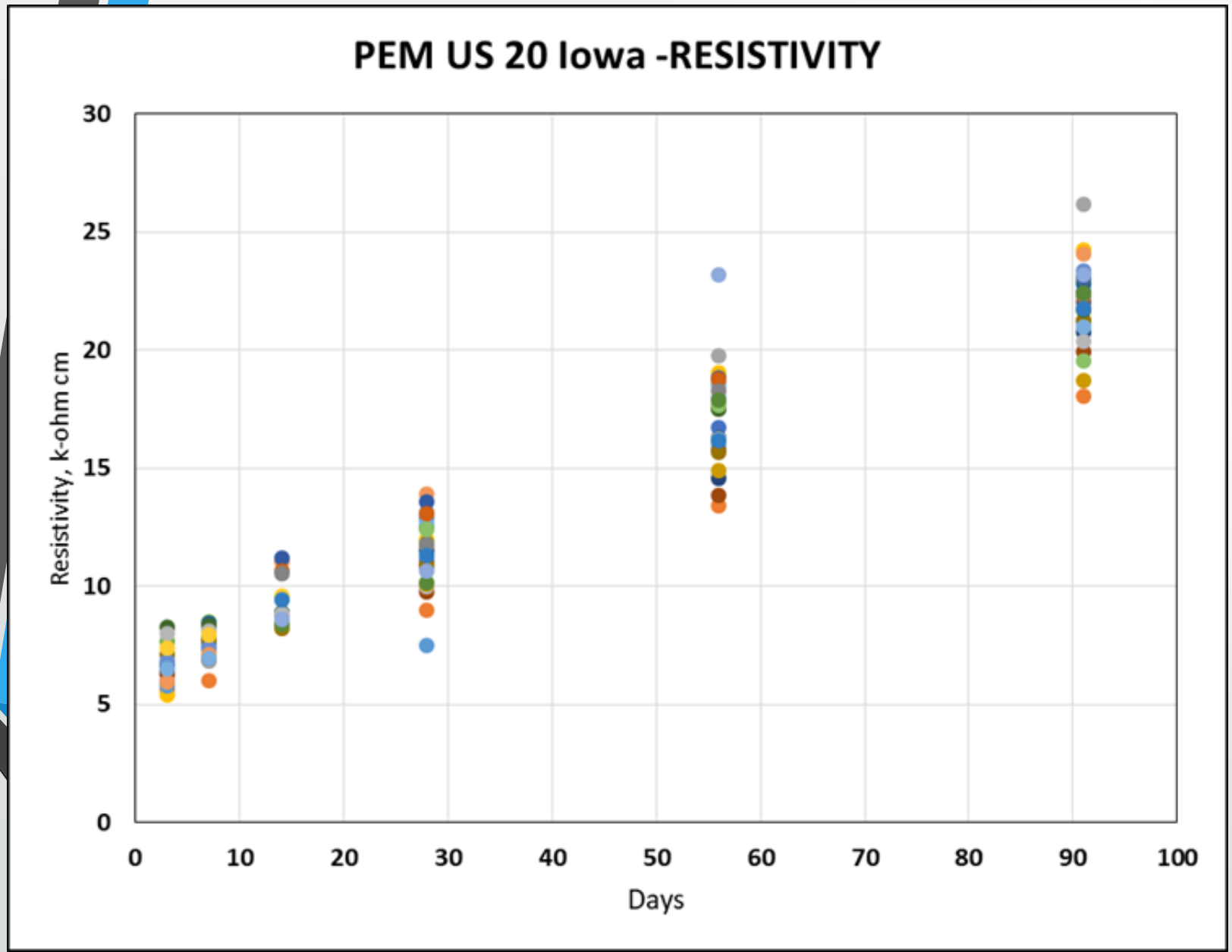
- Resistivity Low Range
  - 18-20 k-ohm-cm
- Formation Factor Moderate to Low range
  - 957

Table X2.1—Relationship between T 277 (ASTM C1202) Results, Resistivity, and the *F* Factor, Assuming a Pore Solution Resistivity of 0.1 Ω · m (based on Spragg et al., 2012)

ASTM C1202 Classification	Charge Passed (Coulombs)	Resistivity (kΩ · cm)[a]	Formation Factor
High	>4,000	<5.2	520
Moderate	2,000–4,000	5.2–10.4	520–1,040
Low	1,000–2,000	10.4–20.8	1,040–2,080
Very low	100–1,000	20.8–207	2,080–20,700
Negligible	<100	>207	20,700

[a] Calculated using first principles.

Transport Properties - Resistivity

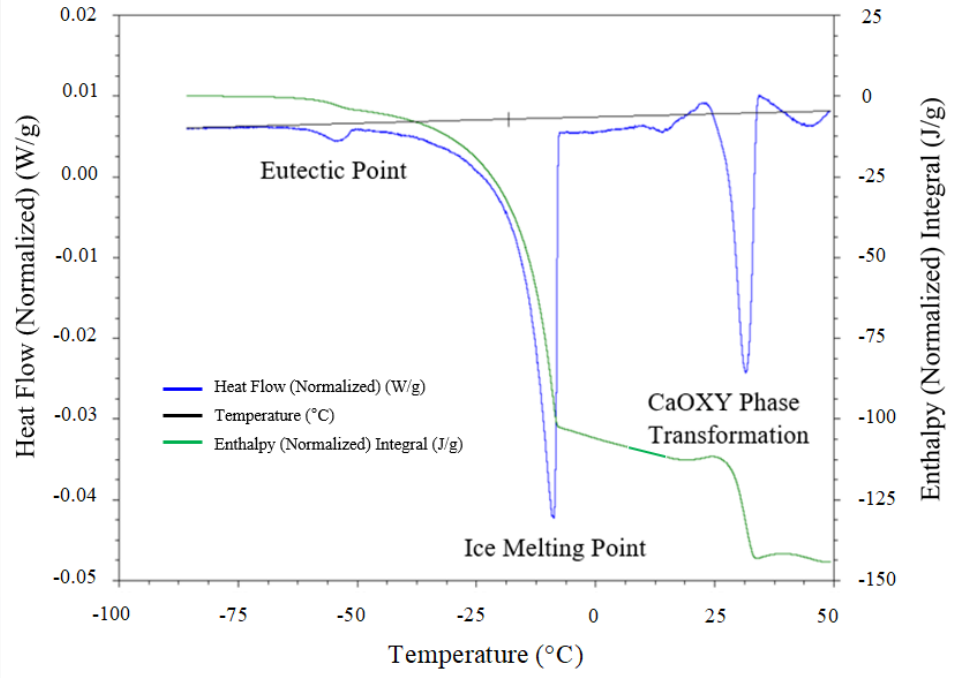


Calcium Oxychloride Potential

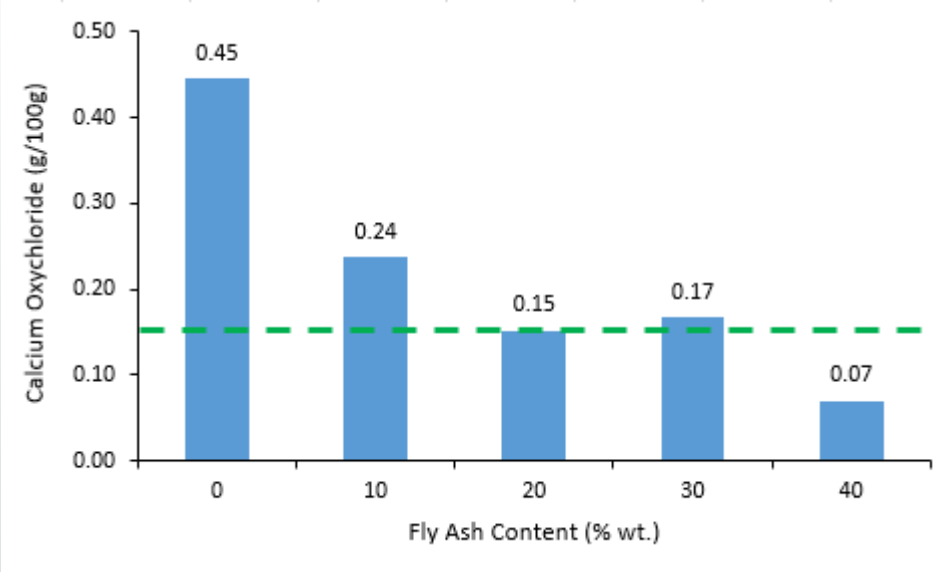
- Salts can cause chemical attack
  - Reaction between $Ca(OH)_2$ and $CaCL_2$ or $MgCl_2$ expands ~30% and will form above 32F
- Low temperature differential scanning calorimetry (LT-DSC)
  - 10 gms hydrated paste ground to minus #200
  - Mix with 10 mg 20% CaCl2 solution and seal
  - Place in LTDSC - low temperature cycling
- Reduce potential with use of SCM's

Calcium Oxychloride Potential

- Limiting the CaOXY formation to values lower than 0.15 (g/100g) reduces oxychloride formation
- 20% Class C fly ash replacement met the limit
- Higher percentage slag/ fly ash replacements will lower results further



Typical curve -low temperature differential scanning calorimetry



US 20 CaOXY formation - different fly ash replacement rates

PEM Mix Design w Lower Cement Content

A Mix	Abs. Vol.	lbs/CY
CEMENT:	0.083	440
FLY ASH:	0.025	110
WATER: w/c=0.474	0.155	261
FINE AGGREGATE (45%):	0.305	1357
COARSE AGGREGATE (55%):	0.372	1680
INTERMEDIATE AGG.:	0	0
AIR:	0.06	0
Paste Content, %	26.3	

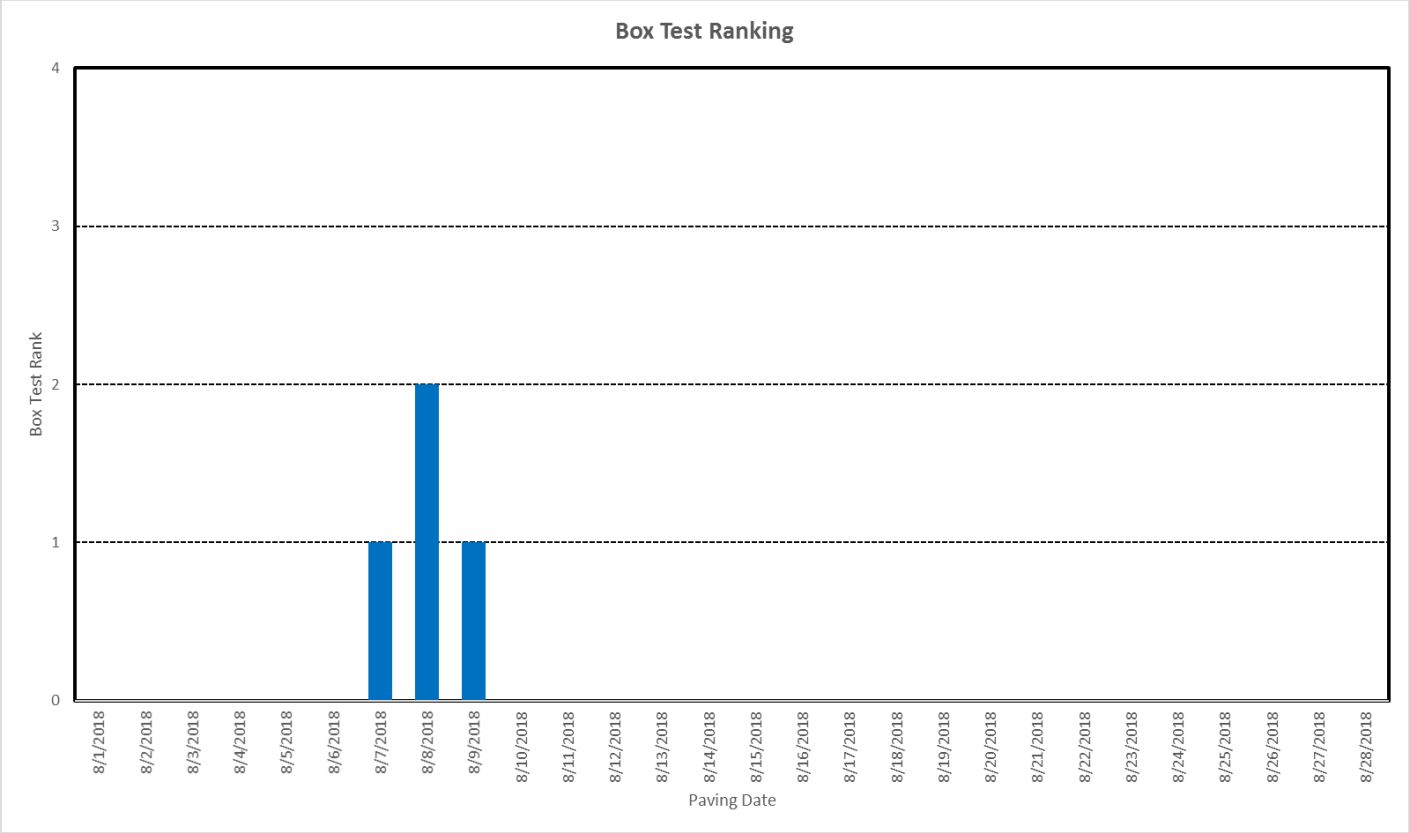
PEM Mix	Abs. Vol.	lbs/CY
CEMENT:	0.078	412
FLY ASH:	0.024	103
WATER: w/c=0.40	0.122	206
FINE AGGREGATE (44%):	0.315	1401
COARSE AGGREGATE (44%):	0.315	1422
INTERMEDIATE AGG. (12%):	0.086	387
AIR:	0.06	0
Paste Content, %	22.4	

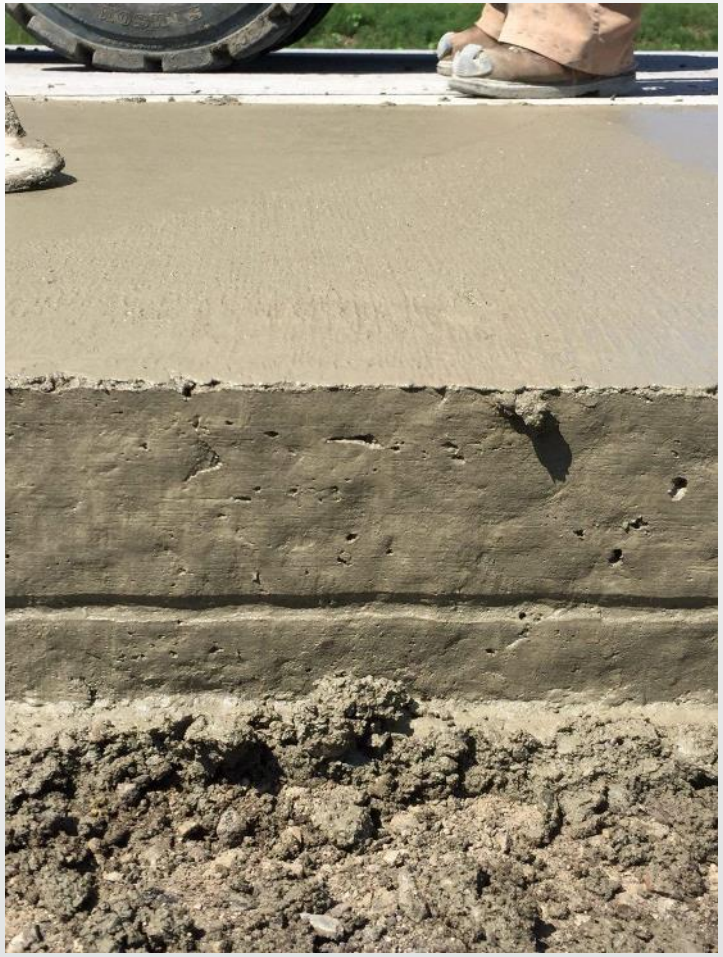
Dr. Peter Taylor estimated cement content based on dry rodded unit weight of combined aggregate.

PEM Mix Design

- Contractor had concerns lowering cement content of standard A mix for shoulder
- Performed trial batch
  - Box Test
- Placement went very well
- Wished they had a chance to try on mainline

PEM Mix Design





FHWA Mobile Lab PEM Open House

What We Learned

Table 3—Specification Worksheet

Section	Property	Specified Test	Specified Value		Mixture Qualification	Acceptance	Selection Details
			6.3 Concrete Strength				
6.3.1	Flexural Strength	T 97	4.1 MPa	600 psi	Yes	Yes	Choose either or both
6.3.2	Compressive Strength	T 22	24 MPa	3500 psi	Yes	Yes	
			6.4 Reducing Unwanted Slab Warping and Cracking Due to Shrinkage (if cracking is a concern)				
6.4.1.1	Volume of Paste	—	25%		Yes	No	Choose only one
6.4.1.2	Unrestrained Volume Change	ASTM C157	420 με	At 28 days	Yes	No	
6.4.2.1	Unrestrained Volume Change	ASTM C157	360, 420, 480 με	At 91 days	Yes	No	
6.4.2.2	Restrained Shrinkage	T 334	Crack free	At 180 days	Yes	No	
6.4.2.3	Restrained Shrinkage	TP XXX	$\Sigma < 60\% f'_r$	At 7 days	Yes	No	
6.4.2.4	Probability of Cracking	Appendix X1		As specified	Yes	No	
Commentary	Quality Control Check	—	—	—	No	Yes	
			6.5 Durability of Hydrated Cement Paste for Freeze–Thaw Durability				
6.5.1.1	Water to Cementitious Ratio	—	0.45	—	Yes	Yes	[a]
6.5.1.2	Fresh Air Content	T 152, T 196, TP 118	5 to 8	%	Yes	Yes	Choose only one
6.5.1.3	Fresh Air Content/SAM	T 152, T 196, TP 118	≥4% air; ≤0.2	%, psi	Yes	Yes	
6.5.2.1	Time of Critical Saturation	"Bucket Test" Specification	30	yr	Yes	No	[a, b]
6.5.3.1	Deicing Salt Damage	—	35%	SCM	Yes	Yes	Choose only one
6.5.3.2	Deicing Salt Damage	M 224	—	Topical treatment	Yes	Yes	
6.5.4.1	Calcium Oxychloride Limit	Test sent to AASHTO	<0.15 g CaOXY/g paste		Yes	No	
			6.6 Transport Properties				
6.6.1.1	Water to Cementitious Ratio	—	≤0.45 or ≤0.50	—	Yes	Yes	Choose only one
6.6.1.2	Formation Factor	Table 1	≥500 or ≥1000	—	Yes	Yes	
6.6.2.1	Ionic Penetration, *F* Factor	Appendix X2	25 mm at 30 yr		Yes, F	Through ρ	
			6.7 Aggregate Stability				
6.7.1	D Cracking	T 161, ASTM C1646	—	—	Yes	No	
6.7.2	Alkali Aggregate Reactivity	R 80	—	—	Yes	No	
			6.8 Workability				
6.8.1	Box Test	Appendix X3	<6.25 mm, <30% surface void			No	
6.8.2	Modified VKelly Test	Appendix X4	15–30 mm/root s			No	

Notes:

Iowa DOT Current Practices QMC

- Strength – avg 640 PSI Flexural
- Volume of Paste = 24.3%
- w/c Ratio = 0.42 max.
- Air Content 6 to 10%
  - SAM Results all below 0.30
- Calcium Oxychloride Limit =0.15 g/100g
- Formation Factor ~1000 w 20% C ash
- Aggregates – Iowa DOT Methods
- Workability Good
  - Combined Aggregate Grading

Where are we going?

- Iowa QMC Paving fairly close to PEM Requirements
  - Ternary mixes & Combined Gradation
- Now have 6 SAM Air Meters
  - PC Techs monitor tests & compare with hardened air
- Resistivity
  - Monitor
- Contractor Mixes at Reduced Cement Content
  - Box Test or V-Kelly to approve

For More Information

https://cptechcenter.org/performance-engineered-mixtures-pem/

Questions ?

Special Thanks to

Cedar Valley Corp. , LLC

Tech Center

IOWA CONCRETE PAVING ASSOCIATION