# *Rethinking Testing for Concrete Pavements*

Braden Tabb, Robert Felice, John Michael Freeman, Robert Frazier, David Welchel, Morteza Khatibmasjedi, Jake LeFlore, Bret Robertson, Dan Cook, Ph.D.

**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
- Box Test
- Super Air Meter
- *The Phoenix!*

# The Big Picture

We need our materials to last as long as possible with little to no maintenance

We need tools to help us achieve this economically and without impacting our productivity

We need to take action!

# What do we need from our concrete?

- Workable
- Durable
- Economical
- Strength

- Every project has a different set of requirements!!!

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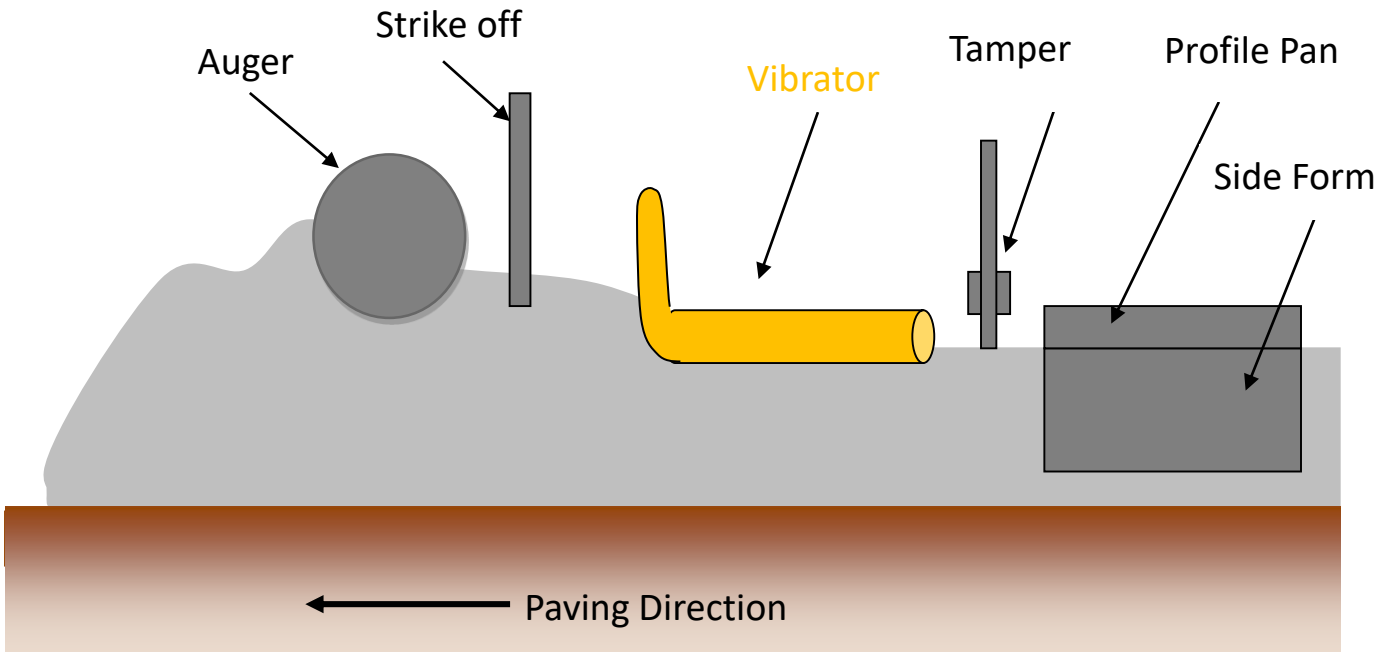
How do we determine if a concrete mixture has the right workability for a concrete pavement?

# Slip Formed Paver

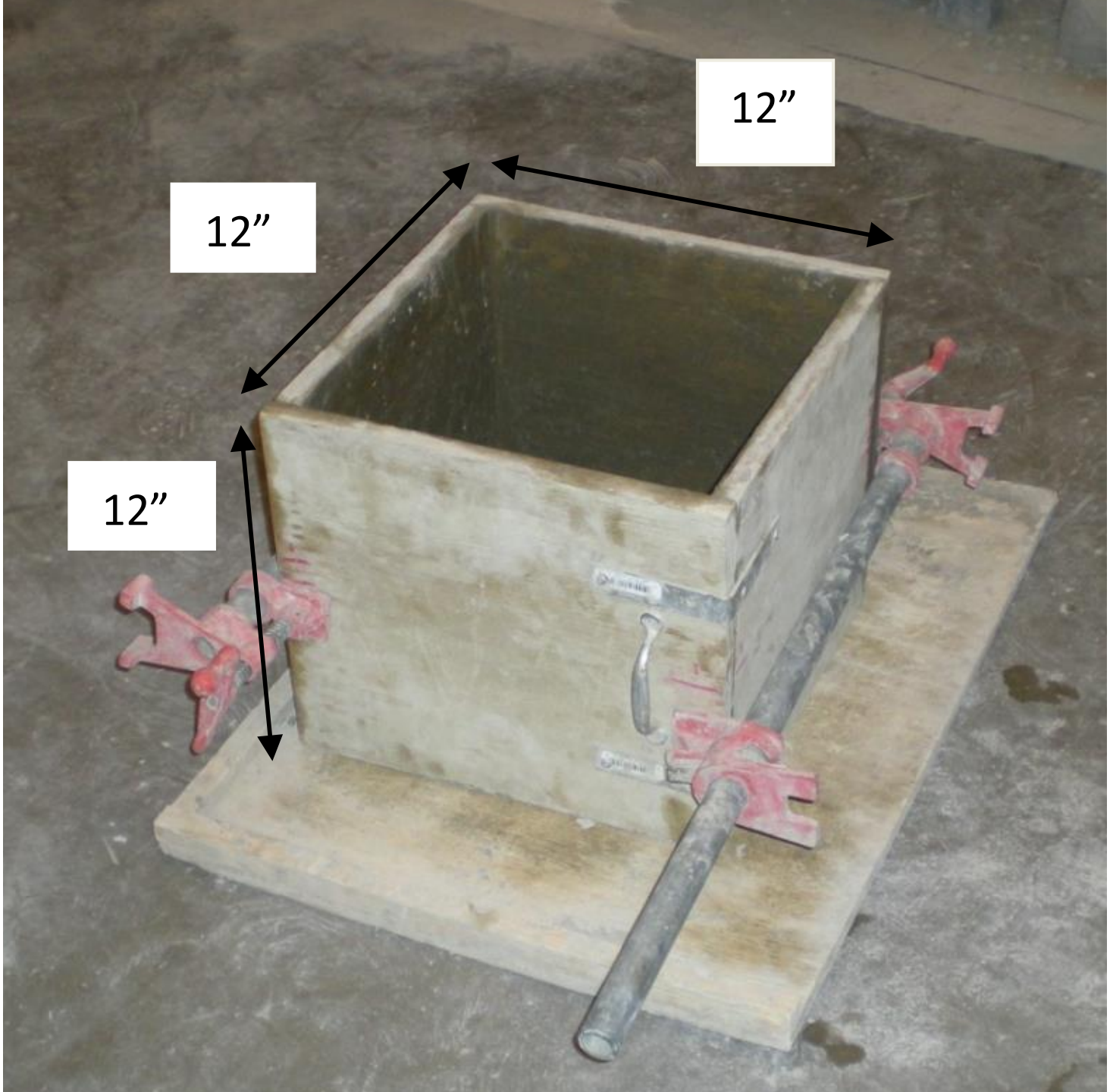
What part of a paver is the most critical for concrete consolidation?



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”

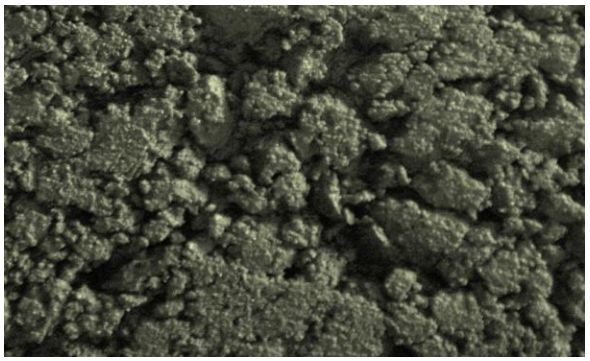
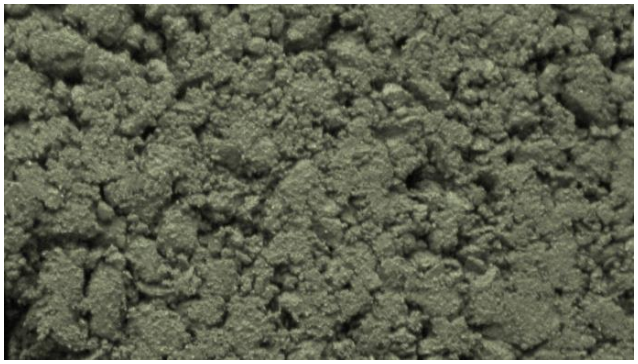
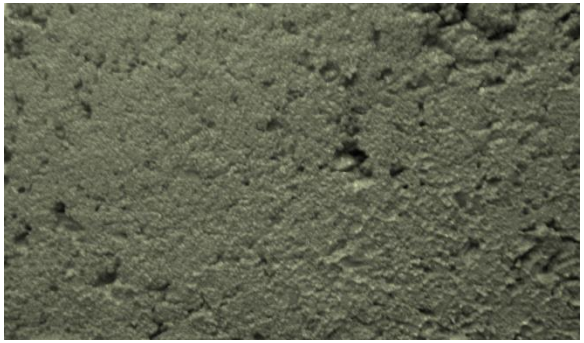
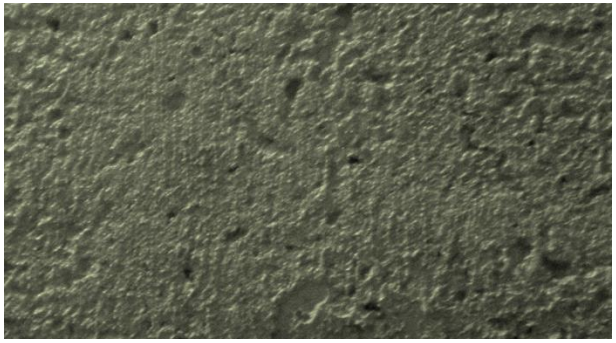
# Box Test

Add 9.5” of unconsolidated concrete to the box

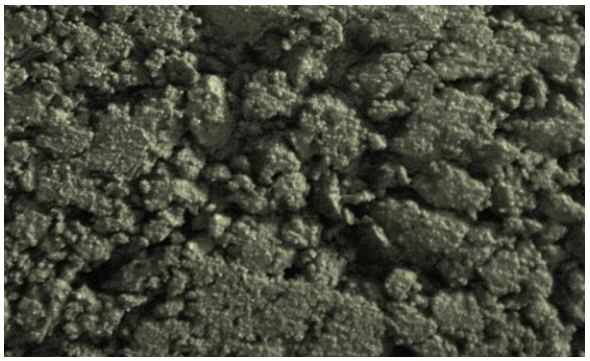
A 1” diameter stinger vibrator is inserted into the center of the box over a three count and then removed over a three count

The edges of the box are then removed and inspected for honey combing or edge slumping

# Box Test Ranking Scale

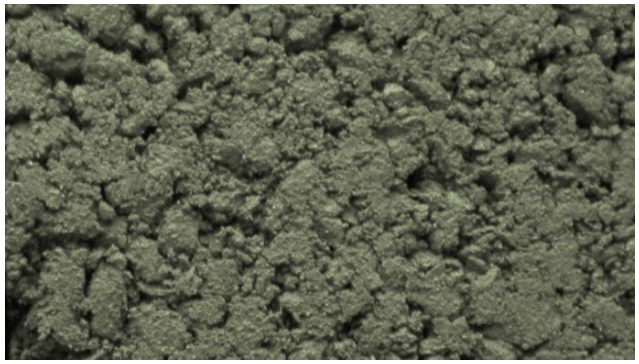
| | |
|---|---|
|  |  |
| **4** | **3** |
| Over 50% overall surface voids. | 30-50% overall surface voids. |
|  |  |
| **2** | **1** |
| 10-30% overall surface voids. | Less than 10% overall surface voids. |

# Box Test Ranking Scale



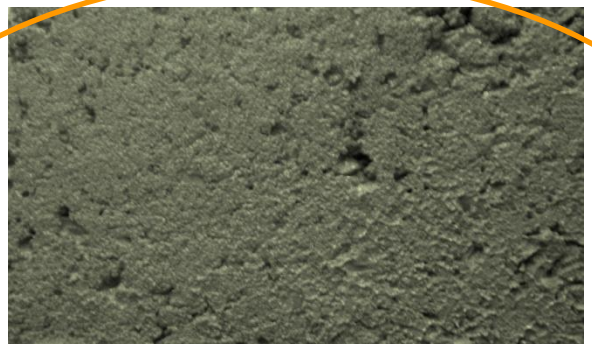
**4**

Over 50% overall surface voids.



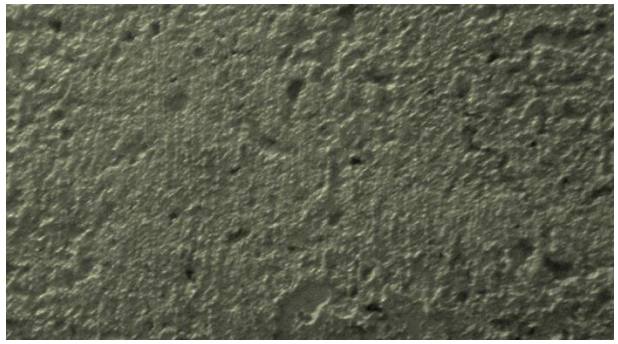
**3**

30-50% overall surface voids.



**2**

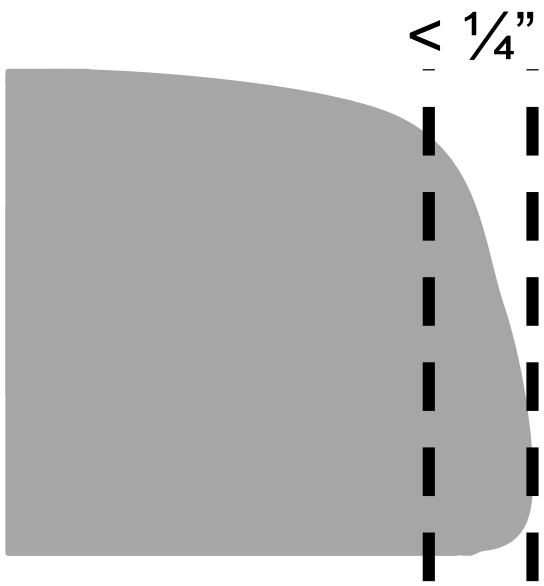
10-30% overall surface voids.



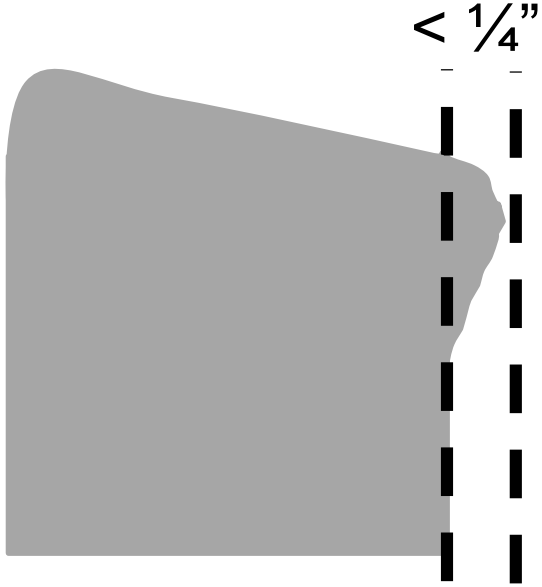
**1**

Less than 10% overall surface voids.

# 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!!!

# The *TARANTULA* curve!

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

Creates surface finishing problems

Not in Scope of work

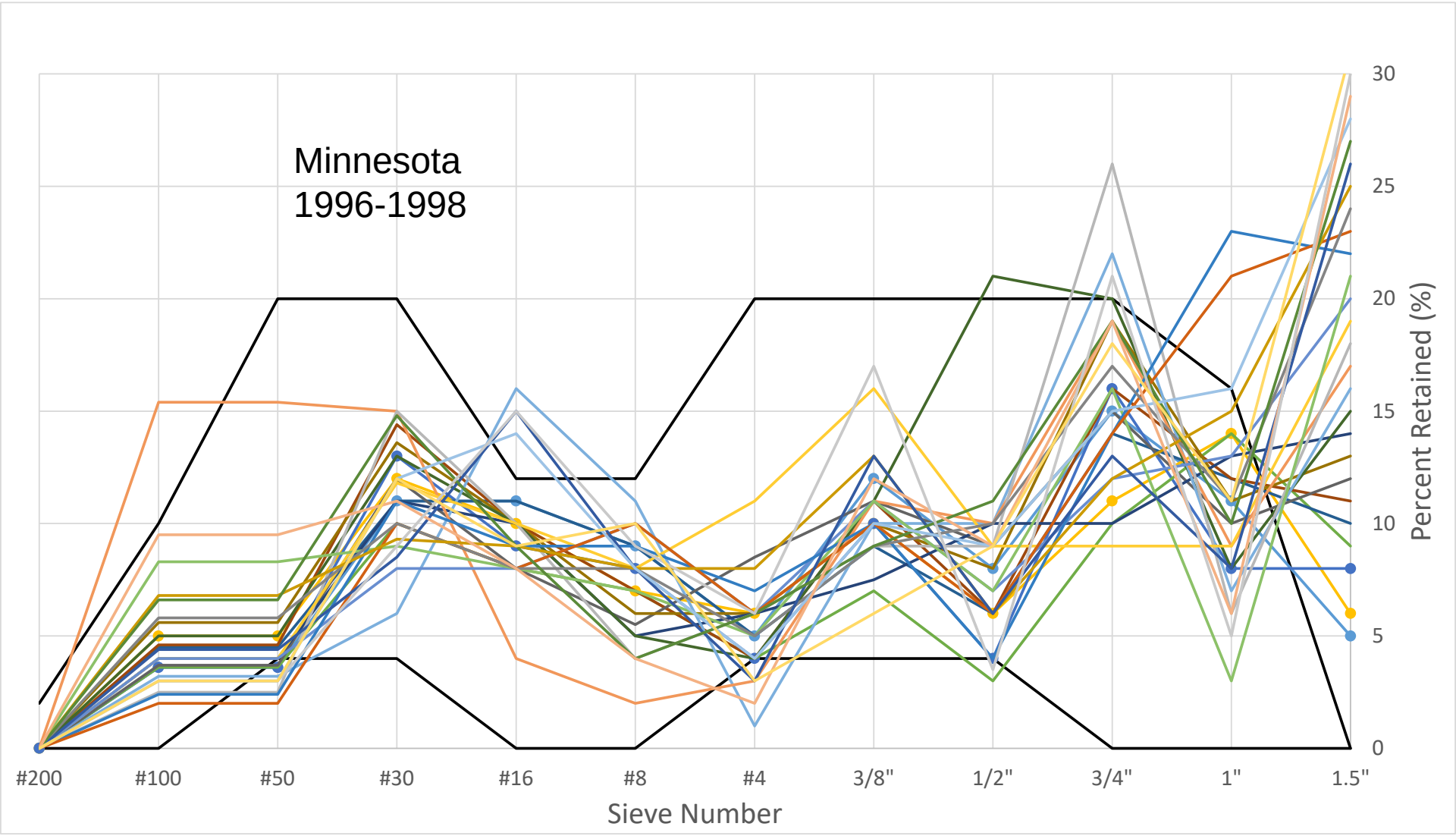
35%
30%
25%
20%
15%
10%
5%
0%

**% Retained**

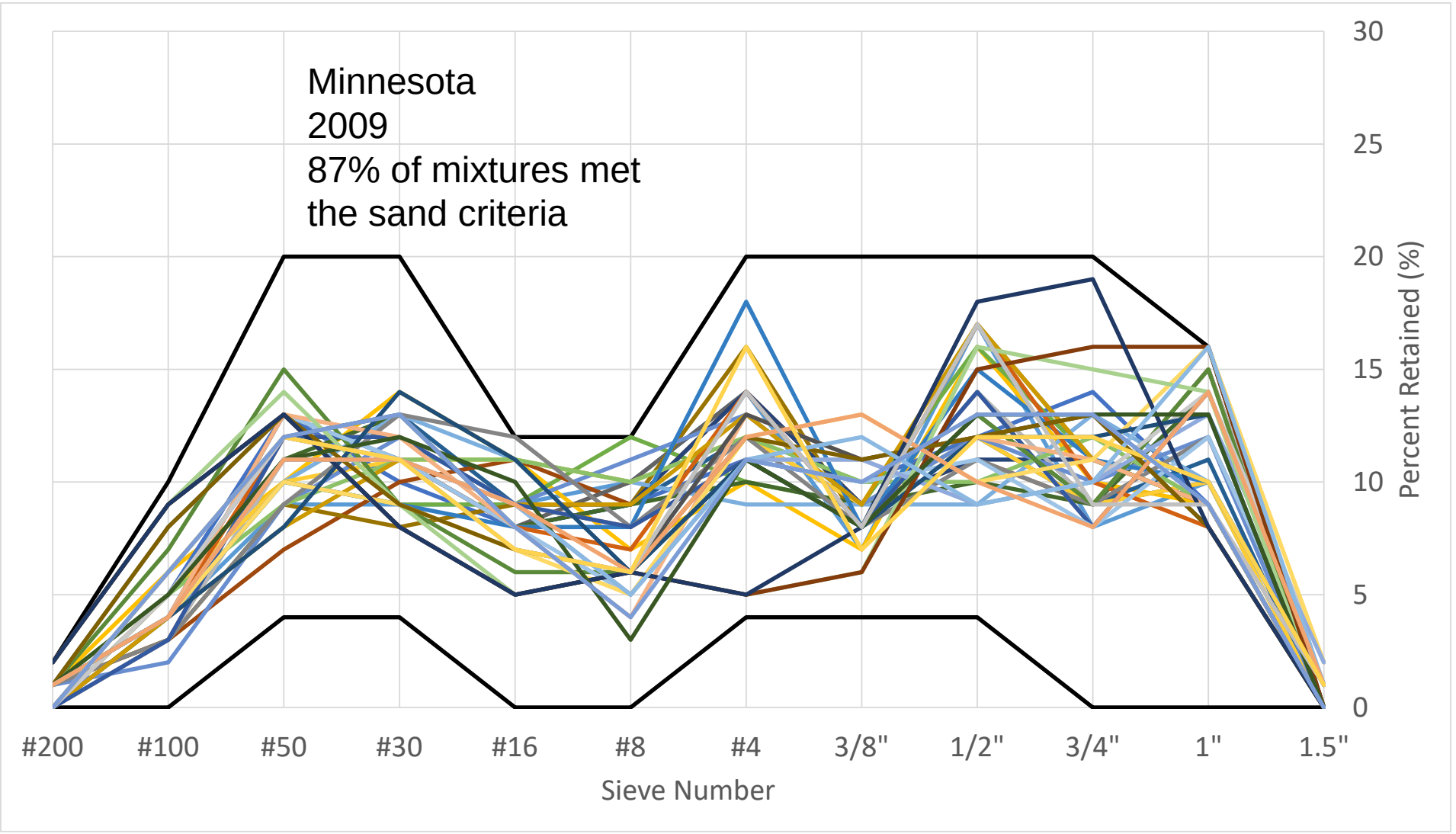
#200 #100 #50 #30 #16 #8 #4 0.375 0.5 0.75 1 1.5

**Sieve No.**

# Use in the field




Data from Maria Masten

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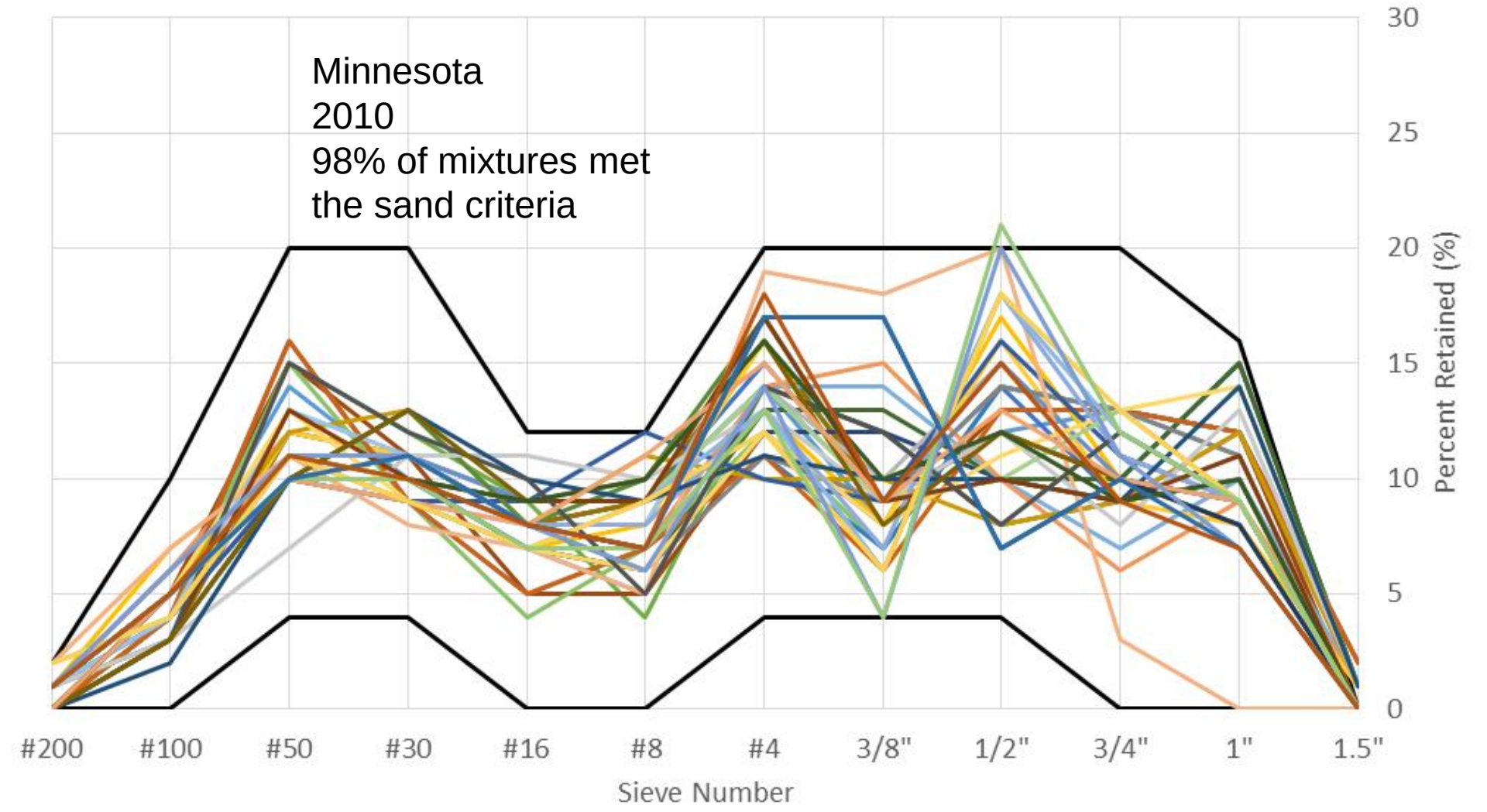


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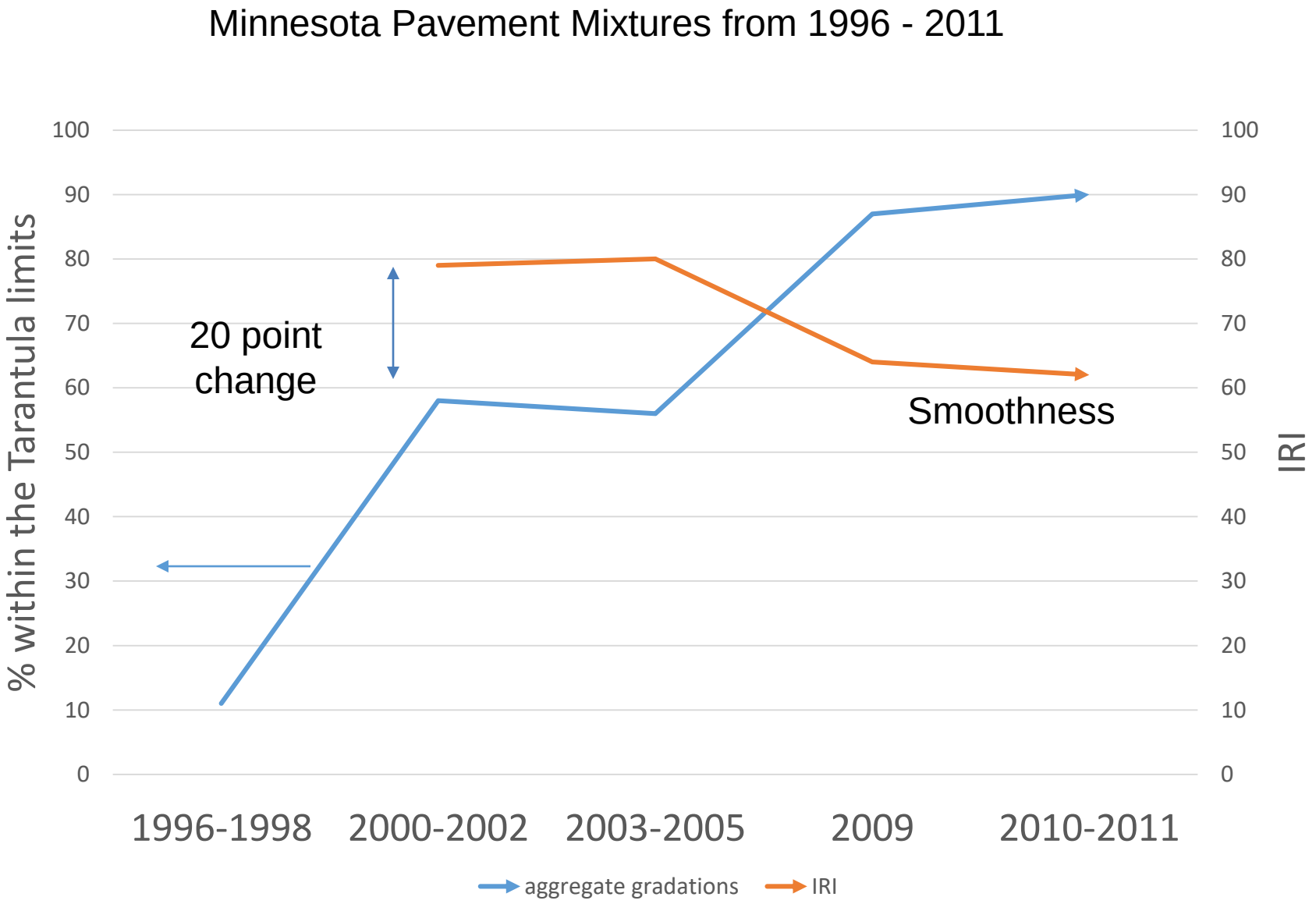


Alturki and Ley 2017

# 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
- Similar data is available for Iowa and Michigan.

# Box Test

# AASHTO TP ??

www.tarantulacurve.com

# What do we need from our concrete?

- Workable
- Durable
- Economical
- Strength

- Every project has a different set of requirements!!!

# Today's topics!

air

water to cement ratio

# 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

Increased paste content

## TABLE 4.4.1 — TOTAL AIR CONTENT FOR CONCRETE EXPOSED TO CYCLES OF FREEZING AND THAWING

| Nominal maximum aggregate size, in.* | Air content, percent | |
|---|---|---|
| | Exposure Class F1 | Exposure Classes F2 and F3 |
| 3/8 | 6 | 7.5 |
| 1/2 | 5.5 | 7 |
| 3/4 | 5 | 6 |
| 1 | 4.5 | 6 |
| 1-1/2 | 4.5 | 5.5 |
| 2† | 4 | 5 |
| 3† | 3.5 | 4.5 |

*See ASTM C33 for tolerance on oversize for various nominal maximum size designations.
†Air contents apply to total mixture. When testing concretes, however, aggregate particles larger than 1-1/2 in. are removed by sieving and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is computed from value measured on the sieved fraction passing the 1-1/2 in. sieve in accordance with ASTM C231.

If f'c > 5,000 psi then these recommendations can be reduced by 1%
ACI 318

# Do you know where this is from?


**TABLE 4.4.1 — TOTAL AIR CONTENT FOR CONCRETE EXPOSED TO CYCLES OF FREEZING AND THAWING**

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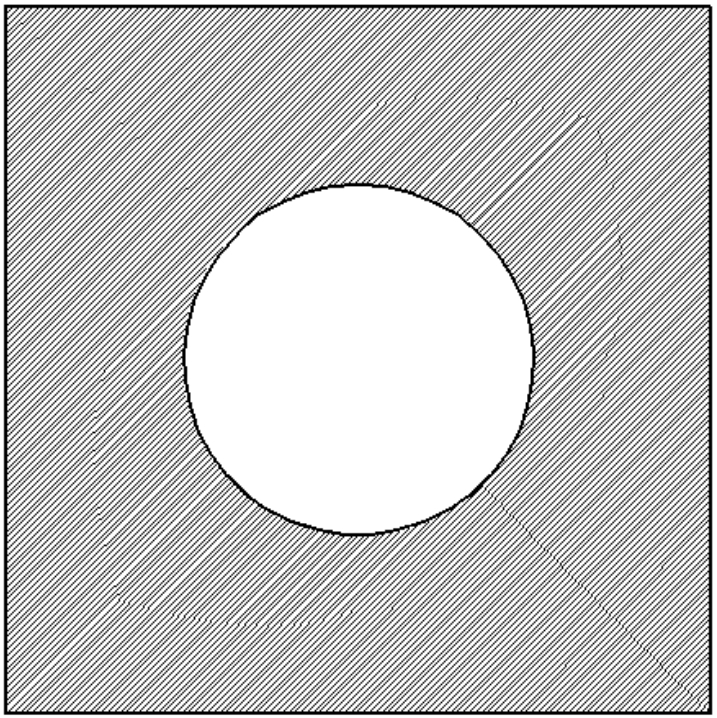
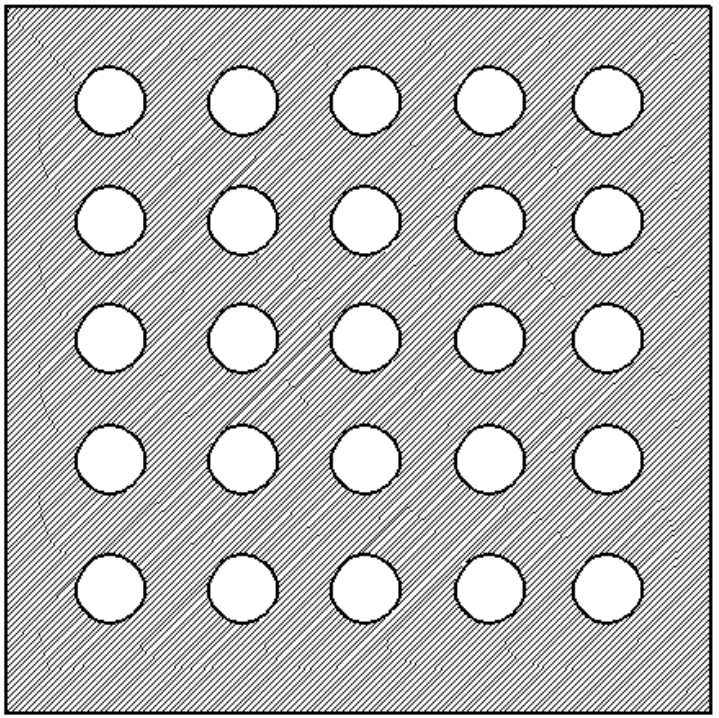
# What Do You Want in an Air-Void System?

A



B



- 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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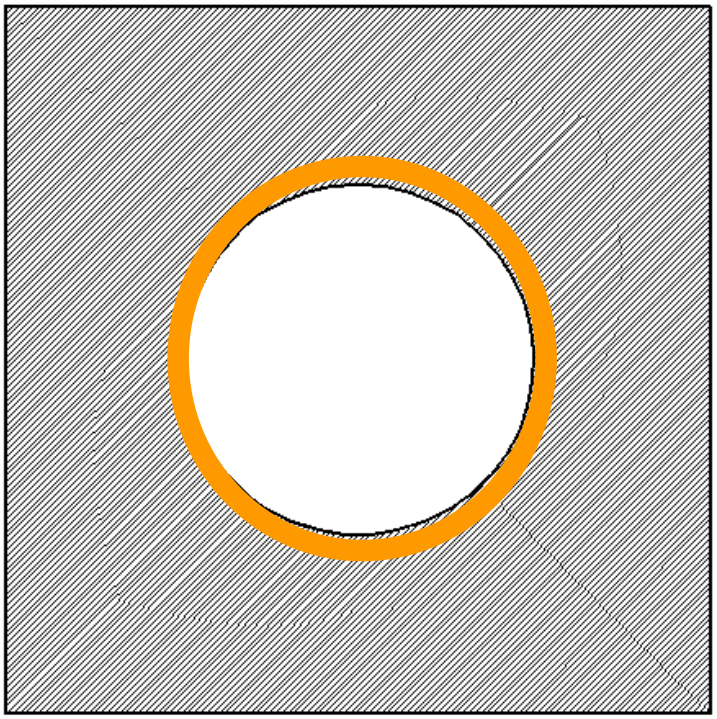
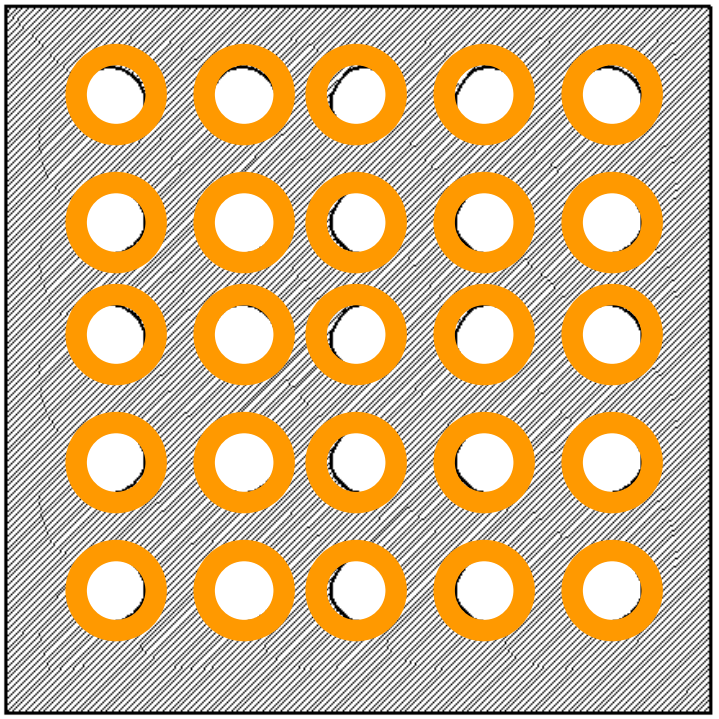


B



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

# What causes large bubbles?

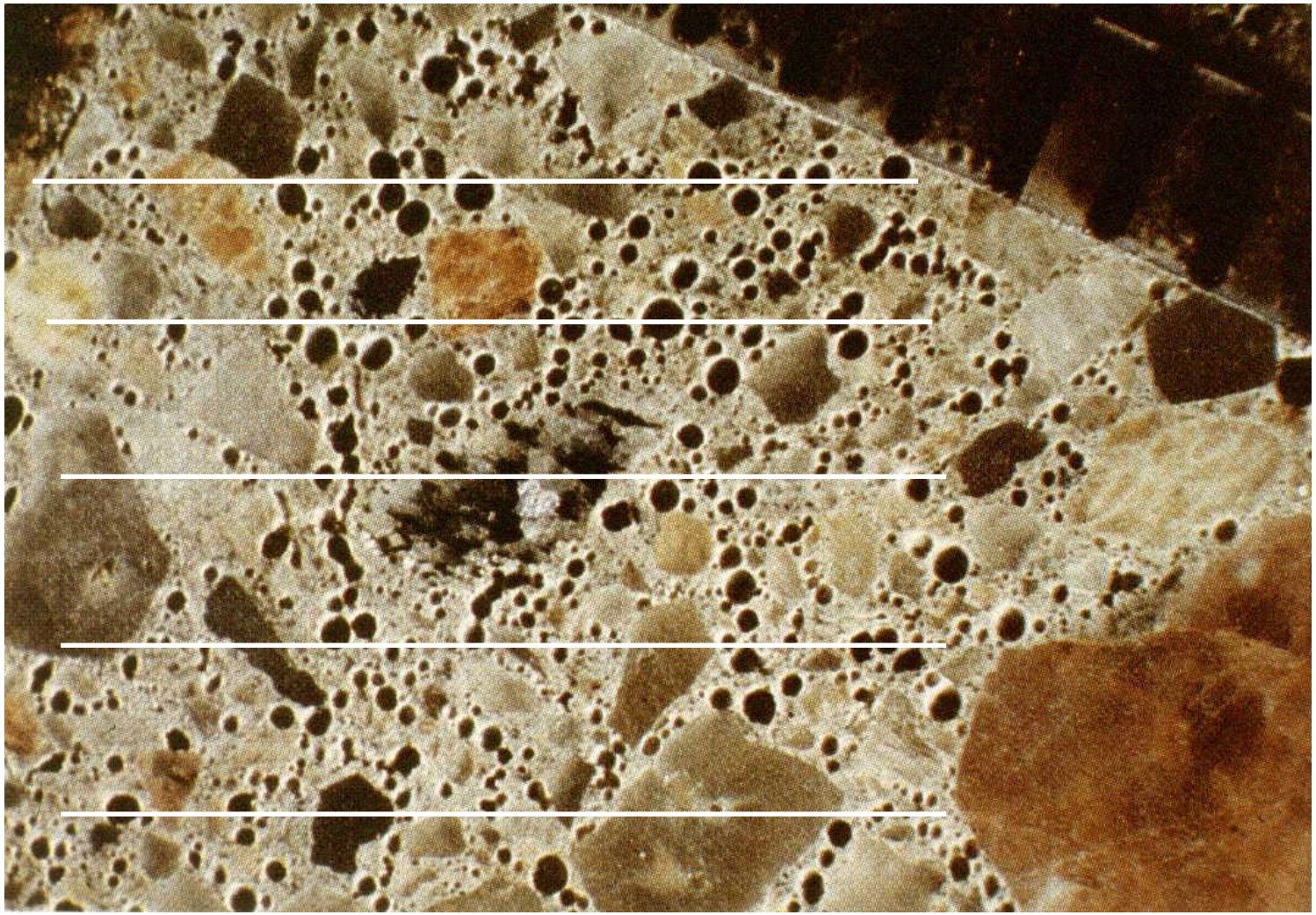
- Admixture incompatibility
- Admixture/cement incompatibility
- Sand gradation
- Inadequate mixing
- Alkali content of binder
- Cement grinding aids
- Changes in temperature

# How do you measure this?

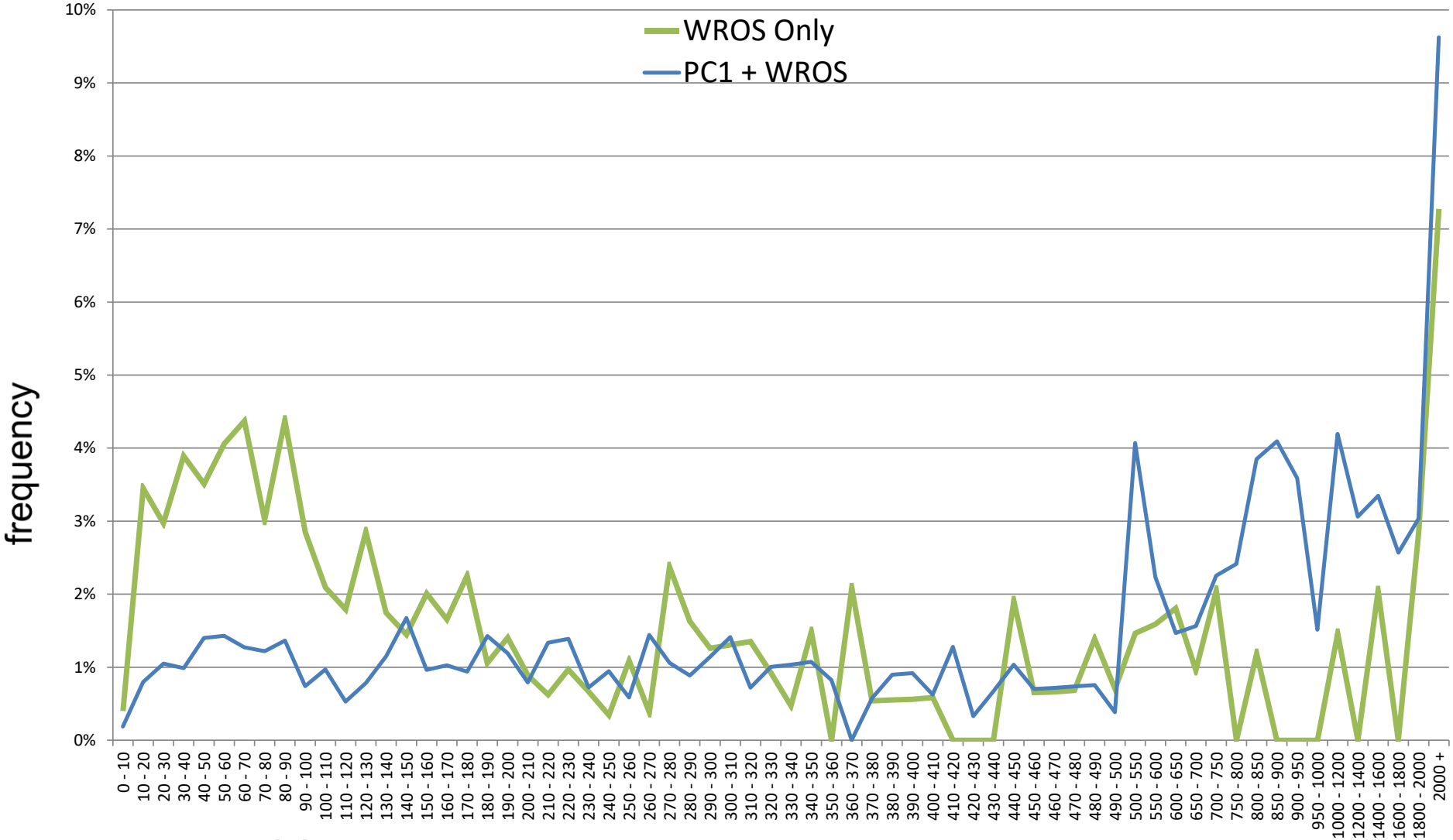
# Hardened Air Void Analysis

From Hover

# Hardened Air Void Analysis



From Hover

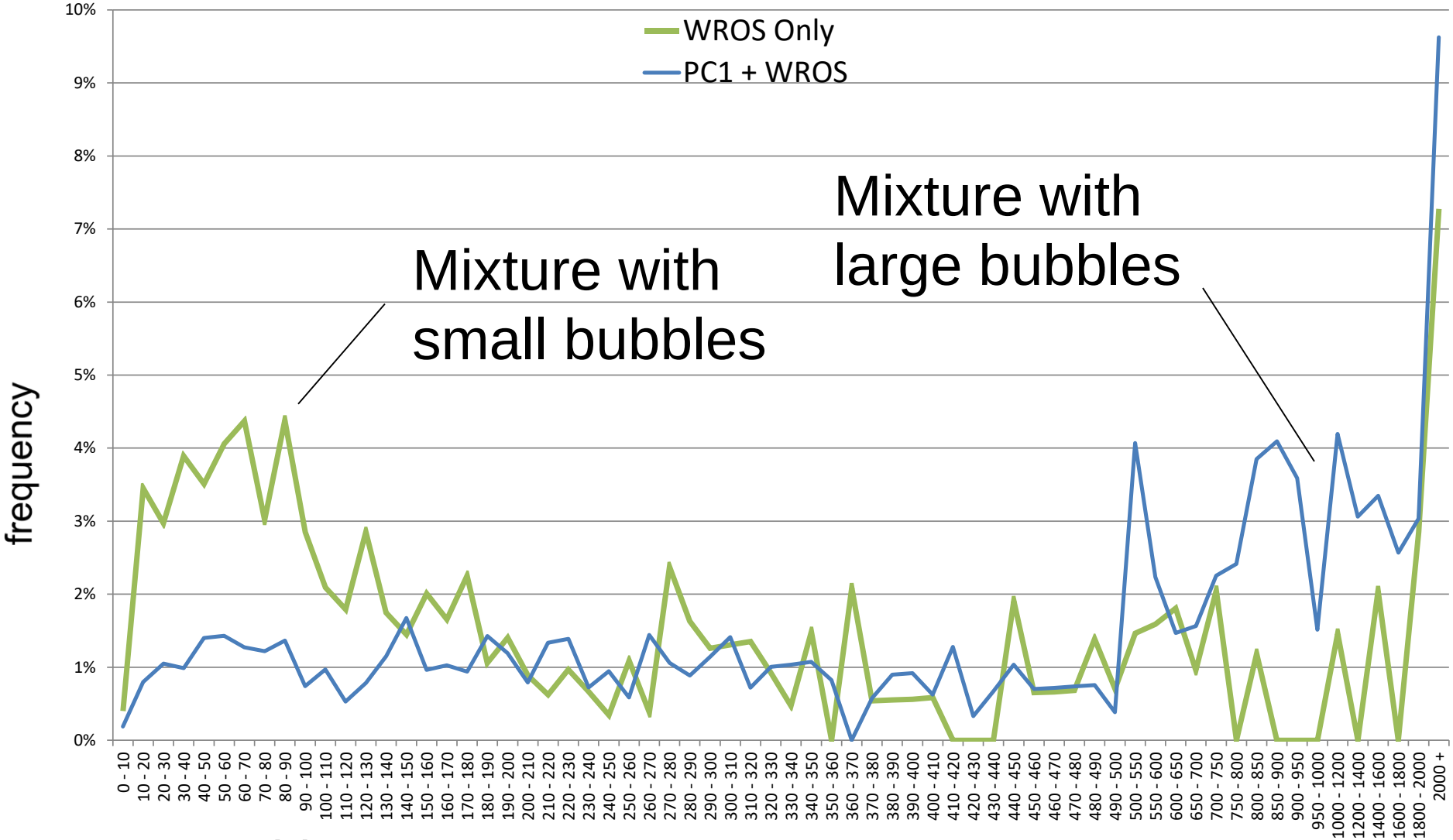



small voids

Chord Size, microns

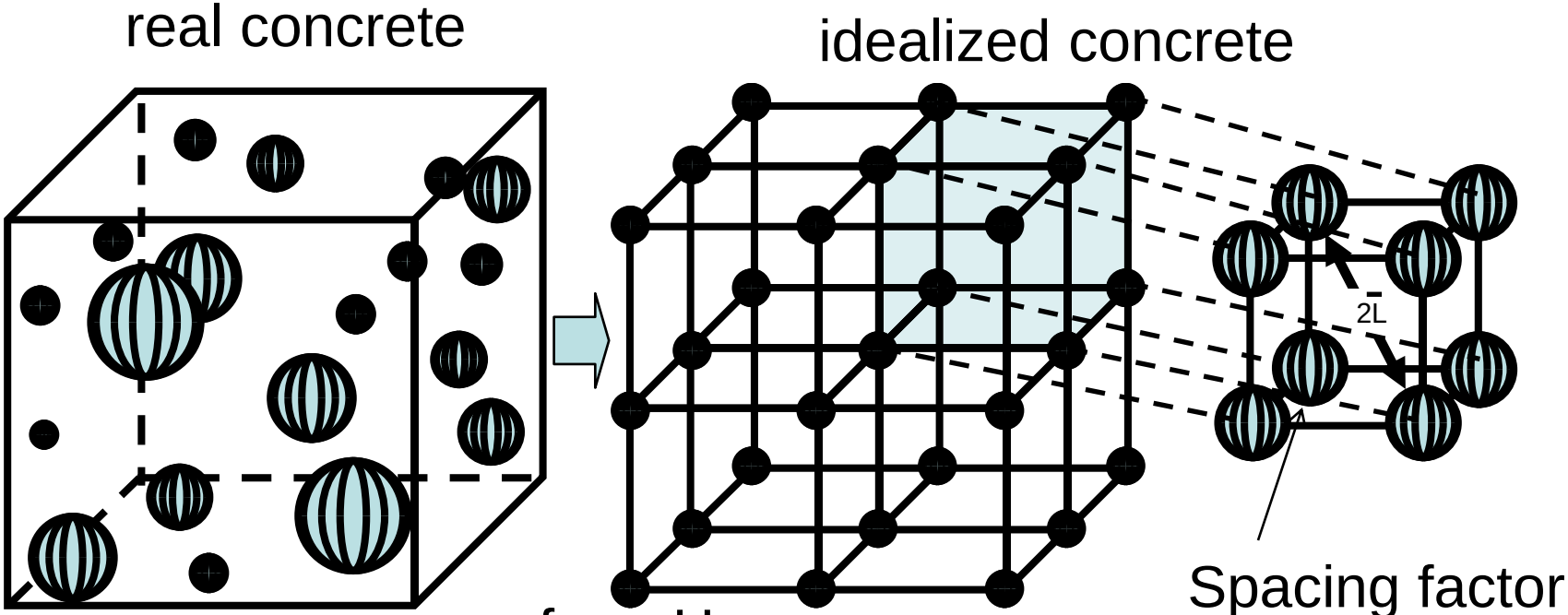
large voids

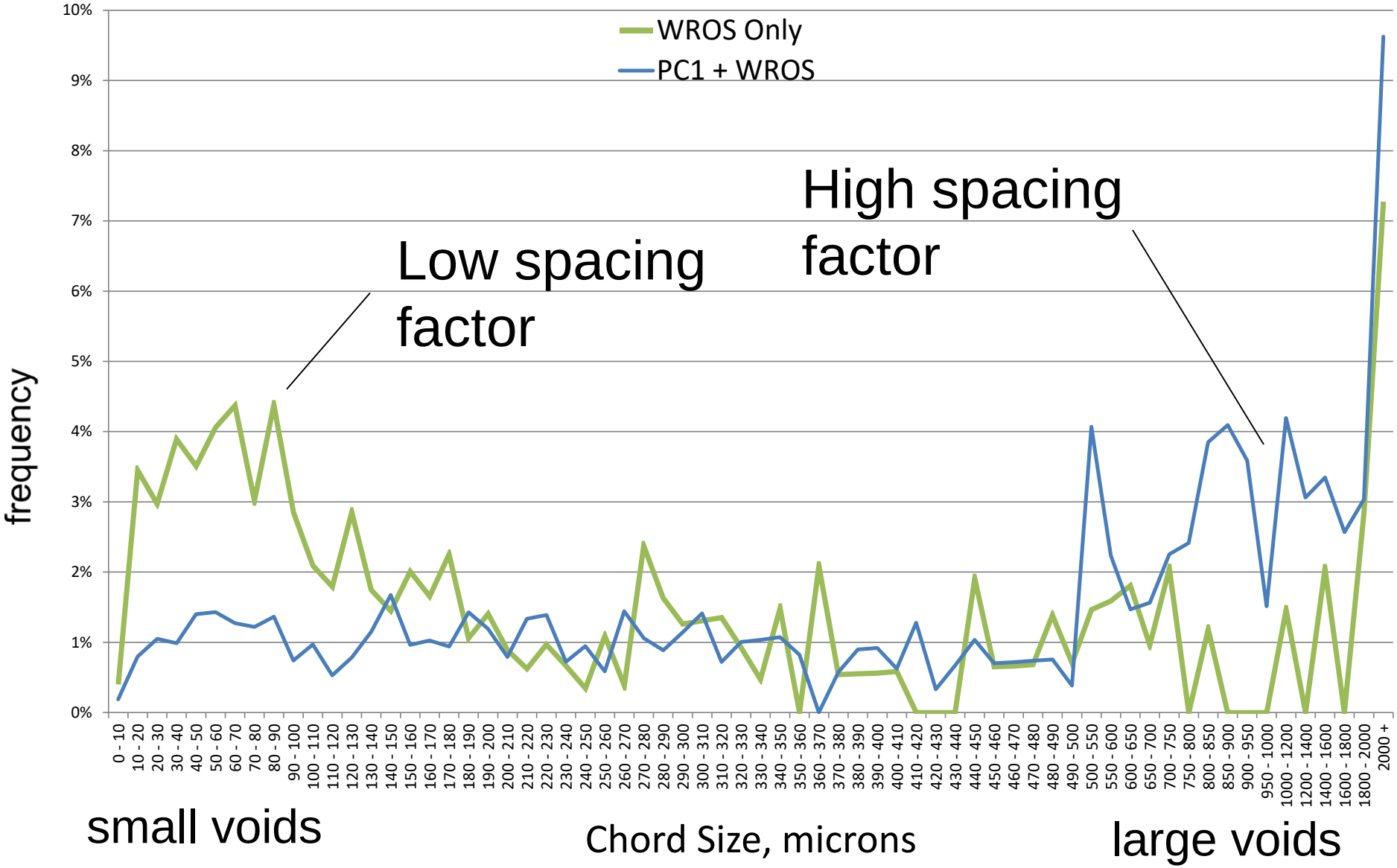
Freeman et al., 2012



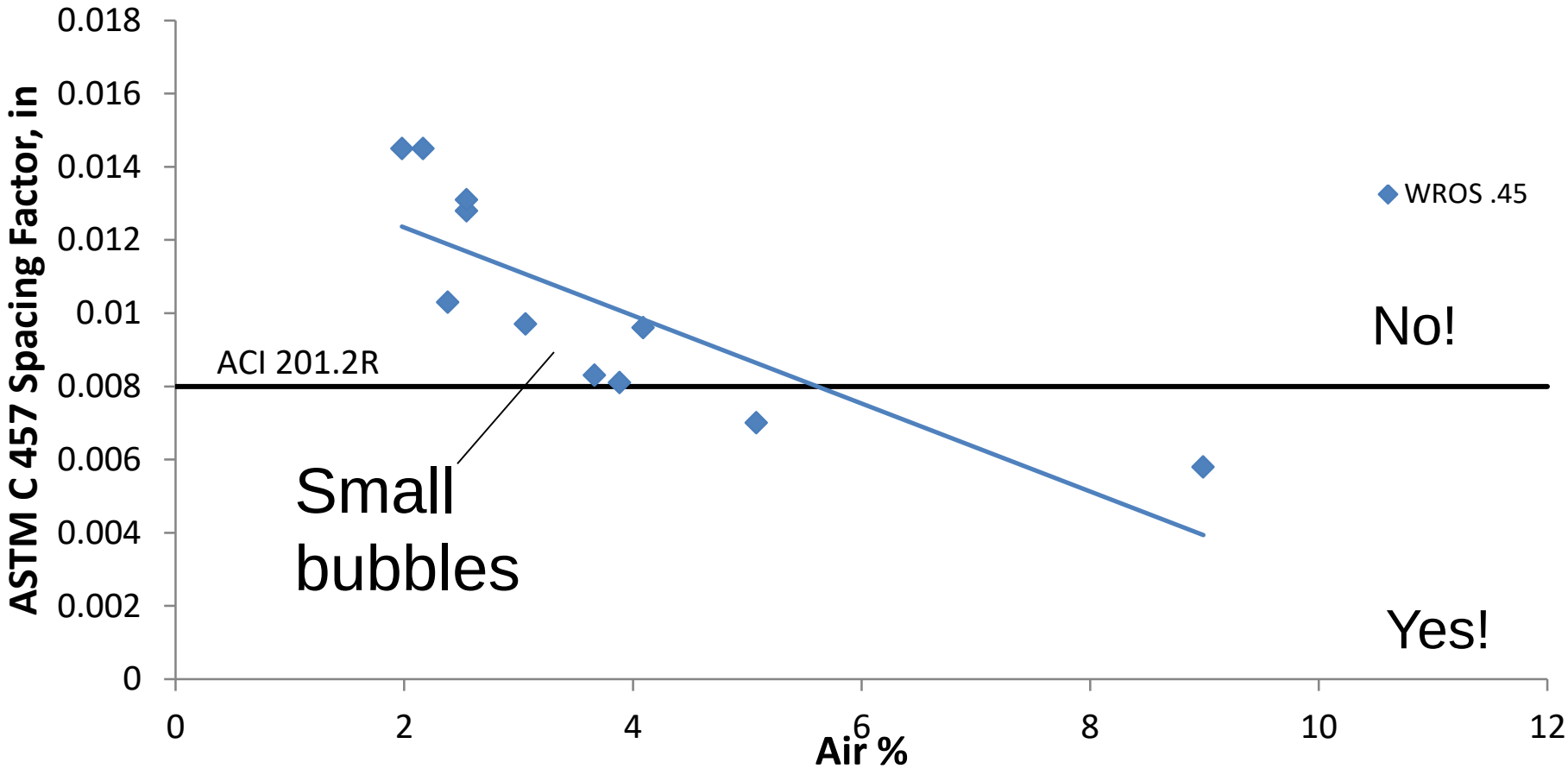

Freeman et al., 2012

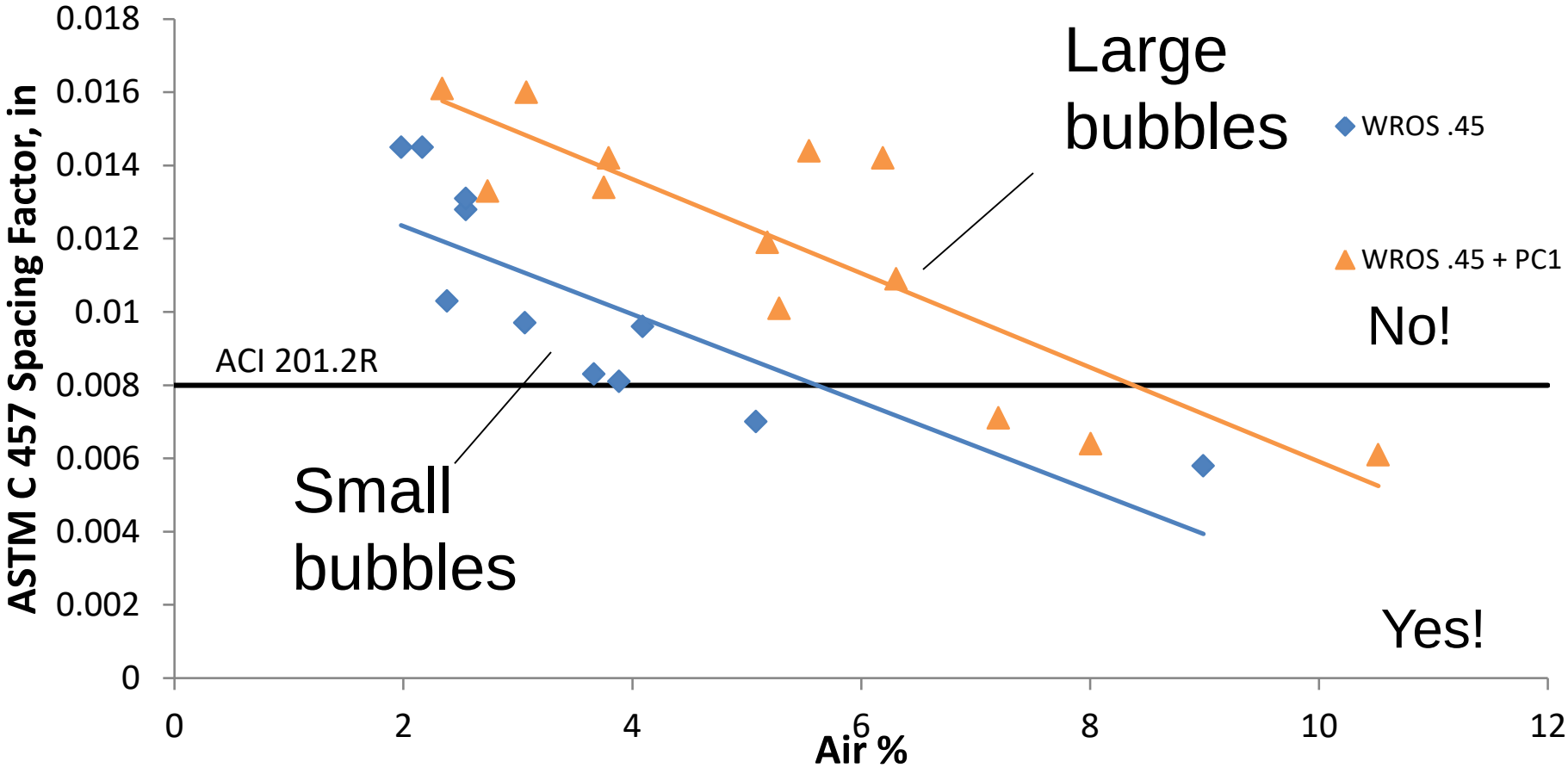
- Spacing Factor – ½ of the average distance of an average sized void uniformly distributed in the paste
- **<u>Desired Value < 0.008 in (ACI 201)</u>**



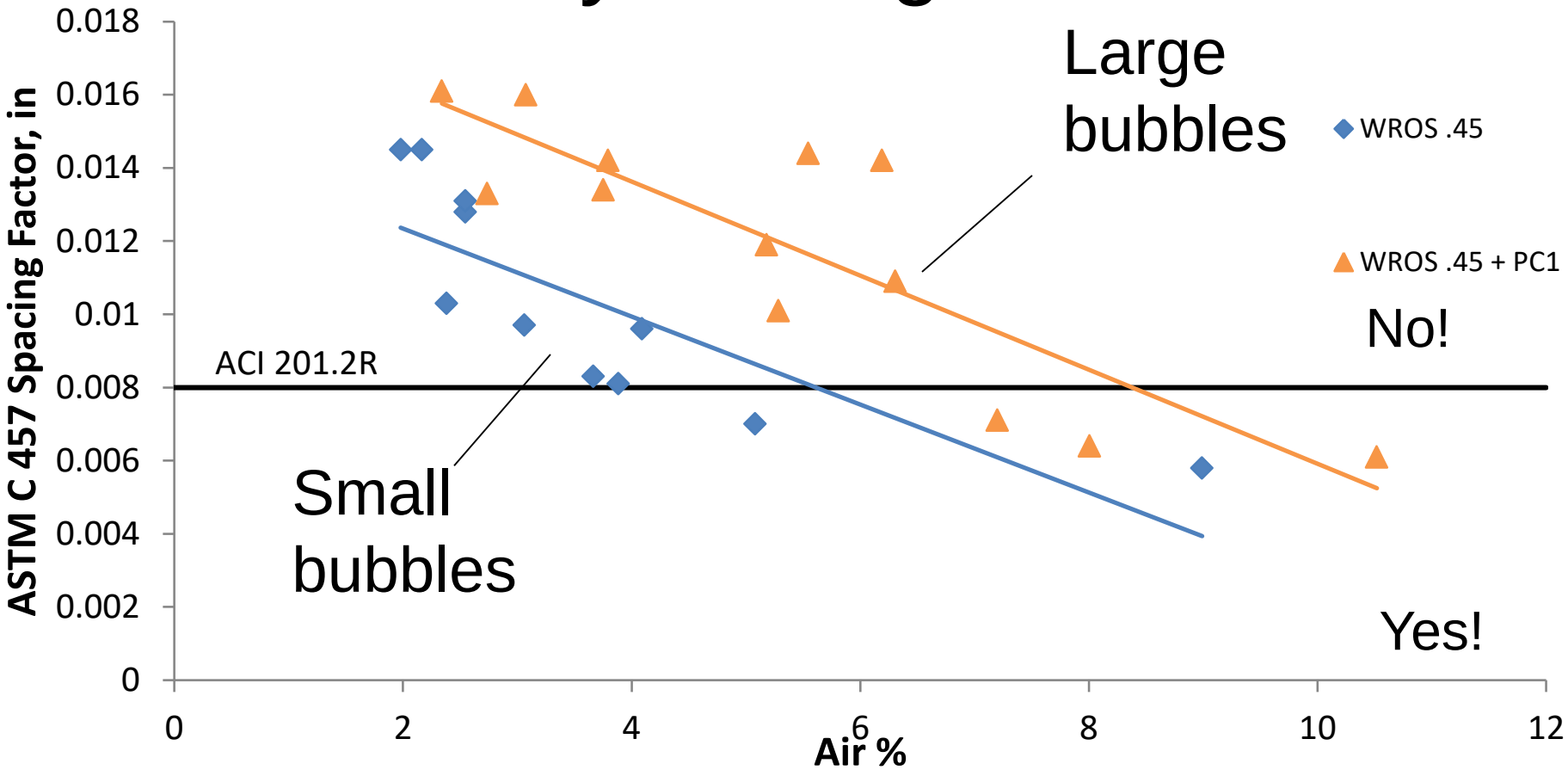


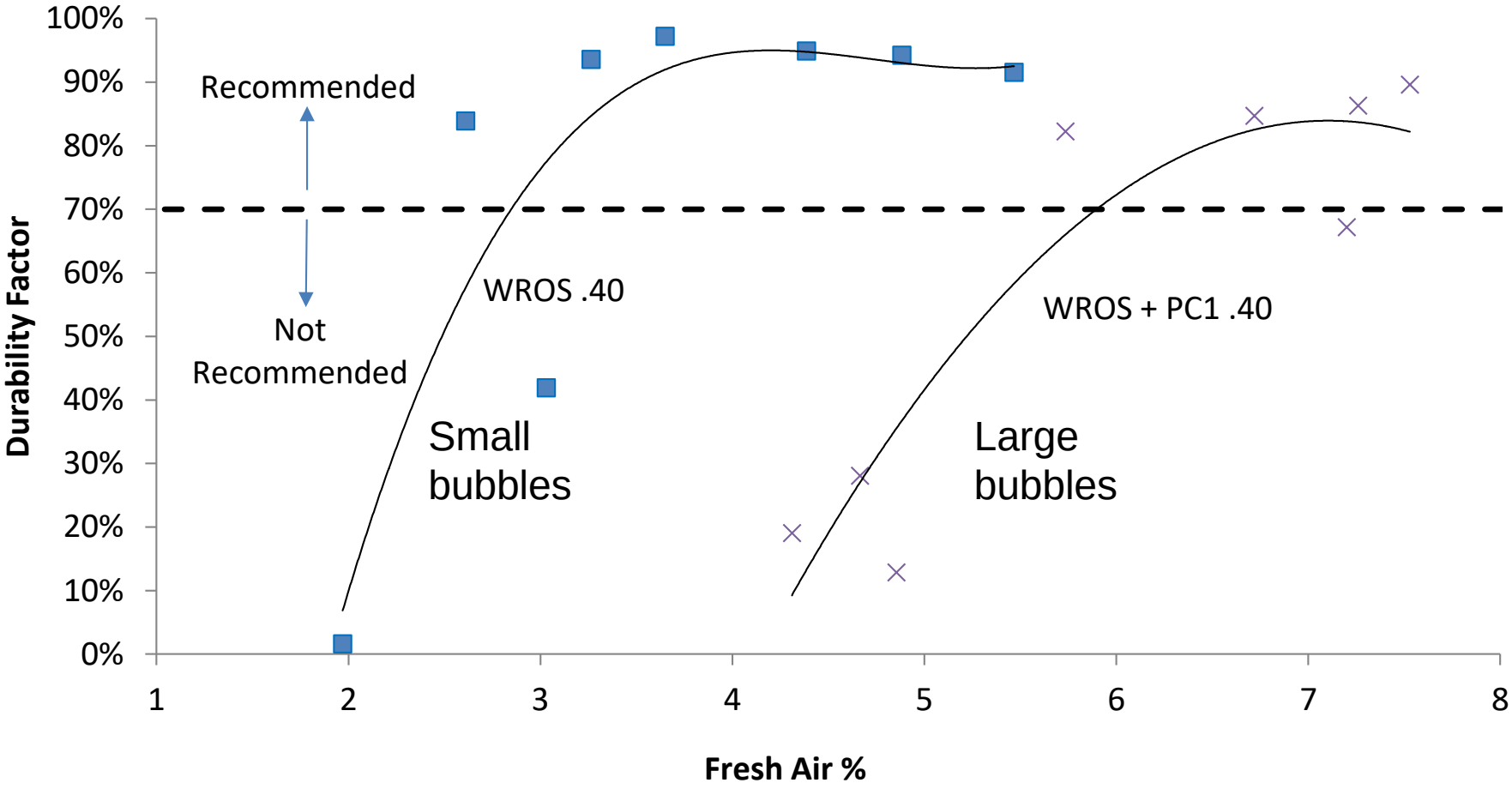

Freeman et al., 2012


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
0
2
4
6
8
10
12
Air %
WROS .45
ACI 201.2R
No!
Small bubbles
Yes!

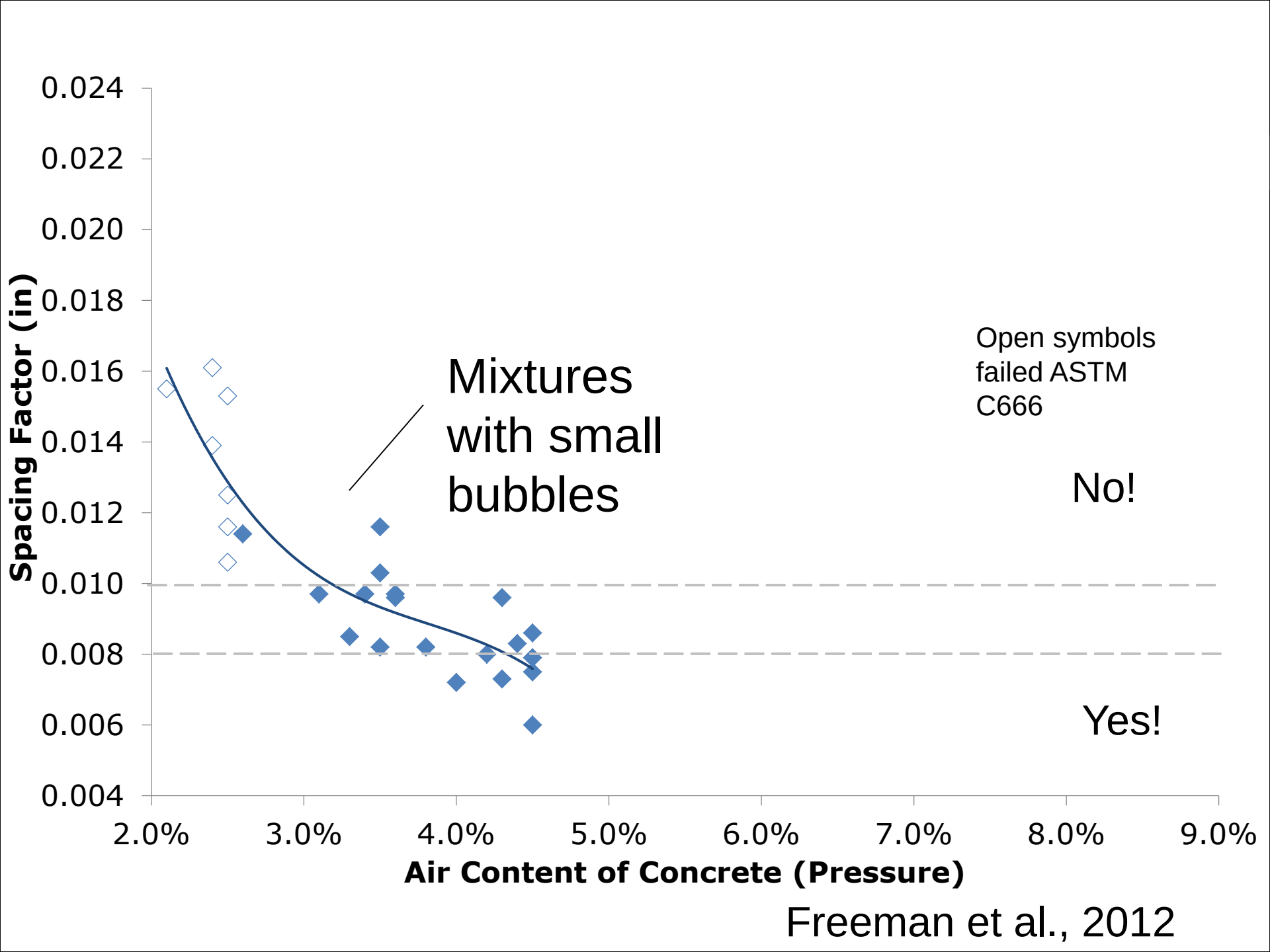

ASTM C 457 Spacing Factor, in
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
2
4
6
8
10
12
Air %
ACI 201.2R
Large bubbles
Small bubbles
WROS .45
WROS .45 + PC1
No!
Yes!

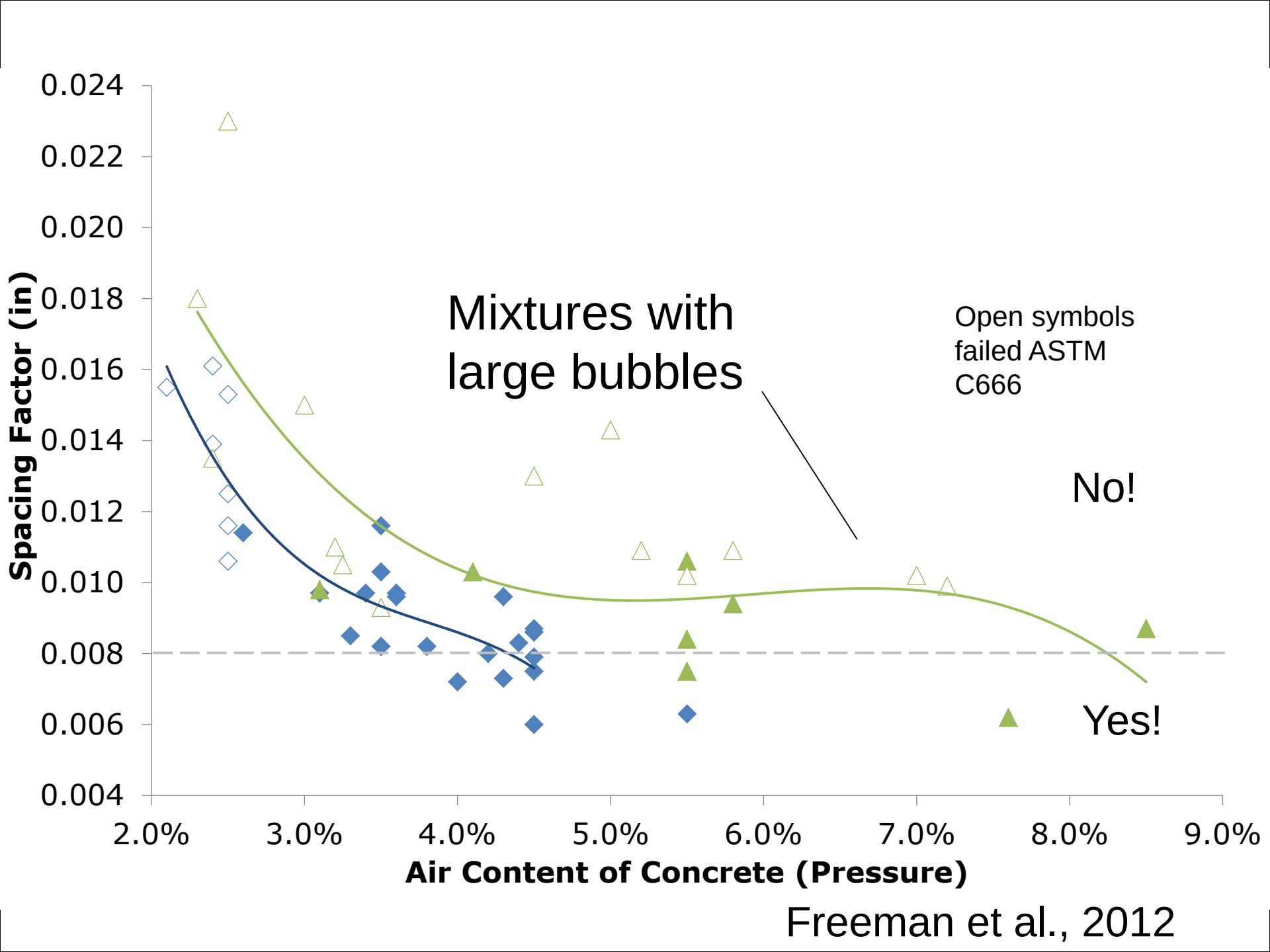
# You can't tell the size of the bubbles by looking at the volume!!!



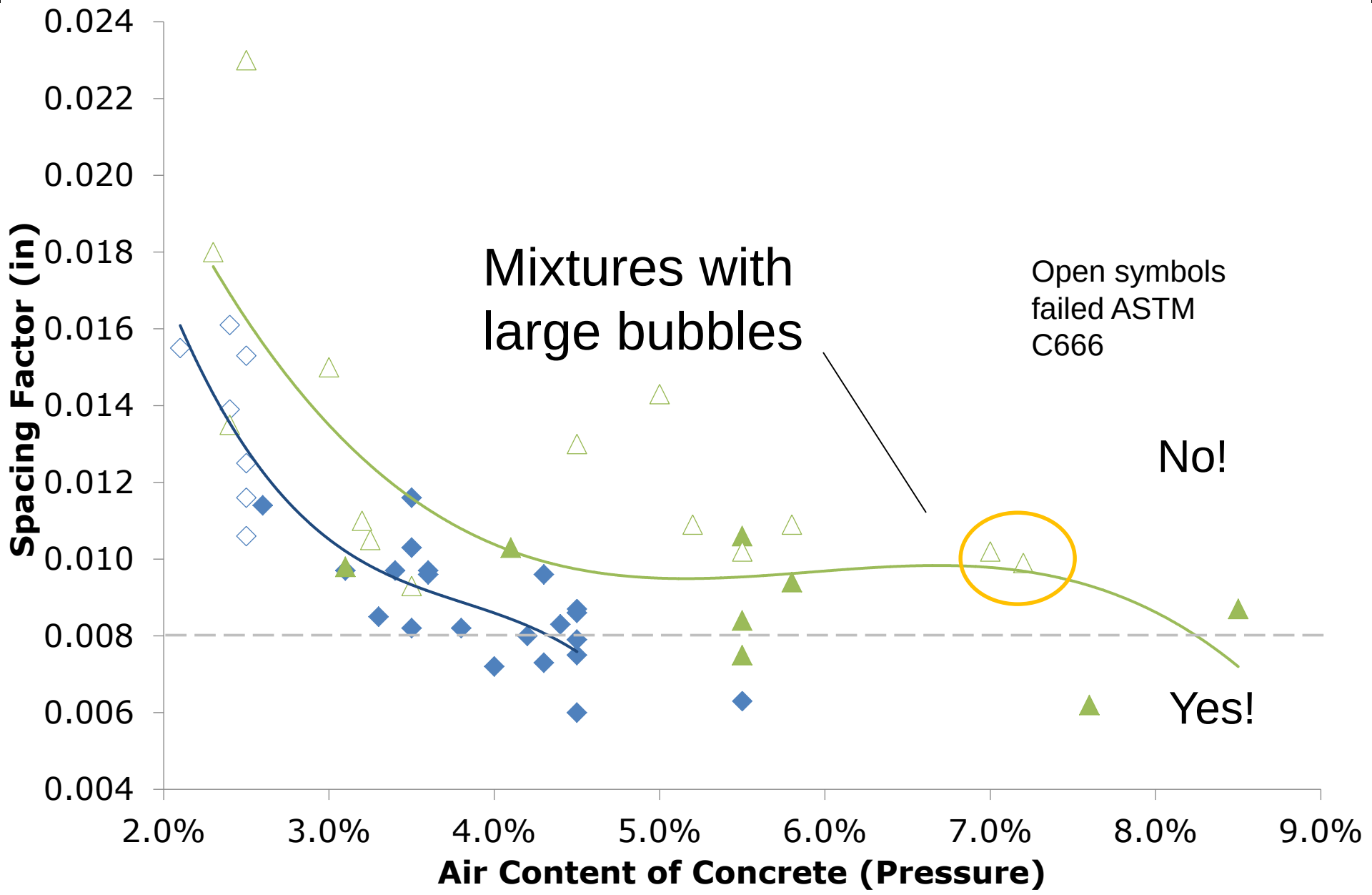



Ley et al., 2017


0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
Spacing Factor (in)
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
Air Content of Concrete (Pressure)
Mixtures with small bubbles
Open symbols failed ASTM C666
No!
Yes!
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

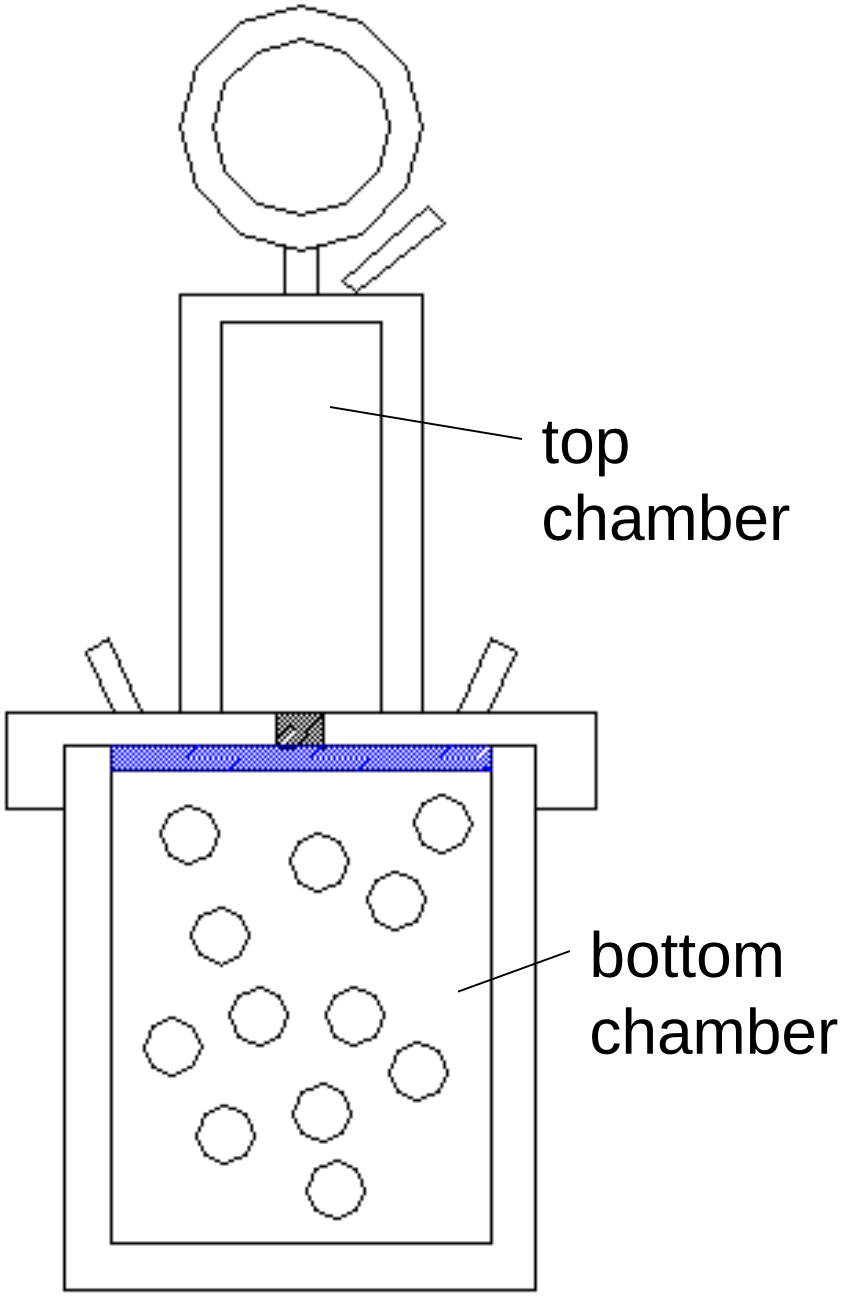
# Super Air Meter (SAM)

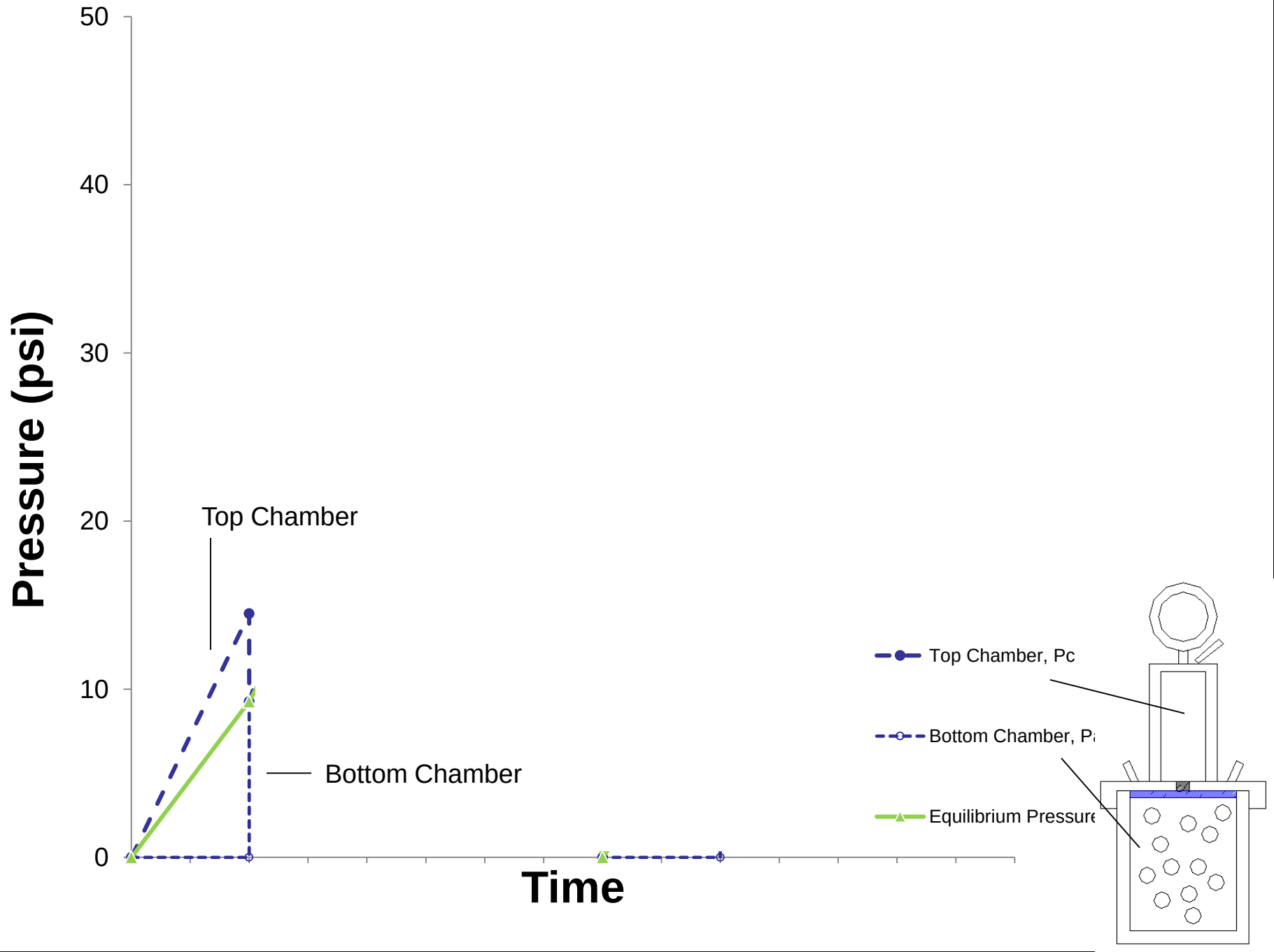
- We have modified a typical ASTM C 231 pressure meter so that it can hold larger pressures
- We have replaced the dial gage with a digital one

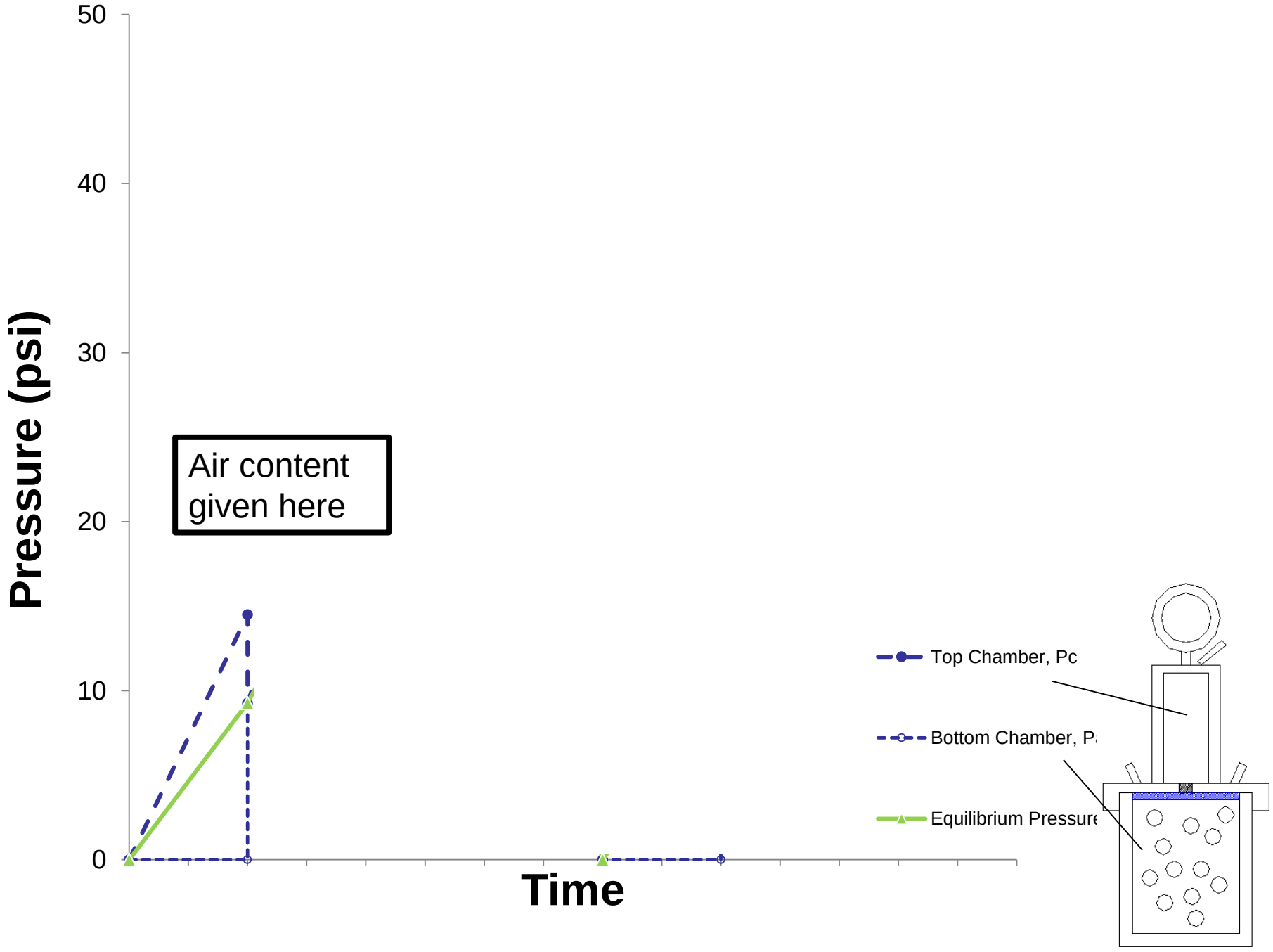

digital
gauge
six
clamps!

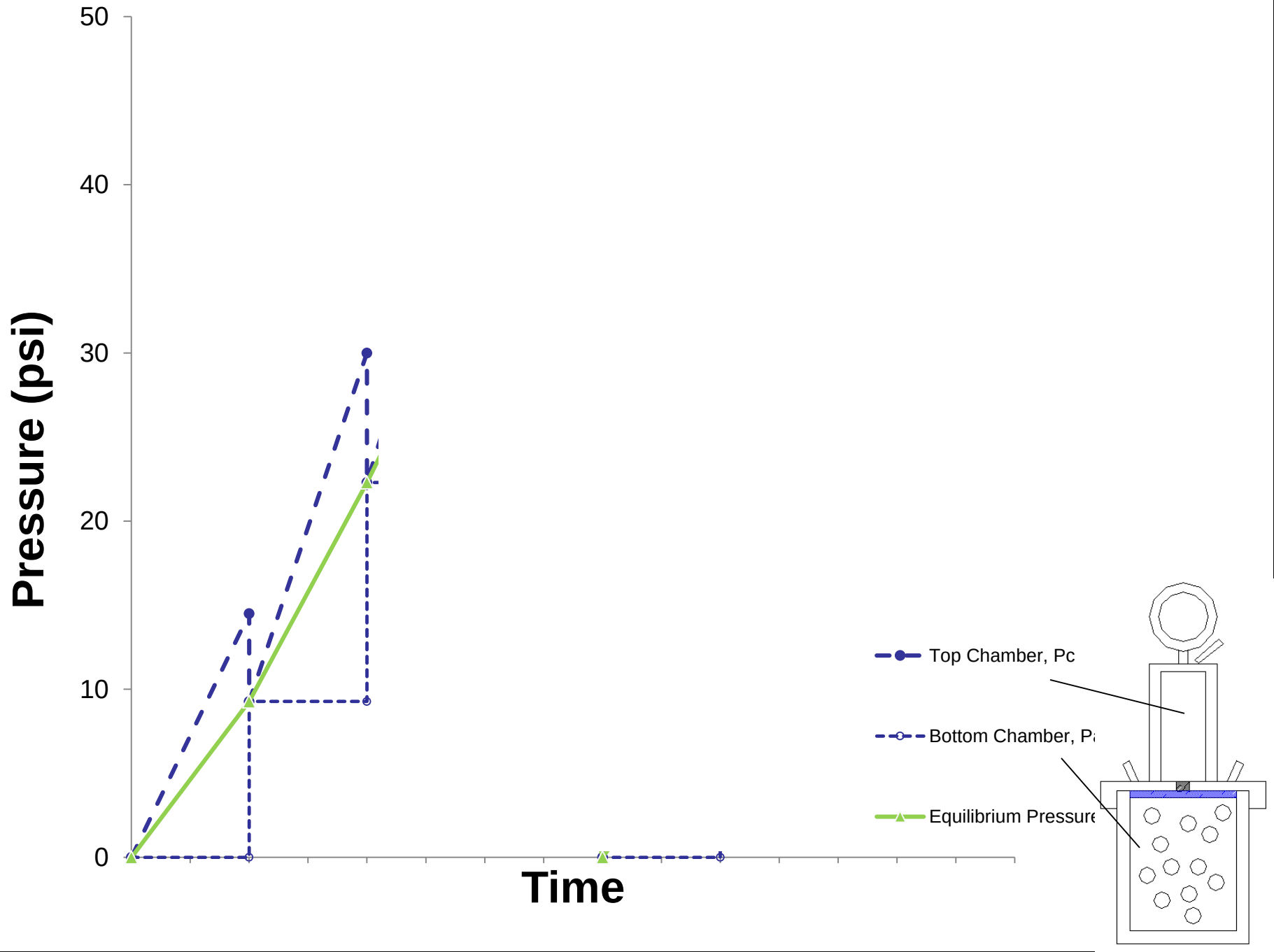
# AASHTO TP 118

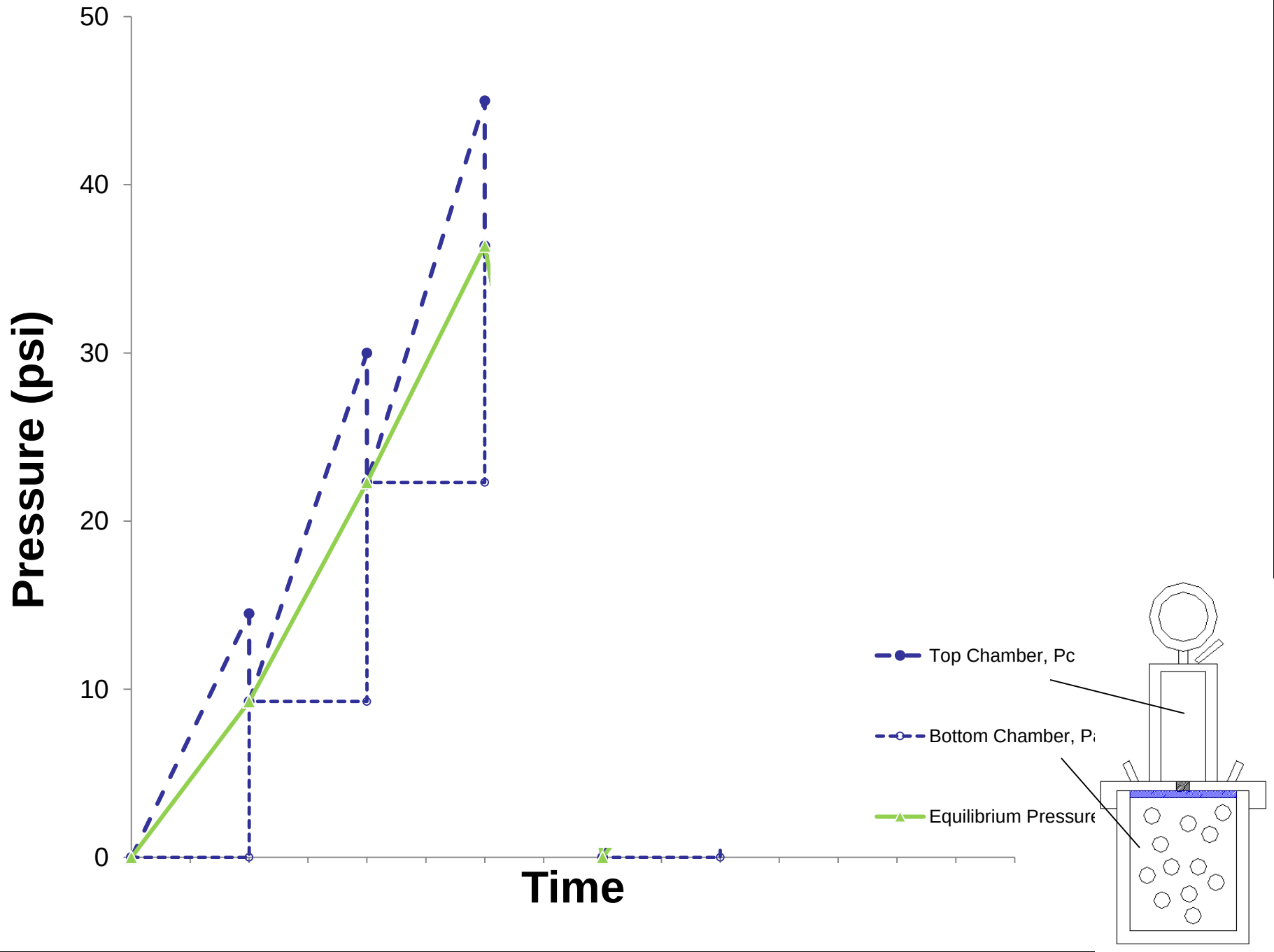
www.superairmeter.com

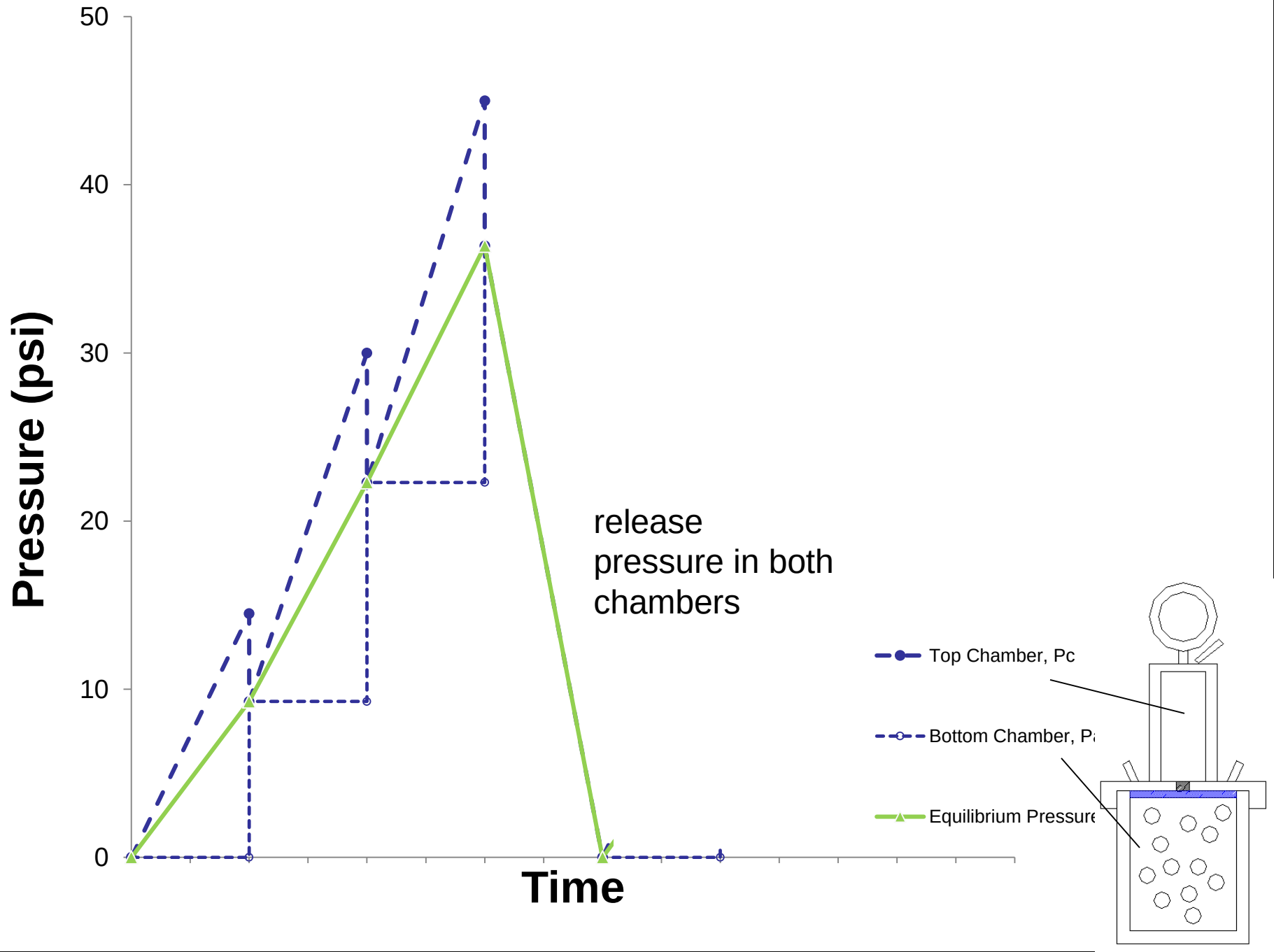

top
chamber
bottom
chamber

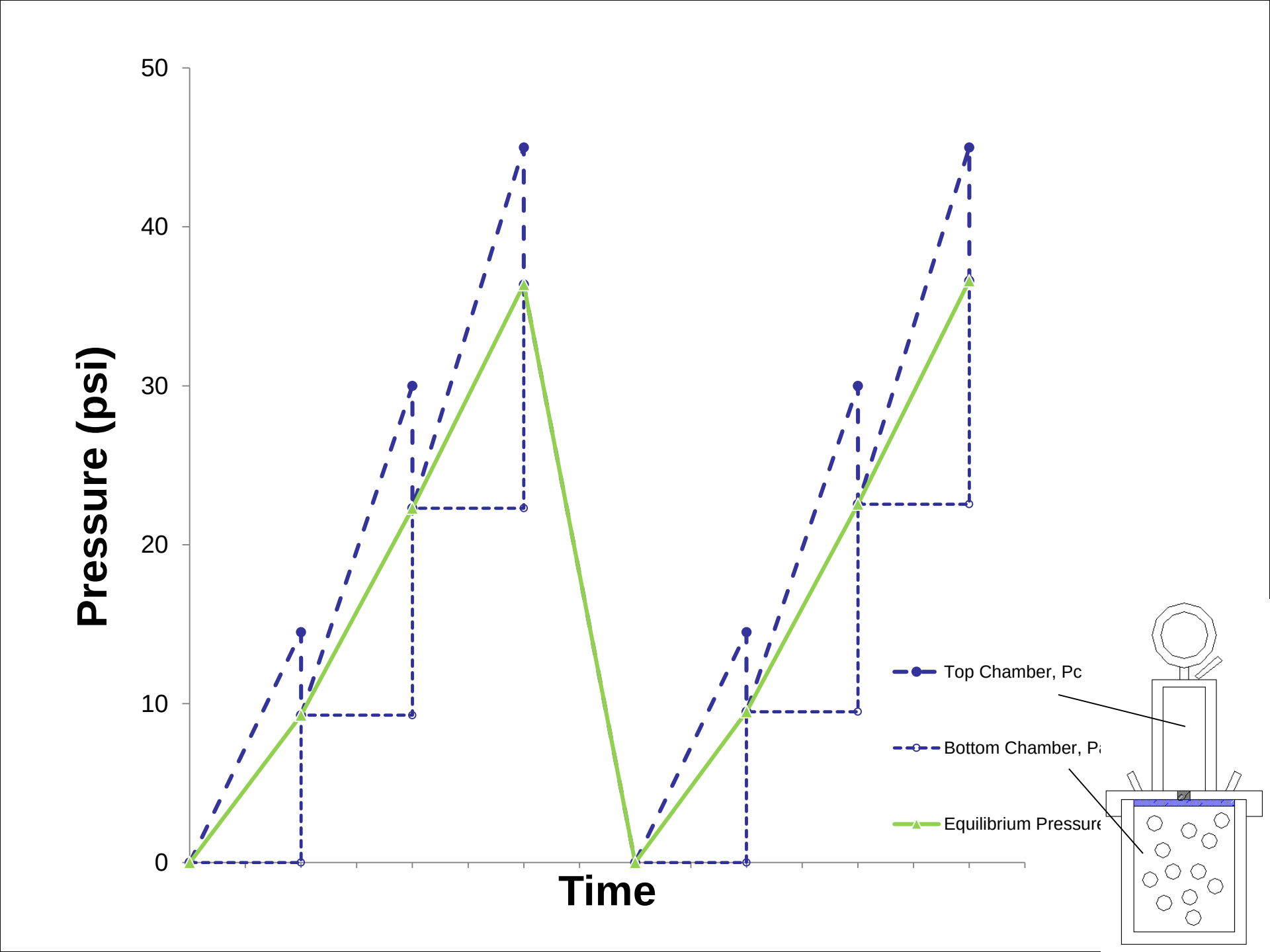

50
40
30
20
10
0
Pressure (psi)
Top Chamber
Bottom Chamber
Time
Top Chamber, Pc
Bottom Chamber, Pi
Equilibrium Pressure

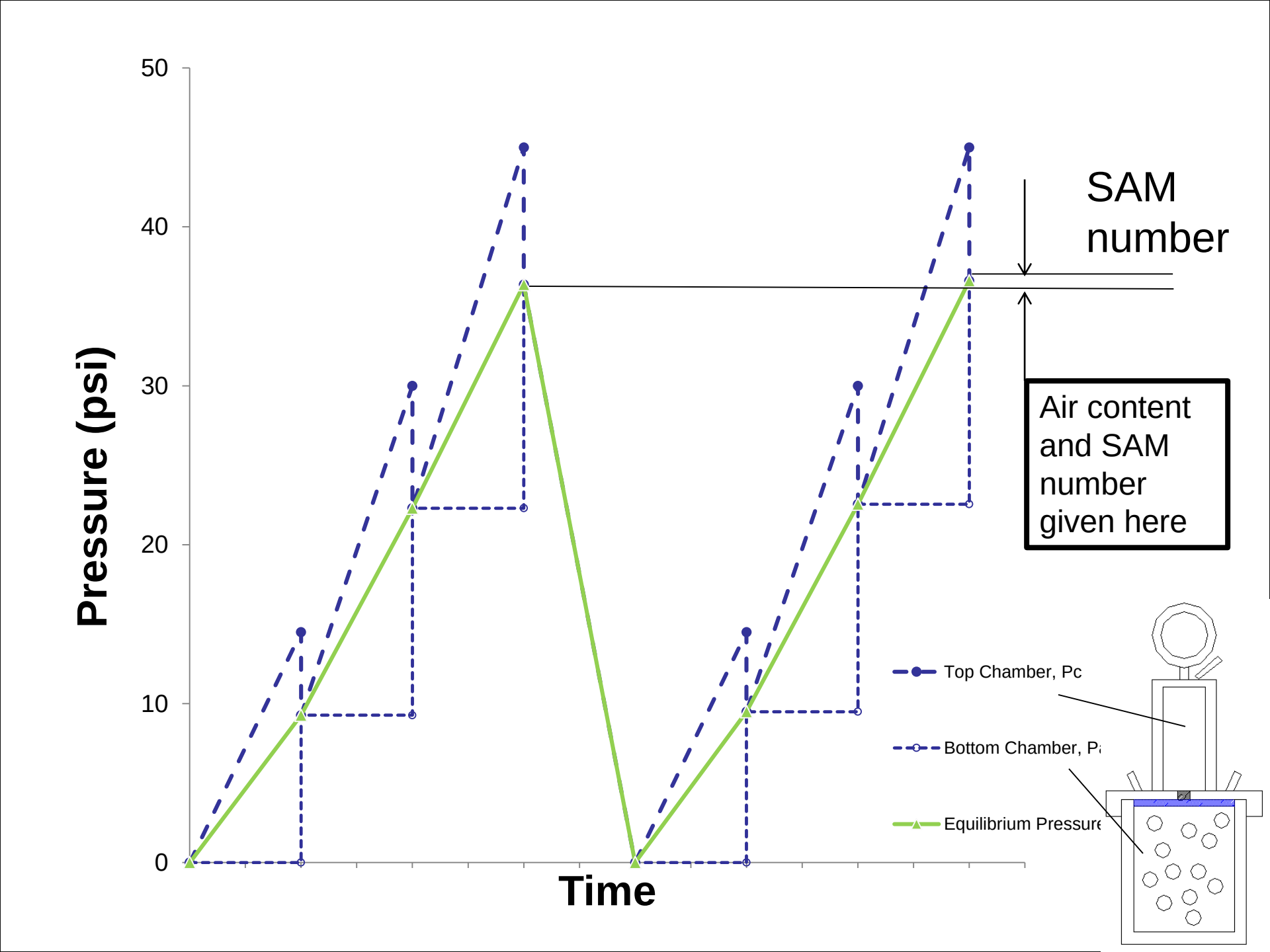

50
40
30
20
10
0
Pressure (psi)
Air content given here
Time
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure


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

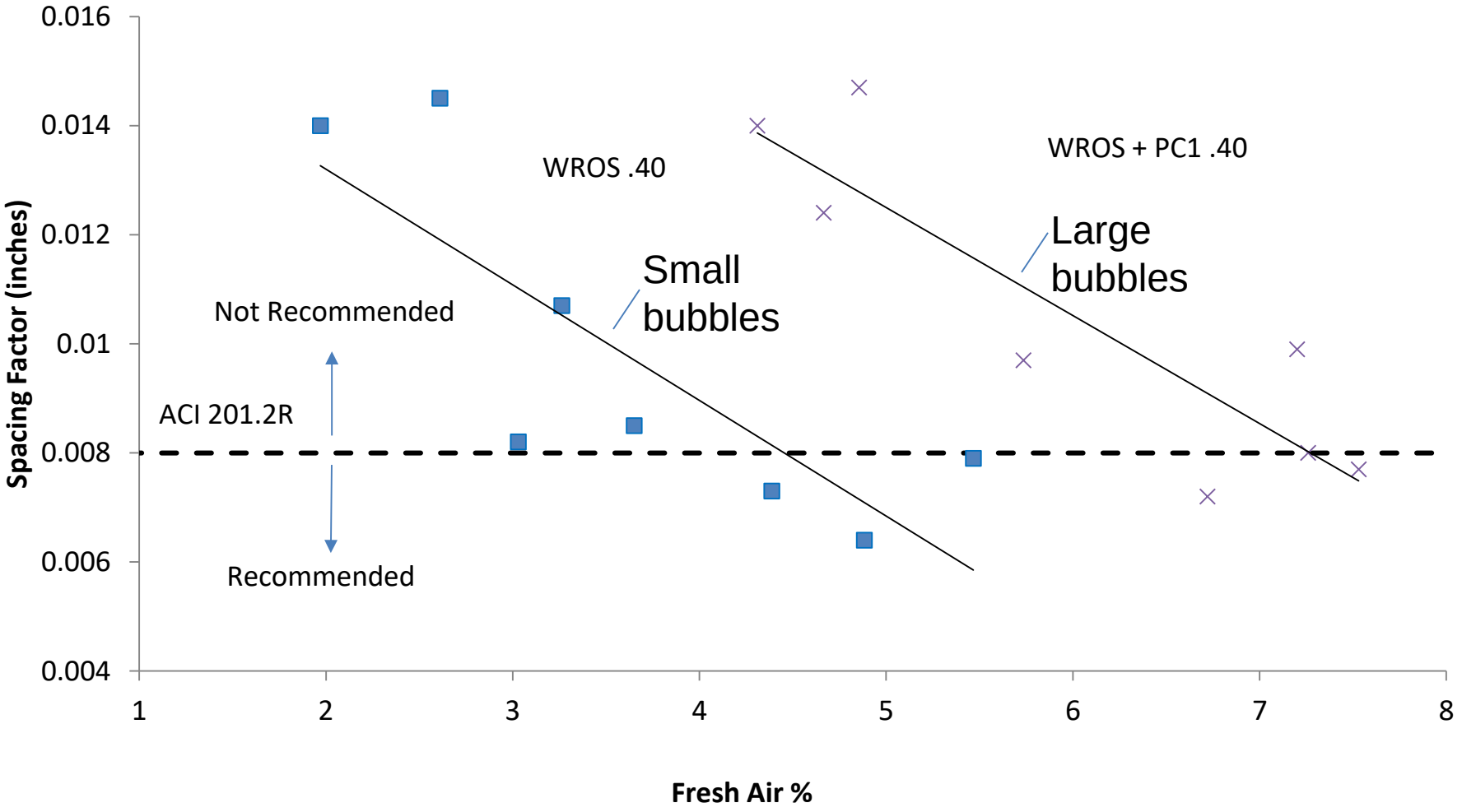

50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, Pi
Equilibrium Pressure


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

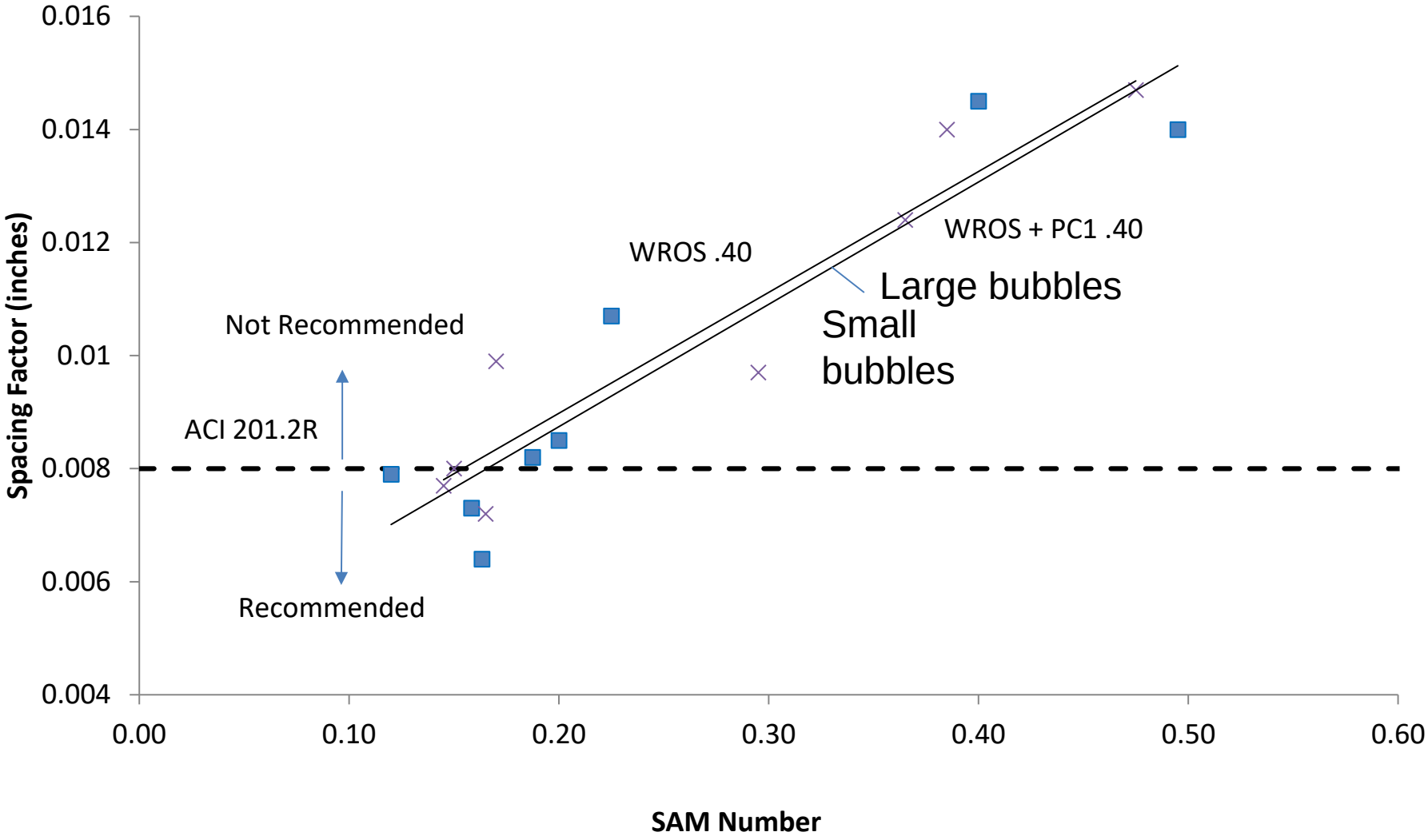

50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, Pi
Equilibrium Pressure


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

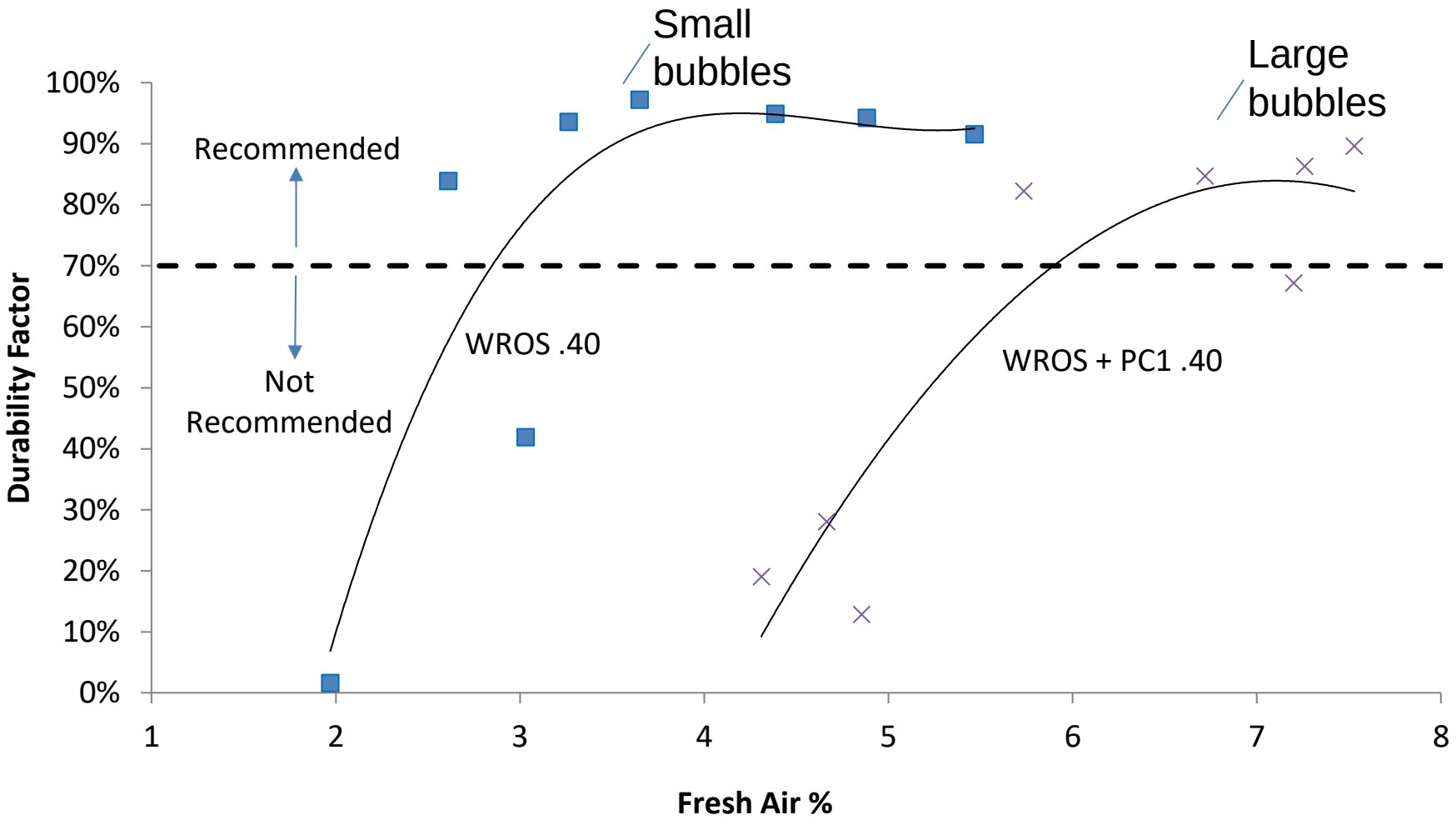
# Why is the SAM number useful?



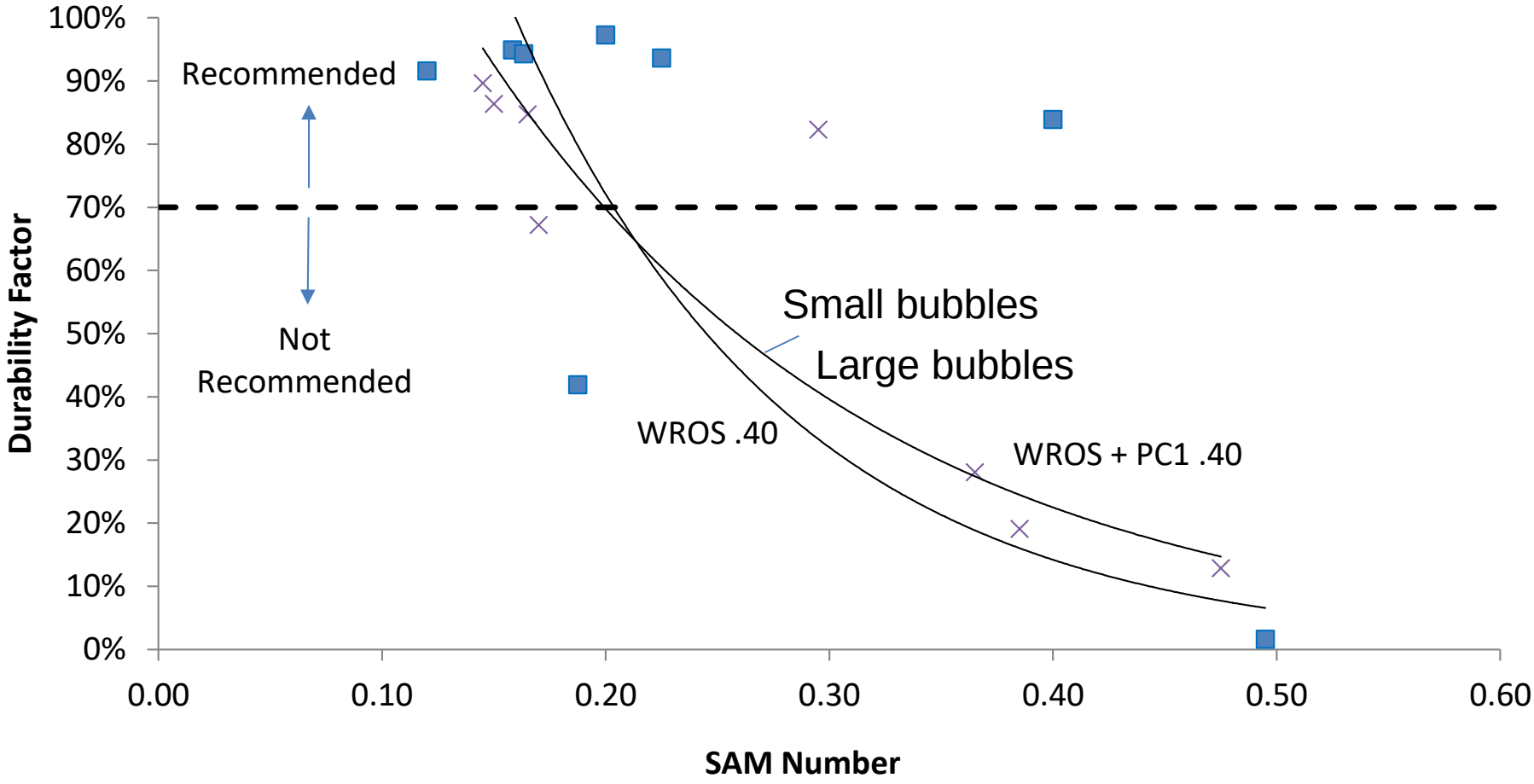

Ley et al., 2017



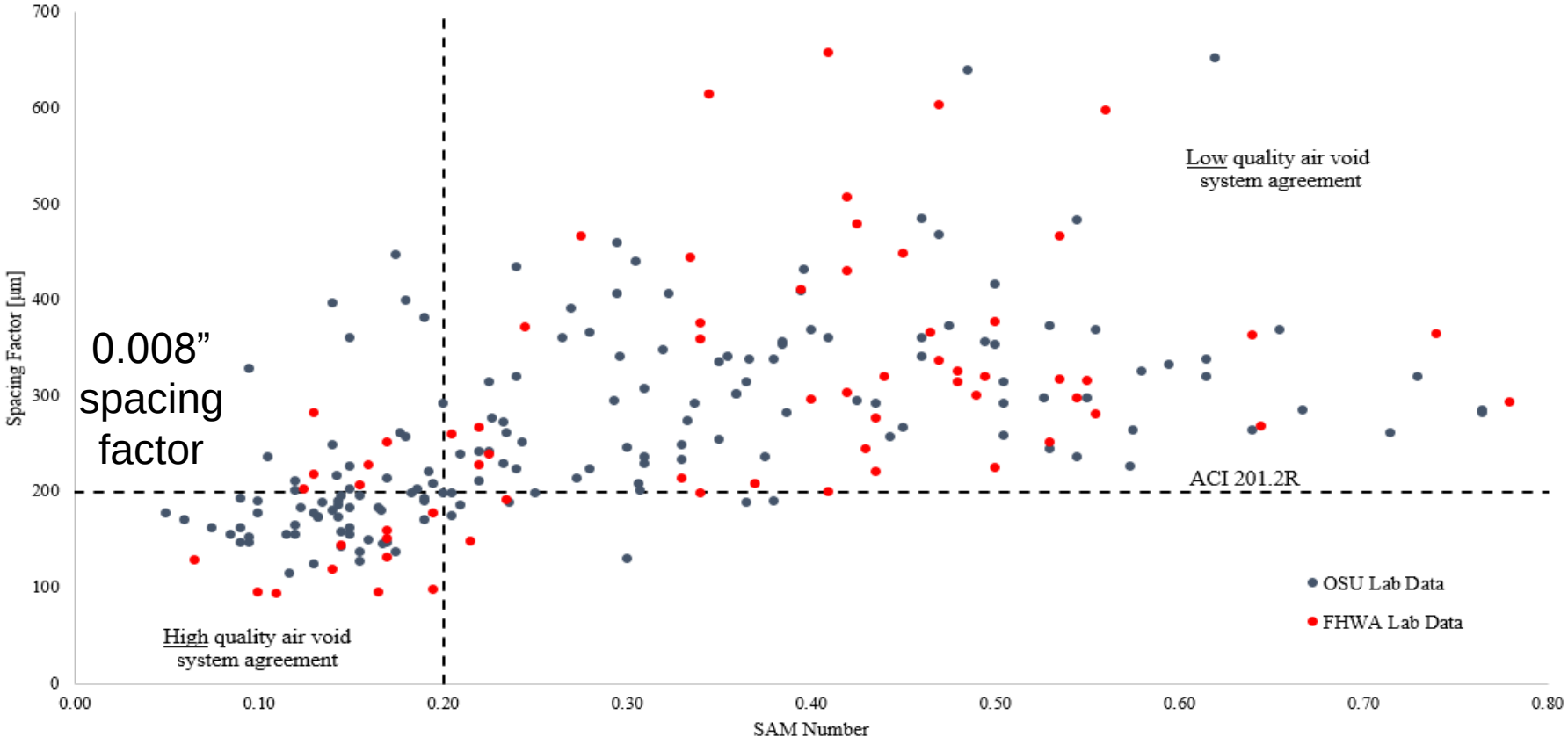

Ley et al., 2017




Ley et al., 2017

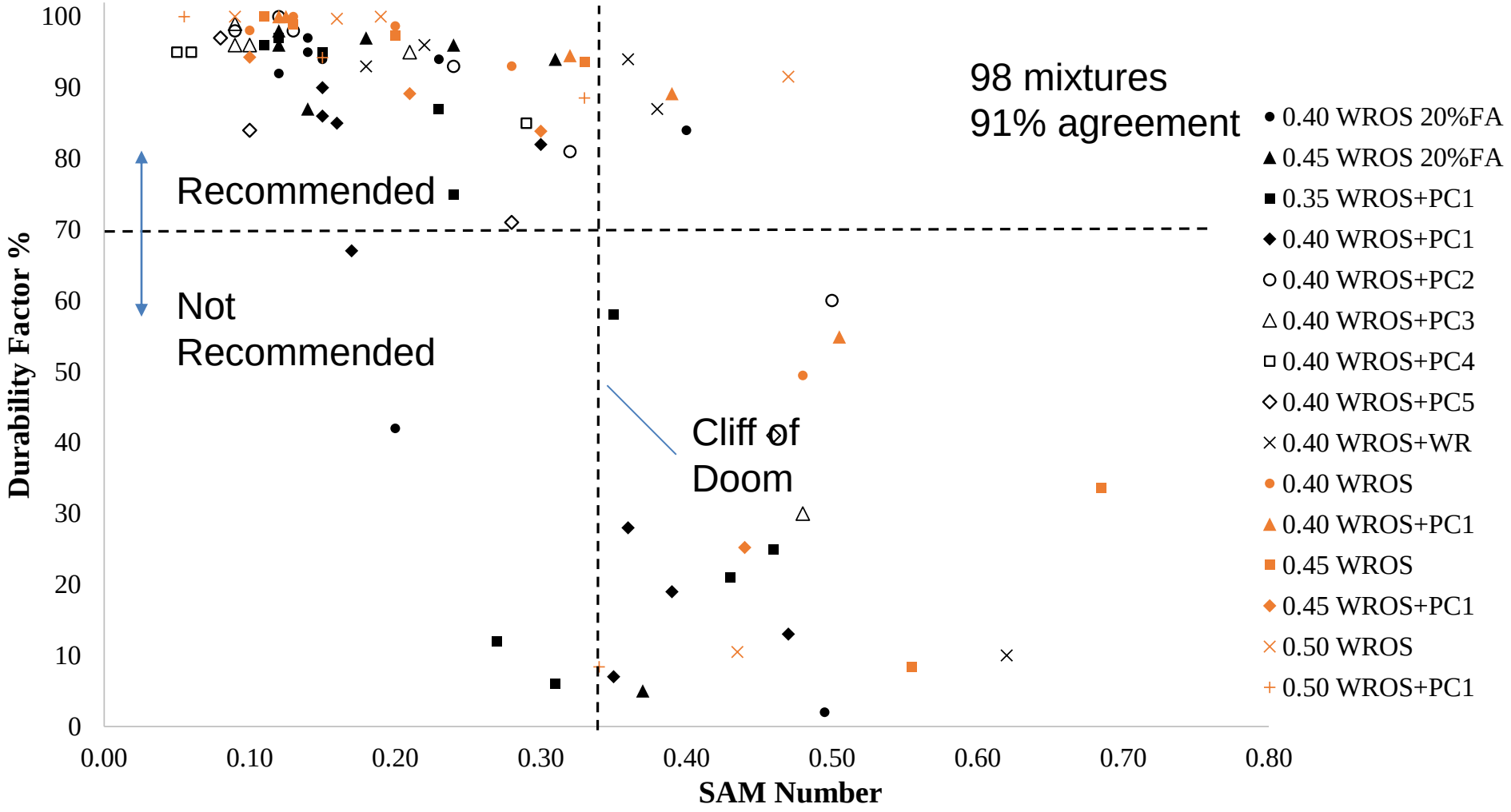



Ley et al., 2017




Over 227 lab mixtures from two different research groups
88% agreement

Ley et al., 2017


98 mixtures
91% agreement
Recommended
Not Recommended
Cliff of Doom
Durability Factor %
SAM Number
100
90
80
70
60
50
40
30
20
10
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.40 WROS 20%FA
0.45 WROS 20%FA
0.35 WROS+PC1
0.40 WROS+PC1
0.40 WROS+PC2
0.40 WROS+PC3
0.40 WROS+PC4
0.40 WROS+PC5
0.40 WROS+WR
0.40 WROS
0.40 WROS+PC1
0.45 WROS
0.45 WROS+PC1
0.50 WROS
0.50 WROS+PC1

# Discussion

The SAM Number does a better job correlating with spacing factor and freeze thaw performance than total air volume.

The test can be completed in fresh concrete!!!

# Sam Field Study

21 State DOTs + 1 Canadian Province helped analyze **231 concrete mixtures from 110 different projects**

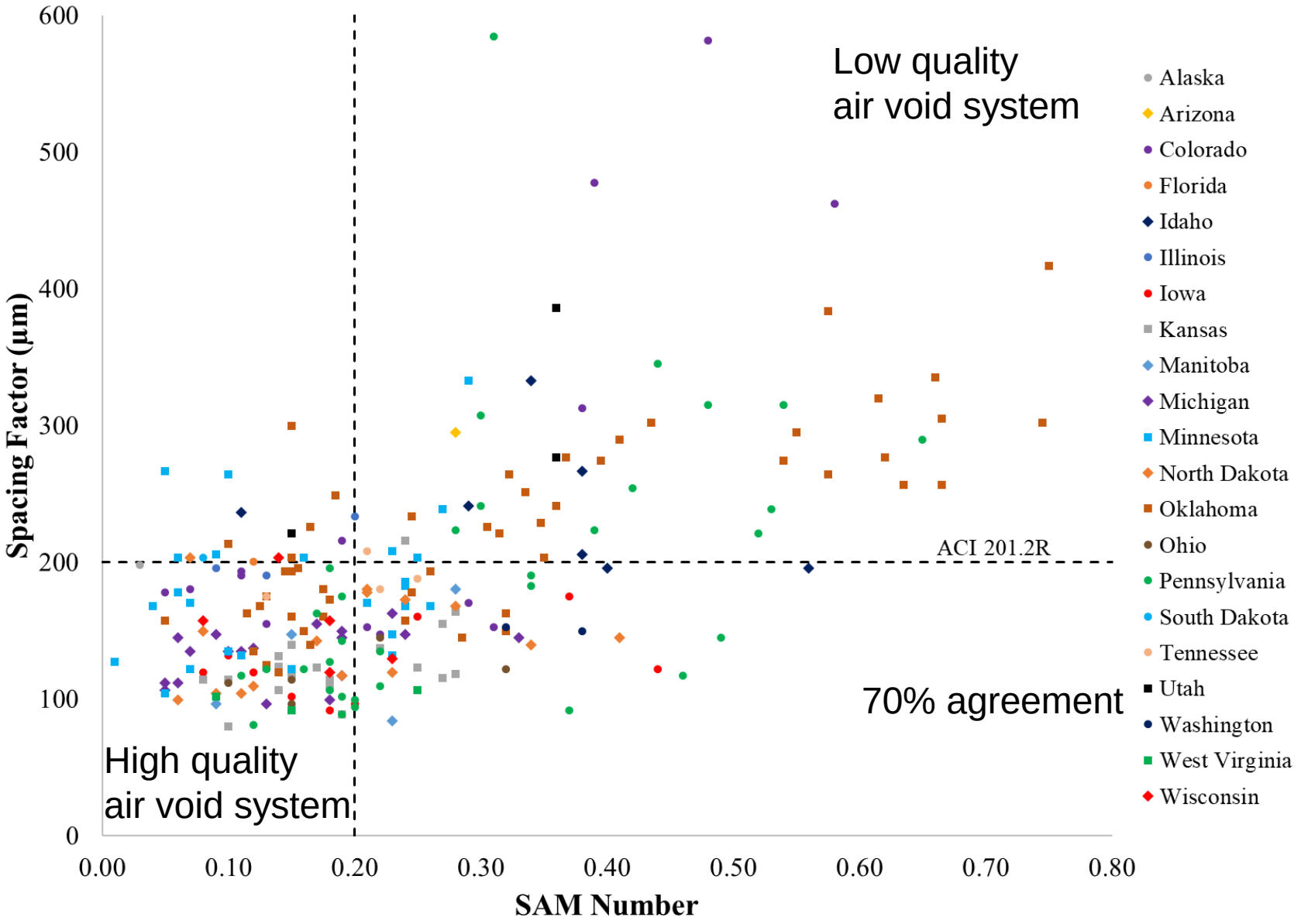
More than: 15 different SAMs and operators, 62 different aggregates, 19 cement sources, 20 different fly ashes , 39 different admixtures

60% pavements, 20% bridge decks, and 20% other

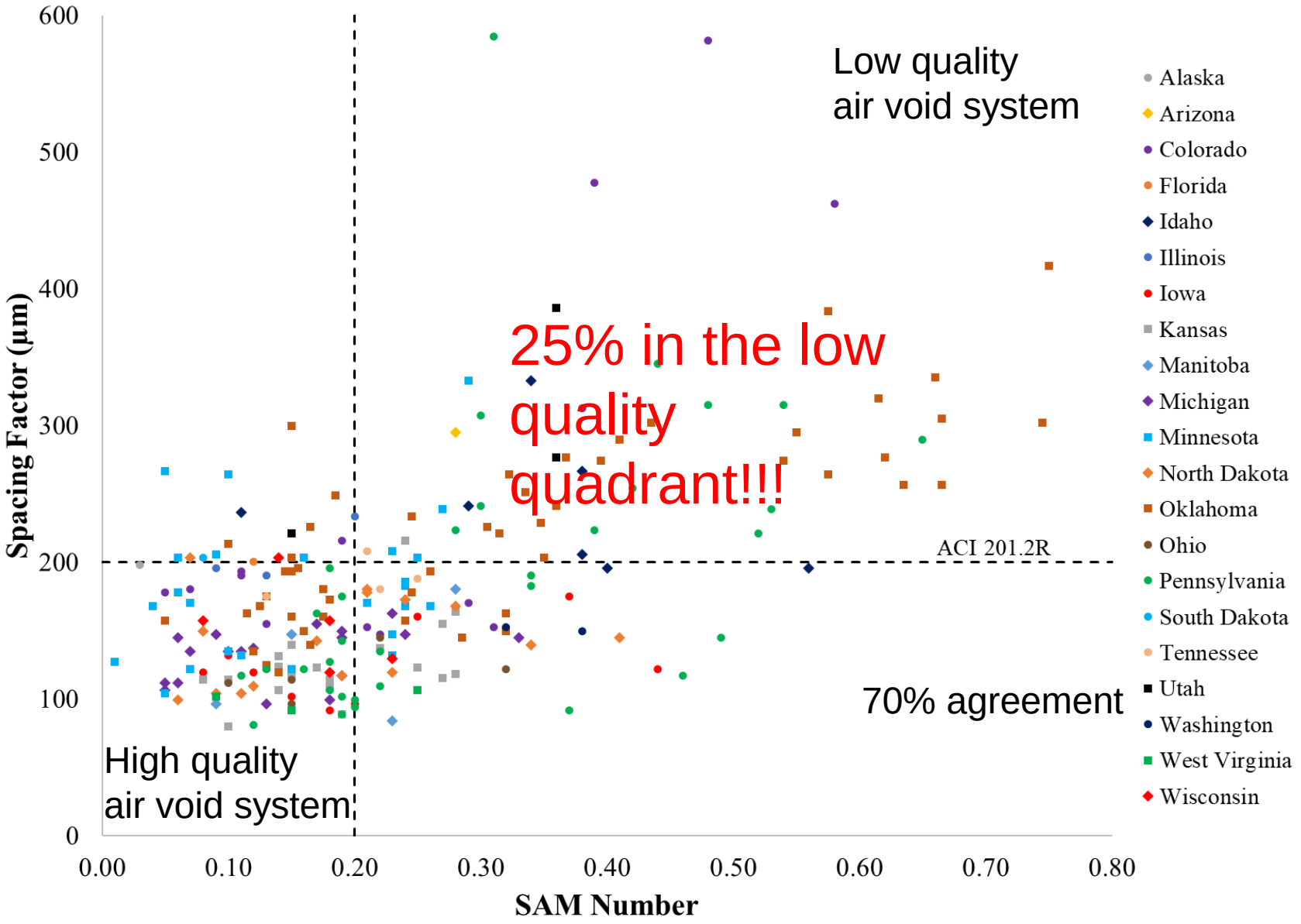
self-consolidating, precast, ready mix, and central mix concrete

Thank you to all that helped!

231 field mixes



231 field mixes



# Discussion

The SAM Number correlates to performance in rapid freeze thaw testing.

A SAM Number of 0.20 correlates to a spacing factor of 0.008” for 458 concrete mixtures completed by 22 different DOTs and two research groups.

- 88% agreement in lab
- 70% agreement in the field

# 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 help us design concrete mixtures that have more reliable and stable air void systems.
- It can better ensure freeze thaw durability.

# 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.

# Why is the w/cm important?

- This lowers your strength and increases your permeability.

- **We need a reliable <u>field test</u> to measure this.**

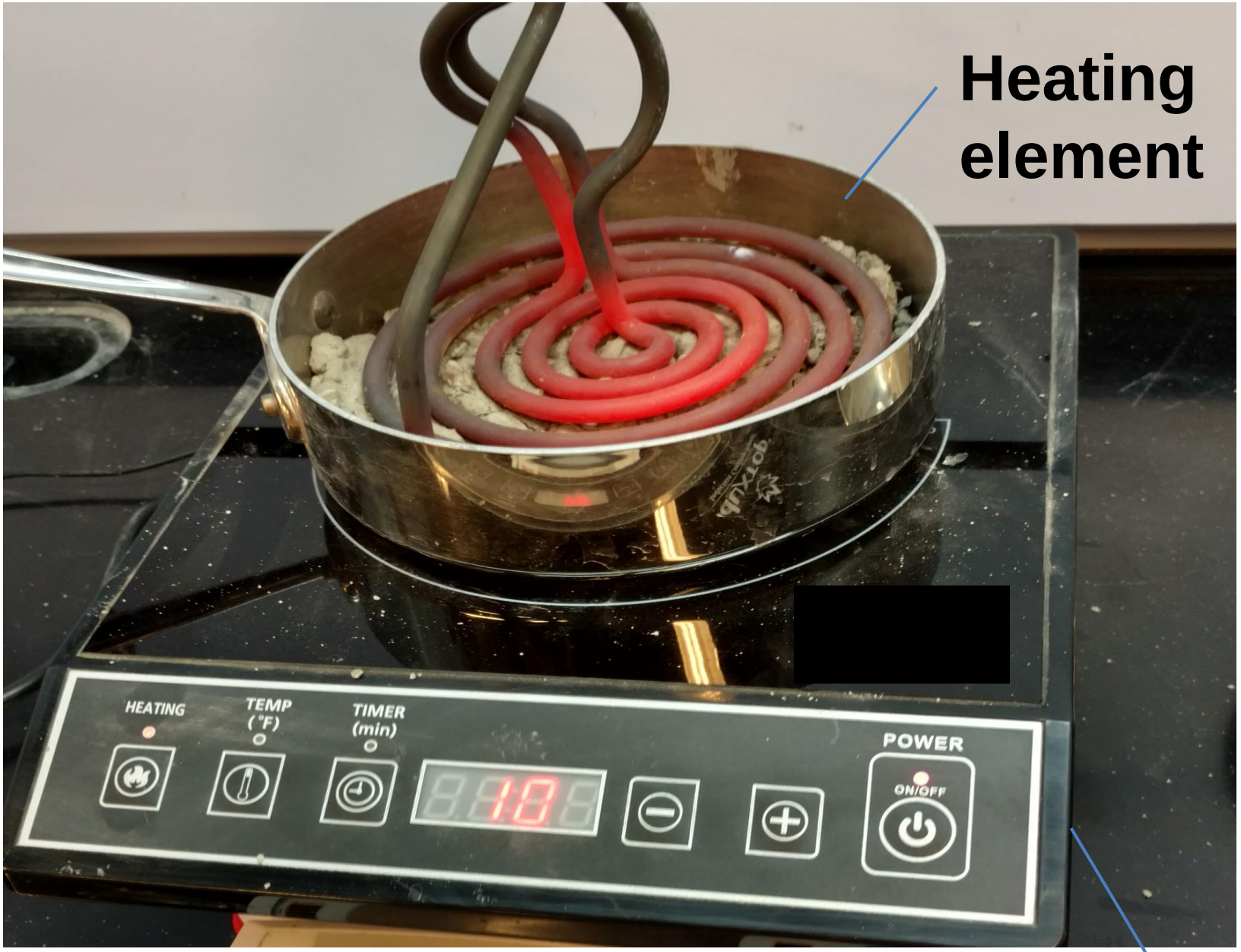
# We call this test “The Phoenix”!!!

# Steps

- Record batch ticket and aggregate properties
- Make and weigh 4x8 cylinder
- Dump cylinder into pan and weigh
- Start test
- Come back when finished
- Weigh pan


Moore: (405) 912-8370
Ardmore: (580) 223-6510
McAlester: (918) 423-46
Tulsa: (918) 660-7141
Denver: (303) 385-71
Weighing
Library
NET
4072.22
Edit Settings
Tare
OHAUS
EXPLORER

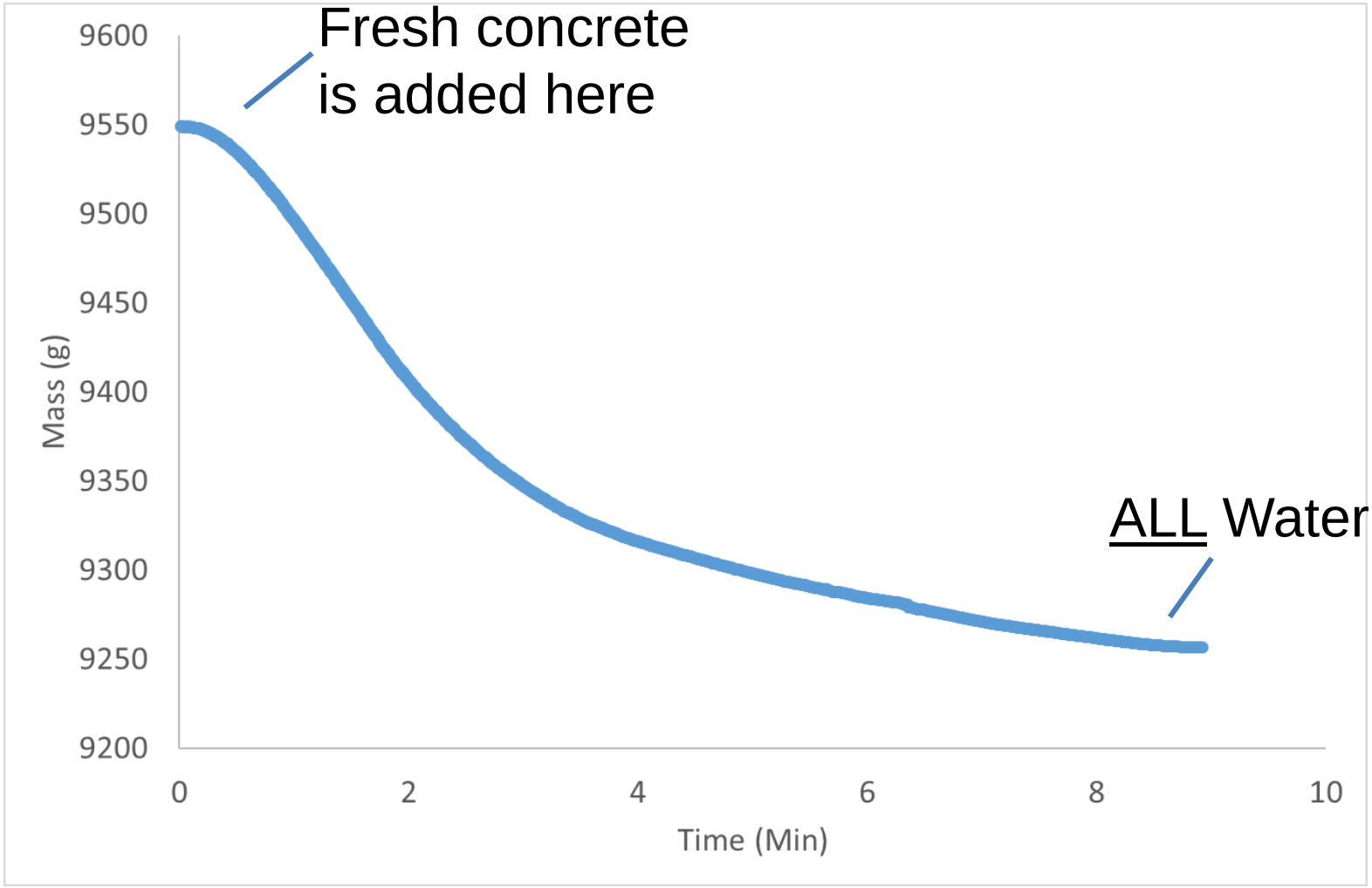

Weighing
Library
5484.73
Edit Settings
Tare
OHAUS
EXPLORER


Heating element
HEATING
TEMP (°F)
TIMER (min)
10
POWER
ON/OFF
Cooktop

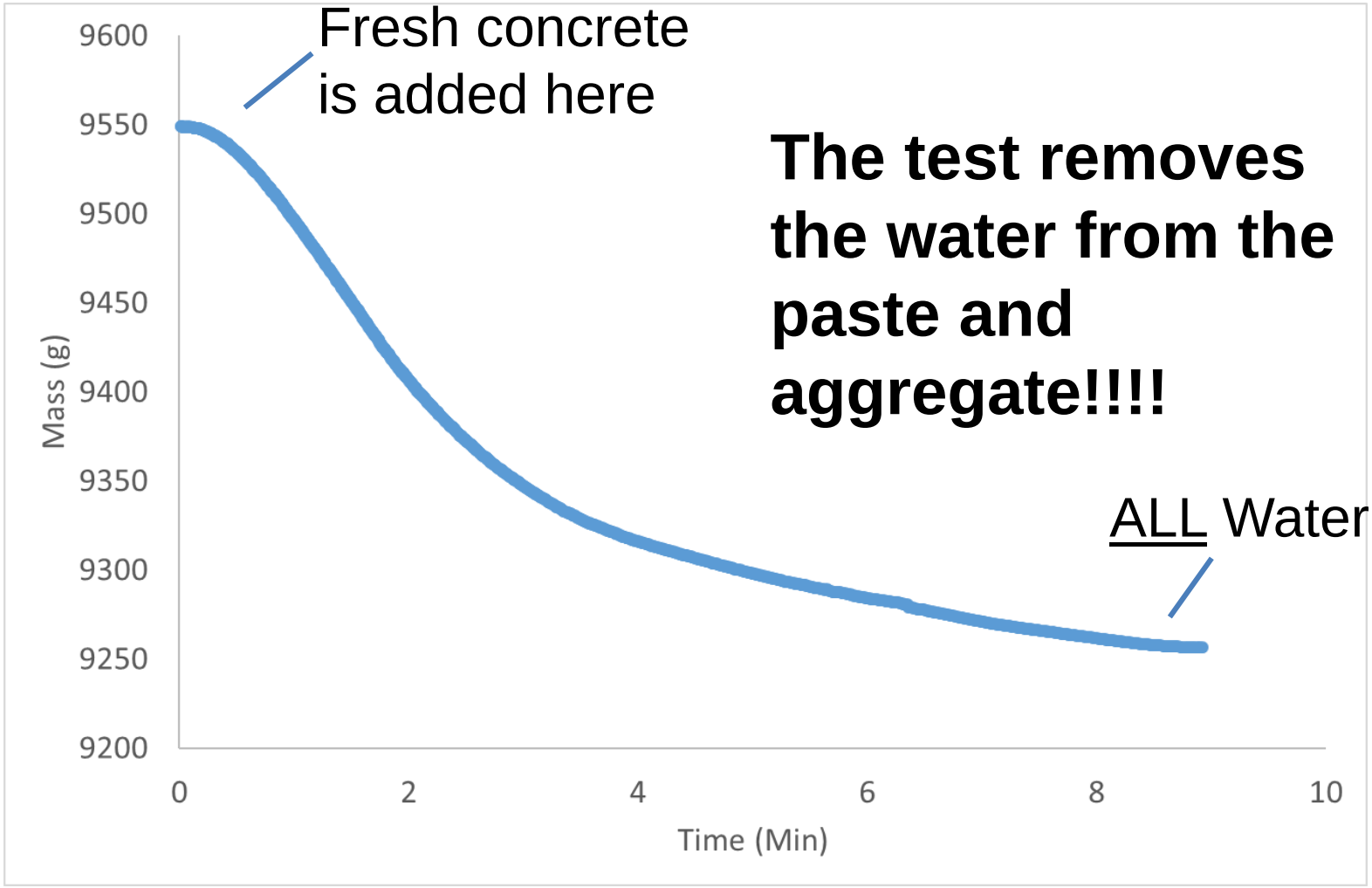
30 min test

# Dry concrete

# Change in mass over time



# Change in mass over time



# The Phoenix removes all the water!!!

- If we know the absorption capacity of the aggregate then we can remove this from the total water content and get the w/cm

- During mixing the moisture content of the aggregate will become SSD

# How do you get w/cm?

- The change in mass before and after cooking = amount of water in the cylinder

- Use the batch ticket information to find the amount of binder within the cylinder

# How do you get w/cm?

- Assume aggregate at SSD and remove the water in the aggregate from the total

- Make a correction based on the measured cylinder unit weight versus the unit weight from the batch ticket - this corrects for air

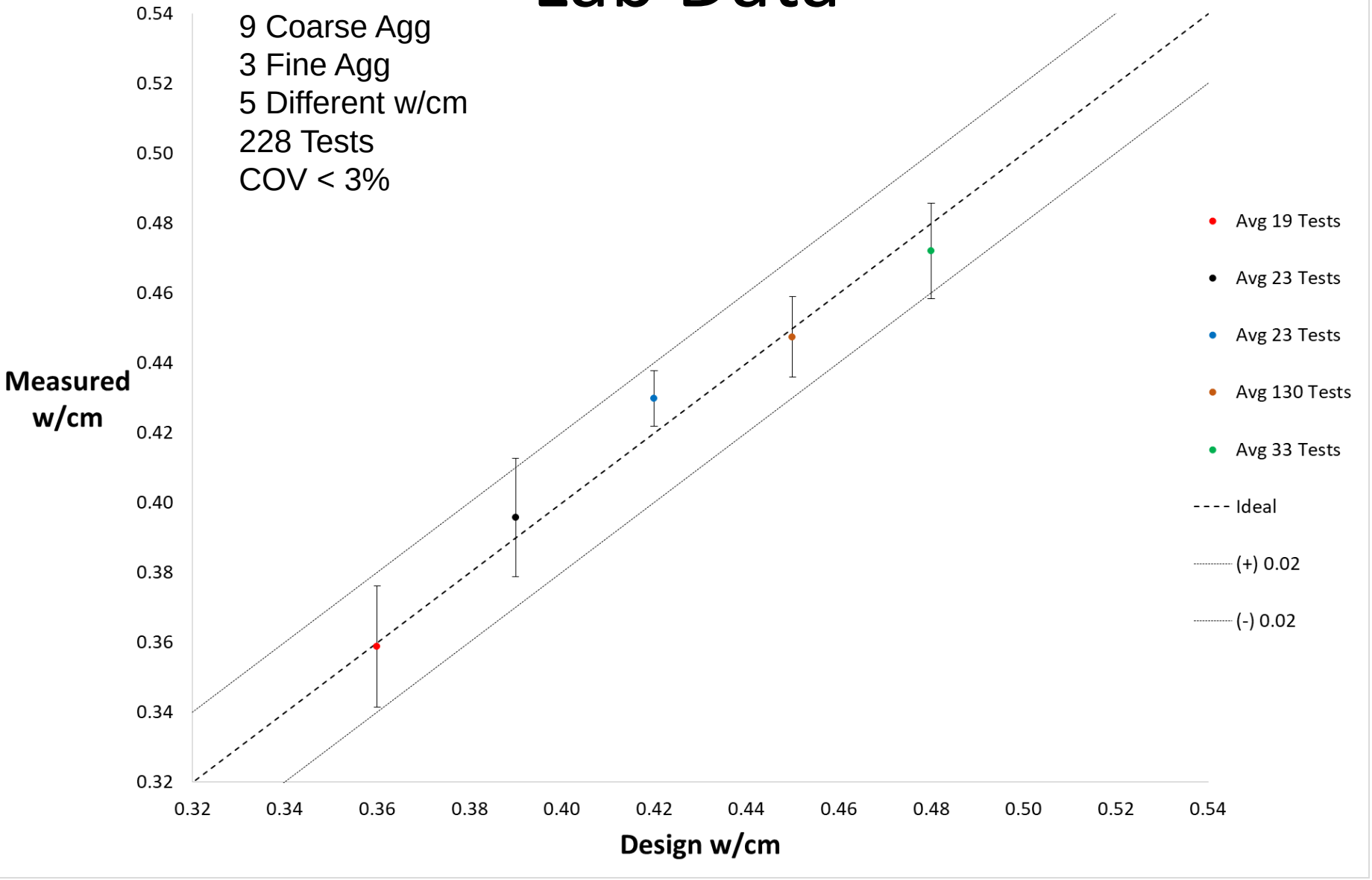
# How can we test in the lab?

- Make mixtures in the lab where we carefully control the moisture contents and batch weights.
- We should know the w/cm very accurately.
- Measure the w/cm with the Phoenix and compare.

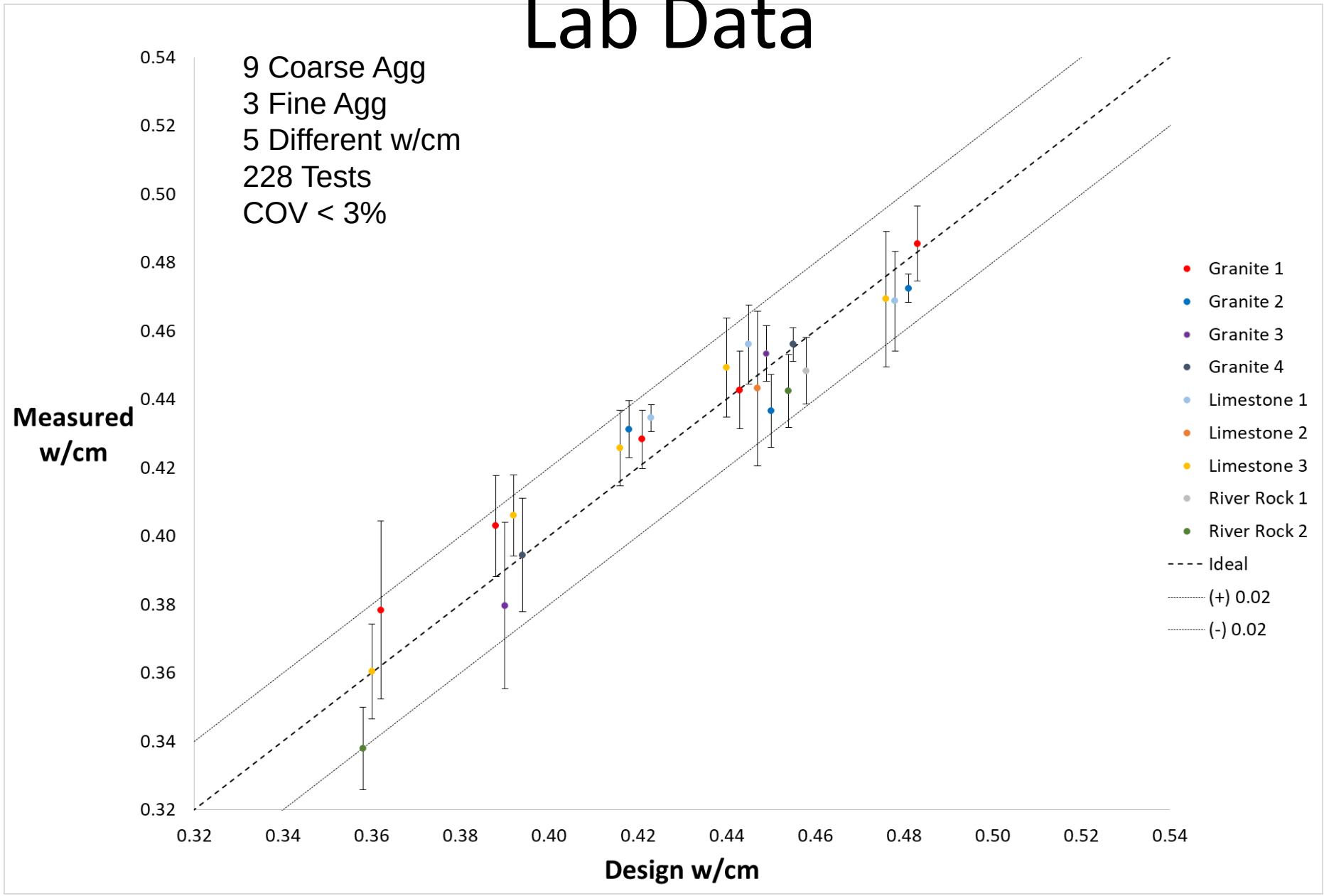
# Mix Information

- 9 Sources of Coarse Aggregate
  - Granites and Limestones
- 3 Sources of Fine Aggregate
  - Natural sands and Manufactured sand
- Specific Gravities: 2.42-2.75
- Absorptions (%): 0.46-4.69
- Five different w/cm
- Different paste contents

# Lab Data


9 Coarse Agg
3 Fine Agg
5 Different w/cm
228 Tests
COV < 3%
Measured w/cm
Design w/cm
0.32
0.34
0.36
0.38
0.40
0.42
0.44
0.46
0.48
0.50
0.52
0.54
Avg 19 Tests
Avg 23 Tests
Avg 23 Tests
Avg 130 Tests
Avg 33 Tests
Ideal
(+) 0.02
(-) 0.02

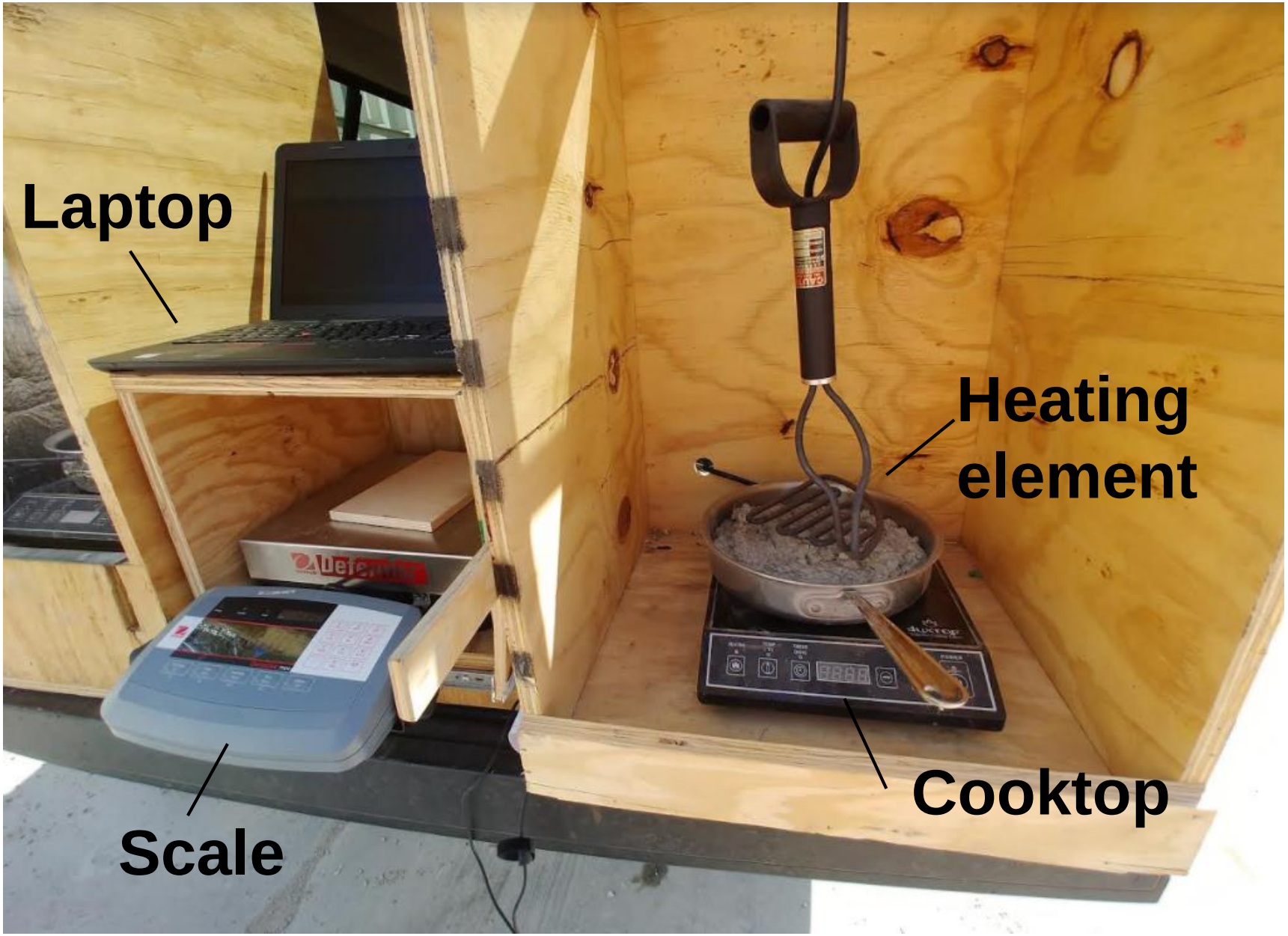
# Lab Data


9 Coarse Agg
3 Fine Agg
5 Different w/cm
228 Tests
COV < 3%
Measured w/cm
Design w/cm
0.32
0.34
0.36
0.38
0.40
0.42
0.44
0.46
0.48
0.50
0.52
0.54
Granite 1
Granite 2
Granite 3
Granite 4
Limestone 1
Limestone 2
Limestone 3
River Rock 1
River Rock 2
Ideal
(+) 0.02
(-) 0.02

# Discussion

- All lab mixes are within +/- 0.02 w/cm with most of them within +/- 0.01 w/cm.
- The COV is < 3%!!!
- What about the field?

# Field Unit

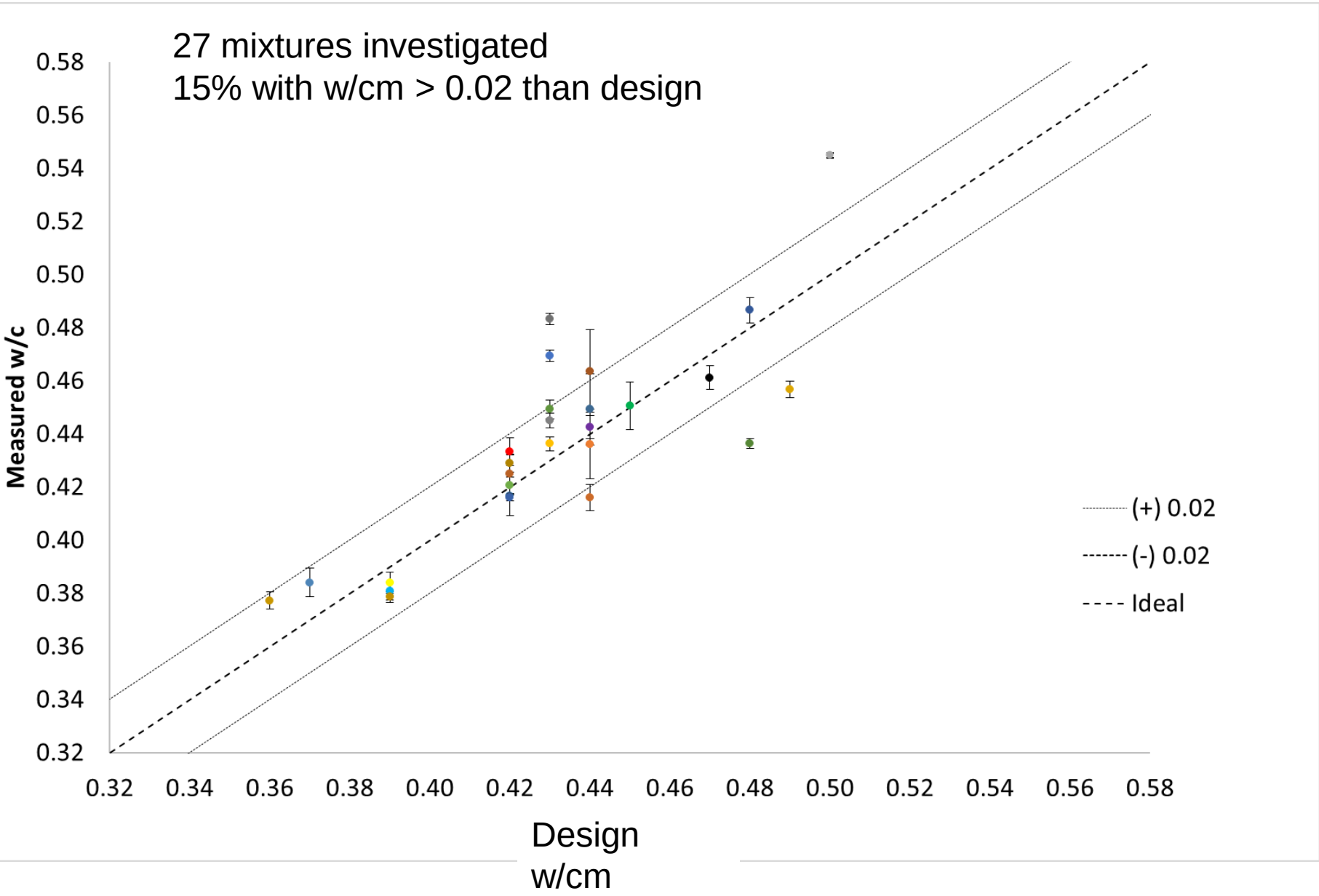


# Field Unit

# How can we test in the field?

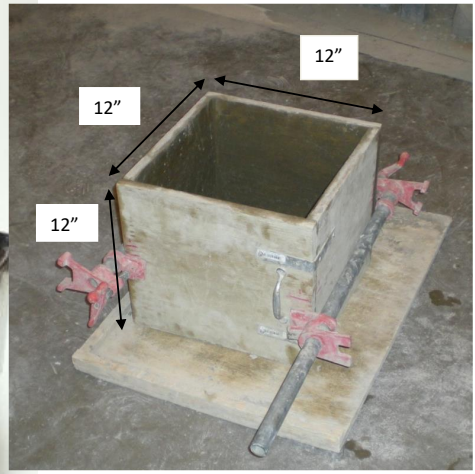
- Use the batch ticket information to determine design w/cm
- Measure w/cm with the Phoenix
- All testing was done at the batch plant
- Four different projects 27 different mixtures
- Paving, bridge decks, substructure

# Field Data


27 mixtures investigated
15% with w/cm > 0.02 than design
Measured w/c
0.58
0.56
0.54
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.32
0.34
0.36
0.38
0.40
0.42
0.44
0.46
0.48
0.50
0.52
0.54
0.56
0.58
Design w/cm
(+) 0.02
(-) 0.02
Ideal

# Discussion

- The Phoenix data looks promising
- 15% of mixtures had a w/cm > 0.02 than what was reported on the batch ticket.
- **We are sampling at the batch plant and everyone knows that we are watching.**


12”
12”
12”

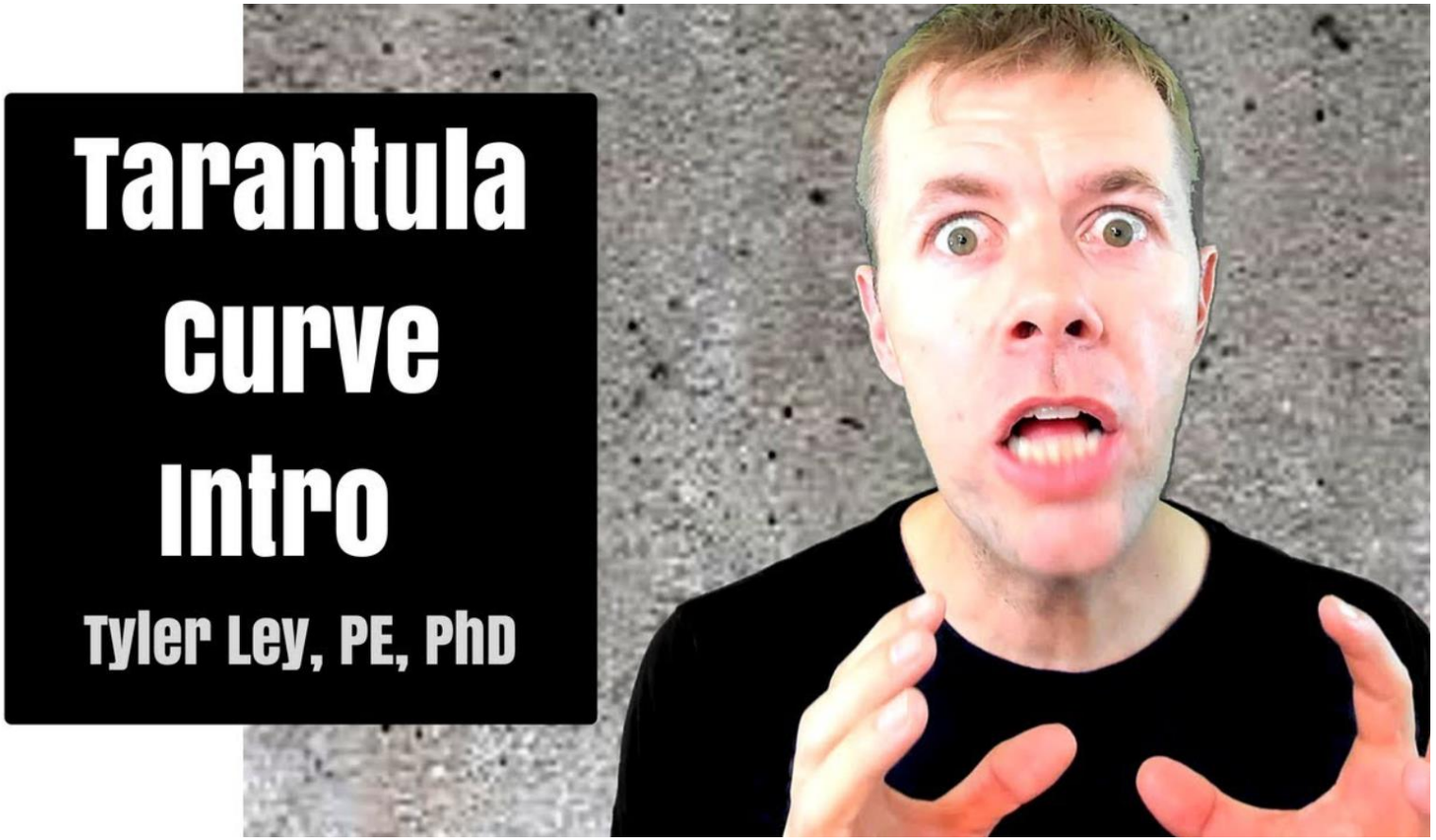
# How can this group help?

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

# Conclusion

- The Box Test is designed to measure the window of workability required for concrete pavements
- The SAM can measure the volume and size distribution of the bubbles in fresh concrete and ensure freeze thaw durability
- The Phoenix can accurately measure the w/cm in fresh concrete in both the lab and the field.

www.youtube.com/tylerley



# Questions???

www.tylerley.com

www.youtube.com/tylerley

| Aggregate Type | Size | SpG | Abs (%) | State |
|---|---|---|---|---|
| Granite 1 | Coarse | 2.75 | 0.46 | OK |
| Granite 2 | Coarse | 2.75 | 0.51 | GA |
| Granite 3 | Coarse | 2.59 | 1.06 | MN |
| Granite 4 | Coarse | 2.66 | 0.66 | MN |
| Limestone 1 | Coarse | 2.42 | 4.69 | IA |
| Limestone 2 | Coarse | 2.67 | 0.70 | OK |
| Limestone 3 | Coarse | 2.67 | 0.64 | OK |
| River Rock 1 | Coarse | 2.67 | 1.52 | MN |
| River Rock 2 | Coarse | 2.68 | 0.81 | MN |
| Natural Sand 1 | Fine | 2.62 | 0.64 | OK |
| Natural Sand 2 | Fine | 2.61 | 0.20 | OK |
| Man Sand | Fine | 2.76 | 1.05 | OK |

# States that have plans to shadow specify the SAM

- Michigan
- Minnesota
- Idaho
- Oklahoma
- Colorado
- Wisconsin
- New York
- Kansas

# 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**

# **C**ontrolled **A**ir **P**ressure **E**xtender aka **CAPE**

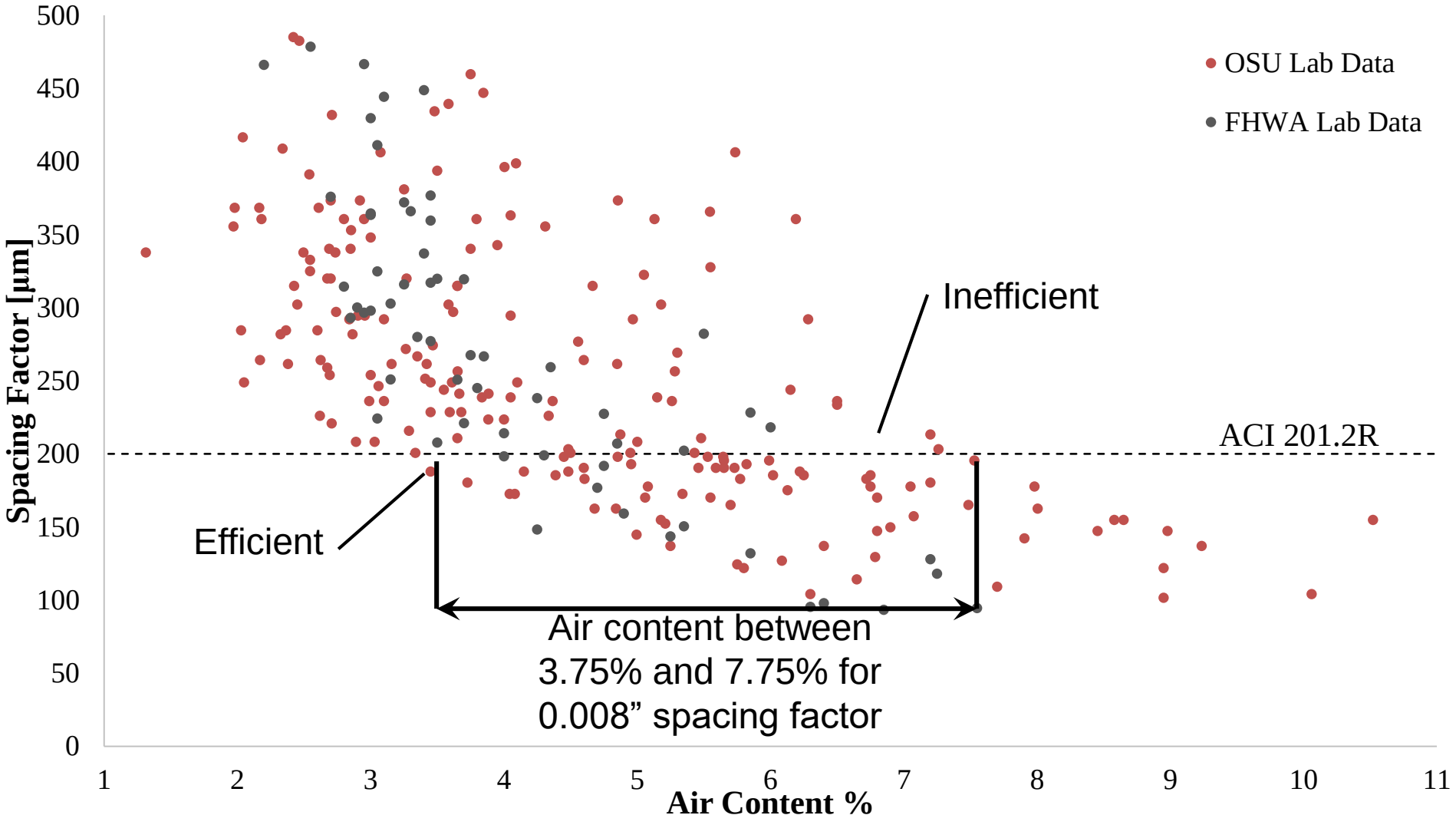

Compressed air

Step 3 (45 psi)

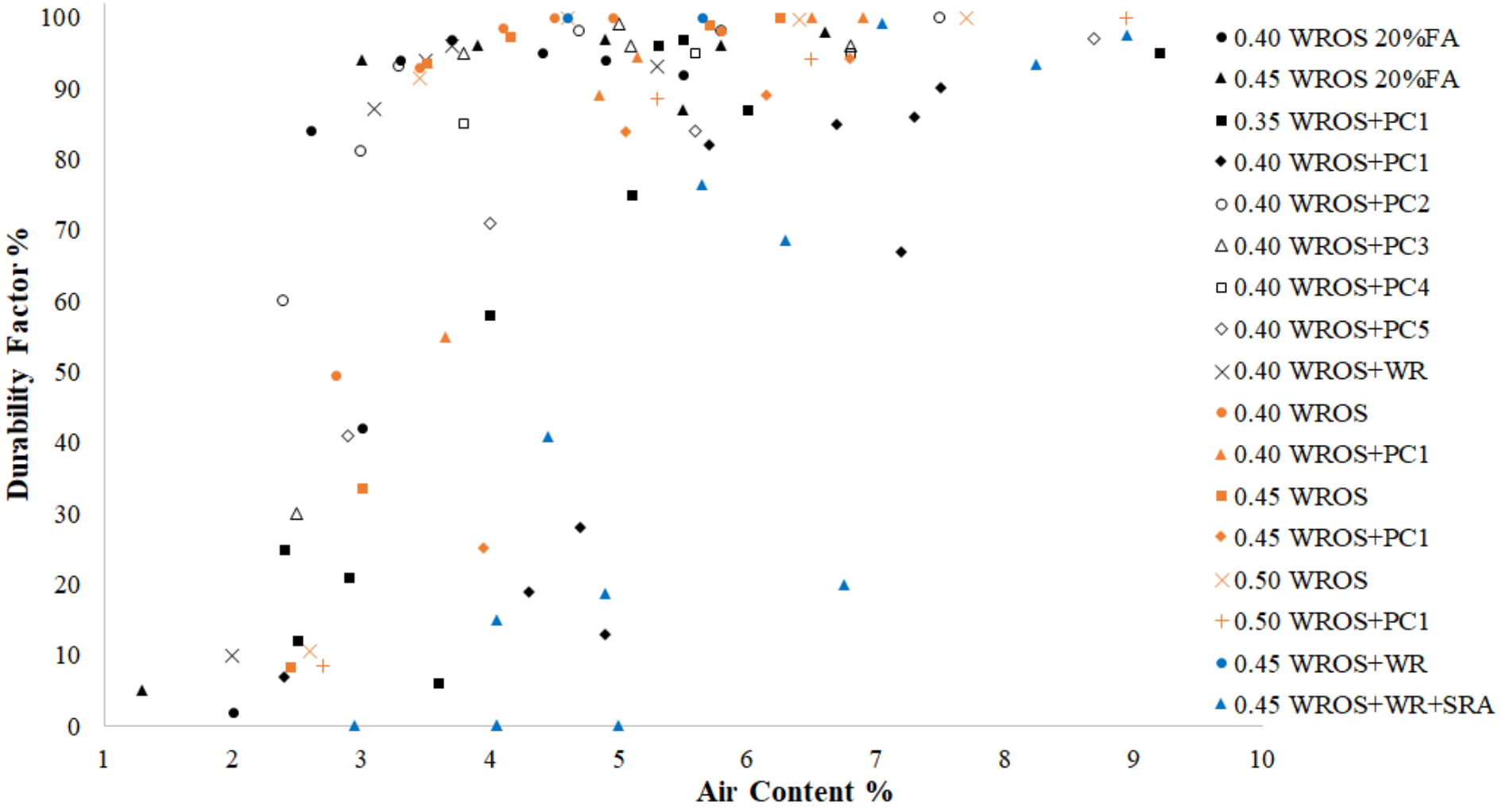
Step 2 (30 psi)

Step 1 (14.5 psi)

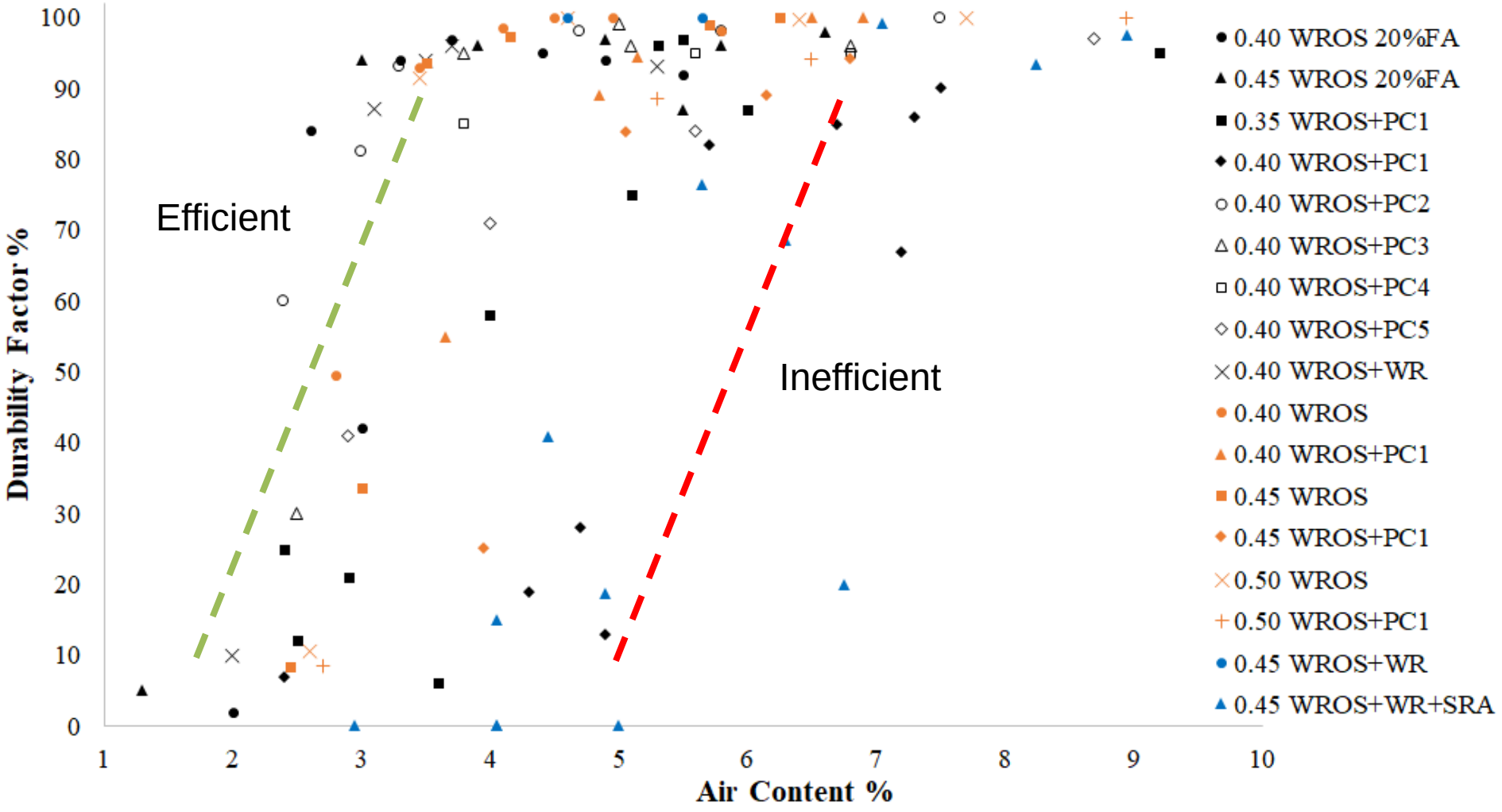
# What air content do you use?

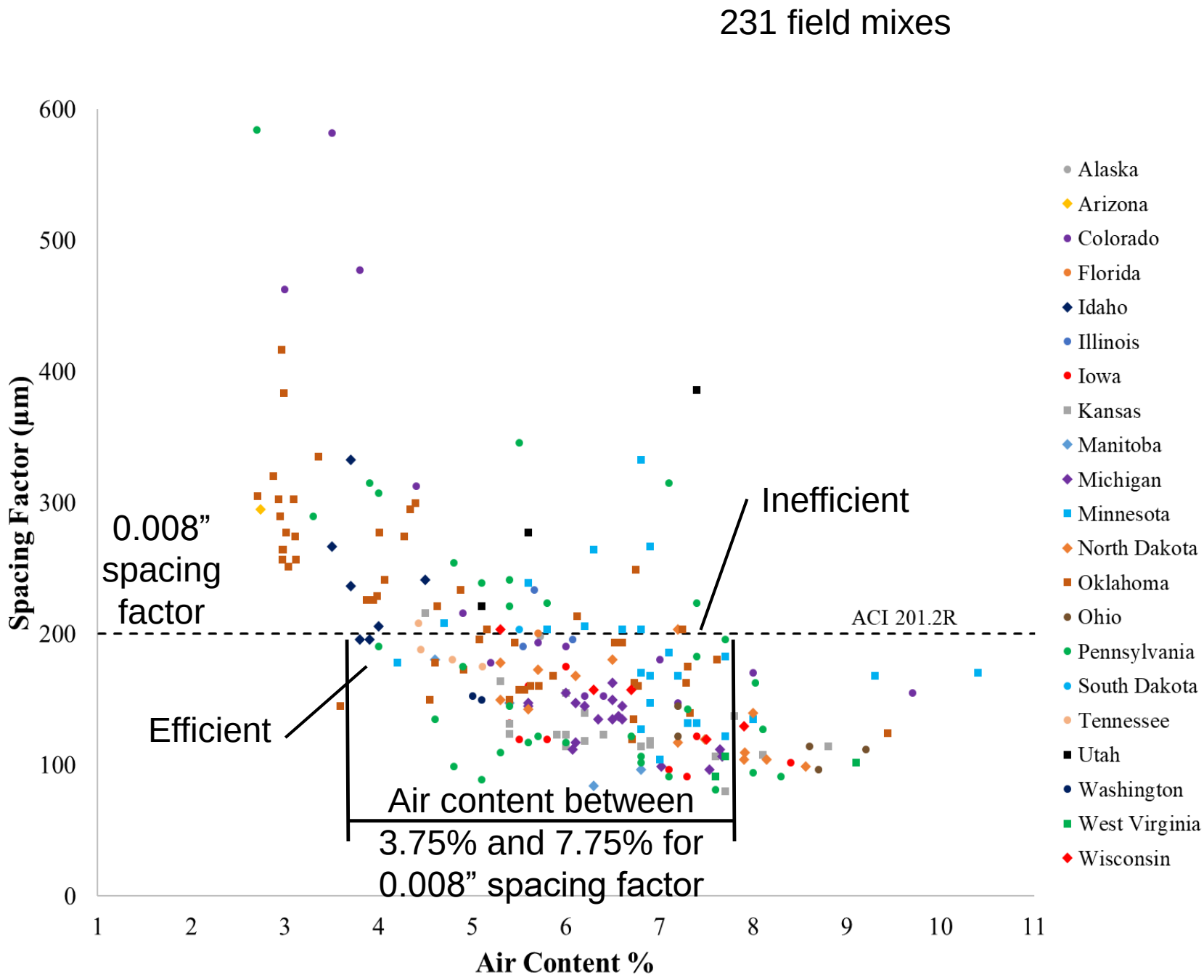


# What air content do you use?



# What air content do you use?




231 field mixes
Spacing Factor (µm)
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
Air Content %
0.008” spacing factor
Inefficient
ACI 201.2R
Efficient
Air content between 3.75% and 7.75% for 0.008” spacing factor
Alaska
Arizona
Colorado
Florida
Idaho
Illinois
Iowa
Kansas
Manitoba
Michigan
Minnesota
North Dakota
Oklahoma
Ohio
Pennsylvania
South Dakota
Tennessee
Utah
Washington
West Virginia
Wisconsin

# How variable is the test?

| 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 0.04

[2]From ASTM C457

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

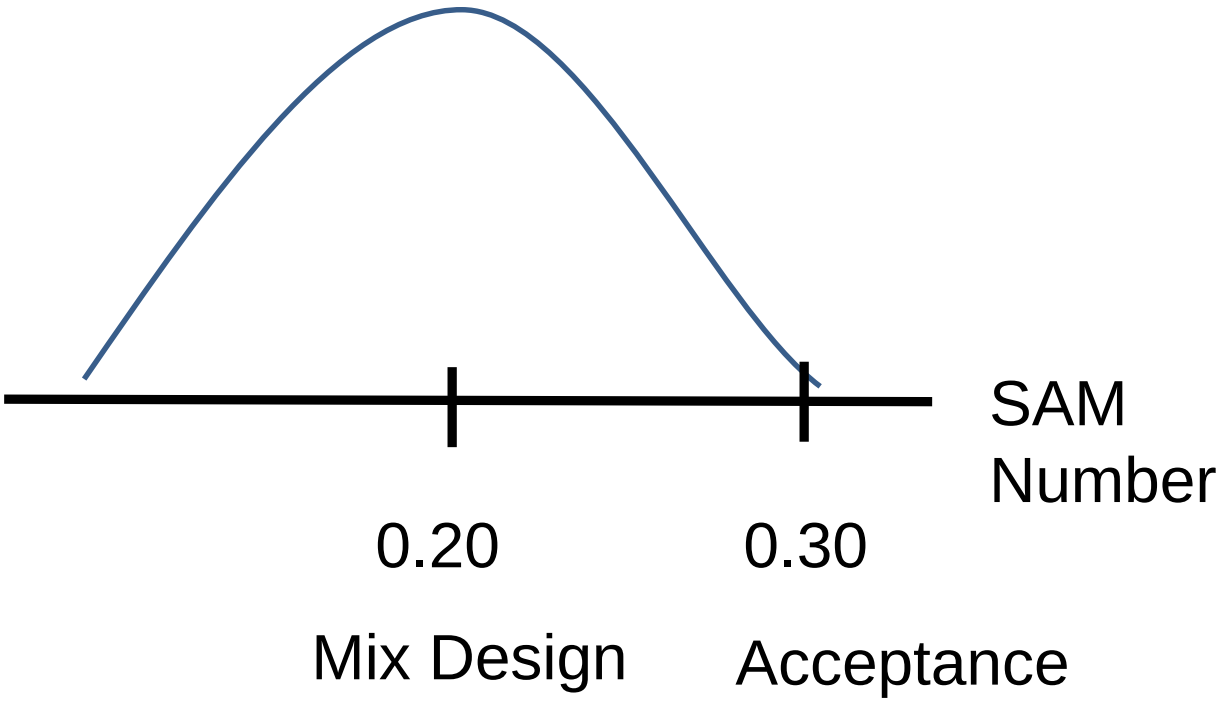
170 SAM comparisons were used to determine this.

# Why are they different?

If the producer designs the SAM Number to be 0.20 at their working air content then they will have < 2% chance of getting a failing test in the field.

The rejection limit is determined by freeze thaw testing (ASTM C 666).

# Why are they different?



# AASHTO PP84-19 Specification

Mixture Design

SAM < 0.20 and Air > 4%

Field

SAM < 0.30 and Air > 4%