Development and Implementation of Aggregate Grading for Pavements

Daniel Cook, Ashkan Ghaeezadeh, Nick Seader, Bruce Russell, Tyler Ley

Acknowledgements

- Oklahoma Department of Transportation (ODOT)
- Oklahoma Transportation Center
- CP Tech Center
- FHWA Highways for Life

Outline

- Packing Models
- The Box Test
- The Tarantula Curve!
- Conclusions

Reoccurring Aggregate Questions:

- How do you proportion aggregate?
- Are packing models useful?
- Is one better than another?
- Do they provide practical answers?

Theory of Packing

"The role of the cement paste is to fill the voids between aggregates, to give a certain workability (like the grease in a ball bearing) and to bind the aggregate together when the past hardens."

-Golterman, Johansen, Palbol 1997

Theory of Packing

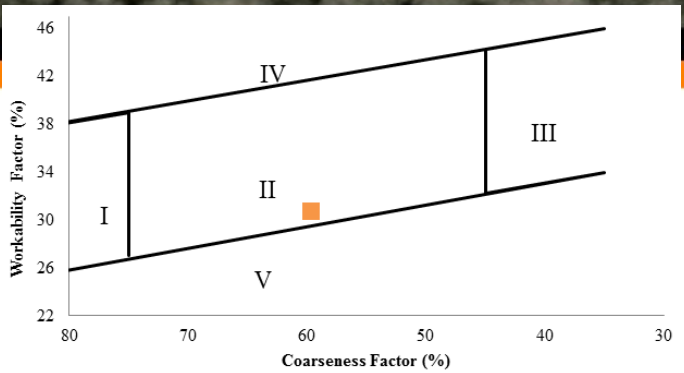
- By reducing the voids between aggregates then we reduce the paste we need.
- While it is a good idea to reduce voids in a mixture, ***we still need to have a mixture that is workable***.

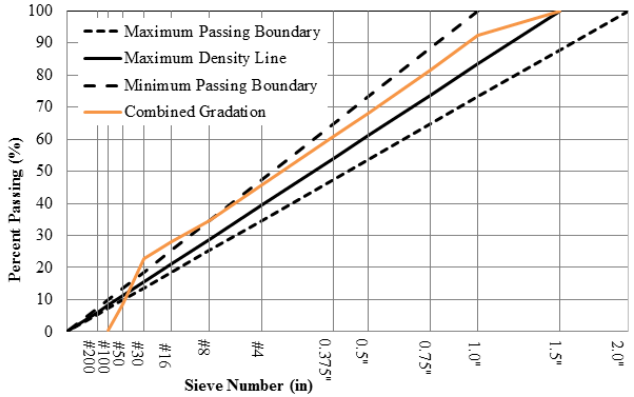
Packing Models

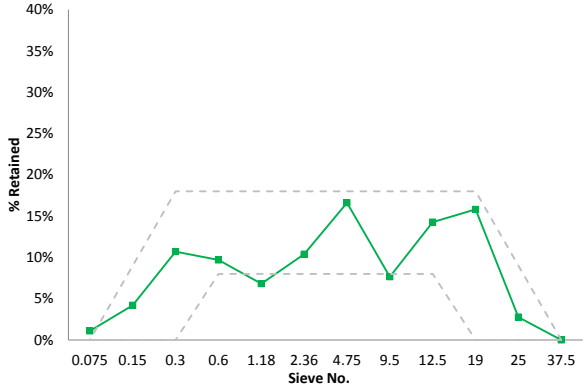
- Modified Toufar Method (2004)
  - Theoretical method that assumes spherical and monosized particles
- De Larrard (CPM) (1999)
  - Theoretical method that takes into account the actual packing, maximum packing density, and the wall effect of the container
- Specific Surface Area
- Combined dry-rodded unit weight

Graphical Methods

- Coarseness Factor
- Power 45
- Percent Retained

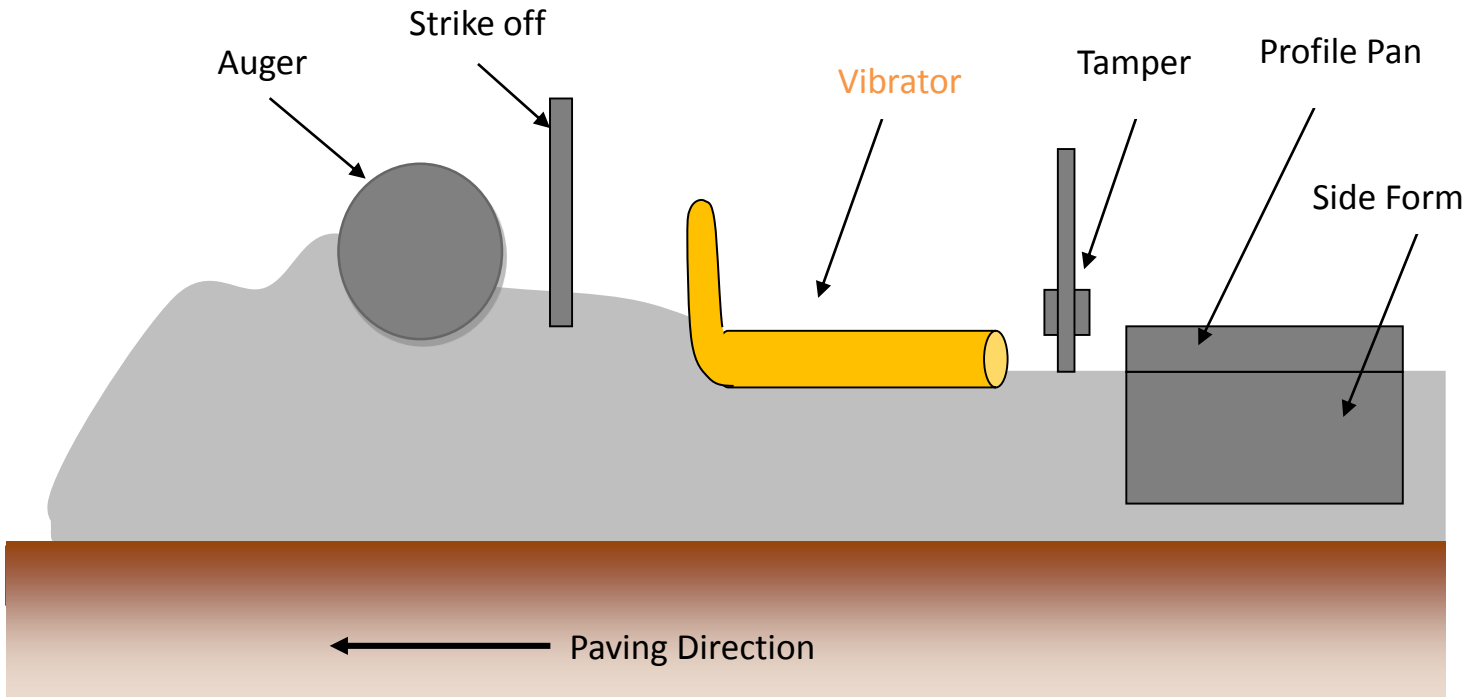




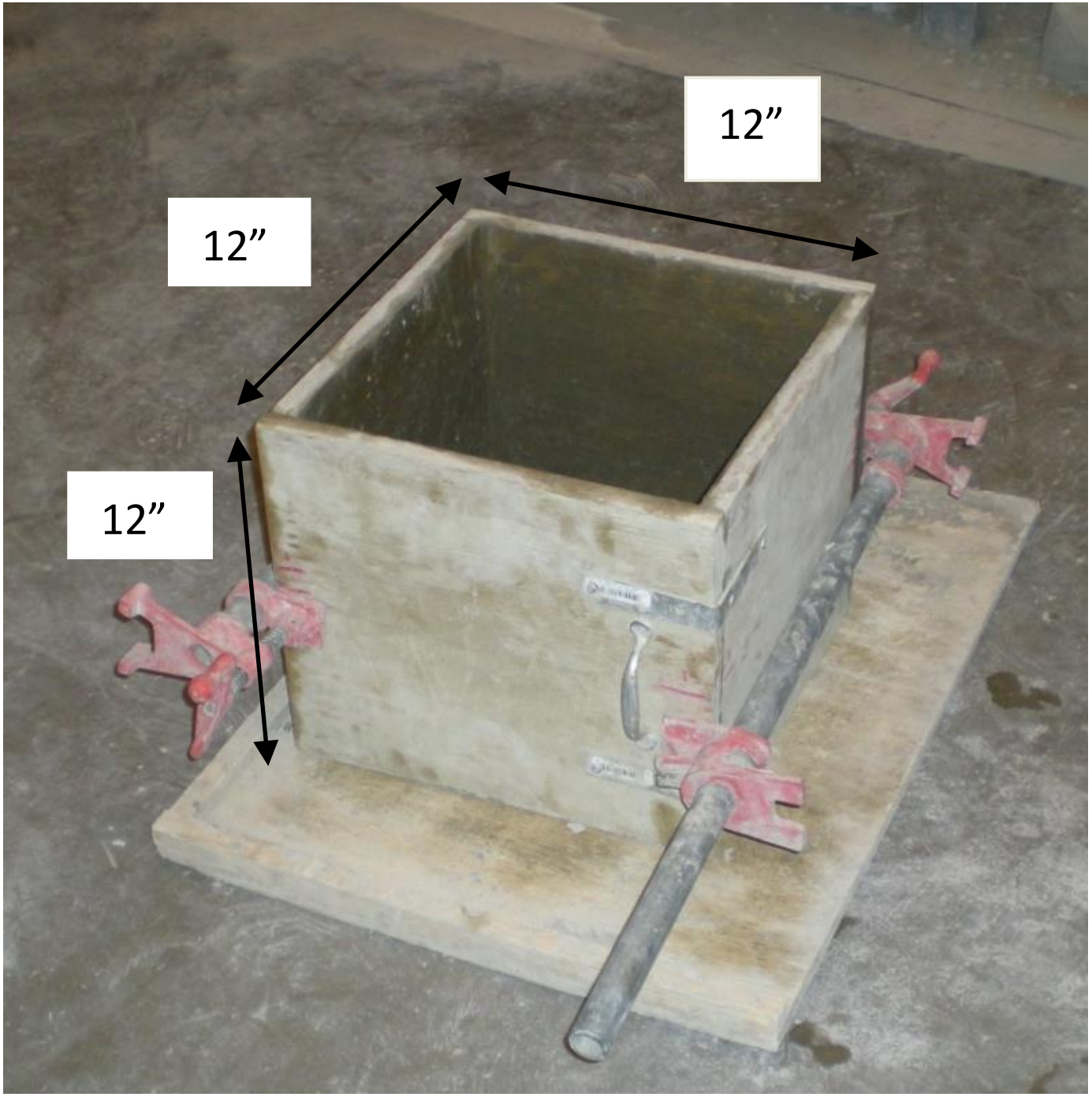


Slip Formed Paver

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



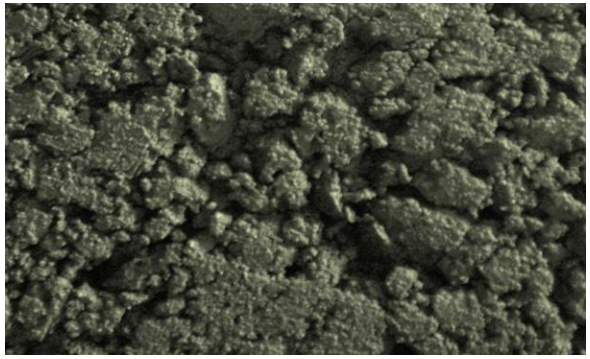
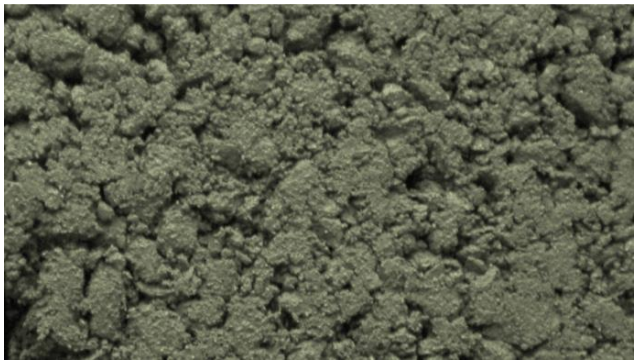
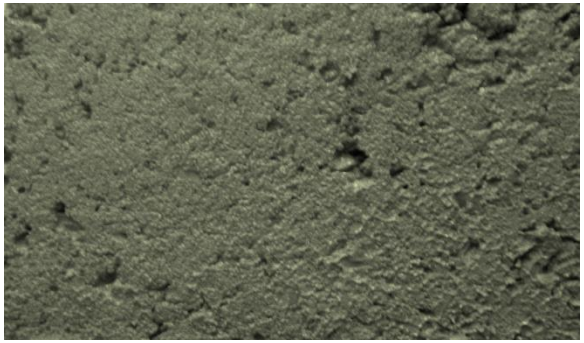
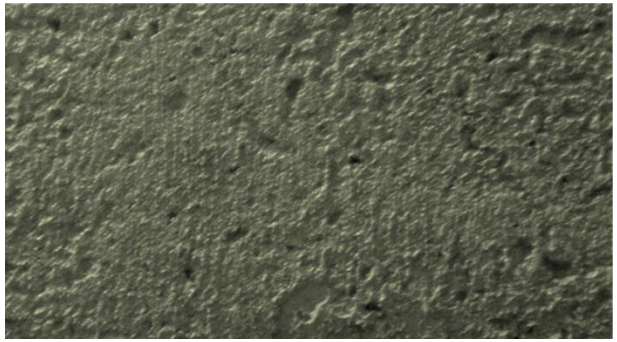
- We want a test that is simple and can examine:
  - Response to vibration
  - Filling ability of the grout (avoid internal voids)
  - Ability of the slip formed concrete to hold a sharp edge (cohesiveness)


12”
12”
12”

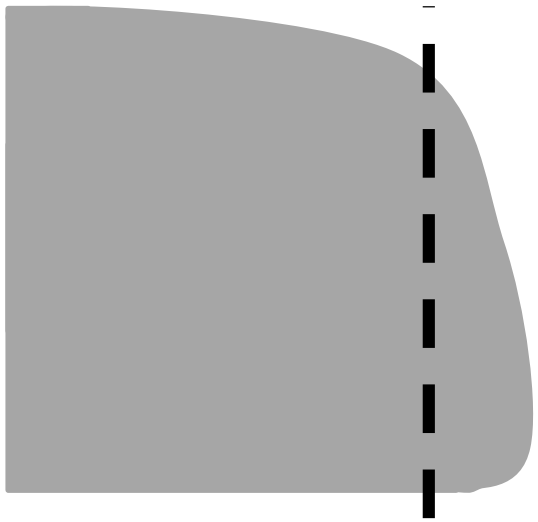
Box Test

- 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

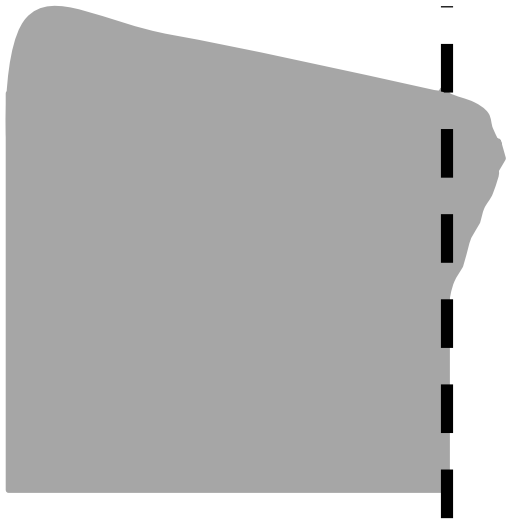
Box Test Ranking Scale

	
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.

Edge Slumping



Bottom Edge Slumping

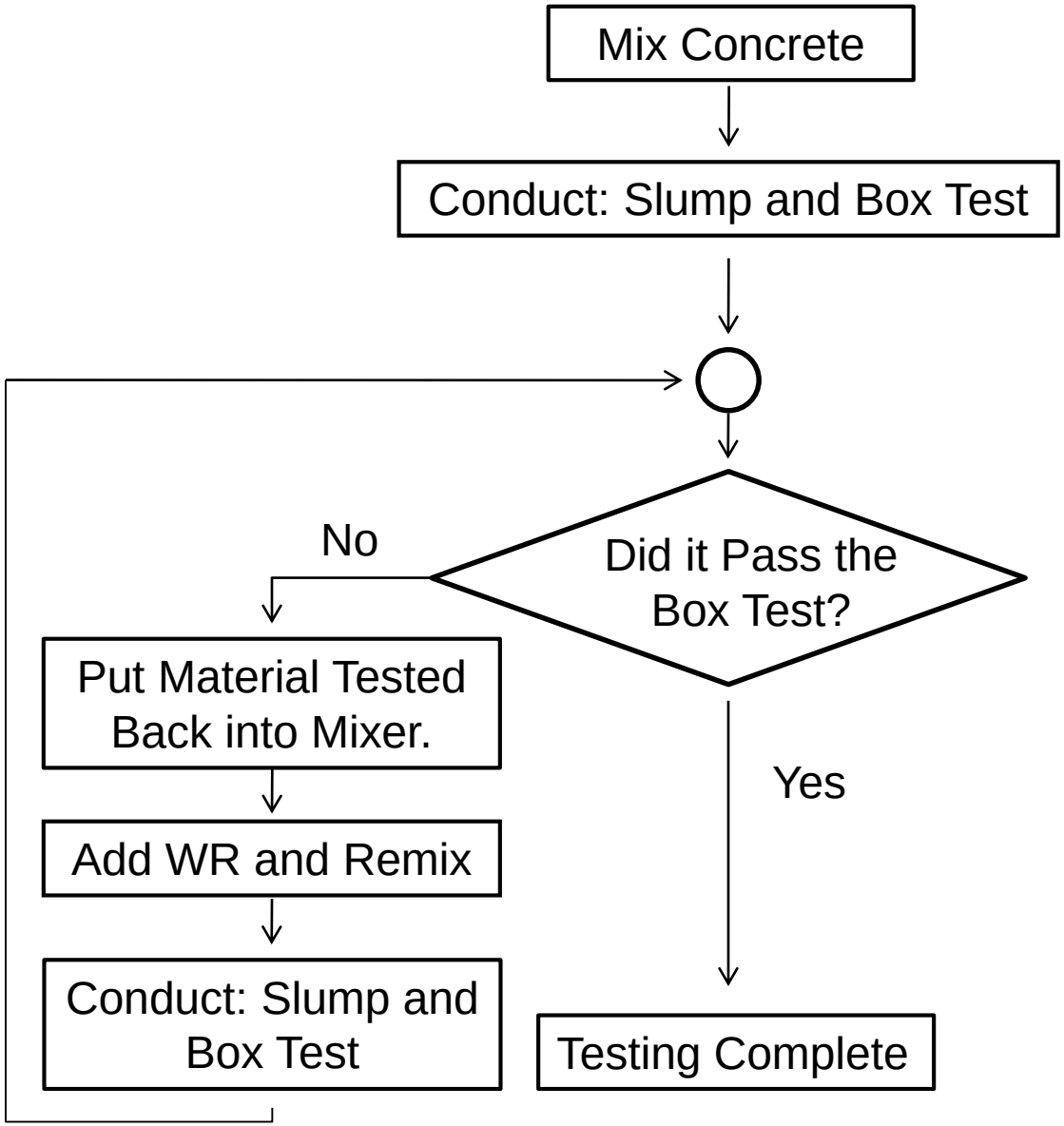


Top Edge Slumping

No Edge Slump

Edge Slump

Evaluating Mixtures with the Box Test



Summary of the Box Test

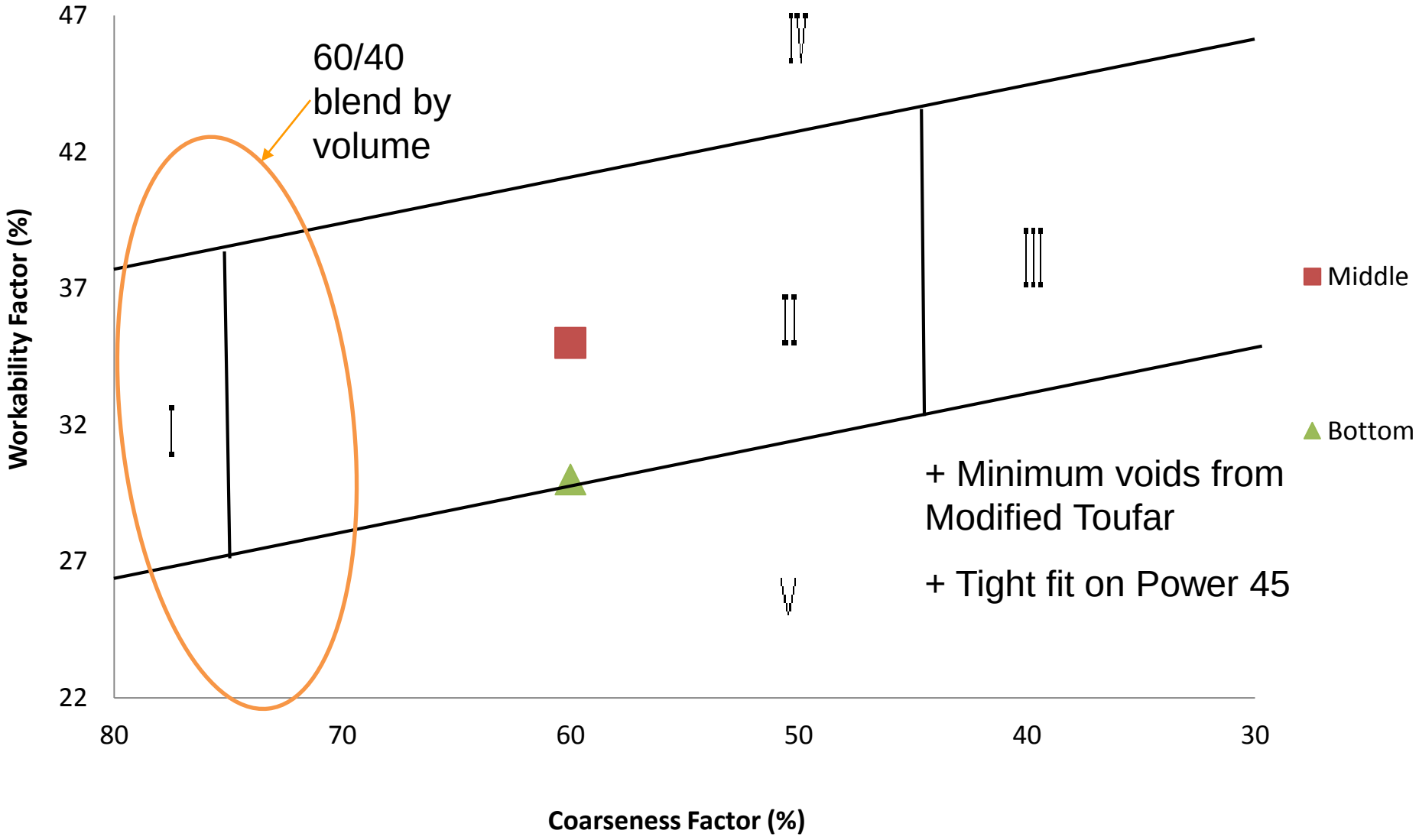
- The box test evaluates the response of a concrete mixture to vibration and the ability to hold an edge.
- We did this because no other test exists that can tell us this information.
- Low amounts of water reducer is good
- High amounts are bad

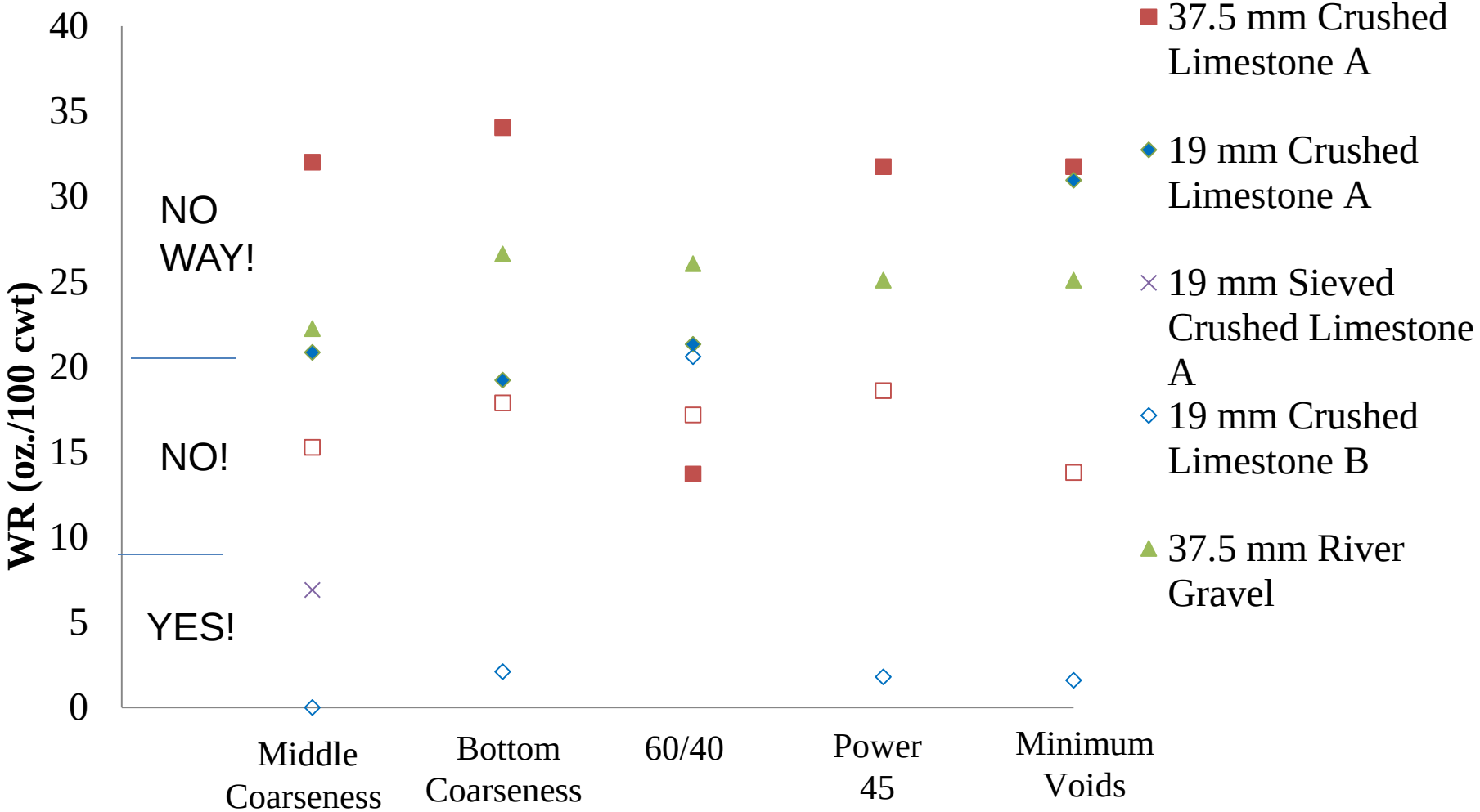
Validation

- Single operator +/- 1.5 oz./cwt
- Multiple operators +/- 3.2 oz./cwt
- Same box test performance was found if the WR was added up front or if added in small dosages
- If the sample did not pass the box test within one hour it was discarded
- The box test has compared well with field paving mixes

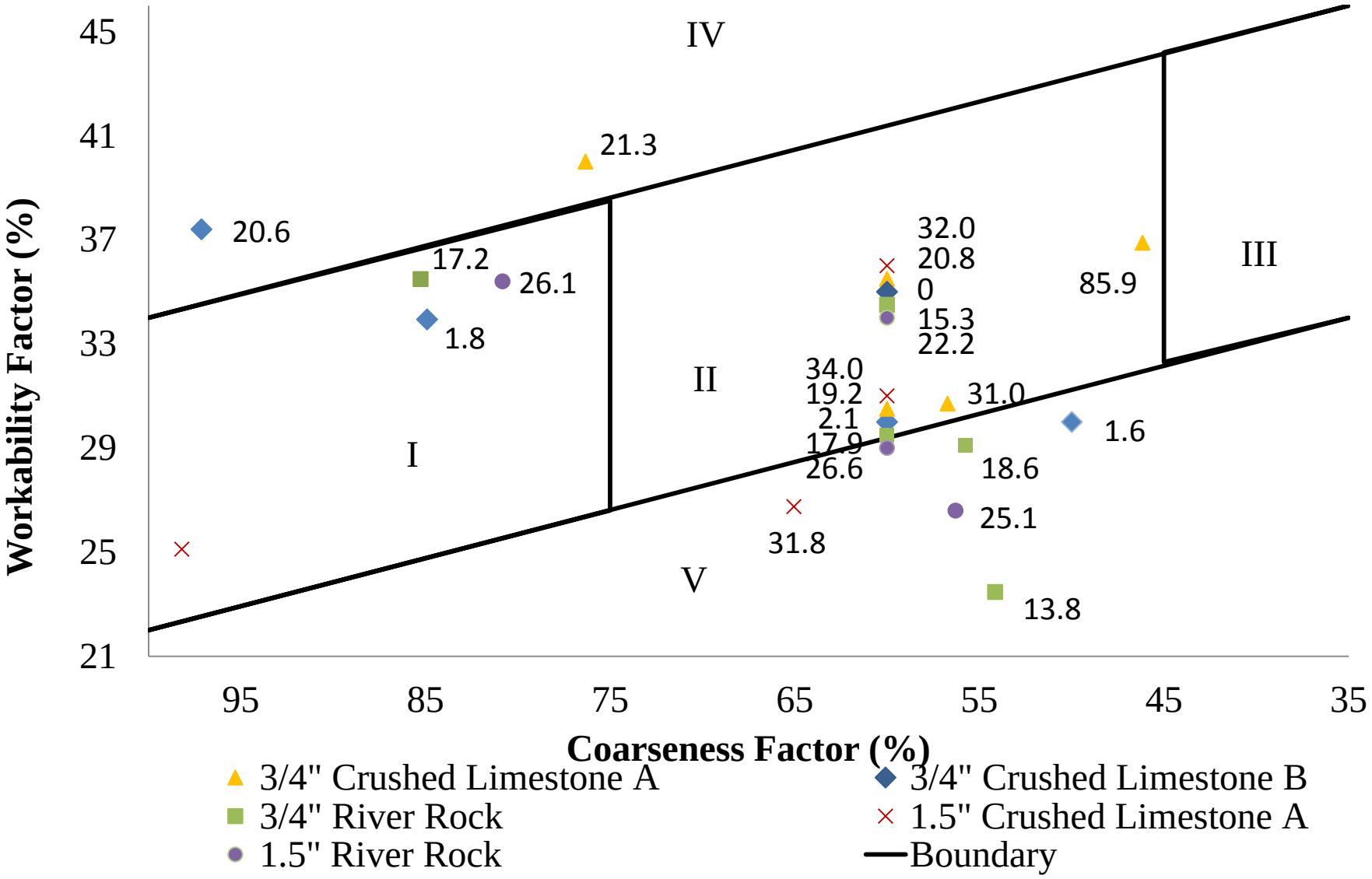
Mixtures

- .45 w/cm
- 5 Sacks total cementitious (470 lbs)
- A single sand source
- 3 coarse and intermediate aggregates:
  - Limestone A
  - Limestone B
  - Crushed River Gravel

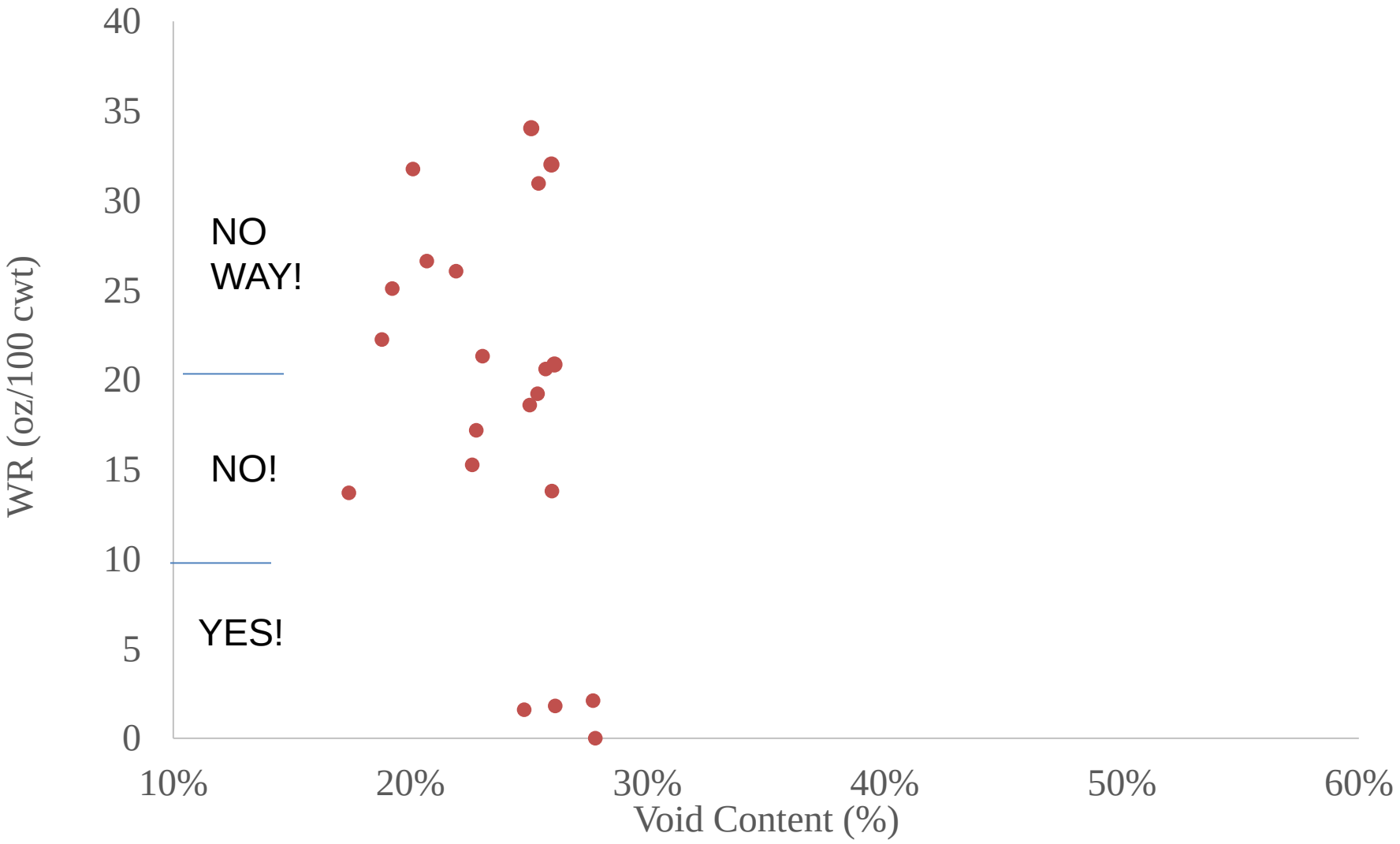

47
42
37
32
27
22
Workability Factor (%)
80
70
60
50
40
30
Coarseness Factor (%)
60/40
blend by
volume
+ Minimum voids from
Modified Toufar
+ Tight fit on Power 45
Middle
Bottom


40
35
30
25
20
15
10
5
0
WR (oz./100 cwt)
NO WAY!
NO!
YES!
Middle Coarseness
Bottom Coarseness
60/40
Power 45
Minimum Voids
37.5 mm Crushed Limestone A
19 mm Crushed Limestone A
19 mm Sieved Crushed Limestone A
19 mm Crushed Limestone B
37.5 mm River Gravel

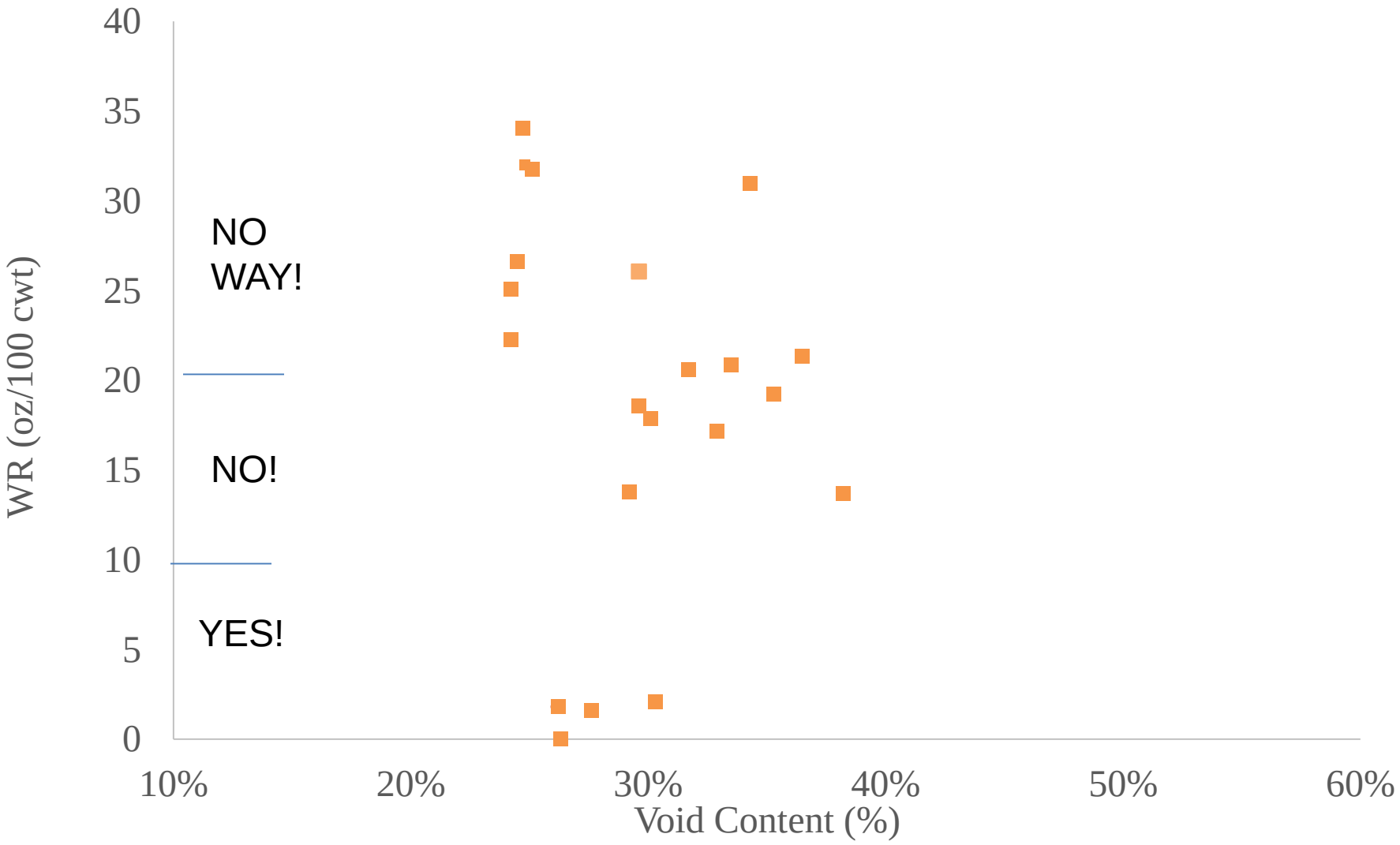
Coarseness Chart



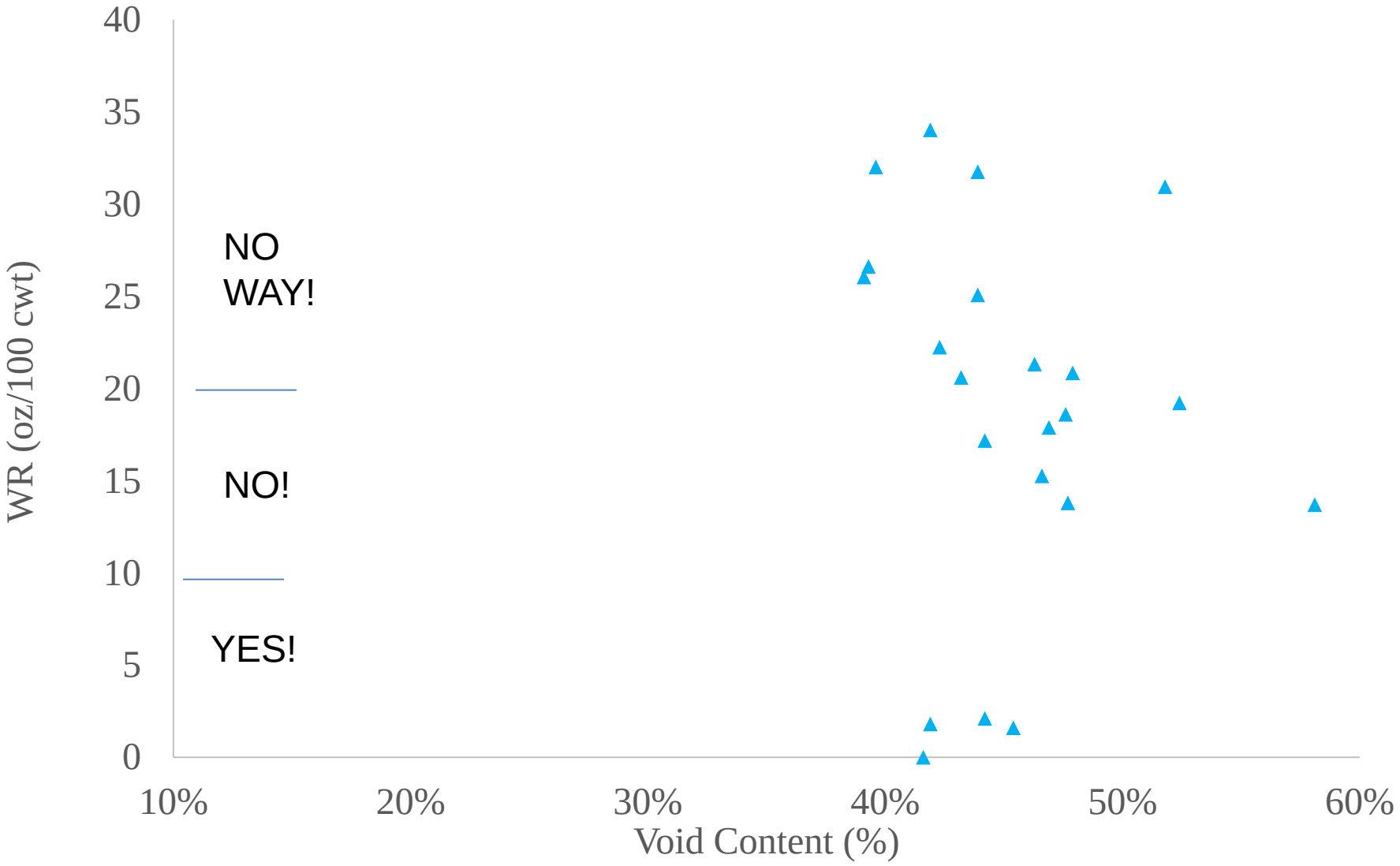
Dry Rodded Unit Weight of Coarse and Fine



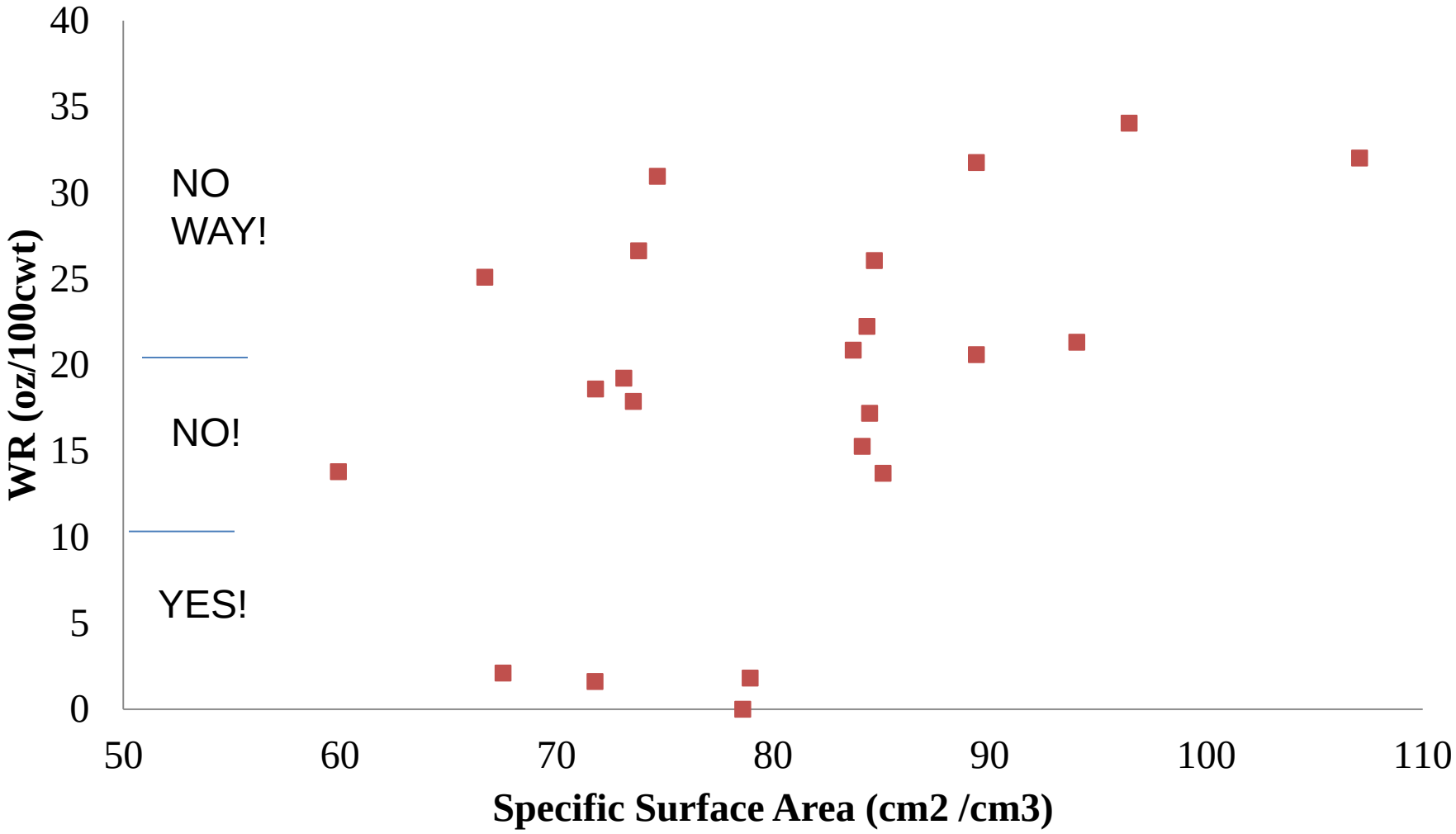
Modified Toufar



De Larrard

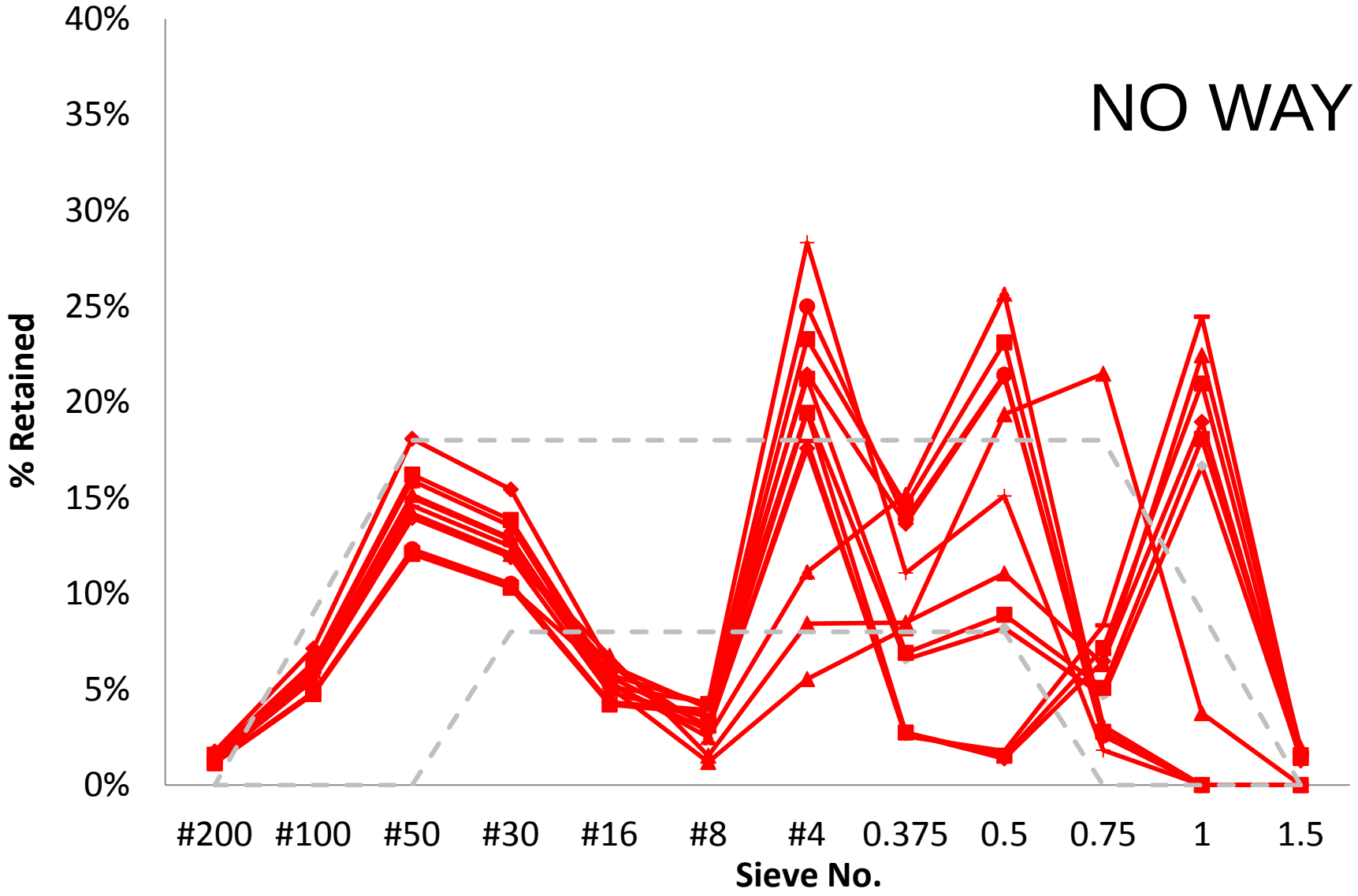

40
35
30
25
20
15
10
5
0
WR (oz/100 cwt)
NO
WAY!
NO!
YES!
10%
20%
30%
40%
50%
60%
Void Content (%)

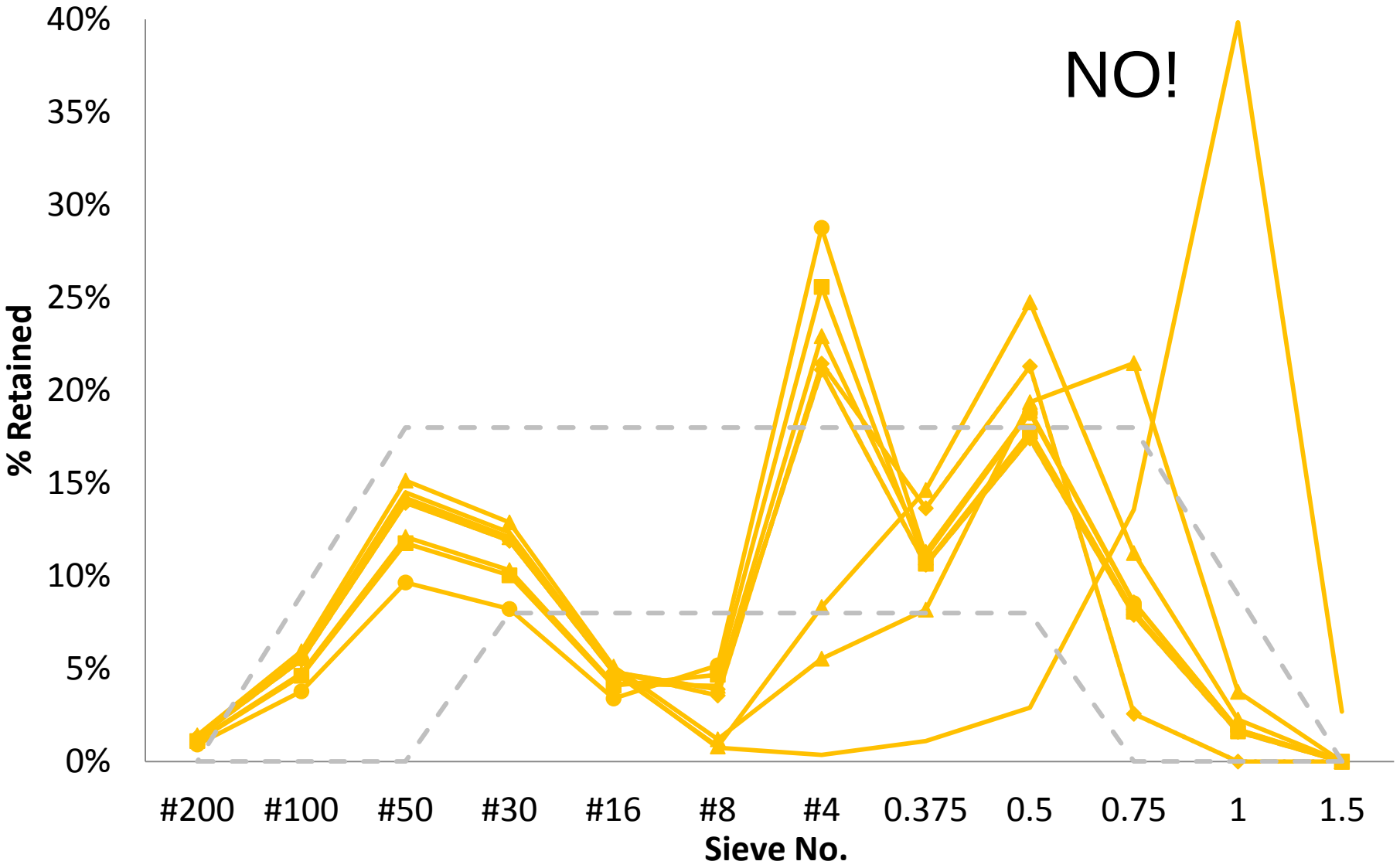
Specific Surface Area (SSA)

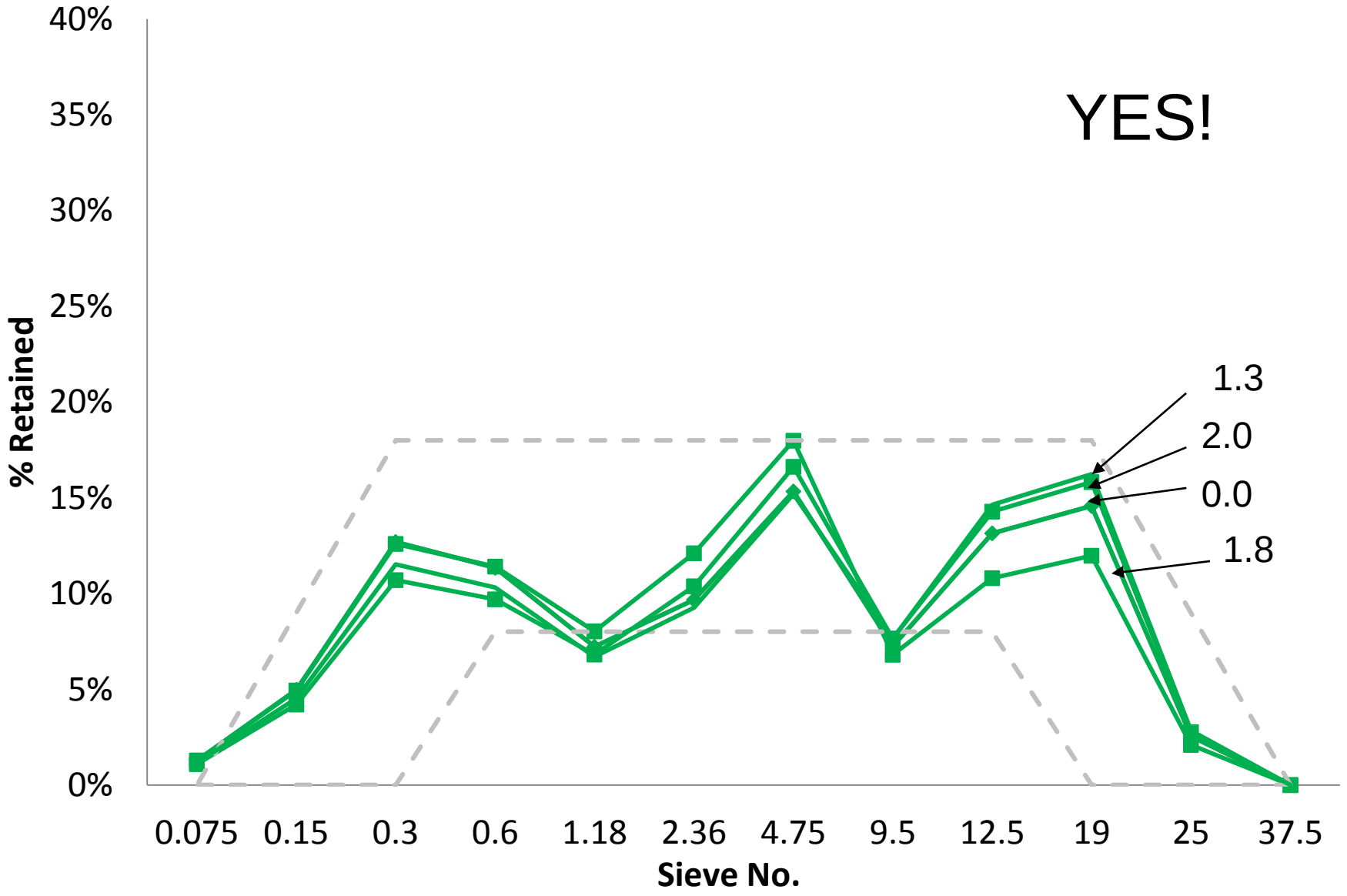


Summary

- None of the following show good correlation to the box test results:
  - Voids content in the two packing models
  - Specific surface area
  - Voids content in the combined dry rodded unit weight
  - Location in the Coarseness Factor Chart


NO WAY!
40%
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.


NO!
40%
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.

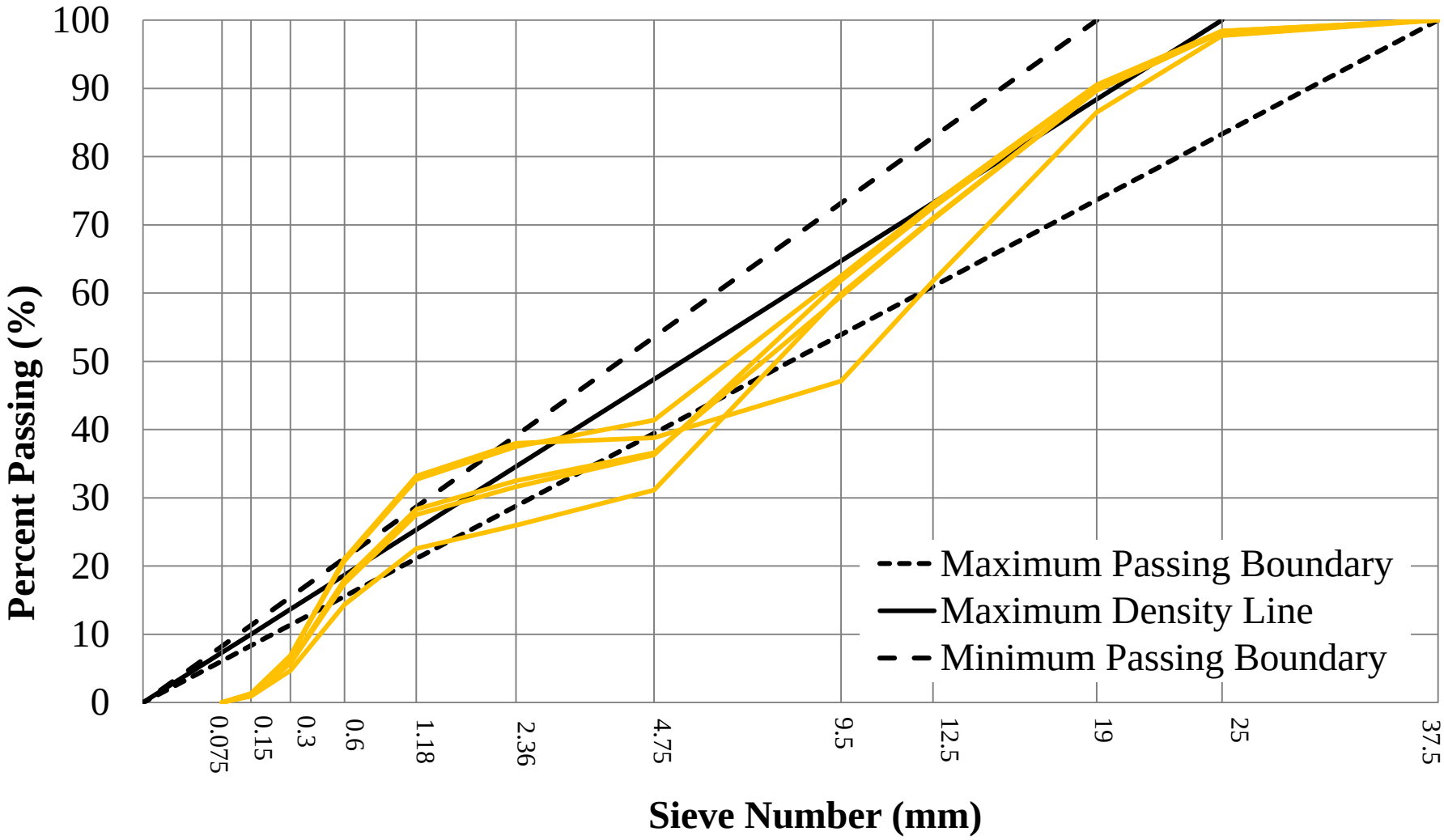

YES!
40%
35%
30%
25%
20%
15%
10%
5%
0%
% Retained
0.075
0.15
0.3
0.6
1.18
2.36
4.75
9.5
12.5
19
25
37.5
Sieve No.
1.3
2.0
0.0
1.8

Summary

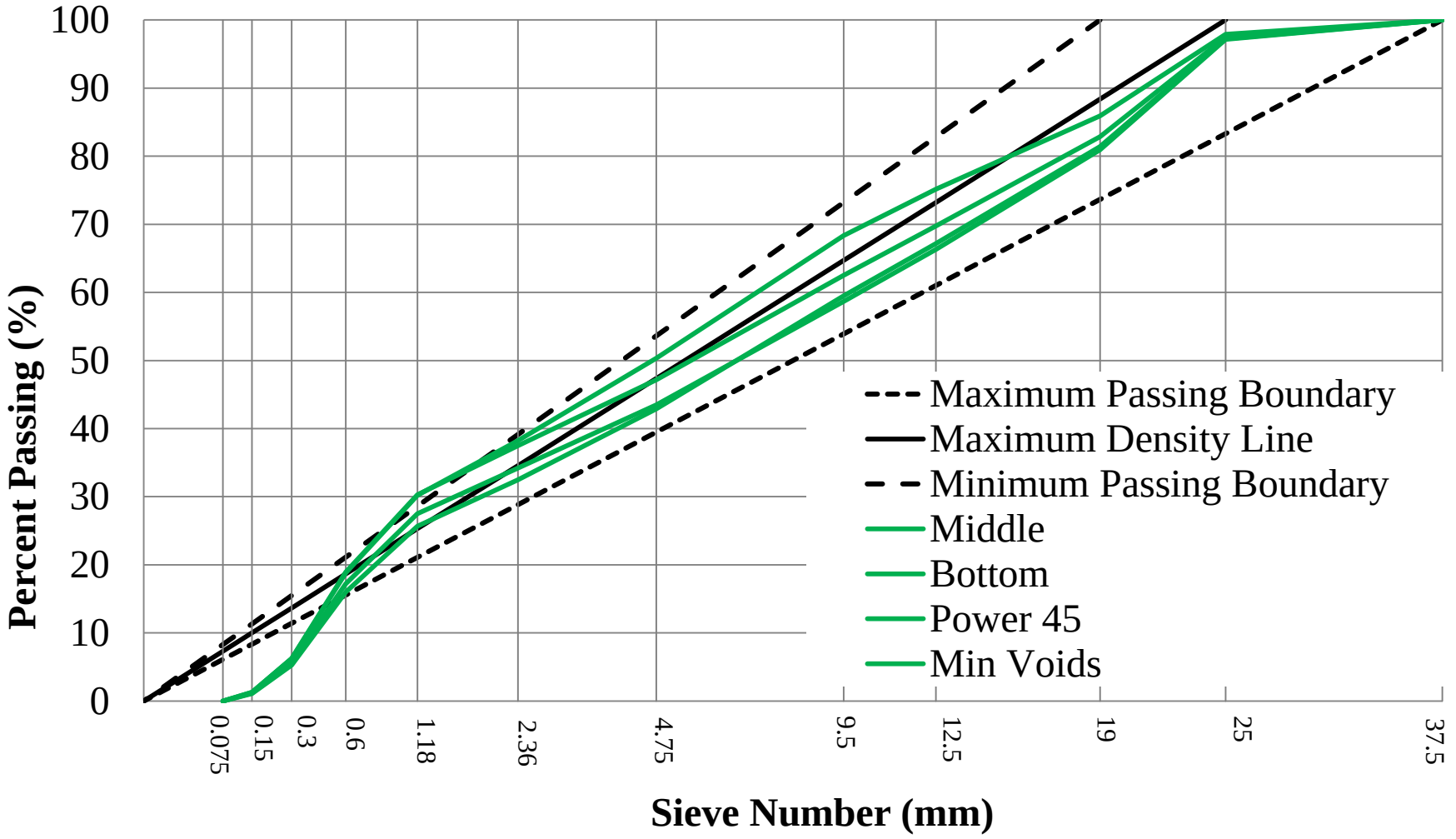
The percent retained chart did a good job of indicating which gradation would have a good performance in the box test!

How about the Power 45?

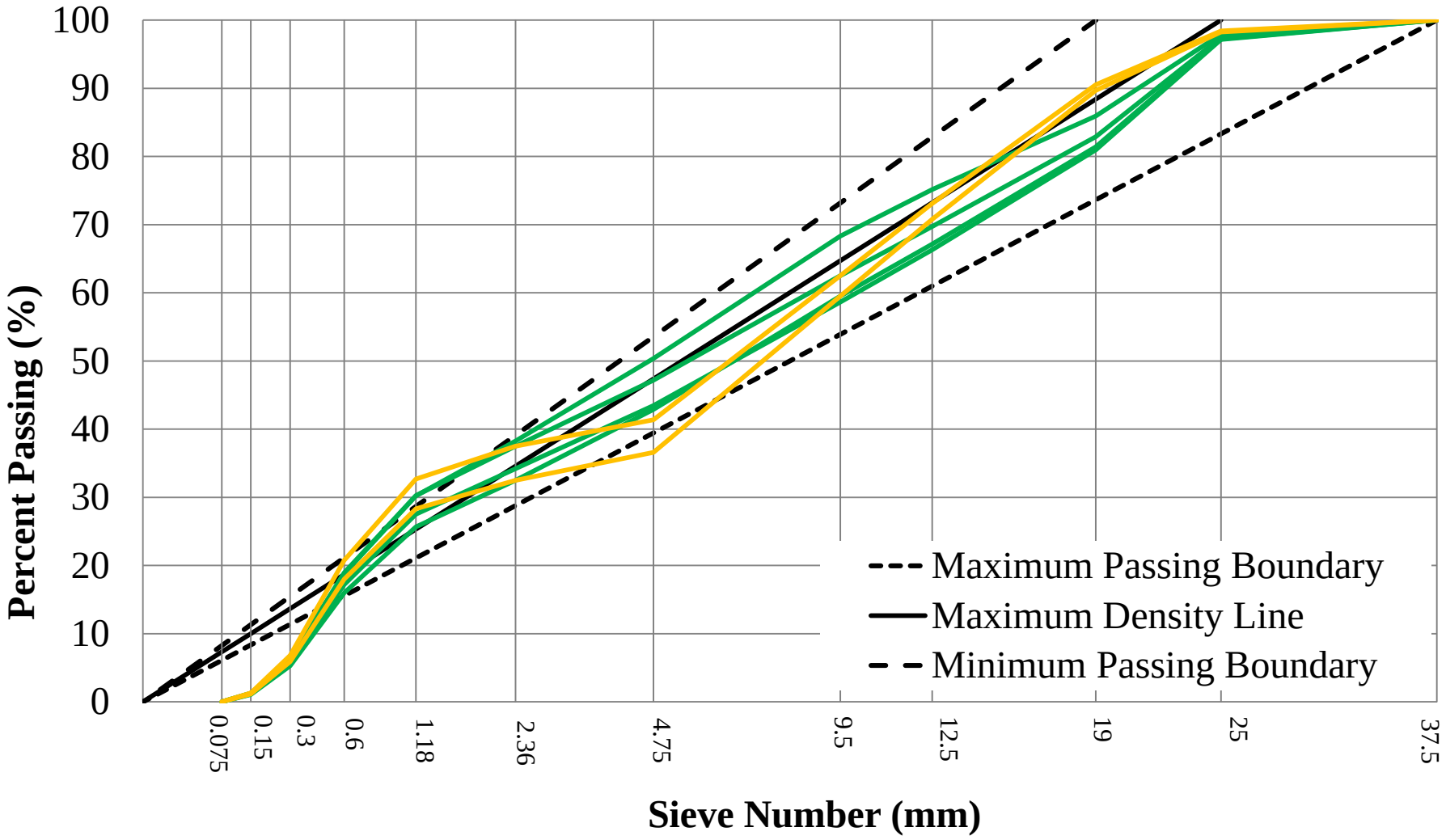
Between 10 & 20 oz./cwt of WR No!



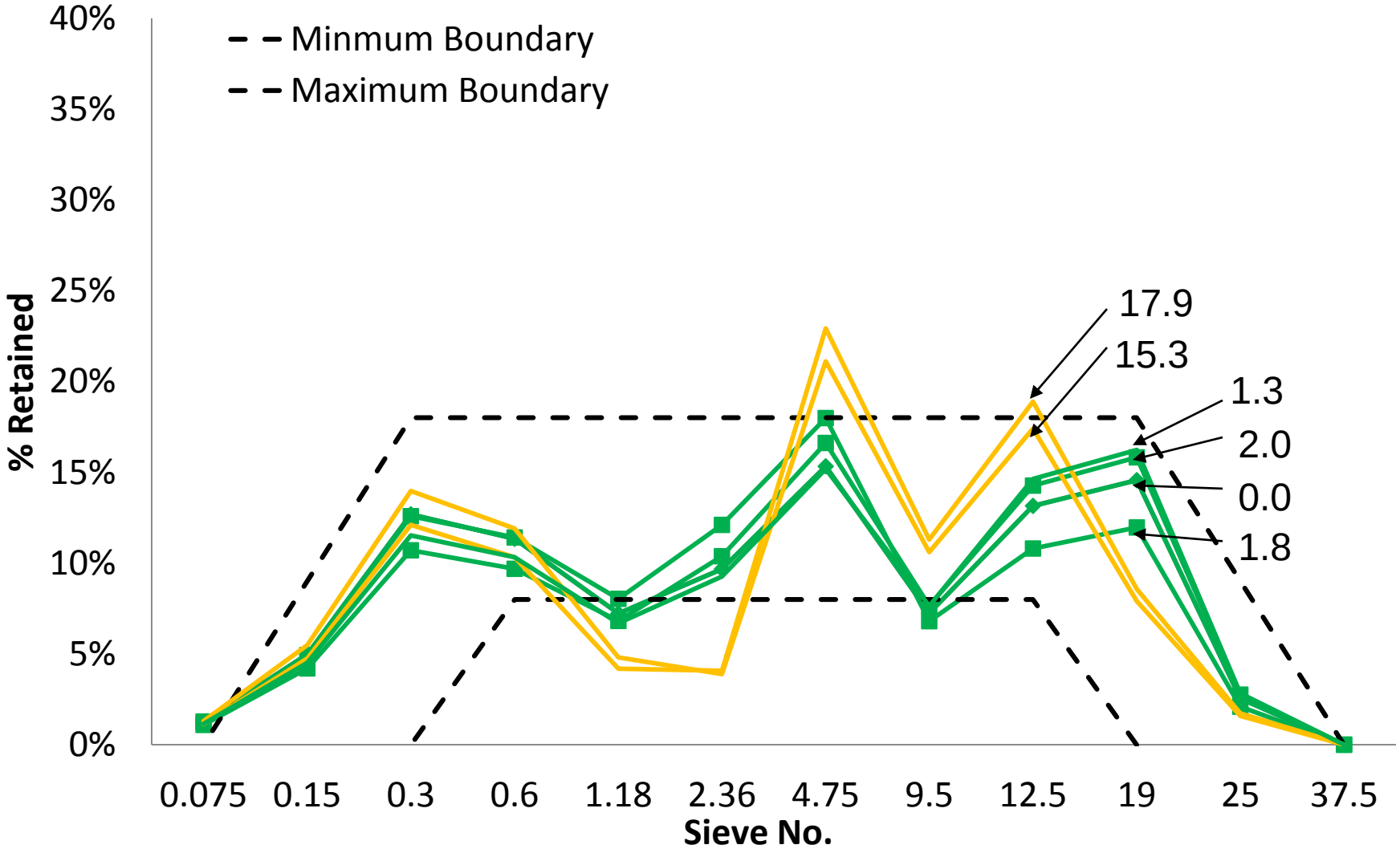
Lower than 10 oz./cwt of WR Yes!



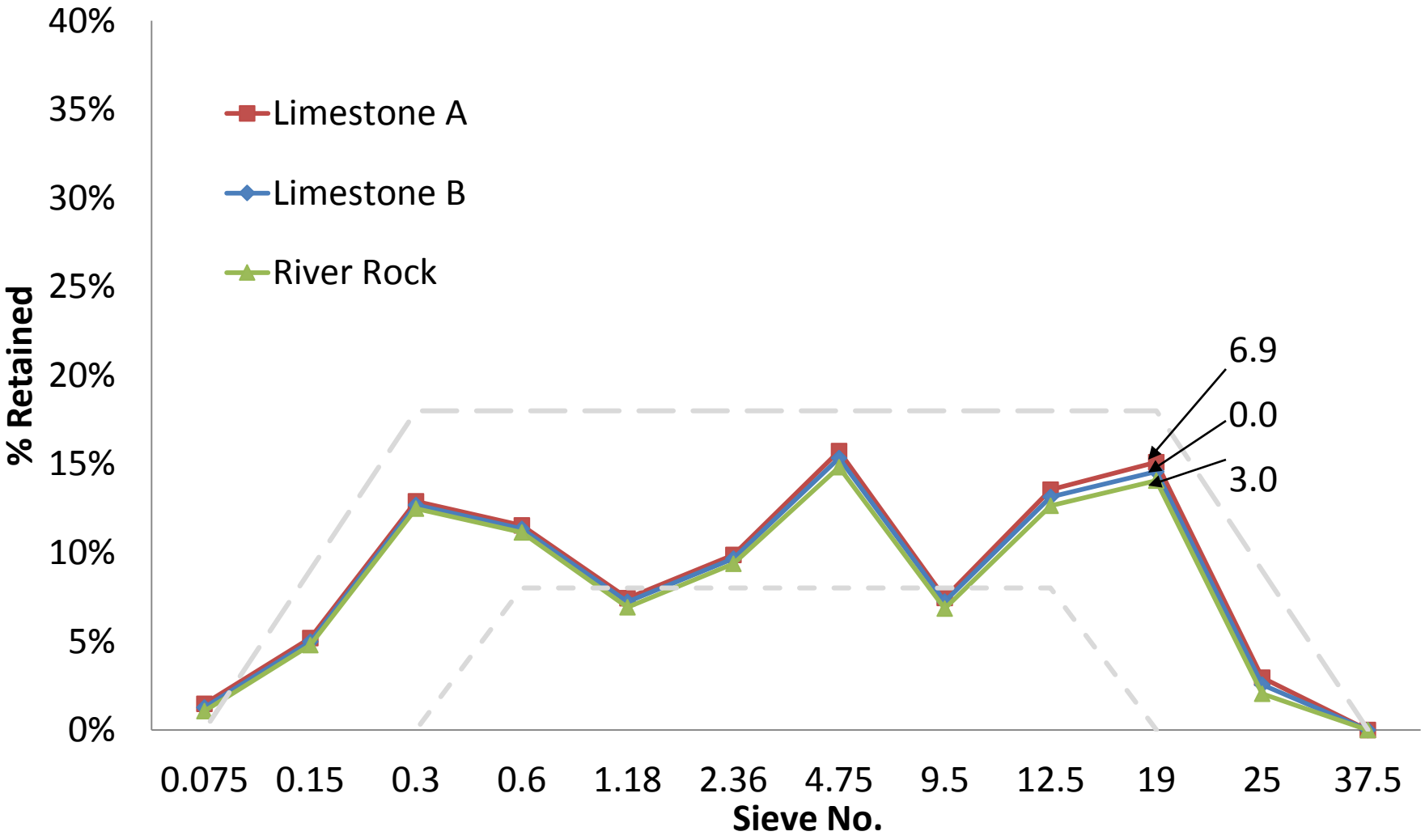
How can you tell the difference?



This helps a lot!



To better compare the performance we sieved the aggregates to have the exact same gradation.


40%
35%
30%
25%
20%
15%
10%
5%
0%
% Retained
Limestone A
Limestone B
River Rock
6.9
0.0
3.0
0.075
0.15
0.3
0.6
1.18
2.36
4.75
9.5
12.5
19
25
37.5
Sieve No.

Why is the WR dosage different?

0.0 oz/cwt

Crushed Limestone B
Cubic Shaped
Medium Angular
Low Texture

3.0 oz/cwt

Crushed Gravel
Slightly Flat Shaped
Low Angular
Low Texture

6.9 oz/cwt

Crushed Limestone A
Flat Shaped
Medium Angular
Medium Texture

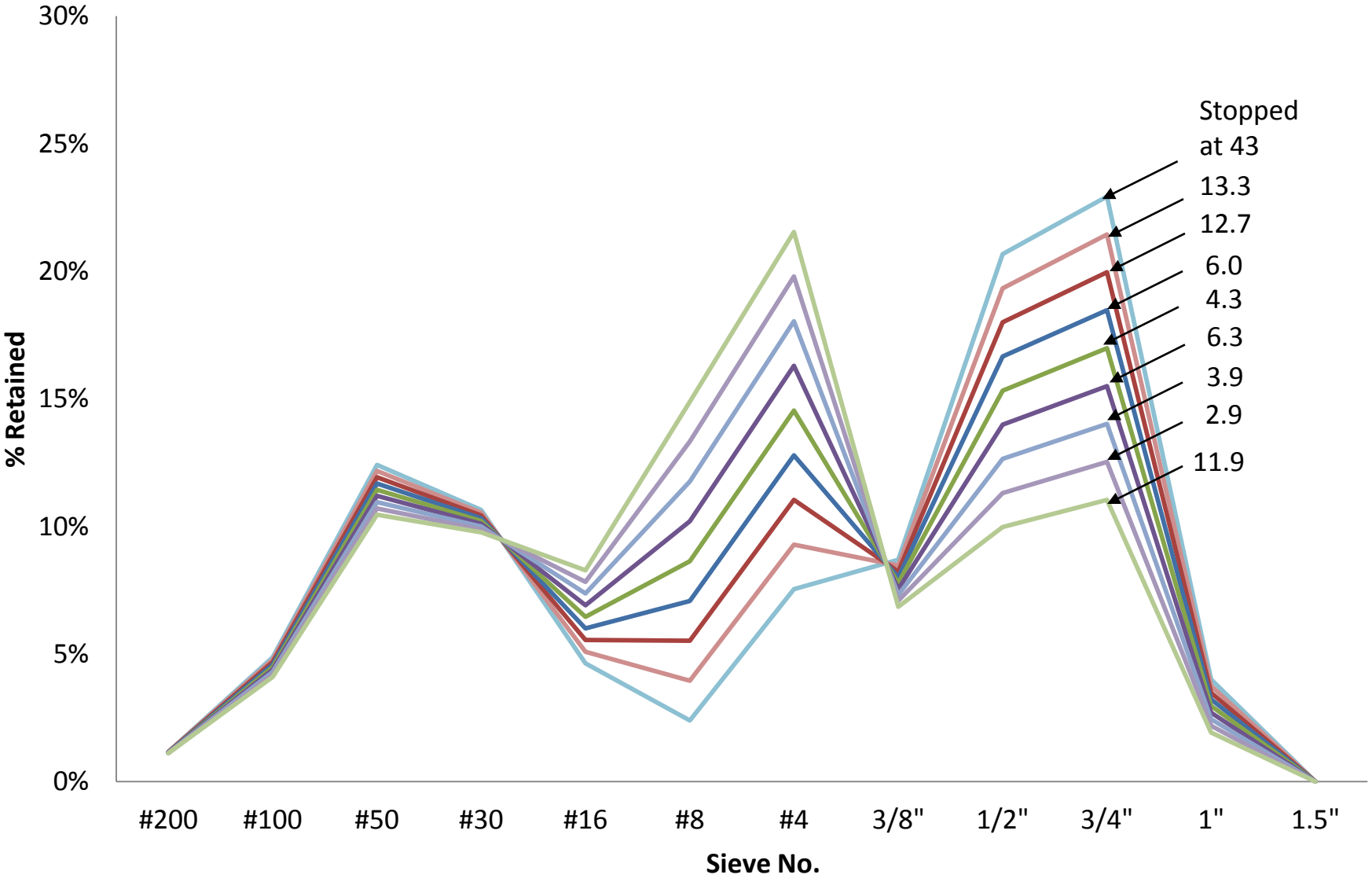
Summary

While the individual percent retained chart did the best job of the techniques investigated, the aggregate flatness and texture plays a role in performance.

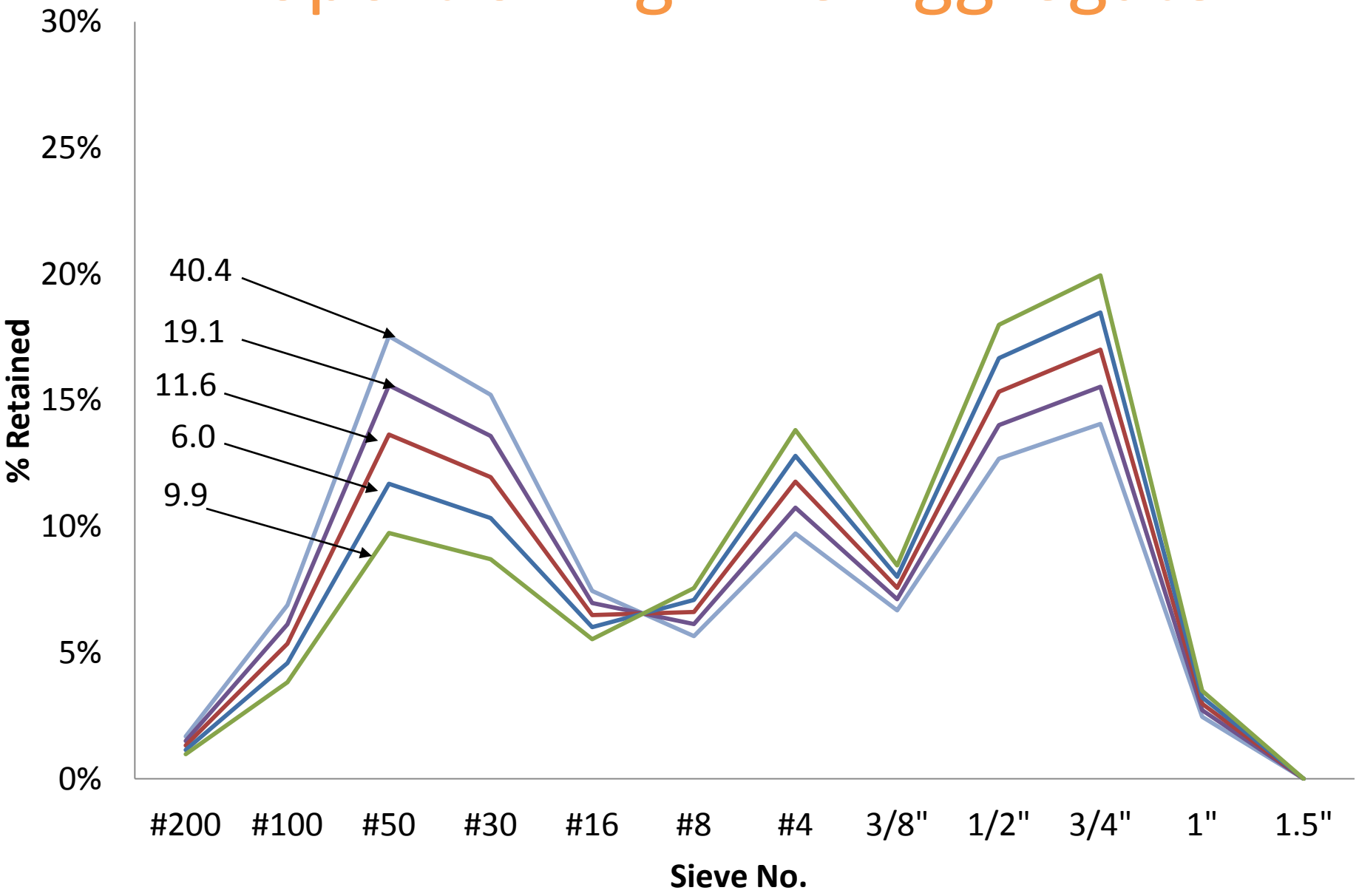
Use of the Box Test to Evaluate Gradations

- .45 w/cm
- 20% fly ash
- Three sand sources
- Used 5 coarse aggregates
  - Three limestones
  - Two river gravels
- All mixtures are 4.5 sack (423 lbs/cy)

Proportioning of Coarse to Intermediate



Proportioning Fine Aggregate



The *TARANTULA* curve!!!!

Excessive amount creates workability issues.

Creates surface finishability problems normally associated with manufactured sands.

Excessive amount that decreases workability and promotes segregation and edge slumping.

Not in Scope of work

20%

20%

20%

16%

10%

12%

Greater than 15% on the sum of #8, #16, and #30

#30-#200 from 24 to 34%

4%

4%

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

% Retained

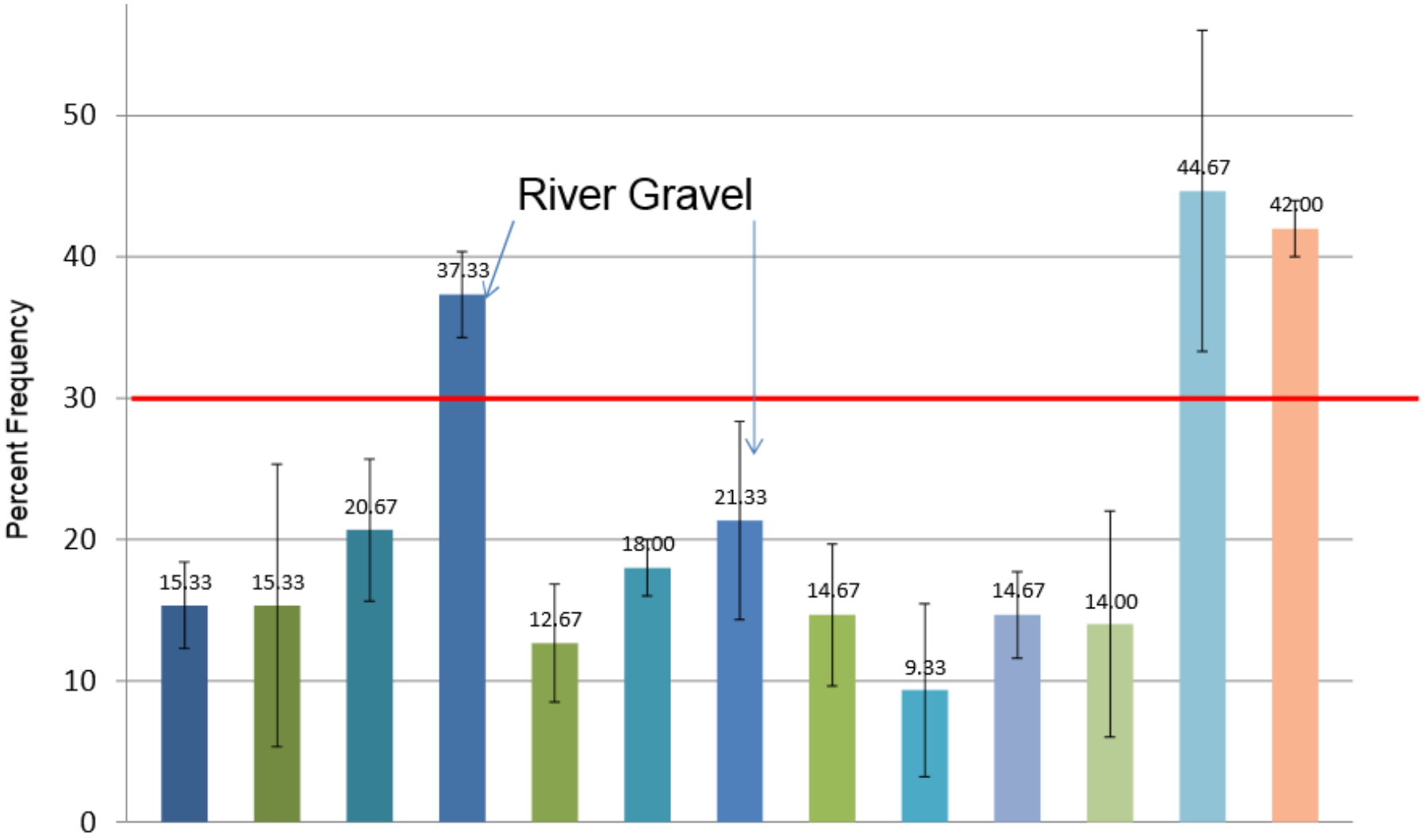
#200 #100 #50 #30 #16 #8 #4 0.375 0.5 0.75 1 1.5

Sieve No.

ASTM 4791

- Measures flatness, elongation, and overall shape of a particle.
- This is based off ratios such as 1:1, 1:3, or 1:5.
- A common limit is less than **15**% on the **1:5** for flat, elongated, or flat & elongated.

ASTM D 4791 for Flatness of 1:2

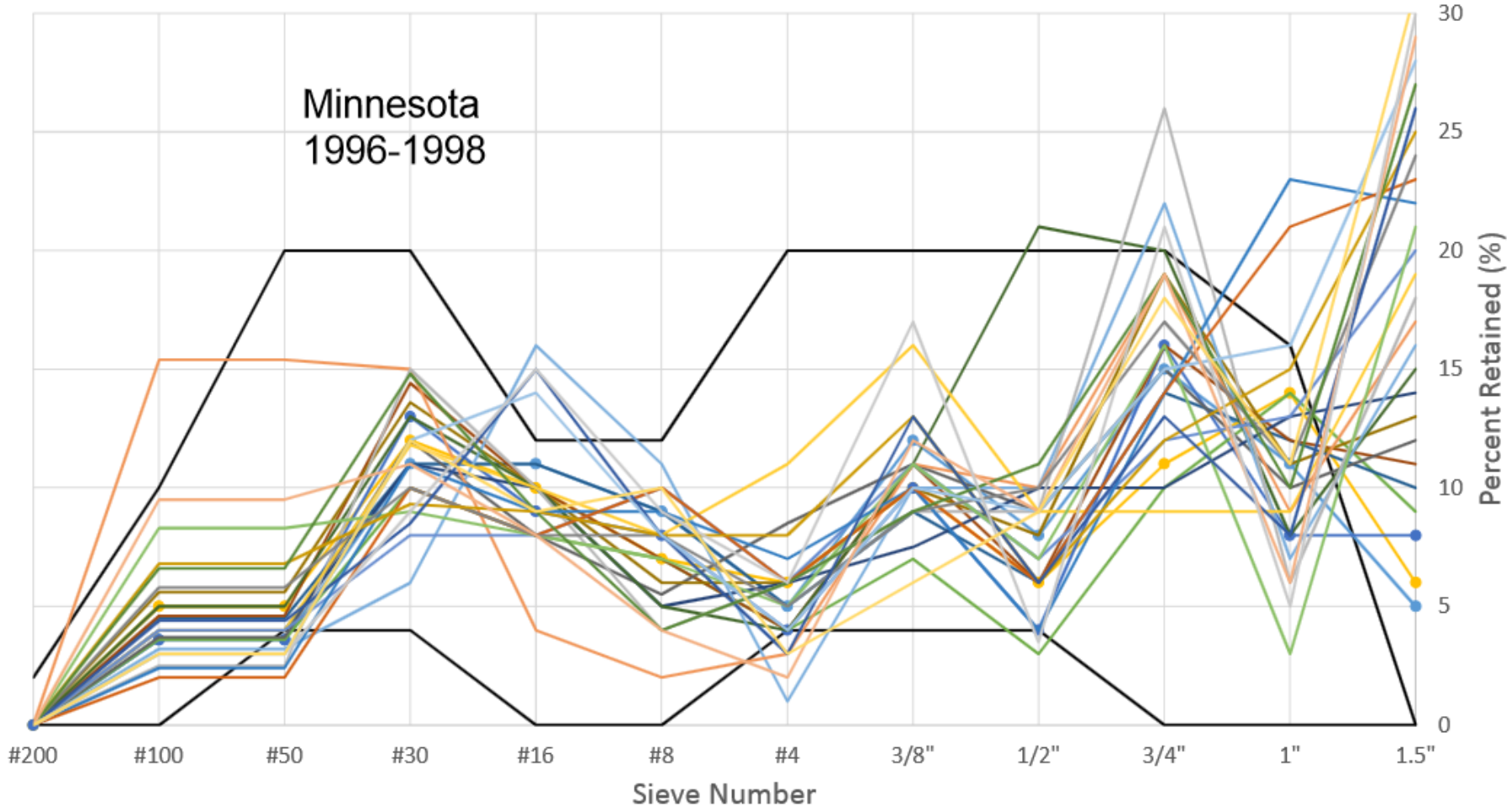


Application

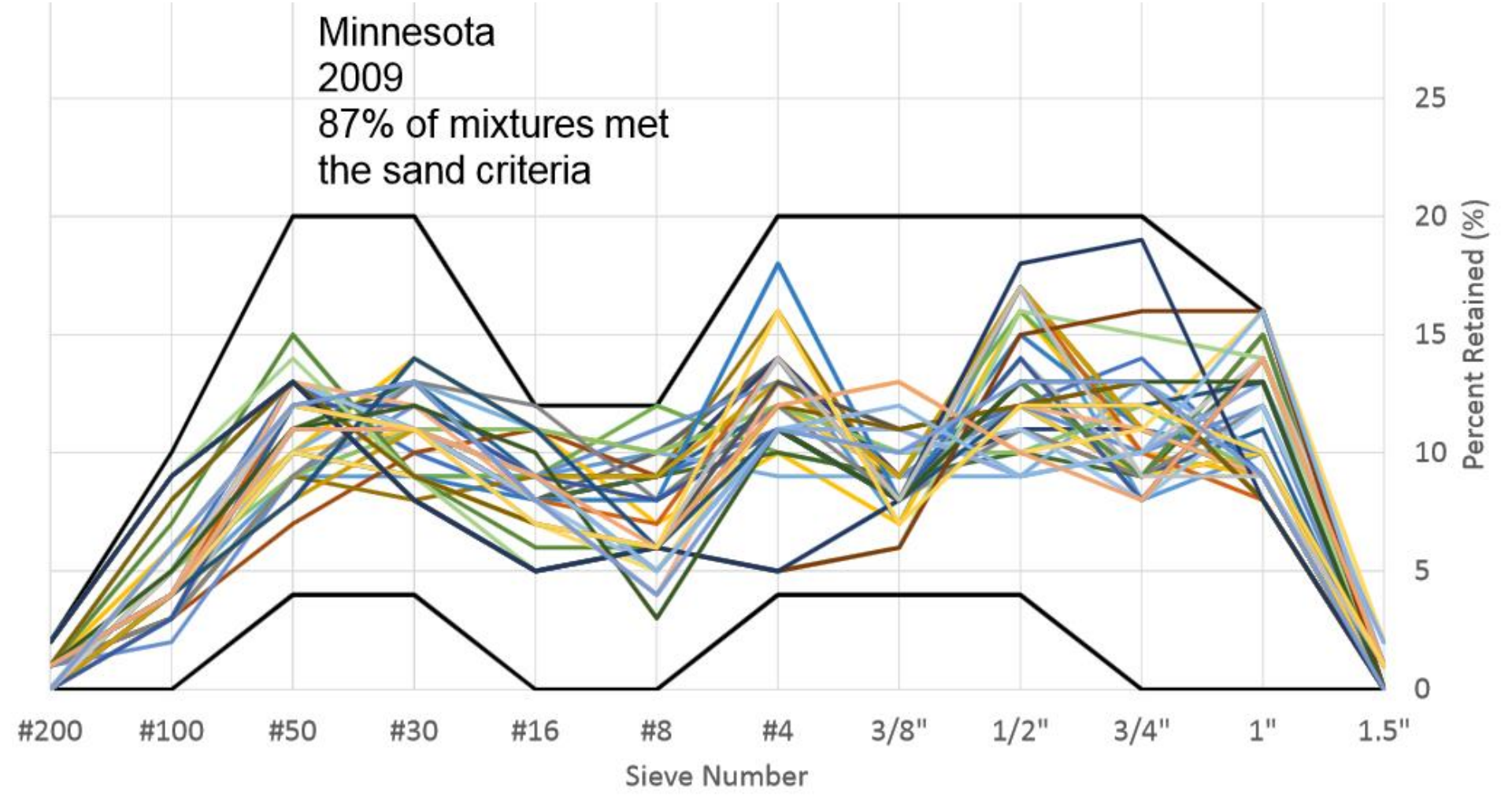
- Five different concrete producers have tried this system and all have seen improvements in their concrete.
- 10 miles of CRCP for the FHWA hfl project have been placed with this system in Texas.
- The contractors saw a 10% cost savings with a 25% reduction in the carbon footprint!

Minnesota Field Mixtures

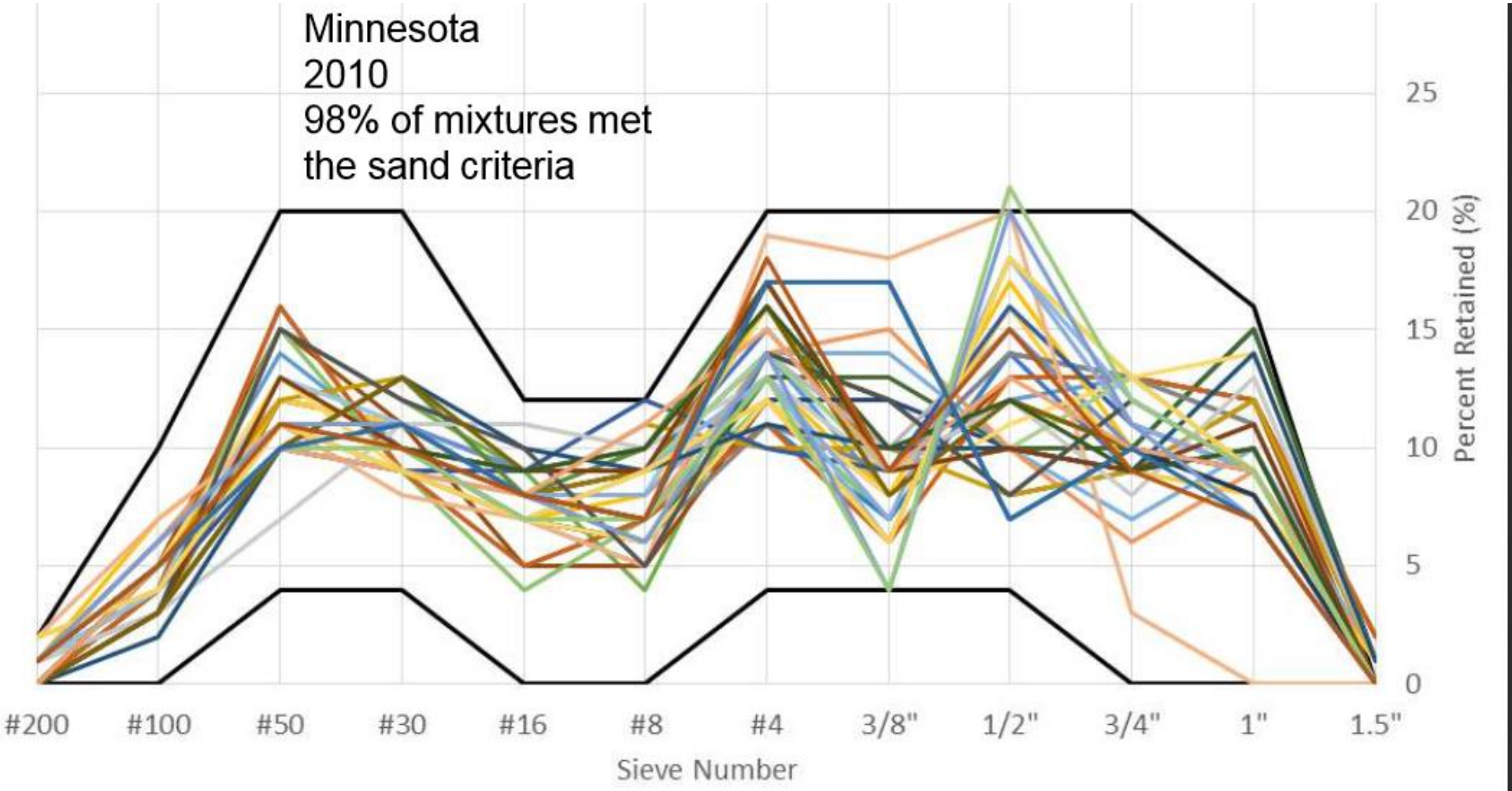
- We tracked optimized graded concrete pavement mixtures from 1996 to 2010 in Minnesota



Data from Maria Masten



Data from Maria Masten



Data from Maria Masten

Field Concrete

- Over time the contractors have iterated on their concrete pavement mixtures to improve them.
- They are doing this with trial and error and no knowledge of the Tarantula Curve
- The large majority of their mixtures are fitting within the Tarantula Curve.

Conclusions

- A single location or region on the Coarseness Factor chart, minimum voids content, or specific surface area does not predict the workability of a mixture with the box test and with these materials
- The voids content and specific surface area may still be important. More research needs to be done.

Conclusions

- The individual percent retained chart was a useful tool to evaluate mixtures.
- The shape and texture of aggregates does have an impact on the workability.
- The Tarantula Curve seems to be a useful technique to determine an aggregate gradation
- The recommendations from the Tarantula Curve seem to match field performance of Minnesota pavement mixtures

Questions?

www.optimizedgraded.com

www.tylerley.com

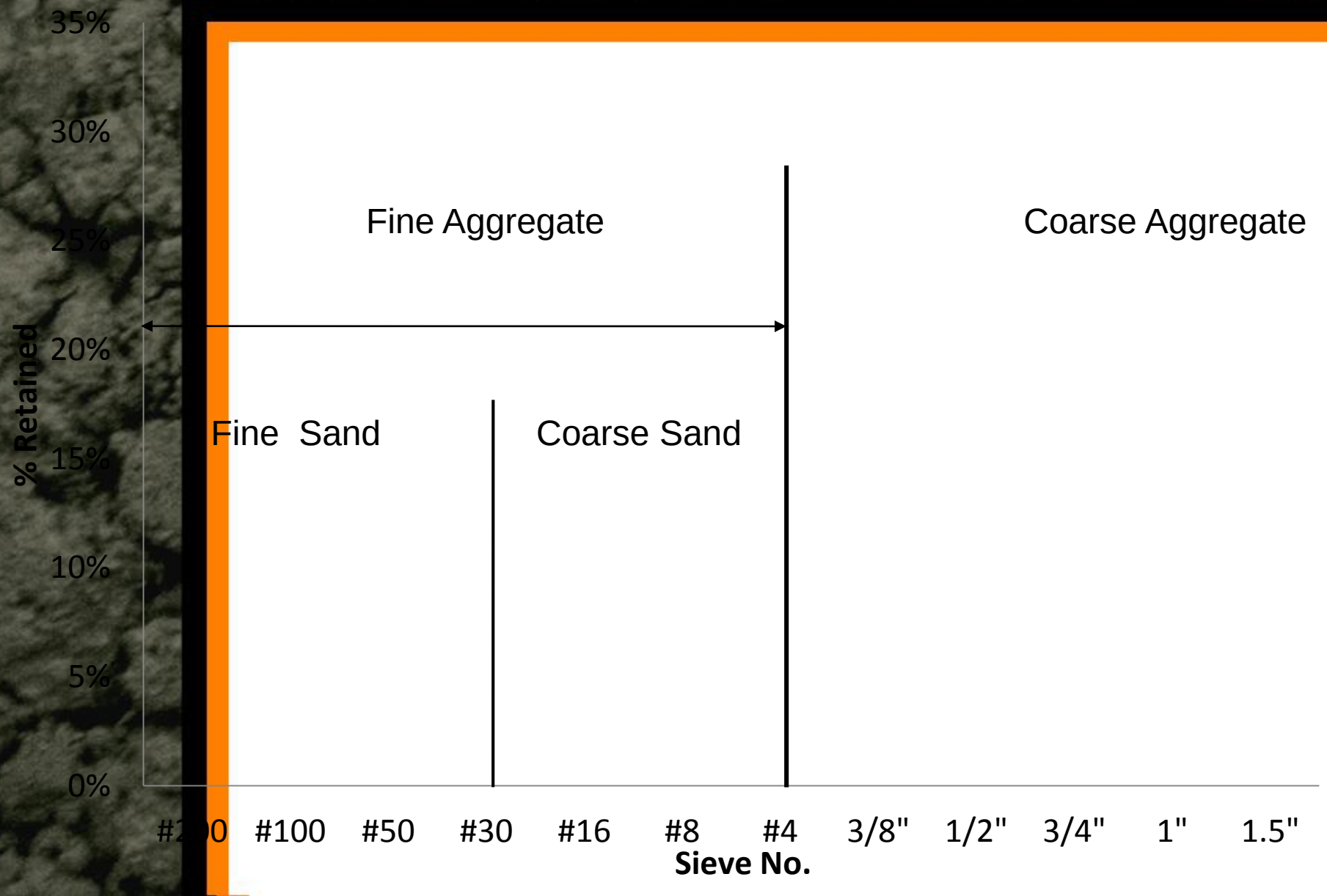
May the Force be with you!!!!

What about Strength?

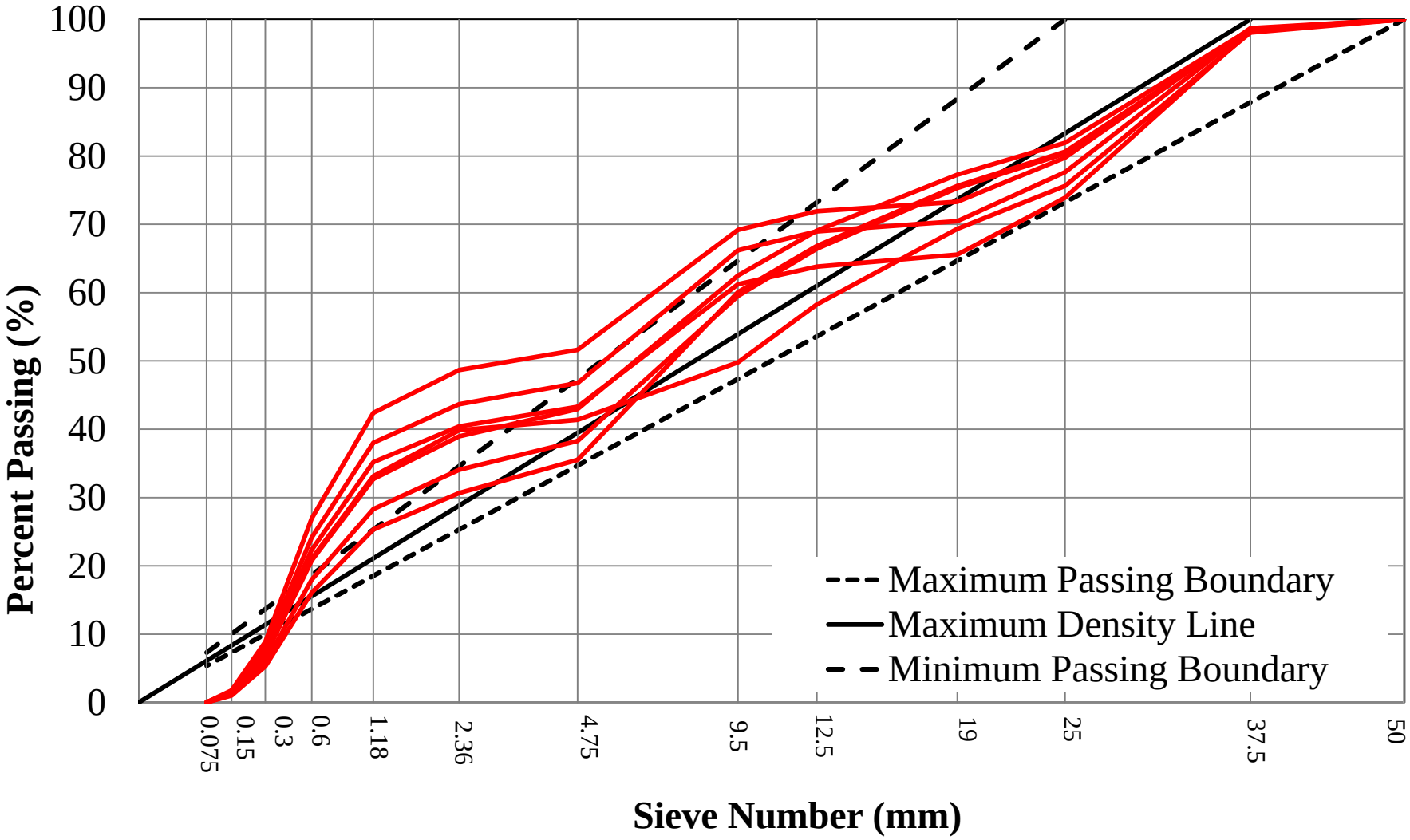
	7 Day Strength		28 Day Strength	
Source	Min-Max (psi)	Average (psi)	Min-Max (psi)	Average (psi)
Limestone A	4000-6320	5180	5330-8890	6940
Limestone B	4990-5270	5130	6220-7940	7450
River Rock	3990-4850	4440	5760-7050	6410

All mixtures had 4.5 sacks of total cementitious with 20% fly ash

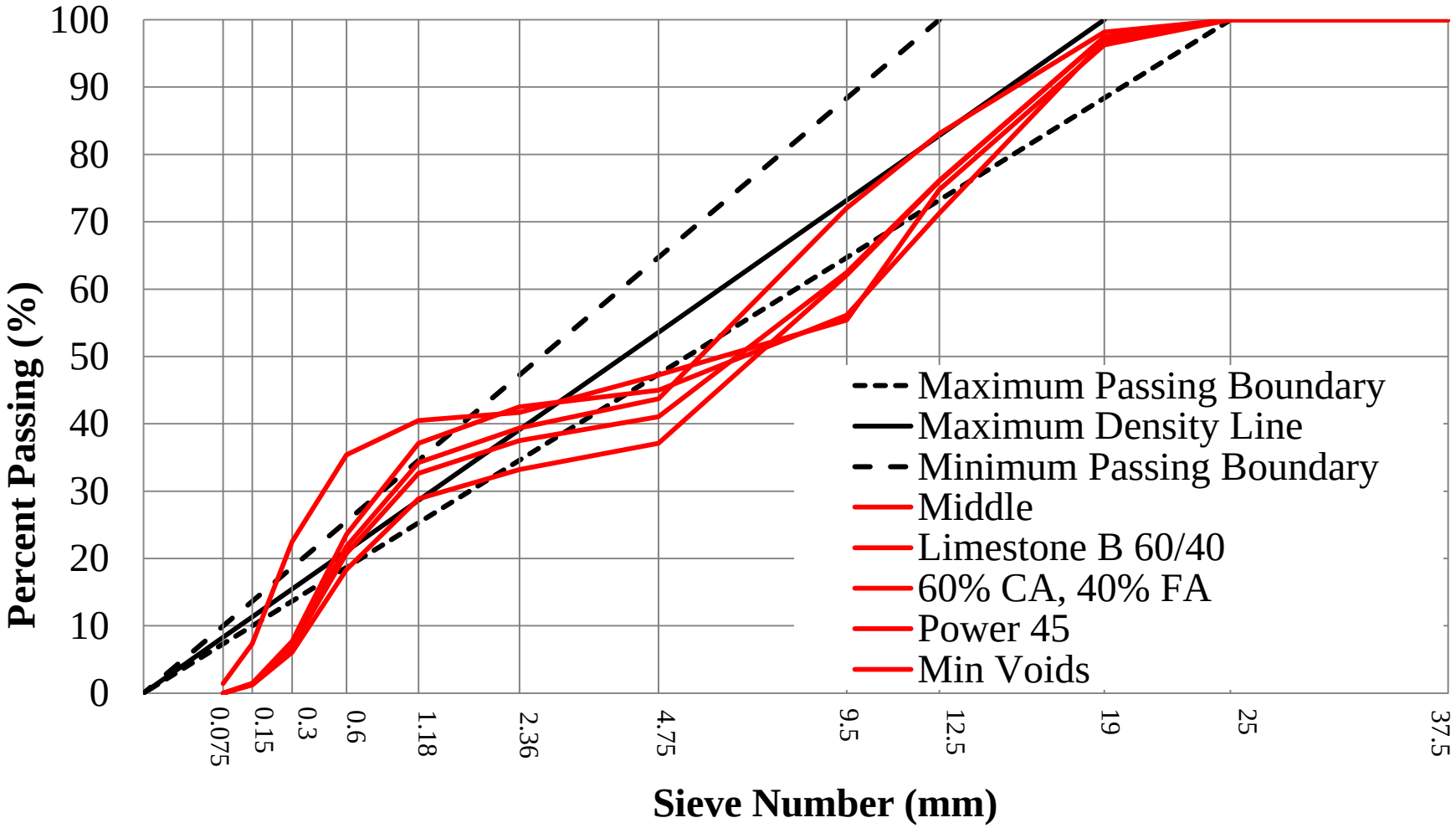
Aggregate Behavioral Division



More than 20 oz./cwt of WR



More than 20 oz./cwt of WR



Reference

- [26] The Transtec Group, Inc. Concrete Mixture Performance Analysis System (Version 1.00.0022) [computer software]. Austin, Texas: 2004
- de Larrard, F. Concrete Mixture Proportioning: A Scientific Approach. London, UK: E & FN Spon; 1999.
- Goltermann, P, Johansen, V, Palbol, L. Packing of Aggregates: An Alternative Tool to Determine the Optimal Aggregate Mix," ACI Materials Journal. 94 (5) Farmington Hills, MI: ACI; 1997. p. 435-443.