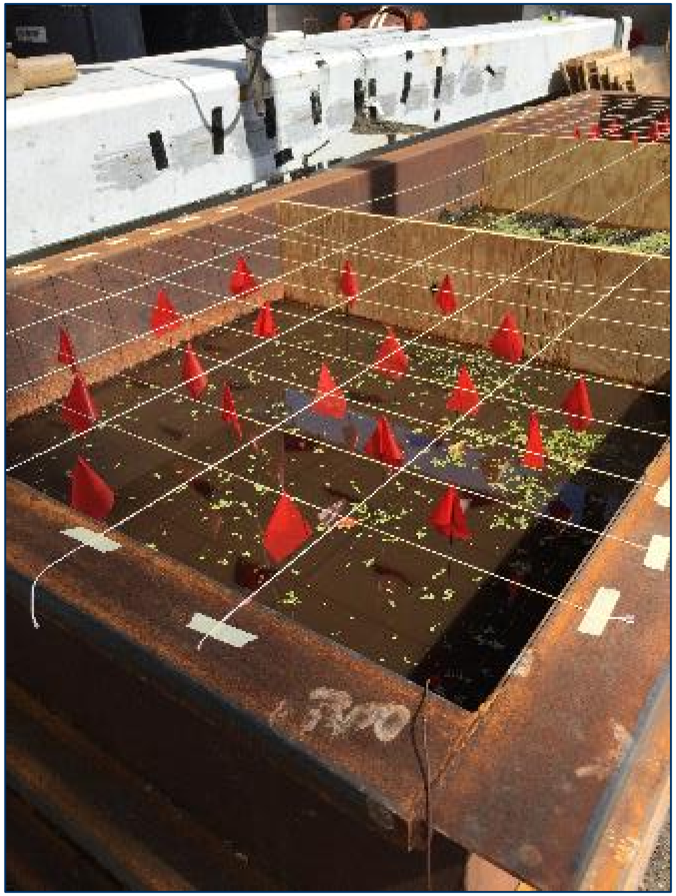
Soil Mixing Design Methods and Construction Techniques for Use in High Organic Soils

GRIP 2015
Gray Mullins, Ph.D., P.E.

UNIVERSITY OF SOUTH FLORIDA
Civil & Environmental Engineering

Overview

- Introduction / Problem
- Background, Soil Mixing
- Small Scale Lab Testing
- Design Recommendations
- Large Scale Lab Testing
- Conclusions



Problem: What to do with soft soils

The FDOT Soils and Foundations handbook:

- 1. Reduce fill height
- 2. Provide waiting period to allow for the majority of consolidation to occur
- 3. Increase surcharge height
- 4. Use a lightweight fill
- 5. Install wick drains within the compressible material to be surcharged
- 6. Excavate soft compressible material and backfill with granular soil
- 7. Ground modification such as stone columns, dynamic compaction, etc
- 8. Deep soil mixing
- 9. Combinations of some of the above

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- **8. DEEP SOIL MIXING**
- 9. Combinations of some of the above

Soil Mixing

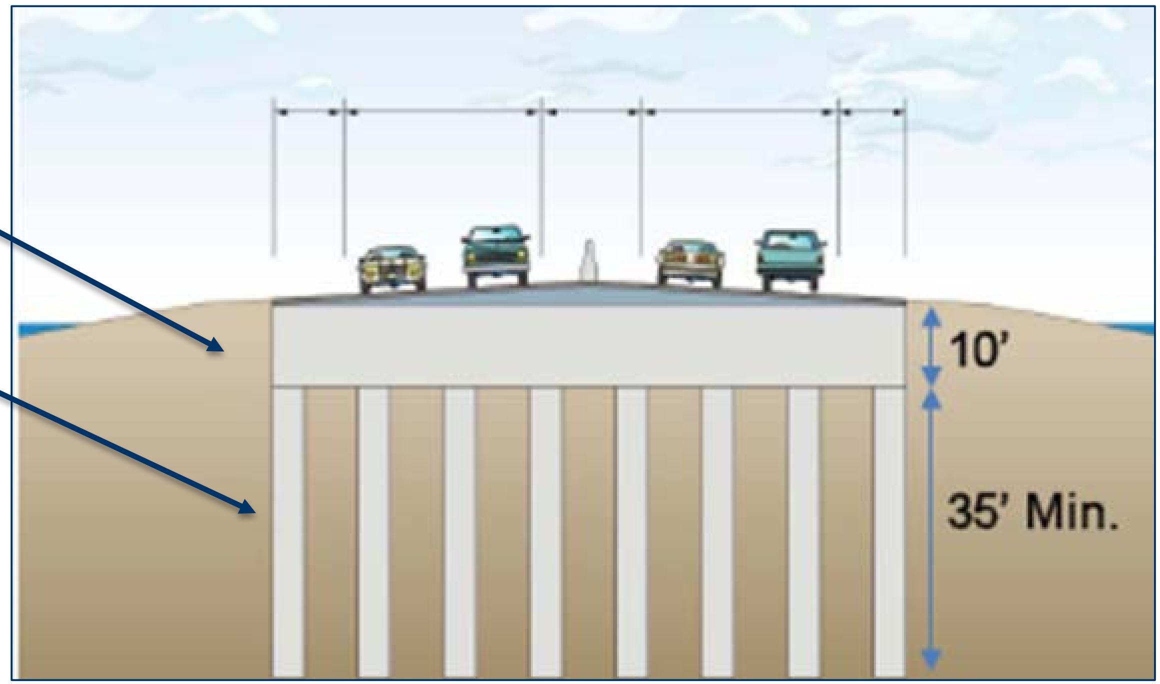
- Treat soils in place
- Avoids cost of disposing of potentially hazardous organic soil (remove and replace)
- May be categorized as either wet mixing or dry mixing
  - Wet mixing injects grout under pressure while mixing
  - Dry mixing introduces the binder as a dry powder

Wet Soil Mixing

Dry Soil Mixing

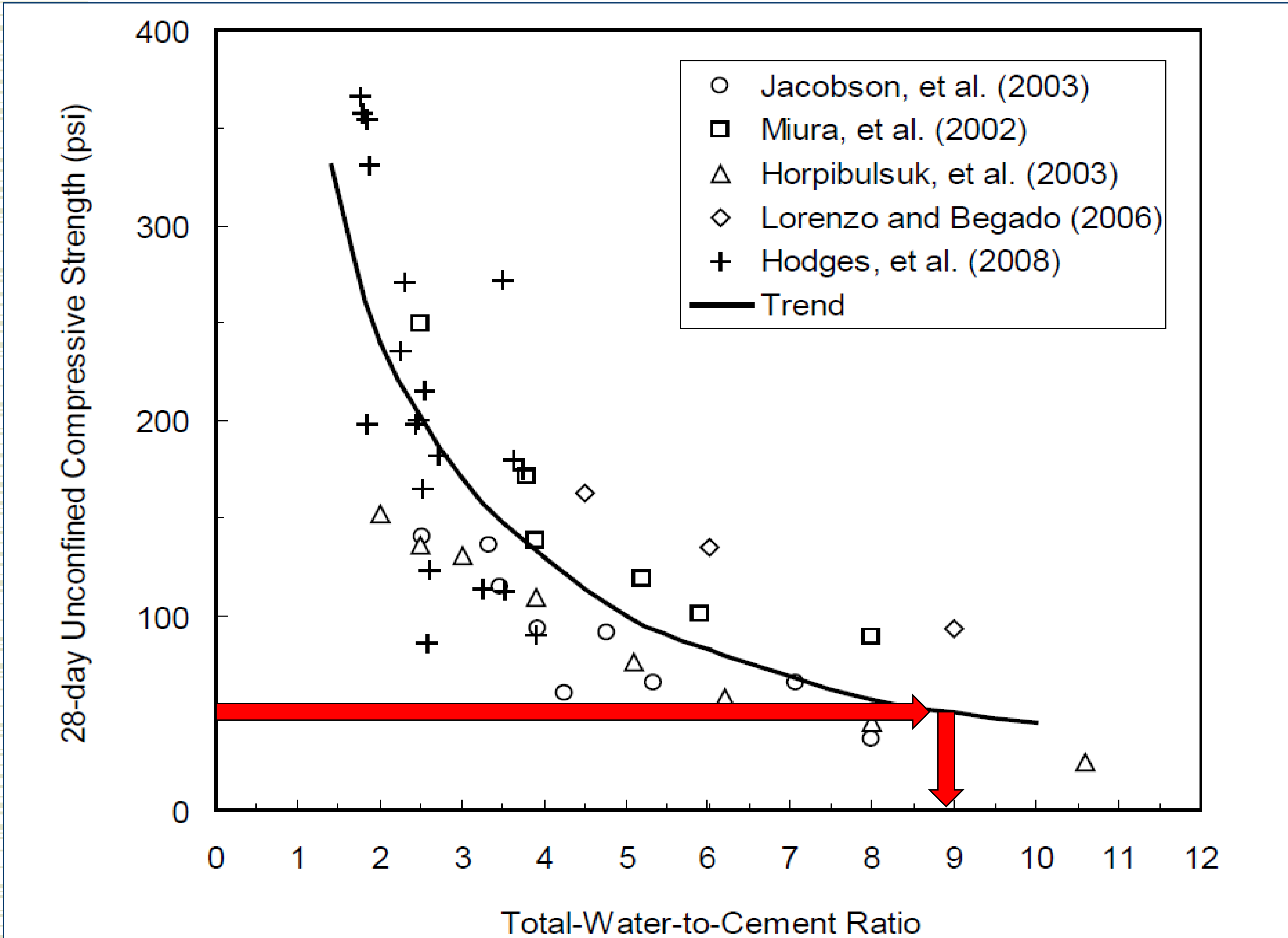
Soil Mixing Configurations

- Mass soil mixing
- Column supported embankments

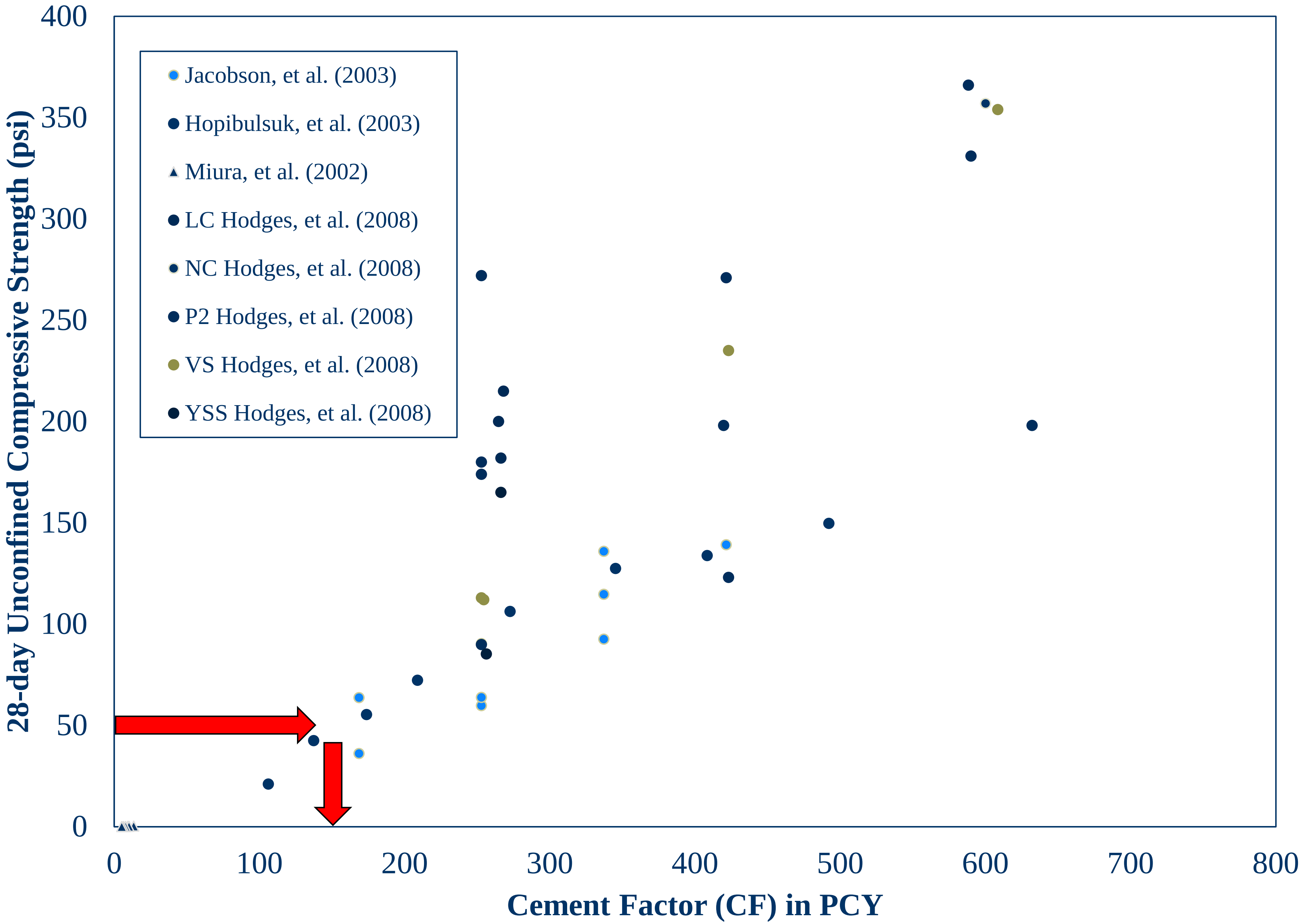


DESIGN: FHWA Design Manual for Deep Soil Mixing

- Comprehensive Manual
- Equipment
- Mixing methods
- Binder Types
- Design Procedures
  - Inorganic soils
  - Function of w/c ratio



28-day Unconfined Compressive Strength (psi)
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
Total-Water-to-Cement Ratio
Jacobson, et al. (2003)
Miura, et al. (2002)
Horpibulsuk, et al. (2003)
Lorenzo and Begado (2006)
Hodges, et al. (2008)
Trend



Jacobson, et al. (2003)
Hopibulsuk, et al. (2003)
Miura, et al. (2002)
LC Hodges, et al. (2008)
NC Hodges, et al. (2008)
P2 Hodges, et al. (2008)
VS Hodges, et al. (2008)
YSS Hodges, et al. (2008)
28-day Unconfined Compressive Strength (psi)
0
50
100
150
200
250
300
350
400
0
100
200
300
400
500
600
700
800
Cement Factor (CF) in PCY

FHWA Design Manual for Deep Soil Mixing

- *"…increasing organic content often requires higher cement content, and organic contents **<u>greater than about 10 percent</u>** may produce significant interference with cementation."*
- *"…organic soils tend to **<u>require more binder</u>** than inorganic soils."*
- *"…soils containing organics/peat are **<u>more costly</u>** to mix."*
- *"**<u>Slag-</u>**cement binders can be **<u>more effective</u>** than pure cement for treating organic soils."*
- Uncertainty is addressed, but no solution is offered

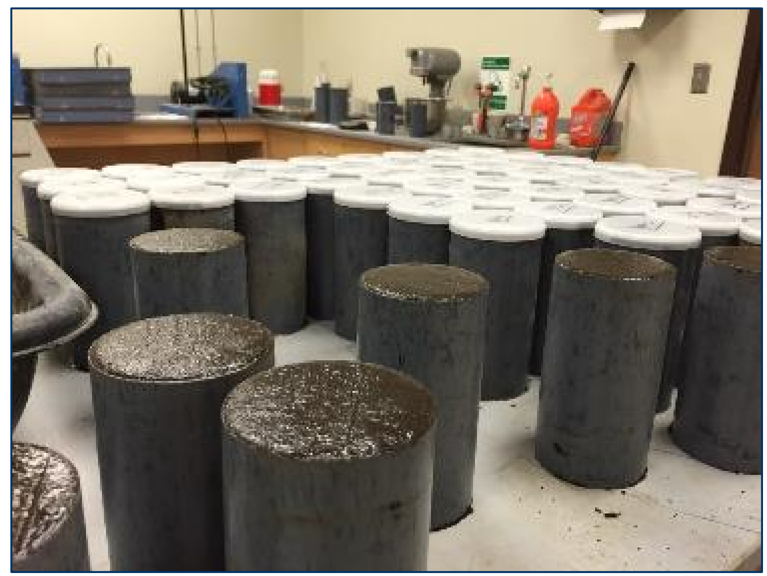
Swedish Deep Stabilization Research Centre

- *"The organic material . . . **negatively affects** the reaction rate of the binders…"*
- *"…the stabilization outcome of a binder **cannot** at present **be** definitely **predicted** merely by determining the organic content…"*
- *"**Cement** is often a **more effective** …in mud and peat soils."*
- *"…in soils with high organic contents . . . the quantity of binder **needs to exceed a 'threshold**' . . . below the threshold the soil will remain unstabilized."*

Small Scale Lab Testing

- Test Matrix:
  - Organic Contents: 0-66% (7)
  - Binder Amount: 100-500pcy (5)
  - Binder Type: 0, 50, and 100% Slag (3)
  - Mixing Method: Wet or Dry (2)
  - Curing Time: 14, 28, 60 days, and higher (4)
- 78 batches, 9 cylinders each
- <u>702 total specimens</u>

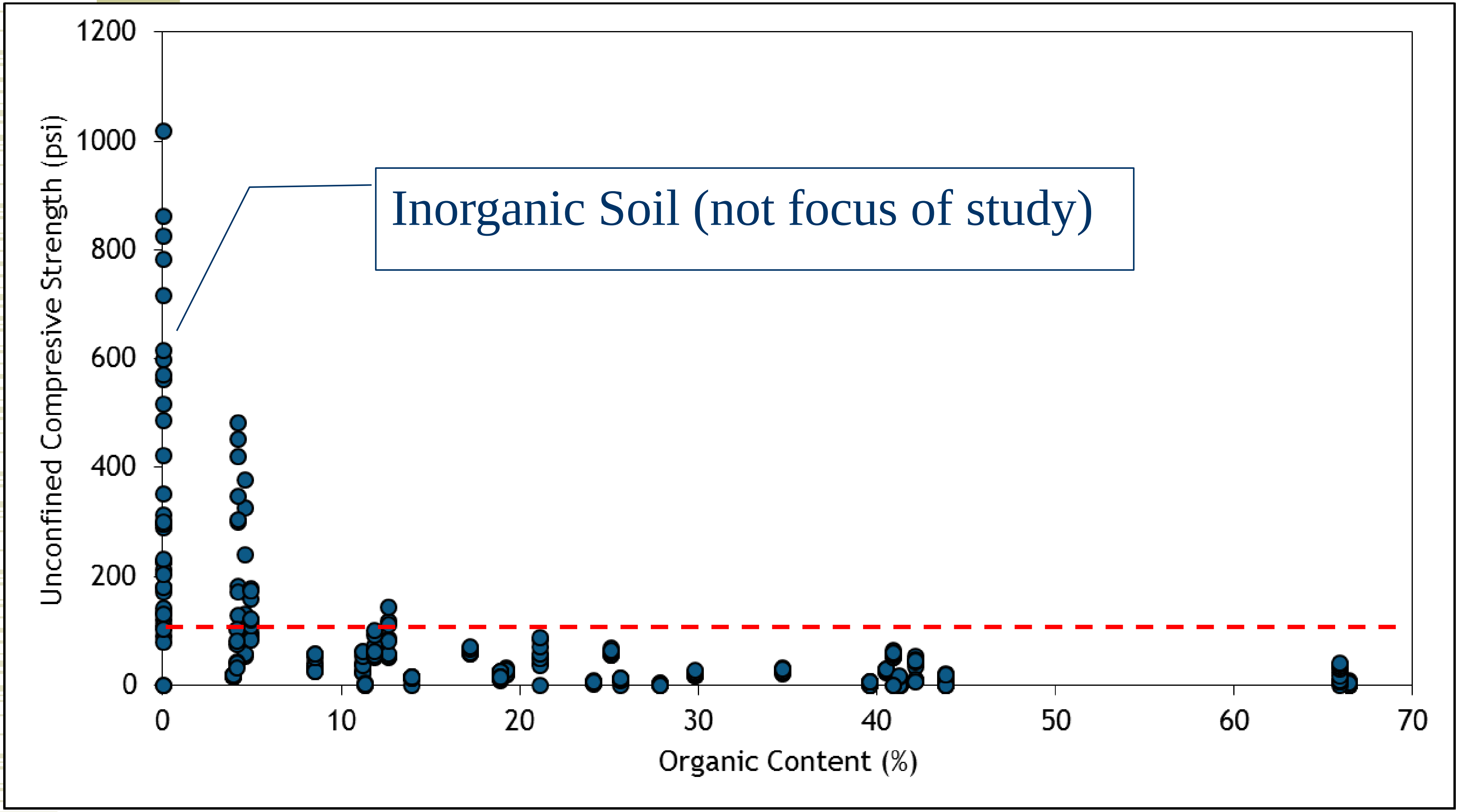
Specimen Prep



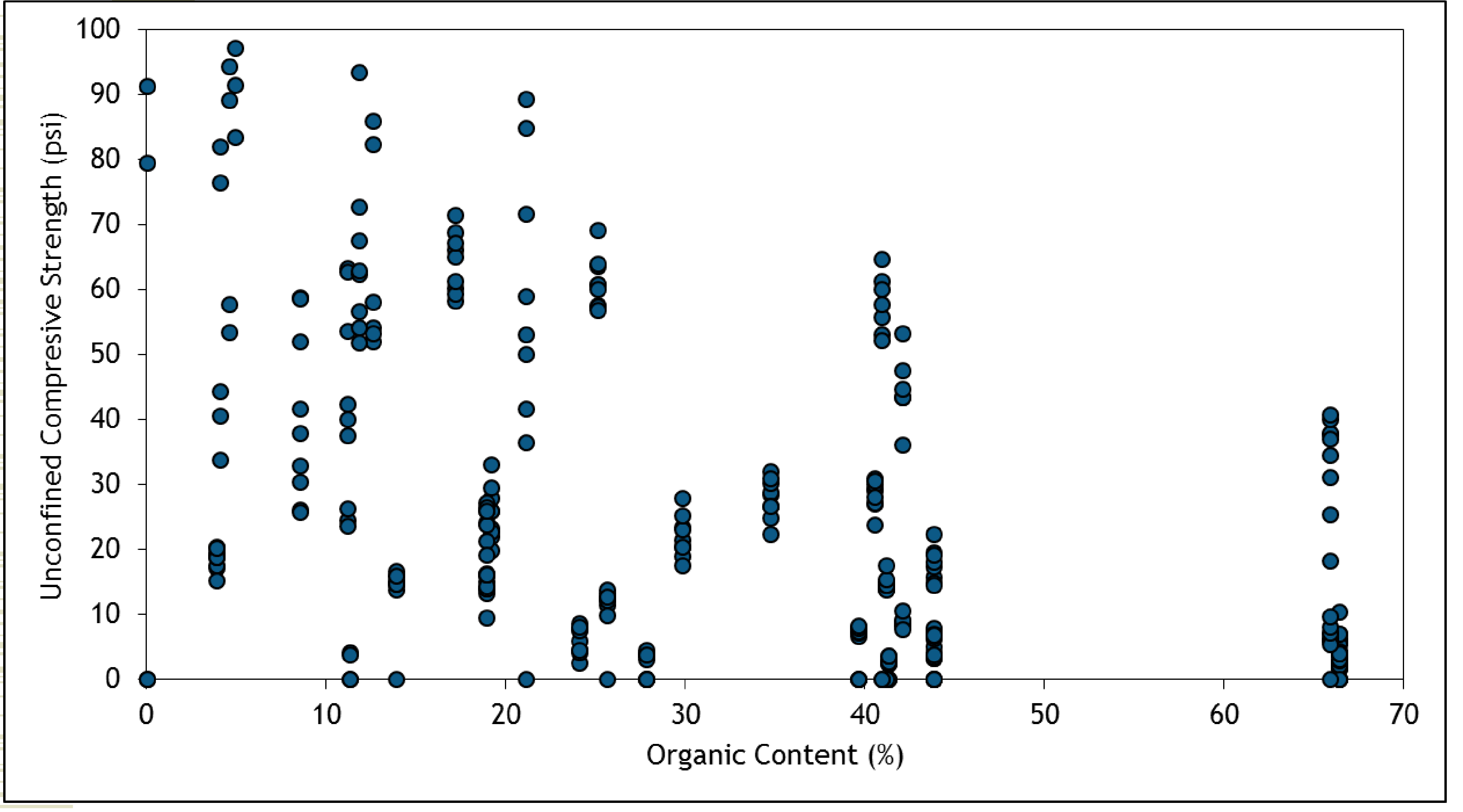
- Calculate the amount of materials needed for nine 3” by 6” cylinders
- Mix the raw soil alone for approximately 4 minutes in the large mixer
- Measure pH with litmus paper.
- Take small samples to calculate moisture content
- Add dry binder. This is either cement, slag, or both. Mix together for 4 minutes
- Measure pH with litmus paper

Unconfined Compression Testing

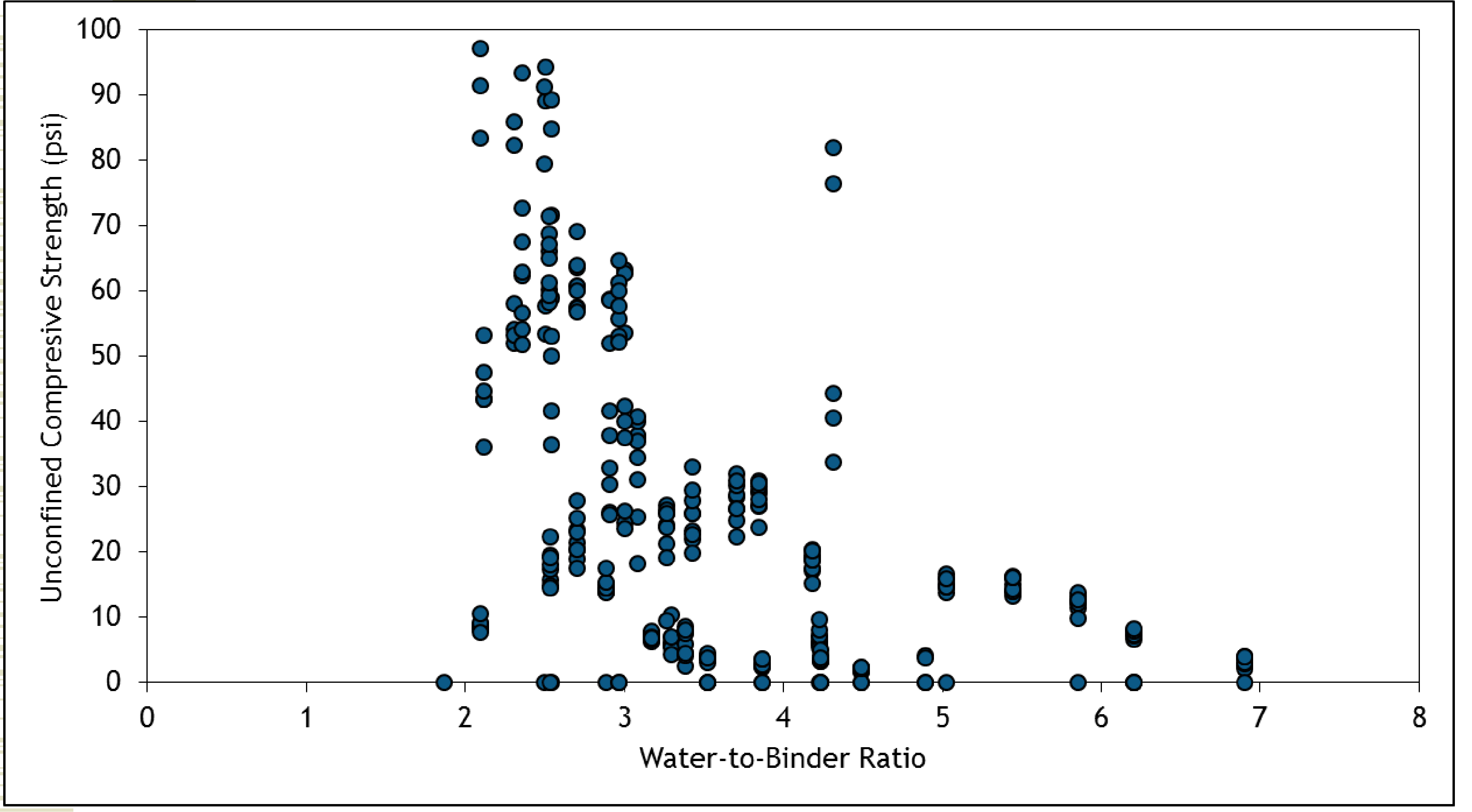
Results


Inorganic Soil (not focus of study)
Unconfined Compresive Strength (psi)
Organic Content (%)
0
200
400
600
800
1000
1200
0
10
20
30
40
50
60
70

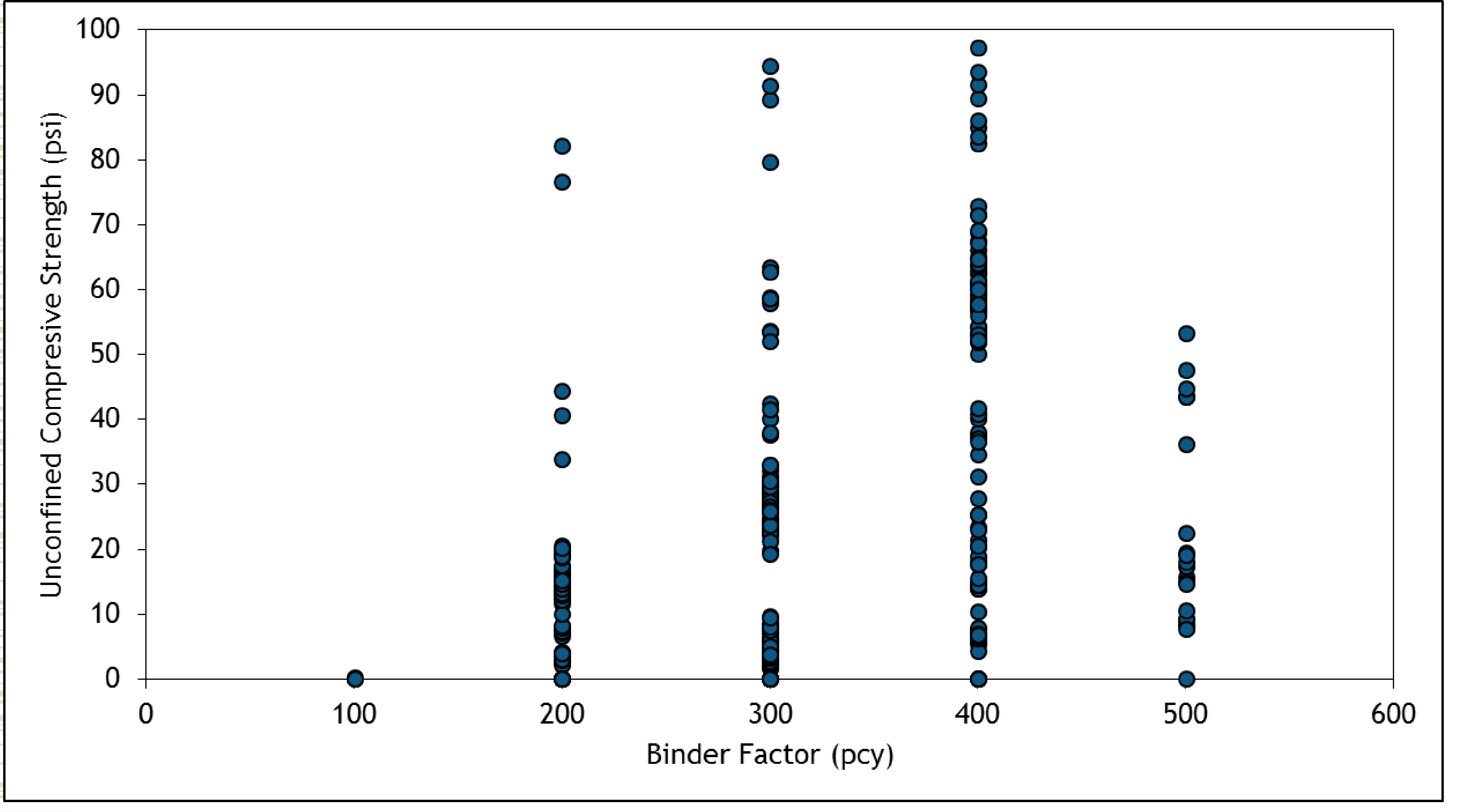
Strength vs Organic Content



Strength vs Water-to-Cement Ratio

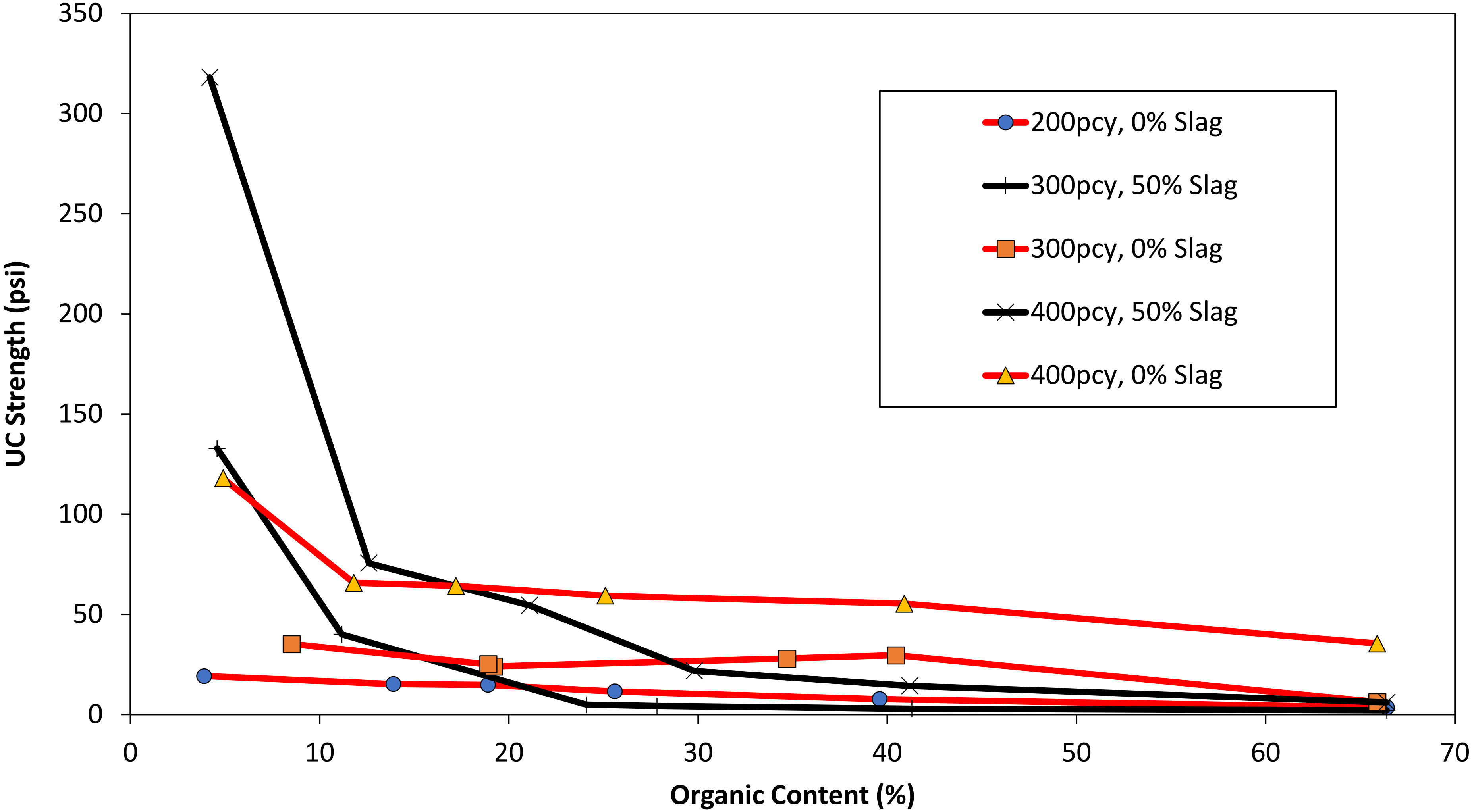


Strength vs Binder Factor



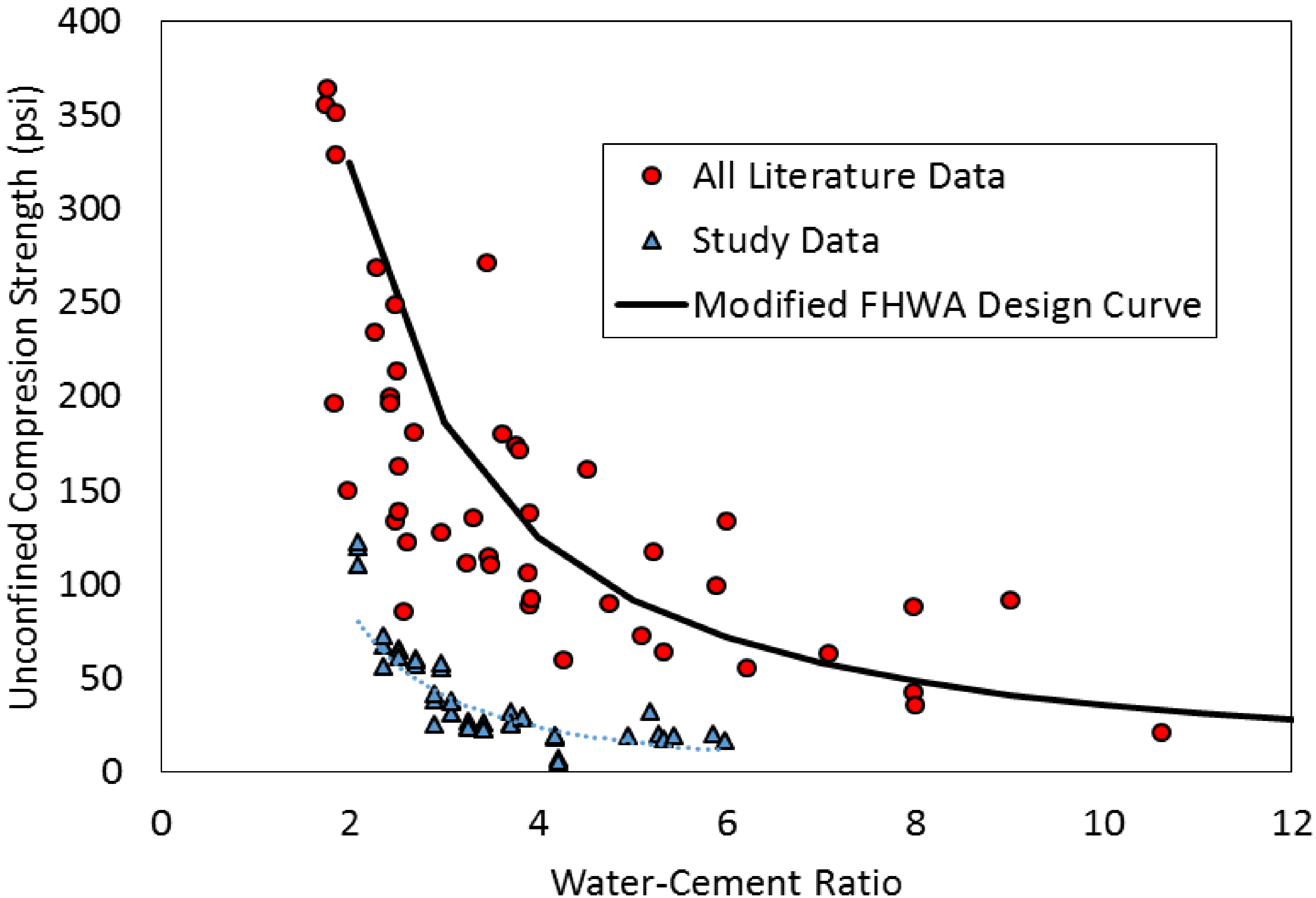
- Plotting vs one variable is not helpful

Strength vs Organic Content



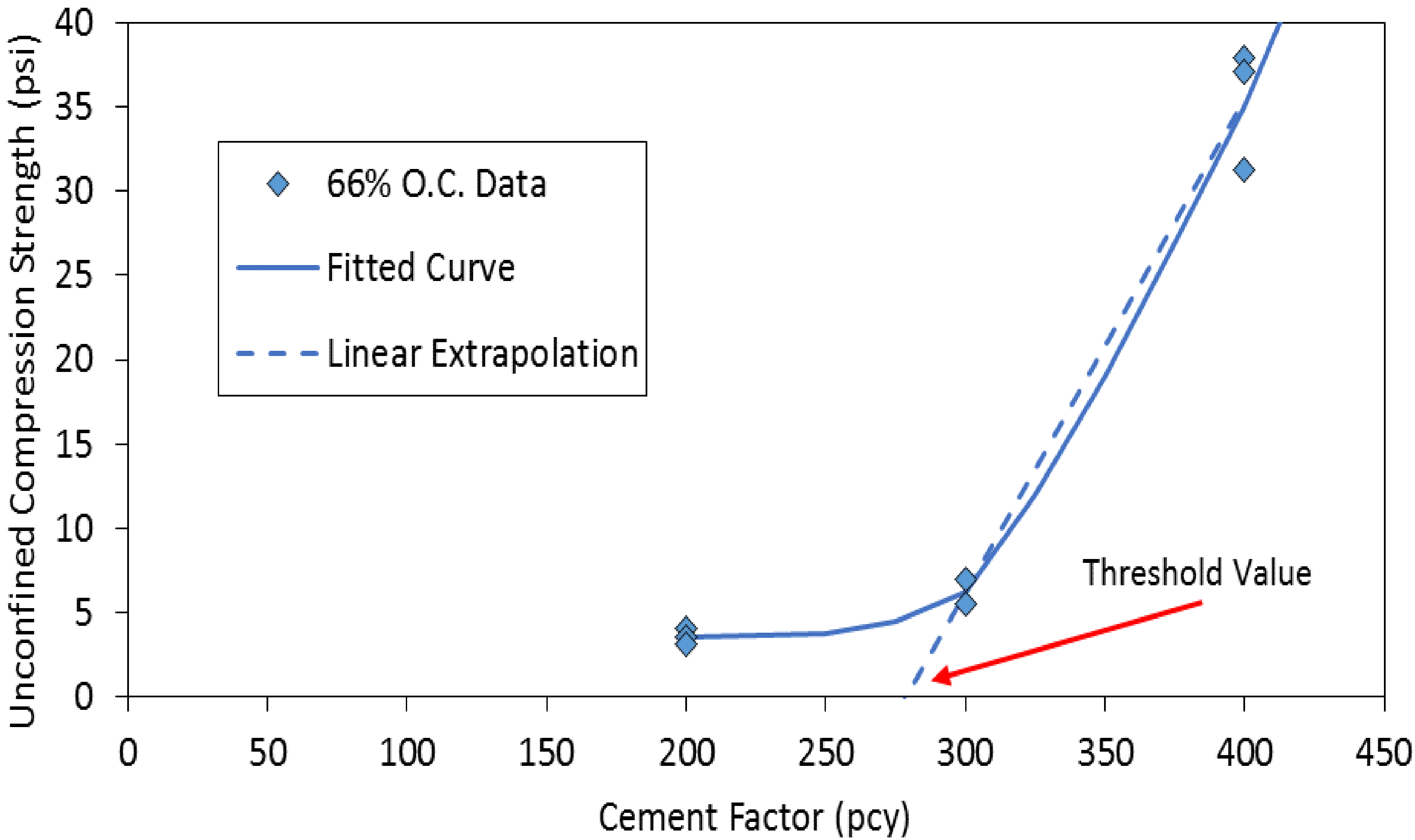
- Slag replacement was not effective at higher organic contents
- Organic content had little effect over the middle range

Unified Design Approach

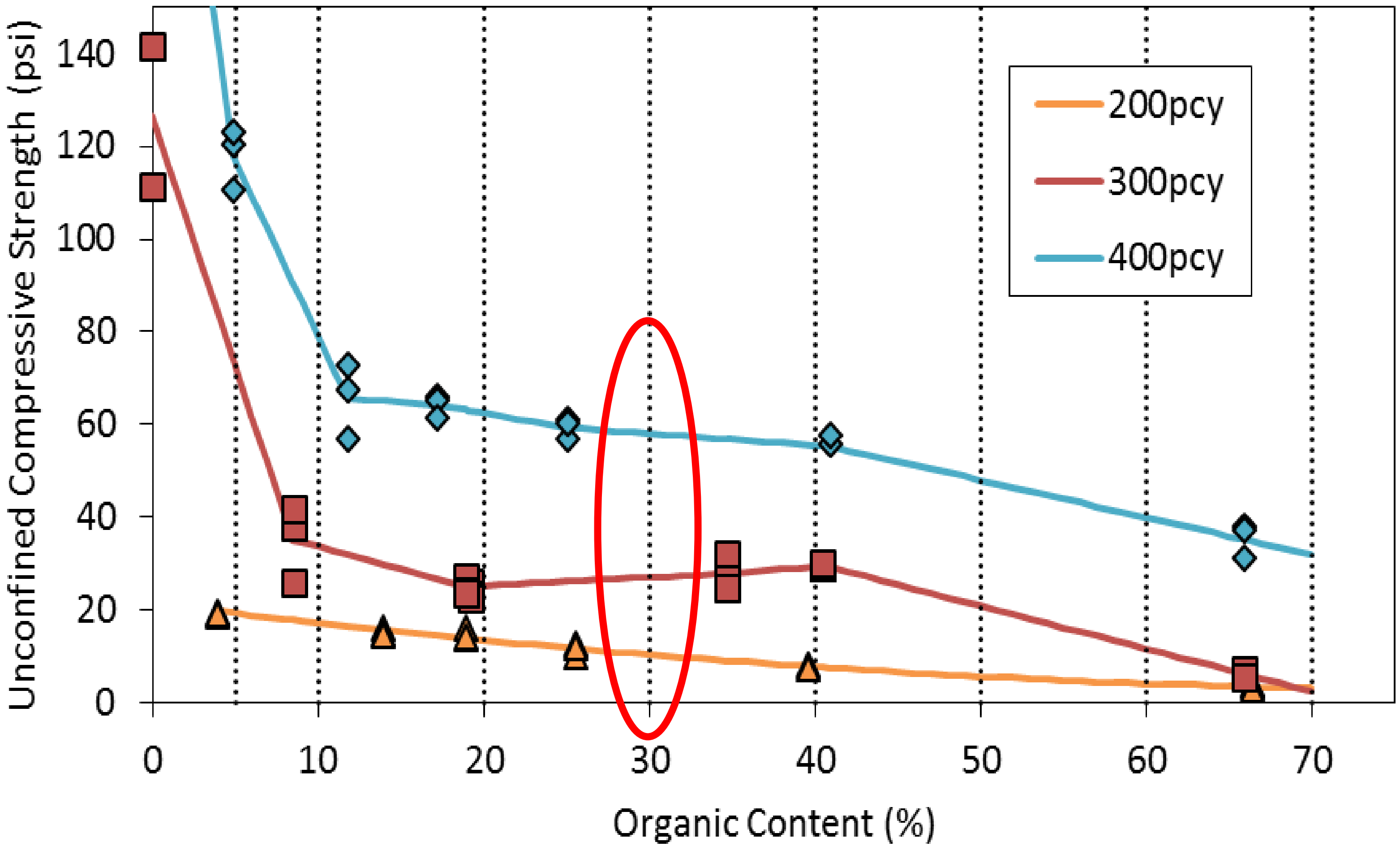


Define a Cement Threshold

below which soil will remain unstabilized



Find Threshold for all OC



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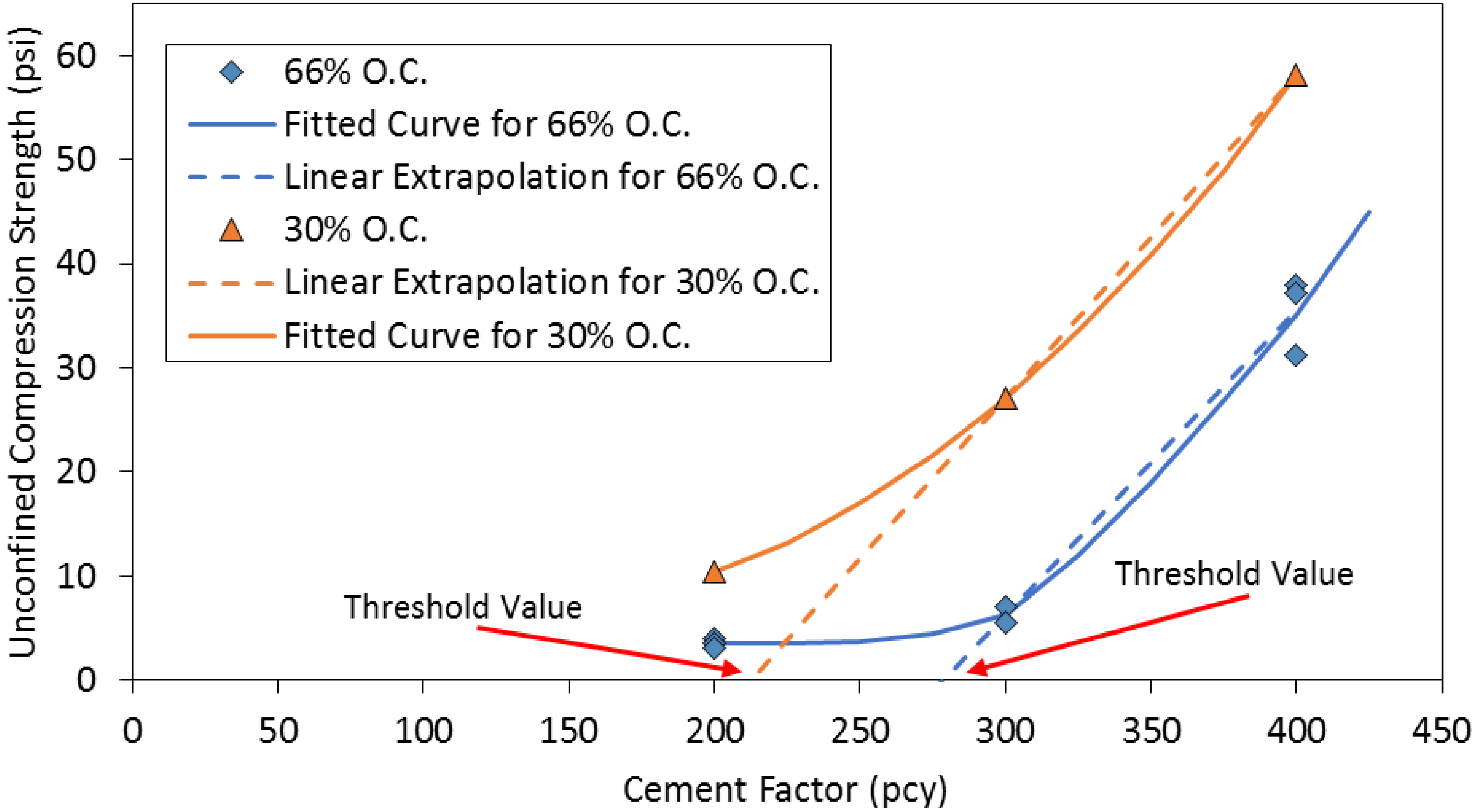
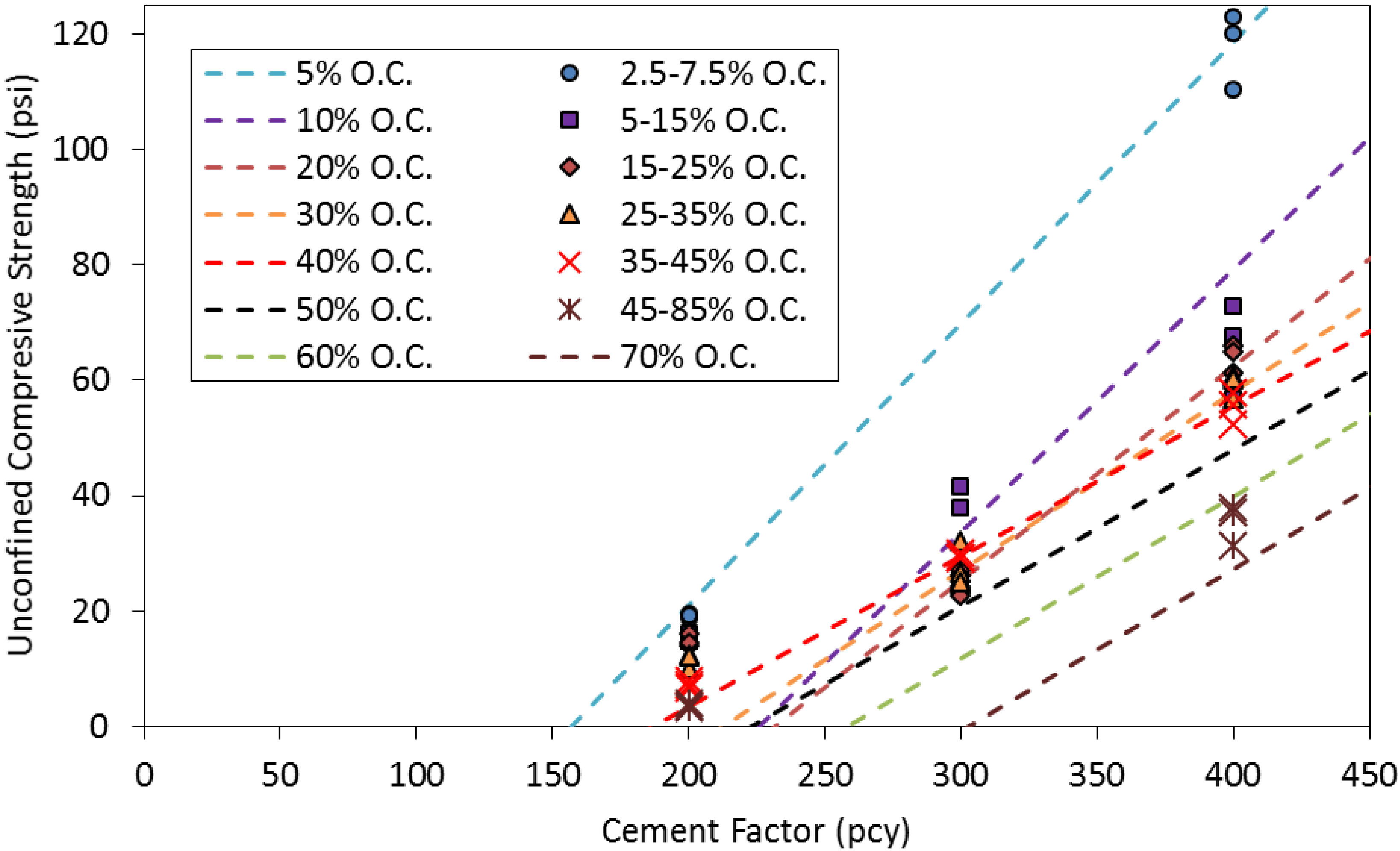
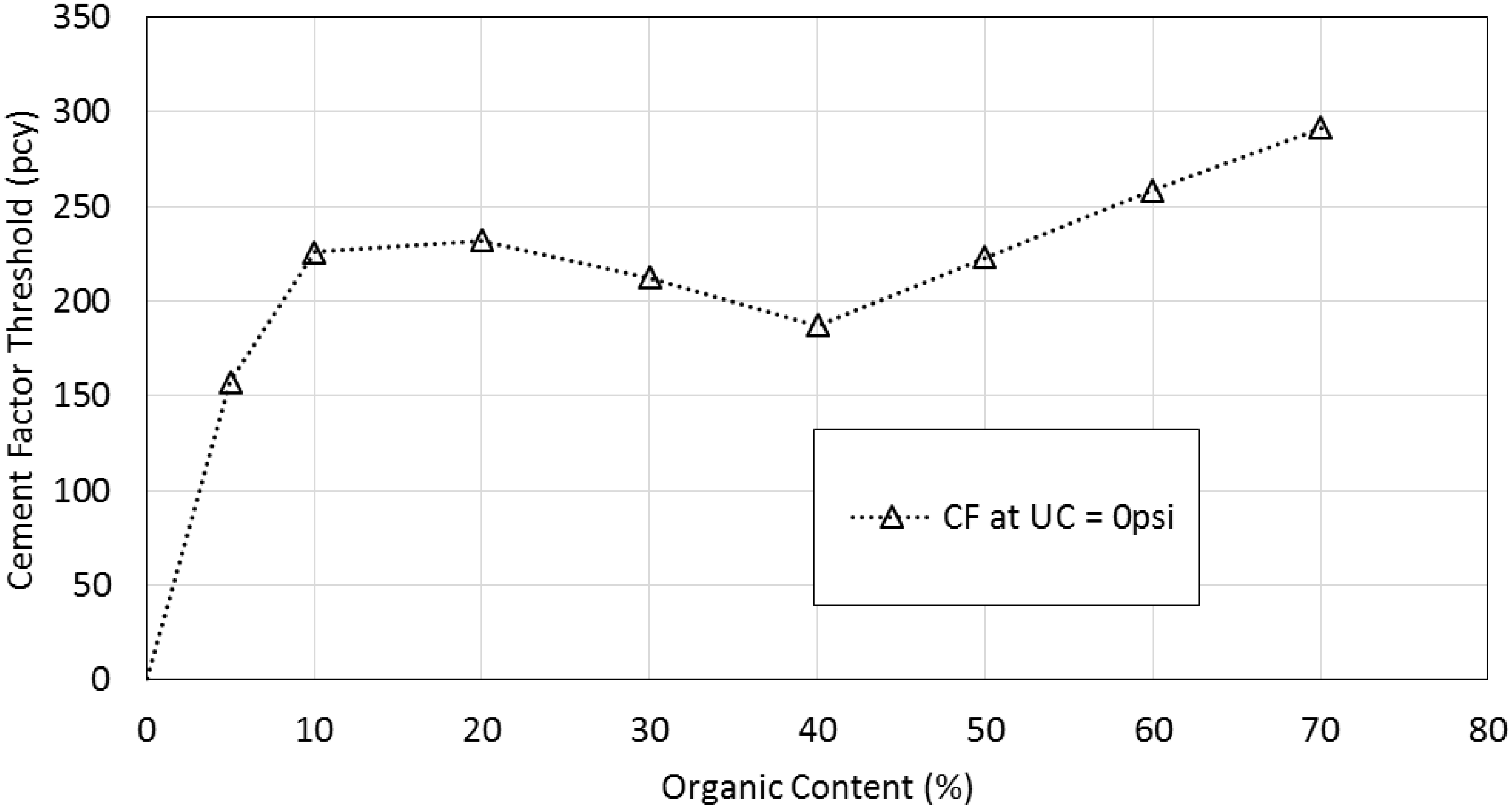


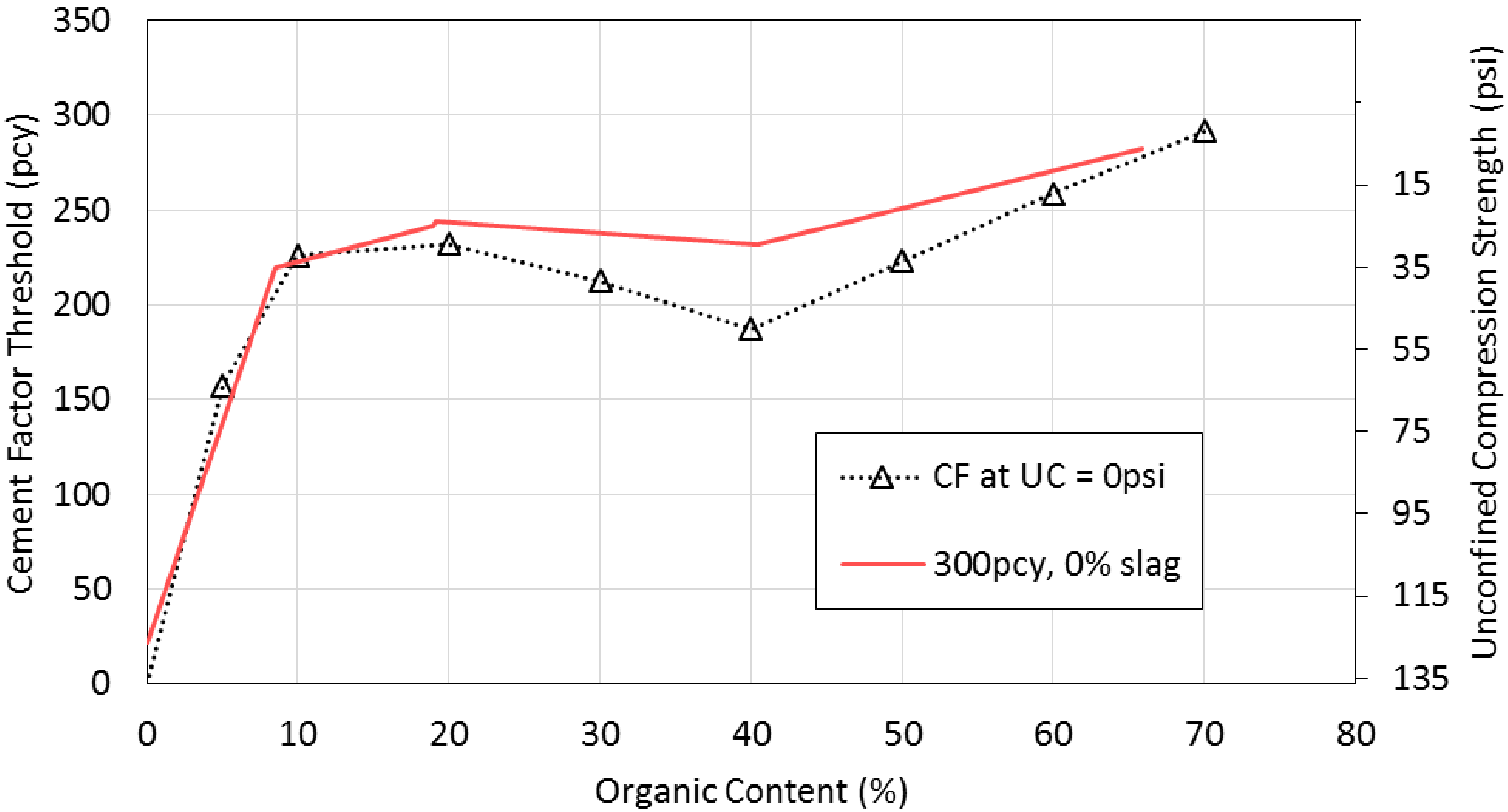
Find Threshold for all OC



Cement Factor Threshold



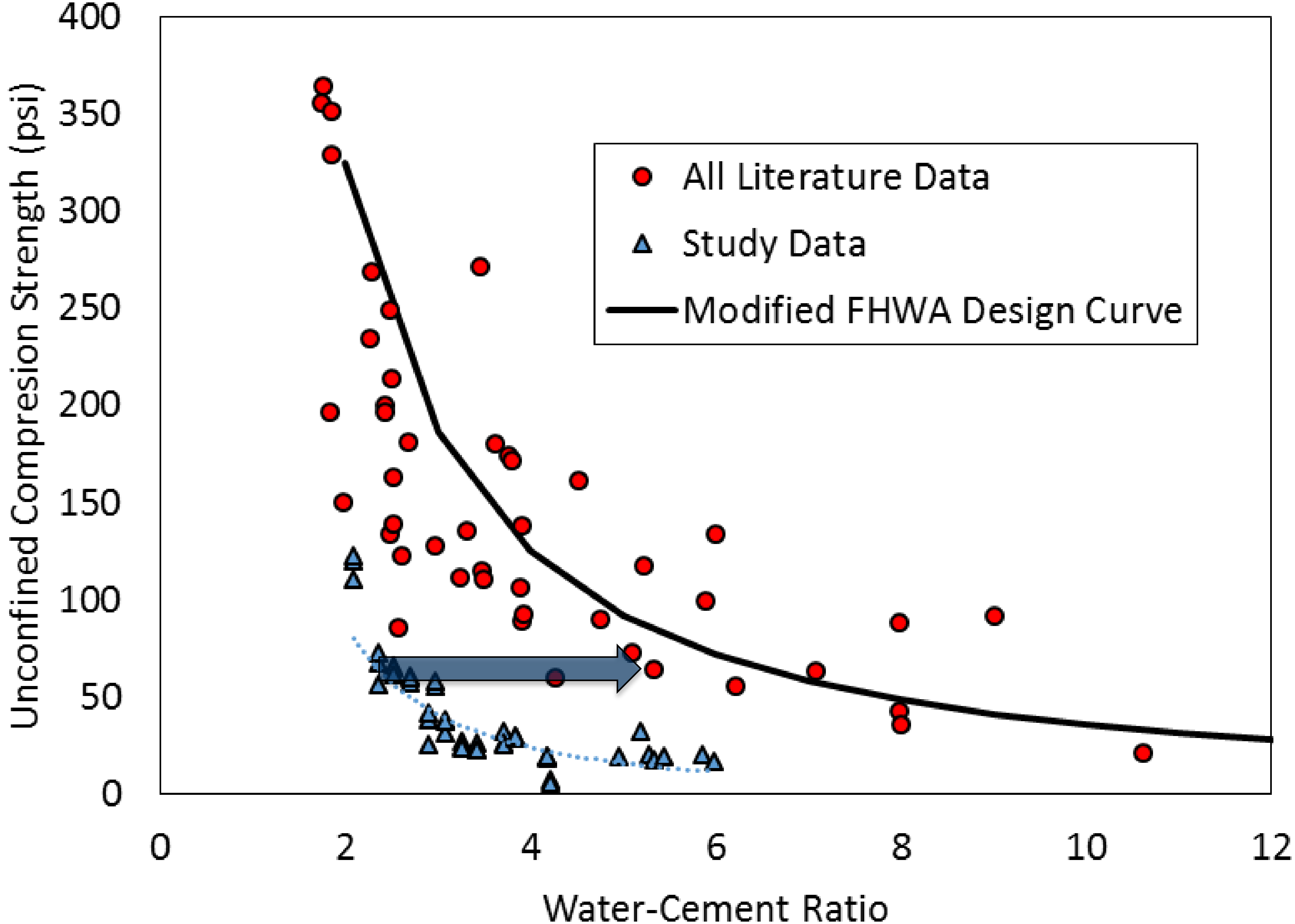
Cement Factor Threshold



Cement Factor Threshold
(Alternate Approach)

$$w/c_{in\ place} = \frac{Wt_{\ water}}{(Wt_{\ effective\ cem} + Wt_{\ threshold\ cem})}$$

Threshold Concept Alternate Approach

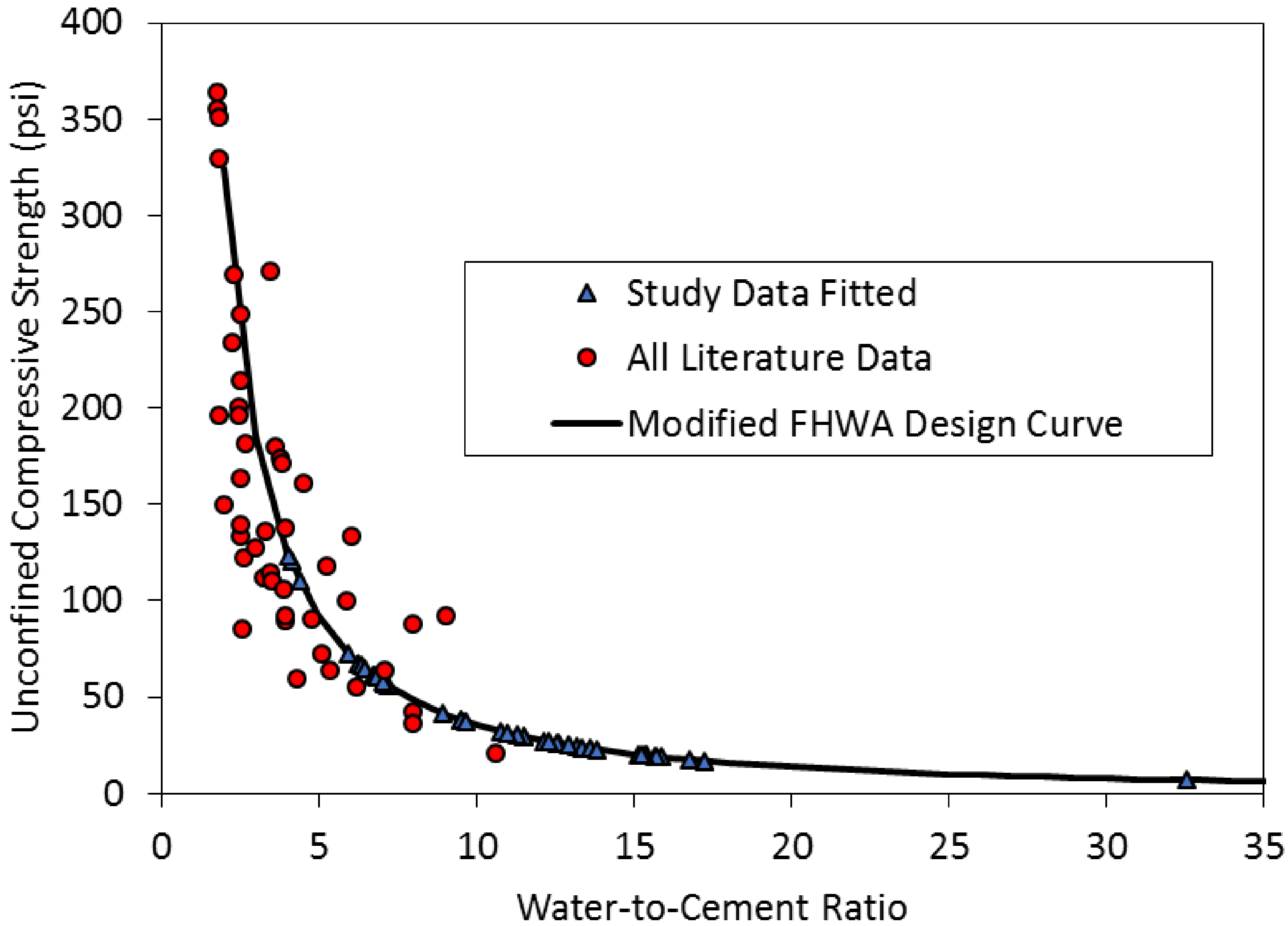


Cement Factor Threshold

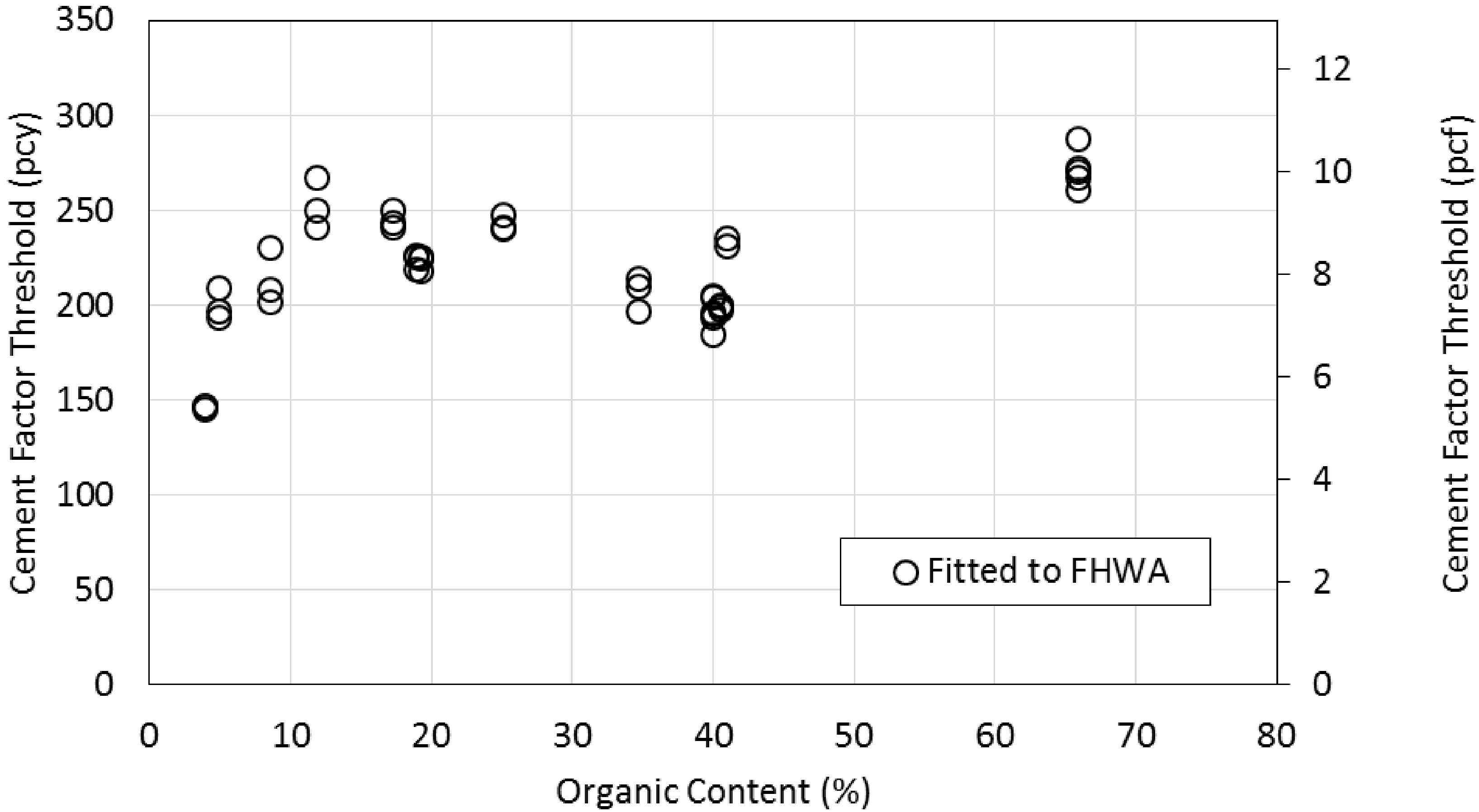
$$w/c_{effective} = w/c_{in\ place} \frac{CF_{in\ place}}{(CF_{in\ place} - CF_{threshold})}$$

Define "effective water-to-cement ratio" as that value used in FHWA design curve

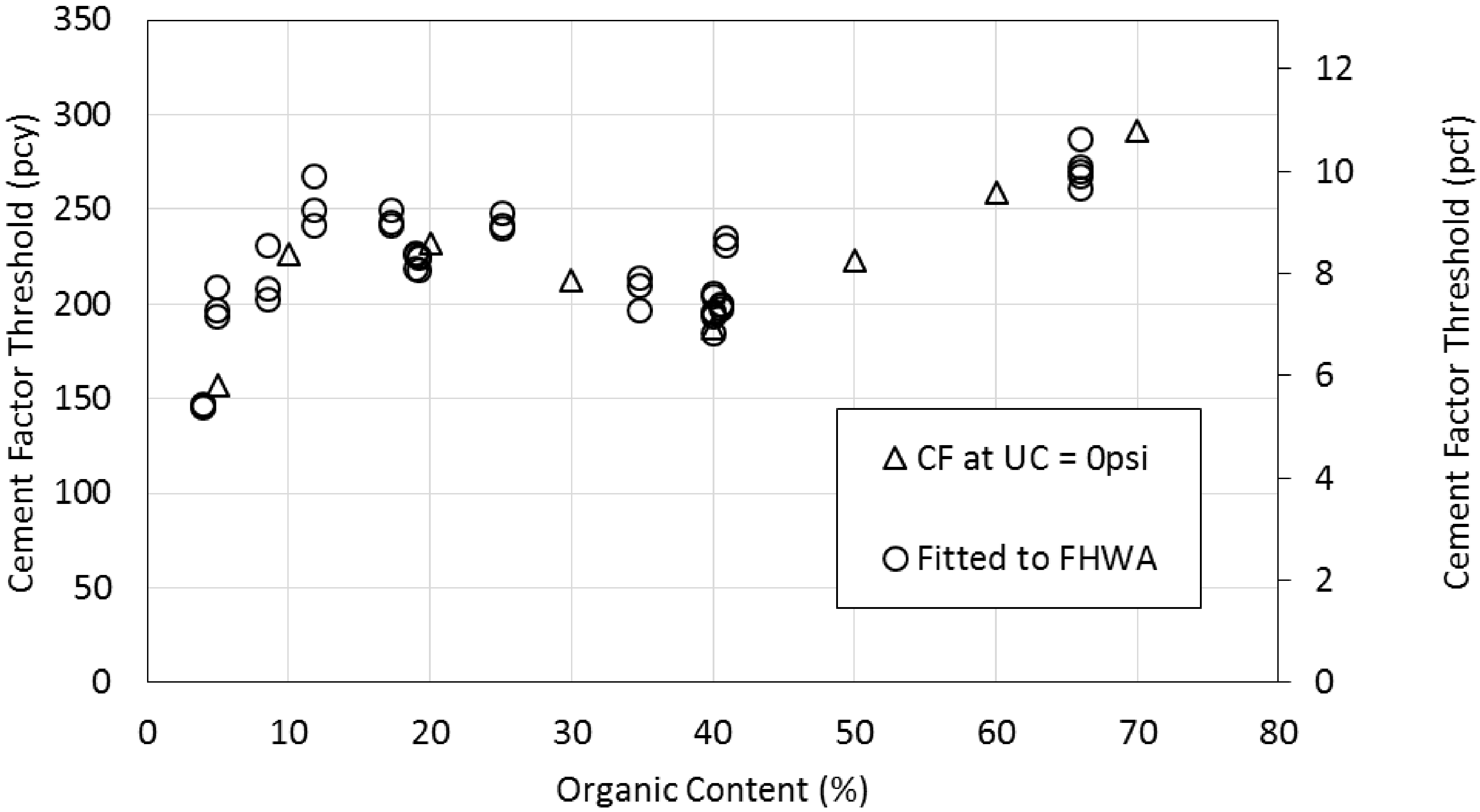
Select threshold for every test to fit FHWA Design Curve



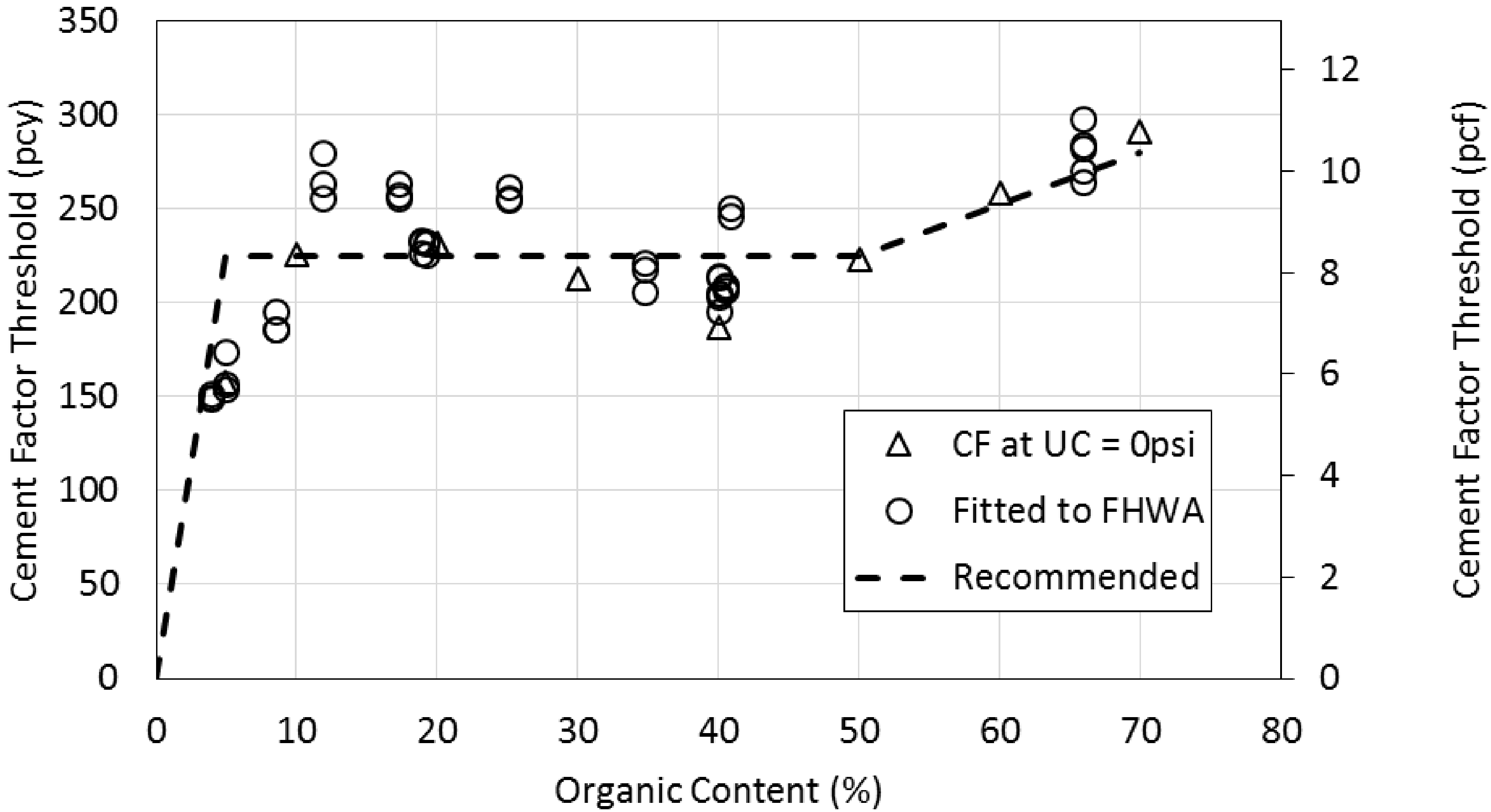
Cement Factor Threshold



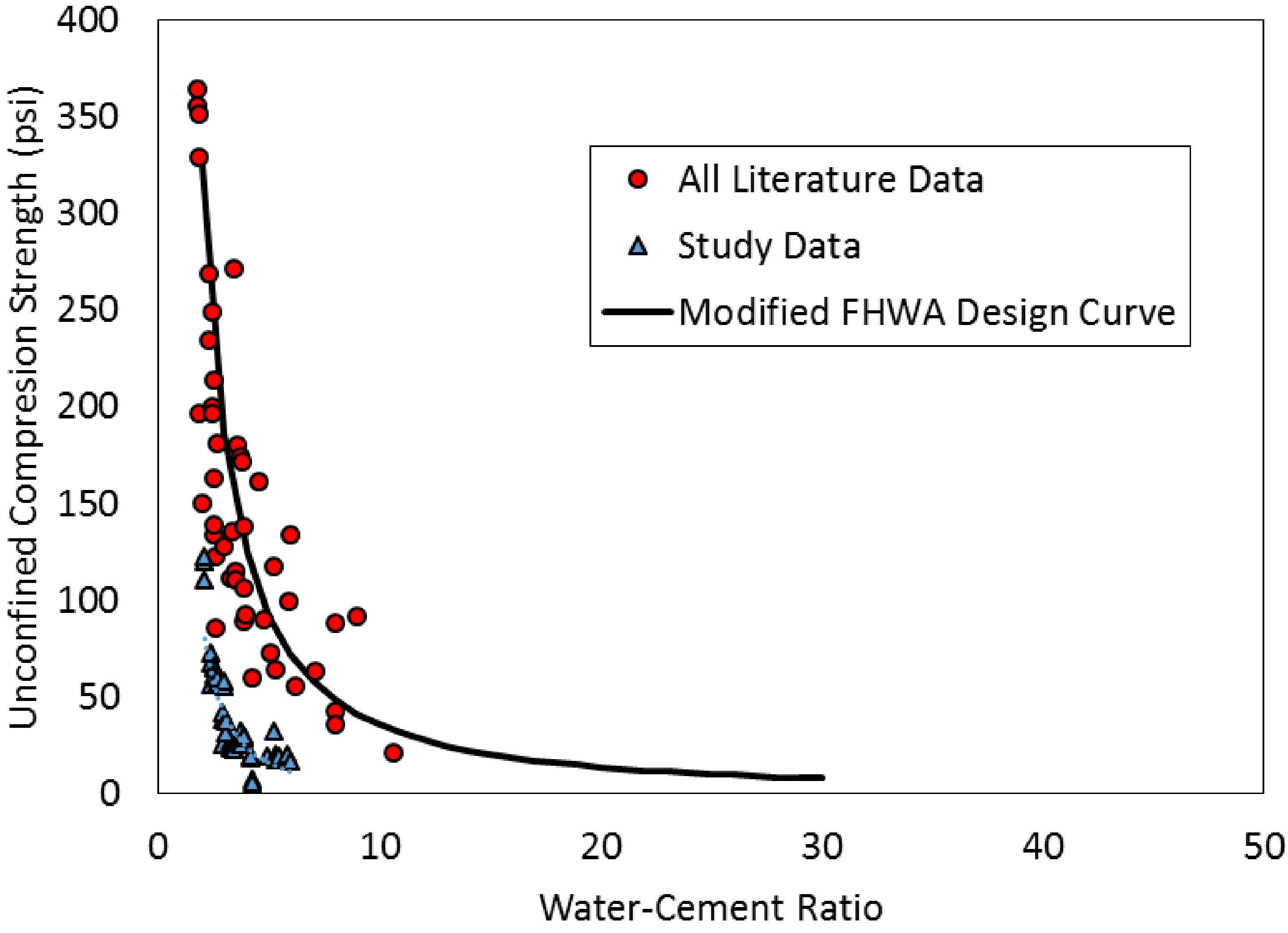
Cement Factor Threshold



Cement Factor Threshold

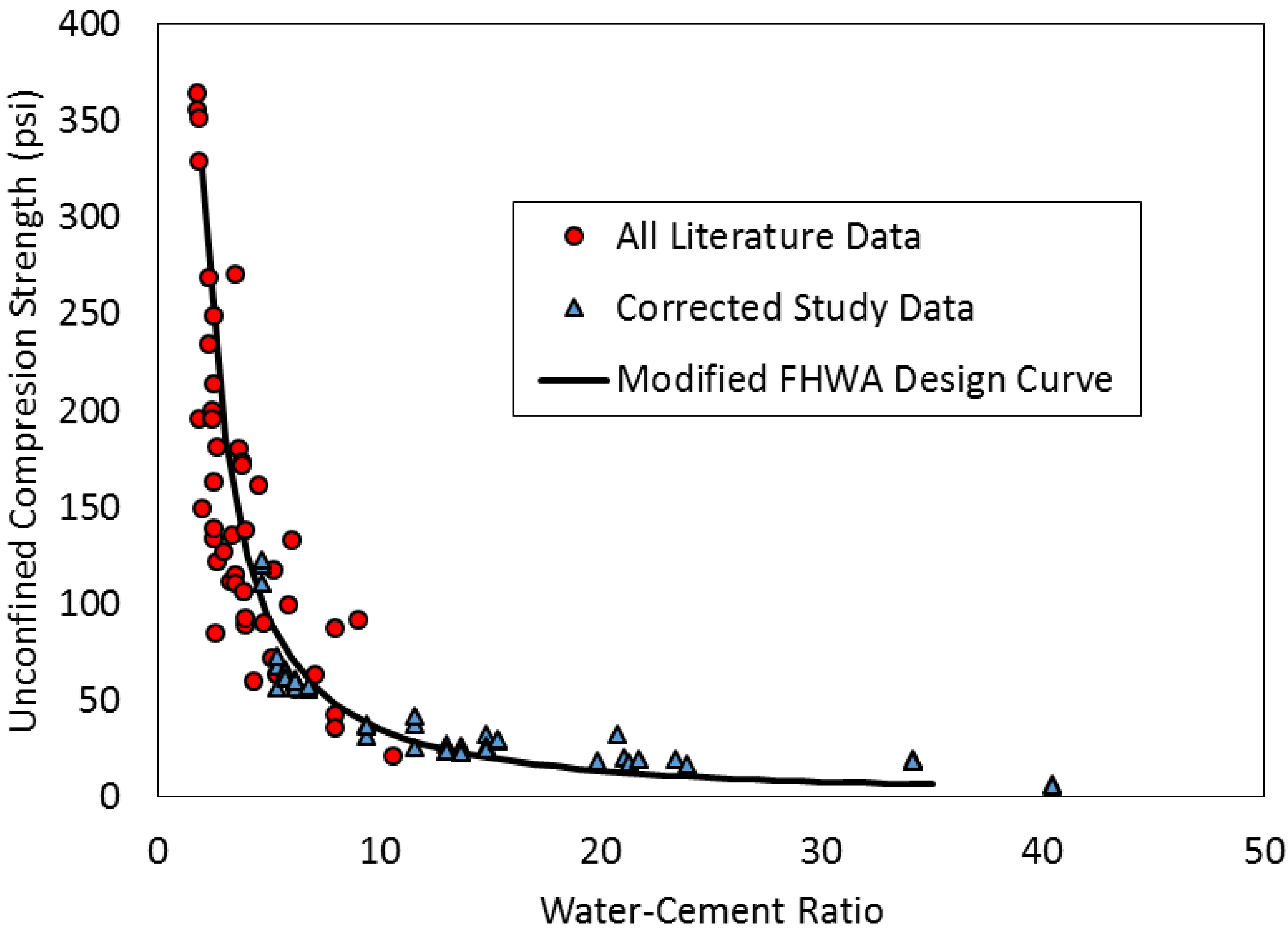


Raw Data



Unconfined Compression Strength (psi)
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
Water-Cement Ratio
All Literature Data
Study Data
Modified FHWA Design Curve

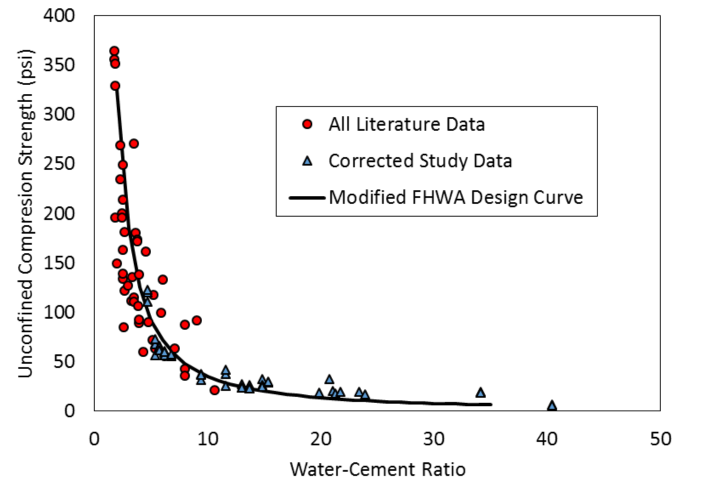
Cement Factor Threshold Factor Applied

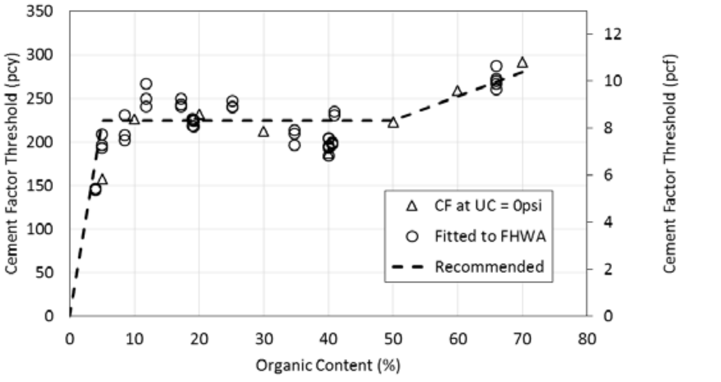


Design Approach

1. Given strength requirement, select w/c from FHWA design curve and associate weight of cement
2. Select cement factor threshold
3. Compute final system volume
4. Compute total cement required

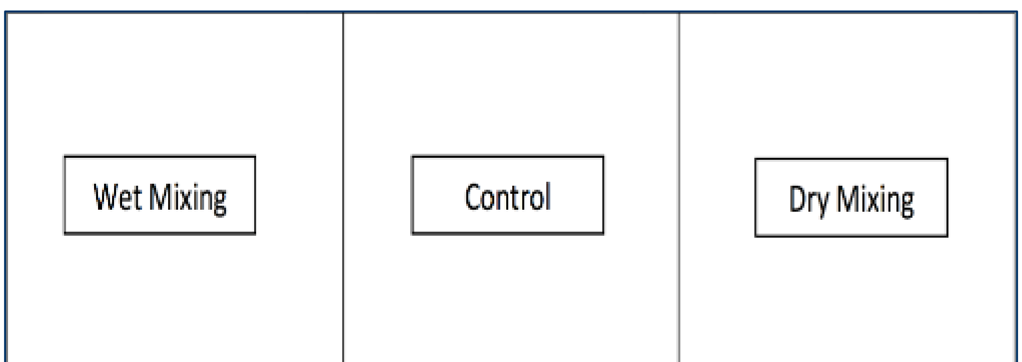
$$wt_{cement} = Step\ 1 + (Step\ 2)(Step\ 3)$$





Large Scale Lab Testing

- Confirms small scale findings
- Simulate field conditions
- Compare both wet and dry mixing methods to a control



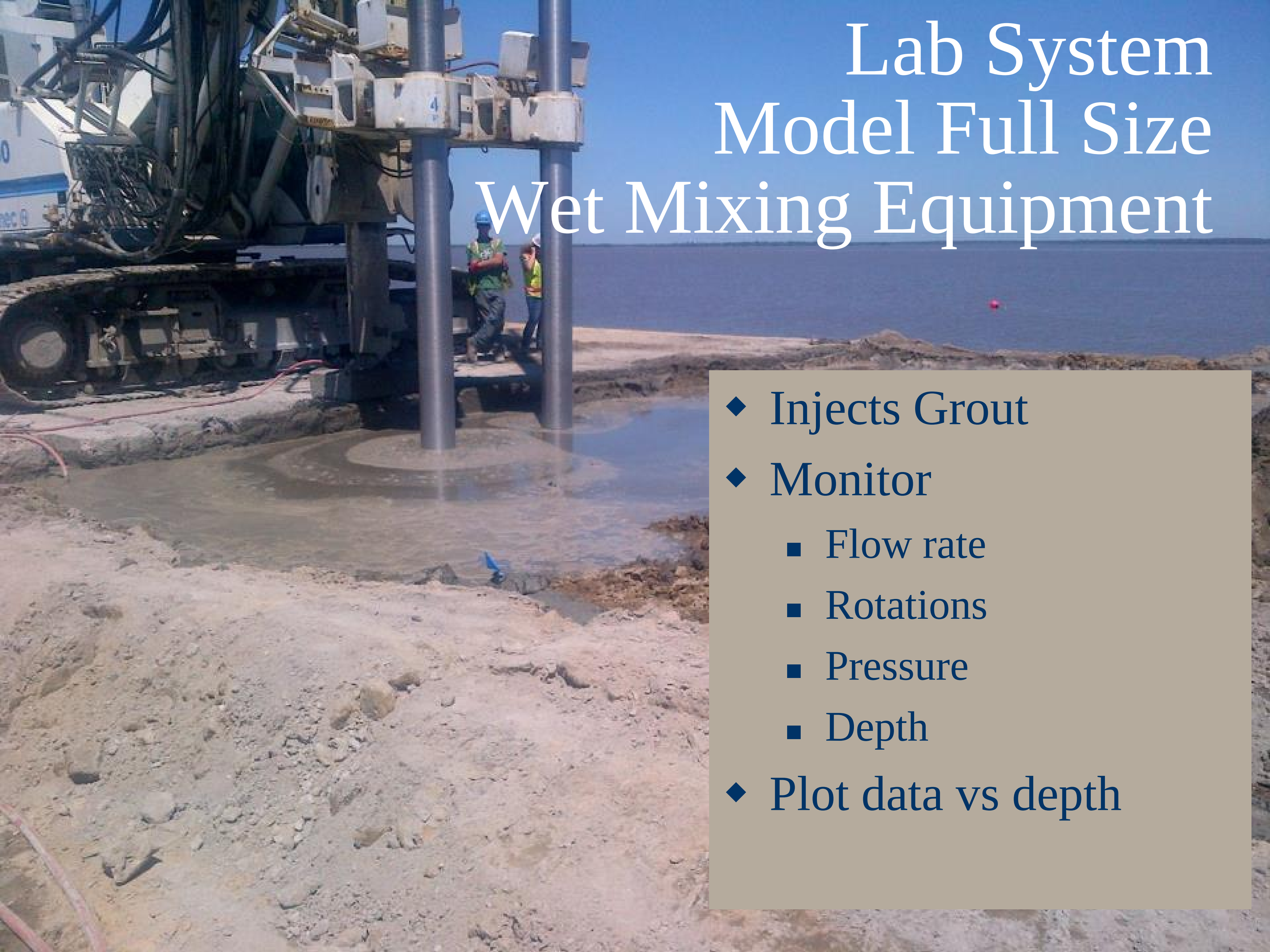

OIL


KUBOTA
bobcat


bobcat
753H

Large Scale Test Bed

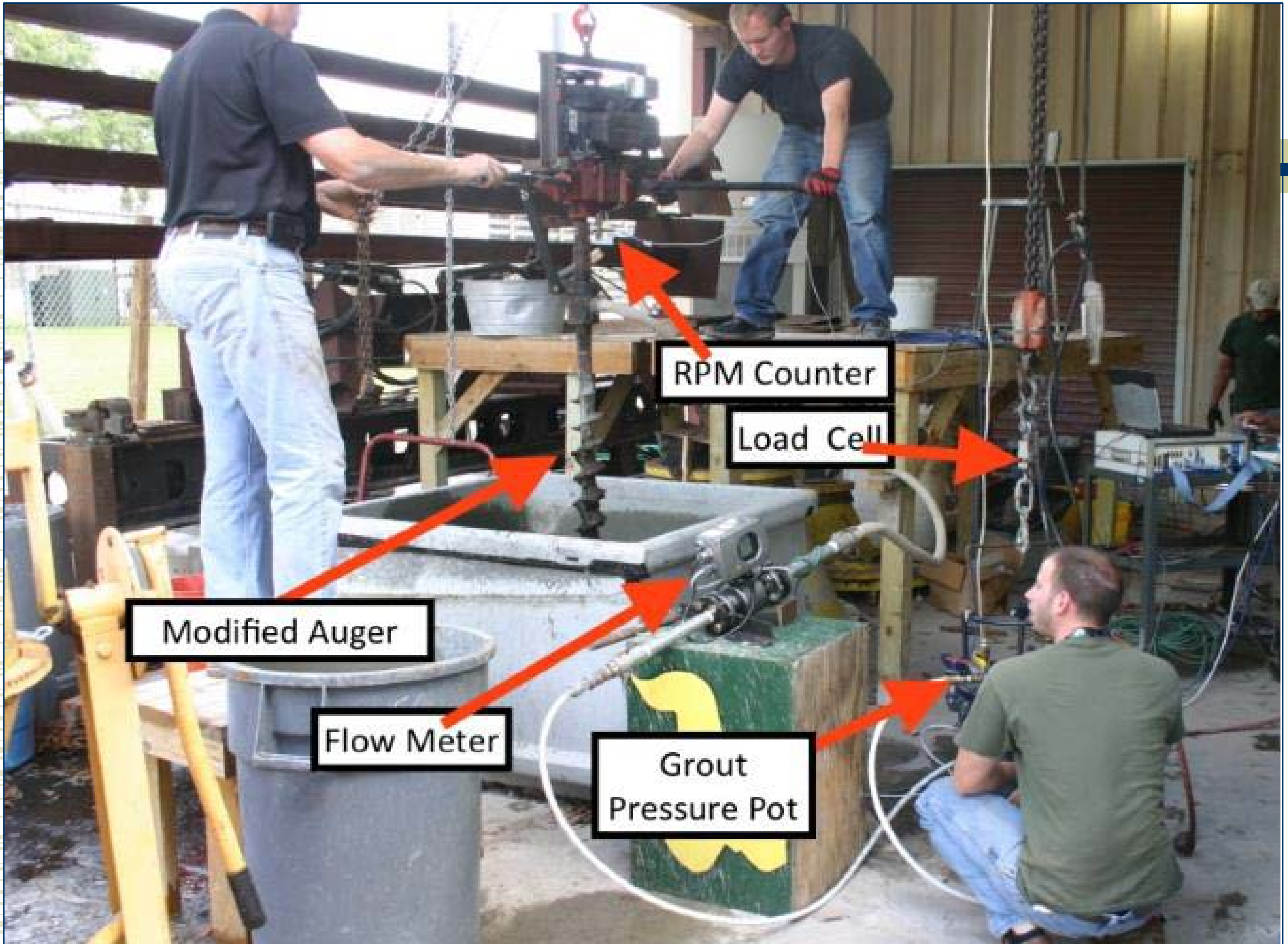
- Bed partitioned
- Conditioned periodically with rainwater to maintain saturated state



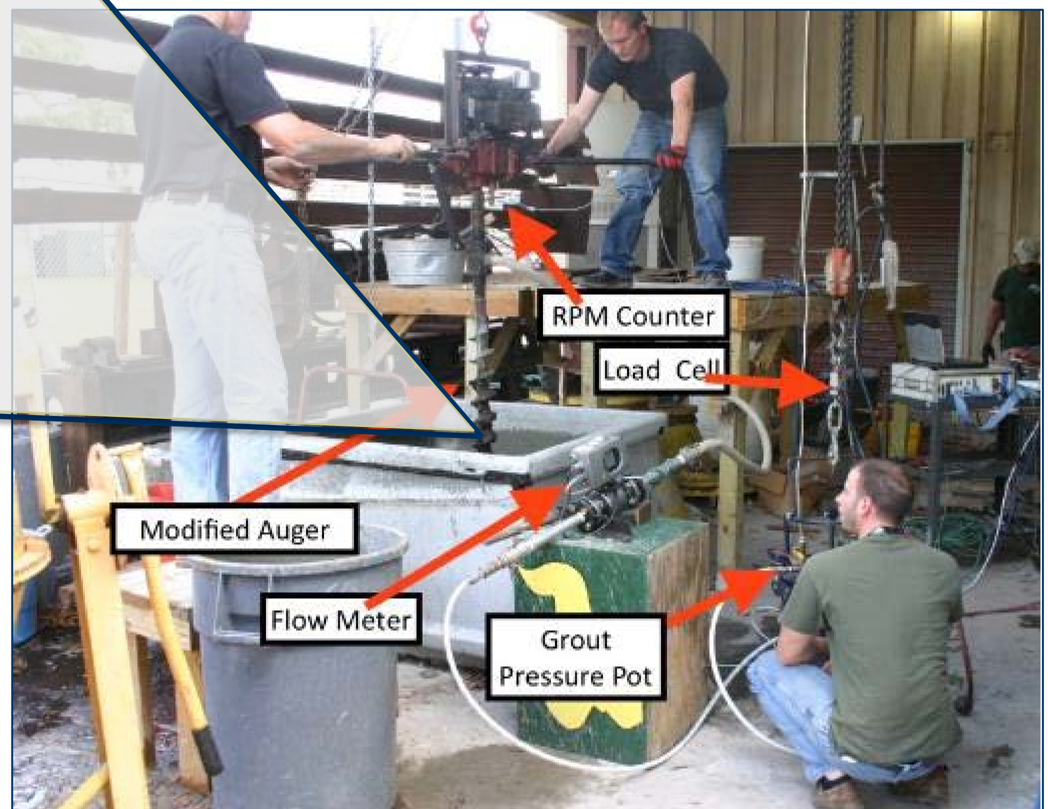
Lab System
Model Full Size
Wet Mixing Equipment

- Injects Grout
- Monitor
  - Flow rate
  - Rotations
  - Pressure
  - Depth
- Plot data vs depth

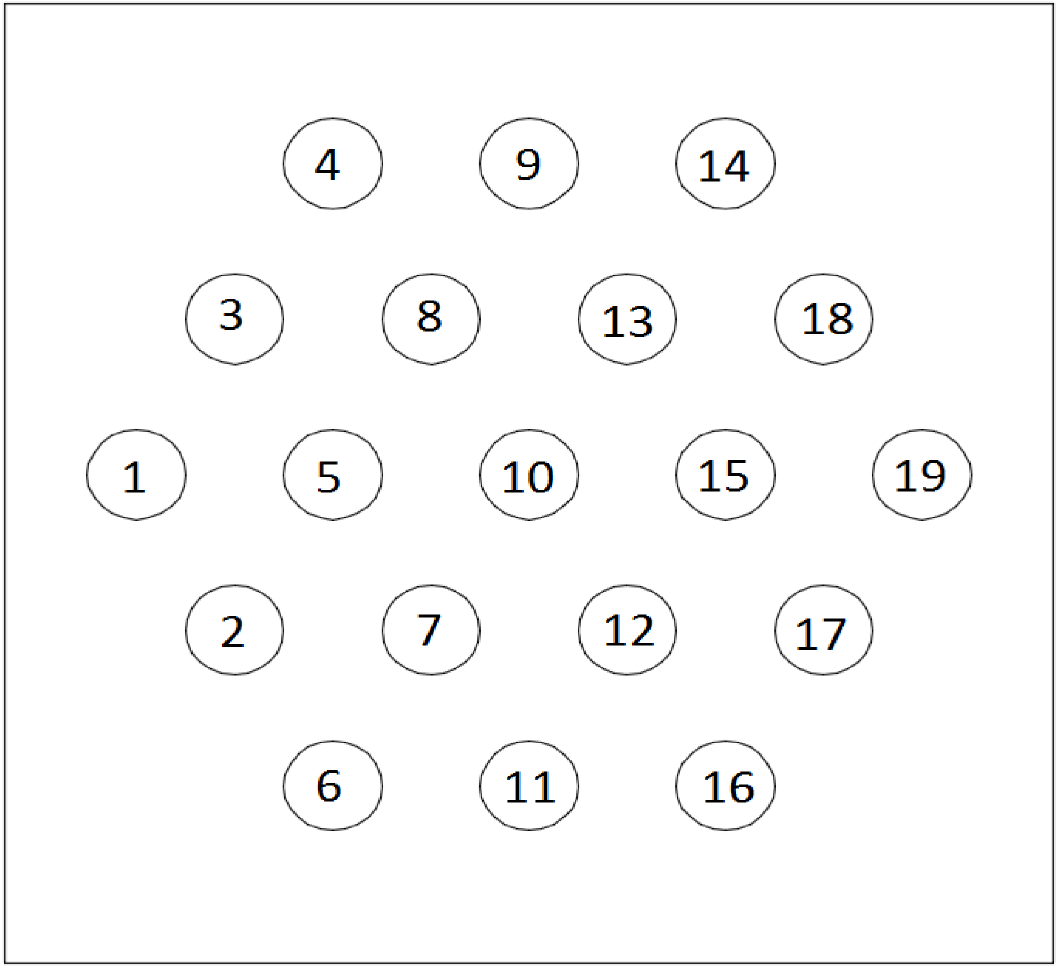
Wet Mixing System

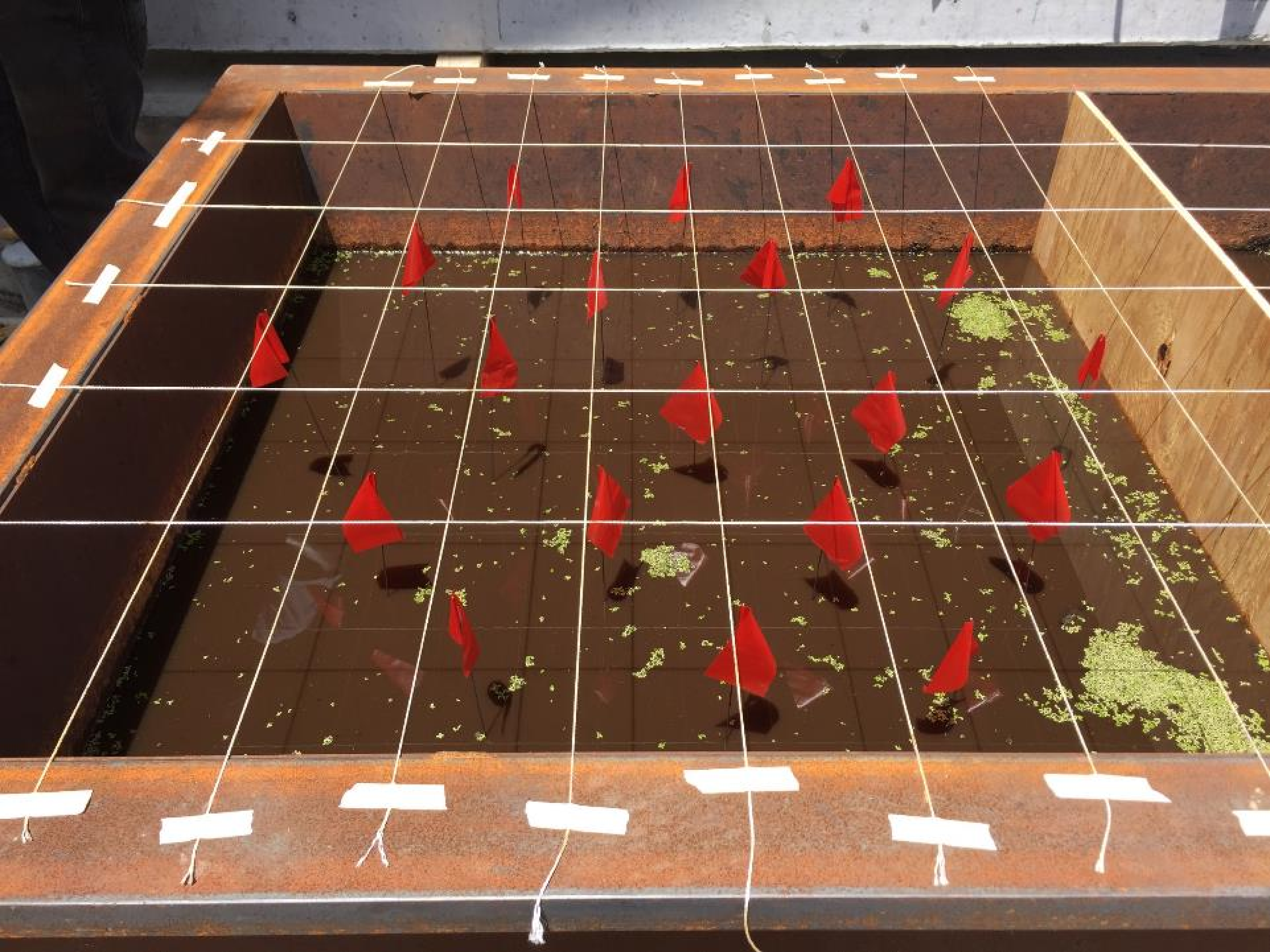


Wet Mixing System



Wet Mixing Column Layout






Wet
Dry
Control

Lab System Model Full Size Dry Mixing

- Preps soil with excavator
- Followed by mixing operations where dry cement/binder injected
- Amount of cement known distribution is not

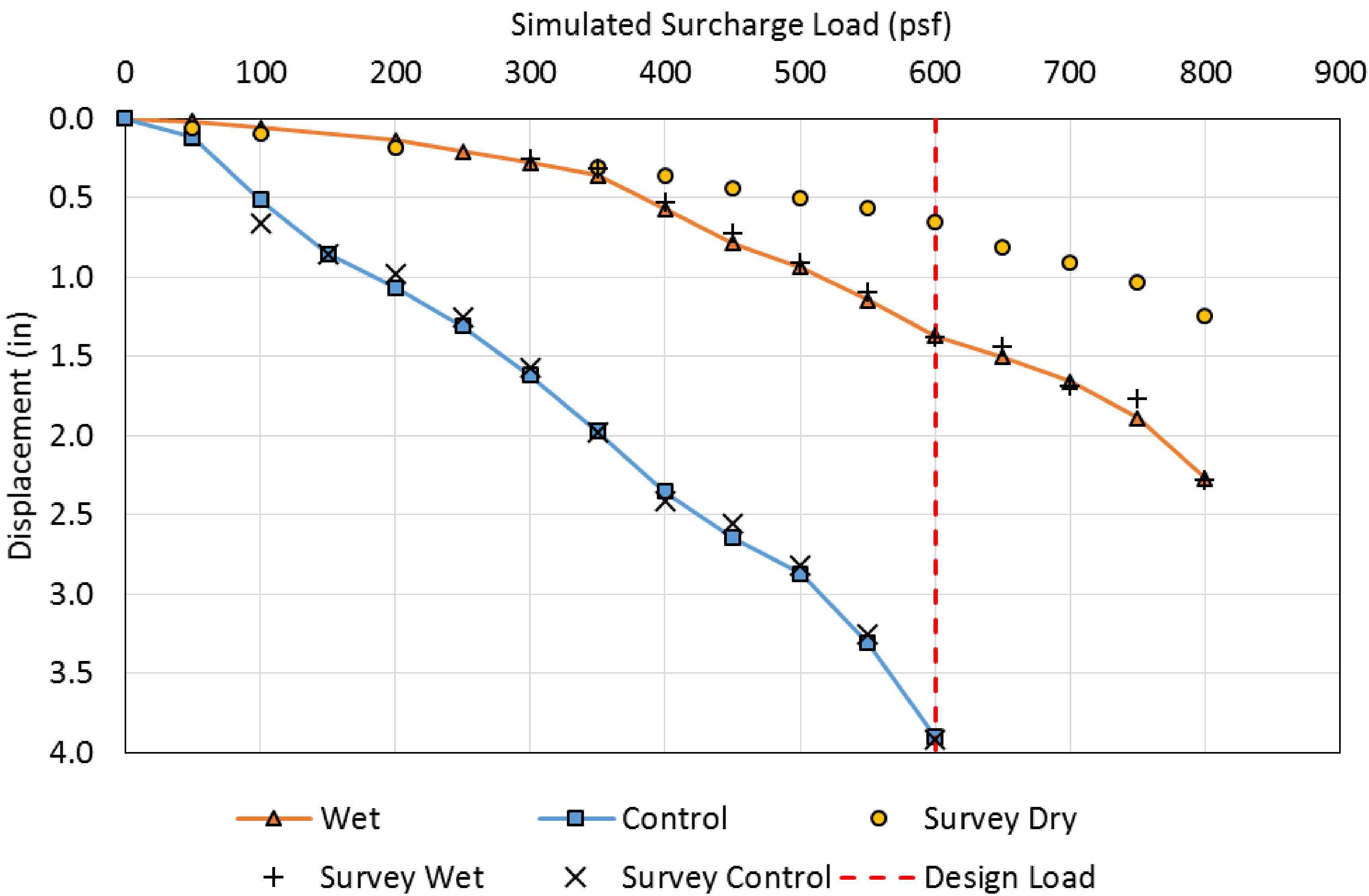
Mass Dry Mixing (prep soil)

Mass Dry Mixing (mixing)

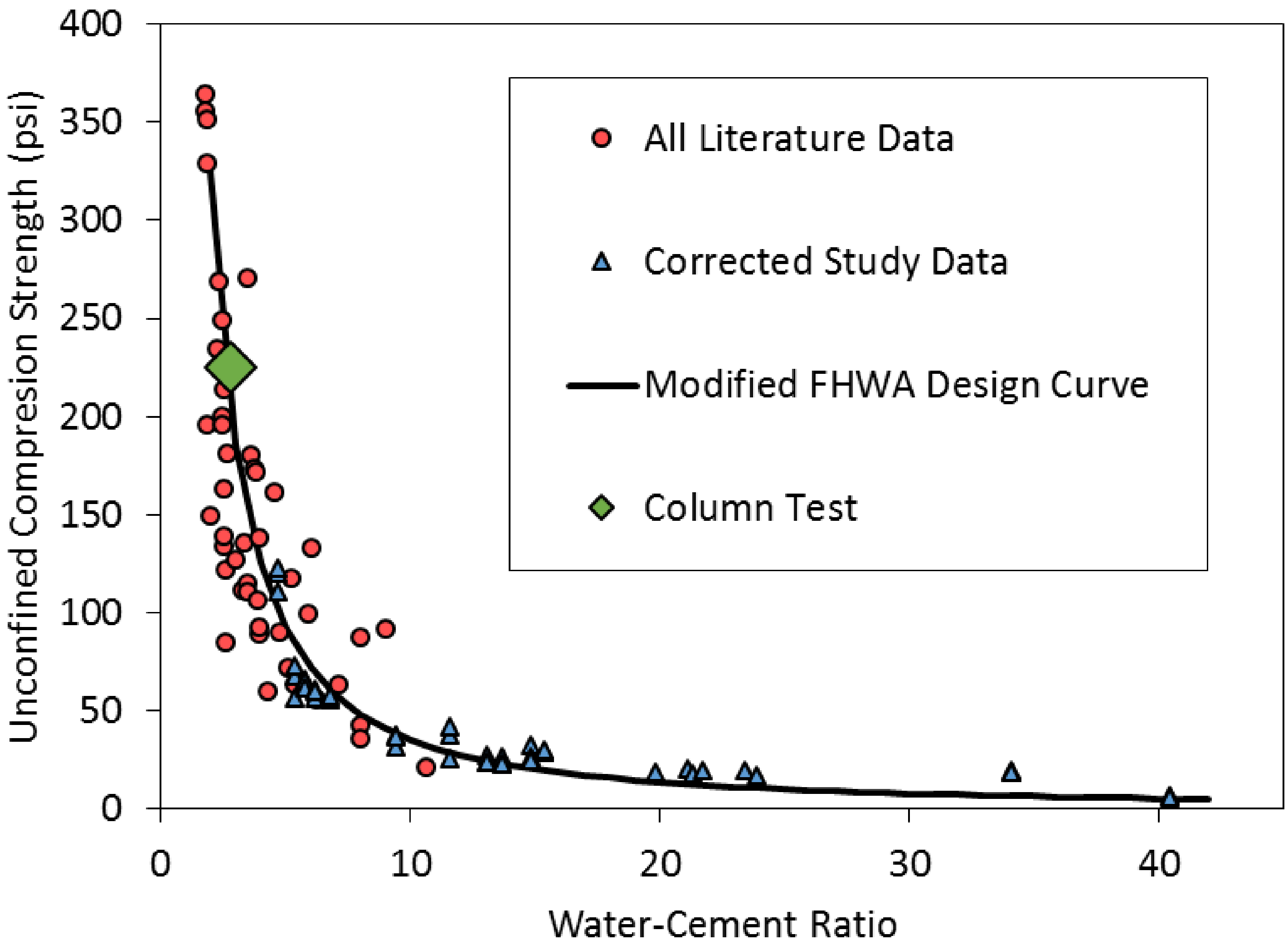
Load Testing Apparatus

Load Testing Apparatus

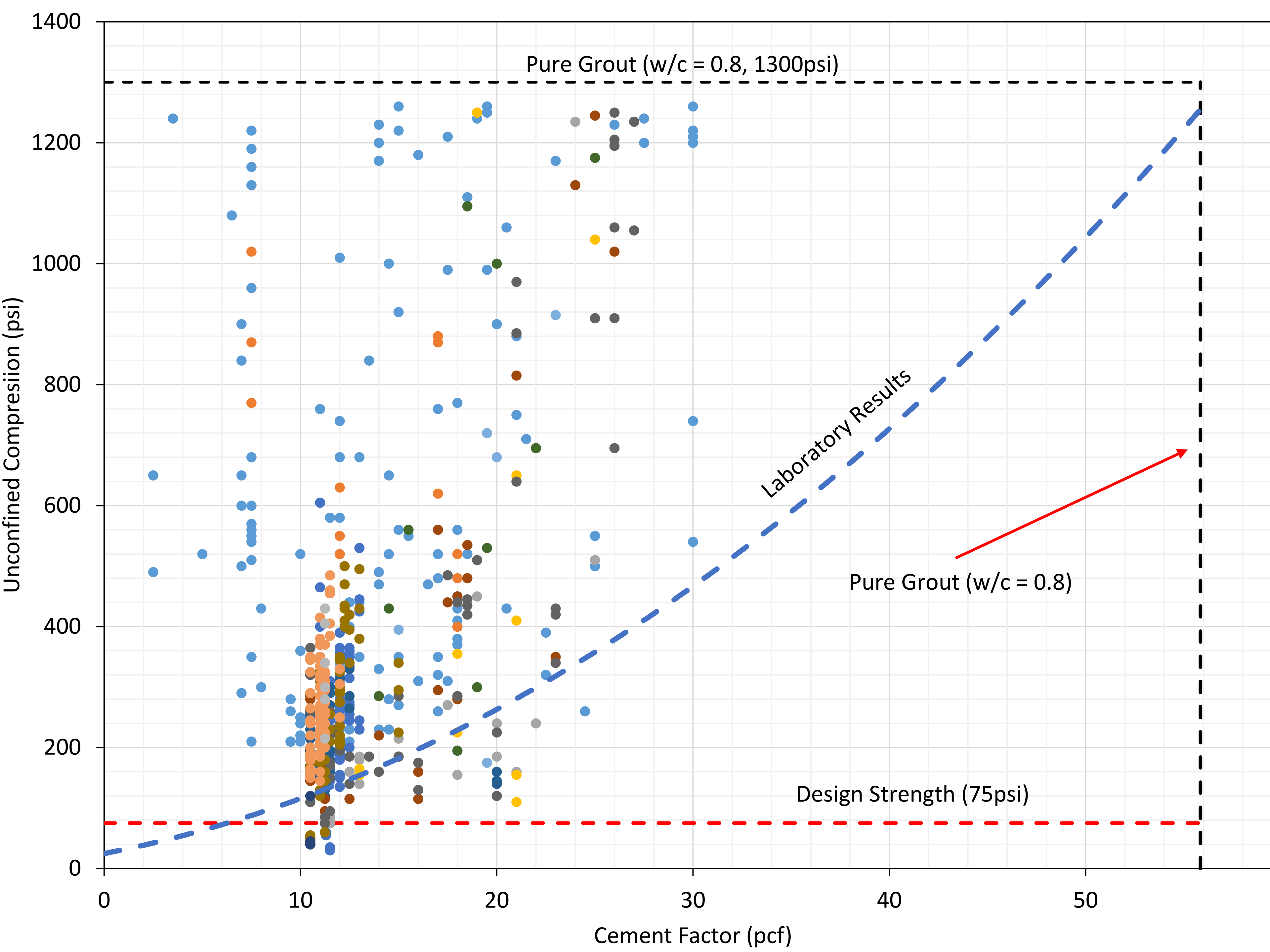
Load Test Results



Testing Threshold



Full Scale Soil Mixing US331

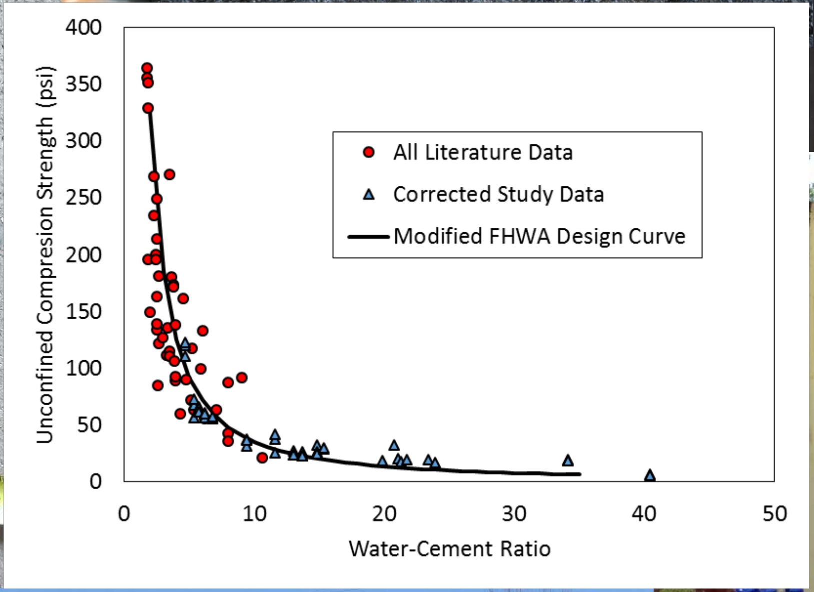


Pure Grout (w/c = 0.8, 1300psi)
Laboratory Results
Pure Grout (w/c = 0.8)
Design Strength (75psi)
Unconfined Compression (psi)
Cement Factor (pcf)
0
200
400
600
800
1000
1200
1400
0
10
20
30
40
50

Conclusions

- A cement factor threshold was defined based on organic content
- w/c of organic soil mixing can be adjusted using this threshold to match the inorganic soil design curve (FHWA)
- This threshold was derived for a specific degree of organic decomposition; values may vary for other degrees
- Field results are far less predicable

Questions?


Unconfined Compression Strength (psi)
400
350
300
250
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Corrected Study Data
Modified FHWA Design Curve


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