	2017 Concrete Summit - Agenda - Hotel Captain Cook			**November 6-7, 2017**
	Day 1		**Monday, November 6, 2017 - Concrete General Sessions - Fore Deck**	
No.	Start	End		Location
	7:30 AM	7:55 AM	Registration / Check in	Foyer
	7:55 AM	8:00 AM	Call to Order; Rich Giessel	Fore Deck
	8:00 AM	8:05 AM	Alaska's Flag Song; Lisa Hawkins	Fore Deck
	8:05 AM	8:15 AM	Welcome; Commissioner Luiken, Randy Brand	Fore Deck
1	8:15 AM	9:05 AM	Super Air Meter; Tyler Ley	Fore Deck
2	9:05 AM	9:25 AM	Efficient, Durable, Electrical Pavement De-icing, Joey Yang	Fore Deck
3	9:25 AM	9:45 AM	Optimizing Concrete Durability for Pavements; Xavier Schlee, Jenny Liu	Fore Deck
	9:45 AM	10:00 AM	Break	
4	10:00 AM	10:40 AM	Bridge Construction Best Practices and Lessons Learned; Leslie Daugherty	Fore Deck
5	10:40 AM	11:30 AM	Best Practices for Placing and Curing Concrete Bridge Decks; Tyler Ley	Fore Deck
6	11:30 AM	11:50 AM	Steel Fiber Reinforced Rubberized Concrete, Pre-cast Panels for Cold Region Applications, Mahear Aboueid	Fore Deck
7	12:00 AM	1:00 PM	Optional Buffet Lunch (Limited to 50 attendees - Cost $10) History of Prestressed Precast Concrete - Cameron West	Adventure
	1:00 PM	1:15 PM	Check in for Afternoon Session	Foyer
8	1:15 PM	2:15 PM	Finishing Concrete Pavement, Sidewalk, Building Floor Slabs; Craig Cottongim	Fore Deck
9	2:15 PM	3:00 PM	Concrete Intersections, Roundabouts; Jim Powell	Fore Deck
	3:00 PM	3:15 PM	Break	
10	3:15 PM	4:10 PM	Designing for Maximum Durability, Service-Life and Minimal Maintenance with CSA Cement Technology; S. Goodman, K. Vallens	Fore Deck
11	4:10 PM	5:00 PM	Cellular Concrete for Lightweight Structural Fills; Rich Palladino	Fore Deck
	5:00 PM	7:00 PM	Hospitality Event	Quarter Deck
	Day 2		**Tuesday, November 7, 2017 - Concrete Classes and Workshops**	
	Start	End	**Hotel Captain Cook - Lower Level**	Location
	7:30 AM	8:00 AM	Registration/Attendance sign in	Foyer
12	8:00 AM	11:00 AM	Troubleshooting Concrete Construction; Frank Kozeliski, ACI	Adventure
15	11:00 AM	12:00 PM	Aggregate gradation design for Pavements & Bridges, Cracking; Tyler Ley	Adventure
13	8:00 AM	9:45 AM	Chemical Admixtures for Concrete; Anton Schindler, ACI	Endeavor
	9:45 AM	10:00 AM	Break	
14	10:00 AM	11:45 AM	Implementing Performance Specifications for Durability; Tara Cavalline	Endeavor
16	12:00 AM	1:00 PM	Optional Buffet Lunch (Limited to 50 attendees - Cost $10) Achieving the best Leadership possible in Construction - Craig Cottongim	Quarter Deck
	1:00 PM	1:15 PM	Check in for Afternoon Session	Foyer
17	1:15 PM	4:15 PM	Concrete QA/QC Workshop; Mike Praul, FHWA, Tyler Ley	Adventure
18	1:15 PM	2:45 PM	Self-Consolidating Concrete; Anton Schindler, ACI	Endeavor
	2:45 PM	3:00 PM	Break	
19	3:00 PM	4:30 PM	Durable Pavement Design-CSA Cement; Susan Goodman, Ken Vallens	Endeavor
	4:30 PM	5:00 PM	Summit Evaluation, Dismissal, Rich Giessel, Xavier Schlee	Fore Deck

The Super Air Meter

Braden Tabb, Robert Felice, John Michael Freeman, Robert Frazier, David Welchel, Morteza Khatibmasjedi, Jake LeFlore

Tyler Ley, P.E., Ph. D

Acknowledgements

- Oklahoma DOT
- FHWA
- Kansas DOT
- Nebraska DOT
- Iowa DOT
- Minnesota DOT
- Idaho DOT
- North Dakota DOT
- Pennsylvania DOT
- Connecticut DOT
- Illinois DOT
- Indiana DOT
- Michigan DOT
- Wisconsin DOT
- New Jersey DOT
- RMC Foundation

Outline

- Introduction to Air entrained concrete
- How to use the SAM?
- Why is the SAM useful?
- How does the SAM work?

Why Do We Add Air to Concrete?

Why Do We Add Air to Concrete?

- Air-entrained bubbles are a key to the freeze-thaw resistance of concrete

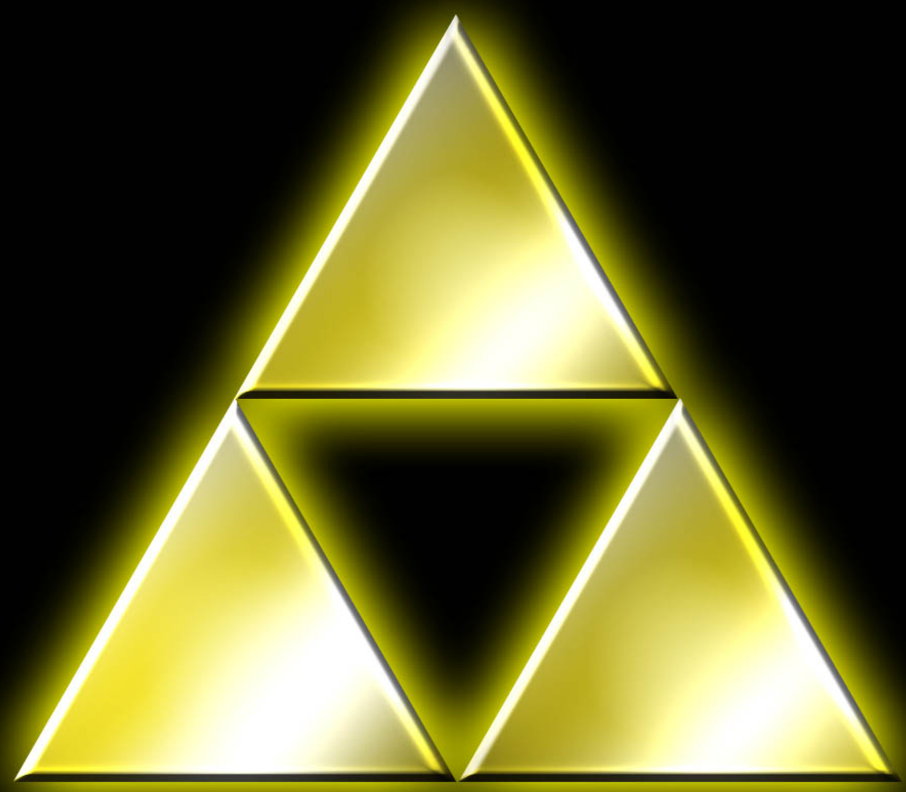
Air volume ≠ freeze-thaw performance

- Smaller bubbles are more effective in providing freeze-thaw resistance and have less of an impact on our concrete than larger bubbles


AAA
Oklahoma
438 176 202408550 4
2009

The Freeze Thaw Triforce!!!

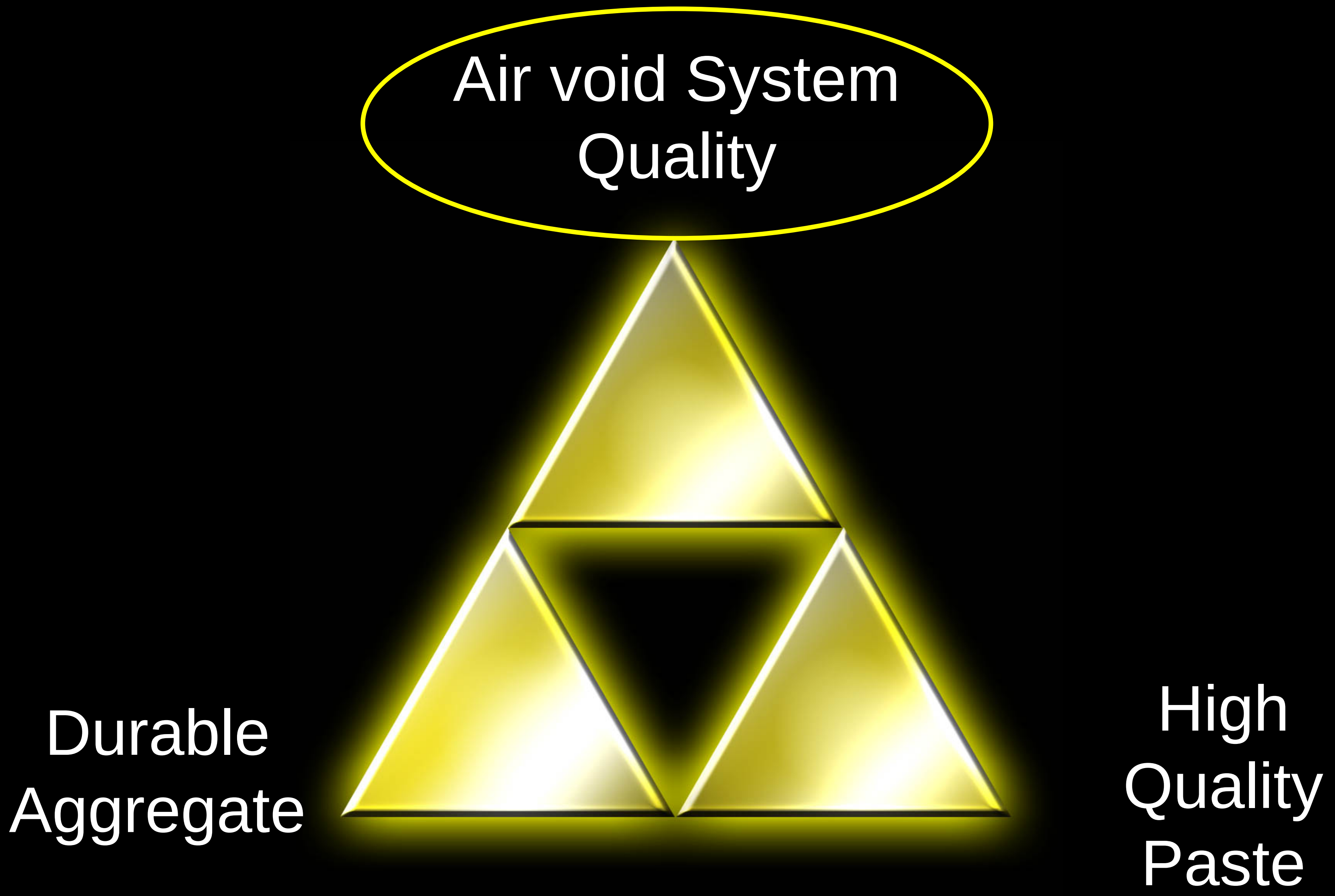
Air void System
Quality



Durable
Aggregate

High
Quality
Paste

The Freeze Thaw Triforce!!!



The Air-Entrainment Blues…

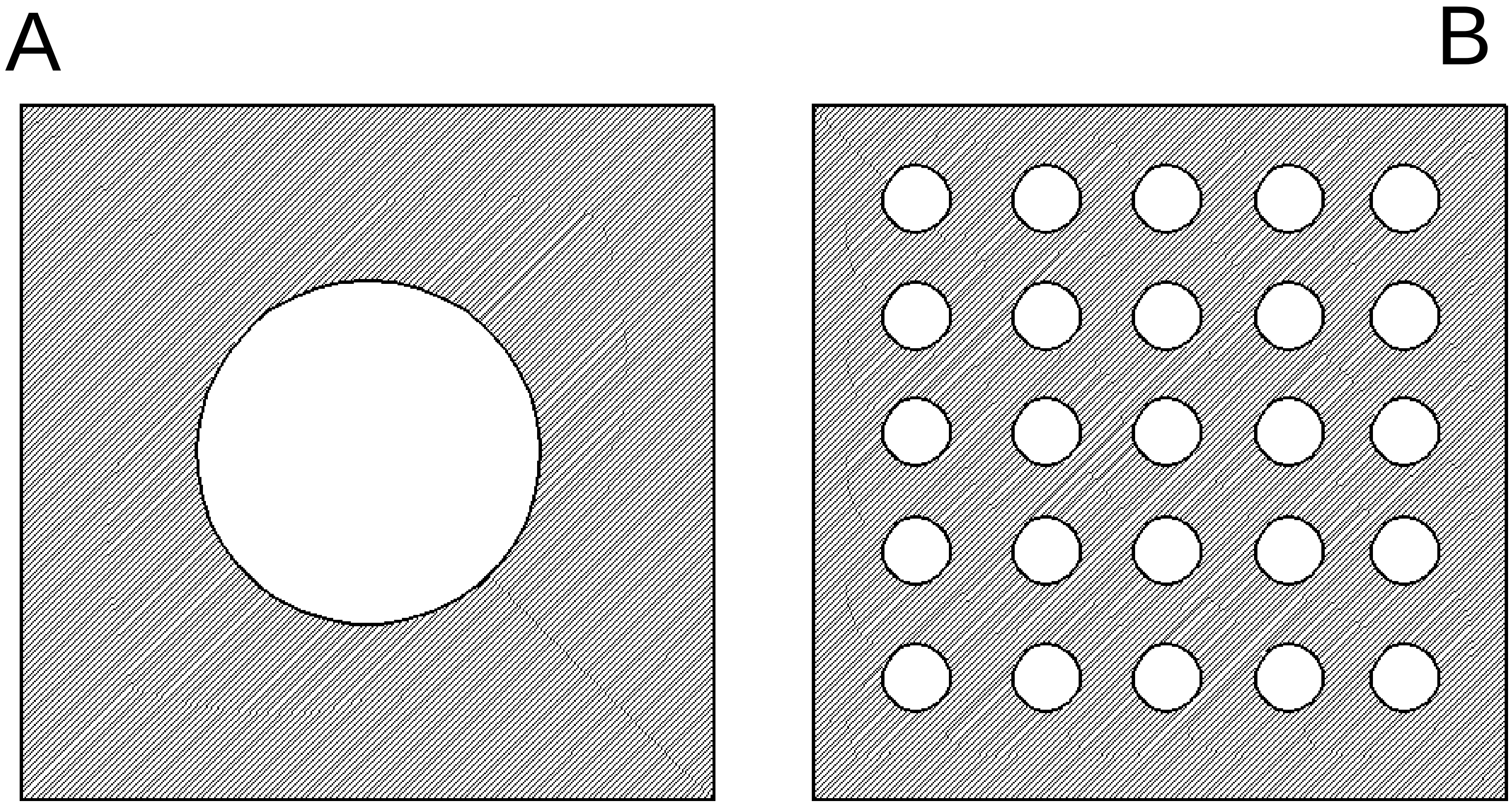
- The most challenging aspect of concrete to get right is the air content.

The Air-Entrainment Blues…

- The most challenging aspect of concrete to get right is the air content.

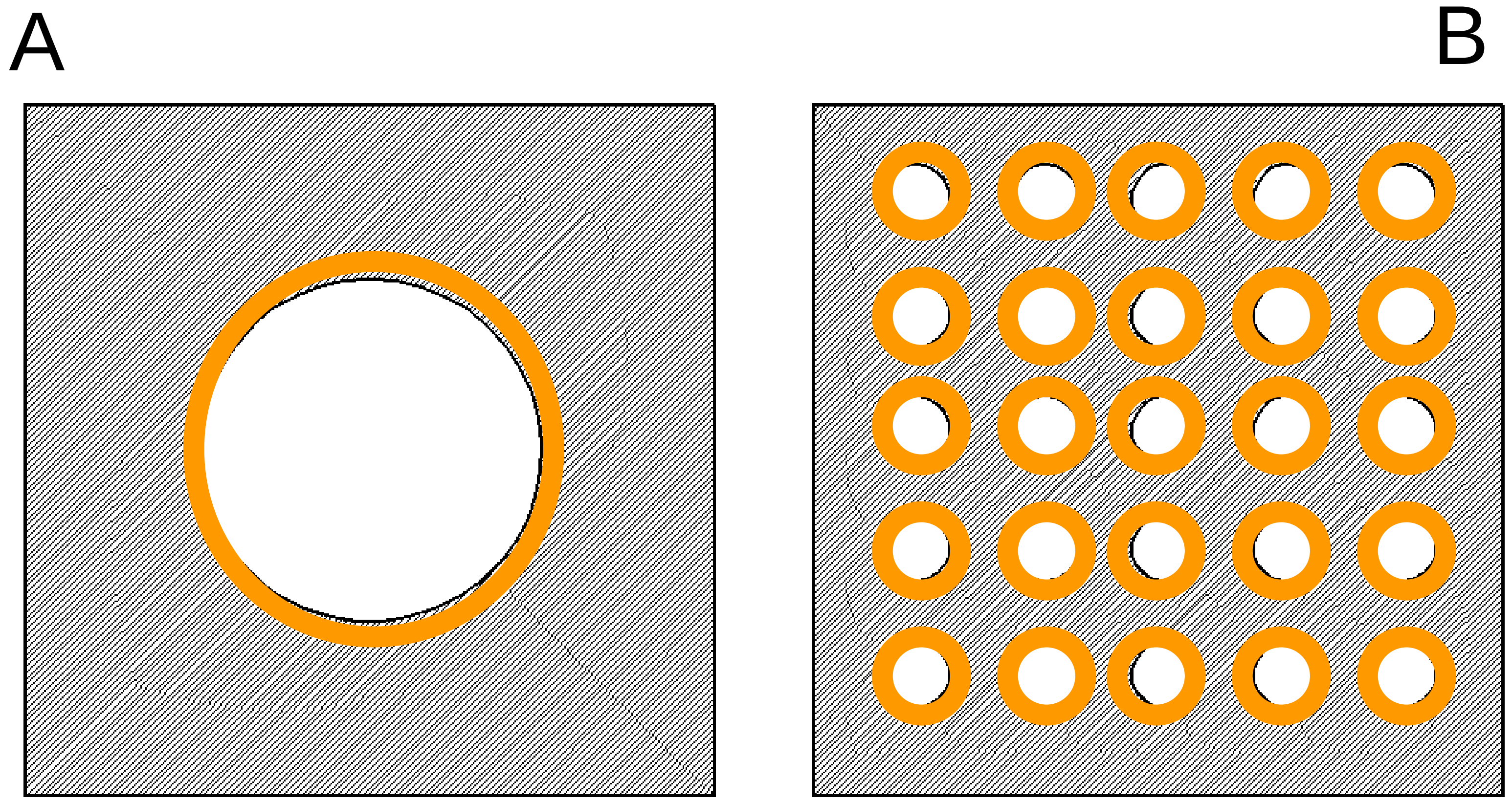
- Large bubbles are the enemy!

What Do You Want in an Air-Void System?



- Volume of air provided is the same for both.
- Case B has a better air void distribution.

What Do You Want in an Air-Void System?



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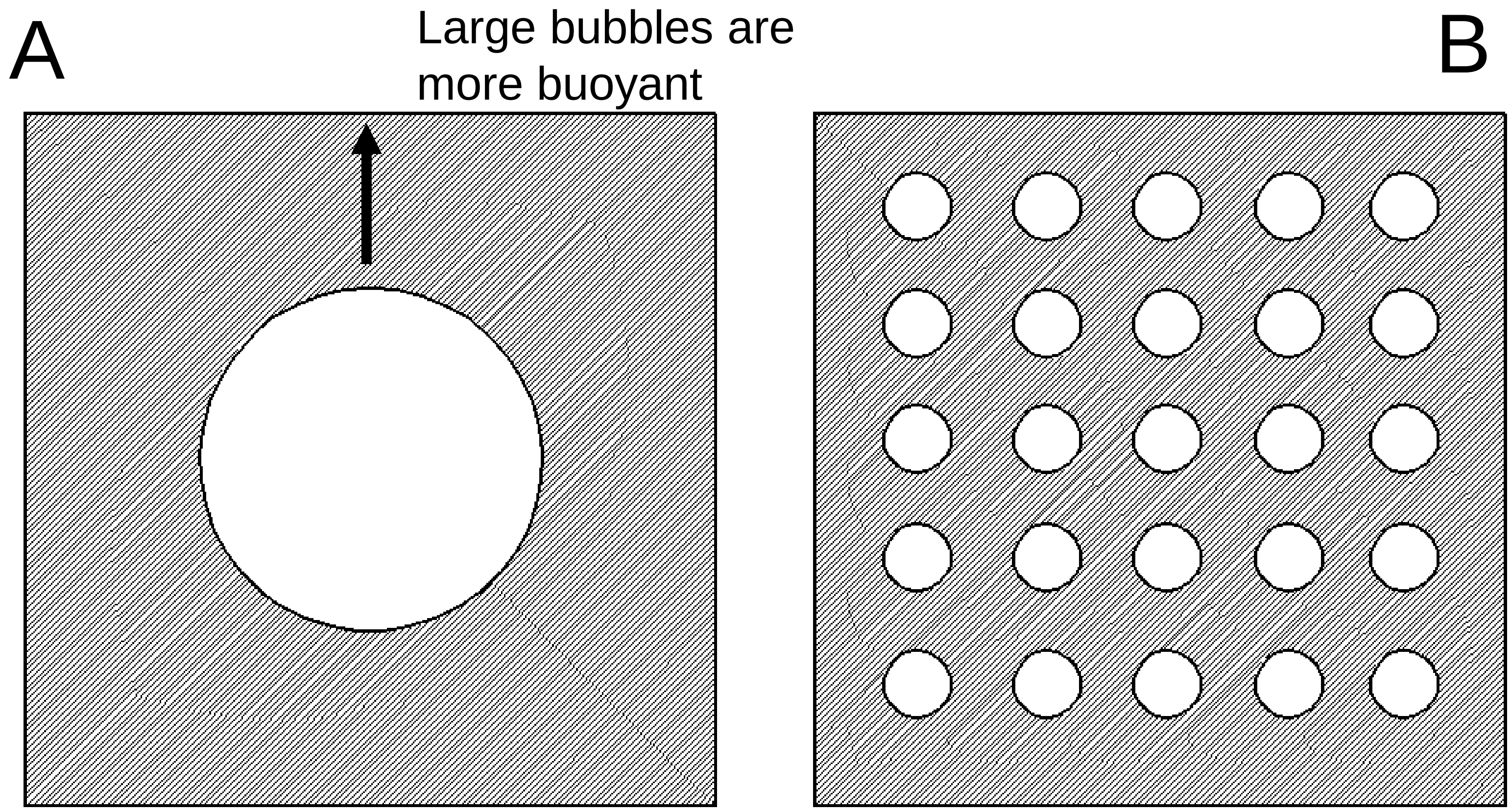
What Do You Want in an Air-Void System?



- Volume of air provided is the same for both.
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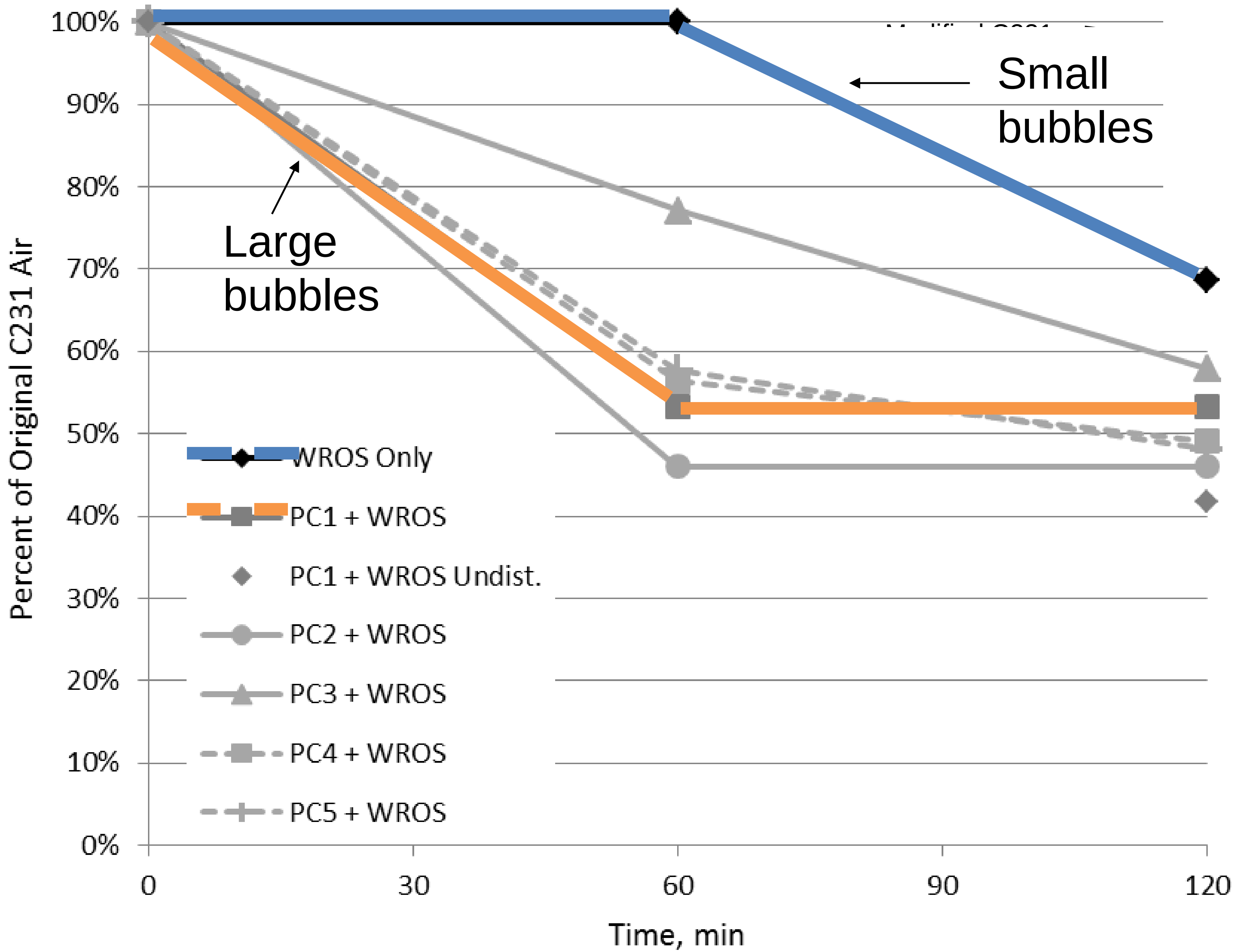


Small
bubbles
Large
bubbles
Percent of Original C231 Air
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
WROS Only
PC1 + WROS
PC1 + WROS Undist.
PC2 + WROS
PC3 + WROS
PC4 + WROS
PC5 + WROS
0
30
60
90
120
Time, min

Why are large bubbles bad?

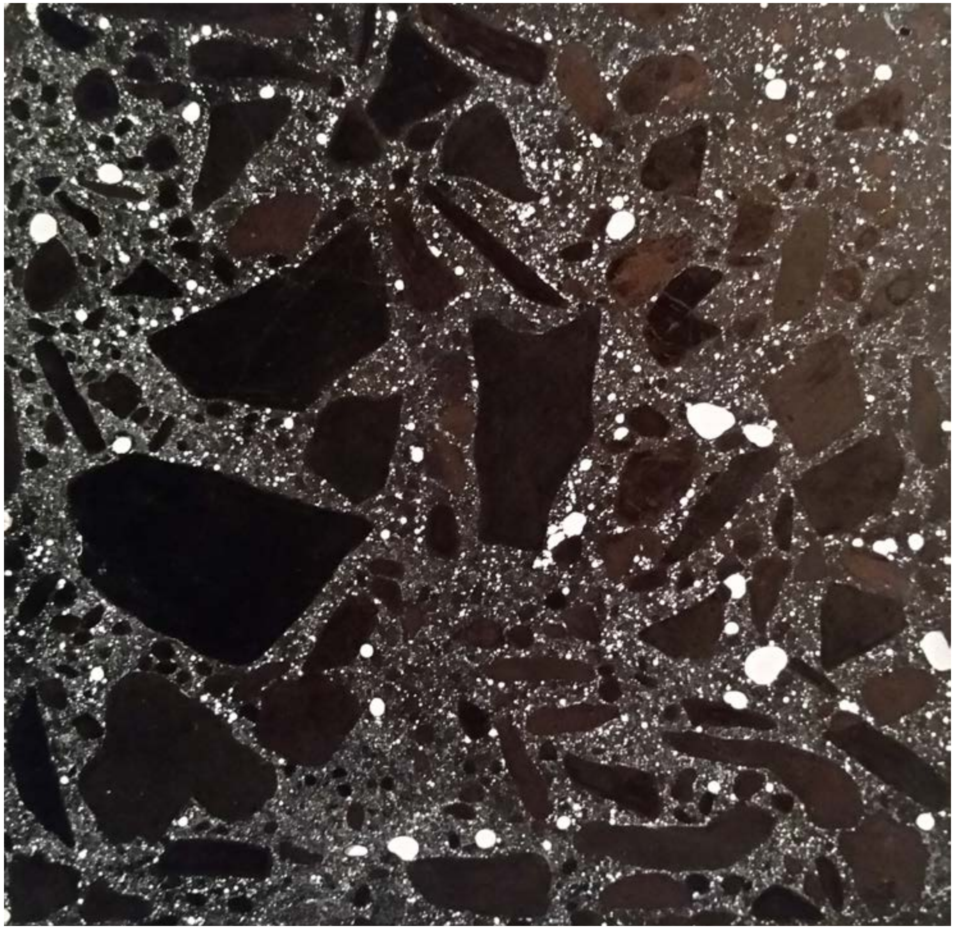
- They leave the concrete and change your air volume
- They don't help with freeze-thaw durability
- They reduce your strength more than smaller bubbles

What causes large bubbles?

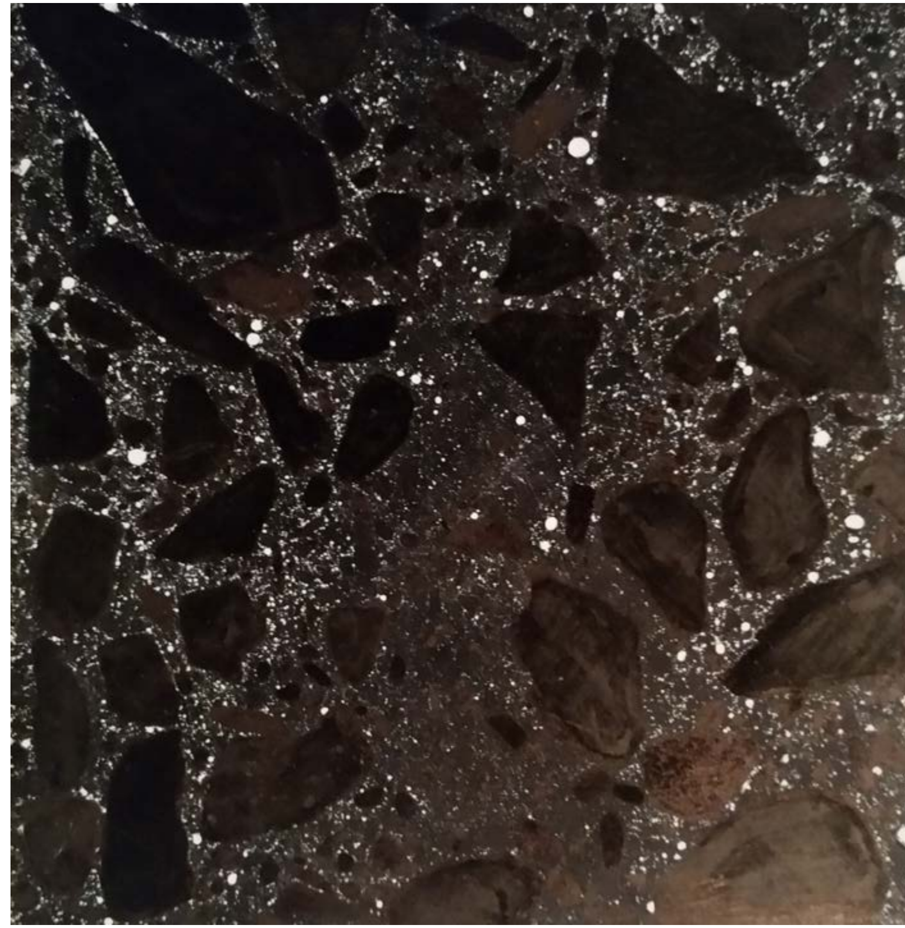
- Admixture incompatibility
- Admixture/cement incompatibility
- Sand gradation
- Inadequate mixing
- Alkali content of binder
- Cement grinding aids
- Changes in temperature
- Pumping

An example…

- A concrete mixture lost 50% air between mixing and placement.
- Changes were made to the admixtures and the problems stopped.



Mix 1 – large air voids



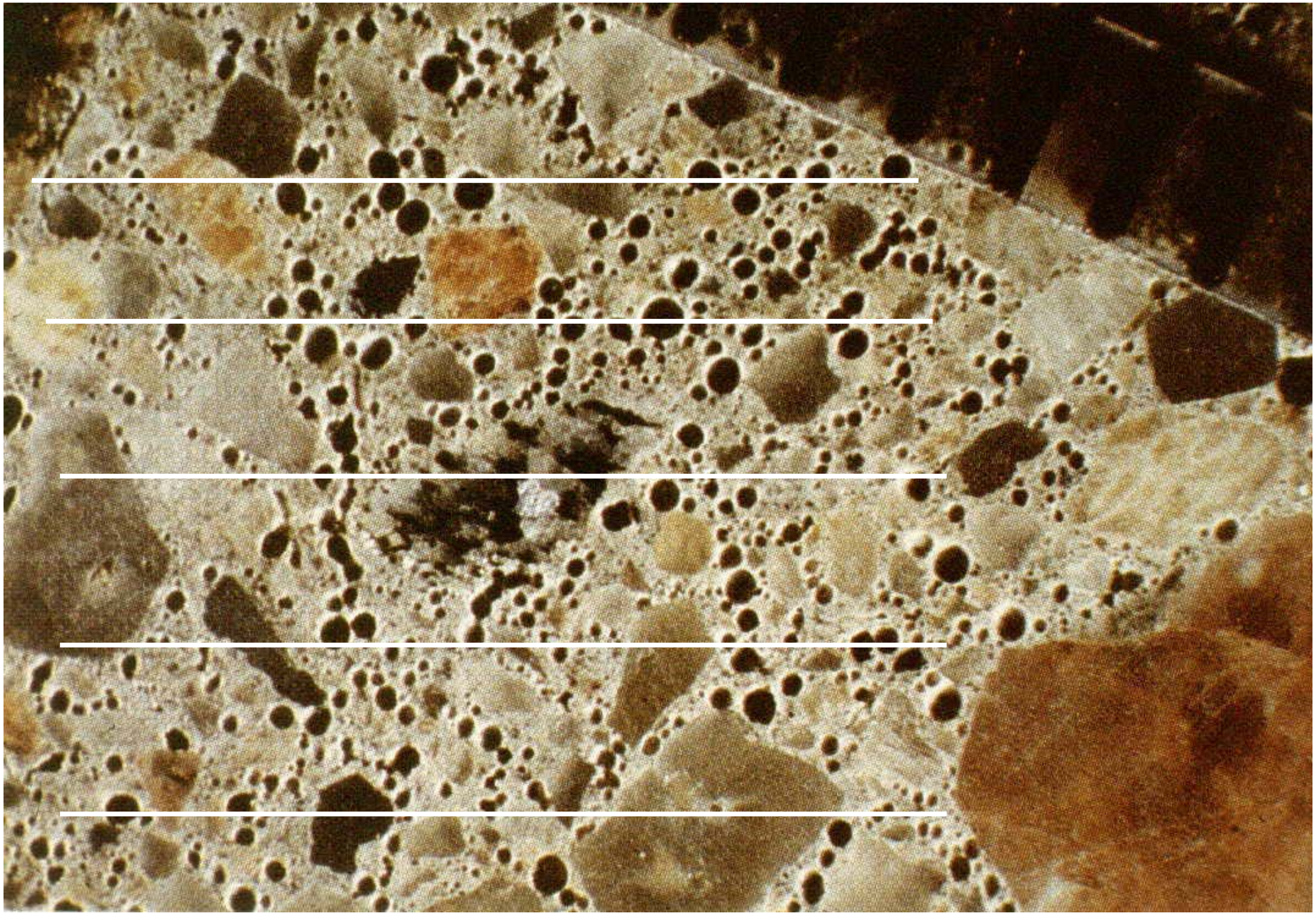
Mix 2 – small air voids

How do you measure this?

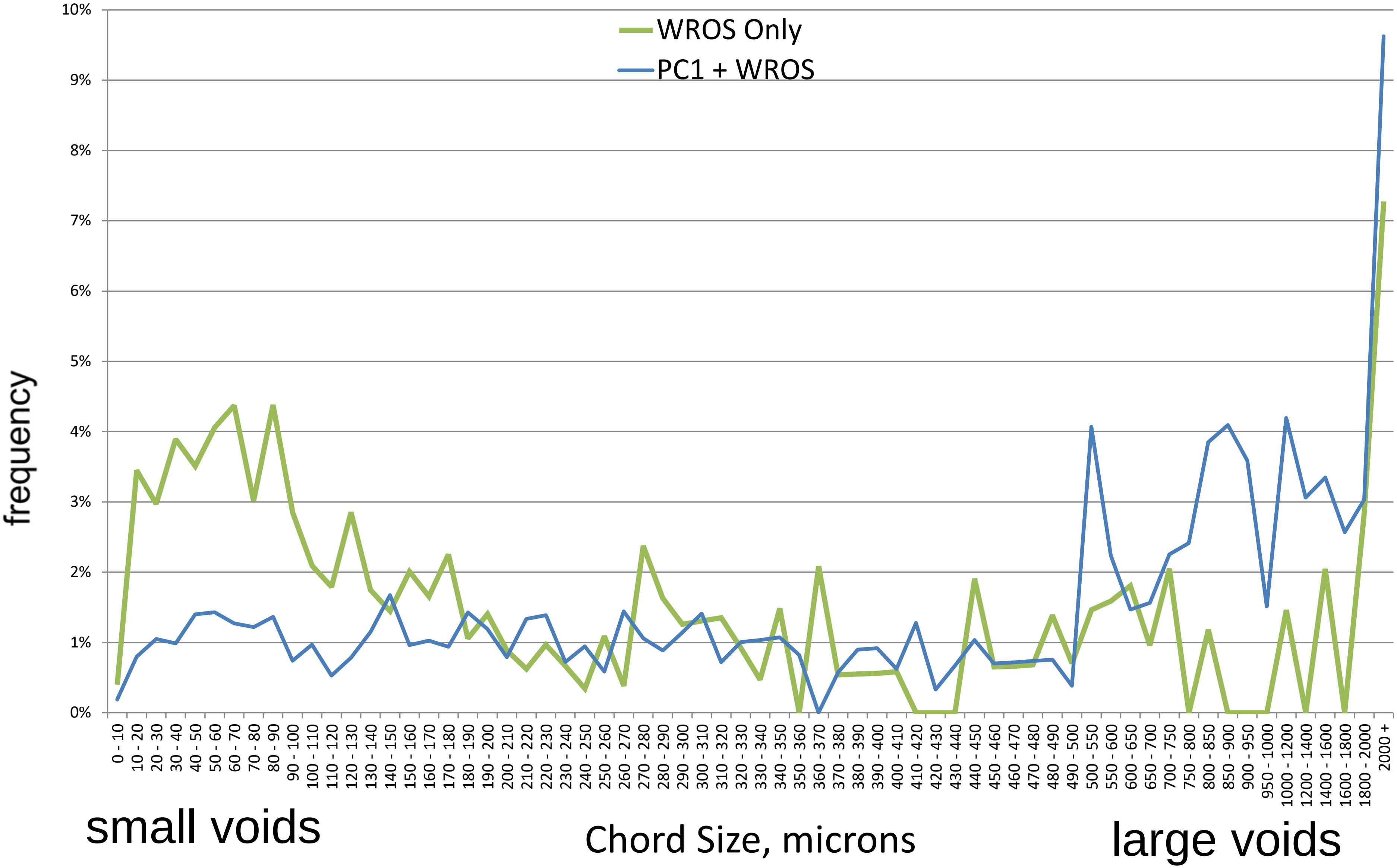
Hardened Air Void Analysis

From Hover

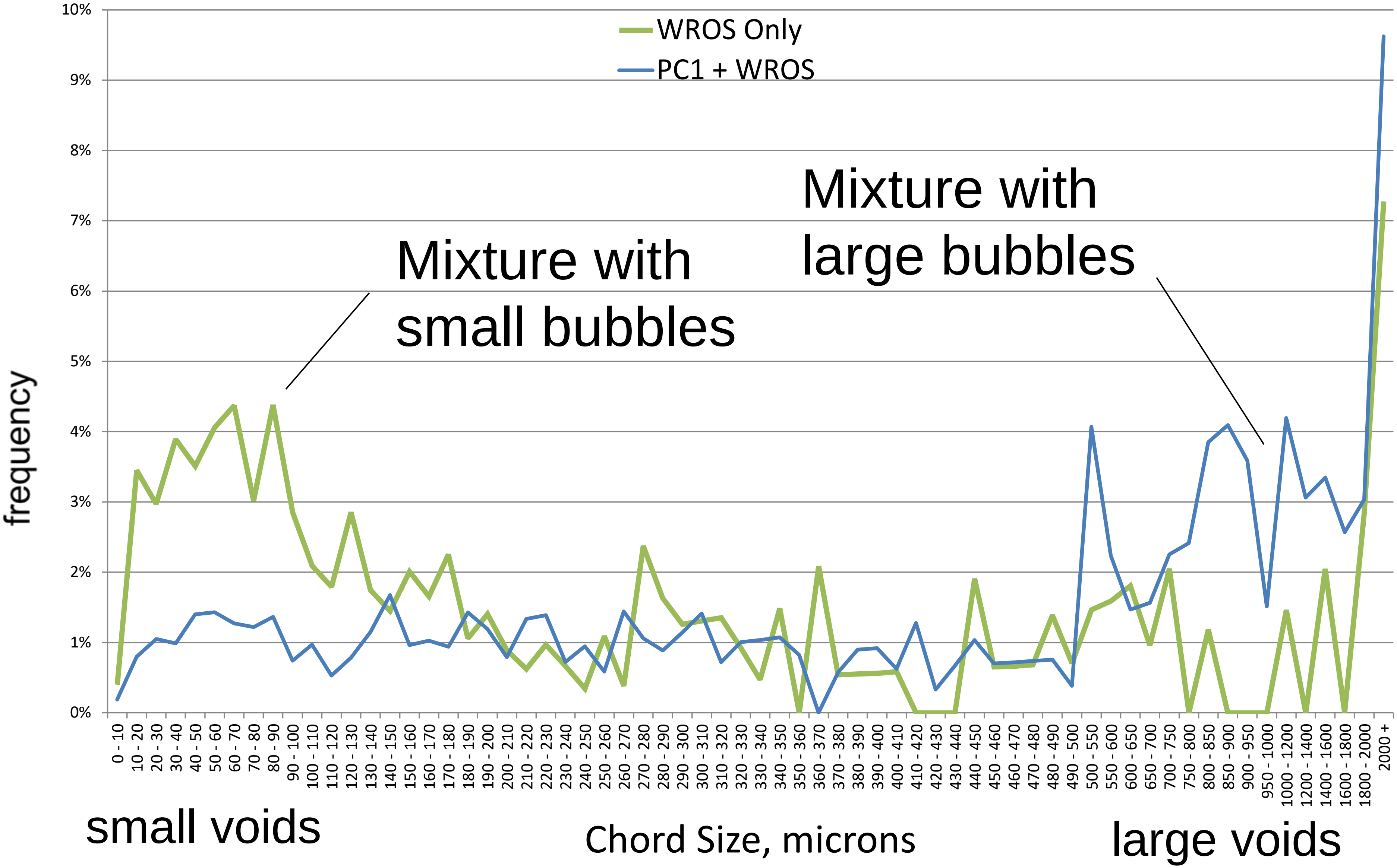
Hardened Air Void Analysis



From Hover

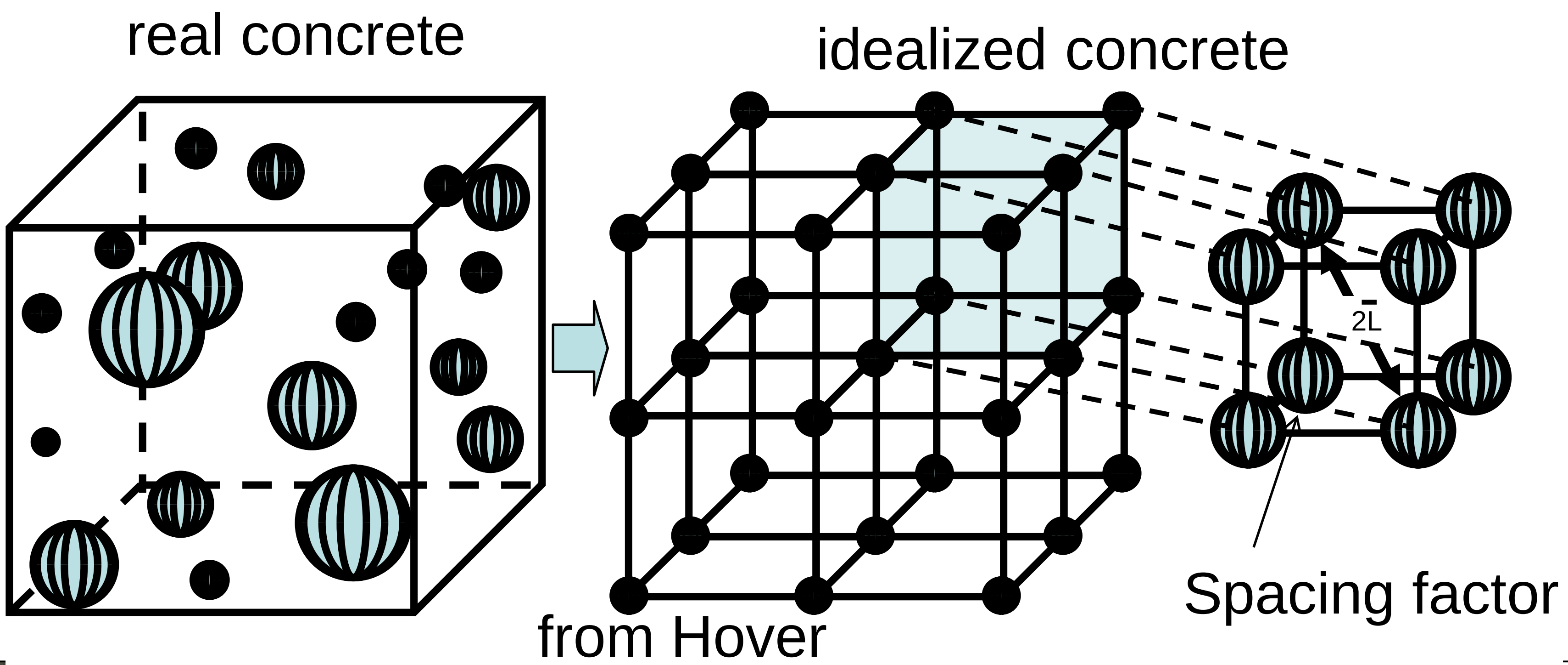


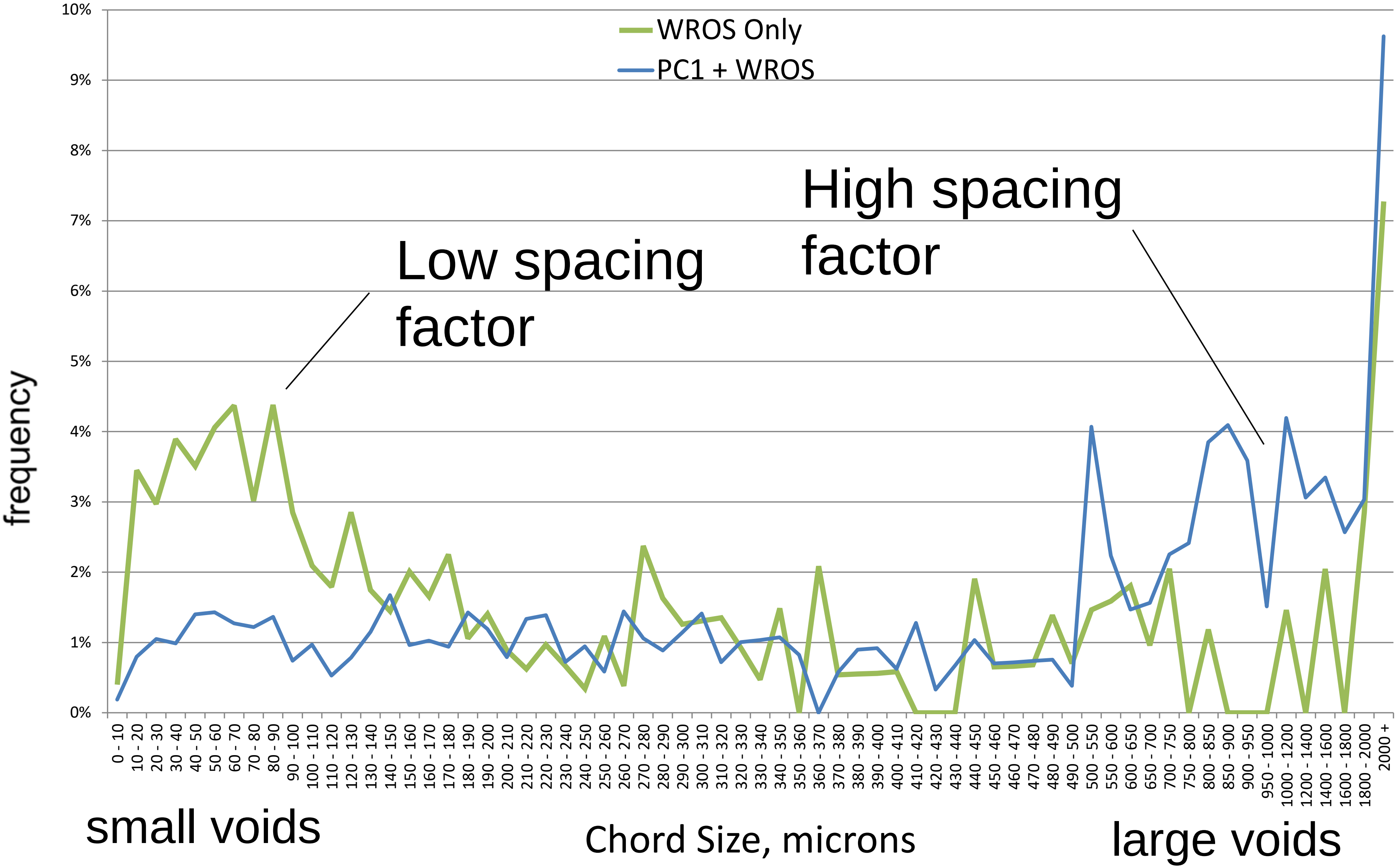
Freeman et al., 2012



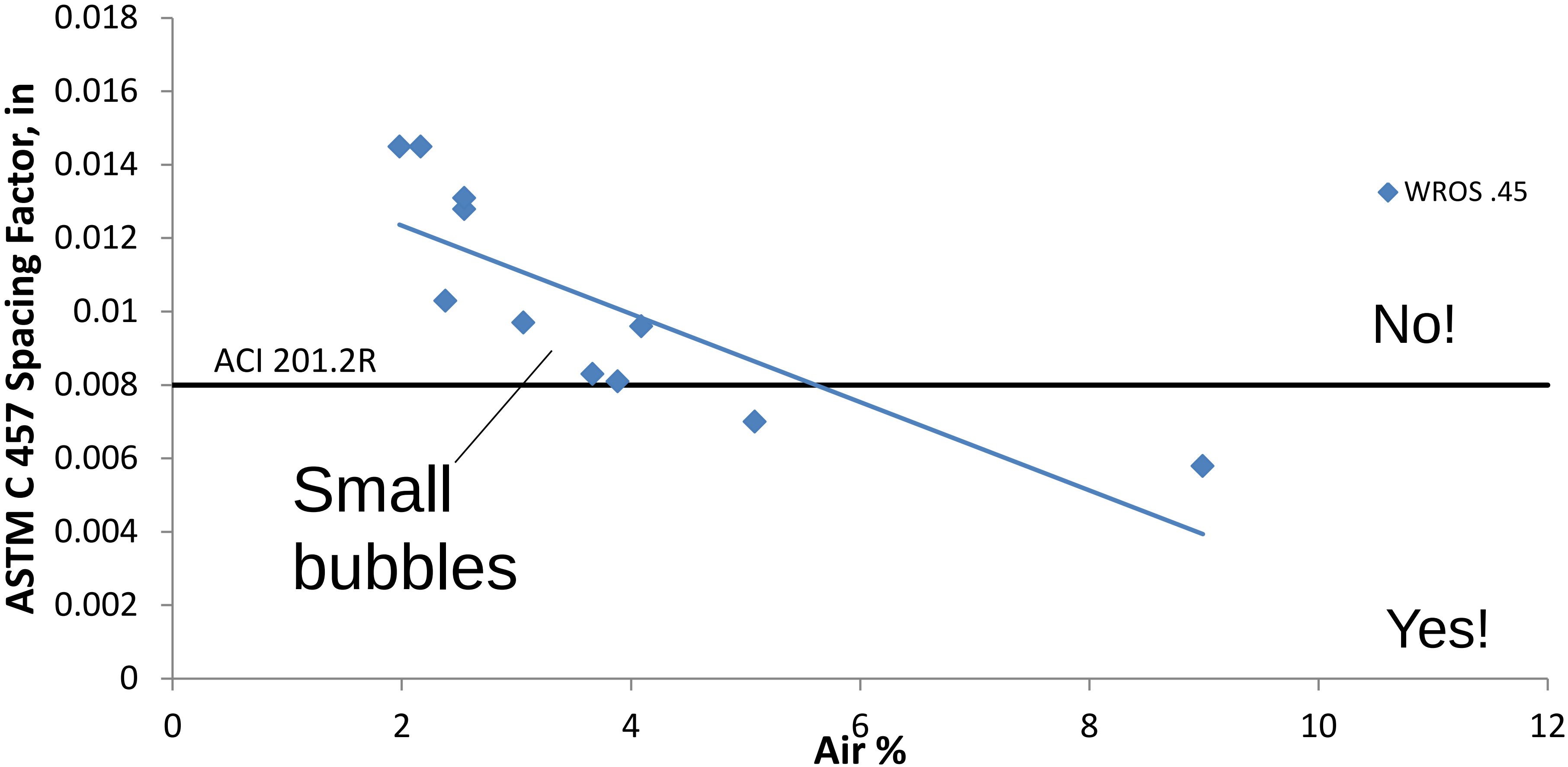
Freeman et al., 2012

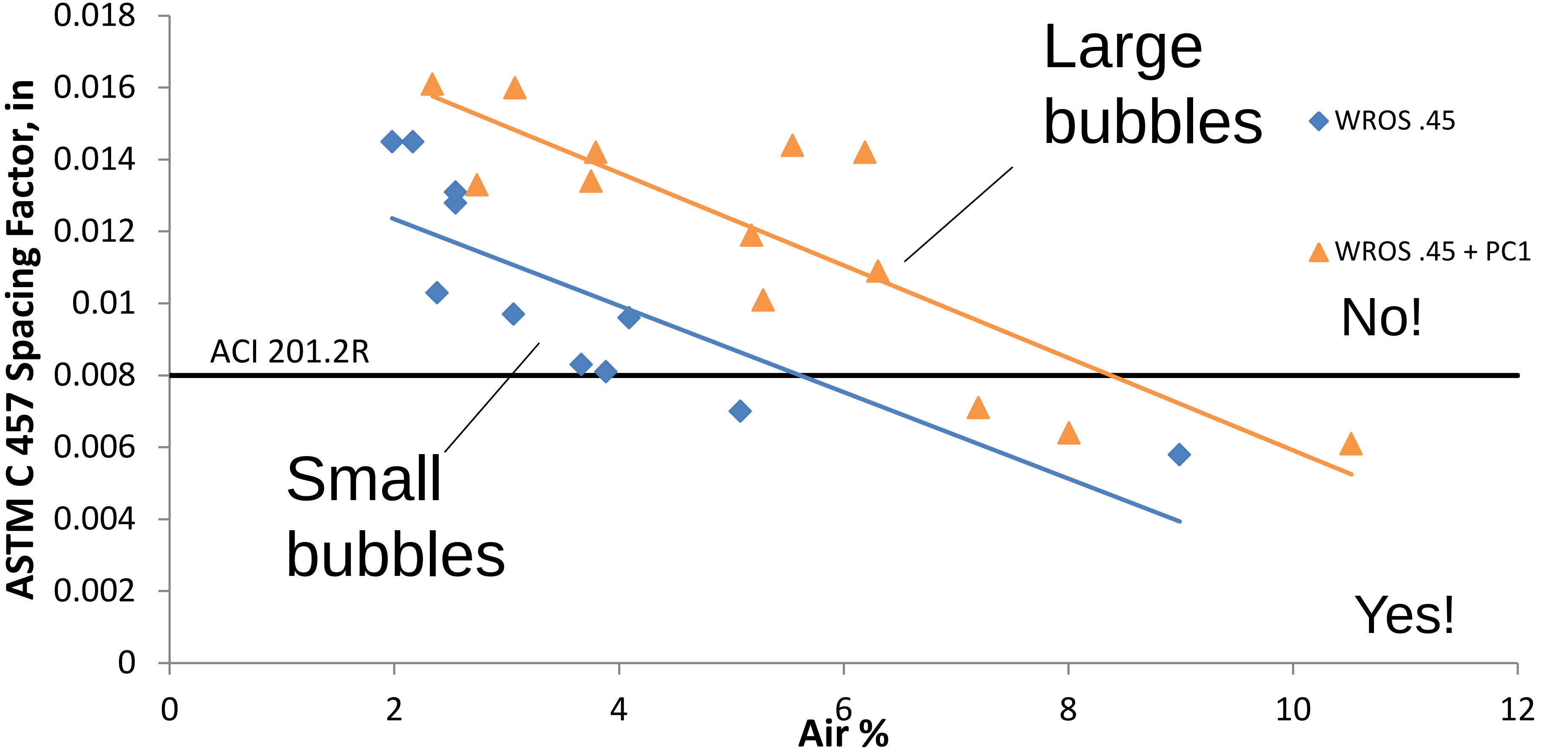
- Spacing Factor – ½ of the average distance of an average sized void uniformly distributed in the paste
- **<u>Desired Value < 0.008 in (ACI 201)</u>**





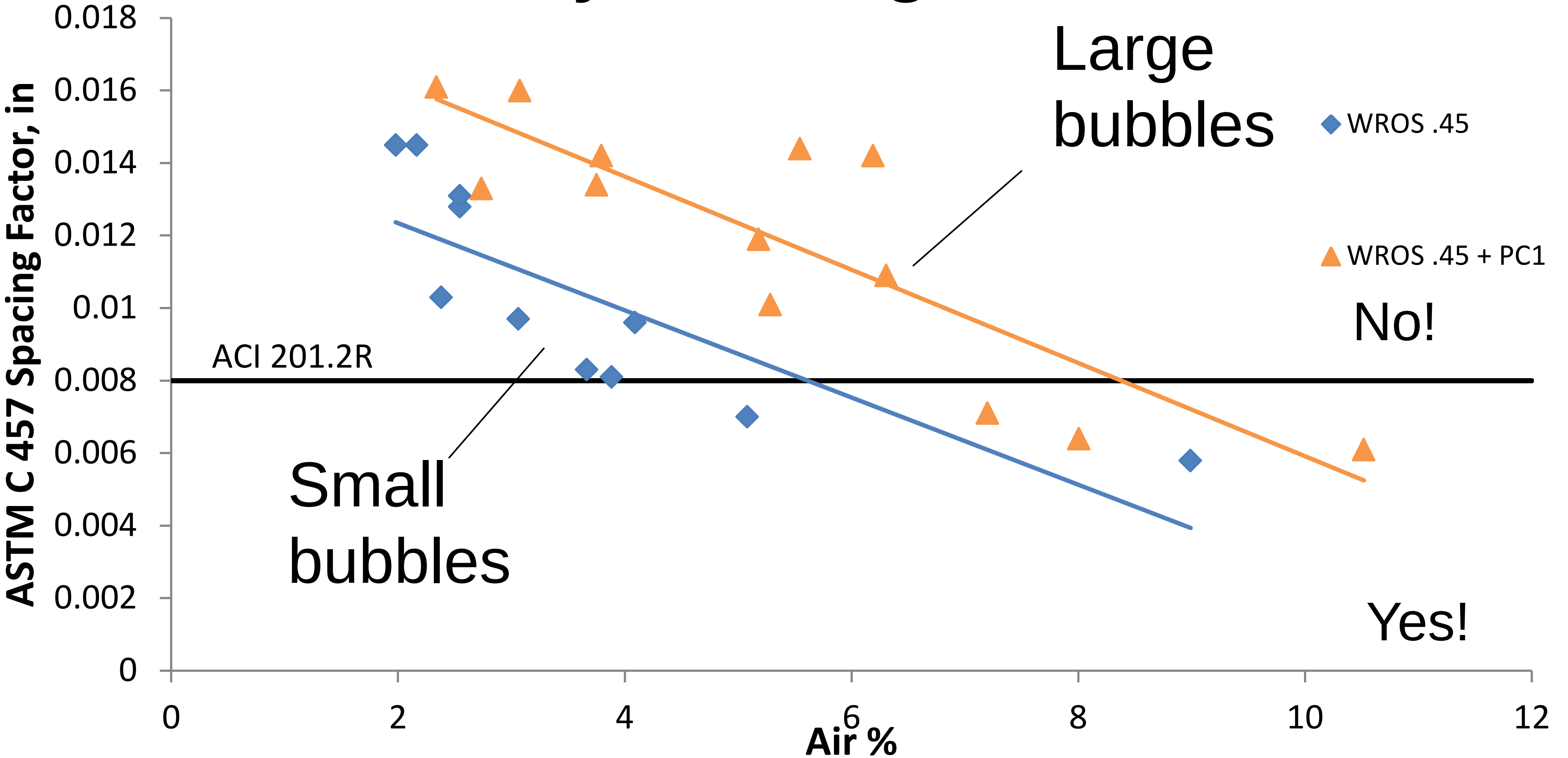
Freeman et al., 2012

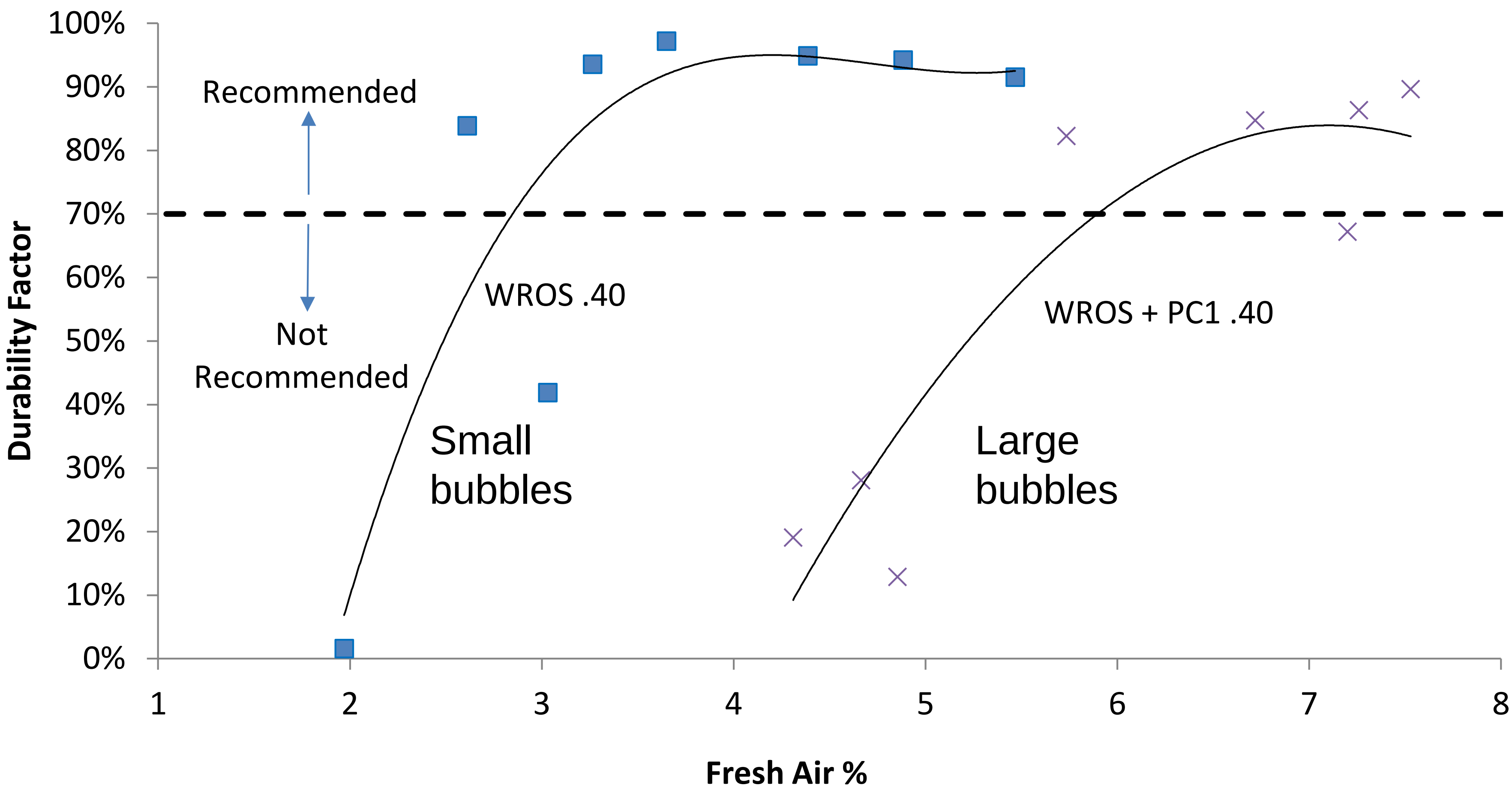

ASTM C 457 Spacing Factor, in
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
ACI 201.2R
Small bubbles
No!
Yes!
WROS .45
0
2
4
6
8
10
12
Air %



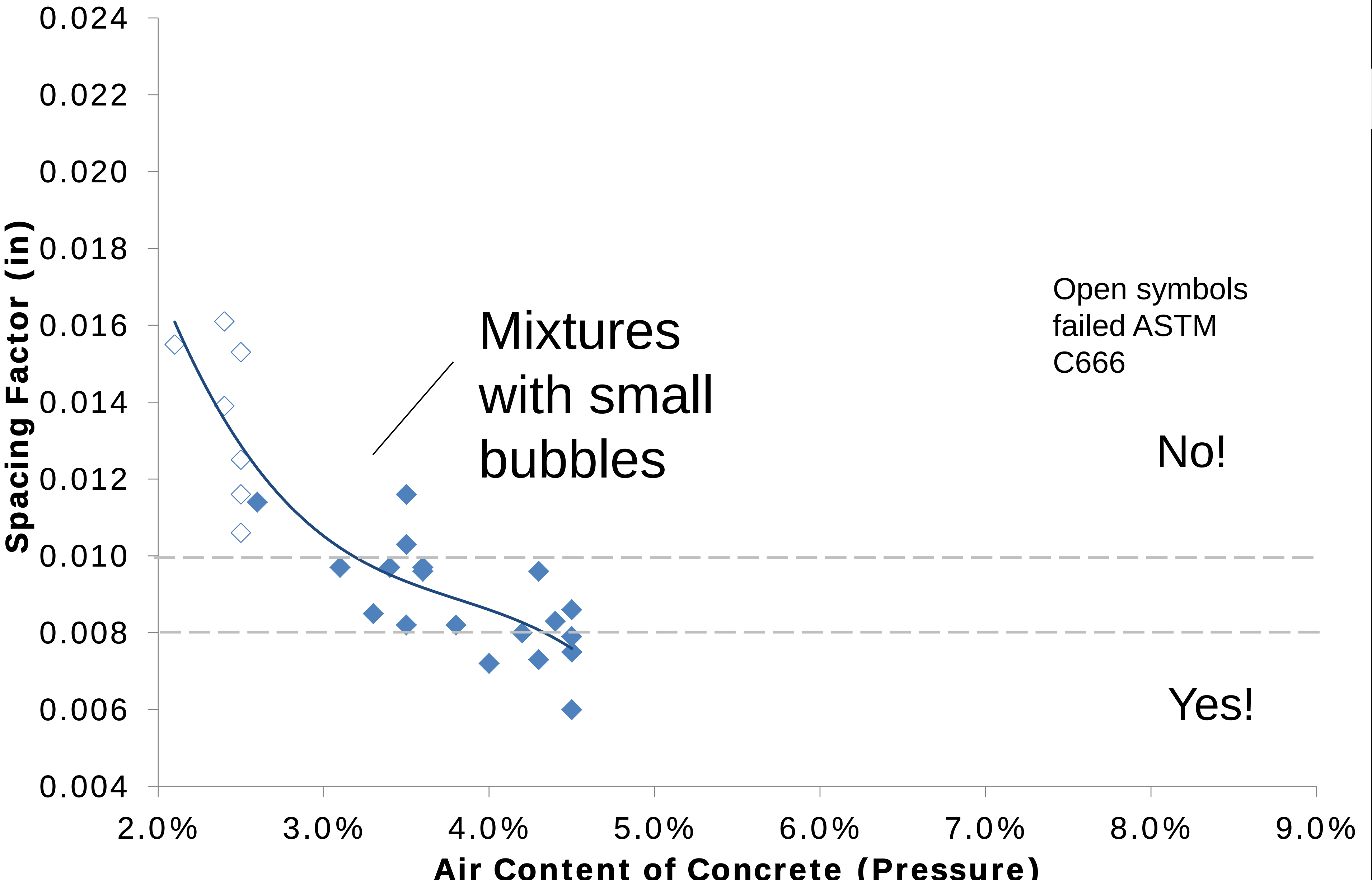
Large
bubbles
WROS .45
WROS .45 + PC1
No!
ACI 201.2R
Small
bubbles
Yes!
ASTM C 457 Spacing Factor, in
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
2
4
6
8
10
12
Air %

You can't tell the size of the bubbles by looking at the volume!!!

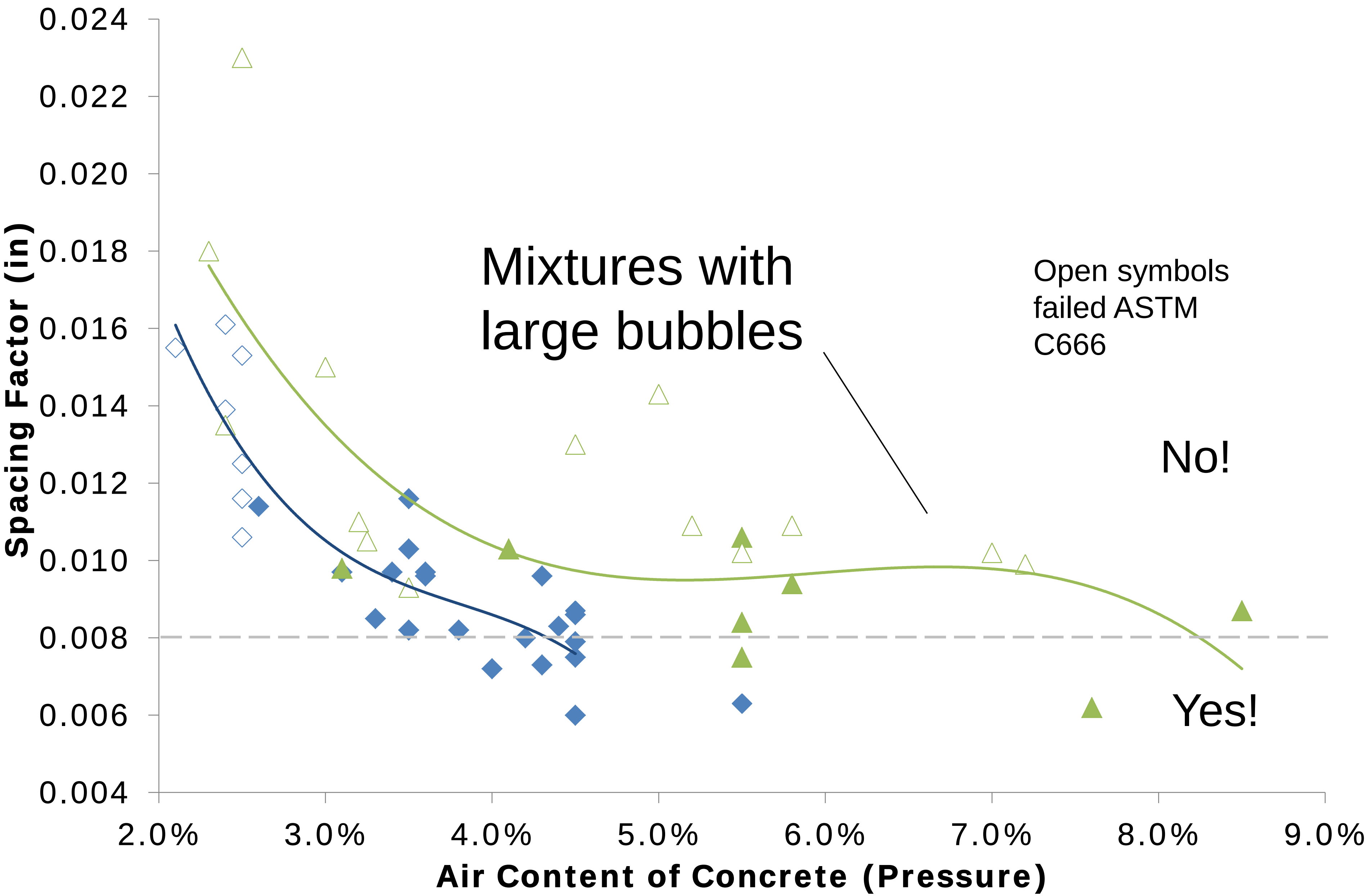




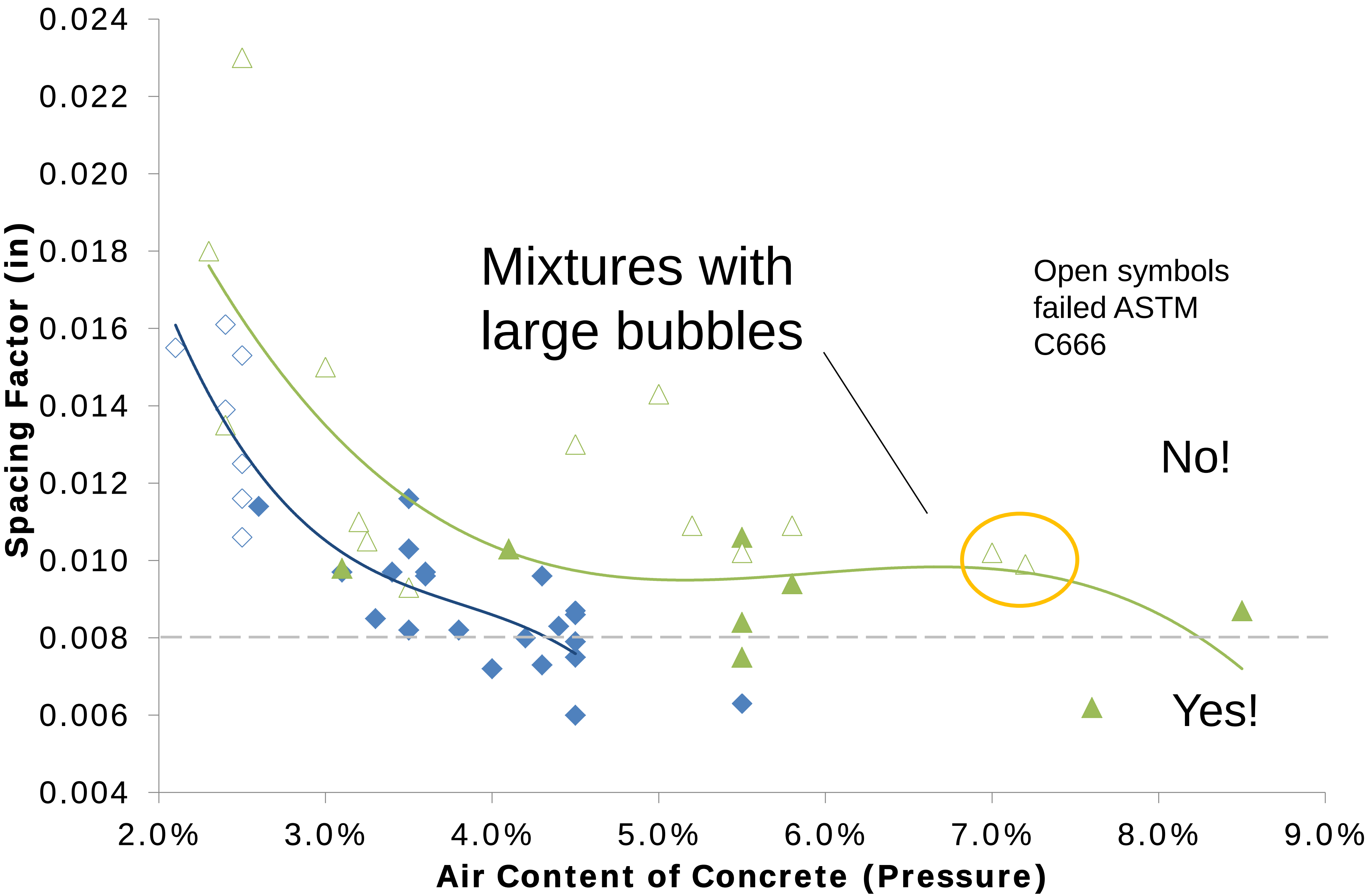
Ley et al., 2017



Freeman et al., 2012



Freeman et al., 2012



Freeman et al., 2012

Summary

- **We need to know the size of bubbles within the concrete**
- *The volume of air does not tell you anything about bubble size*
- Although a hardened air void analysis can measure this, it is not practical to run regularly

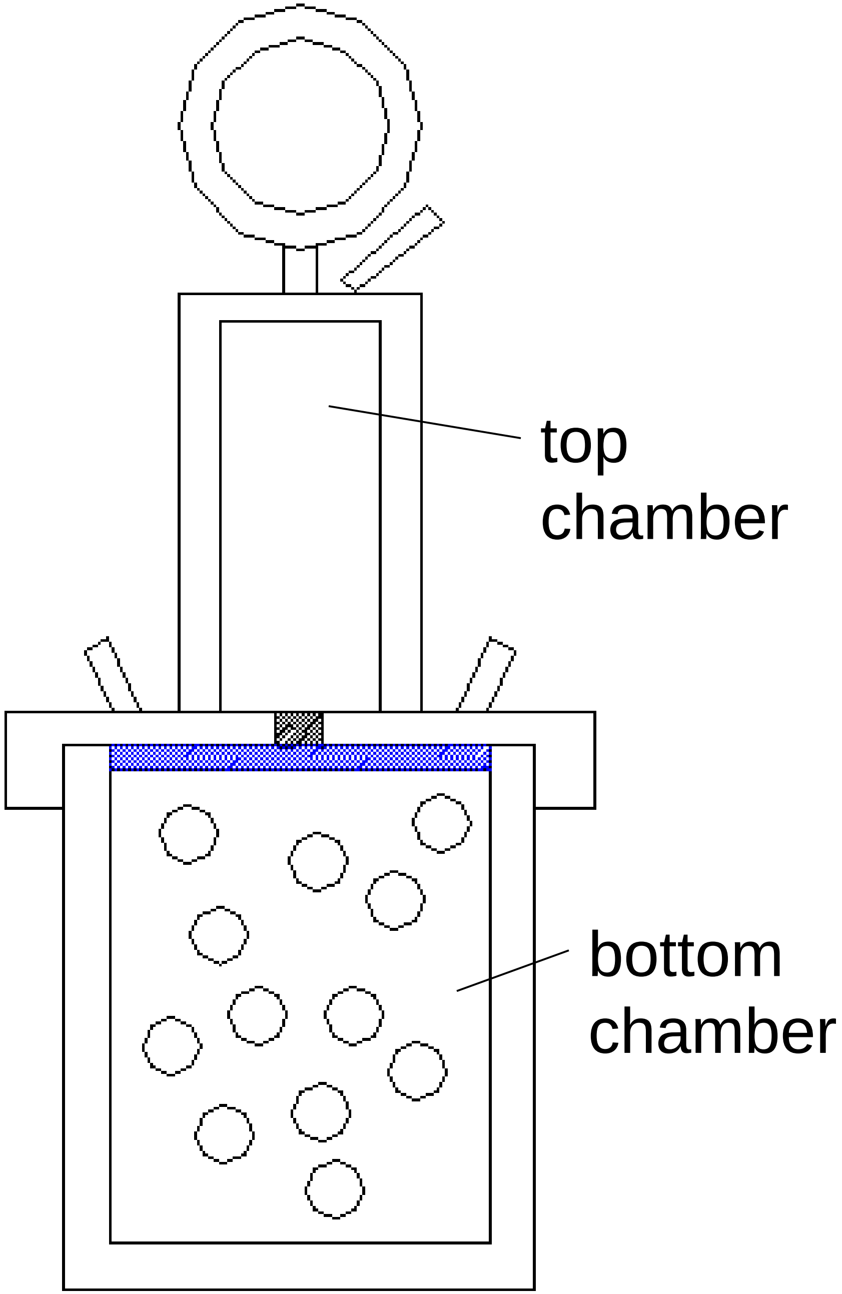
Super Air Meter (SAM)

- We have modified a typical ASTM C 231 pressure meter so that it can hold larger pressures
- We have replaced the dial gage with a digital one

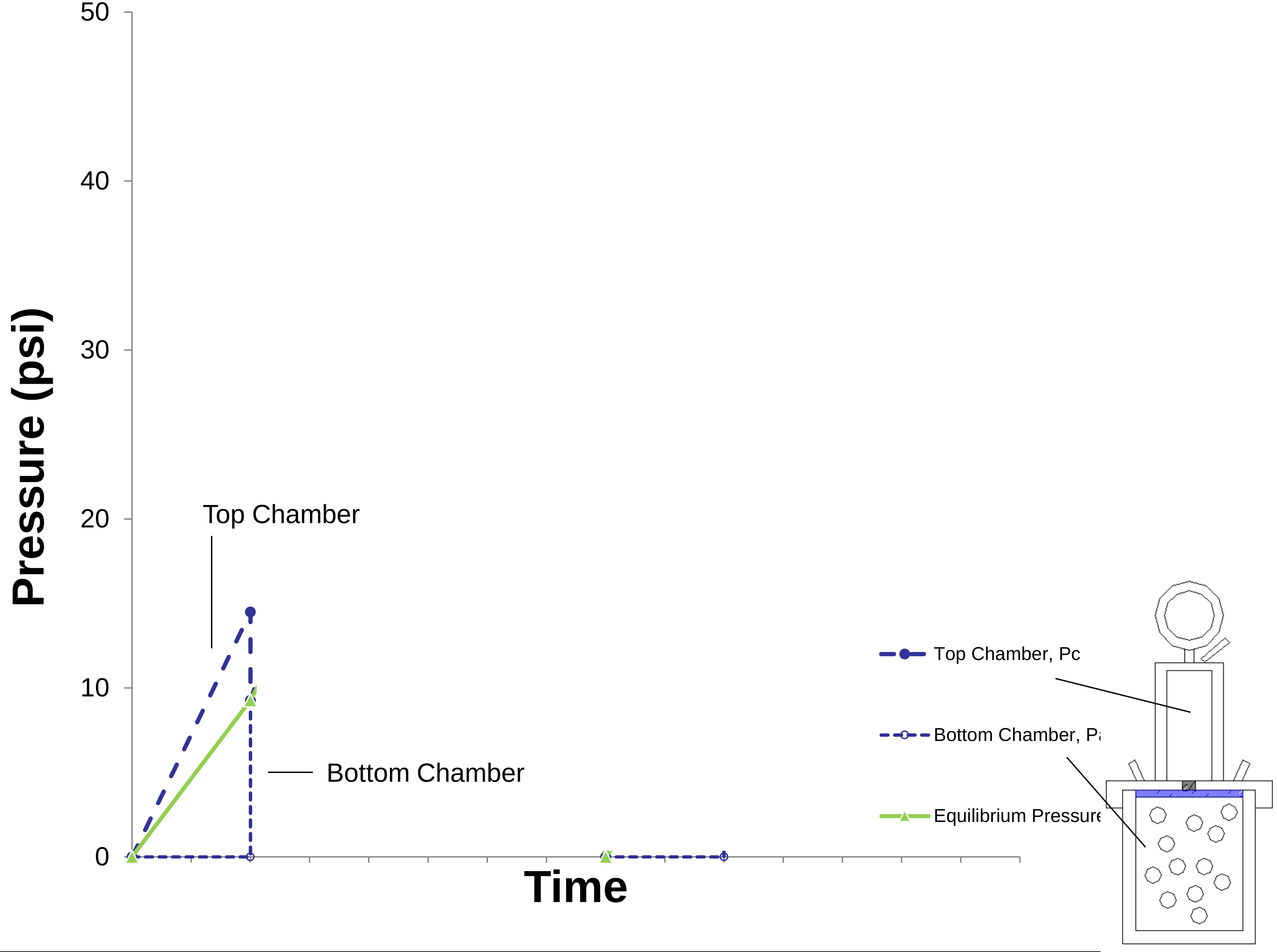

digital gauge
six clamps!

AASHTO TP 118

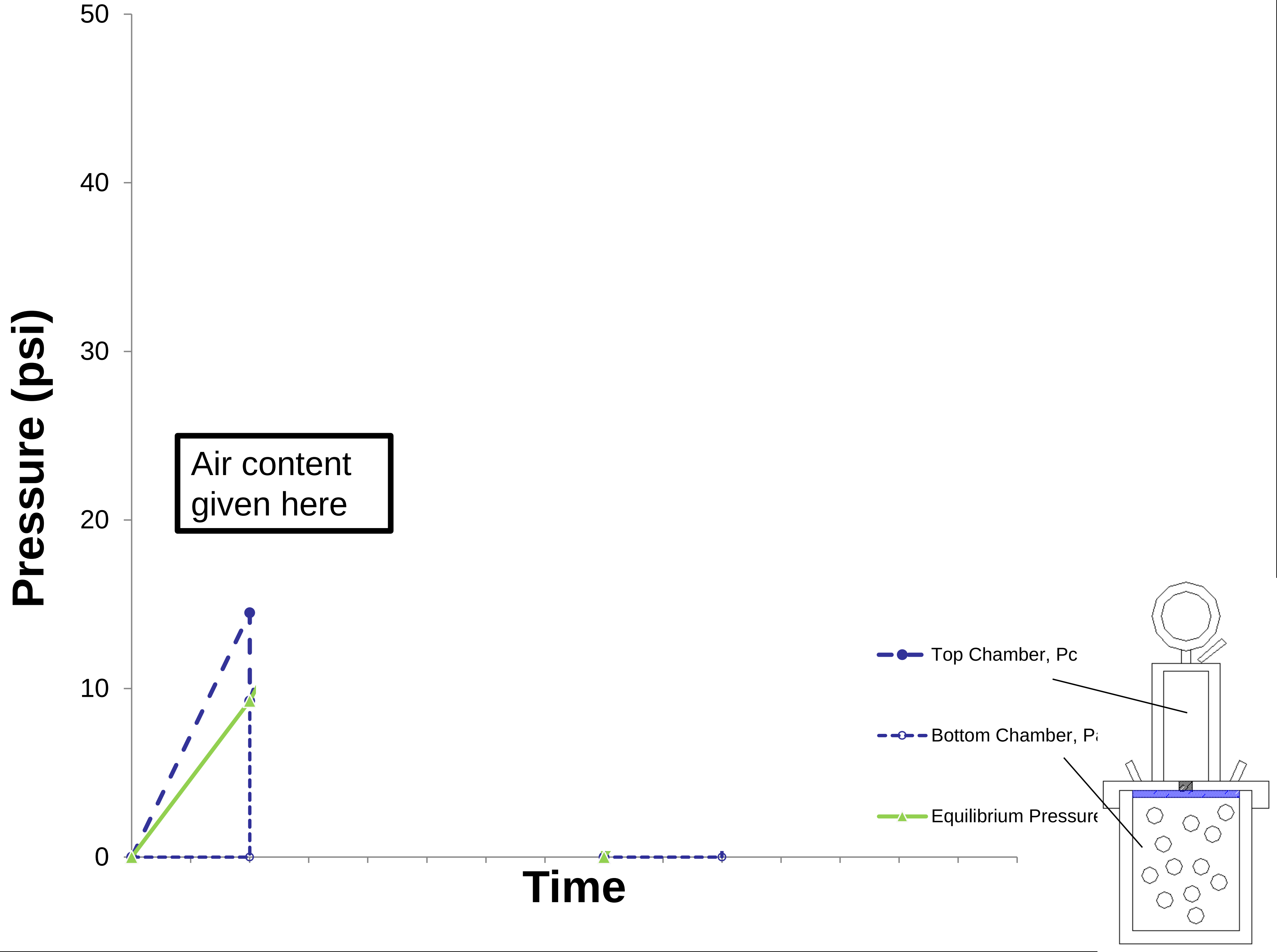
www.superairmeter.com



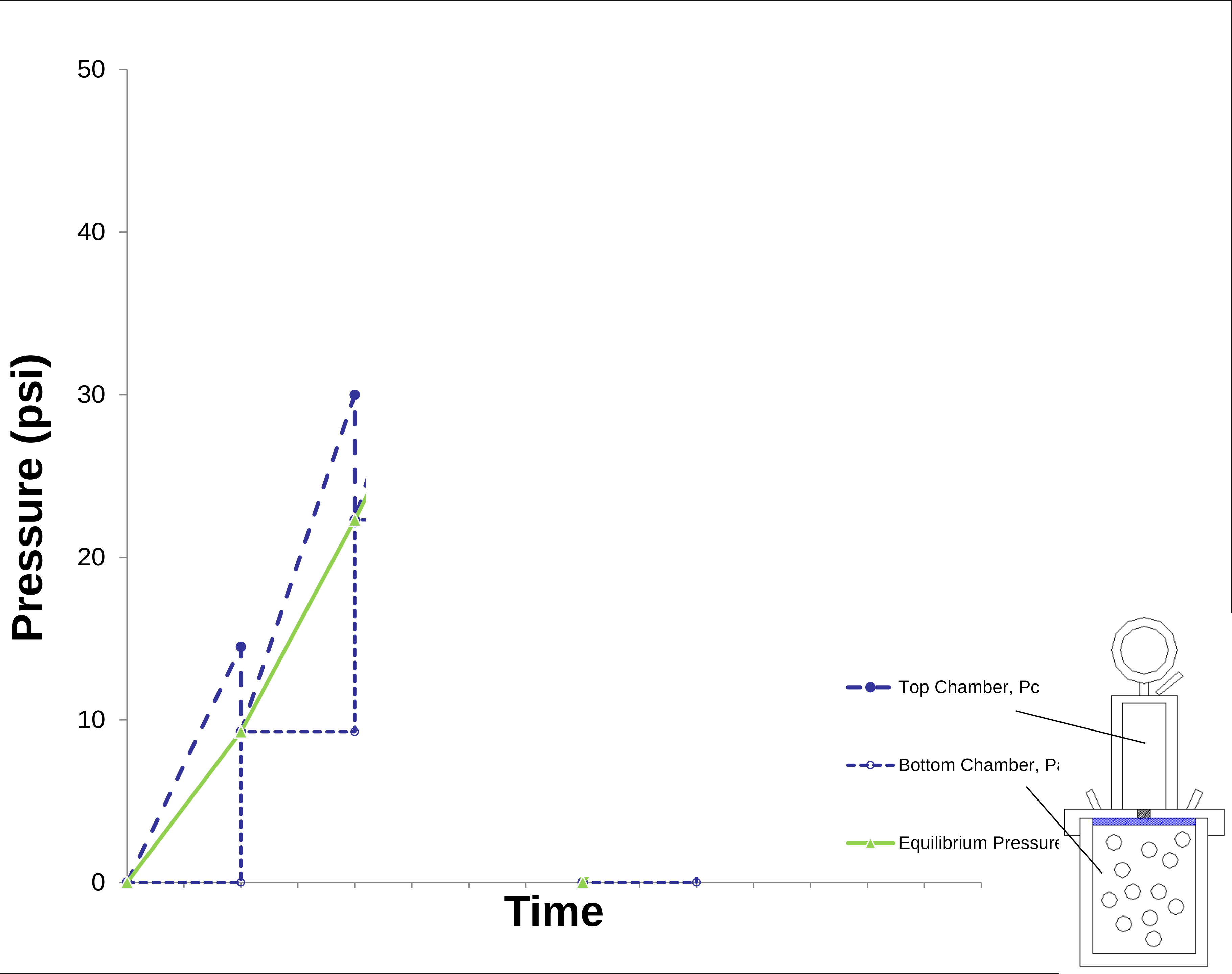
top chamber
bottom chamber

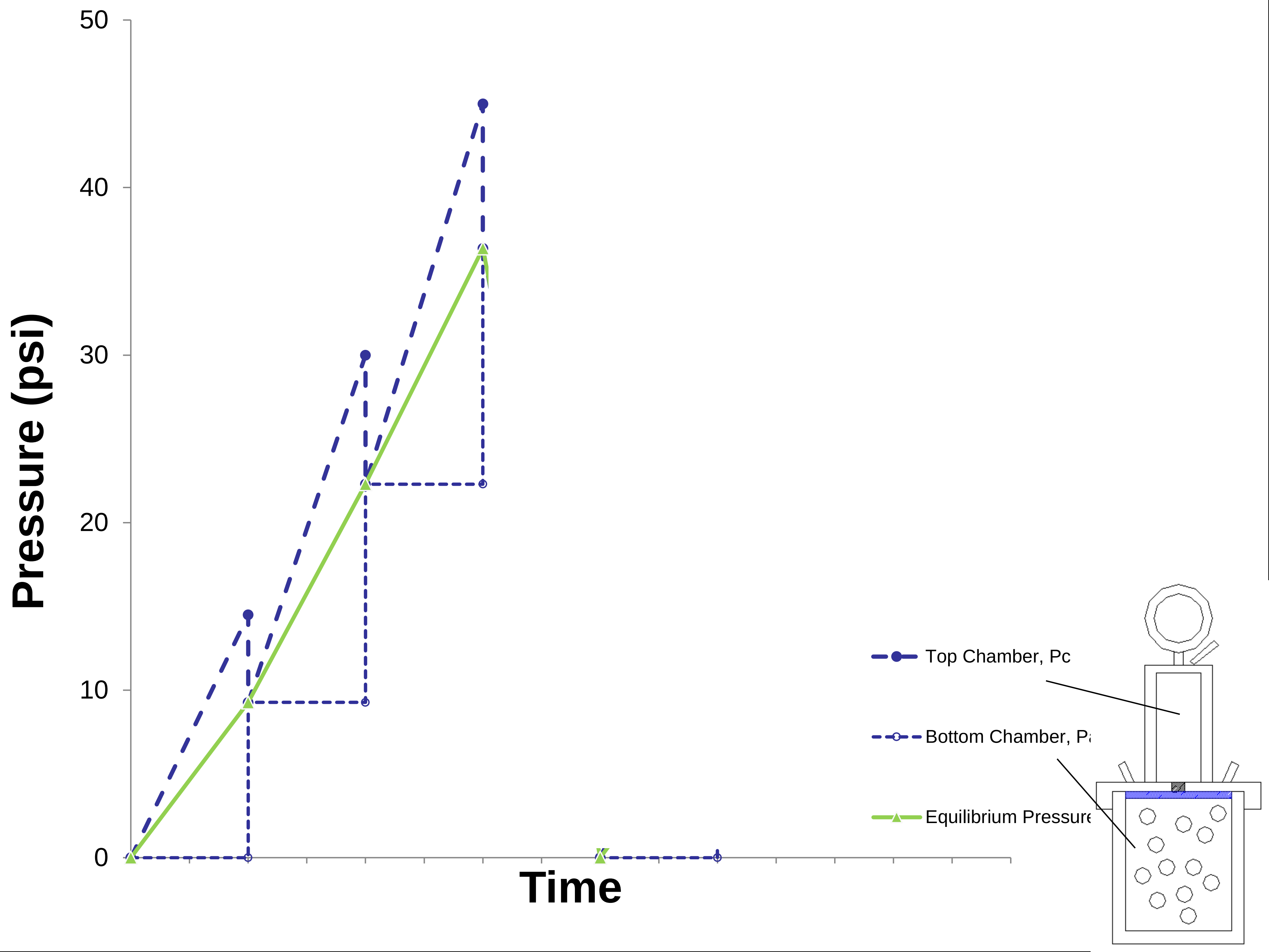


Pressure (psi)
50
40
30
20
10
0
Top Chamber
Bottom Chamber
Time
Top Chamber, Pc
Bottom Chamber, Pa
Equilibrium Pressure

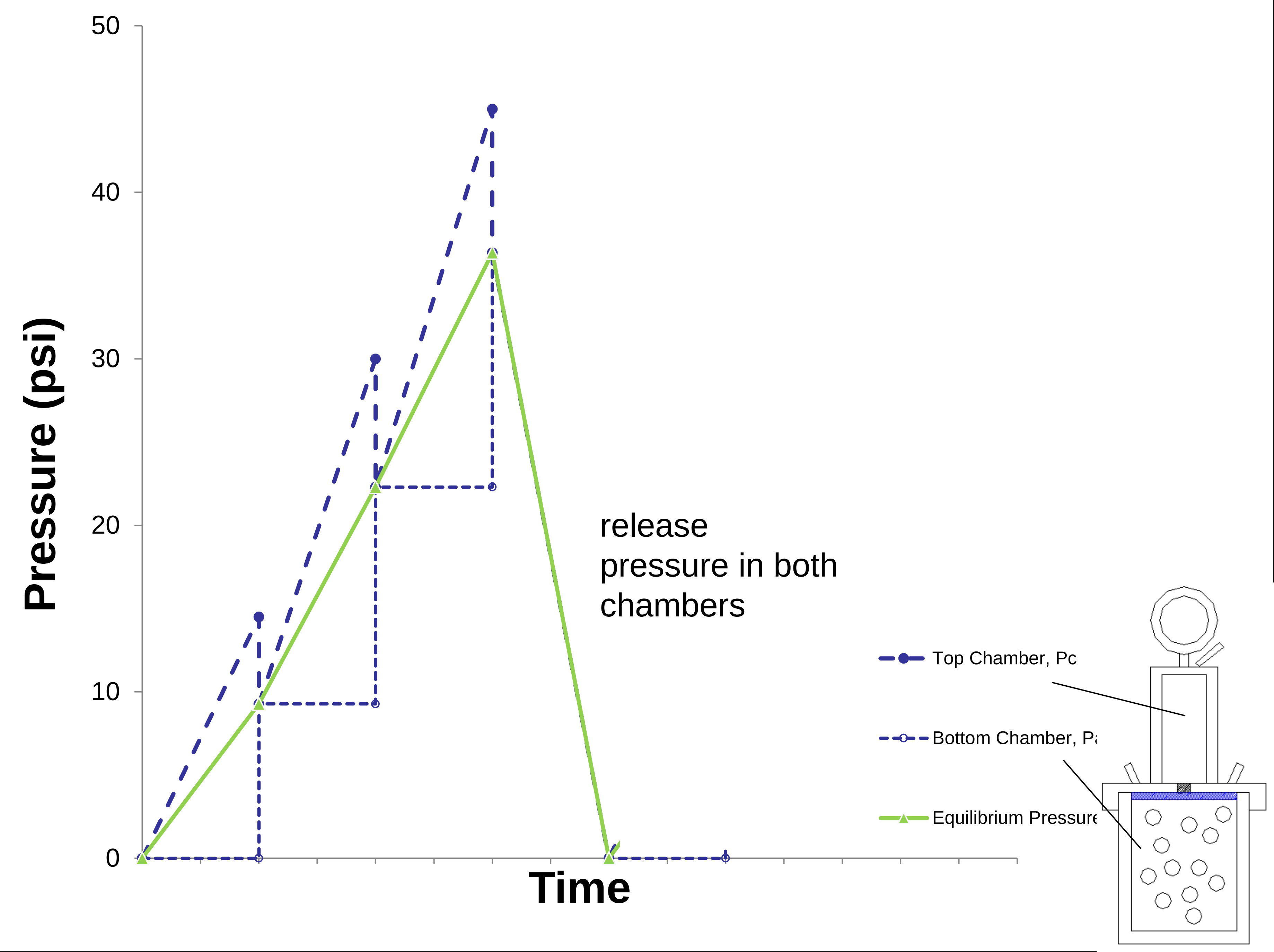


Pressure (psi)
50
40
30
20
10
0
Time
Air content given here
Top Chamber, Pc
Bottom Chamber, Pa
Equilibrium Pressure

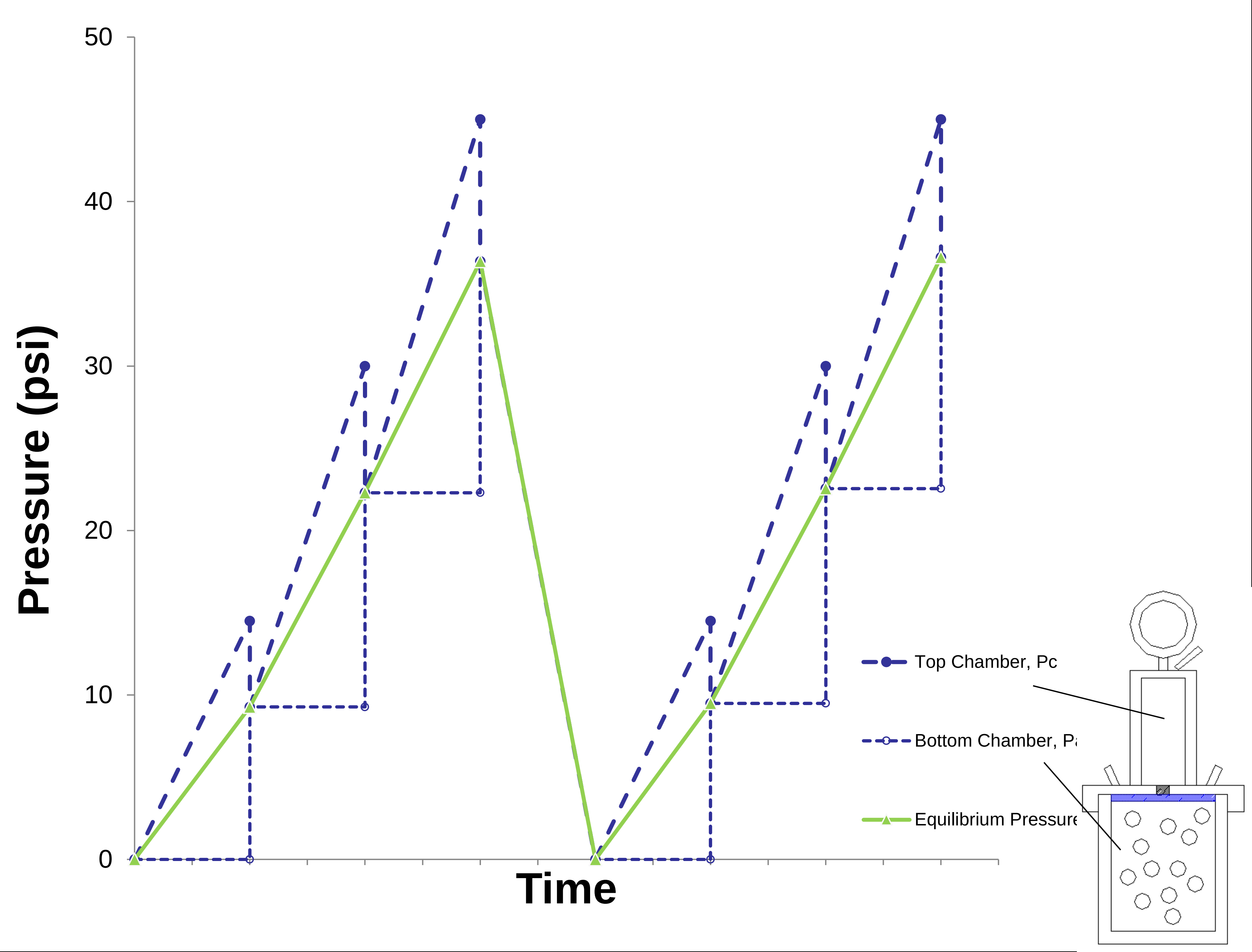

50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, Pa
Equilibrium Pressure



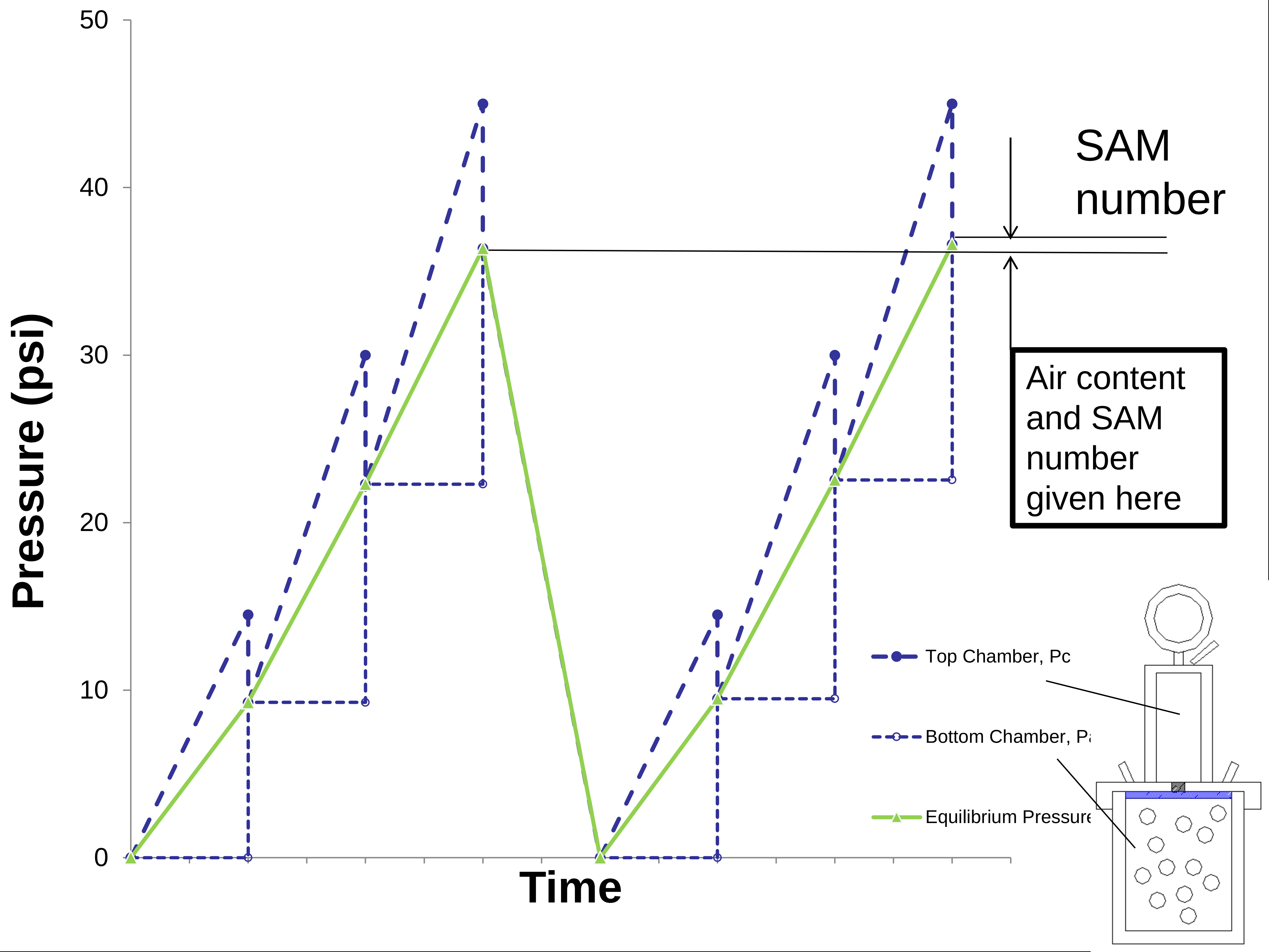
50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure



50
40
30
20
10
0
Pressure (psi)
Time
release
pressure in both
chambers
Top Chamber, Pc
Bottom Chamber, Pa
Equilibrium Pressure



50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, Pa
Equilibrium Pressure



Pressure (psi)
50
40
30
20
10
0
Time
SAM number
Air content and SAM number given here
Top Chamber, Pc
Bottom Chamber, Pa
Equilibrium Pressure

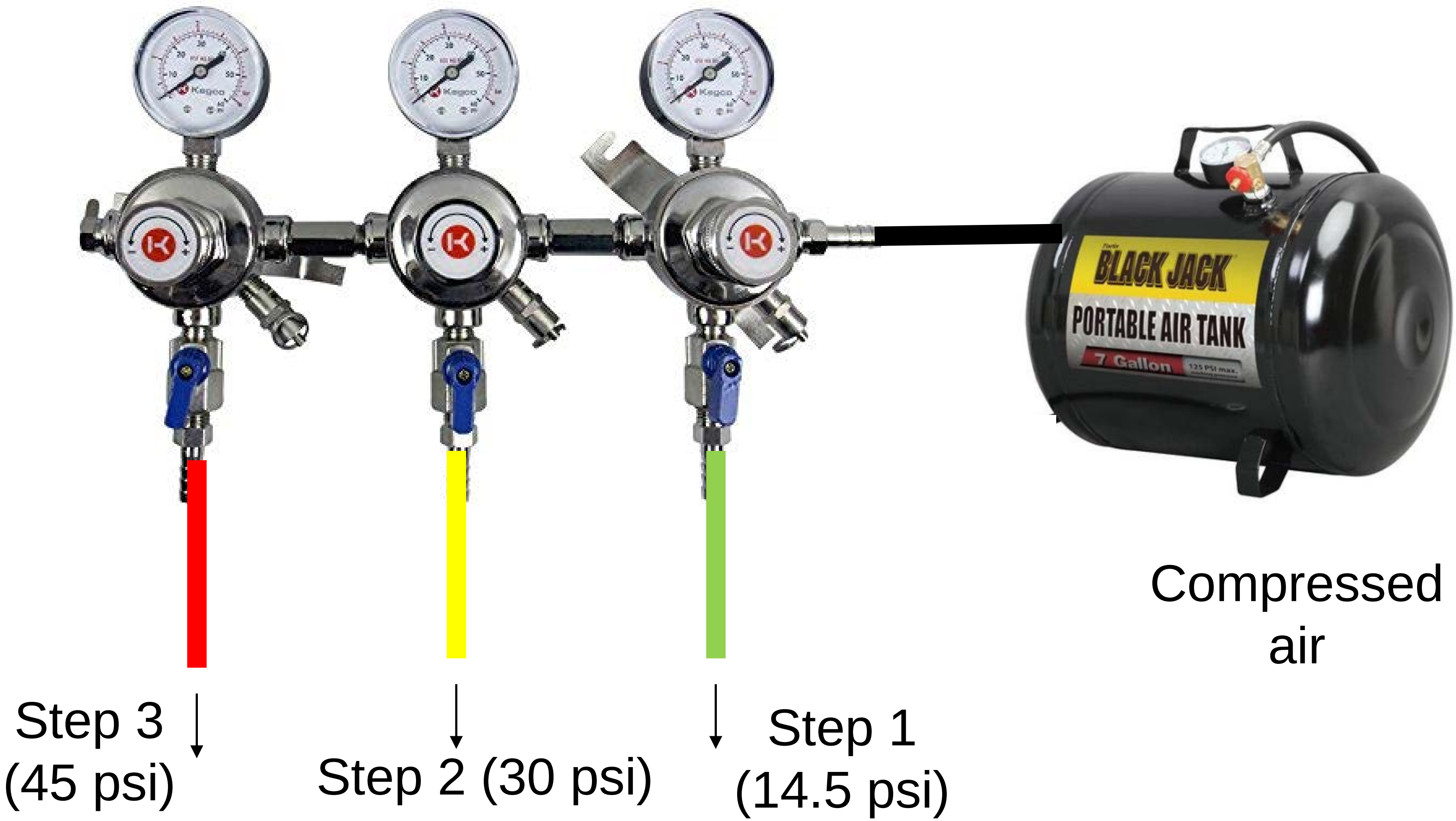
How long does it take?

- With just the SAM
- Inexperienced user – 10 min to 12 min
- Experienced user – 7 min to 9 min

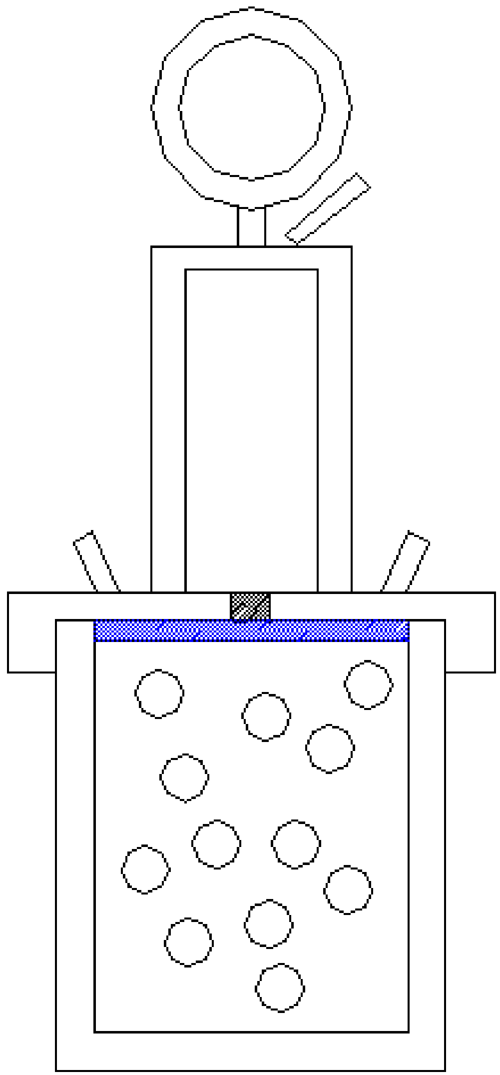
- With the CAPE
- Inexperienced user – 7 min to 9 min
- Experienced user – 4.5 min to 6.5 min

- **Test must be completed within 12 min**

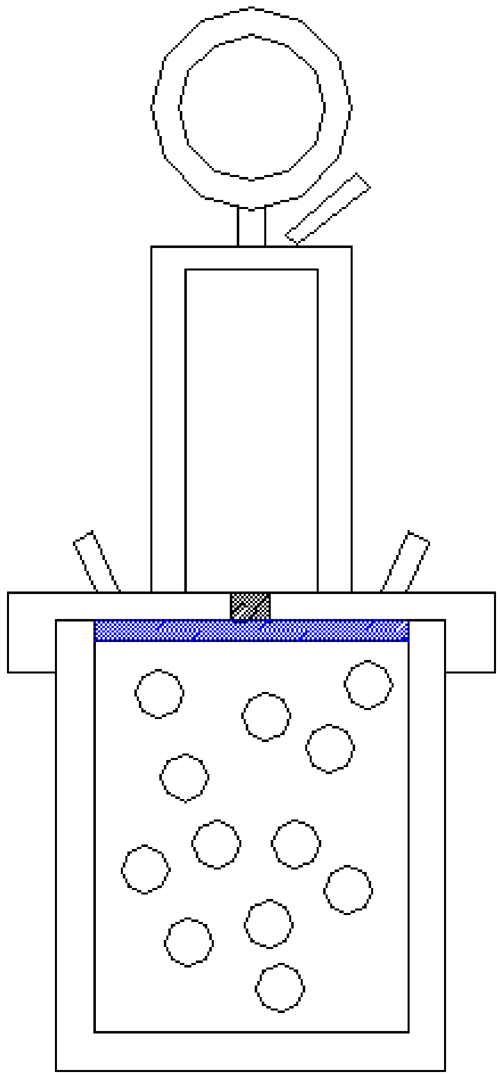
Controlled Air Pressure Extender
aka **CAPE**



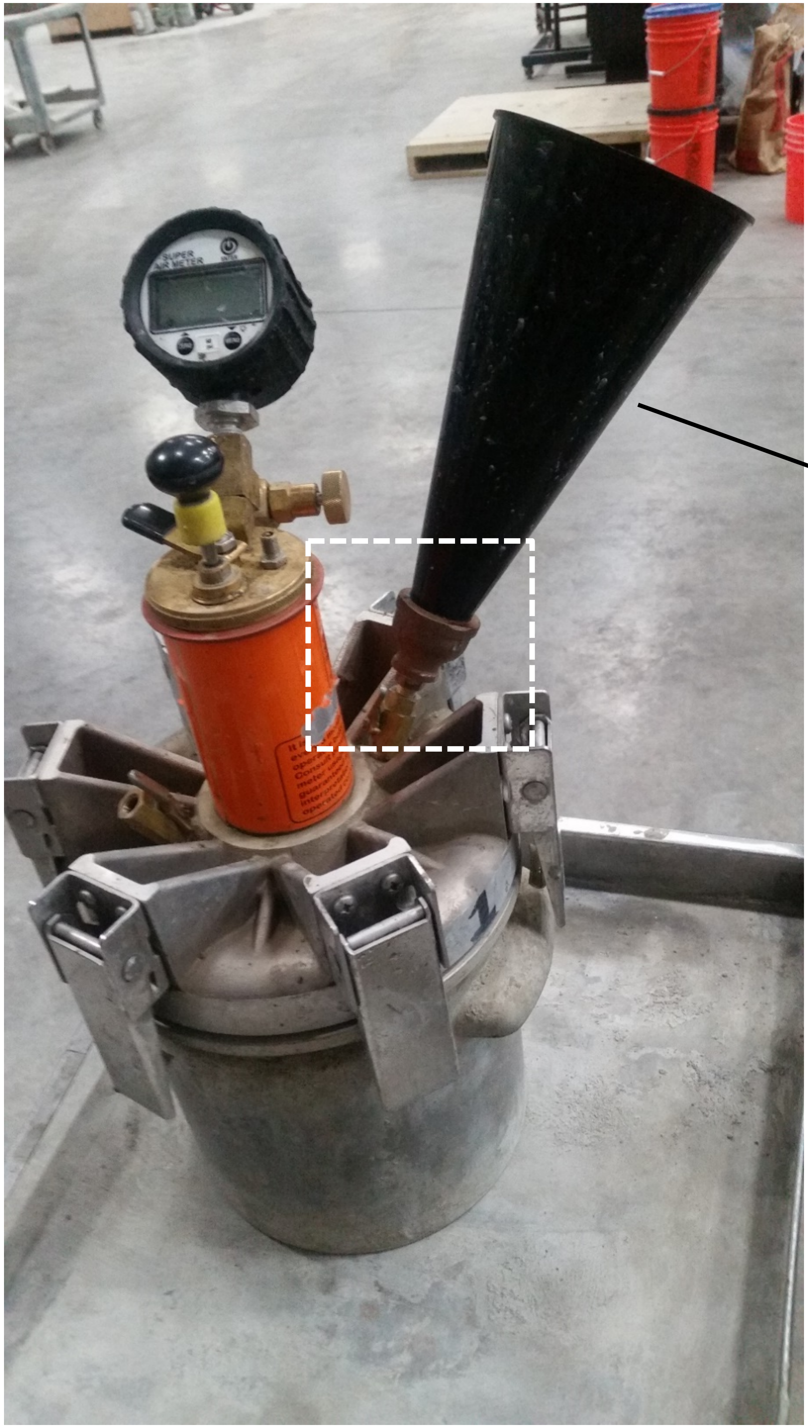
Does anyone hate using the syringe?



What if we used a funnel instead?



Shotgun



Shotgun


Shotgun

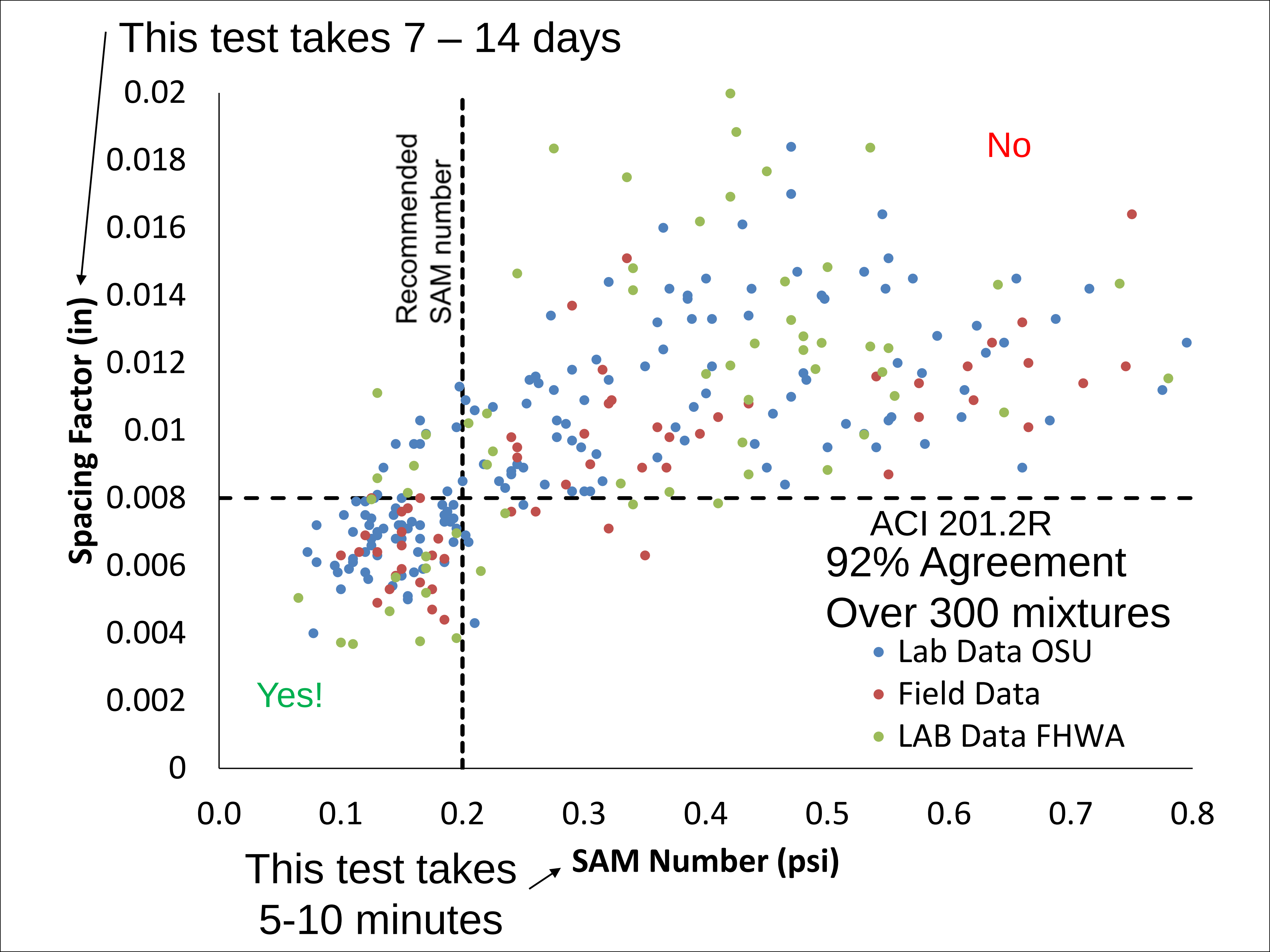
Discussion

- The Super Air Meter gives you the air volume and the SAM number.
- The CAPE is a portable air tank and regulators and the shotgun is a new way to fill the bottom chamber with water.
- These make you run the test faster and more accurately.

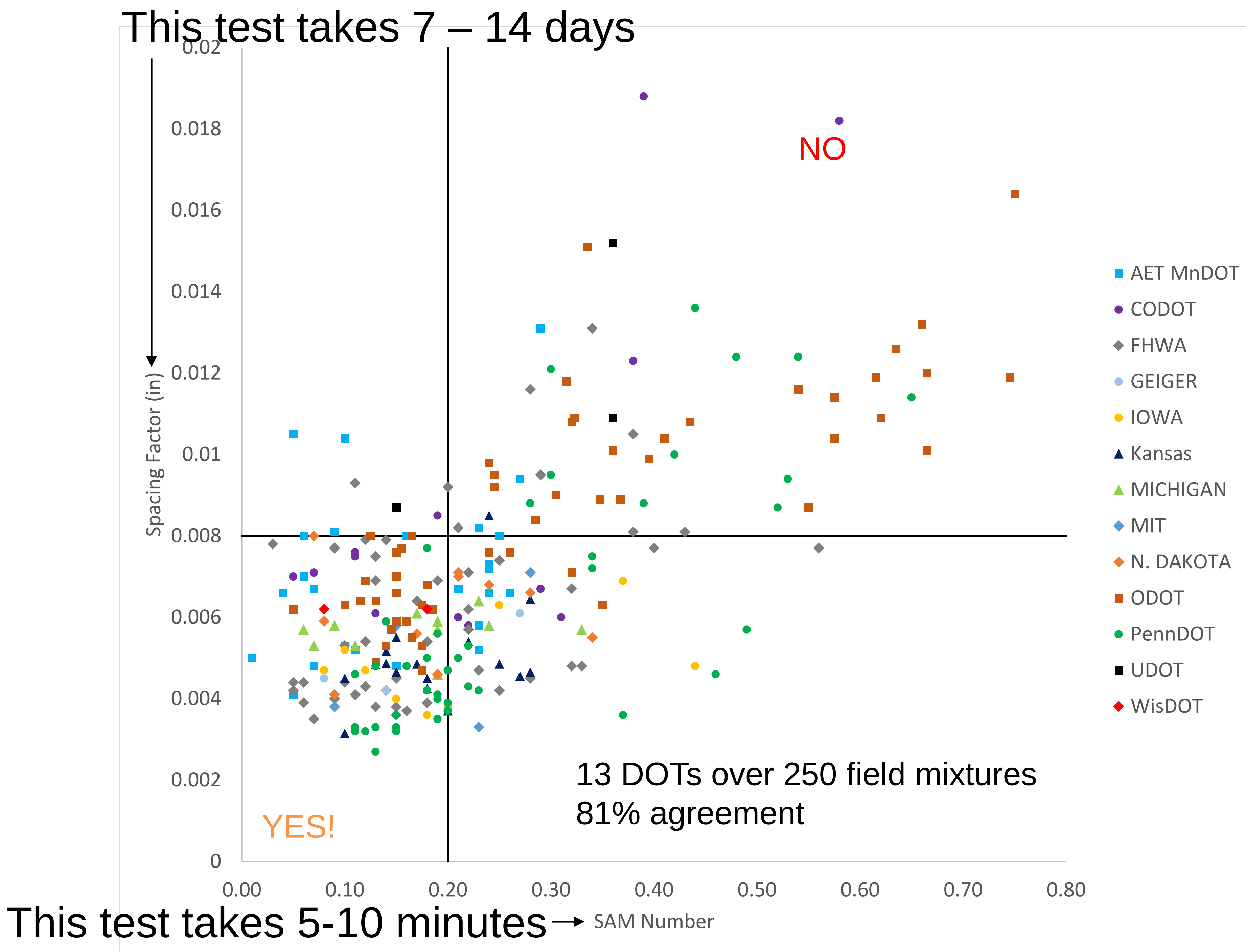
What are reasonable values?

- All SAM values should be between 0.03 and 0.82.
- If the SAM value is not in this range then the test was not completed correctly.

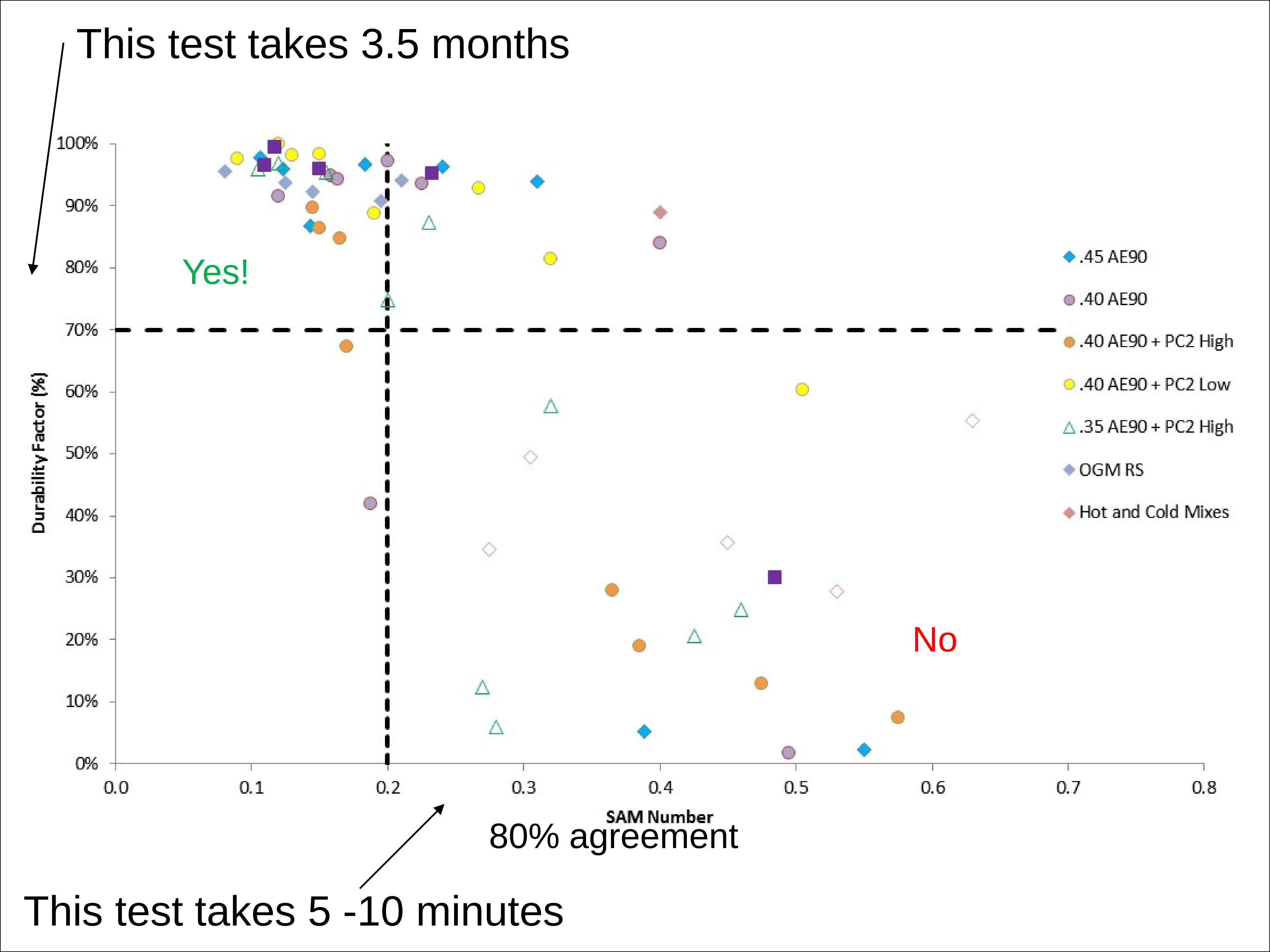
Why is the SAM number useful?



This test takes 7 – 14 days
Spacing Factor (in)
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Recommended
SAM number
No
Yes!
ACI 201.2R
92% Agreement
Over 300 mixtures
Lab Data OSU
Field Data
LAB Data FHWA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
SAM Number (psi)
This test takes
5-10 minutes



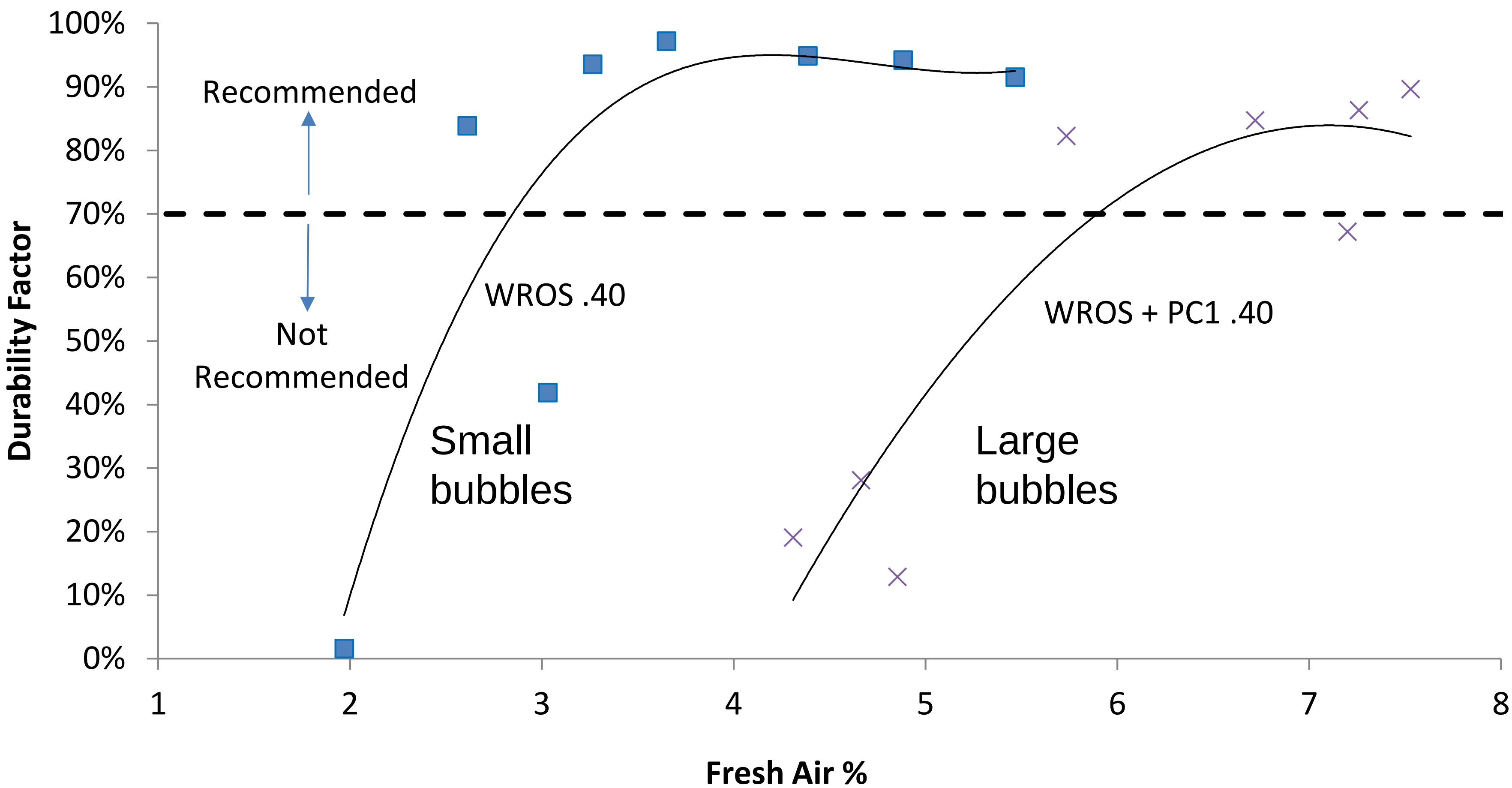
This test takes 7 – 14 days
NO
YES!
13 DOTs over 250 field mixtures
81% agreement
Spacing Factor (in)
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
SAM Number
AET MnDOT
CODOT
FHWA
GEIGER
IOWA
Kansas
MICHIGAN
MIT
N. DAKOTA
ODOT
PennDOT
UDOT
WisDOT
This test takes 5-10 minutes



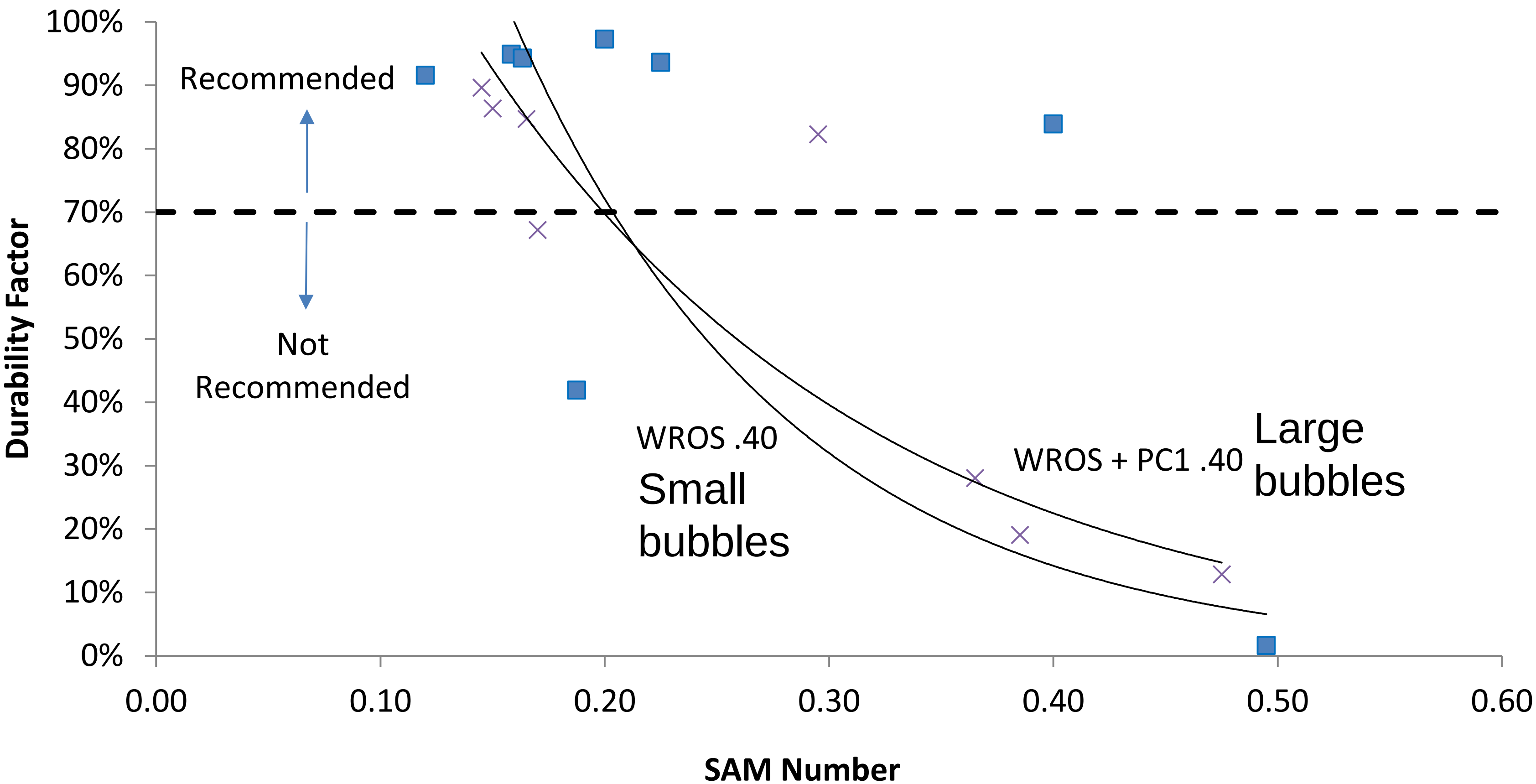
This test takes 3.5 months
Durability Factor (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Yes!
No
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
SAM Number
80% agreement
.45 AE90
.40 AE90
.40 AE90 + PC2 High
.40 AE90 + PC2 Low
.35 AE90 + PC2 High
OGM RS
Hot and Cold Mixes
This test takes 5 -10 minutes

Discussion

- The SAM number of 0.20 correlates well with hardened air void analysis and freeze thaw testing.



Ley et al., 2017



Ley et al., 2017

Why is this useful?

- The SAM can tell us about the quality (size and spacing) of our air void system before the concrete sets
- It can tell us about the freeze thaw durability of our air void system
- It can warn us about air void stability problems during the mixture design process!!!!

How does that help me?

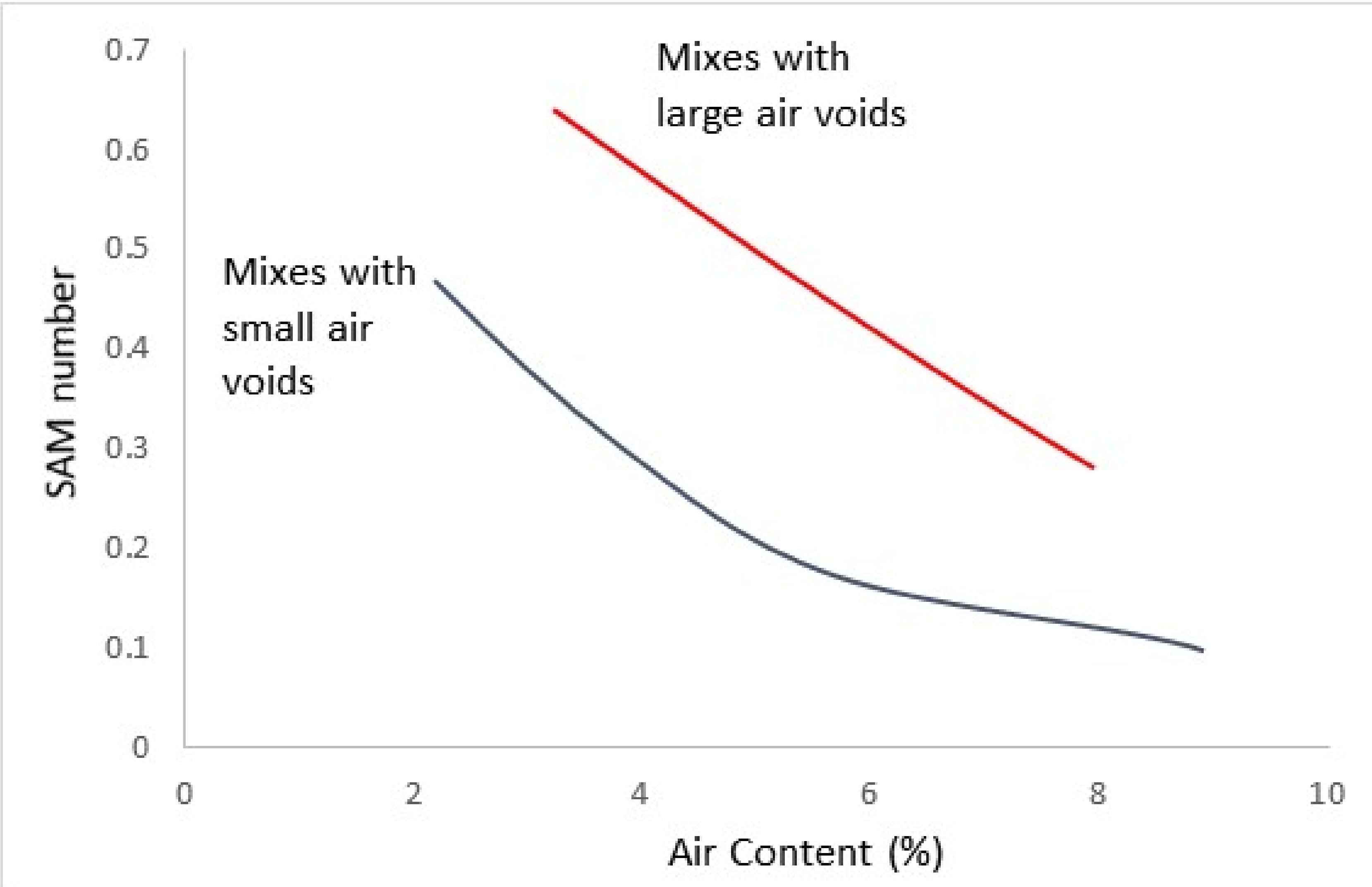
- Big bubbles are BAD!
- This test method can investigate the size and spacing of the bubbles in concrete before it has hardened.
- This makes sure that we get the type of air that we need for freeze thaw durability.

Why is this useful?

- This can give you important testing information that was almost impossible to get in the past

- This is helpful when:
  - mixtures are designed in the lab
  - mixtures are placed in the field
  - trial batching in the field
  - troubleshooting field problems
  - measuring variation in materials

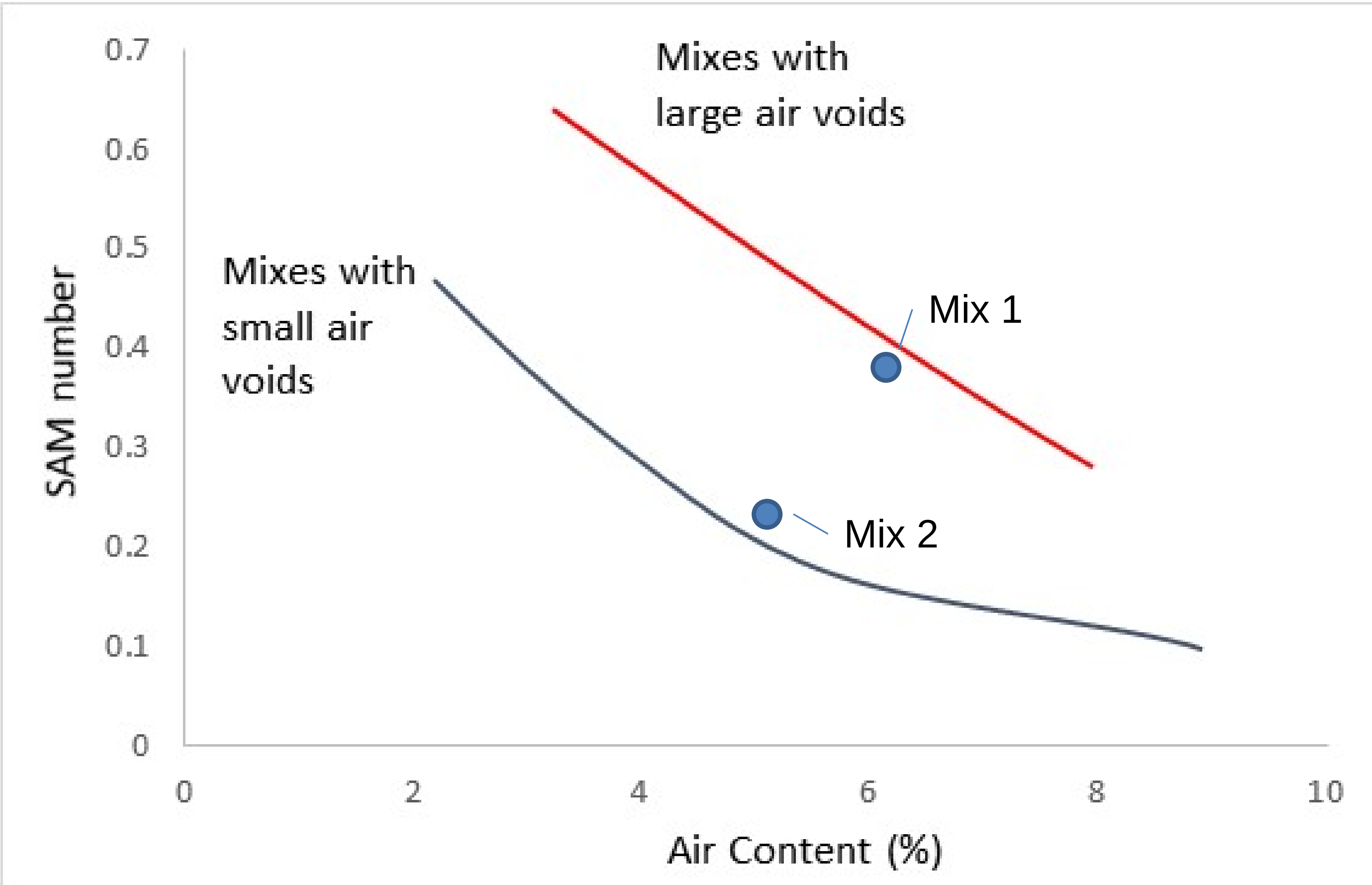
How do I do this?



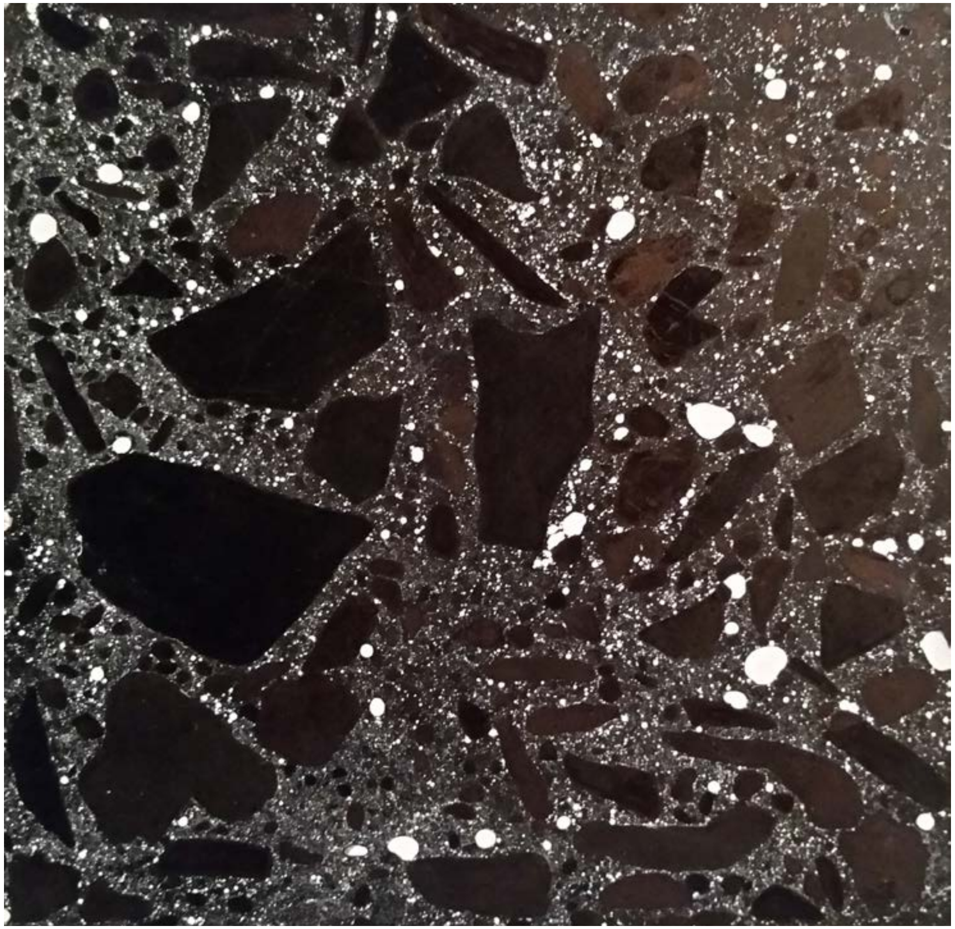
An example

- Mix 1 - SAM number of 0.40 and an air content of 6%

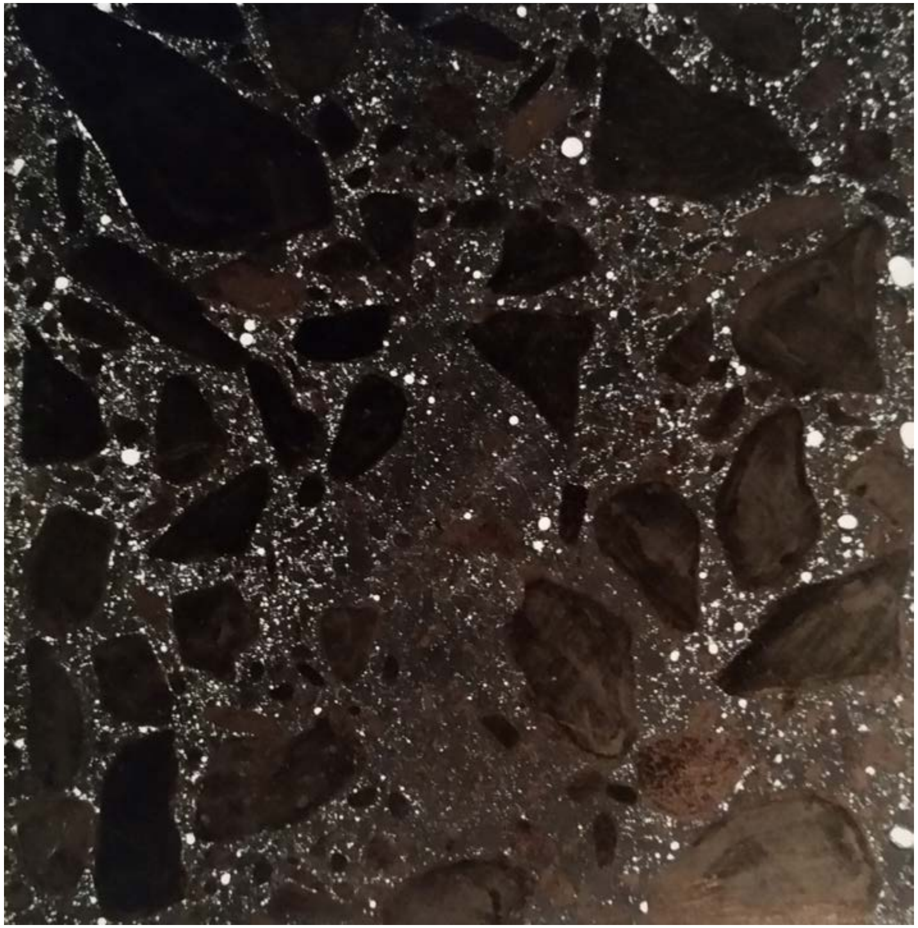
- Mix 2 - SAM number of 0.22 and an air content of 5%



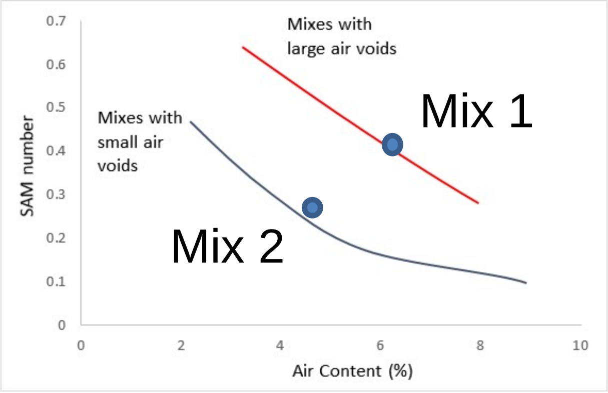
Mixes with
large air voids
Mixes with
small air
voids
Mix 1
Mix 2
SAM number
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
Air Content (%)



Mix 1 – large air voids

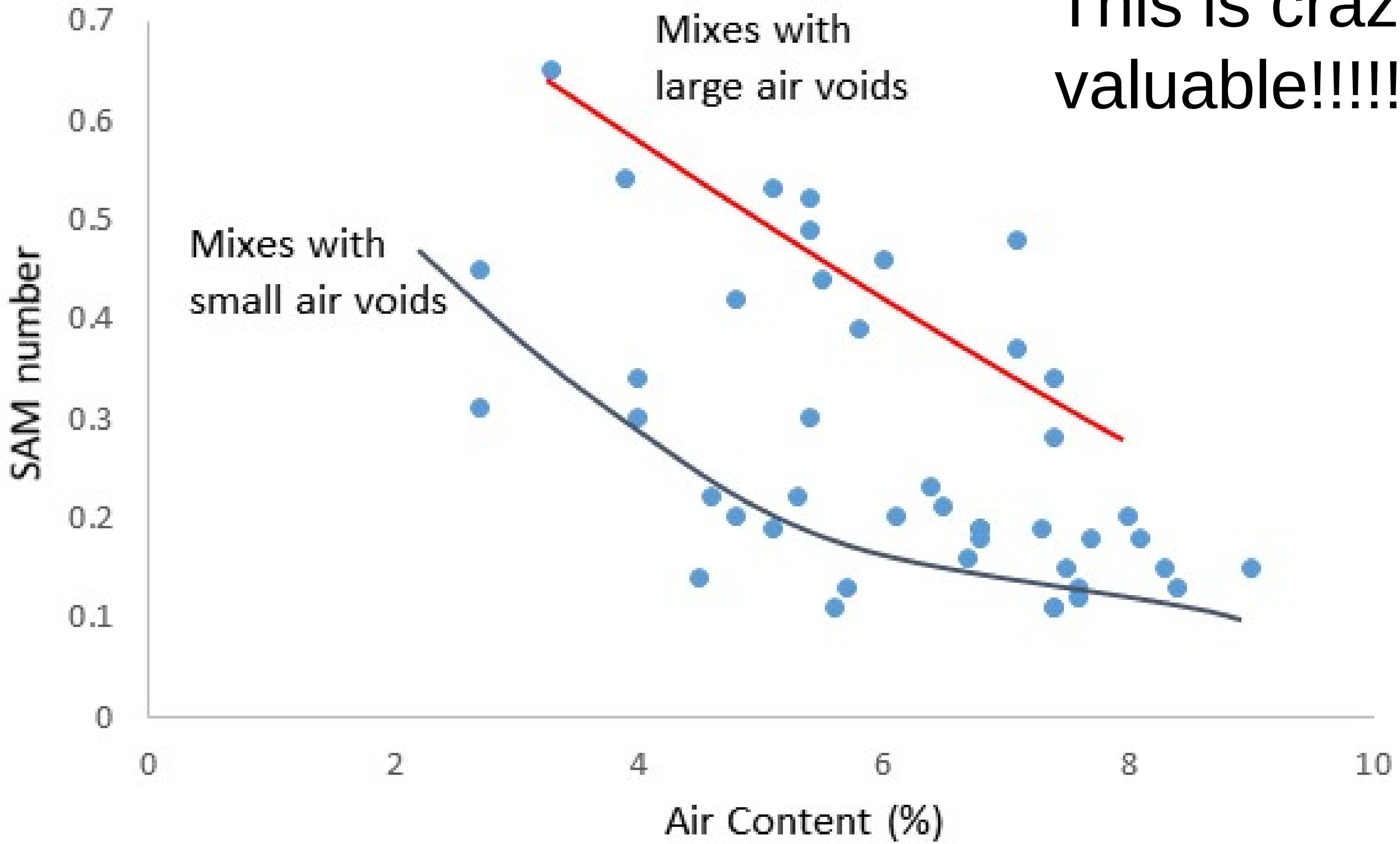


Mix 2 – small air voids



PennDOT

This is crazy valuable!!!!!!



Discussion

- By plotting your data on the SAM Curve you can immediately tell if your air void system is made of large or small bubbles.

- This immediate feedback can be used to troubleshoot field issues and determine what is causing your air problems.

How do I improve my SAM Number?

- Increase the air content in a mixture.
- Redesign your concrete mixture with special attention to your mixture ingredients.
- Carefully examine your construction process

Challenges with the SAM

- The SAM looks like a normal air meter but it is more complicated.
- You must ensure the concrete is properly consolidated and the meter does not leak!
- Some users require specialized training.

How variable is the method?

- We have done multiple operator comparison of mixtures at OSU with four operators and in Chicago with up to six operators.

Test Method	Parameter	COV	Time to complete the test
SAM	SAM Number[1]	15.2%	10 min
ASTM C457	Spacing Factor[2]	20.1%	7 days
ASTM C666	Durability Factor[3]	22.7%	3.5 months

[1]Assumes a SAM Number of 0.32 and a standard deviation of 0.049

[2]From ASTM C457

[3]From ASTM C666 with a durability factor of 75 and Method B

SAM Results based on 170 different mixtures.

Discussion

- The variability of SAM is similar to the variability in the hardened air void analysis and rapid freeze thaw testing
- The results from the SAM correlate with rapid freeze thaw and spacing factor
- The SAM can be run in the field on fresh concrete in less than 10 min.

Discussion

- I don't think it is a coincidence that the variability is so similar between the three different methods.

- Each test is designed to investigate the air void distribution. Air void distribution may be more variable than other concrete properties such as compressive strength.

The following states have a SAM

- Michigan (11)
- Kansas (16)
- Utah (2)
- Colorado (2)
- Iowa (2)
- Illinois (5)
- Indiana (2)
- Wisconsin (10)
- Massachusetts
- Idaho (2)
- Tennessee (2)
- Arizona
- Georgia

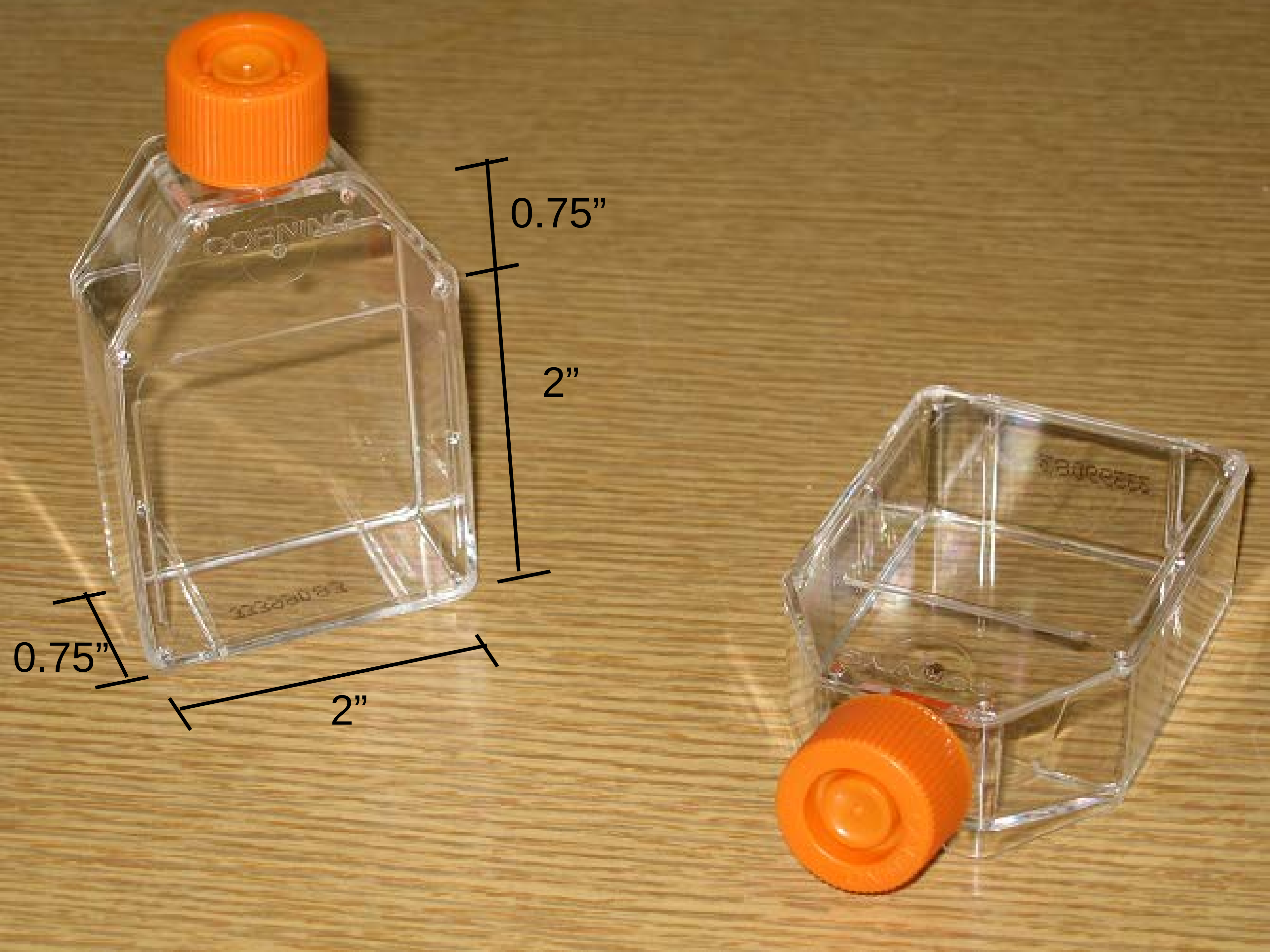
- Pennsylvania (4)
- Missouri (2)
- California
- N. Carolina (3)
- N. Dakota
- Oklahoma (19)
- Nebraska (3)
- Ohio (5)
- Minnesota (7)
- Texas (2)
- Vermont
- FHWA (6)

- New Jersey
- New Mexico
- New York (13)
- S. Dakota
- Mississippi
- Iowa (2)
- Oregon
- Manitoba (5)
- Ontario (2)
- England
- Poland (3)
- Germany

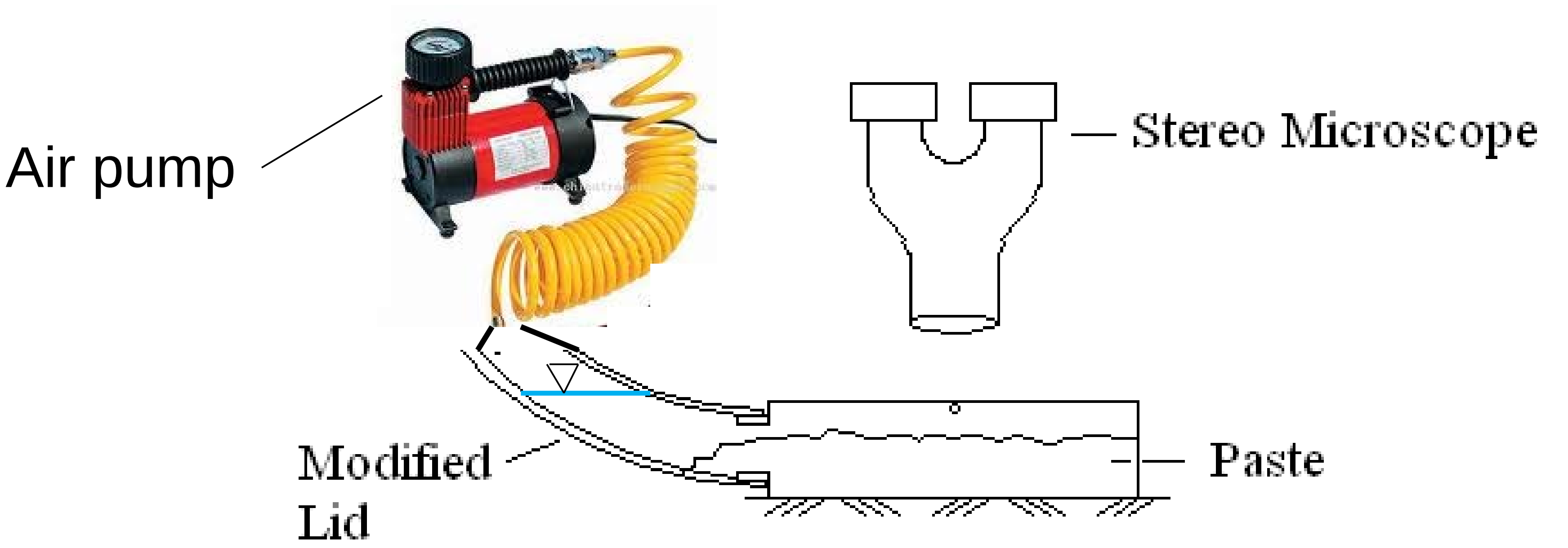
How can this group help?

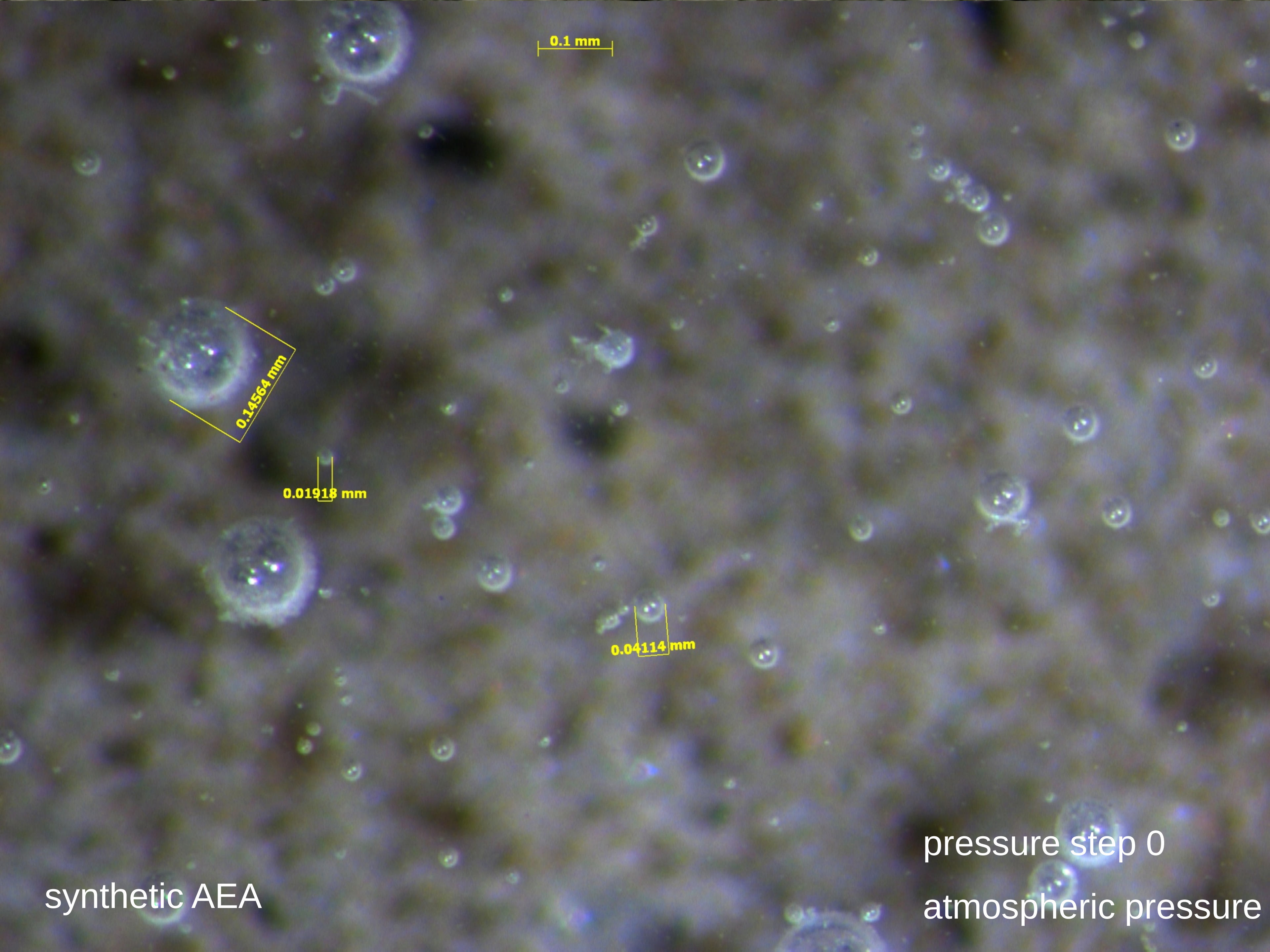
- Taking the industry from a horse and buggy to an internal combustion engine is not easy.
- Ask questions!
- Share what you learn here with others
- Help others become experts with the SAM

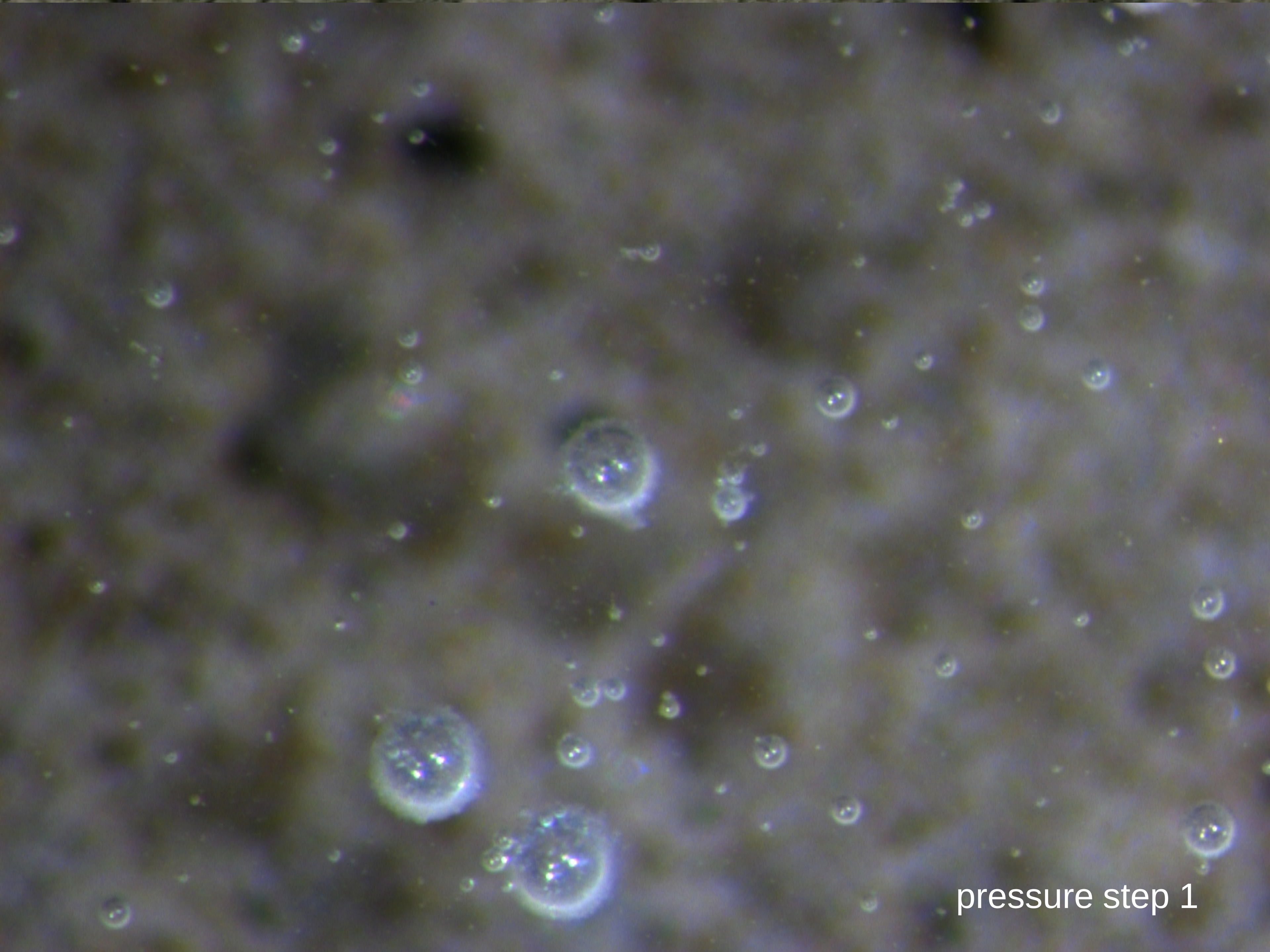
How does the SAM work?

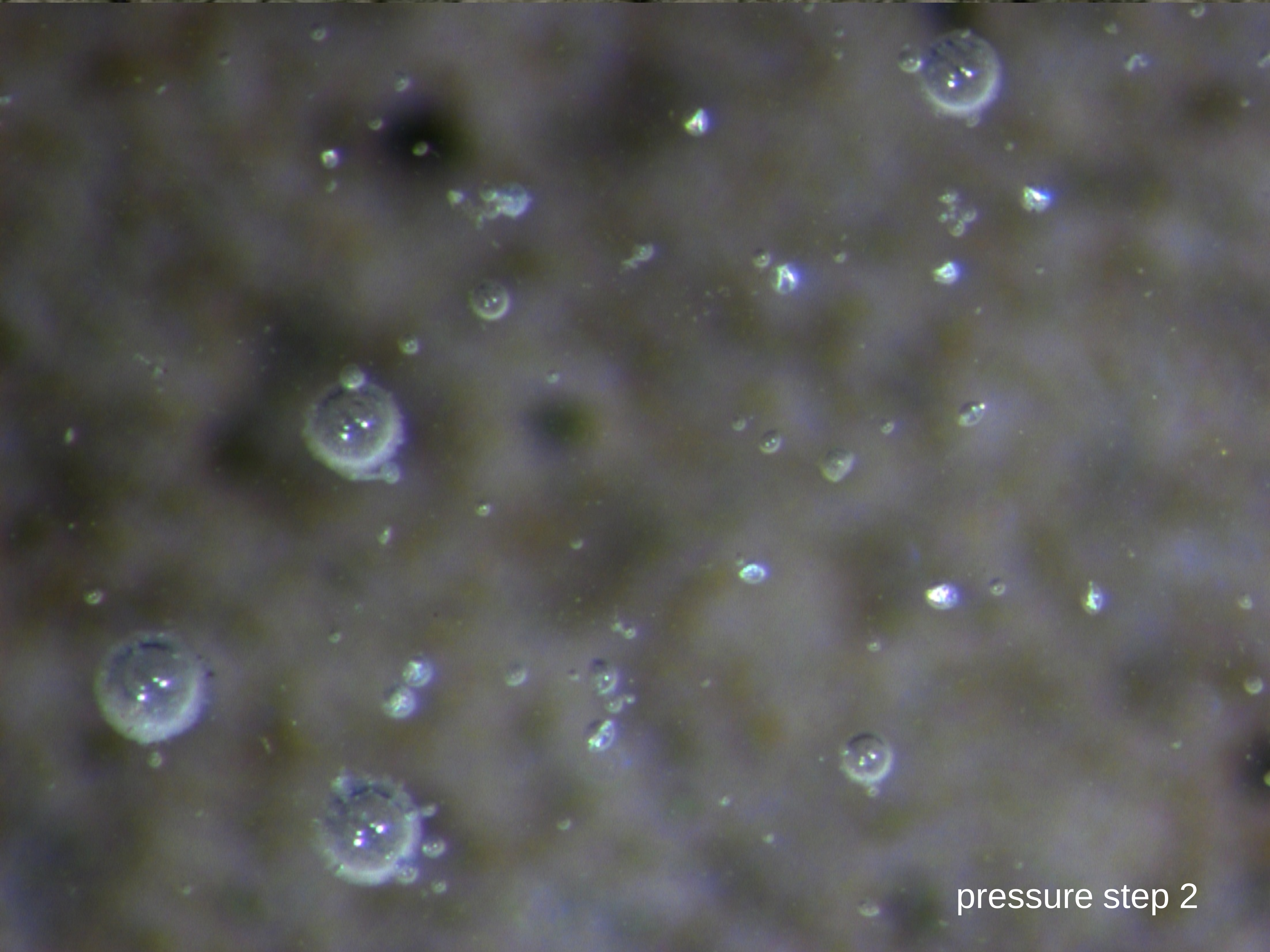

0.75”
2”
0.75”
2”

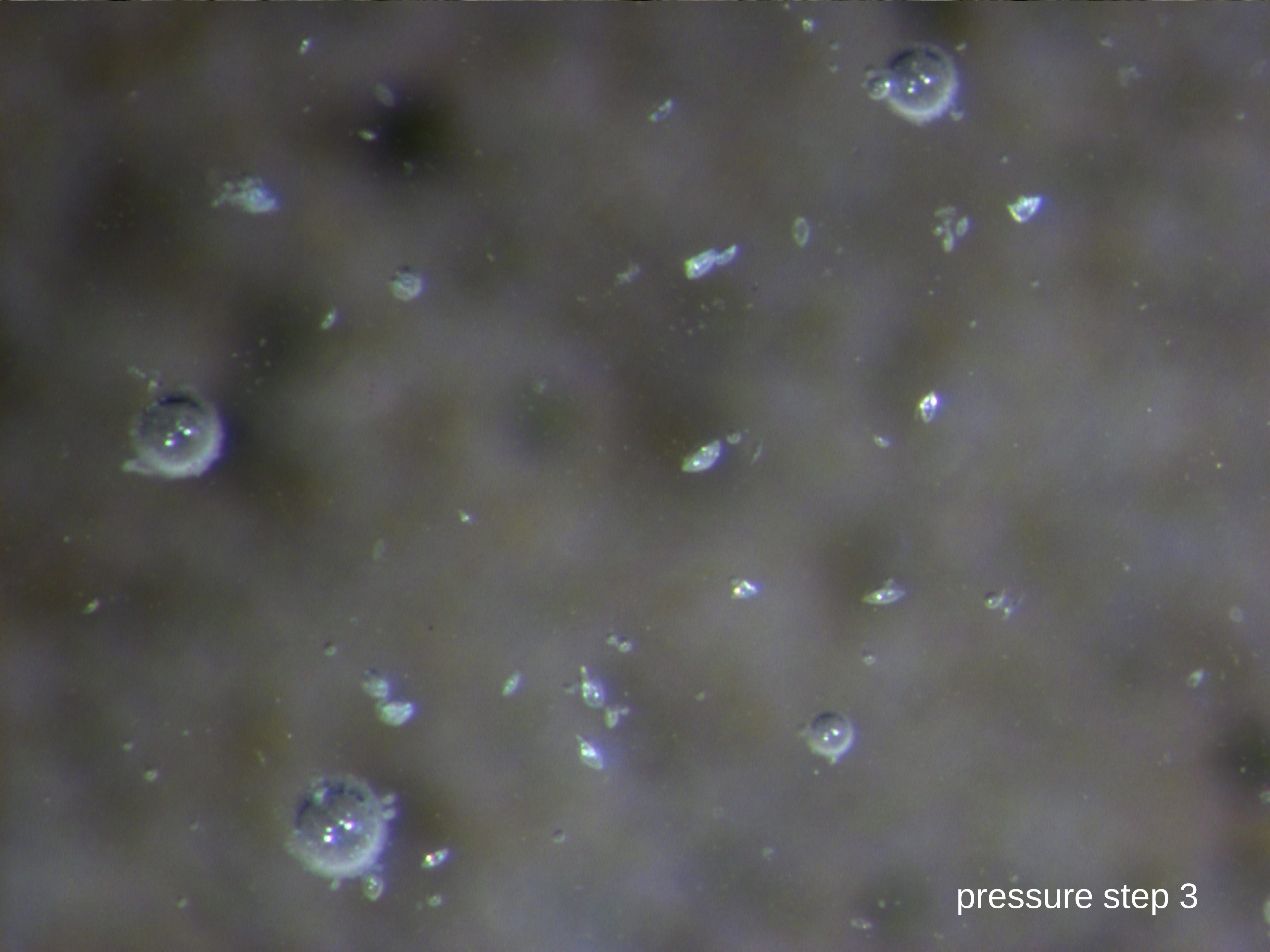

CORNING

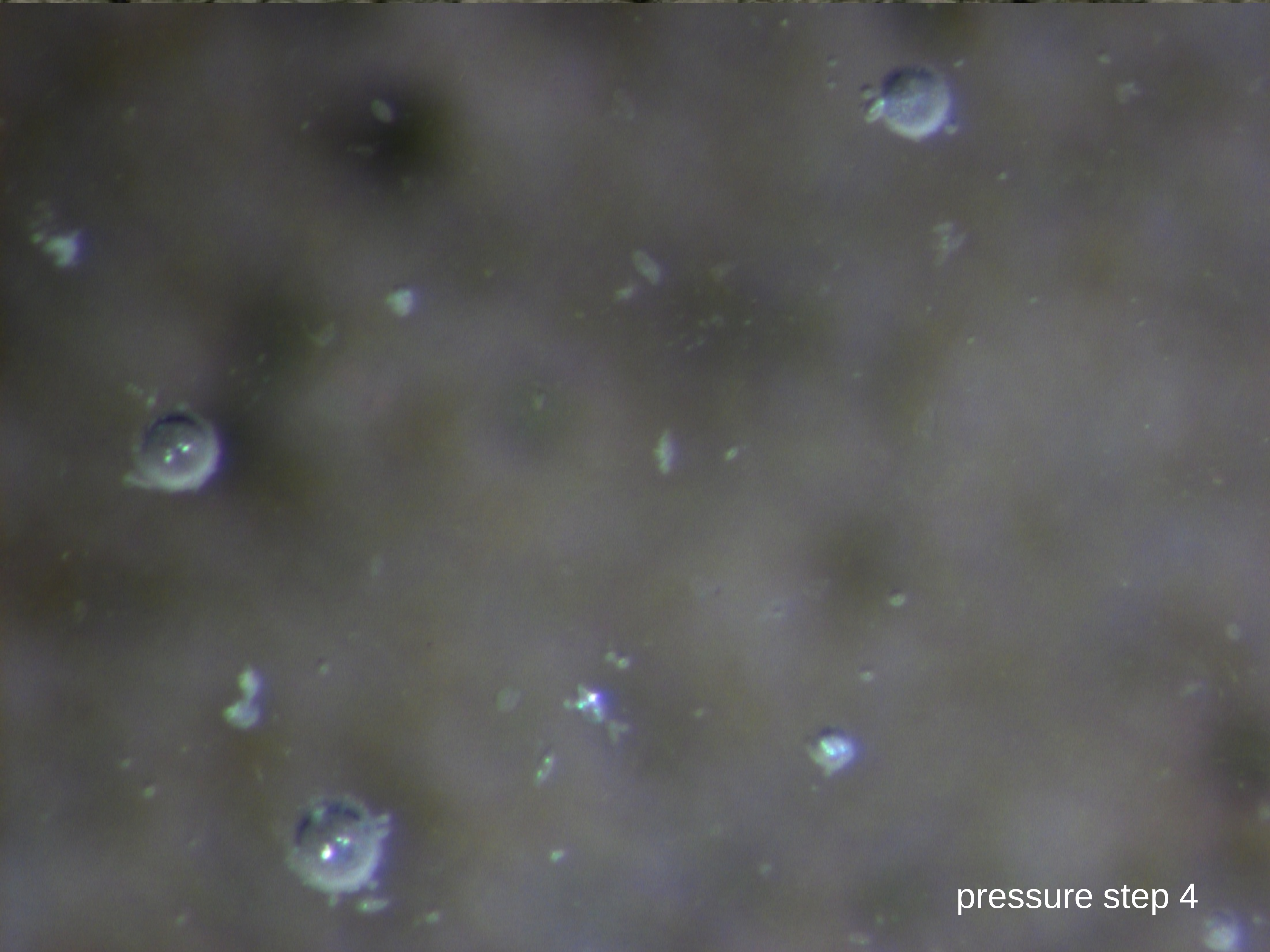

Air pump
Stereo Microscope
Modified
Lid
Paste

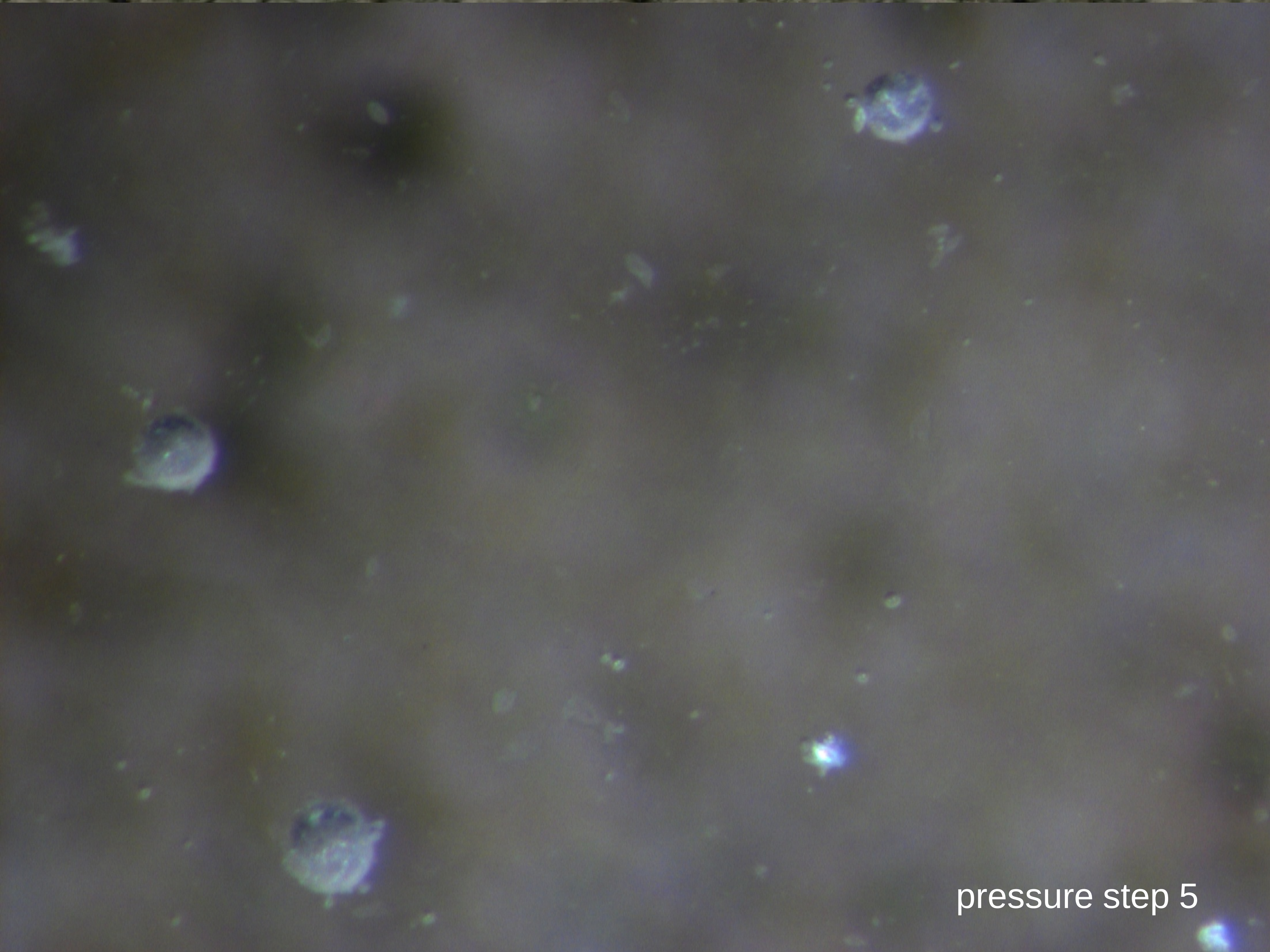

0.1 mm
0.14564 mm
0.01918 mm
0.04114 mm
pressure step 0
atmospheric pressure
synthetic AEA

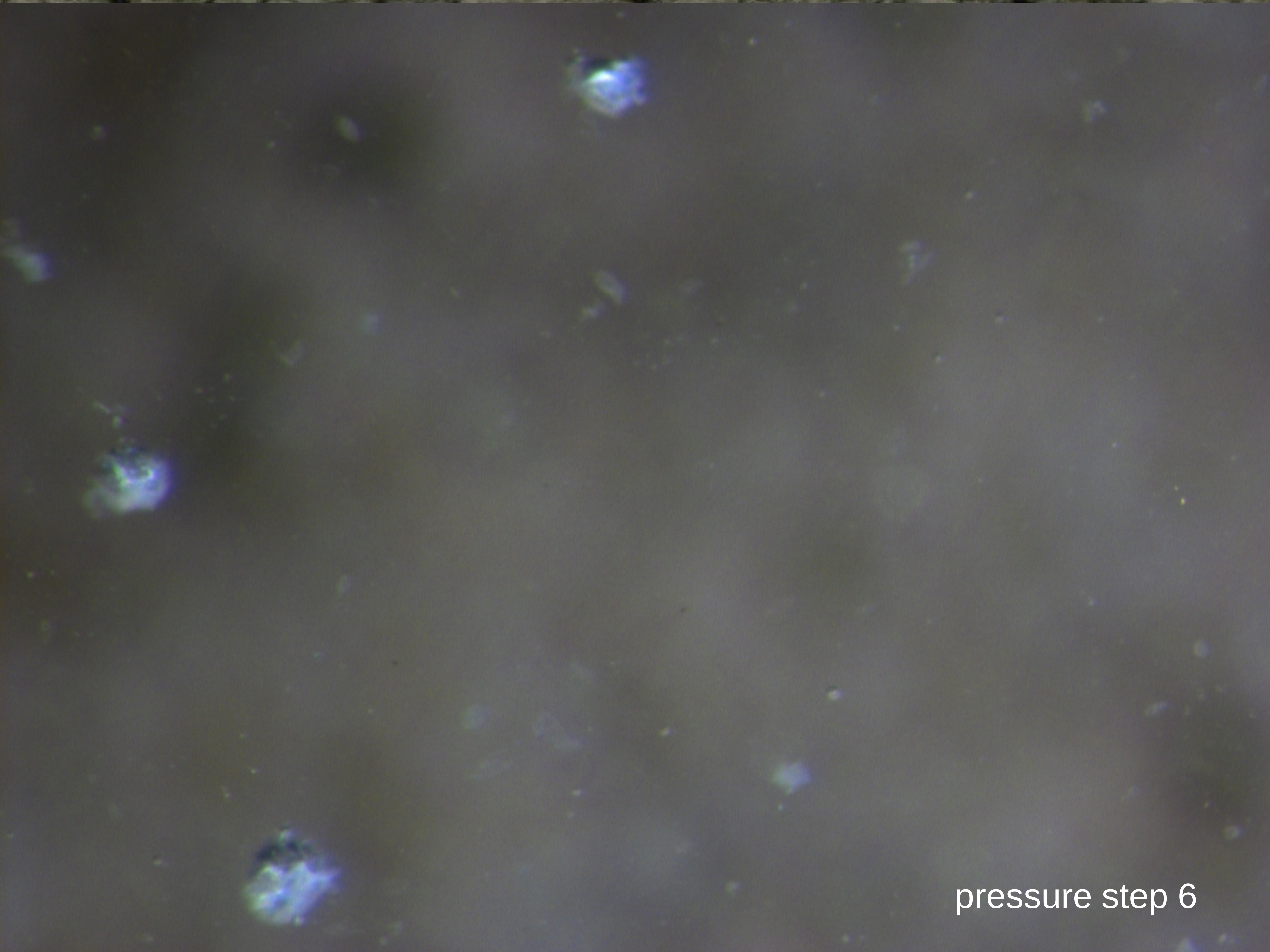

pressure step 1

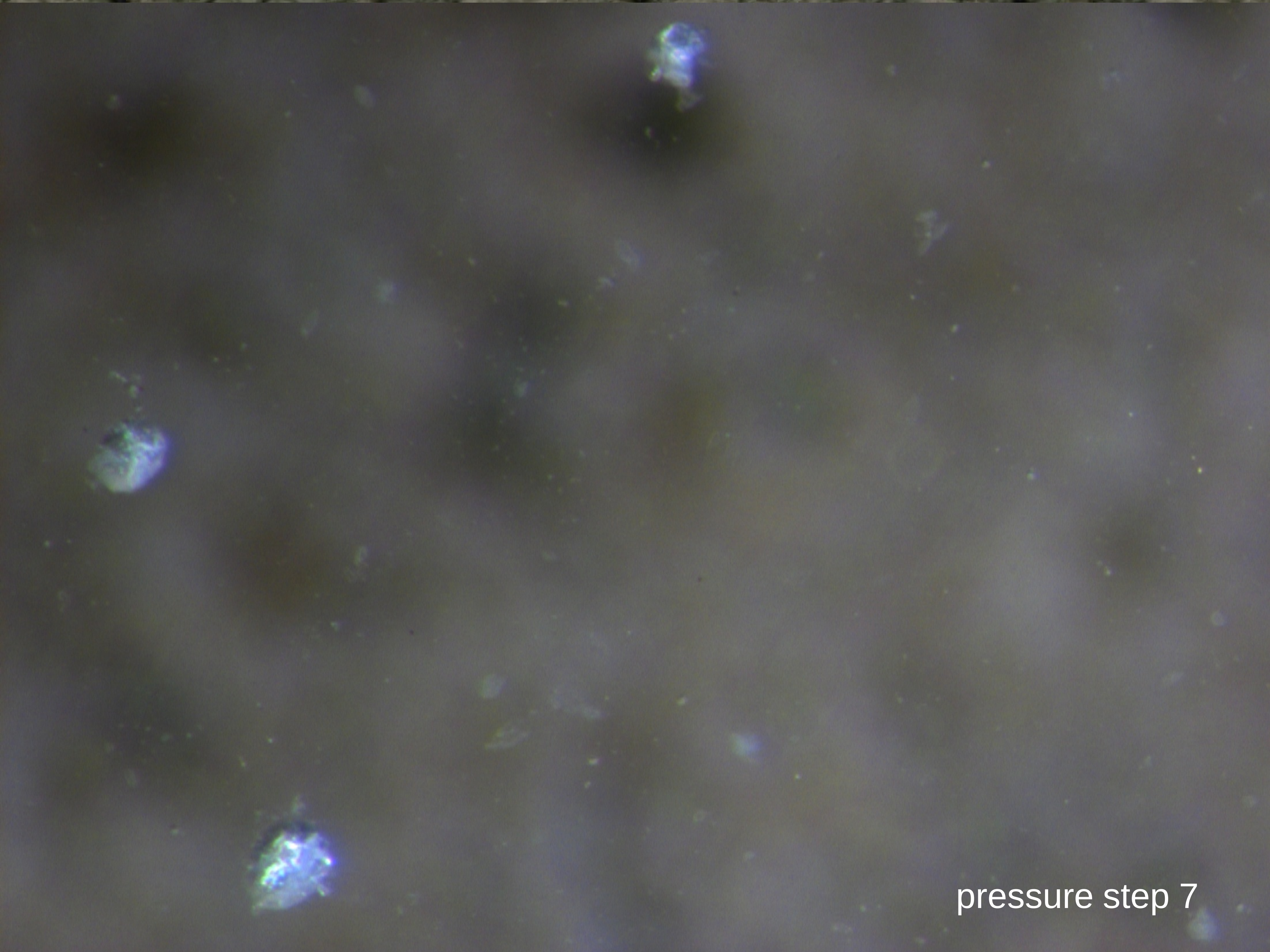

pressure step 2

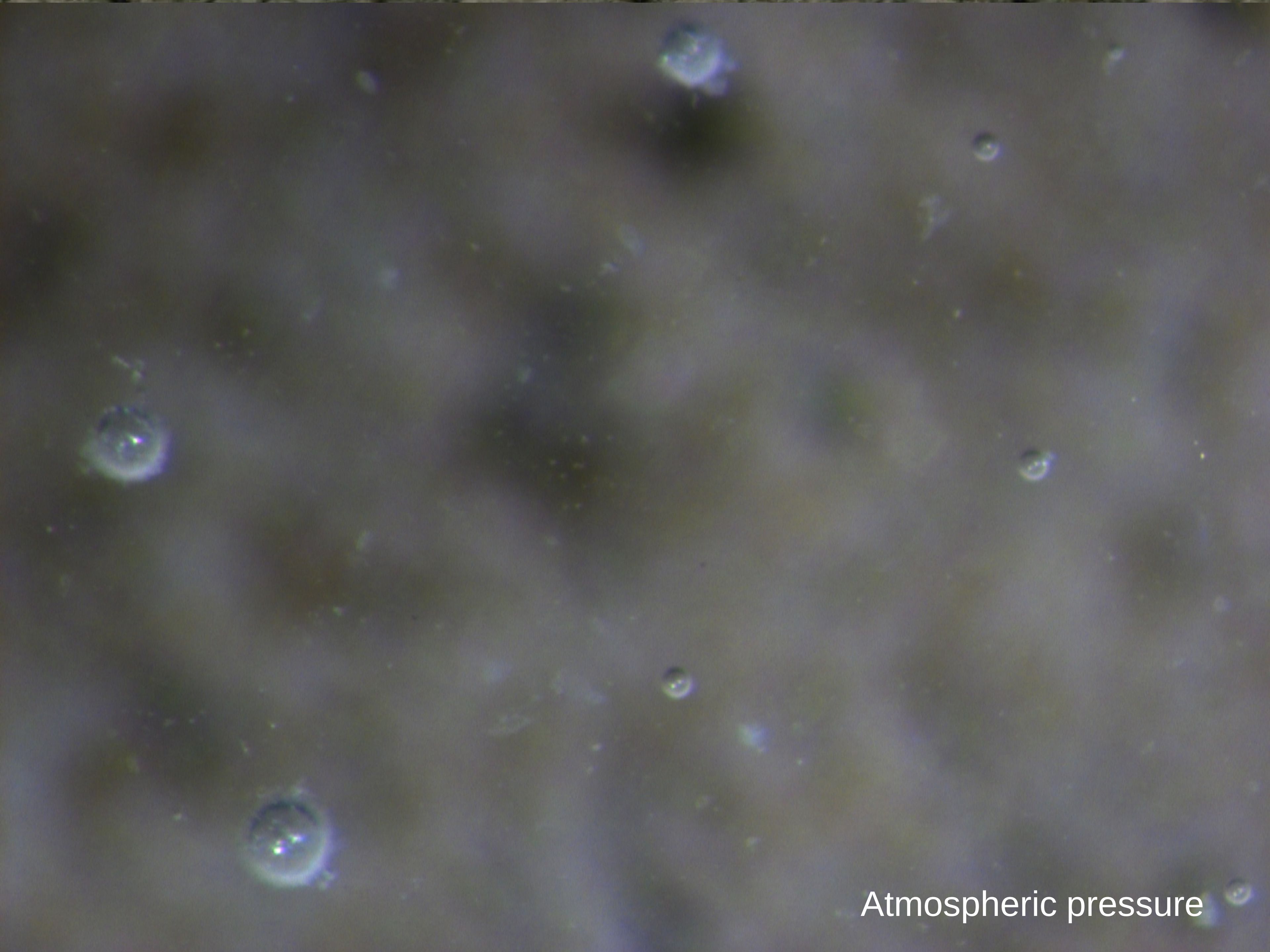

pressure step 3

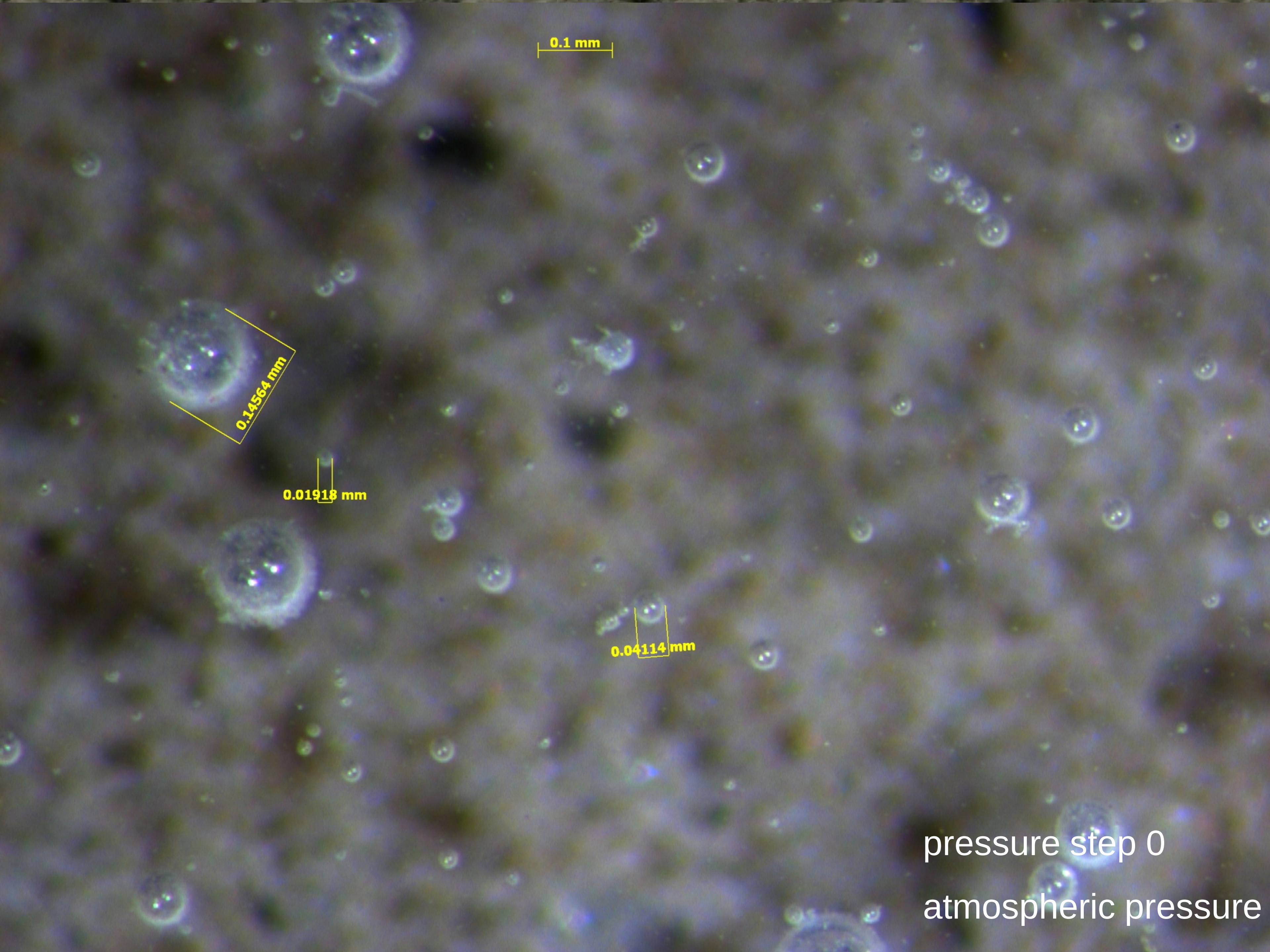

pressure step 4


pressure step 5


pressure step 6


pressure step 7


Atmospheric pressure


0.1 mm
0.14564 mm
0.01918 mm
0.04114 mm
pressure step 0
atmospheric pressure

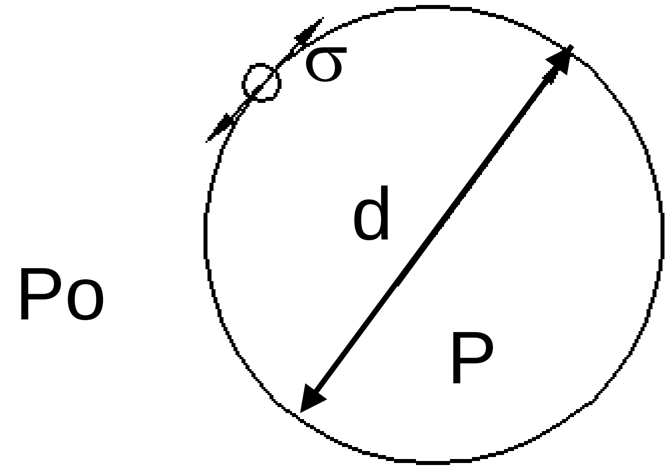
What is happening?

- As the pressure increases the small bubbles dissolve into the surrounding solution
- These bubbles do not immediately come back when you decrease the pressure.
- *Notice that the bubbles in this experiment are not close to one another.*

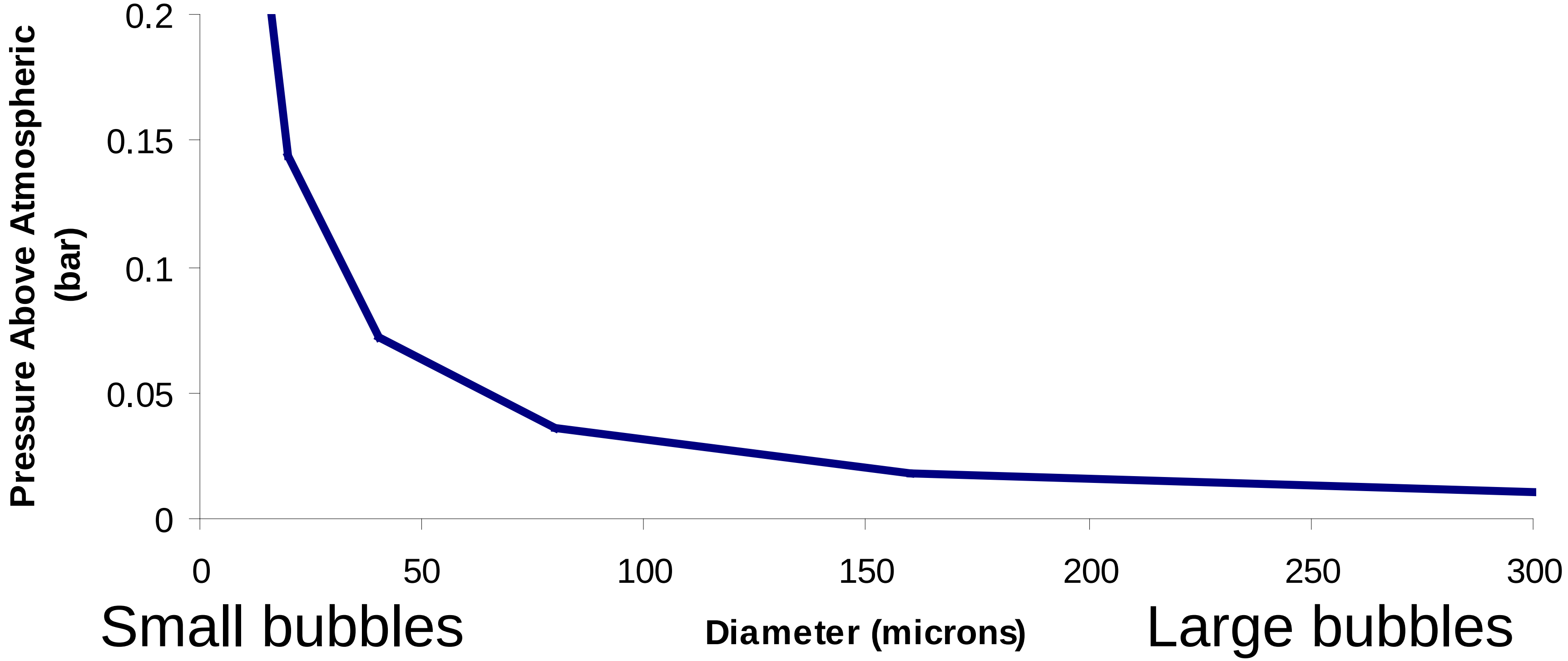
Why is this happening?

- According to the Laplace – Young equation smaller bubbles have higher internal pressures than larger bubbles

$$P = Po + 4\sigma/d$$



- This is caused by the differences in curvature of the bubble wall



Small bubbles

Large bubbles

Assumes σ = 72 dynes/cm

Atmospheric pressure

Why do the bubbles dissolve?

- Henry's Law states that at a given pressure that a certain amount of the gas will dissolve in the liquid

$$p = k_H c$$

p = pressure

c = concentration

k_H = Henry's Law constant

Why do the bubbles dissolve?

- As you increase the pressure air will dissolve in the surrounding solution

- Because the smaller bubbles are at a higher pressure they dissolve before the larger bubbles

More pressure experiments

- We ran additional experiments where we tracked individual bubbles every 5 psi from atmospheric until 35 psi.

- We looked at two different situations:
  1. High spacing factor (bubbles far apart)
  2. Low spacing factor (bubbles close together)

High spacing factor

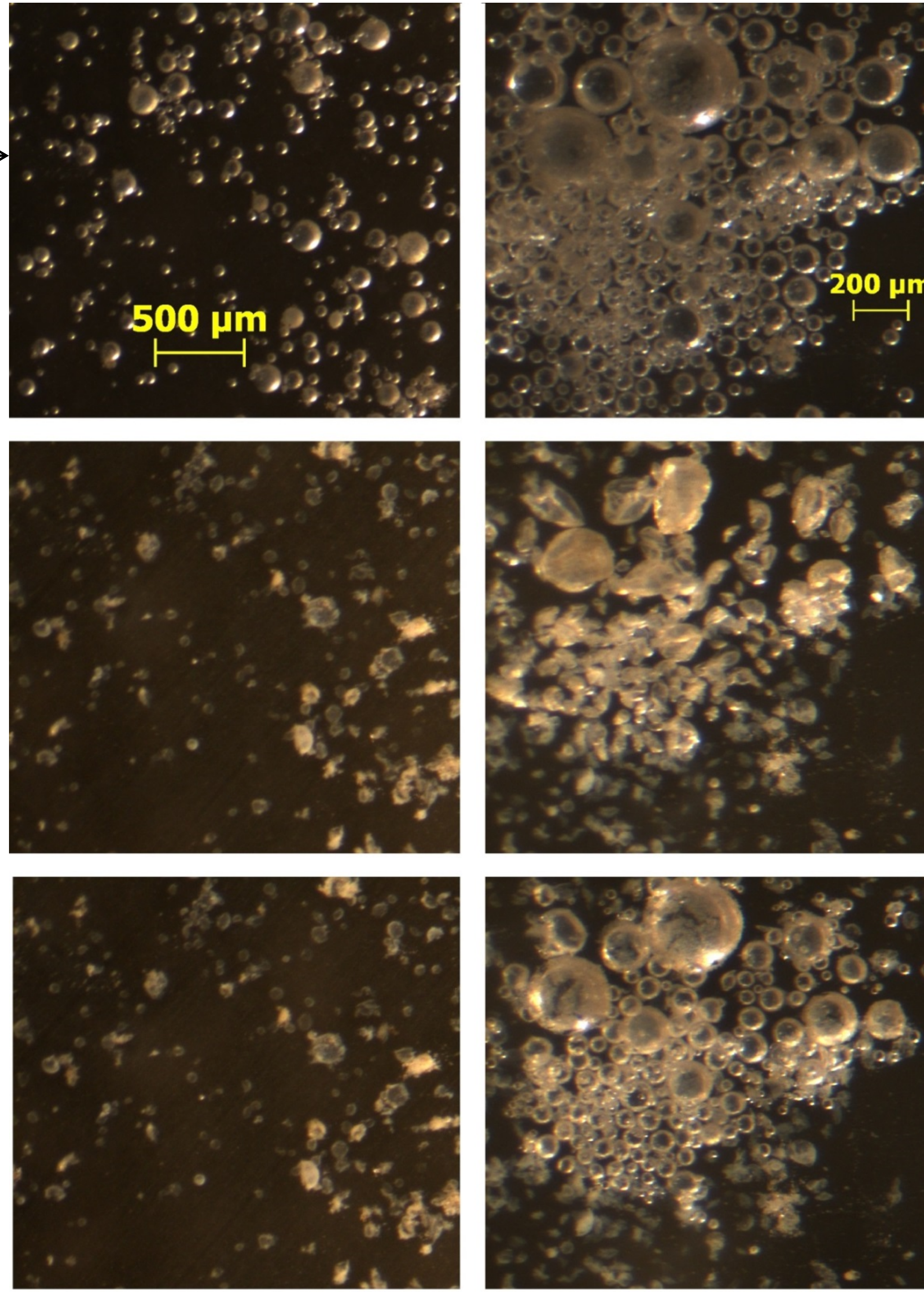
Low spacing factor

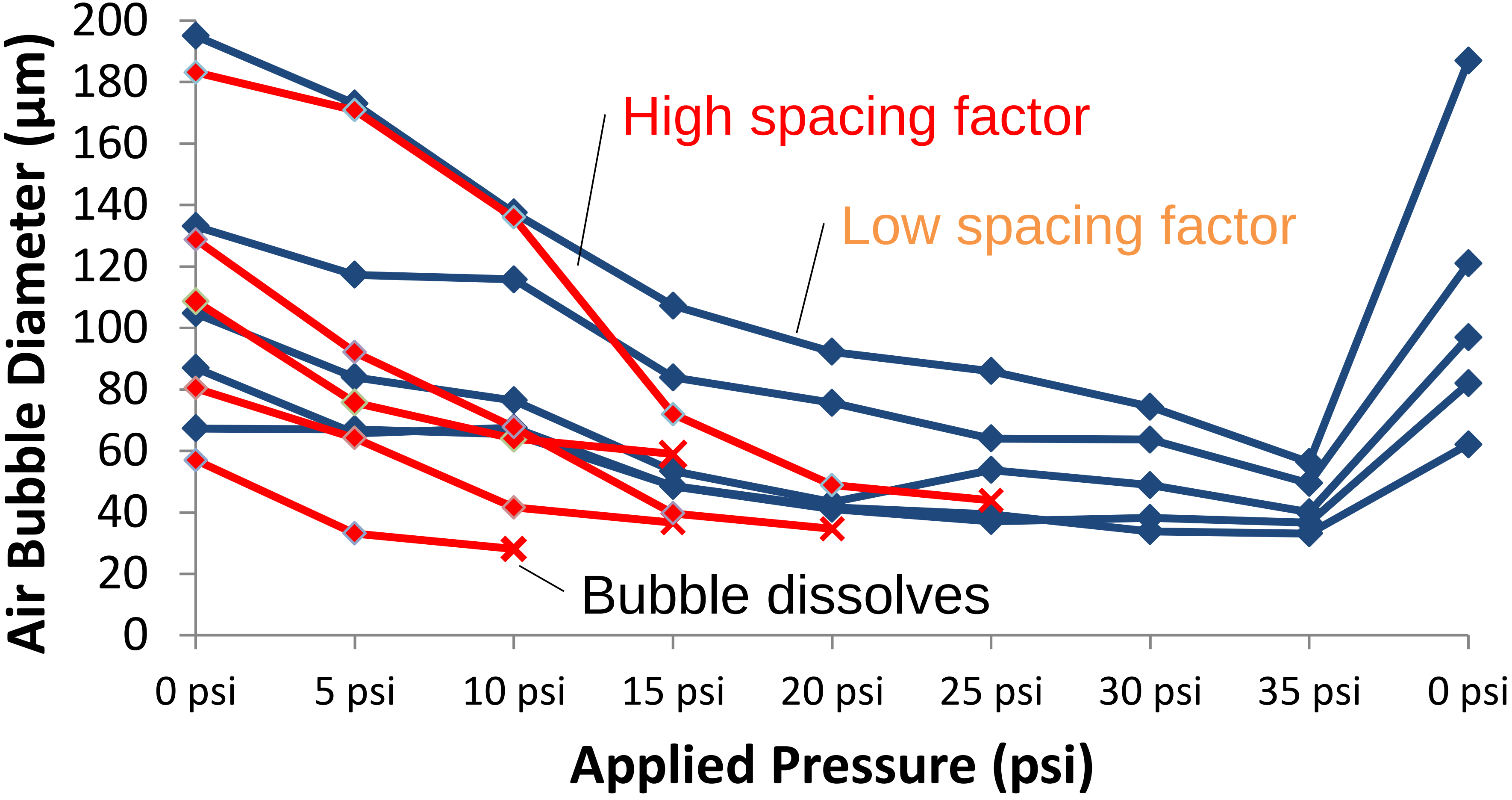
Atmospheric Pressure

35 psi

other pressures not shown

Returned to Atmospheric Pressure





Air Bubble Diameter (µm)
200
180
160
140
120
100
80
60
40
20
0
High spacing factor
Low spacing factor
Bubble dissolves
0 psi
5 psi
10 psi
15 psi
20 psi
25 psi
30 psi
35 psi
0 psi
Applied Pressure (psi)

Results

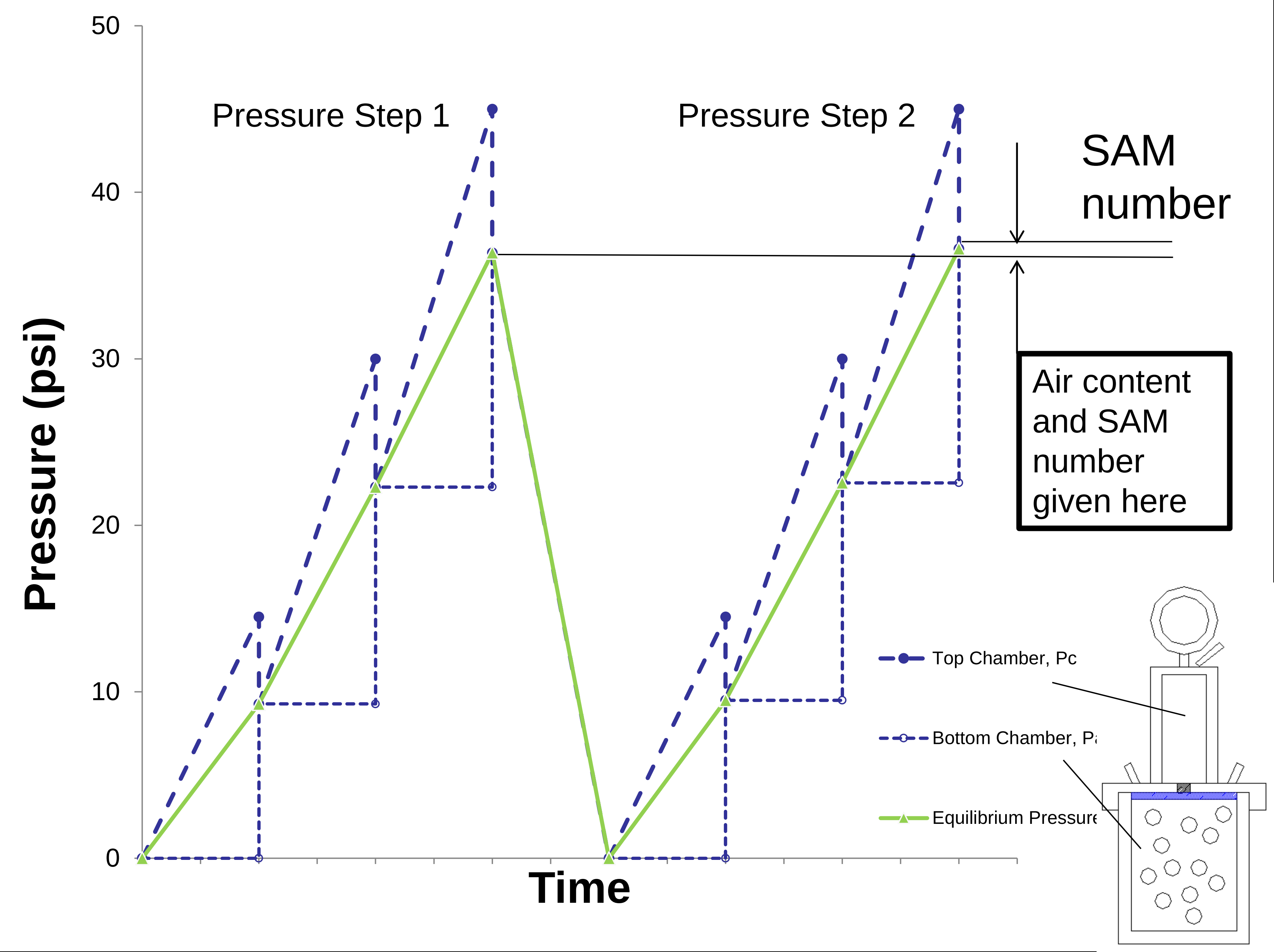
- The bubbles in the high spacing factor system (bubbles far apart) almost entirely dissolve and do not come back.
- The bubbles in the low spacing factor system (bubbles close together) do not dissolve as much.

Why does this happen?

- As bubbles dissolve they increase the local concentration of dissolved air.
- Closely spaced bubbles will cause a localized saturation of air. This will cause the bubbles to no longer dissolve in the solution from increased pressures.

Why does this happen?

- If bubbles are far apart then there will be no localized saturation and the bubbles will continue to dissolve with increases in fluid pressure.



50
40
30
20
10
0
Pressure (psi)
Time
Pressure Step 1
Pressure Step 2
SAM number
Air content and SAM number given here
Top Chamber, Pc
Bottom Chamber, Pa
Equilibrium Pressure

How is this useful???

- If you have a high spacing factor (bubbles far apart) then pressure step 1 will cause the bubbles to dissolve
- When we apply pressure step 2 there will be a large difference in how the concrete responds to pressure.
- This will cause a high SAM number.

How is this useful???

- If you have a low spacing factor (bubbles close together) then pressure step 1 will not dissolve many bubbles
- When we apply pressure step 2 there will be a small difference between the two pressure curves.
- This will cause a low SAM number.

Results

- After learning this we did hundreds of mixtures to develop the SAM Number and how it correlates to the spacing factor and freeze thaw durability of the concrete.

We need your help!

- Making changes in our industry is not easy and often takes a long time.
- A journey of a million miles begins with a single step.
- Please try the SAM!
- Share what you learn here with others
- Help others become knowledgeable about the SAM

Conclusion

- Large bubbles are the enemy!
- Air volume does not tell you bubble size.
- The SAM can measure the volume and size distribution of the bubbles in fresh concrete
- This is helpful for making your air more consistent and ensure freeze thaw durability

Conclusion

- A SAM Number of 0.20 seems to correspond to a spacing factor of 0.008” and performance in the ASTM C666 testing
- The SAM has been investigated on a wide range of concrete mixtures by many groups and similar correlations were found

Questions???

Tyler.ley@okstate.edu

www.tylerley.com

www.superairmeter.com

Home-Grown Tundra Tape Electric Resistive Deicing Technology

Presented at Alaska Concrete Summit

Zhaohui Joey Yang
Professor
University of Alaska Anchorage

December 20, 2017

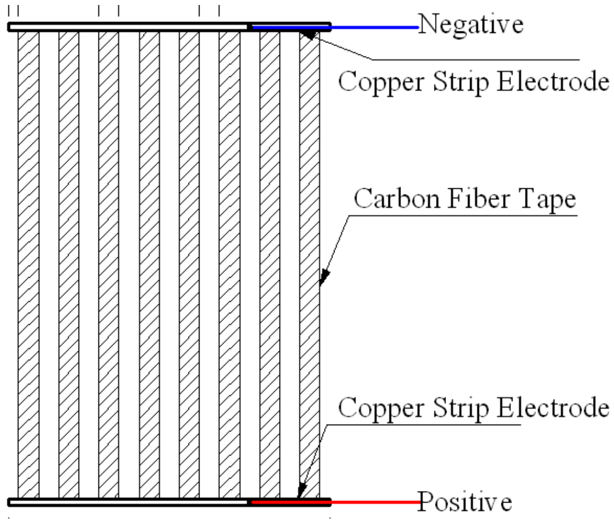
Outline

- **Overview**
- **How it works?**
- **Testing and field applications**
- **Comparison with available technology**
- **Identified issues**
- **New development**

Overview

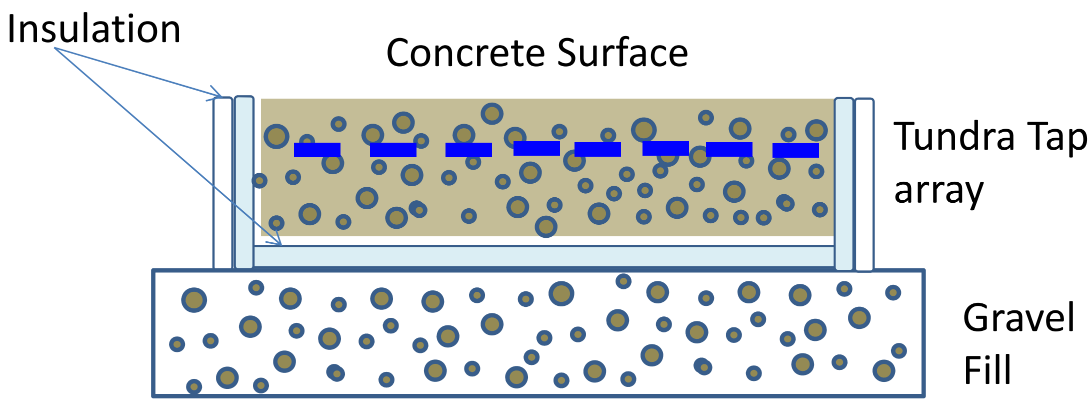
- Amazing mechanical and electrical properties of carbon fiber
- High tensile strength to weight ratio, strong resistance to corrosion and fatigue, and high thermal and electrical conductivity
- Connect carbon fiber tape in parallel and/or series circuit with bus bars and excite it with voltage to provide very uniform heating

Carbon Fiber Tape



How it works?

- Embed tundra tapes in concrete slab with insulation
- Power supply: 120/240V AC or renewable energy sources
- Automatic control w/ surface temp. and moisture, or smart control with additional weather forecast info



Field Experiments






Winter of 2010-2011

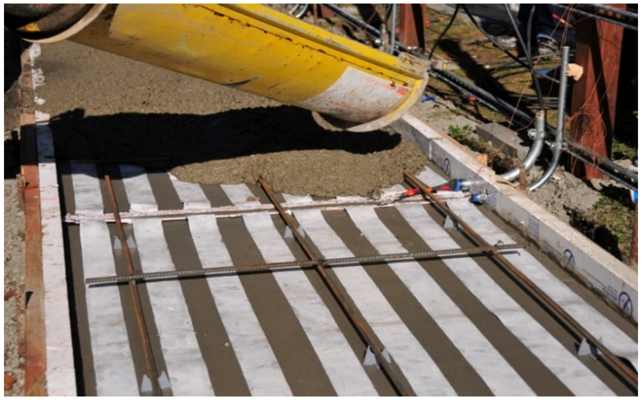
Field Experiments

- Performed very successfully during the record-setting winter of 2011-12 in Anchorage (~130" of snow)

Comparison with Existing Technologies

- **Installation Similar or easier**

Tundra Tape

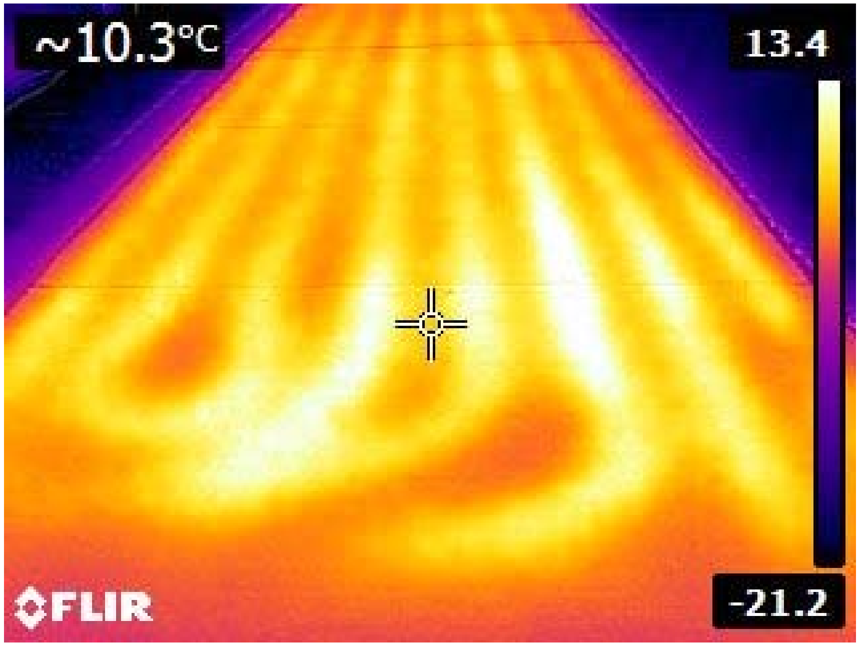


Hydronic

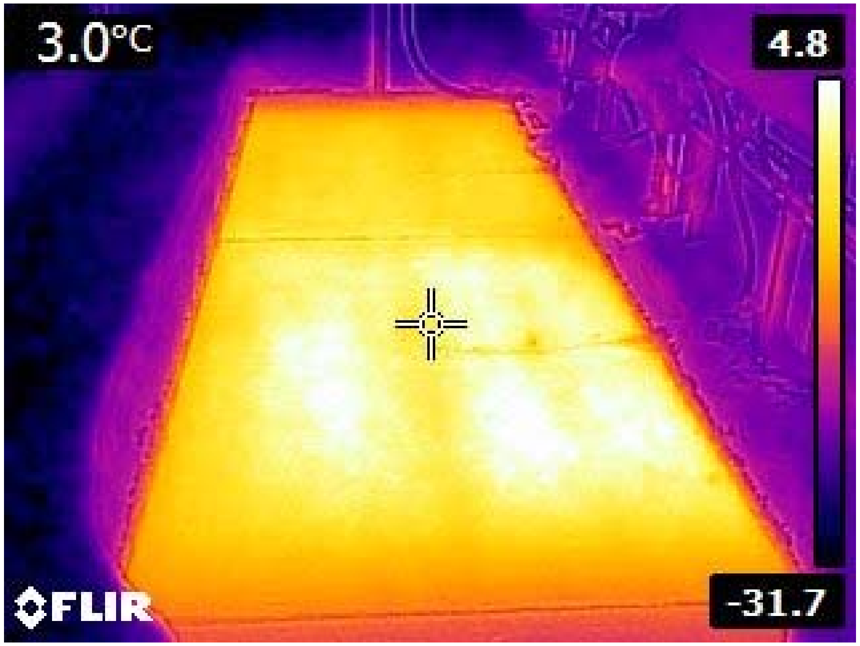
Heat Trace

Comparison with Existing Technologies

- IR Images revealing much more uniform energy delivery
- Much less thermal stress impact to concrete



Hydronic



Tundra Tape

Highlights of Tundra Tape

- **Easy to** install and automate
- **Versatile –** easily customized for flat or curved surface
- **Reliable and durable w/ minimal maintenance** - No moving parts in the ground
- **Efficient** - about $1/ft^2 per yr in Anchorage ($0.1/kW-h)
- **Great scalability –** a small entrance, a few slabs, or a large area
- **Environment friendly** – minimal thermal impact to concrete; no risk of heating fluid leakage; powered by renewable energy sources

Specifications

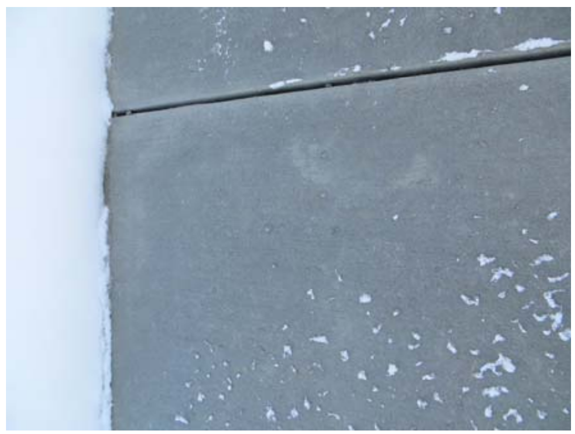
- Tundra tape: typically 3” wide
- Heating panel sizes: variable from 4’x6’ to 10’x10’
- Tunda Tape temperature: not exceeding 70^{o}F
- Power density: Approx. 100-140 BTU/hr or 30-40 Watts per SF
- Operating @ low voltage (24-32 V) or 120V AC

Milestones

- **Pilot testing – 2010**
- **Patent filing – 2012**
- **Start-up CFT Solutions LLC – 2013**
- **1st field installation, UL and MOA inspection – 2013**
- **AAF Investment and Formation of AHT – June 2017**
- **UL Listing Initiated – Sept. 2017**
- **Patent issuance by USPTO (#61/699,372) – Nov. 2017**

Building Pathway Installation

Freezing Rain

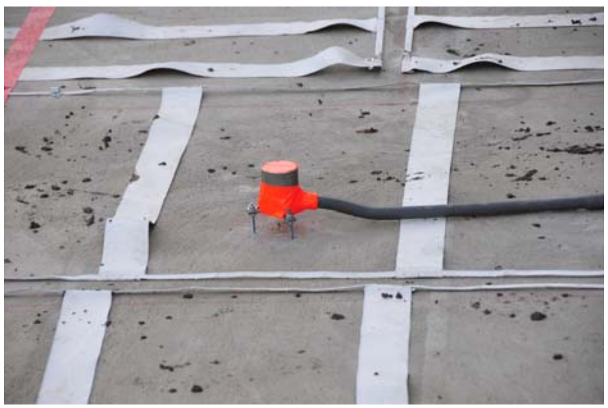


Dry snow

Wet snow

Building Entrance Installation

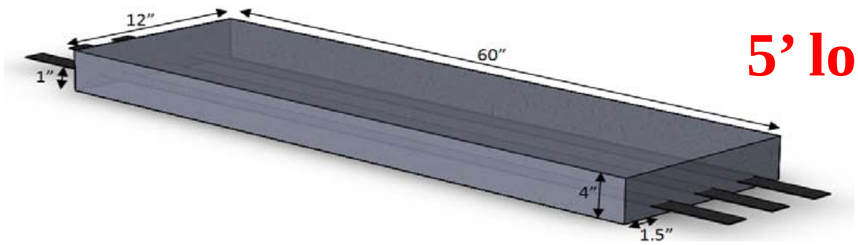


Application Issues

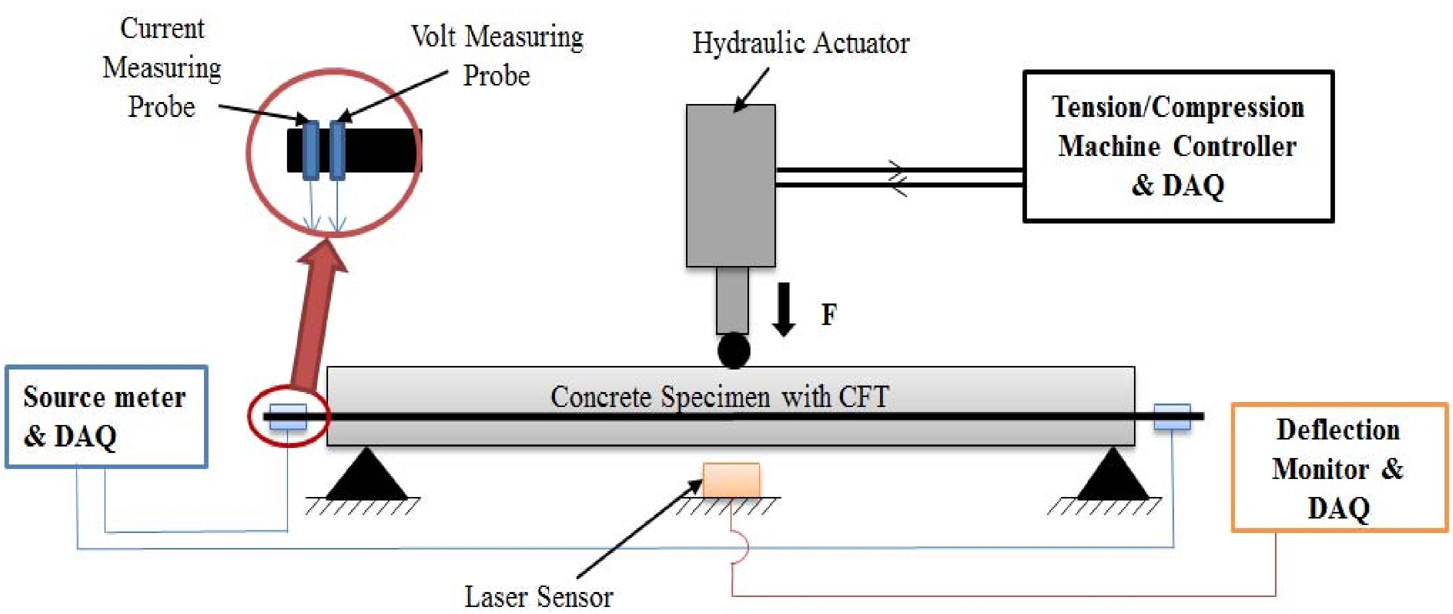
- **Higher cost of electricity than gas for the same BTU**
  - **More than made up by the efficient delivery of heat to the surface and reduced maintenance cost**
- **Large wire size due to large current at low operating voltage**
  - **New product using 110 V AC**
- **Survivability to concrete cracking**
- **Corrosion of rebar due to induced current**

Survivability of Concrete Cracking



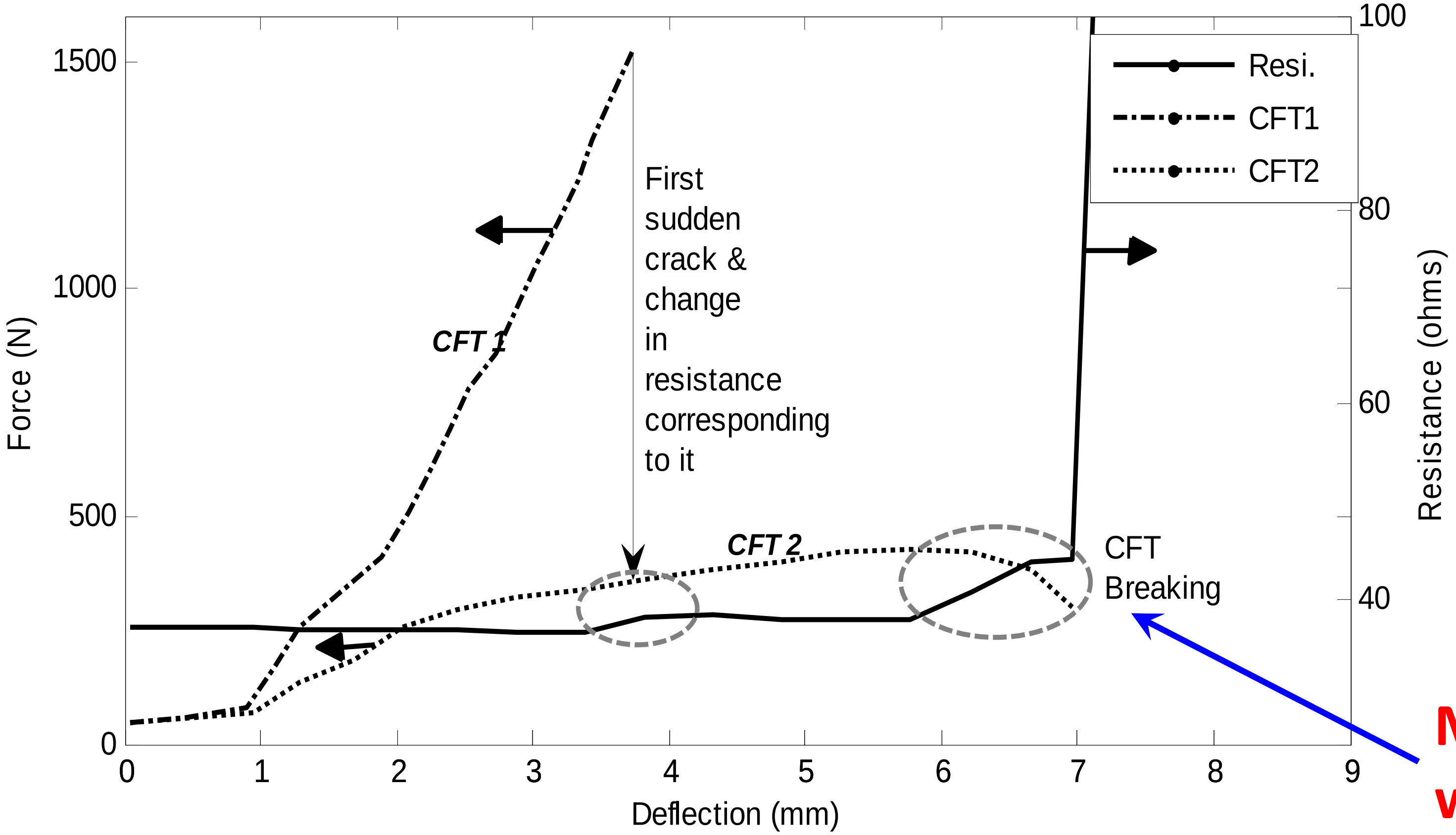
5' long x1' wide x 4" thick slab

Test setup



Survivability of Concrete Cracking

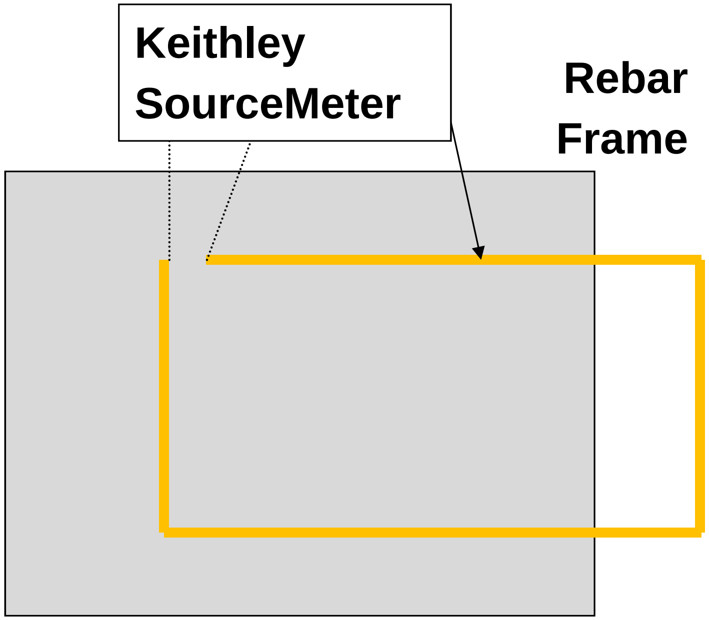
Survivability of Concrete Cracking



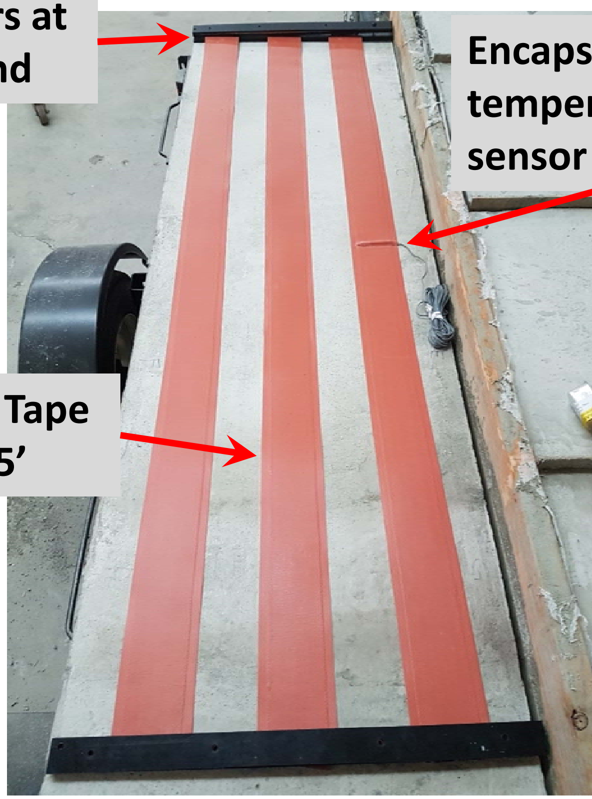
Max. crack width = ¼"

Rebar Corrosion by Induced Current

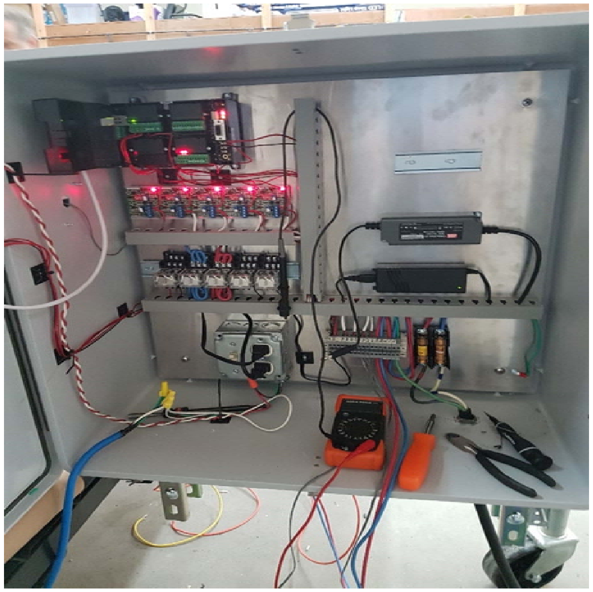
- Current not measurable by a sensitive current meter
- Simulated by using a electro-magnetic software
- Induced current < 5 nA

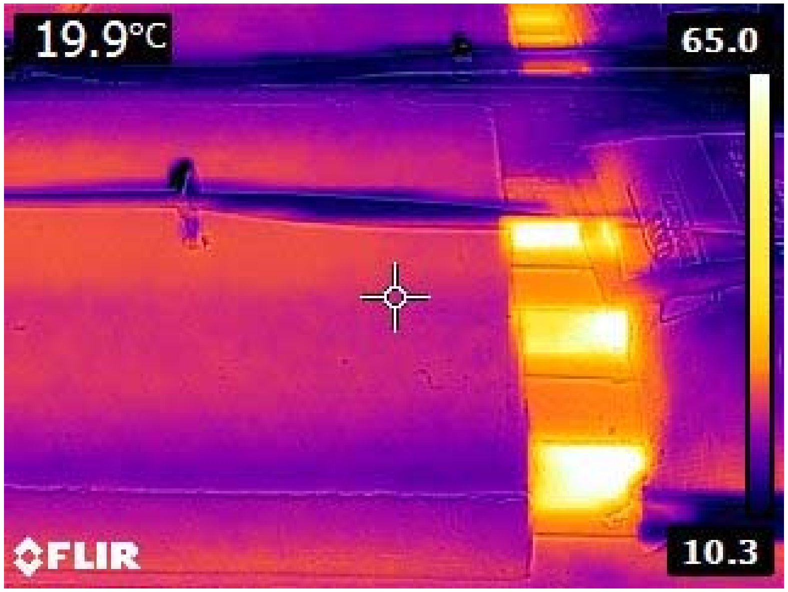


New Product Testing Bed



Durability Testing

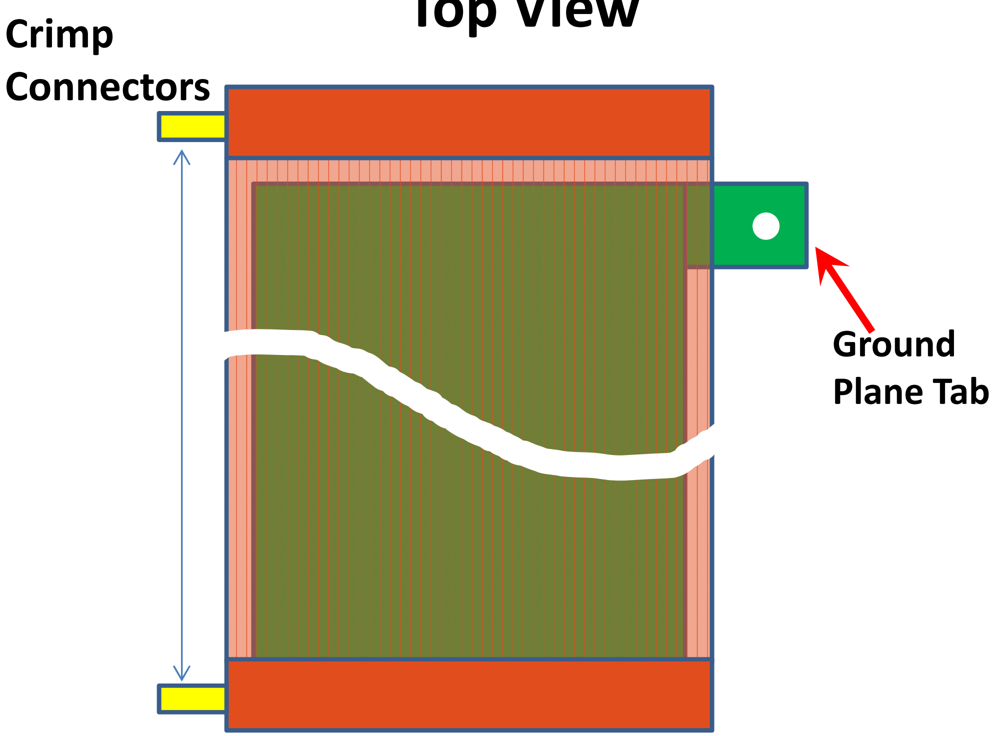




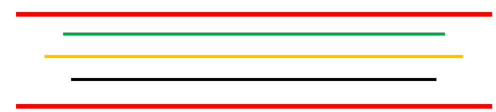
- **First installation operated for six years w/o any signs of aging**
- **Connectors passing 100,000 time cycling test**

Latest Product

Top View



Laminate Cut-away View



Key

- Carbon fiber tape – 0.5mm thick X 76.3mm (3-inches) wide
- Thin, tough, insulating, flexible material – testing plastic
- Grounding plane
- Arlon 27CR non-conducting outer covering – 0.026 thick

Tundra Tape with new crimp connectors

Thank You!

Highly Abrasion Resistant Concrete Paving

Xavier Schlee[1] and Jenny Liu[2]

[1]Anchorage Sand & Gravel
[2]University of Alaska Fairbanks

November 6, 2017

Outline

- Background
- Problem Statement
- Objectives
- Research Plan

Background

Minnesota & Old Seward

O’malley & Old Seward

Dowling Road

UAA & Providence Bus Pull Out

Glen Highway

Problem Statement

Thursday, September 5, 2002 B-7

ce of the Times
CONSERVATIVE VOICE FOR ALASKANS

WILLIAM J. TOBIN
State editor

Solutions to fixing our rutted roads

By JOSEPH L. PERKINS

I'd like to thank Dennis Nolting, for his Voice of the Times article, "Tired of Alaska's rutty roads?"

Dennis correctly identified two of our biggest challenges with building and maintaining roads in Alaska — ruts and pavement failure. As Dennis points out, studded tires are the biggest cause for pavement rutting, particularly in heavy traffic areas like Anchorage.

We spend millions of dollars each summer to replace pavements which are not worn out, but are severely rutted. Our recent work on the Glenn Highway is a good example.

The Department of Transportation and Public Facilities has proposed legislation to ban the sale of heavyweight studs in Alaska but it wasn't passed by the Legislature. Studies have shown that lightweight studs, which have the same tungsten carbide tips as heavyweight studs, produce about half of the pavement wear while providing nearly identical stopping ability.

Some tire companies are now installing lightweight studs, but we still have a considerable number of heavyweight studs on our roads.

A major contributor to the rutting problem is also caused by drivers who do not remove their studded tires in the summer. Studs can cause more damage to our pavements in the summer than in the winter.

Several states, including Minnesota, Michigan, Illinois, Maryland and the Canadian provinces of the Northwest Territories, Ontario and Alberta, as well as British Columbia, have outlawed studded tires altogether. Residents of these states and territories have given up their studs and use new studless snow tire technology to preserve their roads.

As the person responsible for highway maintenance in Alaska, I would like to see Alaska, as a minimum, pass legislation that bans heavyweight studs and increases the penalty for summer stud use from the current "fix it" ticket to a penalty that would get more attention from violators.

THE WORLD WILL END ON THURSDAY

"Hey, Fr! — let's switch our golf game from Thursday to Wednesday."

The department is trying to reduce the severity of the rutting problem. On our high traffic roads, we are using the latest asphalt mix design technologies, called Superpave and Stone Mastic Asphalt.

We are finding that these asphalt mixes in combination with hard rock can produce a more rut-resistant pavement. By placing these types of asphalt we are able to slow stud wear and delay rutting. We are seeing success using these techniques.

For a first-hand view, look at Fifth and Sixth avenues in downtown Anchorage, the Egan Expressway in Juneau and the North Tongass Highway in Ketchikan.

Temperature extremes and water are two causes of pavement failure on our roads. Due to the short construction season in Alaska, we often find ourselves paving in weather conditions that are far from optimum, especially during the late fall.

We have implemented a policy requiring that most asphalt pavements be constructed with at least two layers of asphalt. The first layer is placed in the late summer and used as the temporary driving surface over the winter. The final driving surface, the second layer, is placed early the following summer when weather conditions are much more conducive to obtaining a high quality pavement. By using this approach we are improving the quality and extending pavement life.

Water in our road structure is one of our biggest enemies, and the closer it is to the pavement, the more problems it causes. For years we have placed approximately four inches of crushed rock (D-1) under our pavements.

As Dennis explained, water can collect in this material, freeze and thaw and then cause pavement failure. We recently issued a directive to waterproof the D-1 on all of our high volume roads by treating it with asphalt or cement. This material will not allow water to collect directly under the pavement.

I think this change will pay big dividends in extending pavement life. Pavement performance is something the department and I take very seriously.

I hold an asphalt summit every year with personnel from the department, contractors, private sector engineers, material suppliers and asphalt producers to discuss problems and develop solutions. The exchange of ideas during these summits has been valuable.

In addition, we are working with industry in a newly formed organization called the "Asphalt Pavement Alliance" which will be coming up with some innovative ideas. My goal is to develop pavements strong enough to withstand spring thaw conditions without seasonal reductions in truck weight limits.

The department and the engineering and construction industry certainly haven't solved all of Alaska's pavement problems, but we are working together to make Alaska's roads better.

Joseph L. Perkins is commissioner of the Alaska Department of Transportation and Public Facilities, based in Juneau.

The Anchorage Times

The Voice of the Times does not represent the editorial views of the Anchorage Daily News. This commentary is published

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Tools Fill & Sign Comment

biggest cause for pavement rutting, particularly in heavy traffic areas like Anchorage.

We spend millions of dollars each summer to replace pavements which are not worn out, but are severely rutted. Our recent work on the Glenn Highway is a good example.

The Department of Transportation and Public Facilities has proposed legislation to ban the sale of heavyweight studs in Alaska but it wasn't passed by the Legislature. Studies have shown that lightweight studs, which have the same tungsten carbide tips as heavyweight studs, produce about half of the pavement wear while providing nearly identical stopping ability.

Some tire companies are now installing lightweight studs, but we still have a considerable number of heavyweight studs on our roads.

A major contributor to the rutting problem is also caused by drivers who do not remove their studded tires in the summer. Studs can cause more damage to our pavements in the summer than in the winter.

Several states, including Minneso-

"Hey, Ed — let's switch our golf game from Thursday to Wednesday."

more attention from violators.

The department is trying to reduce the severity of the rutting problem. On our high traffic roads, we are using the latest asphalt mix design technologies, called Superpave and Stone Mastic Asphalt.

We are finding that these asphalt mixes in combination with hard rock can produce a more rut-resistant pavement. By placing these types of asphalt we aim to slow stud wear and delay rutting. We are seeing success using these techniques.

For a first-hand view, look at Fifth and Sixth avenues in downtown Anchorage, the Egan Expressway in

it is to the pavement, the more problems it causes. For years we have placed approximately four inches of crushed rock (D-1) under our pavements.

As Dennis explained, water can collect in this material, freeze and thaw and then cause pavement failure. We recently issued a directive to waterproof the D-1 on all of our high volume roads by treating it with asphalt or cement. This material will not allow water to collect directly under the pavement.

I think this change will pay big dividends in extending pavement life. Pavement performance is something the department and I take very seriously.

I hold an asphalt summit every year with personnel from the department, contractors, private sector engineers, material suppliers and asphalt producers to discuss problems and develop solutions. The exchange of ideas during these summits has been valuable.

In addition, we are working with industry in a newly formed organization called the "Asphalt Pavement

Thursday, September 5, 2002 B-7

ce of the Times

A CONSERVATIVE VOICE FOR ALASKANS

WILLIAM J. TOBIN
Senior editor

Solutions to fixing our rutted roads

By JOSEPH L. PERKINS

I'd like to thank Dennis Nottingham for his Voice of the Times article, "Tired of Alaska's lousy roads?"

Dennis correctly identified two of our biggest challenges with building and maintaining roads in Alaska — ruts and pavement failure. As Dennis points out, studded tires are the biggest cause for pavement rutting, particularly in heavy traffic areas like Anchorage.

We spend millions of dollars each

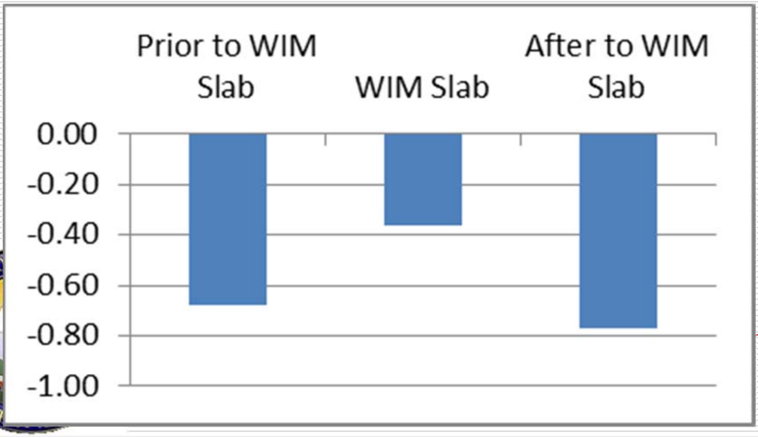
the winter. The final driving surface, the second layer, is placed early the following summer when weather conditions are much more conducive to obtaining a high quality pavement. By using this approach we are improving the quality and extending pavement life.

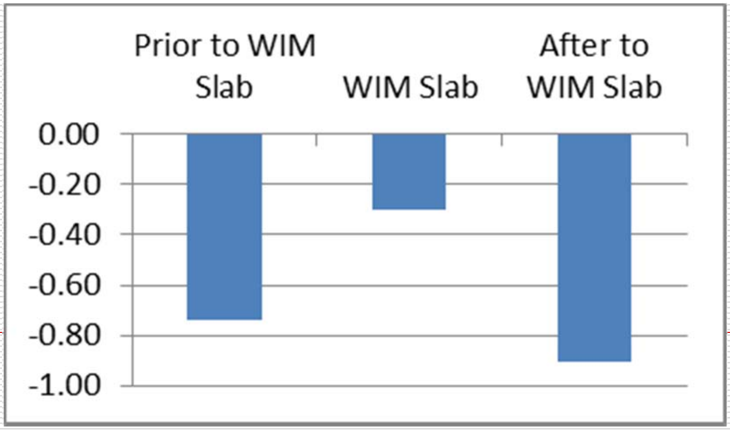
Water in our road structures is one of our biggest enemies, and the closer it is to the pavement, the more problems it causes. For years we have placed approximately four inches of

Seward Highway 5 year old: SMA & PCC

Seward Highway Northbound		
Mix		Average Rut Depth (in.)
2003 SMA	Prior to WIM Slab	-0.68
2003 PCC	WIM Slab	-0.36
2003 SMA	After WIM Slab	-0.77

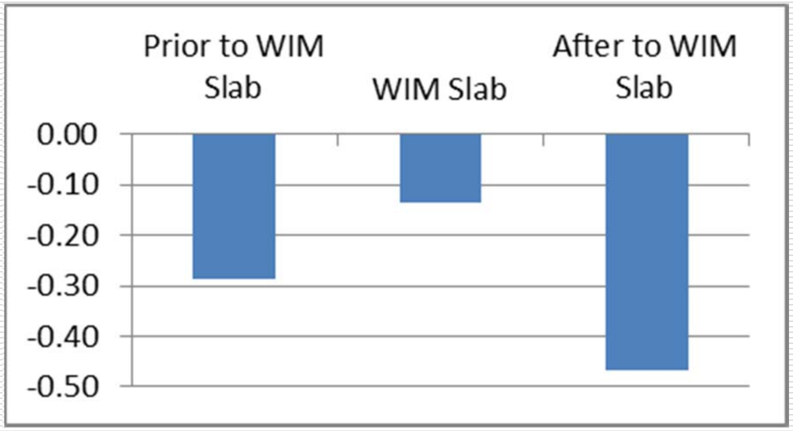
Seward Highway Southbound		
Mix		Average Rut Depth (in.)
2003 SMA	Prior to WIM Slab	-0.74
2003 PCC	WIM Slab	-0.30
2003 SMA	After WIM Slab	-0.91





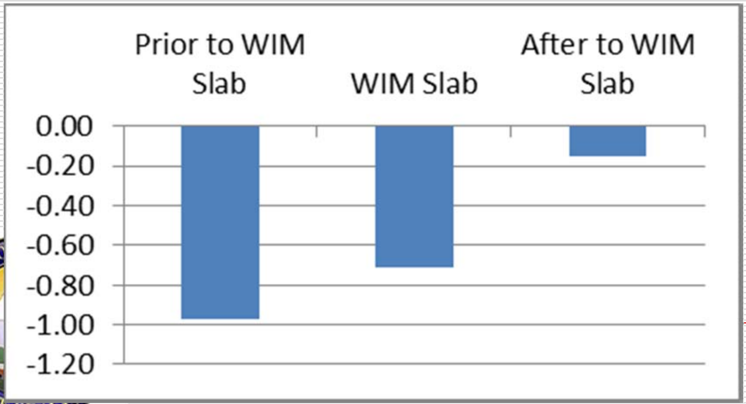
Glenn Highway Northbound 5 Year old: PCC & SMA

Glenn Highway Northbound		
Mix		Average Rut Depth (in.)
2003 SMA	Prior to WIM Slab	-0.29
2003 PCC	WIM Slab	-0.13
2003 SMA	After WIM Slab	-0.47

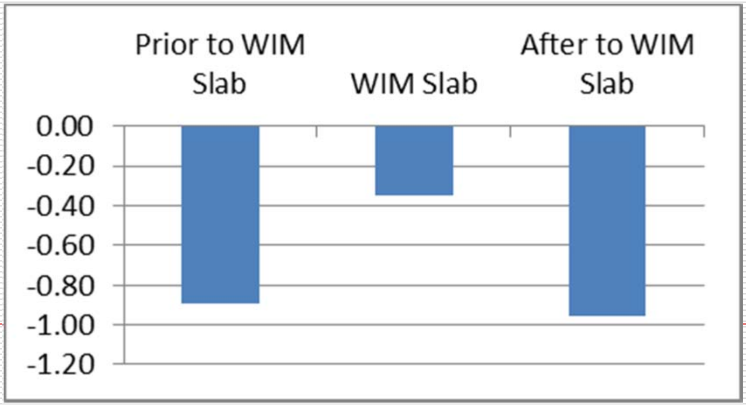


Minnesota South 9 Year Old: SMA & PCC and Minnesota North 8 Year Old: SMA & PCC

Minnesota Drive Northbound		
Mix		Average Rut Depth (in.)
2000 SMA	Prior to WIM Slab	-0.97
2000 PCC	WIM Slab	-0.71
2008 HMA*	After WIM Slab	-0.15



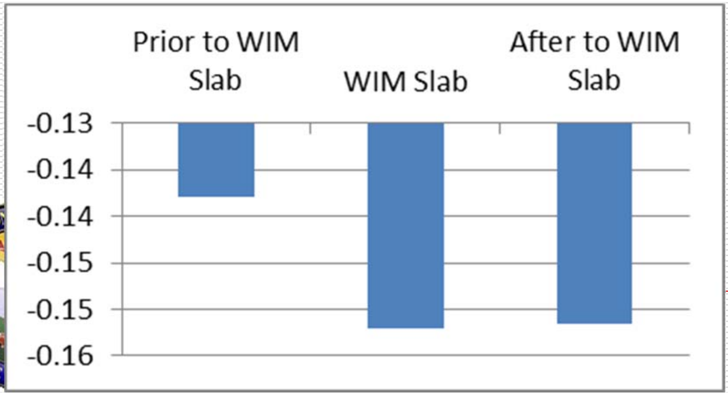
Minnesota Drive Southbound		
Mix		Average Rut Depth (in.)
1999 SMA	Prior to WIM Slab	-0.90
1999 PCC	WIM Slab	-0.35
1999 SMA	After WIM Slab	-0.96

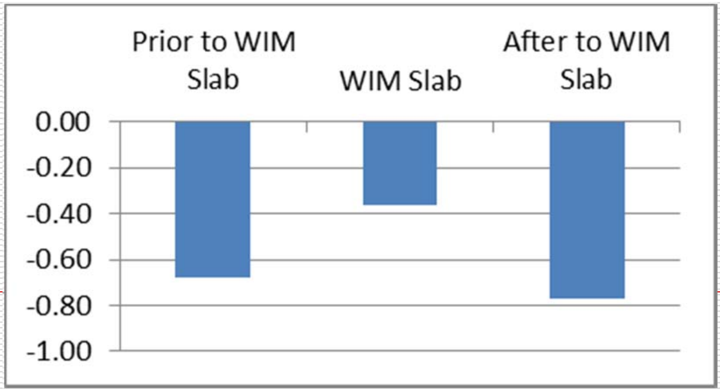


Tudor Road 3 Year VH 5 Year Old: PCC

Tudor Road Eastbound		
Mix		Average Rut Depth (in.)
2005 Type VH*	Prior to WIM Slab	-0.14
2003 PCC	WIM Slab	-0.15
2005 Type VH*	After WIM Slab	-0.15
* Mix with imported hard aggregates		

Tudor Road Westbound		
Mix		Average Rut Depth (in.)
2005 Type VH*	Prior to WIM Slab	-0.23
2003 PCC	WIM Slab	-0.15
2005 Type VH*	After WIM Slab	-0.30
* Mix with local aggregates		





The only difference between a rut and a grave are the dimensions.

Ellen Glasgow

Objectives

- To implement highly abrasion resistant concrete paving
  - Identify and select concrete mix design to provide the lowest cost at the longest performance

Base Mix Design (Compression Strength Data)

DOT 4 (CAST 21) / *6.5 Sack - Silica Fume Mix Design* *ADOT:*									
Product Code	**Date**	**% Air**	**Slump**	**W/C**	**1 DAY**	**2 day**	**3 day**	**7 day**	**28 day**
DOT 4	8/26/2010	4.5	7.50	0.335	3902		8273	9787	12227
DOT 4	8/26/2010	4.5	7.50	0.335				9850	13112
DOT 4	6/28/2011	4.0	5.00	0.335	3181		7823	9760	15482
DOT 4	8/1/2012	6.0	7.50	0.335	2526		5054	8229	11766
DOT 4	8/1/2012	7.5	9.00	0.335	2291		4521	7652	8125
DOT 4	8/23/2012	7.8	9.50	0.336	1754	3645	5453	6994	8251
DOT 4	8/23/2012	7.8	9.50	0.336			5405	6856	8409
DOT 4	8/23/2012	6.8	8.50	0.335	1681	4397	5993	7994	10530
DOT 4	8/23/2012	6.8	8.50	0.335			6006	8139	10748
DOT 4	8/23/2012	6.7	8.50	0.336	2030	4443	5850	8205	10016
DOT 4	8/23/2012	6.7	8.50	0.336			6018	8249	9972
DOT 4	9/4/2012	4.5	7.00	0.336	1461	3762	5659	7820	11040
DOT 4	9/4/2012	4.5	7.00	0.336			5555	7580	11550
DOT 4	9/4/2012	4.0	6.00	0.335	1175	3830	5722	7710	9621
DOT 4	9/4/2012	4.0	6.00	0.335			5454	8650	10705
DOT 4	10/4/2012	6.5	4.90	0.335	3954		5991	8700	
DOT 4	8/29/2012	3.0	8.50	0.335	1634	4520		8696	11150
DOT 4	8/29/2012	3.0	8.50	0.335	2164	4970		9097	11833
DOT 4	10/2/2012	6.8	8.00	0.335	2142		5438	8265	11900
DOT 4	10/4/2012	4.9	6.50	0.335	3954		5991	8700	11750
DOT 4	10/10/2012	8.7	10.00	0.335	1474		3724	7051	9830
DOT 4	10/11/2012	7.8	9.50	0.336	1664		6634	7825	12600
DOT 4	9/24/2014	15.0	9.25	0.336	1728		3350	4160	5530
DOT 4	8/15/2015	7.2	9.50	0.336			7200	9150	14520
	stdv	**2.50**	**7.9**	**0.000**	**918**	**488**	**1144**	**1186**	**2152**
	avg	**6.2%**	**7.92**	**0.335**	**2277**	**4224**	**5767**	**8130**	**10899**

Base Mix Design (Flexural Strength Data)

DOT 4 (CAST 21) / *6.5 Sack - Silica Fume Mix Design* *ADOT:*									
Product Code	Date	% Air	Slump	W/C	1 DAY	2 day	7 Day	28 Day	56 Day
DOT 4	11/6/2015	6.2	7.50	0.335			1118	13500	Pending

Literature Review and Surveys

- Rutting and durability issues in PCC pavements
  - Based on studies and practices in Alaska, Washington, Oregon, Finland, Sweden and Norway
  - Use of studded tires
  - Vehicle (i.e. axle load, tire number, and stud type)
  - Pavement (i.e. geometry, surface material, and surface condition)
  - Environment (i.e. moisture and temperature)
  - Traffic (i.e. volume, speed, wheel track, and contact mode)

Literature Review and Surveys

- Abrasion Resistant and Durable Concrete
  - Use of supplementary cementitious materials (SCM)
    - Materials and design: fly ash, silica fume, slag, natural pozzolans and alternative SCMs, ternary mixtures and others (nano-particles, fiber, resin)
    - Mixing methods for SCMs
  - Experimental Feature Studies
    - Use of combined aggregate gradations, ultra-thin and thin white topping,
    - Experimental finishing methods such as longitudinal tining and carpet drag texturing,
    - Higher flexural strength and high cement content mix designs

Next Step - Research Plan

- Optimize and finalize mix design
  - Refine existing mix design by varying key parameters
    - Combination of supplementary cementitious materials
    - Aggregate Gradation
    - Water-cementitious ratio
    - Curing method

Research Plan

- Lab testing
  - Slump Air and super air meter testing
  - Mechanical properties - compressive strength, flexural strength, and shrinkage
  - Durability
    - Wear resistance
    - Freeze thaw durability
    - Resistivity – is a measure of permeability
    - Frost salt scaling resistance after freezing-thawing cycle

Research Plan

- Construction and monitoring field test sections
  - Construction
  - Regular field surveys
    - Long-Term Pavement Performance (LTPP) survey
    - Annual rutting and International Roughness Index (IRI) data collection
- Life cycle cost analysis and comparison

Center for Environmentally Sustainable Transportation in Cold Climates
CESTiCC

STATE OF ALASKA


INLET HOTEL


GARAGE

Contact

- Jenny Liu, Ph.D., P.E., UAF Professor, jliu6@alaska.edu
- Xavier Schlee, Past President of ACI Alaska Chapter

  907-348-6700, Xavier.schlee@anchsand.com

Alaska Department of Transportation & Public Facilities

Bridge Construction Best Practices & Lessons Learned

Leslie Daugherty, PE, SE

Keep Alaska Moving through service and infrastructure

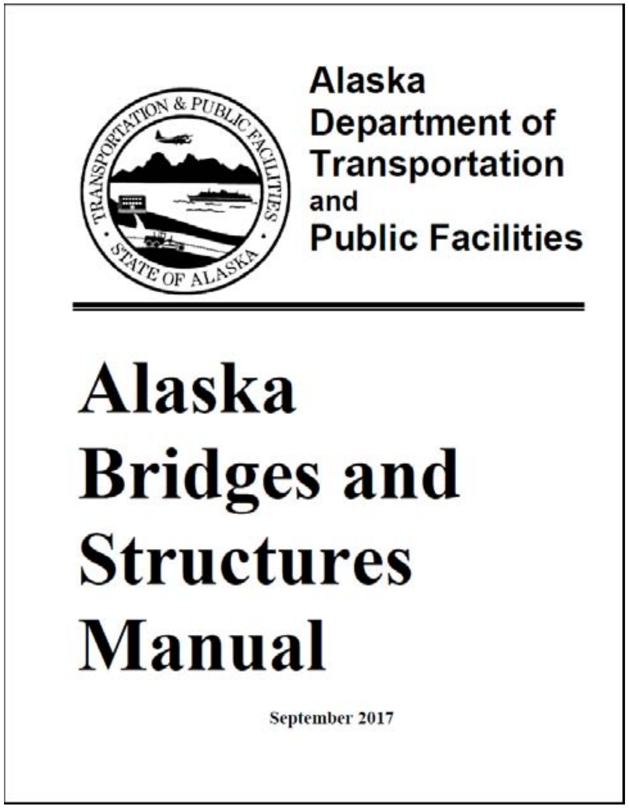
DOT&PF Bridge Section

Chief Bridge Engineer
Richard Pratt

- **Hydraulics**
  Michael Knapp
  Statewide Hydraulics Engineer
- **Bridge Management**
  Larry Owen
  Bridge Management Engineer
- **Bridge Design**
  Leslie Daugherty
  Senior Bridge Engineer
- **Bridge Design**
  Elmer Marx
  Senior Bridge Engineer

Alaska Bridges and Structures Manual

- September 1, 2017
- For use on all DOT&PF bridge projects
- Supplements *AASHTO LRFD Bridge Design Specifications* (Federal minimum standard)


Alaska
Department of
Transportation
and
Public Facilities

Alaska Bridges and Structures Manual

September 2017

Alaska Bridges and Structures Manual

Concrete in:

- Chapter 14 Structural Concrete
  - 14.1 Materials
  - 14.2 Reinforcement
  - 14.3 Structural Concrete Design
  - 14.4 Prestressed Concrete Design
- Chapter 16 Bridge Decks and Rails
- Chapter 23 Bridge Deck Rehabilitation
- Foundation & misc other chapters

Bridge Safety Inspections

- Make work recommendations for M&O or construction contracts
- Collect data to predict bridge deterioration

Bridge Safety Inspections

Silver Bridge
Point Pleasant, WV
December 15, 1967

Bridge Safety Inspections

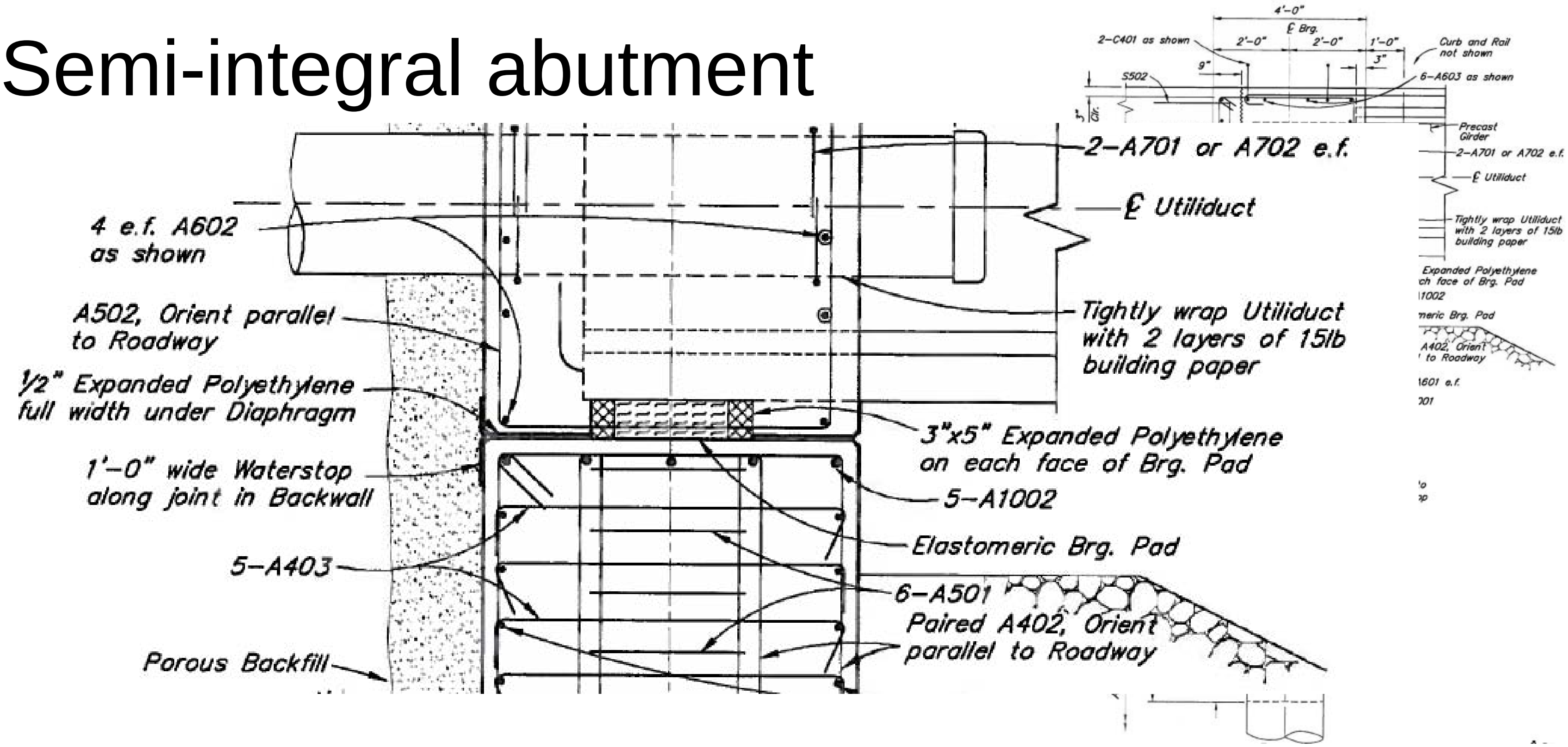
Code	Description
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION
7	GOOD CONDITION
6	SATISFACTORY CONDITION
5	FAIR CONDITION
4	POOR CONDITION
3	SERIOUS CONDITION
2	CRITICAL CONDITION
1	“IMMINENT” FAILURE CONDITION
0	FAILED CONDITION

Lessons Learned

- Practices have improved, but still seeing impacts from poor past practice
- What can we do better??
- Understand why contract specifies things – not arbitrary

Let the Bridge Move…

- Semi-integral abutment
-



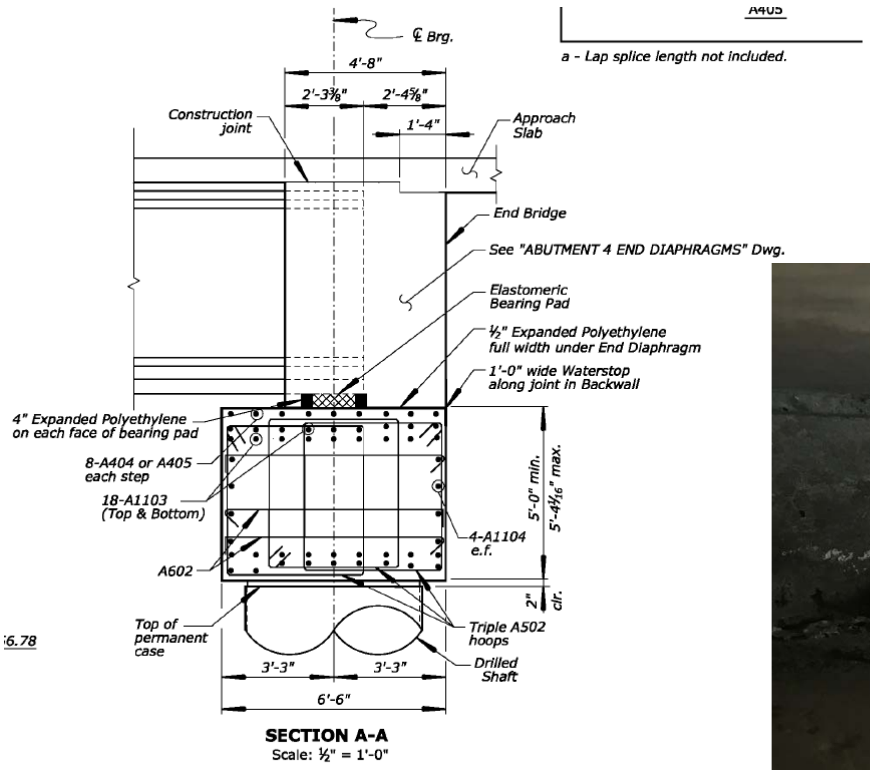
Keep Alaska Moving through service and infrastructure

Improper Chamfers

Improper Chamfers

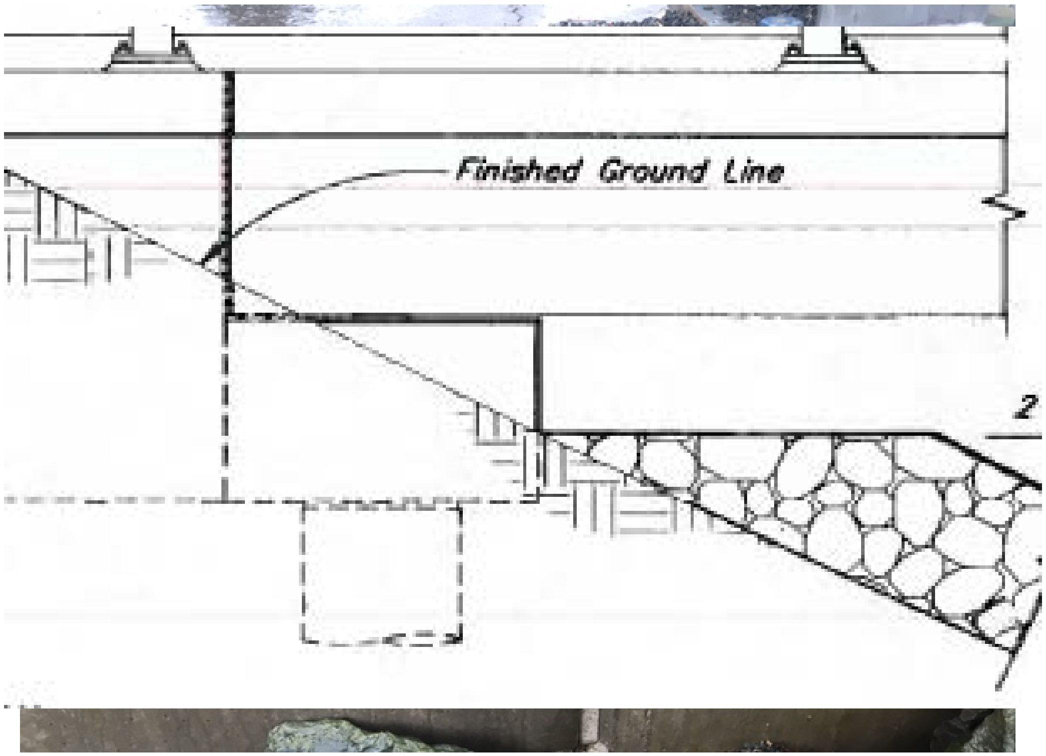
Improper Chamfers

No joint means…

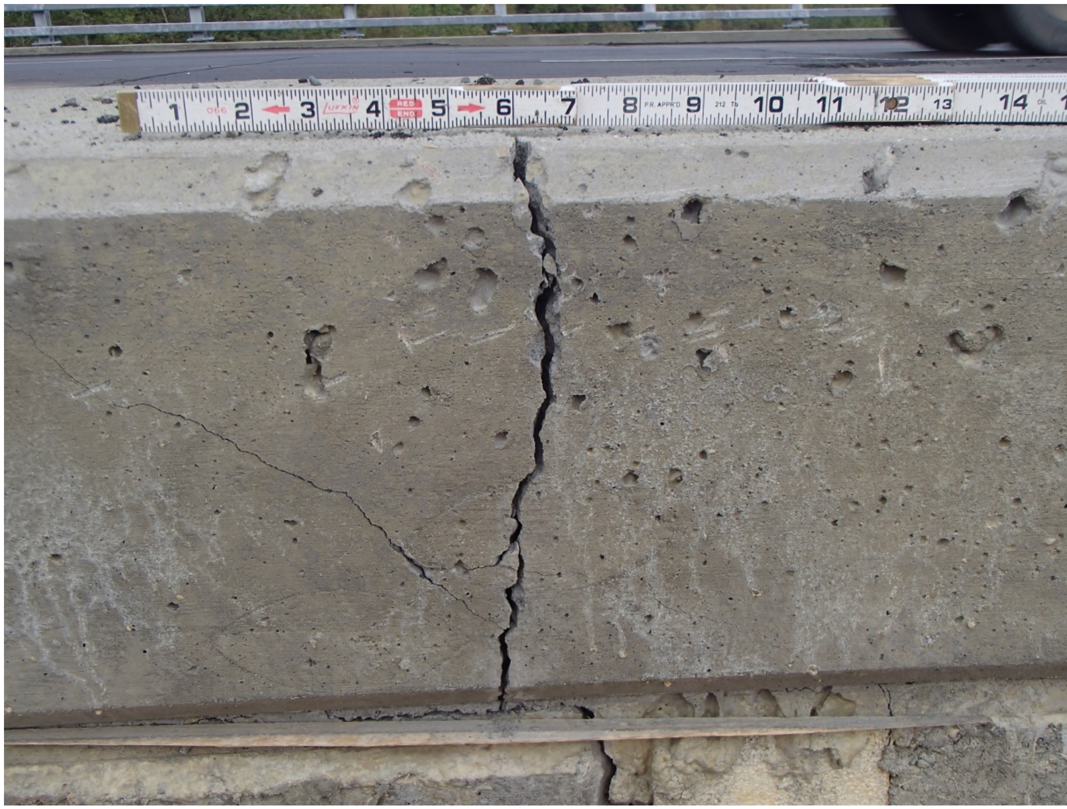


More Expansion/Contraction

More Expansion/Contraction



More (Missing) Joints



More (Missing) Joints

More (Missing) Joints

Rebar that shouldn't be in Joint

Wingwall Joints – Before & After

Green Concrete

End Diaphragm Delamination

Repair

“Rural” Concrete

Fastener Damage

No Fasteners Please!

- *2017 Standard Specifications* limit form fasteners (driven devices) in concrete

Suggestions – Precast Anchors

Suggestions – Hang Forms

Which would you want to own?

Questions/Comments

leslie.daugherty@alaska.gov

(907) 465-8891

Bridge Deck Curing Systems

Tyler Ley, P.E., Ph.D.

Amir Hajibabaee, Mehdi Khanzadeh, Jacob Peery, Jake LeFlore, Travis Ebisch

Disclaimer

- This work has investigated a limited range of materials for a limited range of applications.
- If you do not like the results then I suggest you publish your own measurements.

Acknowledgements

- Oklahoma Department of Transportation
- Kenny Seward
- Matt Romero
- Walt Peters

Outline

- Background
- Experiments
- A New Method of Wet Curing
- Conclusion

What do we want from our bridges?

- Performance over the expected lifespan
- Minimal repairs
- Reasonable cost and construction time

What do we want from our bridges?

- Performance over the expected lifespan
- Minimal repairs
- Reasonable cost and construction time

Economic Durability!

Why is curing important?

If you don’t cure then your concrete may be compromised.

Curing helps the concrete reach its potential

Why do we cure concrete?

1. Reduce evaporation
2. Promote hydration to form a dense microstructure
3. Minimize temperature gradients

What are traditional methods of curing?

- Curing compounds
- Leave the molds in place (form)
- Plastic (sealed)
- Burlap (wet curing)

What are traditional methods of curing?

- Curing compounds
- Leave the molds in place (form)
- Plastic (sealed)
- Burlap (wet curing)

This is what we use for bridge decks

Why don’t we get better curing?

1. People don’t understand how important it is

2. We need to pay for it and verify if we get it

3. We need to make it easier

When do we cure concrete?

- Period 1 - Placement to 6h to stop plastic shrinkage cracking

- Period 2 - 6h to several days to form a dense microstructure

When do we cure concrete?

- Period 1 - Placement to 6h to stop plastic shrinkage cracking

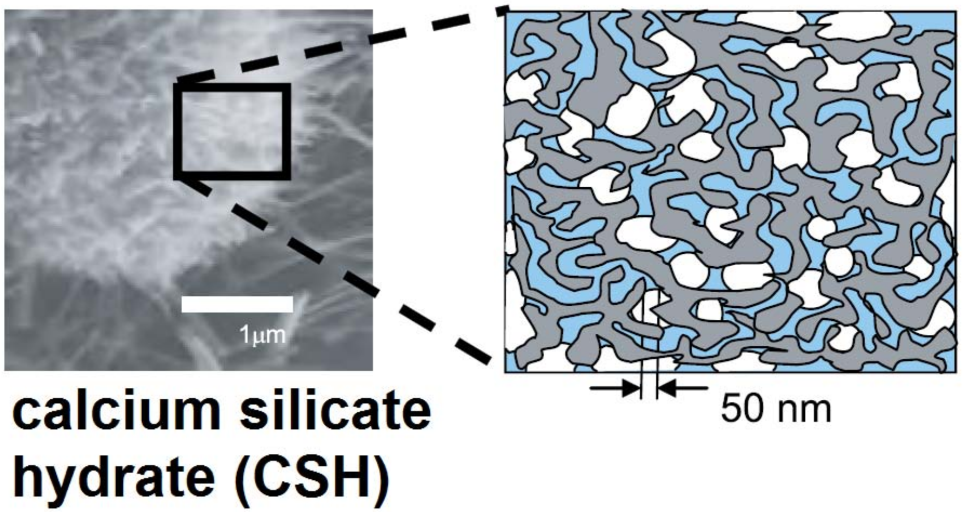
- Period 2 - 6h to several days to form a dense microstructure


Plastic Shrinkage Cracking

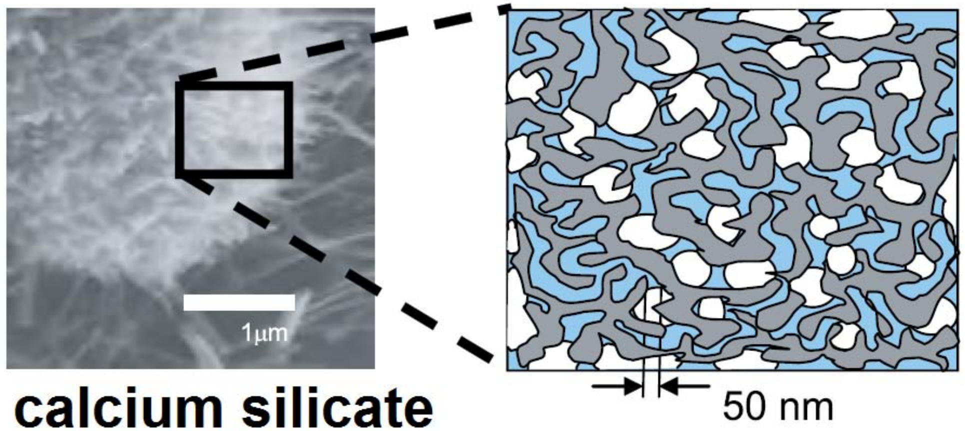
When do we cure concrete?

- Period 1 - Placement to 6h to stop plastic shrinkage cracking
- Period 2 - 6h to several days to form a dense microstructure

Why do we want this?



This is what makes paste strong and hard for water to penetrate or leave the concrete.



calcium silicate hydrate (CSH)

"Good" Curing

"Not as Good" Curing

Let’s compare different curing methods…

Wet curing

Curing compounds

No curing

Why is wet curing challenging?

1. Wet curing requires significant labor
2. If placed too early wet burlap can scar the surface and reduce cover
3. We don’t do a good job of keeping the burlap wet
4. Challenging to inspect
5. Expensive

What is the cost of curing?

	$/sf*	Percentage of Oklahoma bridge cost/sf **
Burlap wet cure	0.42	0.47%
Premium curing compound	0.17	0.19%
Common curing compound	0.06	0.07%

* from an Oklahoma contractor

** Using $89/sf from 2013 NHS

What have people done about it?

In Oklahoma, contractors have proposed using a lithium silicate curing compound in place of wet cure.

This material is applied after the water has evaporated from the surface. This may take 30 minutes to an hour after strike off.

OSU Testing

We developed a testing protocol to evaluate how curing impacts the concrete microstructure.

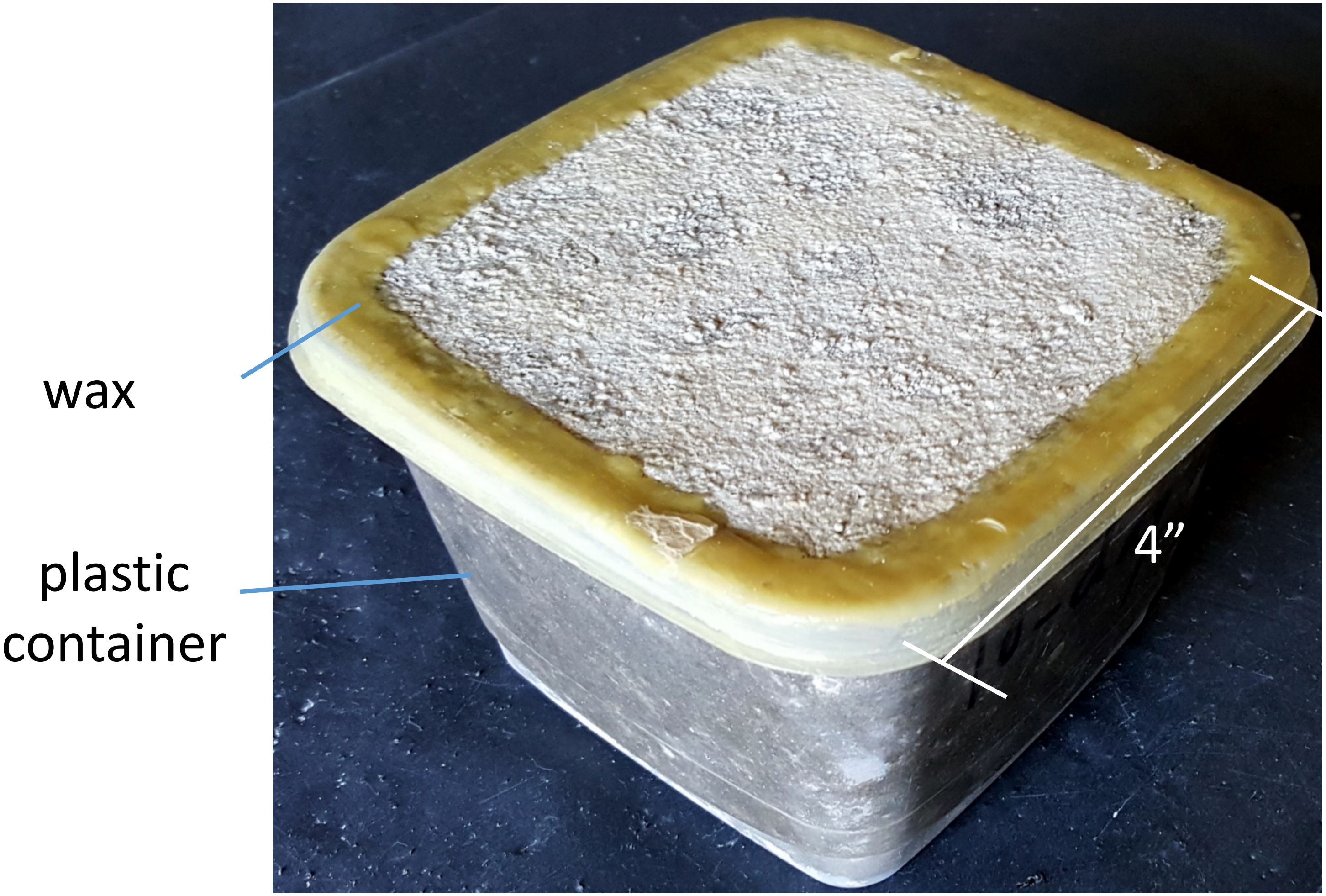
Cast concrete and cure with different methods

- 0.40 w/cm
- 20% Class C ash
- 6.5 sacks (611 lbs)
- Limestone and natural sand
- 5” slump

How did we cure them?

- No curing
- Wet curing for 1, 3, 7, 10, 14 days with wet burlap covered in plastic
- Lithium silicate curing compound
- Poly Alpha Methyl Styrene (PAMS) curing compound

- Curing compounds were applied in two layers with a total coverage of 200 sf/gal
- Lithium silicate representatives and ODOT were present for the testing


wax
plastic
container
4”

OSU Testing

If the concrete is well cured then:

1. It will be hard for the concrete to lose moisture.
2. The concrete will be resistant to water uptake.
3. The concrete will be resistant to chloride penetration.

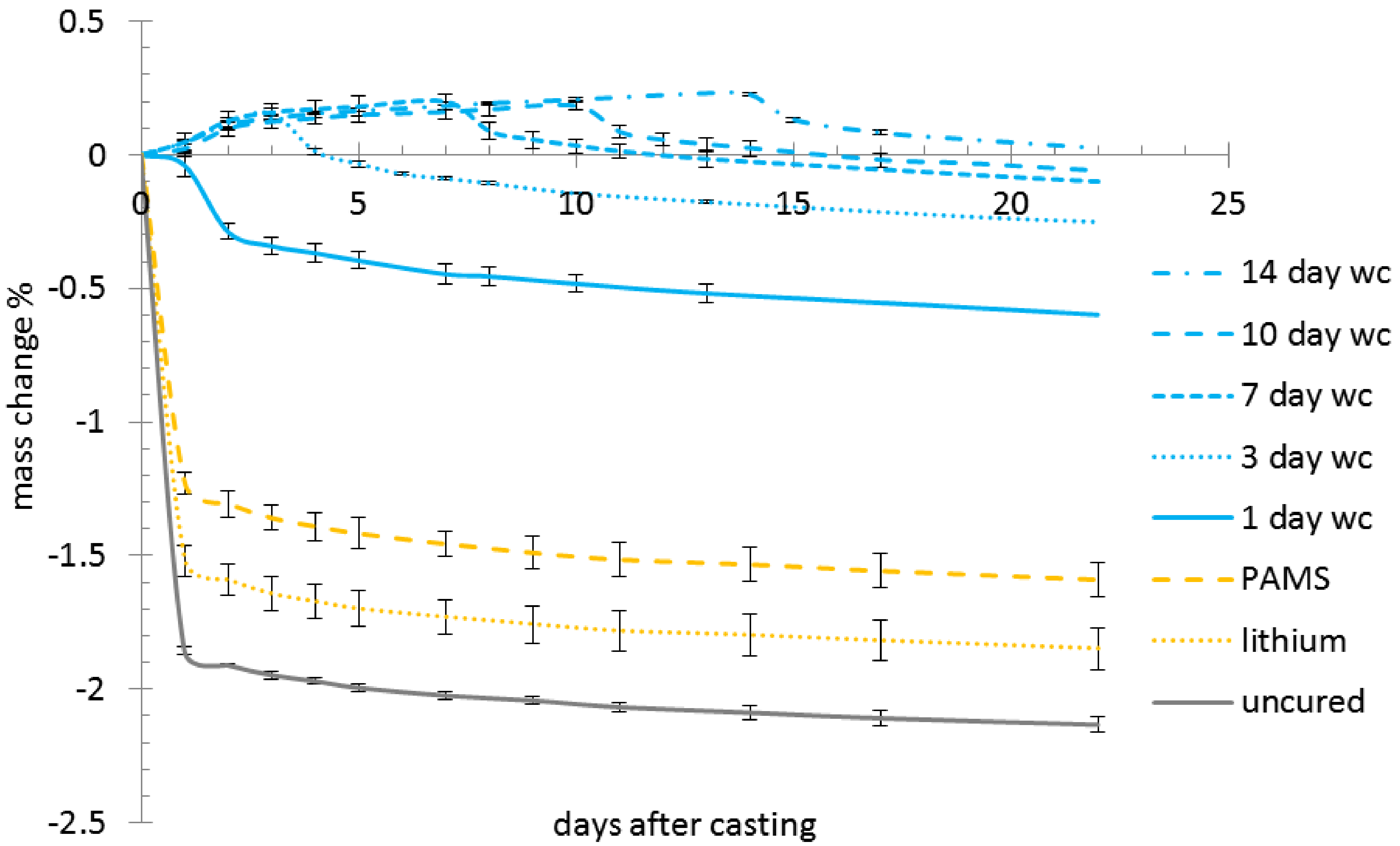
What did we do?

Step	Test	Details
1	drying	Mass change in 40% RH and 73^{o}F for 22 days
2	water uptake	Mass change in lime water for 5 days
3	chloride penetration	Mass change in 5% NaCl for 35 days Chloride profile

Step 1 – Dry the sample

Measure mass change in 40% RH and 73^{o}F for 22 days

1. Mass change in 40% RH and 73°F for 22 days



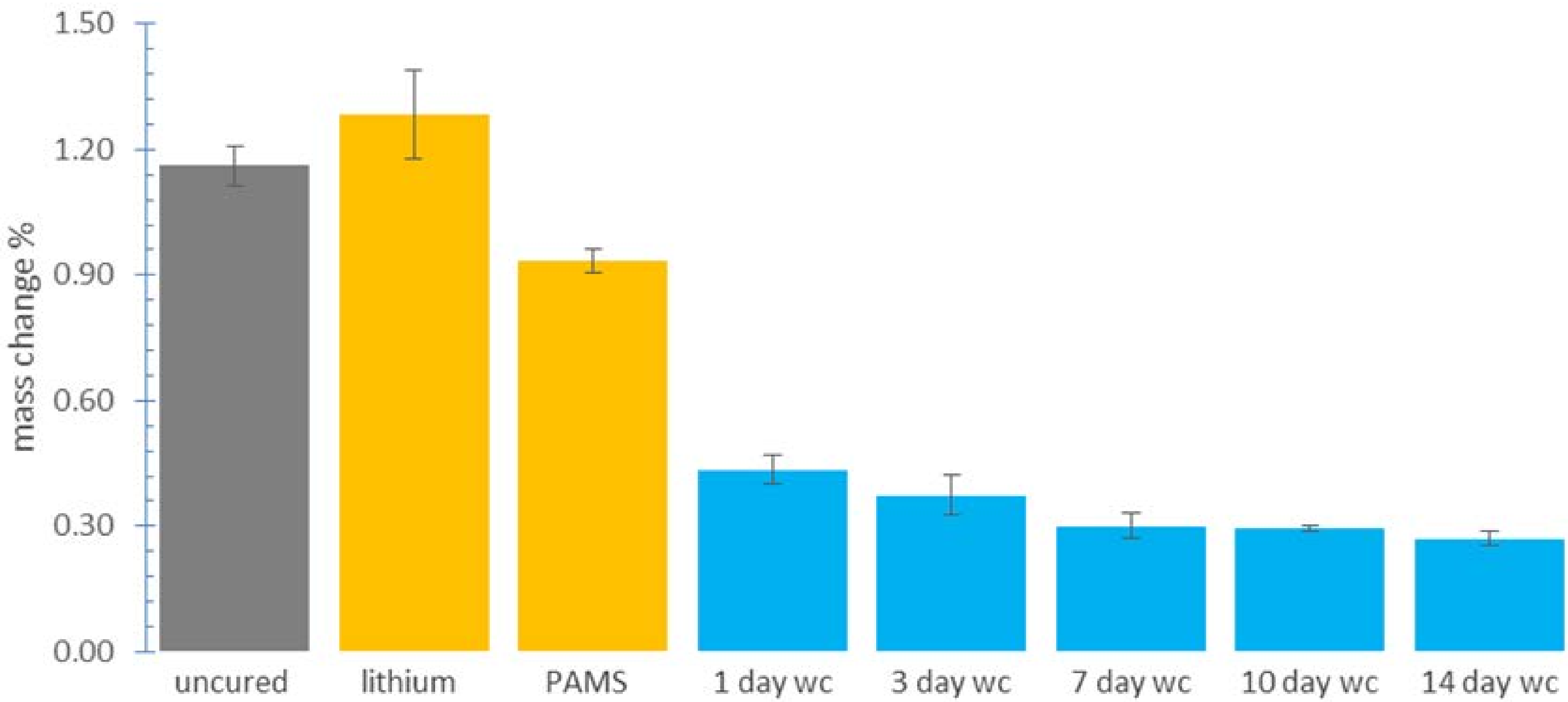
Discussion

- The samples are losing water as they dry.
- The better the curing the less mass was lost.
- Lithium silicate reduced mass loss by 12% and the PAMS by 38% when compared to not curing.
- After 7 days of wet curing there was a low mass loss.
- There was little difference between 7, 10, and 14 days of wet curing for these conditions and materials.

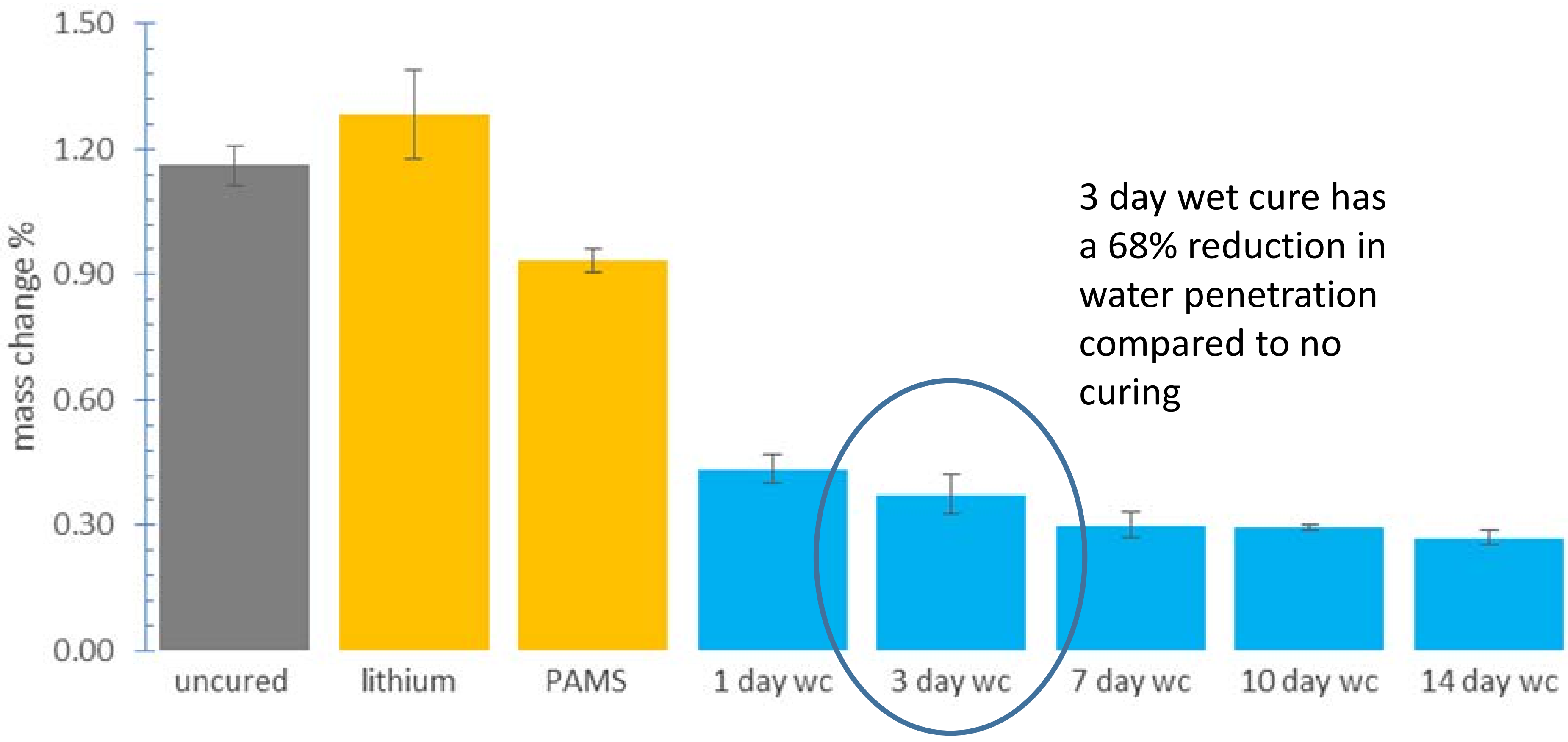
Step 2 – Place concrete in lime water

Measure mass change in lime water for 5 days

2. Mass change in lime water for 5 days



2. Mass change in lime water for 5 days

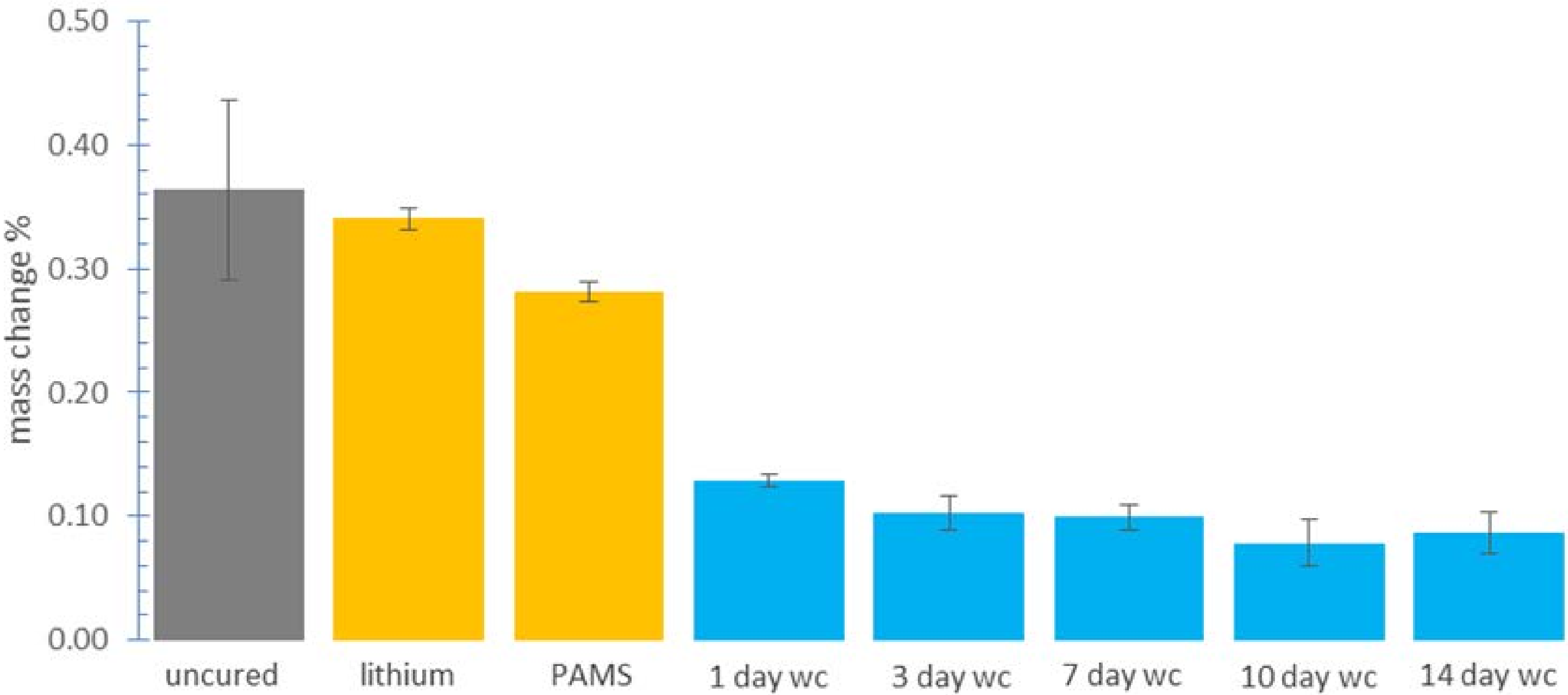


3 day wet cure has a 68% reduction in water penetration compared to no curing

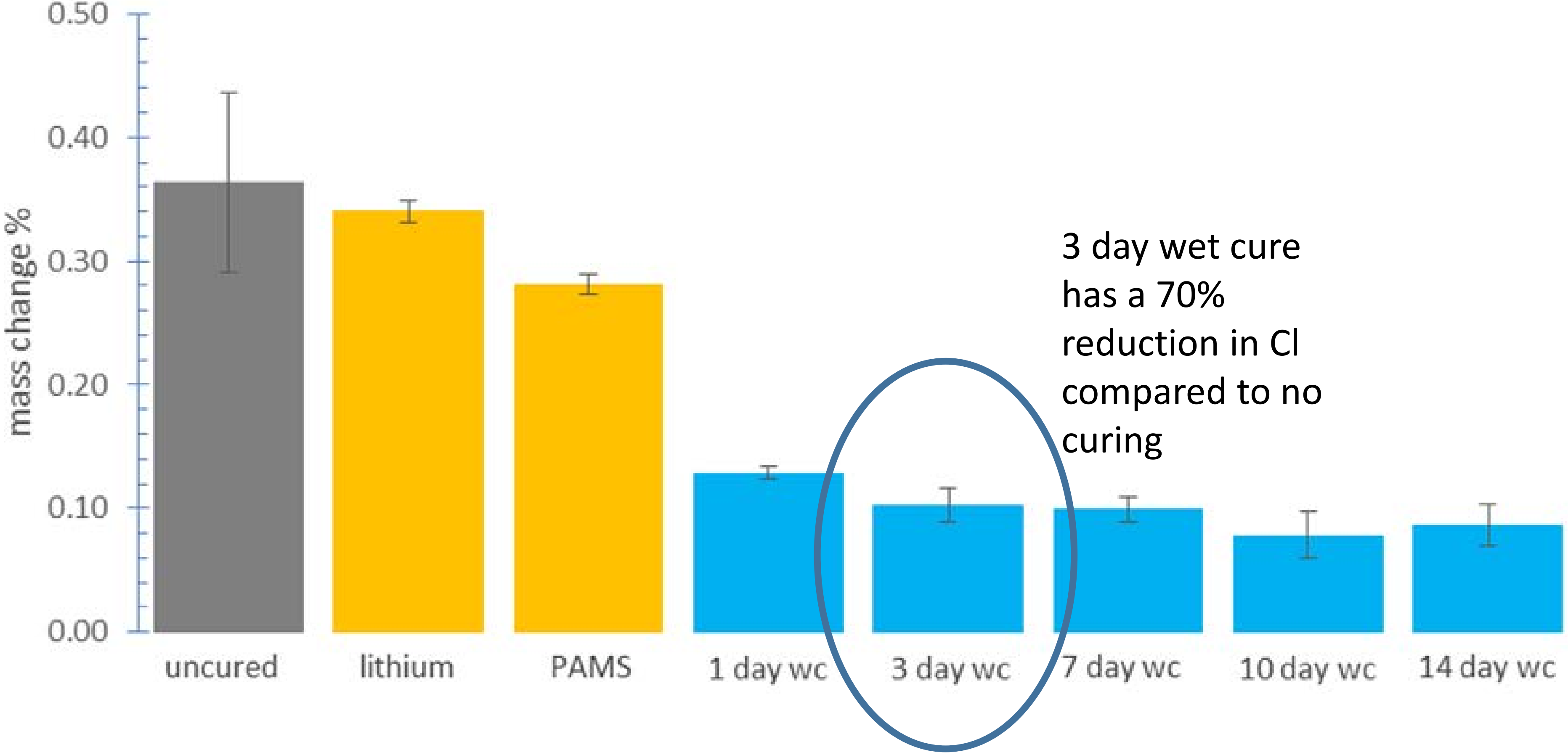
Step 3 – Place concrete in NaCl solution

Measure mass change in NaCl solution for 35 days

3. Mass change in 5% NaCl for 35 days



3. Mass change in 5% NaCl for 35 days



3 day wet cure has a 70% reduction in Cl compared to no curing

Discussion

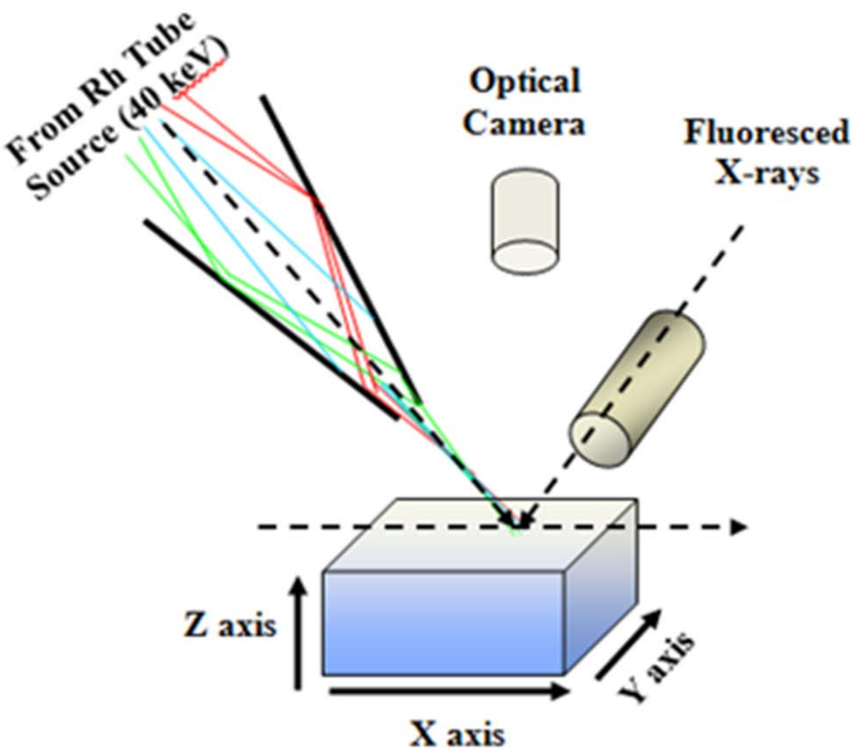
- Concrete with a tighter microstructure will gain less mass when wetting
- The trends are similar for initial water uptake and long term chloride penetration
- Lithium silicates performed similarly to not curing
- PAMS reduced fluid uptake by 25% when compared to not curing
- Wet curing for 3 days reduced fluid uptake by ~ 70%
- Very little difference between the fluid penetration for 3, 7, 10, and 14 days of wet curing

Chloride Profiles

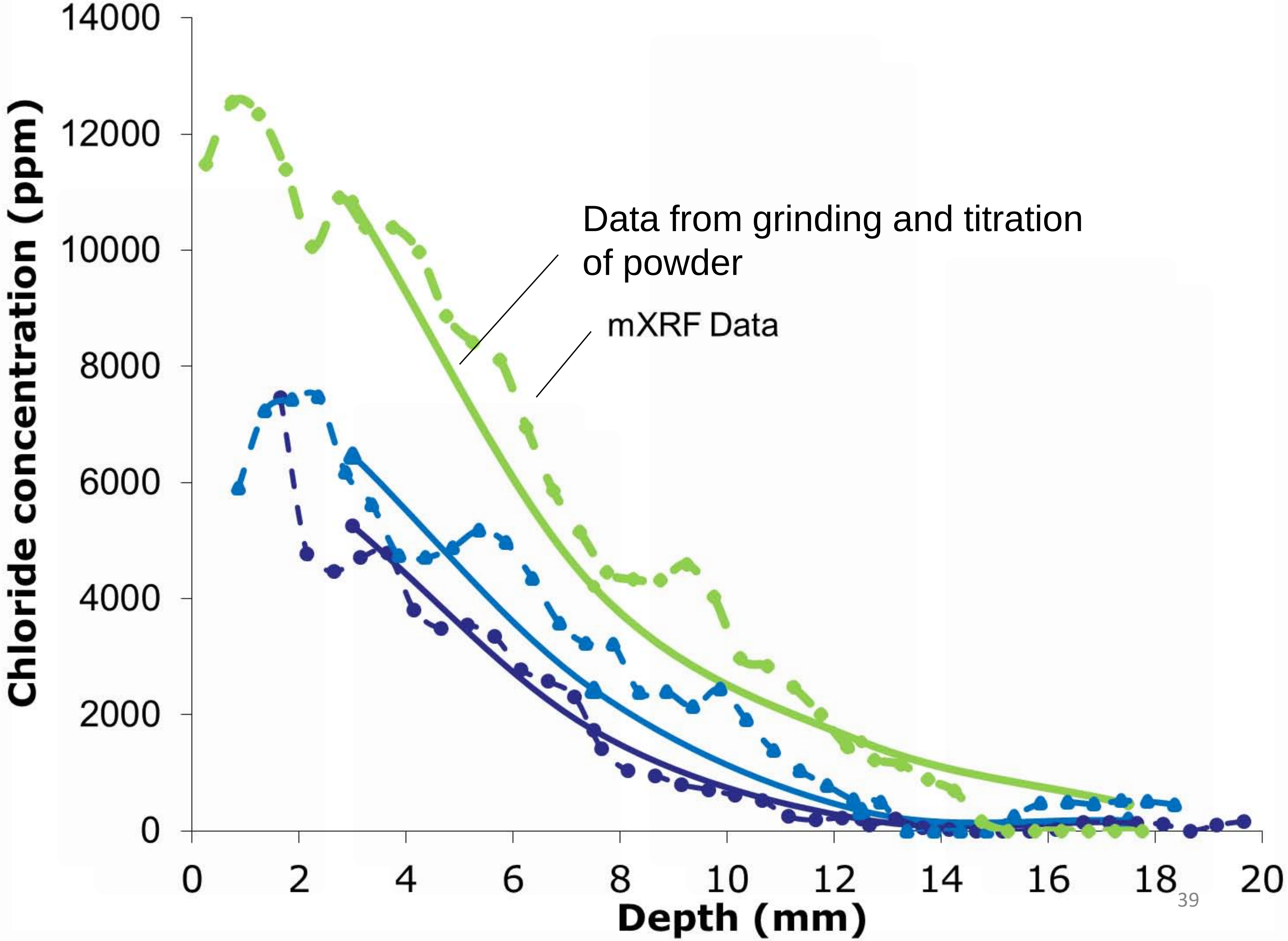
- Next we cut the samples and investigated the surface with a XRF microscope
- This is similar to a bulk XRF instrument but it has extra focusing system so that we can map the surface.

µXRF technique description

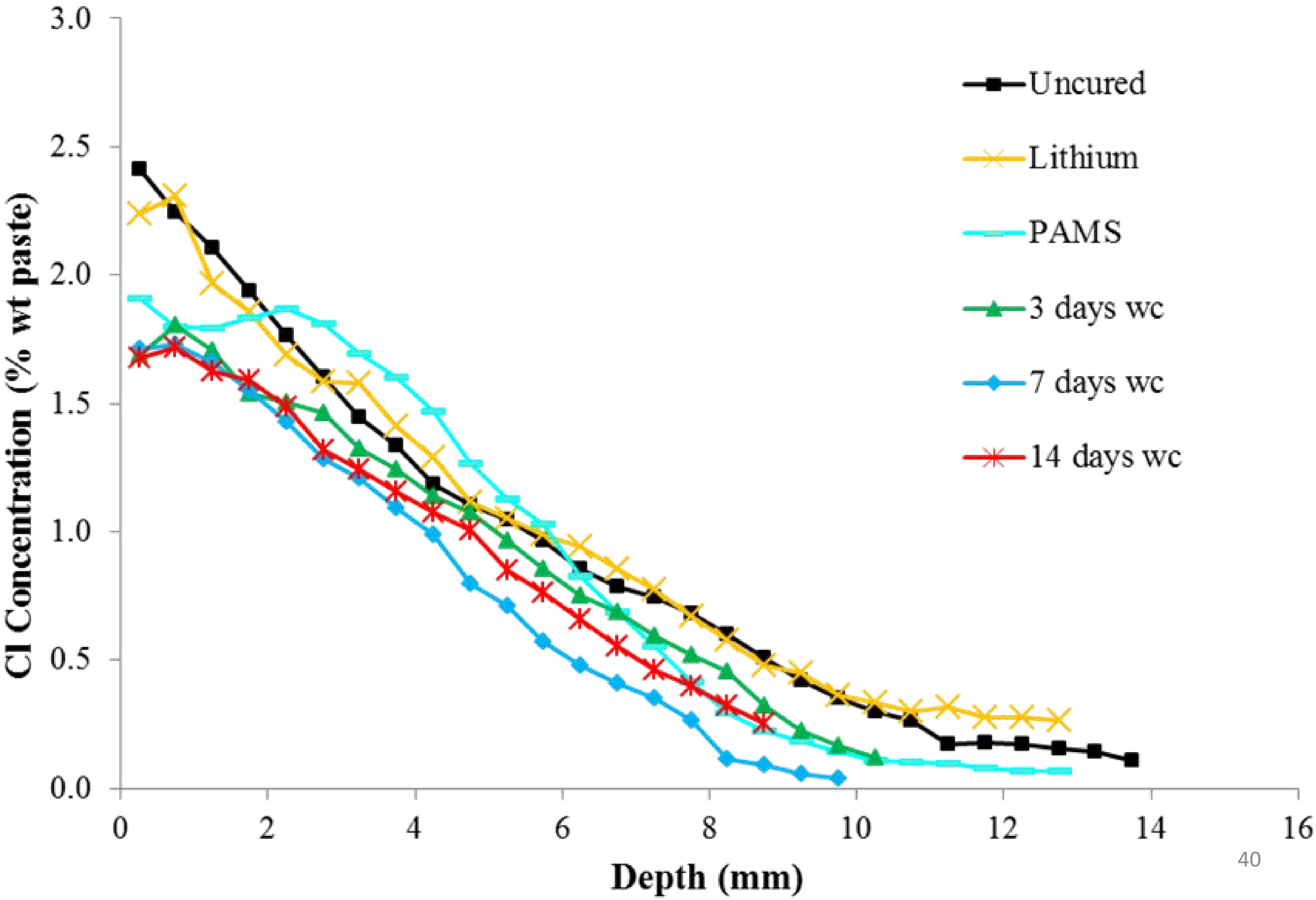
- Uses an X-ray optic to focus a stationary beam of X-rays onto a sample
- The interaction of the X-rays with the electrons emits a secondary fluoresced X-ray
- Every element emits a unique signal
- Uses a polycapillary optic to focus X-rays to a size of approximately 50 µm in diameter



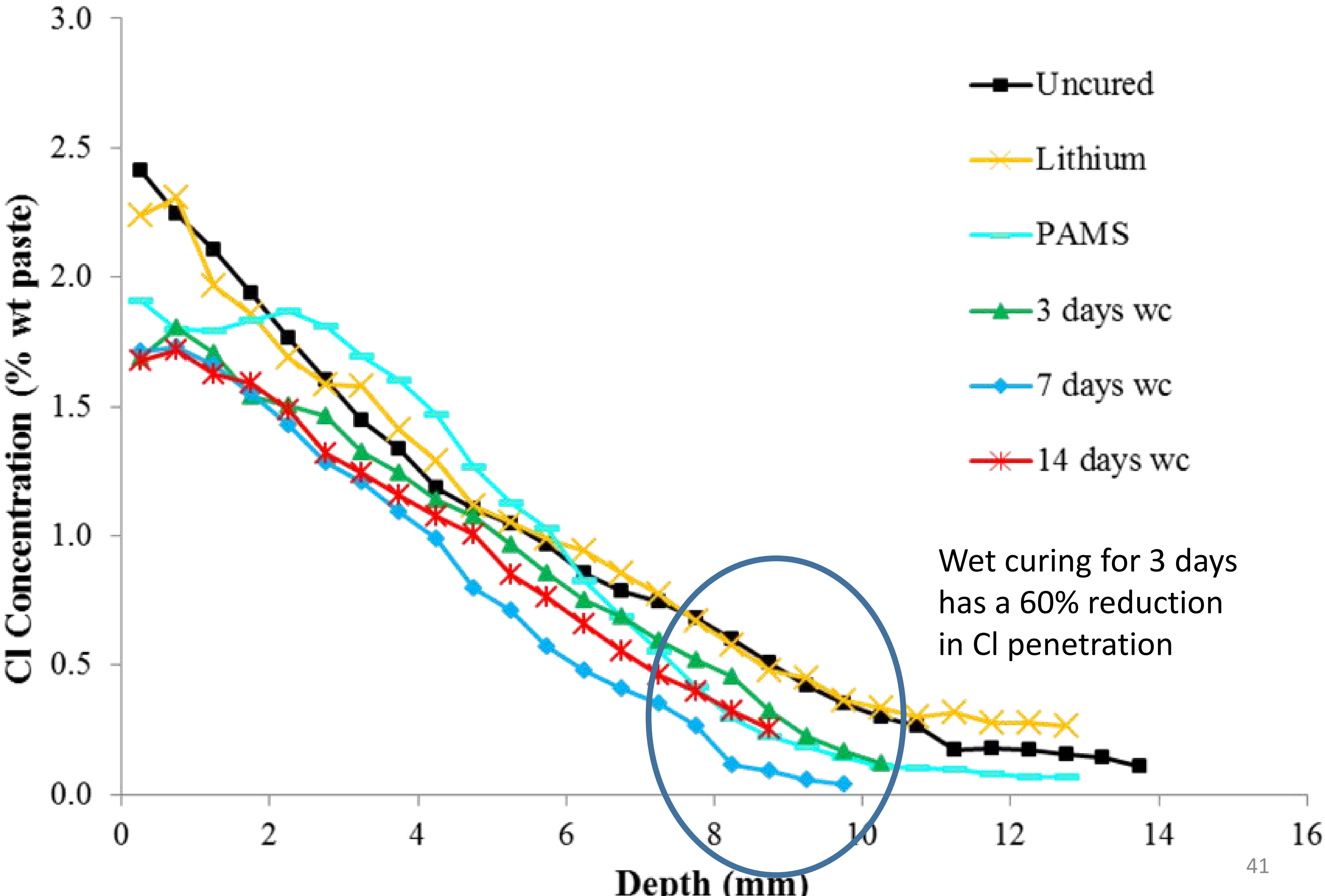
Orbis by EDAX


Data from grinding and titration of powder
mXRF Data
Chloride concentration (ppm)
Depth (mm)
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
16
18
20

4. Chloride profile



4. Chloride profile



Wet curing for 3 days has a 60% reduction in Cl penetration

Discussion

- The chloride penetration data had similar trends as the fluid uptake.
- No cure and lithium silicate performed similarly
- Wet curing performed better than the curing compounds
- There was about a 60% reduction in the chloride ingress for the 3 day wet cured sample compared to the sample that was not cured.
- *This suggests that by wet curing your concrete you approximately double your lifespan compared to not curing.*

What is the cost of curing?

	$/sf*	Percentage of Oklahoma bridge cost/sf **
Burlap wet cure	0.42	0.47%
Premium curing compound	0.17	0.19%
Common curing compound	0.06	0.07%

* from an Oklahoma contractor

** Using $89/sf from 2013 NHS

For ~ .5% of your cost you are doubling the lifespan of your bridge deck

Discussion

- The mass change from drying, moisture absorption, and chloride diffusion showed similar trends
- Lithium silicate and no curing had similar performance
- PAMS showed improved performance but not as good as wet cure
- Curing for 7 days had slightly better performance than 3 days.
- You can approximately double the lifespan of your bridge deck against chloride ingress with wet curing for 3 days over not curing

Can we do this better?

- We have been using burlap to cure concrete for over 70 years.

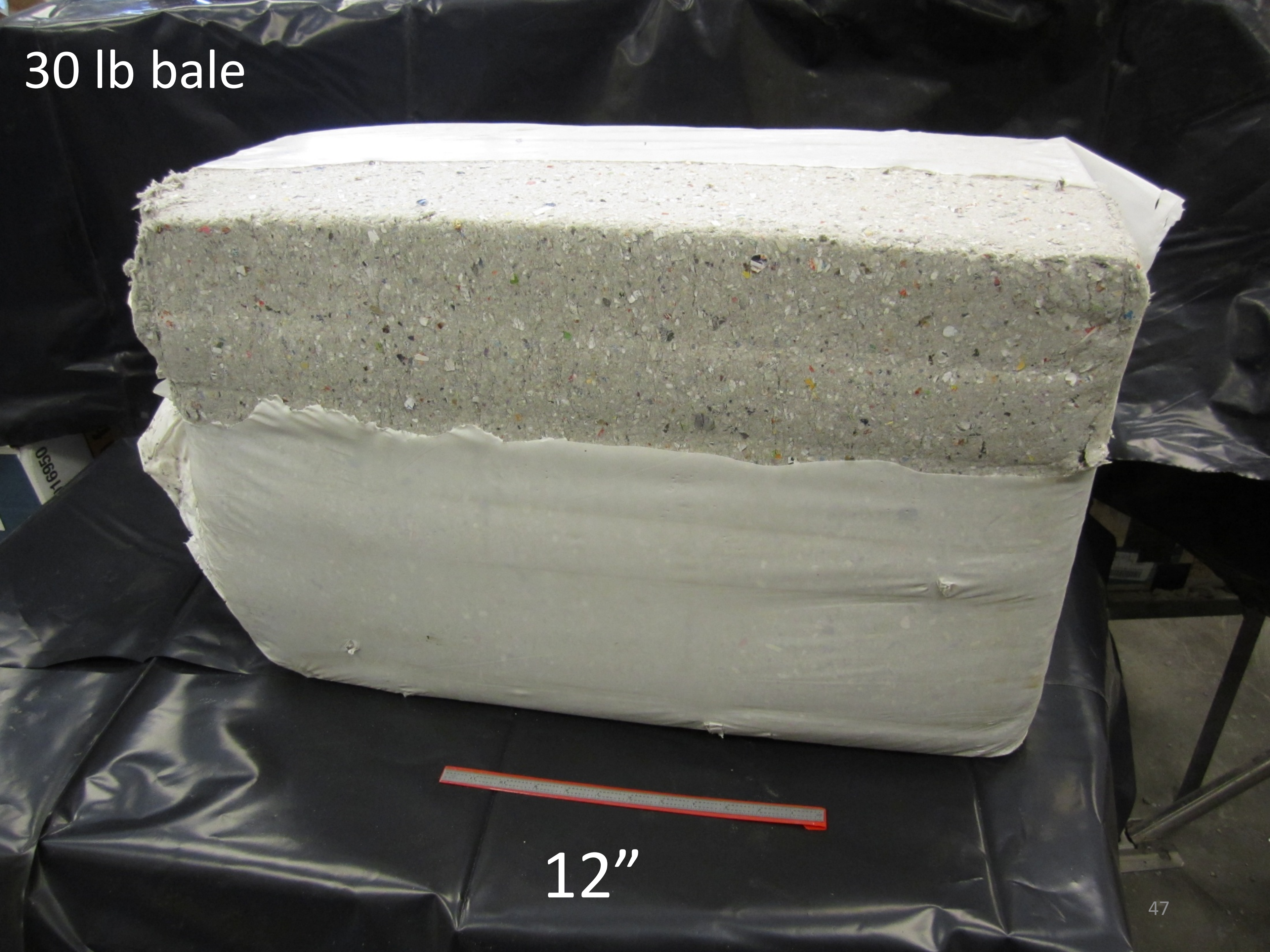
- We need new tools to help us improve our curing while also simplifying our construction.

PulpCure

PulpCure is recycled paper, water, and herbs and spices developed at Oklahoma State University.

It is a spray on wet blanket.

It is non toxic, environmentally friendly, biodegradable, and can be reused!


30 lb bale
12”

How Does It Work?

You mix the product with water and then apply it

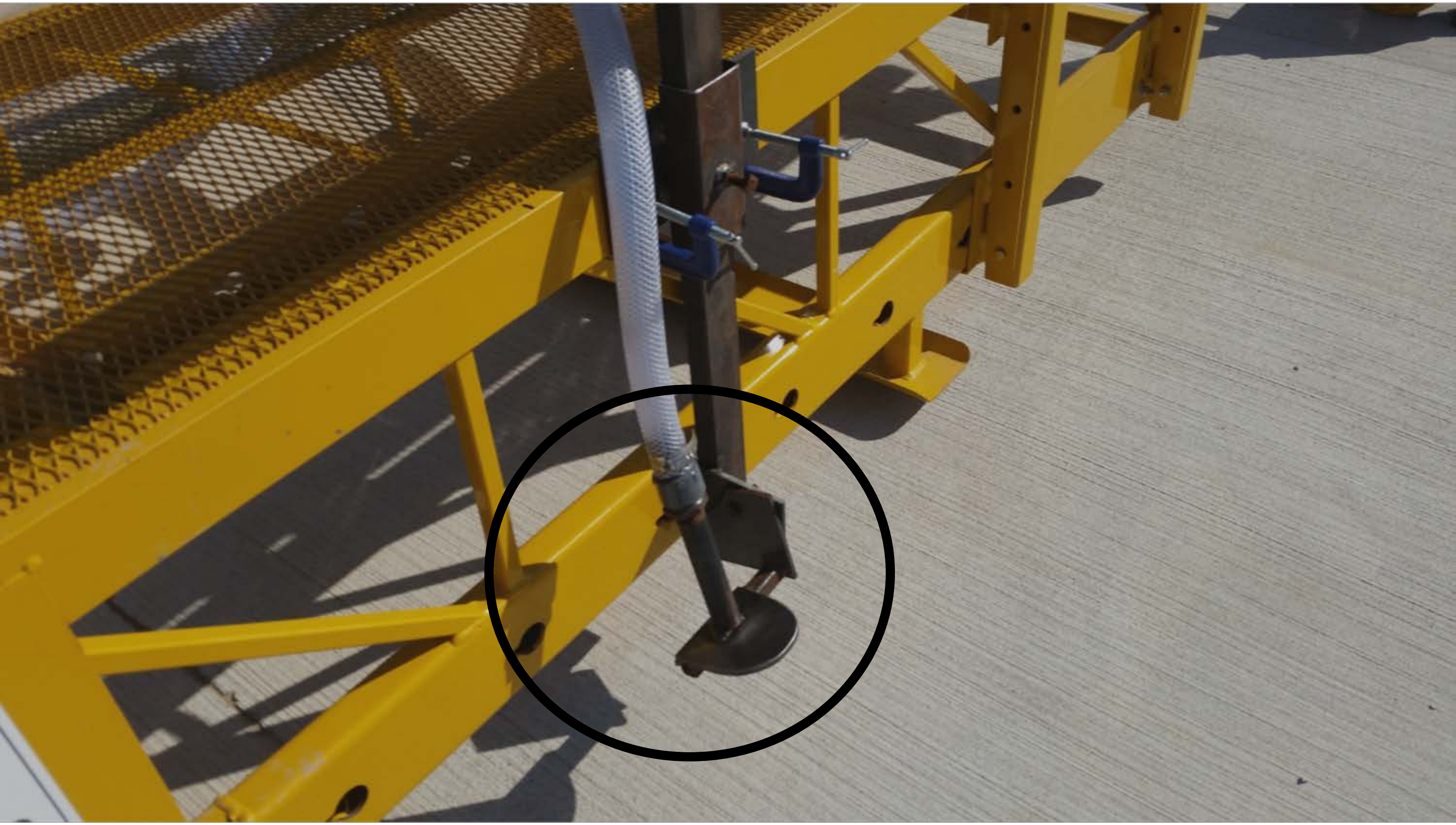
For some applications this is done with a machine and for others it can be done by hand

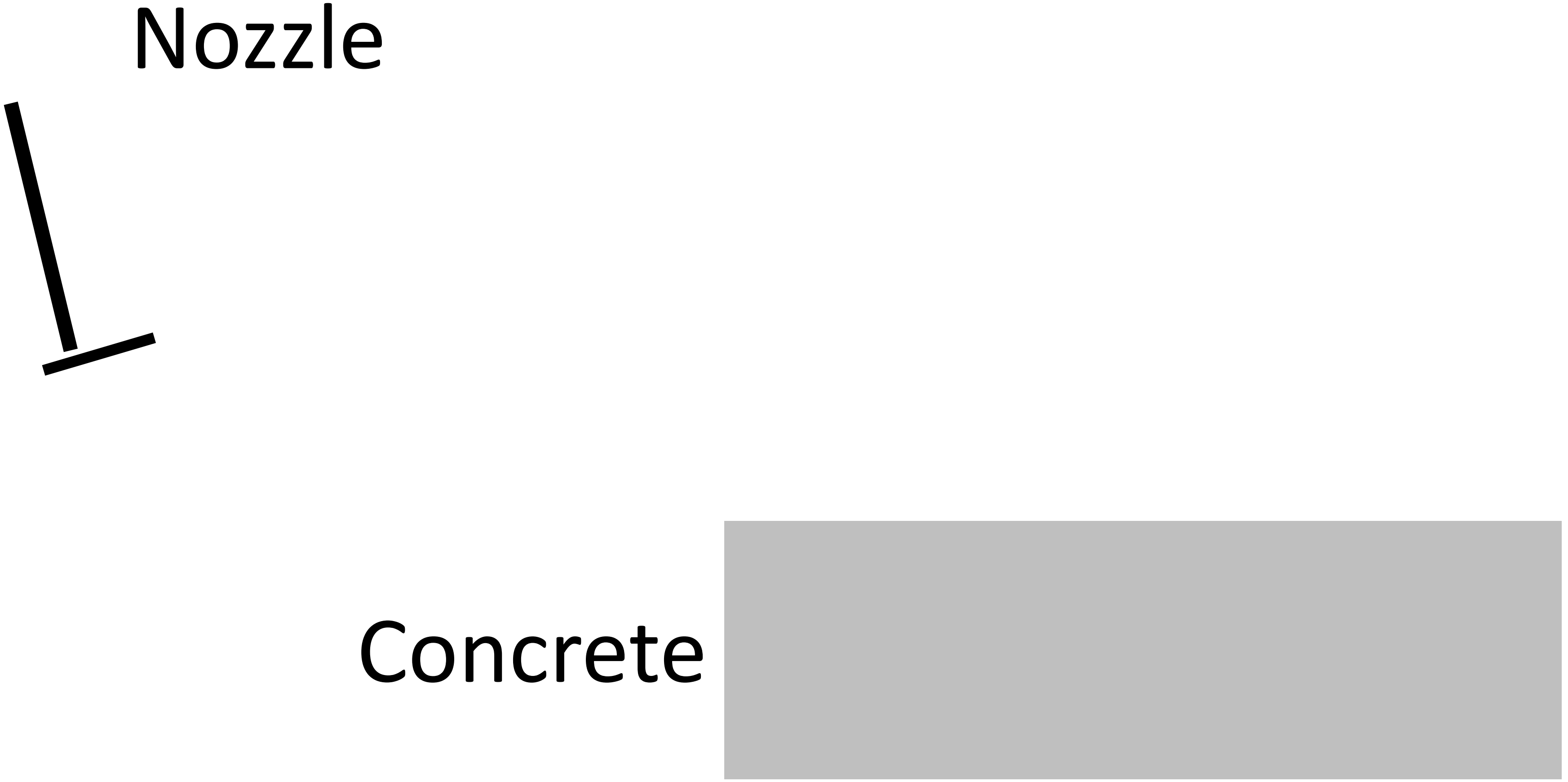
If you use the material in combination with plastic it will hold moisture for months.

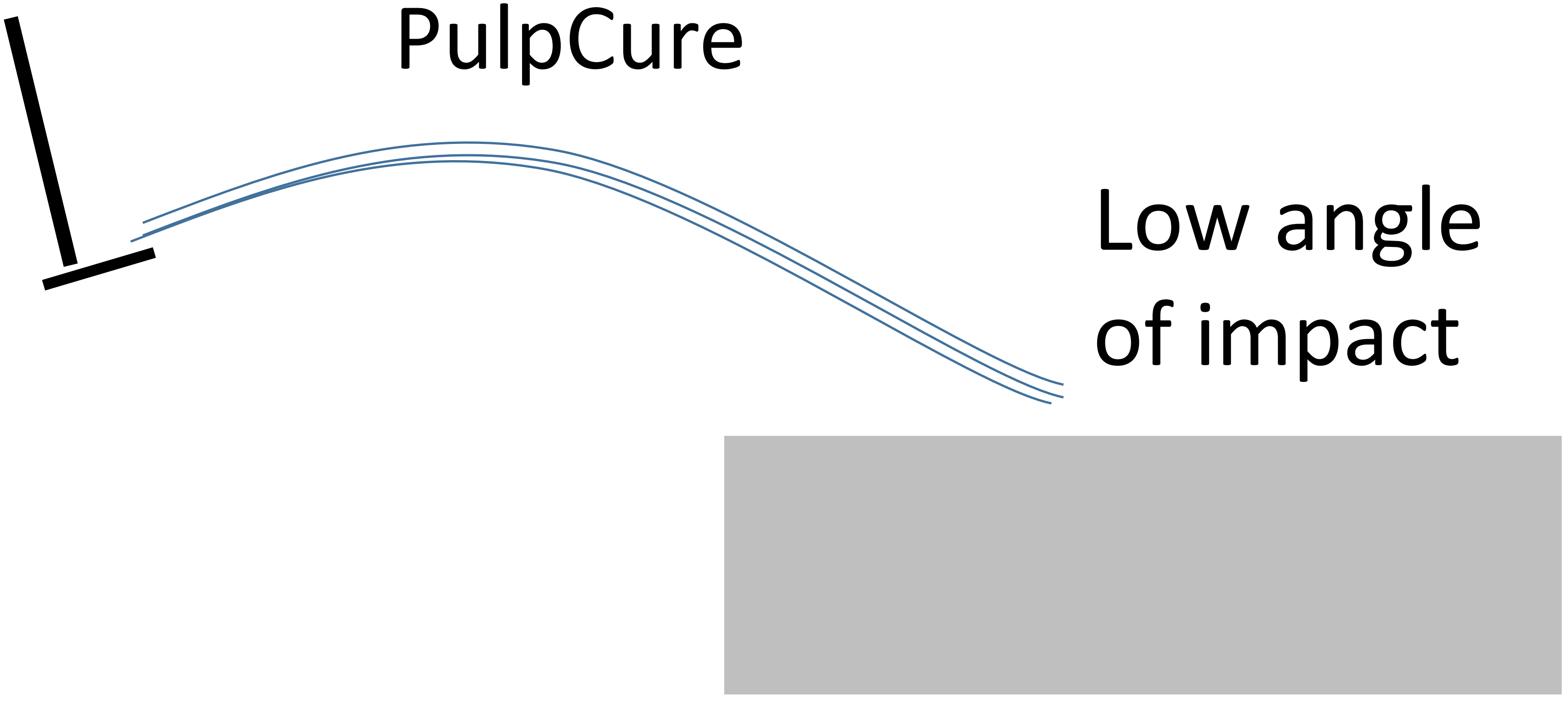
Remove with shovels, street broom, water pressure, or bobcat with a modified shovel

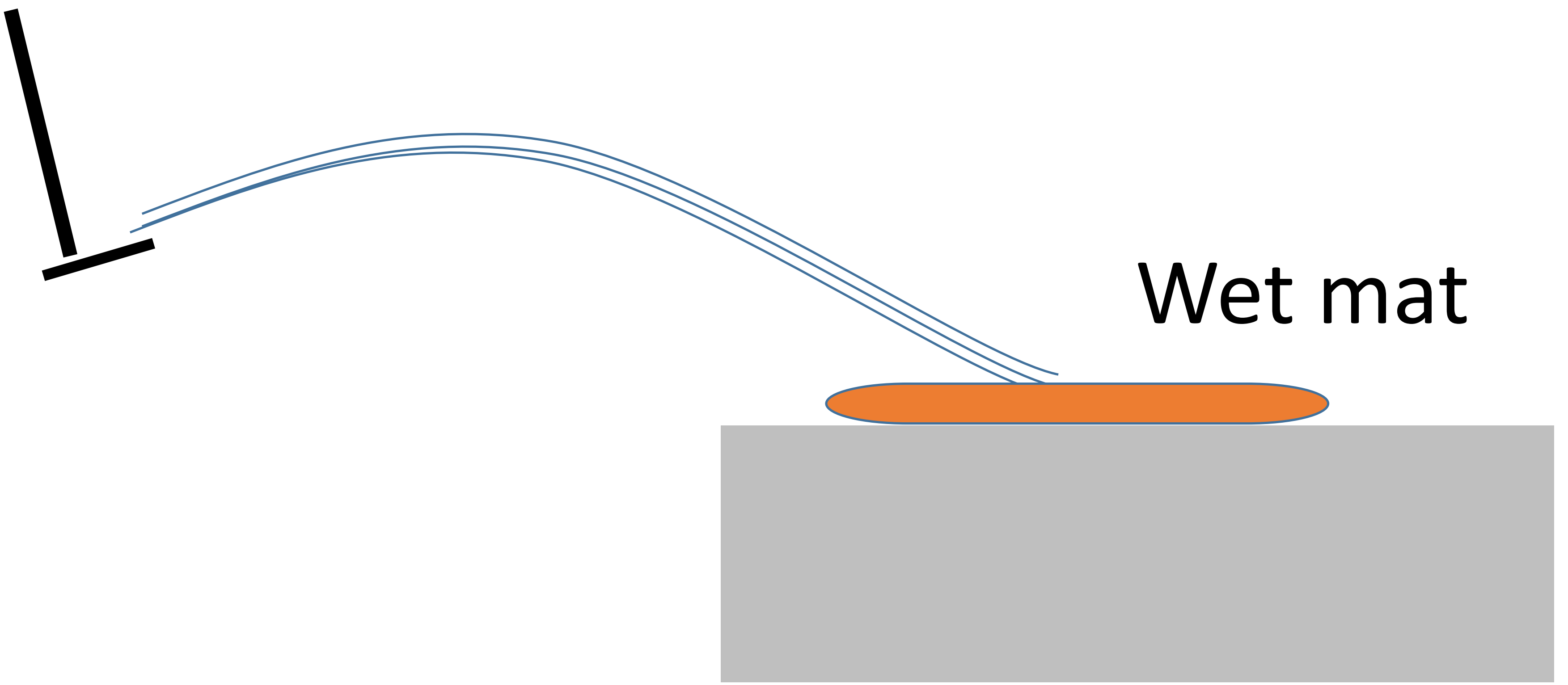
550 gallon applicator


TEREX




Nozzle
Concrete


PulpCure
Low angle
of impact


Wet mat

Watch this video

Google: Youtube pulpcure

https://www.youtube.com/watch?v=oDzPqMqUy7E

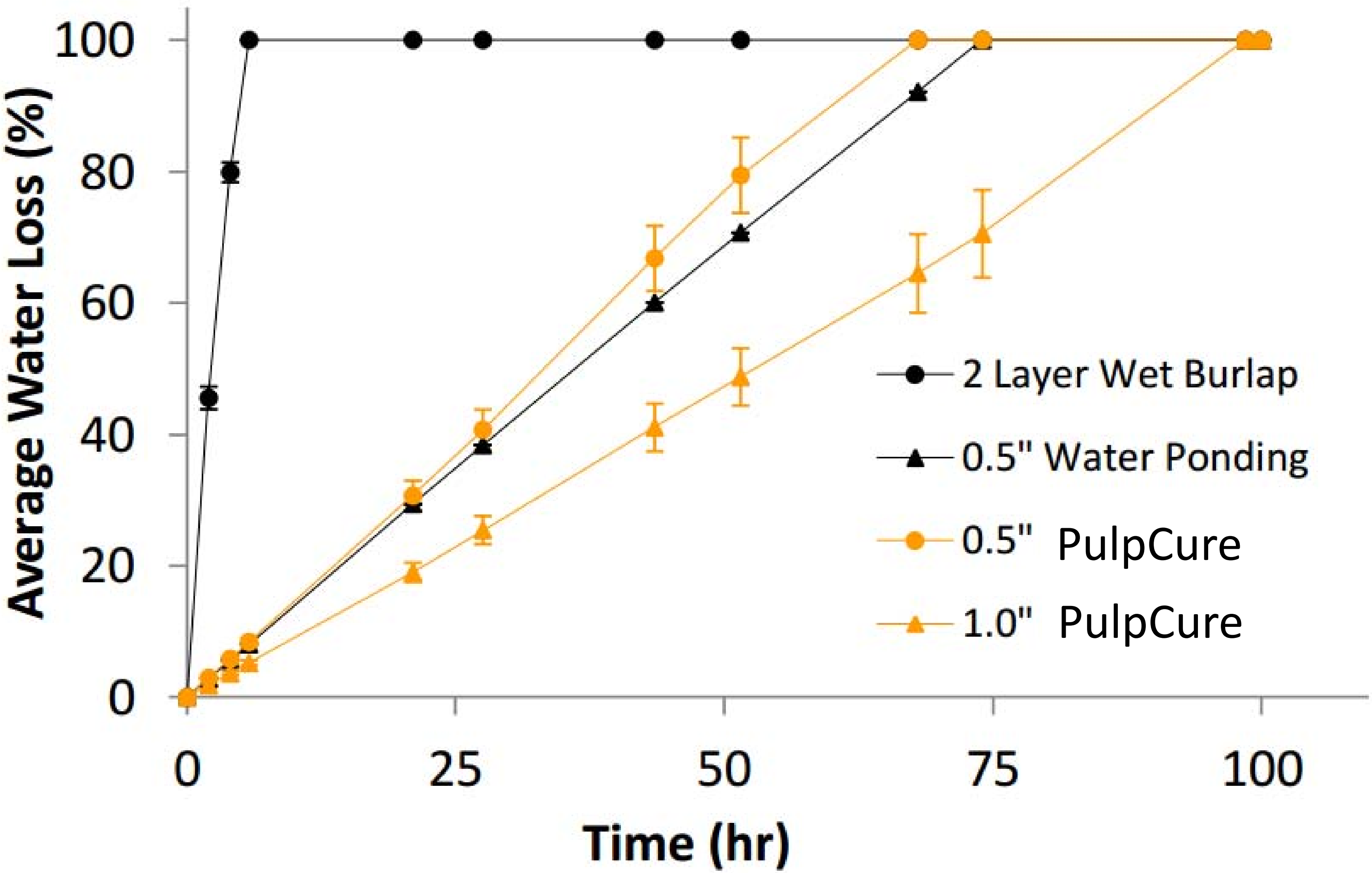

11/03/2015


11/03/2015

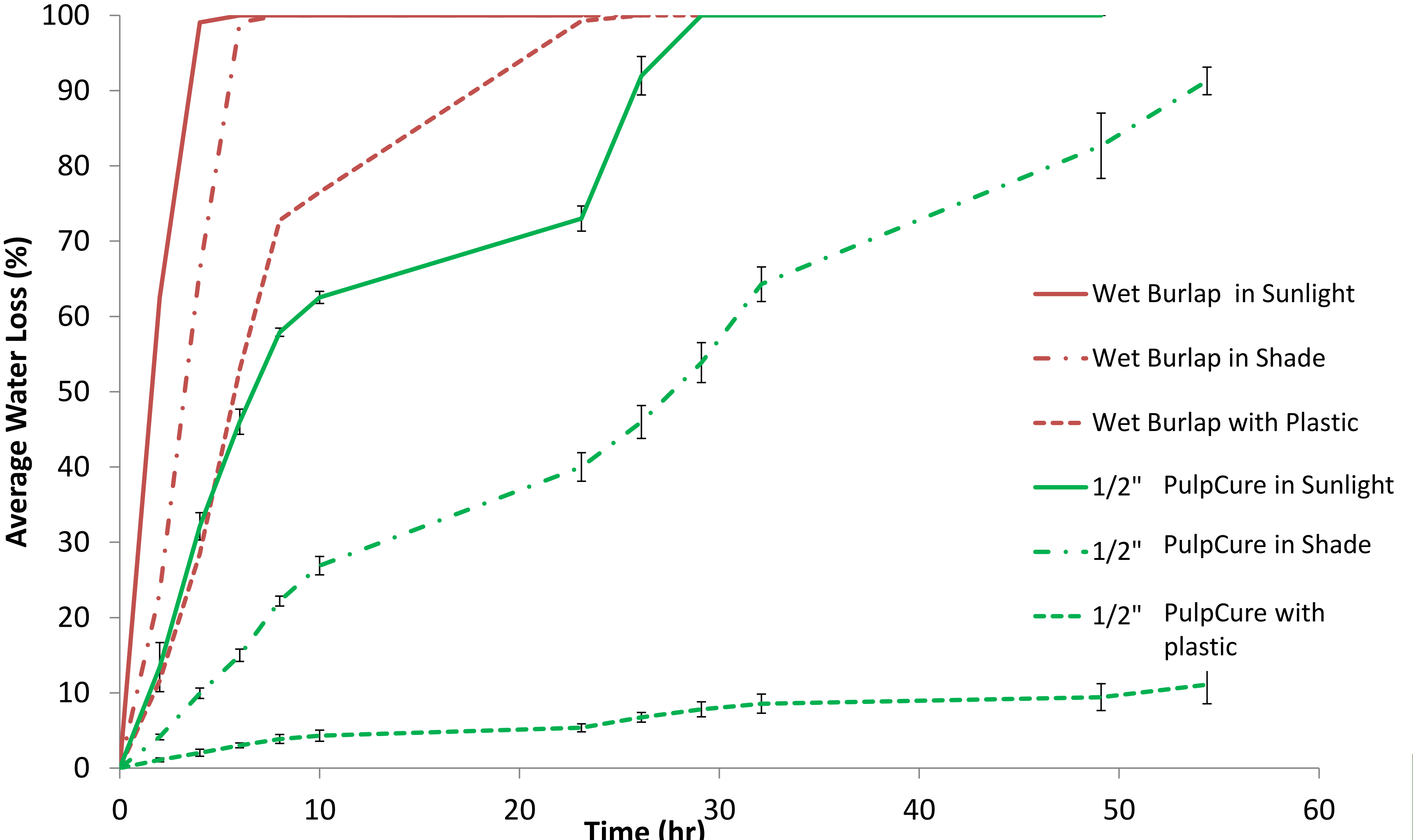

11/03/2015

How Does it Perform?

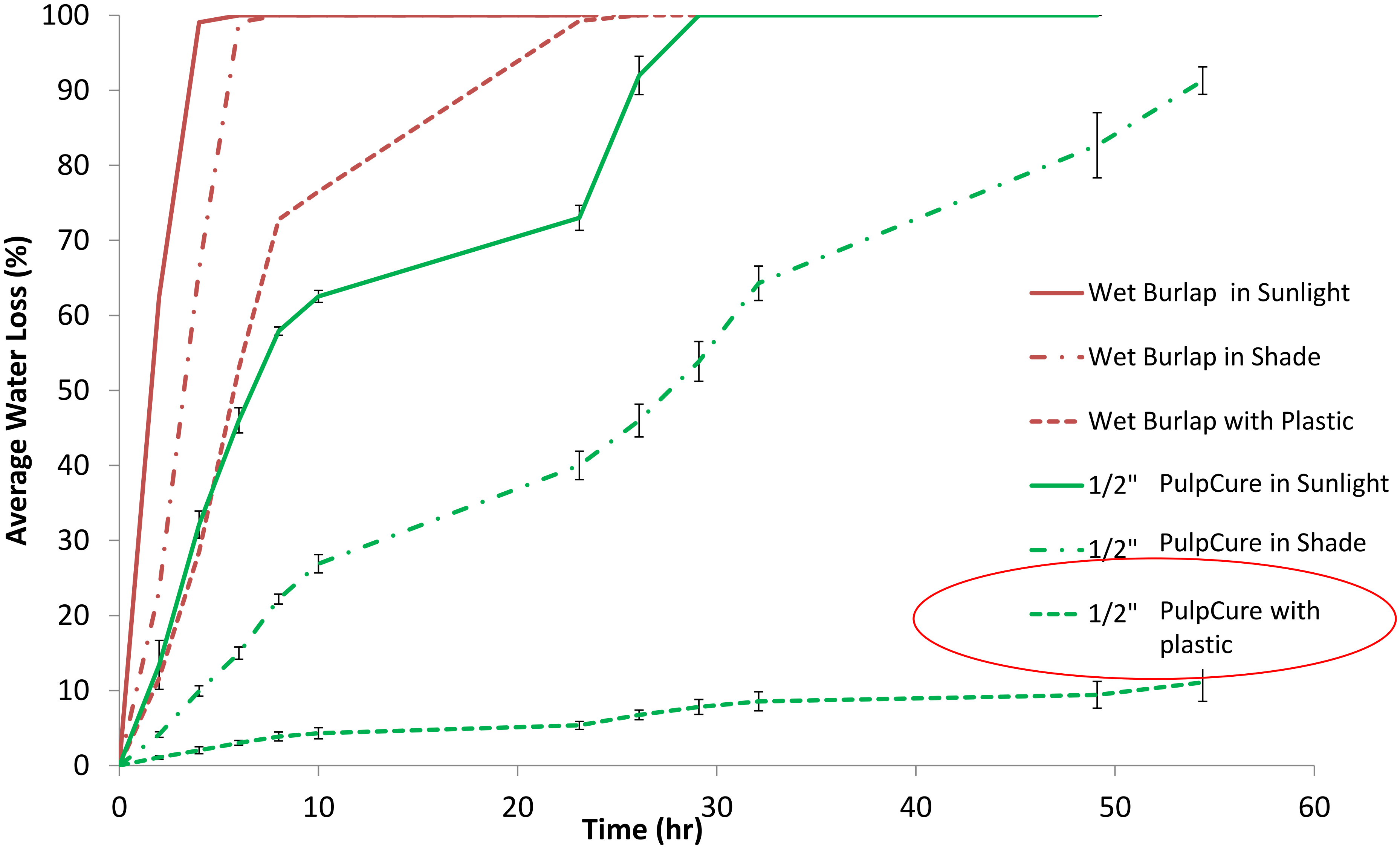
Samples are stored in 73^{o}F and 40% RH



Samples are stored outside in June
Min temp 60°F, Max Temp 105°F and 55% RH



Samples are stored outside in June
Min temp 60ºF, Max Temp 105ºF and 55% RH



Why is wet curing challenging?

1. Wet curing requires significant labor
2. If placed too early wet burlap can scar the surface and reduce cover
3. We don’t do a good job of keeping the burlap wet
4. Challenging to inspect
5. Expensive

What are the benefits?

- Contractors have estimated that curing with PulpCure will cost 30% less than curing with wet burlap
- There are significant savings in labor and water
- Since PulpCure can be placed so rapidly it can minimize plastic shrinkage cracking without harming the surface

What are the benefits?

- It can cut out interim curing steps like evaporation retarder and curing compounds
- Curing is done at the surface where it is needed
- No additional water is needed after application
- Easy to apply and inspect
- The material can be re-used
- It is orange!!!

What are the drawbacks?

- You need a one time investment for specialized equipment ($18K)
- Little local experience with mixing and application

- Doing something new is scary!

Sisal Fiber Mats, 1930s

Pictures from Todd Hansen, Iowa DOT

Sisal Fiber Mats, 1930s

Pictures from Todd Hansen, Iowa DOT

Summary

- PulpCure is a recycled material that can be used to rapidly and economically wet cure with less labor
- It has been used successfully on three bridges in Oklahoma.
- When used at ½” thickness with plastic it will hold water a LONG time with no extra water added
- It is easy to remove when wet
- We are planning on using it on more bridges this spring.

Why is this important?

- Curing is important for our concrete!
- Wet curing creates an improved microstructure over not curing or curing compounds investigated.
- PulpCure makes it easier and cheaper to wet cure
- This is a new tool that has the potential to improve how we do business

Where should this be used?

- Bridge decks
- Substructure under joints
- Repair patches
- Thin overlays
- Sidewalks
- Driveways
- Anyplace where your concrete would benefit from a wet cure!

Summary

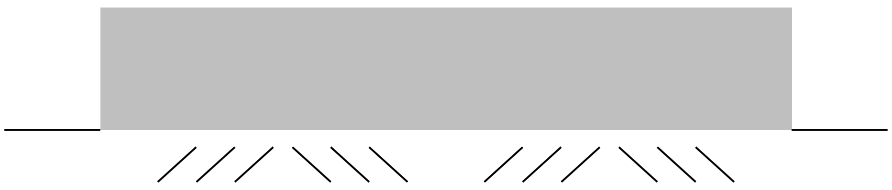
- Lithium silicate curing compound did not perform as well as wet curing or PAMS in drying, water sorption, or chloride penetration
- PAMS showed improved performance over lithium silicate but not as good performance as wet curing
- There was little difference between wet curing for 7, 10, and 14 days for with 20% Class C fly ash replacement at the conditions tested
- ½" of PulpCure with plastic has been used successfully as a replacement for wet curing on bridges in Oklahoma and they are performing well in the field

Questions?

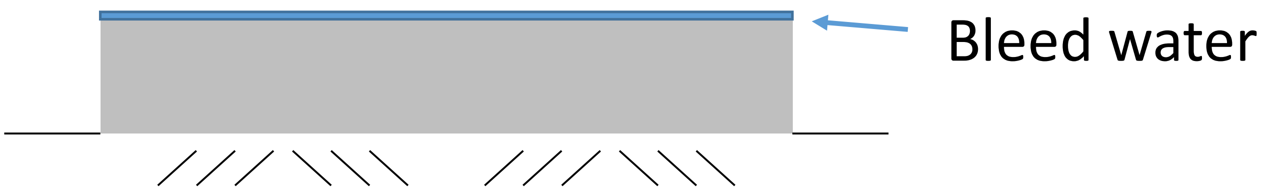
www.tylerley.com

Please subscribe to my concrete YouTube channel!

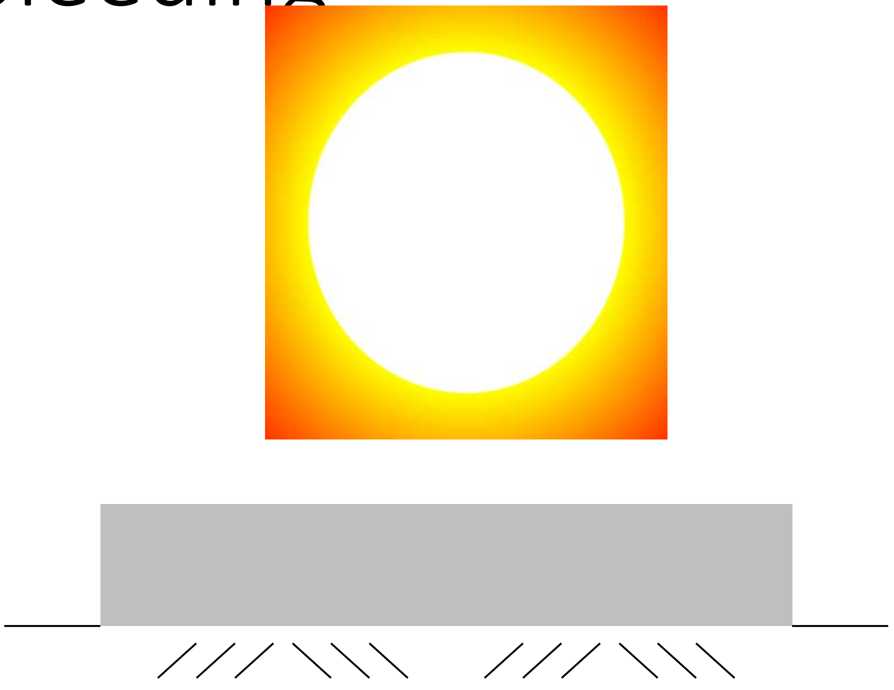
Go here!



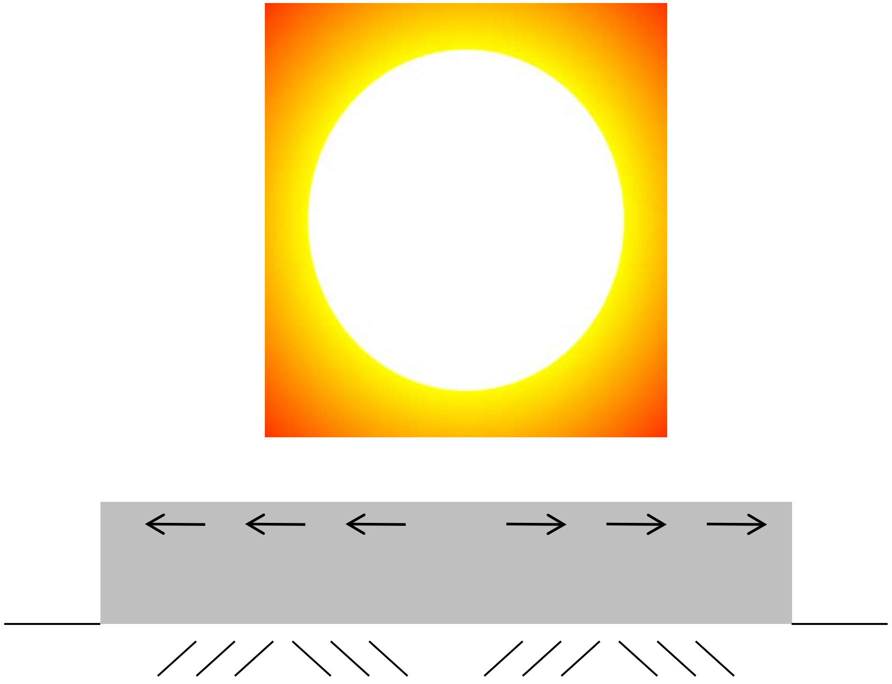
Bleed water appears after finishing



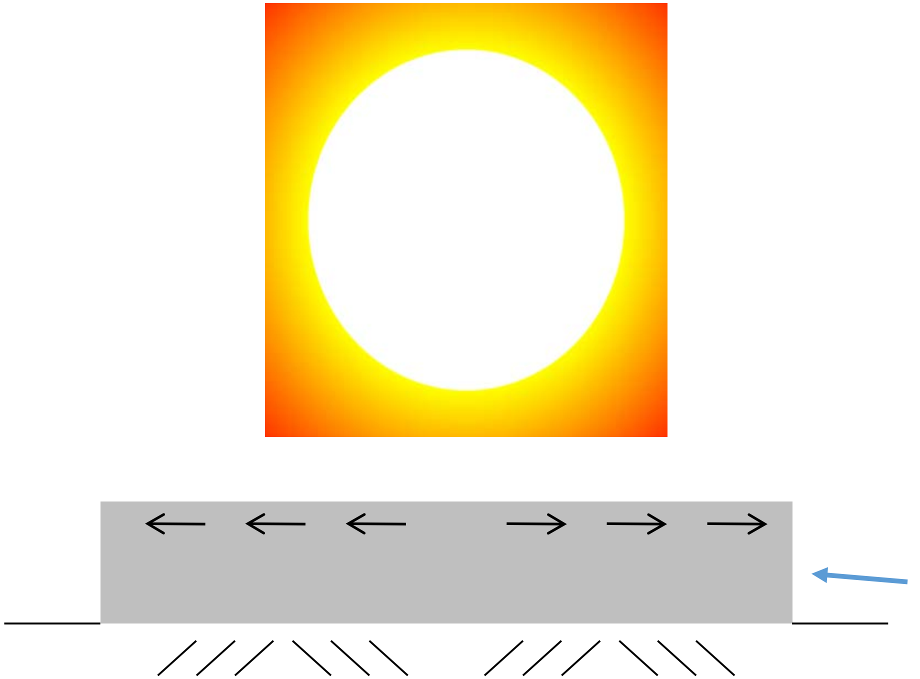
If the evaporation rate exceeds the rate of bleeding



The concrete at the surface dries and shrinks

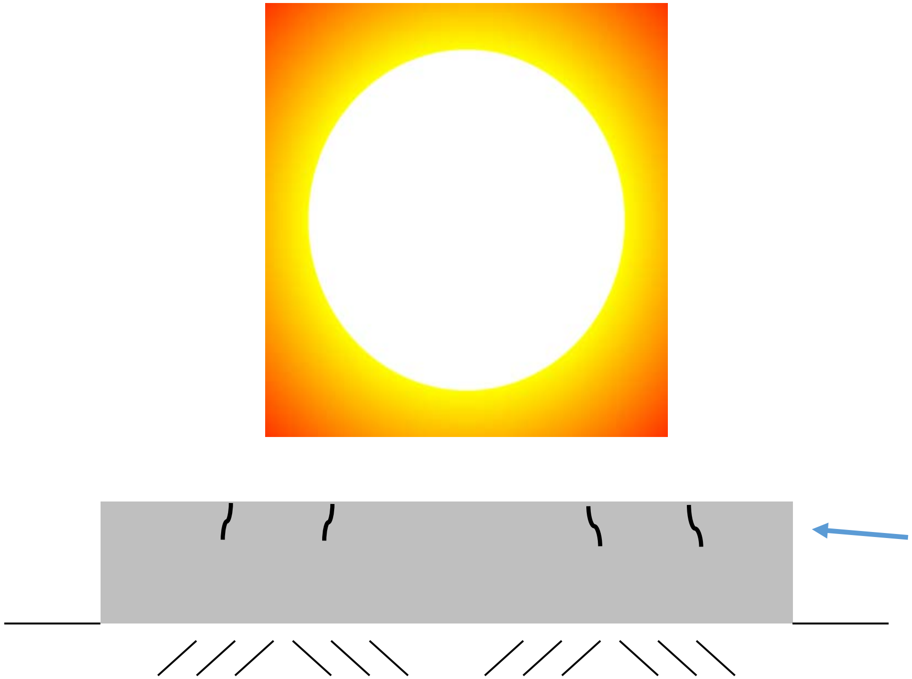


The concrete at the surface dries and shrinks



The moist concrete below restrains the shrinkage

The "plastic" concrete cracks



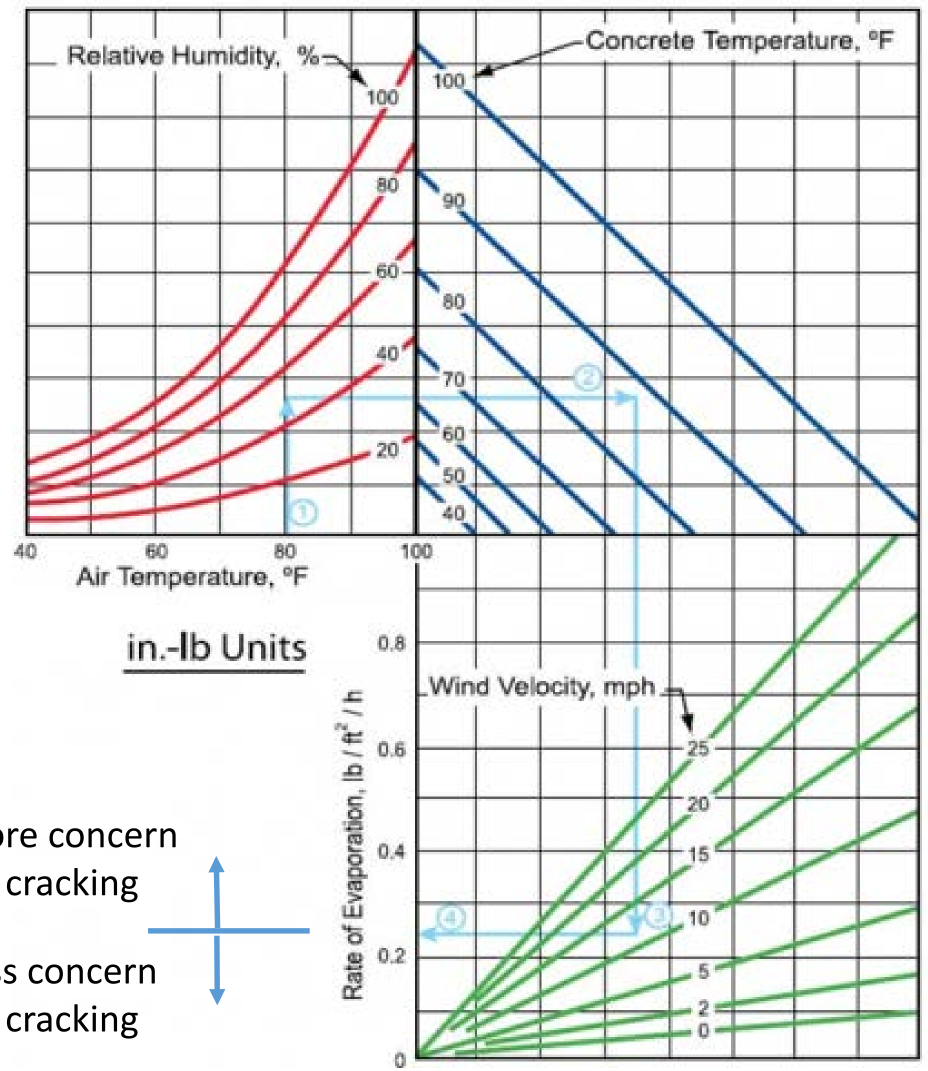
The cracks are near the surface

Plastic Shrinkage Cracking

This process is a function of:

the paste content, the water to cement ratio, the amount of SCMs, age of your mixture at strike off, admixtures

air temperature, relative humidity, concrete temperature, wind speed, sun exposure



More concern
for cracking

Less concern
for cracking

Remember!

Mixtures with more paste and are slower setting are more susceptible.

You can adjust your mixtures to lower the amount of plastic shrinkage cracking.

How do you stop plastic shrinkage cracking?

Fog surface

Evaporation retarder

Wind breaks

Curing compound

Plastic

Design mixtures to have lower amount of paste content

Avoid mixtures with long setting times

Be prepared

Both the weather and concrete is variable and so assume the worst will happen and be prepared.

No one is happy with immediate cracking on a project.

STEEL FIBER REINFORCED RUBBERIZED CONCRETE PRE-CAST PANELS FOR COLD REGION APPLICATIONS

Mahear A. Abou Eid, P.E.

INTRODUCTION

- Current Status
  - Longest studded tire season in US
  - Heavy rutting (>2”)
  - Freeze-thaw cracking

INTRODUCTION

- Current Mitigation
  - Routine Maintenance plans (Resurface ~7 yrs.)
  - Modified Asphalt Mixes (Rubber, Polymers and Hard Aggregates)

PROPOSED MITIGATION

- Steel Fiber-Reinforced Rubberized Concrete (SFRRC)
  - Flat End Steel Fibers
    - Minimize micro cracking
    - Bridge and bond concrete
  - Crumb Rubber
    - Replace Air Entrainment
    - Increase Durability

PRELIMINARY INVESTIGATION

- UAA Research (2012)
  - Steel Fiber Study
    - Flat End
  - Crumb rubber
    - ¼" particle size
  - Compressive Strength
    - 6710 psi
  - Flexural Strength
    - 1010 psi

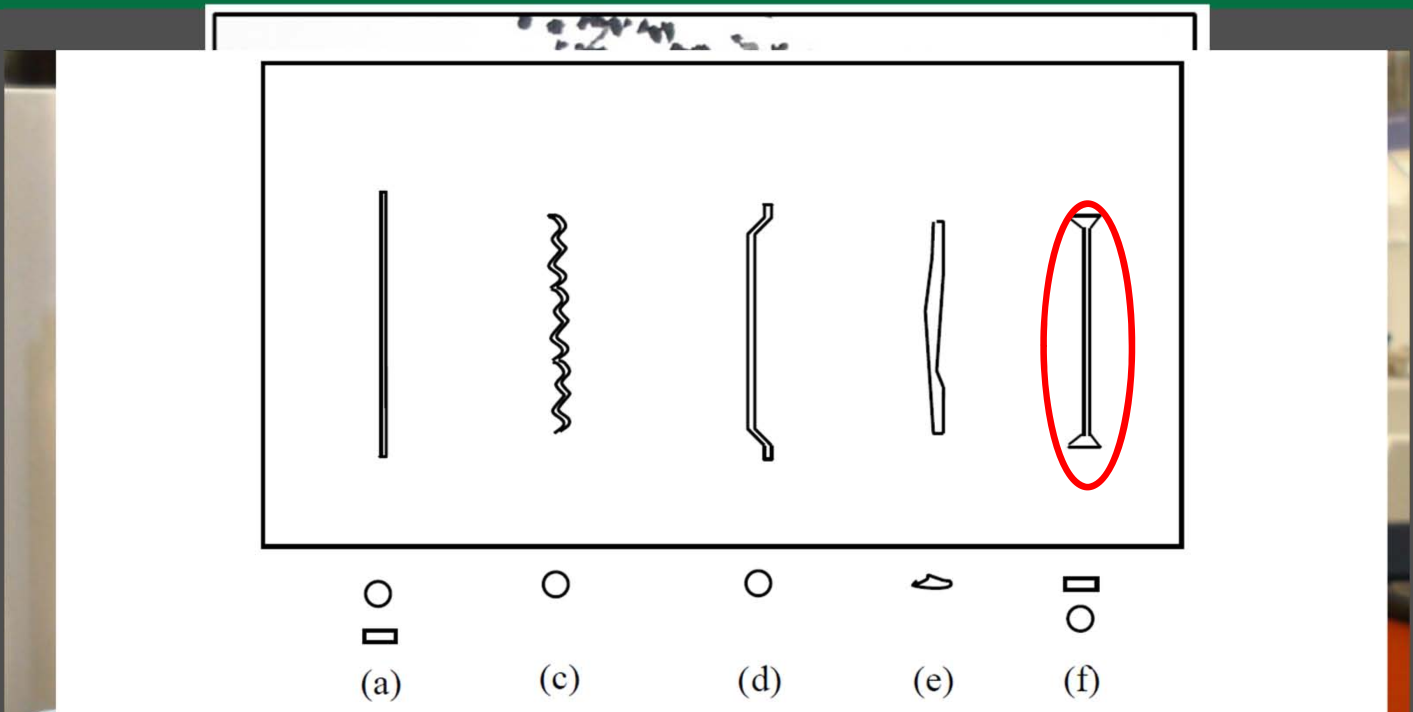


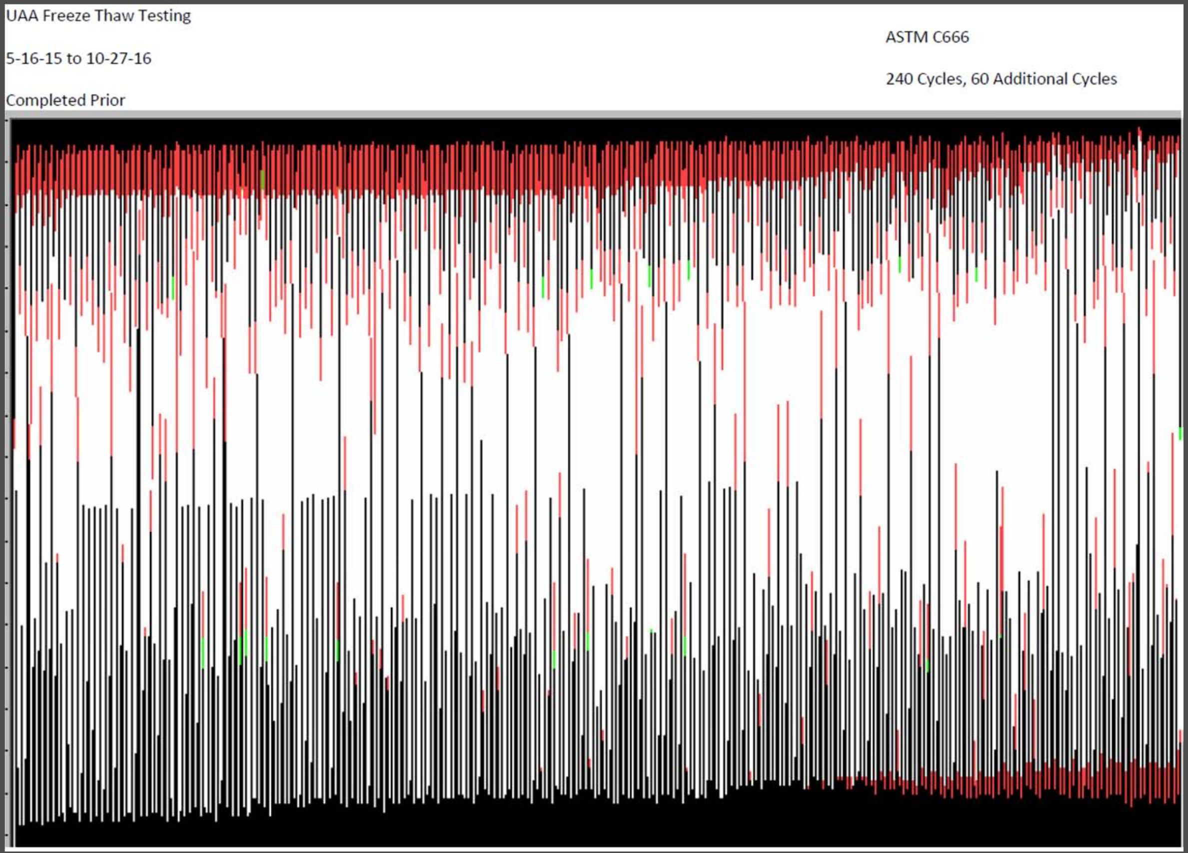
Figure 2.2: Various Shapes of Steel Fibers.
(a) Straight round or rectangular, (c) Deformed, (d)
(b) Crimped-End, (e) Melt extract process, (f) Flat-End round or rectangular

CURRENT INVESTIGATION

- Problem Statement
  - SFRRC in high volume intersections can cost effectively reduce rutting and increase service life.
- Objective
  - Reduce overall rutting compared to HMA
  - Withstand the freeze-thaw cycles

FREEZE-THAW TESTING

- ASTM C666
- 300 cycles
- Test Compressive Strength
- UAA Apparatus had a long duration
- Applied Testing and Geosciences
- Test Relative Dynamic Modulus of Elasticity (RDME)



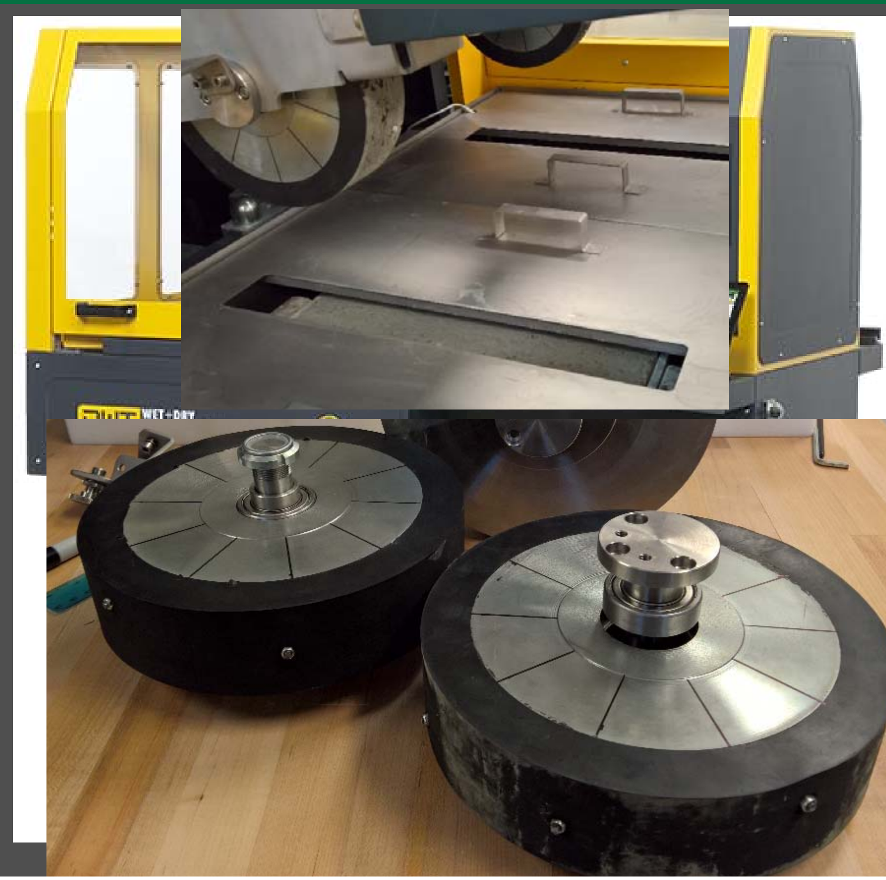
FREEZE-THAW RESULTS

- Applied Testing & Geosciences
  - Trial 1
    - Only 7% drop in compressive strength
    - RDME value of 96%
  - Trial 2
    - Increase of 15% in compressive strength
    - RDME value of 97%

- UAA Apparatus Testing
    - Compressive strength values within 1% Trial 2
    - Increase of 15% in compressive strength

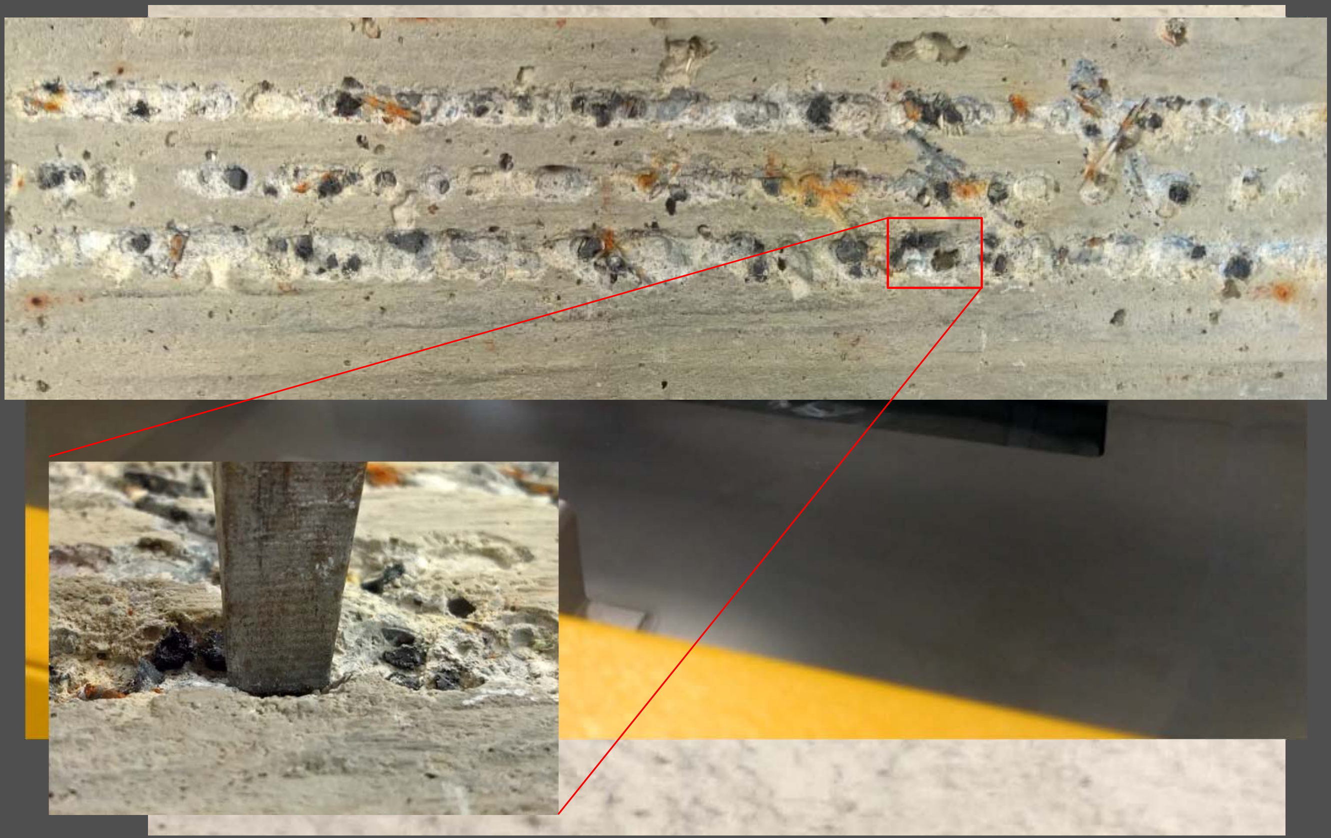
WHEEL TRACKER TESTING

- Controls DWT
- AASHTO T324
  - Steel Wheel Testing
- Studded Tire Testing
  - Stud spacing
  - Rotating wheel
    - 100 cycles



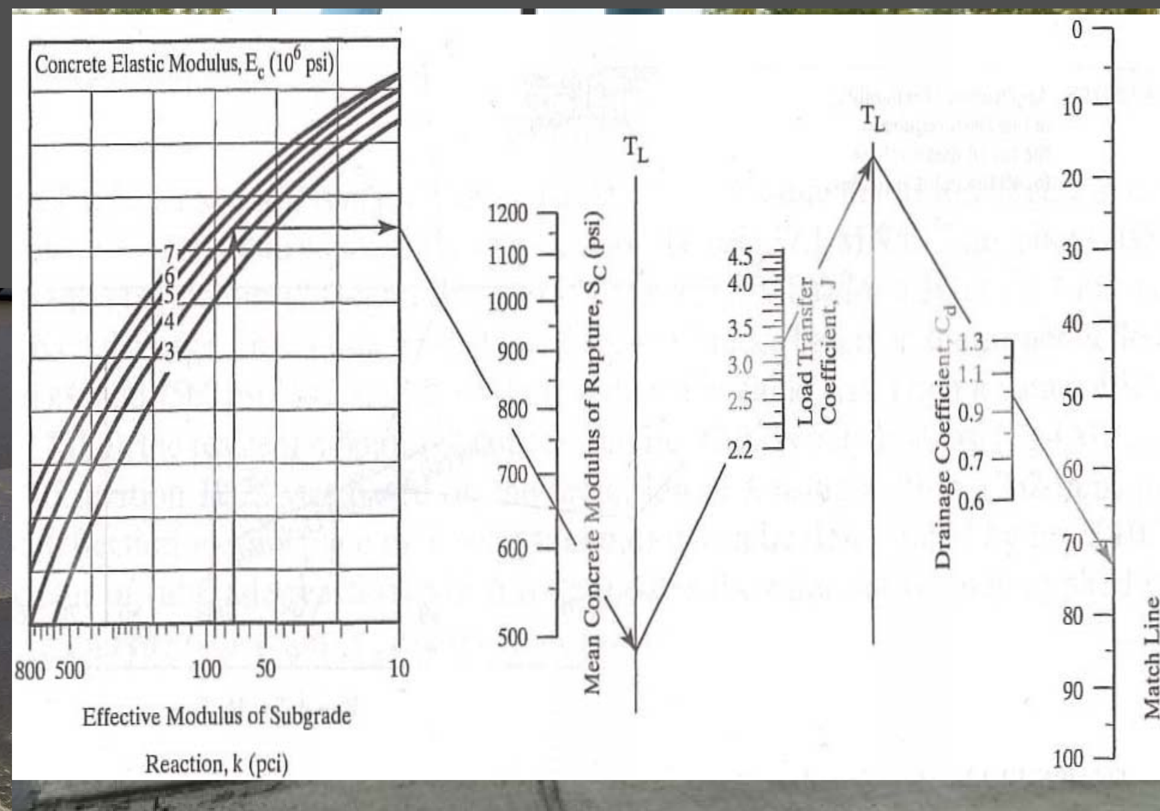
WHEEL TRACKER RESULTS

- Steel Wheel:
  - 20,000 cycles
  - <0.01 inch deformation
  - HMA, approximately 0.07 inch
- Rubber Tire:
  - 20,000 cycles
  - Rotate tire 200 times
  - Stud impacts throughout path
  - <0.25 inch rut
  - Steel fibers distributed across rut path



IN-SITU TEST SLAB

- Purpose
  - Conduct in-situ freeze-thaw and rut testing
  - Gather production mixing and placing data
  - Develop slab design



IN-SITU TEST SLAB OBSERVATIONS

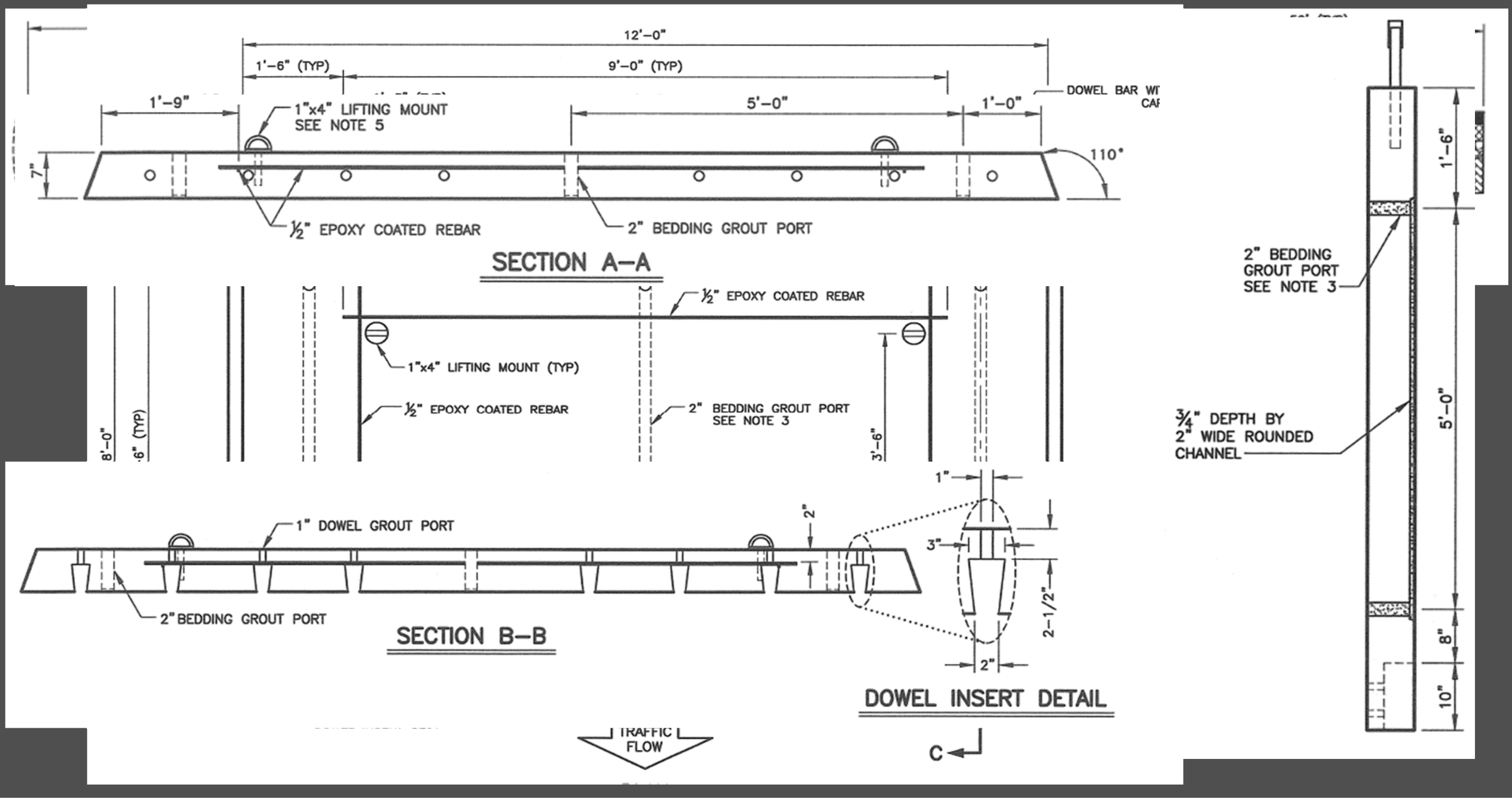
- Initial Conditions
  - Broom texture
  - Smooth transitions
  - No ponding water
- First Season of Use
  - No rutting
  - No thermal cracking
  - Minor delamination of crumb rubber and steel fibers
  - Settlement at Joint

LARGE SCALE TEST SECTION

- Test Section Proposal Accepted by AKDOT
- Capital Project Selected
- Design Constraints
  - Simplified Geometry
  - Pre-Cast Panels

TEST SECTION PANEL DETAILS

- Panel Dimensions
- Cross Sections
- Dowel Design
- Structural Section



TEST SECTION PRE-CASTING

D&S Concrete

- Forms Made
- Strain Gages Installed
- Concrete Poured
- Stored for one season

TEST SECTION PLACEMENT

Contractor QAP

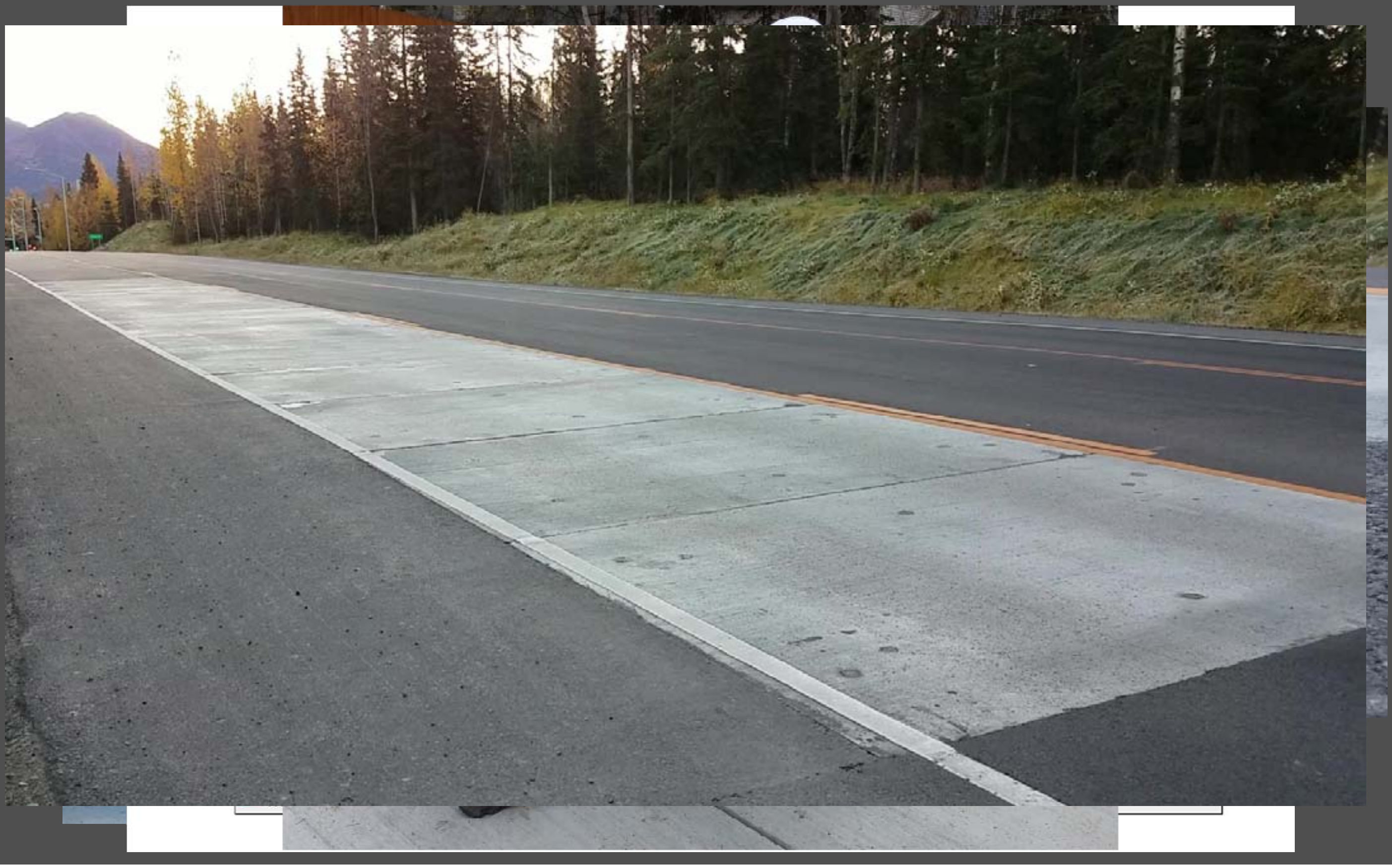
- Prepare Grade and Subbase
- Transport Slabs Onsite
- Place and align panels

TEST SECTION GROUT AND TIE-IN

- Dowel Grout
- Bedding Grout
- HMA ATB Tie-in
- Top Lift HMA

TEST SECTION MONITORING

- Falling Weight Deflectometer
  - Joint Transfer Efficiency
  - Load Bearing Failure
- Strain Gage and ATR Data
- Rut Depth Measurements
- Skid Resistance
- Visual Inspection
  - Dowel Grout
  - Joint Seals
  - Settlement
  - Surface Wear or Deterioration



ACKNOWLEDGEMENTS

- Professor Osama Abaza
- UAA Facilities
- Department of Transportation
- QAP
- AS&G
- Propex

QUESTIONS?

Thank You!

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INNOVATION & QUALITY SINCE 1951

HISTORY OF PRESTRESSED/PRECAST CONCRETE

Cameron West, P.E.
Chief Engineer

What is Precast Concrete?

- Precast concrete is a construction product that is manufactured in a location that is not its service location

- It is usually manufactured in a plant specifically designed for the production of precast concrete

What is Precast Concrete?

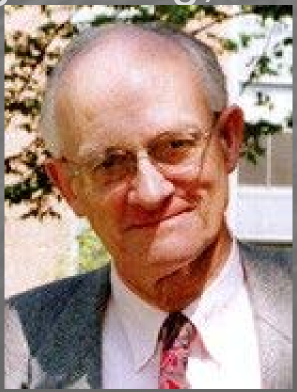
- The products are then sent to the job site by truck, ship, or rail
- Once on site, it is erected into the structure

What is Prestressed Concrete?

"The idea of prestressing, a product of the twentieth century, announced the single most significant new direction in structural engineering of any period of history"

-David P. Billington

Professor of Civil Engineering, Princeton University

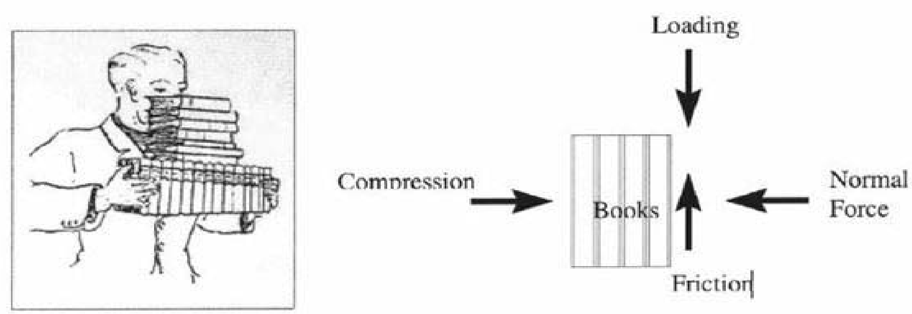


What is Prestressed Concrete?
Basic Theory

- Concrete alone is strong in compression, but weak in tension

- The intent of prestressing is to induce stresses in the concrete opposite to those stresses resulting from applied service loads.

- To visualize this, consider that prestressed flexural members come to the jobsite with camber (upward deflection), while the effect of design loads is to create sag (downward deflection). These theoretically cancel each other.



The figure shows a basic prestressing idea at work.

What is Prestressed Concrete?
Pretensioned vs. Post-tensioned

- Prestressed concrete is concrete that is put in under compressive stress before service loads are applied.

- The two methods to obtain prestressed concrete are pretensioning and post-tensioning

- This pre- and post- are related to the timing of tensioning relative to concrete placement

What is Pretensioned Concrete?

- High strength steel strands are pulled between two abutments.

What is Pretensioned Concrete?

- High strength steel strands are pulled between two abutments.

What is Pretensioned Concrete?

- Concrete is cast around the strands and mild reinforcement.

What is Pretensioned Concrete?

- When the concrete reaches a specified strength, the strands are released. This transfers the prestressing force into the concrete, which pre-compresses the member.
- This force is transferred to the concrete through bond of the strands.
- The precast/prestressed member can now be moved to the storage area.

What is Post-tensioned Concrete?

- Alternatively, concrete is placed and cured prior to tensioning the steel in post-tensioned concrete.
- The precast products are cast with ducts in which the stands will be placed.

What is Post-tensioned Concrete?

- Once the concrete has achieved the required strength, the precast pieces can be assembled.
- High strength strands or bars are installed in the ducts and tensioned.
- The precompression force is transferred to the concrete through anchorages in the product.

What is Post-tensioned Concrete?

- Once the concrete has achieved the required strength, the precast pieces can be assembled.
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What is Post-tensioned Concrete?

- Once the concrete has achieved the required strength, the precast pieces can be assembled.
- High strength strands or bars are installed in the ducts and tensioned.
- The precompression force is transferred to the concrete through anchorages in the product.

Special Considerations

- Transportation
  - Must be able to transport and erect
- Camber
  - How does this affect interfacing with other materials?
  - There are ways to alleviate camber
- Economy Through Repetition
  - Excessive form changes or non-standard sections can be costly

How Did We Get Here?

- Patents related to prestressed concrete go back to the 1870s in US and Europe

- Eugene Freyssinet (1879-1962, France)
  - 1904 – First considers the potential of prestressing
  - 1920s and 1930s – Recognizes the need for high strength steel, affects of creep and shrinkage, develops anchorages and jacking systems

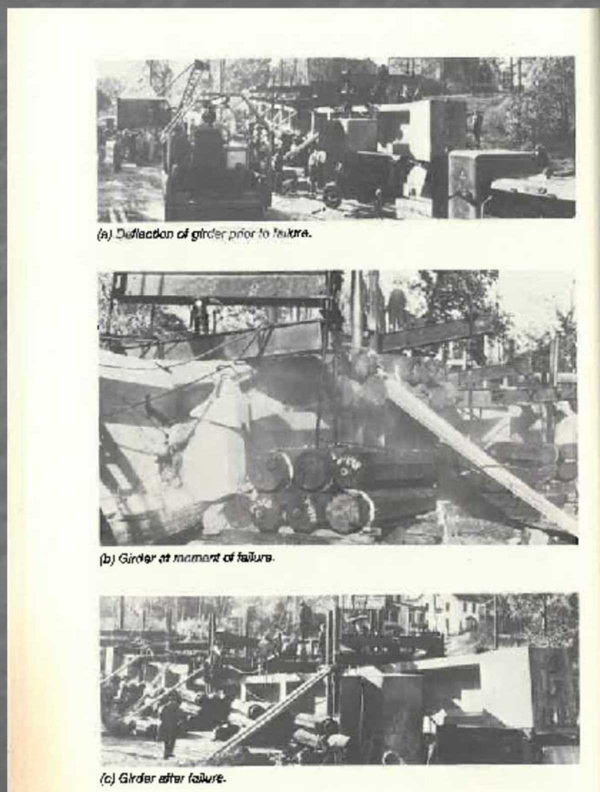
Spreading a New Technology

- Gustave Magnel (1889-1955, Belgium)
  - Also worked on creep and shrinkage
  - Developed anchorage system
  - Influential in Europe and US
  - Travelled to US in 1946

Walnut Lane Bridge

- First prestressed bridge in the US, opened 1951
- Magnel designed and oversaw construction
- 155 ft. center span and 74 ft. end spans
- 79 in. deep girders with 52 in. flanges

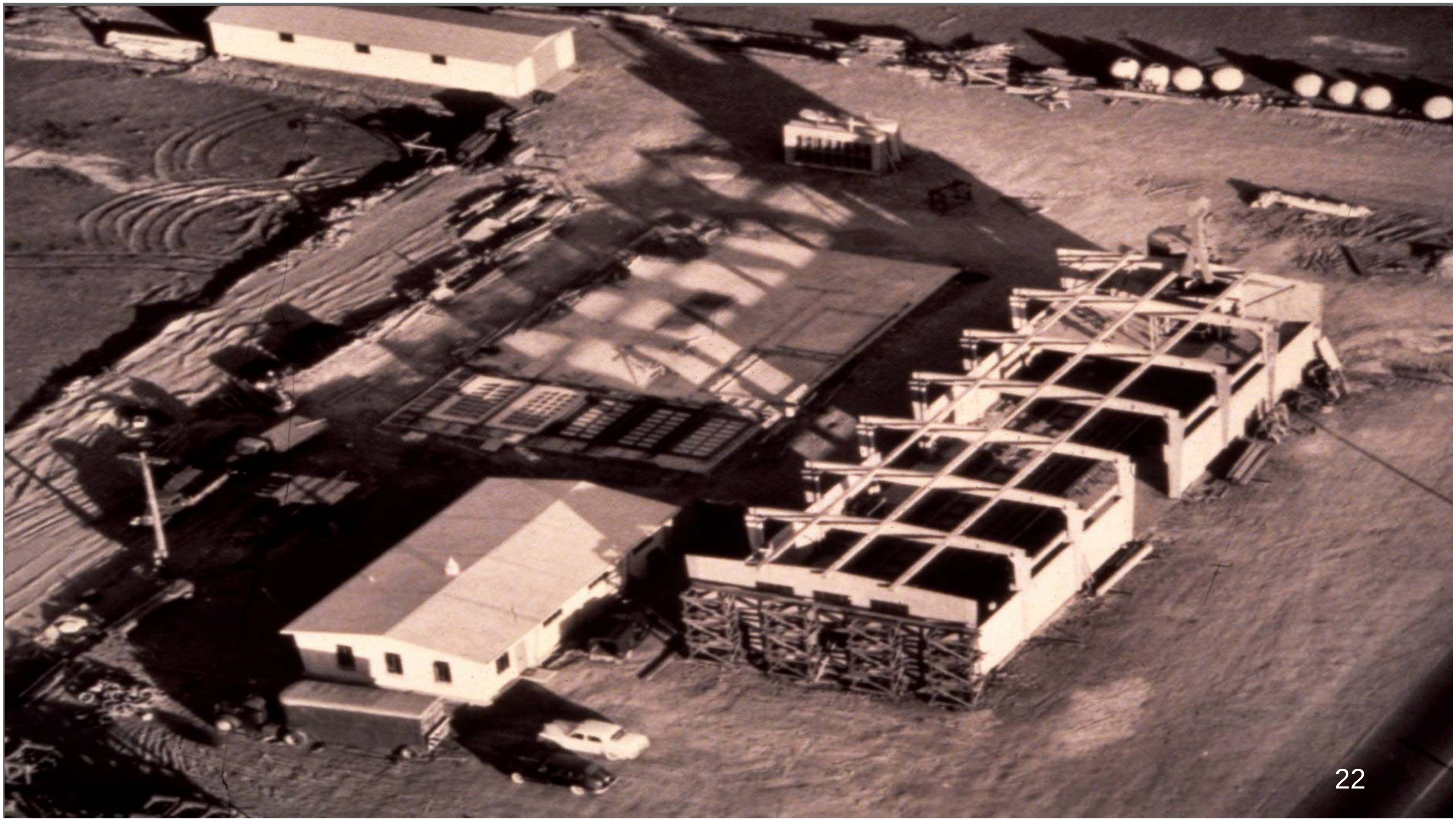
Walnut Lane Bridge Testing



- Included a full-scale test to destruction of a 160 ft. girder in 1949
- Successfully loaded to failure at about 10 times the working load
- Instrumentation by Art Anderson

History of Concrete Tech

- Founded by Art & Tom Anderson in 1951
- Industry pioneers
- One of first prestressed plant in the United States, fully precast, prestressed building
- Our components can be found in thousands of projects in the Pacific Northwest, Alaska, and Hawaii, including bridges, buildings, tanks, piers, and floats




Klickitat County Bridge - 1954
This segmental bridge was the first project to use the Anderson
Post-Tensioning System, the first system capable of using
7-wire prestress strand
LORAIN

Disneyworld Monorail

- 337 beams at 60 tons each shipped to Orlando Florida by train
- Some beams have three-dimensional curves; horizontal, vertical, and super-elevation


MONORAIL COAST-TO-COAST
Walt Disney World FLORIDA

Cheney Stadium

- All-precast construction, 1,650 elements
- Cantilevered roof - completely free of columns in seating area so there are no visual obstructions
- Design-build team completed the facility in 3 ½ months

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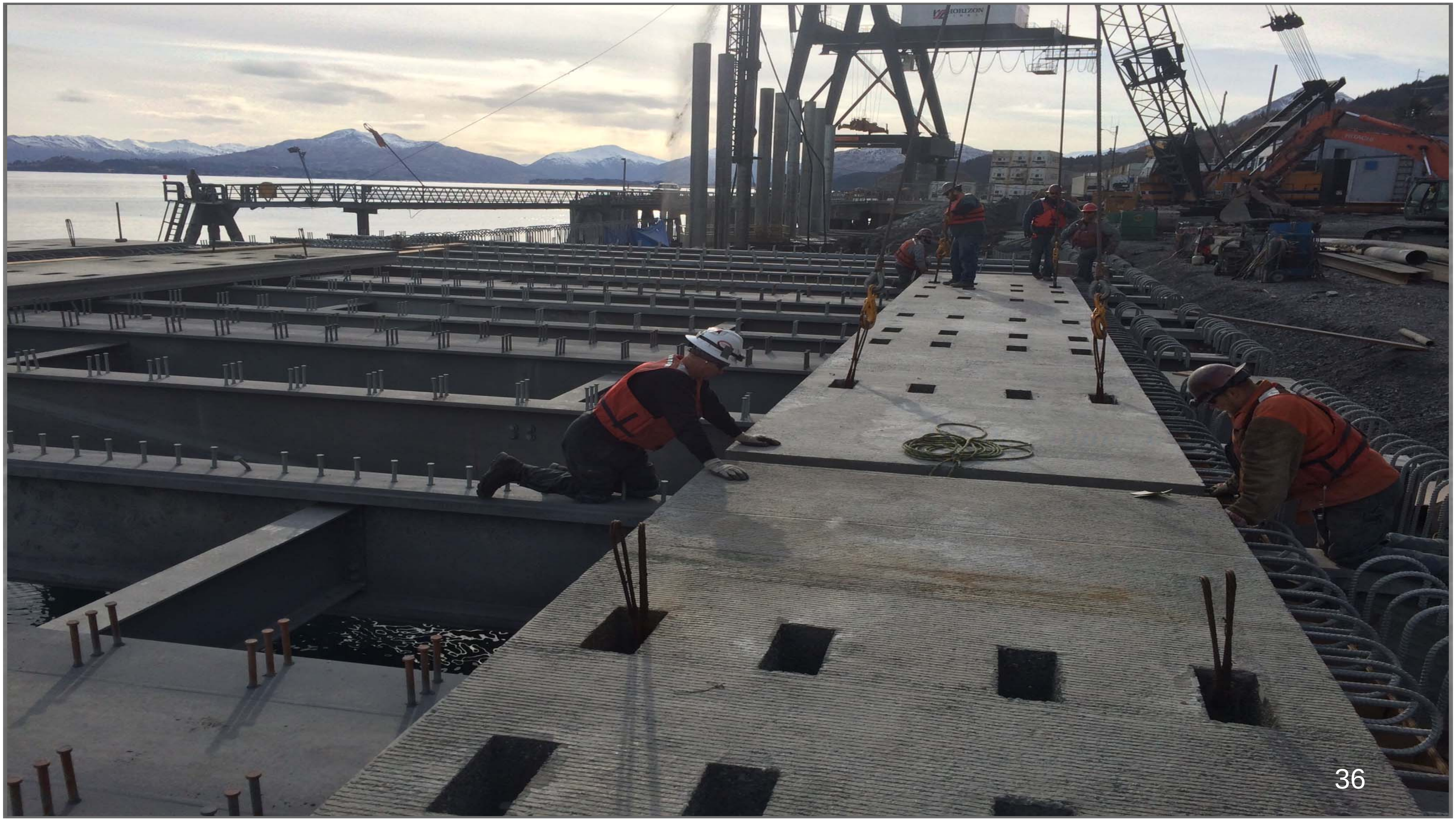
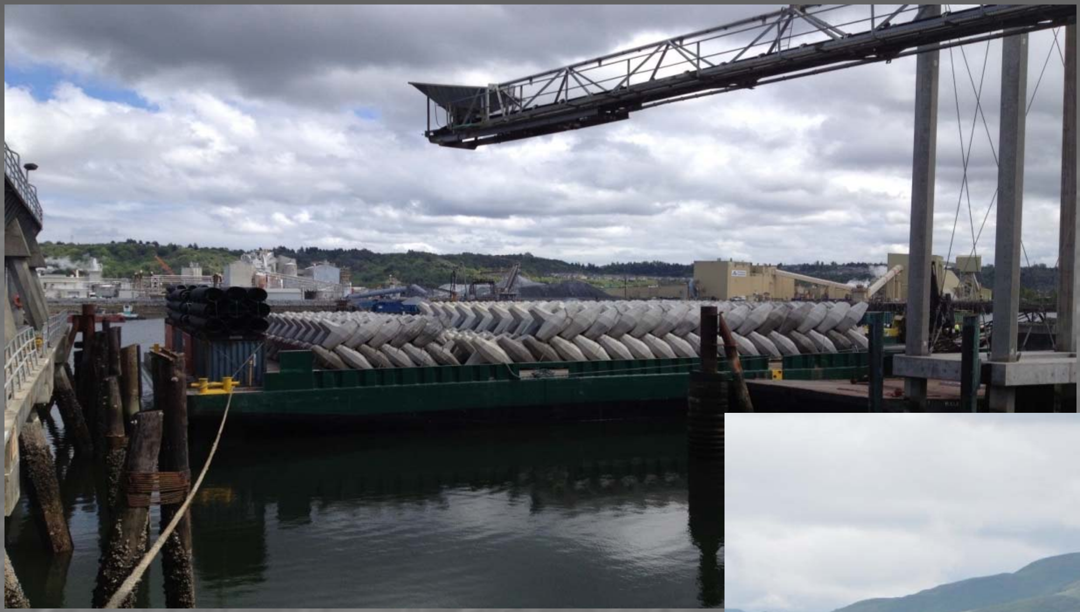
MARINE STRUCTURES


BRIDGE 70T





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Parking Garages, Buildings, and Tanks


JLG


CAUTION
HARD HAT
AREA

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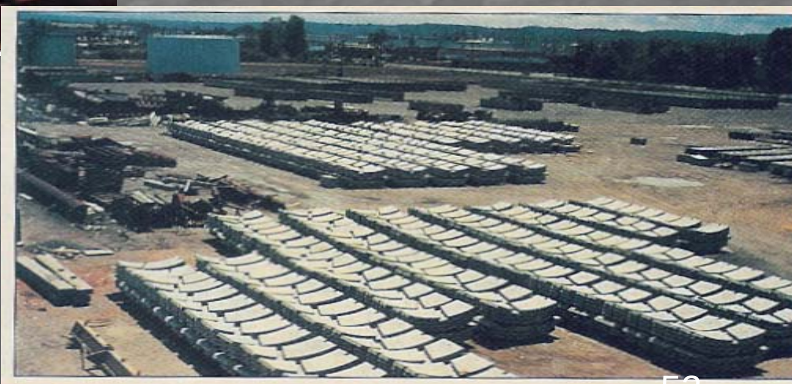
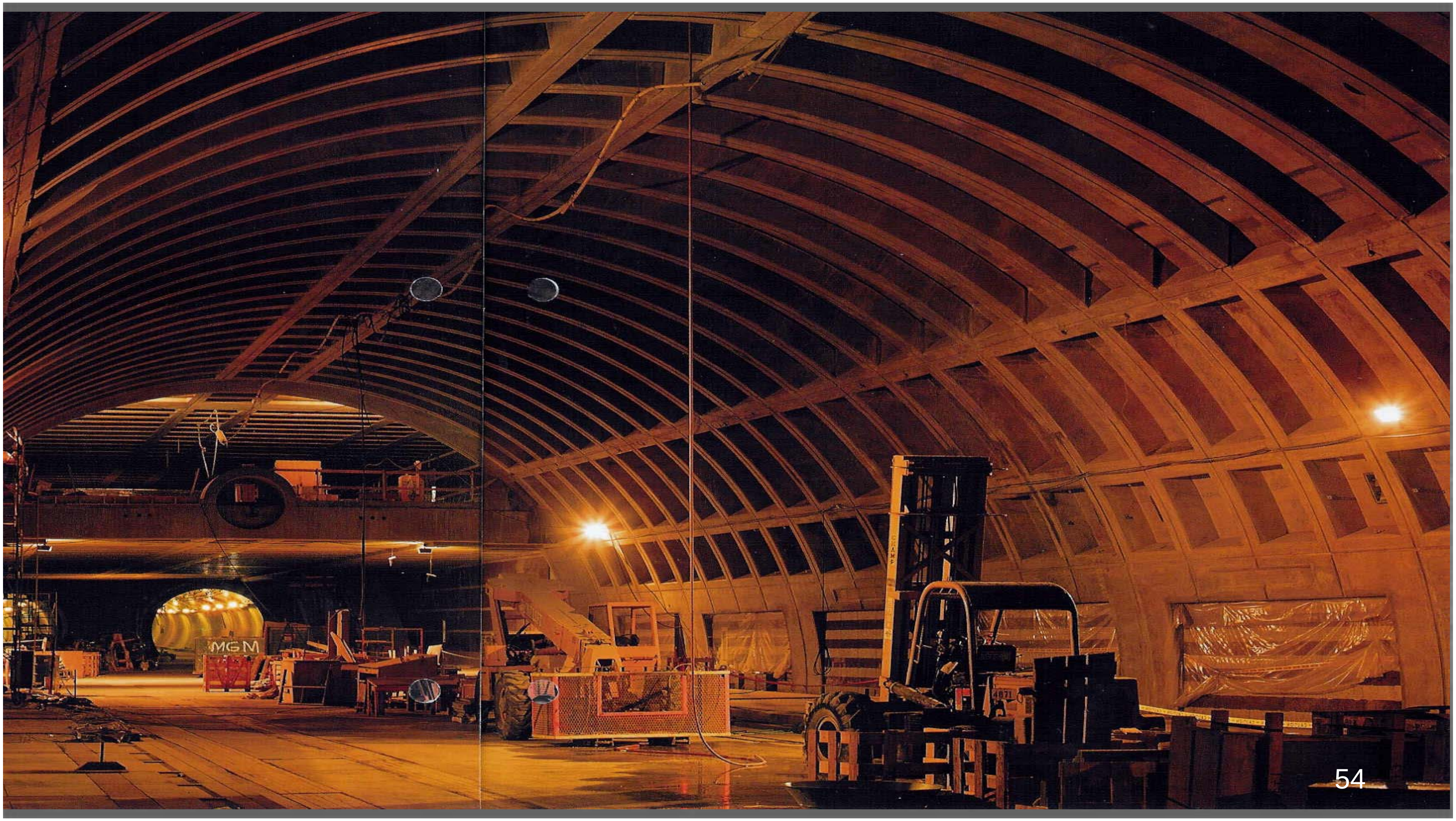
Tunnels

Pedestrian Tunnel
Boeing 747 Facility
Everett, Washington



Part of the 16,000 precast liner segments supplied to the bus tunnel project by Concrete Technology Corp.


MGM


HOIST
BRIDGE


HOIST 5T
BRIDGE 9T


HOIST 5T
BRIDGE 9T


001
TUCKERBILT
T-630
CIFA

CONCRETE TECHNOLOGY CORPORATION
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FLOATING STRUCTURES

ARCO – LPG Float

CONCRETE TECHNOLOGY CORPORATION
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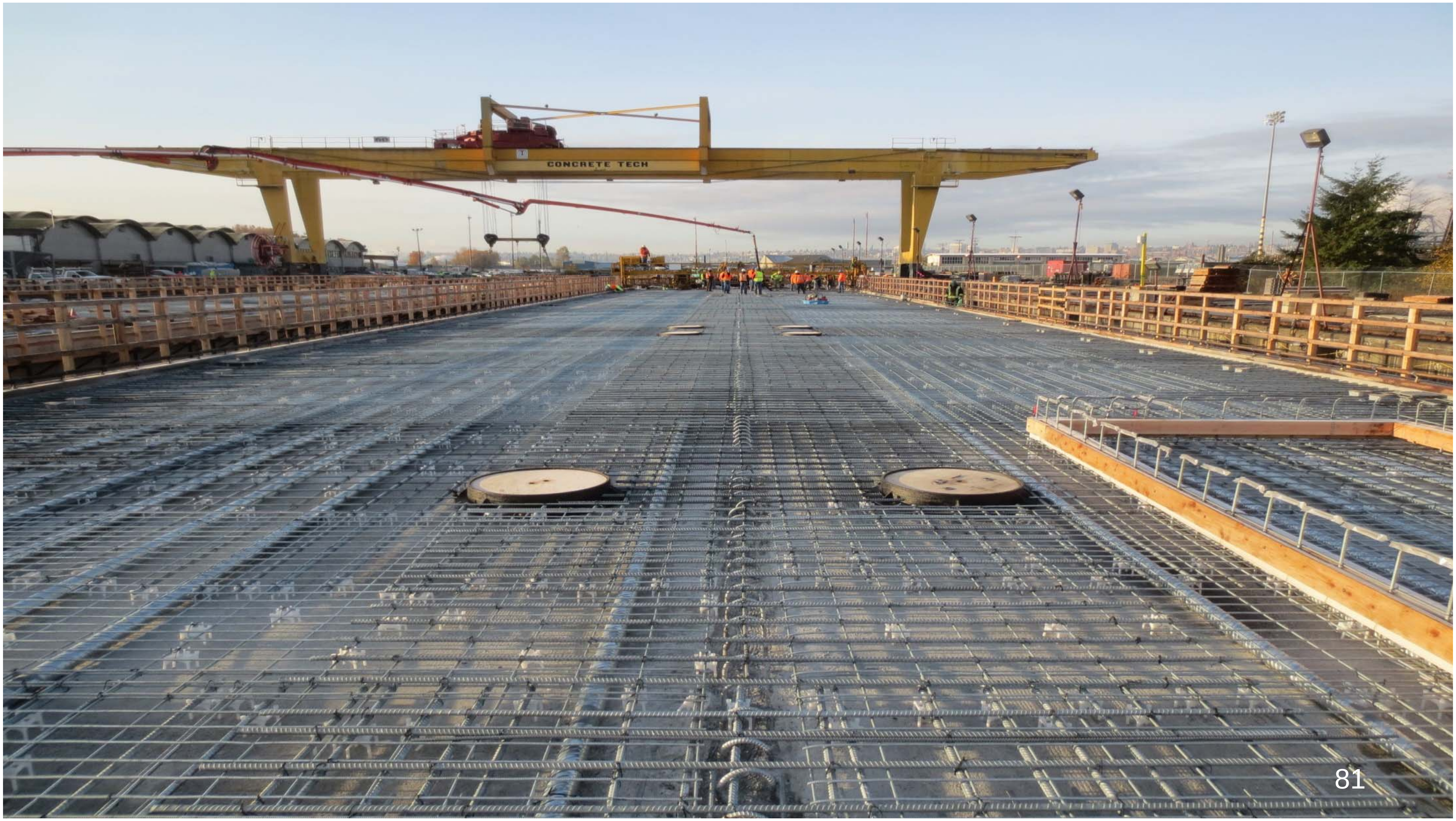
JUNEAU CRUISE SHIP BERTHS


12
KEEP HANDS CLEAR


CONCRETE TECH


Genie


Genie S-65


CONCRETE TECH


DSI

Valdez Float

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CARL E. MOSES BREAKWATER


CONCRETE TECH


WT175D


D.B. SALVATION

2008 - Douglas Harbor- 8’ x 18’ x 230’

Ford Island Hawaii

Marina Floats


SUNNEN CRANE

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INNOVATION & QUALITY SINCE 1951

BRIDGES


001
WARNING


11/26/2008 09:07


OVERSIZE LOAD
HOME SHOW

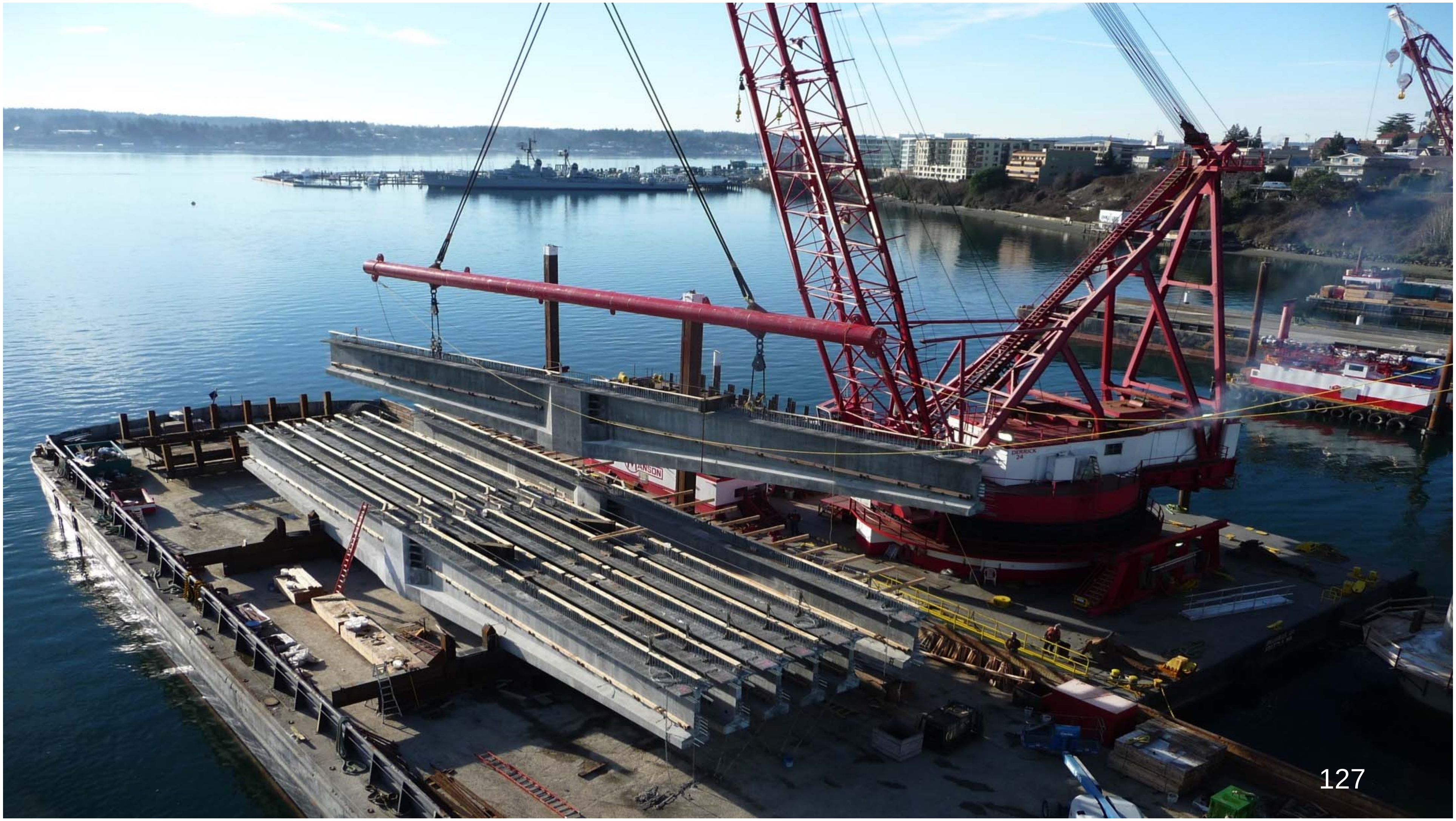

SAN F AN CISCO
9 24 '96

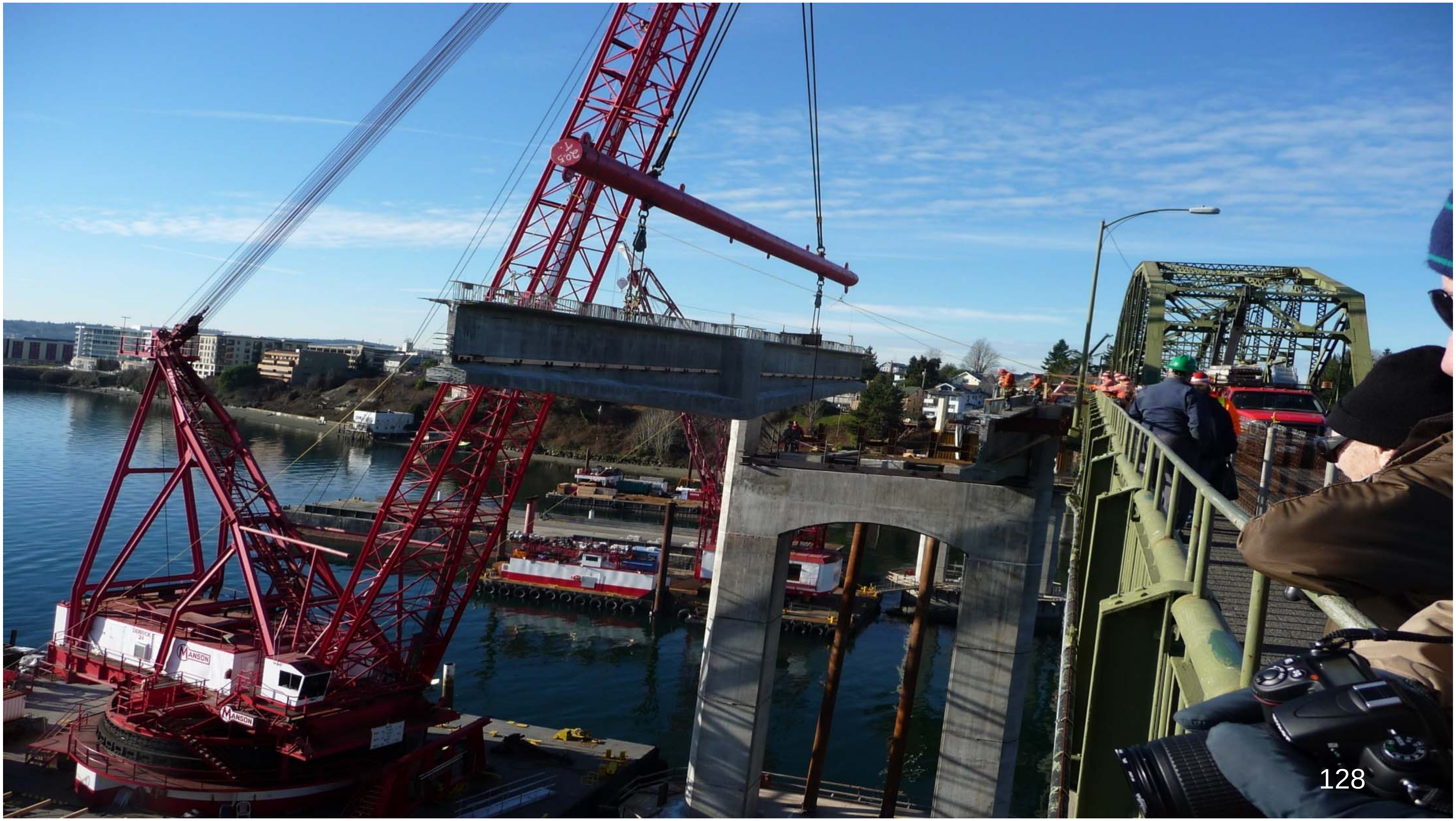
CONCRETE TECHNOLOGY CORPORATION
INNOVATION & QUALITY SINCE 1951

SELECT RECENT PROJECTS

Manette Bridge – Replacement of a 1930 steel truss bridge.

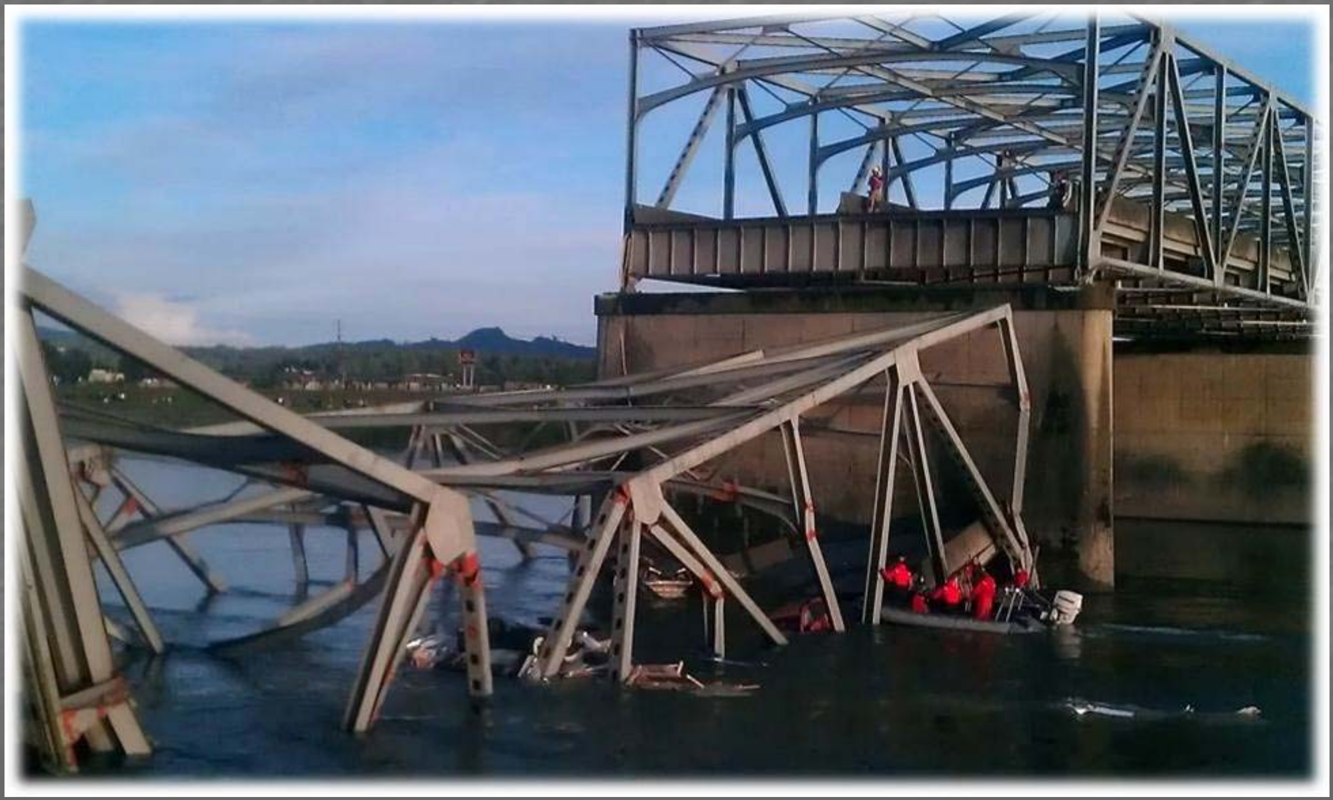

OVERSIZE LOAD




MANSON
MANSON


P3E

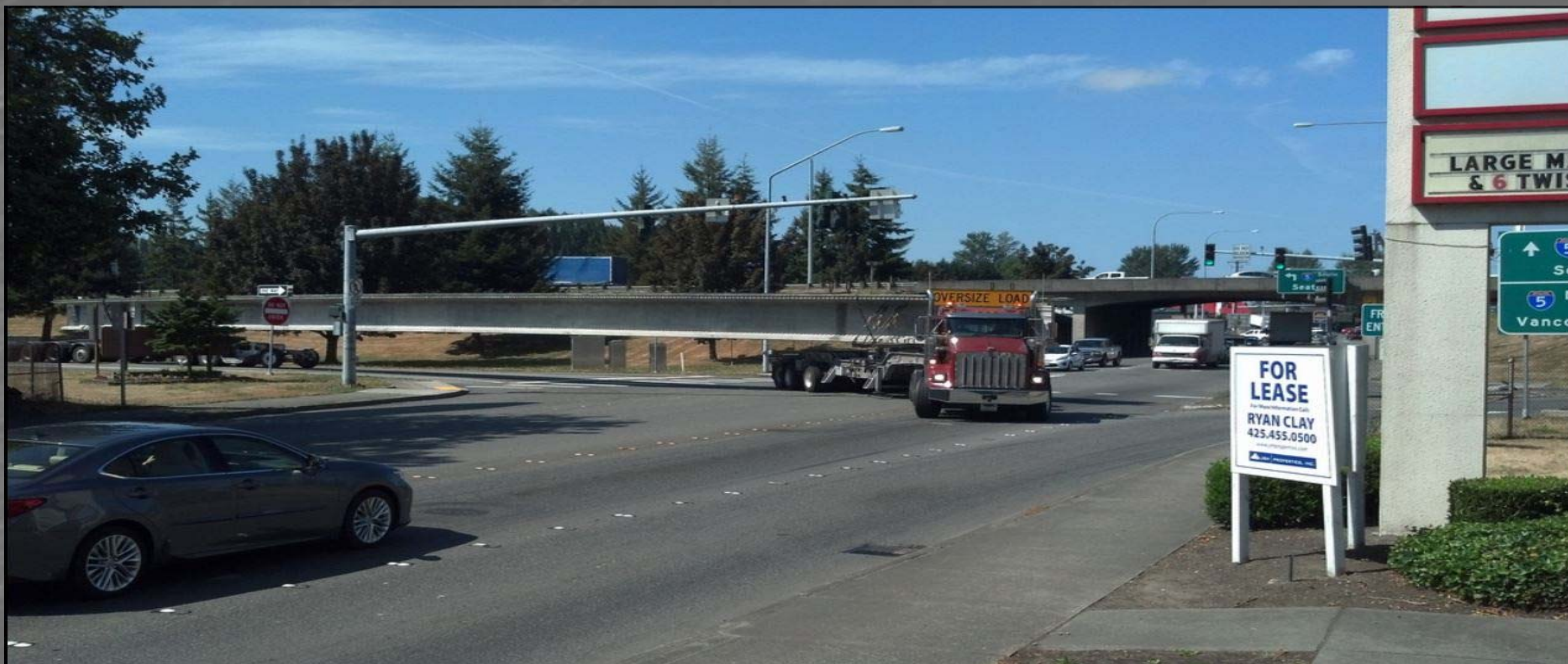
I-5 Skagit River Bridge Collapse



Acrow steel bridge was installed less than four weeks after collapse.

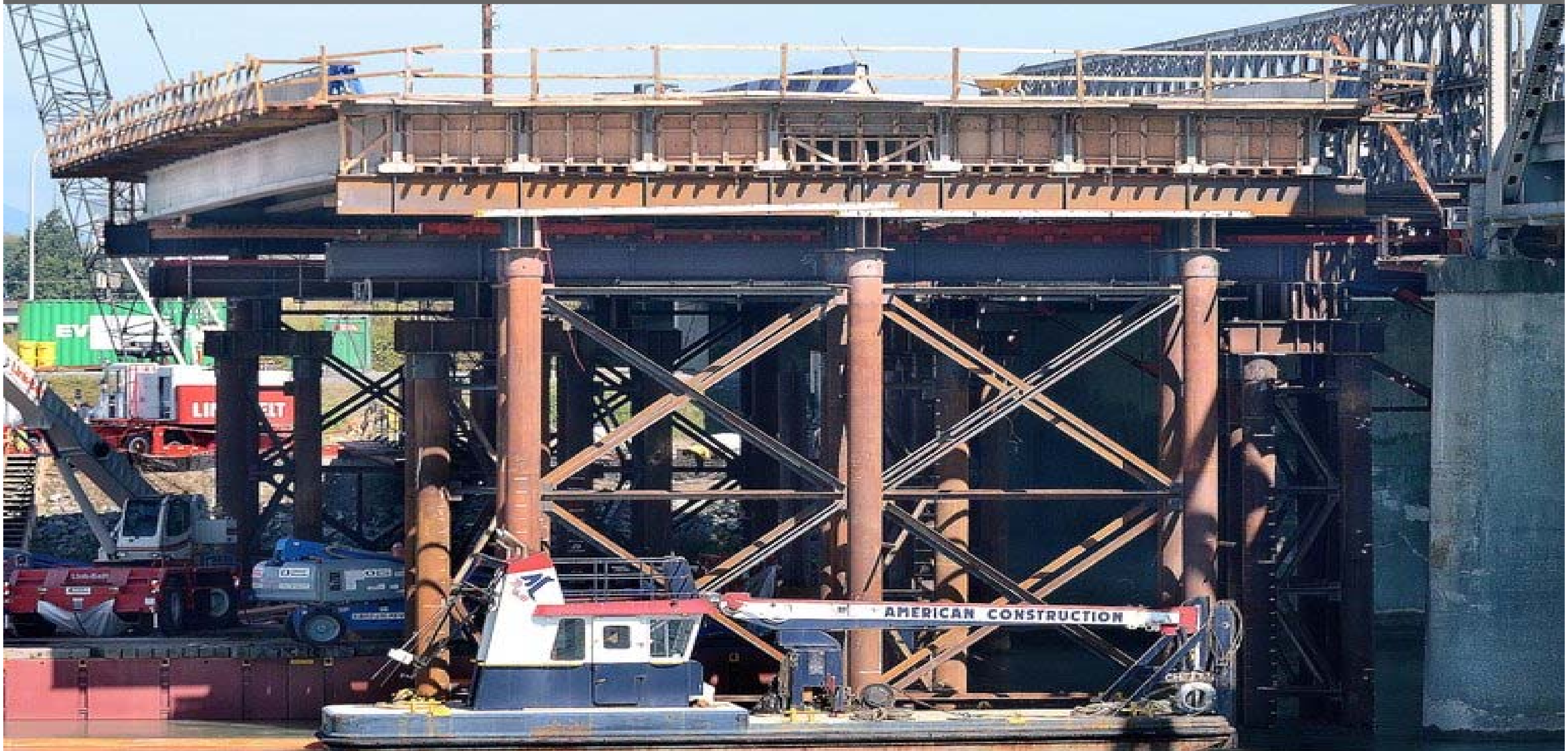
Girder design utilized lightweight concrete. Fabrication in 37 days.


SHUTTLELIFT


OVERSIZE LOAD
FOR
LEASE
RYAN CLAY
425.455.0500
LARGE MA
& 6 TWIS


OVERSIZE LOAD
ASPEN
aspentrailer.com
ASPEN
aspentrailer.com

08/13/2013 16:55


AMERICAN CONSTRUCTION

The bridge was completed on September 15, 2013.

Alaska Way Viaduct Girder 204’-11½”


KENWORTH

I-5 Grand Mound Overpass


04/15/2011 13:56


GROVE


FALLING


SKYJACK
VR-1056D

CONCRETE TECHNOLOGY CORPORATION
INNOVATION & QUALITY SINCE 1951

PRECAMBERED GIRDERS


OVERSIZE LOAD
V. Van Dyke INC.

Current and Future Innovations

- Accelerated Bridge Construction
- Self-consolidating concrete
- Lightweight concrete
- Precambered girders
- UHPC
- Curved girders
- Design of resilient substructures for seismic loads

References

- Nasser, G. (Ed.). (1981). *Reflections on the Beginnings of Prestressed Concrete in America*. Prestressed Concrete Institute.

- Billington, D. (1976, September-October). Historical Perspective on Prestressed Concrete. *PCI Journal*, 48-71.

"FINISHING CONCRETE PAVEMENT, SIDEWALK, BUILDING FLOOR SLABS"

11/6/17 Craig Cottongim

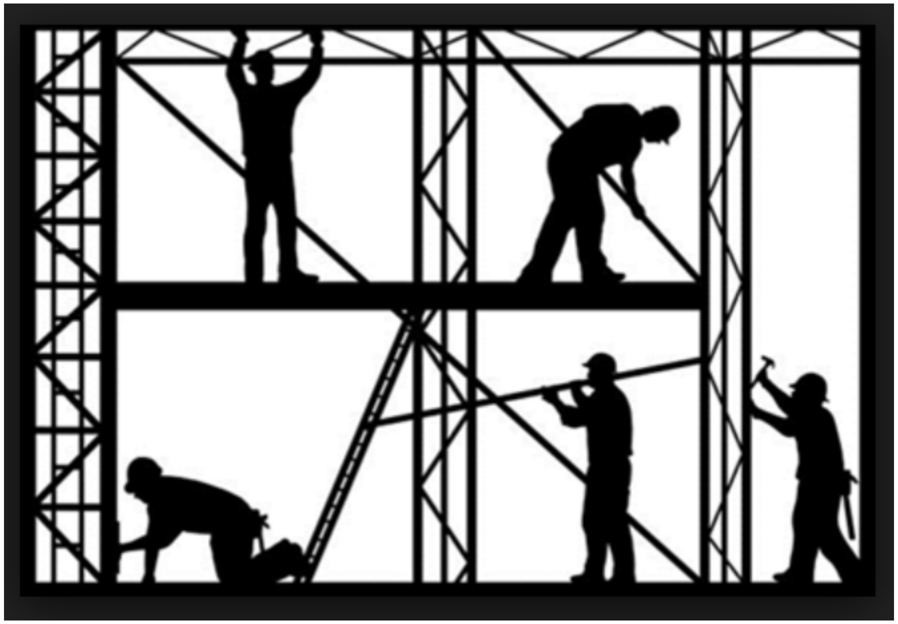
THIS SESSION MIGHT NOT BE FOR YOU, UNLESS THIS IS THE REAL REASON YOU CAN'T FALL ASLEEP AT NIGHT…

OR, IF THIS DOESN'T GET YOUR BLOOD PUMPING…

PROOF YOU LOVE CONCRETE:

WHAT CAN I ADD/TEACH IN *THIS SETTING*…?

- A broader framework/way to conceptualize what we do…



AS FINISHERS, WHO ARE OUR STAKEHOLDERS?

- Contractors/employer
- Community
- Teammates/crew/Mentees
- Family
- I.E., who are those who affect your work or are effected by it?
- Until we ID our SH, like a boat without a rudder…

NEED TO RETAIN/SHARPEN

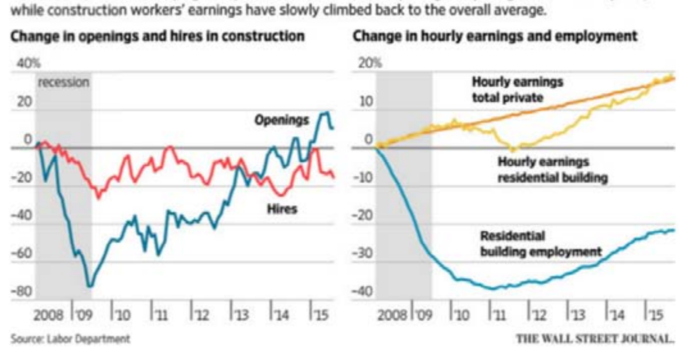
THE WALL STREET JOURNAL.

Home World U.S. Politics **Economy** Business Tech Markets Op

Builders, contractors and economists point to a few reasons for the labor shortage. Wages, particularly in residential construction, are still too low to attract enough qualified workers to the physical and sometimes dangerous work of building houses. Tightened immigration policies, meanwhile, are deterring foreign labor from returning to the U.S. And efforts to train and recruit young trade workers atrophied in past years as many school districts focused less on certain vocational training.

Help Wanted

Home builders have been plagued by a skills mismatch, with openings outpacing hires in recent years, while construction workers' earnings have slowly climbed back to the overall average.



HOW DEMANDING IS THIS HIGH DEMAND CAREER?

FEAST, FAMINE, ETC.

- Hard to budget/seasonal
- Will take it's toll on your body, limp/scars
- Erratic hours
- Eclectic mix of coworkers
- Like competing in an Ironman/Decathlon, every week…

SO, WHY CHOSE A CAREER IN CONCRETE?

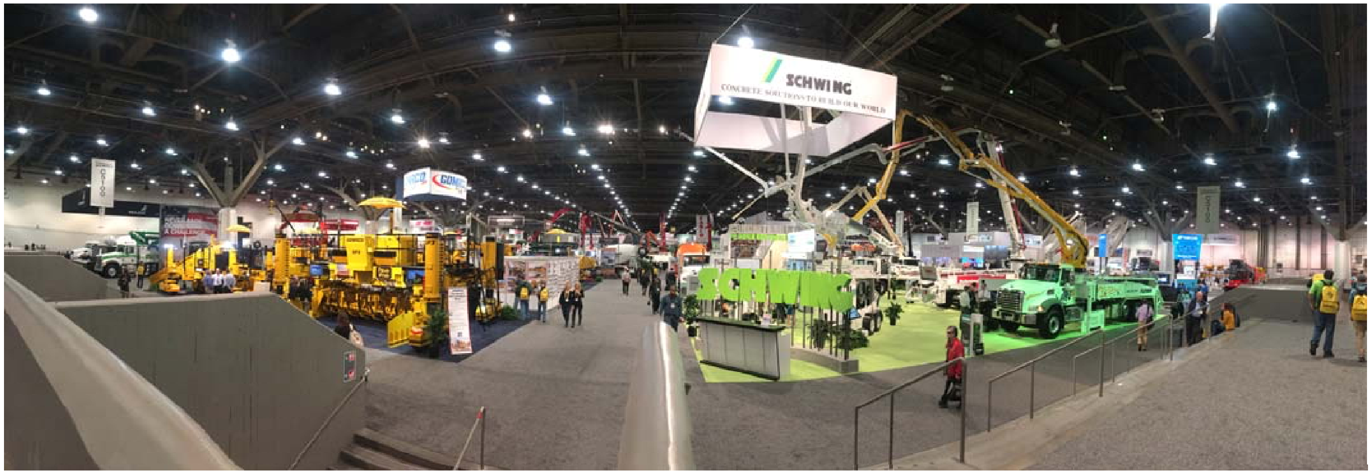
- If you are only in it for the $$$, *you'll never be satisfied with money*.
- Second only to water, Concrete is the most used commodity on earth.
- Concrete is one of the most durable and affordable building materials.
- No greater sense of accomplishment than finishing concrete!
- No limitations on where you can go, what you can do
- Seeing the bigger picture:
- Colleges
- Hospitals
- Infrastructure
- Science/aerospace/industry
- All depend on concrete, so never forget our major contribution to civilization!

A CONCRETE CASTE SYSTEM?

- Footer crew.
- Foundation crew
- Flatwork/finishers
- Curb
- Patching
- Ironworkers/rod-benders
- Stripping/wreaking crew
- Pumpers
- Dispatch/ready mix drivers
- Who is at the top of this totem pole?

SINCE WE ARE PART OF AN ELITE/ESSENTIAL GROUP…

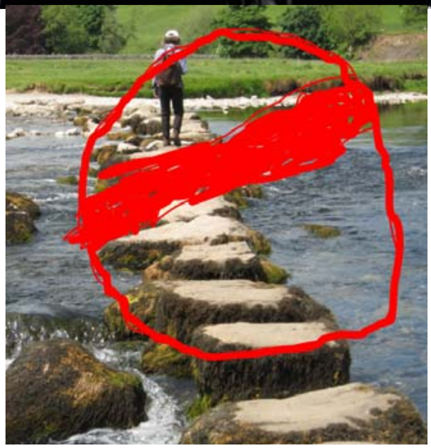
- **Take pride in our work**. Helps to imagine someone with higher than normal standards looking over our end product…
- Pursue excellence in our trade.
- Stay current/up to date…



WHAT ARE PPL LOOKING FOR IN A FINISHER?

- Dependable
- Reliable
- Accountable
- Experienced/knowledgeable/craftsman..
- ***Solid Work Ethic***...
  - Show up early/stay late/don't whine...
  - Pull your weight
  - Problem solver not causer...
  - Focus on quality!

CATEGORIES OF PPL WHO MAKE THE BEST FINISHERS:



DOES ALL CONCRETE RESPOND THE SAME WAY?

- Before PSI, “bag”
- Sand
- Aggregate
- Pump mixes.
- Air-Entrained/freeze-thaw
  - Tear
  - Picking up while finishing
  - Wood floats *can help prevent spalling
- Curing/sealers
- Control joints.
- Decorative concrete/overlays

BAD HABITS ARE HARD TO BREAK

- Sprinkling too much water to seal up a slab/using a Fresno…
- Not cleaning forms as you go
- Not taking care of your tools.
- Neglecting details
- Drug/alcohol abuse
- Corruption/political

MOST IMPORTANT TOOL IN YOUR BUCKET?

SO YOU CALL YOURSELF A FINISHER? KNOW WHAT YOUR PROFESSION IS:


Q&A

Concrete Intersections & Roundabouts

Alaska Concrete Summit
November 6, 2017
Jim Powell, P.E.

Why Concrete Intersections & Roundabouts

- No rutting and shoving due to heavy loads and turning movements…
- Long-term solution…
- Low maintenance…
- Good skid resistance…


15A

Intersection & Roundabout Factors

- Thickness design
- Joint layout
- Staging
- Opening to traffic
- Rehabilitation

Thickness Design

- Use existing design procedures
  - AASHTO 1993 extremely conservative at high traffic volumes and reliability
  - AASHTO ME
  - ACPA StreetPave

Thickness Design

- Use appropriate inputs
  - Traffic
  - Reliability
  - Concrete Strength
    - Min. or avg. ?

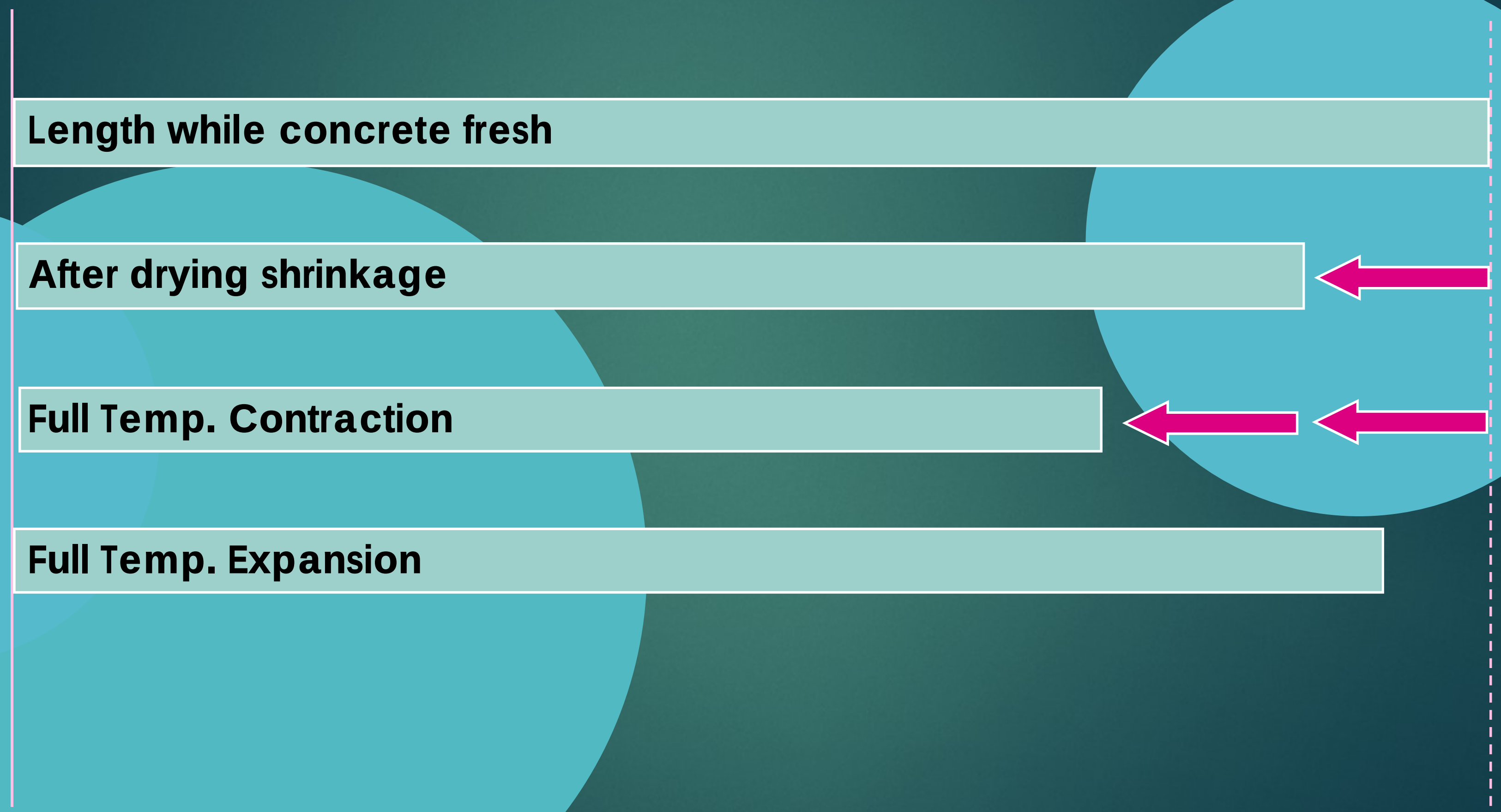
Pavement Joint Types

- Planned
- Unplanned

Why Do Unplanned Joints Occur?

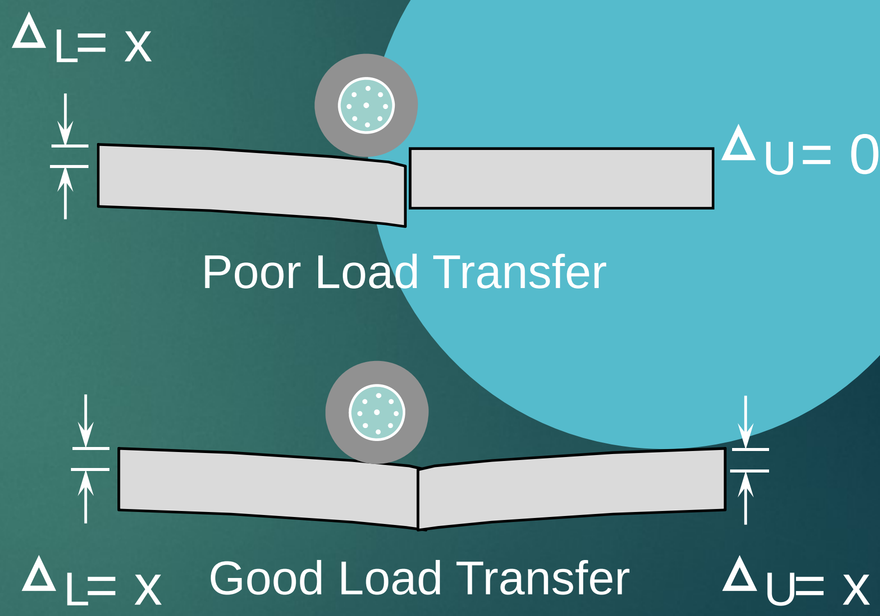
- Concrete drying shrinkage
- Changes in temperature and moisture
  - Ambient (contraction)
  - Gradient (curling)
- Restraint (friction or bond)

Pavement Movement

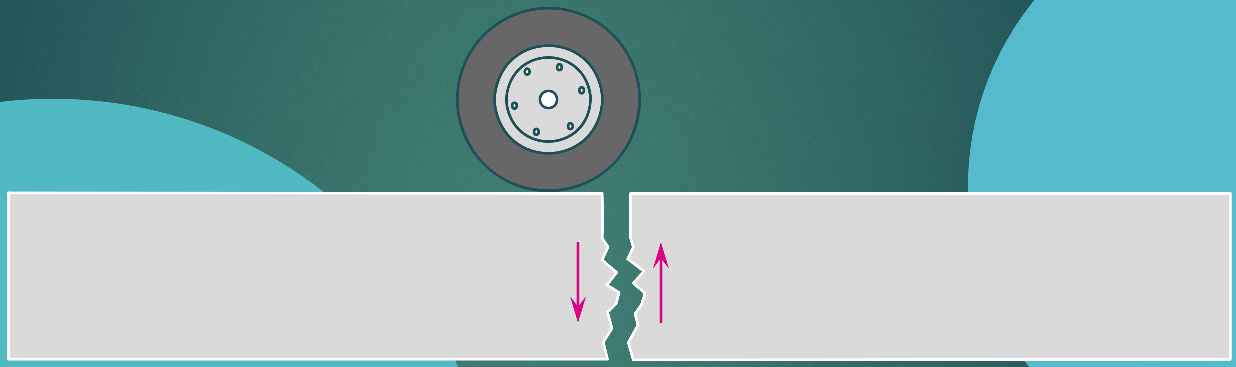


Load Transfer

- The slabs ability to share its load with its neighboring slab



Aggregate Interlock



Shear between aggregate particles
below the initial saw cut

Aggregate Interlock Performance Improves with

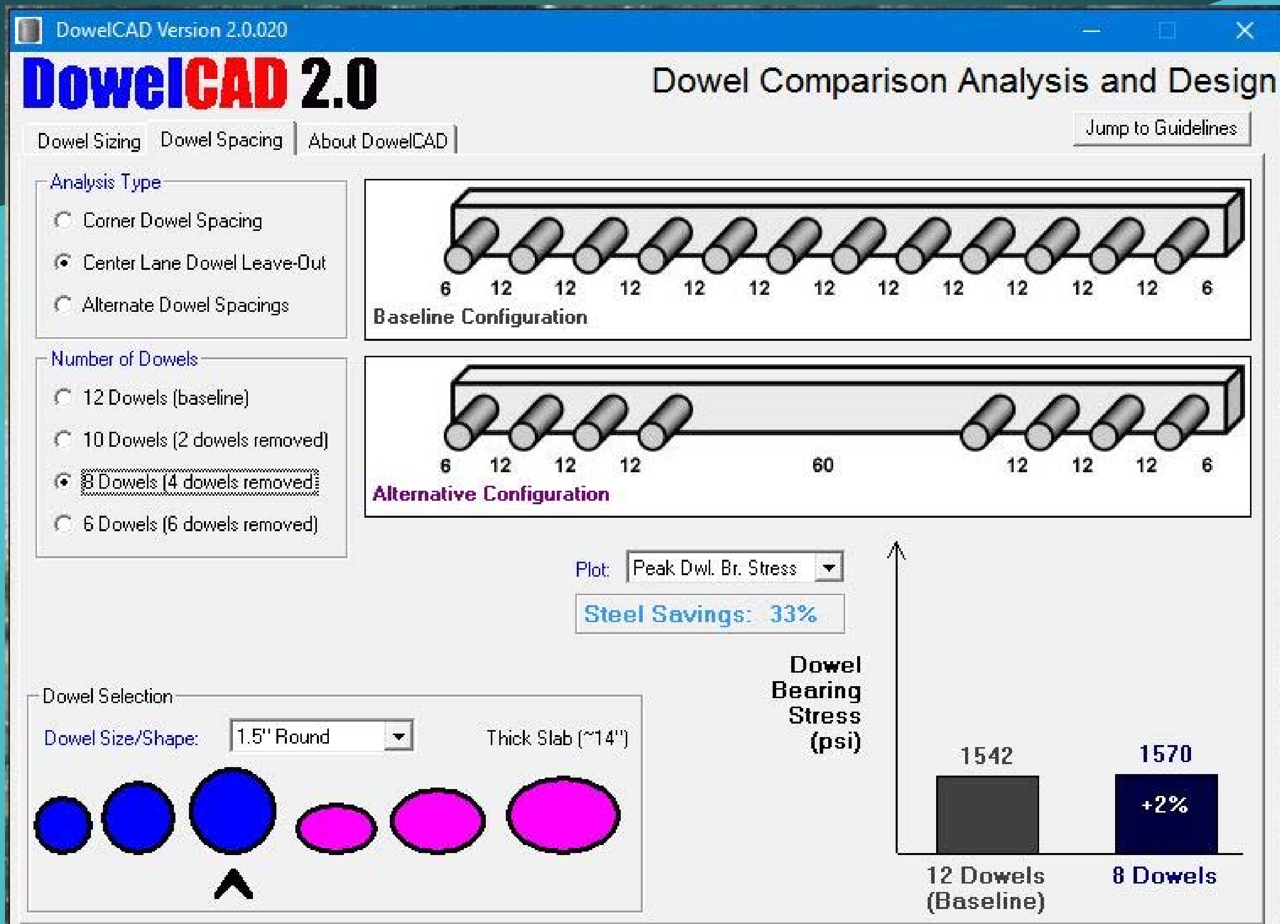
- Larger coarse aggregate in concrete
- Angular coarse aggregate texture (crushed vs. natural)
- Thicker slabs
- Shorter joint spacing
- Stiff subbases
- Edge support
- Coarse-grained subgrade soils
- Functioning drainage system

Dowel bars

Provide:

- Mechanical connection between slabs
- Improved joint effectiveness over aggregate interlock
- Lower slab stresses
- Lower potential for faulting, pumping and future joint distress

Dowel Bars



DowelCAD Version 2.0.020
DowelCAD 2.0
Dowel Comparison Analysis and Design
Dowel Sizing
Dowel Spacing
About DowelCAD
Jump to Guidelines
Analysis Type
Corner Dowel Spacing
Center Lane Dowel Leave-Out
Alternate Dowel Spacings
Number of Dowels
12 Dowels (baseline)
10 Dowels (2 dowels removed)
8 Dowels (4 dowels removed)
6 Dowels (6 dowels removed)
6 12 12 12 12 12 12 12 12 12 12 12 6
Baseline Configuration
6 12 12 12 60 12 12 12 6
Alternative Configuration
Plot: Peak Dwl. Br. Stress
Steel Savings: 33%
Dowel Bearing Stress (psi)
1542
1570
+2%
12 Dowels (Baseline)
8 Dowels
Dowel Selection
Dowel Size/Shape: 1.5" Round
Thick Slab (~14")

Joint Layout

- 24 x T – granular base
- 21 x T – stabilized base
- Maximum of 15’
- L:W ≤ 1.5:1
- Match in-pavement objects

- ☑ Keep it Short!
- ☑ Keep it Uniform!
- ☑ Keep it Perpendicular!
- ☑ Keep it Simple!
- ☑ Keep it Practical!

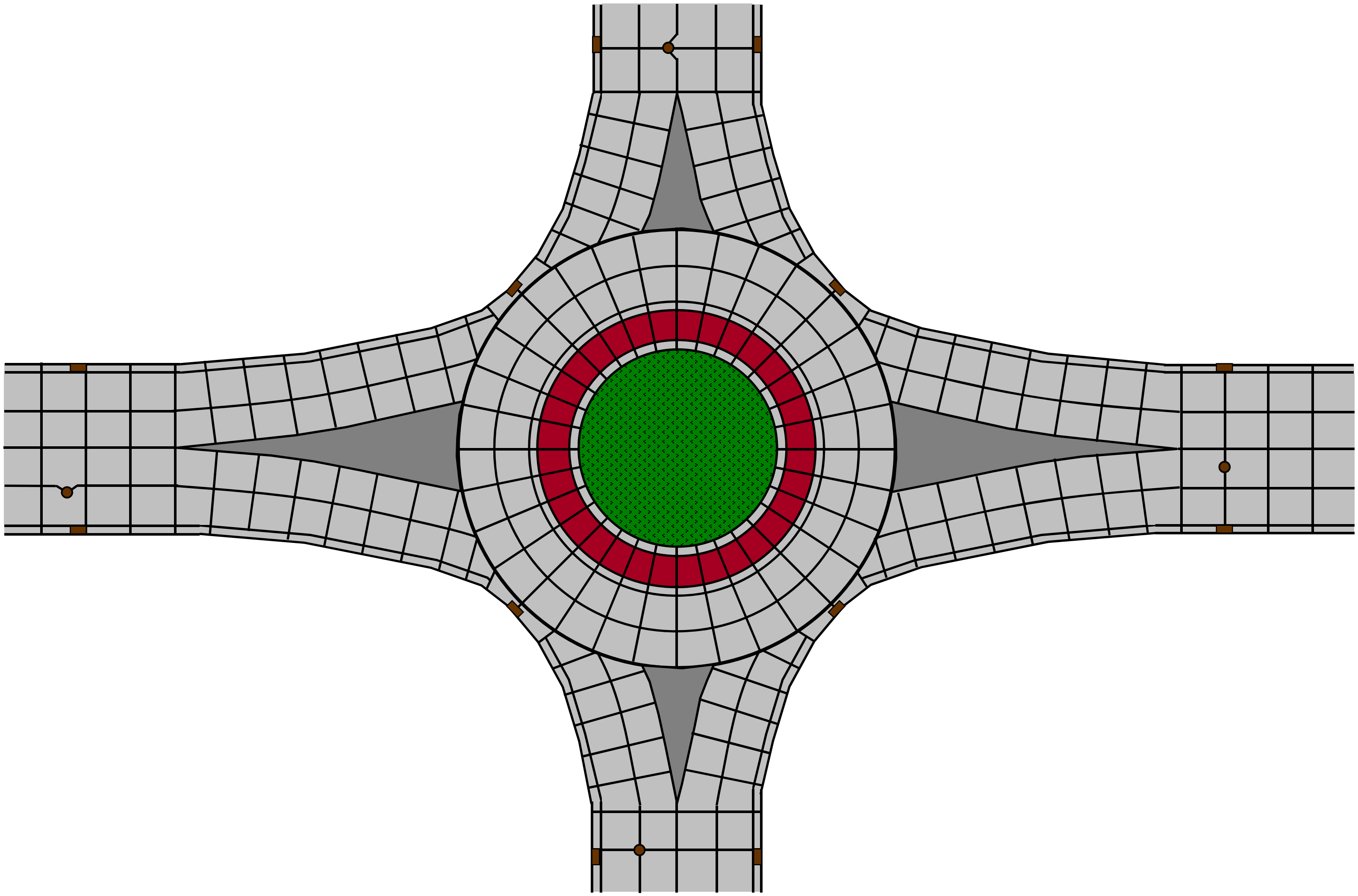
Joint Layout
Follow the Steps

- ACPA Publications on Intersection & Roundabout Joint Layout

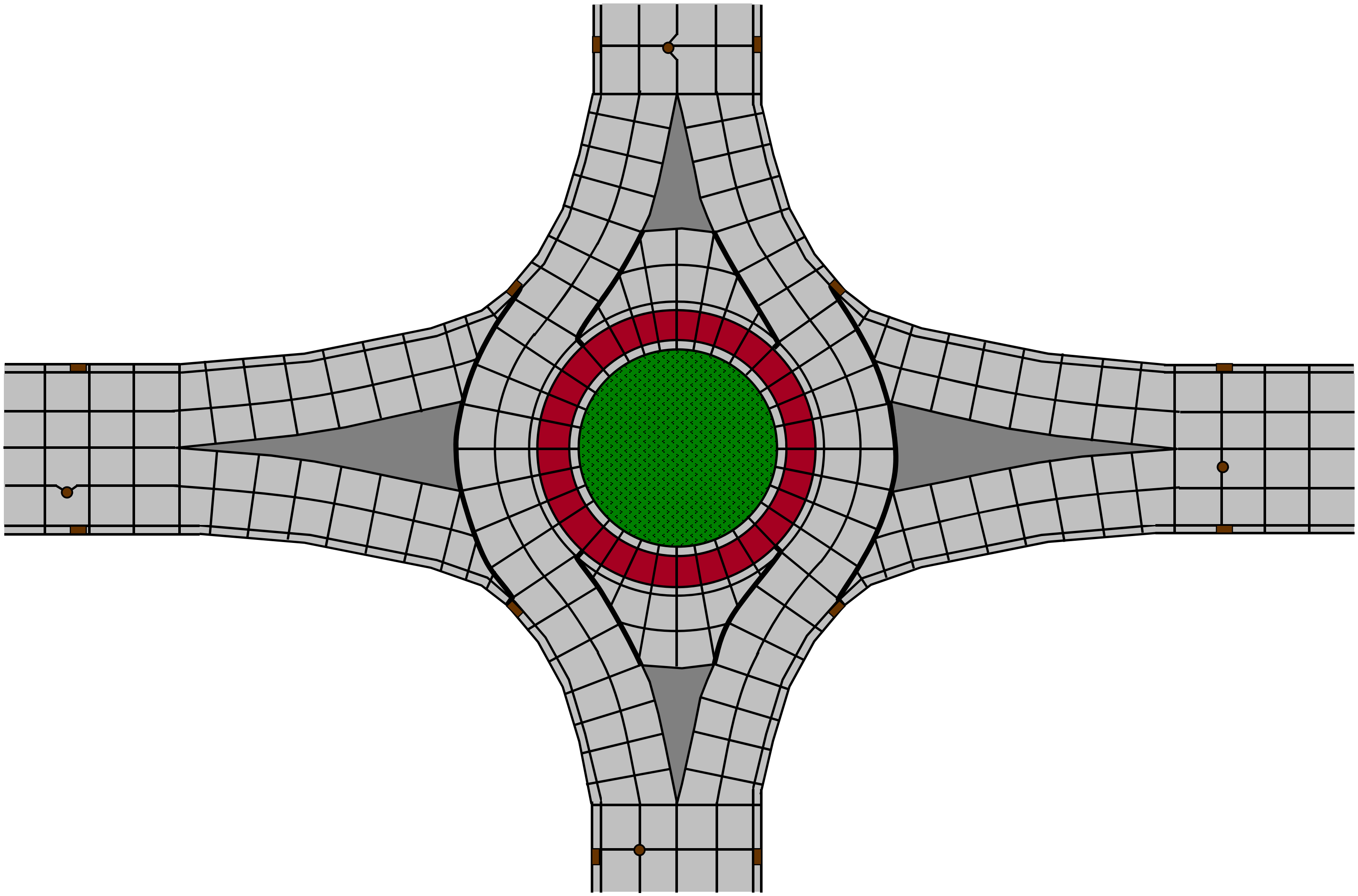
What were they thinking?

Good Practice!

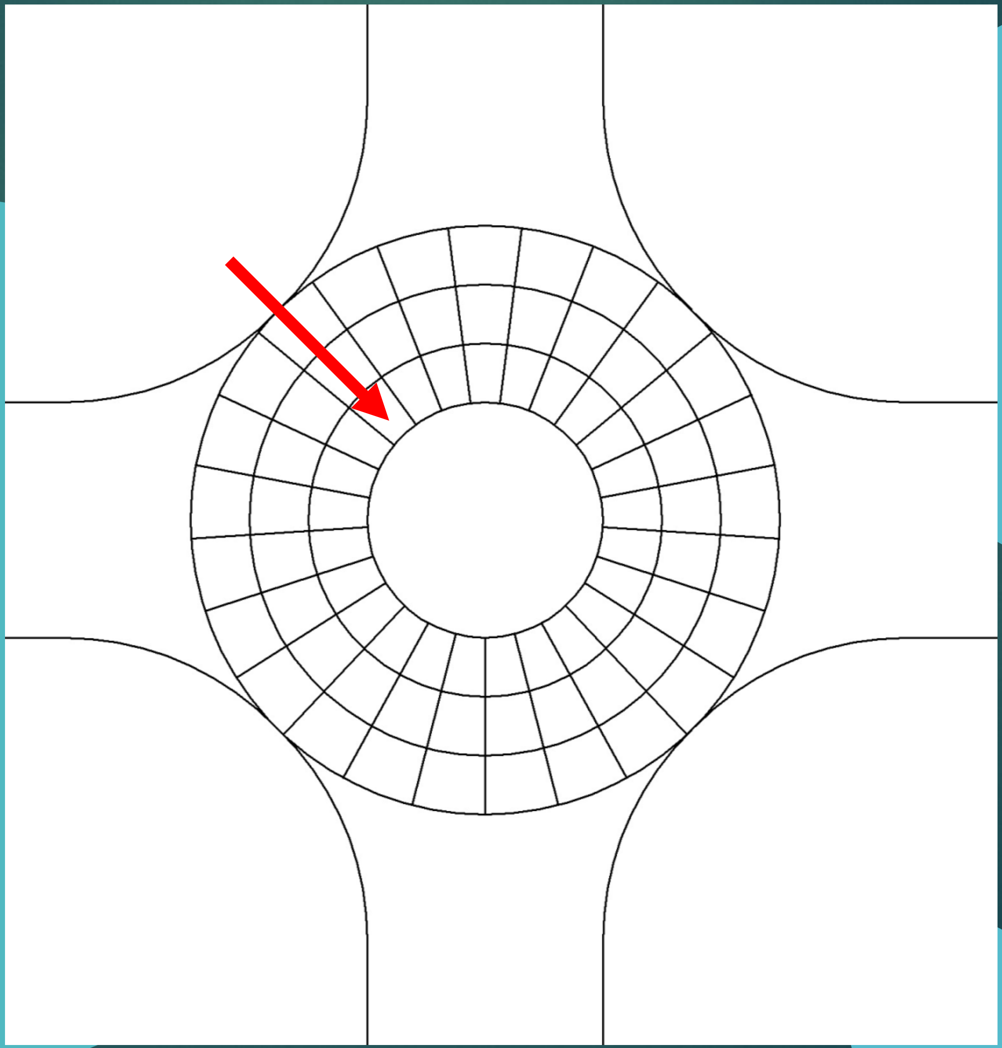
Isolate Circle



Pave Through (Not Common)

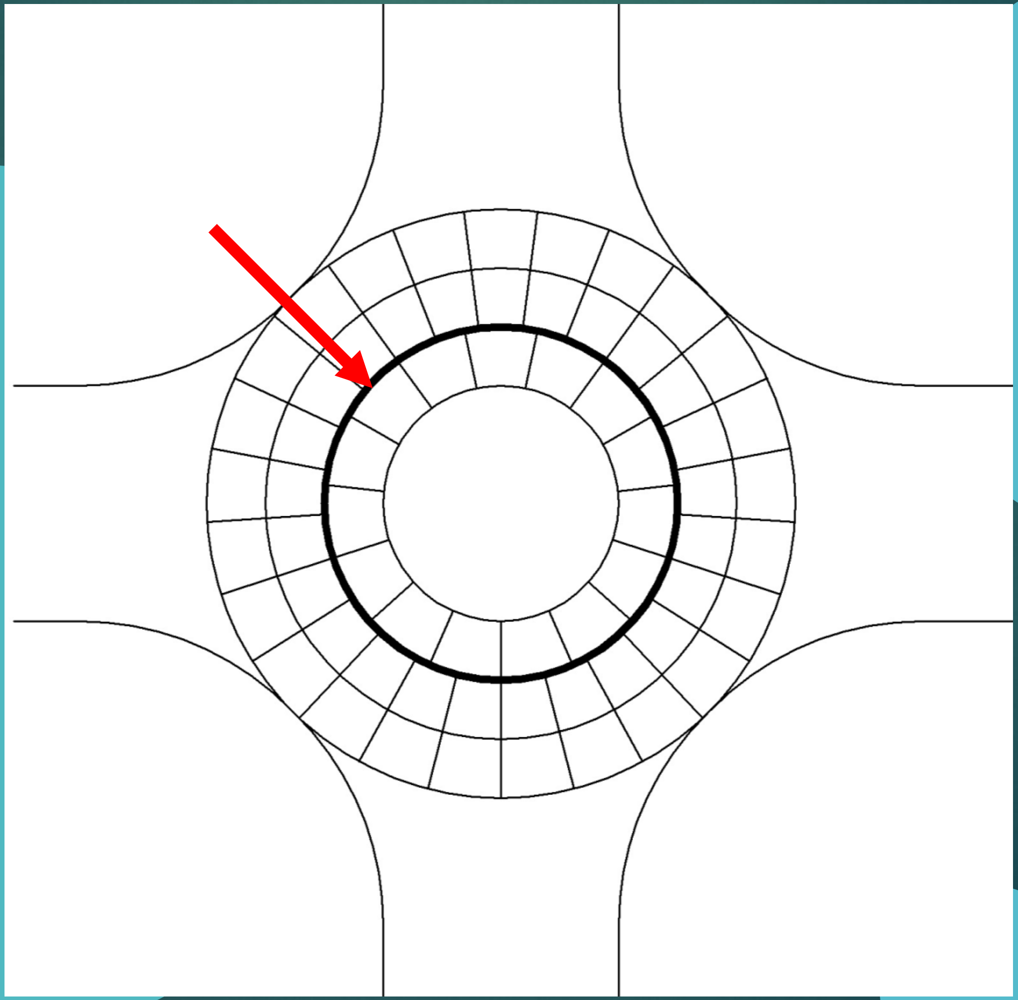


Narrow Radial Slabs/Truck Aprons

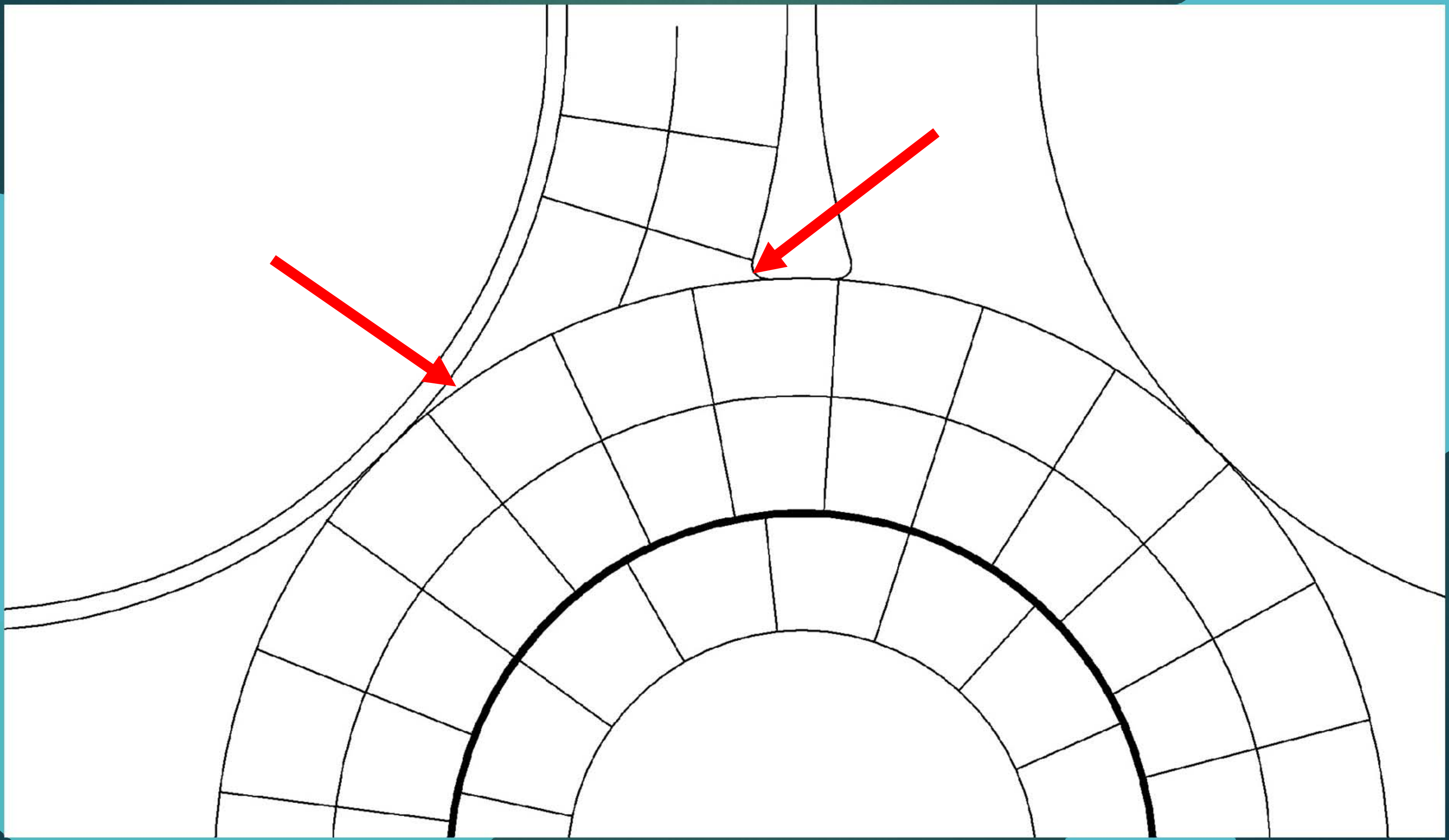


Narrow Radial Slabs/Truck Aprons

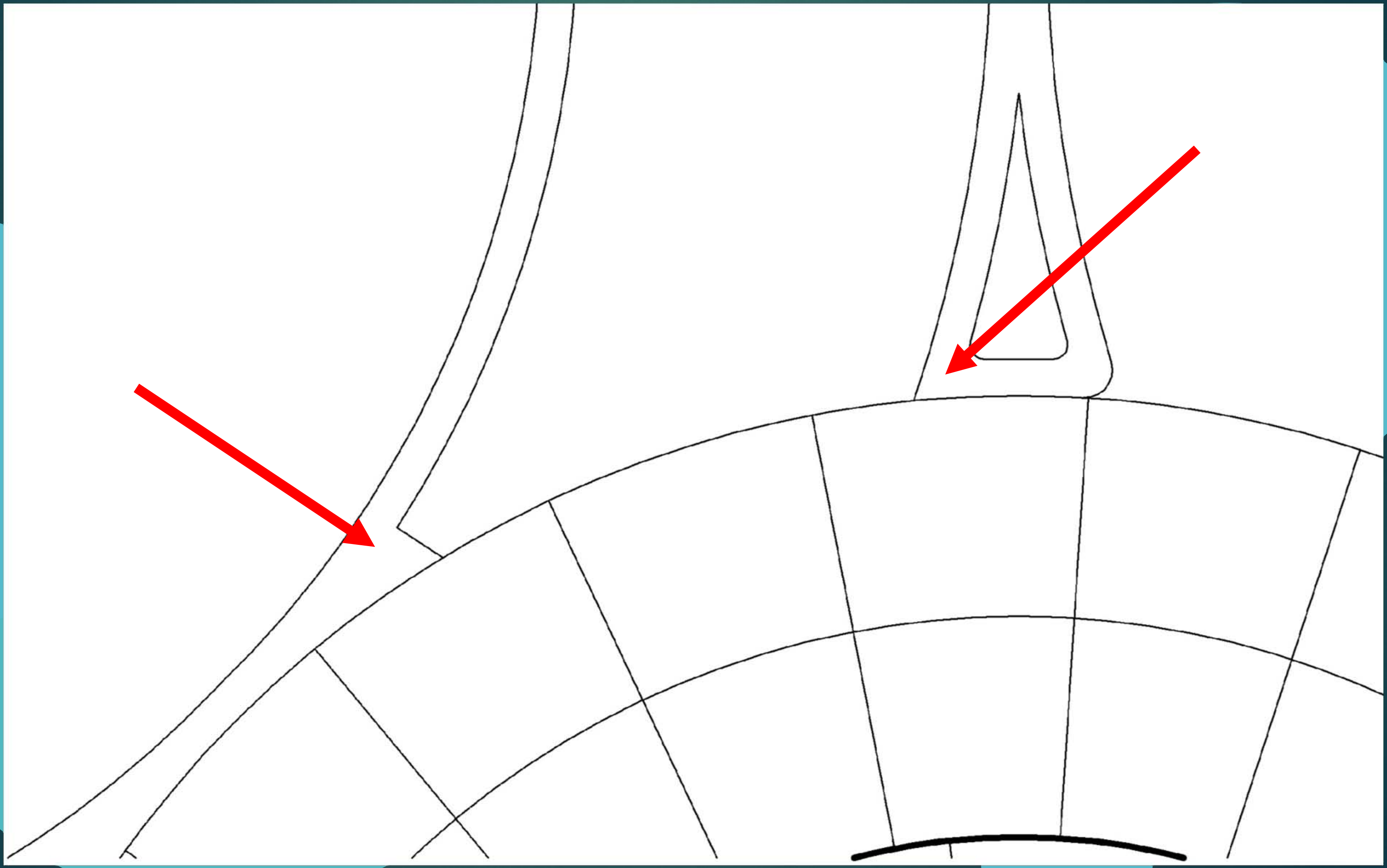
Isolation Joint



Narrow Slivers



Narrow Slivers
Widened Gutter

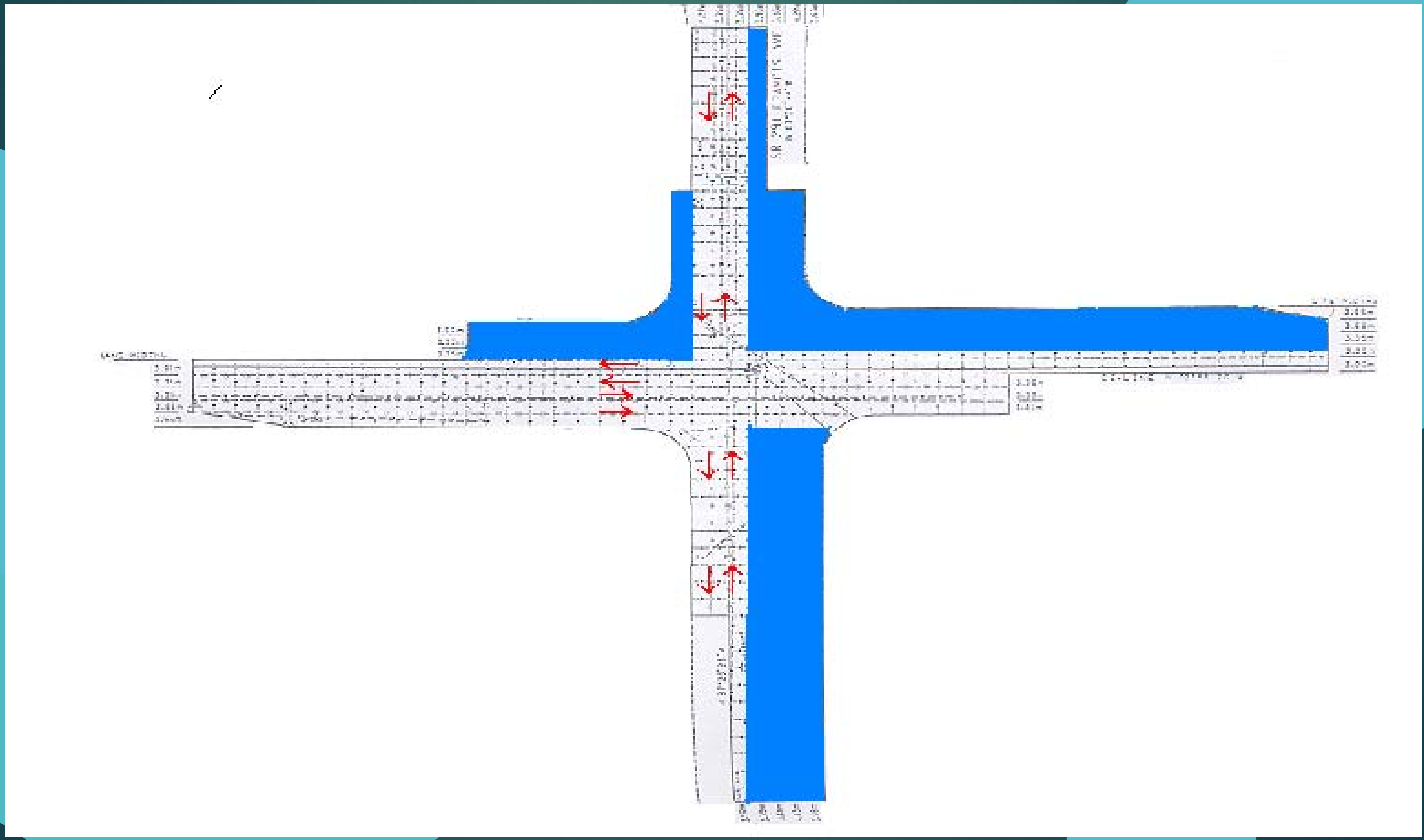


Curb Placement – Widened Gutter

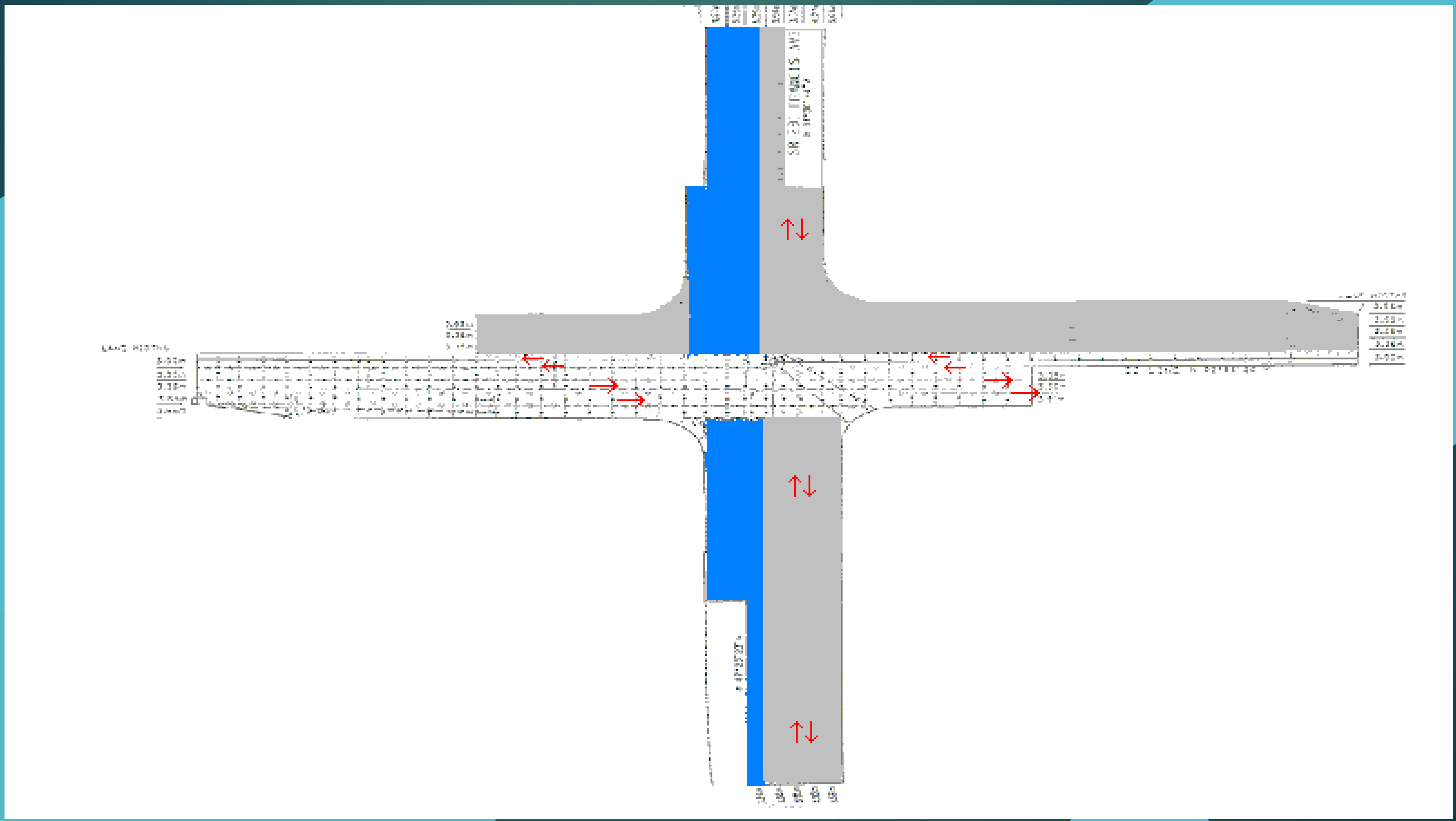
STAGING

- Piece meal
- Partial Closures
- Full Closure

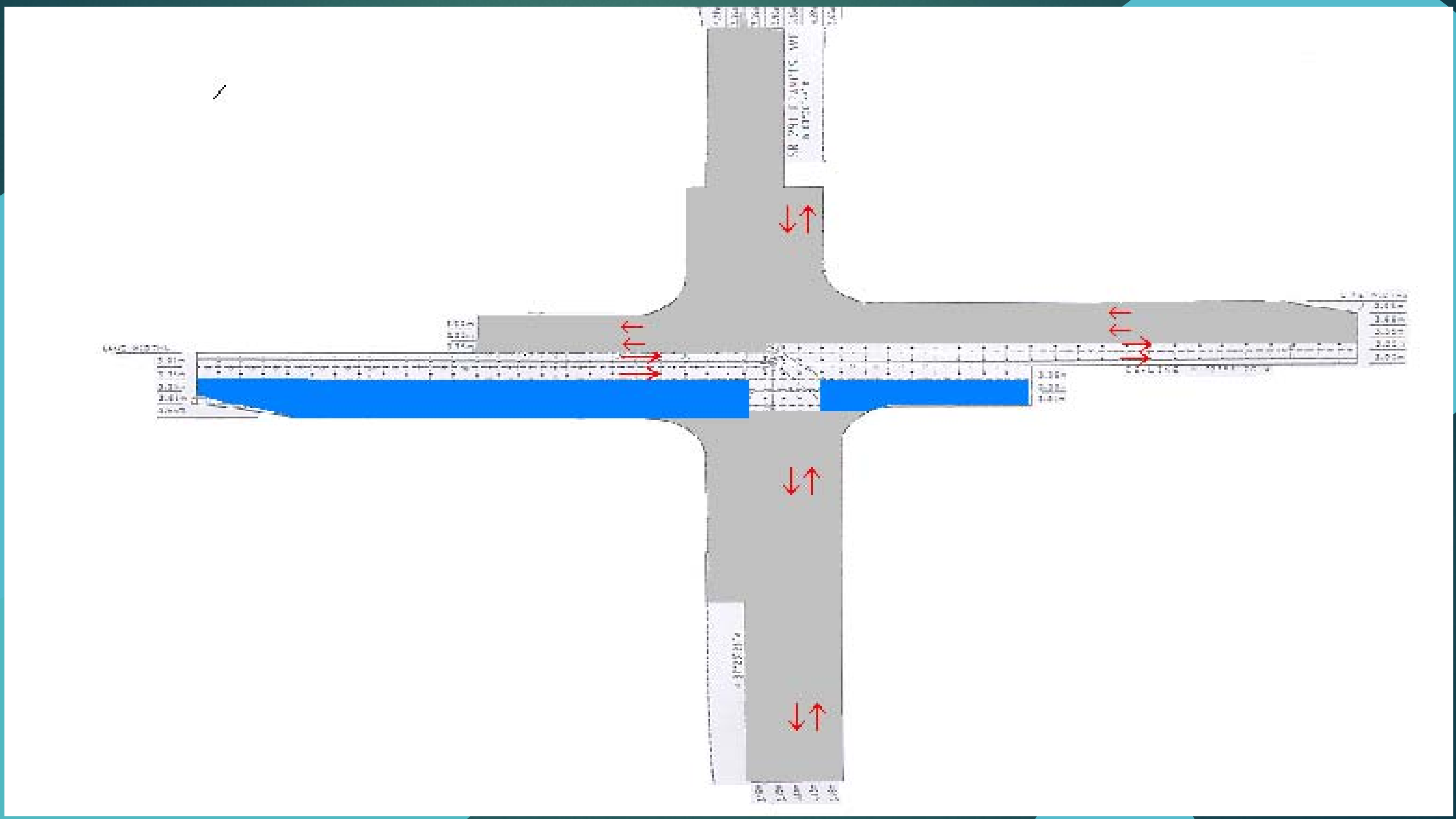
Staging



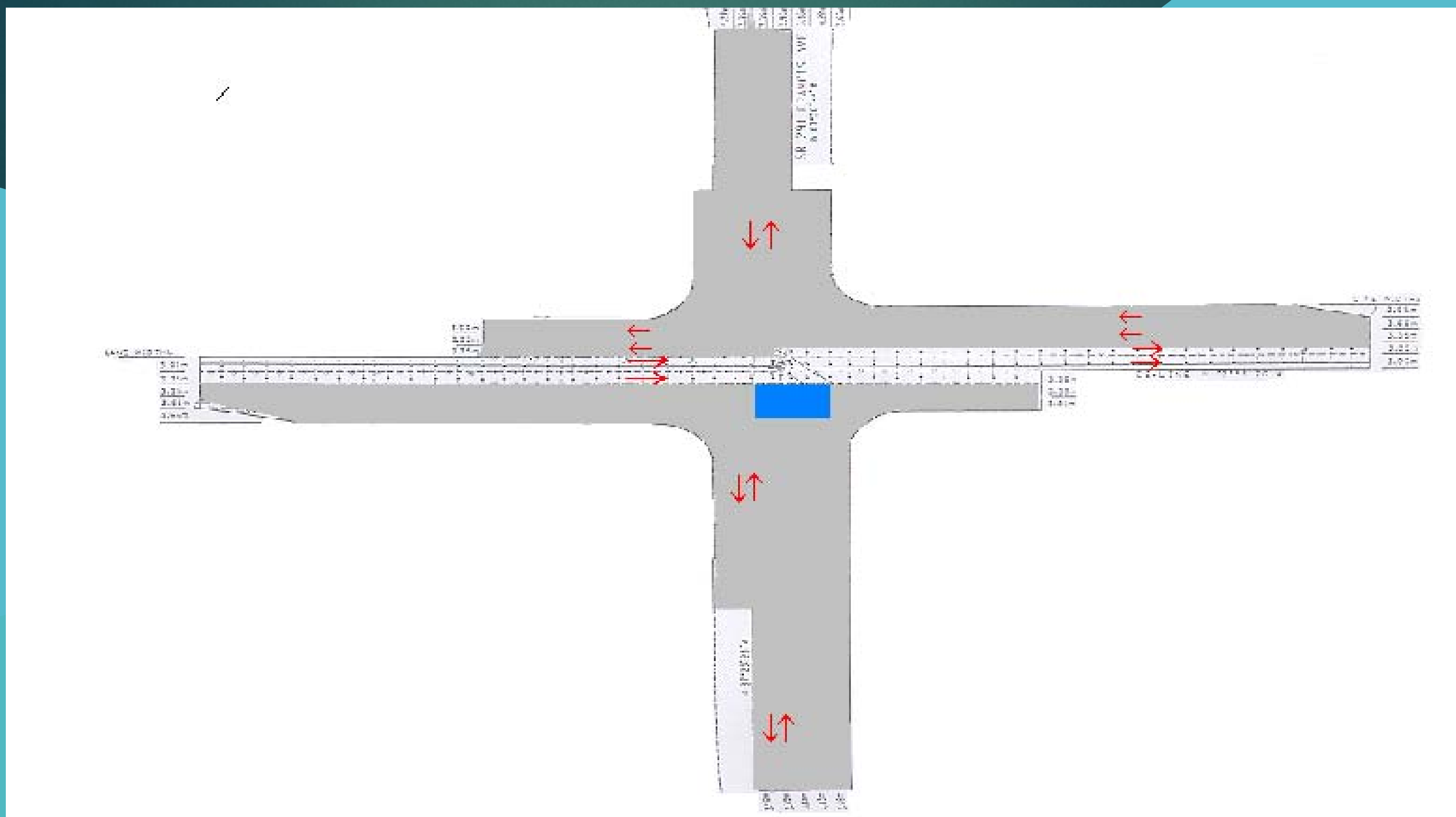
Staging



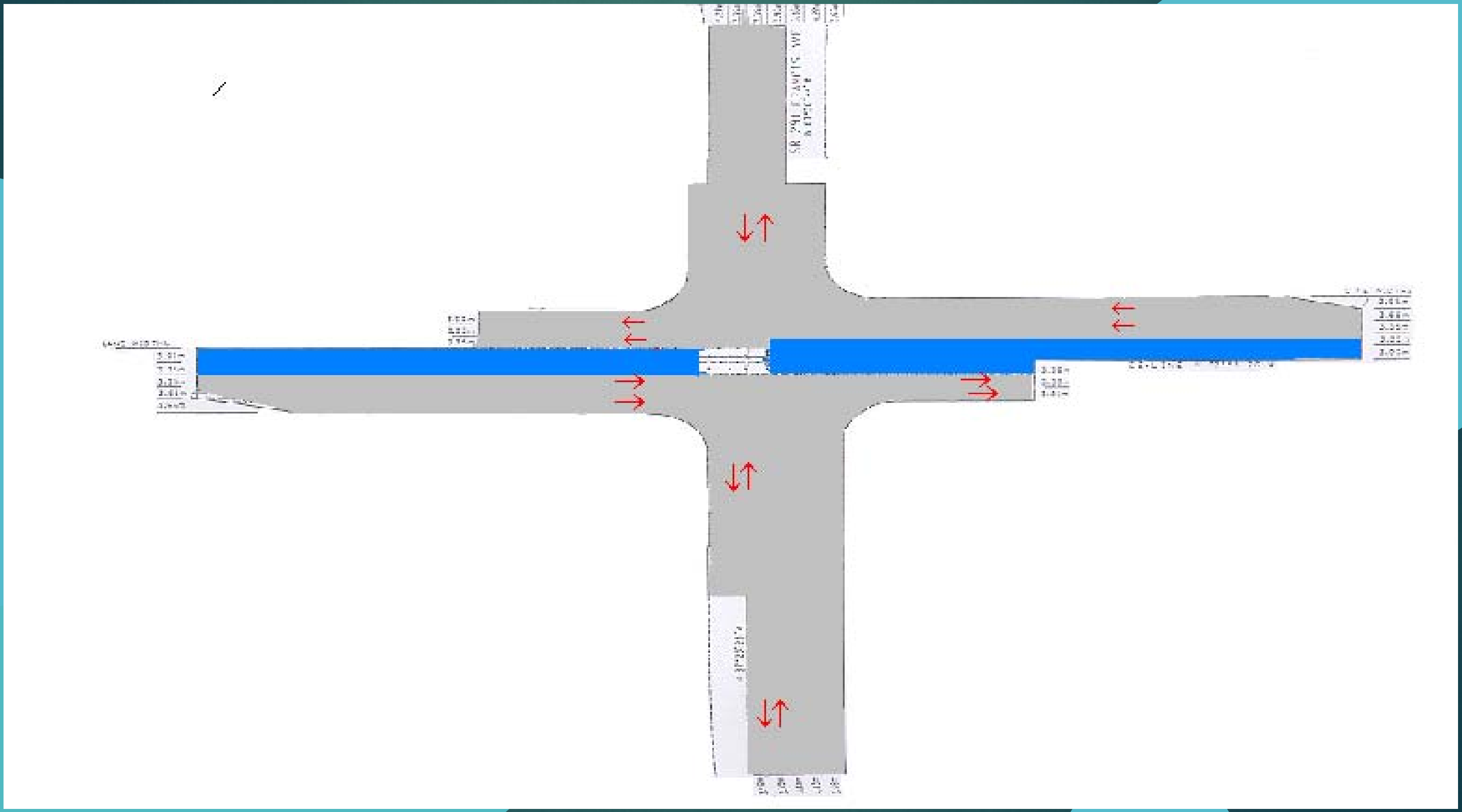
Staging



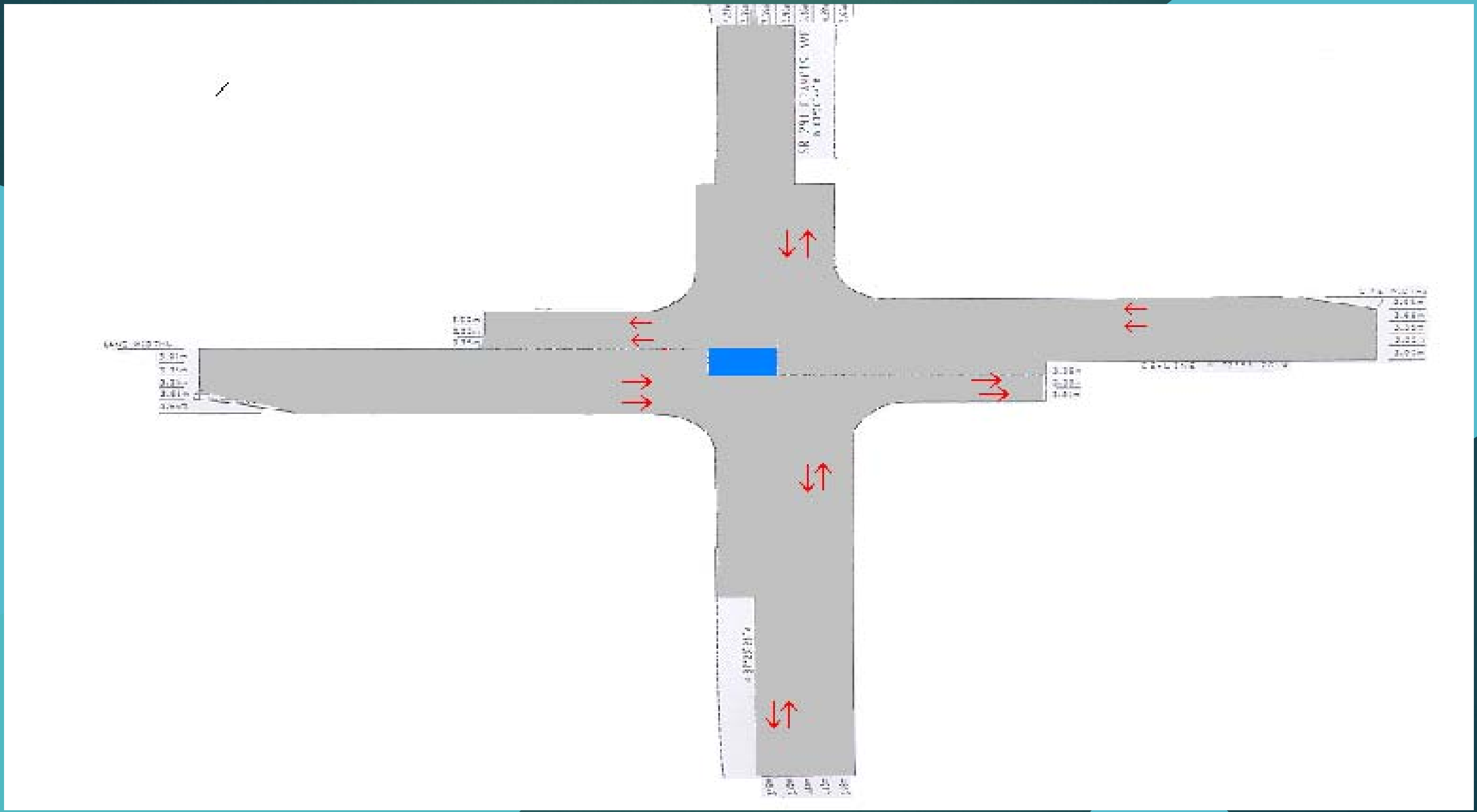
Staging



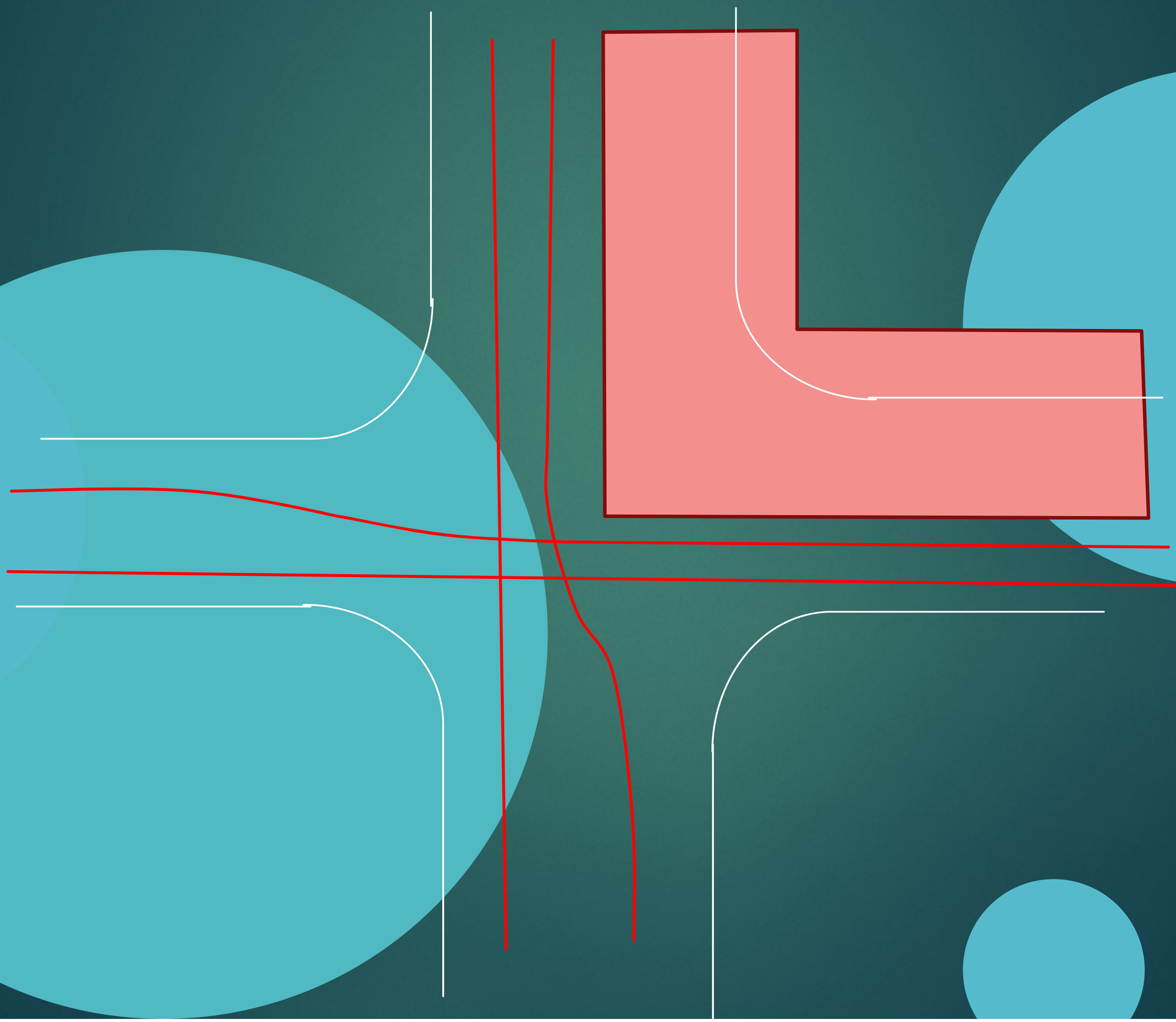
Staging



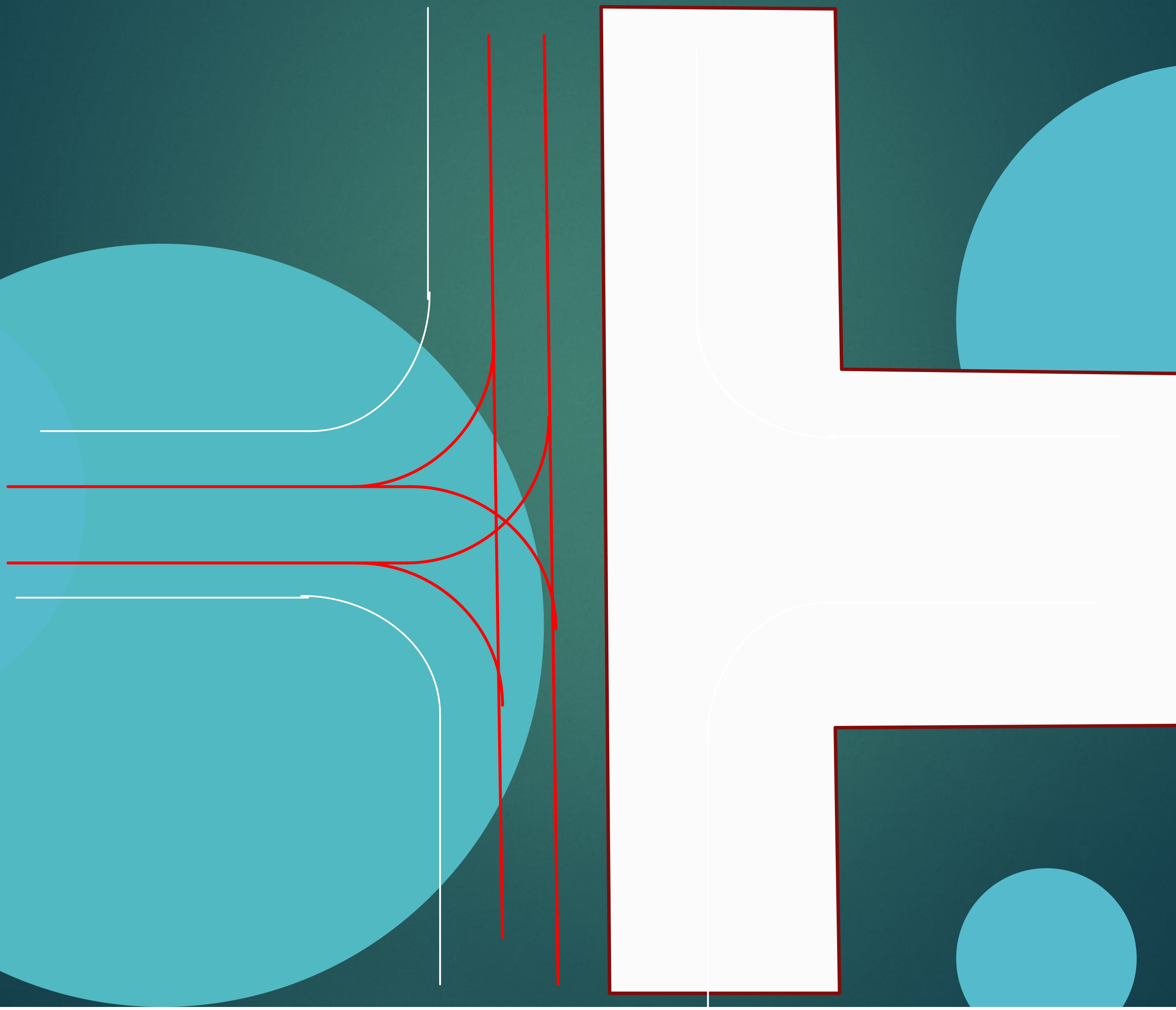
Staging



Quadrant Construction



Half at a Time



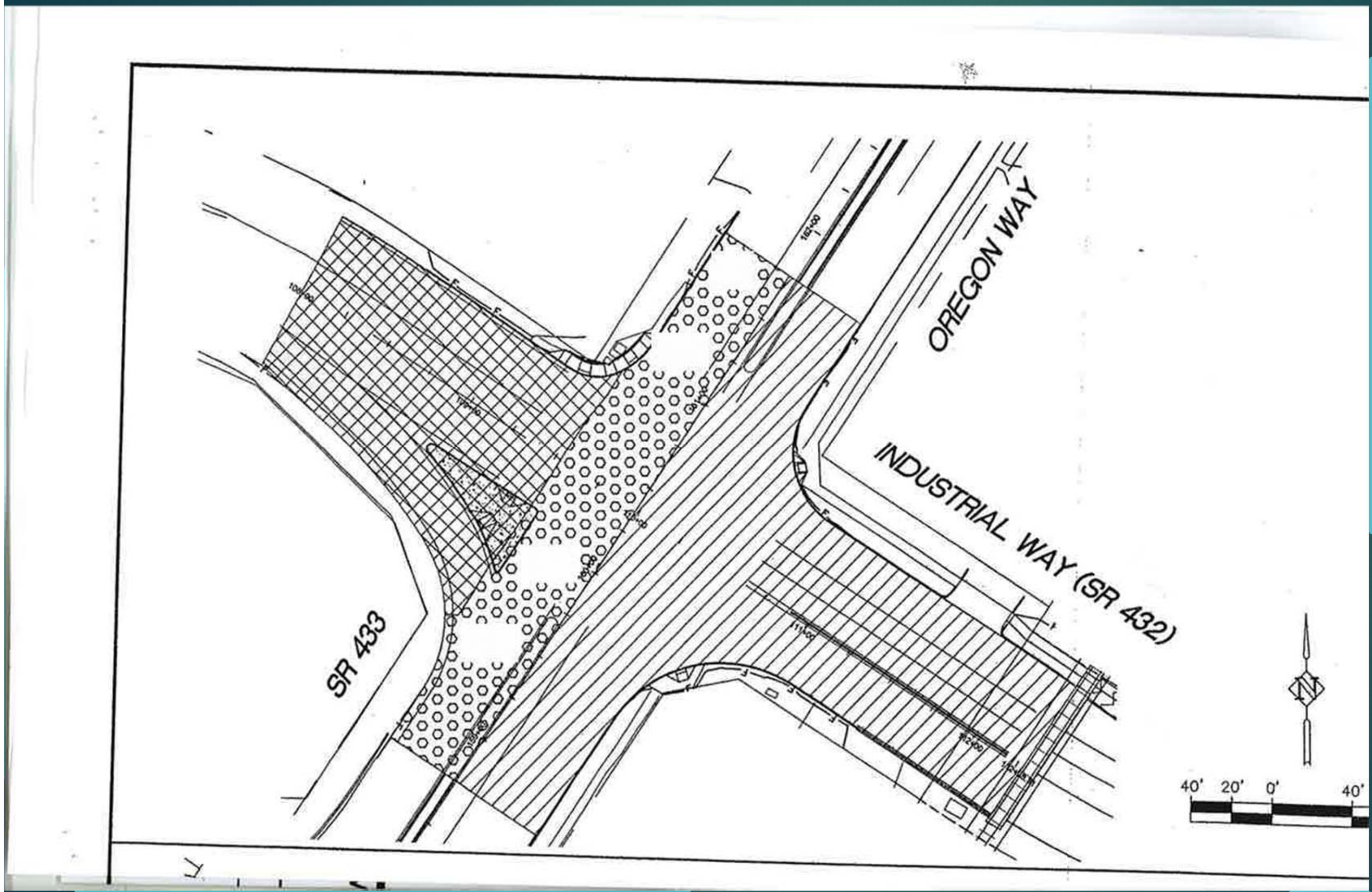
Partial Closure Success Stories

- City of Longview Washington
- City of Redmond Washington

SR 432 / SR 433
PCCP Rebuild
City of Longview

Finished Intersection

Intersection Rebuilt in 3 Phases



Work was around the Clock


CAUTION
2008/09/27

SR 520 Avondale Rd/Union Hill Rd, Redmond WA

100,000 ADT


ONLY


GOMACO
GHP 2800
NE UNION HILL RD

Combination Closures:

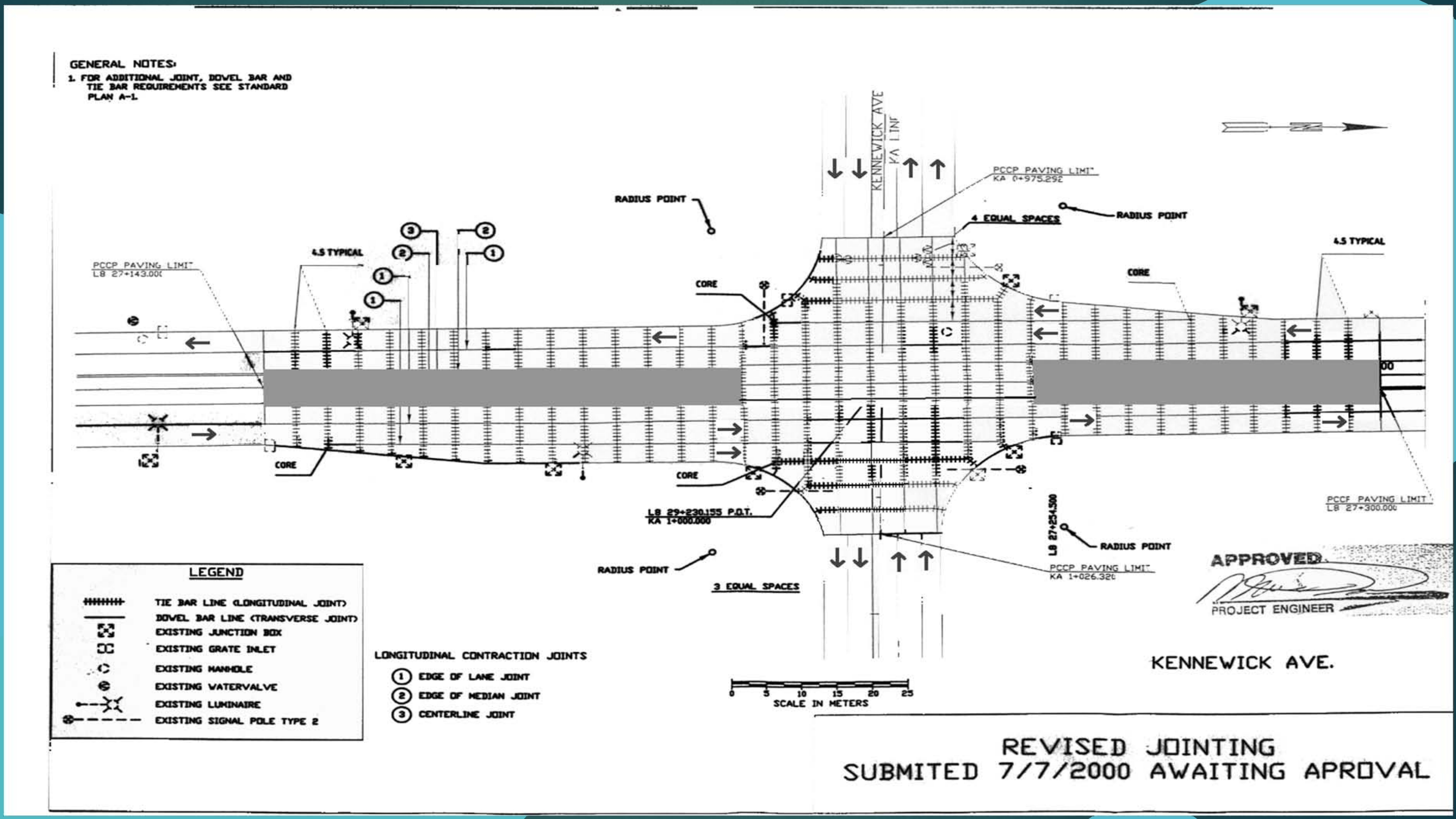
SR-395 & Yelm, Clearwater, Kennewick Avenue:

- Lane Closures Stages 1,2, 4
- Complete Closure Stage 3, Thursday at 7:00 PM to Monday 6:00 AM.
- Late opening penalty of up to $2,400.00 per hour.

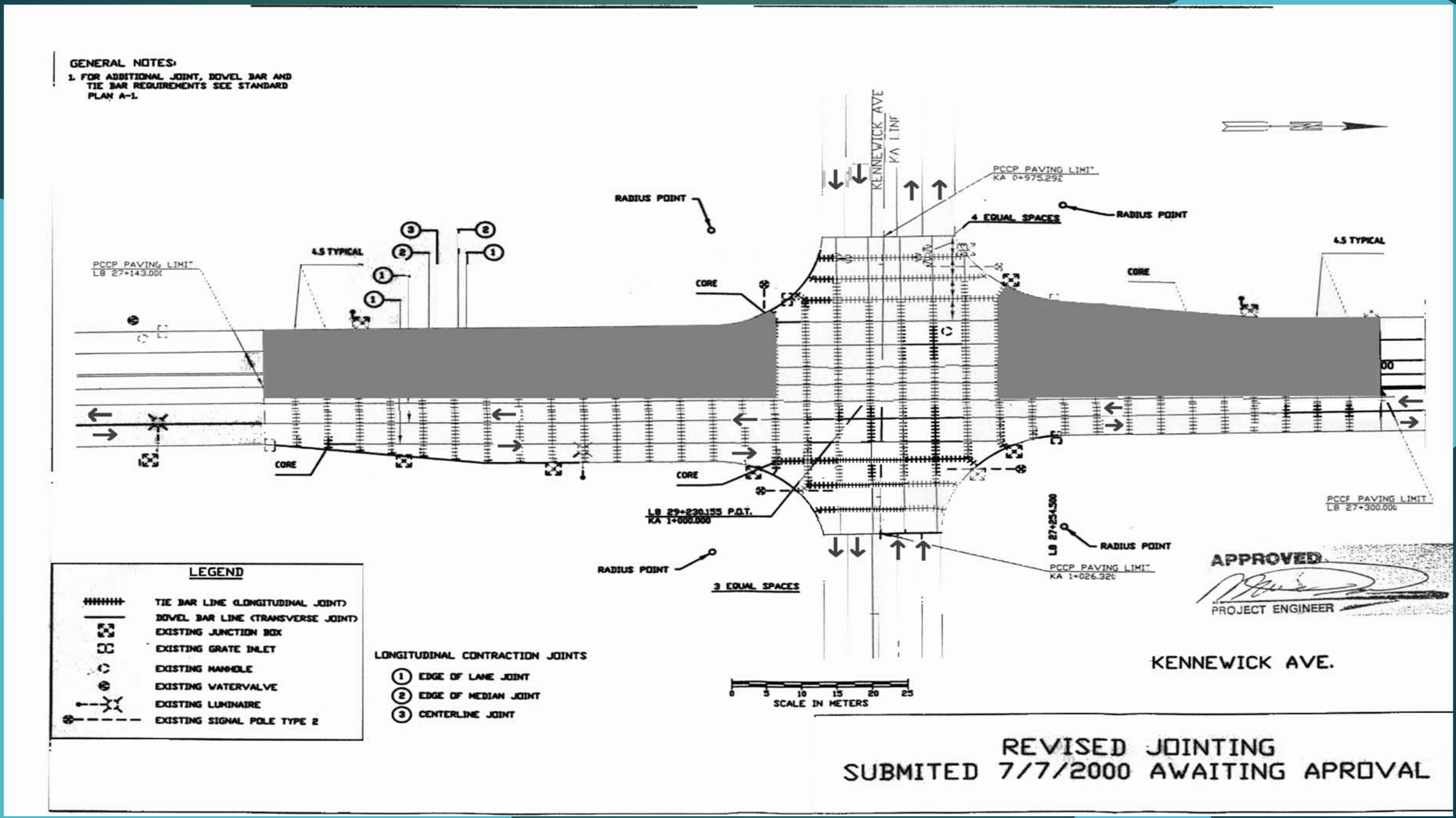
Time for Completion:

- Kennewick Avenue and Clearwater were built concurrently. This saved a considerable amount of time. Crews always had a place to work.
- In 15 days approximately 3384 cubic yards were placed in the two intersections.
- Construction staging was as follows:

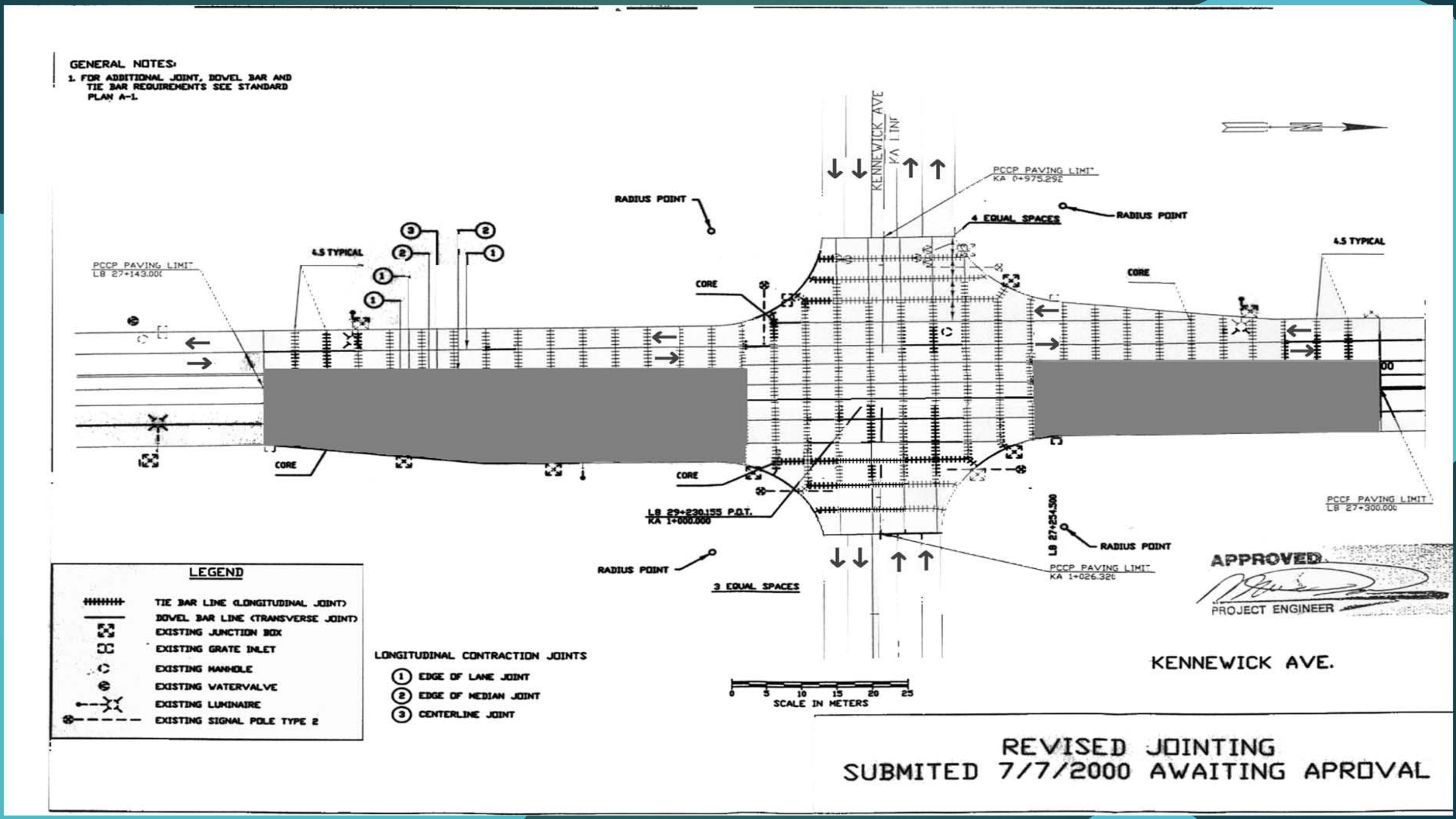
Kennewick Avenue Stage 1:



Kennewick Avenue Stage 2:



Kennewick Avenue Stage 3:



Kennewick Avenue Stage 4:

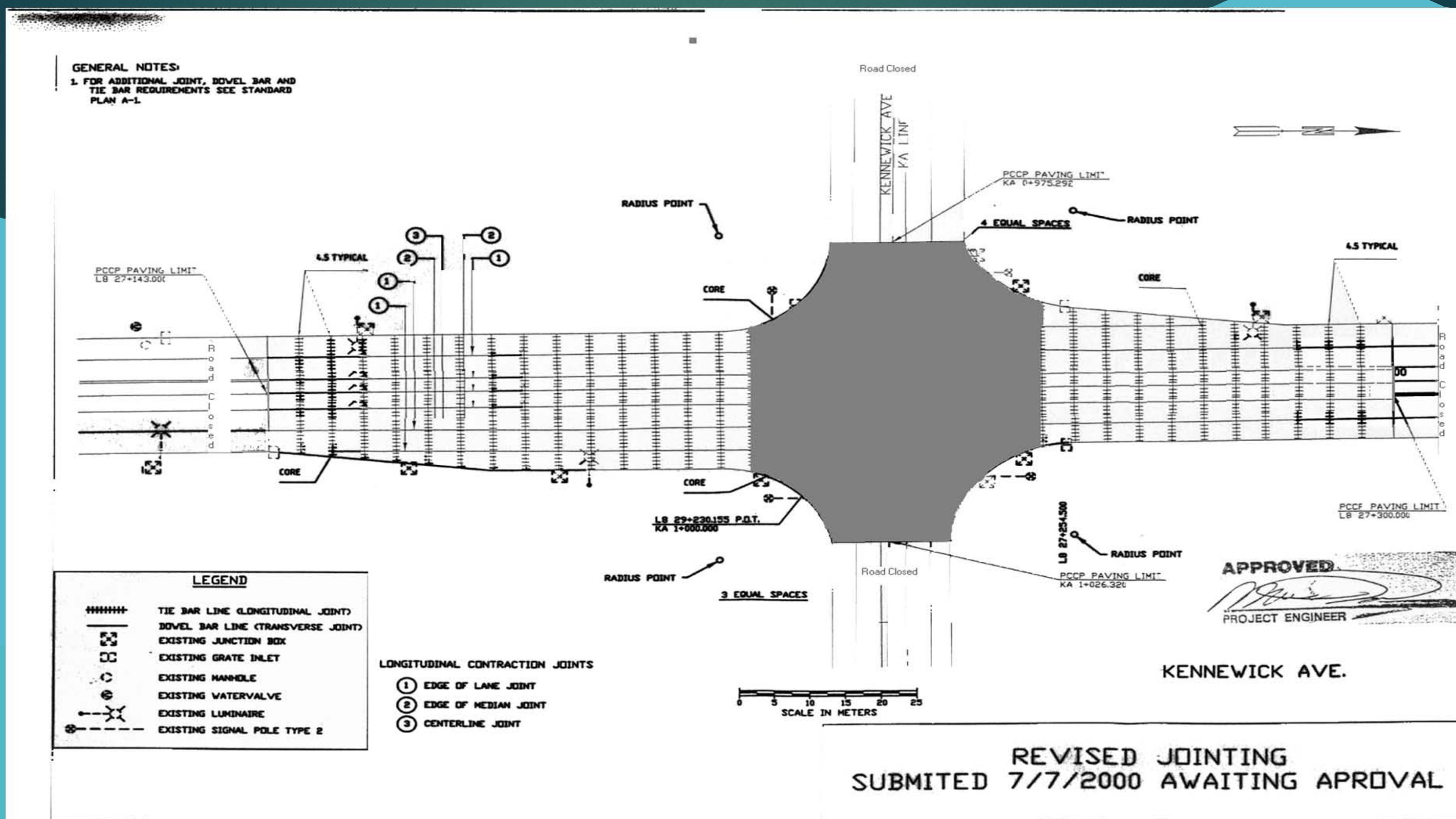


Photo Stage 4:

Crater Lake & McAndrews
Medford, OR

Crater Lake & McAndrews

- 60,000 ADT
- Widening work done prior to any traffic modifications
- Closed half of the intersection for 1 week
- Total 2 weeks to complete

Opening Strength

- Acceptable opening strength dependent on slab thickness
  - 7”   370 psi = 2,040 psi compressive
  - 8”   335 psi = 1,760 psi compressive
  - 9”   275 psi = 1,310 psi compressive
  - 10”   200 psi = 820 psi compressive
- Based on FE analysis assuming 1000 trucks per day, k-value of 200 pci, no edge support.
- Beam strength typically lower than in-place strength by 50-150 psi

Keys to Success:

Meet with stakeholders

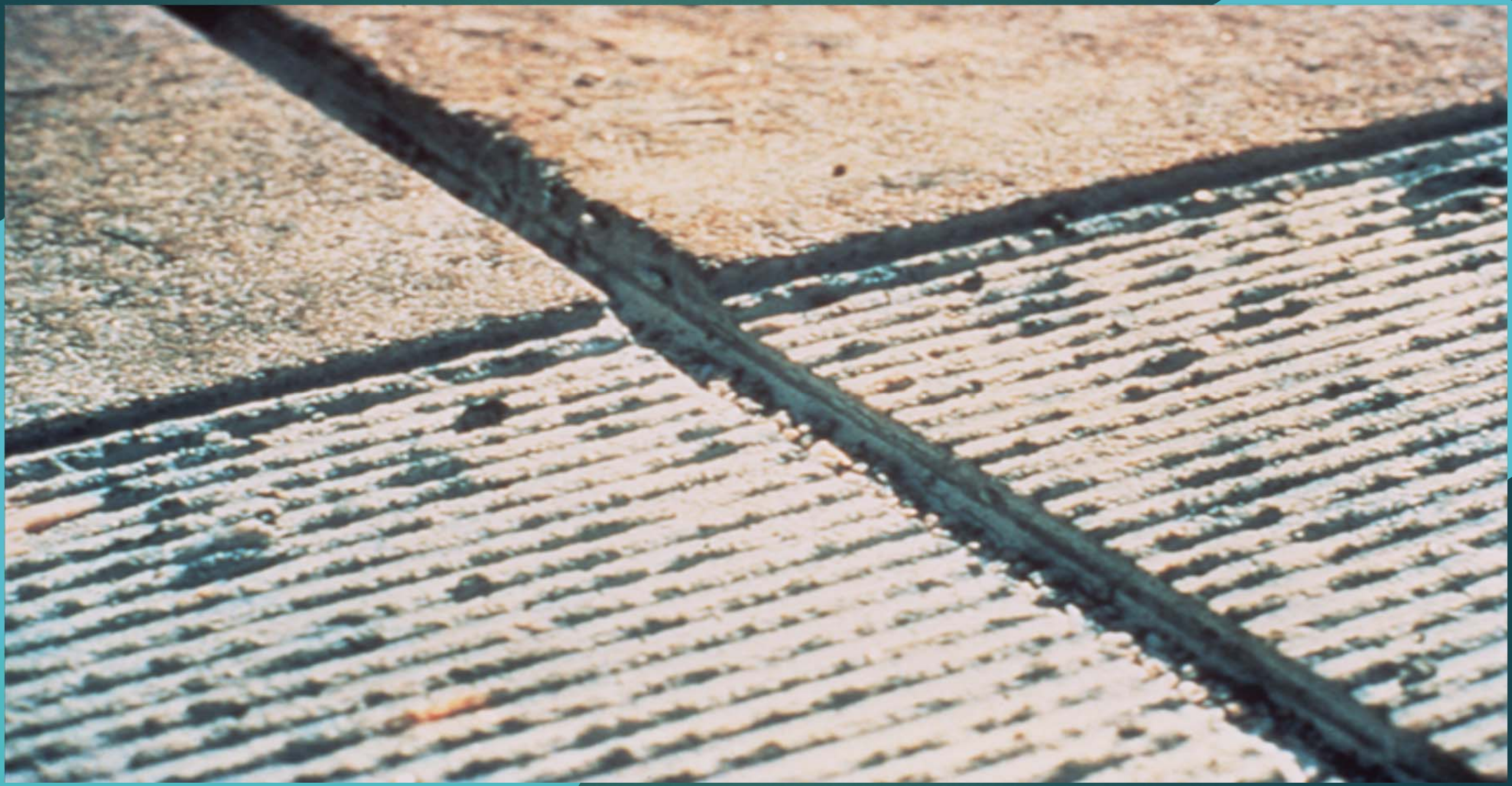
Meet with contractors to discuss feasibility.

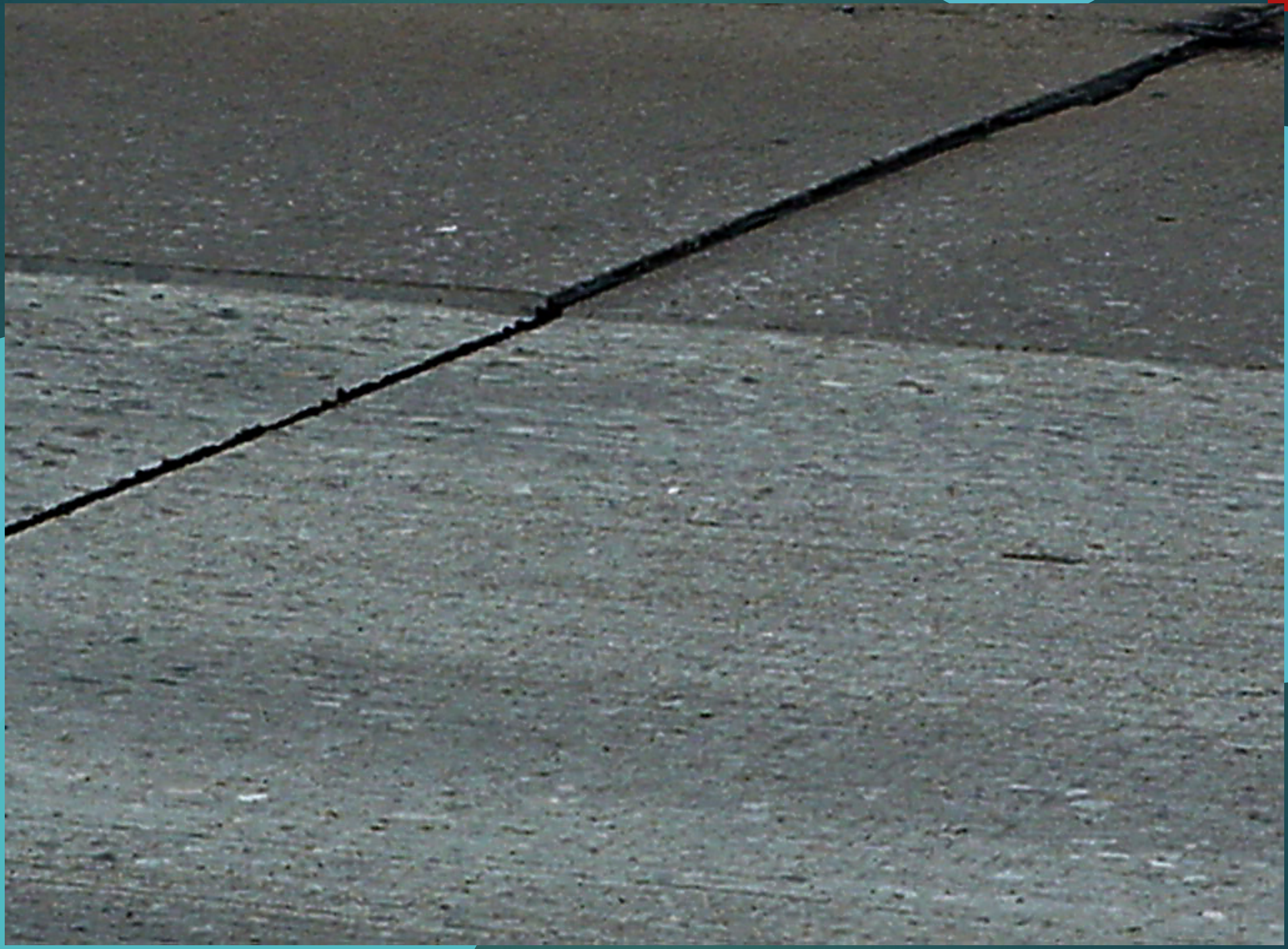
Invite businesses to pre construction meeting.

Keep public informed via newspaper, radio, and television news broadcasts.

Decision makers available to resolve issues.

Diamond Grinding



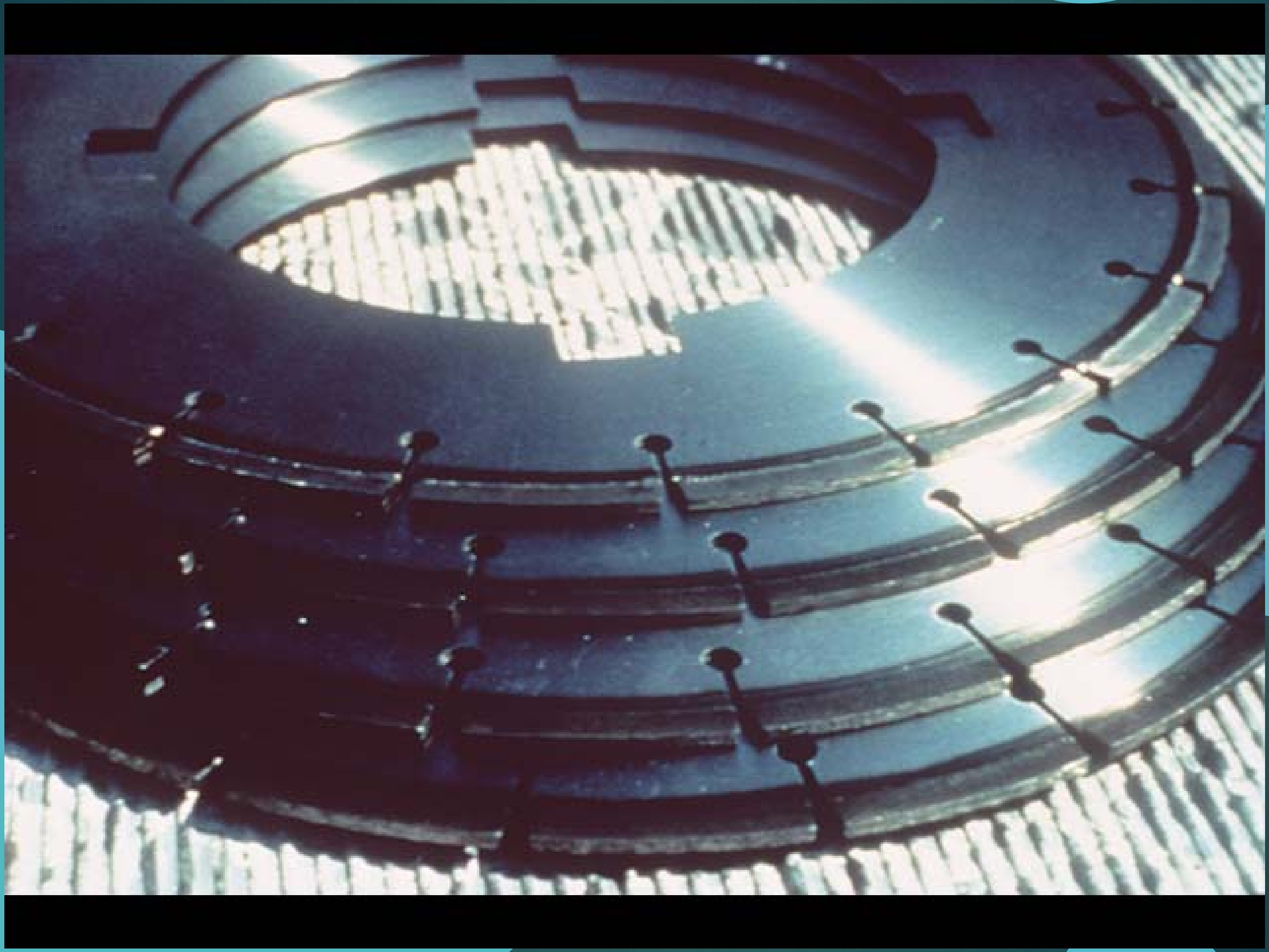


What is Diamond Grinding?

- Removal of thin surface layer of hardened PCC using closely spaced diamond saw blades
- Results in smooth, level pavement surface
- Longitudinal texture with desirable friction and low noise characteristics
- Frequently performed in conjunction with other CPR techniques, such as full-depth repairs, dowel bar retrofit, retrofit edgedrains

Advantages of Diamond Grinding

- Costs substantially less than AC overlays
- Enhances surface friction and safety
- Can be accomplished during off-peak hours
- Grinding of a rough area does not require grinding of adjacent areas
- Blends patching and other surface irregularities into a consistent, identical surface




MITCHELL
- EXIT 332
LEFT 1/2
PRM3804


PRM3804

Pavement Problems Addressed

- Faulting at joints and cracks
- Built-in or construction roughness
- Polished concrete surface
- Wheelpath rutting
- Unacceptable noise level
- Permanent upward slab warping
- Inadequate transverse slope

Thank you!

QUESTIONS?

Building a Safer, More Sustainable World …
One Project at a Time

Designing for Maximum Durability, Service-Life & Minimal Maintenance in New Concrete Structures & Concrete Repair & Renovation Projects with belitic CSA (Calcium Sulfoaluminate) Cement

Presented By:
Susan Foster-Goodman
Director of Strategic Initiatives & Komponent Sales

Rapid Set | KOMPONENT

By CTS Cement Manufacturing Corp.

Who We Are

Leading manufacturer of belitic CSA cement technology in North America

INFRASTRUCTURE
Highways, Roadways, Bridges and Viaducts

GOVERNMENT
Federal, State & Local Agencies, Public Works

MIXED USE
Urban Development, Multi-Family, Residential

INDUSTRIAL
Water/Wastewater, Power & Energy, Manufacturing

MARINE
Dams, Canals, Locks, Levees, Ports & Channels

AVIATION
Runways, Taxiways, Aprons, Hangars

INSTITUTIONAL
Schools, Universities, Healthcare, Correctional

COMMERCIAL
Retail, Hospitality, Recreation, Arenas, Convention Centers

MINING & TUNNELING
Shotcrete, Pumpable Grout, Cavity Fill, Pipe Liners

100% Employee Owned

At the heart of CTS's success is our team of employee-owners whose integrity, commitment and willingness to go the extra mile stand behind everything we do. Every employee has a personal stake in helping you succeed.

Learning Objectives

- Review Industry Objectives & Key Challenges
- Introduce belitic Calcium Sulfoaluminate (CSA) Cement Technology
- Understand the Performance Advantages
- Review Materials Available
- Discover its Design Versatility
- Discuss Sustainability Advantages
- Project Profile Snapshots of Interest


Key Challenges
Improve US Infrastructure by Maximizing…
o Safety
o Durability
o Sustainably
o Asset Life
Ensuring "Best Value"

Key Challenges

Continuous Improvement of Infrastructure to Deliver a Better "Customer Experience" by…

- **Minimizing Commuter & Community Disruptions**
- **Minimizing Inconvenience**
- **Minimizing Lane Closures & Repairs**
- **Enhancing Aesthetic Appeal**
- **Minimize Lifecycle Costs**
- **Fiscally Prudent Spending**

Key Challenges

Primary theories on how deterioration & corrosion in concrete occurs:

Drying shrinkage cracking & porosity of concrete allows…

- **Salts and other contaminants enter the concrete and cause corrosion.**
- **Corrosion of the metal leads to expansive forces that cause cracking of the concrete structure.**
- **Cracks in the concrete allow moisture and salts to reach the metal surface and cause corrosion.**

Key Challenges

Ultimately, Concrete Durability & Service Life is Compromised

- Cracking & Curling
- Spalling & Abrasion
- Sulfates & Chlorides
- Thermal Cycling
- Alkali-Silica Reaction (ASR)
- Carbonation
- Corrosion

Key Challenges

How do We Achieve the Objective to Prevent Deterioration & Failure?

- ✓ **Prevent Deterioration Caused by Shrinkage Cracking**
- ✓ **Prevent Deterioration Caused by Chemical Attack** *(Sulfates, Chlorides)*
- ✓ **Lower Porosity & Permeability**

= **Maximize Durability & Asset Life**

What Is It?

The Performance Advantages of belitic CSA cements can help overcome the key challenges commonly experienced with concrete installations.

"It is one of the most amazing advancements – and best kept secrets – in cement technology in the last 60 years."

- Michael Chusid, RA FCSI CCS

CSA Cement Technology can help achieve these objectives by…

- ✓ Maximizing Durability
- ✓ Extending Service Life
- ✓ Accelerating Construction Practices

- ✓ Minimizing Inconvenience to the Public
- ✓ Minimizing Lifecycle Costs
- ✓ Minimizing Downtime & Lost Revenue

- ✓ Contributing to Smart Construction Practices
- ✓ Contributing to Efficient Technologies
- ✓ Contributing to Low-Impact O&M

Belitic Calcium Sulfoaluminate (CSA) Cement

- **Modified derivative of portland cement clinker**
- **Higher quality hydraulic cement**
- **Developed in the 1950's to overcome common shortfalls of portland cement**
  - *Excessive shrinkage*
  - *Susceptibility to chemical attack*
  - *Destructive reactions with certain aggregates*
  - *Negative consequences of traditional accelerating admixtures*

History

1950's Alexander Klein discovers calcium sulfoaluminate (CSA) cement and focuses on chemical pre-stressing of concrete and shrinkage compensation of portland cement. Type K Shrinkage-Compensating Concrete is invented. Ed Rice was instrumental in these early R&D efforts.

1960's Ed Rubin, Alexander Klein and Ed Rice develop CSA rapid hardening cement.
First industrial production of CSA at the Kaiser Cement Plant.

1970's CSA technology continues to develop and project uses grow. Including:

Los Angeles World Trade Center, Washington, D.C. Subway, Chicago O'Hare Parking Structure, Dallas City Hall, and Ohio Turnpike Bridge Decks, The Pentagon.

1980's Further growth and development of rapid setting technology & bulk products.

1990's Consumer-based product line developed (bag & box / retail & specialty distribution).

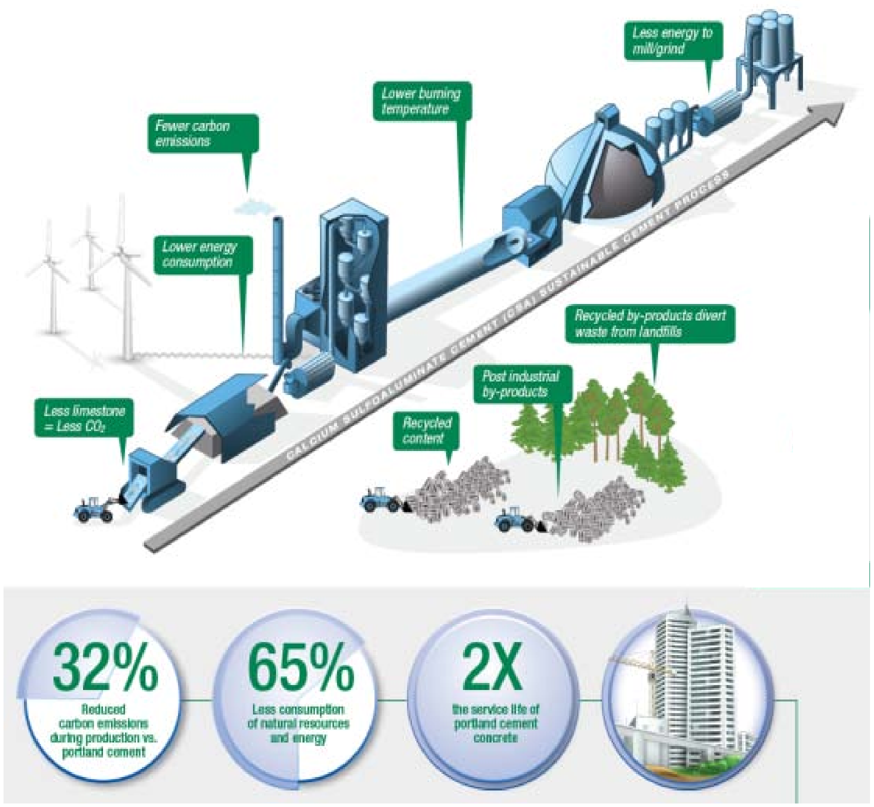
CalTrans – 400 lane miles of concrete highway

2000's International market expansion; product development continues (paint line, mining, self-leveling and polishable cements)

Today, millions of cubic yards of CSA are placed worldwide each year.

Sustainability

- **Less Limestone**
  - *Fewer Natural Resources*
  - *1/3 less CO_2 emissions*
- **Kiln Temperature is ~400°F Lower**
  - *Significant reductions in fuel and CO_2 emissions*
- **Easier to Grind than OPC Clinker**
  - *Less electricity/energy consumption*
- **Recycled & Post Industrial By-Products**
  - *Divert waste from landfills*



Primary Differences

Portland Cement Composition

ASTM C150 TYPE	C_3S (Early Strength Gain)	C_2S (Long-Term Strength Gain)	C_3A (Attacked by Sulfates)	C_4AF	$C\underline{S}$
I	59	15	12	8	2.9
II	46	29	6-8	12	2.8
III	60	12	12-15	8	3.9
IV	30	46	5-7	13	2.9
V	43	36	4-5	12	2.7

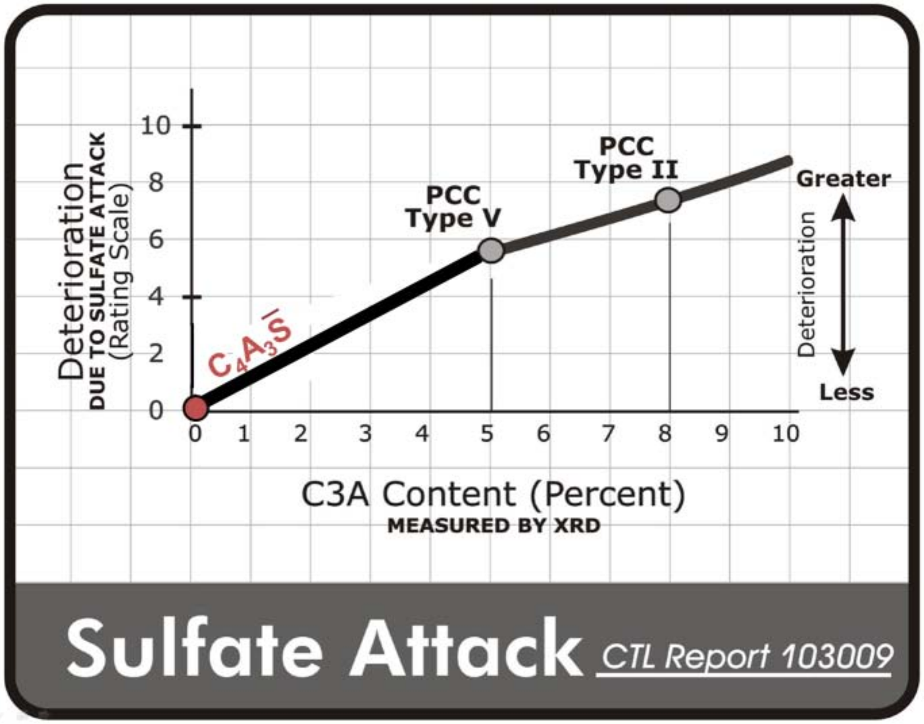
Calcium Sulfoaluminate Cement Composition

ASTM C1600	$C_4A_3\underline{S}$ (Early Strength Gain)	C_2S (Long-Term Strength Gain)	C_3A (Attacked by Sulfates)	C_4AF	$C\underline{S}$
CSA Cement	30	45	0	2	15

Quantities represent % composition

- **Early Strength Gain Element Achieves a Significantly Different Performance**
- **Exceptional Long-Term Strength Gain**
- **Durability is not Compromised for Speed**
- **Negligible C_3A Content Achieves Absolute Sulfate Resistance**

Performance



- **CSA cement** (ASTM C1600) **provides absolute sulfate resistance.**
- **CSA cement expansive additive** (ACI 223, ASTM C845) **enhances sulfate resistance for all OPC mix designs.**

After 2 Years | **After 6 Years**

Type II Portland (8% C_3A) | **$C_4A_3\bar{S}$ Cement** (0% C_3A)

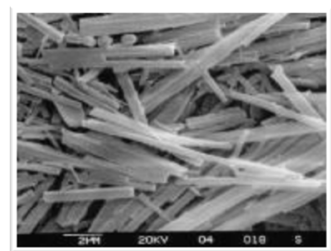
Immersed in 10% Sodium Sulfate Solution
Simulates High Sulfate Soil Conditions

How?

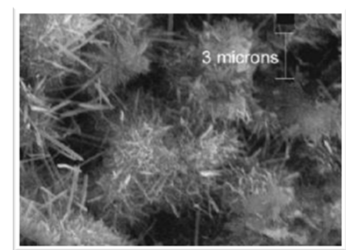
Early Ettringite Formation

- Maximum formation during the first 7 days maximizes strength gain
- Rapid formation allows fast repair & quick in-service turnaround (ASTM C1600)
- Minor controlled early expansion compensates for shrinkage (ASTM C845)

Full consumption of mix water and complete hydration of CSA cement during placement and cure maximizes performance of the placement and helps prevent detrimental delayed ettringite formation.



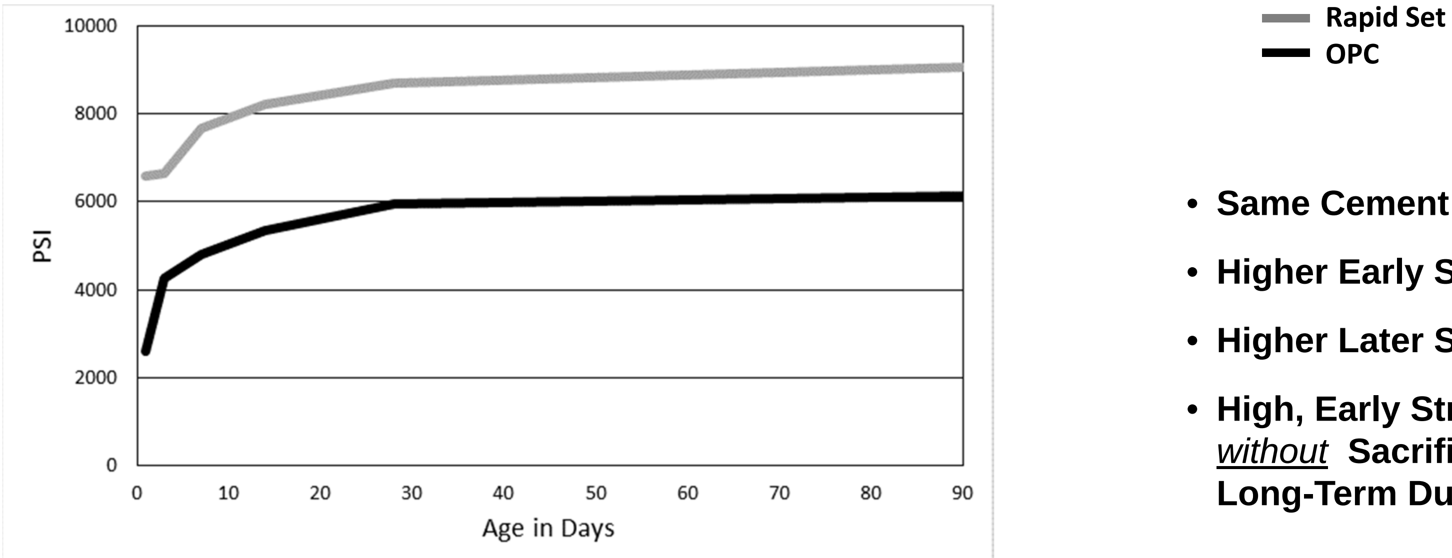
CSA Cement Ettringite Crystals



Portland Cement Crystals & Gel

Performance

Strength Gain Testing – Rapid Set vs. OPC



Testing performed at GCC MX

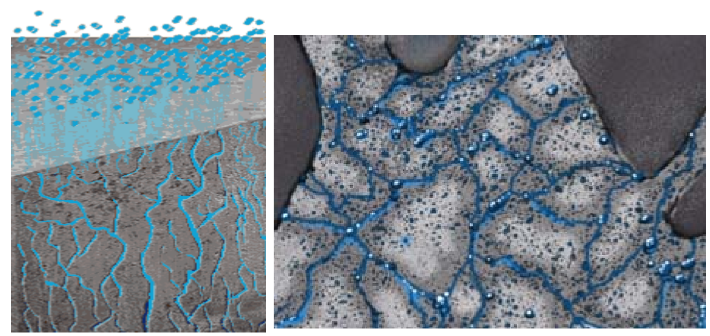
- **Same Cement Content**
- **Higher Early Strength**
- **Higher Later Strength**
- **High, Early Strength *<u>without</u>* Sacrificing Long-Term Durability**

How?

A Different Hydration Mechanism

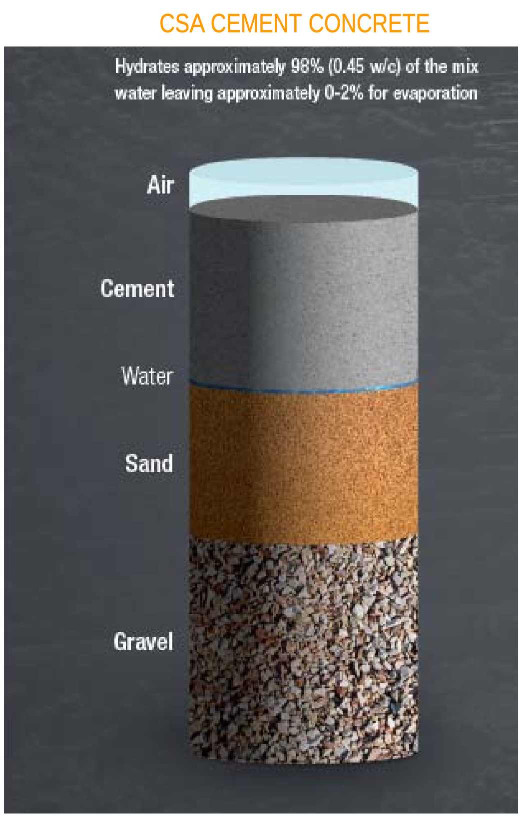
- Mix water is chemically retained (“bound”) within the ettringite structure
- Eliminates bleed water (minimal water of convenience)
- Maintains integrity of the mix designed at the surface; w/c ratio is not compromised
- Improves abrasion & impact resistance
- Prevents voids & capillary channels that lead to drying shrinkage
- Lowers porosity and permeability
- Prevents cracking & curling due to drying shrinkage & volume change
- Prevent laitance and other “debris” from being drawn to the surface

Escape of convenience water in portland cement concrete creates voids & capillary channels that lead to shrinkage & contamination



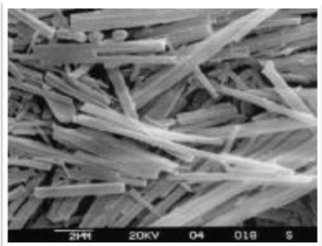
Portland Cement Concrete Egress of Excess Water

Performance



Performance

1



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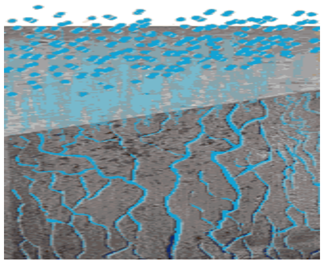

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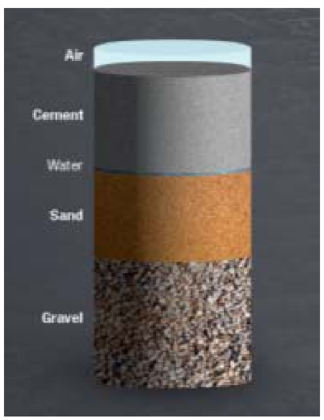


- **Maximum Utilization of H_2O Used in Hydration**
  - Eliminate Capillary Channels and Voids
  - Low Shrinkage
- **Maximum Formation of Ettringite Crystals Achieves High 1 to 1.5 Hr Strengths (Up to 7,000 psi)**
- **Can Have Expansive Qualities**
  (Komponent® cement additive used to create Type K cement)
- **High Sulfate Resistance (No C_3A)**

✓ **Denser Concrete**

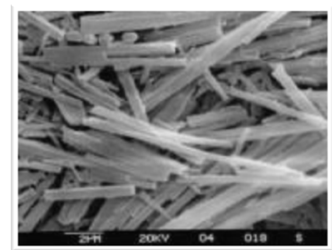
✓ **Lowers Porosity & Permeability**

✓ **Maximizes Durability**

Shrinkage-Compensating Concrete

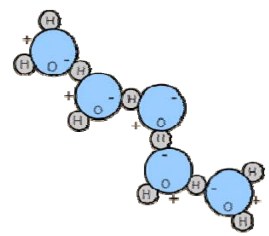
ACI 223 Type K (ASTM C845, C878)

- Designed to **IMPROVE THE CEMENT PASTE** within the concrete structure.
- Engineered to **COMPENSATE** for drying shrinkage – effectively achieving net zero shrinkage of the concrete.



Dimensional stability maintained for the designed service life of the placement.

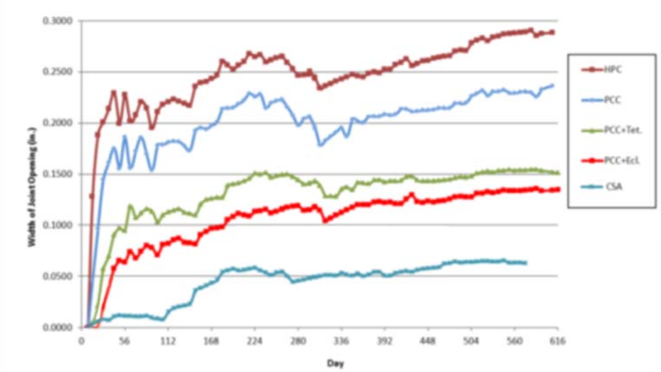
- CSA cement is **NOT** an SRA.
- SRAs affect the surface tension of the pore water.
- They are designed to **DELAY** shrinkage.
- Effects diminish over time.
- Compressive strengths can be affected.



Performance

Joint Width over Time

The Wider the Joint, the Greater the Shrinkage of the Slab



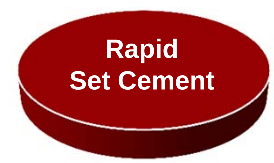
- Shrinkage Compensating Concrete (Komponent®) manufactured by CTS is extremely stable, with little to no long term shrinkage, control joint strain or warping. This stability is noted at both early age and at 10 months.
- Typical PCC and HPC continue to exhibit control joint growth at 10 months.
- Shrinkage Reducing admixtures have a minor impact at early age but do not impact long term sectional stability. Shrinkage, control joint strain and warping are nearly similar to typical PCC but slightly better than High Performance Concrete (HPC)

Used In

1 **Fast-Setting Hydraulic Cement Materials**

ASTM C1600

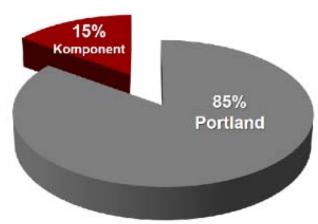
- High Early Strength
- Maximum Durability



2 **Shrinkage Compensating Concrete**

ACI 223 Type-K (ASTM C845)

- Expansive Additive
- Superior Durability



Multi-Functional

FAST!

Just Add Water
Ready to Enjoy!

OR

1 Common Ingredient
Creates 2 Unique Products

Aged to
PERFECTION

Mix with Other Ingredients, Bake for a While, then Enjoy!

Used In

F A S T !

1 **Rapid-Hardening Hydraulic Cement Materials**
ASTM C1600

2 **Shrinkage Compensating Concrete**
ACI 223 Type-K (ASTM C845)

Fast-Setting Hydraulic CSA Cement Materials *ASTM C1600*

- Concrete Mixes
- Concrete Resurfacers
- Mortar Mixes & Repair Mortars
- Non-Shrink Construction Grouts
- Smoothing & Patching Compounds
- DOT & FAA Concrete Paving & Overlays
- Shotcrete
- Flowable Fill (CLSM)
- Cementitious Slurry

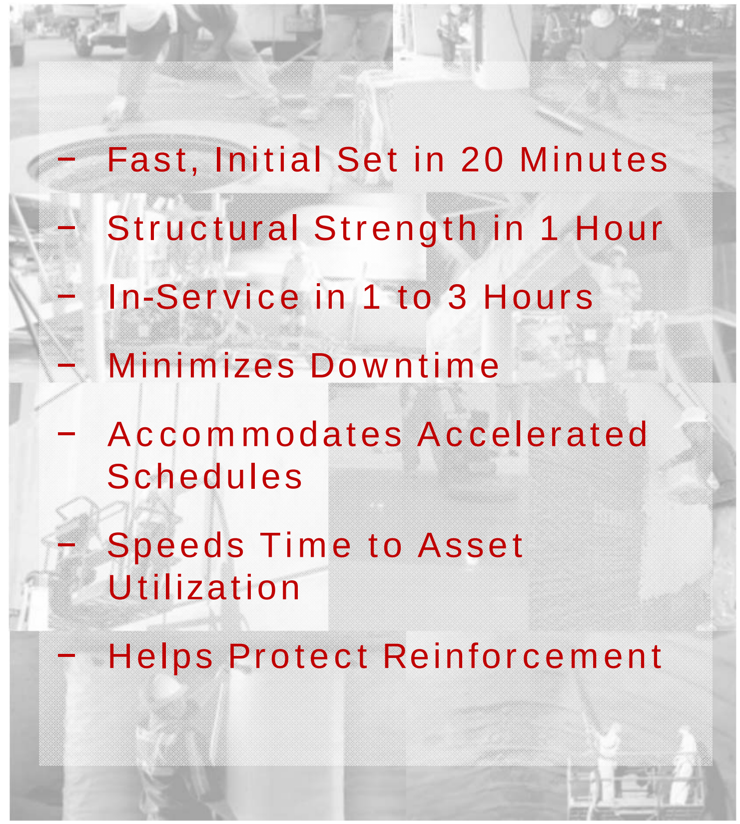
Rapid Set

Advantages

Fast-Setting Hydraulic Cement Materials *ASTM C1600*

Advantages

- CSA Technology
- Minimize Shrinkage
- Improved Durability
- Increased Abrasion & Impact Resistance
- Reduced Permeability
- Increased Service Life



- Fast, Initial Set in 20 Minutes
- Structural Strength in 1 Hour
- In-Service in 1 to 3 Hours
- Minimizes Downtime
- Accommodates Accelerated Schedules
- Speeds Time to Asset Utilization
- Helps Protect Reinforcement

Project Value

CSA cement can be used wherever OPC is used

- **Greatest Value is Realized…**
  - Anywhere Fast Strength Gain is Required
  - Where In-Service Time is Paramount
  - Re-Align Critical Path (Recapture Time)
  - When Project Schedules Fall Behind
  - When Delay Penalties are Impending
  - Opening On Time is Critical
  - Early Formwork Removal is Necessary or Beneficial
  - Revenue Generating Asset
  - Emergency Repairs
  - Fast-Track Projects

Rapid Hardening, High Early Strength Materials Can Be Achieved by…

Using various components in combination

1. Type III or HE high-early-strength cement
2. High cement content >675 cu. yd.
3. Lower w/c ratio (0.20 to 0.45 by mass)
4. Higher freshly mixed concrete temperature*
5. Higher curing temperature
6. Chemical admixtures
7. Silica fume (or other SCMs)
8. Steam or autoclave curing

OR using

Stand-alone specialty rapid hardening cements (ASTM C1600)

Hydraulic cements that exhibit rapid strength gain during the first 24 hours of hydration.

ASTM C1600/C1600M

3.2.1 Terminology

Rapid Hardening Hydraulic Cement – a hydraulic or blended hydraulic cement which exhibits rapid strength gain during the first 24 h of hydration, with or without other constituents, processing additions, and functional additions.

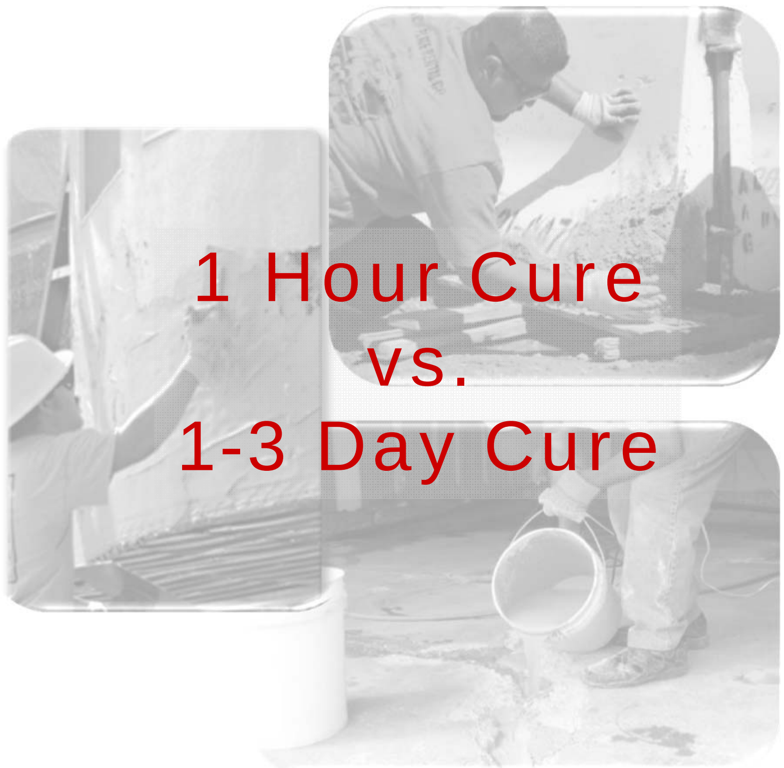
TABLE 1 Standard Physical Requirements

(must be reported on manufacturer's certification)

	Cement Type			
	URH	VRH	MRH	GRH
Compressive Strength (See Section 9 for procedures), min, MPa [psi]				
1½ h	21 [3000]	12 [1700]	. . .	. . .
3 h	28 [4100]	15 [2200]	10 [1500]	7 [1000]
6 h	. . .	. . .	14 [2000]	10 [1500]
1 day	35 [5100]	24 [3500]	17 [2500]	14 [2000]
7 days	41 [6000]	28 [4100]	28 [4100]	24 [3500]
28 days	57 [8300]	35 [5100]	31 [4500]	28 [4100]
Drying Shrinkage, max %				
7 days	0.06	0.06	0.08	0.10
28 days, air storage	0.07	0.07	0.09	0.12
Min Time of Final Set C191 apparatus				
Minutes[A]	10	10	10	10
Autoclave, max expansion %	0.8	0.8	0.8	0.8

[A] The initial setting time typically ranges from 10 to 45 min for rapid hardening cements of various types and composition.

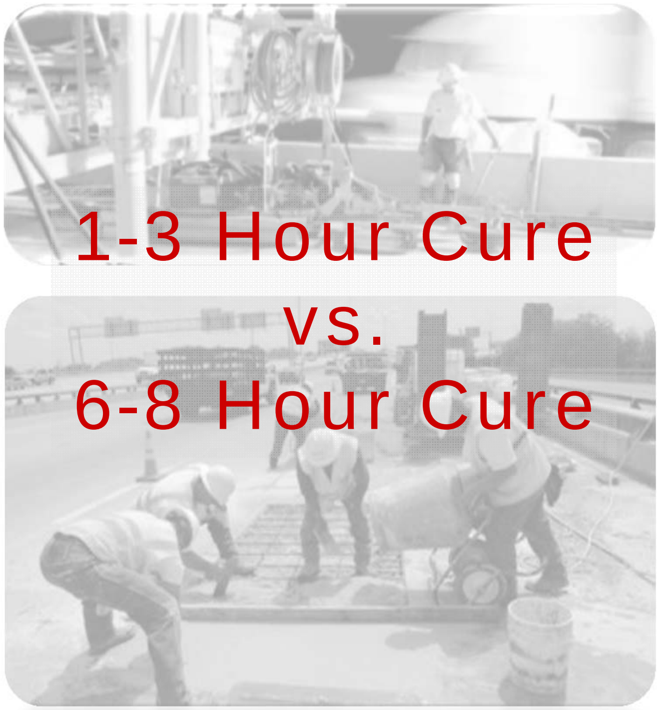
Product Availability



**New Construction,
Repair & Restoration**

- **Concrete Mixes**
- **Concrete Overlays & Sub-Bases**
- **Mortar Mixes & Repair Mortars**
- **Non-Shrink Construction Grouts**
- **Vertical & Overhead Materials**
- **Smoothing & Patching Compounds**

Product Availability



Pavement & Overlays
DOT Approved

- Concrete Mixes
- Concrete Overlays & Sub-Bases
- White Toppings (Bonded & Unbonded)
- Mortar Mixes & Repair Mortars
- Low Permeability Concrete
- DOT & FAA Concrete Paving
- Latex Overlays

Product Availability

Shotcrete, Tunneling, Mining, Geotechnical

- Shotcrete
- Cavity Fill
- Flowable Fill/Backfill
- Lean Base
- Structural Support
- Pipe Liner/Mine Roof Supports
- Underground Road Repair

Panel Replacement

California Freeway System
(CalTrans)

Over 1,000 lane miles since 1995

Roads & Bridges

- Structural Repair of 4 Bridge Hinges
- 60’ W x 25’ L x 5’ Thick Sections
- Self-Consolidating Mix Design

Highway 280
San Francisco

“Replacement work went without a hitch.”
- Joon Kang, Project Manager - CalTrans

Highway 280
San Francisco

Specification		Achieved
1 Hour Workability	✓	Yes
Max. Shrinkage 0.045%	✓	0.019%
1,200 psi @ 3 hrs	✓	2,957 psi @ 3 hrs
3,500 psi @ 4 hrs	✓	4,000 psi @ 4 hrs
28” to 35” Displacement	✓	30”

Highway 280
San Francisco

"We used Rapid Set to improve efficiencies and meet the deadline at it is performing beautifully."
- Joon Kang, Project Manager/CalTrans

Remove & Replace Hinges

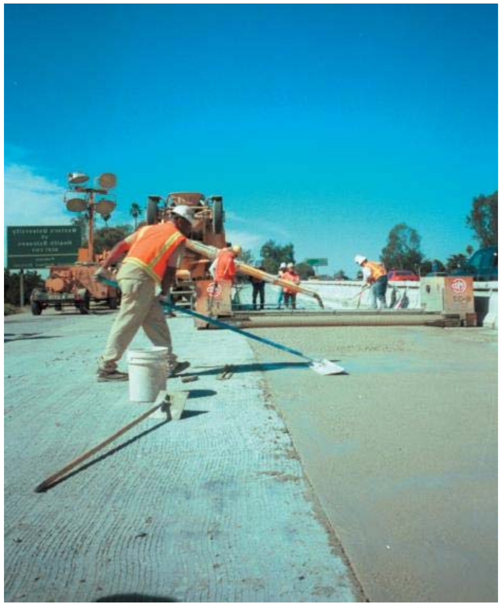
1 Hinge Memorial Day ✓ Opened 3 Hours Early

1 Hinge July 4th ✓ Opened 10 Hours Early

2 Hinges Labor Day Weekend ✓ Opened 7 Hours Early

Pavement Rehabilitation 57/210
Pomona, CA

- **In 1999, CalTrans replaced a two-mile section of freeway from the 57/210 interchange in Pomona, CA.**
- **This rehabilitation project placed**
  - 3,500 cubic yards of Rapid Set cement pavement
  - 9-in thick in 55 hours
  - On-time completion



Crews Placing a Two-Mile Section of the 210 Freeway, 1999

Pavement Rehabilitation I–10 Pomona CA

Replacement of 9" Thick Concrete
3 hour Flex Strength 450 psi

Nevada DOT – PN# Q2-010-12

Remove & Replace Damaged PCCP - 2013

Pavement damage on this main thoroughfare due to rock slide

Nevada DOT – PN# Q2-010-12

Remove & Replace Damaged PCCP - 2013

RMA Group Test Results # 13-068-0/02
Strengths Requirements & Results

		Compressive	Flexural
Spec	½ Hour	1700 psi	N/A
RS Average	1 Hour	3460 psi	455 psi
RS Average	10 Day	5260 psi	620 psi

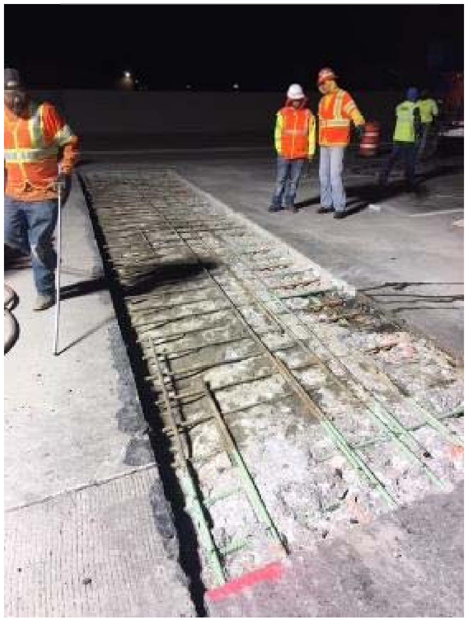
- **Rapid Set chosen for Cast-in-Place Panel Replacement**
- **The Most Cost Effective Solution with Minimal Impact on Commuters and Commercial Transportation**

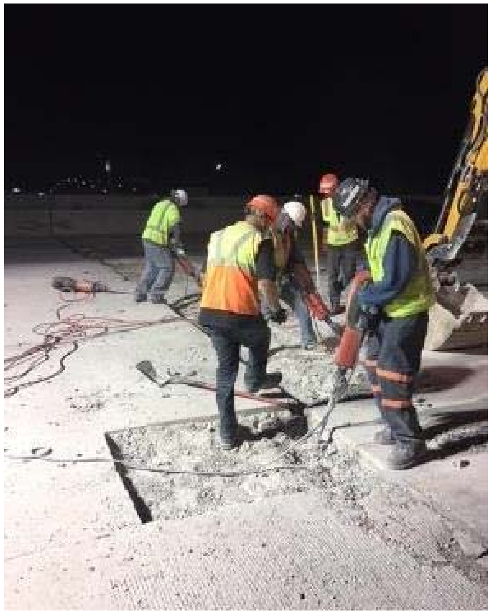
Utah DOT I-80 Patching

- **Sub-Base repair with RS Lean Concrete Base**
- **Full Depth Panels, 10" Thick**
- **Ready Mix Production, 20-25 Transit Time**
- **Opening Strengths in 2 Hours (Retarded Mix for 1 Hour)**

Utah DOT I-15 Patching

Bridge Impact Panels | The “Spaghetti Bowl” I-15 and I-80 Intersection





- **High Traffic Thoroughfare**
- **Closures 6 Hrs/Night**
- **3” to 6” Repair Depths**
- **Chipping Hammer Removal**
- **Ready Mix Production (w/retarder)**
- **Wet Burlap Curing**

CIP Pavement

I-40 NC DOT

Current Project | 4,000 cu. yd.

- **Volumetric Production**
- **Time Restrictions: 8:30pm to 6:30am**
- **Late Opening Penalties: $5,000/Hour**
- **Must meet Flexural (650 psi) AND Compressive (4500 psi) Strengths @ 28 Days**

- **Flexural Spec: 400 psi in 4 Hours**
- **Breaking Flex Beams Nightly**
- **RS is meeting spec in 1.5 Hrs; Over 500 in 2 Hrs**
- **Curing Compound Used on Panels**

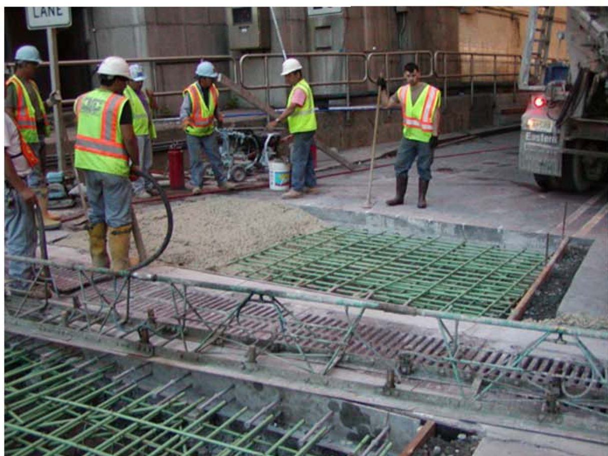
SC DOT I-85 Patching

2016, 8-Weekend Project

- 150-180 cu. yd./weekend
- Opening Compressive Strength Spec: 1,600 psi
- Breaking Cylinders @ 24 Hrs and 28 Days

Lincoln Tunnel

Full Depth Repair



- **Most traveled thoroughfare in the region**
- **Weekend pavement replacement**
- **Demo & prep completed on Saturday**
- **Poured at 6am Sunday**
- **Opened to traffic 6pm Sunday**

CIP Pavement

LaGuardia Airfield | Taxiway Full Depth Panel Replacement

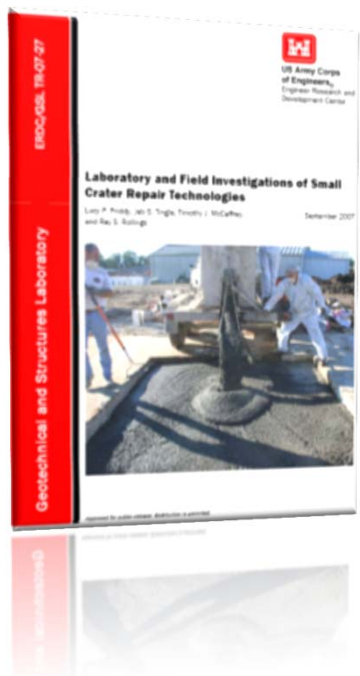
- **300 cu. yd. @ 20" thick**
- **Weekend replacement**
- **Ready mix delivery with batch plant on-site**
- **Opening strengths achieved and on-time performance delivered**

Seismic Repair

- Collapse of Interstate 10 Overpass
- Approach Slab Repairs
- Re-opened 74 days ahead
- $14.5m bonus for the contractor

Tyndall AFB
Laboratory Crater Repair

Government



f. Rapid Set is recommended as the user's choice for crater repairs due to its ease of use, controllable set time, performance, and fast cure time.

g. Future exercises should be conducted to determine if the recommended repairs could be completed in the 4-hr time frame using manpower and equipment similar to that available during expedient and sustainment operations.

h. The required cap thickness as a function of backfill strength and expected aircraft loading should be explored through additional field testing and/or the use of finite element models. Until this testing is complete, Table 34 provides a matrix of layer thicknesses for standard pavement sections for typical design aircraft, traffic levels, conservative material properties, and relevant environmental conditions for expedient and sustainment repair.

Government

- Rapid Set Repair Mix is used by US Military all over the World at Bases for Concrete Repairs
- Shipped in one ton sacks

SEA-TAC Airfield Rehabilitation

Runway 16C Concrete Panel Replacement Program
(1994-2005)

- **1,200 aircraft movements daily**
- **600 aircraft landing on rapid set CSA concrete panels (slabs) daily**
- **35,000 yd^3 of Rapid Set® CSA concrete placed (708 panels)**
- **Runway and Taxiways**

SEA-TAC Airfield Rehabilitation Research

2012

FATIGUE LIFE RESEARCH

"Flexural Fatigue Behavior of Plain Concrete Fabricated with CSA Cement"

OPC Mix | Replacement Rate: 35.5%
CSA Mix (ASTM 1600) | Replacement Rate: 3.8%

Estimation of Fatigue Life = 87 years

Report and Testing by Construction Technology Laboratories, Inc. (CTL)

- *Static Flexural Strength (ASTM C78)*
- *Repetitive Loading at Various Stress Ratios (0.48 – 0.89) (ASTM D1195/D1195M)*

Hartsfield-Jackson Atlanta International

Full Depth Panel Replacement

The World's Busiest Airport with 5,000 Flights/Day

Hartsfield-Jackson Atlanta International

Full Depth Panel Replacement

YouTube

Panel Replacement

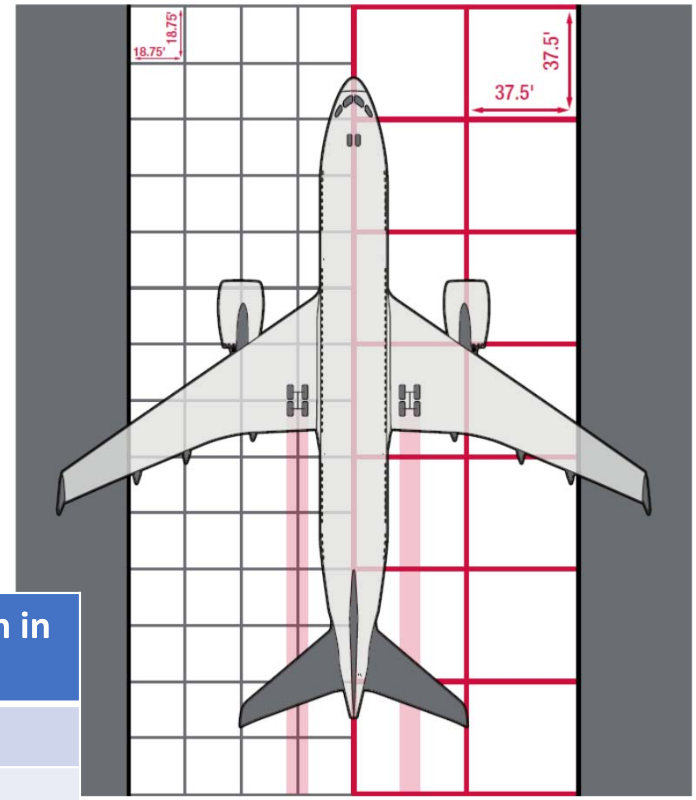
Airports Around the World

- Los Angeles International (LAX)
- Boston Logan (BOS)
- Savannah/Hilton Head (SAV)
- Portland International (PDX)
- Auckland International (AKL)
- And more…

Airport	Date	Application
SEA – Seattle-Tacoma Int'l Airport	1994-1998	Runway Panel R&R
MDW – Midway Int'l Airport	1998	Runway Panel R&R – Bulls-Eye Intersection
SNA – John Wayne Int'l Airport	1998	Parking Garage
BOS – Boston/Logon Int'l Airport	2004	Runway Repairs
ICT - Wichita Dwight D Eisenhower Airport	2004	Runway and Apron Repairs
KCI – Kansas City Int'l Airport	2004	Runway and Apron Repairs
ATL – Atlanta/Hartsfield Int'l Airport	2004	Runway and Taxiway Repairs
EWR - Newark Liberty Int'l Airport	2005	Runway and Taxiway Repairs
JFK - John F. Kennedy Int'l Airport	2006	Runway and Taxiway Repairs
LGA - LaGuardia Int'l Airport	2006	Runway and Taxiway Repairs
TSA – Taipei Songshan Int'l Airport	2007	Panel R&R, Patch work, & ELT Lights
CAE - Columbia Metropolitan Airport	2007	Runway and Apron Repairs
MEM - Memphis Int'l Airport	2008	Runway and Apron Repairs
SDF - Louisville Int'l Airport	2008	Panel R&R
STL - Lambert–St. Louis Int'l Airport	2008	Parking Garage Repairs, Panel R&R
LAX – Los Angeles Int'l Airport	2008	Runway Repair & ELT Lights
PHL - Philadelphia Int'l Airport	2009-2010	Runway and Taxiway Repairs
SYD – Sydney Int'l Airport, Australia	2009	Runway and Taxiway Repairs
PHX - Phoenix Sky Harbor Int'l Airport	2010	Runway and Taxiway Repairs
DXB - Dubai Int'l Airport	2011	Runway Patch repairs
MEL - Melbourne Int'l Airport	2011	Runway and Taxiway Repairs
SPN - Saipan Int'l Airport	2012	Taxiway Panel R&R & ELT Lights
PDX – Portland Int'l Airport	2014	EDR overlay

On-Going Research

- **FAA Standards Limit Airport Slab Sizes to 20-25 feet**
- **Larger Slab Sizes. . .**
  – Reduce Maintenance By Reducing the Number of Linear Feet of Joints
  – Prevent the Outside Wheel of Wide-Bodied Aircraft from Rolling Along a Joint
  – Minimize FOB Concerns



Slab Size	Number of Slab	Linear Feet of Joints	% Reduction in Joints
18.75’	3,840	134,850	---
25’	2,160	98,850	27%
37.5’	960	62,850	53%

On-Going Research

Used In

1 **Fast-Setting Hydraulic Cement Materials**
ASTM C1600

2 **Shrinkage Compensating Concrete**
ACI 223 Type-K (ASTM C845)

Used In

Type K Shrinkage-Compensating Cement

ACI 223 Type-K (ASTM C845)

- **Type K Shrinkage-Compensating Concrete**
- **System-K® Microfiber Reinforced Shrinkage-Compensating Concrete**
- **Low Shrinkage Concrete**
- **Non-Shrink Grouts**

KOMPONENT

Advantages

Type K Shrinkage-Compensating Cement

ACI 223 Type K (ASTM C845)

Advantages

- CSA Technology
- Minimize Shrinkage
- Improved Durability
- Increased Abrasion & Impact Resistance
- Reduced Permeability
- Increased Service Life

EASE OF CONSTRUCTION

- 90+% Fewer Contraction/Control Joints Required
- Larger Slabs (20,000 – 30,000 ft^2)
- Increased Joint Spacing (up to 300 ft)
- Increased L/W Ratio (up to 3:1)
- Prevents Curling & Shrinkage Cracking
- 30-40% Greater Abrasion Resistance
- Reduced Permeability
- Minimizes O&M Costs related to joint deterioration and equipment damage
- No special structural re-design required
- Thinner Slabs Viable
- Reduced Temperature & Shrinkage Steel
- Reduced Dowel Bars/Baskets
- Reinforcement Protected

aci

ACI 223 – Guide for the Use of Shrinkage-Compensating Concrete

KOMPONENT

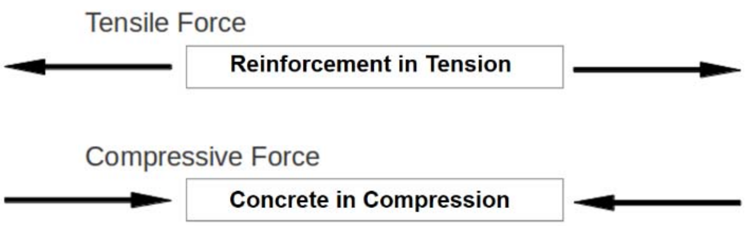
Shrinkage-Compensating Concrete

ACI 223 Type K (ASTM C845, C878)

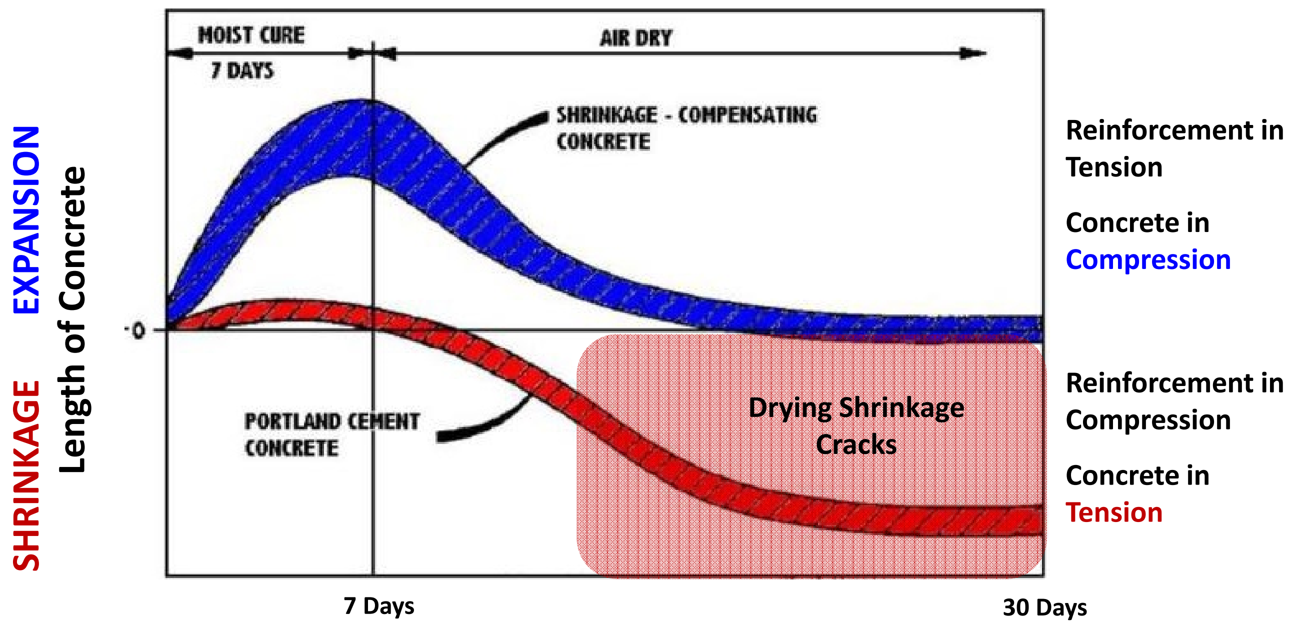
Is based on **expansive cement chemistry** that works **in conjunction with concrete reinforcement** to overcome the drying shrinkage characteristics of portland cement and aggregates.

Section 1.2

"…expansion will induce tension in the reinforcement and compression in the concrete. On subsequent drying the shrinkage merely relieves the expansive strains…"



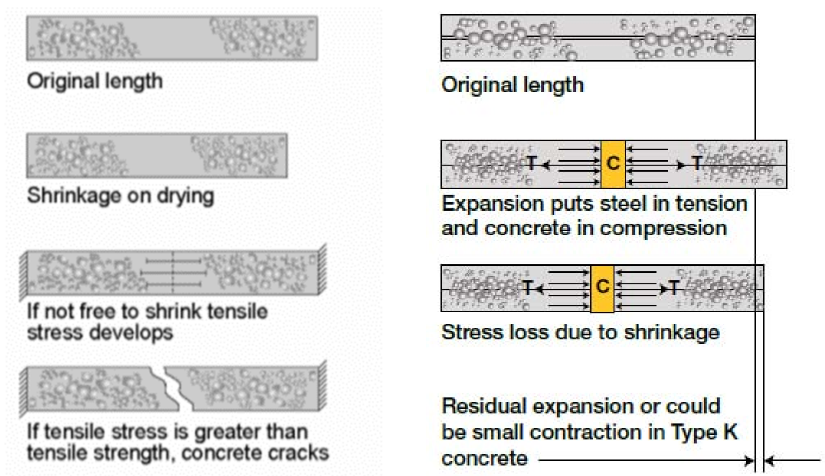
Balance Stresses



ACI 223 Standard Practice for the use of Shrinkage Compensating Concrete
Figure 2.5.3

Drying Shrinkage

- **Restraint forces maximized**
- **Prevents drying shrinkage cracks by pre-stressing forces**
- **Overcomes restraint to shortening challenges**
- **Provides long-term dimensional stability**
- **Helps overcome the biggest challenges w/OPC**
  - Severe Cracking
  - Early Deterioration & Failure
  - Additional Engineering & Construction Measures Required (can be costly & time consuming)



Portland Cement Concrete

Type K Cement Concrete

Ideal Applications

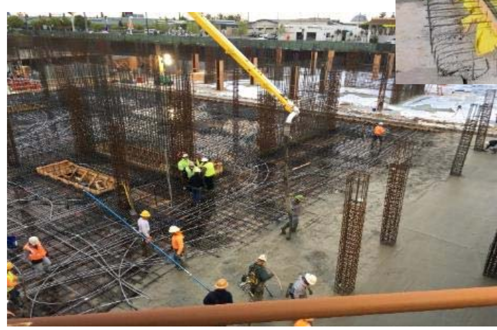
Highly restrained placements maximize the performance advantages of Type K Shrinkage-Compensating Concrete

- Concrete is in Compression Early
- Achieve Net-Zero Shrinkage
- Maximize Joint Spacing
- Minimize Joint Placement
- Maximize Performance with Residual Compressive Stresses

Containment

Parking Structures

Slabs-on-Grade



Post-Tensioned Designs

Bridge Decks

Ideal Applications

Larger slabs & increased L/W ratios make Type K ideal for long, narrow, reinforced construction.

- Bridge Decks
- Parking Structures
- Structural Slabs

250' to 300' Long with No Joints

Ideal Applications

- Manufacturing
- Warehouses/ Distribution Centers
- Retail Stores
- Hangars
- Runways
- Paving
- Bridges
- Parking Structures

- Water Treatment
- Tanks
- Reservoirs
- Secondary Containment
- Hazardous Waste
- Ice Skating Rinks
- Tennis Courts
- Skateboard Parks

- Walls
- Roofs
- Underground Slabs
- Tunnels
- Basements
- Shear Walls
- Piers/Wharves

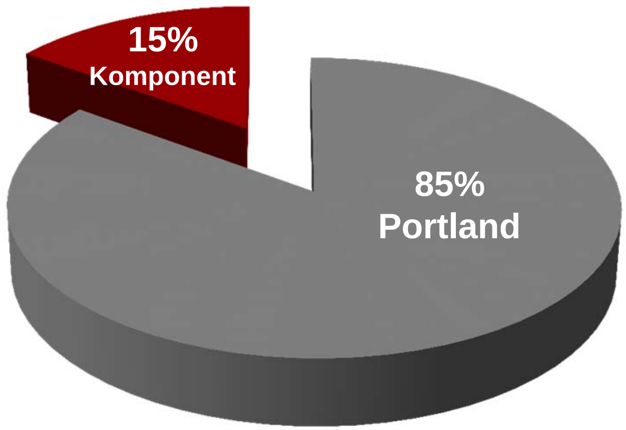
Anywhere minimal joints and/or flat slabs are desirable …

Type K Shrinkage-Compensating Cement

ACI 223 Type K (ASTM C845)

Dosage rate is typically 15 to 17% depending on the shrinkage characteristics of local portland and aggregates.

ASTM C878 is run to quantify the most effective dosage rate.



ASTM C845/C845M Standard Test Method for Expansive Hydraulic Cement
ASTM C878 Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete

Shrinkage-Compensating Concrete

Expansion at 28 days not to exceed 0.15% of 7 day expansion

TABLE 3 Physical Requirements

Time of setting, min, minutes	75
Air content, max, vol %	12.0
Restrained expansion of mortar:	
7-day expansion:	
min, %	0.04
max, %	0.10
28-day, percentage of 7-day expansion, max	115
Compressive strength, min:	
7-day, psi(MPa)	2100(14.7)
28-day, psi(MPa)	3500(24.5)

These limits were chosen due to the ability to substitute Shrinkage-Compensating Cement within this range for any concrete structure without changing the reinforcing or joint detailing.

ACI 223 – Guide for the Use of Shrinkage-Compensating Concrete

5.2.2 *Reinforcement details*—Engineering analysis and design practices for structural elements will normally provide a sufficient amount of steel for restraint. A minimum ratio of reinforcement area to gross concrete area of 0.0015 is desired. This minimum is similar to recommendations of ACI 318 for temperature and shrinkage stresses. Reinforcement should be welded wire reinforcement or steel deformed bars meeting the requirements of ACI 318.

No maximum is defined but is address in ***Section 5.2.3*** *as –*

Concrete member expansion is reduced as the amount of reinforcement is increased but the amount of compressive stress in the concrete will be increased.

- **Minimum reinforcement is required to control expansion and maximize performance of the tensile and compressive stress in the concrete.**
- **The amount of reinforcement has an inverse relationship to the expansion that can be achieved, though compressive stresses will increase as the amount of reinforcement increases.**

ASTM C878
Standard Specification for the Restrained Expansion of Shrinkage-Compensating Concrete

Vs.

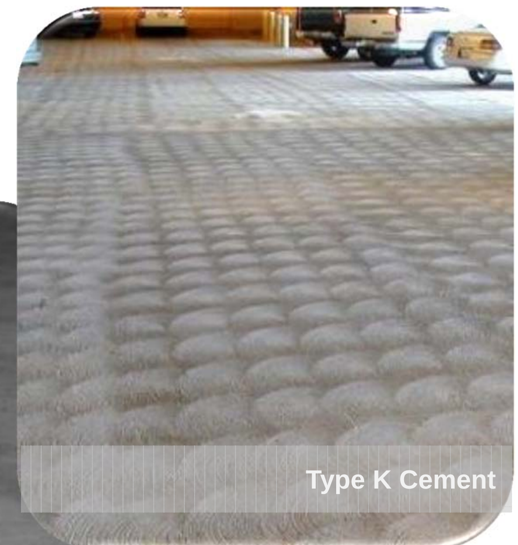
Keeping restrained expansion in perspective….

Parking Structures

John Wayne Airport

Santa Ana, CA

Portland Cement



Type K Cement

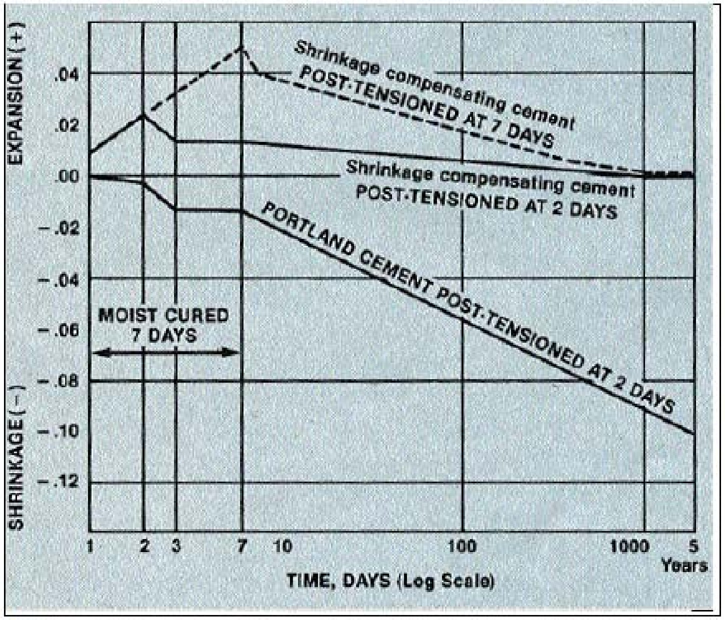
Parking Structures

Minimize Length Change Resulting from Combined Effects of:

- Drying Shrinkage
- Creep of Concrete
- Relaxation of Stress in Steel

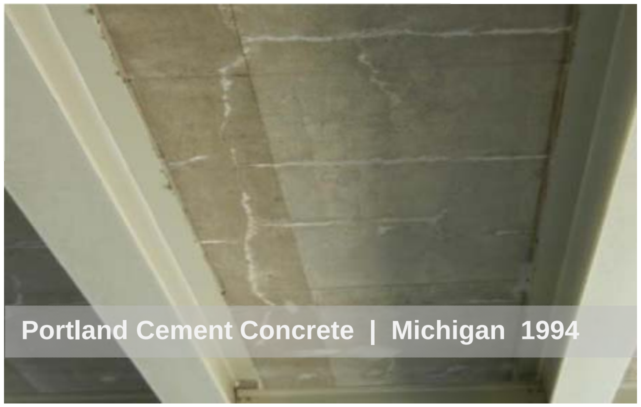
and… Eliminate Closure Strips

Concrete Construction 1996, Publication #C830331



Typical changes in length for post-tensioned concrete in structures over periods of 5 and 15 years. Shrinkage-compensating cement concrete is compared with conventional portland cement concrete. Length changes result from combined effects of drying shrinkage, creep of the concrete and relaxation of stress in the steel.

Michigan Bridge Deck Study
– 18 Years Later…



No Efflorescence and No Transverse Cracks

Bridge & Highway Designs

MDOT Gateway Bridge Complex – 2009

Grand Blanc, MI - 2006

Grout Filled Support Cans
St. Louis, MO

MDOT Bridge - 2012

Bridge & Highway Designs

US Route 675
Dayton, OH
1974

I 80 Ohio Turnpike
Meander Creek, OH
2006

I 80 Ohio Turnpike
Elyria, OH
2012

Achieve an "Ideal Bridge Deck"

- ✓ Crack-Free
- ✓ Low Permeability
- ✓ Minimum Number of Sealed Joints

Bridge Decks

MI & OH Bridge Survey **(2012)**

- Original placement 1994
- Indicated the surfaces are in remarkable condition
- Most have 70% tine left in wheel tracks
- No scaling
- 35 Year Service Life

Wearing Surface After 15 Years

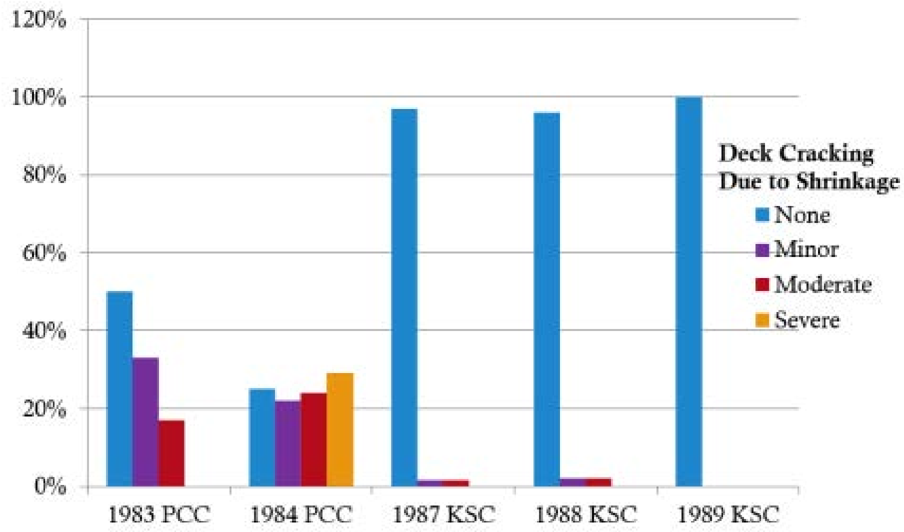
Achieve an "Ideal Bridge Deck"

How does [Type K] effect maintenance costs?

"The answer is quite simple, it is very low cost to maintain the Shrinkage-Compensating Concrete decks – no deck delaminations, spalls or steel corrosion."

Ohio Turnpike Authority

Ohio Turnpike Bridge Performance Using Type K



Achieve an "Ideal Bridge Deck"

"We don't even think about cracks, crack maintenance or spalls on our Shrinkage Compensating Concrete Decks – Expecting 35 Year Life on the deck wearing surface."

Doug Hedrick
Chief Engineer
Ohio Turnpike Authority

"Type K Shrinkage-Compensating Concrete addresses many concerns, from Safety to Ride characteristics."

Richard Hodges
Director
Ohio Turnpike Authority

“Ideal Bridge Deck” Study Noted…

- **Eastbound lanes were completed with Type K Shrinkage Compensating Concrete.**
- **The other half of the bridge was completed with Regular Type I-II Cement.**

Review by District personnel

“Type K deck is out performing the Type I-II Deck.”

Daniel Tobias , Director of Materials & Research
Steve Worsfold, Division Engineer

Illinois Rt. 15 – District 7
8 Miles East of US45
Fairfield, IL
2012

ILLINOIS

Other IL DOT Bridges

- Peoria
- Eureka
- Monmouth
- Jacksonville
- Robinson
- Washington
- Fairfield

"Ideal Bridge Deck" Study Noted...

RESULTS

- **Significantly reduced shrinkage cracking**
  (< 5% deck cracking due to shrinkage)
- **Reduced surface capillaries & surface porosity due to very little bleed water**
- **Compressive and splitting tensile strengths of Type K SCC mixes were superior to those of PCC.**
- **Compressive strengths were greater for simulated cold construction conditions.**
- **Faster placement than portland cement concrete with the preferred method being pumping.**
- **Easier to place, consolidate, finish and tine due to the w/c ratio and greater cohesiveness.**

Performance Advantages

Type K Shrinkage-Compensating Concrete helps prevent…

- **Rebar Corrosion**
- **Crack Propagation due to Heavy Traffic/ Fatigue Loading**
- **Transverse Cracking when Properly Cured**
- **Air Entrainment can be used to Provide Additional Freeze/Thaw Protection**

Wet curing a VA bridge deck
to ensure maximum designed expansion

Performance Advantages

VTRC
Virginia Transportation Research Council

Ultra low and low permeability can be achieved.

Table 3. Type K Trial Batch Test Results

Parameter	Trial Batch 1 (658 lb cementitious) 2/4/14	Trial Batch 2 (715 lb cementitious) 2/4/14
Compressive Strength (psi)		
7 Days	2780	4140
28 Days	3850	5710
Elastic Modulus, 7 days (*10^6 psi)	4.13	4.63
Permeability (coulomb, C)	925	475
Fresh Concrete Properties		
Slump (in)	7	8
Air content (%)	6.4	6.0
Unit weight (lb/ft^3)	146.8	147.0

Table 4. Additional Trial Batch Test Results

Parameter	Trial Batch 3 (715 lb cementitious) 2/26/14	Trial Batch 4 (715 lb cementitious) 6/10/14
Compressive Strength (psi)		
7 Days	2720	2880
28 Days	3940	4040
Elastic Modulus (*10^6 psi)		
7 Days	3.31	3.33
28 Days	3.81	4.01
Permeability (coulomb, C)	1156	1299

Report No.: FHWA/VTRC 16-R15
Published: April 2016

Pavement

Palmdale, CA – Still in Service

Lodi, CA – Still in Service

I-14 Palmdale, CA
First Type K Shrinkage-Compensating
Concrete Pavement
1963

I-12 Lodi, CA
Second Type K Shrinkage-Compensating
Concrete Pavement
1963

As Published in Concrete International

Jan 2006

Usage Conditions

- Highway Type Truck Traffic

Design Requirements Achieved

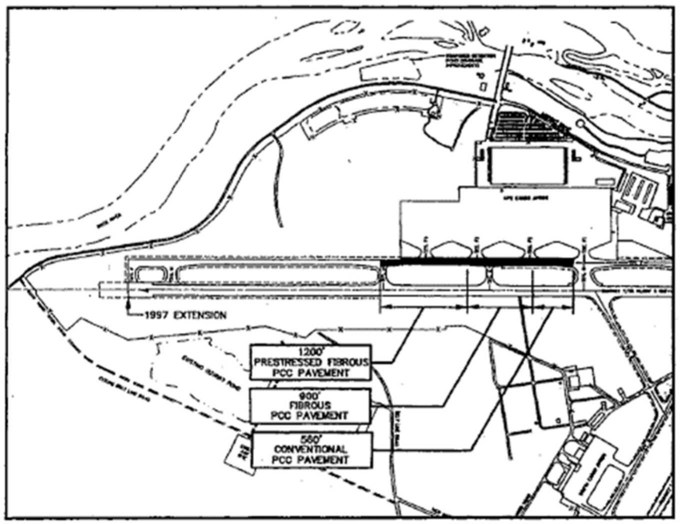
- 25% Thinner Placements
- 42,000 sf placement with no interior joints
- Minimize Joints: Spacing was from 85 to 340 lf
- Minimize Edge Curl & Cracking
- Minimal Maintenance

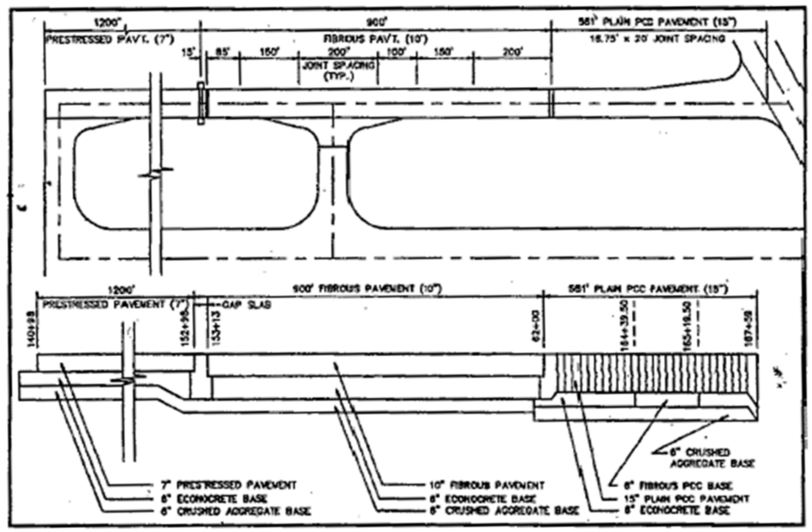
Exterior Concrete Pavement
Atlanta Bonded Warehouse Corp. – Kennesaw, GA - 1993

Air Fields

Rockford IL Airport | FAA Research Project

Type K Shrinkage-Compensating Concrete Research/Field Trial





Evaluate durability and significant joint reduction – the location of spalling, a common source of foreign object debris, safety hazards, costly maintenance and repair projects.

KOMPONENT

Rockford IL Airport | FAA Research Project

Type K Shrinkage-Compensating Concrete Research/Field Trial

Unique Pavement Designs

- Type K Shrinkage-Compensating Concrete/ Steel Fibers
- Type K Shrinkage-Compensating Concrete/ Post-tensioned & Steel Fibers

	Regular PCC	Type K + Steel Fibers	Type K + Post Tensioned + Steel Fibers
Length of Runway Section	580’	900’	1200’
Slab Thickness	15”	10”	7”
Longitudinal Joint Spacing	18.75’	None	None
Transverse Joint Spacing	20’	85’ to 200’	None
PCI Rating (10 Years)	67	82	98

Rockford IL Airport | Constructability Report

10 Year Inspection

$50.36 yd2	**Conventional PCC with Rebar** 520' long, 75' wide, 15" thick Joints: 18.75' longitudinal & 20' transverse	"Severely spalled" – many cracks & spalls Performance Index: Good
$50.72 yd2	**Steel Fibers and Shrinkage-Comp** 900' long, 75' wide, 10" thick Joints: no longitudinal, 85' to 200' transverse	"Performing very well" – a few tight cracks Performance Index : Very Good Condition
$46.29 yd2	**Post-Tensioned and Fibers and Shrinkage-Comp** 1200' long, 75' wide, 7" thick Joints: no longitudinal, no transverse	"Performing exceptionally" Performance Index : Excellent Condition

"The use of Type K did not create handling, storing or delivery problems."

KOMPONENT

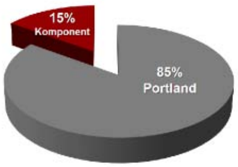
The Cost Question

FAST!

- Evaluate Overall Project Savings
- Cost of Cement vs. Cost of Time
- Cost of Maintenance, Downtime & Replacement vs. Long-Term Durability
- Cost of Penalties and Profit of Incentives
- Impact on Regional Commerce
- Best Use of Constituent Dollars

Rapid Set Cement

Rapid Set



The Cost Question

- ✓ **Are you concerned about design life / asset life?**
- ✓ **Are you concerned about durability?**
- ✓ **Are you concerned about safety/structural integrity?**
- ✓ **Is reducing shrinkage beneficial or necessary?**
- ✓ **Is lifecycle cost important?**
- ✓ **Is eliminating remedial actions worth the cost?**

If YES to any one of the items above, the long-term value and overall project savings Type K Shrinkage-Compensating Concrete offers makes it both a high performance AND cost effective solution.

A higher performance solution at the ***same or lower cost of materials.***

KOMPONENT

Thank You

Thank You!

Susan Foster-Goodman
(714) 614-7392, cell
sgoodman@ctscement.com

www.CTScement.com

Rapid Set | KOMPONENT

By CTS Cement Manufacturing Corp.

An Introduction to Cellular Concrete and Advanced Engineered Foam Technology

Not just products…Solutions

Richard Palladino
President

Aerix Industries™

If you always do, what you always did, you will always get, what you always got.

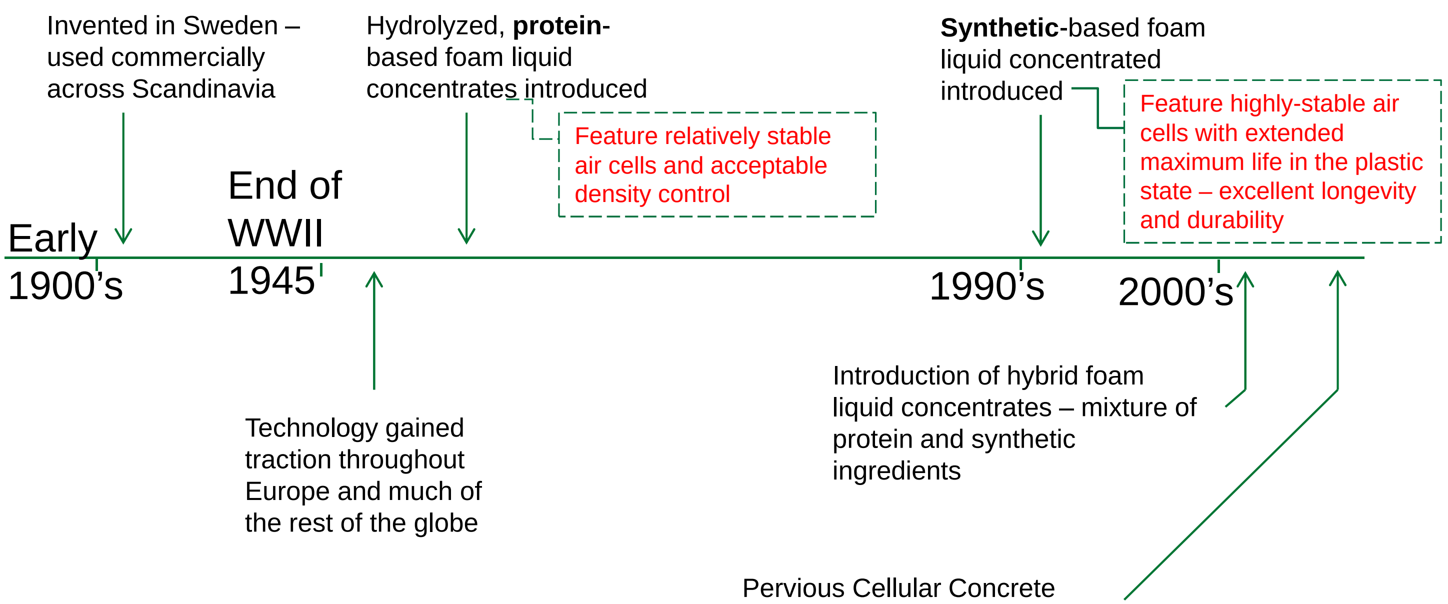
Course Description

The presentation begins with a brief history of the technology, this presentation will answer the basic questions of cellular concrete. We will showcase project histories to relate the applications to real world geotechnical challenges. Finally, this presentation will expose the audience to emerging engineered foam technologies and the exciting new applications these products bring to an already versatile product line, as well highlighting how traditional cellular concrete technology is advancing to meet challenging project parameters.

Learning Objectives

- Discuss the history, definition, and properties of cellular concrete
- Review mix design requirements and testing procedures
- Explore typical applications and highlight some case studies
- Introduce emerging technology, and how traditional cellular concrete technology is advancing to meet challenging project parameter

A BRIEF HISTORY OF CELLULAR CONCRETE



Low-density cellular concrete is defined by ACI 523 as…

Concrete made with hydraulic cement, water and preformed foam to produce a hardened material with an oven dry density of 50 pounds (22.7 kg) per cubic foot or less.

Preformed foam is created by diluting a liquid foam concentrate with water in predetermined proportions and passing this mixture through a foam generator.

Conforms to ACI industry standards

Types of Foam

Preformed
Produced by Foam Generator

ACI 523

Cellular Concrete

Agitated
Produced by the mixing action of a concrete mixer

ACI 229

CLSM

Cellular concrete can be flowable fill (ACI 229 – Chapter 8) but flowable fill (CSLM) cannot be cellular concrete because of the density being higher than 50pcf.

Conforms to ACI industry standards

Preformed

Produced by Foam Generator

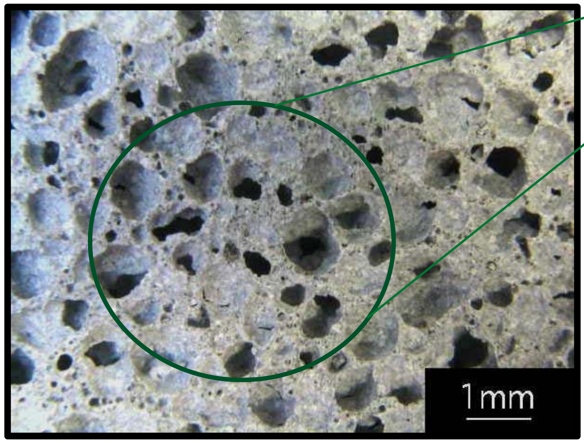
ACI 523

CELLULAR CONCRETE REPLACES COARSE AGGREGATE WITH AIR

The air cells must be resilient in order to withstand the rigors of mixing and pumping in various applications

Foam has the stability to be calculated as a solid but the properties to be placed as a low density fluid material

Cellular concrete pore structure when cured



Cementitious materials encapsulate the air bubbles, then dissipate leaving a void structure as a replacement to traditional aggregate

Lightweight Cellular Concrete differs from conventional aggregate concrete in the methods of production, the density of the material and the extensive range of end uses.

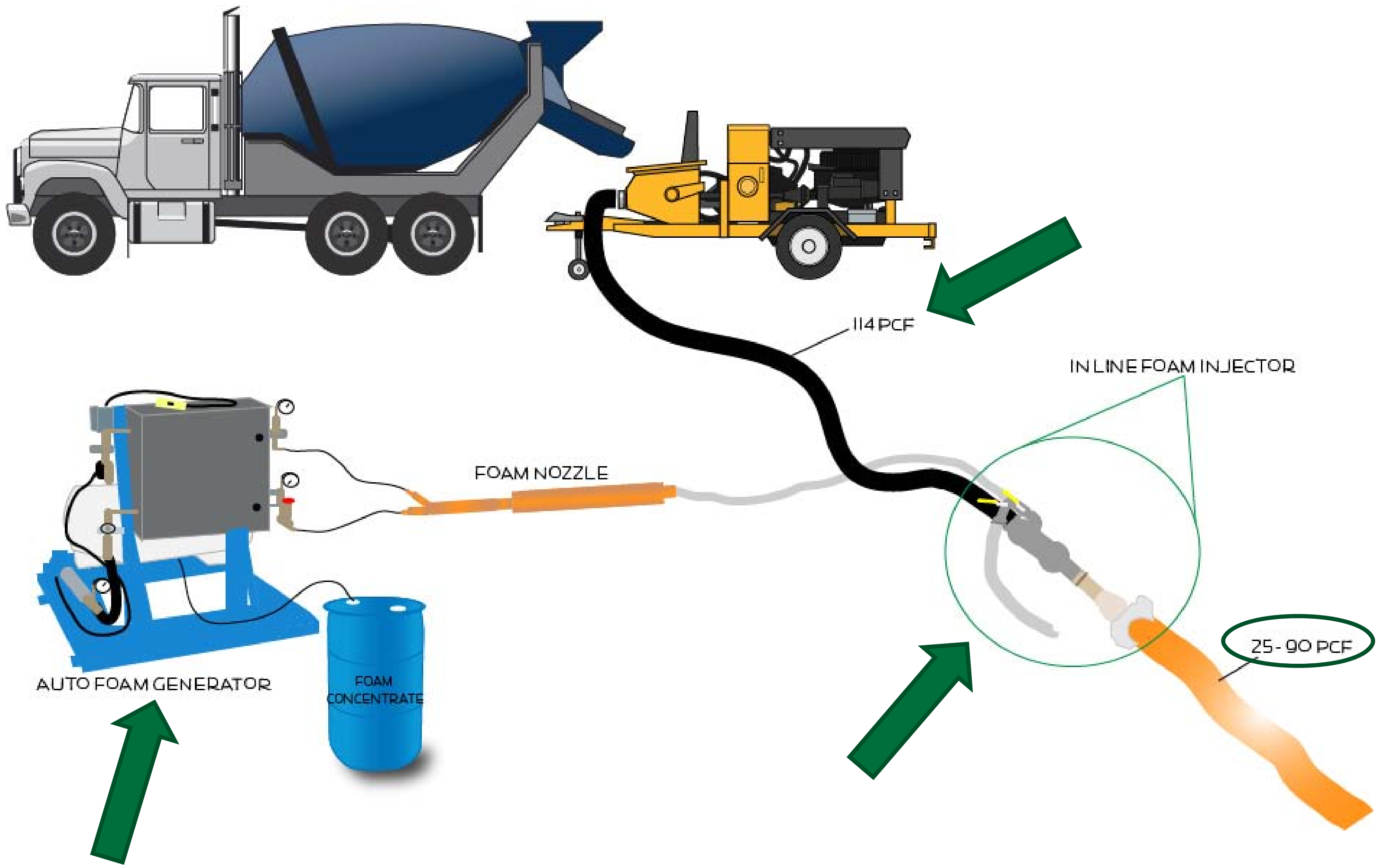
TYPES OF ON-SITE INSTALLATION EQUIPMENT INCLUDE

High production self-contained unit for larger volume projects

Mobile Mixing units

Ready mix wet batch system

CELLULAR CONCRETE BATCHING PROCESS
1 CY OF SLURRY EXPANDS UP TO 4.6 CY



TYPICAL GUIDELINES CELLULAR CONCRETE MIXES

TYPICAL VALUES

Cast Density		Typical Compressive Strength at 28 days		Portland Cement		Water		Foam Volume	
lb/ft³	kg/m³	psi	MPa	lb/yd³	kg/m³	gal	L	ft³/yd³	m³/m³
20	320	50	0.34	328	195	19.7	97.3	22.7	0.84
25	400	80	0.55	420	249	25.2	124.6	21.5	0.80
30	481	140	0.97	512	304	30.7	151.9	20.3	0.75
35	561	210	1.45	603	358	36.2	178.8	19.1	0.71
40	641	330	2.28	695	412	41.7	206.1	17.9	[illegible]
45	721	450	3.10	787	467	47.2	233.4	16.7	[illegible]
50	801	640	4.41	878	521	52.6	260.4	15.5	0.57
55	881	790	5.45	970	575	58.2	287.7	14.3	0.53
60	961	930	6.41	1062	630	63.7	315.0	13.1	0.49

75% of the volume is foam

ASTM TEST METHODS THAT APPLY TO CELLULAR CONCRETE

ASTM C 869

"Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete"

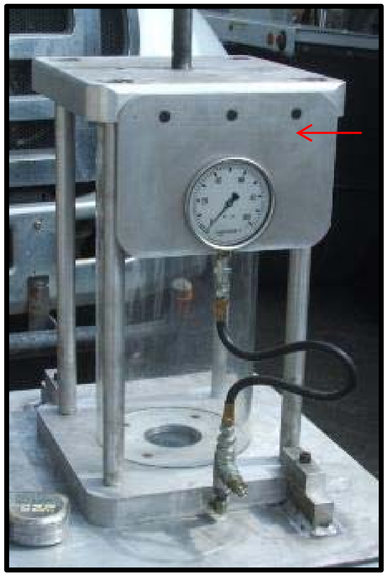
ASTM C 796

"Standard Test Method for Foaming Agents for use in Producing Cellular Concrete using Preformed Foam"

ASTM C 495

"Standard Test Method for Compressive Strength of Lightweight Insulating Concrete"

COMPRESSIBILITY TESTING ON CELLULAR CONCRETE VALIDATES ABILITY TO RESIST BUBBLE COLLAPSE FROM PRESSURE



Compressibility device to evaluate stability of Cellular Concrete

Note: The clear cylinder limits the pressure that can be applied, as does the loading by turning a screw through a threaded top plate. However, the grout is tracked through the pump during calibration, so the test acts as confirmation of the cellular concrete performance that is observed during pumping.

The cellular concrete level was 12 inches at zero pressure

*Information provided by Ardaman & Associates, Inc. Tampa, FL

THE CELLULAR CONCRETE FULLY REBOUNDED TO THE ORIGINAL FILL HEIGHT

At 30 psi pressure, the cellular concrete was reduced in height to 9 inches

*Note there was no visible collapse of the cellular concrete after the test.

*Information provided by
Ardaman & Associates, Inc. Tampa, FL

FOAM TECHNOLOGY HAS MADE HUGE ADVANCEMENTS WITH STABLE BUBBLE TECHNOLOGY

- Typical Foams
  - 3 foot lift thickness
  - Pumping distance limited to 5,000 feet maximum
  - Only non-permeable
  - Viscosity was almost 1
  - Fly ash usage limited
- Advanced Foam Technology
  - 4-20 foot lift thickness
  - Pumping distance increased to more than 17,000 feet
  - Permeable is also an option
  - Thicker material
  - Higher fly ash usage and slag cement usage

Typical Applications

- Tunnel & Mine Abandonment
- Annular Fills for Tunnels, Water & Sewer Lines
- Void Fills
- Soft Soil Remediation
- Tremie Applications
- Retaining Structure Backfills
- Slope Stabilization
- Fill for Underground Utility, Conduit & Pipes
- Tanks & Pipeline Abandonment
- Fill Around Conduits and Pipes
- Green Roof Applications

UTILITY/TUNNEL ABANDONMENT

**Information provided by Mainmark, Australia*

CELLULAR CONCRETE IS AN IDEAL SOLUTION FOR ANNULAR AND TUNNEL BACKFILL

- Highly flowable material able to completely fill annular space
- Lightweight and easily pumped long distances at low pressures
- Reduces floating pipe or damage liner for sliplining
- Strength and density can be customized to project requirements
- Shrinkage of less than 0.3%
- Quick and Easy Installation Environmentally Safe

Cellular Concrete has been pumped over 700 feet vertically and over 17,000 feet

Can accommodate any diameter pipe

Brightwater Conveyance System
Woodinville, WA

Tunnel:
14,000 ft long
18 feet in dia.

Culvert or Annular Application

- 150 yd^3 (114 m^3)of 500psi (3.4 MPa) pumped 100ft (30.5m) under SR 1 for MaineDot

Photo Courtesy of SnapTite

Gravity Sewer Annular Fill
Kaneohe Kailua Tunnel, Honolulu, HI

- 28,000yd³ 50pcf
- 4” injection line
- Material pumped for 3 miles
- Water chilled from 70° to 50°
- Maintained 18” to 24” controlled lifts due to distance and heat

“Aerix Industries provided a quality bubble and the physical bubble was not compromised at all over the entire distance pumped”

Don Painter, Project Manager of Southland/Mole JV

**Information provided by Southland/Mole JV, Kaneohe, HI*

GAS PIPE LINE ABANDONMENT
ATLANTA GAS LIGHT (AGL)

- 12 ½ mile abandonment
- 1,000-1,500 ft placement points
- 6,500 yd³ of 40pcf
- Non-pervious

- 20km abandonment
- 300 – 450 meter placement points
- 8450 m³ of 640kg/m³
- Non-pervious

**Information provided by Gibson Grouting Services, Smyrna, GA*

TYPICAL APPLICATIONS

- Annular Fills for Tunnels, Water & Sewer Lines
- Void Fills
- Soft Soil Remediation
- Tremie Applications
- Retaining Structure Backfills
- Slope Stabilization
- Fill for Underground Utility, Conduit & Pipes
- Tanks & Pipeline Abandonment
- Fill Around Conduits and Pipes

NC 72, FAYETTEVILLE, NC

- Hurricane Matthew Oct ‘16
- washed out backfill
- void of 900 cubic feet
- CC placed in three hours
- Using ready-mix trucks

ABANDONMENT OF ROOSEVELT AVE DRAWBRIDGE COUNTERWEIGHT WELL PITS

- Rapid installation without disturbing traffic pattern
- Minimize bearing pressure

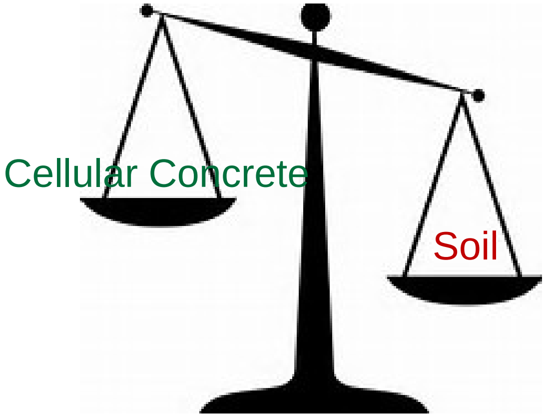
**Information provided by Geo-Cell Solutions Inc., Fresno, CA*

TYPICAL APPLICATIONS

- Tunnel & Mine Abandonment
- Annular Fills for Tunnels, Water & Sewer Lines
- Void Fills
- Soft Soil Remediation
- Tremie Applications
- Retaining Structure Backfills
- Slope Stabilization
- Fill for Underground Utility, Conduit & Pipes
- Tanks & Pipeline Abandonment
- Fill Around Conduits and Pipes
- Green Roof Applications


70% Load Reduction
100% Compaction

APPLICATION: LOAD BALANCING
LARGE FILLS



Comparison of Fill Material Densities:

Cellular Concrete	20 – 70 pcf
Water	62.4 pcf
Lightweight Aggregates	60 – 90 pcf
Soils	120 pcf
Aggregates	125 pcf
Lean Concrete	145 pcf

USE CELLULAR CONCRETE FOR SUBGRADE MODIFICATION WHEN EXISTING SOILS ARE UNDESIRABLE

Cellular Concrete Advantages

- Reduce Vertical Dead Loads
- Increase Strength/Stability with Minimal Weight
- Improve Seismic Stability
- Reduce Settlement Potential
- Increase Bearing Capacity
- Insulating

Big Dig Boston, MA

Subgrade Stabilization

CELLULAR CONCRETE USED TO REPLACE UNSTABLE SOILS AT THE UNIVERSITY OF CONNECTICUT

- Football stadium constructed on unstable soils
- Lightweight Cellular Concrete sub-base equally distributed the loads
- 40,000 yds (30,600 m^3) of 35pcf (480kg/ m^3) material placed at 150 cy per hour (115 m^3/hr)

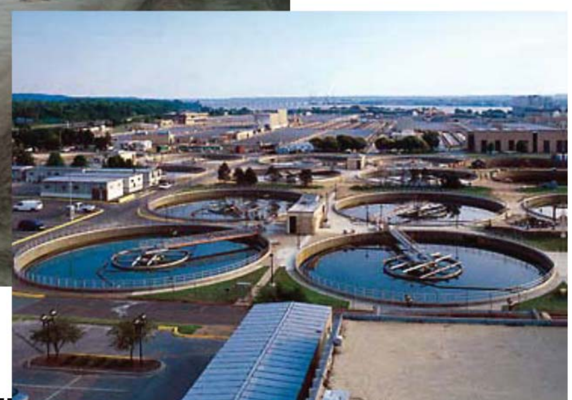
**Information provided by Pacific International Grout., Bellingham, WA*

SR 50, Ocoee, FL

**Information provided by CDM Smith, Orlando, Fl & Aerix Industries*

Blue Plains Treatment Plant, Washington, D.C.

Expansion project
20,000 cubic yard
100 psi backfill
30 pcf density



26,000 cubic meter
0.7Mpa backfill
480 kg/m_3 density

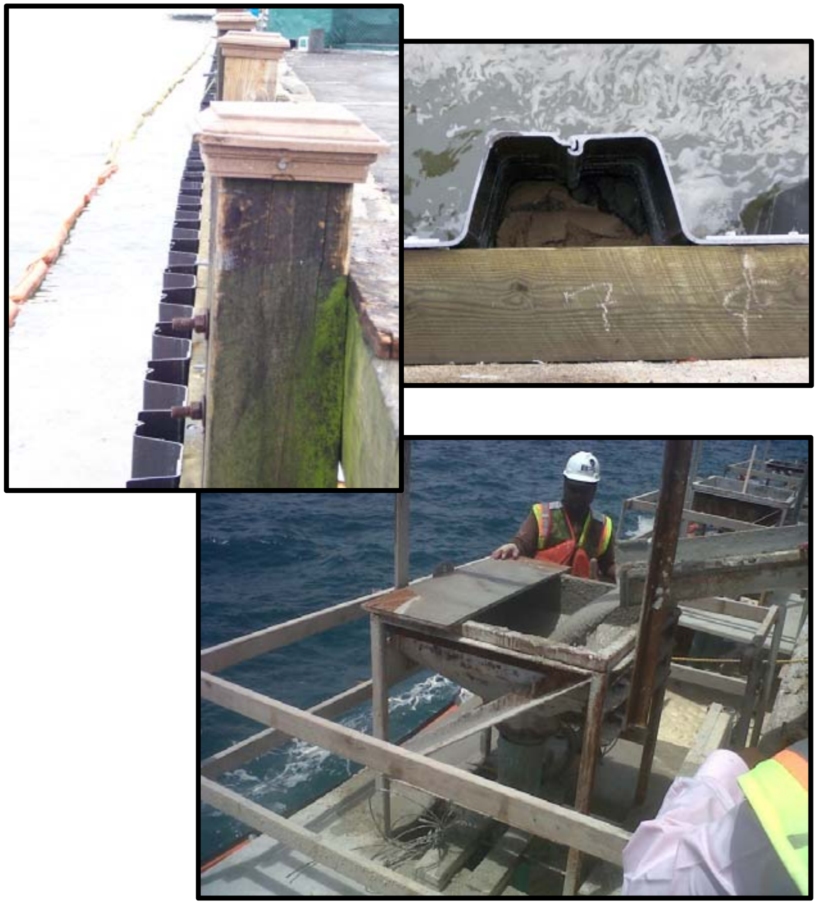
Cellular concrete used to decrease bearing pressure on existing conditions

**Information provided by*
Mixonsite USA Inc., Buffalo Grove, IL

Typical Applications

- Tunnel & Mine Abandonment
- Annular Fills for Tunnels, Water & Sewer Lines
- Void Fills
- Soft Soil Remediation
- Tremie Applications
- Retaining Structure Backfills
- Slope Stabilization
- Fill for Underground Utility, Conduit & Pipes
- Tanks & Pipeline Abandonment
- Fill Around Conduits and Pipes
- Green Roof Applications

THE FLUIDITY OF CELLULAR CONCRETE MAKES IT FAVORABLE FOR TREMIE APPLICATIONS



- Coastal piers compromised by bugs
- Placed sheet pile around existing piers, to isolate wood from water
- 70 pcf Cellular Concrete used as fill between the sheet pile and the pier

- Moving military bases from Japan to Guam
- Seawall needed to be reinforced
- Backfill behind seawall with lean cement/heavy sand mix
- Cellular Concrete material moved 35’ in each direction from tremie

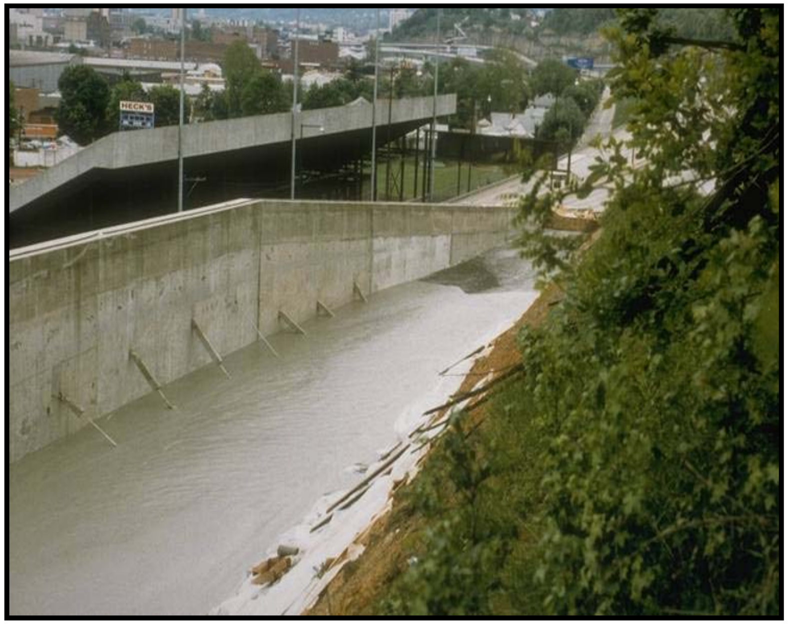
TYPICAL APPLICATIONS

- Tunnel & Mine Abandonment
- Annular Fills for Tunnels, Water & Sewer Lines
- Void Fills
- Soft Soil Remediation
- Tremie Applications
- Retaining Structure Backfills
- Slope Stabilization
- Fill for Underground Utility, Conduit & Pipes
- Tanks & Pipeline Abandonment
- Fill Around Conduits and Pipes
- Green Roof Applications

Cellular Concrete is Ideal Retaining Wall Backfill

Cellular Concrete Advantages

- Reduce Lateral Load
- Ease of Placement
- Increased lift heights
- Reduces schedule impact
- Allows for design flexibility
- Engineered Permeability



CELLULAR CONCRETE IS IDEAL FOR THE CONSTRUCTION/REHAB OF BRIDGE APPROACHES

- Permanent Sub-base
- Load Reduction on Approaches
- Ease of Placement
- Durability and Longevity

CALTRANS LA Bridge Approach

Boston- Logan Airport Bridge Approach

RIVER SCOURING OUT EMBANKMENT ON I-29 THREATENED SAFETY OF MOTORISTS

USING CELLULAR CONCRETE ON THIS PROJECT ALLOWED FOR A SHORTENED SCHEDULE ON THE BACKFILL OF THE WALL SYSTEM

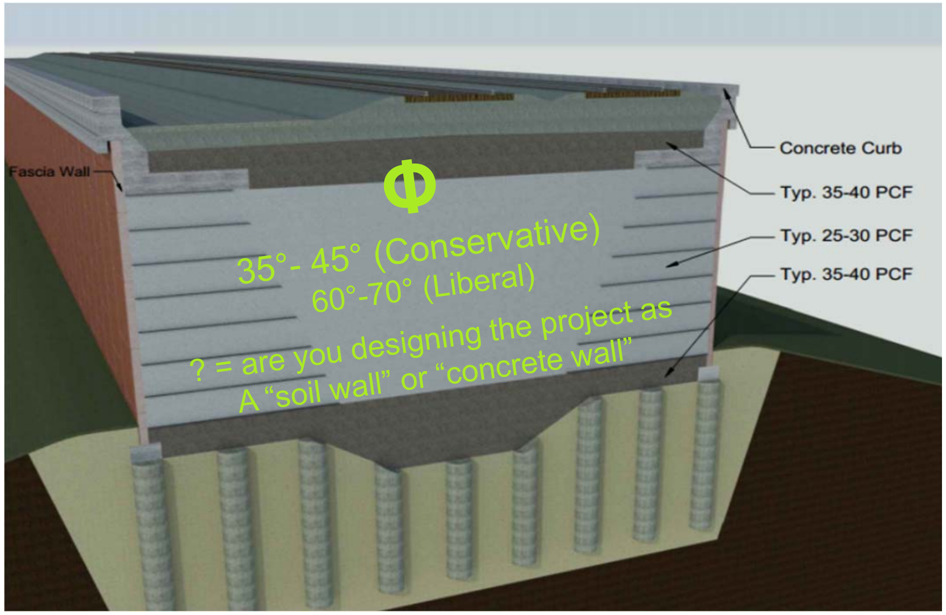
Pumped 2,800 feet
30,000 cubic yards

Pumped 853m
23,000 cubic meters

Mix Design:
35 pcf *(590 kg/m³)*
80 psi *(0.55 Mpa)*

**Information provided by*
Geo-Cell Solutions Inc., Fresno, CA

STRAPPING & INTERNAL ANGLE OF FRICTION



Segmental Wall Configuration IDOT Lake Shore Drive & I-55 Interchange

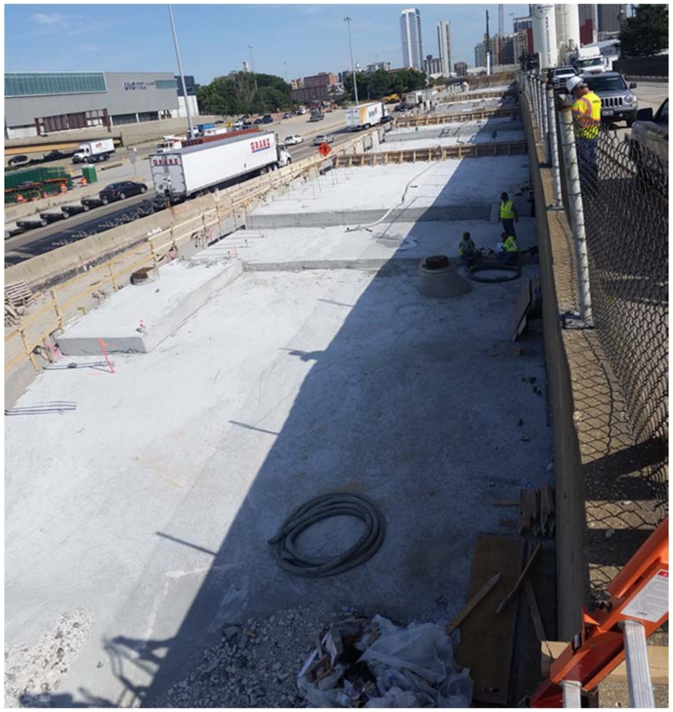
- Elimination of lateral loads as well reduction in vertical loads
- Three new ramps for lane change requirements

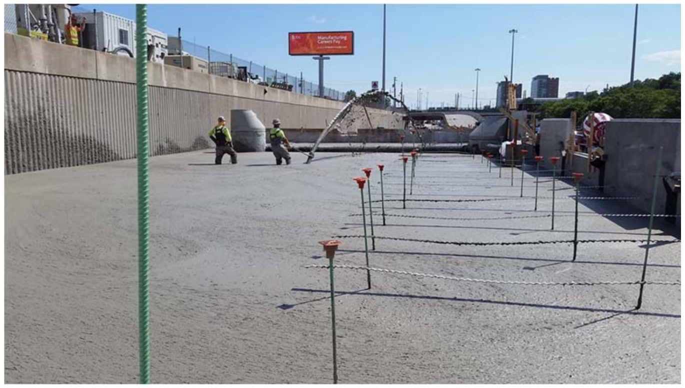
- 22,000 yd³
- 6 phases over 2 years
- 1000yd³ per day of production
- 24-30pcf @ 40psi

**Information provided by MixOnSite USA Inc., Buffalo Grove, IL*

STRAPPING CONFIGURATION
IDOT CIRCLE INTERCHANGE

- 18,000 cubic yards of cellular concrete
- 24-30pcf / 40psi
- 4 phases over a 2 year duration
- Daily production rates > 1000 cubic yards





**Information provided by MixOnSite USA Inc., Buffalo Grove, IL*

Lane Expansion in Philadelphia for rapid installation

Existing soils were soft for traditional compacted fill and accelerated production schedule was needed

Pumped 6,800 cubic yards (5,200 cubic meters)

**Information provided by A-Deck Inc., Norristown, PA*

PennDOT Rt. 30 Sinkhole

Sinkhole remediation in the median

- Fast production
- Self-compacted and self-leveled
- Permeable solution

**Information provided by A-Deck Inc., Norristown, PA*

MSE Backfill
Maine DOT

SR 542, BELLINGHAM, WA

- Vertical Facia walls >50’
- Shotcrete over the facia walls

SR 542, BELLINGHAM, WA

- ≈100 years ago, first highway to eastern Whatcom County was built.
- A wooden bridge spanned Anderson Creek about four miles east of the current Bellingham city limits.
- Crosses the creek using two culverts underneath it.
- These culverts often become clogged with debris, requiring frequent maintenance.
- 2015 WSDOT Goal = To install a bridge to eliminate the maintenance issue, restore the creek to its natural state and enhance fish passage.

SR 542, Bellingham, WA

- $8.1 million project began with the removal of the existing double-box culvert and the fish ladder, which had become functionally deficient.
- existing structure was that the roadway was built directly on the creek's soft-soil embankments, compounding the sedimentation and collection of debris in the waterway.
- To reduce the load placed on the surrounding soft soils, the new bridge would be built on pervious cellular concrete abutments that would support the embankments and the new 350-foot bridge.

SR 542, BELLINGHAM, WA

- Wire Mesh after each 2' lift
- Next lift was placed 1 hour after "rock test"
- Compressive strength tested +100psi
- Shotcrete placed over facia walls

SR 542, BELLINGHAM, WA

- 9,500 cubic yards Pervious Cellular Concrete
- 25 pcf with an accelerant
- Neat cement mix at .50 W/C ratio
- Concentrate diluted 1:50 producing a 2.6#/ft³ foam
- Distance pumped - 2,500 feet.
- Three-person crew installed two 50-foot bridge abutments.

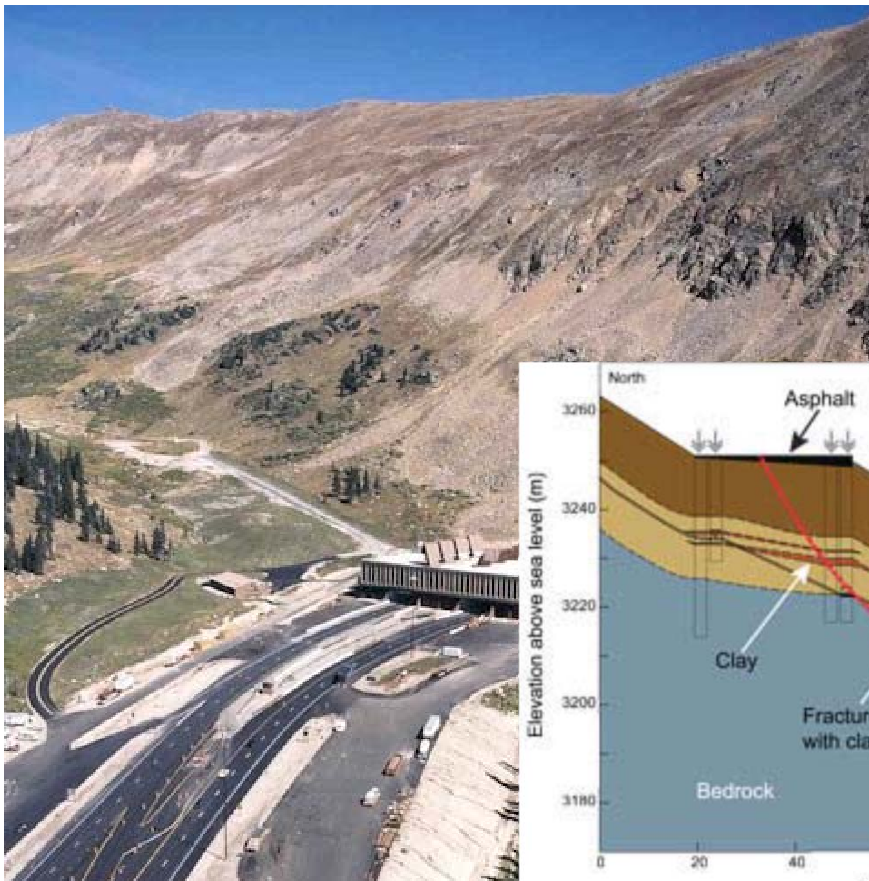
SR 542, Bellingham, WA

- Anderson Creek was just a trickle when the new SR 542 Anderson Creek bridge opened Sept. 15, 2015,
- A few days later it was a free-flowing creek for the first time since the original bridge was build.

TYPICAL APPLICATIONS

- Tunnel & Mine Abandonment
- Annular Fills for Tunnels, Water & Sewer Lines
- Void Fills
- Soft Soil Remediation
- Tremie Applications
- Retaining Structure Backfills
- Settlement Mitigation
- Fill for Underground Utility, Conduit & Pipes
- Tanks & Pipeline Abandonment
- Fill Around Conduits and Pipes
- Green Roof Applications

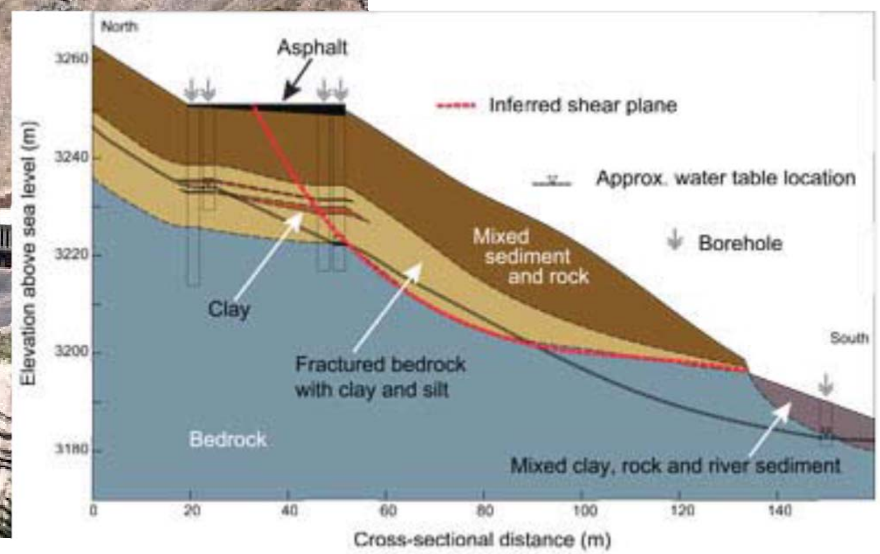
I-70 Roadway Settlement Mitigation
Summit County, CO

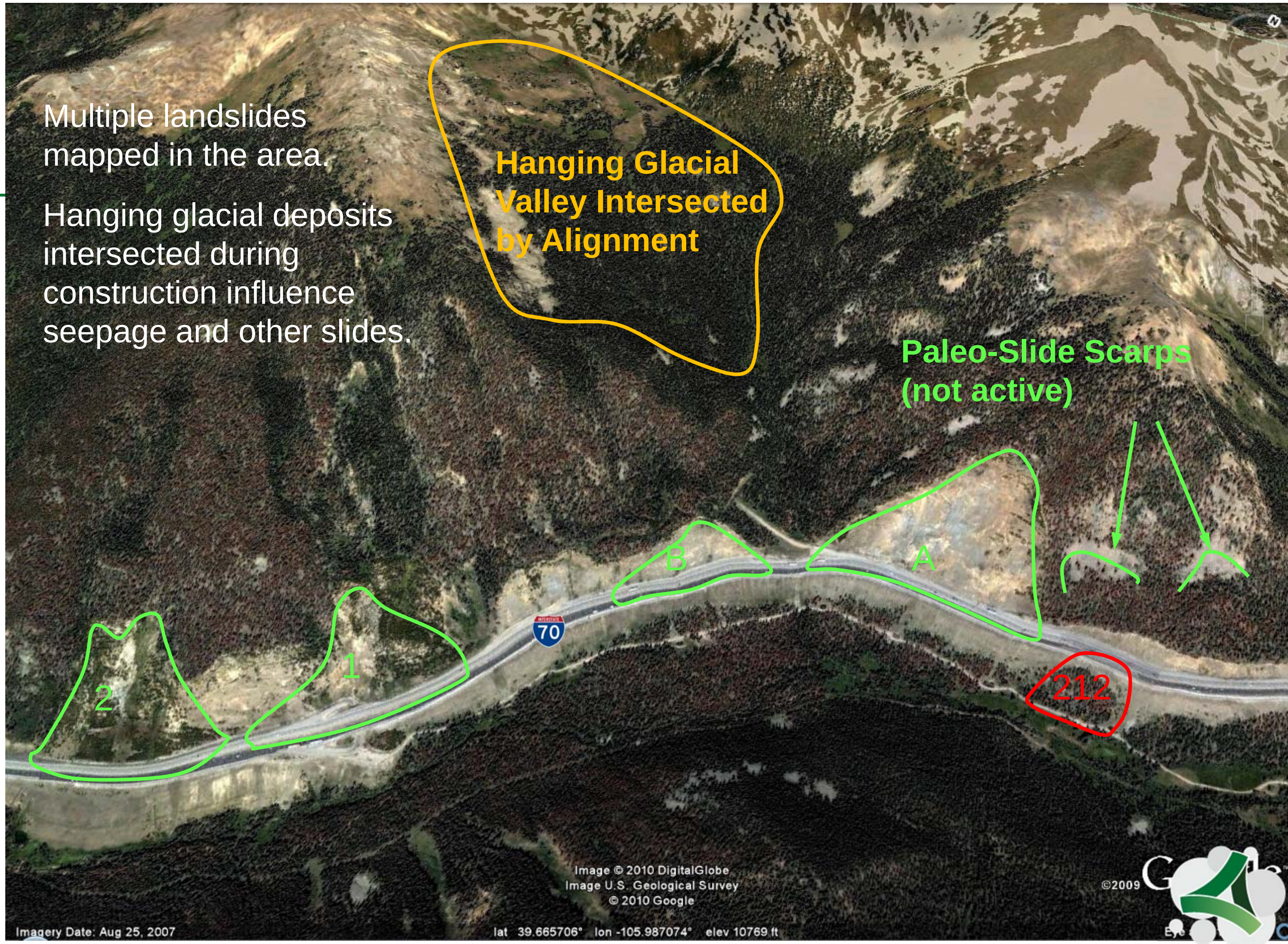


Project Location:

West Side of the
Eisenhower Tunnel

Open 1973

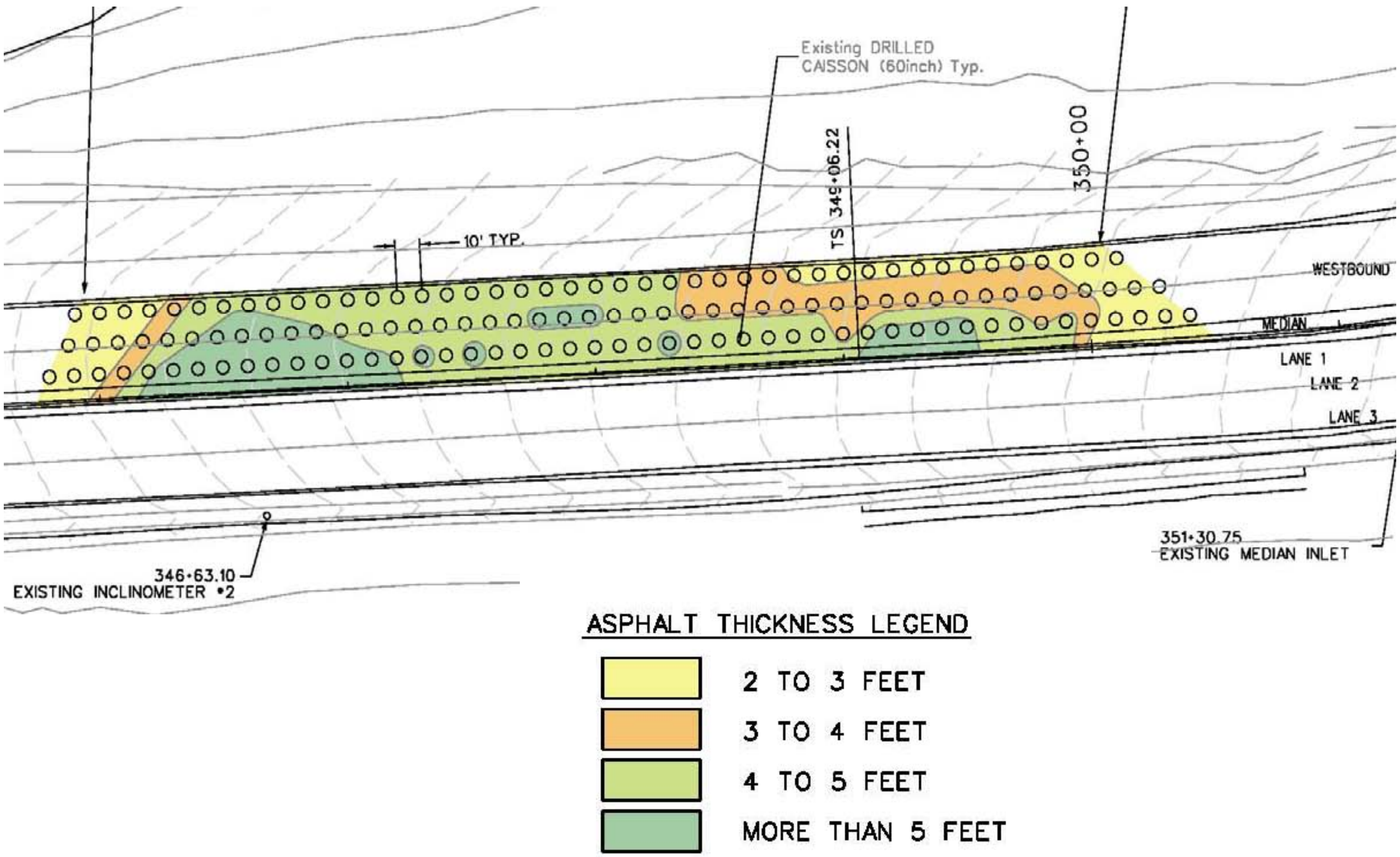




Multiple landslides mapped in the area.
Hanging glacial deposits intersected during construction influence seepage and other slides.
Hanging Glacial Valley Intersected by Alignment
Paleo-Slide Scarps (not active)
A
B
1
2
212
70
Image © 2010 DigitalGlobe
Image U.S. Geological Survey
© 2010 Google
©2009
Imagery Date: Aug 25, 2007
lat 39.665706° lon -105.987074° elev 10769 ft

Animation of installation process

I-70 Roadway Settlement Mitigation
Summit County, CO



CELLULAR CONCRETE IS ALWAYS ADVANCING TO SOLVE NEW CHALLENGES

Landslide activity on I-70 between the Eisenhower Tunnel and Silverthorne causes road damage every year. CDOT was looking for a lasting solution other than resurfacing yearly.

A series of 10’-20’ deep columns of lightweight cellular concrete were installed, reducing the dead load on the slip zone and eliminating the subsidence

I-70 Roadway Settlement Mitigation
Summit County, CO

Why Cellular Concrete

- Light weight with densities approximately 30% of existing soil
- Mobility to flow into intersected void spaces
- Batch onsite, less truck trips
- CDOT understood the added value of cellular concrete
- Ground improvement below the road would be beneficial for future efforts of stabilizing the slide

THE LOW SLUMP MIX FOR THIS PROJECT IS PROGRESSIVE FOR CELLULAR CONCRETE TECHNOLOGY

AASHTO Flow cone test

- The bubble structure remains stable even at densities less than 20pcf
- Mix produces for stiffer material
- Higher placement heights than typical cellular concrete which accelerated the project schedule

Typical Applications

- Tunnel & Mine Abandonment
- Annular Fills for Tunnels, Water & Sewer Lines
- Void Fills
- Soft Soil Remediation
- Tremie Applications
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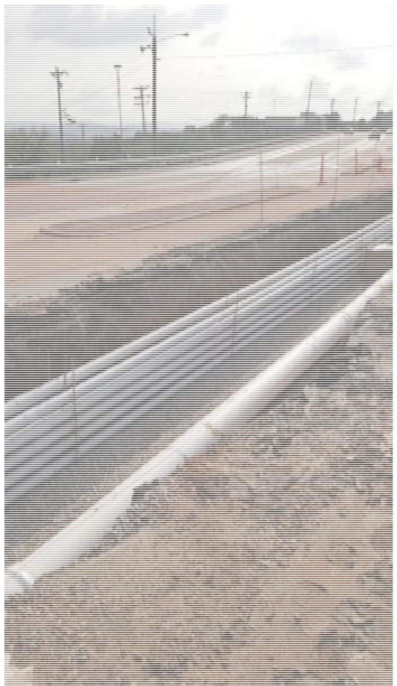
- Slope Stabilization
- Fill for Underground Utility, Conduit & Pipes
- Tanks & Pipeline Abandonment
- Green Roof Applications

Trench BackFill Opportunities



- Allows for narrower trench and less disturbance to the native material.
- Widths may be reduced to within 6-in of utility
- enough space to properly place the cellular in the pipe haunch areas
- Eliminates backfill compaction.
- Fills all voids

WATER MAIN ABANDONMENT IL TOLLWAYS PROJECT (ALTERNATIVE TO CLSM)

- 13,400 LF ; 60" and 90" water main abandonments for three Tollway projects

- 13,000 cubic yards of
  24-30pcf / 40psi

- Staging area for dry mix equipment (photo above) was over 1,000 feet to injection points.

**Information provided by MixOnSite USA Inc., Buffalo Grove, IL*

IDENTIFY BURIED UTILITIES WITH A DYE

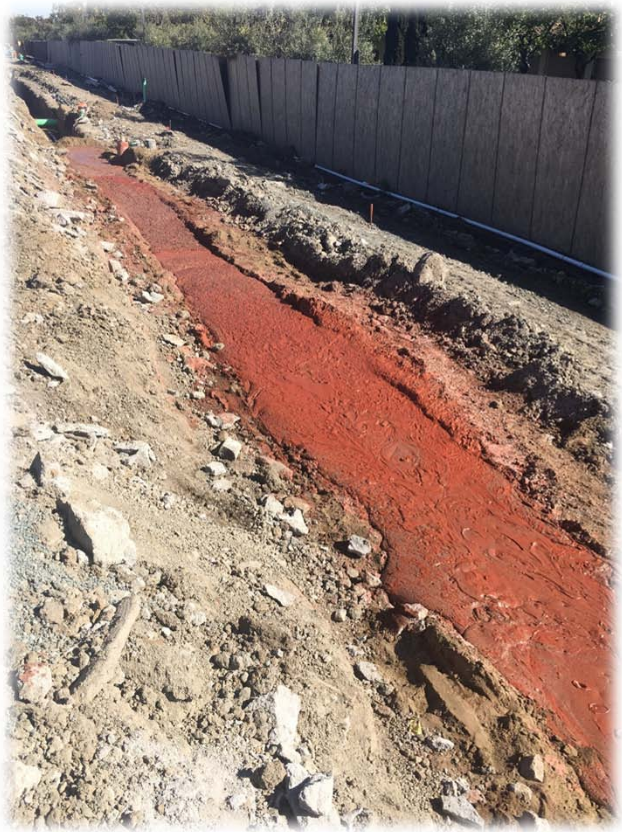


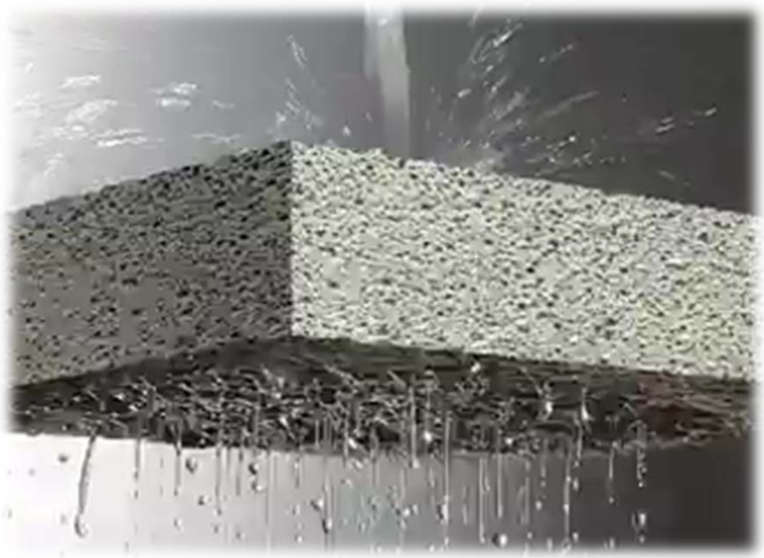
Photo Courtesy of Throop Cellular Concrete

- clear indicator for future operators
- Different colors can be used
  - Red - fiber optics or high voltage lines
  - Blue – water lines
  - Yellow – sewer lines

Fully Excavatable & Versatile

EMERGING TECHNOLOGIES AND ENGINEERED FOAM SOLUTIONS

Pervious Cellular Concrete (PCLWC)



PERVIOUS VS. NON-PERVIOUS

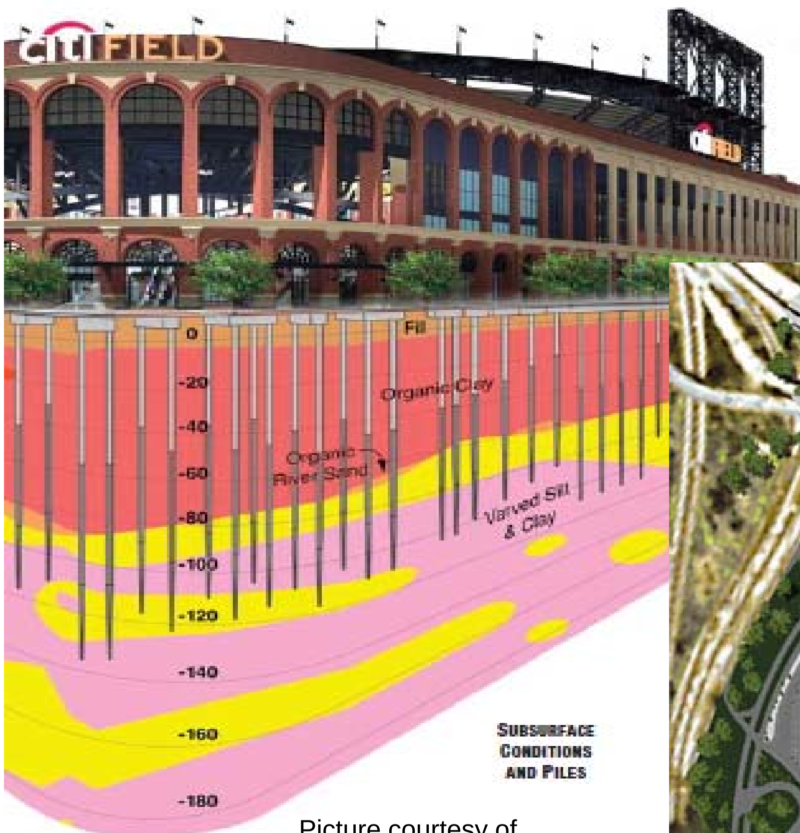
- Bubble Chemistry is different
  - In non-pervious we need to maintain the bubble structure
  - With Pervious we need to coalesce the bubble structure

TYPICAL USES AND APPLICATIONS FOR PERVIOUS CELLULAR CONCRETE

- Sports Field Sub-base Fills
- Bridge Approach Fills
- Retaining Wall Backfills
- Foundation Fills
- Pervious Pavement Sub-base Fills
- Pipeline Bedding Fills
- Culvert Relining Fills
- Pool Deck Sub-base Fills
- Pervious Paver Sub-base Fills

PERVIOUS CELLULAR CONCRETE USED AS A SUB-BASE AT THE NEW YORK METS BALLPARK SAVING THE OWNER OVER $500,000 DOLLARS

The site of the new ball park was on poor soils. Pervious Cellular Concrete was used as a sub-base under the playing field area to allow for drainage.

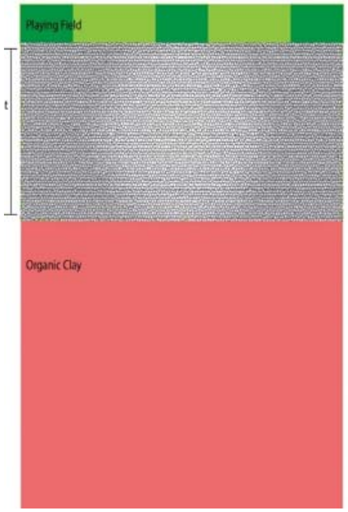


Picture courtesy of Civil Magazine 2009 Article

PERVIOUS CELLULAR CONCRETE USED AS A SUB-BASE AT CITIFIELD

The site of the new ball park is on organic clay

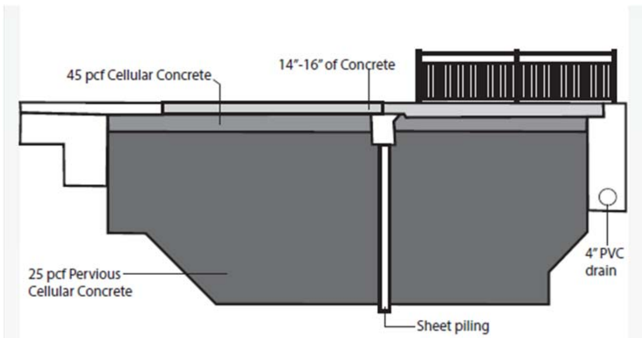
The original design called for 4' of lightweight aggregate. Cellular Concrete was proposed as a value engineering alternative.



**Information provided by Mixonsite USA Inc., Buffalo Grove, IL*

Rose Coulee Bridge
Fargo, ND

PERVIOUS CELLULAR CONCRETE USED ON BRIDGE APPROACH TO ALLOW FLOOD WATERS TO DRAIN



**Information provided by Cellular Concrete Inc., Zimmerman, MN*

2,600 CUBIC YARDS OF 25PCF PERVIOUS CELLULAR CONCRETE

Pervious Cellular Concrete Advantages

- Reduced Settlement
- Increase Bearing Capacity
- Improve Seismic Stability
- Permeability of 1×10^{-2} cm/sec

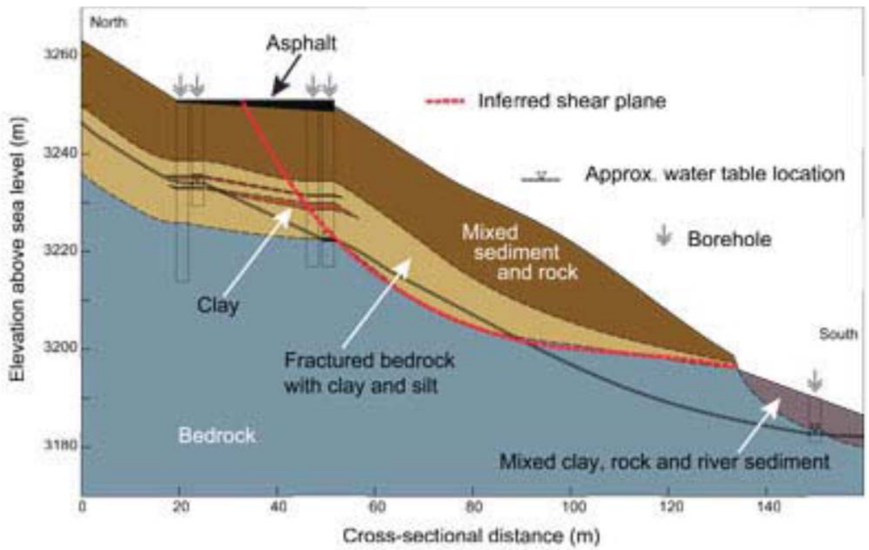
PERVIOUS CELLULAR CONCRETE USED ON BRIDGE APPROACH TO ALLOW FLOOD WATERS TO DRAIN

Using pervious cellular concrete on the bridge approach allowed the flood waters to drain alleviating pooling and potential deterioration

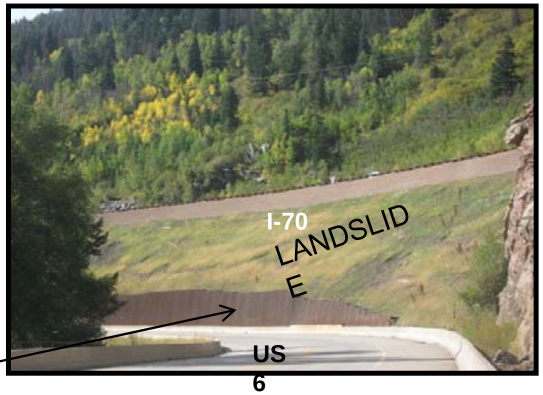
Standing water from flooding of Red River in Fargo, ND had deteriorated the bridge approach.

**Information provided by Cellular Concrete Inc., Zimmerman, MN*

PERVIOUS CELLULAR CONCRETE USED FOR RETAINING WALL BACKFILL TO PROVIDE DRAINAGE



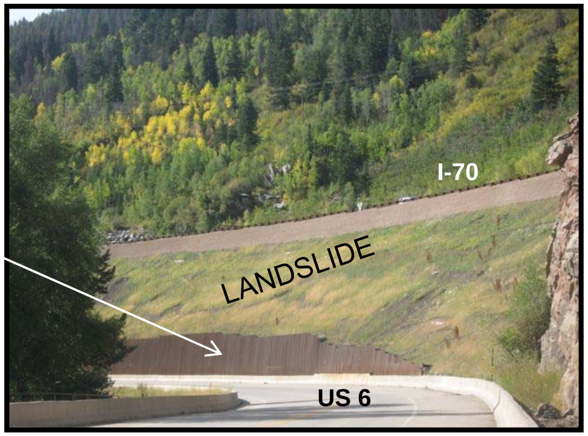
Due to the close proximity of the retaining wall to the concrete block anchors installed to tie back the landslide, the lightweight pervious backfill reduced the lateral earth pressure on the new block wall while still allowing for proper draining, which is key to reducing the potential for future slope failure



Pervious fill behind lower bin wall

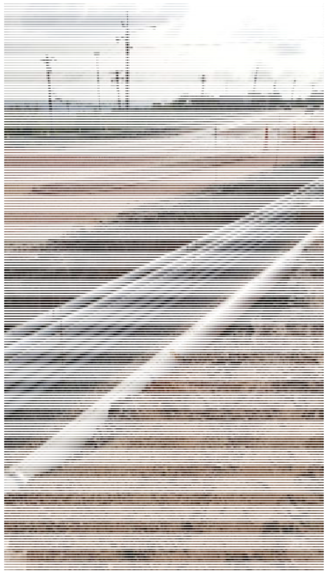
PERVIOUS CELLULAR CONCRETE USED FOR RETAINING WALL BACKFILL TO PROVIDE DRAINAGE AT TOE OF LANDSLIDE

Pervious fill behind lower bin wall



Due to the close proximity of the retaining wall to the concrete block anchors installed to tie back the landslide, the lightweight pervious backfill reduced the lateral earth pressure on the new block wall while still allowing for proper draining, which is key to reducing the potential for future slope failure

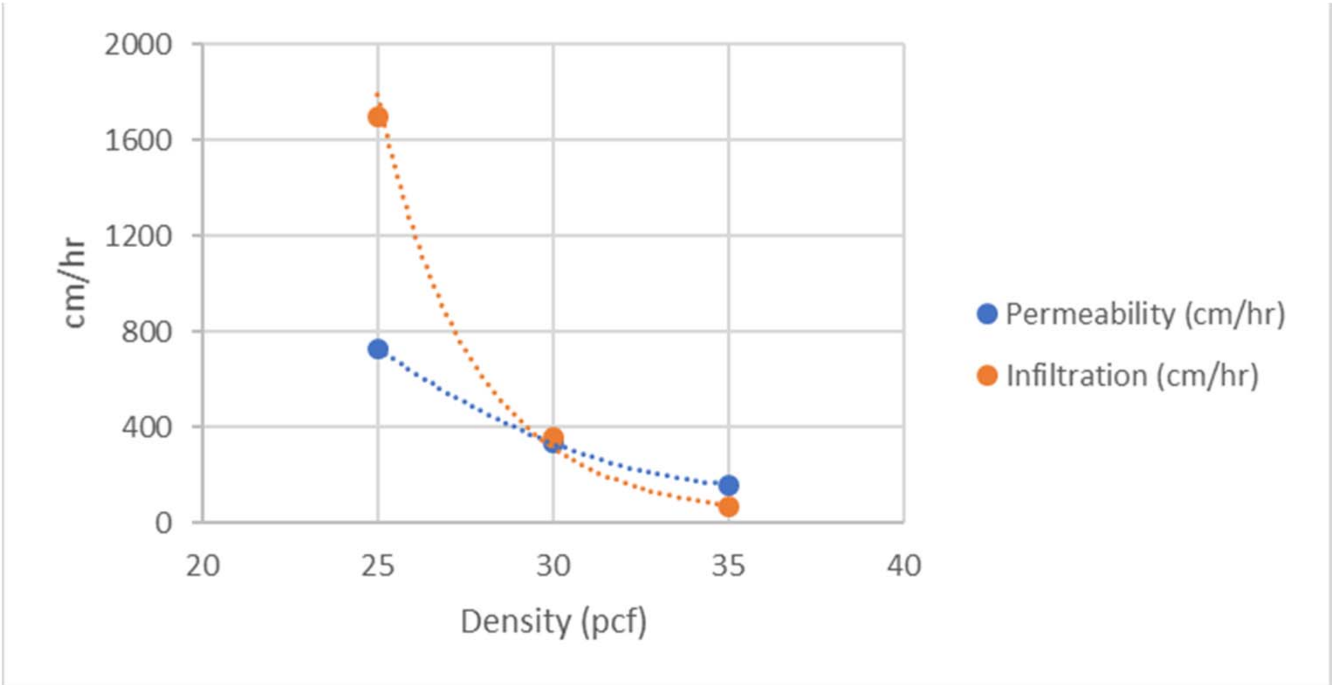
MODOT TEST OF PERMEABILITY CELLULAR CONCRETE



Observation of Permeability 24 hours after placement

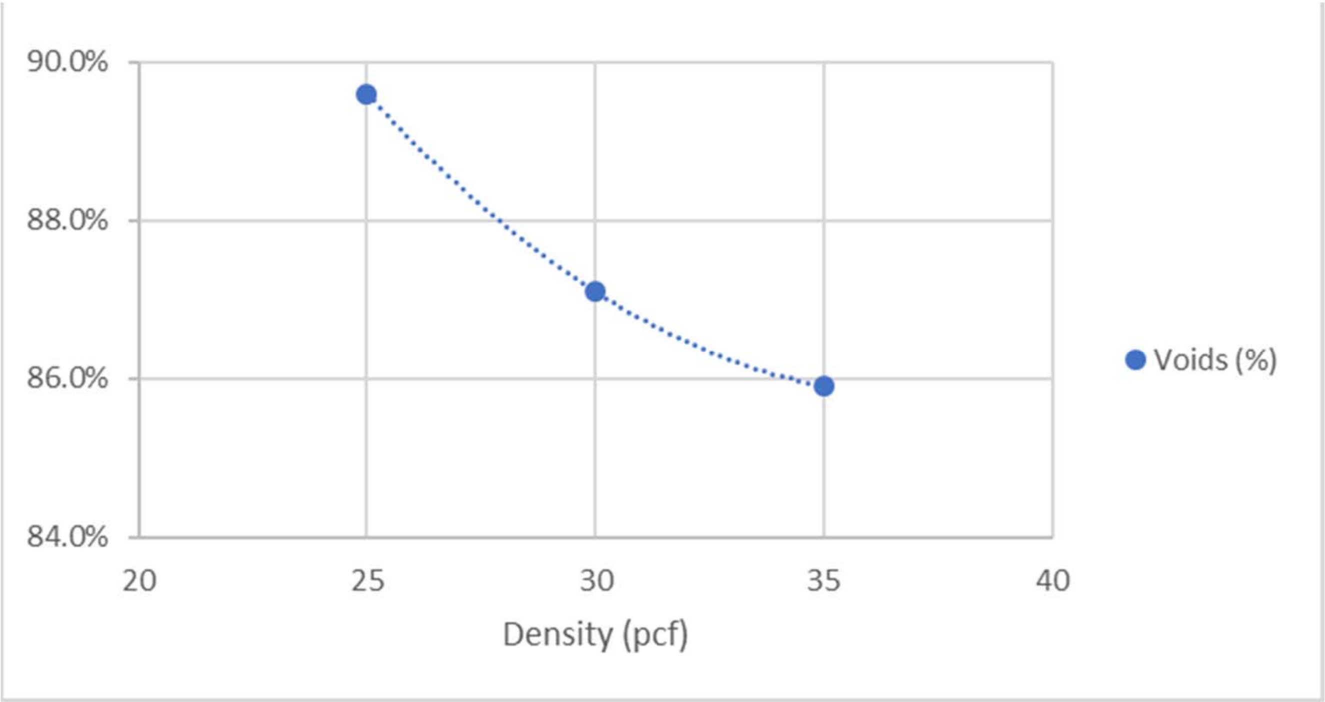
**Information provided by CellFill, Grove, OK*

PCLWC Permeability / Infiltration**



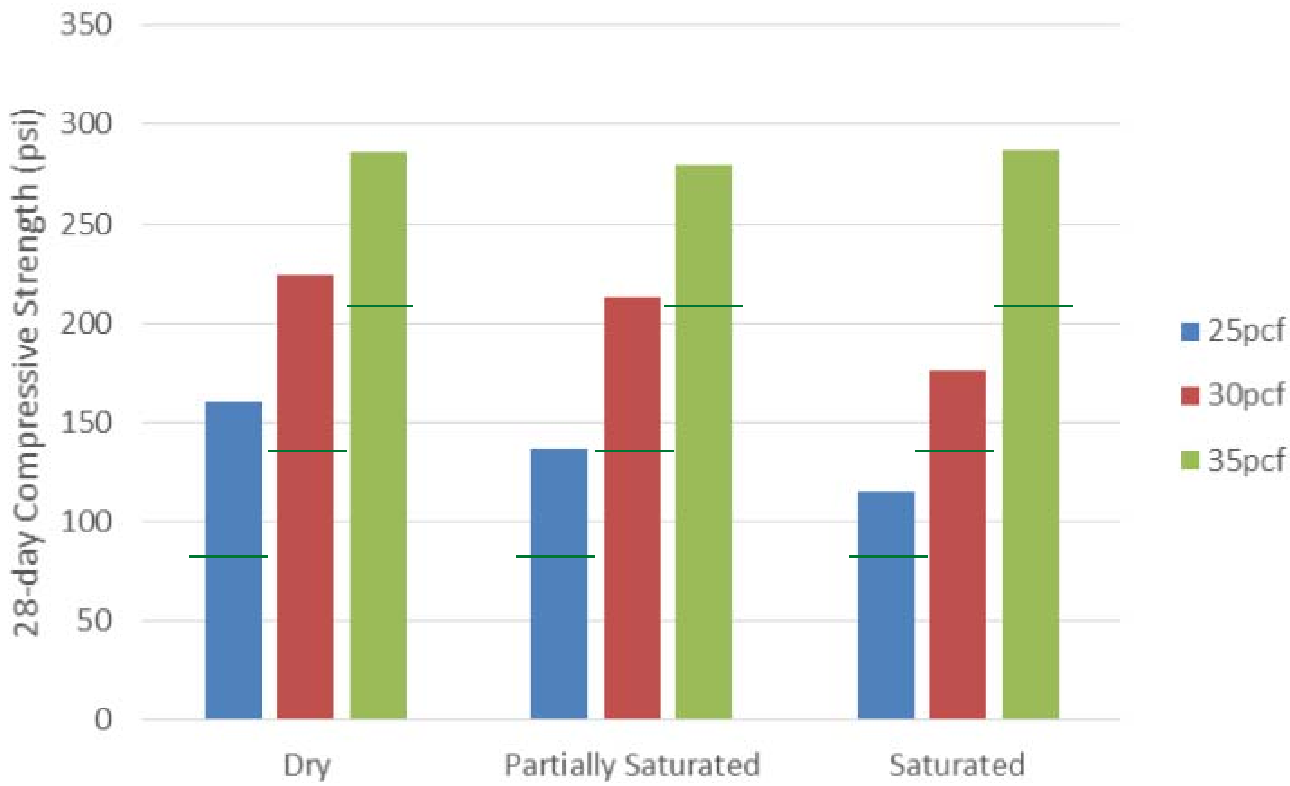
** University of Missouri, J.T. Kevern

VOID FACTORS OF PCLWC

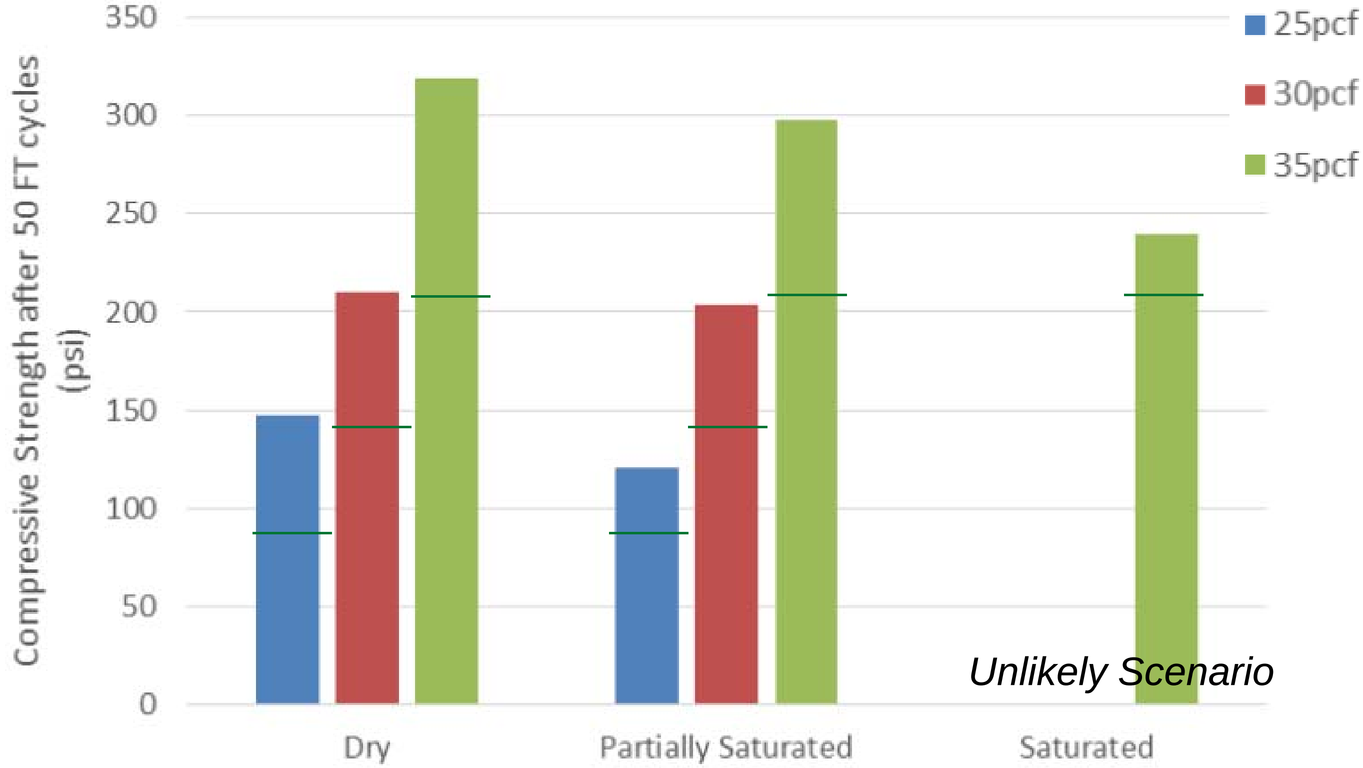


** University of Missouri, J.T. Kevern

PCLWC COMPRESSIVE STRENGTH - UMKC



PCLWC Freeze/Thaw 50 Cycles - UMKC



EMERGING TECHNOLOGIES AND ENGINEERED FOAM SOLUTIONS

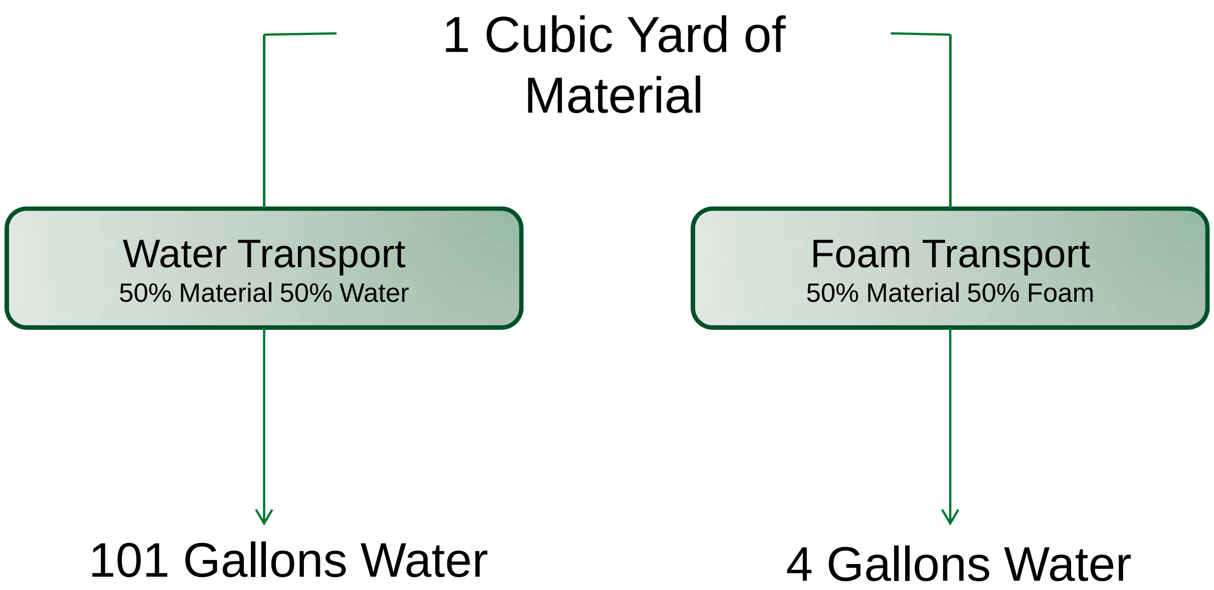
Foam Transport of Fill Materials

Traditional fill materials and tailings transport uses WATER as the transport medium

Foam Technology involves the introduction of AIR BUBBLES to replace the water as the main transport medium

Provides a less expensive and Environmentally friendly alternative

WATER USAGE IN FOAM TRANSPORT OF FILL MATERIALS IS DRAMATICALLY REDUCED



FOAM TRANSPORT WAS USED SUCCESSFULLY IN A MINE RECLAMATION PROJECT FOR THE STATE OF COLORADO

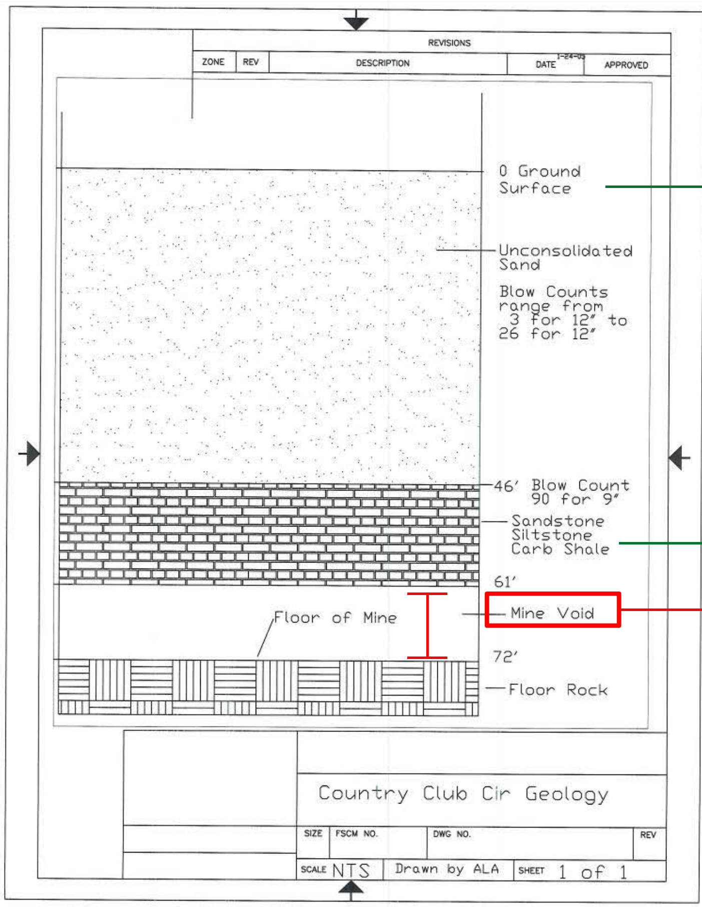
Project Location:

Country Club Circle Subdivision

Colorado Springs, Colorado

COLORADO DIVISION OF RECLAMATION MINING & SAFETY

THE SUBDIVISION HAD EXPERIENCED SEVERAL SUBSIDENCE EVENTS THAT CAUSED SIGNIFICANT DAMAGE, INDICATING LARGE VOIDS



Damage from 2005 subsidence event

The strata in the sub-division consists of about 45' of sand over 15' of rock

The coal mine created 8' to 9' of void space

LARGE VOIDS WERE FOUND AND EVALUATED USING BOREHOLE CAMERA, SONAR SCANNING, AND CROSS HOLE TOMOGRAPHY

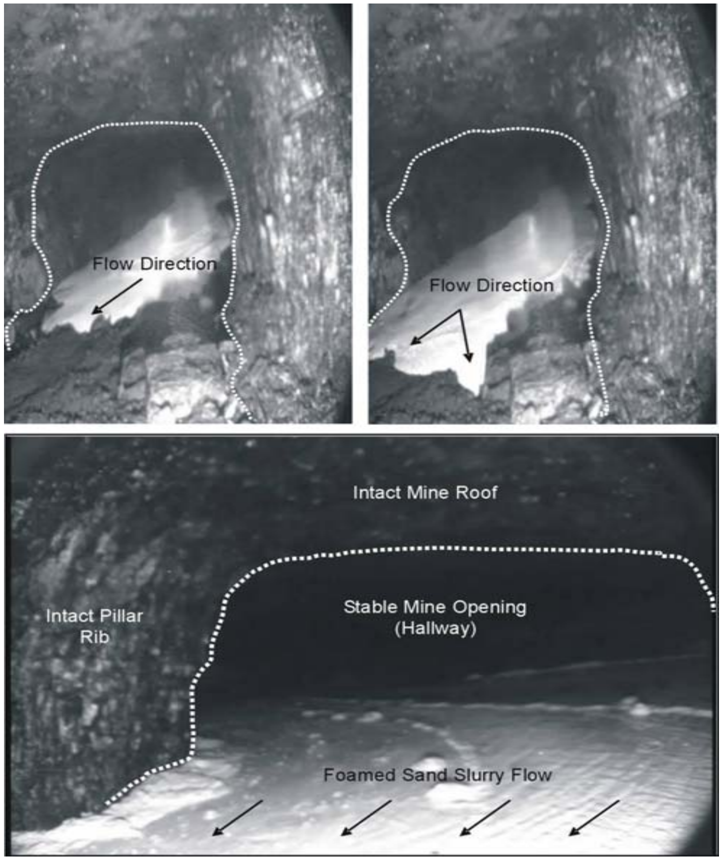


Figure 12 – Video Images in Borehole CCC13 During Foamed Sand Injection in Borehole CCC6

In May 2009, 267 cubic yards of a foamed sand slurry was injected into open mine entry

Borehole camera images show foamed sand slurry flowing through the voids

LARGE VOIDS WERE FOUND AND EVALUATED USING BOREHOLE CAMERA, SONAR SCANNING, AND CROSS HOLE TOMOGRAPHY

267 cubic yards of a foamed sand slurry was injected into open mine entry

Borehole camera images show foamed sand slurry flowing through the voids

Foam transport has been tested for material delivery underwater

<u>Test Parameters:</u>

Trench cut in test location
- 70' long
- 4' wide
- 6' deep

- Material Tremmied in at half way point

SANDED FOAM MIX MOVED THE ENTIRE LENGTH OF THE TRENCH – 35' EACH DIRECTION FROM TREMIE POINT

Underwater movement of fill material was monitored by Sonar Recording Equipment

WHAT CONCLUSIONS CAN WE DRAW ABOUT CELLULAR CONCRETE?

- Broad Range of Densities
- Economical
- Versatile
- Easily Placed
- Rapid Installation
- Durable
- Permanent and Stable
- Environmentally Friendly

Foaming Agents and Technical Support Provided By
Aerix Industries™
Engineering Solutions for Project Savings

No One Foam Does it All

We can customize our products to meet your project needs

SUMMARIZING THE LEARNING OBJECTIVES

- Introduced the history, definition, and properties of cellular concrete
- Reviewed various mix design requirements and testing procedures
- Highlighted some typical applications and exampled some case studies
- Introduced emerging technology, and how traditional cellular concrete technology is advancing to meet challenging project parameters

FUTURE EDUCATIONAL PRESENTATION

Troubleshooting Concrete Problems

Surface Defects In Flatwork

Overview

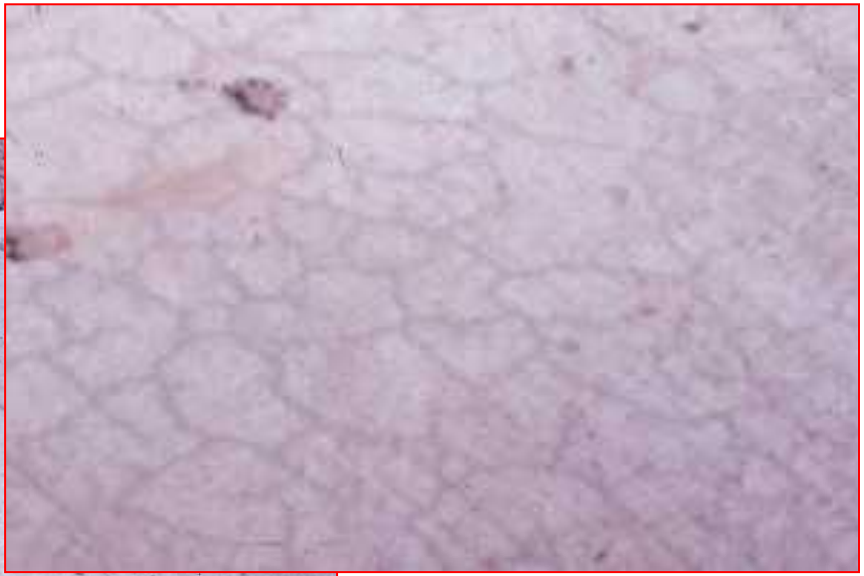
- Crazing Cracks
- Dusting
- Poor Abrasion Resistance
- Thin Surface Delamination
- Blisters
- Discoloration
- Pop-Outs
- Scaling
- (cure the concrete)

Crazing Cracks

Crazing Cracks—Fine random cracks or fissures in a surface of cement paste, mortar, or concrete.

- **Occurs while concrete is in plastic state**
- **May be difficult to find**
- **Affects Aesthetics**

Crazing Cracks…..



Crazing Cracks…..

due to Excess Surface Moisture

Crazing Cracks…..

due to Excess Surface Moisture

Crazing Cracks…..

Finishing Excess Water into Surface

Crazing Cracks…..
Potential Causes

- Curing water more than 20 F (11 C) cooler than the concrete
- Sprinkling water onto the surface of a slab during finishing
- Premature wetting and drying of the concrete surface
- Excessive fines
  - Overuse of jitterbugs, vibrating screeds, and bull floats
  - Premature floating and troweling
  - Dusting dry cement onto a surface
  - Too much clay and dirt in aggregates
- Premature drying of the top surface
  - Prevailing ambient conditions
  - Delay in curing

Crazing Cracks…..
The "Remedies"

- Avoid premature drying of the top surface
  - Fog spray, evaporation retarder, wind breaks
  - Early curing
- Control excess water and fines at the top surface
  - Reduce slump, use water reducers and air entrainment
  - Protect surface if rain is forecasted, and from elements
- Proper finishing
  - Do not overdo finishing operations
  - Do not add water and dry cement to surface

Dusting

Dusting**—The development of a powdered material at the surface of hardened concrete.**

Dusting.....

Dusting.....

Potential Causes

- High surface water-cementitious materials ratio
  - significant bleeding due to excessive slump, etc.
  - finishing bleed water or rainwater into top surface
- Early finishing
- Carbonation
  - unvented heaters
- Dry heat
- No curing

Dusting….. The "Remedies"

- Control bleeding & surface water content
  - Better gradation to reduce bleeding
  - Reduce slump, use water reducers and/or air entrainment
  - Protect surface if rain is forecasted, and from elements
- Proper finishing & construction practices
  - Remove bleed or rain water
  - Delay finishing
  - Vent heaters to outside, use water jackets on heaters
  - Cure
- Avoid premature drying of the top surface
  - Fog spray, evaporation retarder, wind breaks
  - Early curing
- Surface Hardeners

Low Abrasion Resistance

Low Abrasion Resistance—Ability of a surface to resist being worn away by rubbing and friction

- **Typically problem on floors**
  - **Fork lift traffic**
  - **Sliding pallets & heavy objects**
- **Highways**

Abraded Surface…..

Low Abrasion Resistance…..

Potential Causes & Remedies

- Surface compressive strength
  - water-cementitious materials ratio
  - surface hardeners
  - curing
- Aggregate type & hardness
- Carbonation
  - unvented heaters
- Finishing
  - Premature
  - Burnished hard trowel finish
- Curing

Thin Surface Delaminations

Mortar Flaking—Loss of a thin layer of mortar on the top surface typically exposing coarse aggregate

- Affects Aesthetics

Mortar Flaking…..

Larger Mortar Delamination's.....

Mortar Flaking & Other Mortar Delaminations… Potential Causees

- Excessive mortar at top surface
  - high amplitude vibrating screeds
  - improper (slow) vibrating screed speed
  - Jitterbug
  - early finishing
  - excessive finishing
- Excessive water at top surface
  - bleeding, etc.
- Drying of top surface

Mortar Flaking…..

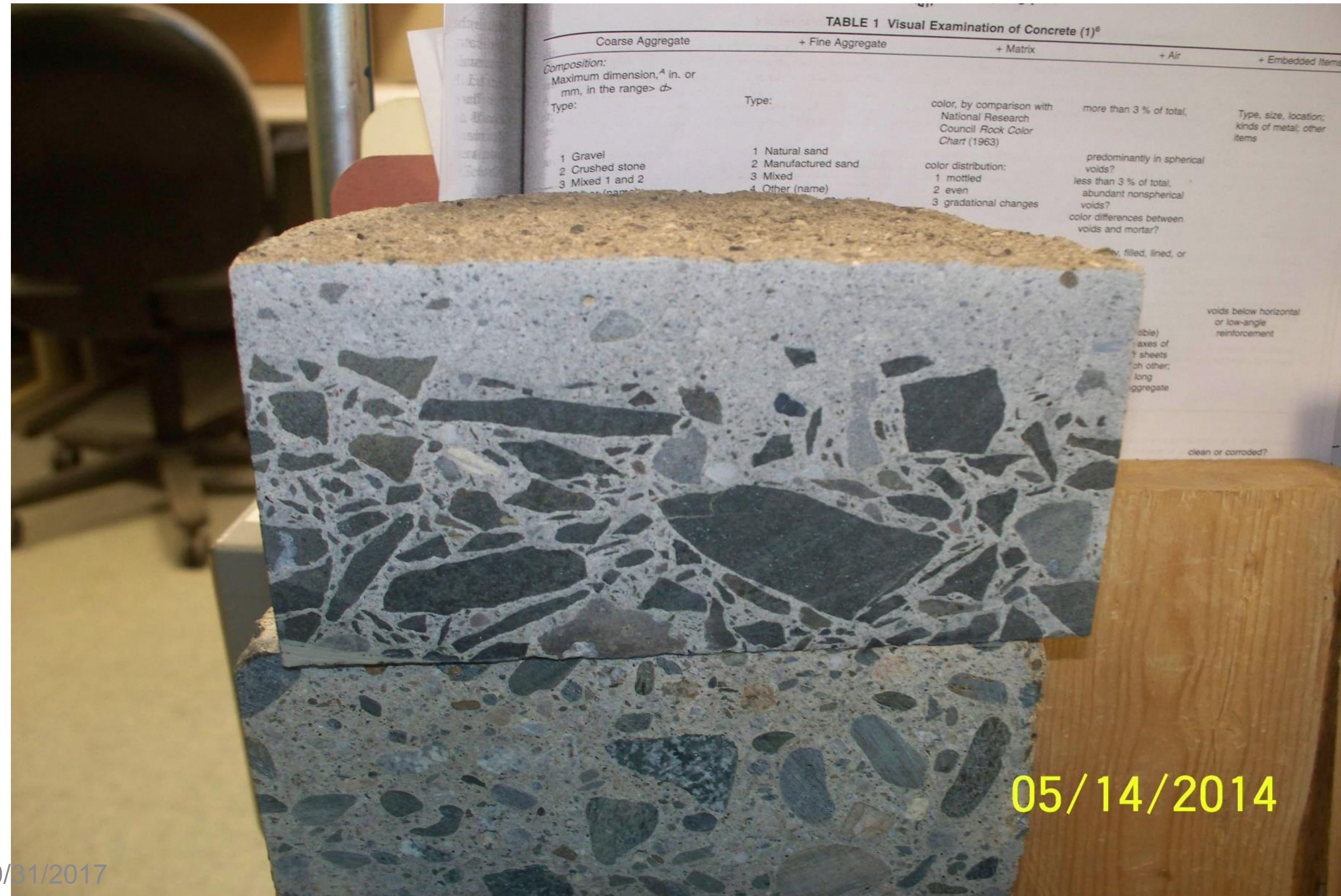
Consolidation Related…..

high amplitude vibrating screeds

Consolidation Related…..

- Jitterbug

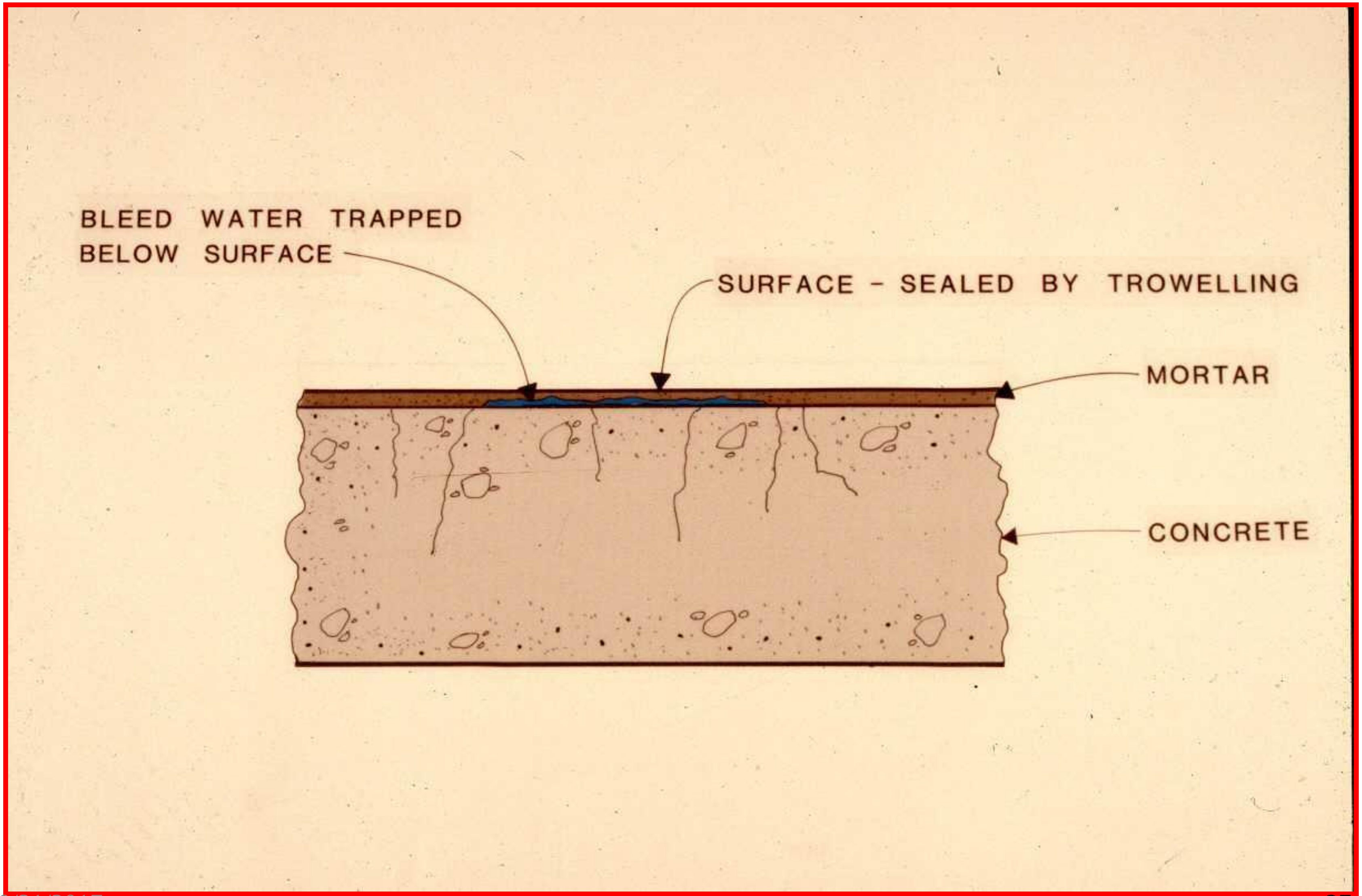
Mortar on the Top



Roller Screed.

Laser screed

The Mechanism…..



Evaporation Reducers

- Can be applied after:
  - Strike-off
  - Floating
  - In between toweling
- Evaporation reducers are not finishing aids
- Evaporation reducers are not curing compounds
- Evaporation reducers must not be left on a slab, but must be floated or toweled into the concrete surface.

- Use **1 part Evaporation Reducer concentrate to 9 parts water** – agitate/mix
- Use a constant-pressure or industrial sprayer
- Treat surfaces until a greenish-yellow film forms

Application of Evaporation Reducers

Weak Zone Under the Surface…..

Mortar Flaking of the Surface

Flaking in the Gutter pad of Driveway

Blisters

Blisters—The irregular raising of a thin layer at the surface of placed mortar or concrete during or soon after completion of the finishing operation.

Blisters…..
Potential Causes

- Typically, Premature Finishing
- Worst-Case Scenario
  - warm days, cool nights
  - warm top surface
  - slow bleeding rate / air-entrainment
  - concrete sets from top to bottom
- Agglomerations of Shrinkage-Compensating Materials or other Contaminants
- First Stages of Freeze-Thaw Deterioration

Blisters…..

The "Remedies"

- Limit air content on exterior flat slabs that require burnished hard-trowelled finish
- Prevent top from drying out between finishing passes
- Note soft and spongy top surface
- Batch and mix Expansive Materials properly

Plastic Shrinkage Cracking (& Crusting)

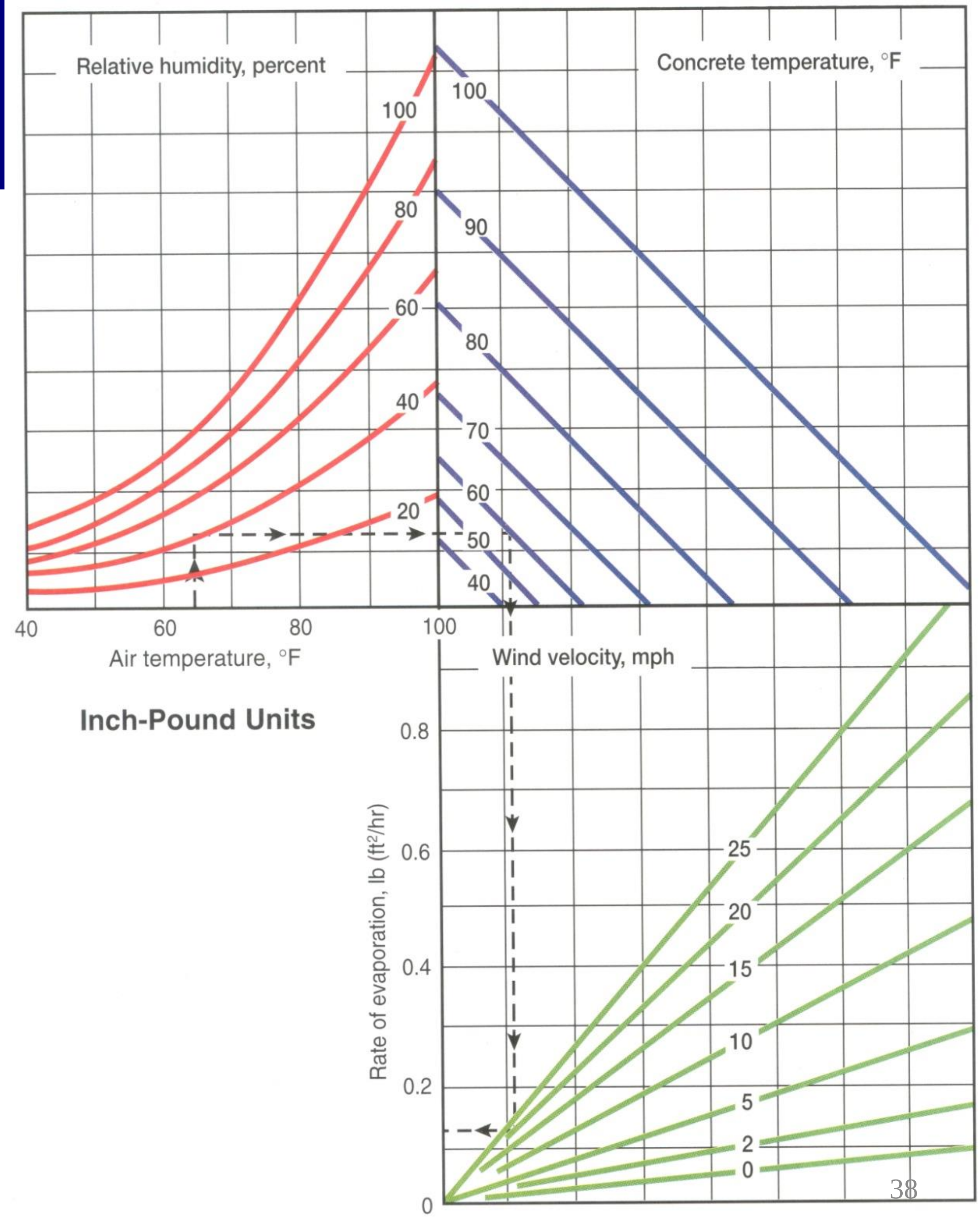
PLANT ORIGIN

- Concrete temperature
- "Water-starved" mixture
- Low bleeding concrete
- Excessive retardation

JOB SITE ORIGIN

- Ambient conditions
- Added admixture
- Member depth
- Consolidation & finishing
- Lack of

Effect of Temperature, Relative Humidity and Wind Speed on Evaporation Rate



Plastic Shrinkage Cracks after 20 years

How to take measurements for evaporation

Air Temperature

- Measure at 4 to 6 ft above concrete surface

Relative Humidity

- Measure in shade on windward side 4 to 6 ft above concrete surface

Concrete temperature

- Measure at concrete surface

Wind speed

- Measure 20 inches above concrete surface

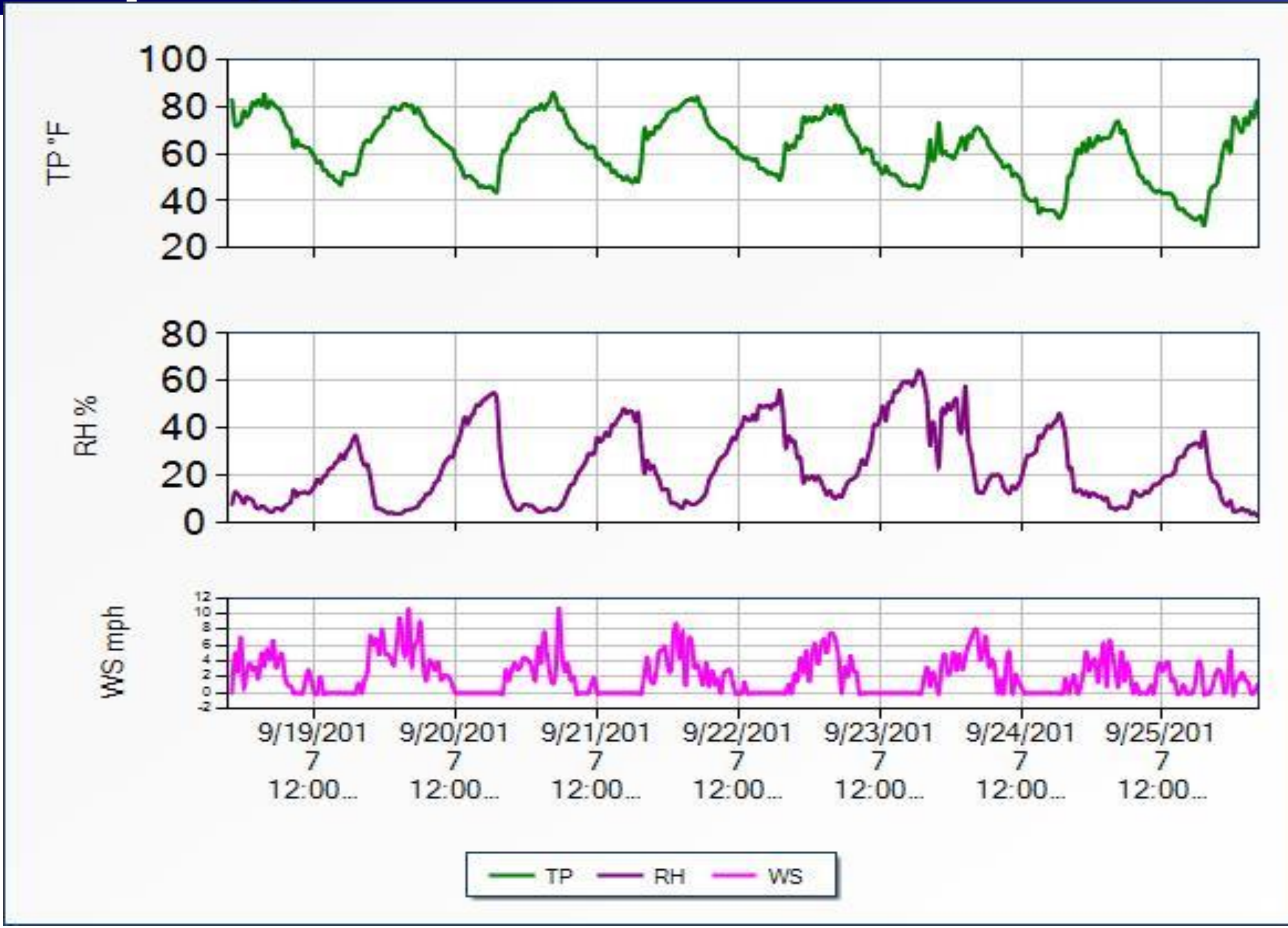

01/20/2008


07/25/2017

Kestral weather station

- Wind Speed
- Temperature
- Wind Chill
- Relative Humidity
- Heat index
- Due Point
- Bratometer pressue Evaporation Rate
- Need concrete temperature

Kestrel graphs that can tell what has happened



Discoloration

Discoloration:

- Departure from normal or desired color

- Typically dark spots distributed through out the slab

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Troubleshooting Concrete Curing

Discoloration…..

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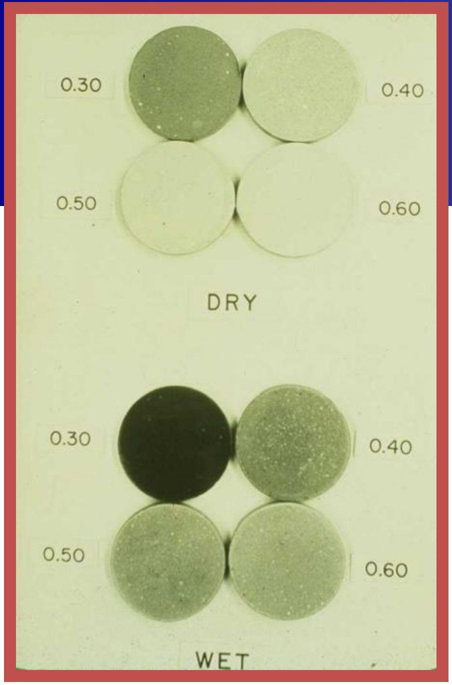
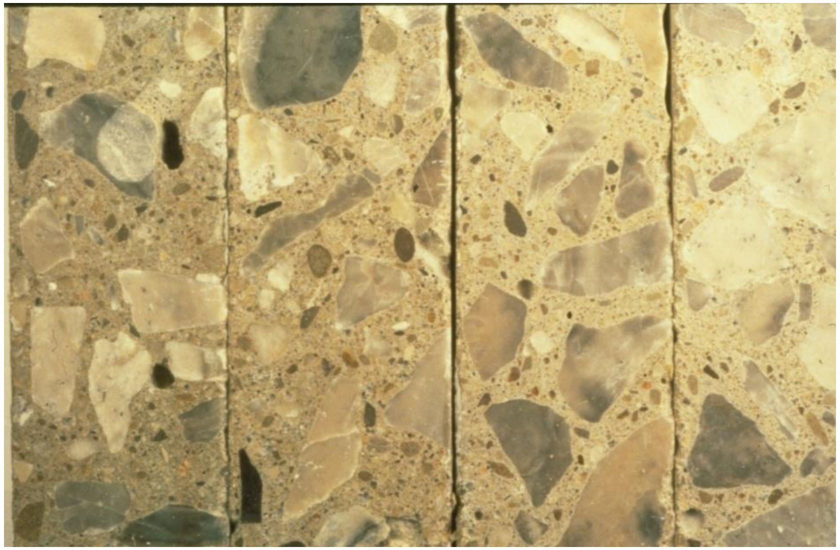
Troubleshooting Concrete Curing

Green House effect with plastic

Discoloration…..



0.4 w/c	0.5 w/c	0.6 w/c	0.7 w/c



Discoloration from amount of Pigment

Discoloration…..
Potential Causes

- Different Water Contents
- Different Materials
- Calcium Chloride
- Aggregate Contamination
- Bluish-Green Color from GGBFS (slag)
- Stains
  - red mud
  - dark materials
- Hard Troweling
- Improper Curing
  - little to none
  - “Greenhouse Effect”

Discoloration…..
The "Remedies"

- Control water-cementitious materials ratio
  - Use water reducers
- Use same source materials for the same concrete mixture
- Avoid the use of calcium chloride; use nonchlorides / Type III
- When color is critical, use consistent materials or purchase all of the materials for the project
- Trowel only at proper time
- Use good curing procedures & avoid use of polyethylene or other coverings that stain or discolor concrete
- GGBFS (slag)
  - Typically bleaches out within 7 days But may never bleach out
  - May take longer for high strength concrete

Discoloration…..

The "Fix"

- Stain Concrete Slab Preferably with a Darker Color
- Ammonium Citrate Di-Basic
  - Mix 2 pounds of granular ammonium citrate with one gallon of water
  - Apply to top of slab & scrub into slab with soft brush
  - Wait until material gels, then rinse and scrub off
  - Slab will lightened with two weeks
- Phosphoric Acid—10% solution
  - Wet slab
  - Spray coat of acid & wait until dries
  - Slab will lighten immediately
- Pressure Wash with Cleaner
- For slag Cement, apply sodium hydroxide

Pop-Outs

Popouts—the breaking away of small portions of a concrete surface due to localized internal pressure that leaves a shallow, typically conical, depression;

- Small popouts: holes up to 0.4 in (10 mm) in diameter;
- Medium popouts: holes 0.4 to 2 in. (10 to 50 mm) in diameter;
- Large popouts: holes greater than 2 in. (50 mm) in diameter.

Aggregate Pop-outs…..

Popouts…..
Potential Causes

- Soft Aggregate
  - chert
  - soft fine-grained limestone
  - shale
- Impurities
  - hard-burned lime
  - hard-burned dolomite
  - pyrite
  - coal
- Agglomerations of Shrinkage-Compensating Materials

Lime Inclusions

Soft Aggregates in the Concrete

Clay Balls from the Fine Aggregated

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Troubleshooting Concrete Curing

Clay under the stock piles

Popouts.....

The "Remedies"

- Use aggregates that meet ASTM C 33 requirements
  - Remove deleterious materials through processing
  - Certain areas have aggregates that are prone to popouts
- Use two-course floor construction method
- Control cross-hauling of Expansive Materials
- Batch and mix Expansive Materials properly

Scaling

Scaling—Local flaking or peeling away of the near-surface portion of hardened concrete or mortar

- Light—does not expose coarse aggregate
- Medium—loss of surface mortar to 5 to 10 mm in depth exposure of coarse aggregate
- Severe—loss of surface mortar to 5 to 10 mm depth with some loss of mortar surrounding aggregate particles 10 to 20 mm in depth
- Very severe—loss of coarse aggregate particles as well as mortar generally to a depth greater than 20 mm.

Scaled Concrete. iphone

Dog Urinated in the snow on Concrete

Freeze Thaw

Need 4000 psi concrete with 6% entrained air.

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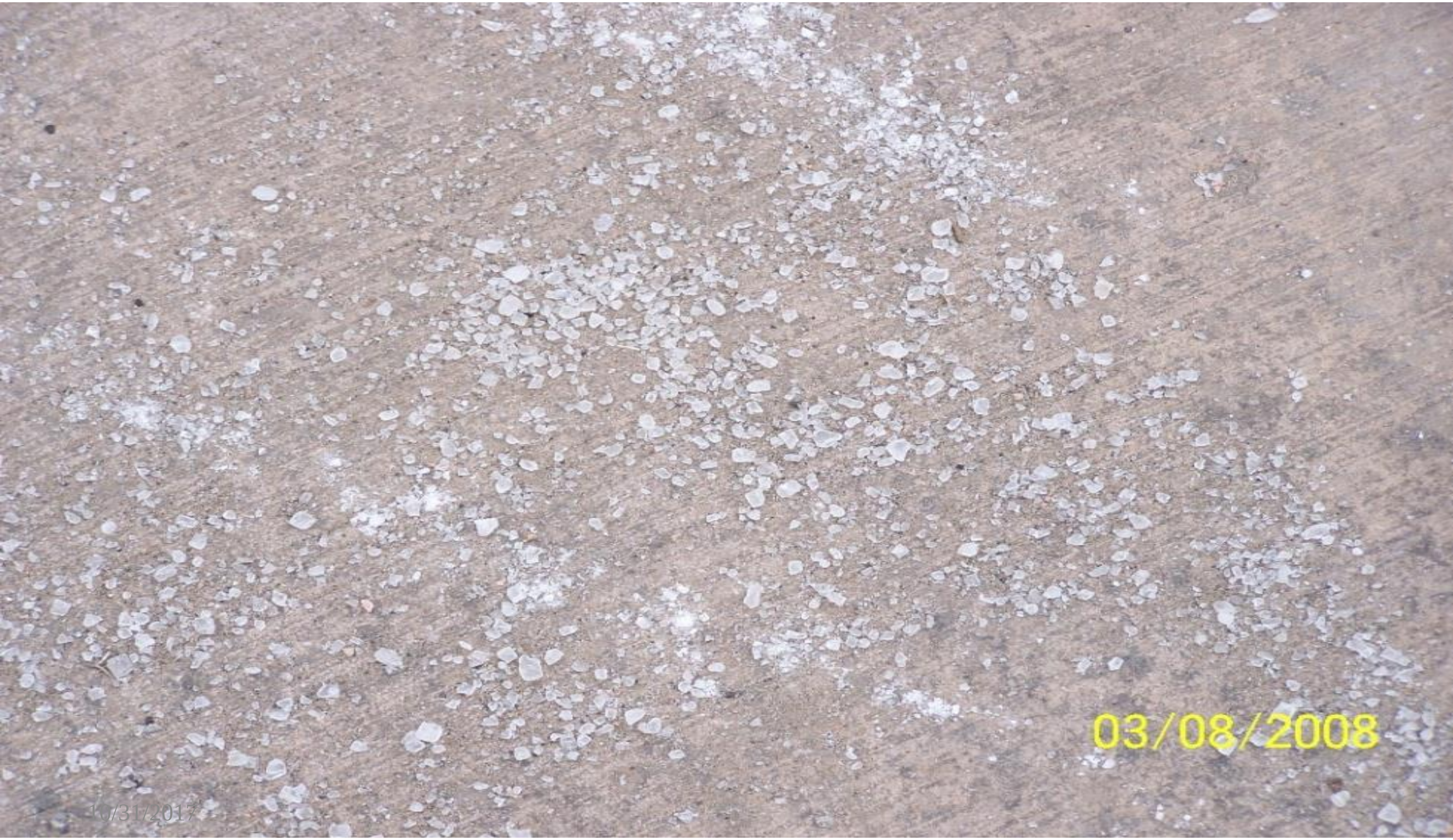
Troubleshooting Concrete Curing

Salt on the concrete



Salt used on the concrete

Scaling due to Salt

Scaling…..

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Troubleshooting Concrete Curing

Need Drying Period for New Pavements & Exposed Slabs…..

Question's ???

Thank You

Frank A. Kozeliski, P.E.

Pronounce "Cause-a-liskey"

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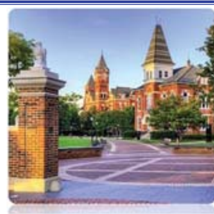
2017 Alaska Concrete Summit

Chemical Admixtures

By: Anton Schindler, Ph.D., P.E., FACI

Professor and HRC Director
Department of Civil Engineering
Auburn University

November 2017



Outline

- **Introduction**
- Water-reducing Admixtures
- Set-controlling Admixtures
- Air-entraining Admixtures
- Incompatibility
- Closing Remarks

Admixtures

Definition (ACI CT 2016):

- Admixtures are any ingredients in concrete other than:
  - Cementitious materials
  - Water
  - Aggregates, and
  - Fiber reinforcement
- Admixtures are added to the batch before or during mixing
- Admixtures are used to modify concrete's freshly mixed, setting, or hardened properties

Why Use Chemical Admixtures

To modify fresh concrete properties:

- Decrease water content
- Increase workability
- Retard or accelerate setting time
- Reduce segregation
- Reduce the rate of slump loss
- Improve pumpability, placeability, finishability
- Modify the rate and/or capacity for bleeding, etc.

Why Use Chemical Admixtures

To modify hardened concrete properties:

- Improve resistance to cyclic freezing & thawing
- Inhibit corrosion of embedded metals
- Inhibit expansion due to alkali-silica reaction (ASR)
- Reduce long-term drying shrinkage
- Reduce permeability
- Improve impact resistance
- Produce colored concrete

Main Types of Chemical Admixtures

Water Reducers:
- Normal, mid-range, high-range (superplasticizers)

Set Control:
- Accelerators, retarders (hydration control)

Durability Enhancing:
- Air-entraining admixtures
- Corrosion inhibitors
- Shrinkage reducers
- ASR inhibitors

Other:
- Viscosity modifiers & Rheology control
- Coloring admixtures
- Foaming agents, etc.

Water-Reducing & Set-Control Admixtures

ASTM C 494 Classification	
Type A	Water-Reducing Admixtures
Type B	Retarding Admixtures
Type C	Accelerating Admixtures
Type D	Water-Reducing & Retarding
Type E	Water-Reducing & Accelerating
Type F	High-Range Water-Reducing
Type G	High-Range Water-Reducing & Retarding
Type S	Specific Performance Admixtures

Note: ASTM C 260 for Air-Entraining Admixtures

Chemical Admixtures Dosage

- Most chemical admixtures are dosed in **oz/cwt**

What does oz/cwt mean?

oz/cwt = fluid ounces per 100 pounds of cement

- EXAMPLE:
  - Admixture dosage = 4 oz/cwt
  - Cement content = 600 pcy
  - Amount of admixture
    = 4 oz×(600 lb/yd^3)/100 lb
    = 24 oz / yd^3

    (≈ 2 × soda cans / yd^3)

Outline

- Introduction
- **Water-reducing Admixtures**
- Set-controlling Admixtures
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Water-reducing Admixtures

Definition (ACI CT 2016):

Admixtures that either increase slump of freshly-mixed concrete without increasing water content **OR** maintain slump with a reduced amount of water…

The same admixture could be a water-reducer or plasticizer:

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Water-reducer: Water content reduced while maintaining slump. Results in reduced *w/cm* leading to improved strength and durability.

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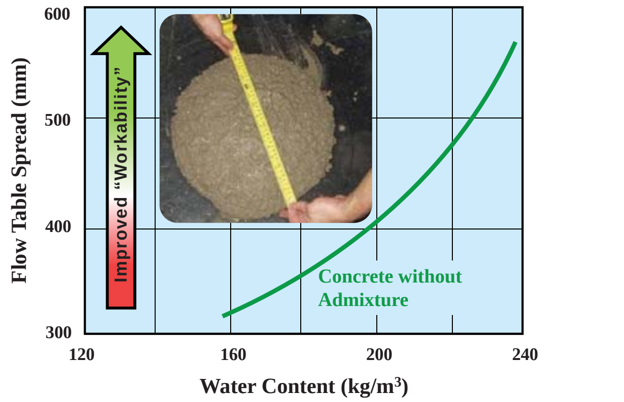
The same admixture could be a water-reducer or plasticizer:

Water-reducer: Water content reduced while maintaining slump. Results in reduced *w/cm* leading to improved strength and durability.

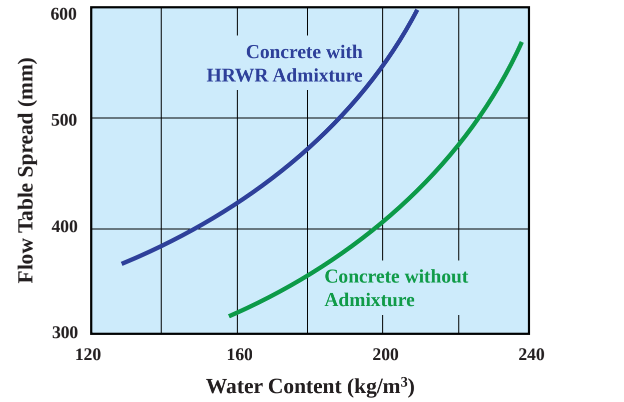
Plasticizer: Workability increased while maintaining water content (& *w/cm*). Results in improved placing characteristics without adversely affecting strength and durability.

Water-reducer versus Plasticizer



(Source: Neville 1995)

Effect of Superplasticizer



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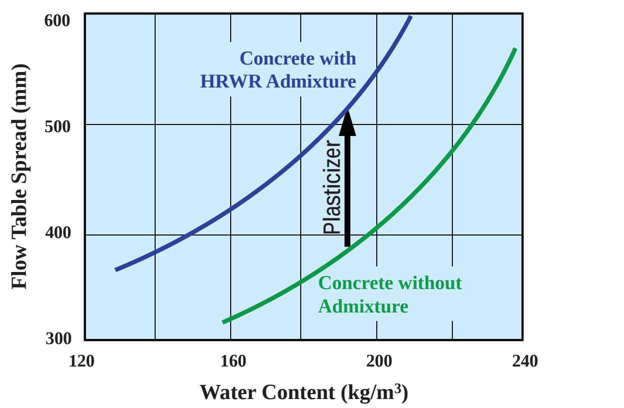

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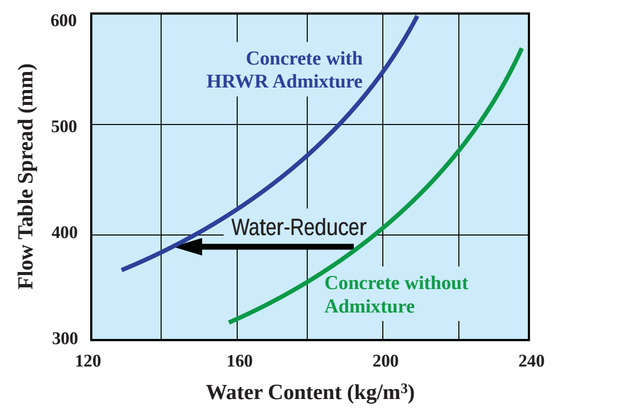
Effect of Superplasticizer



(Source: Neville 1995)

Classification	% Water Reduction	or Increased Workability
Conventional water-reducing admixtures (WRA): Type A	**5 - 10**	
Mid-range water-reducing admixtures	**6 - 12**	
High-range water-reducing (HRWR) admixtures or Superplasticizers: Type F	**12 - 30**	

Water-reduction Mechanisms

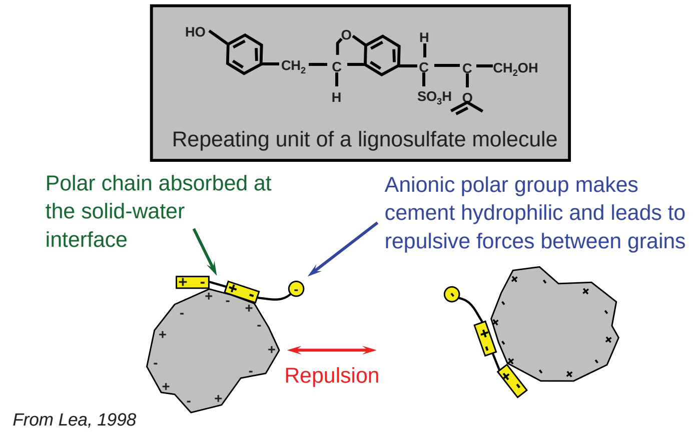
- All water-reducing admixtures are **surfactants** which are absorbed at the **cement-water interface** and **prevent the cement grains from flocculating** by changing the **nature of the surface charge**

Note: Surfactants are wetting agents that lower the surface tension between two liquids or between a liquid and a solid

Water-reduction Mechanisms

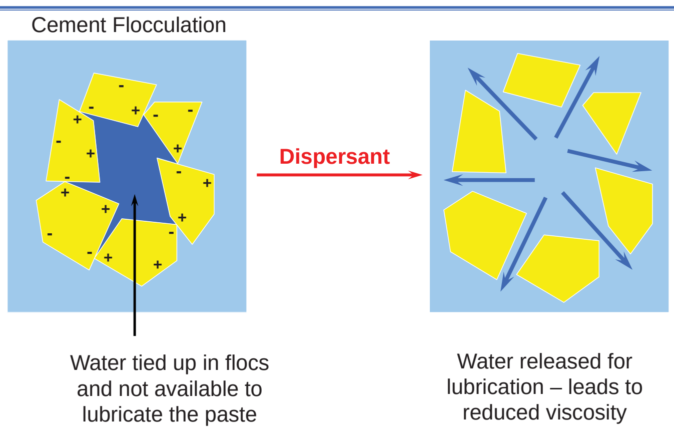
1. **Dispersive Action**
   - Type A water reducers
   - 1st Generation HRWR admixtures (Sulfonated melamine)
   - 2nd Generation HRWR admixtures (naphthalene formaldehyde condensates)
2. **Steric Repulsion**
   - 3rd Generation HRWR admixtures (Polycarboxylate ether)

1. Dispersive Action

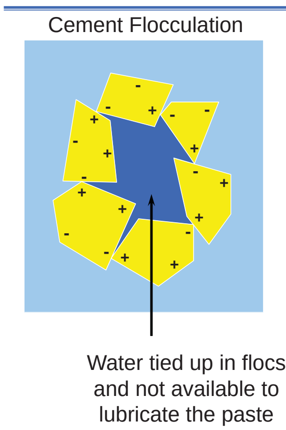


From Lea, 1998

1. Dispersive Action

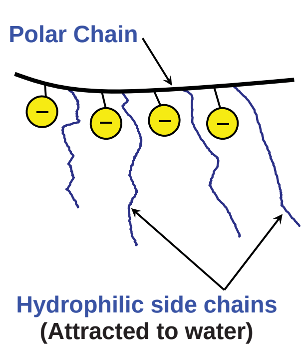


Water-reduction Mechanisms



Greater dispersion obtained with water addition !!

2. Steric Repulsion Mechanism



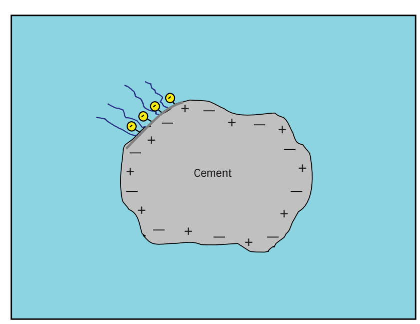
Unlike past generations of superplasticizers, molecules of **polycarboxylate ether** consist of :

1) a very flexible **polar chain** carrying negative functional groups, and
2) long **hydrophilic side chains**

(Slide courtesy of Dr. M.D.A. Thomas)

2. Steric Repulsion Mechanism

As with past generations of superplasticizers, **polycarboxylate ether** is dissolved in water, and the polar chain is absorbed at the solid-water interface.



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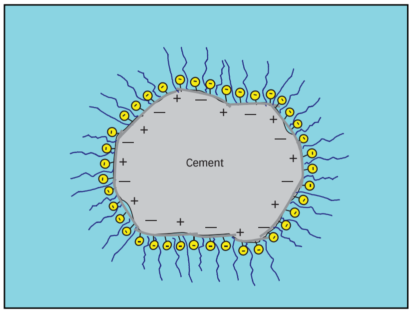
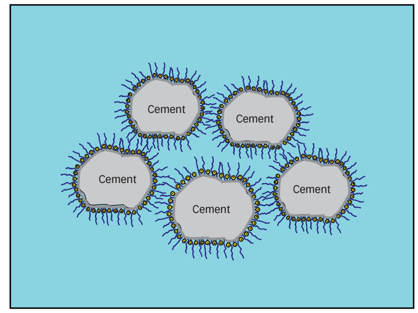


(Slide courtesy of Dr. M.D.A. Thomas)

2. Steric Repulsion Mechanism

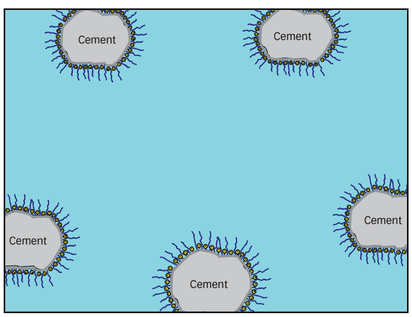
The long side chains **physically** help hold the cement grains apart allowing water to totally surround the cement grains (**steric hindrance**).



(Slide courtesy of Dr. M.D.A. Thomas)

2. Steric Repulsion Mechanism

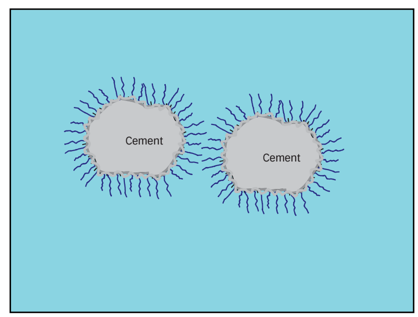
Additionally, the polar chain imparts a negative charge causing the cement grains to repel one another (**electrostatic repulsion**).



(Slide courtesy of Dr. M.D.A. Thomas)

2. Steric Repulsion Mechanism

As the electrostatic repulsion dispersing effect wears off due to cement hydration, the long side chains still physically keep the cement dispersed.

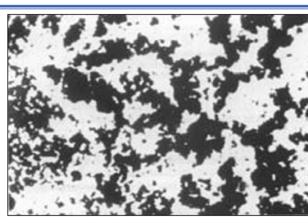


(Slide courtesy of Dr. M.D.A. Thomas)

Micrograph of Cement Grains Suspended in Water

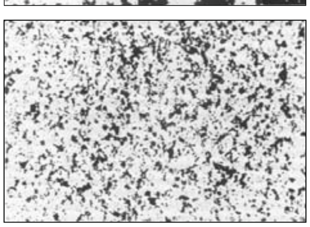
No admixture →

Cement grains are flocculated, which traps water.



With HRWRA →

Cement grains are dispersed, which frees trapped water.



(Source: Lea 1998)

Water-reducing Admixtures (ASTM 494 Type A)

- Uses of water-reducing (WR) admixtures
  1. Increase consistency (WR + fixed w/c)
  2. Increase strength (WR + less water, fixed slump)
  3. Save cement (WR + less water, fixed w/c)

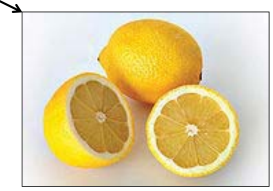
Action	Mix ID	Cement (pcy)	Water (pcy)	*w/c*	Slump (in.)	f_c at 28d (psi)
Control Mixture	C	300	186	0.62	2	4,000
Add WR	No. 1	300	186	0.62	4	4,000
Add WR, W↓, equal slump	No. 2	300	168 (-10%)	0.56	2	4,500
Add WR, W↓, C↓, equal *w/c*	No. 3	270 (-10%)	167	0.62	2	4,000

Water-reducing Admixtures (ASTM 494 Type A)

- Provide minimum 5% water reduction
- Used in concretes with moderate to high water-cementitious materials ratios (w/cm)
- Used in production of concrete with slump up to 5 in. (125 mm)
- Also used in combination with HRWRA at low w/cm
  - Reduce slump loss and stickiness

Water-reducing Admixtures

- Conventional Water Reducers:
  - Lignosulfonate Salts
  - Hydroxycarboxylic Acids
    - Citric acid
    - Gluconic acid
  - Carbohydrates
    - Corn syrup
    - Dextrin



Water-reducing Admixtures (ASTM 494 Type A → D)

- Water-reducing admixtures often retard setting
  - This may limit the dosage at which they can be used practically
- The retarding effect of WRA's can be partially (or wholly) offset by the use of an accelerating admixture

Conventional Water-reducing Admixtures

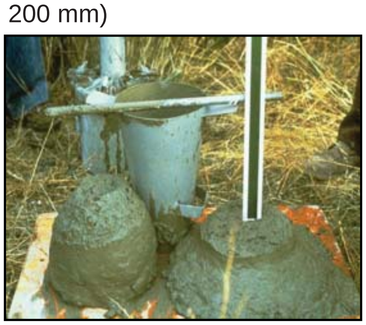
Effects of Increasing Dosage of Type A ...

- Diminishing returns
- Excessive retardation / bleeding
- Slow strength development

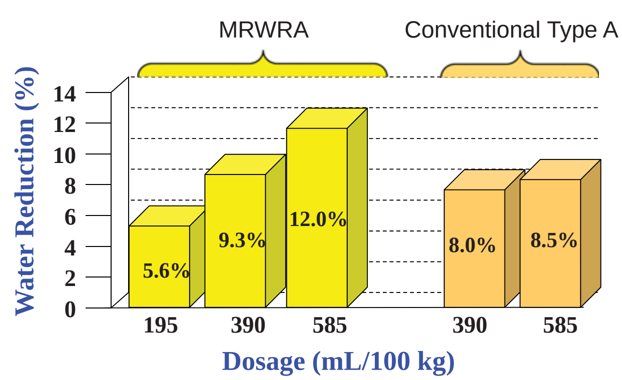
Mid-Range Water Reducers

Mid-range Water-reducing Admixtures

- Provide mid-range (6 - 12%) water reduction
- Used in production of concrete with slump between 5 - 8 in. (125 - 200 mm)
- Used in concretes with moderate *w/cm*
- Also used in combination with HRWRA at low *w/cm*
  - Reduce slump loss and stickiness

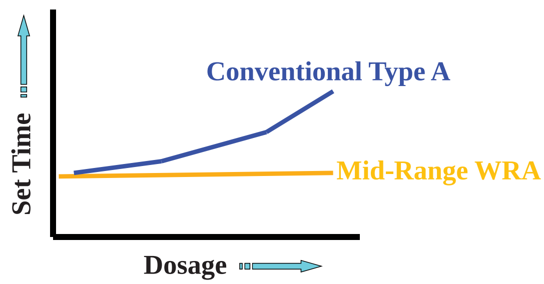


Water Reduction Comparison



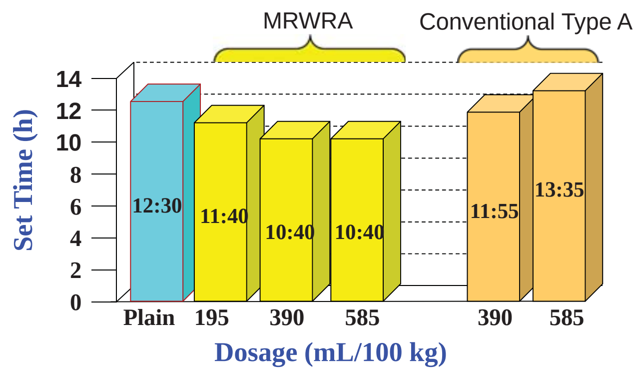
(Slide courtesy of Dr. Charles Nmai, BASF)

Set Time Comparison (MRWRA vs. Conventional Type A)



(Slide courtesy of Dr. Charles Nmai, BASF)

Set Time Comparison (MRWR vs. Conventional Type A)



(Slide courtesy of Dr. Charles Nmai, BASF)

Benefits of Mid-range WR Admixtures

- **True Mid-Range Performance**
  - 6 - 12% Water Reduction (in between Type A and F)
  - Slump range of 5 - 8 in.
  - Controlled setting characteristics
- **Enhanced Finishability Characteristics**
  - Lean and harsh mixtures (Manufactured sands)
  - Silica fume mixtures
  - Flatwork, curb and gutter, etc.

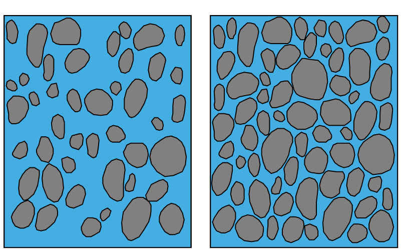
Composition of WRA's & Superplasticizers

- 1930 — Lignosulfates (WRA - Type A)
- 1950 — Hydroxycarboxylic Acid (WRA - Type A)
- 1970 — Sulfonated melamine or naphthalene formaldehyde condensates (HRWA)
- 1990
- Polycarboxylates (3rd Generation HRWA)

Synthetic materials made for use in concrete

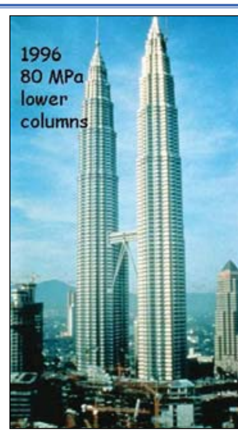
Enabled low *w/c* concretes, i.e. high strengths

High-Strength Concrete



w/c = 0.60 no SP   w/c = 0.30 + SP

Before cement hydration



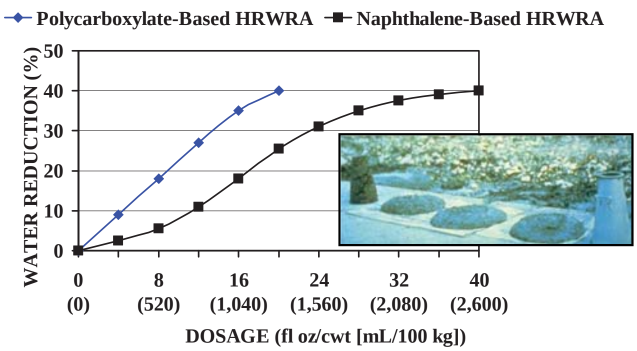
Polycarboxylate Ether-Based HRWRs

Performance Benefits:

- Works at low dosage levels
  - Much more potent than melamine- or naphthalene-based HRWR admixtures
- Can be used at relatively large amounts without causing excessive set retardation or segregation
- Linear water reduction: **20 to 40%**
- Improved slump retention

(Slide courtesy of Dr. Charles Nmai, BASF)

Polycarboxylate Ether-Based HRWRs
…Water Reduction Comparison



(Pictures courtesy of Dr. Charles Nmai, BASF)

High workability required for members that are very congested…

… flowing, self-levelling concrete, or self-consolidating concrete

Special Applications of HRWRA

- United States:
  - SCC = Self-Consolidating Concrete
- Europe and Japan:
  - SCC = Self-Compacting Concrete

ACI 237 Definition

"SCC is a **highly flowable**, **non-segregating** concrete that can spread into place, fill the formwork, and encapsulate the reinforcement **without any mechanical consolidation**."

Self-Consolidating Cocnrete

Video clip courtesy of Obayashi Corp

High-Range Water Reducing Admixtures

Potential issues that will depend on type of HRWR admixture:

- Different HRWR admixture formulations are incompatible
- High segregation potential if dosage and total water content are out of balance
- Impact on air-void system
  - Spacing and size of air voids may be altered
- Retardation potential at high dosages
  - Much less likely with polycarboxylate ether chemistries

(Slide courtesy of Dr. Charles Nmai, BASF)

Outline

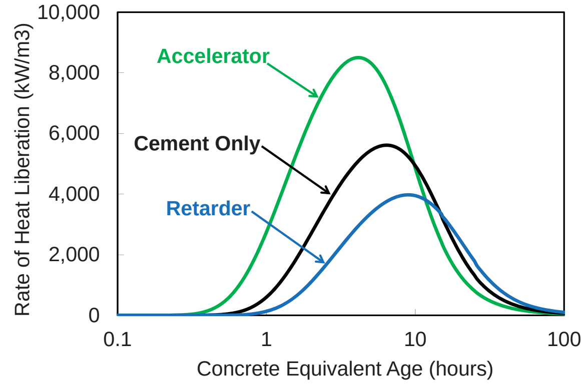
- Introduction
- Water-reducing Admixtures
- **Set-controlling Admixtures**
- Air-entraining Admixtures
- Incompatibility
- Closing Remarks

Set-Controlling Admixtures

Definition from ACI Concrete Terminology:

- **Accelerating admixture** causes an increase in the rate of hydration of the hydraulic cement and thus shortens the time of setting, increases the rate of strength development, or both
- **Retarding admixture** causes a decrease in the rate of hydration of the hydraulic cement and lengthens the time of setting

Effect of Retarders and Accelerators



(Source: Schindler, Prediction of concrete setting, RILEM Publications, 2004)

Accelerating Admixture

- Add accelerating admixtures to concrete to shorten set times and accelerating early strength development
  - Used in **cold weather** to maintain normal setting behavior and strength development
    - Construction process not slowed
    - Risk of damage due to early freezing is reduced

Behaviour without Accelerator	
Temperature	**Setting Time (approx.)**
21ºC (70ºF)	6 hours
16ºC (60ºF)	8 hours
10ºC (50ºF)	11 hours
4ºC (40ºF)	14 hours
-1ºC (30ºF)	19 hours
-7ºC (20ºF)	Concrete may freeze

Accelerating Admixture

- Add accelerating admixtures to concrete to shorten set times and accelerating early strength development
  - Used at **normal temperatures** to:
    - Increase productivity (in precast or cast-in-place)
    - Compensate for slow strength gain when pozzolans are used
    - Increase early strength in repair materials (e.g. patch repairs in pavements)

Accelerators: Use of Calcium Chloride

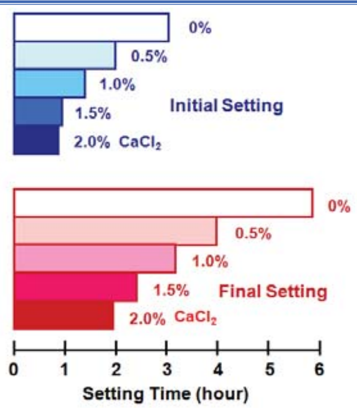
Calcium chloride ($CaCl_2$) **is the most effective and economical accelerator for concrete. However, its potential to cause corrosion of reinforcing steel limits its use.**

Types of Accelerators

- **Calcium Chloride**:
  - Regular flake (ASTM D 98 Type 1) - 77% $CaCl_2$ Min.
  - Pellet or granular (ASTM D 98 Type 2) - 94% $CaCl_2$ Min.
  - Solution (ASTM D 98) – 29% $CaCl_2$ Min.
- **Non-chloride Accelerators:**
  - Wide range of soluble inorganic salts of calcium or sodium
  - Soluble organic salts
  - Calcium formate or **calcium nitrate** are commonly used

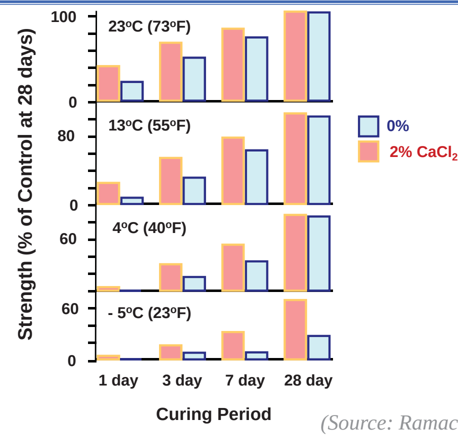
Should meet requirements for Type C or Type E in ASTM C 494

Accelerators: Effect on Concrete Properties



(Source: Ramachandran 1971)

Accelerators: Effect on Concrete Properties



(Source: Ramachandran 1971)

Retarding Admixtures

- Add retarding admixtures to concrete to delaying set times
  - Used to offset effects of hot weather on hydration
  - Enable longer haul times

Behaviour without Retarder	
Temperature	Setting Time (approx.)
38°C (100°F)	2 hours
32°C (90°F)	3 hours
27°C (80°F)	4 hours
21°C (70°F)	6 hours

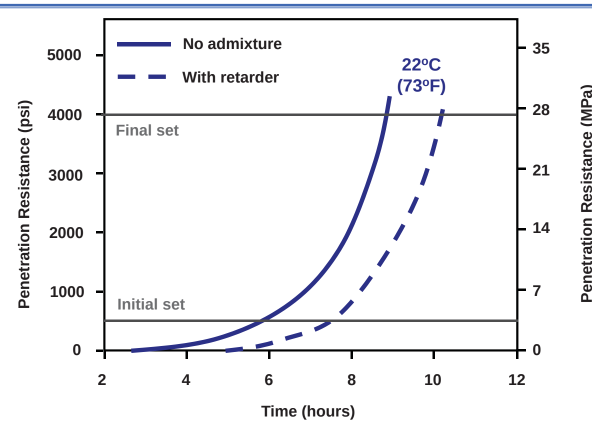
Retarding Admixtures

- Add retarding admixtures to concrete to delaying set times
  - Used to offset effects of hot weather on hydration
  - Enable longer haul times
  - Keep concrete workable during placing and finishing thereby:
    - Eliminating deflection cracks in suspended slabs
    - Eliminating cold joints in large or complicated pours
    - Extending time for finishing and jointing

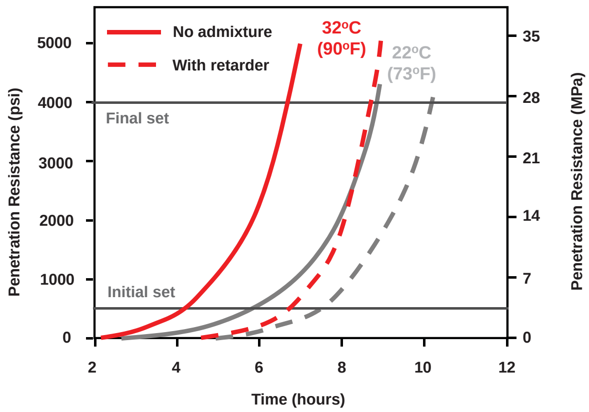
Types of Retarding Admixtures

- Lignosulfates (can serve as WRA)
- Hydroxycarboxylic acid
- Sugars
- Tartaric Acid and Salts

Retarders: Effects on Concrete Properties



Retarders: Effects on Concrete Properties

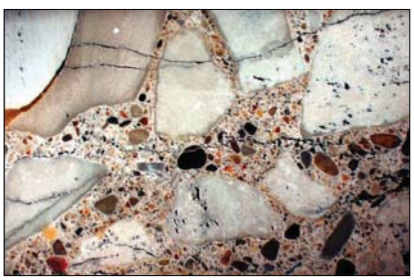


Outline

- Introduction
- Water-reducing Admixtures
- Set-controlling Admixtures
- **Air-entraining Admixtures**
- Incompatibility
- Closing Remarks

Freezing-Thawing Deterioration

- Improper air void system in concrete
- Progressive expansion of hcp due to freeze-thaw cycles

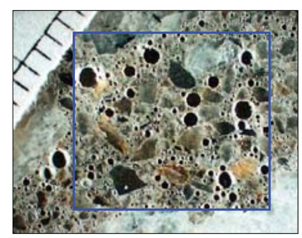



(Source: Kosmatka and Wilson 2016)

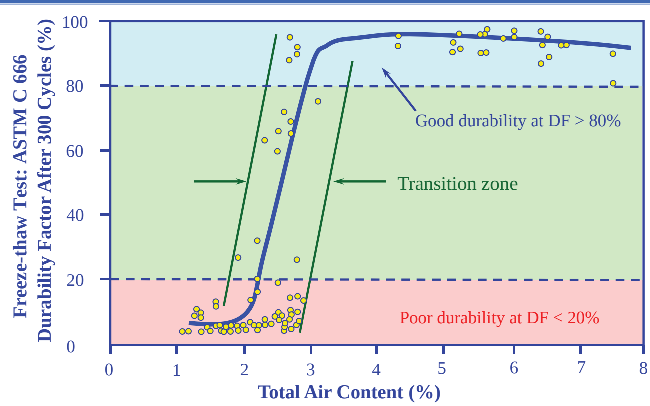
Air-Entraining Admixture (AEA)

Definition from ACI Concrete Terminology:

- An admixture that causes the development of a system of microscopic air bubbles in concrete, mortar, or cement paste during mixing, usually to increase its workability and resistance to freezing and thawing



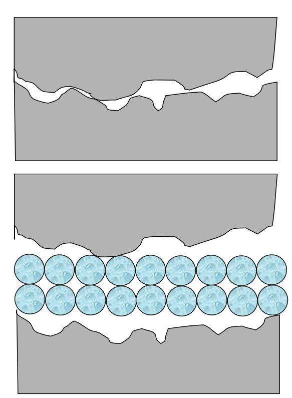
Air Entrainment Provides Freezing and Thawing Resistance to Concrete



(Adapted from Newlon and Mitchell 1994)

Air Changes Workability

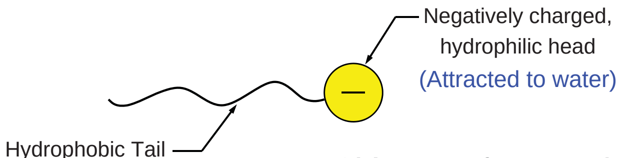
- Air-entraining admixture introduces microscopic air bubbles that act as a lubricant to reduce friction between the cement and aggregate particles
- The water demand is thus less when air-entrained concrete is used



(Image from Weiss 2006)

Mechanism of Air-Entrainment

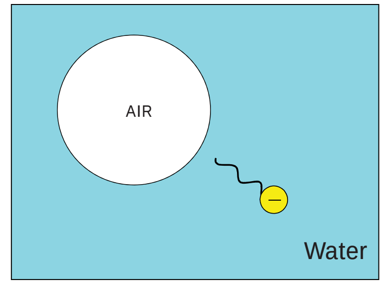
- Air-entraining admixtures are **surfactants** (surface-active agents) which concentrate at the air-water interface and reduce the surface tension, **which stabilizes the air bubbles generated during the concrete mixing process**
  - Air-entraining admixtures have a negatively charged head which is hydrophilic, and a hydrophobic tail



(Slide courtesy of Dr. M.D.A. Thomas)

Acts at Air-Water Interface

The hydrophobic end is attracted to air within bubbles while the polar end (hydrophilic) is oriented towards water



(Slide courtesy of Dr. M.D.A. Thomas with source from Lea 1998)

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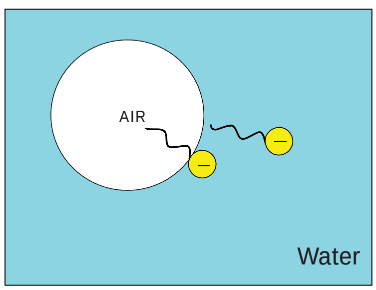

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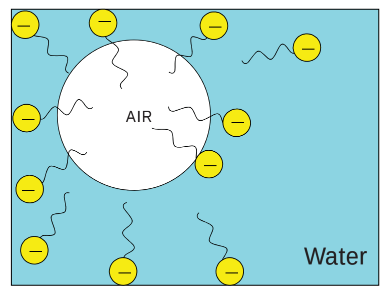
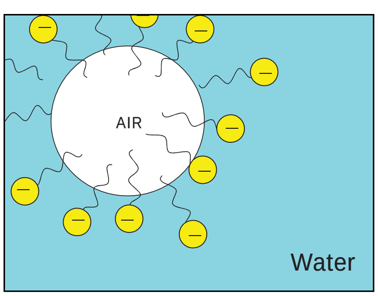


(Slide courtesy of Dr. M.D.A. Thomas with source from Lea 1998)

Acts at Air-Water Interface

More surface-active agents concentrate at the air-water interface, reducing surface tension and encouraging the formation of **charged and stable bubbles**



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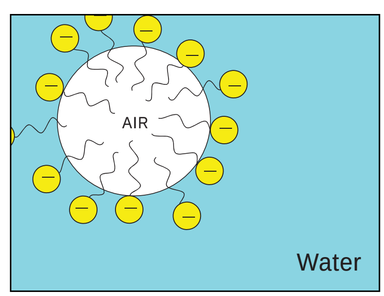

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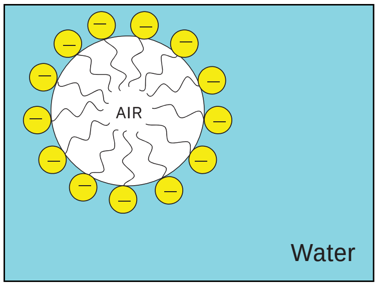

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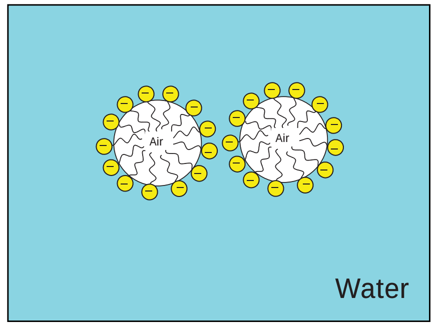
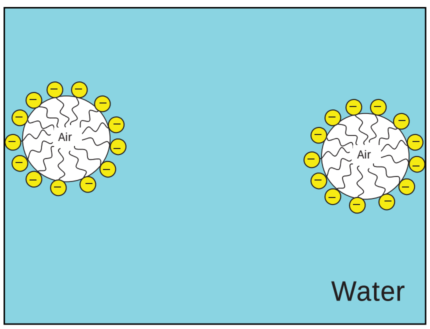
Mechanism of Air-Entrainment



The charge around each bubble leads to repulsive forces which prevent the coalescence of bubbles

(Slide courtesy of Dr. M.D.A. Thomas with source from Lea 1998)

Mechanism of Air-Entrainment



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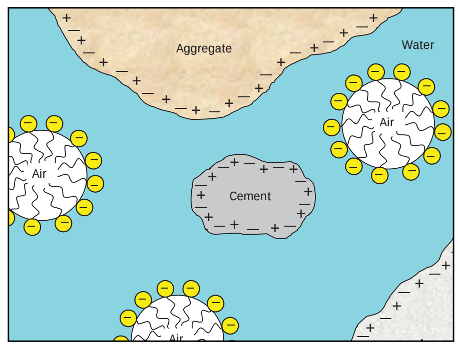
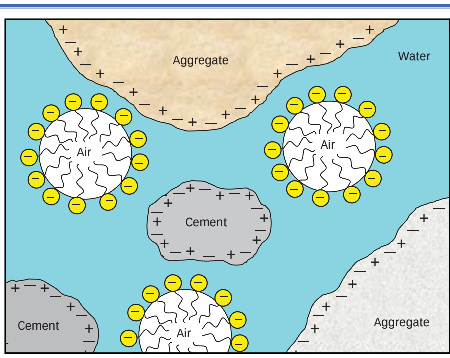
Mechanism of Air-Entrainment



The surface charge causes the air bubble to be adhered to the charged surfaces of cement and aggregate particles

(Slide courtesy of Dr. M.D.A. Thomas with source from Lea 1998)

Mechanism of Air-Entrainment



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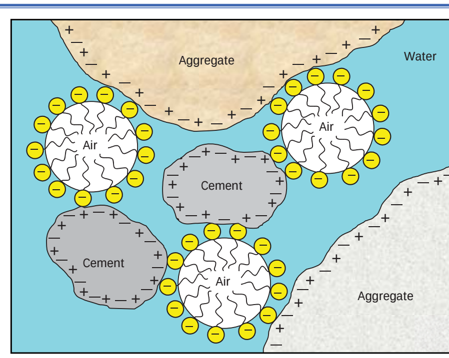
Mechanism of Air-Entrainment



Adherence of the air bubbles to the cement and aggregate particles improves the cohesion of the mix and further stabilizes the air bubbles

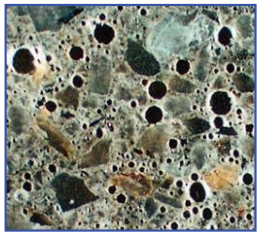
(Slide courtesy of Dr. M.D.A. Thomas with source from Lea 1998)

Air-Entraining Admixtures

Added to concrete to stabilize microscopic air bubbles (Governed by ASTM C 260)

Performance Benefits:

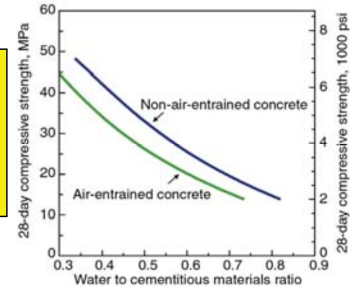
- Improved resistance to freezing and thawing
- Improved workability
- Increased slump
- Adds cohesiveness – reduced segregation risk
- Reduced bleeding
- Increased yield



Effect of Air Content on Strength

- Increase in entrapped or entrained air will increase the porosity of the hcp ⇒ *decrease* in strength

Rule of Thumb:
(Normal-Strength Concrete)
1% increase in air content, causes a ***5% reduction*** in f_c



Outline

- Introduction
- Water-reducing Admixtures
- Set-controlling Admixtures
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- **Incompatibility**
- Closing Remarks

Cement/Admixture Compatibility

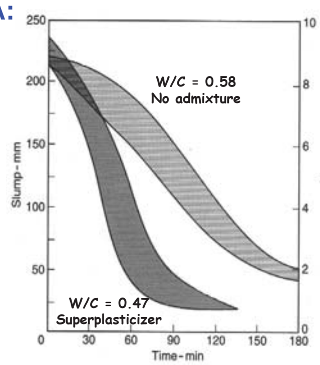
Fresh concrete problems can develop due to cement-admixture incompatibility – or incompatibility between admixtures:

- Less than expected water reduction
- Abnormal slump loss
- Less than expected retardation
- Abnormal retarded setting
- Early stiffening

Cement/Admixture Compatibility

Slump Loss with HRWRA:

- HRWRA's are only effective for a limited period before they are overwhelmed by the hydration products
- The rate of slump loss depends on:
  - Type of HRWRA
  - C_3A, SO_3 & Alkali
  - Concrete temperature
  - Cement fineness



(Source: Neville 1995)

Cement/Admixture Compatibility

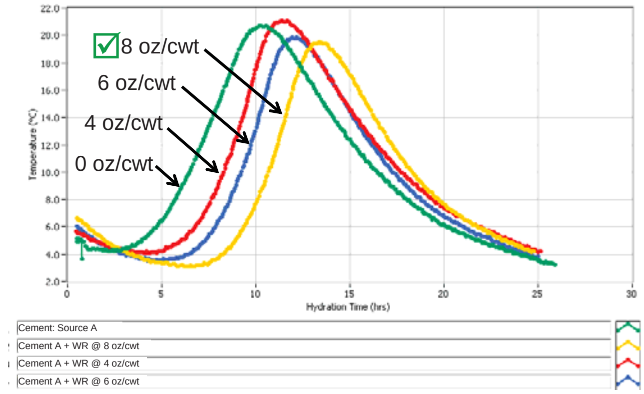
Unusually fast stiffening rate (slump loss) caused by:

- Too little admixture
- Hot weather, hot concrete components
- Very reactive C_3A or C_3S
- Particle size distribution
- Time of addition
- False set
- Flash set

Isothermal Calorimetry

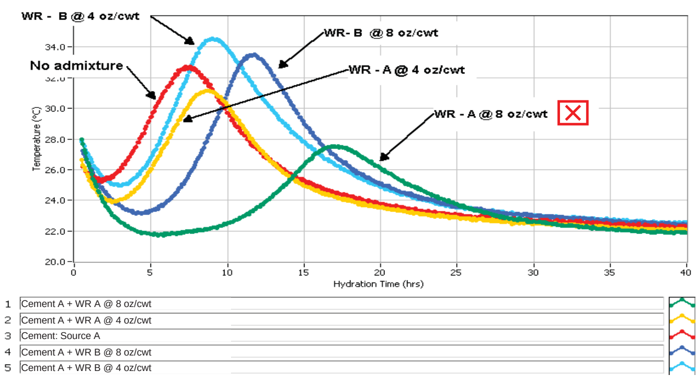
- Reaction temperature remains constant (i.e. isothermal)
- Test cement paste or mortar samples
- Effect of heat released due to reaction of cement is measured
  - Differences in hydration curves provide a quick indication of cement-admixture interaction

Cement with Retarder



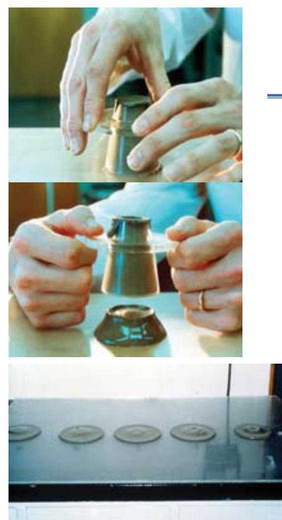
(Source: Gary Knight, Heidelberg Cement Group)

Cement WR Admixture Compatibility

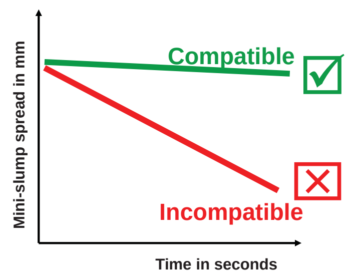


(Source: Gary Knight, Heidelberg Cement Inc.)

The Mini-Slump Test



Evaluate slump loss behaviour over time



(Adapted from Aitcin, 1998)

Avoiding Problems

- Laboratory or field trial mixtures
  - Use specific concrete components
  - Simulate field conditions (temperatures, haul time)
- Beware of abnormally low C_3A and SO_3 contents in cements used with water-reducing/set-retarding admixtures
- Monitor cement alkali content
- Adjust batching sequence
  - Delayed addition of retarders may reduce severity of set-reducing problems
  - Delayed addition may not be practical for paving, mass concrete, or precast

Outline

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Closing Remarks

Many other admixtures available:

- Hydration-Control Admixtures
- Shrinkage-Reducing Admixtures (SRA)
- Coloring Admixtures
- Corrosion Inhibitors
- Workability Agents
- Permeability-Reducing
- ASR Inhibitors
- Grouting
- Gas-forming
- Anti-Washout
- Foaming
- Pumping Aids
- Etc.

Closing Remarks

- Chemical admixtures are used to modify concrete’s freshly mixed, setting, or hardened properties
- Most modern concretes will contain chemical admixtures to engineer its performance to meet the project requirements
- Within a given classification of admixtures, there are different formulations available with varying performance

Closing Remarks

- Use of an admixture to enhance or control one property of concrete may have an (adverse) effect on another property
- Some cement-admixture or admixture-admixture combinations may be incompatible

Implementing Performance Specifications for Durability

Tara Cavalline, PhD, PE
Assistant Professor
Dept. of Engineering Technology and Construction Management
University of North Carolina at Charlotte
November 7, 2017

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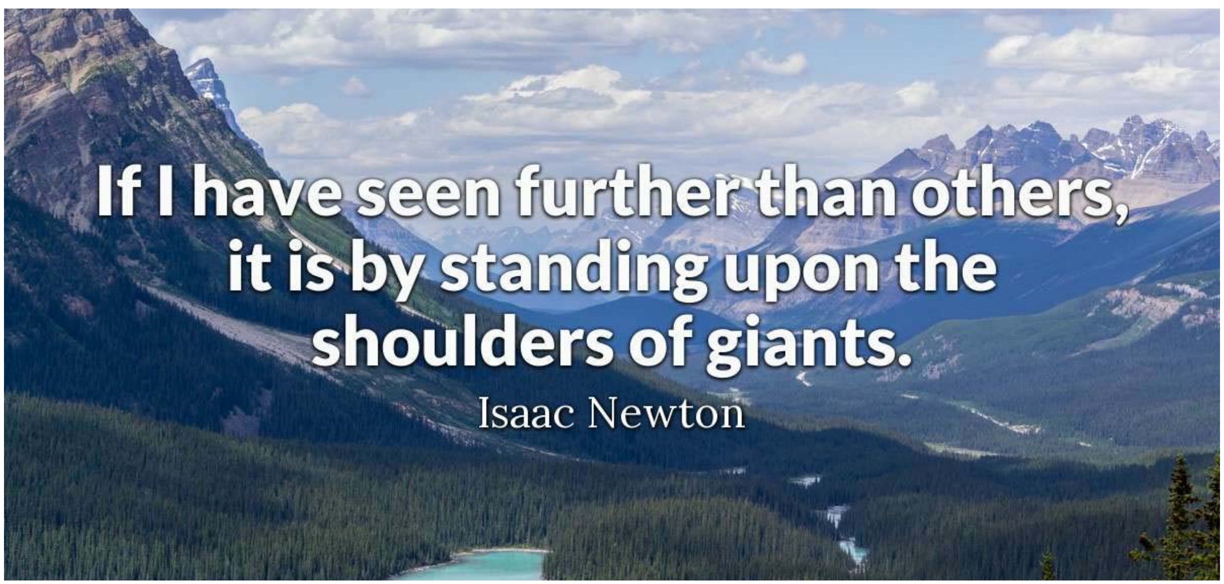
- Jason Weiss, PhD, PE – Oregon State University
- Tom Van Dam, PhD, PE - NCE



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PEM - The Path to Implementation

- What are Performance Engineered Mixtures (PEM) for concrete infrastructure?
- Why do we need to move towards PEM?
- Brief history of PEM initiative
- PEM specification basics
- Future plans for PEM - nationally
- Moving towards implementation in North Carolina

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How did we get here?

Concrete materials/mixtures have evolved slowly
BUT
construction has changed

Tests for specification and acceptance of concrete typically center around three criteria:

- Slump
- Air content
- Strength

These test results historically do not correlate well with durable performance over the service life

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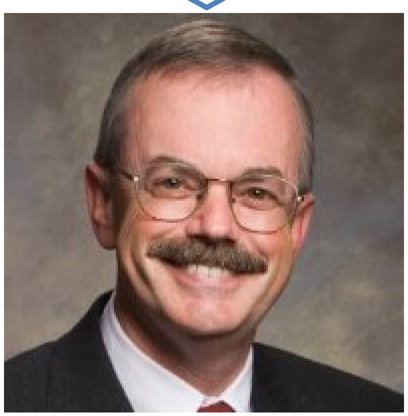
Joint issues, early age cracking, incremental cracking, cold-weather durability issues… and more

"We keep measuring the same old things, and we still get cracking and other durability problems arising."



Current specifications typically:

- Do not measure critical engineering parameters associated with durability
- Make changing materials and proportions difficult
- Result in mixtures that are often:
  - Over-cemented
  - High paste contents
- Are often built around previous failures – thereby introducing unintended consequences.

For the contractor and supplier: innovation is often stifled

Why are PEM specifications needed?

- Concrete infrastructure has not always performed as designed.
- Premature distress in concrete elements has become more severe with changes in cements, SCMs, and winter maintenance practices.
- Economic and policy environment has driven the need to shift to more durable infrastructure
  - Must reduce maintenance cost and frequency
  - Reduce replacement costs
  - MAP-21 legislation focus on performance, sustainability

PEM specifications foster:
durability, innovation, and sustainability

Progress over the last 30+ years

- Improvements in materials selection/use selection
- Better understanding of deterioration mechanisms and mitigation strategies
- New testing technologies

We have a gained a far better understanding of the:

Materials
Mixture proportions, and
Tests

required to specify and construct durable concrete.

… but specifications have not kept up.

What is Performance-Engineered Concrete?

1) Is workable / constructable
2) Provides adequate strength
3) Provides the desired durability performance

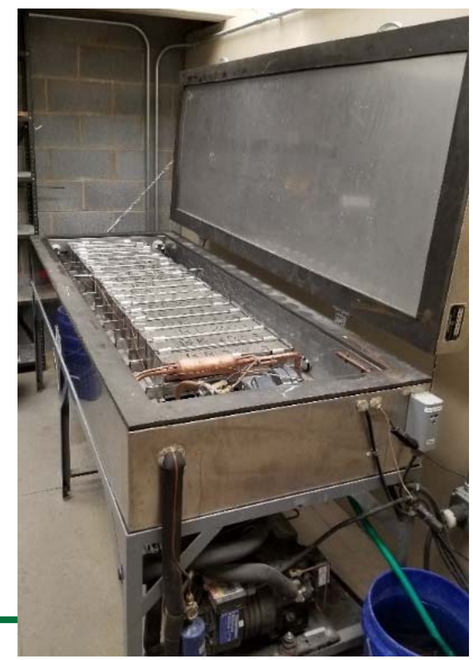
4) Achieves other desired special properties or performance requirements
   - Sustainability goals
   - Service life / maintenance goals
   - Addresses construction challenges
     - Pumpable
     - Flowable
     - Temperature issues

What does Performance-Engineered Concrete need?

Appropriate material selection/proportioning

- Appropriate cement contents
- Lower paste contents
- Use of SCMs
  - fly ash
  - portland limestone cement
  - slag
- Stable (non-reactive) aggregates
- Optimized aggregate gradation
- Materials/mixtures that provide:
  - workability/strength
  - reduced permeability
  - reduced cracking/curling
  - freeze-thaw durability

Tests for enhanced acceptance criteria



PEM Goals

PEM initiative challenges state agencies to:

- Identify the performance characteristics and properties that are desired
- Specify, measure, and accept based on these characteristics
- Measure the right things at the right times

Don't specify/test for everything – just the right things…

What performance do you need from this element?

Preventing issues, rather than spending money/efforts monitoring or addressing them

Drilled powder samples tested for chloride content

vs.

Resistivity testing for mixture acceptance

Moving towards performance specifications, an agency lets the contractor know what is needed for a particular concrete element, and allows him/her to innovate and meet the performance test requirements with minimal prescriptive direction.

Prescriptive Specifications

Sometimes called:

- methods specifications
- materials and methods specifications
- "recipe" specifications (for construction materials)

Tells contractor what to do, or how to do something

- Method specifications

Tells contractor what to use.

- Materials specifications

"Specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material." from NCHRP Synthesis 346.

Performance Specifications

Also called:

- Performance-based specifications (PBS)
- End result specifications (ERS)

Instead of telling contractor (or material supplier, etc.) how to do something or what to do, provides minimum standard of performance for completed product/service.

"Specifications that describe how the finished product should perform over time." - NCHRP Synthesis 346

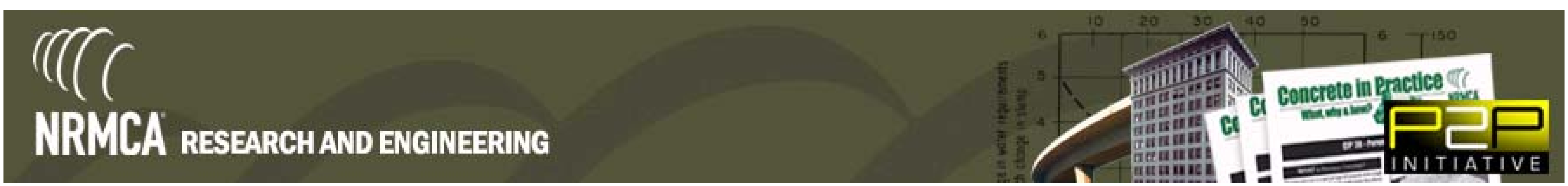
P2P Initiative

National Ready Mixed Concrete Association (NRMCA)

P2P = Prescriptive Specifications to Performance Specifications

"A shift to performance-based specifications for concrete focuses on innovation, quality and customer satisfaction."

www.nrmca.org/p2p

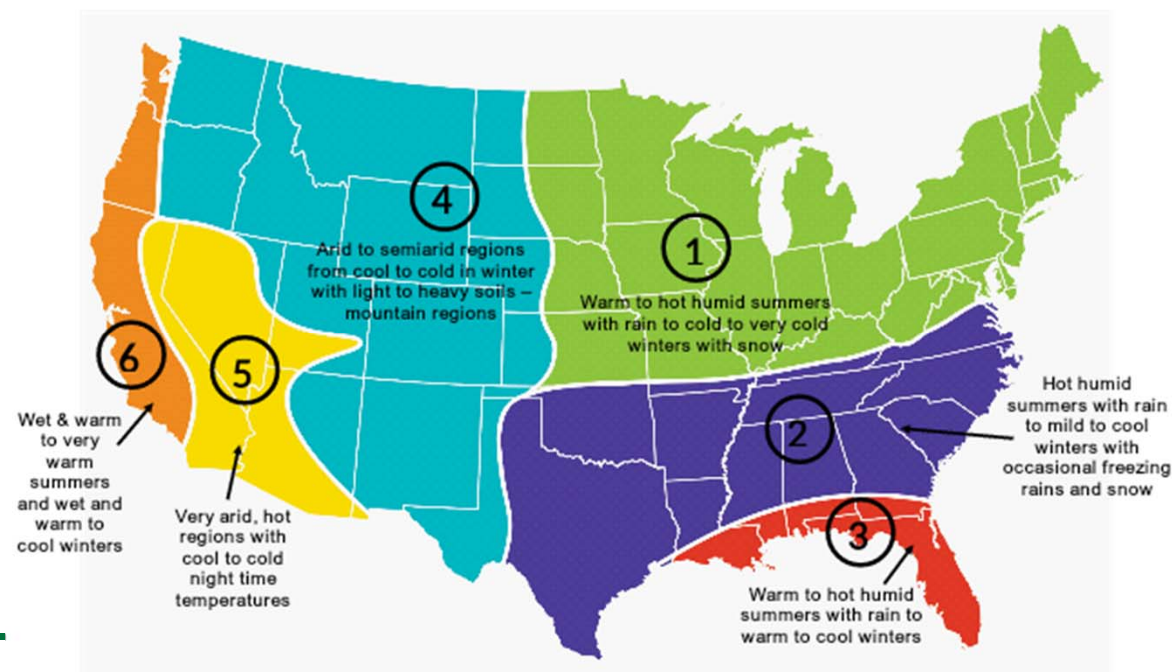


PEM Specifications for Concrete

Require the things that matter:

- fluid transport properties (low permeability/diffusion)
- aggregate stability
- strength
- freeze-thaw resistance
- resistance to shrinkage cracking
- workability

The needed performance for these characteristics varies by application...



This can seem a bit scary...

- Where would an agency even start?
- We aren't familiar with some of these tests…
- Agencies and industries will be learning at the same time…
- What will be the attitudes of the stakeholders?
- How can we balance the risk?
- Ongoing advances in research, testing, performance evaluation...

PEM - Partners in Implementation

Development Team

- Dr. Peter Taylor, Director CP Tech Center
- Cecil Jones, Diversified Engineering Services, Inc.
- Dr. Jason Weiss, Oregon State University
- Dr. Tyler Ley, Oklahoma State University
- Dr. Tom VanDam, NCE
- Mike Praul, FHWA
- Tom Cackler, CP Tech Center

PEM Expert Task Group formed in 2013 through National Concrete Consortium

Industry Participants/Reviewers

- Champion States & ACPA Chapter Execs
- ACPA National
- PCA
- NRMCA
- Others

PEM Initiative – The Vision

Concrete Mixtures that are **<u>engineered</u>** to meet or exceed the design requirement, are predictably durable, with increased sustainability.

Keys:

- Design and field control of mixtures around engineering properties related to performance
- Development of practical specifications
- Incorporating this knowledge into an implementation system (Design, Materials, Construction, Maintenance).
- Is validated and refined by performance monitoring

PEM - The Path to Implementation

What has been accomplished:

1. New testing technologies that measure properties related to critical engineering properties have been integrated into a specification framework

2. Ongoing evaluation of new test methods has been supported

3. Transportation Pooled Fund (TPF) established to assist DOTs with implementation

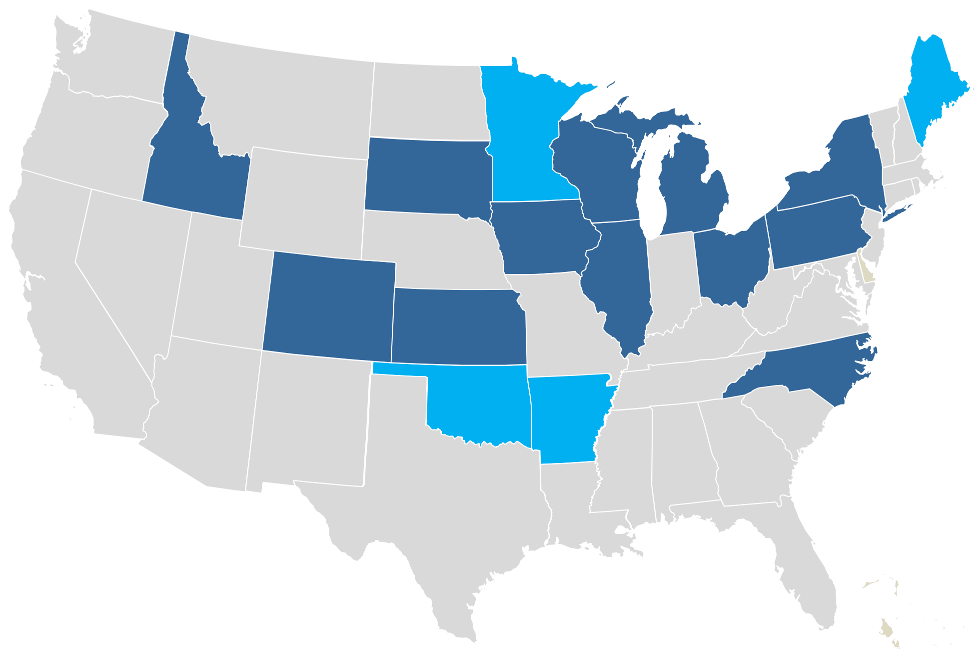
4. AASHTO voted to approve a PEM standard, serving as a guide specification for PEM

PEM Pooled Fund - TPF-5(368)
The Path to Implementation

<u>Provide technical support for performance approach to concrete</u>

- Introduce PEM and a performance approach to concrete acceptance programs
- Support PEM with Mobile Concrete Trailer
- Provide additional guidance on new PP 84 tests/implementation
- Develop quality control guidance (aimed at industry)
- Incentive Fund Program

12 States + FHWA & Industry (August 2017)



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PEM Pooled Fund Work Tasks

Phase 1

- 5 years (2017-2021)
- $3 million
  - FHWA $200k/year = $1M
  - DOTs 14@$15k/year = $1.05M
  - Industry $200k/year = $1M

- Implementing what we know:
  Education, Training & Technical Support
- Performance monitoring and specification refinement
- Measuring and relating early age concrete properties to performance

Phase 2

to support performance monitoring

- 5 years (2022-2026)
- $ TBD

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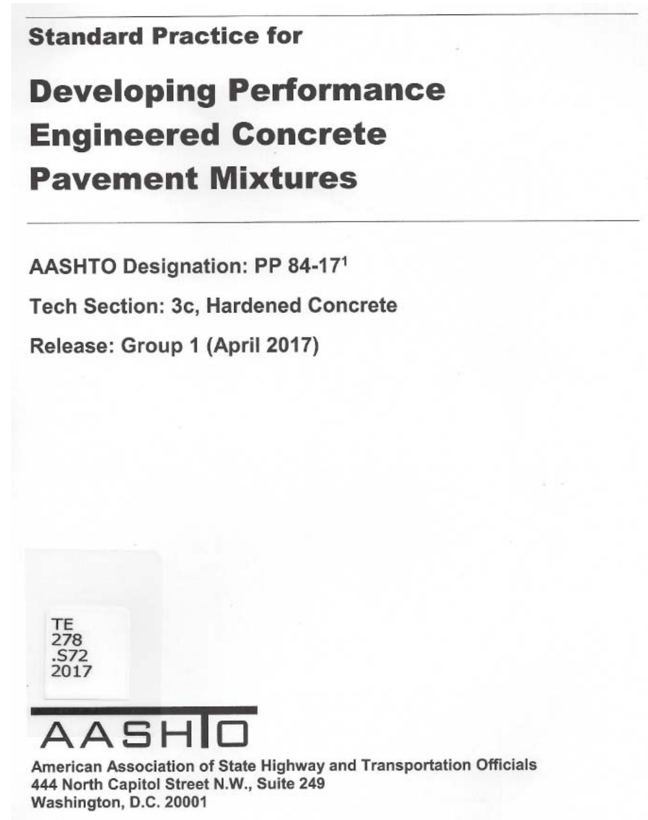
<u>AASHTO PP84-17</u> (April 2017)

Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures

- Guide Specification
- A sufficient start
- Provisional = meaning we can modify as we learn things
- Evolving as we speak...


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

Provides guidance to move towards better, more performance-related specifications

PEM starts with a Better Specification

Specification framework:

Measure the right things at the right time

- Prequalification
- Process control
- Acceptance

A "buffet" or "menu" of approaches for agency to chose from

- Intended to work for SHAs and local agencies
- Intended to respect organizational traditions while offering performance options

Table 3 – Specification Worksheet of AASHTO PP 84

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PEM Mixture Design Parameters

Test the things that matter!

- Strength
- Cracking tendency (dimensional stability)
- Freeze-Thaw durability
- Resistance to Fluid Transport
- Aggregate stability
- Workability*

<u>Performance</u> and <u>prescriptive</u> options for each, except strength

AASHTO PP84-17 Scope

- Facilitates movement toward specifying the performance characteristics – shifting responsibility and providing opportunity for innovation.

- Highlights test methods and values
- SHA traditions of using prescriptive methods respected
- Intended to provide flexibility for SHA
- Sets values at 30 years performance level
- Notes that inclusion of performance measures increases the importance of Quality Control (QC)

Specification Basics

- Specification describes process and choices
  - Includes acceptance requirements
  - Includes quality control provisions
- Requires contractor to submit a Quality Control Plan to be approved
  - Minimum requirements listed
- Provides guidance for QC
  - Requires QC testing and control charts
  - Testing targets, frequency, and action limits
  - Guidance expands on this

Afternoon QA/QC Workshop!

Various Approaches/Test Methods Included

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
6.3 Concrete Strength							
6.4 Reducing Unwanted Slab Warping and Cracking Due to Shrinkage (If Cracking is a Concern)							
6.5 Durability of Hydrated Cement Paste for Freeze-Thaw Durability							
6.6 Transport Properties							
6.7 Aggregate Stability							
6.8 Workability							

Afternoon QA/QC Workshop!

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Specification Basics - Strength

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
6.3 Concrete Strength							
6.3.1	Flexural Strength	AASHTO T 97	4.1 MPa (600 psi)	Yes	Yes	Choose either or both	---
6.3.2	Compressive Strength	AASHTO T 22	24 MPa (3500 psi)	Yes	Yes		---

Specification Basics – Warping and Cracking

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
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 $\mu\varepsilon$ (28 days)	Yes	No		Curing conditions
6.4.2.1	Unrestrained Volume Change	ASTM C157	360, 420 480 $\mu\varepsilon$ (91 days)	Yes	No		
6.4.2.2	Restrained Shrinkage	AASHTO T 334	crack free (180 days)	Yes	No		
6.4.2.3	Restrained Shrinkage	AASHTO TP XXX	σ < 60% f'r (7 days)	Yes	No		Dual ring test provisional
6.4.2.4	Probability of Cracking	Appendix X1	As specified	Yes	No		
Commentary	Quality control check	---	---	No	Yes		Variation controlled w/several measures

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Specification Basics – Paste Durability

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
6.5 Durability of Hydrated Cement Paste for Freeze-Thaw Durability							
6.5.1.1	Water to Cementitious Ratio	---	0.45	Yes	Yes	Choose Either 6.5.1.1 or 6.5.2.1	---
6.5.1.2	Fresh Air Content	AASHTO T 152, T 196, TP 118	5 to 8	Yes	Yes	Chose only one	
6.5.1.3	Fresh Air Content/SAM	AASHTO T 152, T 196, TP 118	≥ 4% Air; SAM ≤ 0.2	Yes	Yes		
6.5.2.1	Time of Critical Saturation	"Bucket Test" Specification	30	Yes	No	Choose either 6.5.1.2, 6.5.1.3, or 6.5.2.1	Variation controlled w/several measures
6.5.3.1	Deicing Salt Damage	---	35%	Yes	Yes	Choose only one	Ca/Mg Cl used?
6.5.3.2	Deicing Salt Damage	AASHTO M 224	---	Yes	Yes		Ca/Mg Cl used? Sealers
6.5.4.1	Calcium Oxychloride Limit	Test sent to AASHTO	< 0.15g CaOXY/g paste	Yes	No		Ca/Mg Cl used?

Specification Basics – Transport Properties

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
6.6 Transport Properties							
6.6.1.1	w/cm ratio	---	≤ 0.45 or ≤ 0.50	Yes	Yes		based on F/T conditions
6.6.1.2	Formation Factor	Table 1	≥ 500 or ≥ 1000	Yes	Yes	Choose only one	F/T conditions, others possible
6.6.2.1	Ionic Penetration, F Factor	Appendix X2	25 mm at 30 yr	Yes, F	Through ρ		Appendix X2 guidance

Specification Basics – Aggregate Stability

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
6.7 Aggregate Stability							
6.7.1	D-Cracking	AASHTO T 161, ASTM C 1646	---	Yes	No	---	---
6.7.2	Alkali-Aggregate Reactivity	AASHTO PP 65	----	Yes	No		---

Standard Practice for

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

AASHTO Designation: PP 65-11

AASHTO
THE VOICE OF TRANSPORTATION

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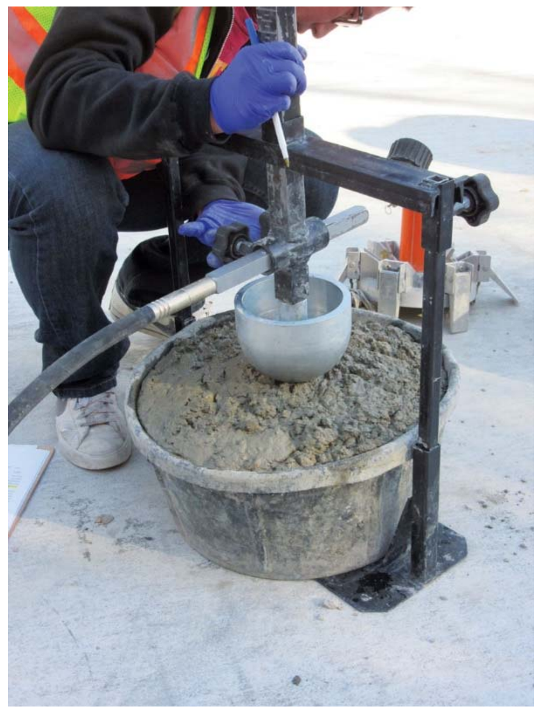
Specification Basics – Workability

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
6.8 Workability							
6.8.1	Box Test	Appendix X3	<6.25 mm, < 30% Surf. Void	---	Yes	---	---
6.8.2	Modified V-Kelly Test	Appendix X8	15-30 mm per root seconds	---	Yes		---



Hey! Where is slump?

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New and Emerging Test Methods

- Information in the Appendices
  - Cracking and volume change
  - Formation factor and pore solution resistivity
  - Box test
  - V-Kelly test
  - Bucket test
  - Transport and pore structure… and more!

Afternoon QA/QC Workshop!

along with...

- Commentary
- Detailed discussion of each section
- References for more detailed background

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PEM Recent Activity

Identifying Revisions to PP 84 for new edition

– Incorporating Industry comments
– Referencing standards (as appropriate) when approved
– Other minor modifications
– Intent was to keep stable to allow evaluations this past construction season

AASHTO PP 84-**18**

- Updated standard to Technical Session 3c in May 2017
- TS 3c ballot prior to August meeting
- Participated in August AASHTO Subcommittee on Materials meeting
- Addressed ballot comments
- Committee on Materials and Pavements (COMP) ballot closed October 20
- Passed with no negatives

AASHTO PP 84-18 coming Spring 2018

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PEM Next Steps

- Evaluate tests and guidance this construction season
- Revise this fall as needed
- Form Technical Advisory Group this fall to press forward with TPF Project
- Meeting held Oct 2017 to address 2018 changes, address COMP ballot results
- Establish a forum to better obtain all stakeholder input

- Can still join Pooled Fund...

NEW! FHWA PEM Incentive Fund Program

This PEM thing sounds GREAT!

But <u>where</u> (and how) would we even <u>start</u>?

Implementation Considerations

- What concrete performance characteristic(s) do we want to improve?
- How much pushback (or support) from the industry can we expect?
- What are people willing to try?
- If we "put a toe in the water," what would that look like?

"The agency should make the choices that best fit their situation and willingness to share risk."

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PEM for NCDOT

Motivations

- Current/former NCDOT personnel active in NCC
- Time for a change...

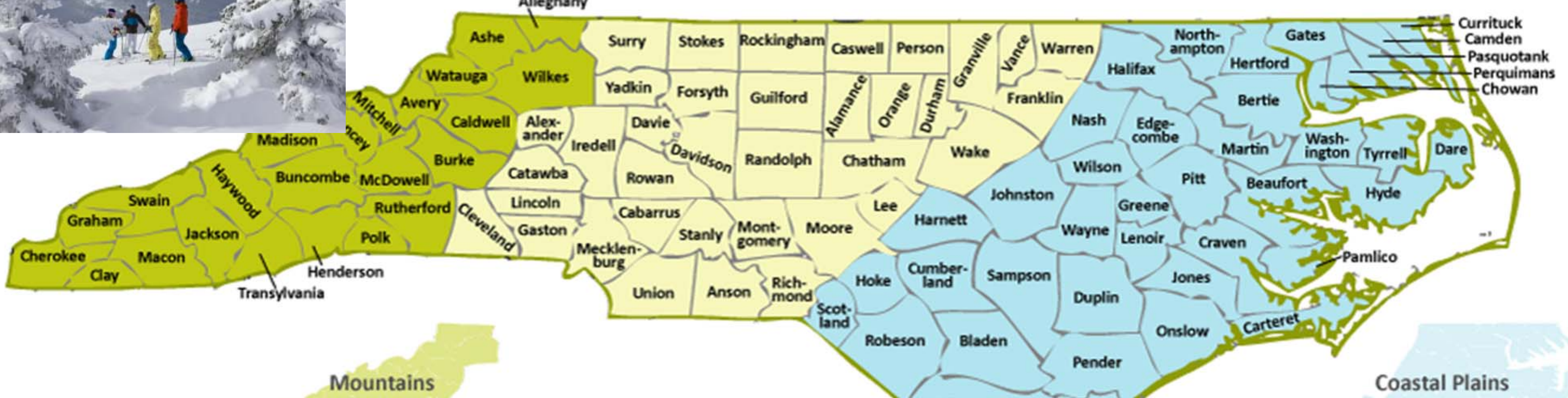
- UNC Charlotte performing research to support durability performance data on bridge/pavement concrete mixtures

- Moving towards use of portland limestone cements
- Increased use of fly ash
- Potential scarcity of fly ash
- Promising early age test results - resistivity / SAM

North Carolina – Regional Differences

Differences in:

- Materials
- Exposure conditions
- Construction



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Durable and Sustainable Concrete Through Performance Engineered Concrete Mixtures

NCDOT Research Project 2018-14

Project Kick-off Meeting

October 6, 2017

Tara Cavalline, Brett Tempest

Robert (Blake) Biggers, Ross Newsome, Austin Lukavsky

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Emerging QA/QC testing technologies utilized in AASHTO PP 84-17 show promise when used as part of previous research projects

- Field studies – decks
- Lab studies
  - MEPDG inputs (pavements)
  - Internal curing (decks/pavements)
- Technical Assistance Projects
- Surface resistivity, SAM, restrained cracking

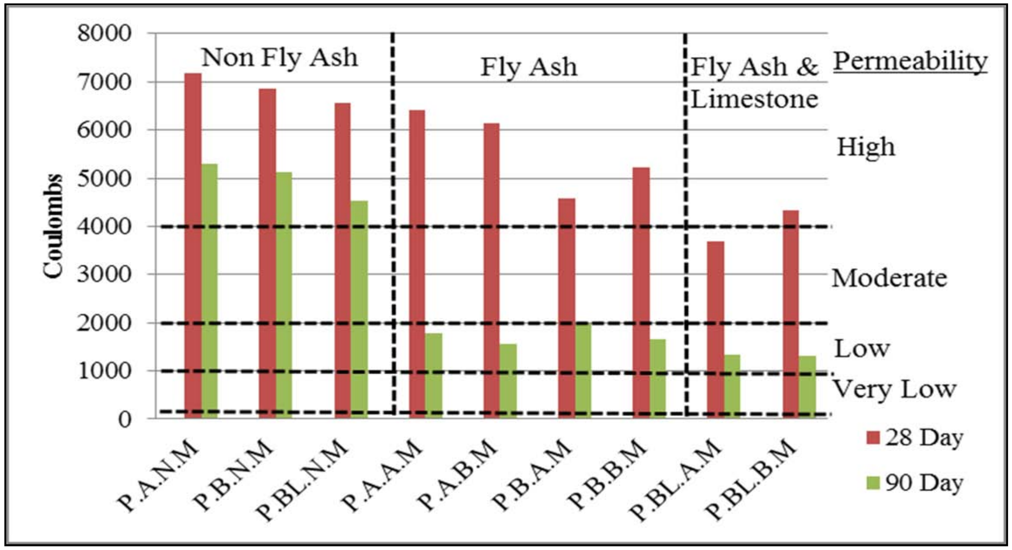
Current specifications allow binary and ternary cement blends

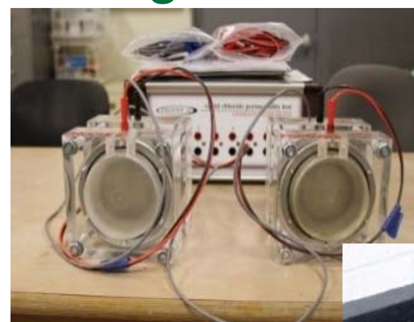
- Fly ash, slag, portland limestone cements, etc.
- Benefits of fly ash / PLC mixtures confirmed in RP 2015-03
- Additional work needed to optimize these blends

Improved Durability

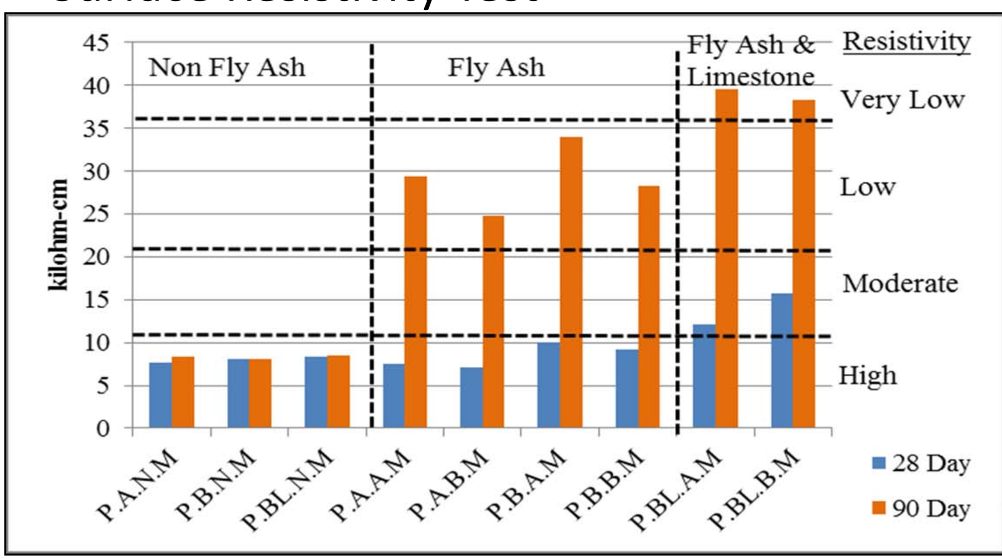
Can be achieved with SCMs and measured with rapid early-age testing technologies...

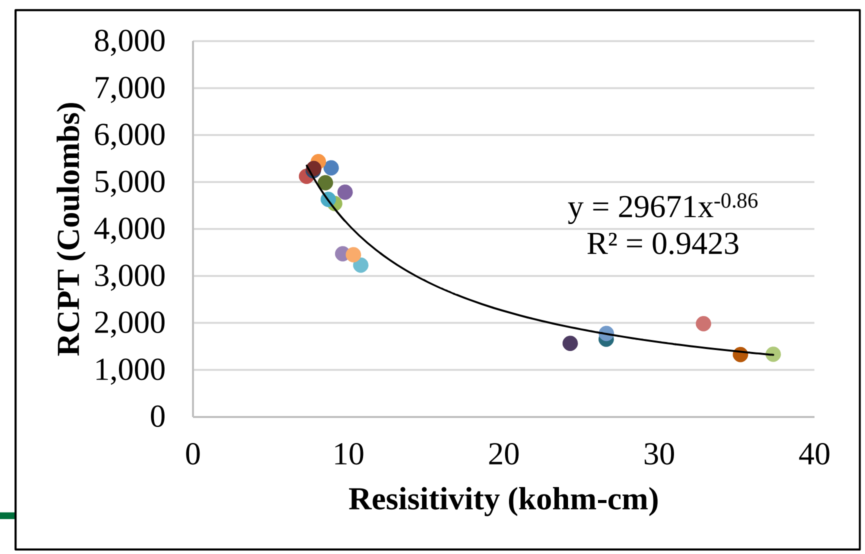
Rapid Chloride Permeability Test





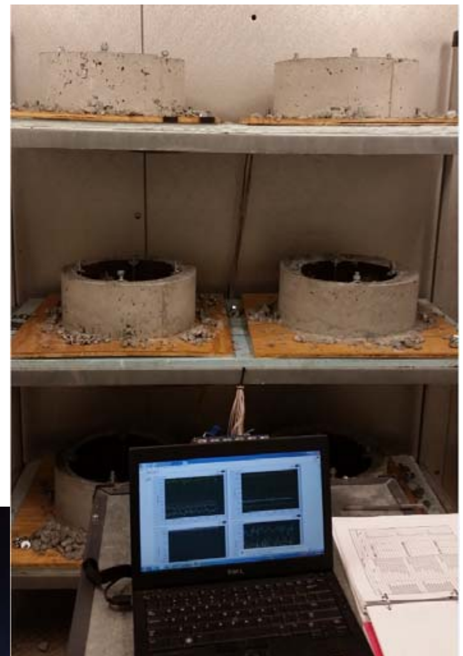
Surface Resistivity Test

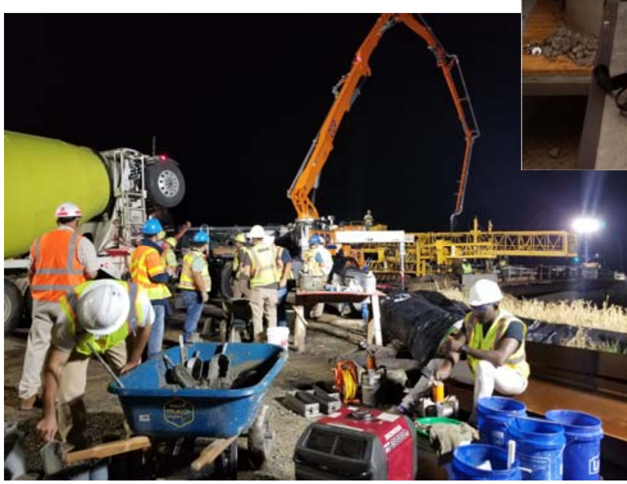


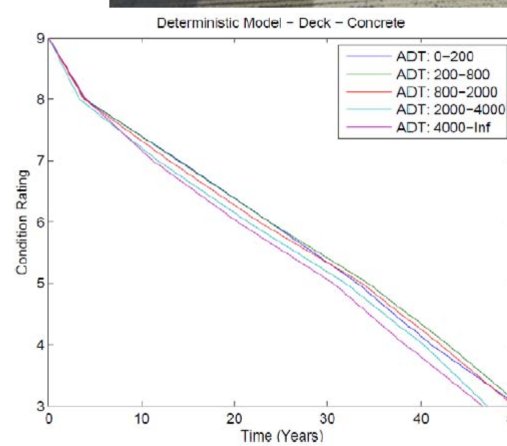


Leveraging data from previous research to support PEM

Laboratory and field – what do we already know?







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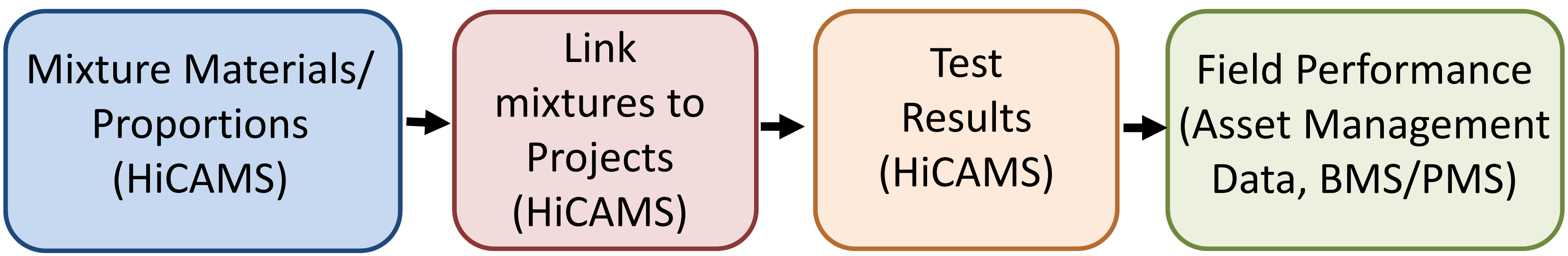
Task 1: Data Analysis

- Identify trends in materials and proportions, and link to unacceptable, acceptable, and excellent QA/QC test performance

- Correlate mixture characteristics and QA/QC test results with observed condition data, if possible



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What concrete are we placing and how is it doing?

Approved mixtures database: 17+ years (33,000+ mixtures)

- Decision to focus on Class A/AA (structural) and pavement concrete
- Possibly precast/prestressed

Early age test data:

- Strength
- Air content
- Slump

Asset management databases:

- Pavement management system (PMS) – XXX years of condition data
- Bridge Management System (BMS) – 35 years of NBI inspection data (plus some additional), 2 years of element-level data

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Data Analysis – Goals and Challenges

Key parameters of interest:

- Paste volume and cement content
- Confirm performance improvement from SCMs
- Good actors/bad actors

Link mixture characteristics and early age test results to good/acceptable/poor performance

Challenges:

- Multiple approved mixtures for same project
- Linking projects to asset management system data
  - structure number, roadway segment
- Data quality

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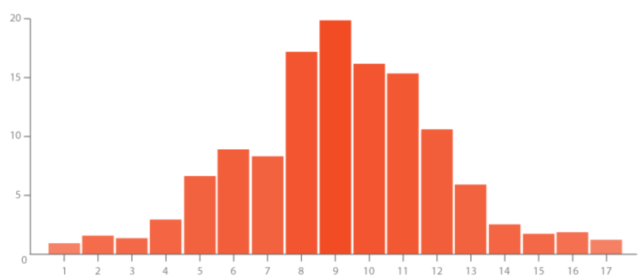
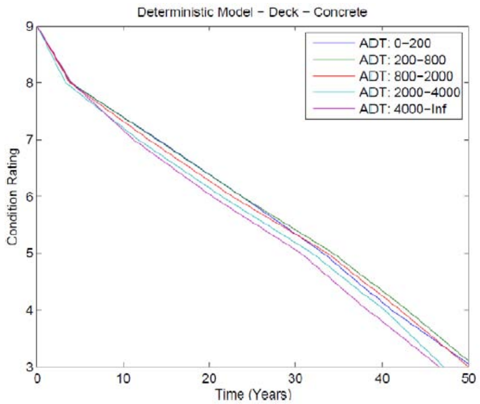
Data Analysis – Goals and Challenges

Identifying trends will:

- Identify performance/prescriptive measures to include in new PEM specification
- Help justify decision to move towards PEM to stakeholders
- Help increase stakeholder buy-in
- Guide decisions on pilot project(s) for shadow testing or implementation
- Guide development of the laboratory program



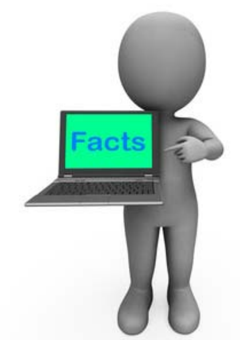


Pairing Data Analysis Results with Agency Input

Identify performance criteria, prescriptive measures, and tests of interest from AASHTO PP 84-17 specification:

> "What do you want concrete for bridges/pavements to do? What is measured gets managed..."

- Steering and Implementation committee input
- Surveys of key personnel
  - particularly on construction side
- Workshop through FHWA Implementation Fund Program



Task 2: Laboratory Testing/Evaluation

1) Establish performance-related criteria using several rapid, early age QA/QC tests to assess durability currently of interest to NCDOT.

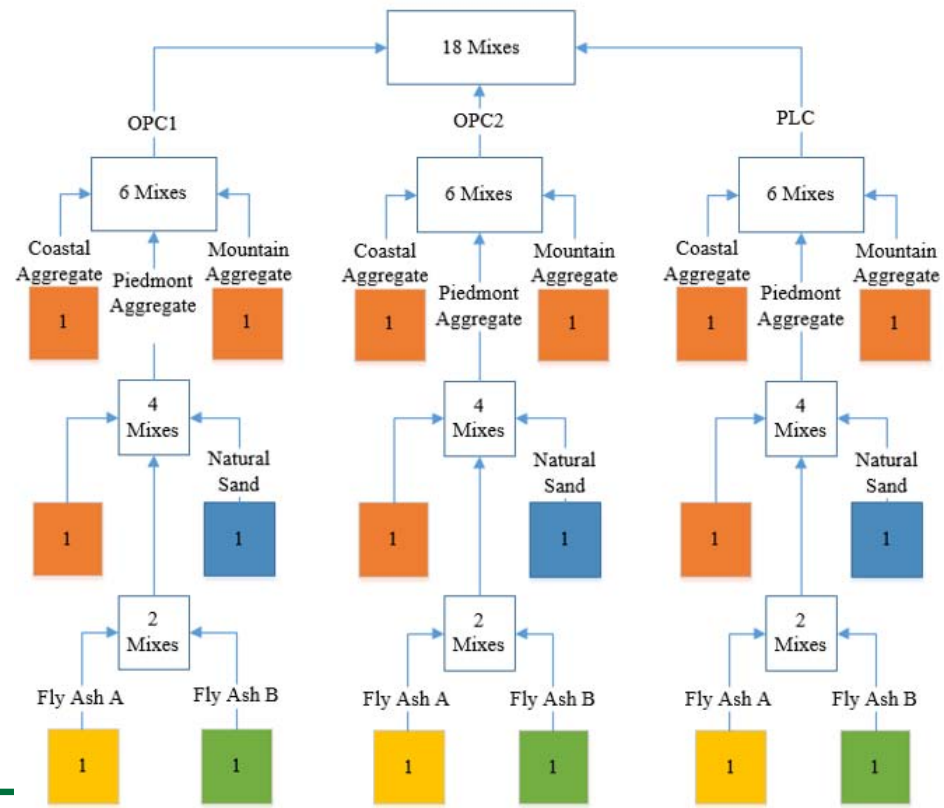
2) Produce additional performance data on concrete containing PLC and fly ash

   – better understanding the potential enhanced durability/economy
   – provide additional justification for use.

Task 2: Laboratory Testing/Evaluation

- Mixture matrix will be developed based on data analysis findings and NCDOT preferences

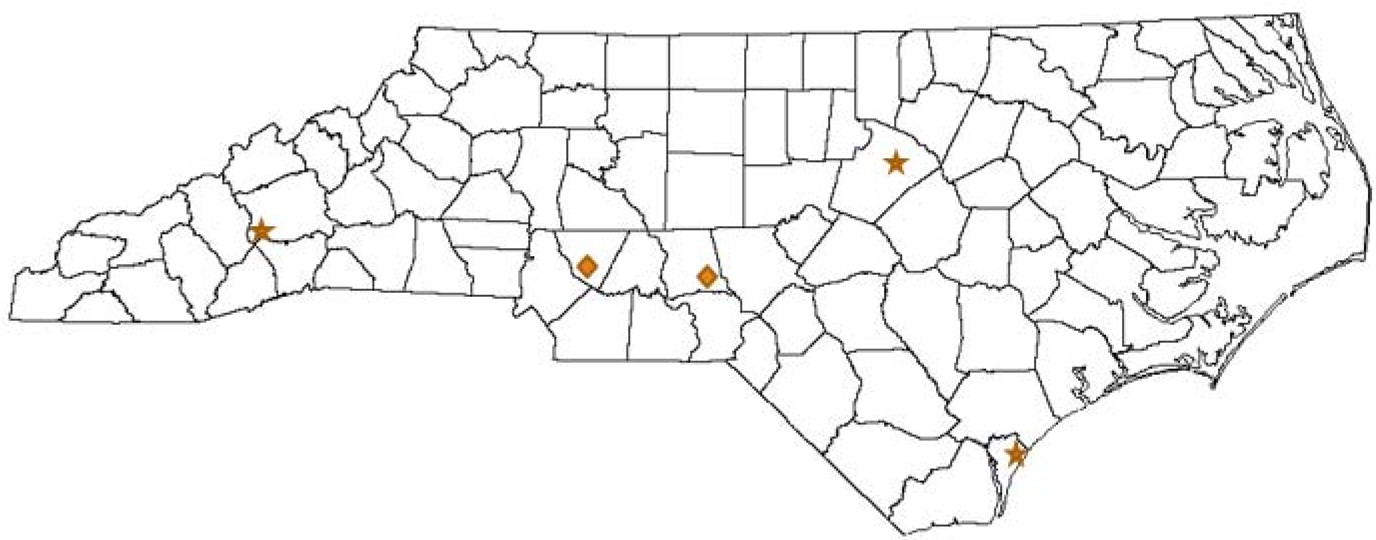
- Leverage results of previous and ongoing NCDOT research projects with new targeted test data to support establishment of QA/QC criteria for the targeted technologies.
  - Surface resistivity meter
  - SAM
  - Workability tests



Task 2: Laboratory Testing/Evaluation

Consistency in materials and suppliers can be maintained:

- Type I/II cement from SC plant, PLC produced at same plant
- Piedmont coarse aggregate, natural and/or manufactured sand
- Fly ash from same sources



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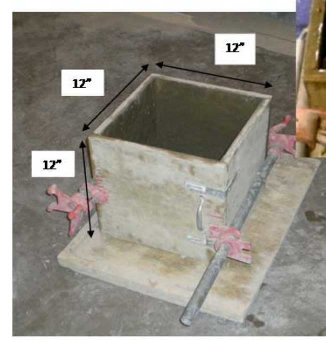
Testing Program

	Test	Method	
Fresh Concrete Properties	Fresh density (unit weight)	ASTM C138	
	Slump	ASTM C143	
	Air content	ASTM C231	
	SAM Number	AASHTO TP 118	
	Box Test	Method by Cook et al. (2014)	



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	Test	Method
Hardened Concrete Properties and Durability Performance Evaluation	Compressive strength	ASTM C39
	Modulus of rupture	ASTM C78
	Modulus of elasticity	ASTM C469
	Freezing and thawing resistance	ASTM C666
	Rapid Chloride Permeability Test	ASTM C1202
	Surface resistivity	AASHTO TP95-11
	Shrinkage	ASTM C157
	Cracking potential	AASHTO T334 or ASTM C1581

Task 3: Development of a "roadmap" towards a performance-engineered concrete specification

Goals:

1) Recommend performance criteria for use:
   - targeted technologies (surface resistivity, SAM, workability, etc.) and
   - prescriptive performance measures (w/cm, paste content, etc.)

2) Outline a "roadmap" for additional tasks recommended to facilitate a move towards a performance-engineered concrete specification.

3) Develop a project special provision document for use on one or more pilot projects

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FHWA PEM Incentive Fund Program

- Available to pooled fund participating states
- Must include mainline paving projects
- $40,000 for two or more new tests in the mix design/approval process (shadow testing acceptable)
- $20,000 for one or more new tests in the acceptance process (shadow testing acceptable)
- $20,000 for requiring an "enhanced" QC Plan from the contractor
- $20,000 for requiring the use of control charts
- Report required within 4 months of construction

- National announcement through Divisions soon

See Mike Praul!
Afternoon QA/QC
Workshop!

U.S. Department of Transportation
Federal Highway Administration

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Synergies between NCDOT RP 2018-14 and FHWA Incentive Fund Program

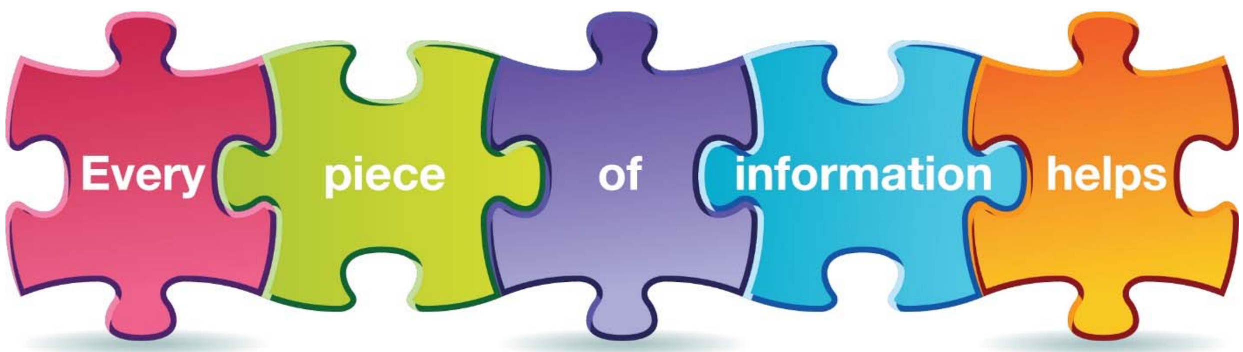
- Training and technology transfer
  - Training with new equipment
  - Participation in implementation workshop
- Assistance in identification of pilot project(s) for shadow testing with new equipment
- Use of data from shadow projects to supplement RP 2018-14
- Assistance with documentation and reporting

Anticipated Research Products

- Analysis of the characteristics of currently utilized and historically utilized concrete mixtures

→ trends linked to good, acceptable, and poor performance.

- Data to support movement towards PEM for
  - Test data on typical conventional highway concrete mixtures
  - Additional PLC and PLC/fly ash concrete blends



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Anticipated Research Products

- Suggested performance criteria for the targeted technologies
  - surface resistivity
  - SAM
  - workability
  - Some prescriptive specification measures
    - such as w/cm ratio or paste content)

- Provisional specification or project special provisions document

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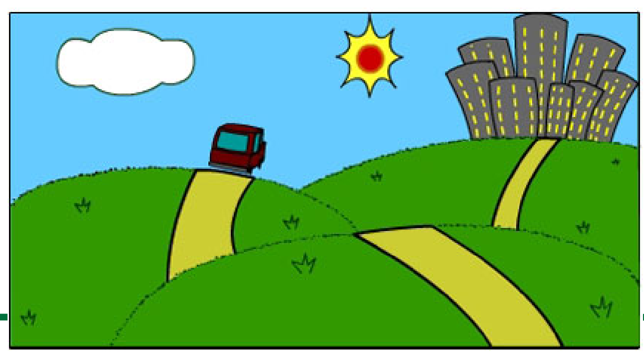
Closing Thoughts

- Movement towards PEM will help us specify and construct the infrastructure we need for the 21st century and beyond.

PEM Initiative:
Coordinated effort to provide guidance and tools to states and industry to advance concrete Quality Assurance programs in the direction of performance.

- Each agency will have its own path to implementation
  - North Carolina movement towards PEM will build on existing knowledge
  - Inform data-driven decisions on feasible, justifiable movements towards PEM
  - Leveraging state-funded research with participation in FHWA Pooled Fund



Concrete Mixture Design for Pavements and Bridge Decks

Tyler Ley, Daniel Cook,
Nick Seader, Ghazal Sokhansefat
Ashkan Ghaeezadeh, Bruce Russell

Acknowledgements

- FHWA Highways for Life
- Oklahoma Department of Transportation (ODOT)
- Oklahoma Transportation Center
- CP Tech Center
- Trinity Construction
- Dolese Bros Company
- Martin- Marietta
- Arkhola Sand and Gravel
- Central Plains Cement

Outline

- Introduction
- Workability Tests
- *Tarantula Curve!*
- Why?
- Field Performance
- Conclusions

Components of a concrete mixture

Aggregate control

Aggregates make up 70% to 80% of the volume of a concrete mixture.

If you ever hope to have control over the quality of your concrete then you need to understand your aggregates.

Aggregate control

The following mixtures have the same amount of rock, sand, cement, and water.

However the gradations of the aggregates are different for each mixture.

A gradation is the size distribution of the rock and sand.

Deficient Fine Sand

High Intermediate

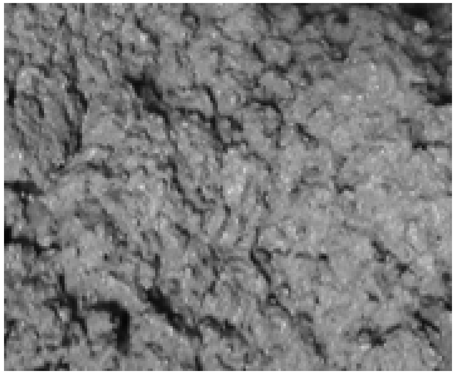
Just right…

Excessive fine sand

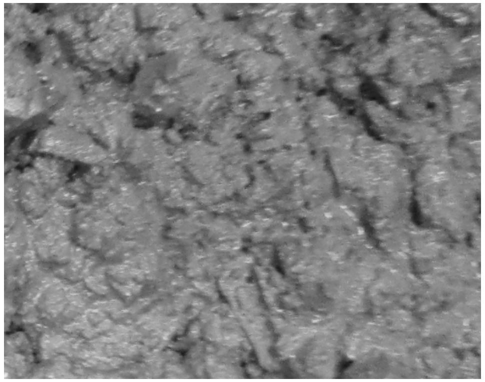
High Coarse

Deficient Fine Sand

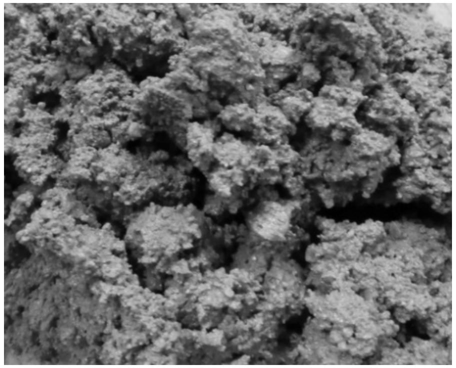
Excessive Intermediate



Just right…

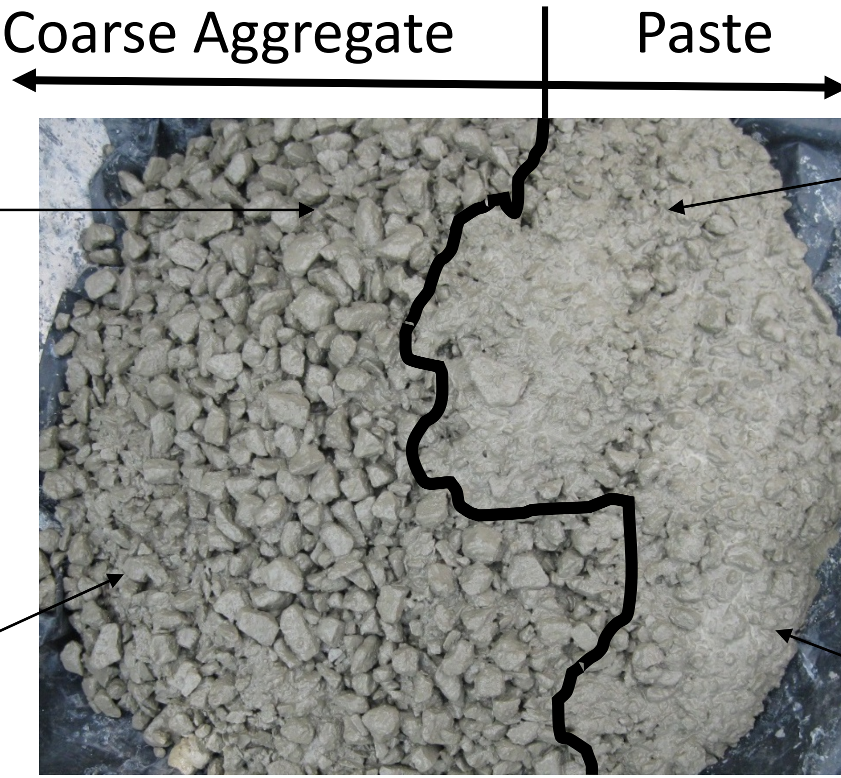


Excessive Fine Sand



Excessive Coarse

Lack of Cohesion aka Segregation



Why would you control aggregates?

Reduce cost

Improve strength

Improve durability

Improve sustainability

Control over your mixtures

Overview of the Research

- Use a suite of tests to evaluate how aggregate gradation impacts the practical workability properties of concrete.
- Provide simple tools to help you design and troubleshoot your concrete mixtures.

- We will present data for mixtures from a wide range of concretes
  - Slip formed to flowable concrete
  - Slump from 0” to 8”

Research by Dan Cook, PhD

Overview of tests

- Useful workability tests should measure the practical workability of concrete, such as:

  - Can we **place** it?
  - Can we **drag** it?
  - Can we **pump** it?
  - How does it **vibrate**?
  - Can we **finish** it?

Can it be used in the field?

Workability Tests

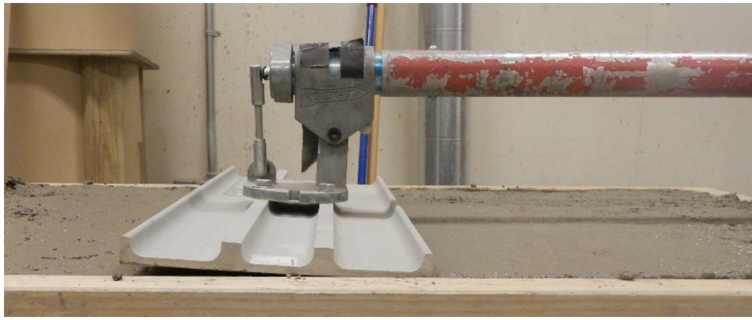
- **Slump**
- **The Box Test**
- **ICAR Rheometer**
- **Visual Observation**
- **The Float Test**
- **Use in a Pump**

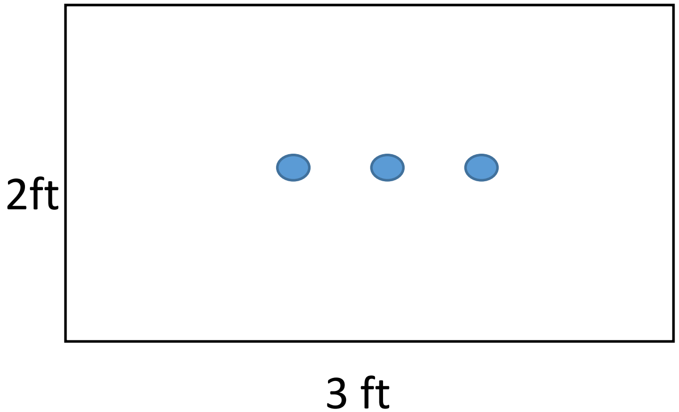
The Float Test

Evaluates the surface finish of a mixture.

Steps:

1. Place concrete in 3’ x 2’ x 3” forms and strike concrete
2. Create 3 known 1” diameter and 1” deep holes
3. Move bull-float at a fixed angle over surface at a constant speed
4. Measure number of passes to:
   -close the 3 holes
   -create a smooth finish





1. Place and Level Concrete

2. Create Three Holes

Place Template

Create Holes

3. Float Surface

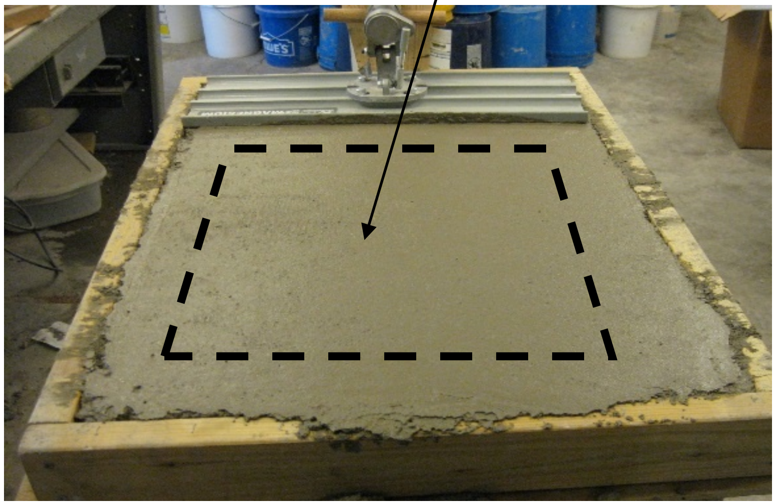
- The sides of the form are marked and a metronome is used to help the operator move at a constant rate.

The float is trimmed to only ride on the concrete

The yolk keeps the angle constant

Evaluate only this area

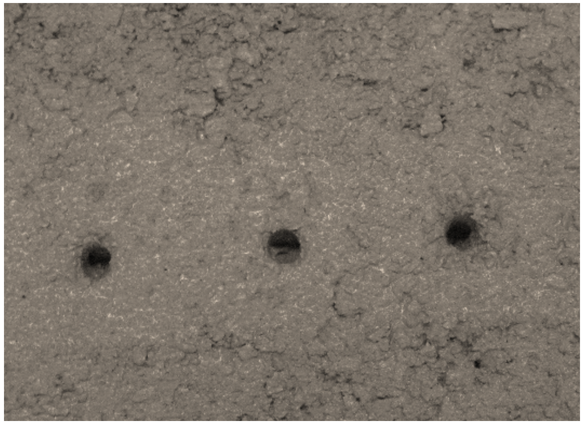
First Pass with Bull Float



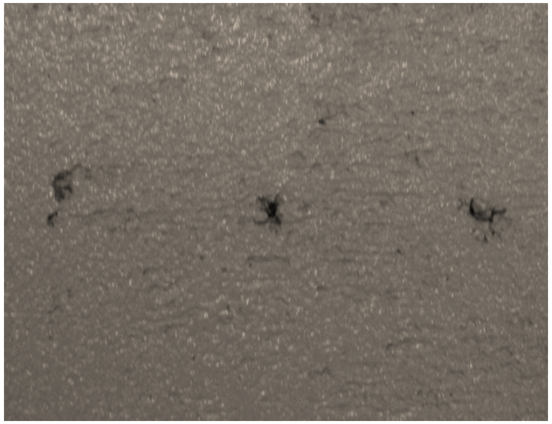
Last Pass with Bull Float

Example of Holes Closing

0 Passes



2 Passes

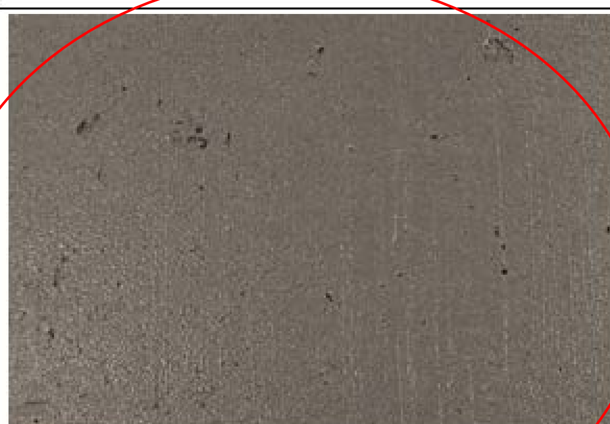


4 Passes

The Float Test

	
4	**3**
Over 50% of area was textured	30 to 50% of area was textured
	
2	**1**
10 to 30% of area was textured	Less than 10% of area was textured

The Float Test

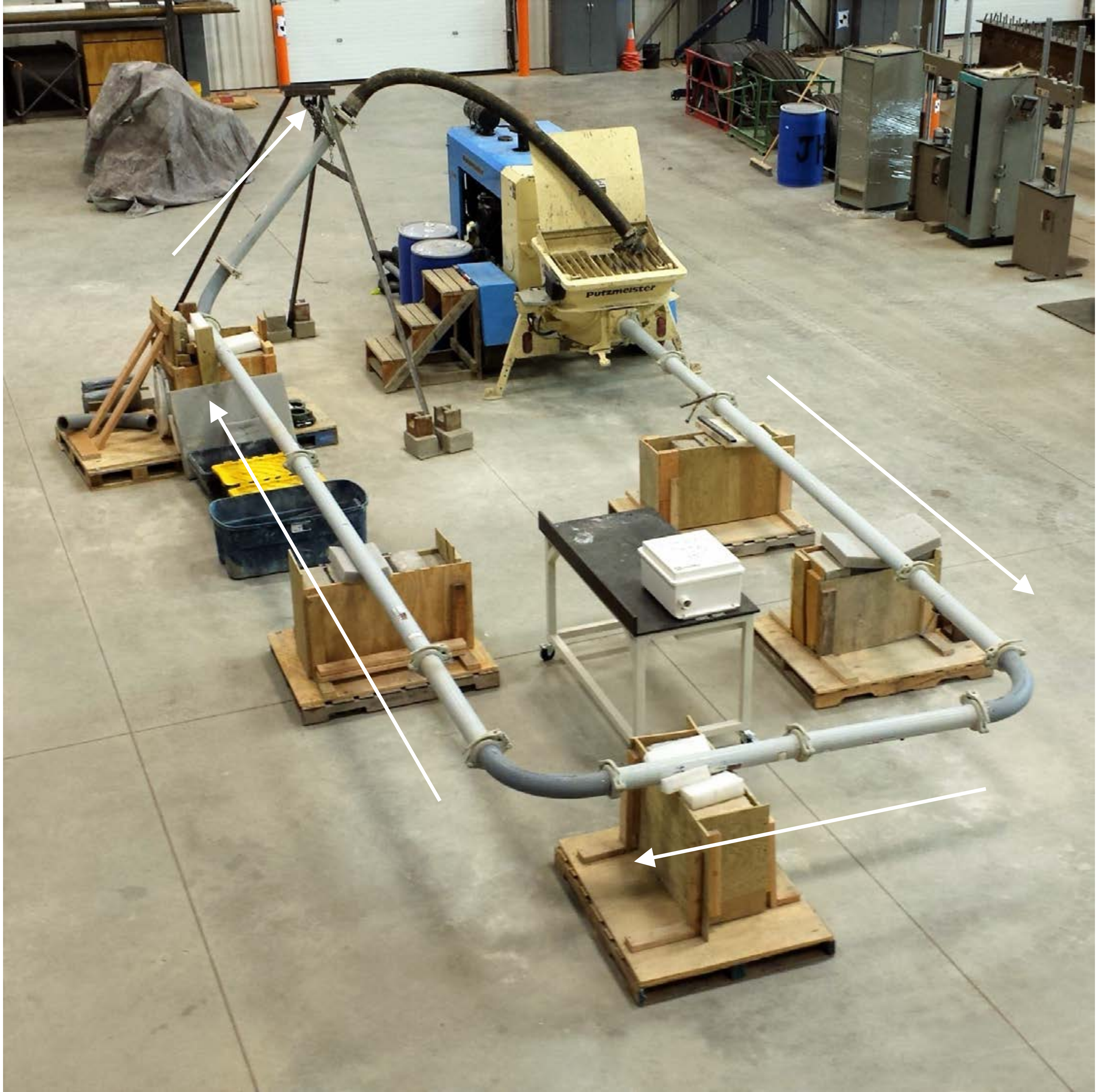
	
4	**3**
Over 50% of area was textured	30 to 50% of area was textured
	
2	**1**
10 to 30% of area was textured	Less than 10% of area was textured

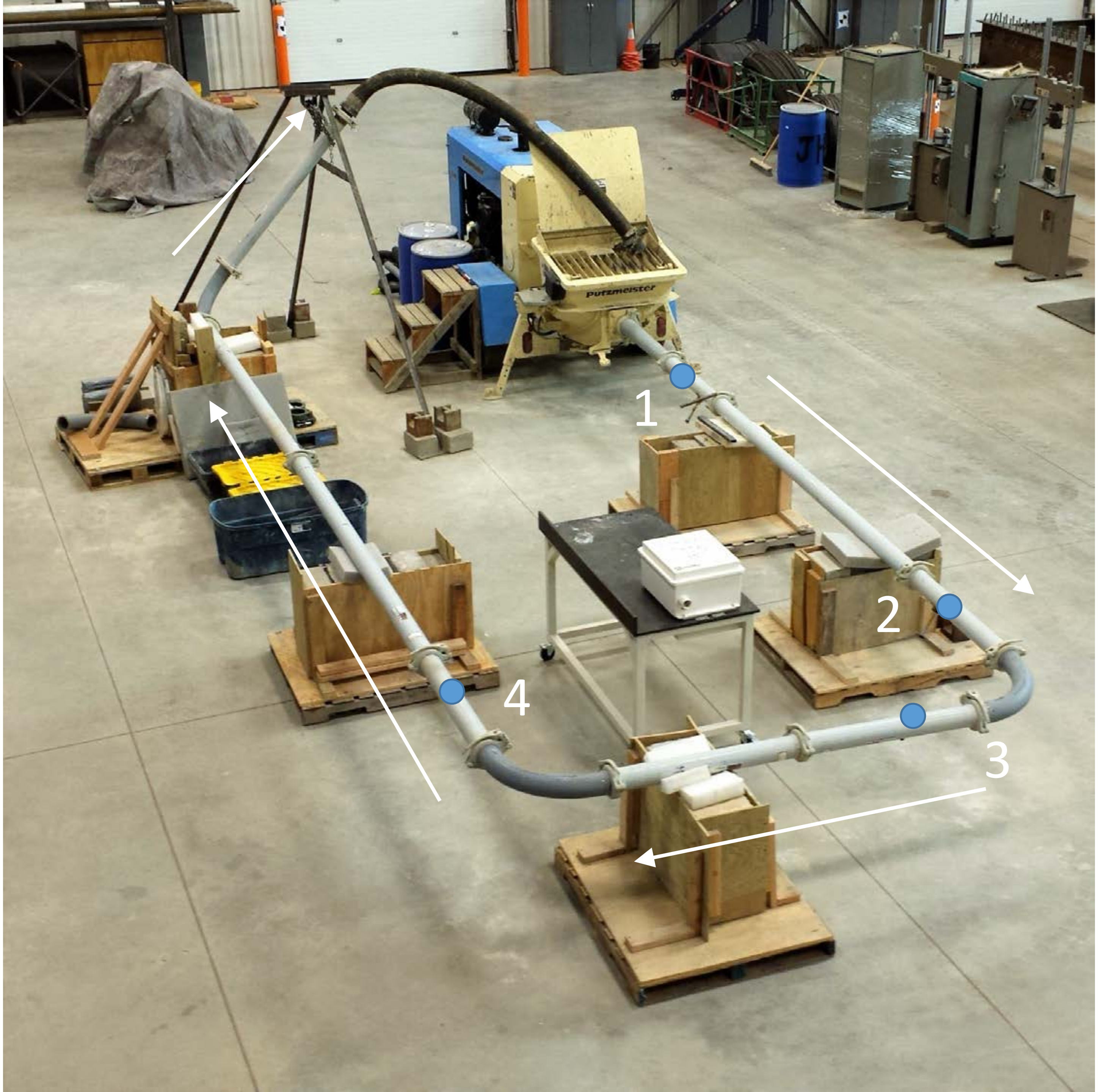
Evaluation with a concrete pump

Concrete Pump Limit States

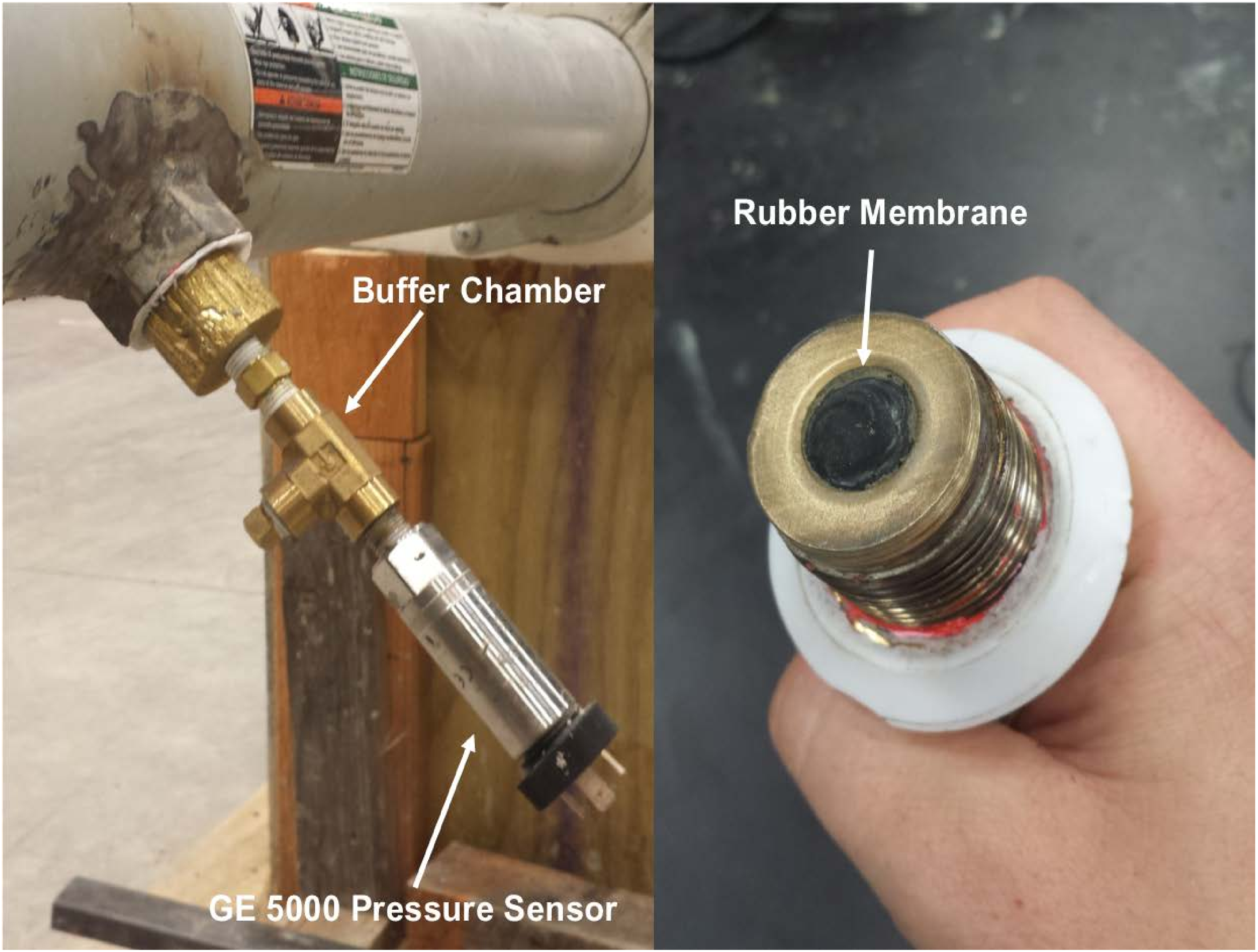
- Force needed is too high
  - Friction between pipe and concrete
  - Concrete itself resists flow
- Mixture segregates while pumping
  - Gradual segregation causes pipe pressures to increase until the pump jams
  - Sudden segregation causes very high and erratic pressures in the pipe

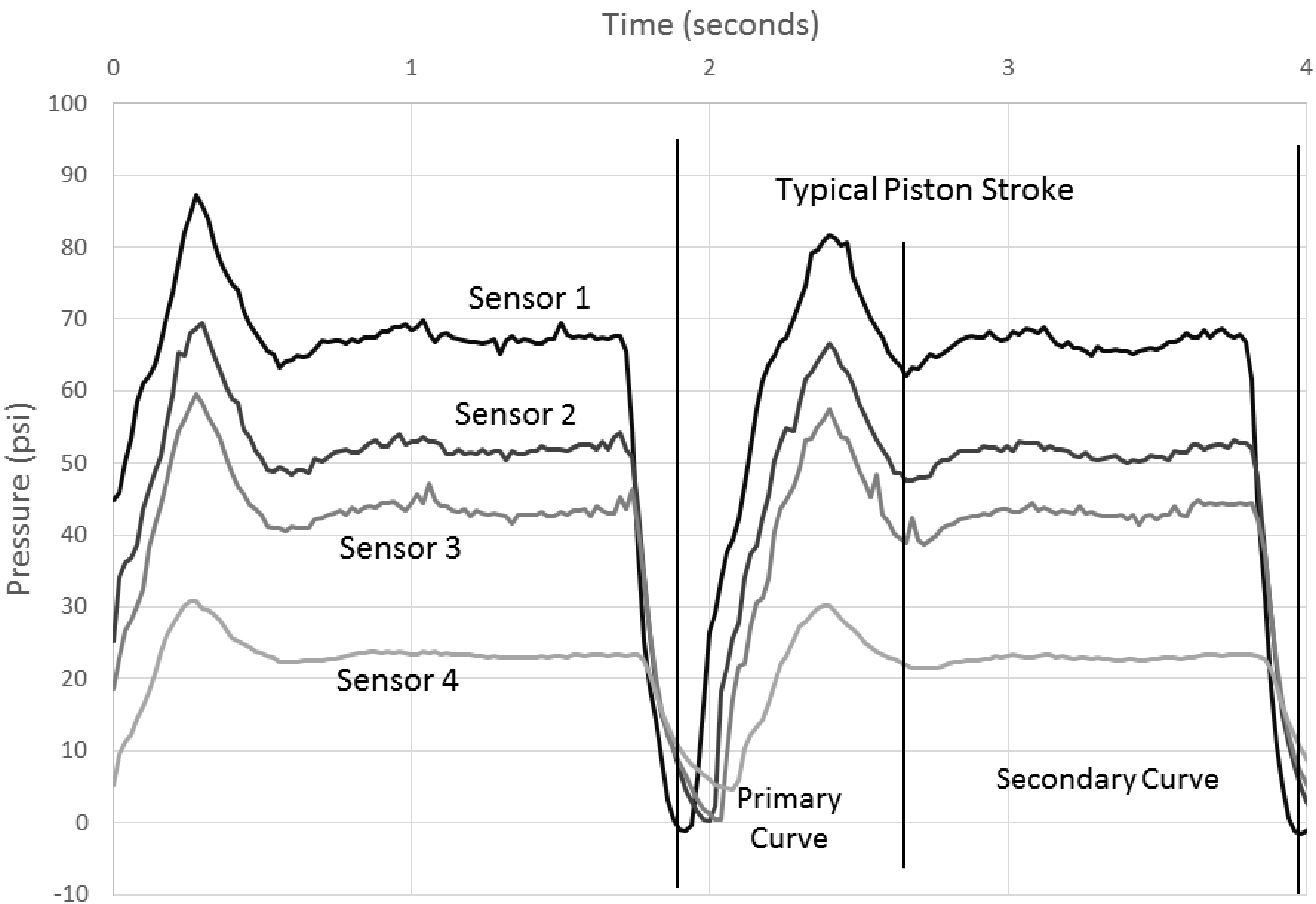

Putzmeister


Putzmeister



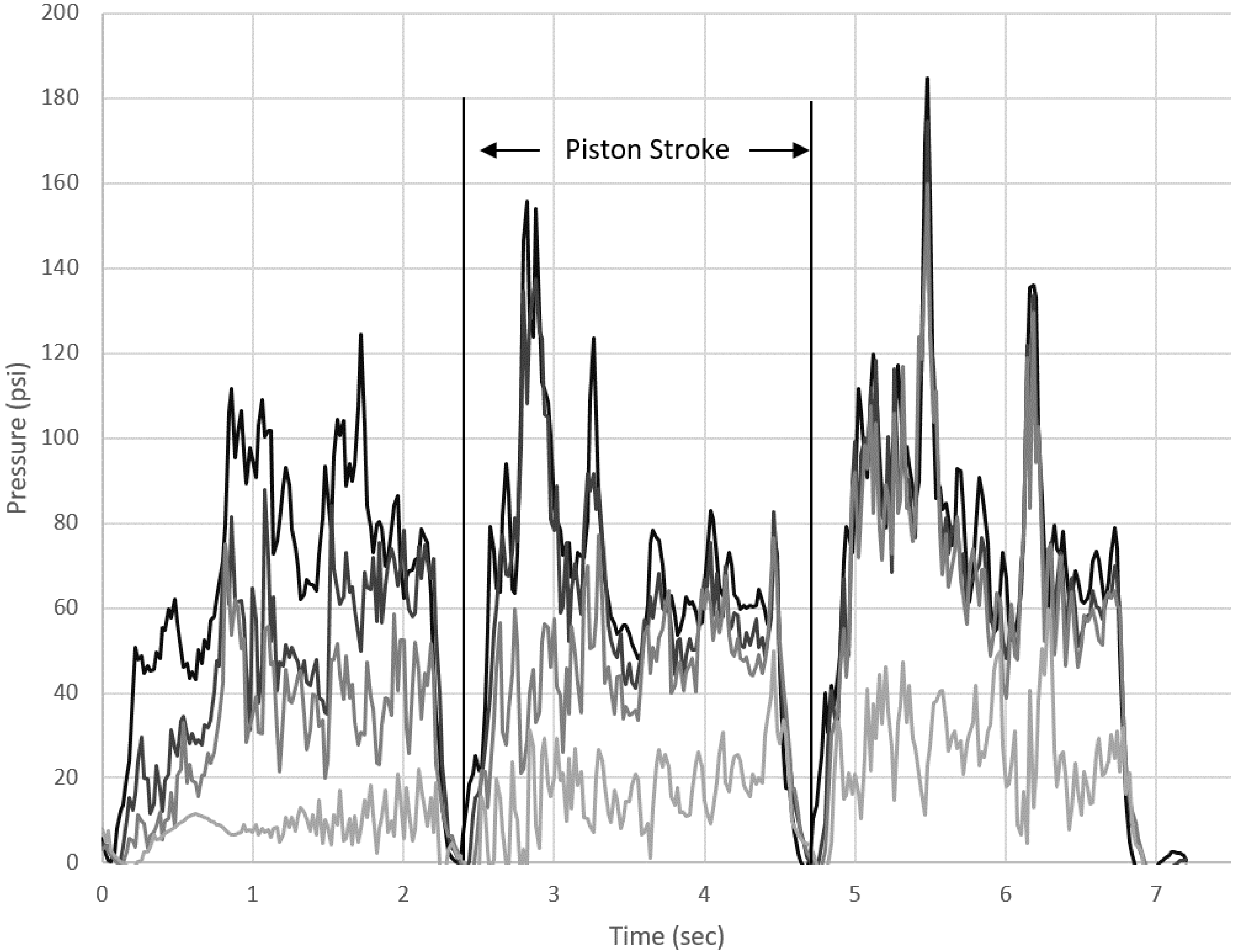
Putzmeister
1
2
3
4


Buffer Chamber
GE 5000 Pressure Sensor
Rubber Membrane

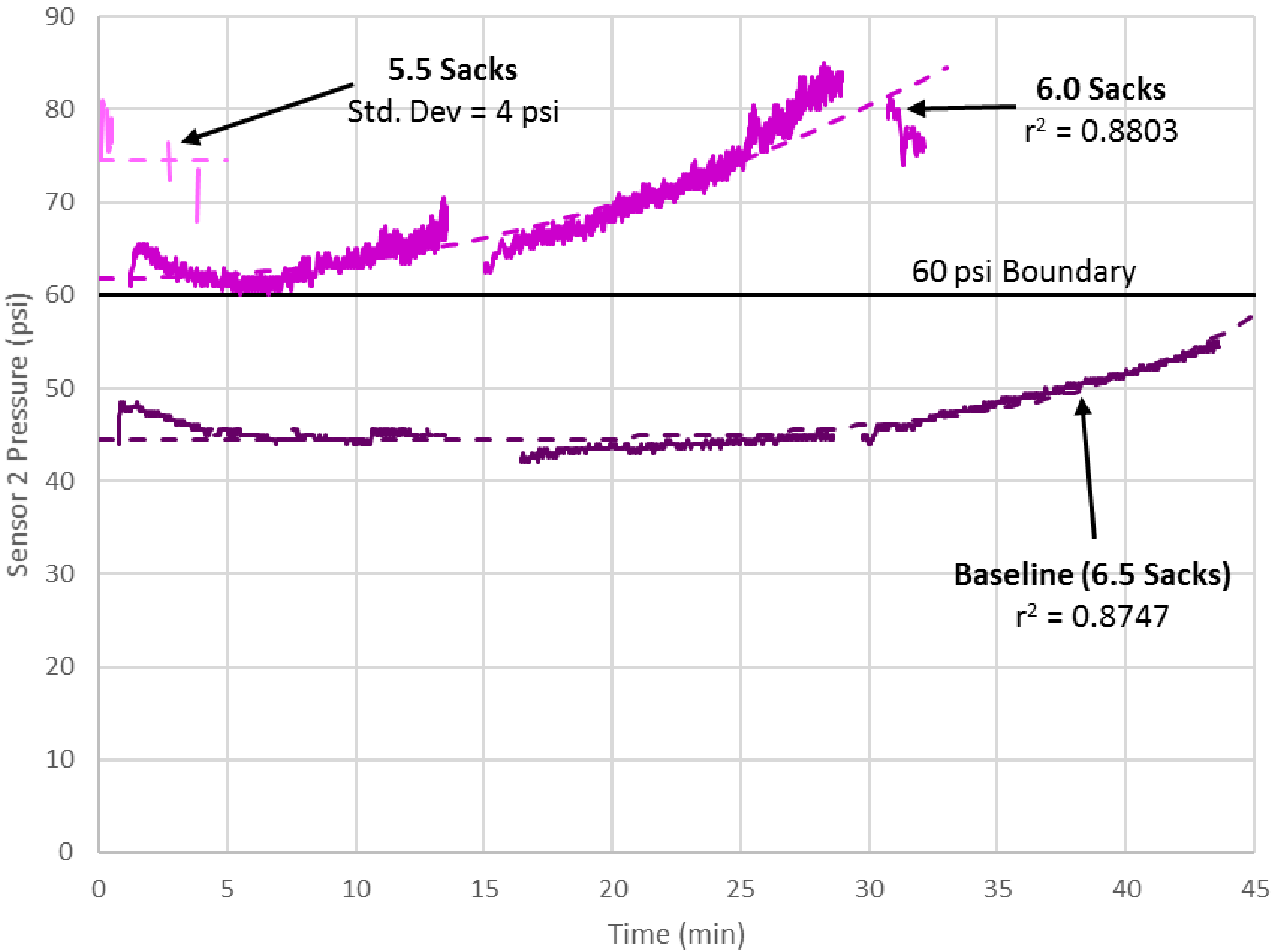


Time (seconds)
0
1
2
3
4
100
90
80
70
60
50
40
30
20
10
0
-10
Pressure (psi)
Typical Piston Stroke
Sensor 1
Sensor 2
Sensor 3
Sensor 4
Primary Curve
Secondary Curve

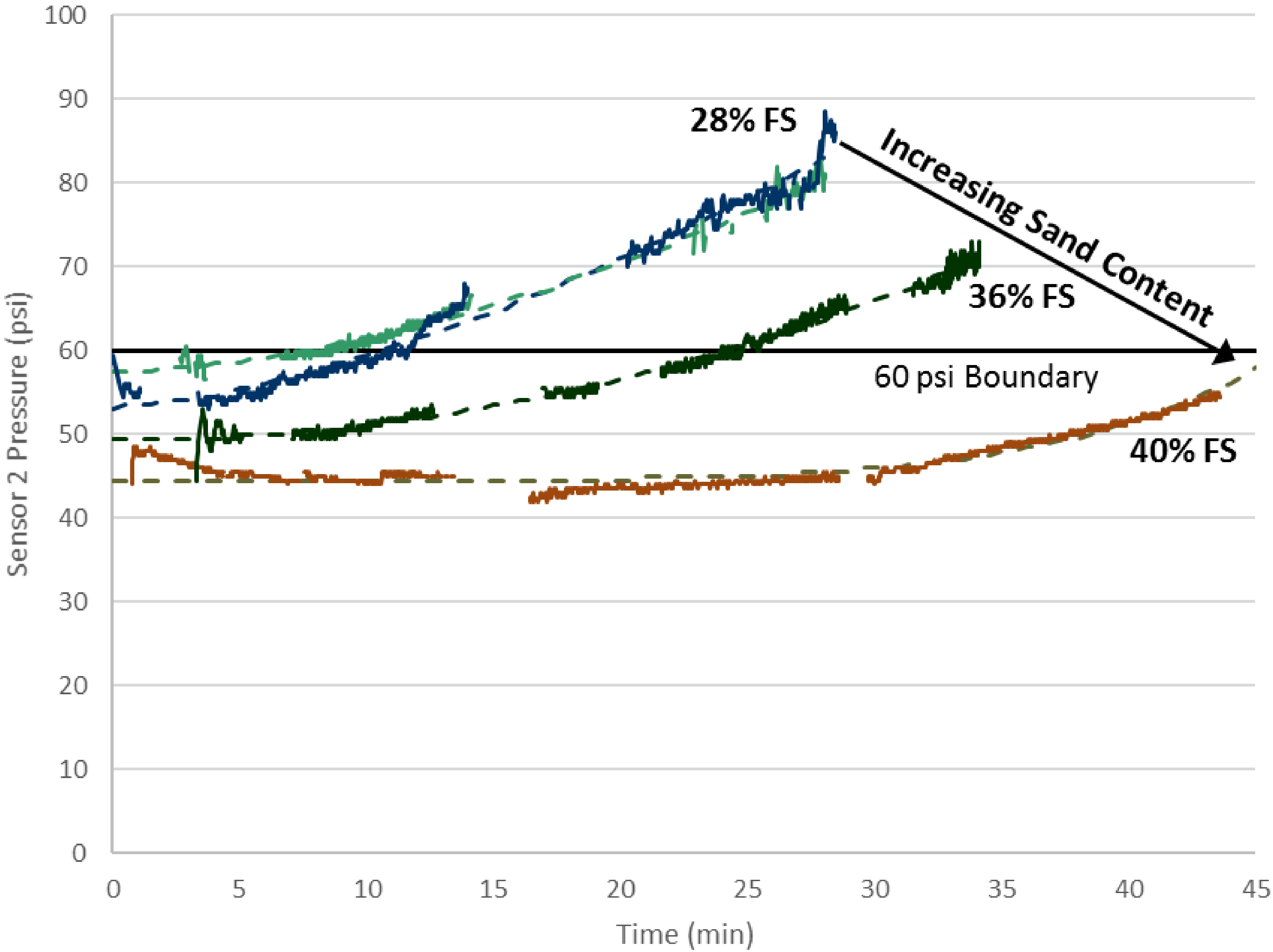

Segregation



200
180
160
140
120
100
80
60
40
20
0
Pressure (psi)
Piston Stroke
0
1
2
3
4
5
6
7
Time (sec)



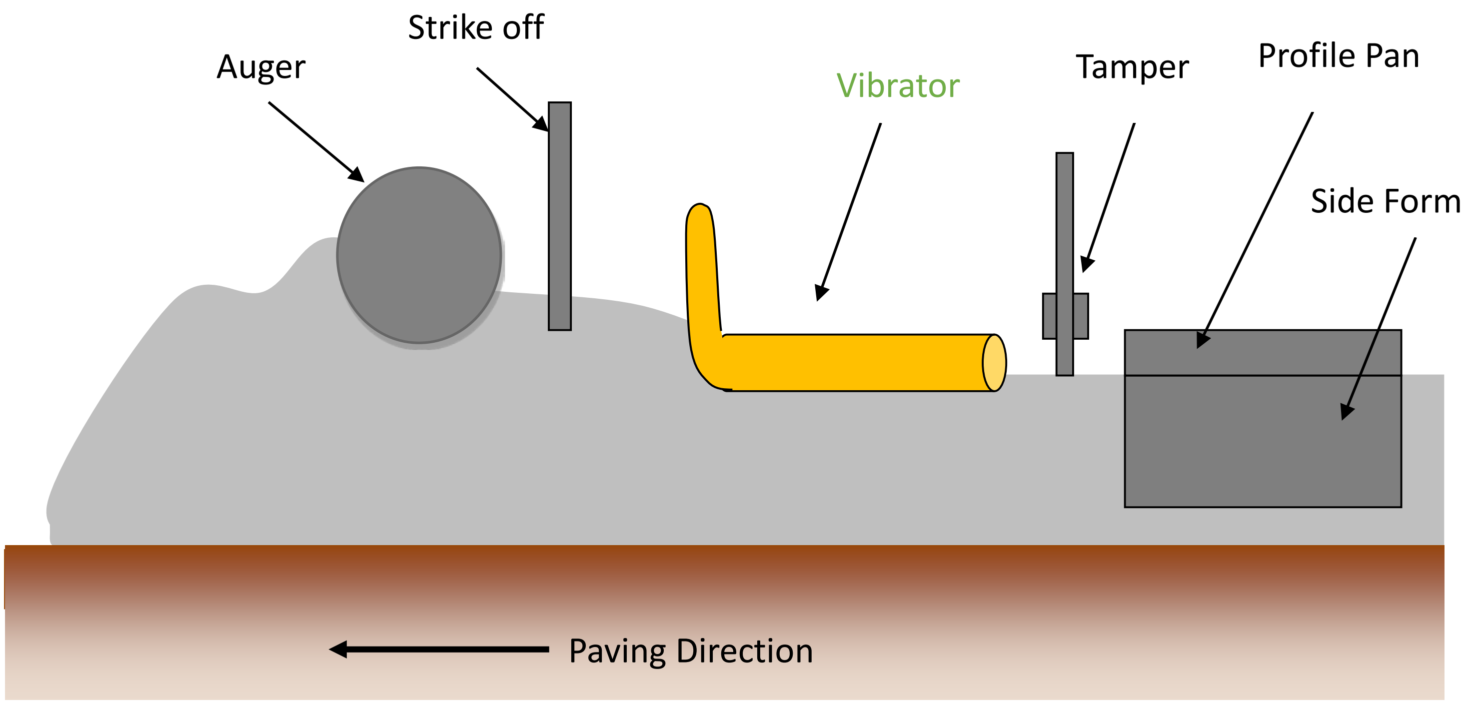
5.5 Sacks
Std. Dev = 4 psi
6.0 Sacks
r2 = 0.8803
60 psi Boundary
Baseline (6.5 Sacks)
r2 = 0.8747
Sensor 2 Pressure (psi)
Time (min)
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
35
40
45



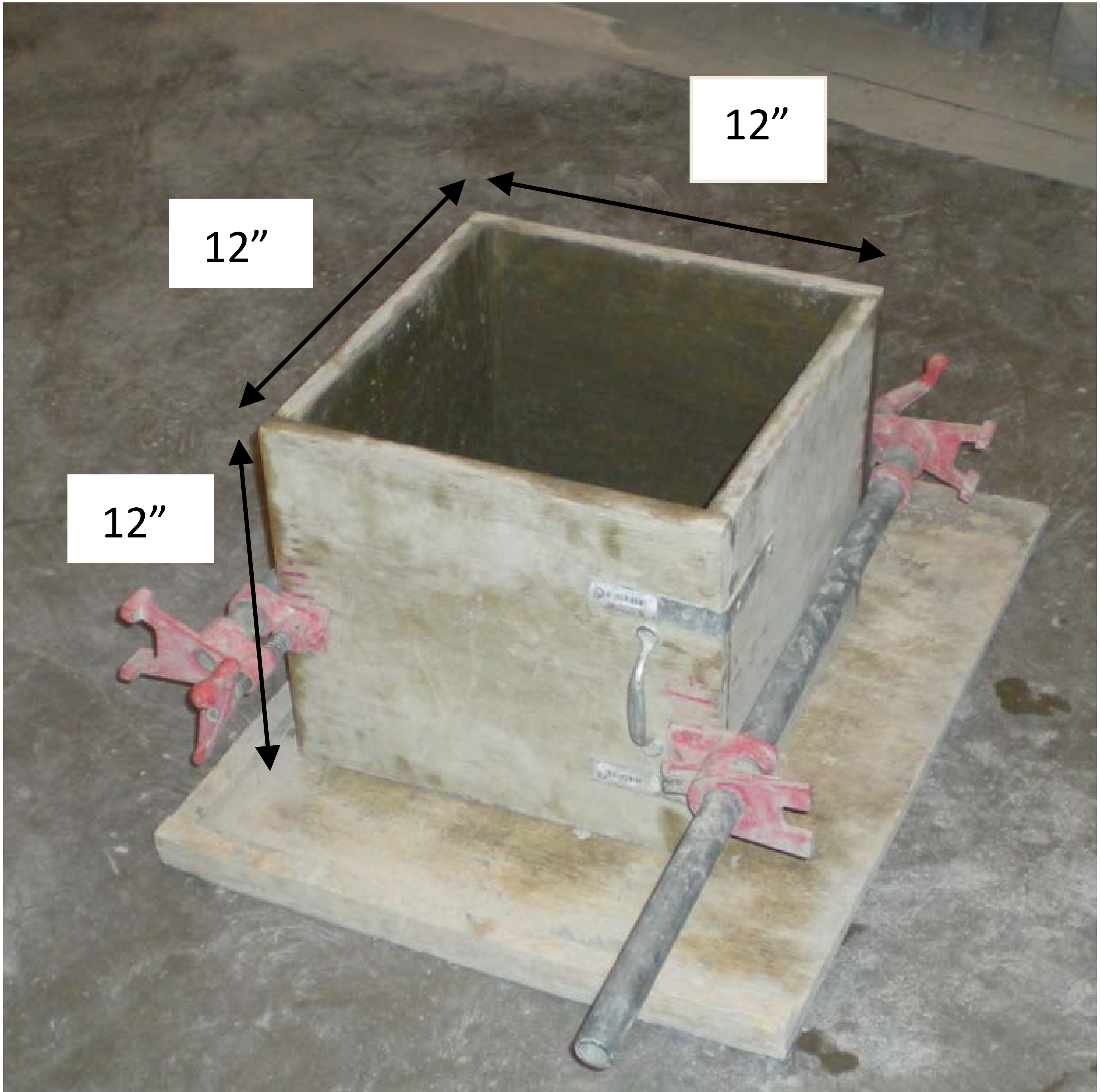
100
90
80
70
60
50
40
30
20
10
0
Sensor 2 Pressure (psi)
0
5
10
15
20
25
30
35
40
45
Time (min)
28% FS
Increasing Sand Content
36% FS
60 psi Boundary
40% FS

Slip Formed Paver

What part of a paver is the most critical for concrete consolidation?



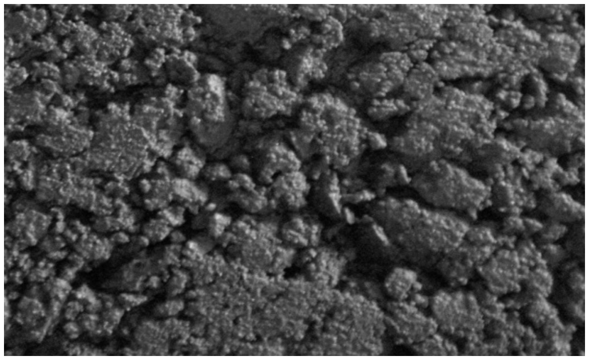
- We want a test that is simple and can examine:
  - Response to vibration
  - Filling ability of the grout (avoid internal voids)
  - Ability of the slip formed concrete to hold a sharp edge (cohesiveness)
- **The slump test can not tell us this!**


12”
12”
12”

Box Test

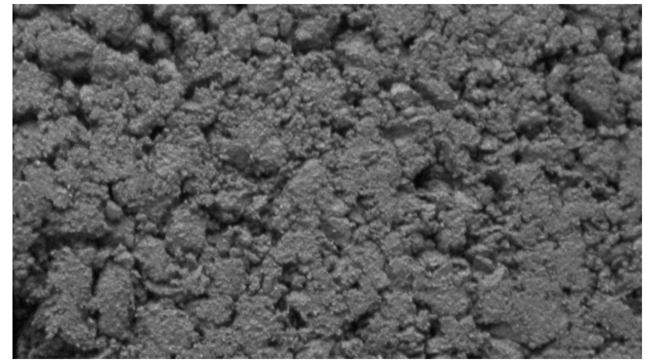
- Add 9.5” of unconsolidated concrete to the box
- A 1” diameter stinger vibrator is inserted into the center of the box over a three count and then removed over a three count
- The edges of the box are then removed and inspected for honey combing or edge slumping

Box Test Ranking Scale



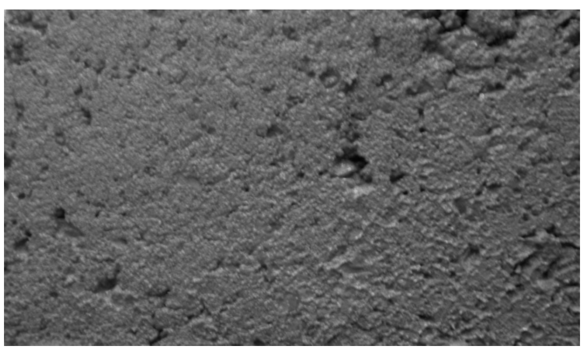
4

Over 50% overall surface voids.



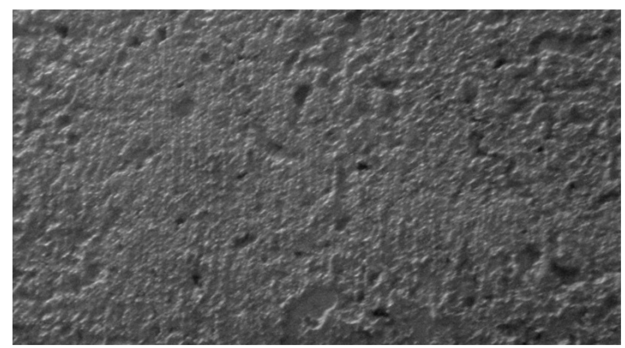
3

30-50% overall surface voids.



2

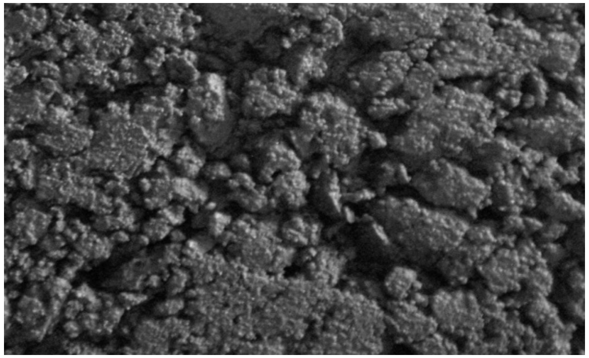
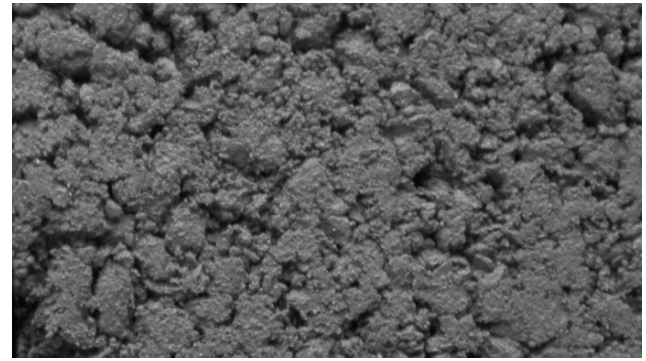
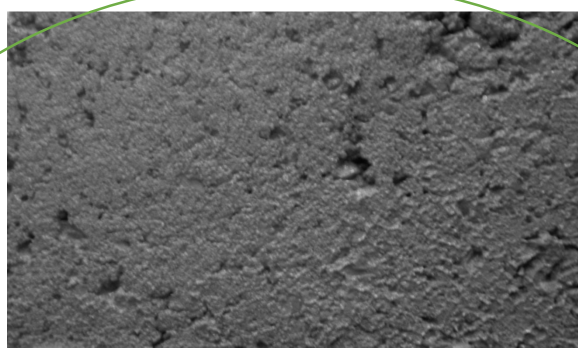
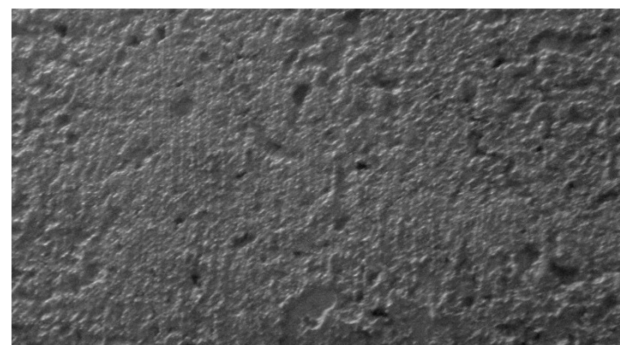
10-30% overall surface voids.



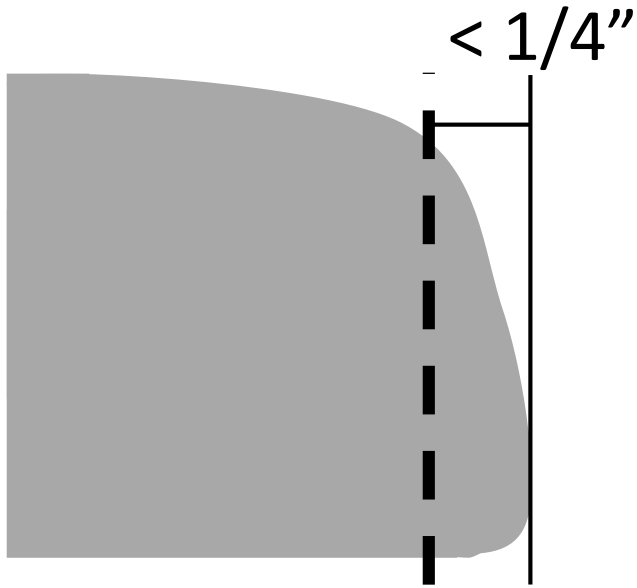
1

Less than 10% overall surface voids.

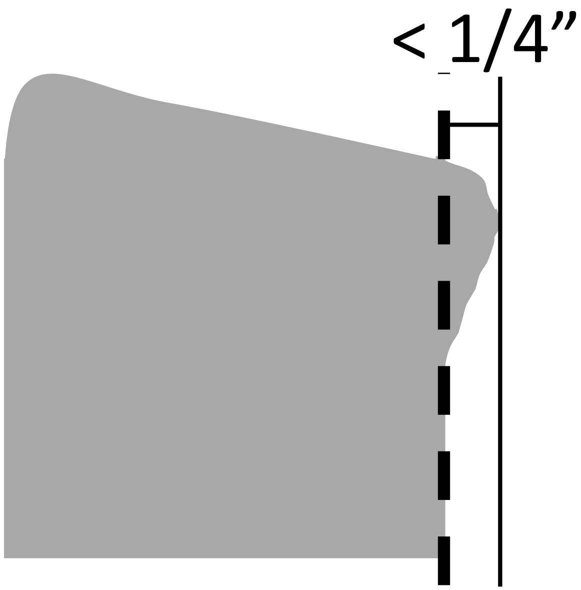
Box Test Ranking Scale

	
4	**3**
Over 50% overall surface voids.	30-50% overall surface voids.
	
2	**1**
10-30% overall surface voids.	Less than 10% overall surface voids.

Edge Slumping



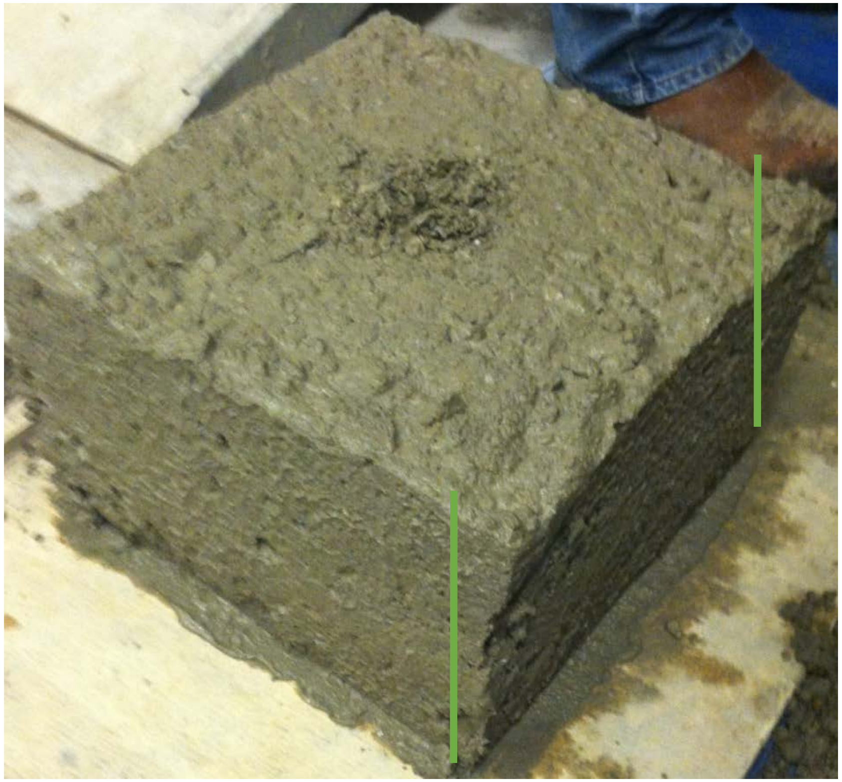
Bottom Edge Slumping



Top Edge Slumping

No Edge Slump

Edge Slump



Summary

- The Box Test examines the window of workability for concrete pavement mixtures
- This is helpful when:
  - mixtures are designed in the lab
  - trial batching in the field
  - troubleshooting field problems
  - measuring variation in production

- It is like having a miniature paver!!!

Testing Overview

We evaluated over **650** concrete mixtures

- 13 coarse aggregate sources
- 4 fine aggregate sources

Looked at low to high workability concrete

Looked at the following:

- different aggregate gradations
- paste contents
- w/cm
- water reducer dosages

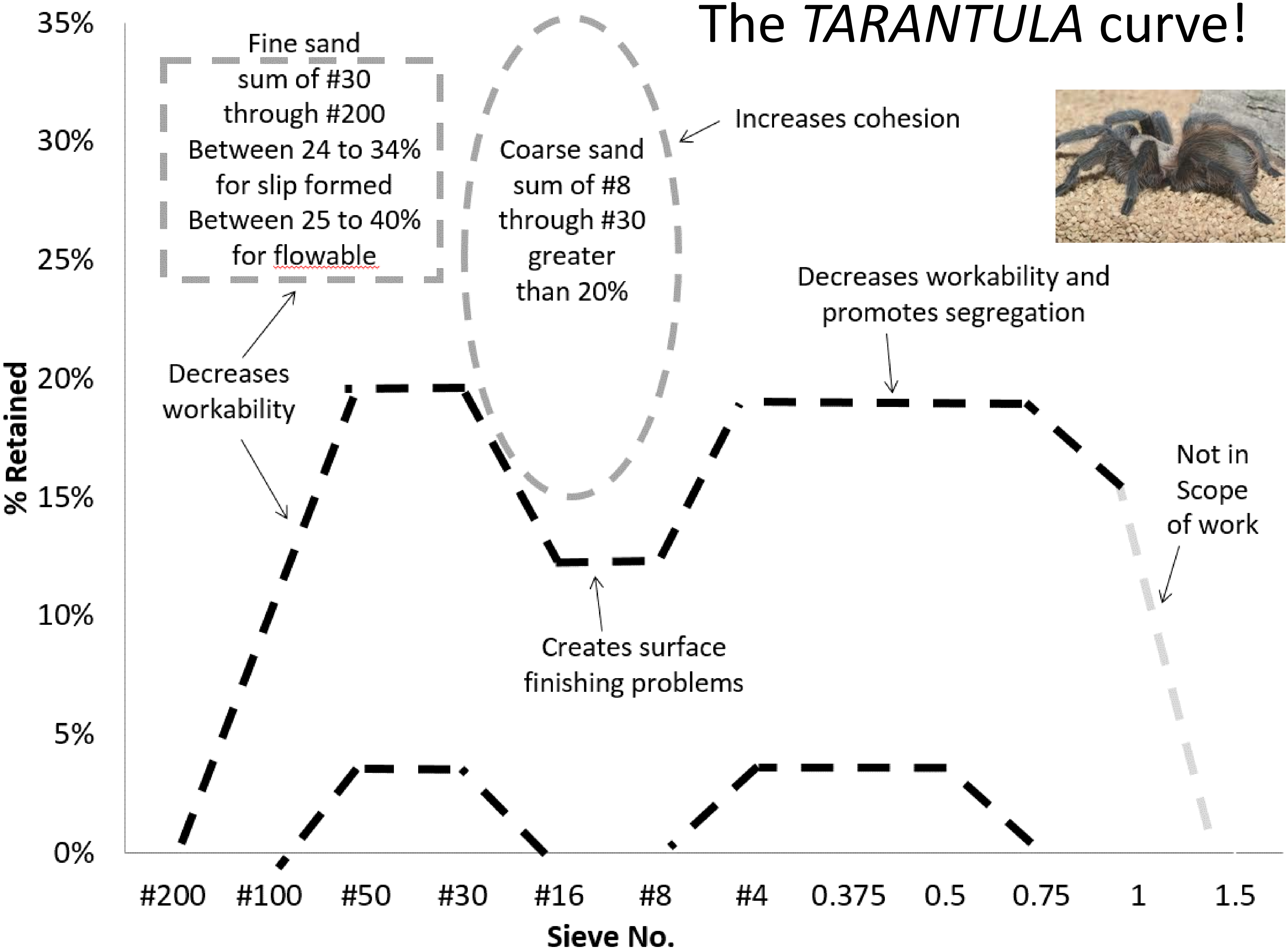
Important point

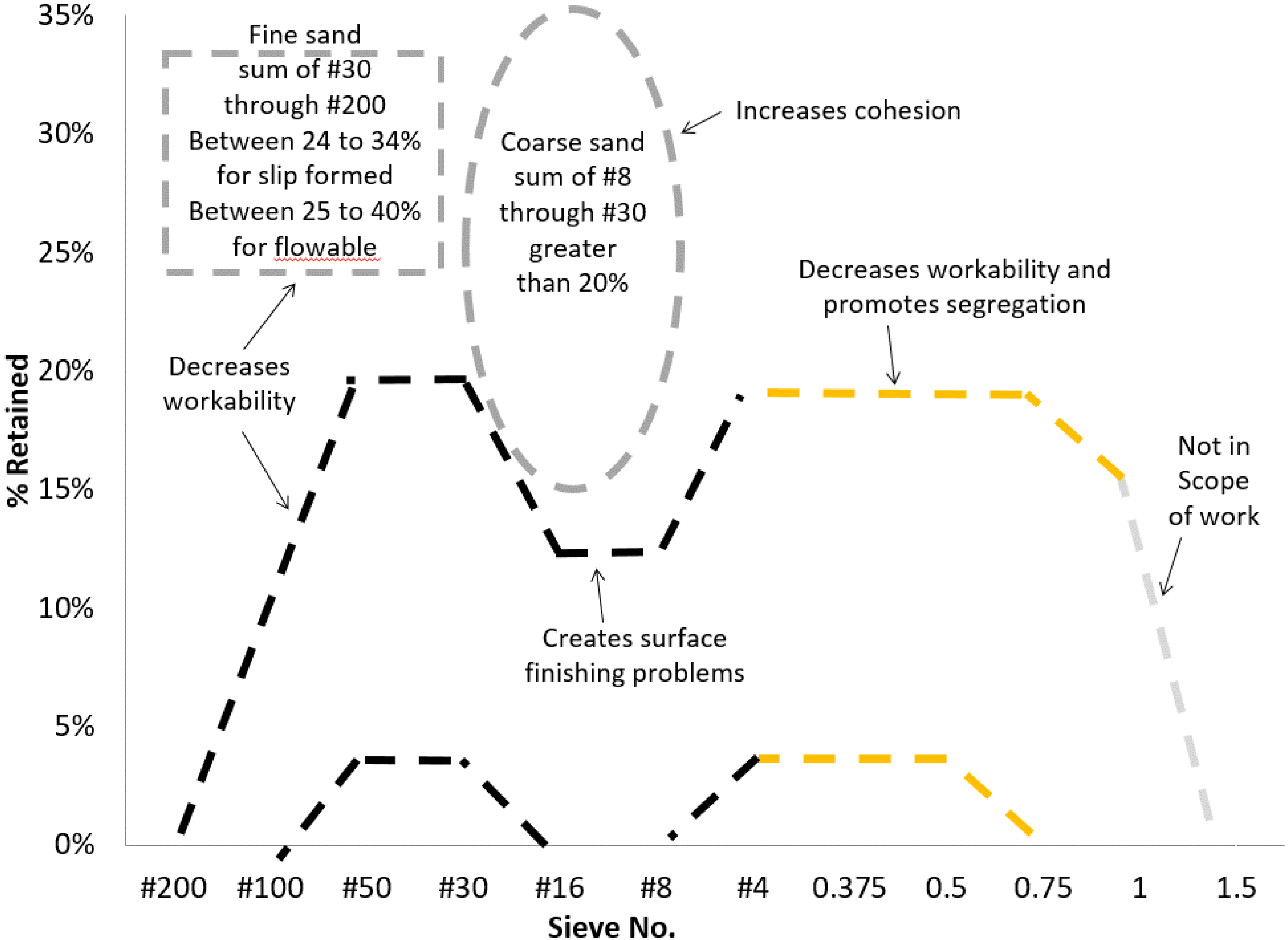
- We used the workability tests to find how gradation impacted performance.

- As we changed the gradation we could see how this impacted the performance in each of these tests.

- This helped us establish limits and give reasons why these limits exist!

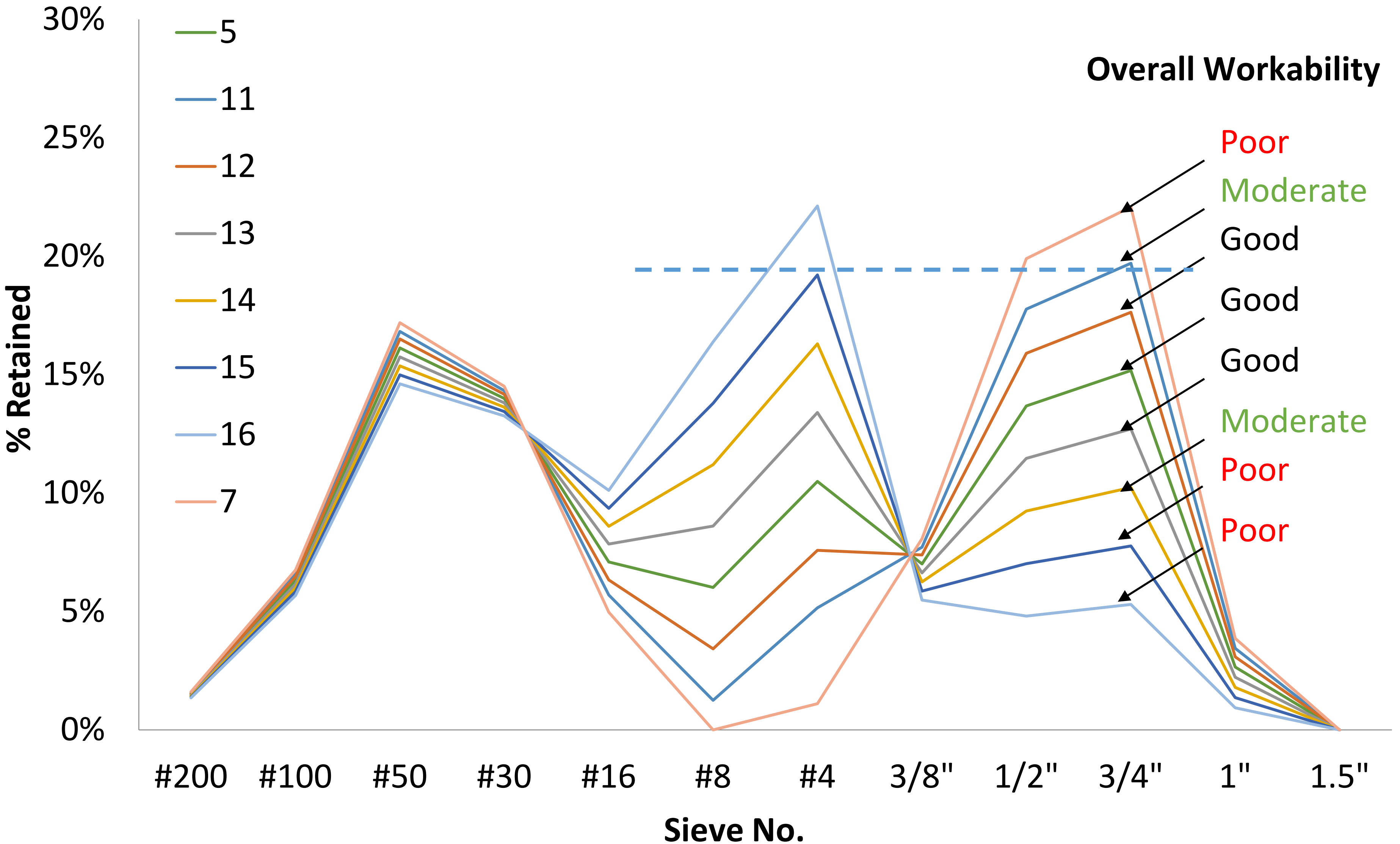
The *TARANTULA* curve!





35%
30%
25%
20%
15%
10%
5%
0%
% Retained
Fine sand
sum of #30
through #200
Between 24 to 34%
for slip formed
Between 25 to 40%
for flowable
Coarse sand
sum of #8
through #30
greater
than 20%
Increases cohesion
Decreases workability and
promotes segregation
Decreases
workability
Not in
Scope
of work
Creates surface
finishing problems
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

Limestone A

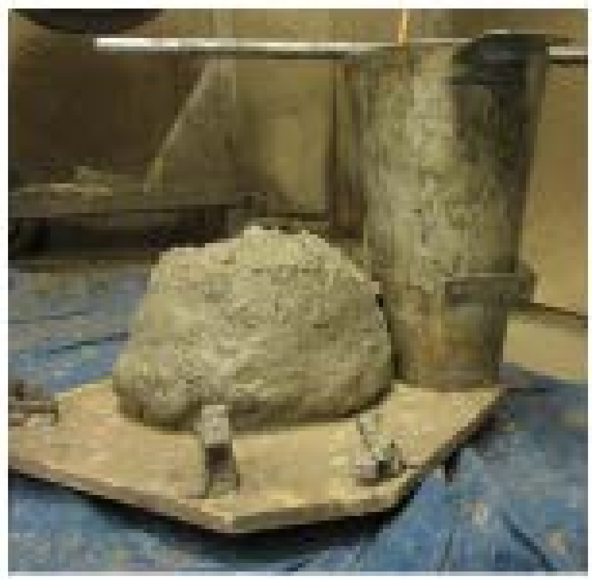


30%
25%
20%
15%
10%
5%
0%
% Retained
5
11
12
13
14
15
16
7
Overall Workability
Poor
Moderate
Good
Good
Good
Moderate
Poor
Poor
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.

Slump Test

High Coarse

Moderate Amount

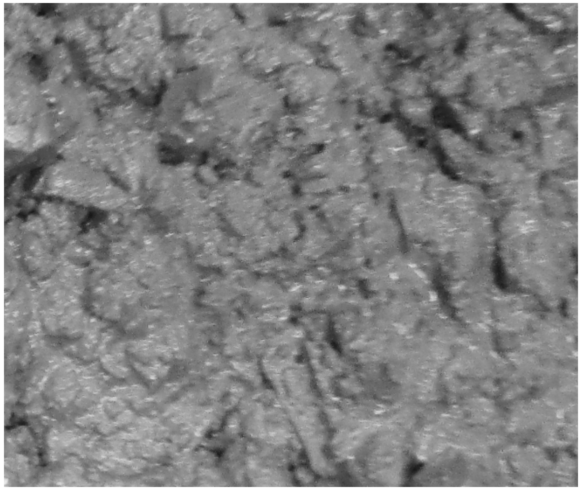


High Intermediate

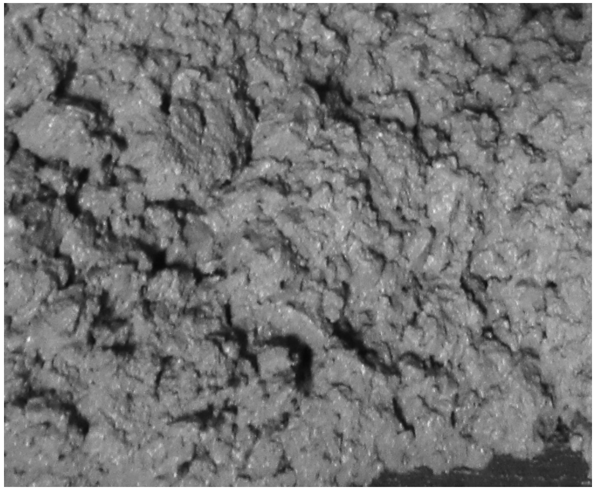
Visual Observations

Excessive Coarse

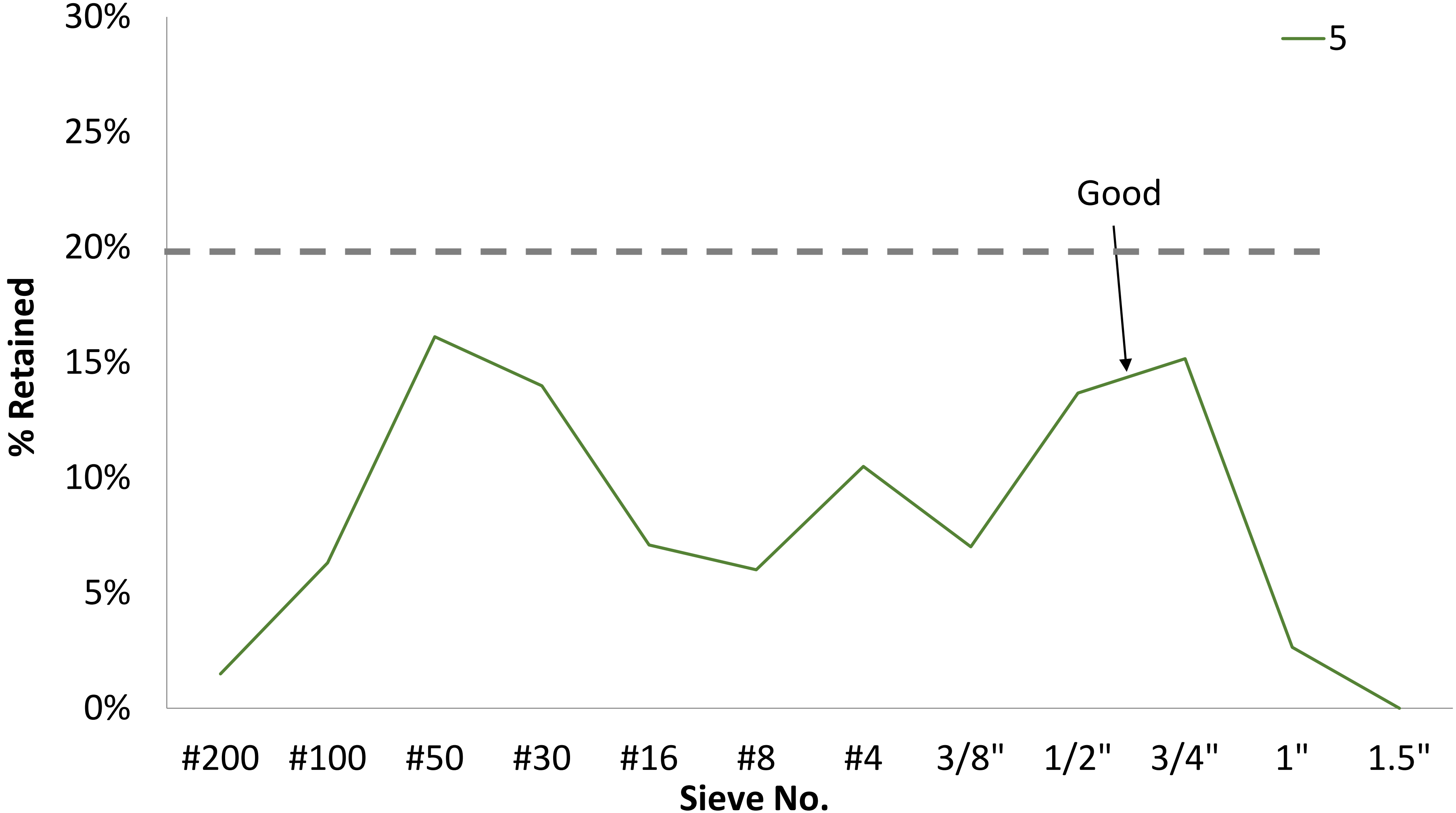
Sufficient Amount



Excessive Intermediate

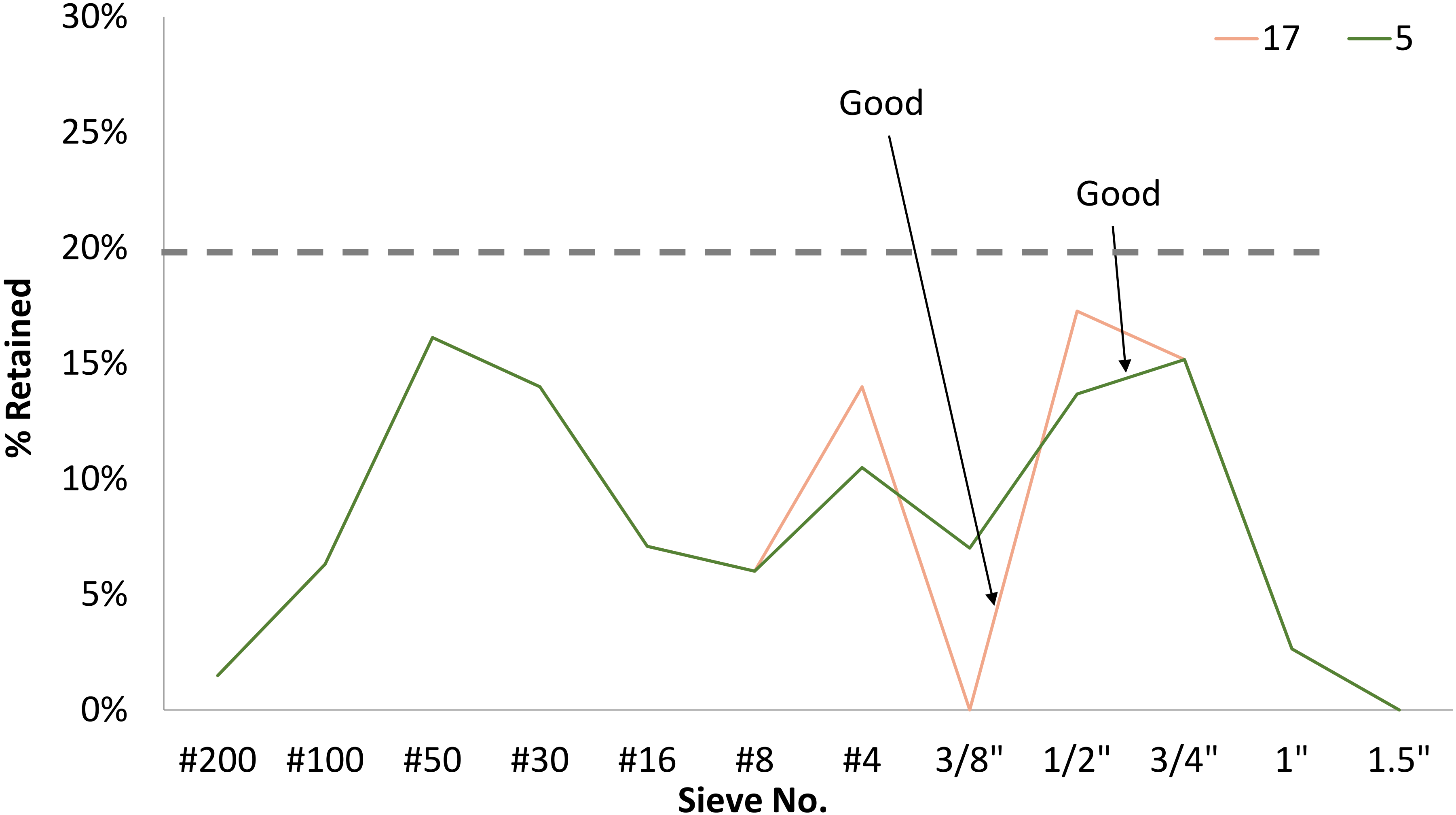


Valleys

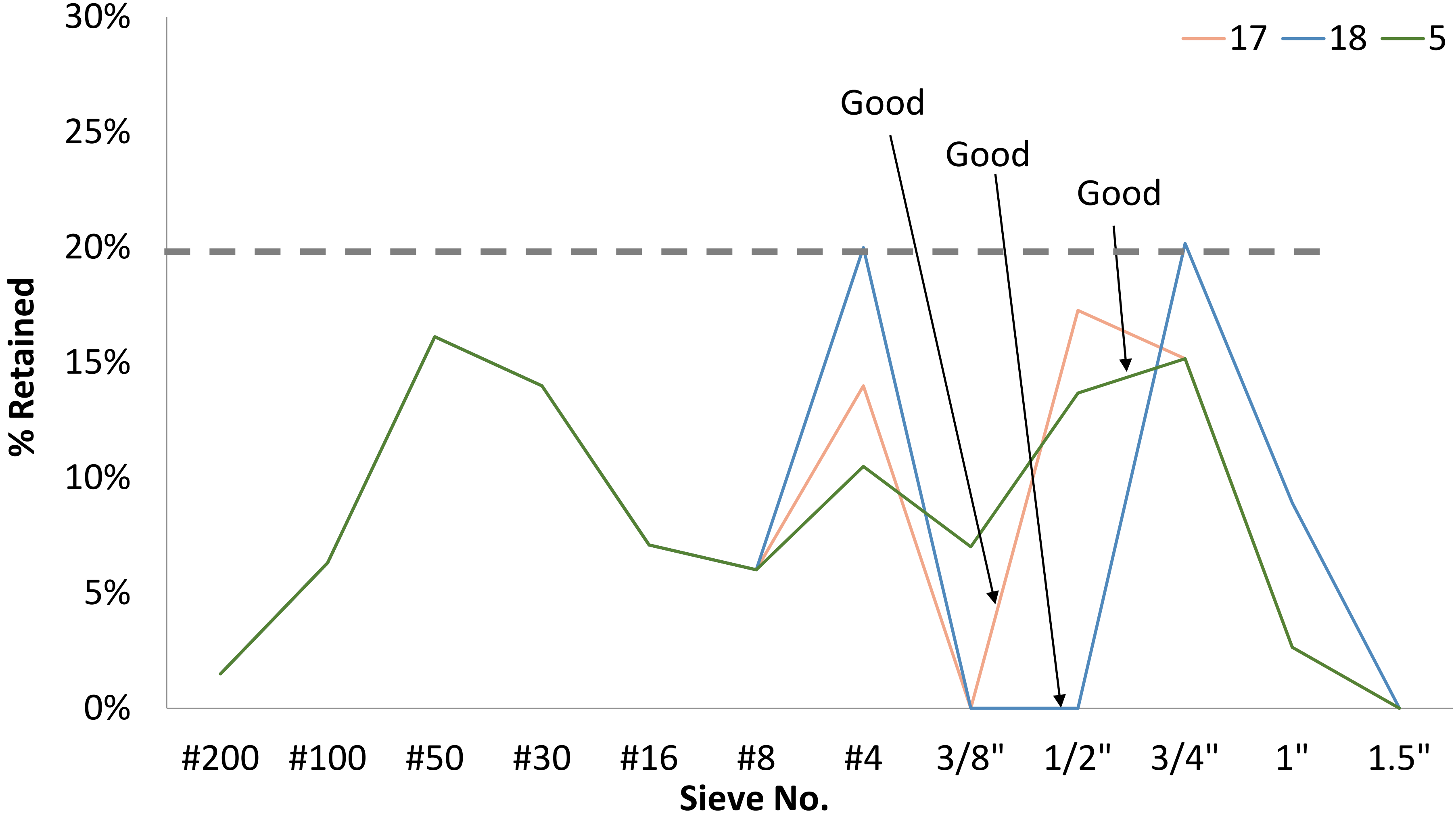


30%
25%
20%
15%
10%
5%
0%
% Retained
5
Good
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.

Valleys


30%
25%
20%
15%
10%
5%
0%
% Retained
17
5
Good
Good
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.

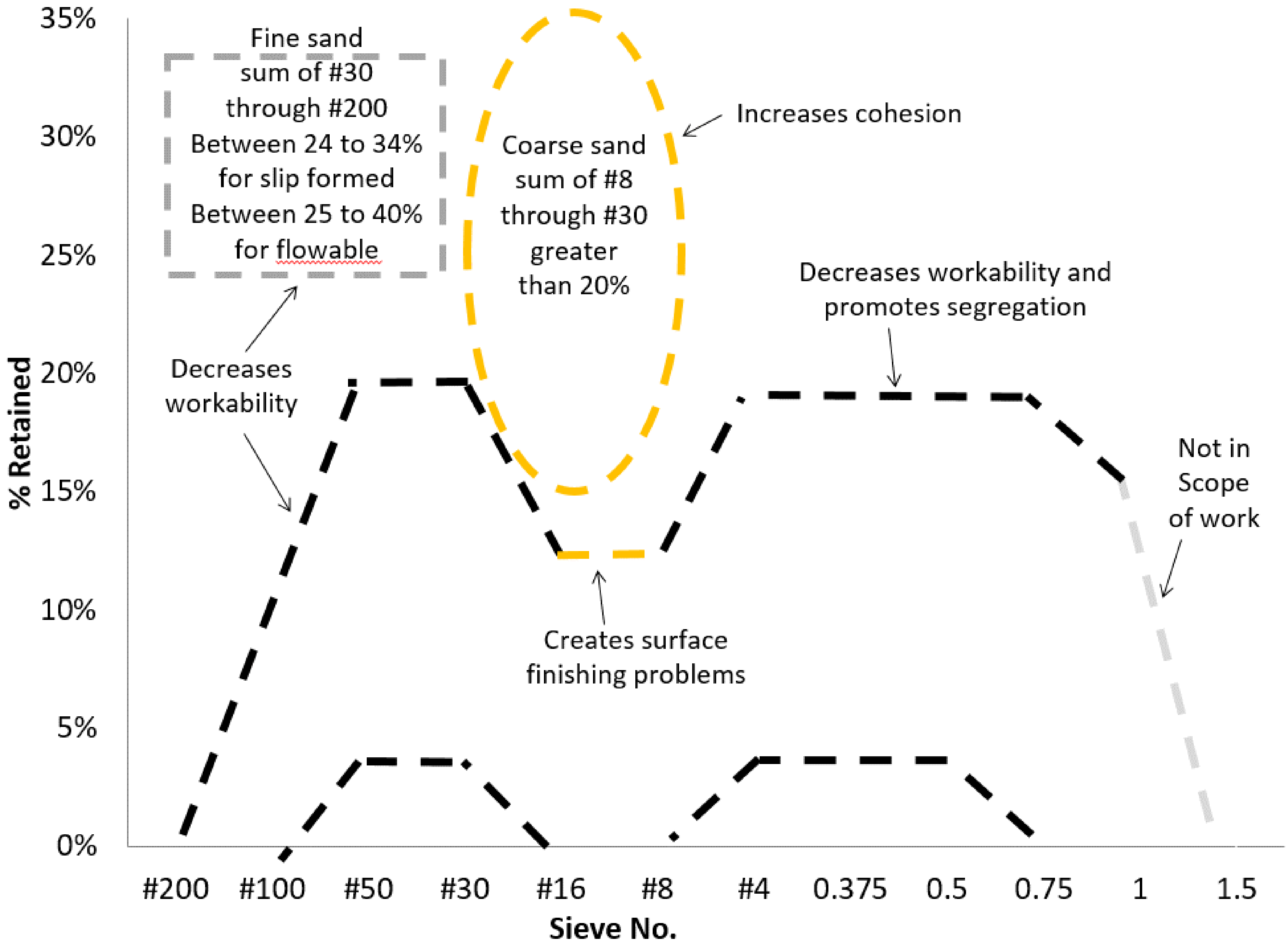
Valleys



30%
25%
20%
15%
10%
5%
0%
% Retained
17
18
5
Good
Good
Good
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.

Discussion

- Maximum boundary limit of 20 % on ¾” to #4 sieve size
- The **double or single valley** did not drastically change the workability of the concrete as long as no coarse sieve size went above 20%.



35%
30%
25%
20%
15%
10%
5%
0%
% Retained
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sum of #30
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for flowable
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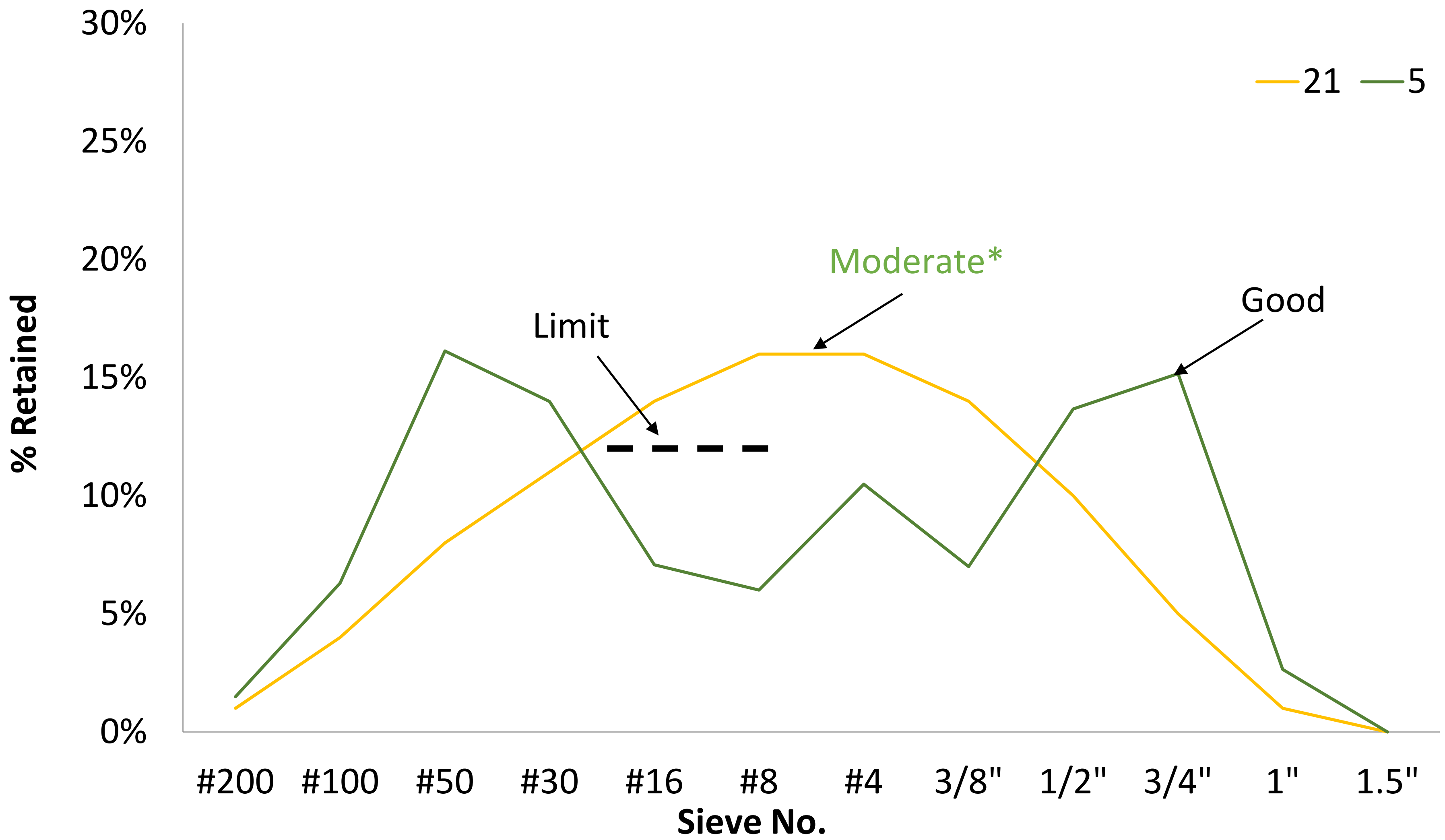
Decreases workability and
promotes segregation
Decreases
workability
Not in
Scope
of work
Creates surface
finishing problems
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

Ideal Bell Shaped Curve



Visual Observation Of Ideal Bell Shaped Curve

Before Finishing

After 8 Passes

Sand

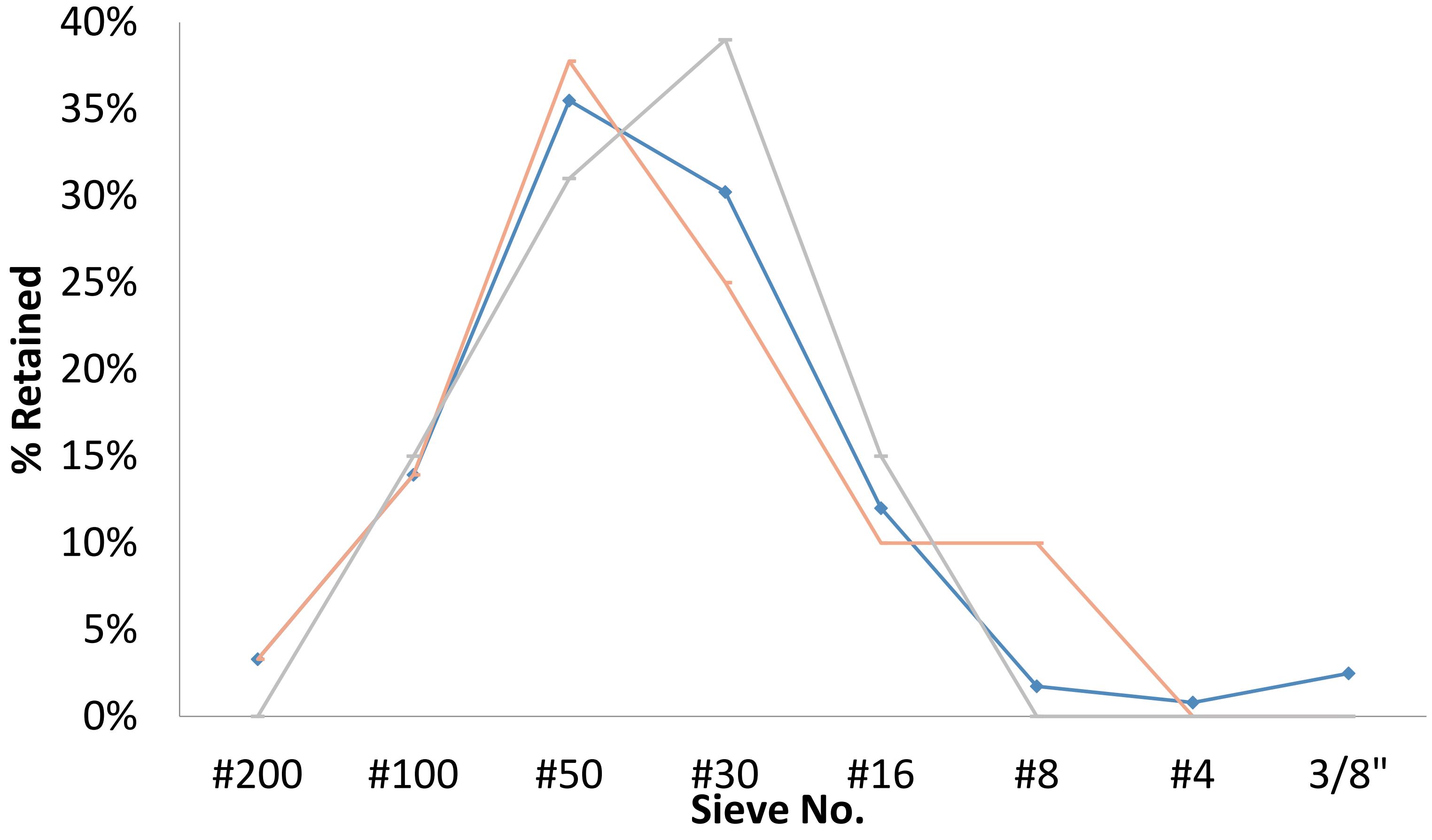
- The fineness modulus is the most common method to investigate sand gradation (Abrams, 1916).

- It can take an entire sand gradation curve and express it as one number.

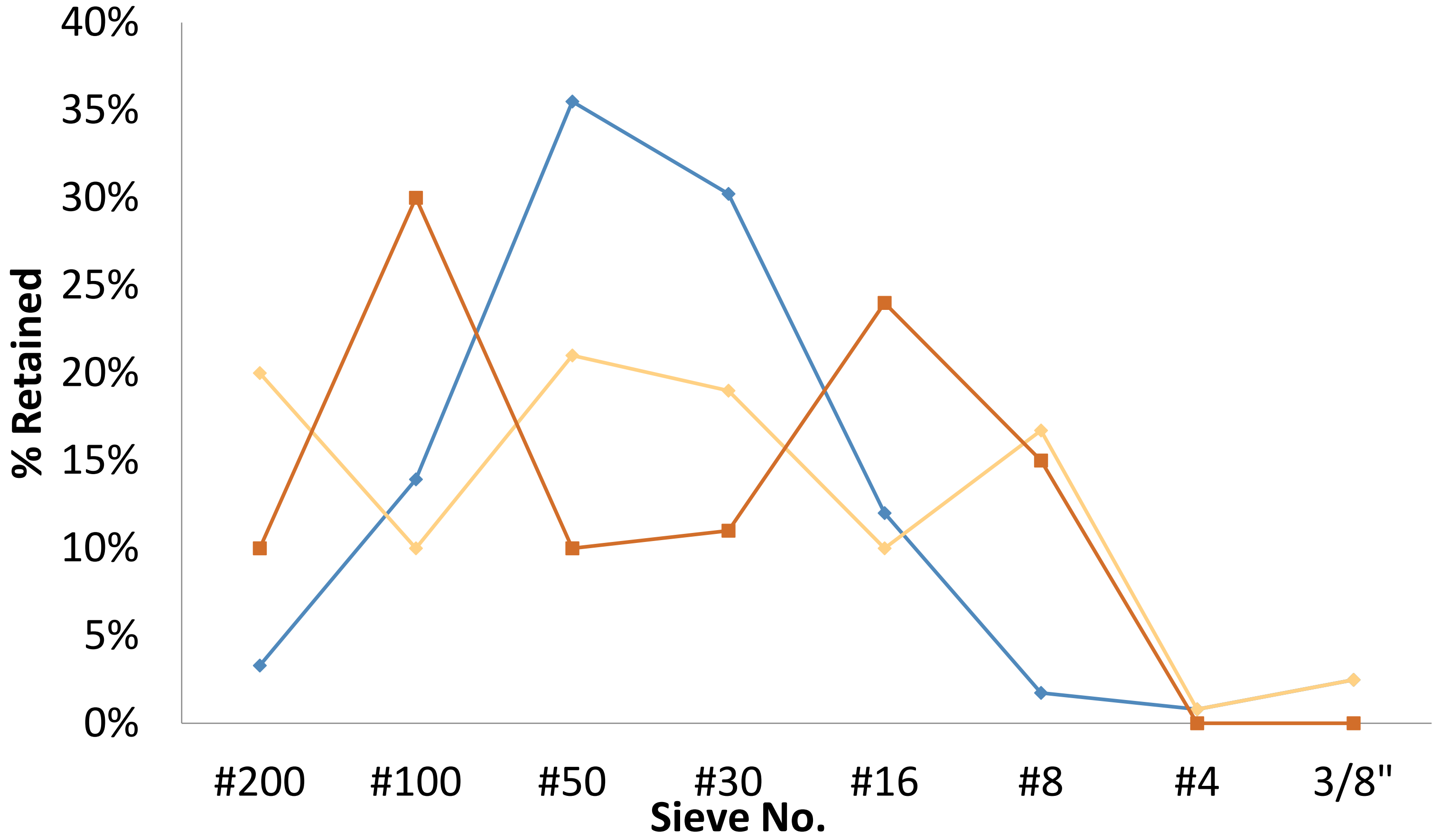
- When you have typical natural sands than it can be very helpful.

- When you use manufactured or blended sands than it means nothing.

Gradations with 2.54 FM



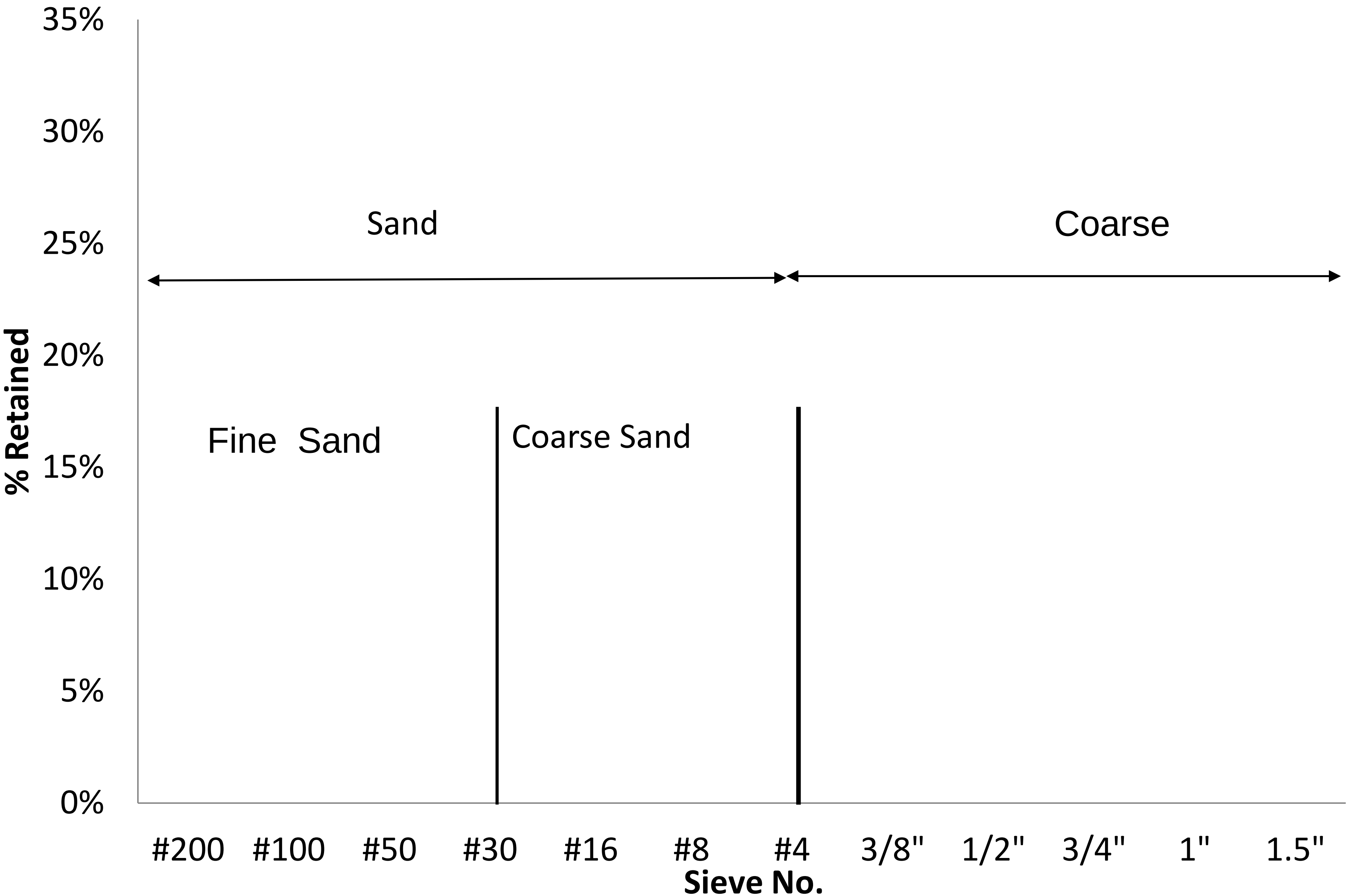
Gradations with 2.54 FM



Sand Gradation

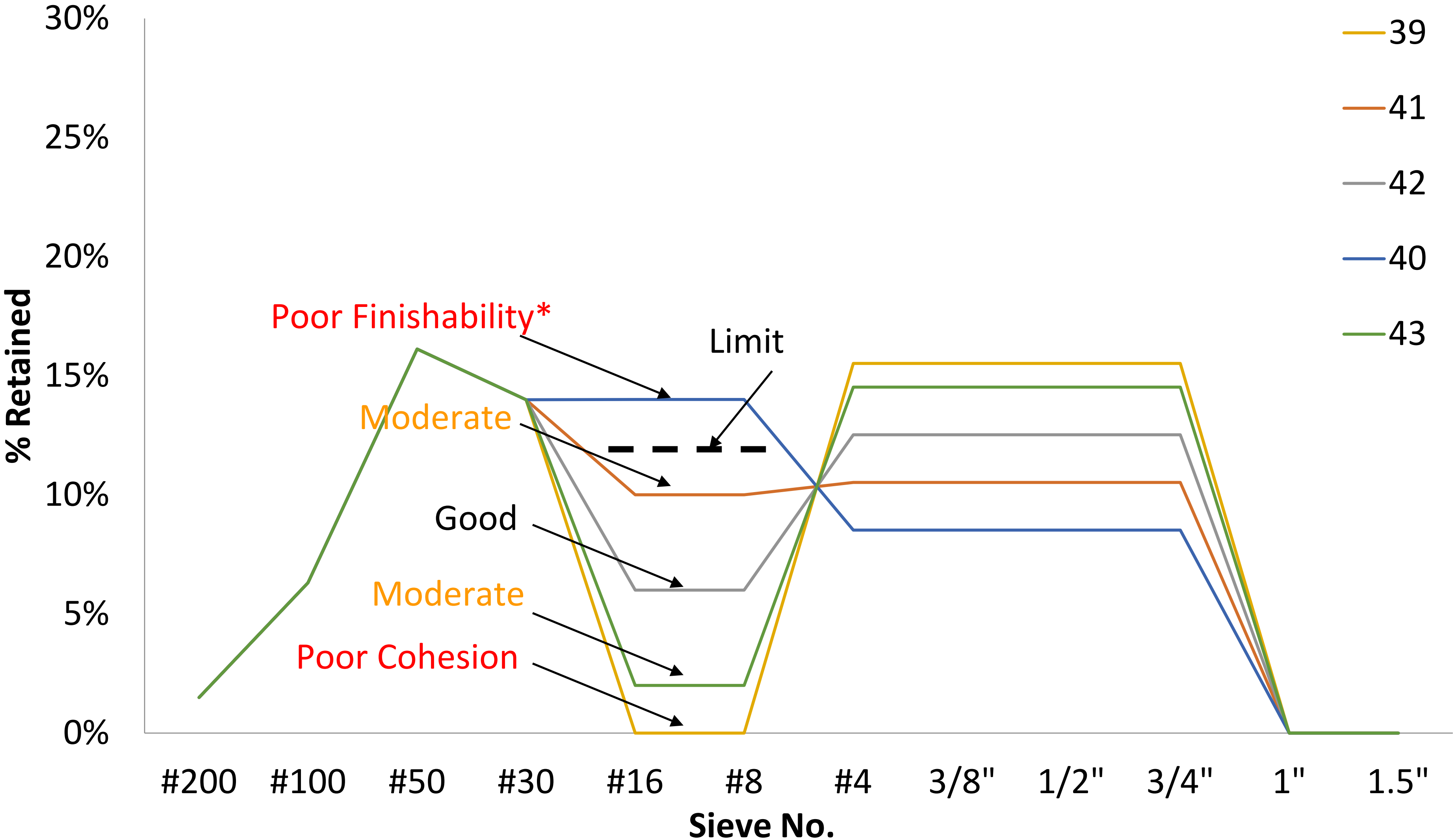
- While FM is useful, it is challenging to explain any gradation with a single number
- It is common to think of coarse aggregate in terms of the amount of large and intermediate aggregate
- Why don’t we do this with sands?

Fine Aggregate

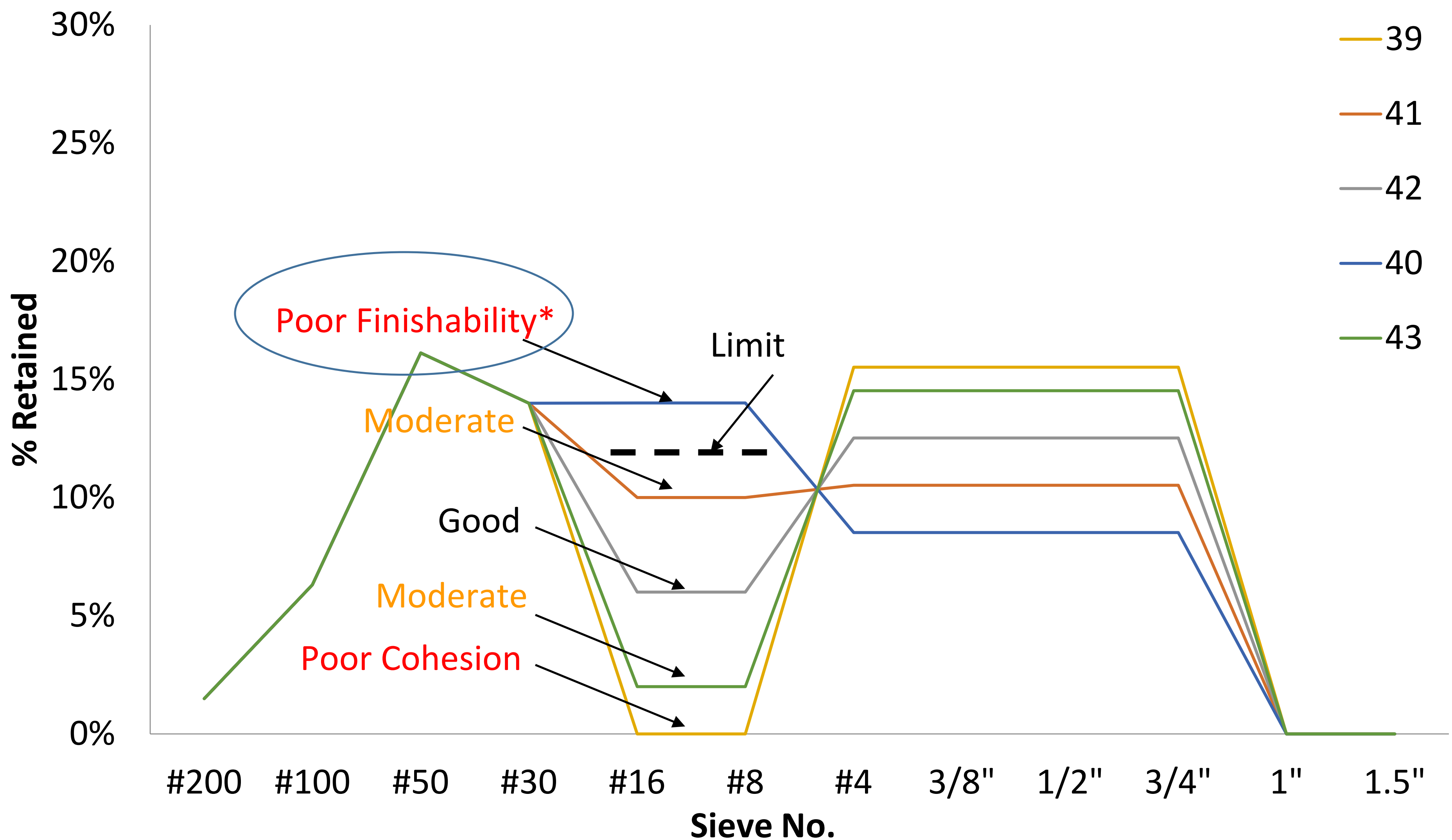


Investigation of Coarse Sand

- To understand and observe the coarse sand behavior #8, #16, and #30 sieve sizes were **removed**.
- Various amounts of each sieve size was **gradually added**.



30%
25%
20%
15%
10%
5%
0%
% Retained
Poor Finishability*
Limit
Moderate
Good
Moderate
Poor Cohesion
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.
39
41
42
40
43



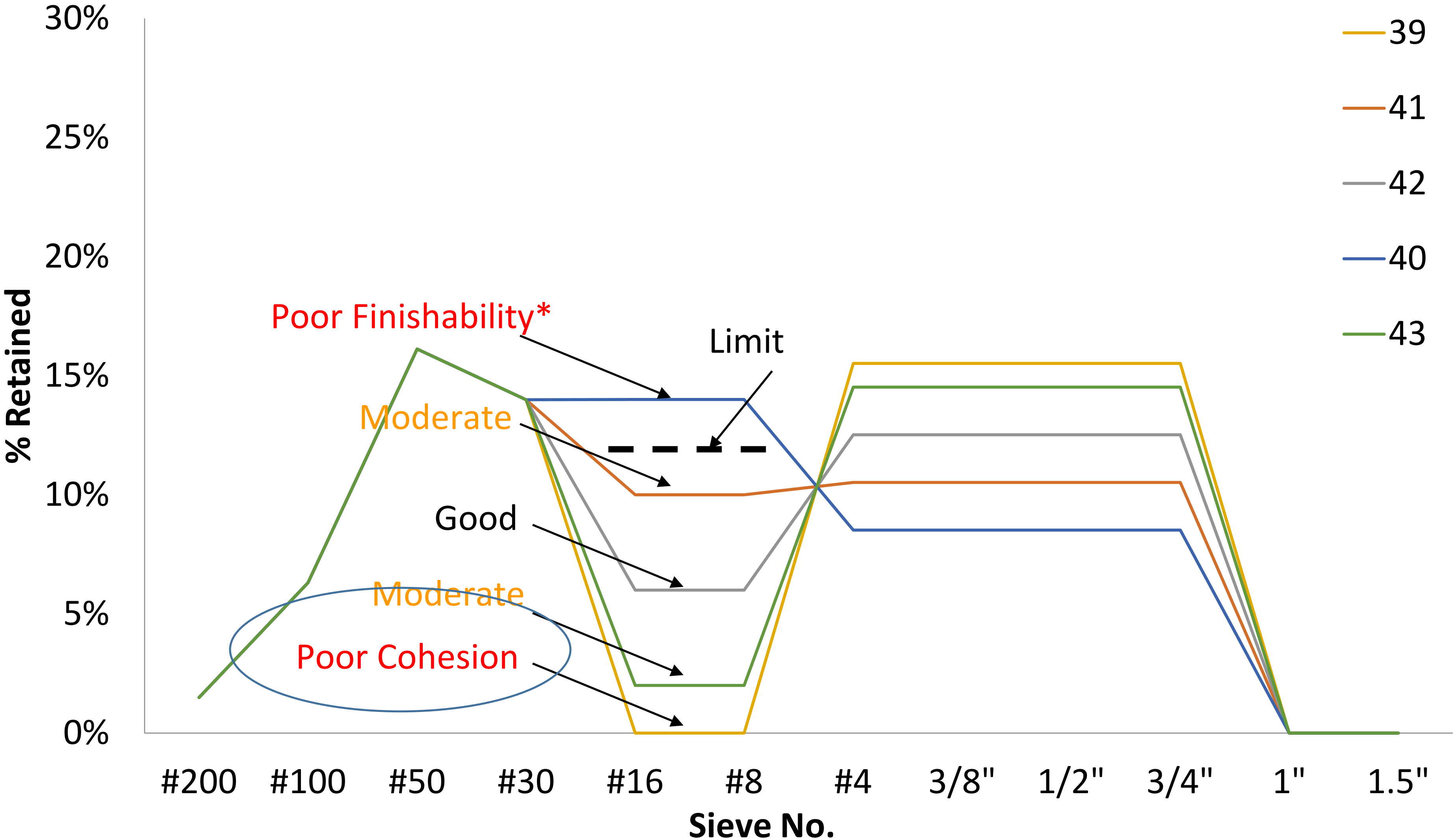
30%
25%
20%
15%
10%
5%
0%
% Retained
Poor Finishability*
Limit
Moderate
Good
Moderate
Poor Cohesion
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.
39
41
42
40
43

Coarse Sand-Poor Finishability

0 Passes

8 Passes

18 Passes


30%
25%
20%
15%
10%
5%
0%
% Retained
Poor Finishability*
Limit
Moderate
Good
Moderate
Poor Cohesion
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.
39
41
42
40
43

Coarse Sand-Poor Cohesion

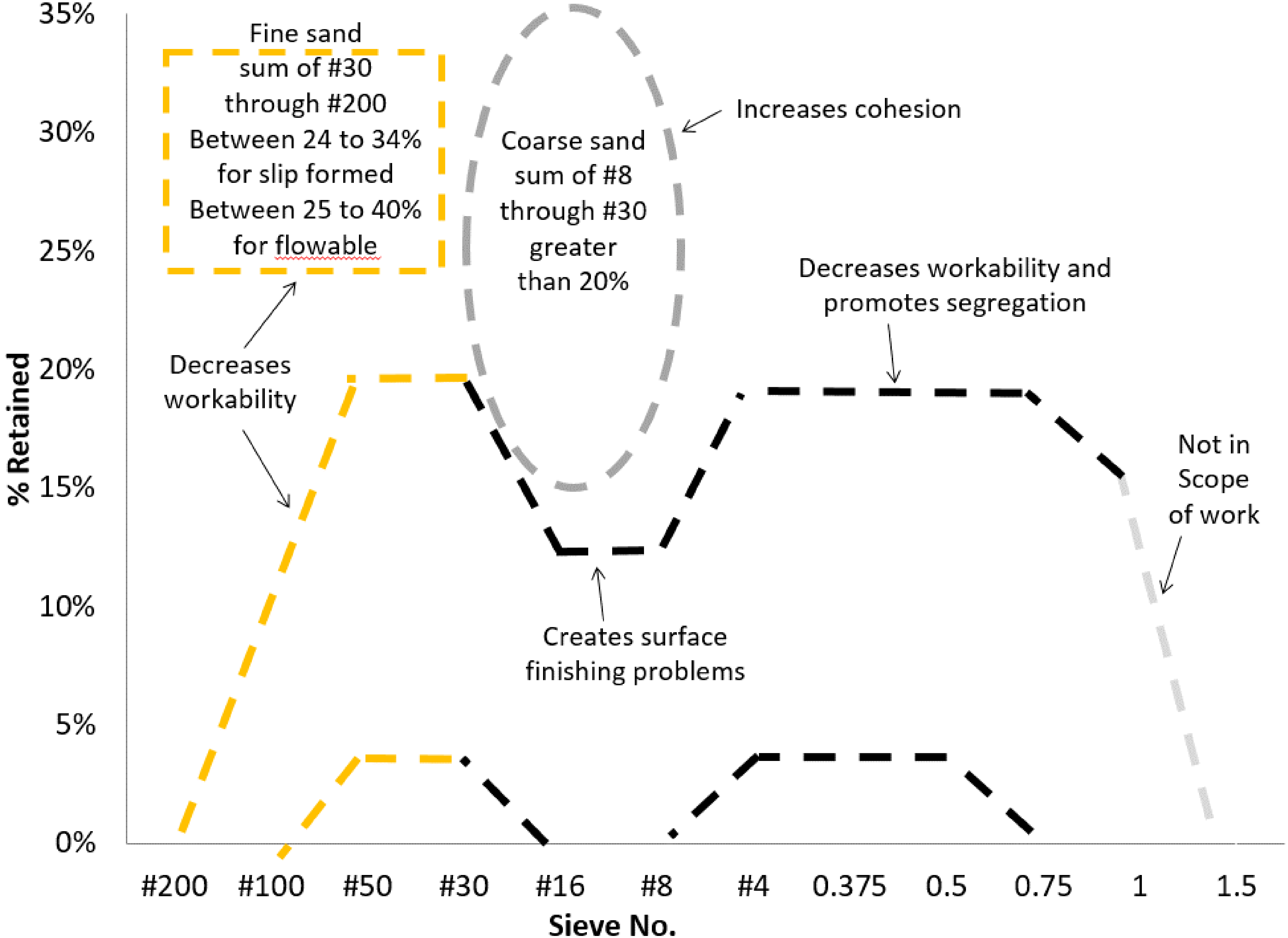
Coarse Sand-Poor Cohesion

Mostly Coarse Aggregate!

Mostly Paste!

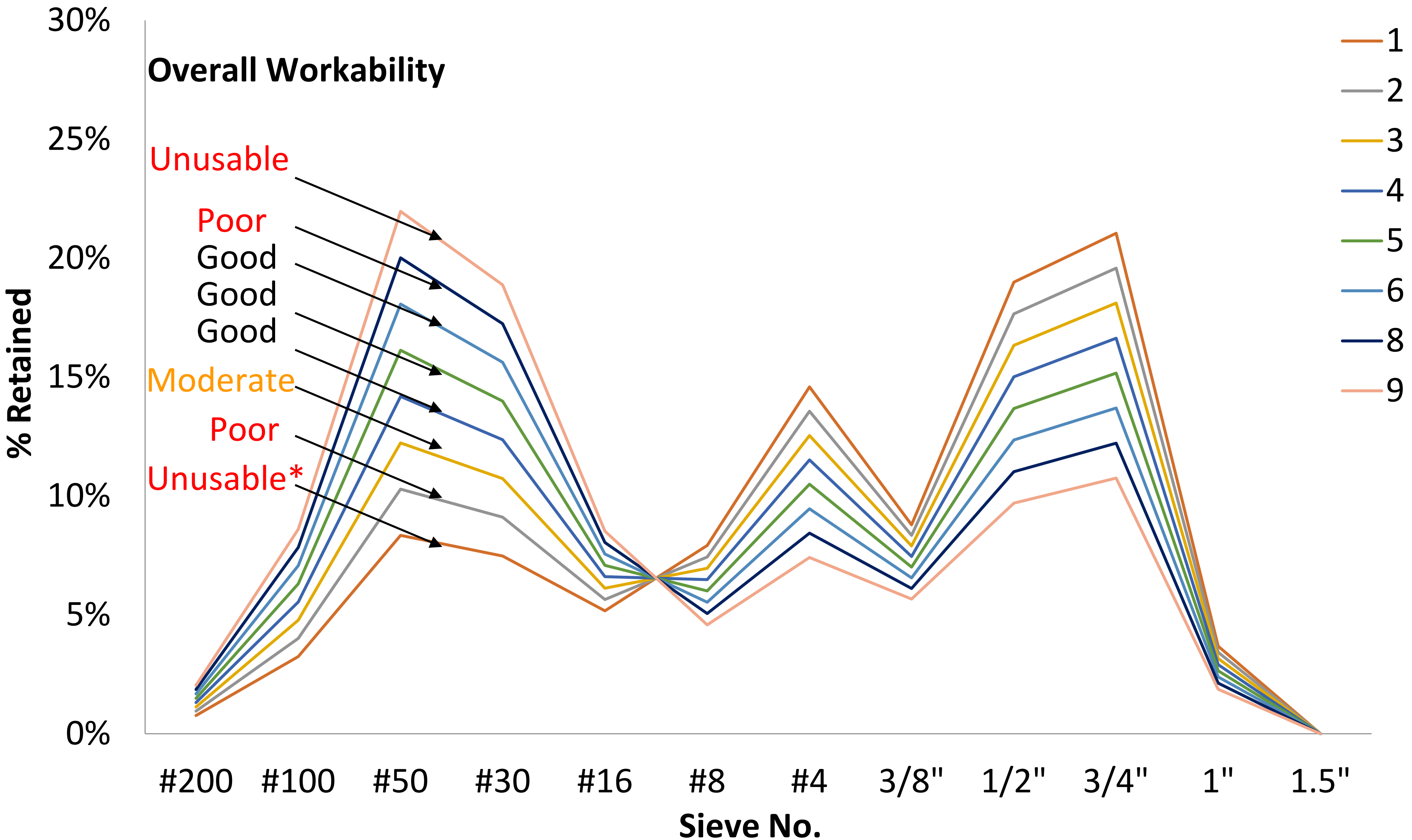
Discussion of Coarse Sand

- For cohesion, a minimum of **20%** retained on the #8-#30 sieve sizes was needed.
- Finishability issues created a maximum boundary limit on # 8 & #16 of **12%** on each sieve size.



35%
30%
25%
20%
15%
10%
5%
0%
% Retained
Fine sand
sum of #30
through #200
Between 24 to 34%
for slip formed
Between 25 to 40%
for flowable
Coarse sand
sum of #8
through #30
greater
than 20%
Increases cohesion
Decreases workability and
promotes segregation
Decreases
workability
Not in
Scope
of work
Creates surface
finishing problems
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

Fine Aggregate Proportioning



From the Slump Test

Excessive Sand

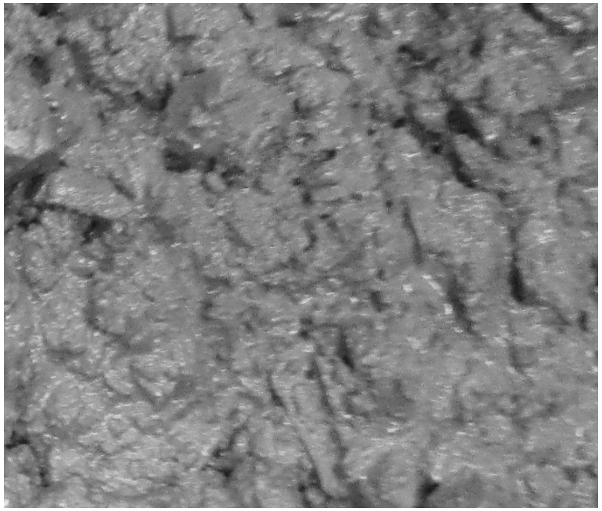
Sufficient Sand

Deficient Sand

Visual Observations

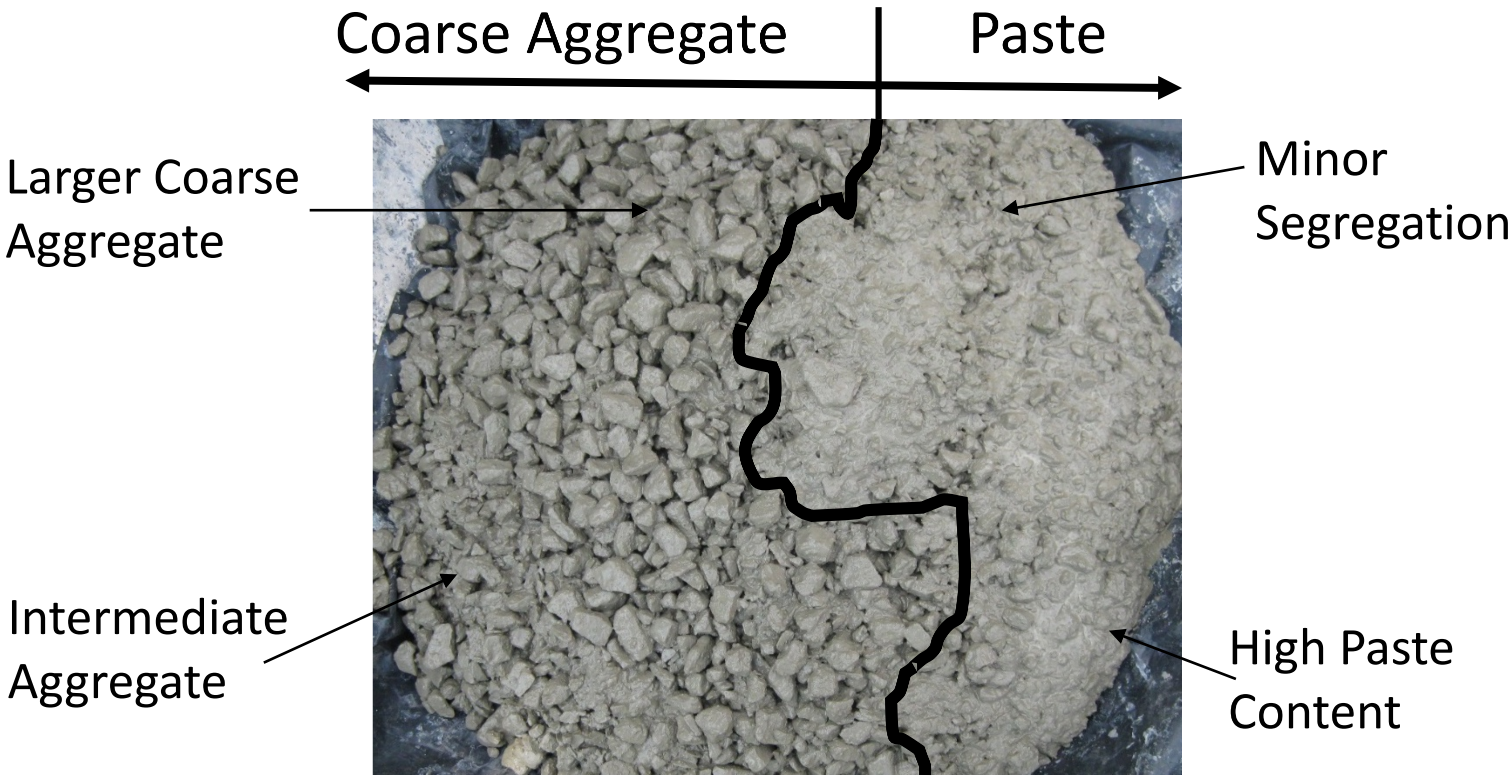
Excessive Sand

Sufficient Sand

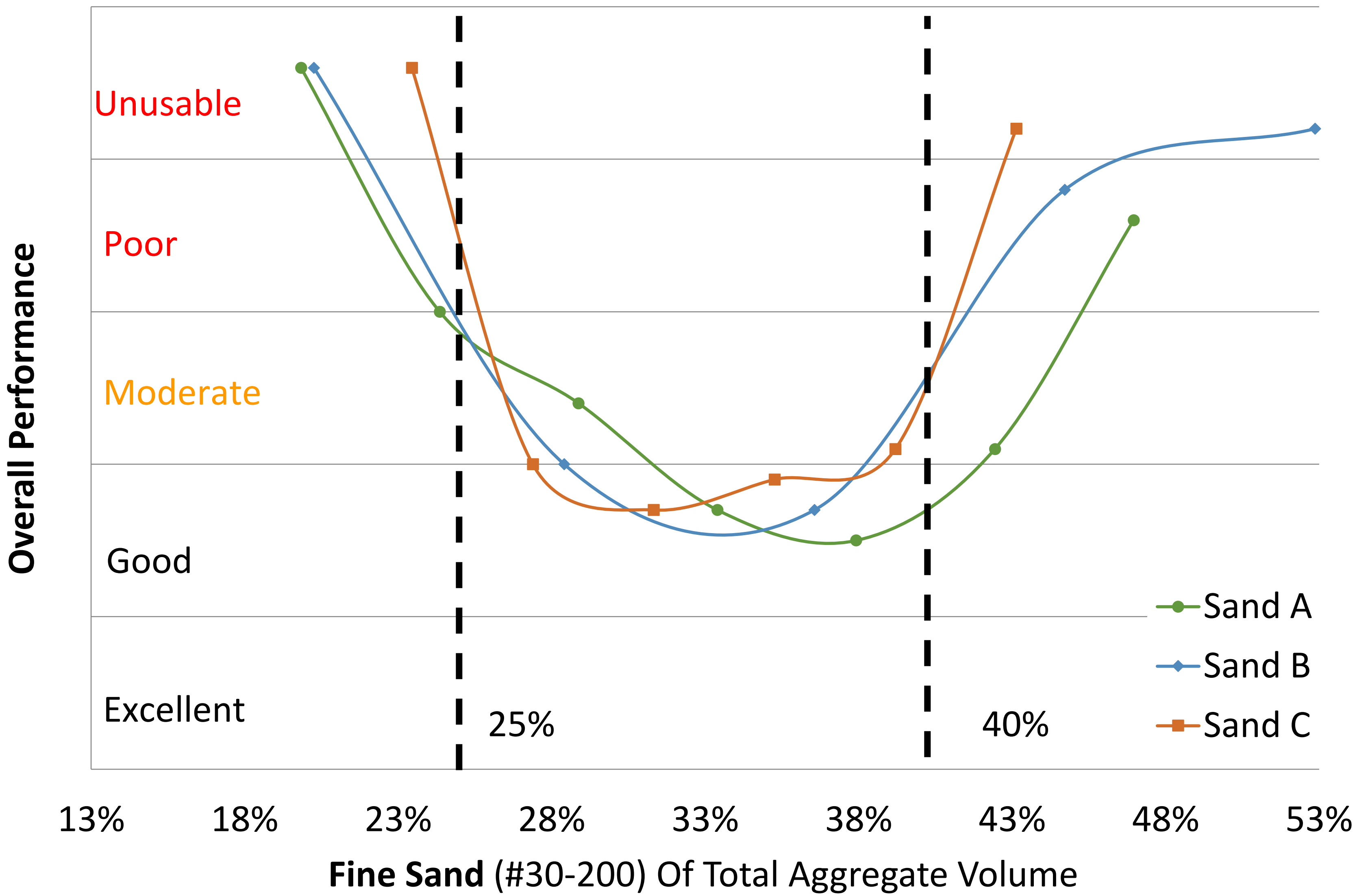


Deficient Sand

Lack of Cohesion aka Segregation



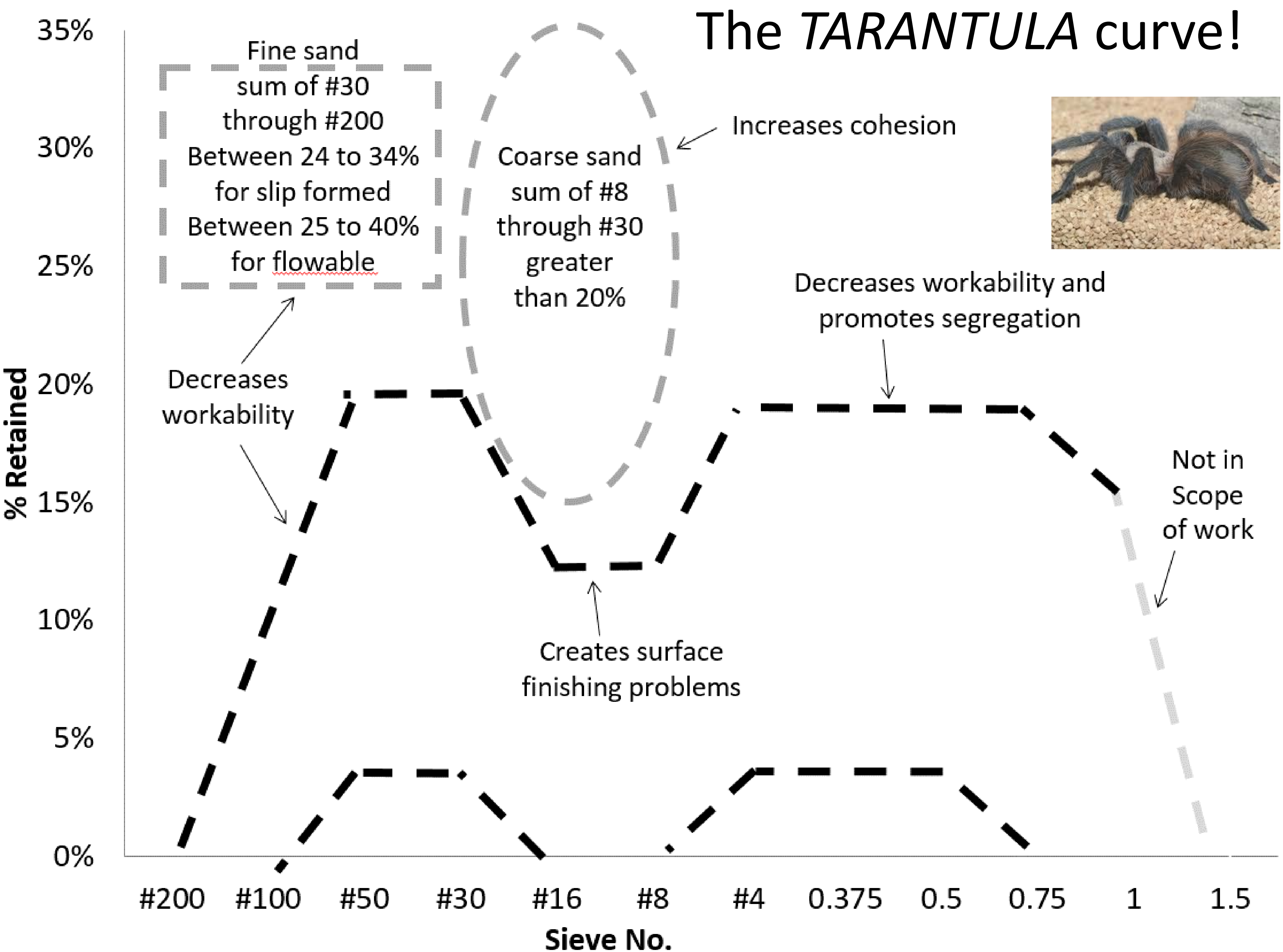
Developing a Fine Sand Range



Summary of Fine Sand (#30-200)

- The distribution of fine sand can vary largely without effecting the workability.

- The volume of fine sand can be:
  - between 25% to 40% for flowable concrete
  - between 24% to 34% for slip formed
  - Slip forming needs more cohesion

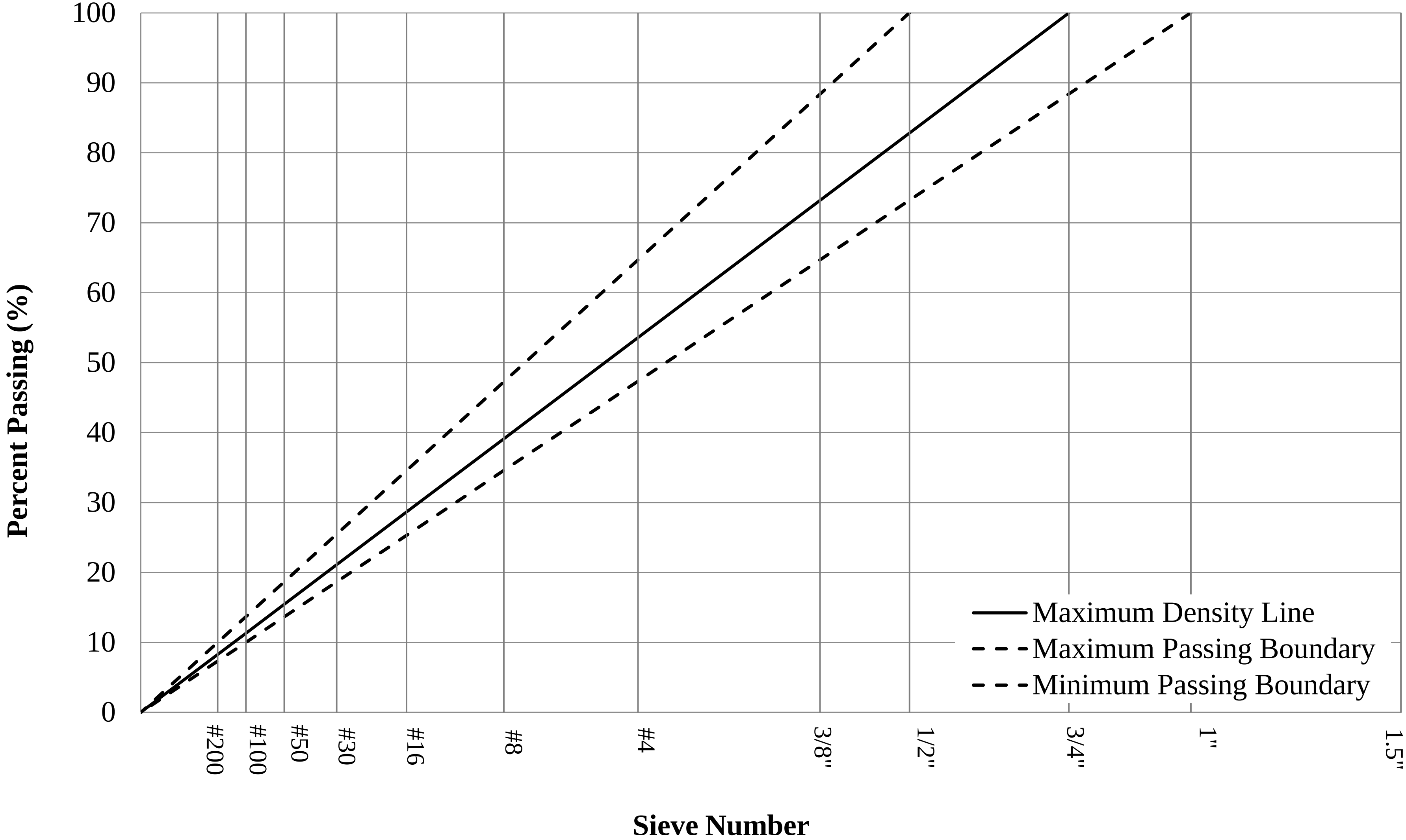


The TARANTULA curve!
35%
30%
25%
20%
15%
10%
5%
0%
% Retained
Fine sand
sum of #30
through #200
Between 24 to 34%
for slip formed
Between 25 to 40%
for flowable
Coarse sand
sum of #8
through #30
greater
than 20%
Increases cohesion
Decreases workability and
promotes segregation
Decreases
workability
Not in
Scope
of work
Creates surface
finishing problems
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

What about other mixture procedures?

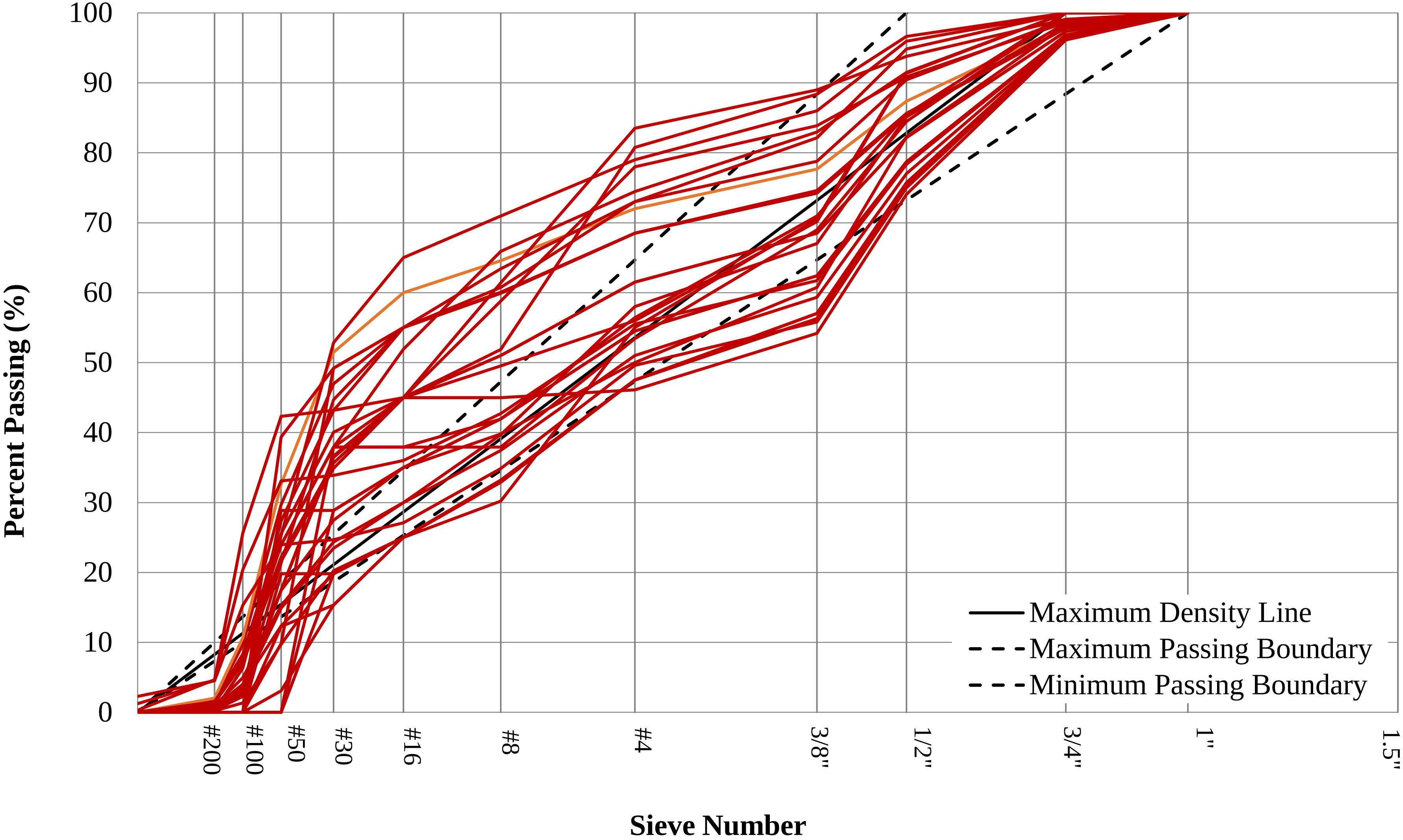
- Power 45
- Coarseness Factor

Power 45

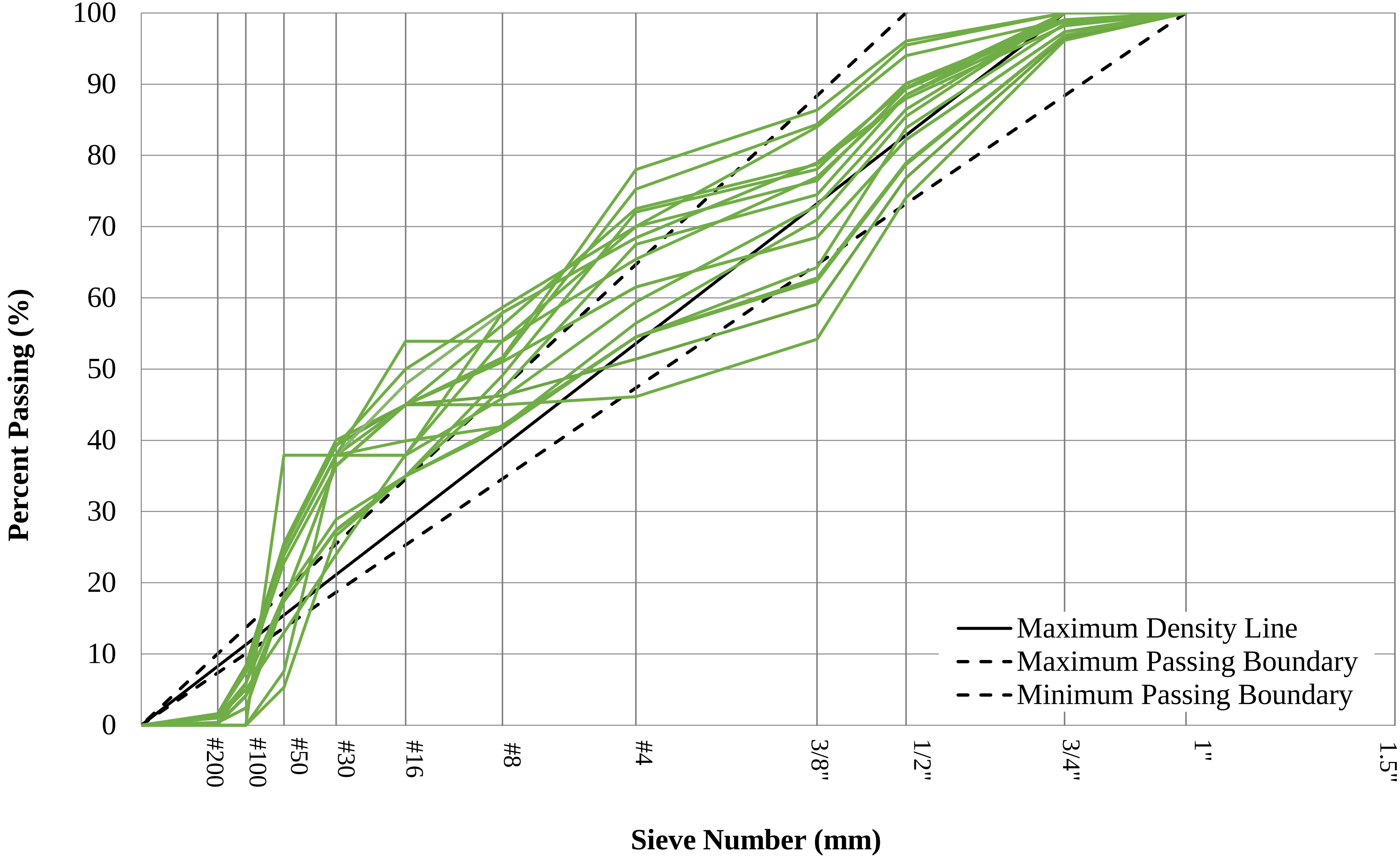


Percent Passing (%)
100
90
80
70
60
50
40
30
20
10
0
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve Number
Maximum Density Line
Maximum Passing Boundary
Minimum Passing Boundary

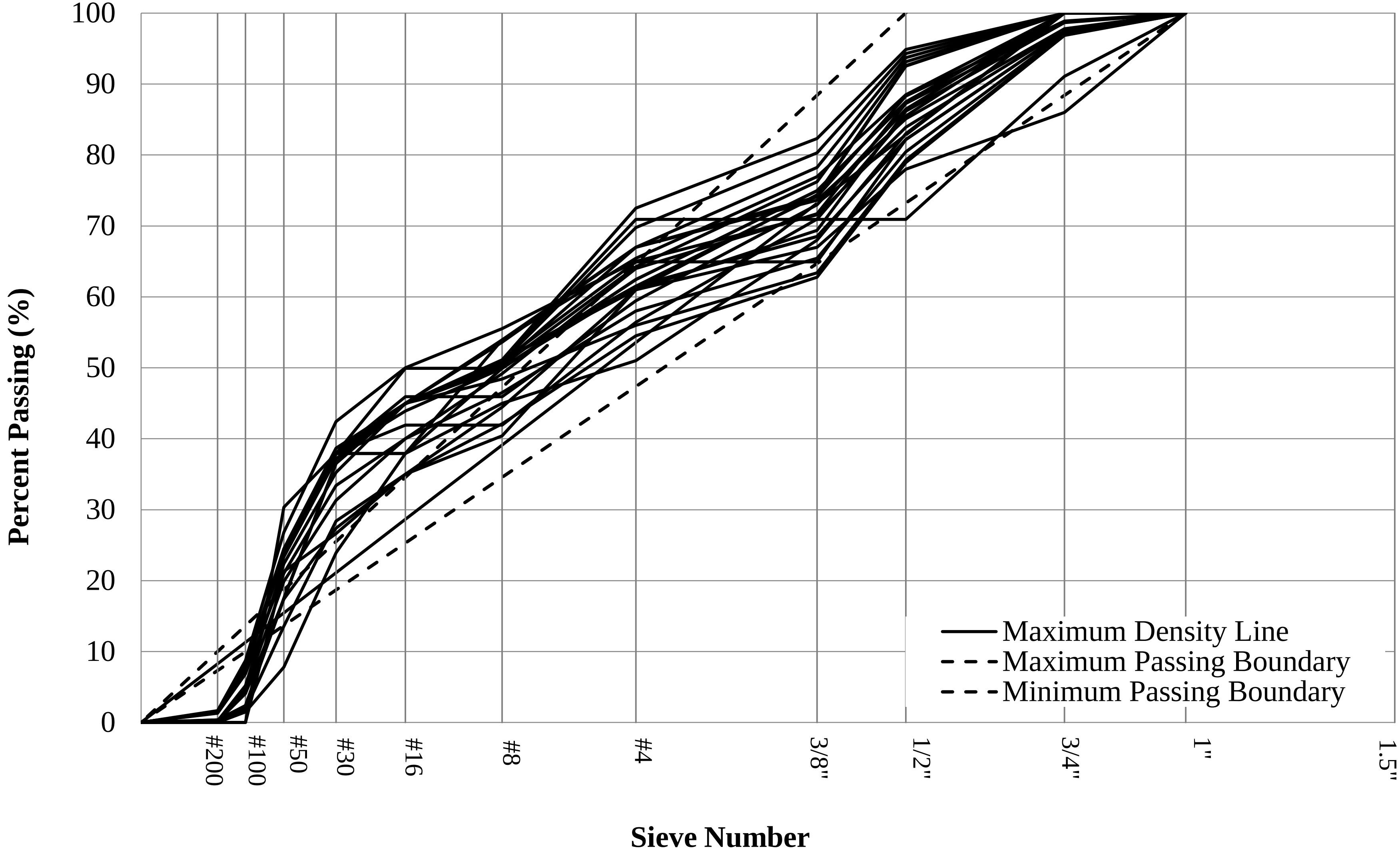
Power 45-Poor Workability



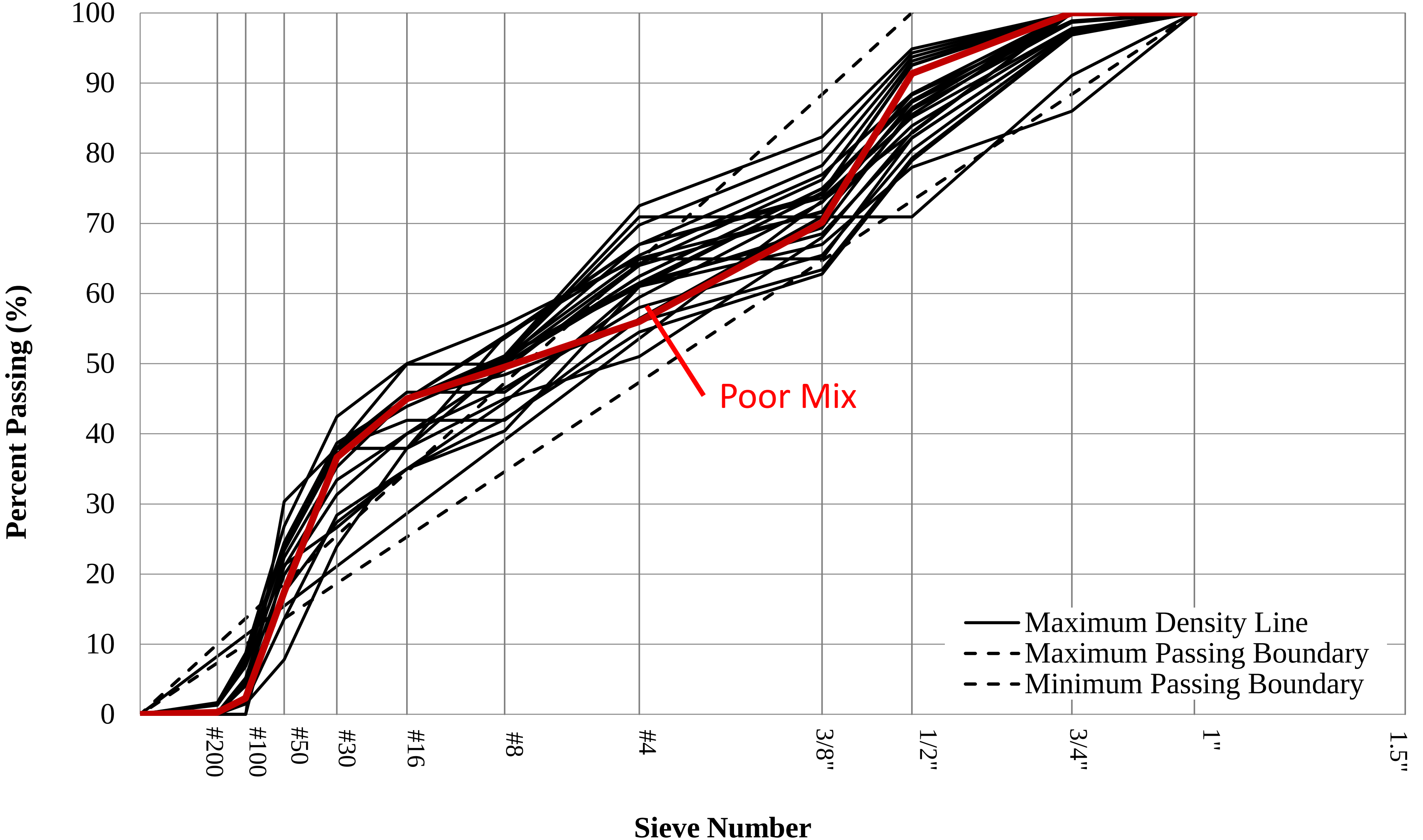
Power 45-Moderate Workability



Power 45-Good Workability



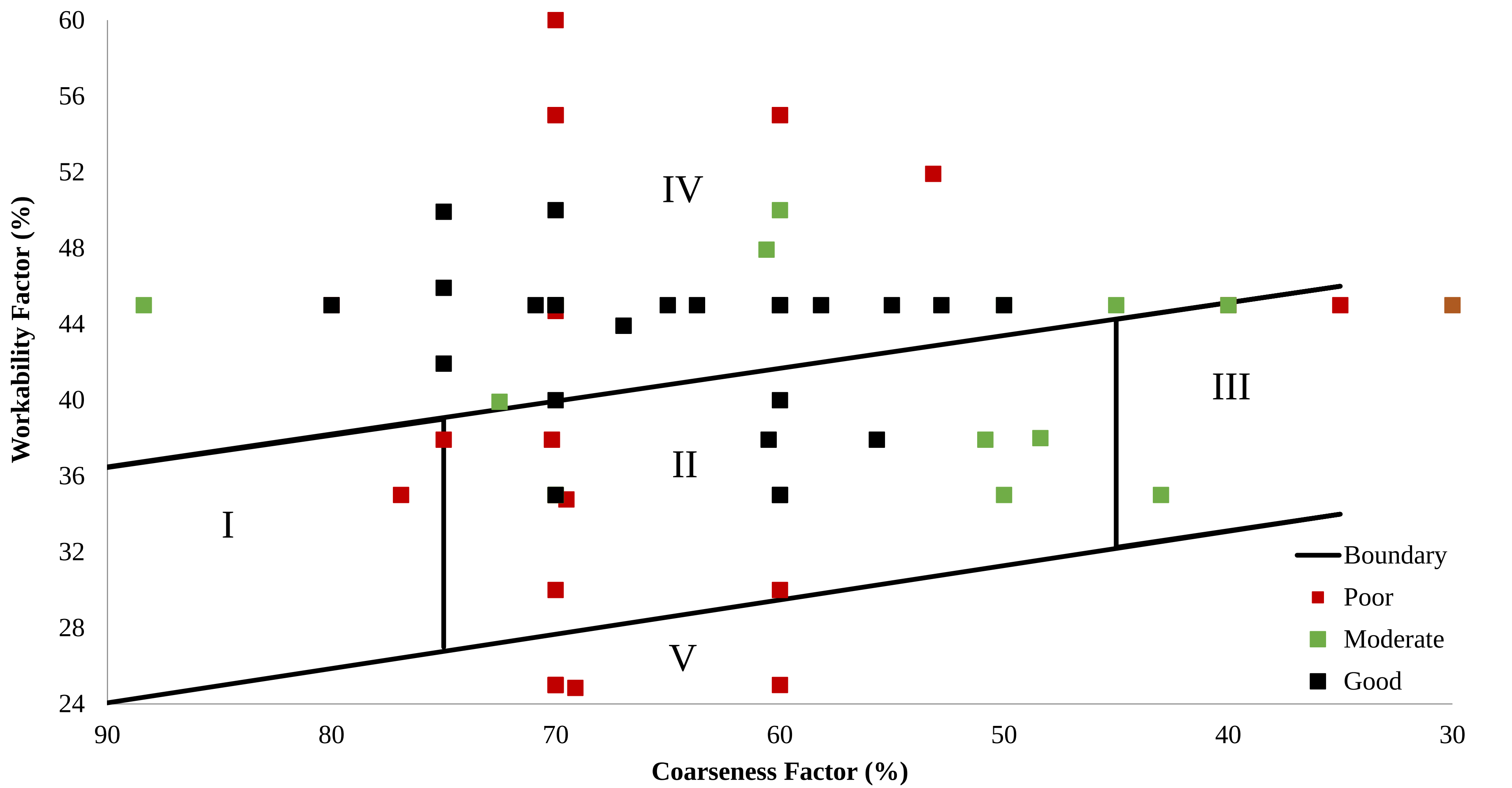
Where is the Detail?



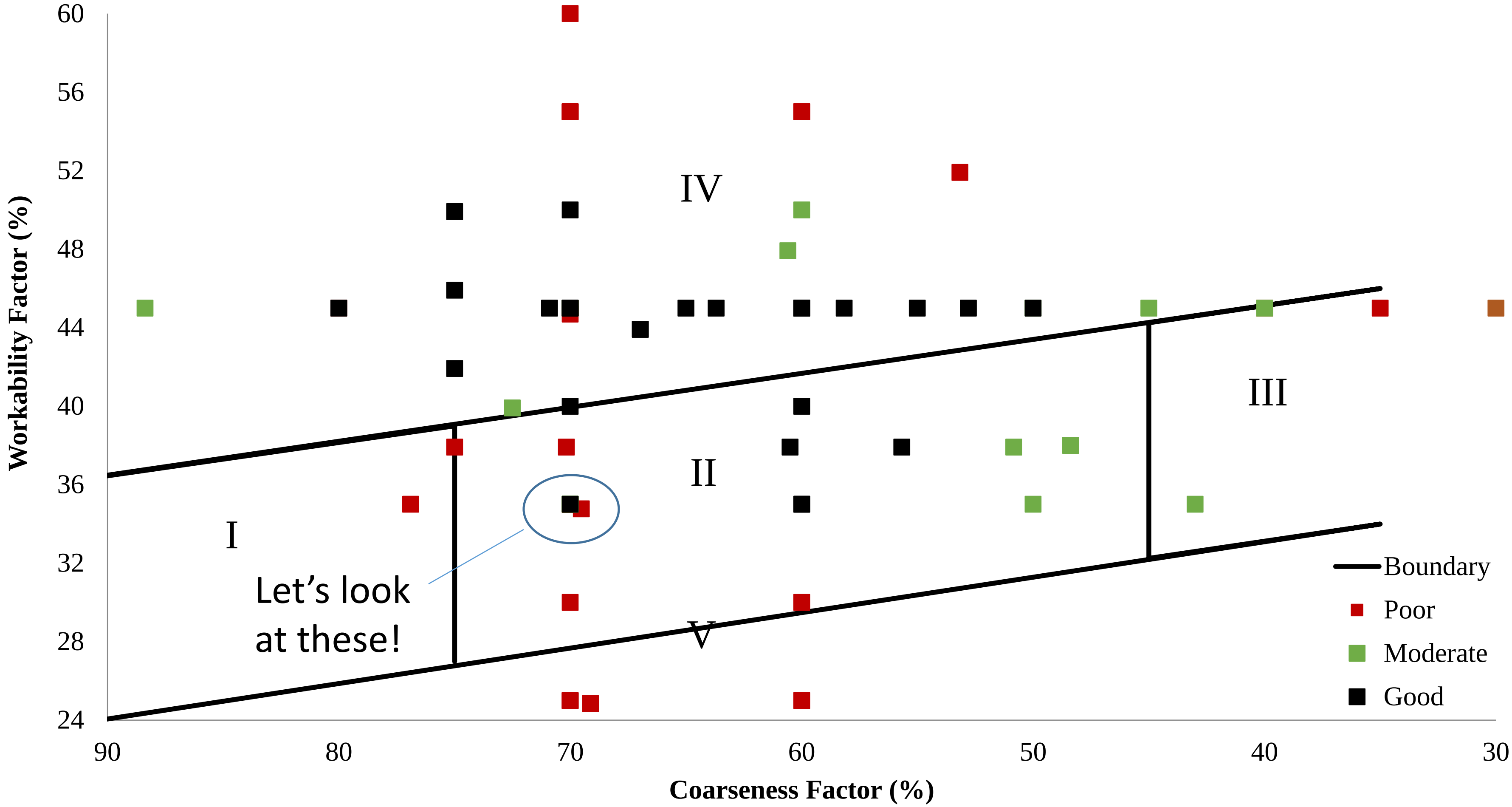
Summary Of Power 45

- At first glance, the Power 45 has the potential to be helpful.
- Using a best fit line on the Power 45:
  - Just does not show enough detail to the changes in slope of the gradation line.
  - Does not address the volumes ranges of fine and coarse sand.
- We think the Tarantula Curve is more intuitive.

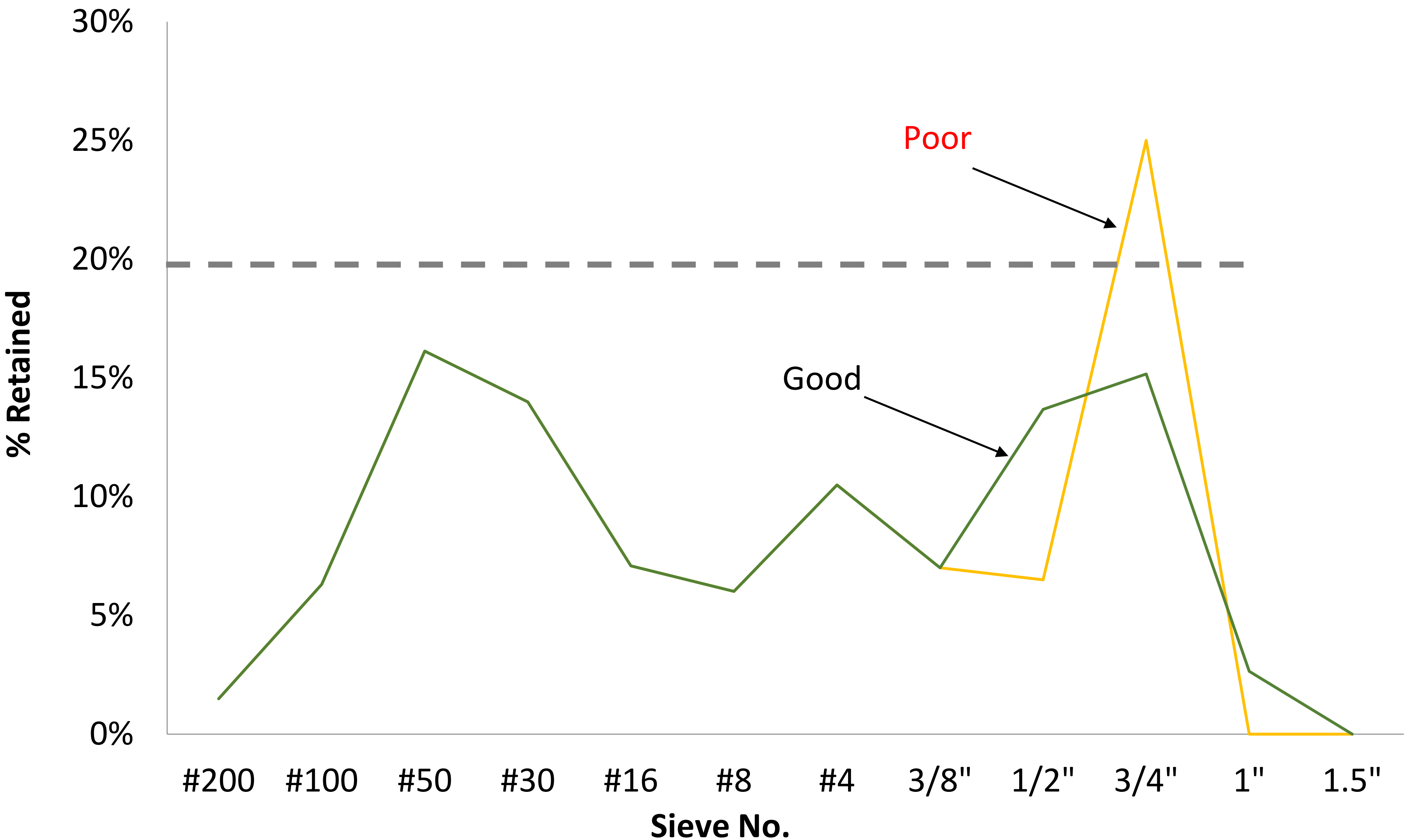
Coarseness Factor Chart



Coarseness Factor Chart



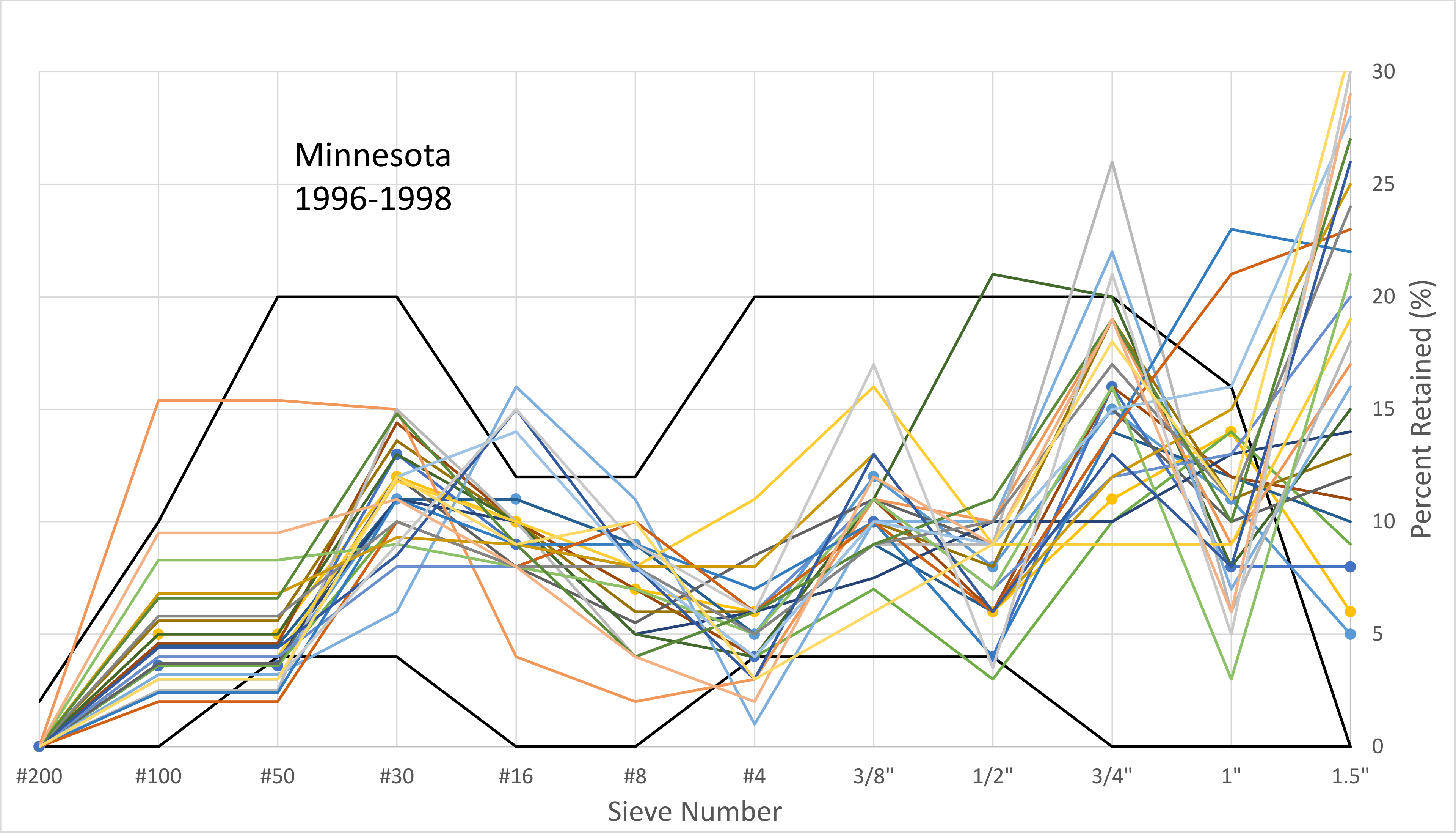
Same Points, But Different Results



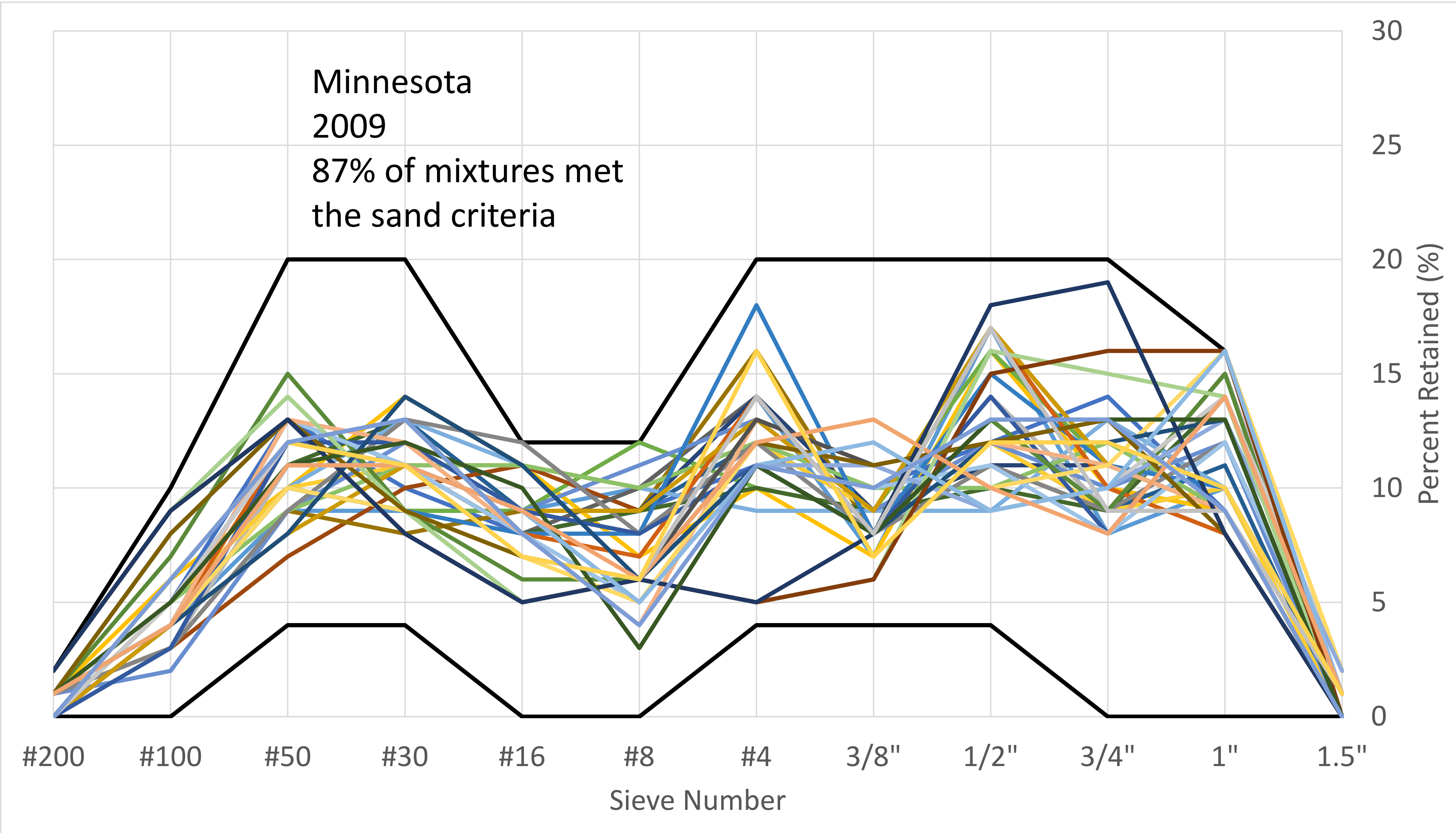
Summary

- The limits in the Coarseness Factor Chart do not always produce mixtures with satisfactory workability.
- The Coarseness Factor and Workability Factor equations were a good start but they are too basic.

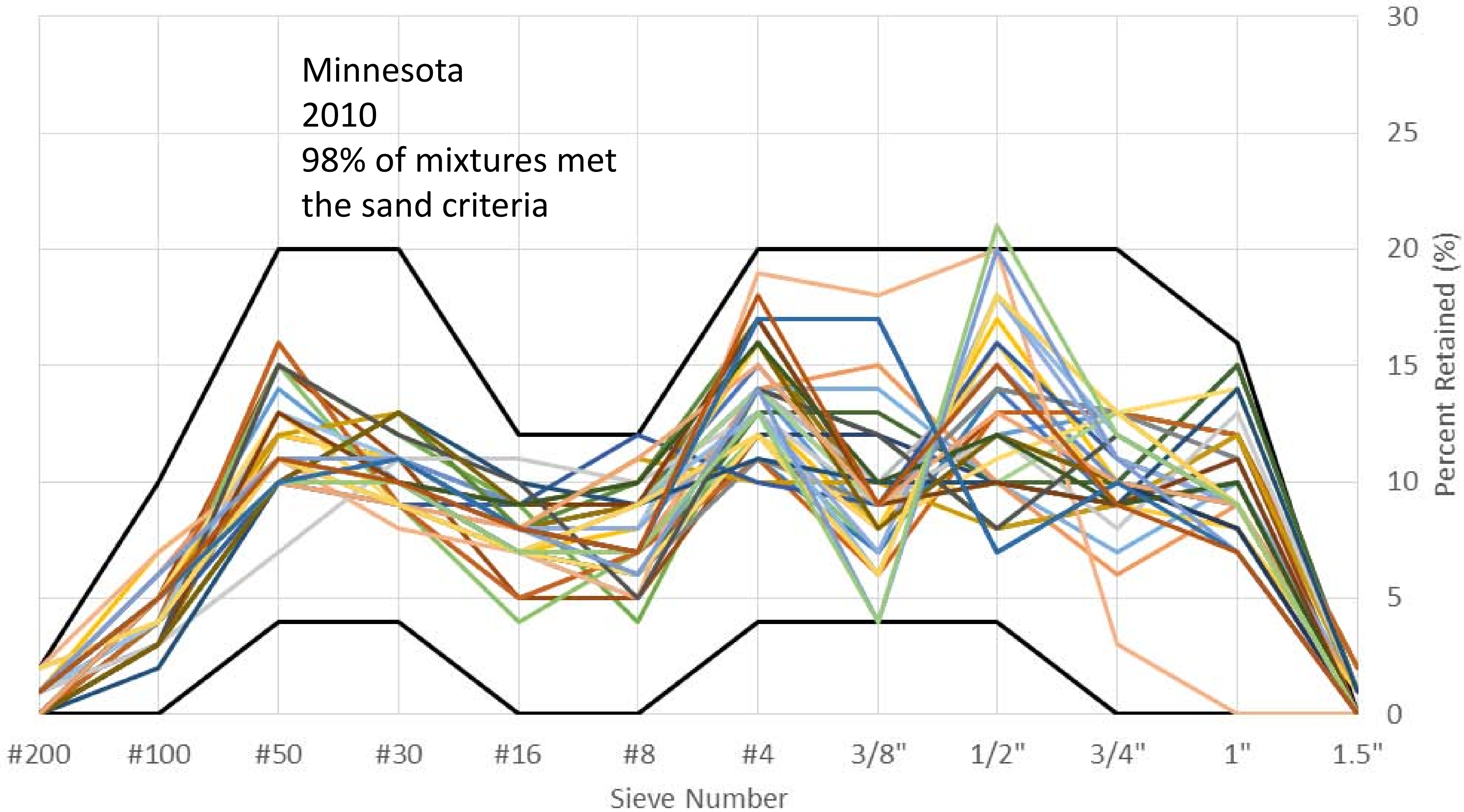
Use in the field



Data from Maria Masten



Data from Maria Masten



Data from Maria Masten

Field Concrete

The Minnesota contractors are producing gradations that fit within the Tarantula and having good success with them

They are doing this with trial and error and no knowledge of the Tarantula Curve

As more mixtures entered the Tarantula Curve the smoothness of the pavement increased

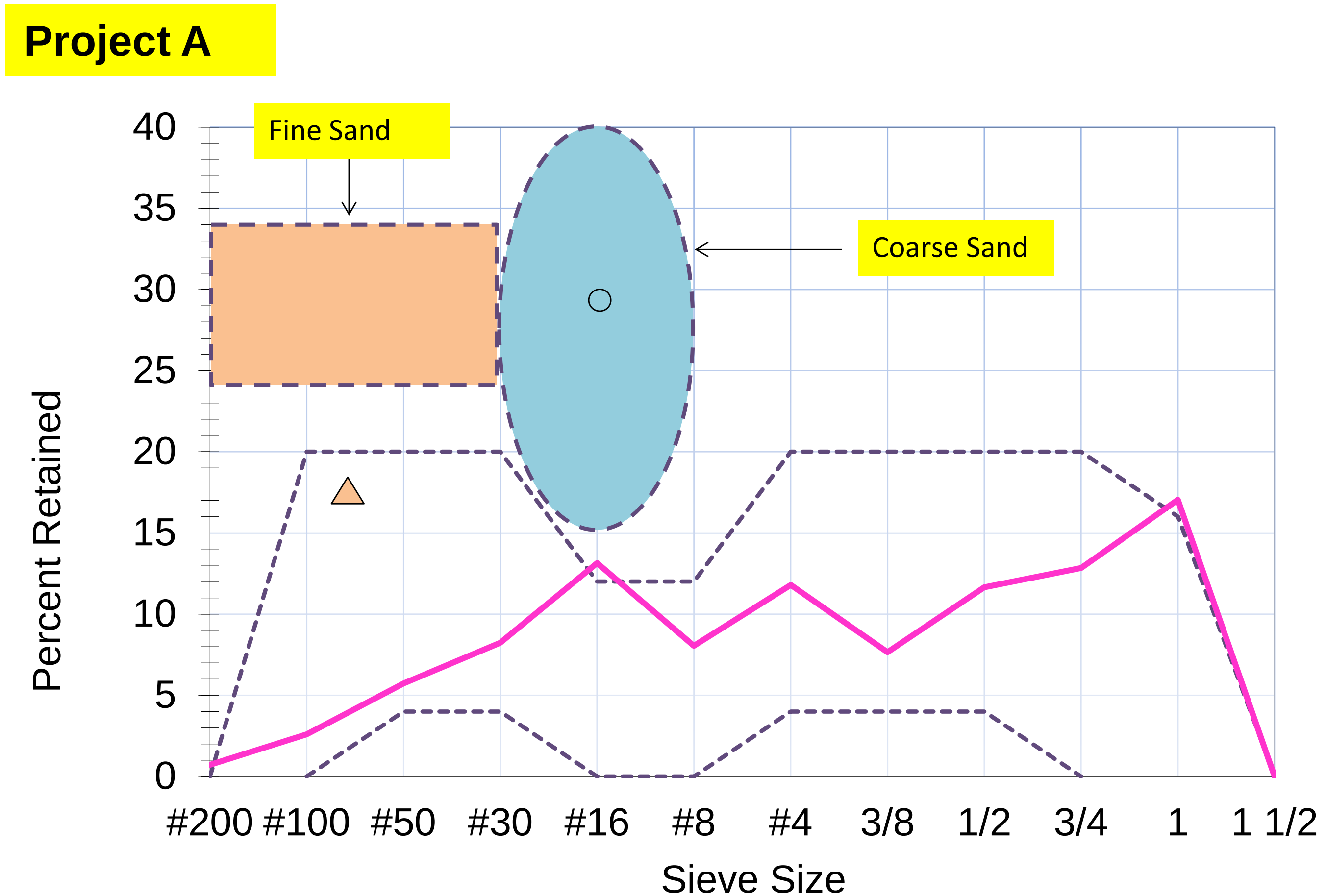
Oklahoma, Minnesota, Texas, and Pennsylvania have integrated the Tarantula Curve into their specifications

Data from the FHWA Mobile Concrete Lab

- Slides from Jagan Gudimettla

Images from Jagan Gudimettla

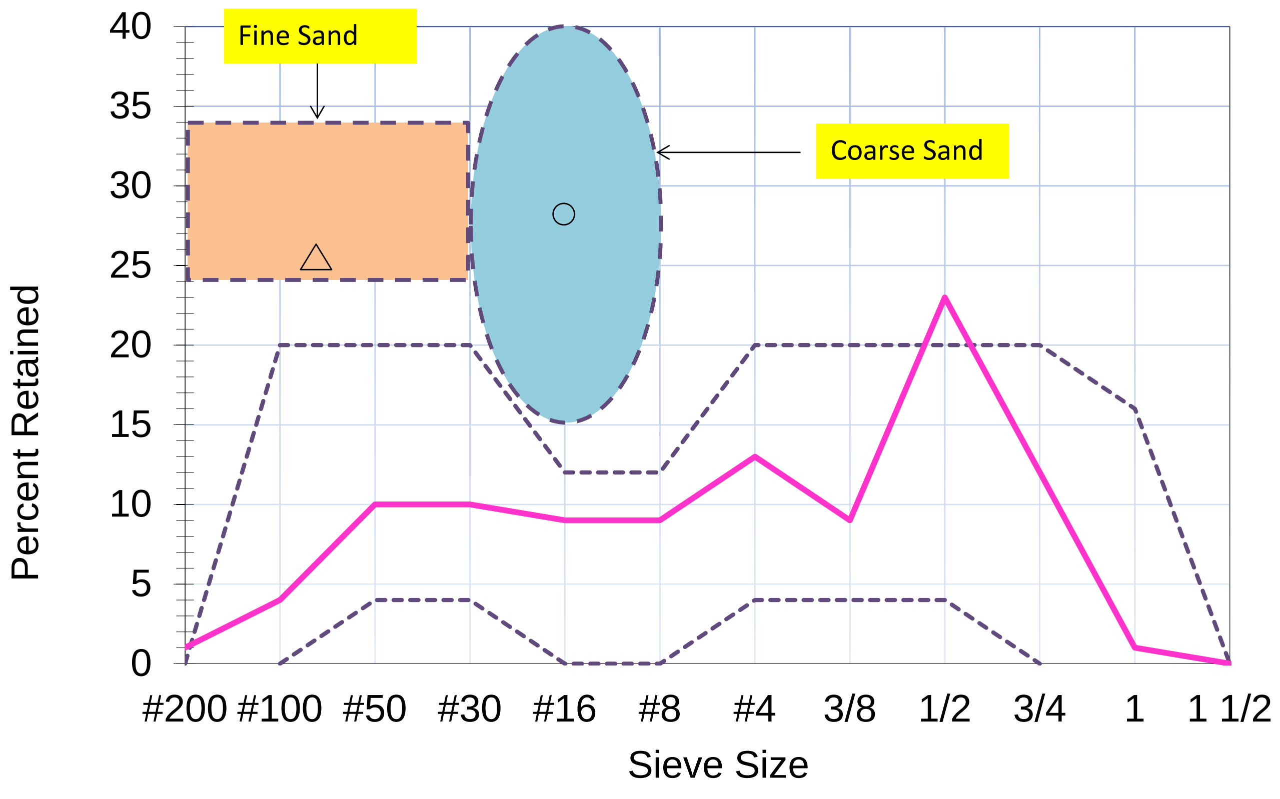
Tarantula Curve



Images from Jagan Gudimettla

Images from Jagan Gudimettla

Tarantula Curve



Images from Jagan Gudimettla

How can you troubleshoot aggregate gradation?

Pay attention to how your concrete changes with a new delivery of rock.

Know where your sieve analysis is when you start a project and then monitor how it changes.

Use the spreadsheet in the handout and website to plot your mixtures in the Tarantula Curve

Talk to your supplier and keep in constant contact with them.

How do I get my mixture into the Tarantula Curve?

You usually need at least three different sizes of aggregates to get within the Tarantula Curve.

Coarse aggregate

Intermediate aggregate

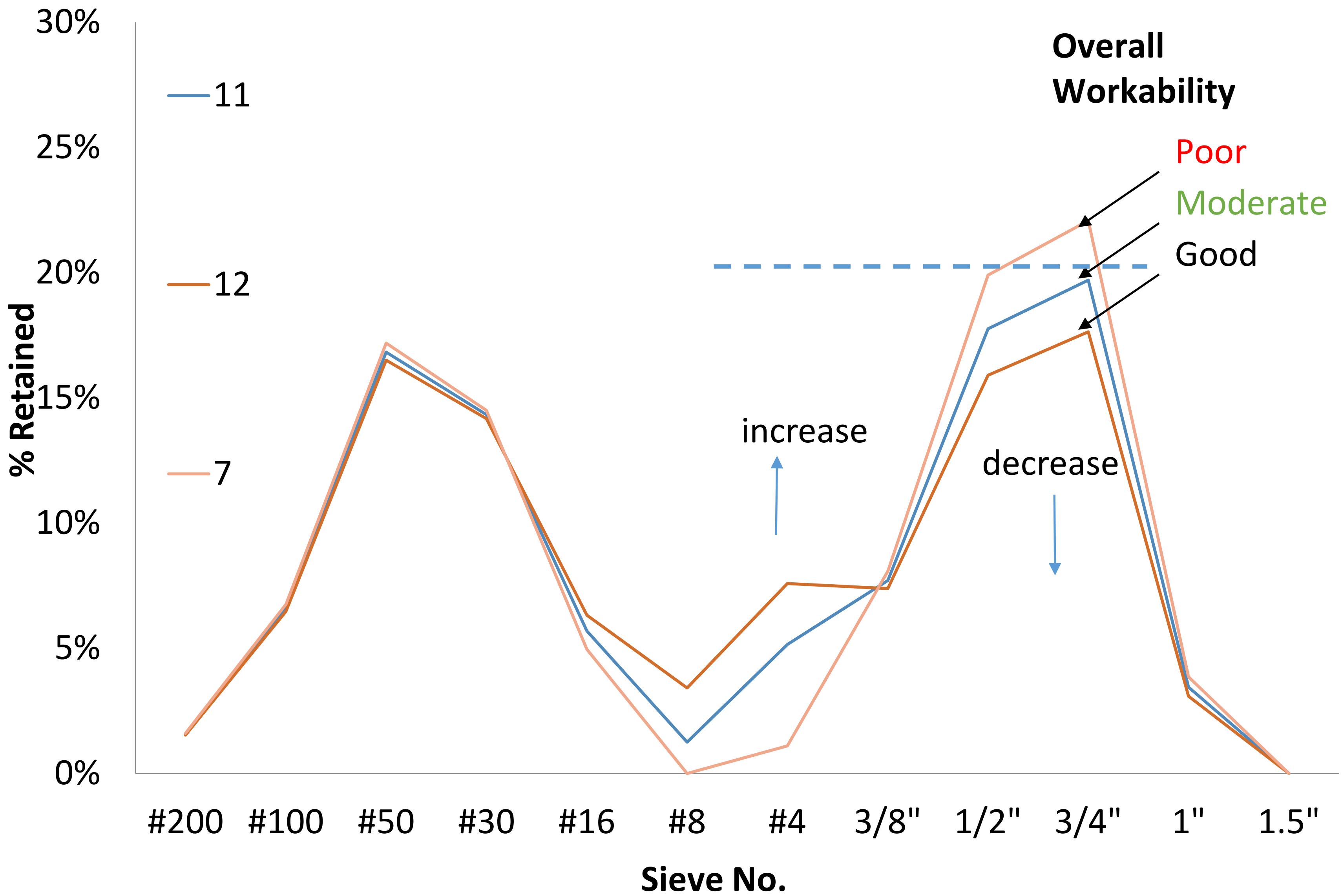
Fine aggregate

How do I get my mixture into the Tarantula Curve?

You usually need at least three different sizes of aggregates to get within the Tarantula Curve.

- Coarse aggregate
- Intermediate aggregate
- Fine aggregate

If you are out on one area then use the other two to bring it back.



30%
25%
20%
15%
10%
5%
0%
% Retained
11
12
7
Overall
Workability
Poor
Moderate
Good
increase
decrease
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.

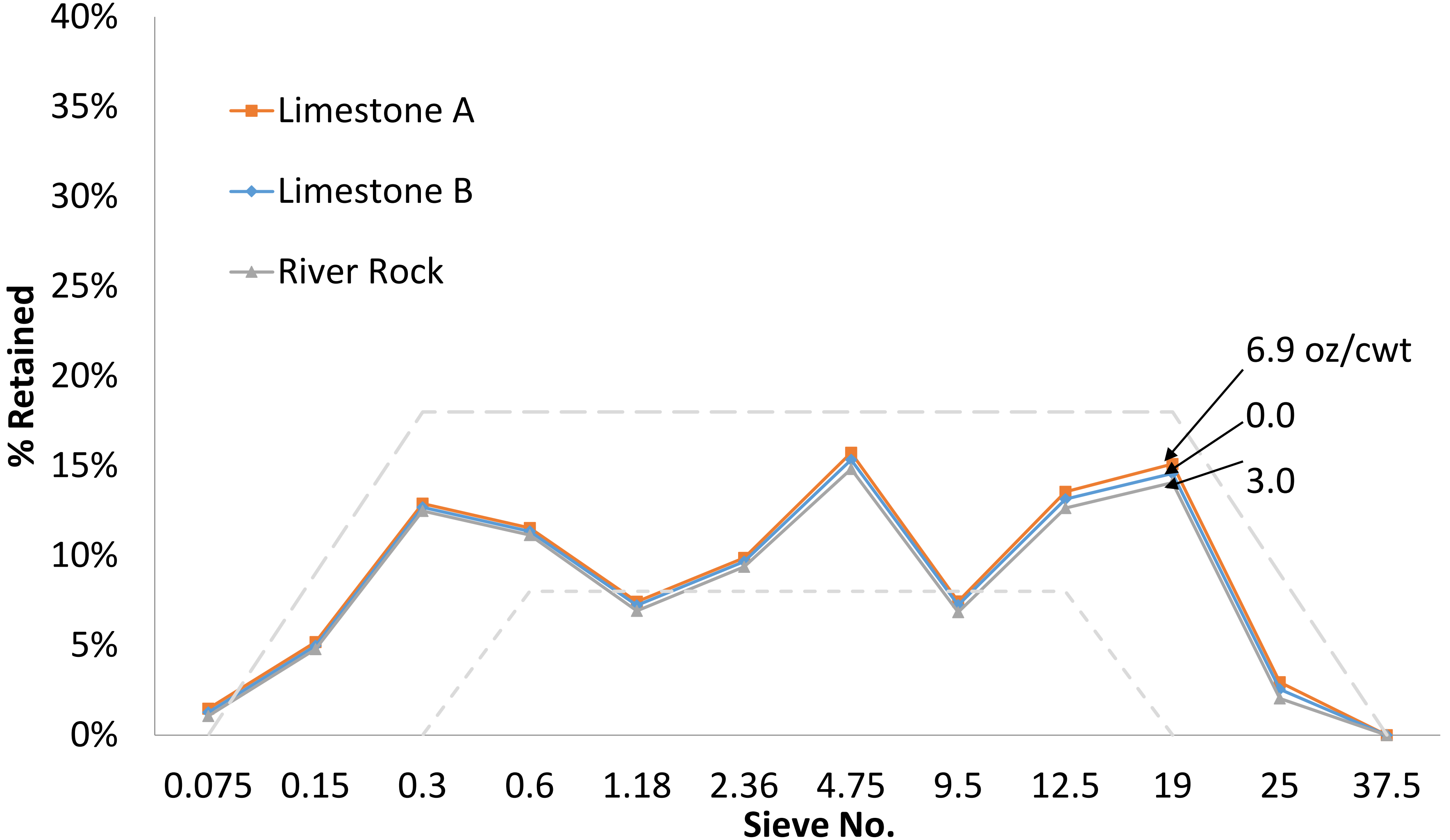
Do my mixtures have to be within the Tarantula Curve?

No!

But you may need more paste (binder + water) if you are out.

This usually means more cost and greater risk for cracking.

What about aggregate shape?

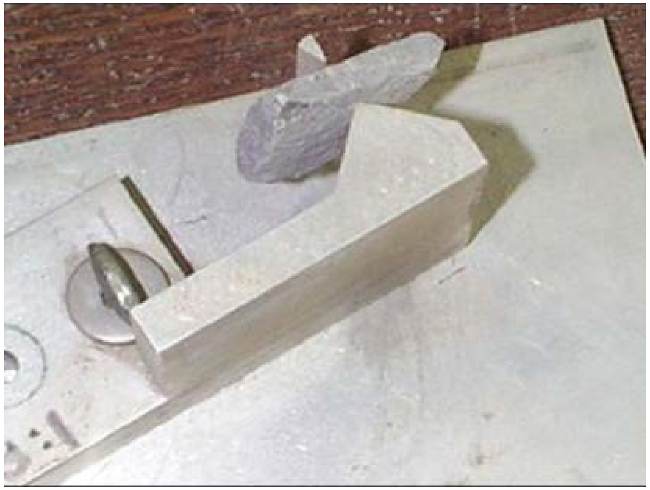


Why is the WR dosage different?

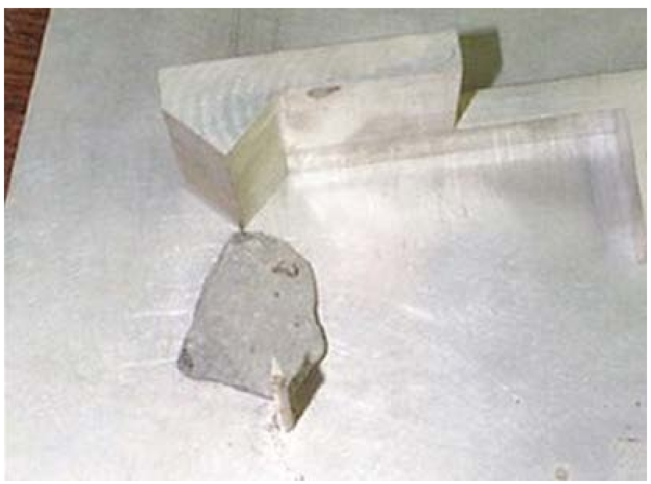
0.0 oz/cwt	3.0 oz/cwt	6.9 oz/cwt
		
Crushed Limestone B Cubic Shaped Medium Angular Low Texture	Crushed Gravel Slightly Flat Shaped Low Angular Low Texture	Crushed Limestone A Flat Shaped Medium Angular Medium Texture

ASTM D4791

Measures flatness, elongation, and overall shape of a particle.



Min dimension



Max dimension

Min/Max = flatness ratio

If less than **15**% of your particles have a flatness ratio of **1:3** then this will improve your workability.

How do dirty aggregates impact the results?

Dirty aggregates reduce your workability.

These mixtures typically require a high paste content.
This again can increase the cost of your mixture.

Is there an easy way to compare this?

Fill mason jar half ¾ full of aggregate.
Add water until full.

Shake for three minutes.

Look at how clean the water is.

Do this at the beginning of the project and compare to new shipments

Photo from Dan Cook

What is next?

- We are working on using the Tarantula Curve for manufactured sand
- Using our concrete pump to look at impacts on air void system
- Using our X-ray CT scanner to look at 3D aggregate and air void distribution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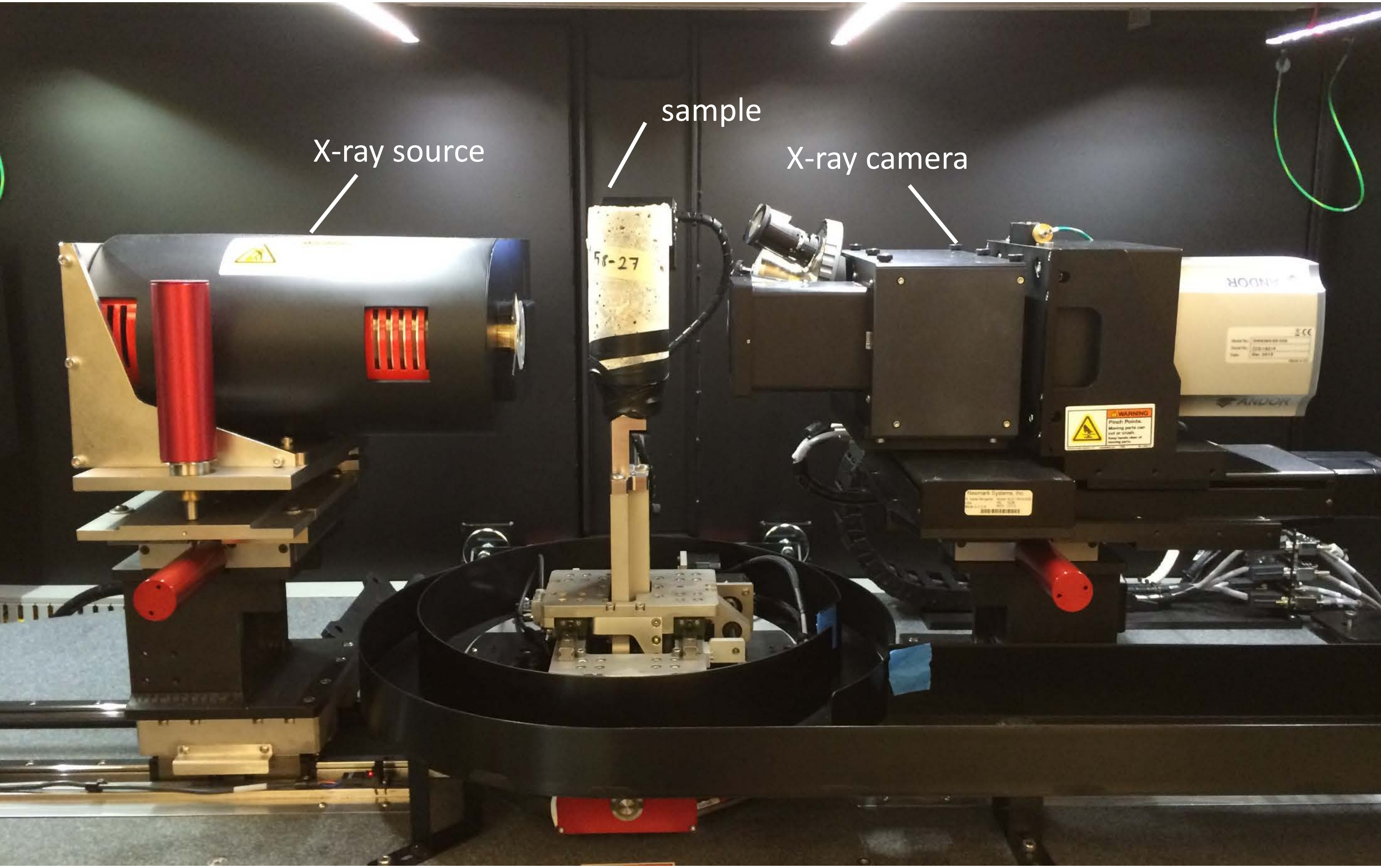
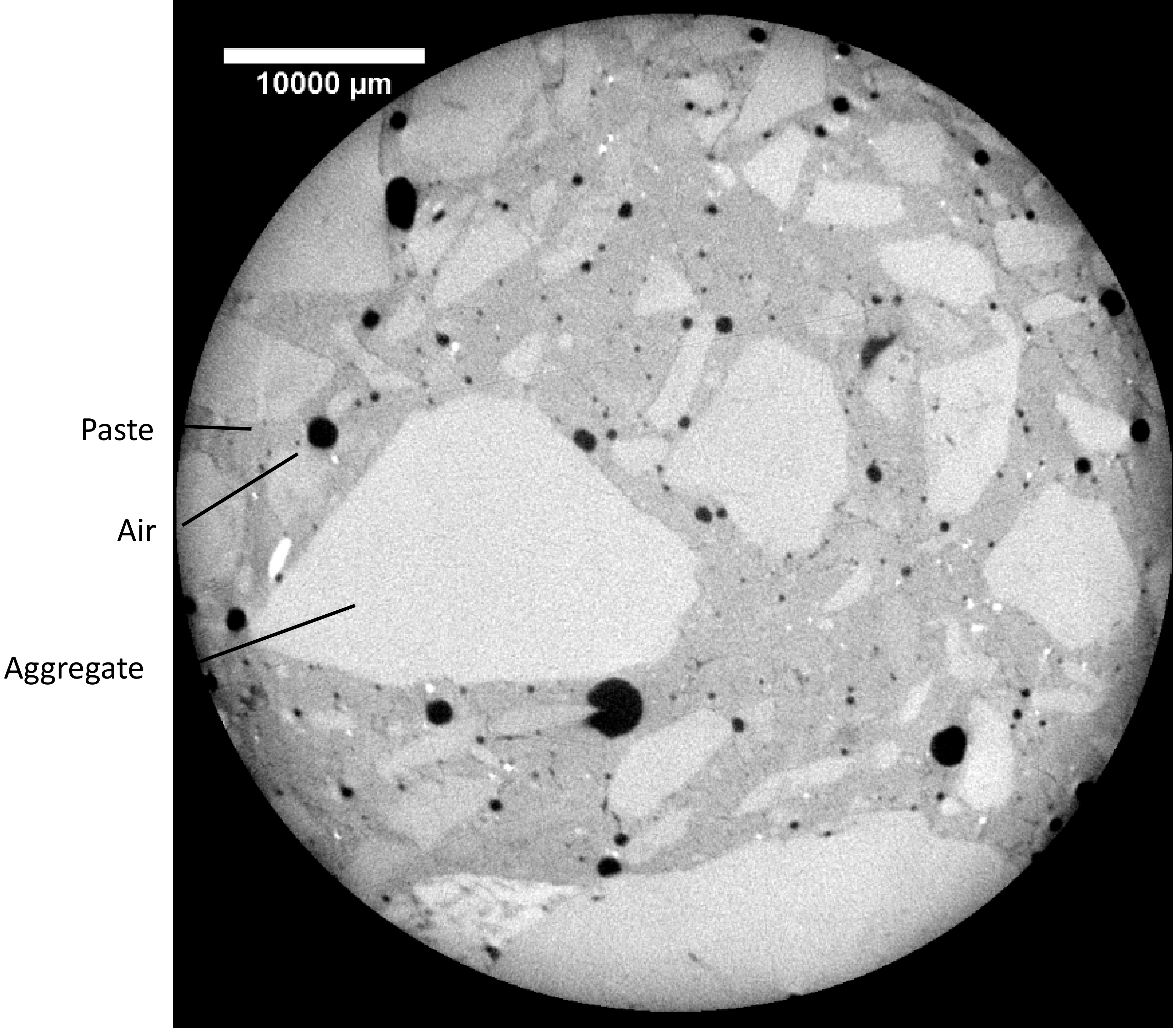
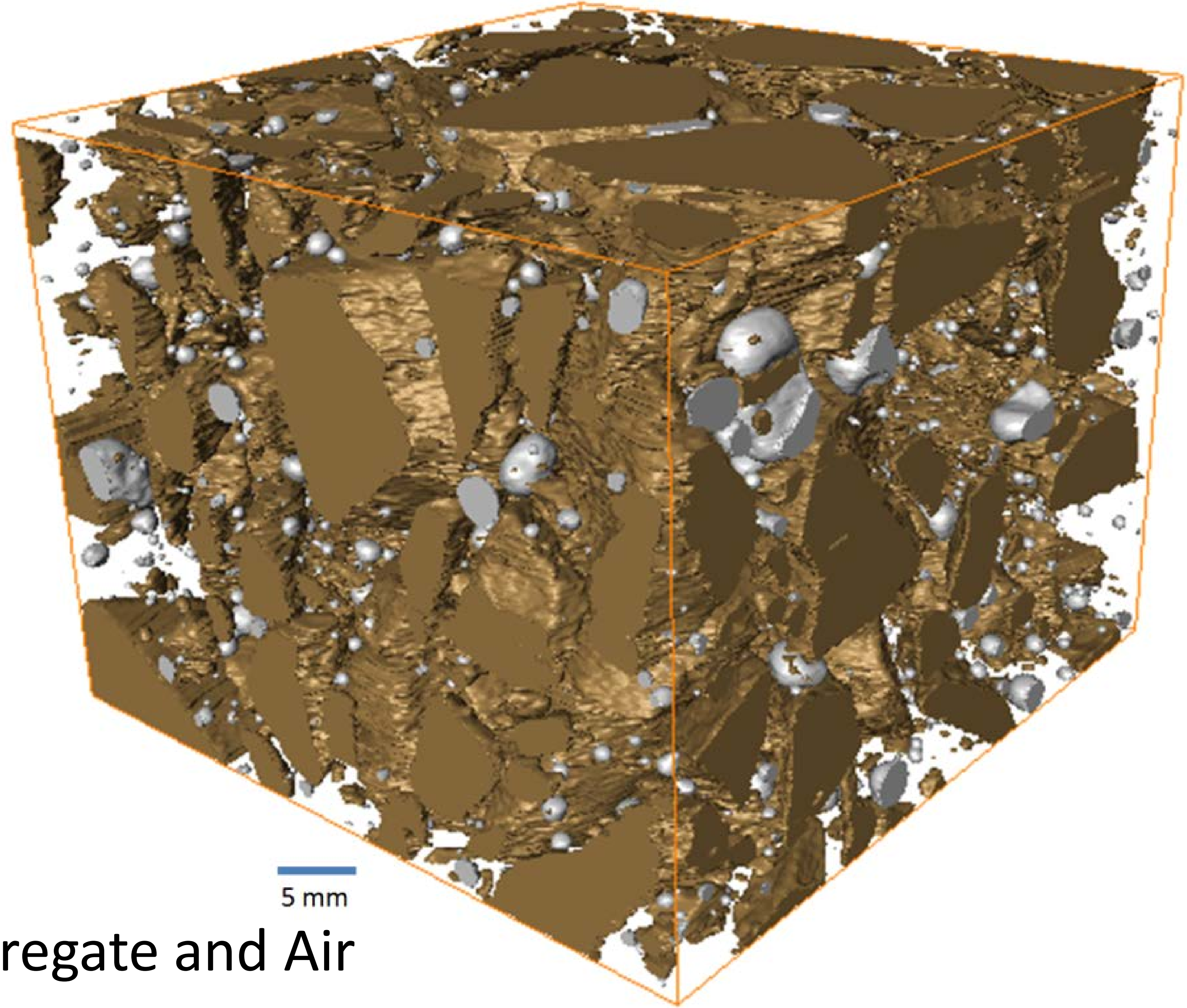
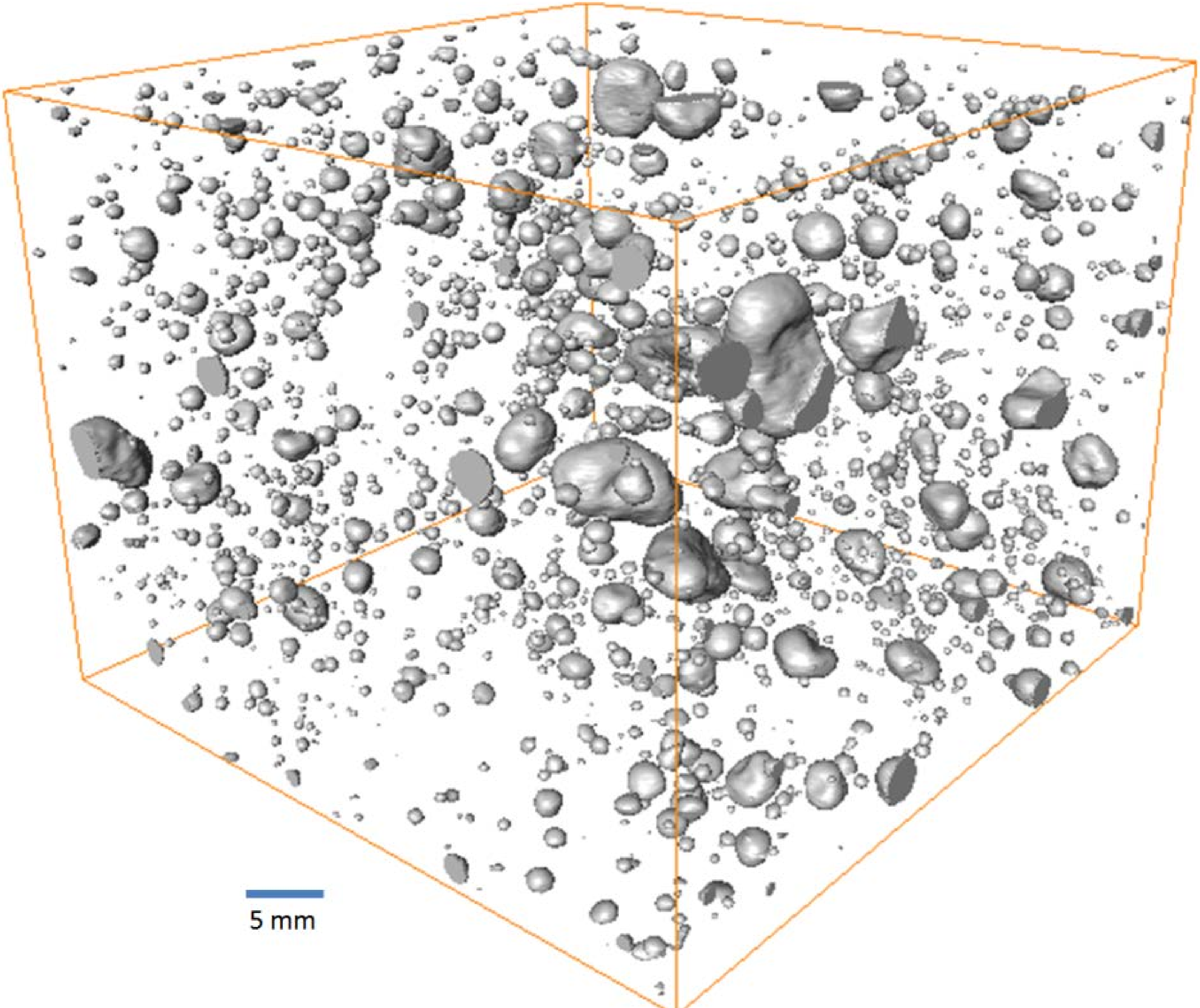
ZEISS
Xradia 410 Versa
EMO


sample
X-ray source
X-ray camera
58-27

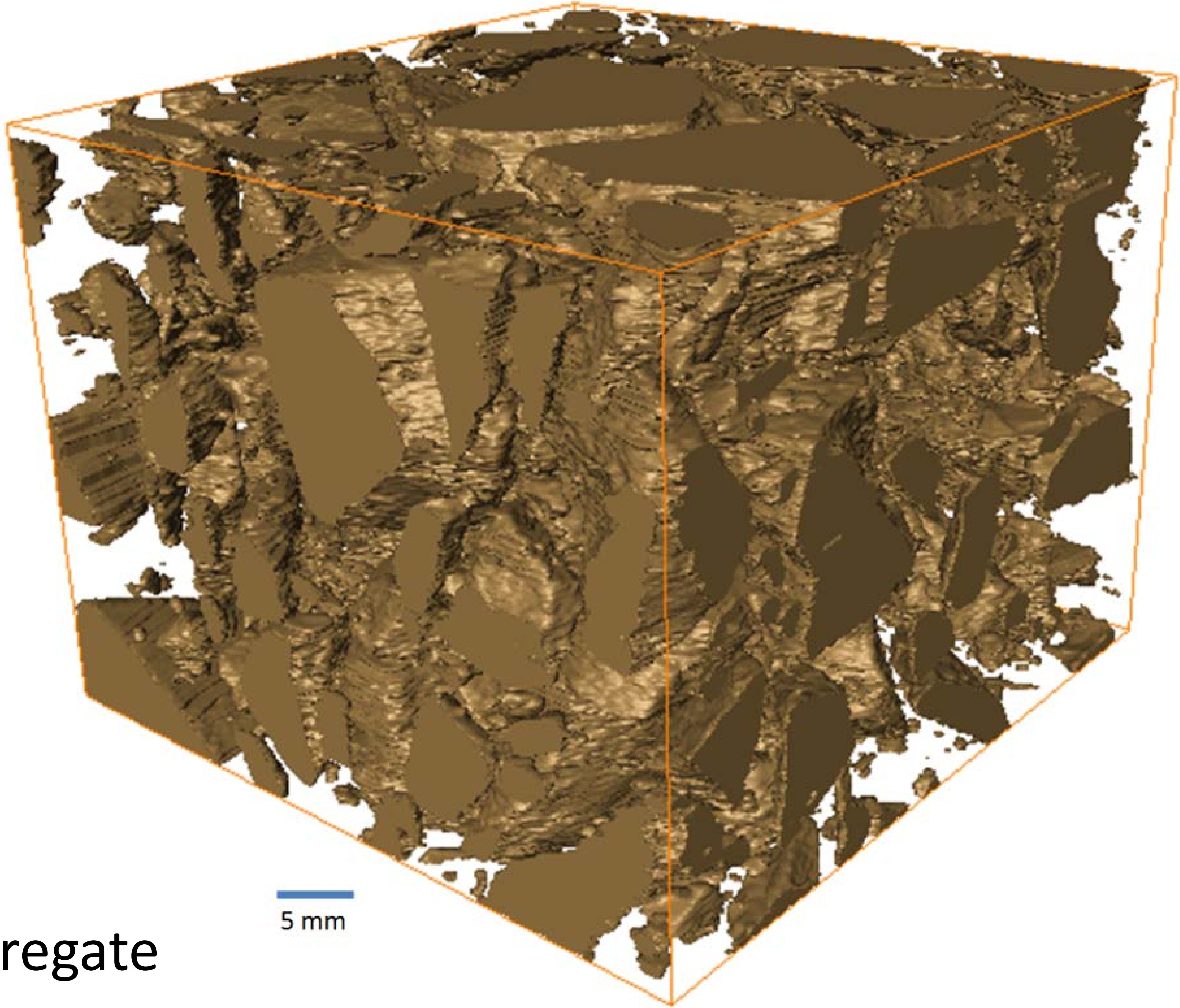

10000 µm
Paste
Air
Aggregate



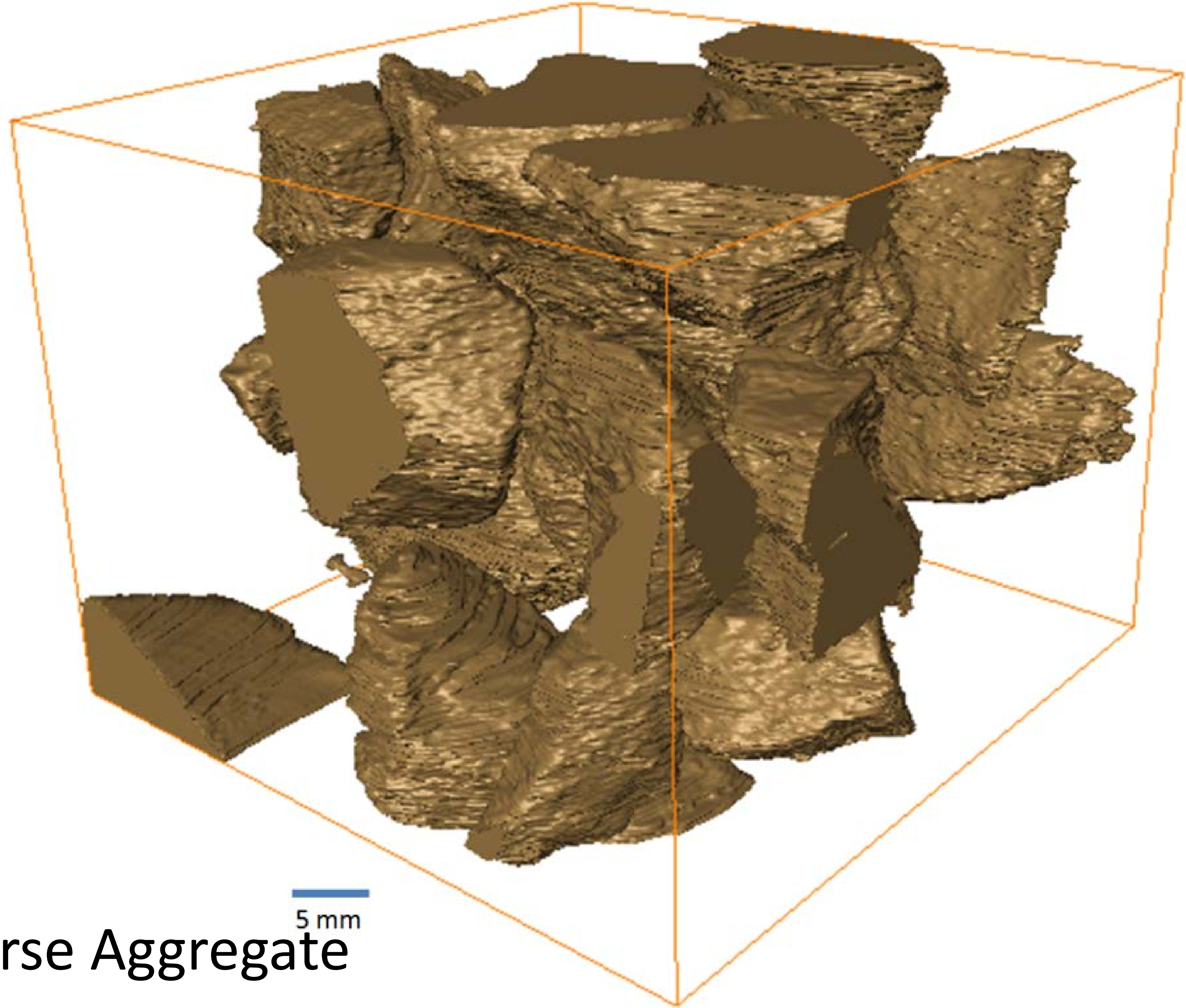
Aggregate and Air



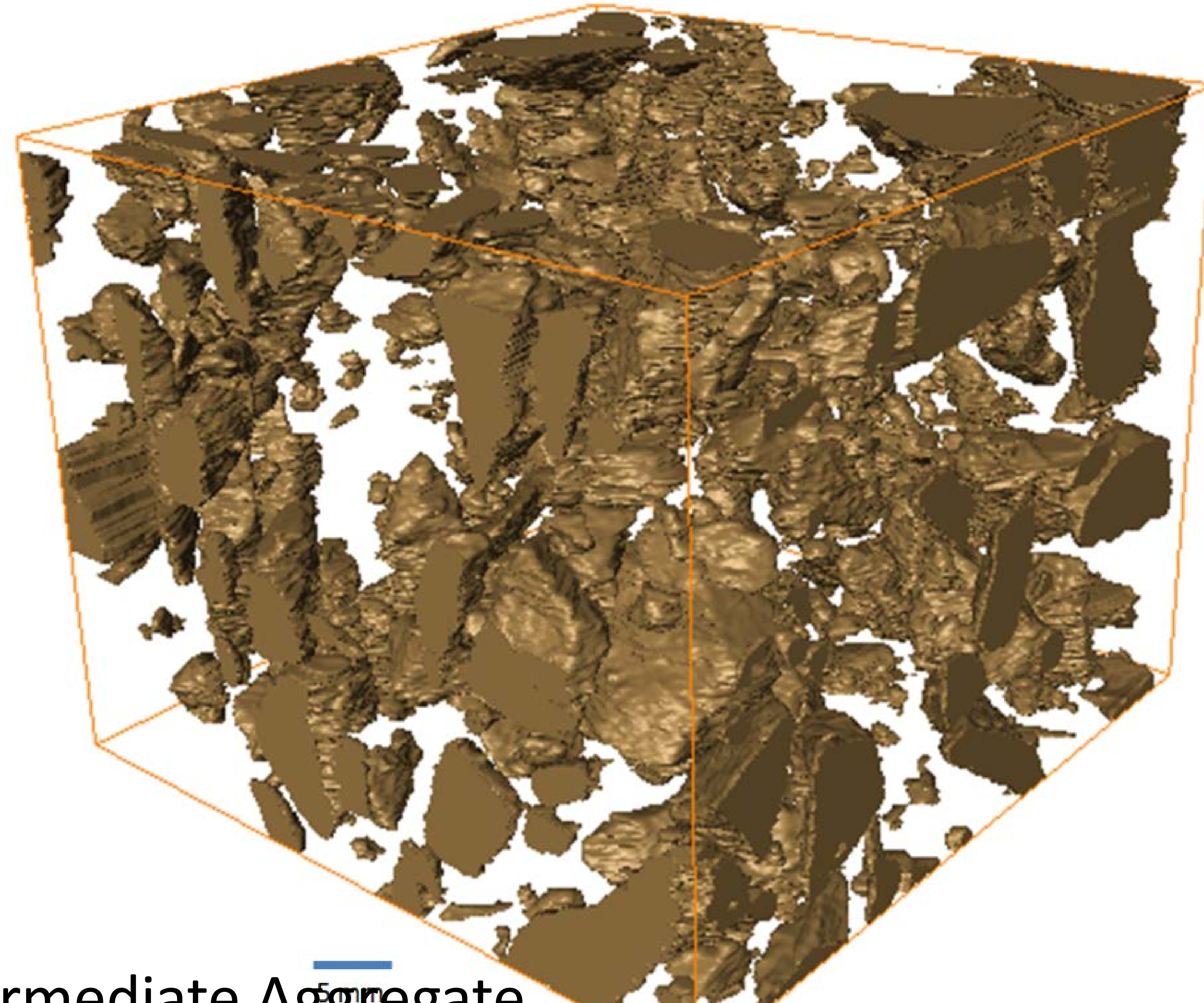
Air



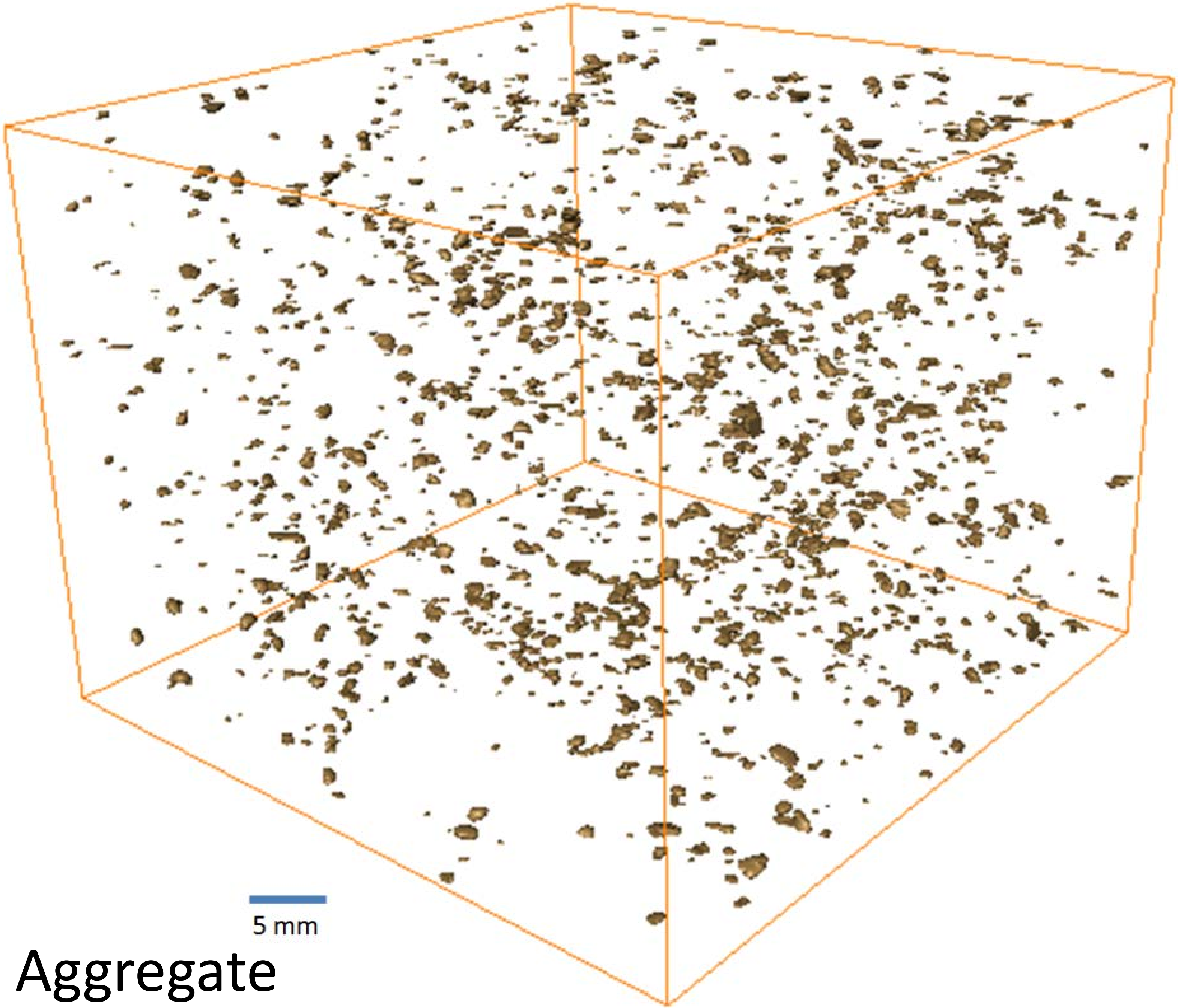
Aggregate



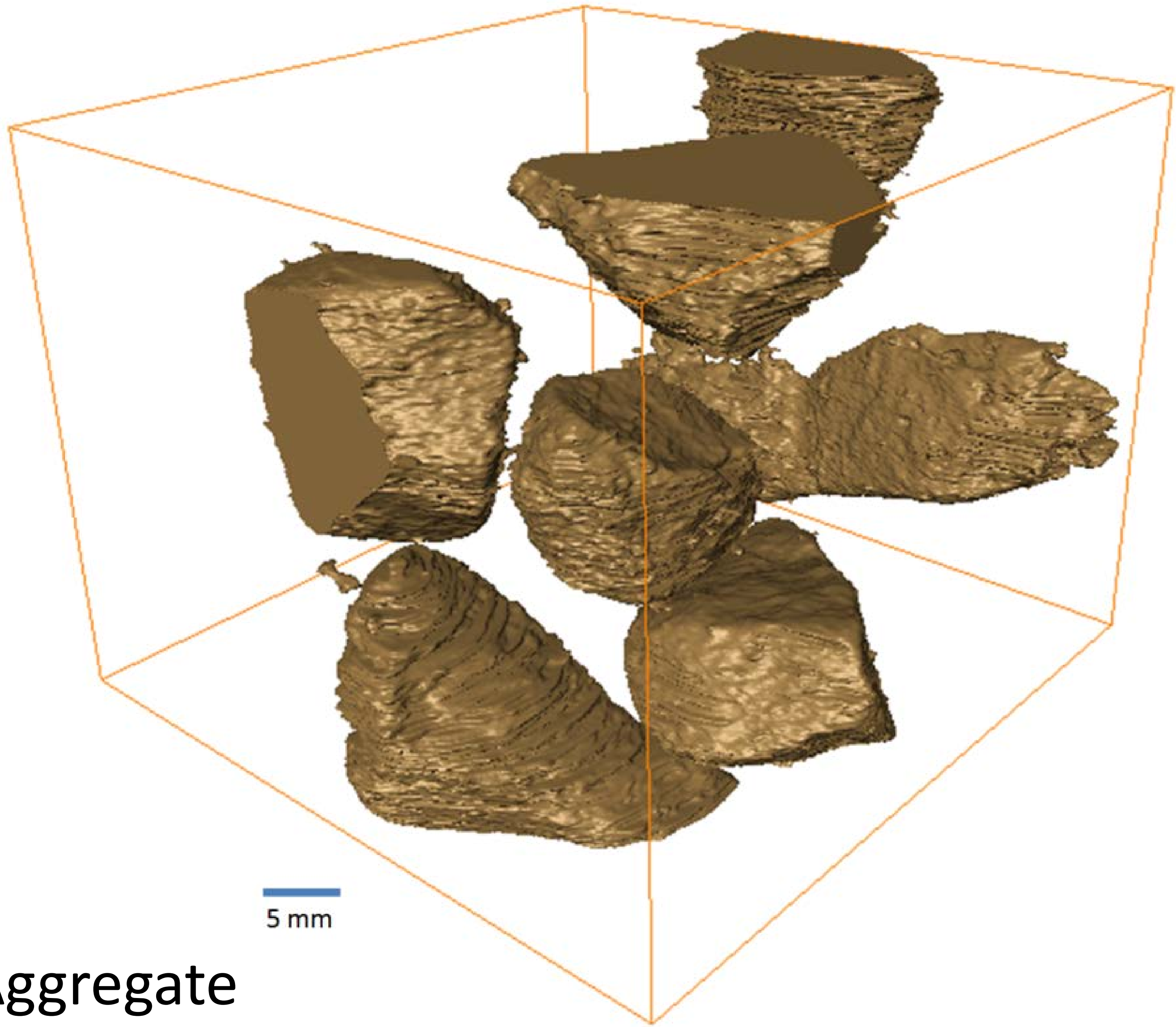
Coarse Aggregate



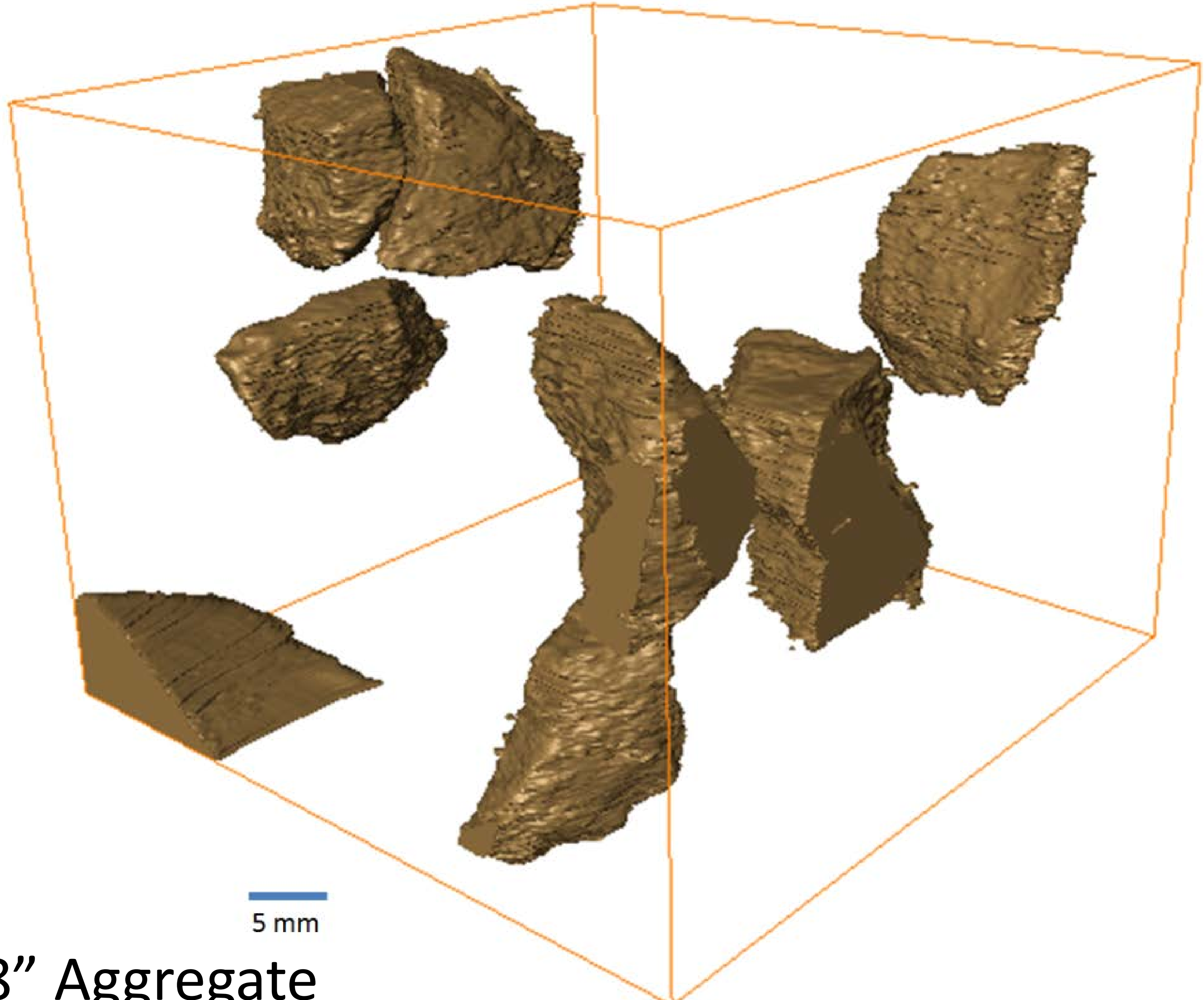
Intermediate Aggregate



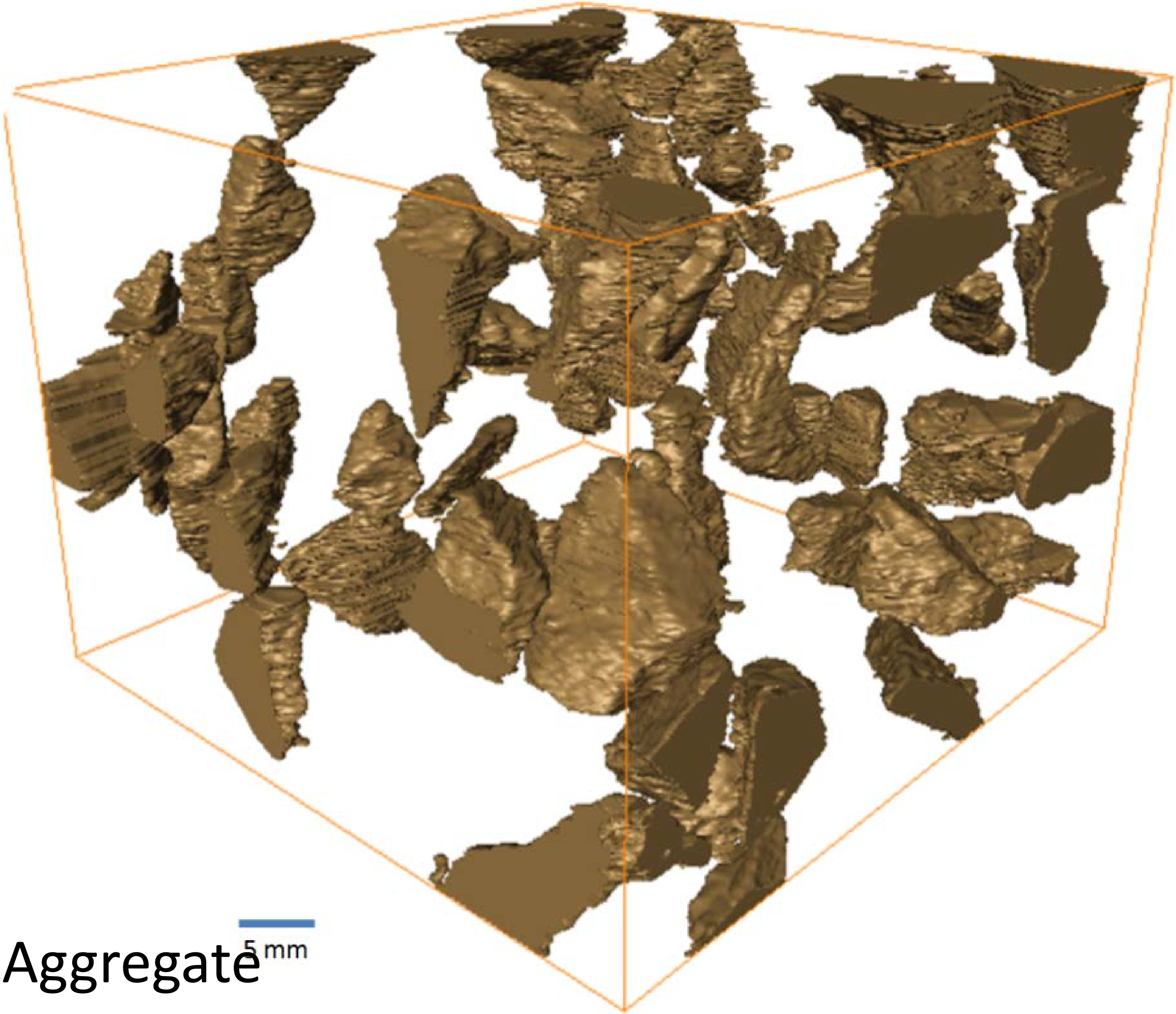
Fine Aggregate



½" Aggregate



3/8” Aggregate

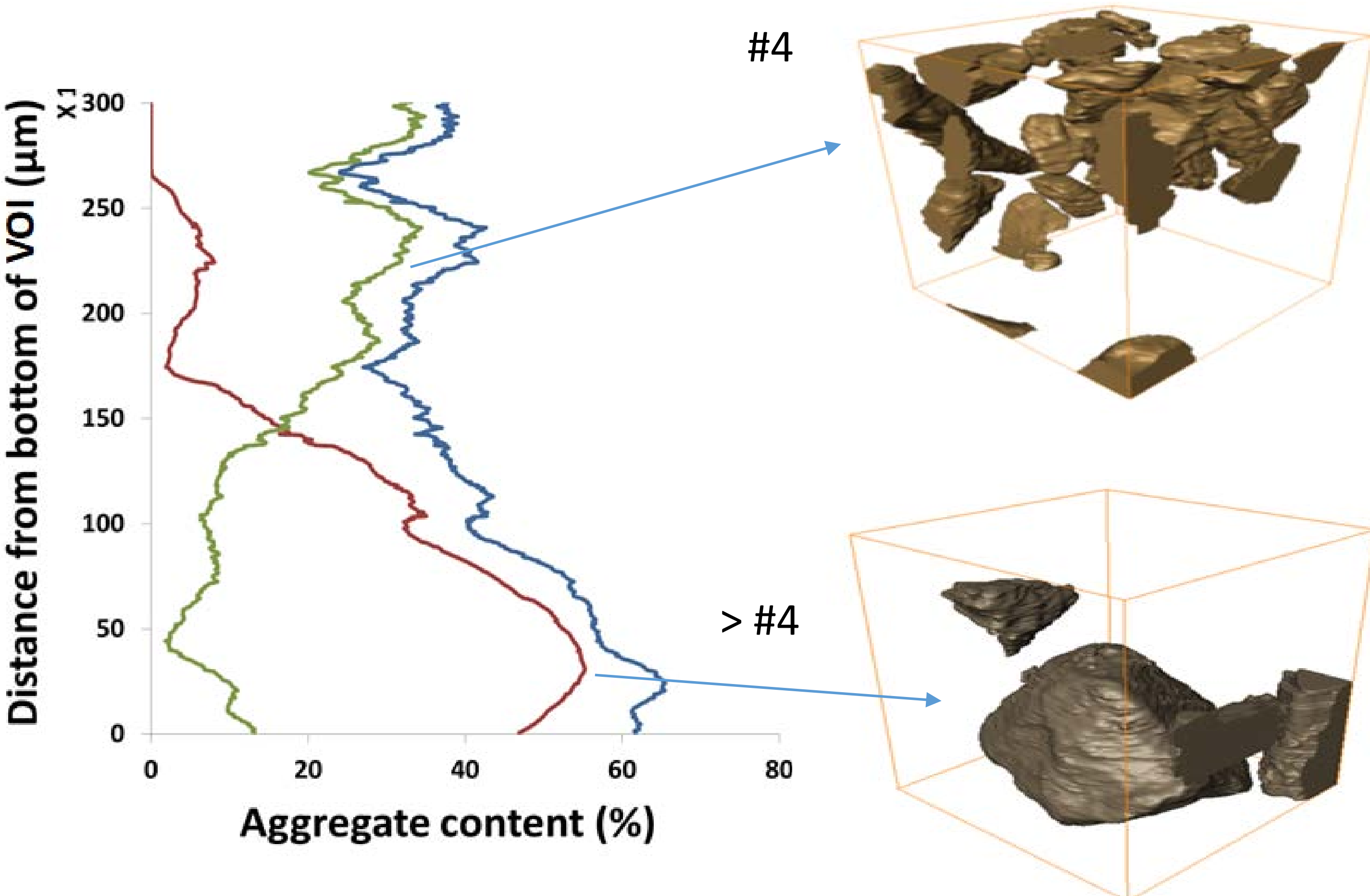


#4 Aggregate

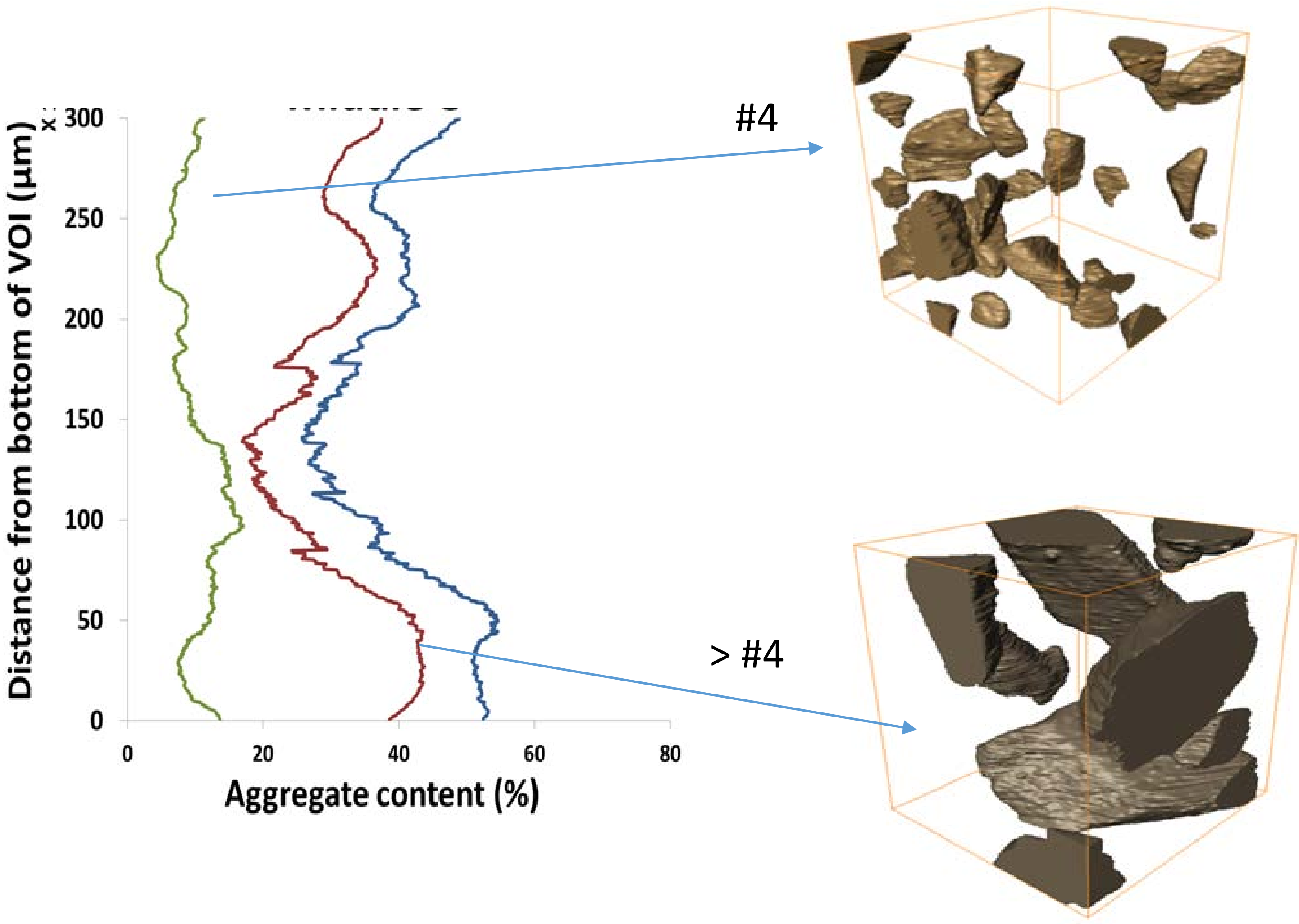
Why are we doing this?

- This allows us to see the spacing and distribution between the particles.
- We can “see” the segregation within the concrete.
- We think this can open improved approaches to aggregate gradation design.

Mixture Outside of the Tarantula Curve



Mixture Inside of the Tarantula Curve



Conclusion

- The aggregate shape, gradation, and cleanliness are important in concrete mixture designs
- Recommendations were made for aggregate gradation curves and shapes for flowable and non flowable concrete.
- The Tarantula Curve recommendations correspond to concrete mixture performance in the field.

Will you help me?

- Examine if your mixtures fall within the Tarantula Curve and let me know how they are performing.

- Search: YouTube Tarantula Curve Example

To get a spreadsheet that you can fill out or send me an email.

Questions?

www.tylerley.com

Please subscribe to my concrete YouTube channel!

Go here!

"Achieving the best Leadership possible in Construction"

Craig Cottongim

Concrete Leadership Training

www.concreteleadershiptraining.com

“State of the Union” In the trades:

- Avg age of tradesmen: 50 yrs old
- Only one replacement for every five who retire
- Many who left the trades during the recession never returned…
- Besides this: We’ve neglected training our leaders…

What are the challenges to leading in our industry?

CONSTRUCTION WORKERS NEEDED: Lake Fork area. Please do not apply if you oversleep, have court often, do not have a babysitter every day, have to get rides to work later than our work day begins, experience flat tires every week, have to hold on to a cell phone all day, or will become an expert at your job with no need to learn or take advice after the first day. Must be able to talk and work at the same time. Must also remember to come back to work after lunch. Should not expect to receive gold stars for being on time. If you qualify, leave name and number at 903-243-5279.

Challenges, on top of weakened workforce:

- Medic, mentor, surrogate father, therapist, mechanic, liaison, ambassador, weatherman, material's expert, master tradesman, coach, motivational speaker, teacher, disciplinarian, and…

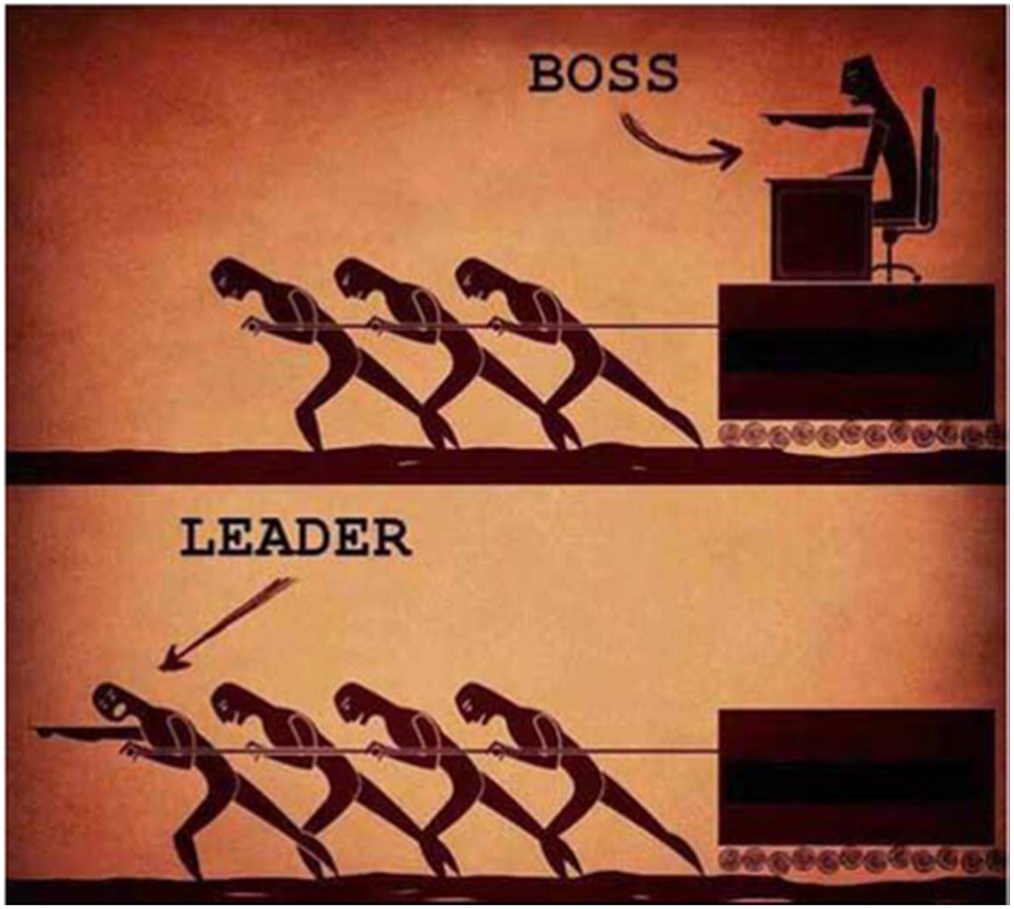
Why is leadership in construction so important?

- We make the greatest contributions to humanity!
- Infrastructure
- Homes
- Schools
- Hospitals
- Churches
- Colleges
- Grocery stores…
- ***Civilization wouldn't exist as it does*** – **Without Concrete/Asphalt progress comes to a screeching halt!**

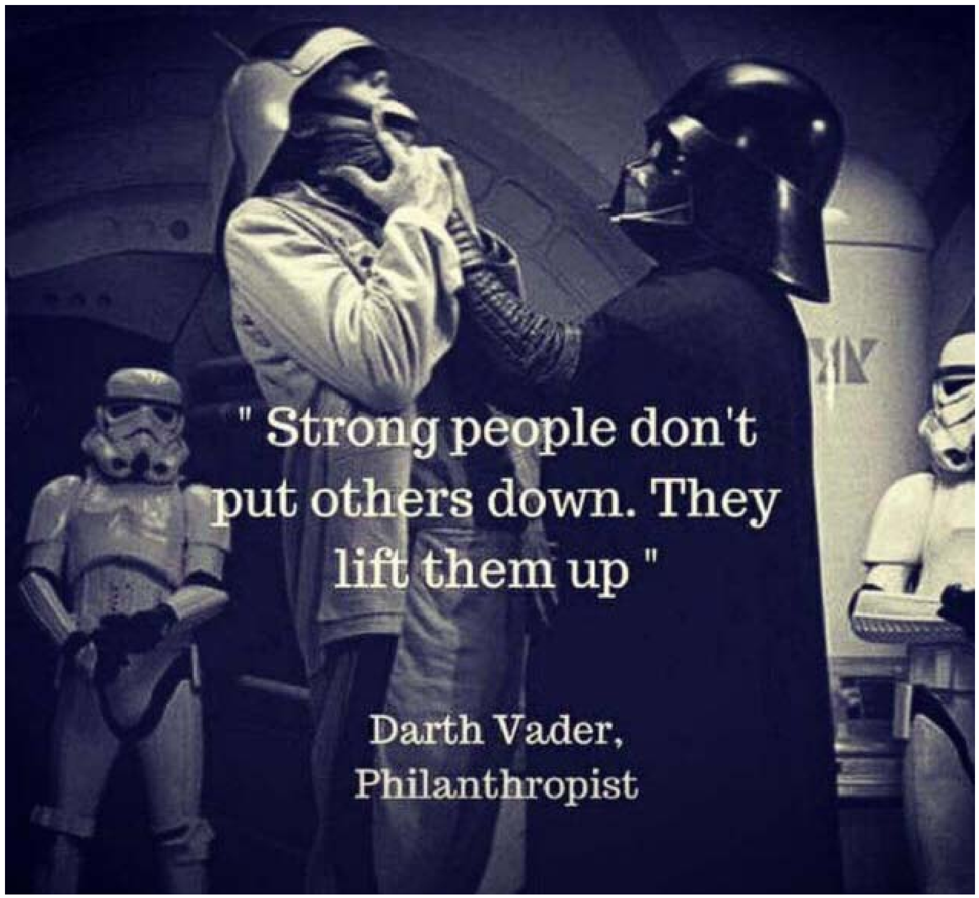
Who is the most difficult one on the jobsite to lead?

It matters how you see yourself

Greatest challenge: Bad examples (fear/intimidation) that led to Confusion between "Driving" & "Leading"



How are you using your force…?



45% of average employees are planning on leaving their place of work within 12 months

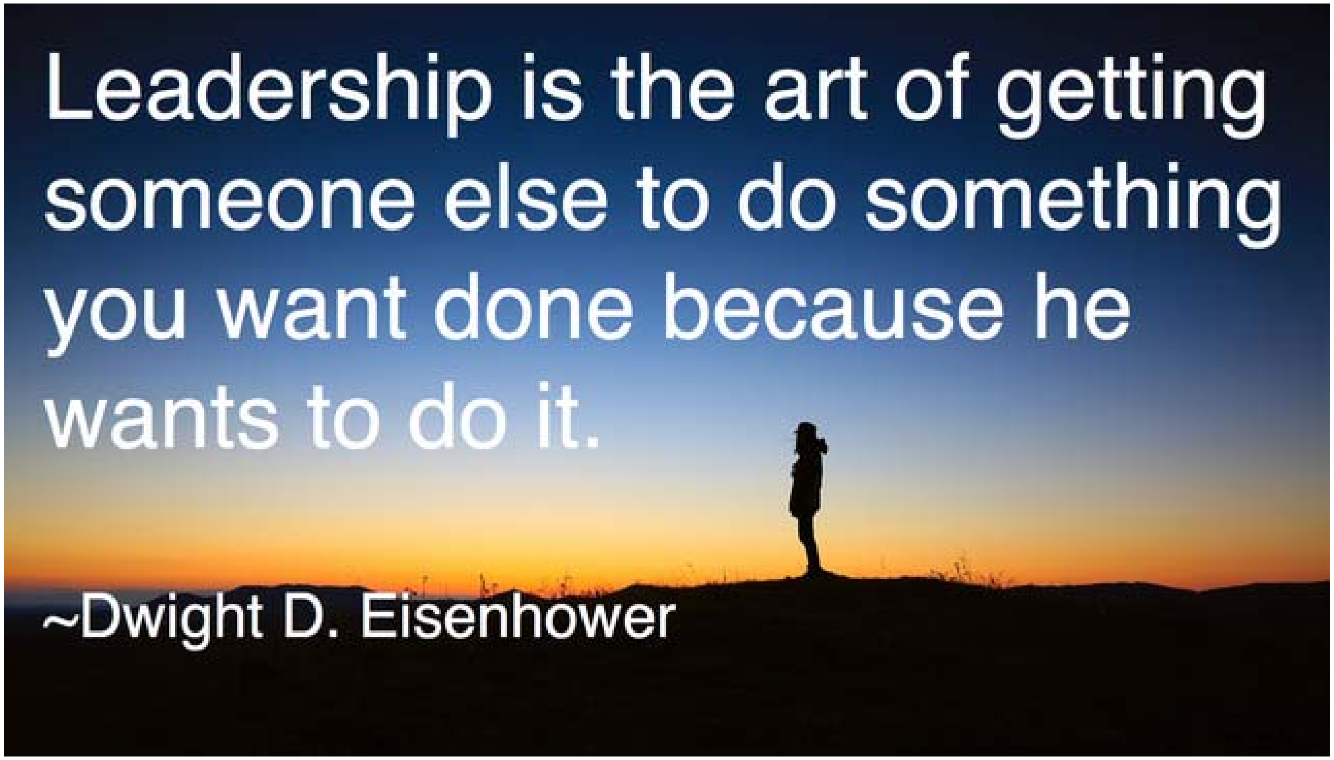
- In the "State of the American Workforce Report" released by Gallup in 2017, only 13% strongly agree the leadership of the company communicates effectively with the rest of the organization.
- Just 15% of employees strongly agree the leadership in their company makes them enthusiastic about the future.
- In another study, only 23% say that their leaders, overall, are effective (Ketchum Leadership Communication Monitor, 2016).
- ***Takeaway for Leaders***: Self-preservation is self-sabotage…


ANYONE CAN
HOLD THE HELM
WHEN THE SEA
IS CALM.
PUBLILIUS SYRUS


Thank You!
The first responsibility of a leader is to define reality. The last is to say thank you. In between the two, the leader must become a servant and a debtor. That sums up the progress of an artful leader. - Max DePree

The only "thank you" note we have…?

What is leadership?



What is a leader…?

- Simply put: A leader is someone people follow – willingly…
- Jack Welch: "Before you are a leader, **success is all about growing yourself**. When you become a leader, **success is all about growing others."**

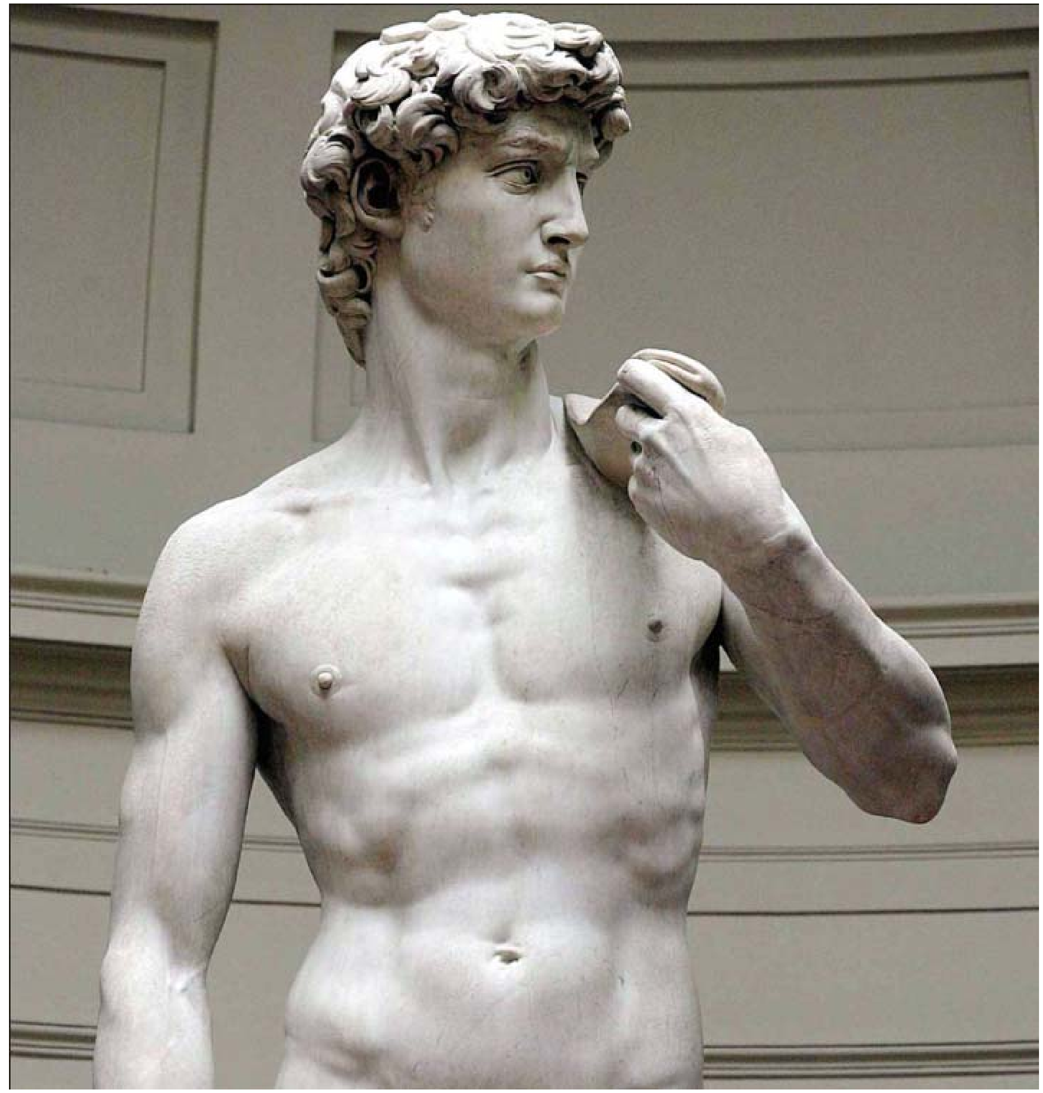
Roles/goals/responsibilities of leaders:

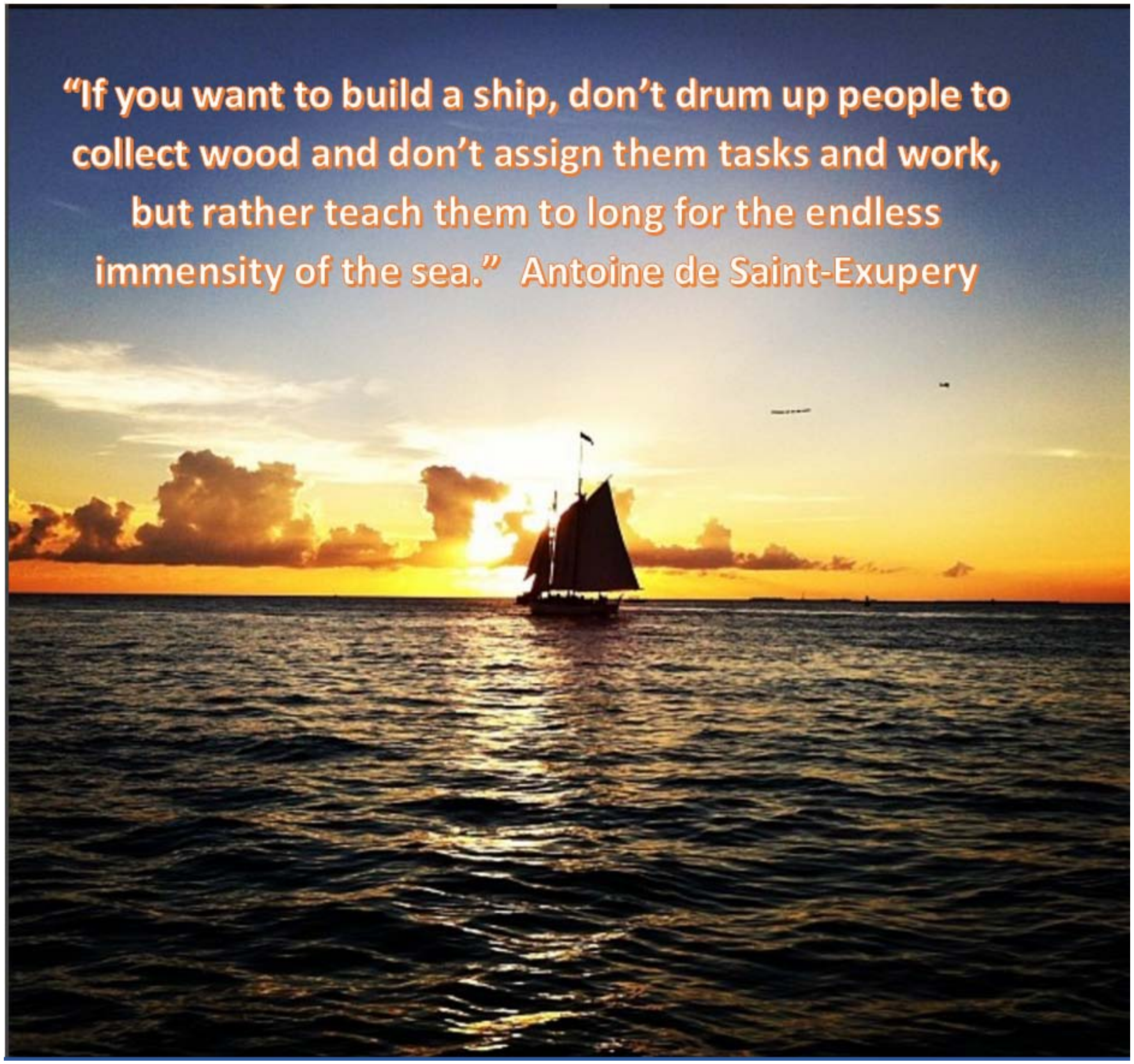
- Set tone/tempo
- Increase/improve morale
- Develop their replacements…
- Clarify expectations.
- Take on the responsibility for completing the task, accept fault, and give the credit to their team...
- Knows how to get people to follow.
- ***Remember forever***: Followers rarely outperform their leaders….

How to get people to <u>follow us & develop loyalty</u>: (Here's getting your $$$ worth)

- Be a leader worth imitating…
- Be competent & roll up your sleeves…
- Be connected & committed.
- Complement excellence. (**Currency for critiques**)
- Communicate, communicate, communicate…
- **Put others 1st & never ask your followers to do what you won't… <u>because leadership isn't about doing less, it's about doing more…</u>**
- **Invest time in your followers**: TRUST them & share your AUTHORITY *<u>to multiply yourself</u>*
  - By leading by example, (**Equip**)
  - partnering with new leaders on the site, (**Empower**)
  - Actively observing them lead, **(Deploy/release**)
  - offering them follow-up advice
- Pass on your wisdom daily!

Developing leaders:




"If you want to build a ship, don't drum up people to
collect wood and don't assign them tasks and work,
but rather teach them to long for the endless
immensity of the sea." Antoine de Saint-Exupery

Be out front, and beat the odds... thermophiles' style


Q & A

Insights into Performance Engineered Mixtures AASHTO PP84-17

Tyler Ley, PE, PhD

Acknowledgements

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  - Mike Praul, FHWA
  - Tom Cackler, Woodland Consulting
- Industry Participants/Reviewers
  - Champion States & ACPA Chapter Execs
  - ACPA National
  - PCA
  - NRMCA

Documents

- AASHTO PP84-17
  Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures

The Past

- Near the millennium, concerns about concrete durability and poor pavement performance became a common topic of discussion in many concrete intensive states.

Projects related to PEM

- CP Tech Center Mix Track – TTCC Pooled Fund
- Indiana led Mass Transport Pooled Fund
- NCHRP Freeze Thaw
- Michigan SAM STIC implementation
- Expert Task Group
- PEM Champion States
- ACI Performance Specification Workshop
- Wisconsin DOT PEM Implementation
- Oklahoma led Freeze Thaw Pooled Fund
- North Carolina PEM Funded Research
- Performance PRS models
- ….
- **National PEM Pooled Fund**

The Past

Current Tests are not Identifying durability issues

Specifications typically:

- Do not measure critical engineering parameters.
  - Historically we commonly specify air, slump, strength, and local aggregate requirements.
- Changes in source materials is difficult.
- Mixes are often over cemented.
- Are often built around previous failures – thereby introducing unintended consequences.

What is PEM?

Performance – Choosing what we need

Engineered – Delivering what is needed

Mixtures – Let's engineer our mixtures to perform

The Concrete

Gray .... ☑

Strong .... ☑

Cracked .... ☑

Slide from Peter Taylor

How are we going to do this?

- The heart of this effort is using adequate tests and correctly applying tests that investigate the key performance of concrete.

What gets measured gets managed.
- Peter Drucker

What do we want these tests to do?

- Measure critical performance criteria
- Be completed economically and rapidly in the lab or the field
- Allow innovation while evaluating the performance that matters

What is the concept

- Provide a ***guide*** specification with tests completed either during mixture design or at placement or both that focus on concrete performance.

- Allow DOTs to take what they like from the document and make it their own.

- DOTs should not give up what they already know is important for them.

What is the concept

- A commentary is included that gives the technical background behind the tests and limits
- There are both prescriptive and performance approaches
- This is a tool to help you improve your concrete
- The document is not designed to be used without modifying for local practice and experience

The document is not designed to be used without modifying for local practice and experience!!!

This is just like a concrete buffet!!!!

This is just like a concrete buffet!!!!

This is just like a concrete buffet!!!!

This is just like a concrete food buffet!!!!

This is just like a concrete food buffet!!!!

You pick what you like!

If you don't like it then don't take it.

For example:

- If you are in a warm climate then don't use freeze thaw requirements
- If you are in a moist climate then don't use the drying shrinkage requirements

Only choose the specifications that you need!

Only choose the specifications that you need!

Not every time

This is balanced

Use your best local practices!!!

- If you have something that is working for you then keep using it!

Use your best local practices!!!

- If you have something that is working for you then keep using it!

Use your best local practices!!!

- If you have something that is working for you then keep using it!

- But consider trying new things to see if they make things better

Not all approaches are the same

- Some approaches are better than others!
- The simplest approach is rarely the best
- You have to balance your needs to the complexity of the test

Not all approaches are the same

- Some approaches are better than others!
- The simplest approach is rarely the best
- You have to balance your needs to the complexity of the test

Increasing complexity

Is it worth the extra effort?

What properties are needed?

- Sufficient strength
- Dimensional stability
- Resistance to cold weather
- Fluid transport resistance
- Aggregate stability

- Constructability

Slide from Peter Taylor

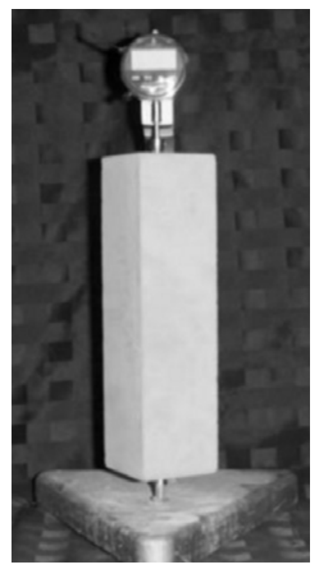
Strength

Choose one!

	Flexural Strength	Compressive Strength
Test method	AASHTO T 97	AASHTO T 22
Value	4.1 MPa 600 psi	24 MPa 3500 psi
Approval?	Yes	Yes
Acceptance?	Yes	Yes

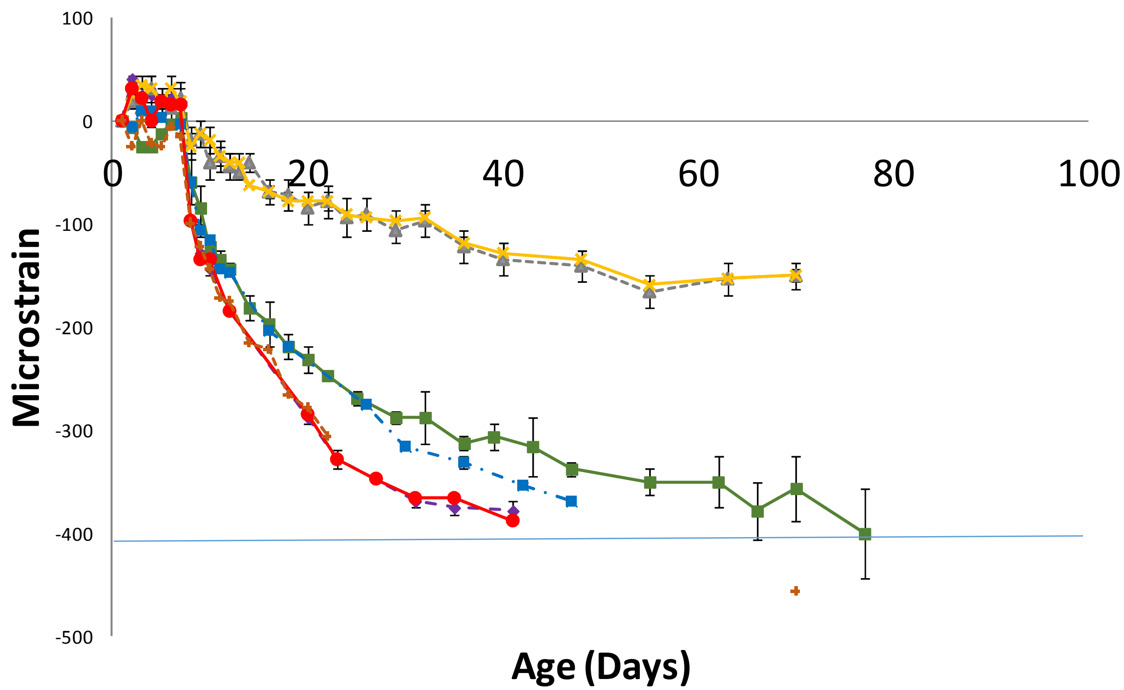
Dimension changes and cracking from drying shrinkage 1

	Volume of paste	Axial shrinkage 1	Axial shrinkage 2
Test method		ASTM C157	ASTM C157
Value	< 25%	< 420 με	< 360, 420, 480 με
Time		28 days	91 days
Approval?	Yes	Yes	Yes
Acceptance?	No	No	No



ASTM C 157

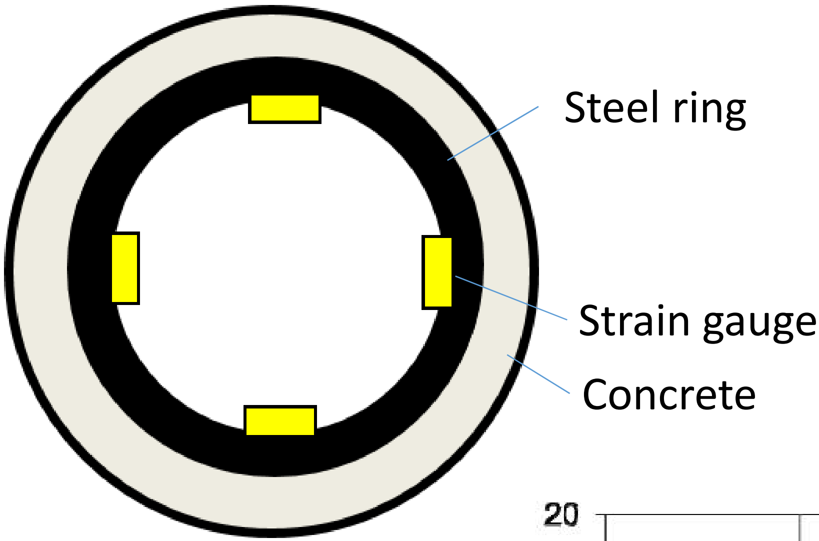
- Cure samples for 28 days in fog room
- Demold and place in drying room (50% RH and 73F)
- Measure their length change over time.



Dimension changes and cracking from drying shrinkage 2

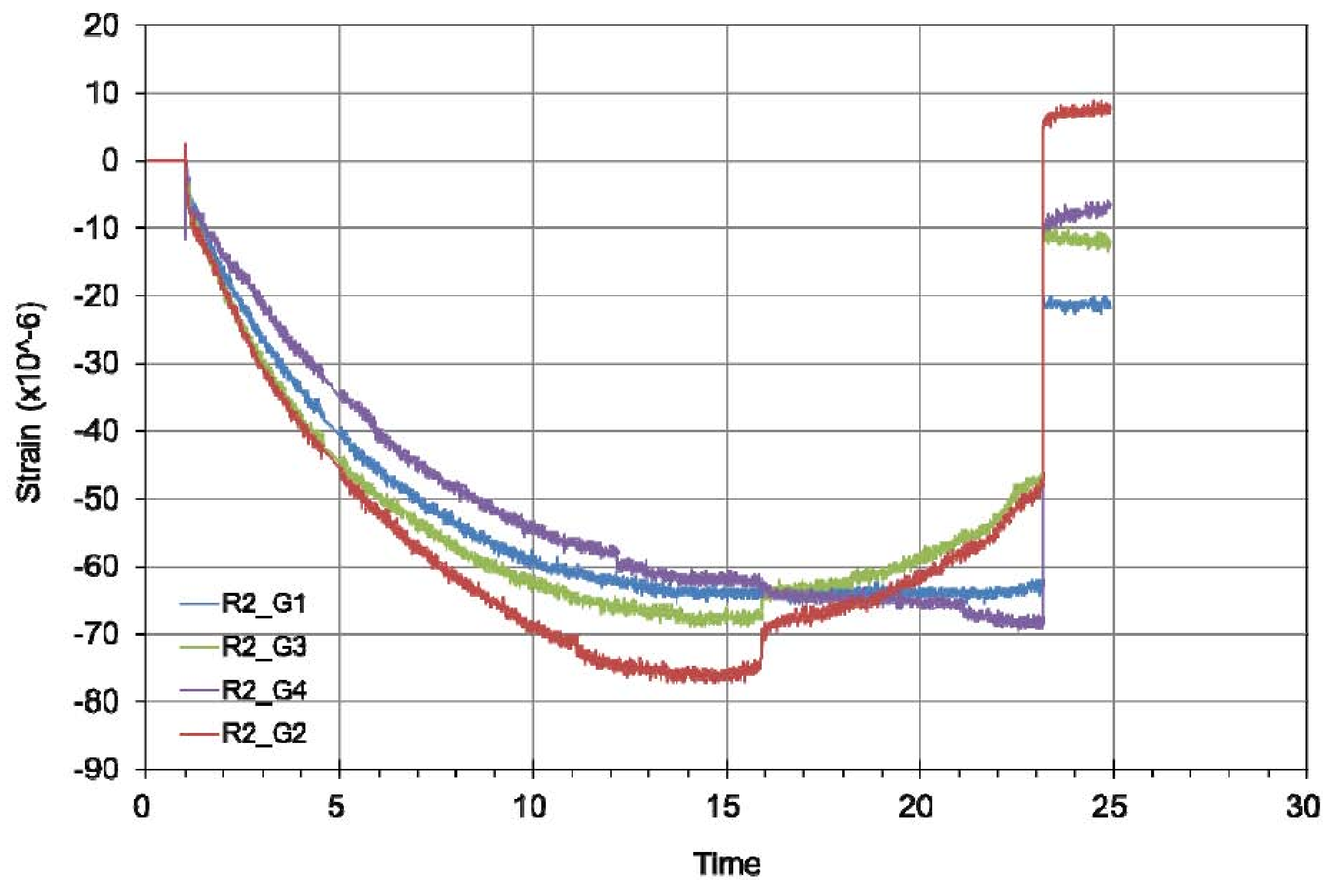
	Ring Test	Dual Ring	Modeling
Test method	AASHTO T 334	AASHTO TP363	-
Value	crack free	$\sigma < 60\%$ f'r	5, 20, 50% cracking prob
Time	180 days	7 days	
Approval?	Yes	Yes	Yes
Acceptance?	No	No	No

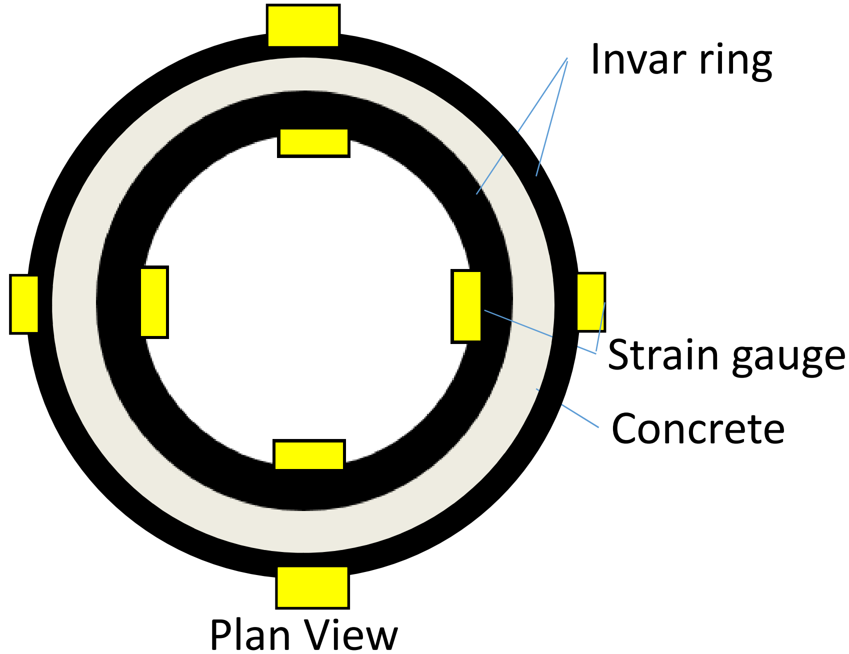
Ring Test

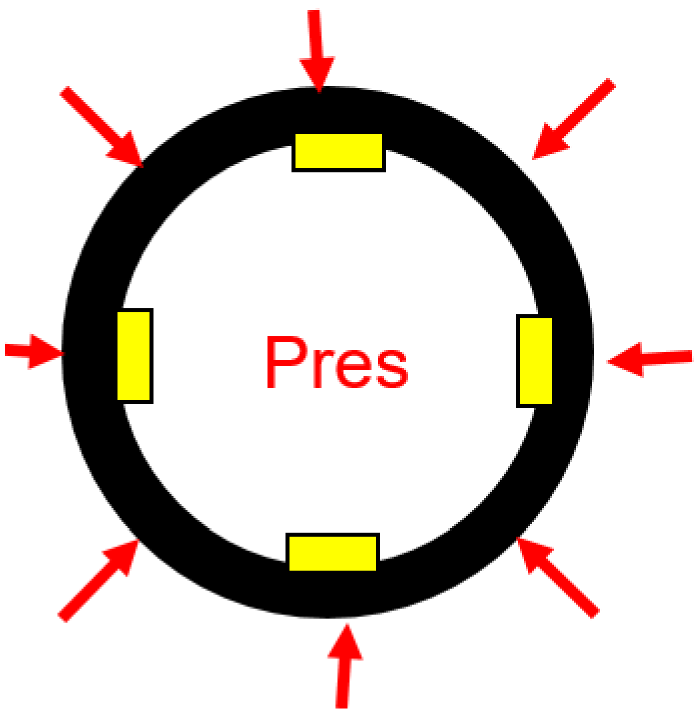


Plan View

Store in 73F
and 50% RH





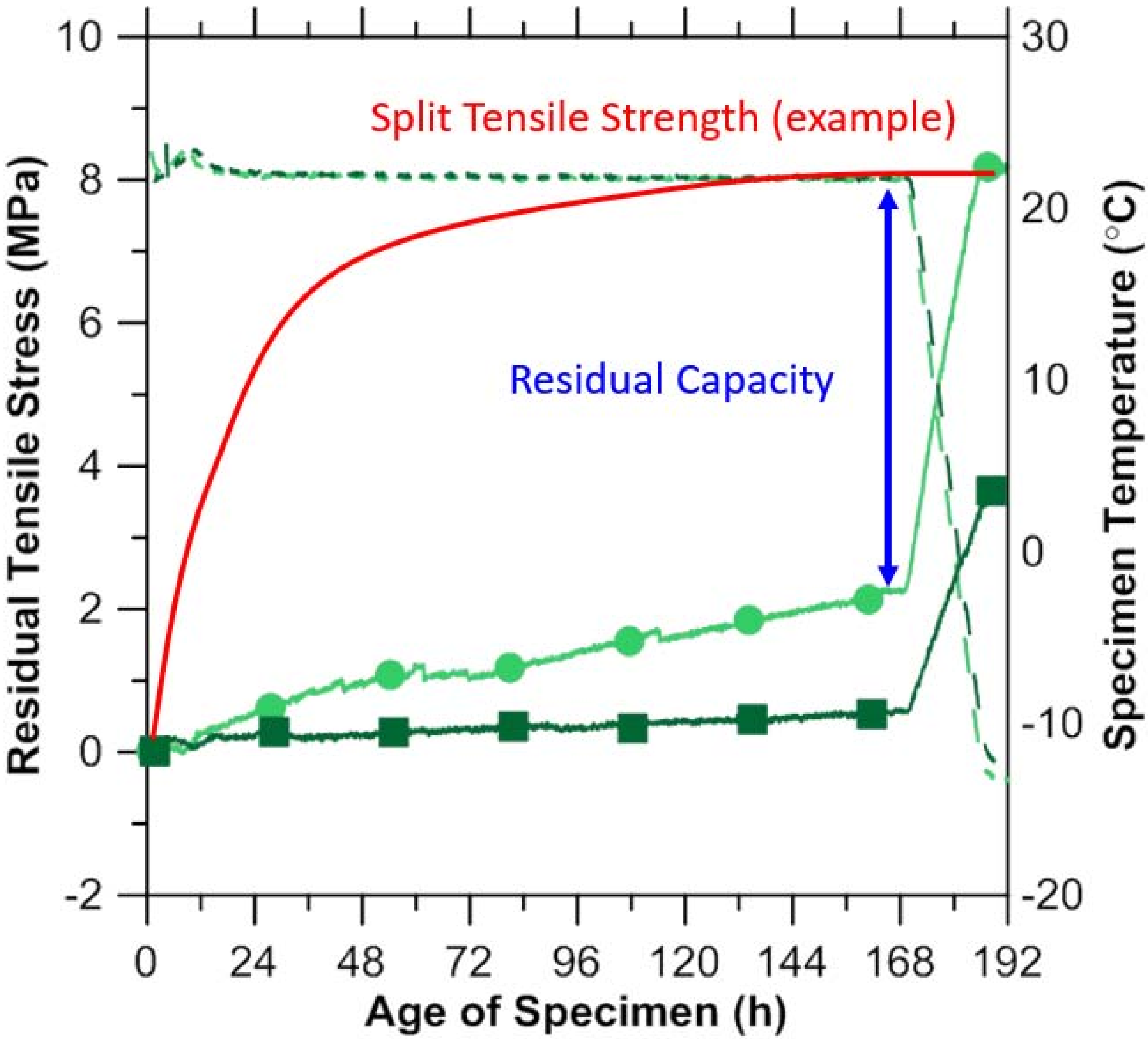


Dual Ring Test

This ring can measure both expansion and contraction.

As the concrete shrinks the ring can measure the strains that occur.

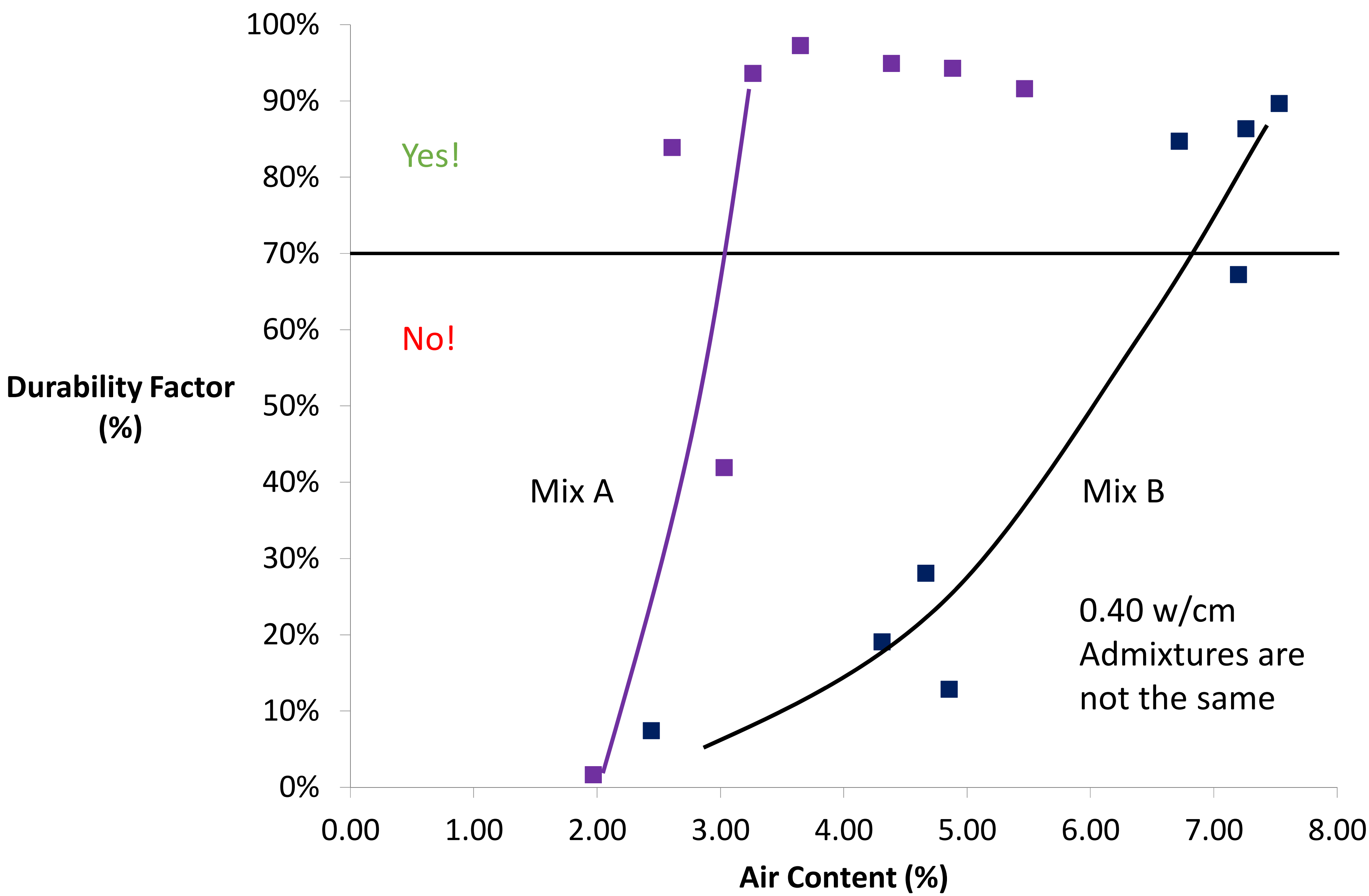
We force a temperature gradient in the concrete and make it crack and compare that to 60% of the split tension capacity after 7 days.



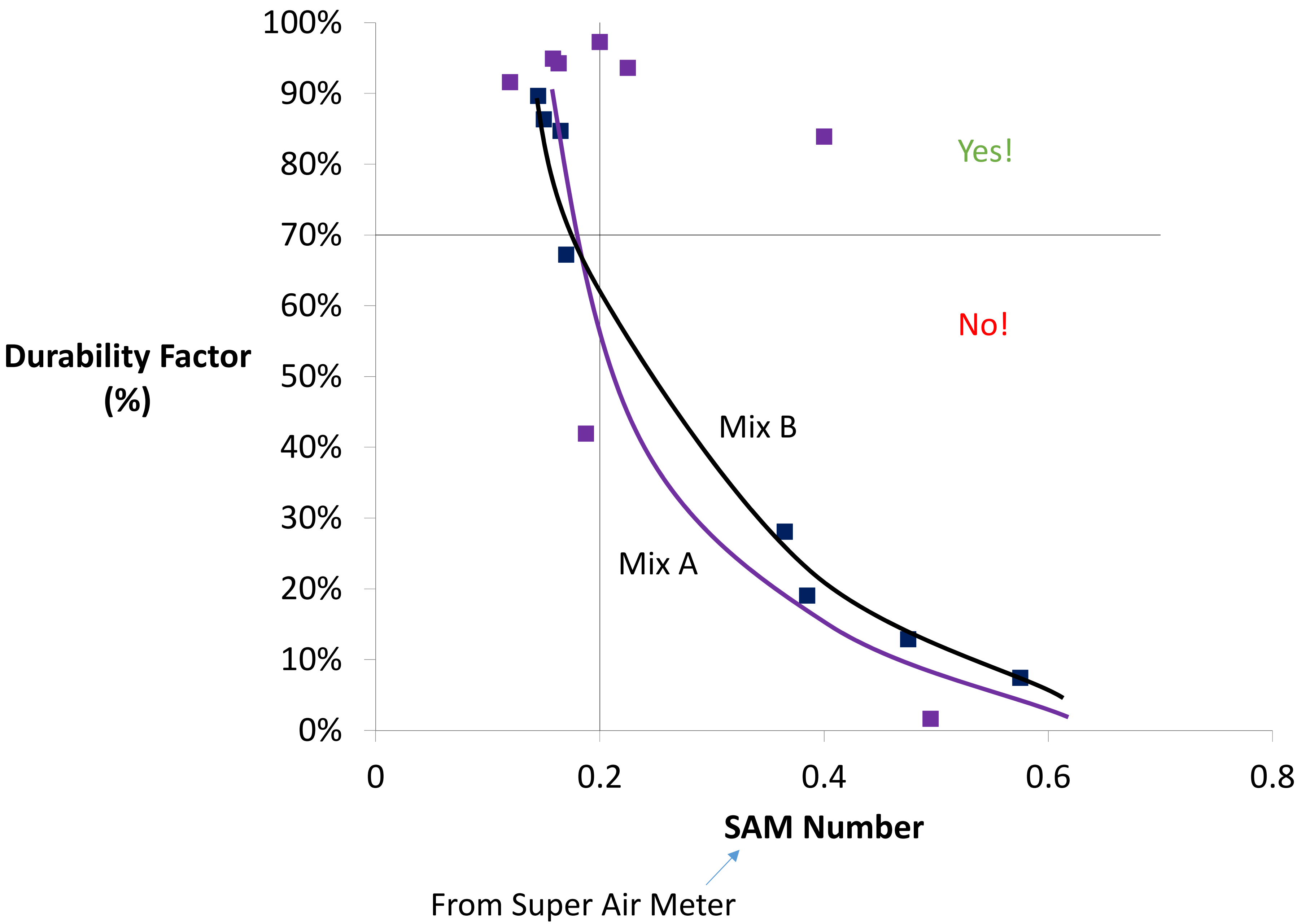
Split Tensile Strength (example)
Residual Capacity
Residual Tensile Stress (MPa)
Specimen Temperature (°C)
Age of Specimen (h)
10
8
6
4
2
0
-2
30
20
10
0
-10
-20
0
24
48
72
96
120
144
168
192

Freeze Thaw durability

	w/cm	Air void volume	Air void system	Time to Critical Saturation
Test method	-	AASHTO T 152, T196, TP 118	AASHTO TP 118	-
Value	< 0.45	5 to 8%	≥ 4% Air SAM ≤ 0.20	30 Yrs
Approval?	Yes	Yes	Yes	Yes
Acceptance?	Yes	Yes	Yes	No

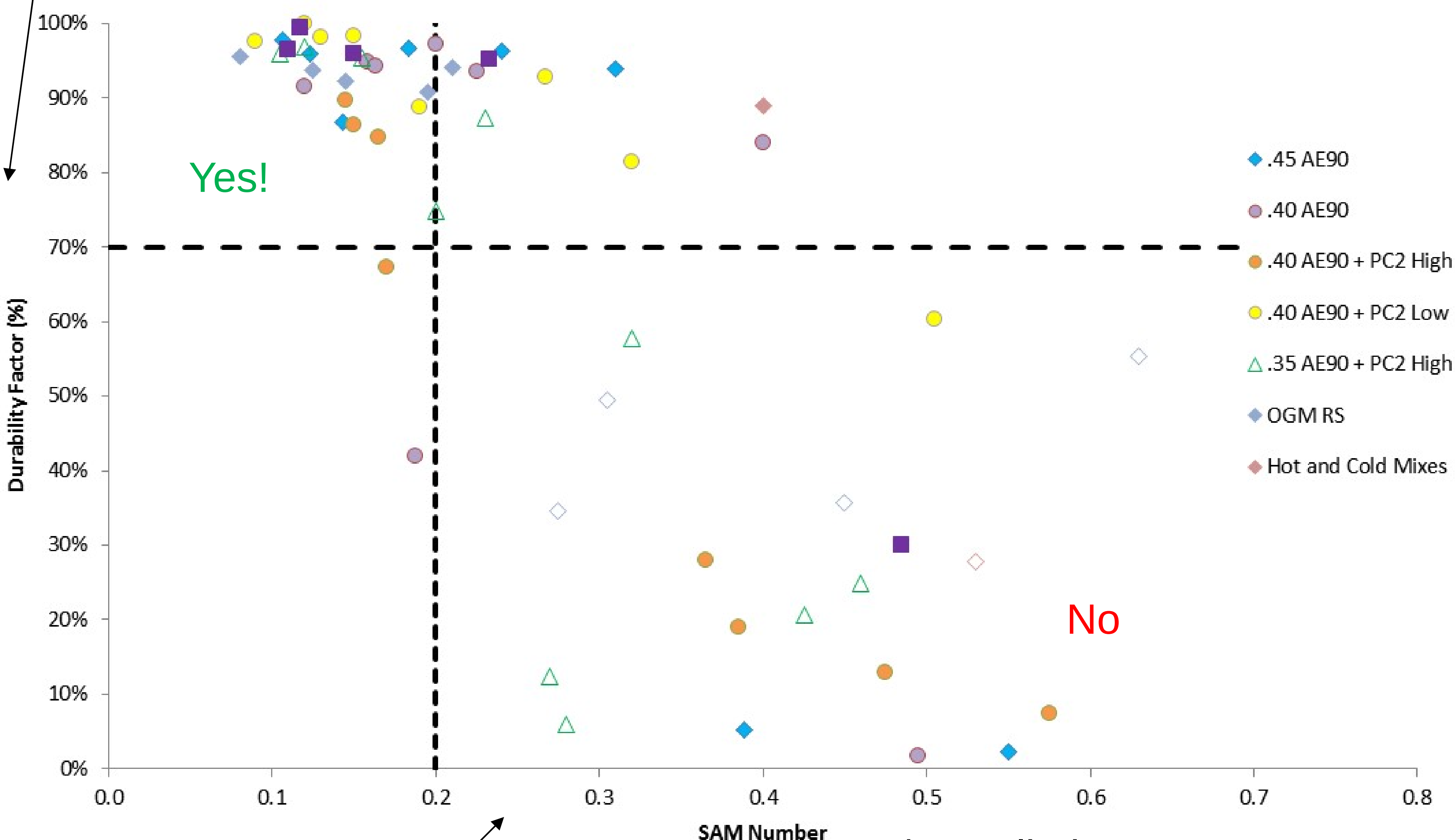


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Durability Factor (%)
Yes!
No!
Mix A
Mix B
0.40 w/cm
Admixtures are not the same
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
Air Content (%)



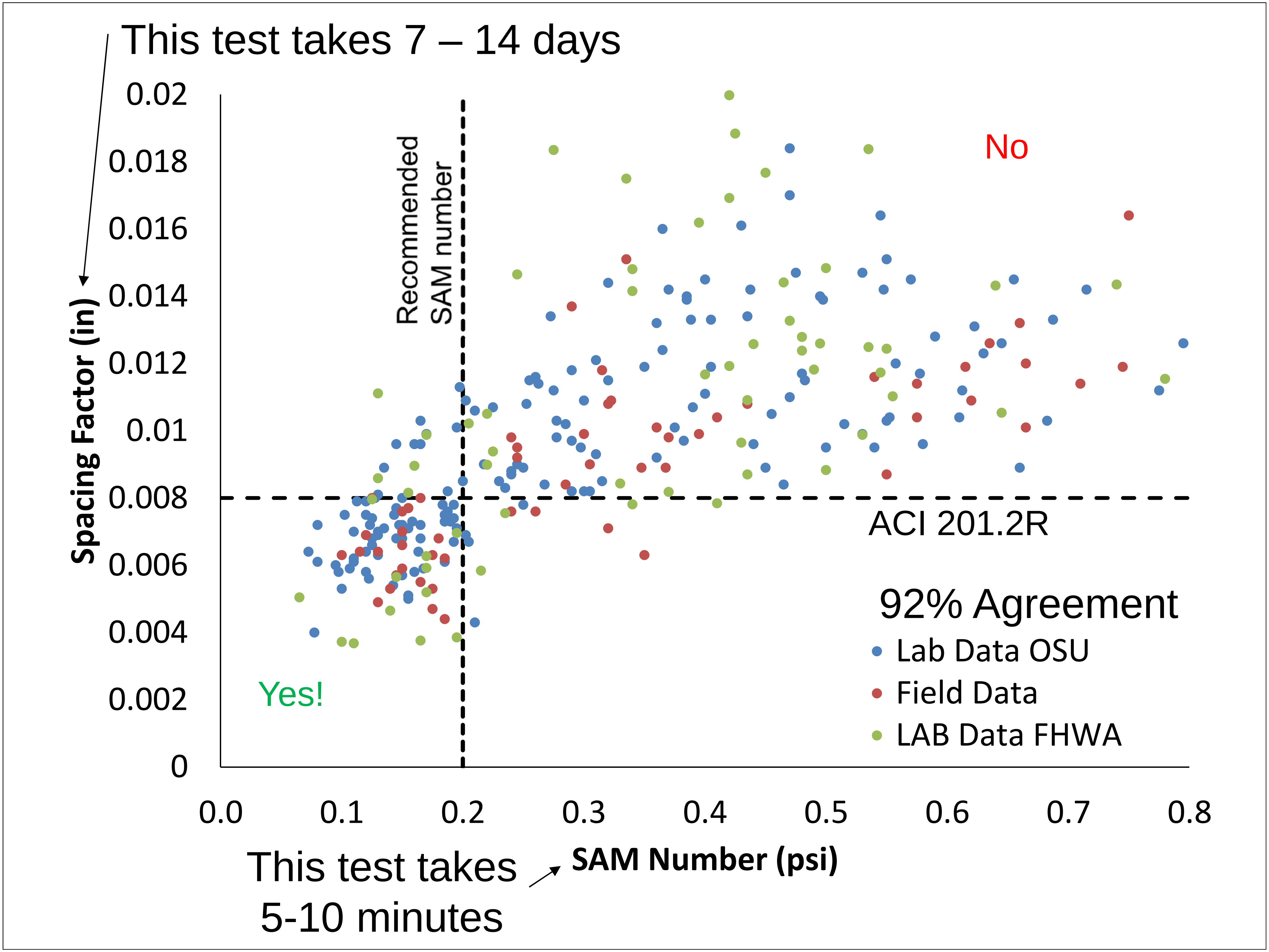
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Durability Factor (%)
Yes!
No!
Mix B
Mix A
0
0.2
0.4
0.6
0.8
SAM Number
From Super Air Meter

This test takes 3.5 months



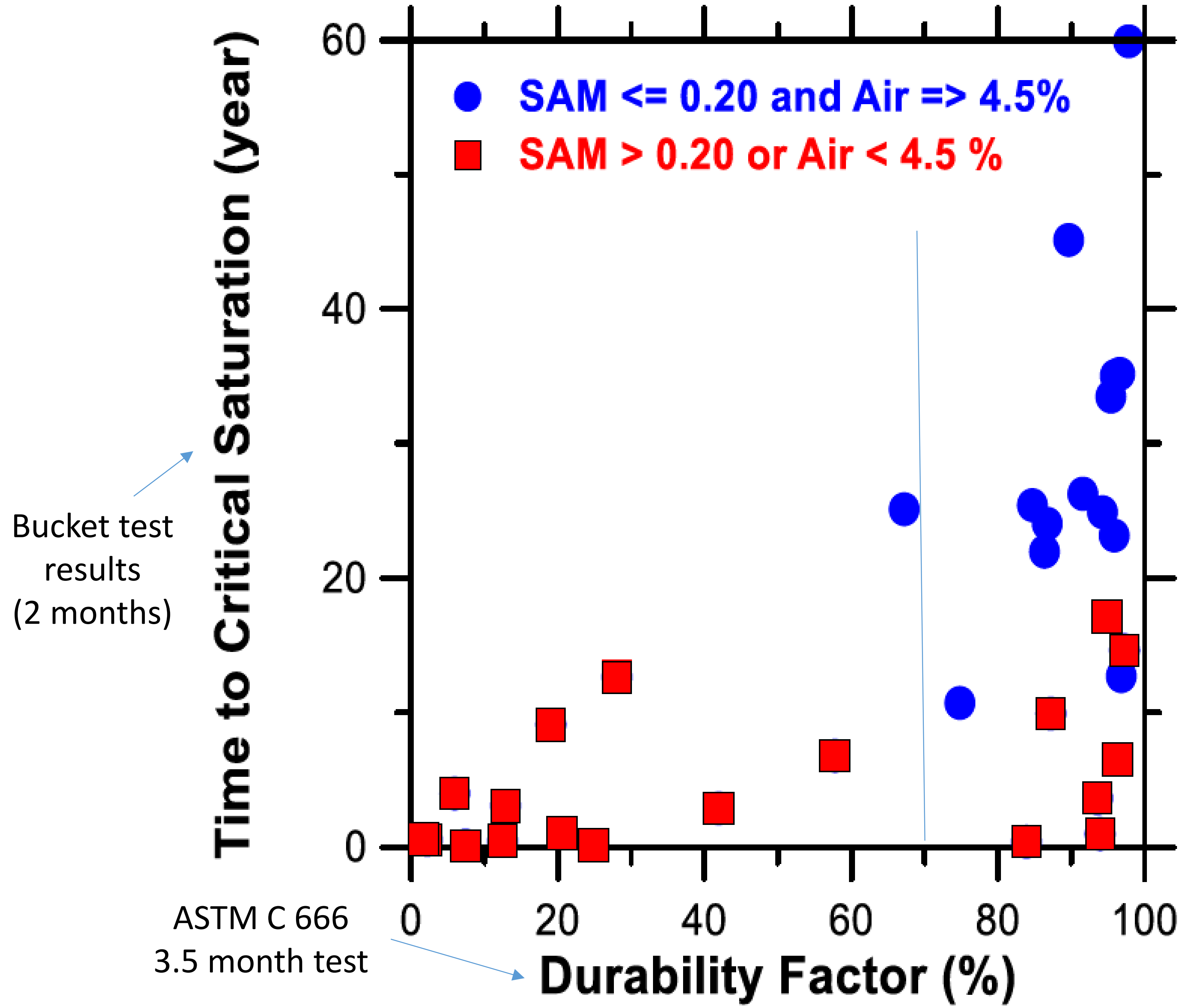
80% agreement w/ 0.20 limit

This test takes 5 -10 minutes

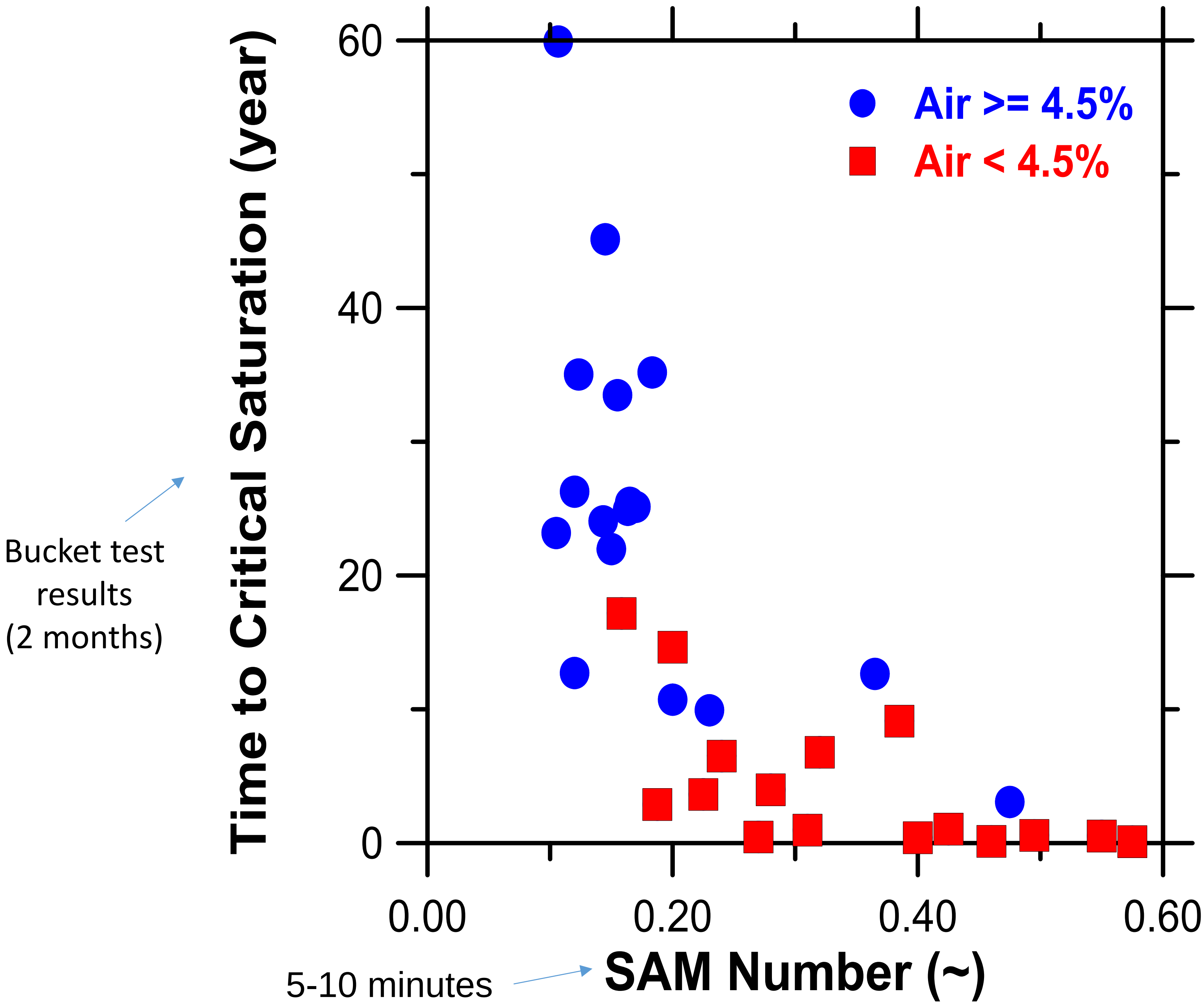

This test takes 7 – 14 days
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Spacing Factor (in)
Recommended SAM number
No
ACI 201.2R
92% Agreement
Lab Data OSU
Field Data
LAB Data FHWA
Yes!
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
SAM Number (psi)
This test takes 5-10 minutes

The Bucket Test

- Cast concrete and keep sealed for 14 days
- Measure the cylinder mass after demolding
- Place three concrete cylinders in lime water
- Measure their mass at 5 days
- Measure their mass again every 10 days until they are 60 days old
- Oven dry cylinder and take mass
- Vacuum saturate cylinder and take mass
- Calculate the time to critical degree of saturation.



Bucket test results (2 months)
ASTM C 666 3.5 month test
Time to Critical Saturation (year)
Durability Factor (%)
SAM <= 0.20 and Air => 4.5%
SAM > 0.20 or Air < 4.5 %
0
20
40
60
80
100



Time to Critical Saturation (year)
60
40
20
0
0.00
0.20
0.40
0.60
SAM Number (~)
Air >= 4.5%
Air < 4.5%
Bucket test
results
(2 months)
5-10 minutes

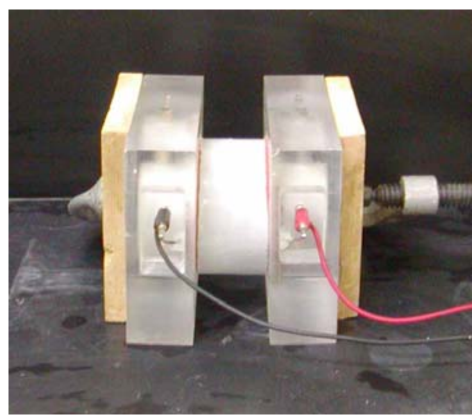
Deicer Salts

Are calcium or magnesium chloride deicer salts used?

Approach	use SCMs	use sealer	AASHTO T 365
Value	> 35%	-	< 0.15g CaOXY/g paste
Approval?	Yes	Yes	Yes
Acceptance?	Yes	Yes	No

Moisture penetration

	w/cm	RCPT Value	Formation Factor
Test method	-	AASHTO T 277	AASHTO T 358
Value	0.45	< 2000	> 500
Approval?	Yes	Yes	Yes
Acceptance?	Yes	Yes	Yes



What is the formation factor?

- It is a true measurement of how hard it is for ions to move through concrete.
- If we can get this information then it will be much easier to predict moisture penetration into concrete and the subsequent long term performance.

How do we get it?

- The resistivity test gives you a single number that is an indication of a lot of different things -
  - Moisture
  - Temperature
  - Geometry
  - Curing conditions
  - **Ionic concentration of the pore solution**
  - **Formation Factor**

- We can fix all of the other variables but the last two. *If we can figure out the chemistry of the pore solution then we can back out the formation factor*

How do we get pore solution chemistry?

- Three approaches
  1. *Assume a value*
  2. *Calculate a value based on the cement and SCMs*
  3. *Squeeze out the solution and measure it*

Assume a value based on testing.

Take mill sheets of ingredients and use an online calculator.

Aggregate Stability

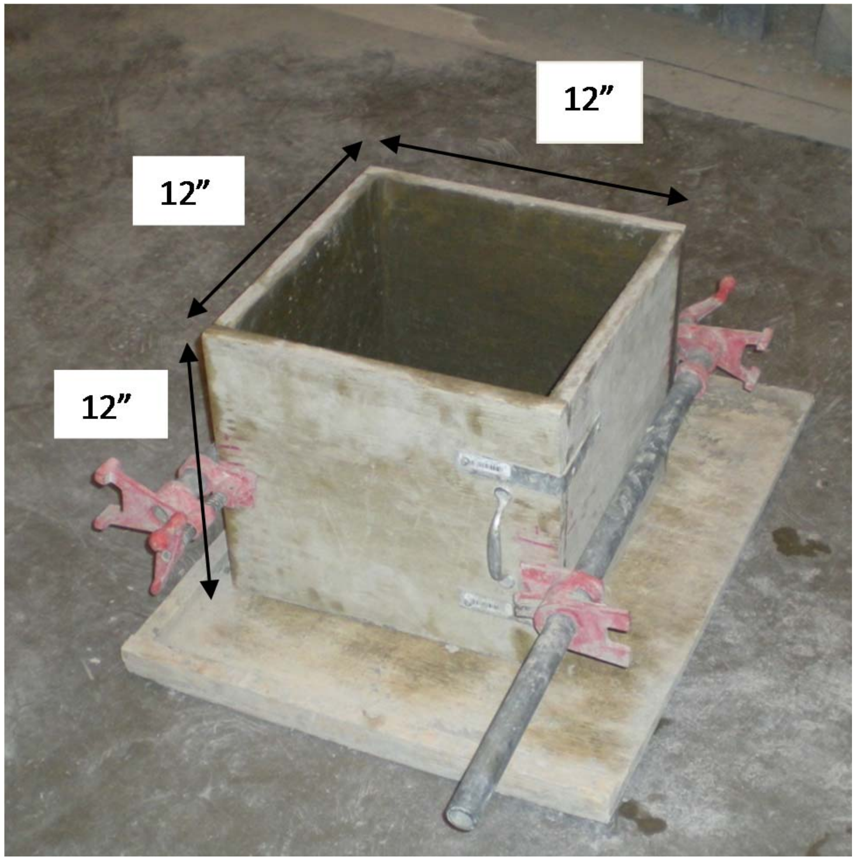
	D Cracking	Alkali Aggregate Reactivity
Test method	AASHTO T 161 ASTM C 1646	AASHTO PP 65
Approval?	Yes	Yes
Acceptance?	No	No

Constructability

	Box Test	V-Kelly
Criteria	<6.25 mm, < 30% Surf. Void	15-30 mm per root seconds
Approval?	Yes	Yes

Box Test

- A <u>simple</u> test that examines:
  - Response to vibration
  - Filling ability of the grout (avoid internal voids)
  - Ability of the concrete to hold an edge



Ley

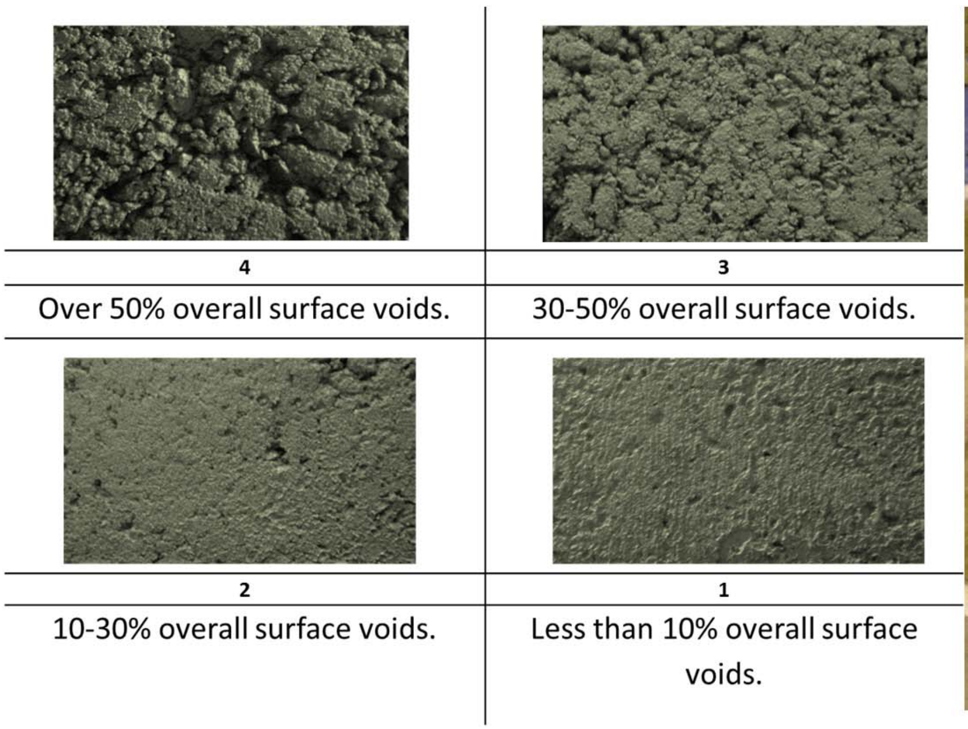
Box Test

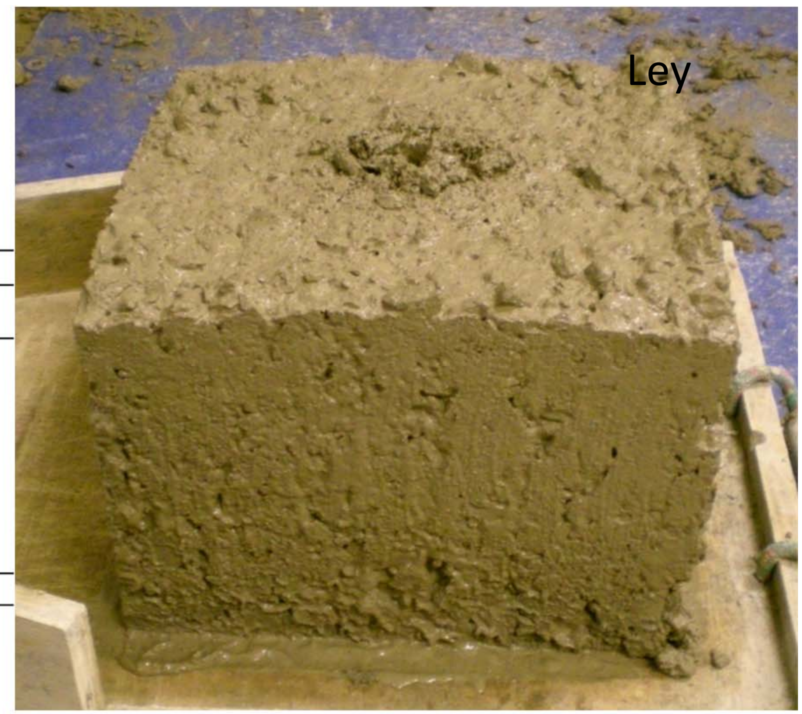
- Add 9.5” of unconsolidated concrete to the box
- Insert 1” diameter stinger vibrator (8000 vpm) into the center of the box over a three count and then remove over a three count

Ley

Box Test

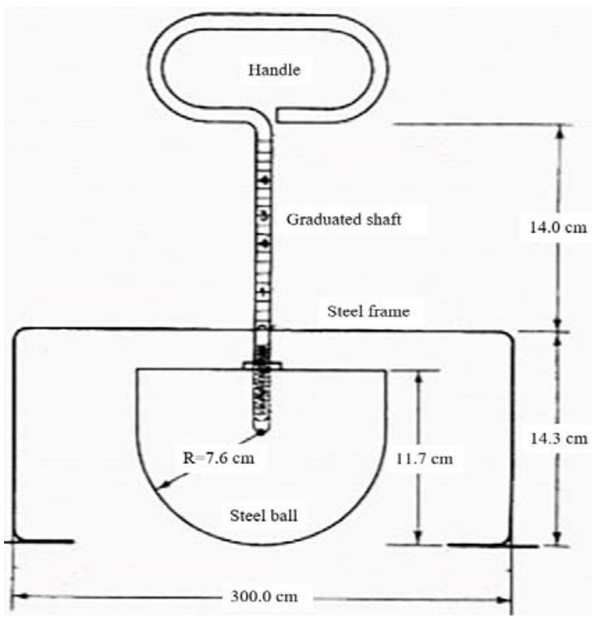
- The edges of the box are then removed and inspected for honey combing and edge slump





VKelly

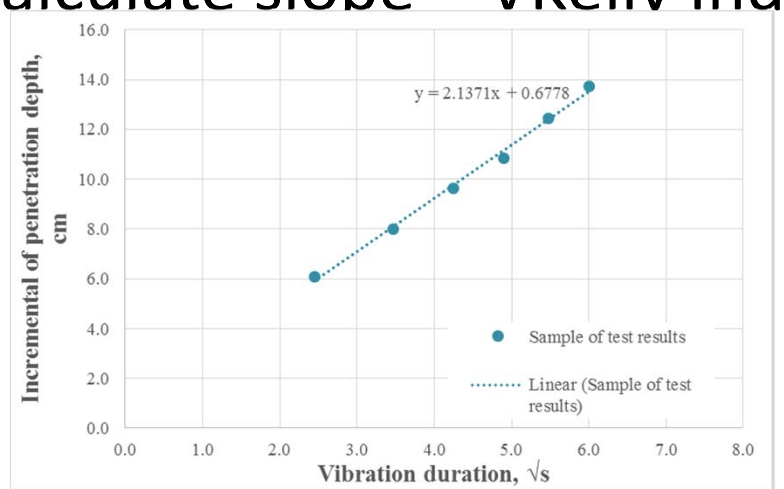
- Kelly ball test
  - Developed in the 1950s in US
  - Standardized in California DOT test
  - Comparable to slump test
    - 1.1 to 2.0 times the Kelly ball reading

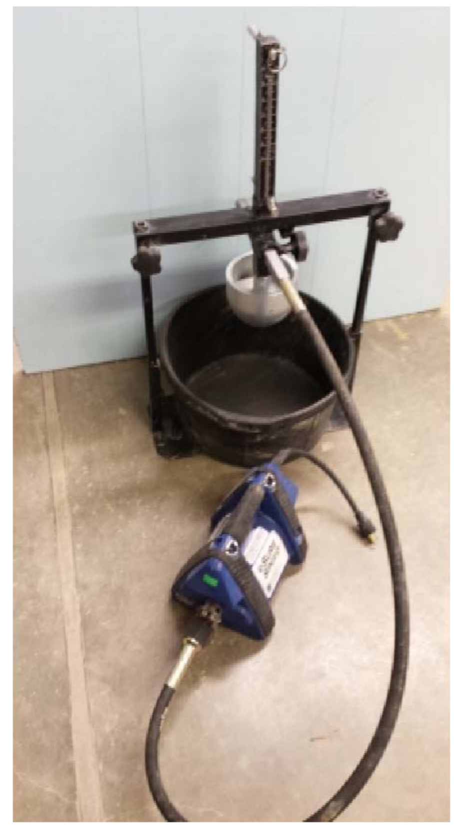


Taylor

VKelly

- Measure initial slump (initial penetration)
- Start vibrator for 36 seconds at 8000 vpm
- Record depth every 6 seconds
- Repeat
- Plot on root time
- Calculate slope = VKelly Index





Taylor

Quality Control

- Why don’t we track how our concrete varies?
  - Unit weight
  - Air content/SAM
  - Water content
  - Formation Factor
  - Strength
- This is important information that we are ignoring.
- PEM will provides guidance for QC
  - Testing targets, frequency, and action limits
  - Guidance will expand on this

Slide from Tom Cackler

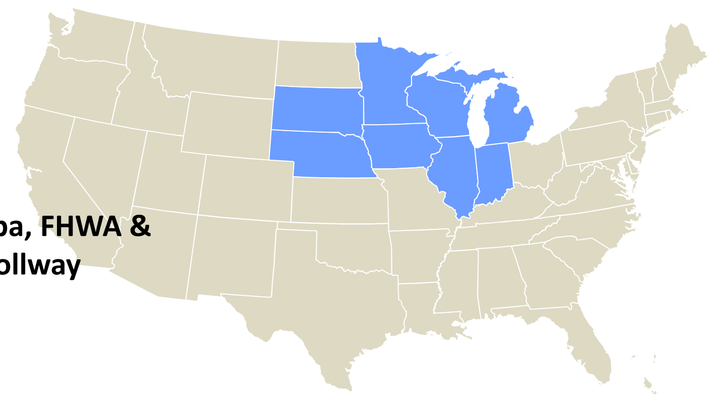
This is a beginning…

- We have used the best approaches to provide guidance on critical durability issues

- Over time everything will improve:
  - Tests
  - Specification
  - Commentary
  - Implementation
  - People's attitude
  - Our concrete

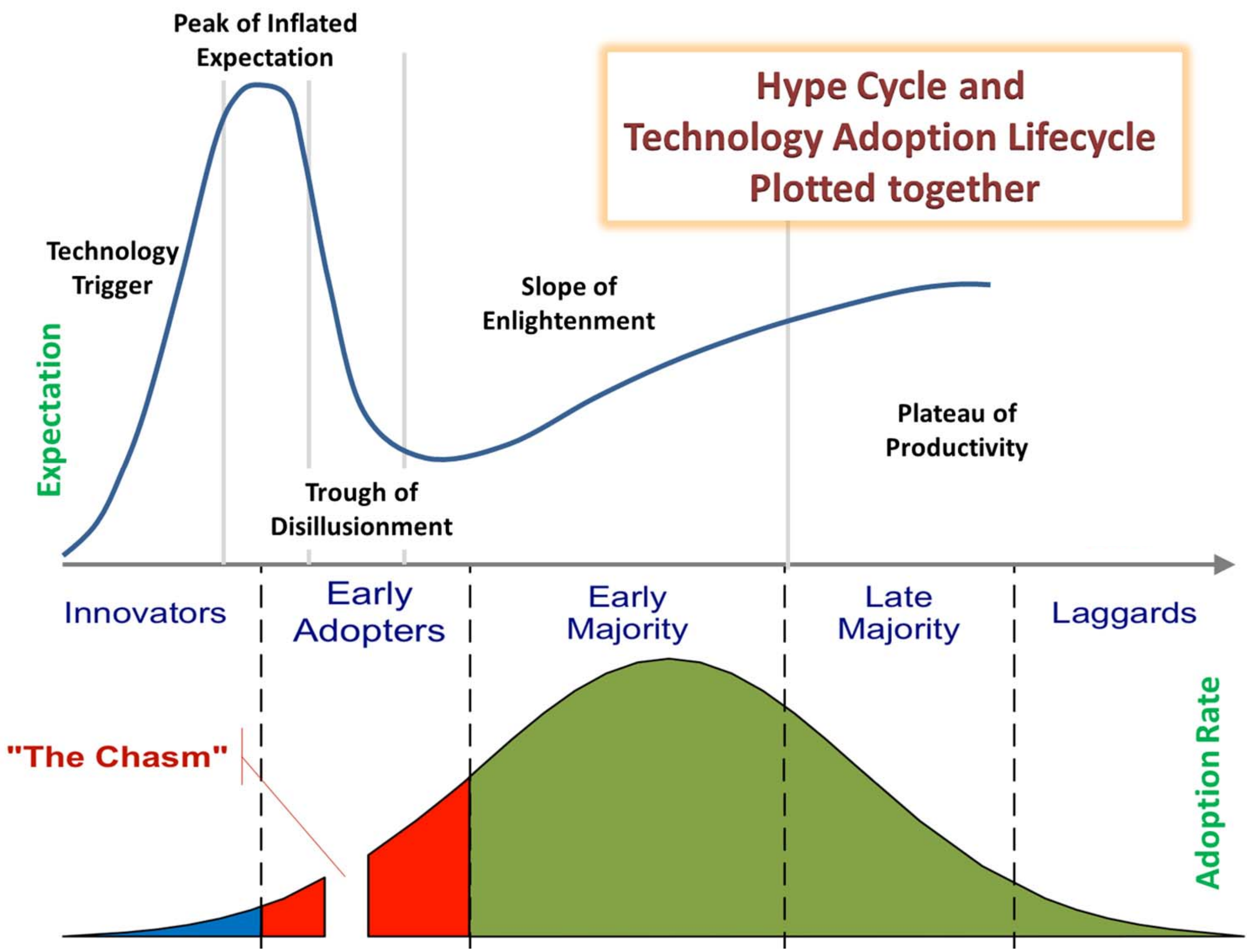
What have we learned?

<u>Every state is different.</u>



You have to:

1. Introduce the concepts and tests
2. Learn where they need help
3. Give them specific training
4. Repeat steps 2 and 3 <u>a bajillion times</u>


Hype Cycle and
Technology Adoption Lifecycle
Plotted together
Peak of Inflated
Expectation
Technology
Trigger
Slope of
Enlightenment
Plateau of
Productivity
Trough of
Disillusionment
Expectation
Innovators
Early
Adopters
Early
Majority
Late
Majority
Laggards
"The Chasm"
Adoption Rate

Need help

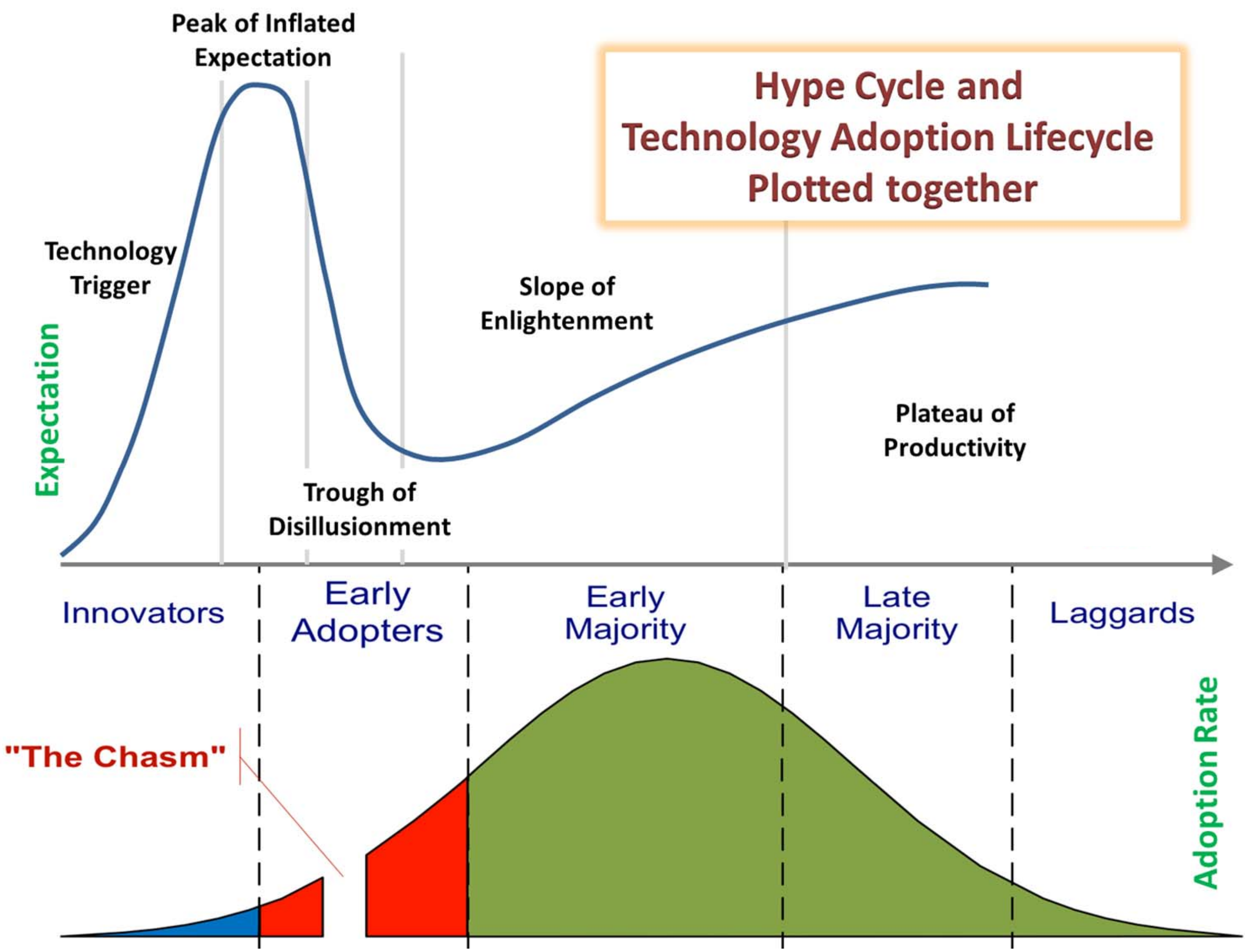
Introduction

Real training

Adoption

Initial training

Shadow spec



This is our immediate future!!!

Introduction

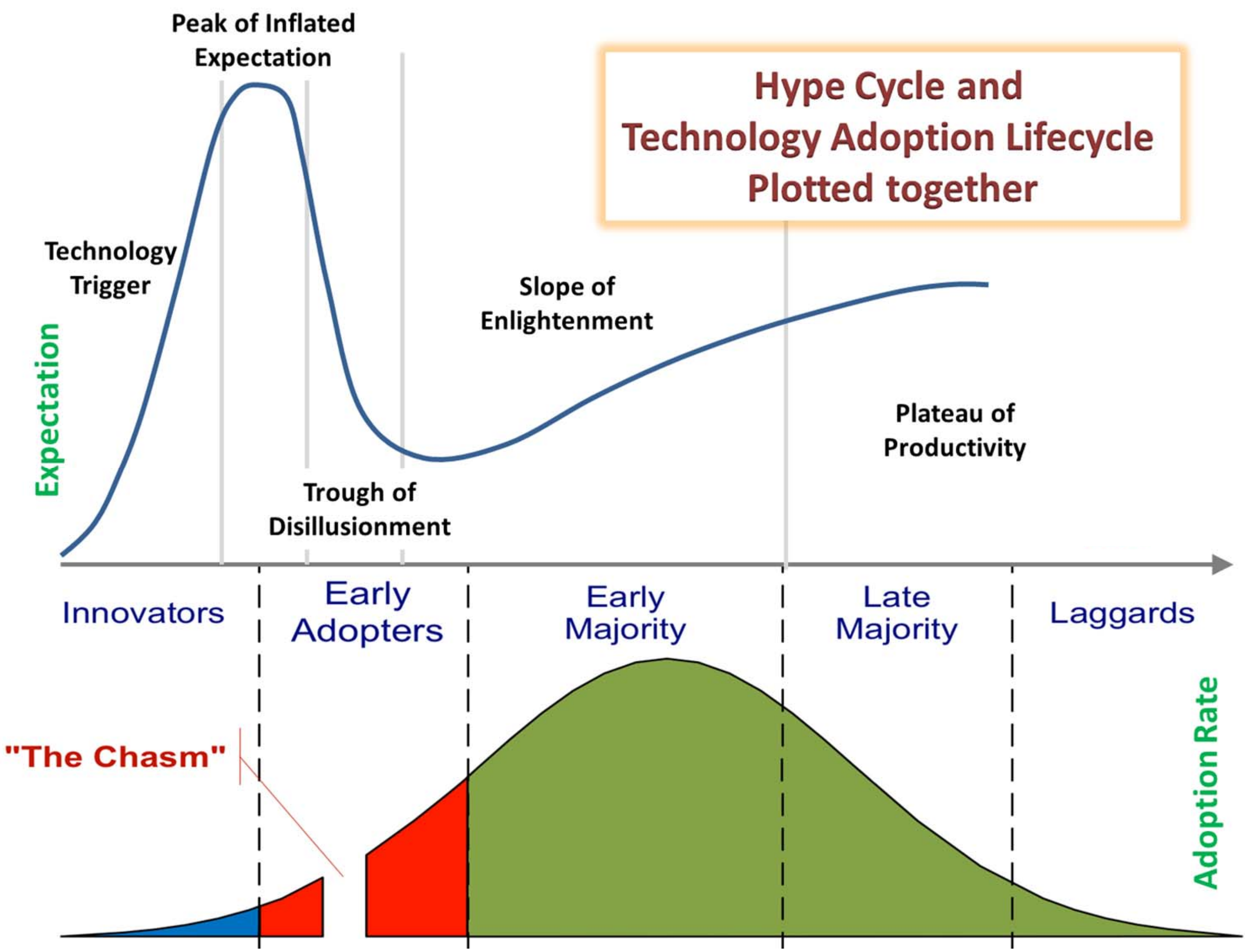
Initial training

Need help

Real training

Shadow spec

Adoption



This is like jumping off a cliff and assembling an airplane on the way down.

Reid Hoffman – Founder of LinkedIn

This is like jumping off a cliff and assembling an airplane on the way down.

Reid Hoffman – Founder of LinkedIn

Every state is a new cliff and new type of airplane…

What are the obstacles?

- Communication
- Implementing new tests
- Test development

Communication

- We need outstanding communication between states, industry, other experts and amongst ourselves
    - We have to be honest, patient, and supportive.
    - Every question/comment is extremely valuable and **must be contemplated and addressed**.

Implementing new tests

Our industry rarely implements new tests.

- Type B Air meter (Klein and Walker, 1949)

  68 years

- Rapid Chloride Permeability Test (Whiting, 1981)

  36 years

Implementing new tests

- Doing something for the first time is hard.

- Many people in our industry have not implemented a new test in their lifetime.

- You have to:
  1. Introduce the concepts and tests
  2. Learn where they need help
  3. Give them specific training
  4. Repeat steps 2 and 3 a **bajillion times**

Why a Bajillion Times?

- Doing something new is hard.

- We need to plan on multiple hands on training sessions for each test that we are going to implement.

- There is too much to learn in one visit.

Test Development

- With feedback from users the tests are evolving, this is why they are TP.

- **This allows the tests to iterate to the best document it can be at a high speed.**

- Give people our best method right now and give them an even better method in the future.

Test Development

- The only way to get user feedback is to get these tests into the DOT, contractor, concrete supplier, testing company, and **get their feedback**.

- We need to realize that we are going to have to repeat ourselves a lot and not everyone will get it.

Test Development

- We have to get people over the idea that these tests are:
  - Expensive
  - Hard
  - Not useful
  - Weird
  - New
  - ….

Test Development

- The best way to handle this is:

- Education
- Get people using the equipment
- Specialized in-person and hands on certification training that is tailored to the needs of the state

Test Development

- Before we can implement a test for acceptance a precision and bias statement needs to be developed.

- Our industry needs more education on precision and bias statements.

How are we going to do this?

- Build strong teams of industry, state, and local experts.
- Outstanding communications with all stakeholders
- Show industry how this will benefit them and solicit their help
- Encourage the state to fund their local experts to help with the effort

How are we going to do this?

- Everyone needs to be honest, patient, and supportive.
- Get ready for some things to go wrong.
- Celebrate the wins.
- Don’t ever say can’t.

Questions?

Anyone hungry?

Performance Engineered Concrete

--It's Time For a Change--

Michael F. Praul, P.E.
Senior Concrete Engineer
FHWA Office of Preconstruction, Construction, and Pavements


BILLS

We Are Horrible With Change

- Timeframe for widespread use of SCM's

- 28-day strength testing
- Slump test

Evolution of Concrete Testing

Concrete

Slump Cone

1922
ASTM C143

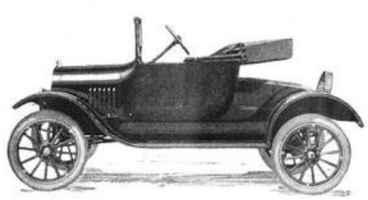
Pressure Meter

1949
ASTM C231

Rapid Chloride Permeability Test

1981
FHWA/PCA

Cars



1920 **1940** **1960** **1980** **2000**

Motivation

- Increase in premature concrete deterioration
- MAP-21 and FAST ACT legislation focus on performance
- Desire by Public Agencies and Industry to move toward performance
  - Optimized mixture designs (gradation, cement content)
  - Improved durability
  - Sustainability
- Testing technology advancements
- Changes in agency and industry skills and personnel levels

Performance Engineered Mixture Concept

- Understand what makes concrete last and what failure mechanisms we see
- Specify critical properties to address those failure mechanisms and test for them
- Starting point for a performance-driven QA specification and acceptance program for owner agencies

PEM Specification Development

- The Team
  - Dr. Peter Taylor, Director, CP Tech Center/Iowa State
  - Dr. Jason Weiss, Oregon State University
  - Dr. Tyler Ley, Oklahoma State University
  - Dr. Tom Van Dam, NCE
  - Cecil Jones, Diversified Engineering
  - Tom Cackler, CP Tech Center
  - Mike Praul, FHWA
- Industry Participants/Reviewers
  - Champion States
  - ACPA National, ACPA Chapter Execs
  - PCA
  - NRMCA

AASHTO PP 84: A Better Specification

Require the things that matter

- Strength
- Shrinkage
- Cold weather resistance
- Transport properties (Permeability)
- Aggregate stability
- Workability*

Why We're Excited

Concrete Evolution

- PEM/PP 84: It's our Superpave
- Most significant field-level advancement in decades
- Answers the question "With our loss of staff and resources, how are we going to be able to get the job done in the future?"
- Collaboration with industry (It's more than just the tests!)

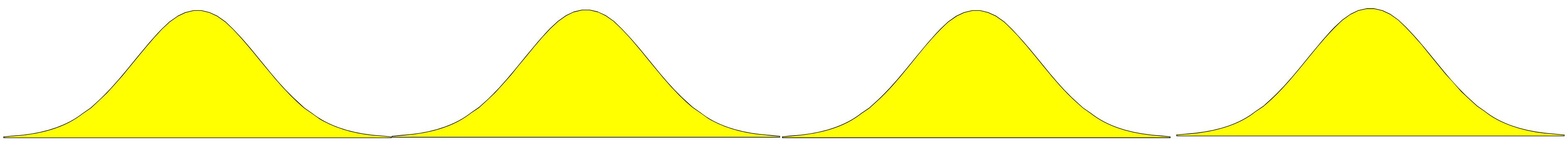
Jerry Voigt, ACPA

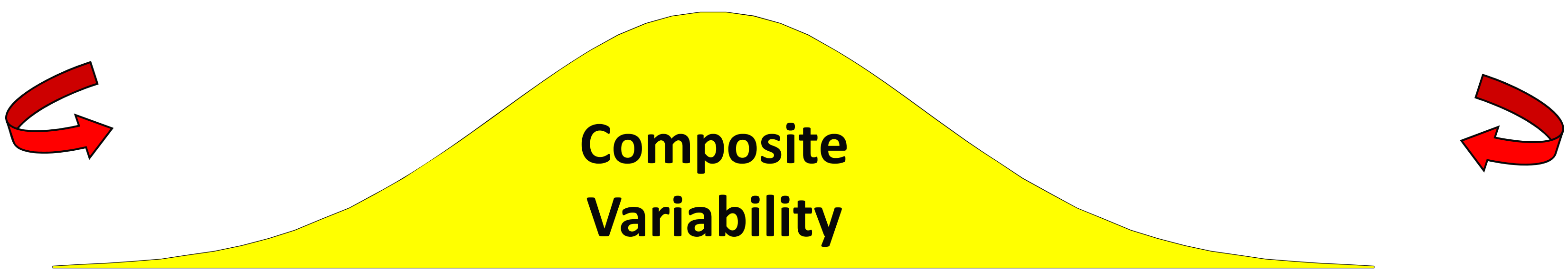
"It's the agency's responsibility to allow for innovation. It's the contractor's responsibility to deliver."

How Do Contractors Deliver in a Performance Specification

Sources of Variability

Material **Process** **Sampling** **Testing**





Controlling Sampling and Testing Variability

- Standard procedures (AASHTO, ASTM, state)
- Laboratory accreditation/qualification program
- Technician training and certification programs
- State Independent Assurance Program
- Calibrated equipment schedules

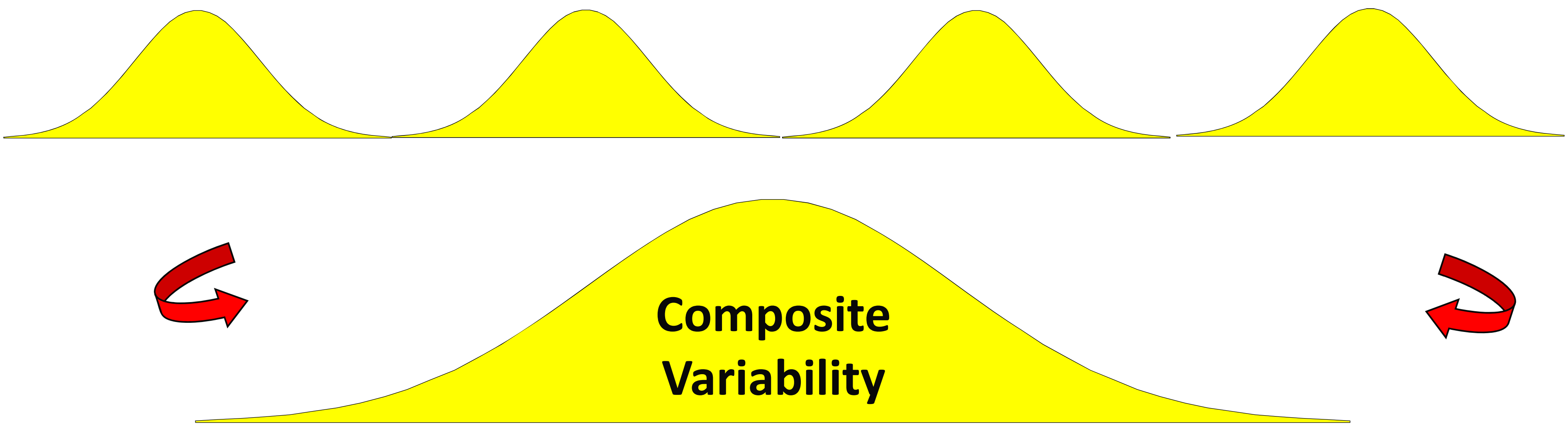
Testing Variability

Procedure		95% Lower Limit	Test Result	95% Upper Limit
Sieve analysis (% passing ½")		24%	28%	32%
Slump		2"	2 ½"	3"
Air content		4.9%	5.5%	6.1%
Rodded unit weight for aggregate		114.5 lb/ft^3	120 lb/ft^3	125.5 lb/ft^3
Compressive strength		3,390 lb/in^2	3,600 lb/in^2	3,810 lb/in^2
Flexural strength		602 lb/in^2	700 lb/in^2	798 lb/in^2

Sources of Variability

Material **Process** **Sampling** **Testing**



Controlling Material and Process Variability

Prescriptive vs. Performance Specifications

Prescriptive

- Agency dictates how the material or product is formulated and constructed
- Based on past experience
- Minimal/uncertain ability to innovate
- Requires agency to have proper manpower and skill set to provide oversight

Performance

- Agency identifies desired characteristics of the material or product.
- Contractor controls how to provide those characteristics
- Maximum ability to innovate
- Reduced oversight burden on the agency

Quality Assurance Defined

23 CFR 637

- Agency Acceptance
- Contractor Quality Control

- Qualified (certified) Personnel
- Qualified Laboratories
- Independent Assurance
- Dispute Resolution for Test Results

} State processes, independent of material

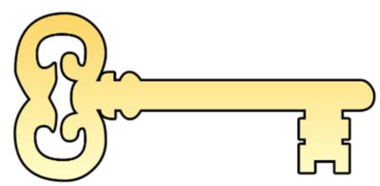
Quality Control

- PP 84 acknowledges the key role of QC in a performance specification
- Requires an approved QC Plan
  - Testing targets, frequency, and action limits
  - Equipment and construction inspection
  - ➢ Mirror design-build experience
- Requires QC testing and control charts
  - Unit weight
  - Air content/SAM
  - Water content
  - Formation Factor (via Surface Resistivity)
  - Strength

Mirror Design-Build (DB) Experience

- DB shifts control from agency to contractor
  - Risk shifts with control
- Agency retains responsibility and accountability to the taxpayers
- Contractor submits proposal including <u>how</u> they will develop and deliver the project
- Post-award, contractor submits a <u>detailed QC Plan</u>
- Performance specifications have a similar shift of risk and control

✓ QC Plans are analogous



Quality Control

- Uses real time feedback
  - Now possible with innovation and new tests

- A good Contractor QC system:
  - Doesn't just echo Agency requirements
  - Implements QC procedures as standard practice
  - Isn't just paperwork…it's a mindset

QC Plan

A project-specific document prepared by the contractor which identifies QC personnel and procedures that will be used to maintain production and placement processes in control and meet the agency specification requirements.

Scope of Quality Control Activities

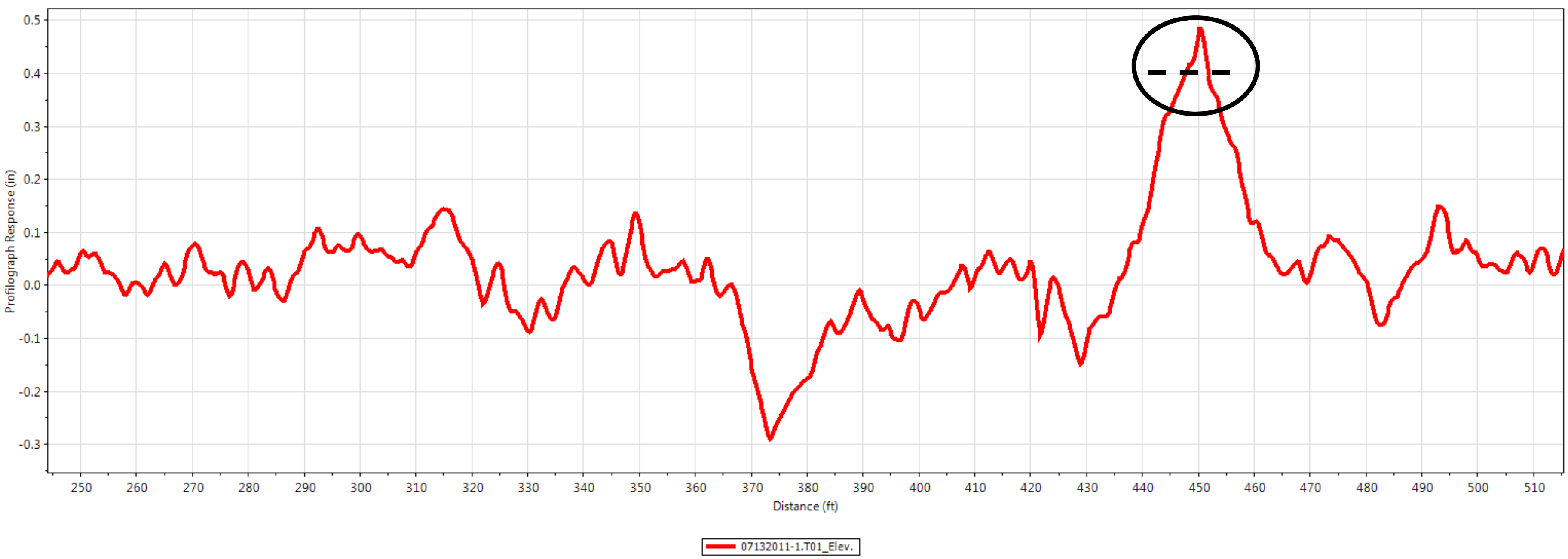
- Contractor's QC Plan should address:
  - Materials production processes
  - Materials transportation and handling
  - Field placement procedures
  - Calibration and maintenance of equipment
  - Activities (sampling, testing and inspection) to maintain each process in control
  - Means to make timely adjustments and corrections

QC Plan

- QC Plan serves as an extension of the project specifications
- Agency should review the QC plan to ensure:
  - Includes all required items
  - Contains sufficient detailed content addressing project specifics
- When QC plan is deficient, agency should require revision

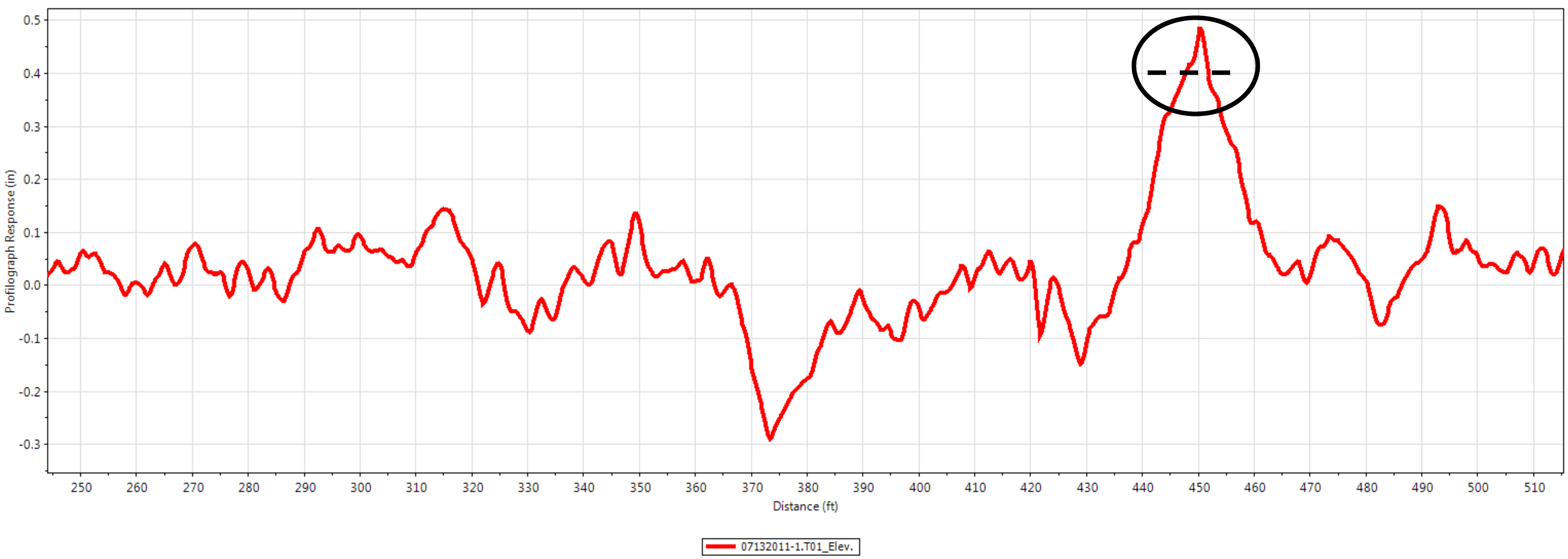
QC Example

- Smoothness testing shows a must-grind bump from the previous day's paving



QC Example

- What information would help us determine the cause(s) of the bump?



Poor QC Plan Approach

For Smoothness, Contractor's QC plan states:

- "Materials, equipment and methods used to construct concrete pavement will conform to Section 501 of the specifications"
- "Quality control testing will be performed in accordance with Section 501.14 of the specifications"

Better QC Plan Approach

For Smoothness, Contractor’s QC plan states:

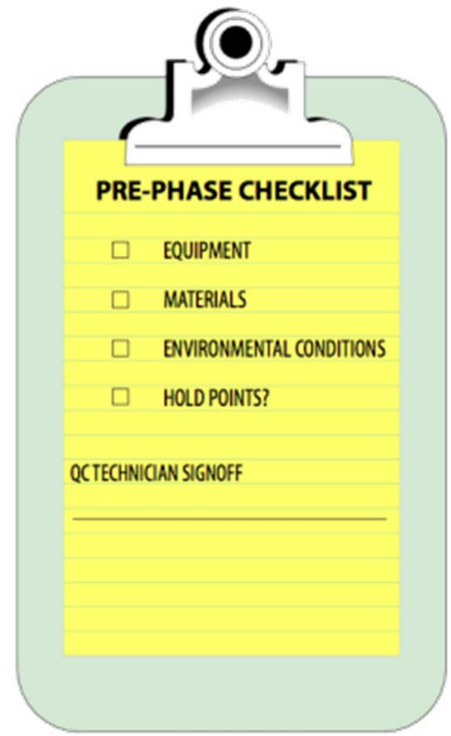
- 20’ straightedge advanced at 10’ increments
- Paving foreman will maintain a log of all “events” indexed by station
- Smoothness test results will be provided to the paving foreman for analysis and approval within one hour of testing

Foreman’s Diary Notes

Sta.	Notes
348+50	start day, paver out of super transition, tangent section now
349+00	ADJ paver on right side so that I could get the 12" I need on profile, crank down one
349+50	paver stopped because of TBI
349+50	XXXXX hit me - on right side with his straightedge
350+00	RF steering sensor wand hit dowl bar bundle
350+50	crank down one on right side
353+00	paver was over loaded
354+00	paver stopped to fuel
354+00	roll size of OCB 1' in
354+50	XXXXX speeded up paver a bit 8' 4" fpm
354+85	paver stopped
355+50	mud box is about half full only

QC Inspection Documentation

- Inspection Report Forms
- Pre-Phase Checklists
  - Used prior to start of a major production or placement operation
  - Include all inspection components that have an impact on quality
  - Identify responses when non-compliant conditions are identified
- Test Report Forms



QC and Safety

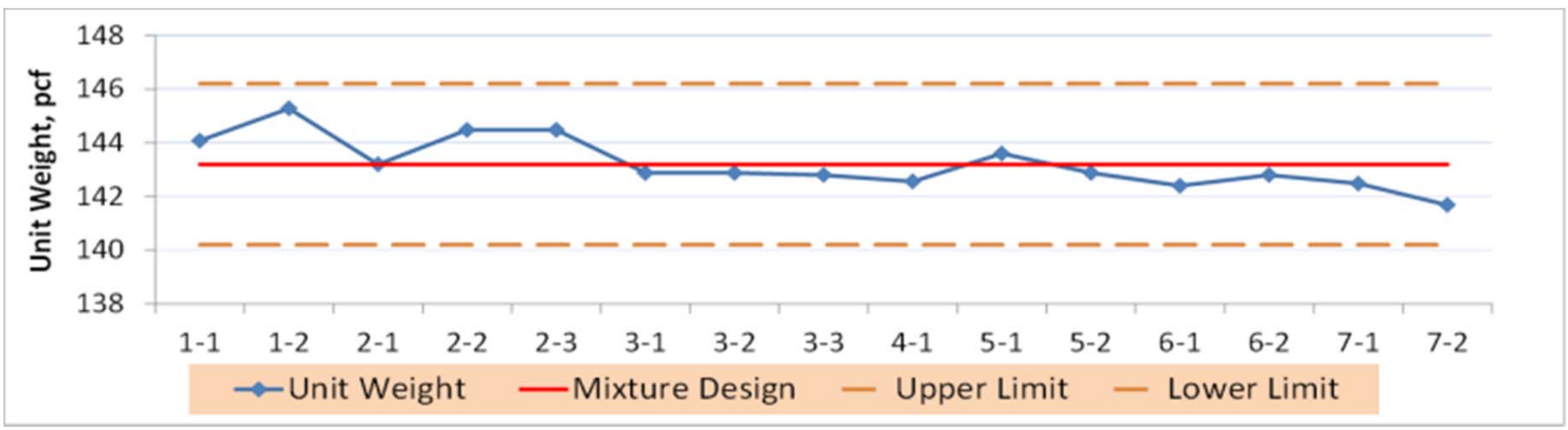
- Safe Facilities: quality construction critical to providing safe transportation facilities

July 2006 motorist fatality from partial collapse of tunnel ceiling on I-90 in Boston

- Contractor insurance story

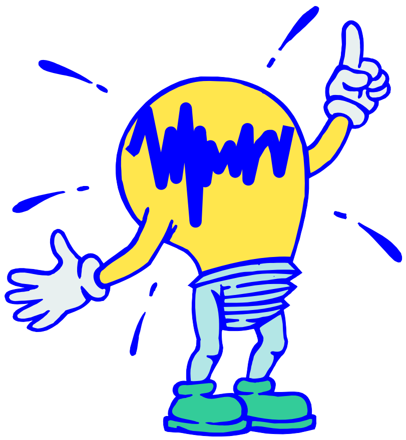
Control Charts

- Used to plot and monitor consecutive test results
- Results can be tracked against a process target/limits
- Can help to identify whether the process is in control
- May indicate that adjustments process is necessary



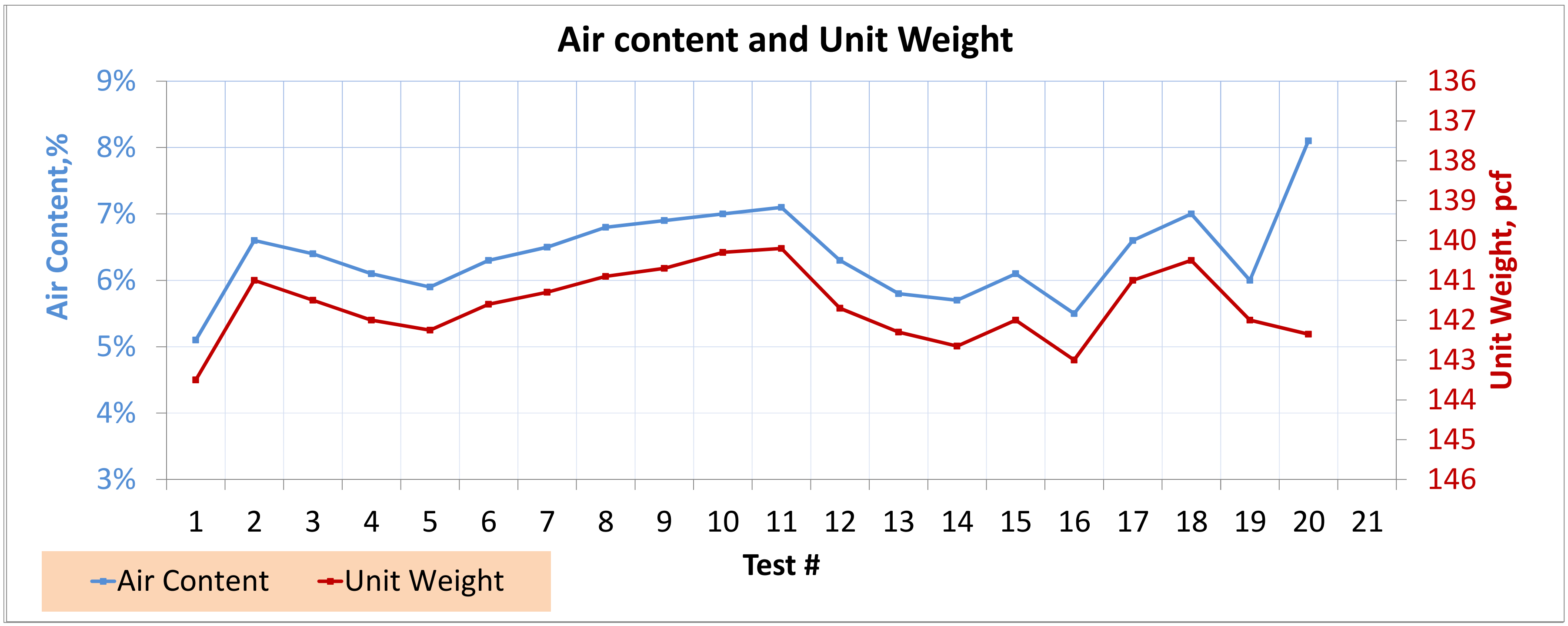
Control Charts

- Control charts do not
  - Eliminate variability
  - Tell you where your problem lies
  - Tell you how to correct the problem
- Some control charts
  - Help distinguish between the inherent chance causes of variability and assignable causes

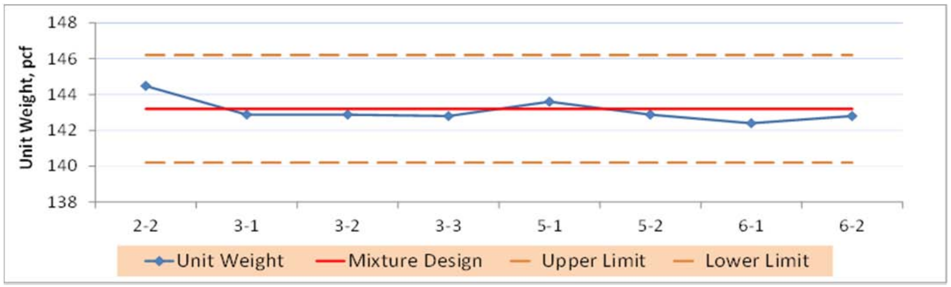


Dual Axis Plot Example

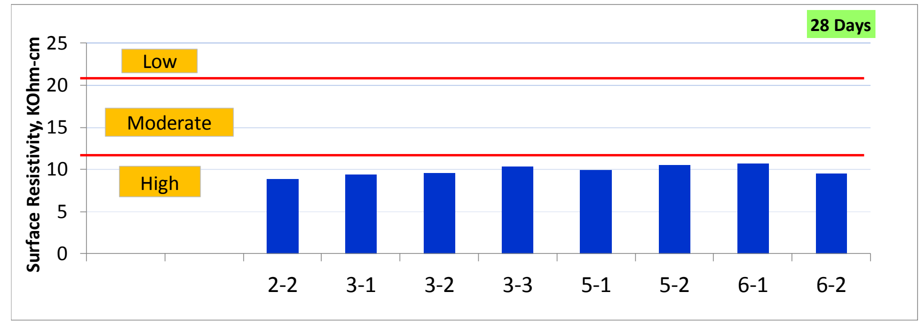
- Air content plotted on the left vertical axis
- Plot unit weight on the right vertical axis



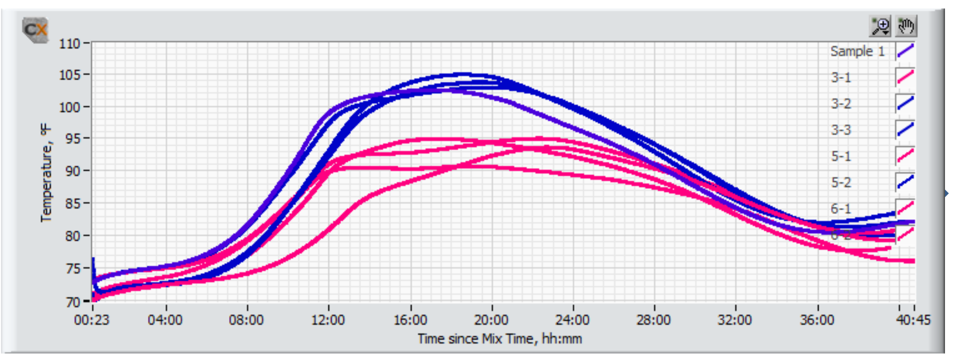
Unit Weight / Heat Signature / Permeability



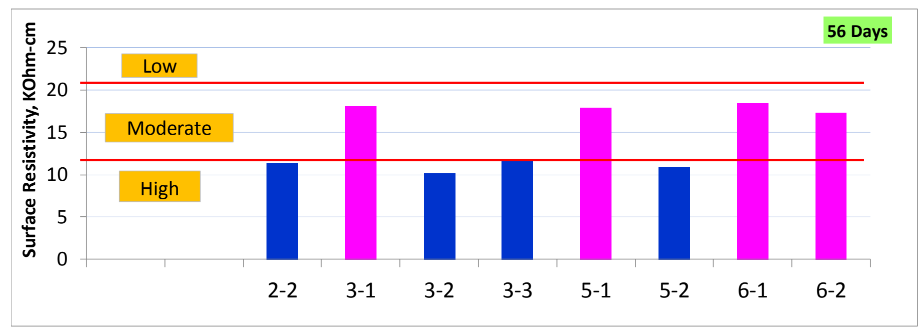
Unit Weight – Real Time



Surface Resistivity – 28 Days



Heat Signature – Info in a day



Surface Resistivity – 56 Days

Real Time

28 / 56 days

Field Data from an MCT project

Quality Control Evolution

- Change state mindset that QC is not their business
  - Gordon Smith example
- Change (some) industry mindset that QC is not their business
- Provide guidance on developing state specification language
- QC Testing Guide (very similar to guidance for the acceptance program but slanted to industry)
  - QC tests “one-pagers” and videos
  - Frequency
  - Control charts and usage
- QC Plan template and guidance

"But Mike, You're Asking for a Lot of Change"

Change has already happened!

- Cements
- Widespread use of SCM's
- Advancements in chemical admixture technology

- De-icers

- Agency personnel and experience levels
- Industry knowledge base

Proven Concepts

- 1996 move to QA approach
- Contractor mix designs
- No agency personnel in plants
- Meaningful QC Plans (enforced)
- Cooperative approach
- Results!

Moving Forward--A Transportation Pooled Fund Project

PERFORMANCE ENGINEERED CONCRETE PAVING MIXTURES (***PEM***)

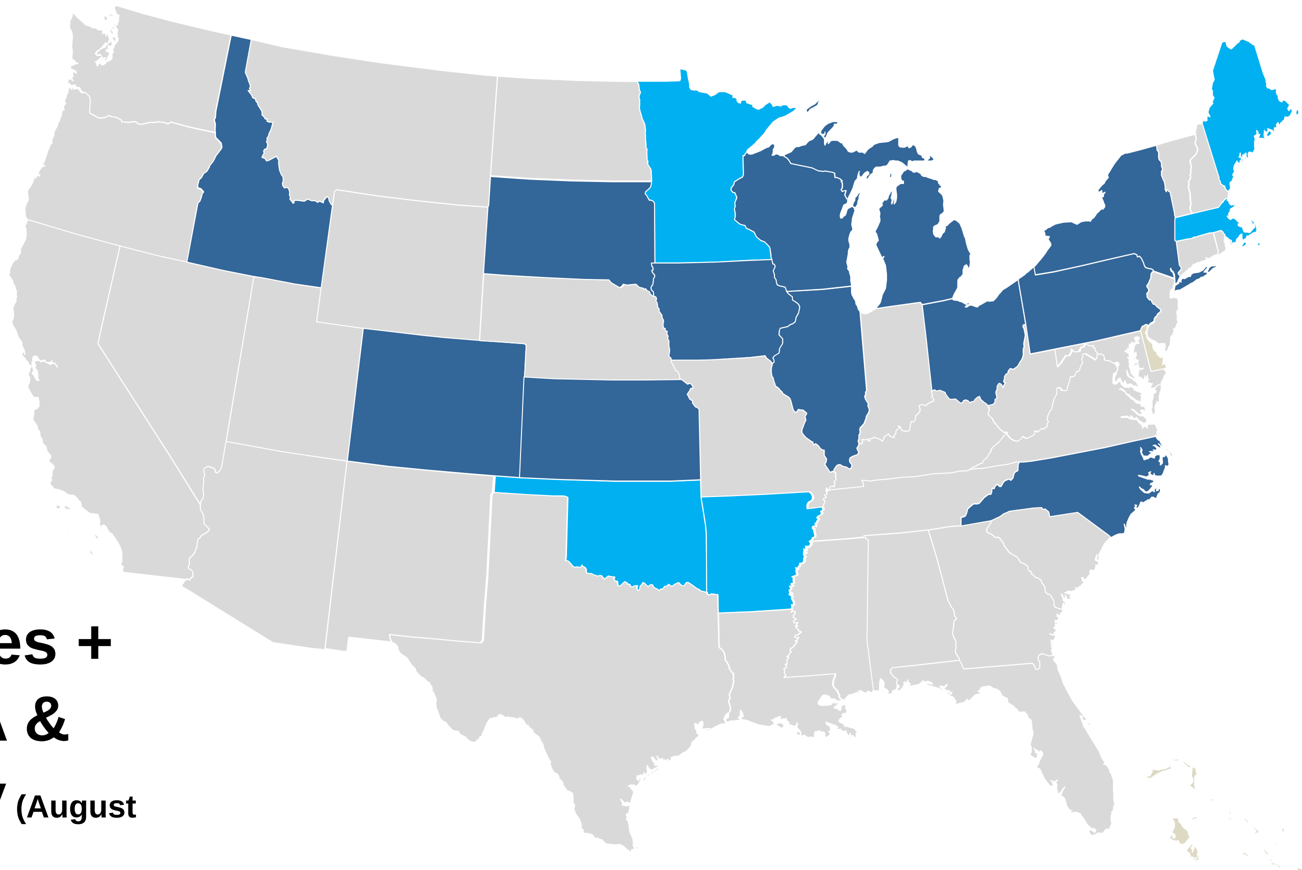
PEM/TPF Project

- Starting Date – August 2017
- Length of Phase 1 – 5 years
- Phase 1 Funding - $3 Million
- Phase 2 – Consideration in year 4 – with objective to continued emphasis on Task 2 (Performance Monitoring) and Task 3(Relating Properties to Performance)

PEM/TPF Partners

- Federal Highway Administration (FHWA)
- State Departments of Transportation (DOTs)
- Industry (ACPA-PCA-NRMCA-SCA-Others)

PEM POOLED FUND PARTICIPANTS
TPF-5(368)



12 States + FHWA & Industry (August 2017)

Industry Commitments

- ***PCA*** – $100,000 committed in 2017 (future participation to be considered annually)
- ***ACPA*** – intent to contribute $50,000 annually for five years
- ***RMC Foundation*** – commitment to contribute $50,000 annually for five years

Industry Commitments

- ***State Paving Chapters/Associations***
  Commitment (to date) to contribute $19,000 annually for five years (others considering)
- ***Slag Cement Association (SCA)***
  Commitment to contribute $10,000 annually for 5 years
- ***American Coal Ash Association (ACAA)***
  Participation under consideration
- Others (admixture, aggregate, etc.) - will be asked to consider.

PEM Implementation – TPF-5(368)

Proposed Funding : $3 million over 5 years

FHWA Mobile Concrete Trailer (MCT)

PP 84 Implementation

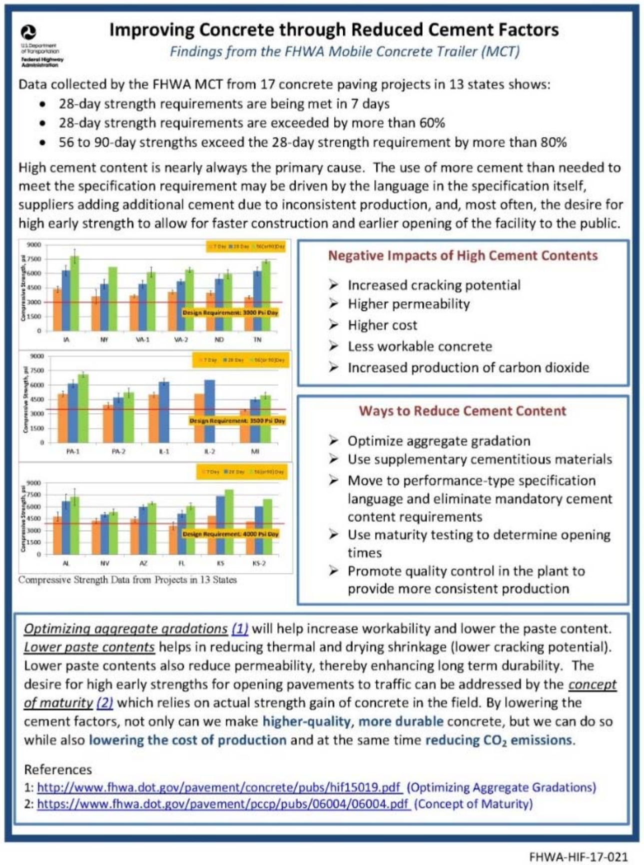
- Assisting PEM Team and TFHRC with ongoing PEM-related research
- Continue to assist with Super Air Meter deployment
- Shadow PP 84 and state testing during field visits
- Demonstrating PP 84 equipment and testing
- Conferences and other venues
- Developing videos on new tests

Equipment Loan Program

- States or industry can borrow MCT equipment
- MCT staff will provide training, if desired
- PP 84 focus
- Anticipate substantial new equipment purchase for Spring 2018
- Currently enhancing information on our website

One Pagers

- New effort to use MCT data
- Narrowly focused
- Meant to stir interest and point reader to resources
- 1st: Cement content
- 2nd: Optimized Mix Design
- 3rd: Cylinders vs. Cores
- Three more by May
- Some focus on PP 84



Improving Concrete through Reduced Cement Factors

Findings from the FHWA Mobile Concrete Trailer (MCT)

Data collected by the FHWA MCT from 17 concrete paving projects in 13 states shows:

- 28-day strength requirements are being met in 7 days
- 28-day strength requirements are exceeded by more than 60%
- 56 to 90-day strengths exceed the 28-day strength requirement by more than 80%

High cement content is nearly always the primary cause. The use of more cement than needed to meet the specification requirement may be driven by the language in the specification itself, suppliers adding additional cement due to inconsistent production, and, most often, the desire for high early strength to allow for faster construction and earlier opening of the facility to the public.

Compressive Strength Data from Projects in 13 States

Negative Impacts of High Cement Contents

- Increased cracking potential
- Higher permeability
- Higher cost
- Less workable concrete
- Increased production of carbon dioxide

Ways to Reduce Cement Content

- Optimize aggregate gradation
- Use supplementary cementitious materials
- Move to performance-type specification language and eliminate mandatory cement content requirements
- Use maturity testing to determine opening times
- Promote quality control in the plant to provide more consistent production

Optimizing aggregate gradations (1) will help increase workability and lower the paste content. *Lower paste contents* helps in reducing thermal and drying shrinkage (lower cracking potential). Lower paste contents also reduce permeability, thereby enhancing long term durability. The desire for high early strengths for opening pavements to traffic can be addressed by the *concept of maturity* (2) which relies on actual strength gain of concrete in the field. By lowering the cement factors, not only can we make **higher-quality**, **more durable** concrete, but we can do so while also **lowering the cost of production** and at the same time **reducing CO_2 emissions**.

References

1: http://www.fhwa.dot.gov/pavement/concrete/pubs/hif15019.pdf (Optimizing Aggregate Gradations)
2: https://www.fhwa.dot.gov/pavement/pccp/pubs/06004/06004.pdf (Concept of Maturity)

FHWA-HIF-17-021


END OF THE ROAD
MILE 92.5
DENALI NATIONAL
PARK AND PRESERVE

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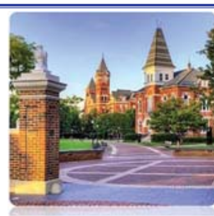
AUBURN UNIVERSITY **2017 Alaska Concrete Summit**

Self-Consolidating Concrete

By: Anton Schindler, Ph.D., P.E., FACI

Professor and HRC Director
Department of Civil Engineering
Auburn University

November 2017



Presentation Overview

- Introduction
- Key Properties and Test Methods
- Materials and Proportioning
- Example Applications
- Market Acceptance
- Closing Remarks

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Introduction

- United States:
  - SCC = Self-Consolidating Concrete
- Europe and Japan:
  - SCC = Self-Compacting Concrete

ACI 237 Definition

"SCC is a **highly flowable**, **non-segregating** concrete that can spread into place, fill the formwork, and encapsulate the reinforcement **without any mechanical consolidation**."

Traditional Construction

Vibrated Concrete with 6.5 in. slump

Self-Consolidating Concrete

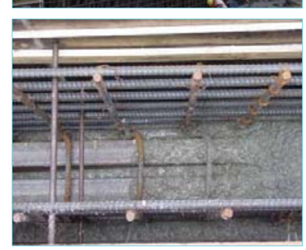
Potential Benefits

- **Economics:**
  - May reduce labor by 30-40%: less labor to place, no labor to vibrate, less surface patching
  - Faster placement
  - Reduced member cost
- **Environment:**
  - Less energy used
  - No noise from vibratory equipment
  - Improved worker satisfaction
- **Safety:**
  - Fewer labors on-site and on formwork
  - No injuries associated with use of vibratory equipment

Video clip courtesy of Obayashi Corp

Potential Benefits

- **Flowability:**
  - Placements with difficult access to vibrate conventional concrete
    - I-4 Pedestrian Overpass, Seminole County, Orlando, FL
    - Valley Creek Wastewater Treatment Plant in Jefferson County, Alabama



Pedestrian Overpass, FL

Potential Benefits

- **Construction of highly congested members:**
  - Few or no "bug-holes" after from removal
- **Aesthetics:**
  - Smoother formed surfaces, virtually no "honeycombing" or "bug holes"
    - Architectural concrete
    - Decorative forms

Benefits - Aesthetics

(Pictures courtesy of Dr. Charles Nmai, BASF)

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Key Fresh Properties of SCC

1. **Filling ability:**
   - SCC must flow into all spaces within the formwork under its own weight
2. **Stability (Resistance to segregation):**
   - SCC must not segregate during transportation, placement, and while in the form
3. **Passing ability:**
   - SCC must flow through reinforcement and tight openings without aggregate blocking

Key SCC Properties

1. Filling ability:

- ability of the SCC to flow into all spaces within the formwork under its own weight
- Test method:
  - **Slump flow**
  - ASTM C1611
  - Most common QC/QA Test

Slump Flow (ASTM C 1611)

Slump Flow for SCC: **18 to 30 in.**

Drilled Shafts

I-Girders

Slump Flow = 18 in.

Slump Flow = 30 in.

Key SCC Properties

2. Stability (Resistance to segregation):

- **Dynamic Stability** - the ability of a concrete mixture to flow into place without segregation of the paste from the aggregates
  - Use: **Visual Stability Index (VSI) test**
- **Static Stability** - the ability of a concrete mixture to resist segregation of the paste from the aggregates after placement
  - Use: **Column Segregation Test**

Key SCC Properties

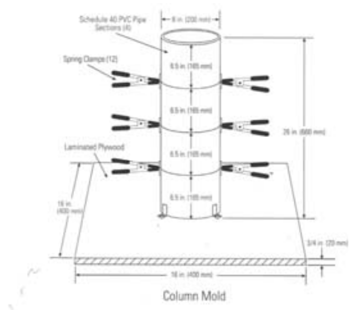
2. Stability (Resistance to segregation):

- **Dynamic** stability test: Visual Stability Index (VSI) obtained from slump flow "patty"
- Subjective visual assessment ?
  - VSI = 0 **No segregation**
  - VSI = 0.5
  - VSI = 1
  - VSI = 1.5
  - VSI = 2
  - VSI = 3 **Clear segregation**

Visual Stability Index (**VSI**)

(See ASTM C 1611)

Column Segregation Test



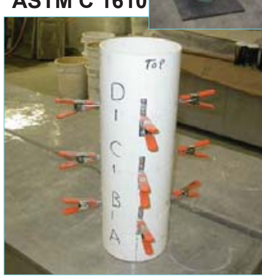
ASTM C 1610

The mass of the coarse aggregate is determined for the top and bottom sections, and a segregation index is calculated

Column Segregation Test

- Measures **static** segregation potential of SCC
- Fill a cylinder with SCC
- Weigh coarse aggregate in top and bottom sections
- Segregation Index (SI) = percent difference in mass between top and bottom sections
  - SI ≤ 15% ⇒ Acceptable

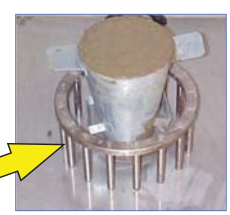
ASTM C 1610



Key SCC Properties

3. Passing ability:

- Ability of SCC to flow through reinforcement and tight openings without aggregate blocking
- Test method:
  - J-Ring: ASTM C 1621
  - This test forces the concrete producer to use small coarse aggregate sizes



J-Ring Test (ASTM C 1621)

Slump Flow = 28.0 in. **Flow with J-Ring = 26.5 in.**

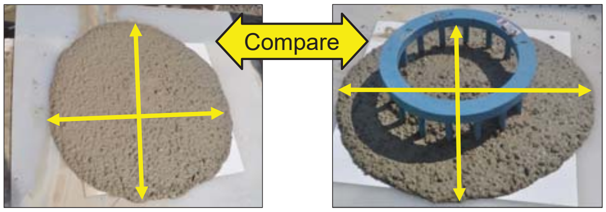
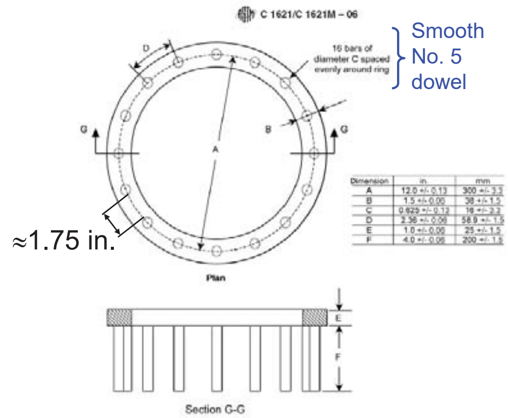


TABLE 1 Blocking Assessment

Difference Between Slump Flow and J-Ring Flow	Blocking Assessment
0 to 1 in. [0 to 25 mm]	No visible blocking
>1 to 2 in. [>25 to 50 mm]	Minimal to noticeable blocking
>2 in. [>50mm]	Noticeable to extreme blocking

J-Ring (ASTM C 1621)



What about other Typical Tests ?

- Continue to measure as usually required:
  - Air content
  - Compressive strength
  - Other mechanical/durability properties

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Materials and Proportioning

- Generally, similar materials as for vibrated concrete
- SCC proportions are different when compared to vibrated concrete
  - More chemical admixtures are used in SCC
  - Cost of SCC / yd^3 is more expensive
    - Range from 110% to 160% / yd^3 more for SCC relative to vibrated concrete
      - ***Larger*** cost difference for ***lower*** strengths (higher cementitious materials content required for SCC)

Materials and Proportioning

- High dosage of high-range water-reducing admixture (HRWRA):
  - Provides the necessary fluidity
- After adding HRWRA, avoid segregation by increasing the viscosity. Use:

1. High volume of cementitious/fine powder:

- Adds cohesiveness to SCC
- Fly ash, silica fume, and/or slag cement
- Limestone fines

Materials and Proportioning

- Recommendations from ACI 237 (2007)

Table 4.1—Suggested powder content ranges*

	Slump flow of < 22 in. (<550 mm)	Slump flow of 22 to 26 in. (550 to 600 mm)	Slump flow of >26 in. (>650 mm)
Powder content, lb/yd^3 (kg/m^3)	600 to 650 (355 to 385)	650 to 750 (385 to 445)	750+ (458+)

*or as needed for strength.

Note: Normal 4,000 psi, 5 in. slump concrete has a powder content ≤ **600 pcy**

Materials and Proportioning

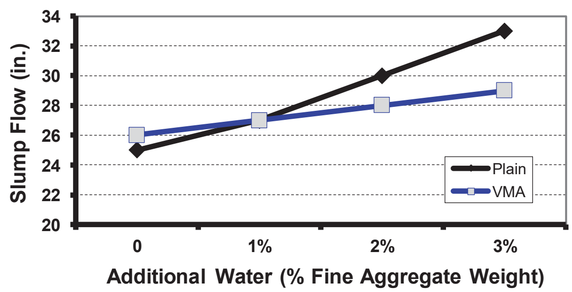
- After adding HRWRA, avoid segregation by increasing the viscosity. Use:

1. High volume of cementitious/fine powder

2. Viscosity-modifying admixtures (VMA)

- These reduce the risk of bleeding + coarse aggregate segregation
  - VMAs can be expensive
- Makes mixtures more “robust” and may improve reproducibility of SCC

Effect of VMA on Slump Flow



(Graph courtesy of Dr. Charles Nmai, BASF)

Materials and Proportioning

- **Use an increased paste volume:**
  - Improves the filling ability (slump flow)
- **Size and amount of coarse aggregate:**
  - Affects the passing ability
  - Use lower coarse aggregate volume (i.e. more sand)
  - Use smaller coarse aggregates (No. 67 or No. 78)
    - Improves the resistance to segregation
- **Type of coarse aggregate:**
  - SCC can be made with any aggregate type
  - Crushed aggregates require increased paste contents

Example Proportions for Prestressed Girders

Material / Properties	SCC	Conventional HPC
Type III Cement	650 pcy	752 pcy
Class C fly ash	279 pcy (30%)	132 pcy (15%)
Water	260 pcy	265 pcy
w/cm	0.28	0.30
Coarse Aggregate (SSD)	1,535 pcy	1,976 pcy
Coarse Agg. Type	#78 Limestone	#78 Limestone
Fine Aggregate (SSD)	1257 pcy	950 pcy
Sand/Total Agg.	0.45	0.32
Air-Entraining Admixture	7 oz/cy	11 oz/cy
HRWR Admixture	12 oz/cwt	8 oz/cwt
f'_c (28 days)	13,300 psi	9,000 psi
f'_{ci} (0.75 days)	8,860 psi	7,060 psi
E'_c (28 days)	7,350 ksi	6,300 ksi
E'_{ci} (0.75 days)	**5,900 ksi**	**5,900 ksi**

Example Proportions for Drilled Shafts

Mixture Constituents	SCC	Conv. DSC
Type I/II Cement	465 pcy	500 pcy
Class F Fly ash	230 pcy (33%)	125 pcy (20%)
Water	284 pcy	270 pcy
w/cm	0.40	0.43
Coarse Aggregate Type	No. 78 River Gravel	No. 67 Stone
Coarse Aggregate Amount (SSD)	1,616 pcy	1,811 pcy
Fine Aggregate (SSD)	1,280 pcy	1,216 pcy
Sand/Aggregate (by volume)	0.44	0.40
Extended-Set Control Admixture	6 to 10 fl oz/cwt	6 to 10 fl oz/cwt
Mid-Range Water-Reducing Admixture	4 fl oz/cwt	-
High-Range Water- Reducing Admixture	4 to 6 fl oz/cwt	4 to 6 fl oz/cwt
Viscosity-Modifying Admixture (VMA)	2 fl oz/cwt	-

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New Marquette Interchange: SCC Use

(Picture courtesy of Dr. Charles Nmai, BASF)

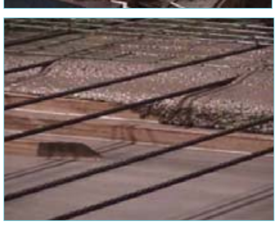
New Marquette Interchange: SCC Use

Precast wall panels:

- 7.5 and 9.5 in. thick
- 10 to 25 ft length
- 8 and 19 ft widths

Concrete Mixture:

- 3/8 in. max. size aggregate
- High-range water reducer
- Slump flow: 26 to 28 in.
- No vibration or finishing
- 8,000 to 10,000 psi @ 8 hr



New Marquette Interchange: Spires

(Picture courtesy of Dr. Charles Nmai, BASF)

Intricate Forming: The Citadel

The Citadel - Charleston, SC

- Barracks with 10,000 yd^3 concrete
- 4,000 yd^3 of difficult 6 in. thick, 12 ft high walls
- Previous projects with same wall design experienced severe cost overruns:
  - high placement and patching costs
- Conventional wall pours were problematic
- **Changed to SCC**

7 in. slump vibrated concrete

Intricate Forming: The Citadel

(Slide courtesy of Dr. Charles Nmai, BASF)

Doorways - After SCC Flowed 35 Feet

(Slide courtesy of Dr. Charles Nmai, BASF)

Intricate Forming: The Citadel

(Picture courtesy of Dr. Charles Nmai, BASF)

Meudon Art Center, France

- Cultural center with 450-seat auditorium, stage, exhibition hall, lobby and offices
- Monolithic cast walls: 27 ft x 66 ft x 8 in.
- Built mostly with SCC

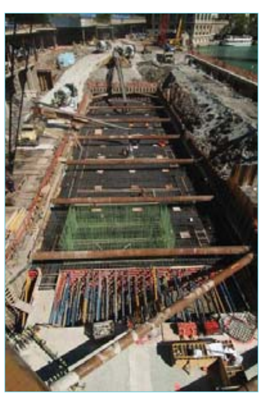
(Picture courtesy of Dr. Charles Nmai, BASF)

Meudon Art Center, France

(Picture courtesy of Dr. Charles Nmai, BASF)

Mat Foundations: Trump Tower

Trump Tower Project, Chicago (09/30/05)



(Picture courtesy of Dr. Charles Nmai, BASF)

Mat Foundations: Trump Tower

Trump Tower Project, Chicago
~ 5,000 yd^3 of SCC

(Slide courtesy of Dr. Charles Nmai, BASF)

Precast Bridge Slab Units

- Minimal constraints, large top surface area
- Slump flow of 25 to 27 in.
- Fill from one location and let flow in place


(Slide courtesy of Dr. Charles Nmai, BASF)

I-4 Pedestrian Overpass, Florida

Seminole County, Orlando

(Slide courtesy of Dr. Charles Nmai, BASF)

I-4 Pedestrian Overpass, Florida


Compressive Strengths:
1,800 psi @ 24 and
2,500 psi @ 30 h

(Slide courtesy of Dr. Charles Nmai, BASF)

Auburn Research: SCC I-Girders

- Project located on AL 22 over Hillabee Creek near Alex City, AL
  - First full-scale I-Girders produced for ALDOT
  - Four prestressed spans
    - Inner spans: 135' Long – 72" Tall Girders
    - Outer spans: 100' Long – 54" Tal Girders

- **Acknowledgements:**
  - Drs. R.W. Barnes and Sam Keske, AU
  - ALDOT
  - Hanson Pipe & Precast Prestress Concrete Products, Pelham, AL
  - GCP Applied Technologies

Use of SCC in Prestressed Girders

Project on AL 22 over Hillabee Creek near Alex City, AL

Statewide Spec. in 2014 !

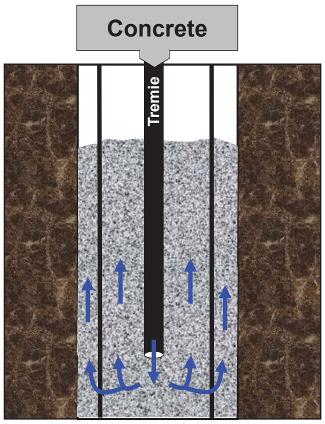
Production on Full-Scale I-Girders

Conventional Slump Concrete

Slump ≈ 6.5 in.

Auburn Research: SCC – Topoff

Tremie Placement in Drilled Shafts



- Concrete is extensively retarded to allow completion of placement
- No vibration can be used
  - **Concrete is expected to self consolidate**
- Concrete is expected to freely pass through the reinforcement cage

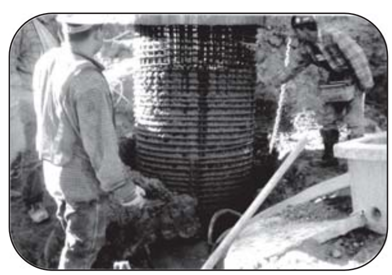
Problems with Drilled-Shaft Concrete

- Tremie placement
- Very large shaft diameters
- Extended placement times
- Very tight rebar cages

Problems with Drilled-Shaft Concrete

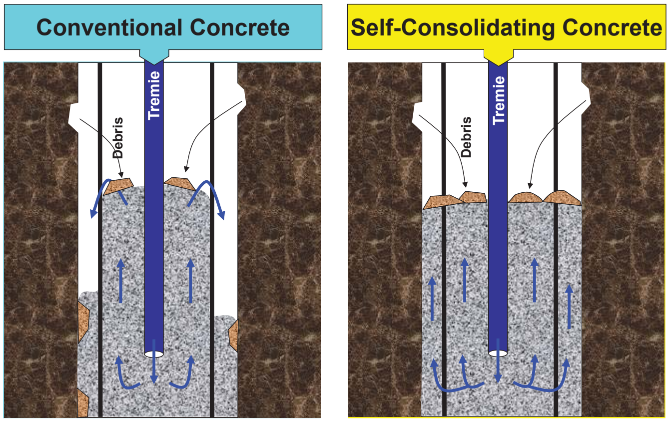
Picture courtesy of
Rick Manegetti, CalTrans

Need for Sufficient Passing Ability



Pictures courtesy of Dr. Dan Brown

Problems with Drilled-Shaft Concrete



Auburn Research: SCC in Drilled Shafts

- SCC has great potential for drilled-shafts as it:
  - offers high flowability
  - can be proportioned to be passable enough based on level of congestion
  - reduces the amount of bleed water
  - can be proportioned to have sufficient workability after extended times (6-10 hours)
- SCC may thus minimize some of the problems encountered in the past

Use of SCC in Drilled Shafts at AU

1st U.S. Trial in Auburn ('03)

1st U.S. Project: SC ('05)

Major Project in Minnesota ('08)

I35W Replacement Bridge
(80+ shafts, 100-120-ft deep)

1st Project in Alabama ('09)

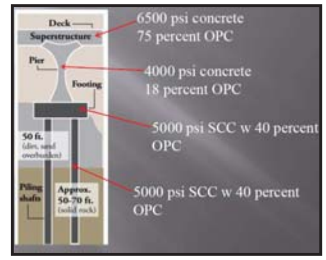
Required Slump Flow ?

- Typical slump flow for prestressed SCC: **27 ± 2 in.**
- Recommended slump flow for drilled shafts:
  - **21 ± 3 in.**
  - (Note: 16 in. slump flow ≈ 9 in. slump)

Full-Scale Construction: B.B. Comer Bridge, AL

National Use of SCC in Drilled Shafts

- I35W Replacement Bridge, Minneapolis, MN
  - 80+ shafts, 100 to 120 ft deep, 7 and 8 ft diameter



Source: Dr. K. MacDonald (NRMCA 2008)

- Mullica River Bridge (NJ DOT) in 2011
  - 200 ft deep, 8 ft diameter

Presentation Overview

- Introduction
- Key Properties and Test Methods
- Materials and Proportioning
- Example Applications
- **Market Acceptance**
- Closing Remarks

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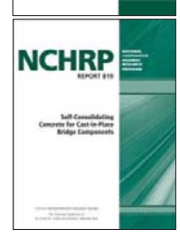
Completed NCHRP Projects on SCC

- **NCHRP Report 628: Self-Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements**
  - Project 18-12
  - Published in 2009

- **NCHRP Report 819: Self-Consolidating Concrete for Cast-in-Place Bridge Components**
  - Project 18-16
  - Published in 2017



ASTM Standardization Efforts

- Task Groups created to address:
  - Definitions
  - Performance Requirements
  - Modification of Existing Test Methods
  - Development of New Test Methods
- Five Test Methods Developed:
  - ASTM C 1611: Slump Flow, VSI and T50
  - ASTM C 1621: Passing Ability by J-Ring
  - ASTM C 1610: Static Segregation (Column Method)
  - ASTM C 1712: Static Segregation (Penetration Method)
  - ASTM C 1758: Fabricating Test Specimens

AASHTO Standardization Efforts

- Test Methods Developed
  - T 345 : Passing Ability of SCC by J-Ring
  - T 347: Slump Flow of SCC
  - T 349: Filling Capacity of SCC by Caisson Test
- Provisional Practice
  - PP 58: Segregation of Hardened SCC Cylinders
  - TP 80: Visual Stability Index (VSI) of SCC
  - TP 93: Determining Formwork Pressure of SCC Using Pressure Transducers

Why is SCC not Routinely Used?

- Usual slow nature associated with the introduction of “new” techniques into the concrete industry
- Lack of training/certification available for new test procedures
  - ACI will offer certification late in 2017!
- Uncertainty regarding the applicability of current design procedures to members made with SCC
  - Long-term performance data ?
    - Creep and shrinkage, modulus, bond, etc.

SCC - Concerns

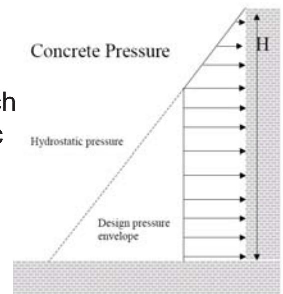
- PCI Interim Guidelines (2003)

> “SCC will require a higher level of quality control, a greater awareness of aggregate gradation, mix water control, and …”

- Not all concrete producers can consistently produce high-quality SCC
- Not yet “Tried and True” – more experience is needed

SCC - Concerns

- High flowability:
  - Mixer capacity
    - Inclines and low *w/cm*
  - Increased formwork pressures
    - A great deal of research is ongoing on this topic
      - Fully hydrostatic or not?
  - Paste leakage from forms



SCC - Concerns

(Abutment Pedestal in Des Moines, Iowa)

Trial Placement

- A trial placement on a mock-up of the actual member is recommended for **first time users** of SCC
- Reproduce and evaluate the following:
  - Member size and intricate formwork details
  - Congestion of actual member
  - Placement temperature conditions
  - Haul time of concrete including potential delays
  - Evaluate:
    - Placement characteristics, fresh properties
    - Strength, shrinkage, permeability, etc.
    - Aggregate distribution

Presentation Overview

- Introduction
- Key Properties and Test Methods
- Materials and Proportioning
- Example Applications
- Market Acceptance
- **Closing Remarks**

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Closing Remarks

- “SCC is a **highly flowable**, **non-segregating** concrete that can spread into place, fill the formwork, and encapsulate the reinforcement **without any mechanical consolidation**.” (ACI 237 2007)

Closing Remarks

Compared to vibrated concrete, SCC typically has:

- **Increased paste volume**
  - Not because of more water, but because of higher cementitious materials content
  - Not always the case in high strength applications
- **Lower coarse aggregate content**
  - i.e. a higher fine aggregate (sand) content
- **Smaller coarse aggregate size**
  - Depends on the application
- **Increased chemical admixture content**
  - HRWRA (and VMA, if needed)

Closing Remarks

- SCC has excellent fresh concrete properties, which may make it best choice for your project
  - SCC may minimize some concrete placement problems encountered in the past
- Increased form pressures are expected and should be managed by the Contractor
- SCC requires an increased level of quality control, admixture knowledge, and production control
- SCC will not replace conventional-slump concrete in all applications

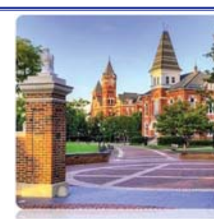
AUBURN UNIVERSITY **2017 Alaska Concrete Summit**

Thank you for listening.

Questions are welcome !

By: Anton Schindler, Ph.D., P.E., FACI
Professor and HRC Director
Department of Civil Engineering
Auburn University

November 2017



Building a Safer, More Sustainable World …
One Project at a Time

Durable Pavement Design Using Rapid Setting, Hydraulic belitic CSA Cement Concrete

Presented By:
Susan Foster-Goodman
Director of Strategic Initiatives & Komponent Sales

By CTS Cement Manufacturing Corp.

Full Systems Approach

Durability in Pavement Designs Requires a "Full Systems" Approach

- Service Conditions
- Quality Design
- Quality Materials
- Optimized Mix Design
- Quality Installation

Whether you're installing full depth pavement, repairing partial depth placements, or replacing panels, the same fundamentals hold true…

- ✓ Maximizing Durability
- ✓ Extending Service Life
- ✓ Accelerating Construction Practices

- ✓ Minimizing Inconvenience to the Public
- ✓ Minimizing Lifecycle Costs
- ✓ Minimizing Downtime & Lost Revenue

- ✓ Contributing to Smart Construction Practices
- ✓ Contributing to Efficient Technologies
- ✓ Contributing to Low-Impact O&M

Belitic Calcium Sulfoaluminate (CSA) Cement

- **Modified derivative of portland cement clinker**
- **Higher quality hydraulic cement**
- **Developed in the 1950's to overcome common shortfalls of portland cement**
  - *Excessive shrinkage*
  - *Susceptibility to chemical attack*
  - *Destructive reactions with certain aggregates*
  - *Negative consequences of traditional accelerating admixtures*

What Is It?

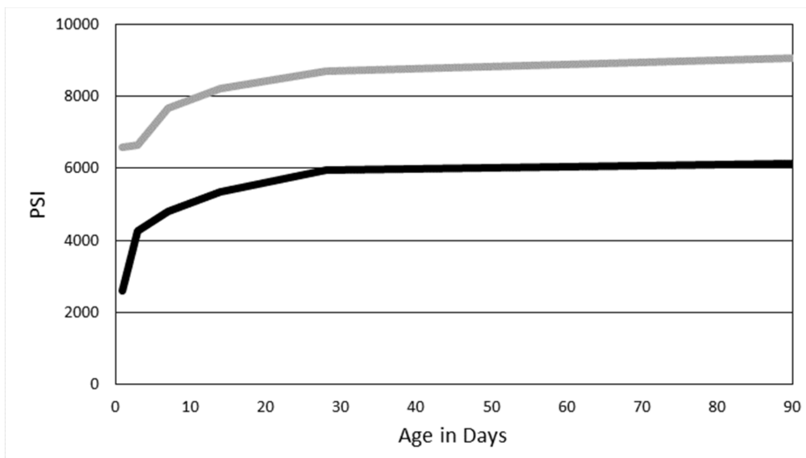
Belitic Calcium Sulfoaluminate (CSA) Cement

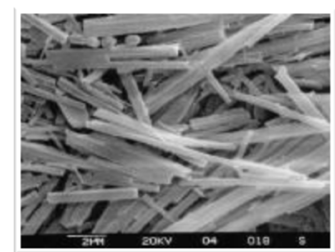
- **High CSA Hydraulic Cement**
- **Not an Admixture**
- **No Accelerators | No Calcium Chloride**
- **Increased Blaine Fineness** (ASTM C204)
  - Approximately 6500 cm^2/gm (vs. OPC 3500-4000 cm^2/gm)
  - The finer the cement particles, the greater the surface area, the faster the rate of reaction
  - Contributes to greater strength, faster set times, enhanced flow properties
- **Minimizes Shrinkage & Improves Performance**

How?

Early Ettringite Formation

- Maximum formation during the first 7 days maximizes strength gain
- Rapid formation allows fast repair & quick in-service turnaround (ASTM C1600)





CSA Cement Ettringite Crystals

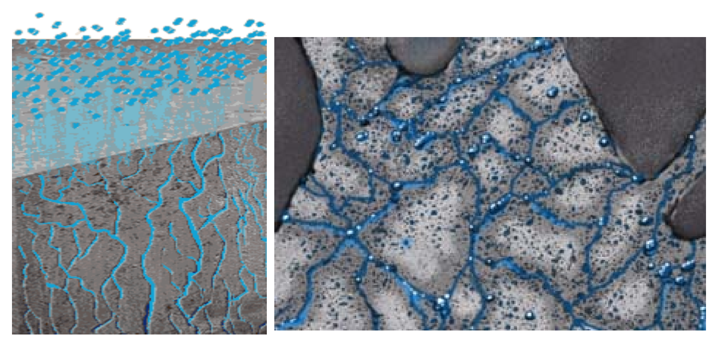
Performance

How?

A Different Hydration Mechanism

- Mix water is chemically retained (“bound”) within the ettringite structure
- Eliminates bleed water (minimal water of convenience)
- Maintains integrity of the mix designed at the surface; w/c ratio is not compromised
- Improves abrasion & impact resistance
- **Prevents voids & capillary channels that lead to drying shrinkage**
- Lowers porosity
- Prevents cracking & curling due to drying shrinkage & volume change
- Prevent laitance and other “debris” from being drawn to the surface

Escape of convenience water in portland cement concrete creates voids & capillary channels that lead to shrinkage & contamination



Portland Cement Concrete Egress of Excess Water

DIMENSIONAL STABILITY

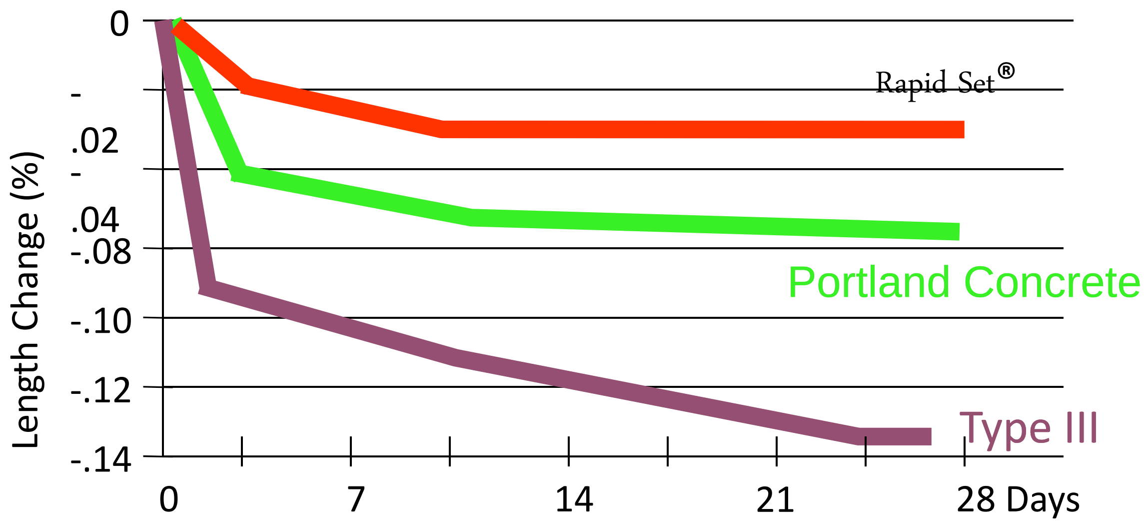
- Concrete in new construction requires dimensional stability to ensure long-term performance is achieved.
- For repairs, dimensional stability requires a strong bond between existing material and new material.
- Bond failure is usually caused by shrinkage. Commonly soon after the new concrete material is cast.
- Repair materials must be essentially "shrinkage-free" to maintain a strong bond.

RS Belitic CSA Cement provides dimensional stability by providing

- ✓ **Early, marginal expansion and ultra low shrinkage**
- ✓ **Tenacious bond making it ideal for concrete repair & renovation and restrained placement applications**
- ✓ **Compatible with portland cement-based materials**
- ✓ **Creates a strong bond that eliminates shrink-back at patch or repair perimeters**
- ✓ **Prevents de-bonding**

Shrinkage Comparison

Shrinkage Comparison of Rapid Set® Cement Concrete vs. Type III with 2% Calcium Chloride & PCC



Shrinkage

Ring Test

Concrete Study
NTL Project #1150-13

- **Ring test Compared Belitic CSA Cement to an Accelerated Portland Mix**
- **90 Day Test to Evaluate Crack Potential**
- **Uses Steel Rings to Restrain Expansion and Strain Gauges to Measure Stresses**
- **Standard for determining crack resistance for quantifying the age of initial cracking of restrained concrete or mortar material**
- **Results are based on evaluation of shrinkage, tensile strength, modulus of elasticity, and tensile creep**
- *Goal….* **Maximize Performance by Preventing Cracking and Minimizing Stresses**

Mix 2013-009 (ASTM C1581 @ 24 Hours)
Belitic CSA Cement Samples

Mix 2013-010 (ASTM C1581 @ 24 Hours)
Accelerated Portland Cement Samples

ASTM C1581 | Restrained Shrinkage

NELSON TESTING LABORATORIES

EXPERIENCED | INNOVATIVE | AUTHENTIC

Concrete Study
NTL Project #1150-13

- **No Cracking @ 90 Days with RS belitic CSA Cement**

Mix 2013-009 (No Cracking at 90 Days)

Mix 2013-009 (No Cracking at 90 Days)

Mix 2013-009 (No Cracking at 90 Days)

- **Crack Rate of 8.9 Days with Accelerated Portland Cement**

Mix 2013-010 (Cracked at 9.21 Days)

Mix 2013-010 (Cracked at 9.54 Days)

Mix 2013-010 (Cracked at 7.94 Days)

Susceptibility to cracking is relative to tensile stresses exceeding tensile strength of the material.

Ring Test | C1857 Results

NELSON TESTING LABORATORIES
EXPERIENCED | INNOVATIVE | AUTHENTIC

Concrete Study
NTL Project #1150-13

METHOD	TRADITIONAL OPC + ADDITIVES	RS BELITIC CSA CEMENT	PERFORMANCE
ASTM C157 • Length Change • 3x3 Shrinkage Bars • 28 Day Water Cure • 28 Day Air Cure	Average -0.045%	Average -0.020%	Less than 1/2 the Shrinkage of OPC Concrete
ASTM C1581 • Restrained Shrinkage, Net Time to Cracking • 3 Ring Specimens • 50% RH, 73ºF	Average Cracked at 8.90 Days	Average None at 90 Days	Exceptional Crack Resistance
ASTM C1581 • Restrained Shrinkage, Stress Rate • 3 Ring Specimens • 50% RH, 73ºF	Average 22.53 psi/day	Average 1.66 psi/day	14x Lower Stress Rate
ASTM C1581 • Restrained Shrinkage, Cracking Potential • 3 Ring Specimens • 50% RH, 73ºF	Moderate to High	Low	Exceptional Crack Resistance

Results:

	Belitic CSA Cement Mix #2013-009	Accelerated Portland Mix #2013-010
Net Time to Cracking		
*Specimen 1	none @ 90.00 days	cracked @ 7.94 days
**Specimen 2	none @ 90.00 days	cracked @ 9.54 days
**Specimen 3	none @ 90.00 days	cracked @ 9.21 days
AVERAGE	**none @ 90.00 days**	**cracked @ 8.90 days**
Stress Rate		
*Specimen 1	1.35 psi/day	33.16 psi/day
**Specimen 2	0.27 psi/day	13.15 psi/day
**Specimen 3	3.36 psi/day	36.28 psi/day
AVERAGE	**1.66 psi/day**	**22.53 psi/day**
Potential For Cracking		
*Specimen 1	Low	Moderate-High
**Specimen 2	Low	Moderate-High
**Specimen 3	Low	Moderate-High
AVERAGE	**Low**	**Moderate-High**

**Specimens cast from Mix 1*
***Specimen cast from Mix 2*

✓ **Low Shrinkage**
✓ **High Performance**

Caltrans

1 Year Study Performed by Cal Trans Certified Independent Laboratory

Panel Rehabilitation Program: 500,000yd3
100,000 panels / 300 Lane Miles

	Compress Strength	Flexural Strength	Shrinkage* (ASTM C157)
1 Hour	3,950 psi / 22.24 MPa	551 psi / 3.8 MPa	-0.008
7-Day	6,470 psi / 44.62 Mpa	775 psi / 5.3 MPa	-0.006
28-Day	7,710 psi / 53.17 Mpa	911 psi / 6.3 MPa	-0.009
1 Year	10,334 psi / 71.30 Mpa	1,053 psi / 7.3 MPa	-0.027

**Well below the US Corps of Engineers limit of -0.05*

Caltrans

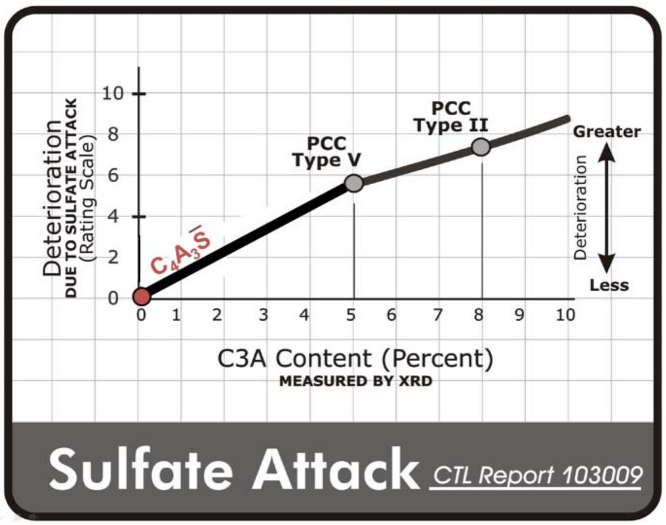
1 Year Study Performed by Cal Trans Certified Independent Laboratory

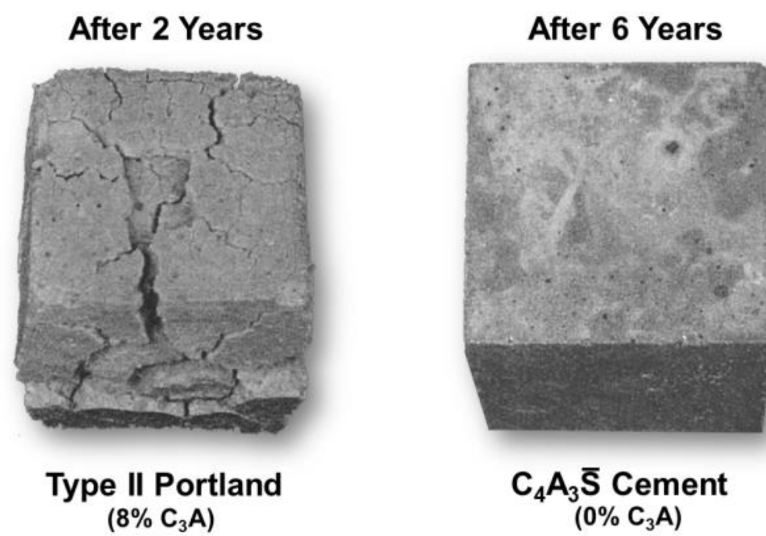
Panel Rehabilitation Program: 500,000yd3
100,000 panels / 300 Lane Miles

Installed	Project	Avg. Daily Traffic	Service Expectancy
Aug 1998	SR 60/71 Pomona 07-384114	340,000	**12 years**
Feb 2000	I-10 Pomona 07-181304	282,000	**10 years**
May 2000	SR 91 Anaheim 12-089704	300,000	**10 years**
Sept 2000	SR 60 Hacienda Hts 07-467304	225,000	**10 years**

SULFATE RESISTANCE

- Requires minimizing C_3A content





RS Belitic CSA Cement offers absolute sulfate resistance

✓ **Contains negligible C_3A content**

Performance

CHLORIDE ION PENETRATION

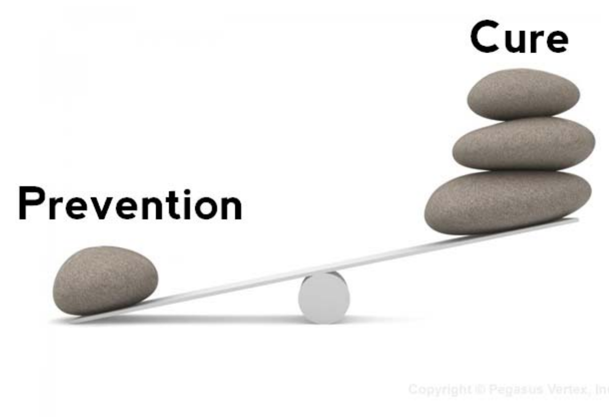
- This destroys the protective film on metal reinforcement.
- When oxygen and moisture reach the unprotected reinforcement, corrosion begins.

RS Belitic CSA Cement helps prevent corrosion due to chloride ion penetration by reducing common penetration points
(shrinkage cracks, voids & capillary channels)

✓ **Minimizing or eliminating drying shrinkage cracking**

✓ **Reducing the porosity and permeability* of the concrete**

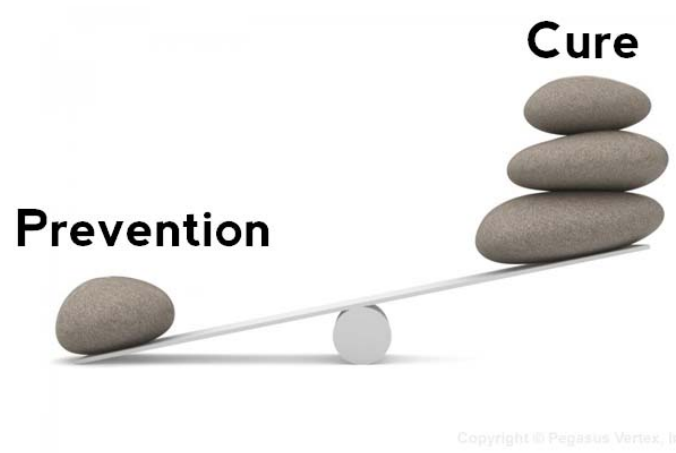
Optimize mix design compatibility and versatility to achieve permeability requirements and maximum performance



Performance

ALKALI-SILICA REACTION (ASR)

- Swelling reaction that occurs over time
- Reaction between highly alkaline cement paste and reactive non-crystalline aggregates in the presence of moisture



RS Belitic CSA Cement helps mitigate ASR effects

✓ **Ultra-low alkaline cement**

FREEZE/THAW RESISTANCE

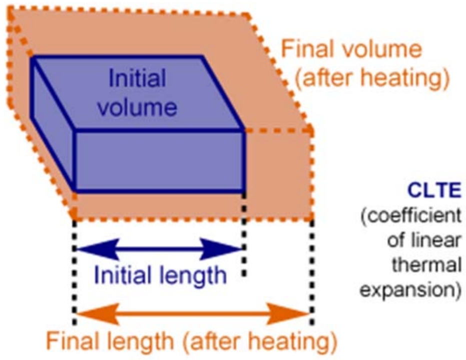
- When water freezes it expands, producing pressure in the pores of the concrete.
- If pressure exceeds the tensile strength of the concrete, the cavity will expand and rupture.
- Cumulative freeze-thaw cycles and disruption of paste and aggregate eventually cause cracking, scaling, and crumbling of the concrete.

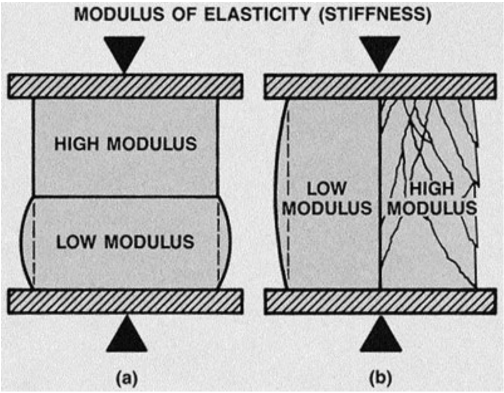
RS Belitic CSA Cement helps prevent freeze/thaw deterioration by advanced, rapid hydration mechanism and rapid strength gain

- ✓ **Rapid strength gain is ideal for lower temperature installations**
- ✓ **Ideal for emergency repairs in lower temperature conditions**
- ✓ **Efficient and essentially complete consumption of mix water**
  - Helps prevent detrimental freeze/thaw effects (voids & capillaries within the concrete are prevented)
  - Addition of entrained air provides exceptional freeze/thaw performance (more consistent "small bubbles")

COEFFICIENT OF THERMAL EXPANSION & MODULUS OF ELASTICITY

- Due to the high aggregate and sand content in concrete mix designs the coefficient of thermal expansion performance, as well as modulus of elasticity are substantially the same.
- The influence of the performance of the cement paste itself will be immaterial.





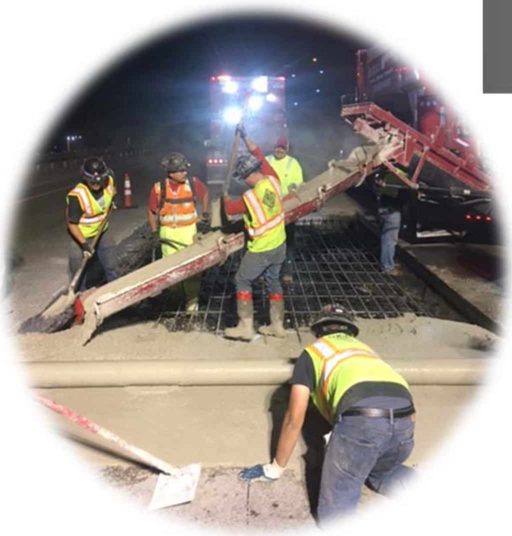
Product Availability

Highways, Bridges, Roadways & Airfield Products

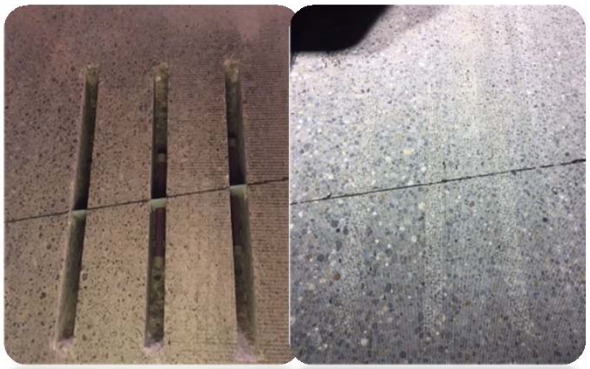
Fast-Setting Hydraulic CSA Cement Materials *ASTM C1600*

- Concrete Mixes
- Concrete Resurfacers
- Mortar Mixes & Repair Mortars
- Non-Shrink Construction Grouts
- Smoothing & Patching Compounds
- DOT & FAA Concrete Paving & Overlays
- Shotcrete
- Flowable Fill (CLSM)
- Cementitious Slurry

Common Pavement Applications

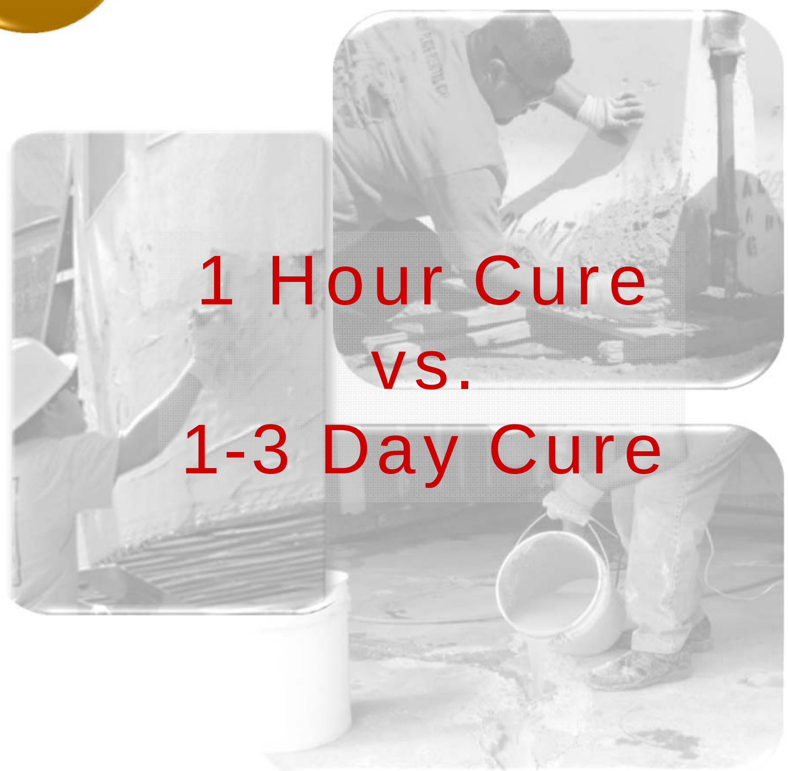


- Approach / Departure Slabs
- Control Density Fill
- Dowel Bar Retrofits
- Spall Repairs
- Bridge Joint Seals
- Closure Pours
- Pavement Notch Extensions
- Bridge Deck Hinge
- Partial & Full Depth Repairs
- Cast-in-Place Pavement
- Continuous Reinforced Pavement
- Panel Replacements
- Bridge Deck Overlays



Quality Materials

Product Availability



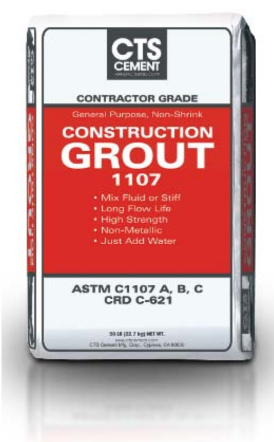
New Construction, Repair & Restoration

- Concrete Mixes
- Concrete Overlays & Sub-Bases
- Mortar Mixes & Repair Mortars
- Non-Shrink Construction Grouts
- Vertical & Overhead Materials
- Smoothing & Patching Compounds

Rapid Set

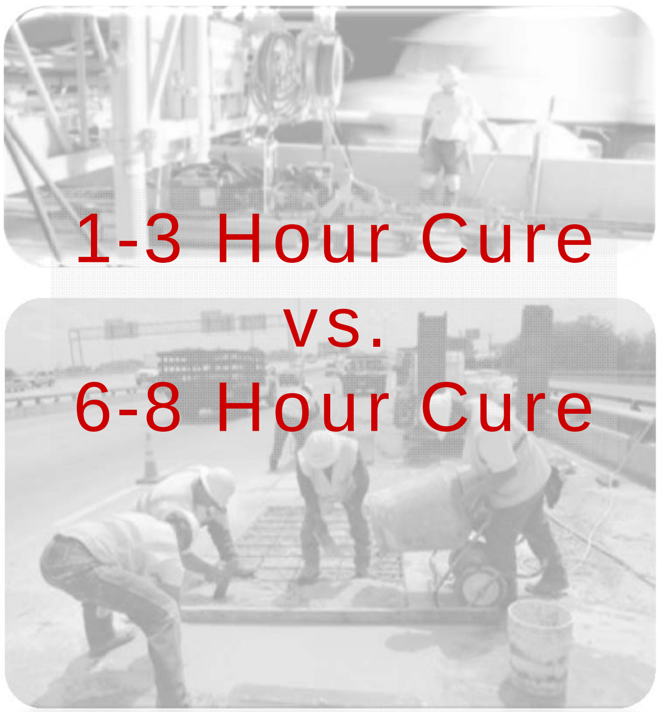
Repair Products

Just a snapshot of the many products available for new concrete and concrete repair and restoration projects…



Quality Materials

Product Availability



Pavement & Overlays

DOT Approved

- **Concrete Mixes**
- **Concrete Overlays & Sub-Bases**
- **White Toppings (bonded & unbonded)**
- **Mortar Mixes & Repair Mortars**
- **Low Permeability Concrete**
- **DOT & FAA Concrete Paving**
- **Latex Overlays**

Quality Materials

General Performance Guidelines

- Structural strength in 1-3 Hours
- Meet and exceed new and repair material specifications
- Open times are achieved during construction
- Long-term performance maximized

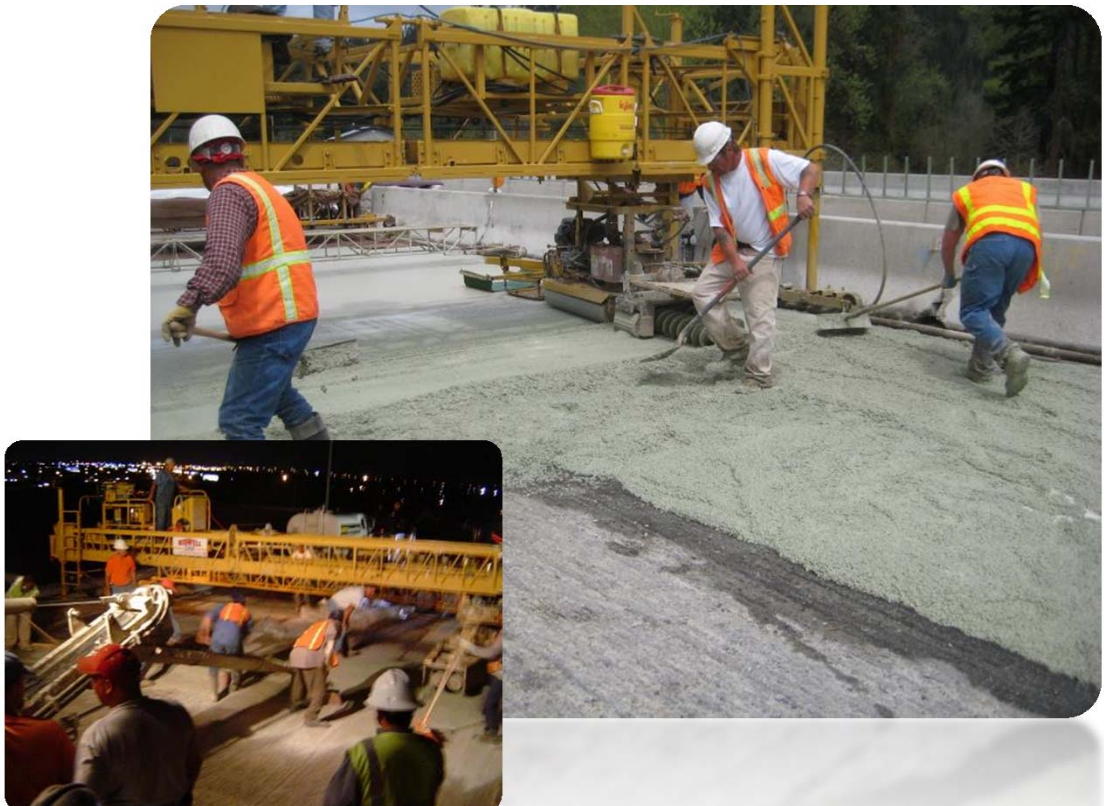
Quality Materials

General Performance Guidelines

- Exceptional workability
- Exceptional freeze/thaw resistance
- Lower porosity
- Low permeability formulations
- Polymer modified formulations
- Ultra-low alkali cement minimizes ASR reactivity
- No chlorides added
- Non-metallic

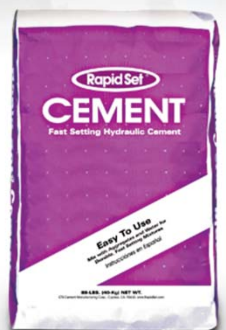
General Performance Guidelines

Quality Materials



- Pour & pump formulations
- Air entrained formulations
- Integral fly ash formulations further aid ASR mitigation
- Integral fiber formulations
- Integral dry latex formulations
- Integral corrosion inhibitor formulations

Cement Products

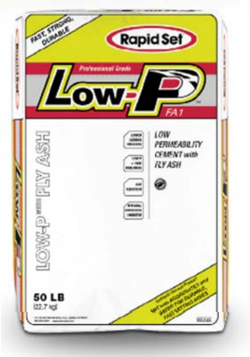


50 lb bags
2000 lb super sacks
Bulk Delivery

- **Advanced Rapid Hardening Cement Technology**
- **Structural Strength in 1 Hour**
- **Create Fast-Setting**
  - Concrete
  - Mortar
  - Grout
- **Sulfate Resistant**
- **Ultra-Low Alkali Cement helps mitigate ASR Reactivity**
- **High Strength**
- **Low Shrinkage**
- **Crack Resistant**
- **Non-Metallic**
- **No Chlorides Added**
- **W/C typically 0.35-0.46**

Working Time	
Time	10 - 120+ minutes
Slump, ASTM C143	
Slump	0 - 8 inches
Compressive Strength, ASTM C39	
1 hour	Up to 4,000 psi (27.6 MPa)
7 days	Up to 8,000 psi (55.2 MPa)
28 days	Up to 10,000 psi (68.9 MPa)
Flexural Strength, ASTM C78	
1 hour	Up to 400 psi (2.8 MPa)
3 days	Up to 700 psi (4.8 MPa)
7 days	Up to 850 psi (5.9 MPa)
Length Change, ASTM C157	
28 days	< 0.025%

Cement Products

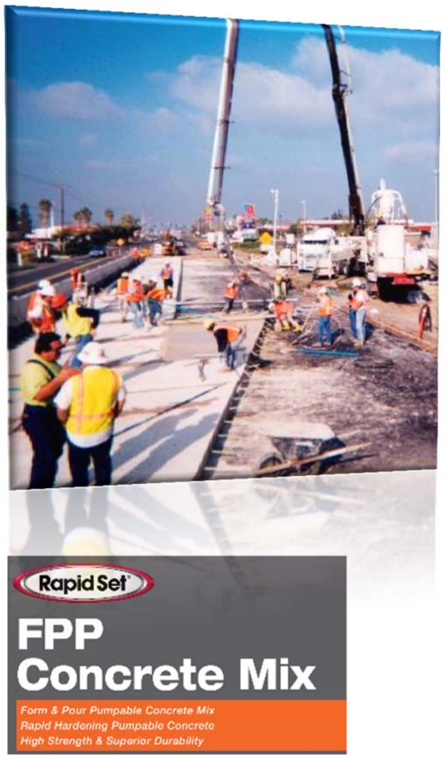


50 lb bags
2000 lb super sacks
Bulk Delivery

- **Low Permeability**
- **Ready for Traffic 1 to 3 Hours**
- **Non-Metallic**
- **No Chlorides Added**
- **Sulfate Resistant**
- **Integral Fly Ash further aids in ASR Mitigation**
- **Integral Corrosion Inhibitor**
- **Corrosion Protection from Chlorides & Deicing Salt Penetration**
- **Exceptional Freeze/Thaw Resistance**

MIX DESIGN:	
Cement – 658 lbs Washed Concrete Sand ASTM C33 – 1512 lbs 3/8" Rock Aggregate – 1417 lbs Water to Cement Ratio – 0.42	
Setting Time, ASTM C191 Mod.	
Initial set	30 minutes
Final set	40 minutes
Compressive Strength, ASTM C39	
3 hours	3200 psi (22.1 MPa)
24 hours	5000 psi (34.5 MPa)
7 days	6000 psi (41.4 MPa)
14 days	7000 psi (48.3 MPa)
28 days	7500 psi (51.7 MPa)
Slant Shear Bond Strength, ASTM C882 Mod.	
24 hours	1200 psi (8.3 MPa)
28 days	2000 psi (13.8 MPa)
Shrinkage, ASTM C157 Mod.	
7 days	0.003%
28 days	0.023%
Density	
Specific Gravity	2.86
Rapid Chloride Penetration, ASTM C1202	
28 days	< 1000 Coulombs
Freeze Thaw, ASTM C666 Procedure	
300 Cycles RDF Weight Loss	95 0.29

All data produced at 70°F (21°C)



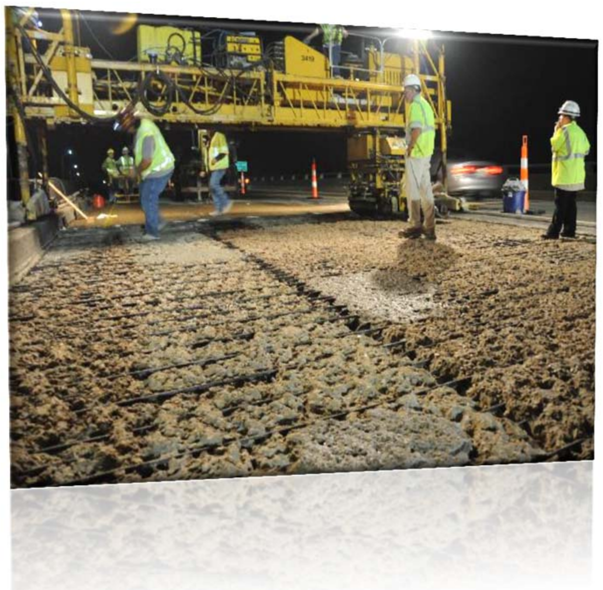
60 lb bags
2000 lb super sacks
Bulk Delivery

- **Pour & Pump Placement**
- **45 Minute Working Time**
- **Traffic Ready in 4 Hours**
- **Polymer Modified**
- **Integral Corrosion Inhibitor**
- **Low Permeability**
- **Protects Embedded Reinforcement**
- **Durable in Wet Environments**
- **Non-Metallic**
- **No Chlorides Added**
- **Sulfate Resistant**

PHYSICAL DATA	
Set Time, ASTM C403 Mod.**	
Initial set	3 hours
Final set	4 hours
Compressive Strength, ASTM C39 Mod.**	
6 hours	2500 psi (17.2 MPa)
1 day	3500 psi (20.7 MPa)
3 days	4500 psi (31.0 MPa)
7 days	5000 psi (34.5 MPa)
28 days	6000 psi (41.4 MPa)
Slant Shear Bond Strength, ASTM C882 Mod.**	
1 day	1000 psi (6.90 MPa)
28 days	2000 psi (13.8 MPa)
Splitting Tensile, ASTM C496 Mod.**	
7 days	600 psi (4.14 MPa)
28 days	700 psi (4.83 MPa)
Length Change, ASTM C157 Mod. (max)**	
28 days in air	-0.04
28 days in water	0.02
Rapid Ion Chloride Penetration, ASTM C1202	
28 days	< 1000 Coulombs
Freeze Thaw, ASTM C666 Procedure A	
300 Cycles RDF	95

*After final set
**Data obtained at 7" slump by ASTM C143 at 70°F (21°C)
***Results may vary depending on jobsite and environmental conditions

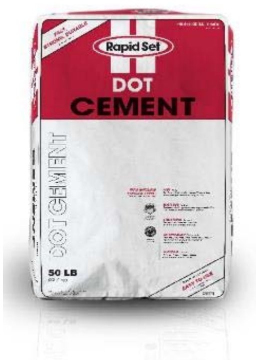
Cement Products



- **RSCement + High Performance Additives**
- **Set in 20 Minutes**
- **Ready for Traffic 1 Hour**
- **Ultra-Low Alkali Cement Minimizes ASR Reactivity**
- **Non-Metallic**
- **No Chlorides Added**
- **Sulfate Resistant**
- **Exceptional Freeze/Thaw Resistance**

PHYSICAL DATA	
Compressive Strength	
1.5 hours	3140 psi
3 hours	3725 psi
24 hours	4650 psi
28 days	5500 psi
Flexural Strength	
4 hours	500 psi
1 day	650 psi
28 days	1200 psi
Bond Strength, ASTM C882	
24 hours	2000 psi
28 days	2200 psi
Freeze/Thaw, ASTM C666	
1,000 cycles (weight loss 1.07%)	Dynamic modulus: 91%
ASTM C666 in a 10% solution of Sodium-Chloride (as per North Eastern spec.)	
25 cycles	0.3% loss

All data produced at 70°F (21°C)



60 lb bags
2000 lb super sacks
Bulk Delivery

Repair Products

60 lb bags
2000 lb super sacks
Bulk Delivery

- **Ready for Traffic in 2 Hours**
- **Integral Corrosion Inhibitor**
- **Polymer Modified**
- **Fiber Reinforced**
- **Air Entrained for Freeze/Thaw Durability**
- **3/8" Aggregates**

PHYSICAL DATA	
Compressive Strength, ASTM C39 Mod.*	
2 hours	3000 psi (20.7 MPa)
24 hours	4500 psi (31.0 MPa)
7 days	6000 psi (41.4 MPa)
28 days	6500 psi (44.8 MPa)
Splitting Tensile Strength, ASTM C496	
28 days	300 psi (2.1 MPa)
Modulus of Elasticity, ASTM C469	
28 days	3.6×10^6 psi
Scaling Resistance, ASTM C672	
50 cycles	Visual rating - 1
Freeze Thaw Resistance, ASTM C666	
Durability factor	97%
Length Change, ASTM C157 modified per C928 (Air Storage)	
28 days	0.035%
Length Change, ASTM C157 modified per C928 (Water Storage)	
28 days	0.020%
Rapid Chloride Ion Penetration, ASTM C1202	
28 days	< 1000 Coulombs

Data obtained at 4" slump by ASTM C143 at 70°F (21°C)

Repair Products

55 lb bags

- Ready for Traffic in 1 Hour
- 100% Extendable
- Apply Up to 4” Neat, 24” Extended
- Durable in Wet Environments
- RS Cement + High Performance Additives
- Non-Metallic
- No Chlorides Added
- Low Shrinkage
- High Durability
- Easy Flow

PHYSICAL DATA		
Neat Bag (3.0 to 4.5 quarts)	60% Extension (3.5 to 4.75 quarts)	100% Extension (3.5 to 5.0 quarts)
Yield		
0.5 ft³	0.7 ft³	0.9 ft³
Compressive Strength, ASTM C109 Mod., ASTM C39		
1 hr* 3300 psi	1 hr* 2800 psi	1 hr* 2500 psi
3 hrs 5000 psi	3 hrs 4600 psi	3 hrs 4200 psi
24 hrs 7000 psi	24 hrs 6800 psi	24 hrs 6500 psi
7 days 7500 psi	7 days 7200 psi	7 days 7000 psi
28 days 9500 psi	28 days 9000 psi	28 days 8500 psi
Flexural Strength, ASTM C78		
4 hrs 450 psi	4 hrs 400 psi	4 hrs 400 psi
7 days 700 psi	7 days 650 psi	7 days 600 psi
28 days 900 psi	28 days 850 psi	28 days 800 psi
Modulus of Elasticity, ASTM C469		
7 days 4,400,000 psi	7 days 4,100,000 psi	7 days 3,900,000 psi
28 days 5,100,000 psi	28 days 4,500,000 psi	28 days 4,000,000 psi
Slant Shear Bond Strength, ASTM C882		
1 day 1500 psi	1 day 1200 psi	1 day 1100 psi
7 days 2000 psi	7 days 1800 psi	7 days 1700 psi
Splitting Tensile Strength, ASTM C496		
7 days 700 psi	7 days 500 psi	7 days 390 psi
28 days 900 psi	28 days 600 psi	28 days 415 psi
Resistance of Concrete to Rapid Freezing and Thawing, ASTM C666 Procedure A (Air Cured)		
Durability Factor 300 Cycles: 95%	Durability Factor 300 Cycles: 95%	Durability Factor 300 Cycles: 95%

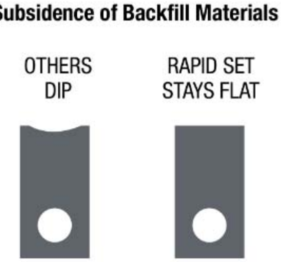
Quality Materials

Product Availability

Shotcrete, Tunneling, Mining, Geotechnical

- **Shotcrete**
- **Cavity Fill**
- **Flowable Fill/Backfill**
- **Lean Base**
- **Structural Support**
- **Pipe Liner/Mine Roof Supports**
- **Underground Road Repair**

Lean Base (Flowable Fill)



PHYSICAL DATA	
Typical Compressive Strength of Rapid Set Flowable Fill*	
1 hour	3 psi (0.02 MPa)
3 hours	10 psi (0.07 MPa)
24 hours	20 psi (0.14 MPa)
1 year	75 psi psi (0.52 MPa)

*Humidity, ambient and water temperature will vary your results.
All data produced at 70°F (21°C).

- **Self-Compacting Sub-Base**
- **Non-Structural Fill**
- **Minimize Subsidence**
- **Sets in 45 Minutes**
- **MIL Spec Formulations Available**

A sand mix is best suited for use in trenches where high flow and future diggability are important.

Sand Mix:	Rapid Set Cement	l00 lbs (45.4 kg)
	Sand (ssd)	2900 lbs (1315.4 kg)
	Water	480 lbs (217.7 kg)

A rock mix is suitable for structural applications such as pavement base and foundation backfill.

Rock Mix:	Rapid Set Cement	88 lbs (40 kg)
	Coarse Aggregate	1800 lbs (816.4 kg)
	Sand (ssd)	1700 lbs (771.1 kg)
	Water	400 lbs (181.4 kg)

Repair Products

Rapid Set

LOW-P™ SHOTCRETE

Low Permeability Dry Process Shotcrete

55 lb bags
2000 lb super sacks
Bulk Delivery

- **Fast Set Minimizes Dropout**
- **Fast Strength Gain**
- **Low Alkali**
- **Polymer-Modified**
- **Exceptional Durability in Harsh Freeze/Thaw Environments**
- **Low Chloride Ion Permeability**
- **Improved Resistance to De-Icing Salts**
- **Corrosion Protection**
- **No Chlorides Added**
- **Low Rebound**
- **Use Anywhere Dry Process Shotcrete is Used**

Tunnel interiors, underneath bridge decks, vertical & overhead applications, and more…

PHYSICAL DATA	
Yield	
Appx. 0.5-cu.ft. per bag	
Set time	30 minutes
Working time	15 minutes
Compressive Strength, ASTM C1604, C39	
1 hour*	1500 psi (10.3 MPa)
3 hours	2500 psi (17.2 MPa)
24 hours	4000 psi (27.5 MPa)
28 days	5000 psi (34.5 MPa)
Slant-Shear Bond Strength, ASTM C882	
28 days	750 psi (5.17 MPa)
Rapid Chloride Ion Penetration, ASTM C1202 / AASHTO T-277	
28 days	<500 Coulombs
Hang Thickness	
Up to 10 inches	Varies with water content
Freeze-Thaw Resistance, ASTM C666	
Durability Factor of < 90 after 300 cycles	

* After final set
All data produced at 72°F (22°C)

Repair Products

Rapid Set

HTF SHOTCRETE

Fast-Setting, Fiber-Reinforced Dry Process Shotcrete

3000 lb bulk bags

- **Fast Set Minimizes Dropout**
- **Fiber Reinforced**
- **High Strength**
- **High Sulfate Resistance**
- **No Chlorides Added**
- **Low Alkali**
- **Low Rebound**
- **Use Anywhere Dry Process Shotcrete is Used**

Tunnel interiors, mine ribs, underneath bridge decks, vertical & overhead applications, and more…

PHYSICAL DATA	
Yield	
Approximately 0.8 cu. yd. per 3000-lb bulk bag	
Set time	30 minutes
Working time	15 minutes
Compressive Strength, ASTM C1604, C39	
1 hour*	1000 psi (6.89 MPa)
3 hours	3000 psi (20.7 MPa)
24 hours	4500 psi (31.0 MPa)
28 days	8000 psi (55.2 MPa)

* After final set
All data produced at 72°F (22°C)

Mix Design Considerations

Quality Materials

Mix Design Versatility

- **Mix Designs Generally the Same for RSCC as for OPC**
  - Substitute on a Pound for Pound Basis
- **Slump is Generally 4” to 6”**
- **Air Entrainment Generally 5% +/- 1%**
- **Melamine-Based Plasticizers can be used to Increase Flow with Lower W/C Ratio Mix Designs**
- **In lower temperature applications, recommended air content is 5-8%; use in conjunction with a lower W/C ratio for best results**

Quality Materials

Mix Design Versatility

- **Mix Designs Can Be Customized To Suit the Project**
  - Provide Structural Strength in 1 up to 12 Hours
  - Accommodate Accelerated Schedules
  - Can Slow Set Time to Provide More Working Time
  - Offers Flexibility in Phasing
  - Fibers, Latex, Corrosion Inhibitors can be Incorporated

Rapid Set

Quality Materials

Mix Design Versatility

- **Set Times**
  - Typically 15-30 minutes at 70^{o}F
  - Use Citric Acid Based Retarders to Extend 2-4 Hours
  - Temperature of materials, substrate and ambient conditions will affect set times; plan accordingly
  - Adjust using:
    - Retarding Admixtures
    - Amount and temperature of water added
    - Temperature of materials at time of mixing
    - Method of production

Rapid Set

Keys to Successful Installations

Quality Construction

Placement

Best Practices are Generally the Same for RSCC & OPC

ACI 305R-91 – Hot Weather Concreting

- 90°F (32°C) and above
- Keep all components cool
- Cold water or ice is recommended
- Retarder and plasticizer may be required; modify dosage to meet project conditions
- **Evaporation retarder is highly recommended**
- **Timely wet curing is essential**
- **Ensure sufficient manpower**

BEST PRACTICES GUIDELINES FOR CONCRETE CONSTRUCTION

Rapid Set

Best Practices are Generally the Same for RSCC & OPC

ACI 306R – Cold Weather Concreting

- **Adherence to best practices is more critical due to more rapid heat gain related to strength gain with RSCC**
- 40°F (4.5°C) and below
- Factor both ambient and base temperatures
- Do not pour if temperature is dropping
- Keep all components warm (e.g., tarp and heaters)
- Warm water if set times are delayed
- **Use insulating blankets for 2-3 hours is typically sufficient to allow initial strength gain prevent thermal cracking**
- On-board water heater (pool heater) can be very beneficial in cold weather applications

BEST PRACTICES GUIDELINES FOR CONCRETE CONSTRUCTION

Surface Prep

Quality Construction

- **Use standard trade practices**
- **Substrate must be sound and properly prepared**
- **Bond breakers are recommended**
  - Minimize cracking potential due to sub-grade friction
  - Avoid moisture loss into the substrate
- **Over existing concrete**
  - Saturated Surface Dry (SSD) (saturated with no standing water)

Most Common

- **Standard trade practices for transporting, placing and consolidating apply**
- **Must provide enough time to allow for transport & placement**

Method of Delivery

Volumetric On-Site Batch Plant

- **Most common method for RS Concrete**
- Mixed on-demand; produce the precise amount needed (“fresh concrete every time”)
- On site control of set time and slump
- Reduces waste
- Measures by volume instead of by weight
- Uniform proportioning
- Prevent short load challenges - Pay for actual usage
- Unaffected by traffic delays
- Ideal for remote locations

Method of Delivery

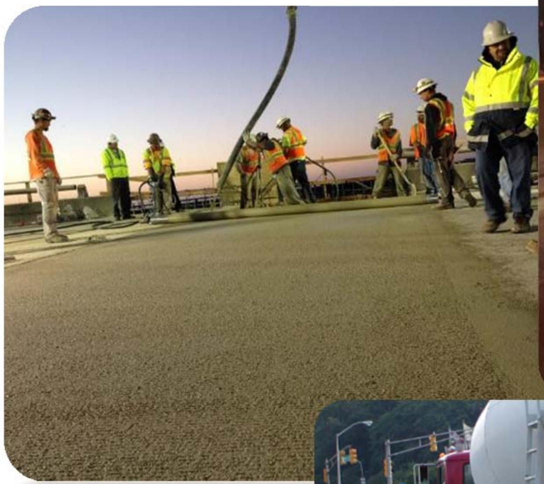
Ready Mix Delivery

- Produced at a local batching plant
- Delivered to job site by tuck mounted in-transit mixers
- Measured by weight of ingredients
- Final quality & working time influenced by time in transit
- **Retarders must be used**
- Additional fees can apply

Quality Construction

Mixing

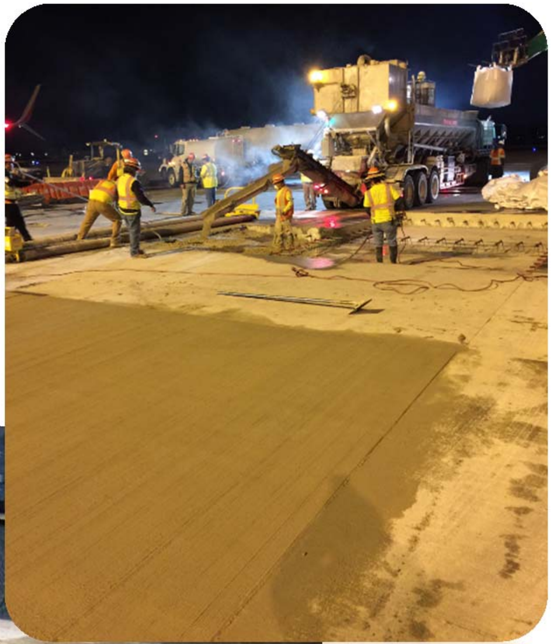
- **Poured or pumped using conventional methods**
- **Pumping considerations are generally the same as with portland cement mixes:**
  - Reduced amount of free water may increase line friction
  - Heat generated from line friction may accelerate the set time
  - Slump loss may be experienced
  - Keep material moving through the line & purge hoses whenever stops are necessary



Quality Construction

Application

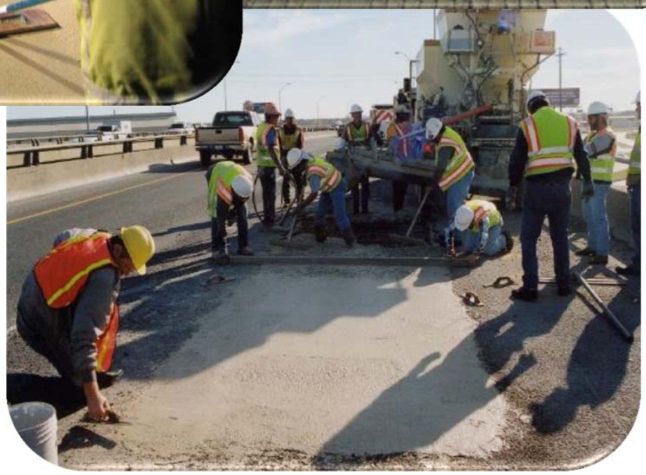
- **Apply bulk material at any thickness**
- **Place flatwork/pavement at full depth for best performance**
  - When lifts are necessary, ensure the 2nd lift is placed while the 1st lift is still plastic to avoid a horizontal cold joints
- **Repair materials can achieve feather edge up to any thickness required**
  - Use coarser aggregates for thicker materials
  - Rule of thumb – minimum thickness is 2x the largest aggregate size



Quality Construction

Finishing

- **Conventional methods can be used**
- **Special considerations**
  - Lack of bleed water due to complete consumption of mix water
  - **Start finishing operations as soon as possible after placing (before the surface looses its sheen)**
  - Initial strike off to finish elevation (avoid re-screeding)
  - Finish by vibrating screed, brooming or tining



Quality Construction

Curing

- **Curing**
  - Wet Burlap & Polyethylene is very effective
  - High Solids, White Pigmented, Water-Based Poly-Alpha-MethylStyrene (PAMS) curing compound can be used
  - Resin or wax-based curing compounds can be used
- **White color provides easy visibility of full coverage**
- **Apply all compounds to full coverage (surface should be as white as copy paper – coat it, don't mist it)**
- **Keep the surface wet with water spray/wet cure**
  - Water spray/fog/wet cure for 1 to 2 hours
  - Maintain water cure until material has gained sufficient strength
  - Maintain a sheen

RapidSet

Quality Installation…

The Devil's in the Details

Construction Procedures

Quality Construction

- ✓ **Pre-Pour Communication**
  - ❑ Owner, Contractor, Producer, Testing Lab
- ✓ **Contractor Training**
- ✓ **Approve Mix Design**
- ✓ **Recommended Trial Slab**
  - ❑ ASTM C109 Calibrate Volumetric Mixer
  - ❑ Trial Slab Simulate Size & Job Site Conditions
  - ❑ Evaluation of All Parties / Materials
    - – Concrete Producer
    - – Contractor
    - – Testing Laboratory

Construction Procedures

Quality Construction

- ✓ Complete Perimeter Saw Cutting
- ✓ Remove Panels
- ✓ Inspect / Analyze Existing Base
- ✓ Install Joint Filler as Needed
- ✓ Take Nightly Material Samples
- ✓ Load Materials into Volumetric Mixers
- ✓ Begin Concreting Process

Volumetric Production

Quality Construction

- **Beginning of Production**
  - Expect a small bit of waste while dialing the mix design in.
- **Stop and Start Production**
  - Continuous production will produce most consistent concrete.
  - When you stop and start, concrete may be a little bit wetter initially.
- **Monitoring by Operator**
  - Vibrators on cement bins. (Automated)
  - Examine belt from time to time.
  - Ensure all materials are on target.

Construction Procedures

BEST PRACTICES GUIDELINES FOR CONCRETE CONSTRUCTION

- ✓ **Place Concrete**
- ✓ **Consolidate/Vibrate**
- ✓ **Finish**
  - Finish from the middle to the outside to ensure edges are sealed
- ✓ **Texture**
  - Broom, Tine or Burlap
- ✓ **Cure**

Quality Control Procedures

Quality Control

Quality Construction

✓ **Trial Slab Prior to Start is Recommended for 1st Time Use**

✓ **QCP Can be Submitted for Review**

- ❑ State Certifications or ACI Field & Lab Tech as Required
- ❑ Contractor / QCM / Engineer Meeting
- ❑ List Testing Equipment
- ❑ Test first placement for:
  - Unit Weight
  - Air
  - Slump
  - Temperature
  - Flex Beams or Compressive Cylinders

Quality Control

Payment is Determined by Test Results, so…

- **Ensure Testing Lab is Familiar with Rapid Setting Materials**
- **Improper Testing will Affect Results**
- **Ensure Proper Testing Methods with Supervision PRIOR to the Pour**
- **Ensure all Equipment is Calibrated Prior to the Pour**

Quality Control

Quality Construction

- Test Slump, Air, Beams and/or Cylinders as required
- Test Unit Weight
- Confirm opening strengths are achieved
- Confirm 7 and 28 day strengths are achieved

Full Systems Approach

Thank You

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