Aggregate Proportioning and Gradation for Slip Formed Pavements

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Acknowledgements

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Outline

- Introduction of OG concrete
- The Box Test
- The *TARANTULA* curve!

What is OG concrete all about?

- The goal of OG concrete is to **increase** the volume of **aggregate** and **decrease** the volume of **paste**
- paste = binder + water
- The paste is the most costly, least sustainable concrete ingredient and has the biggest impact on the durability

Why would you do this???

Reduce cost

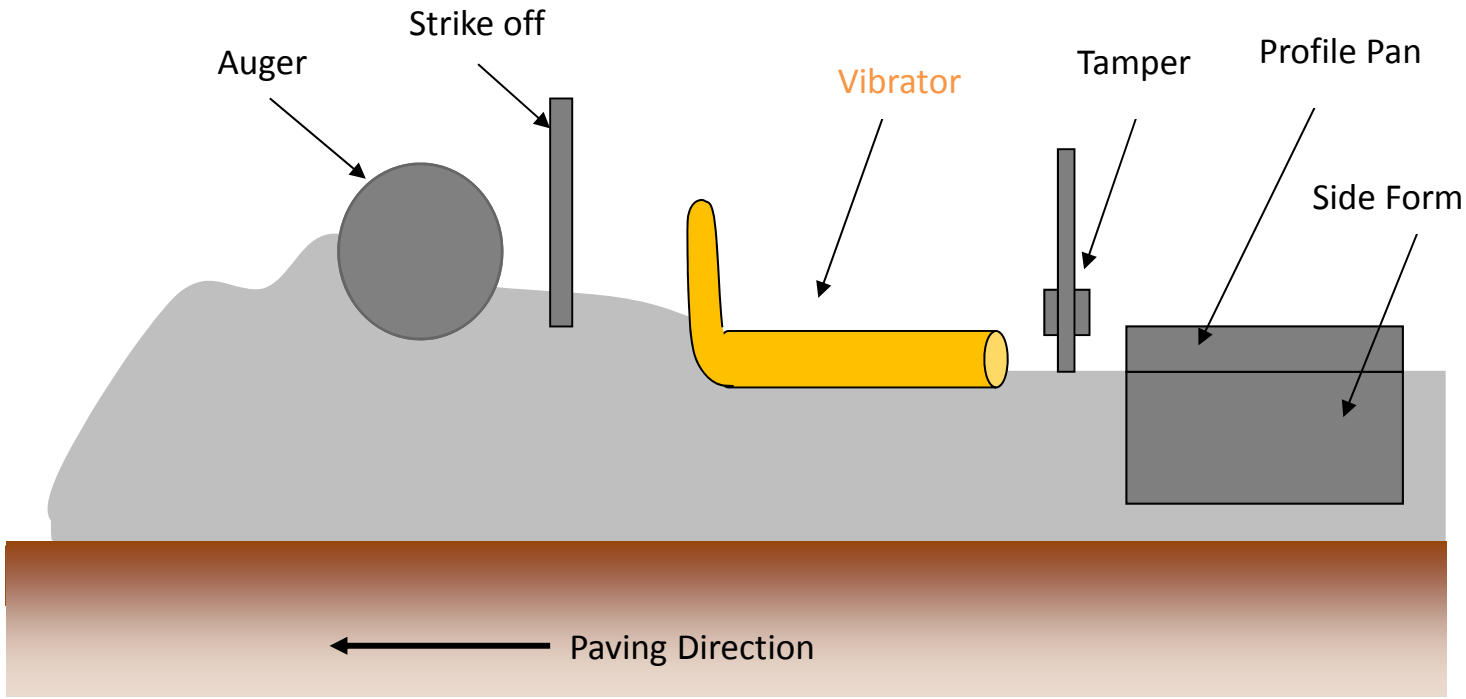
Improve strength

Improve durability

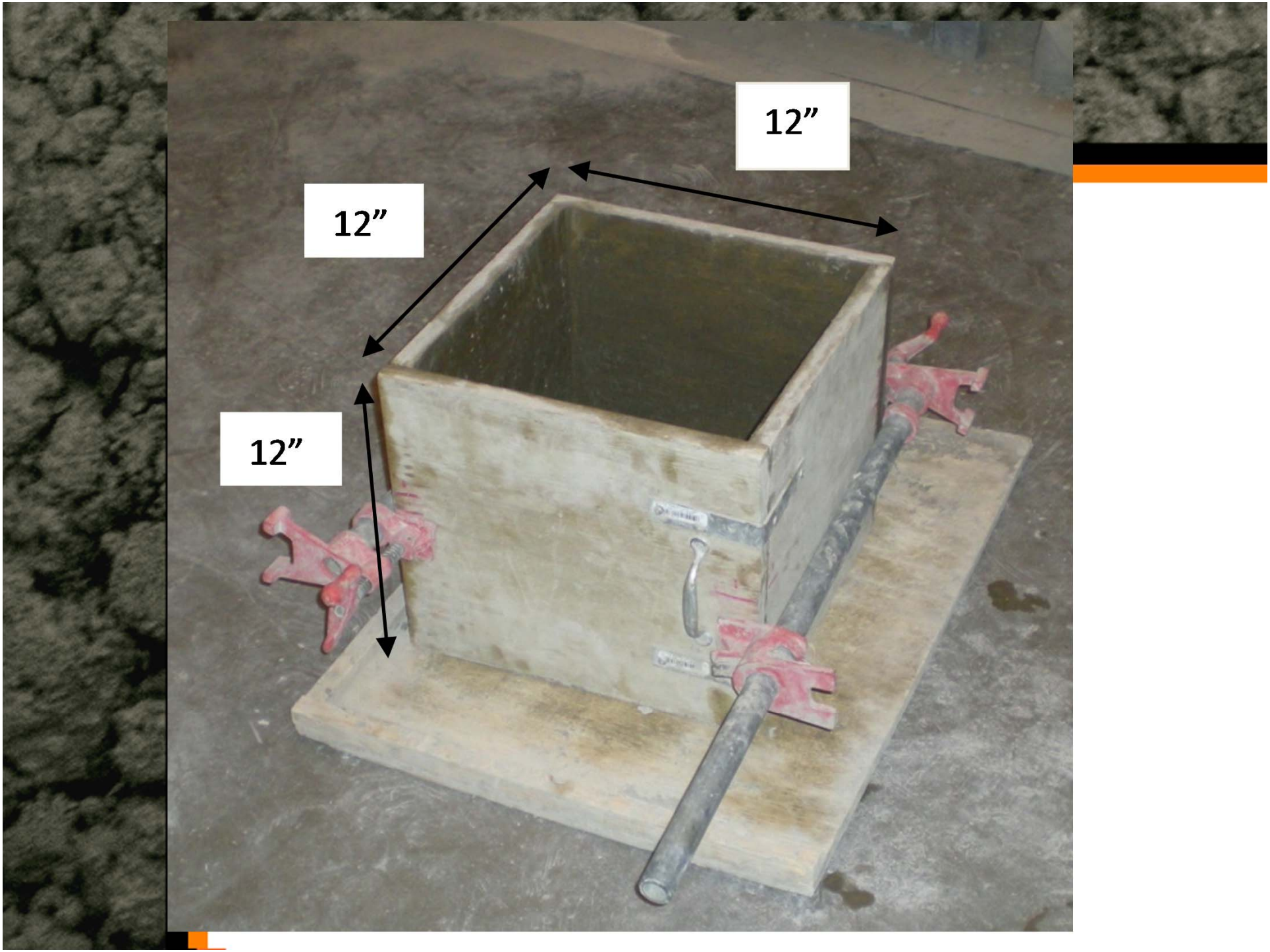
Improve sustainability

Slip Formed Paver

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



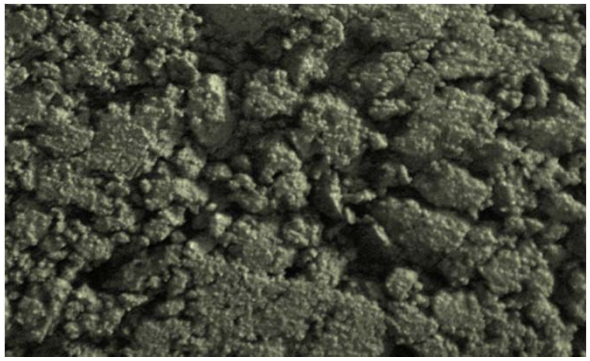
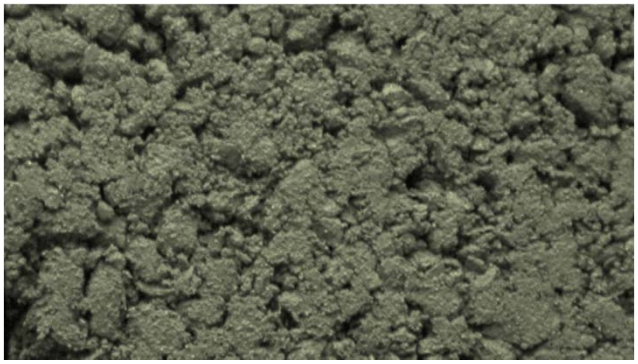
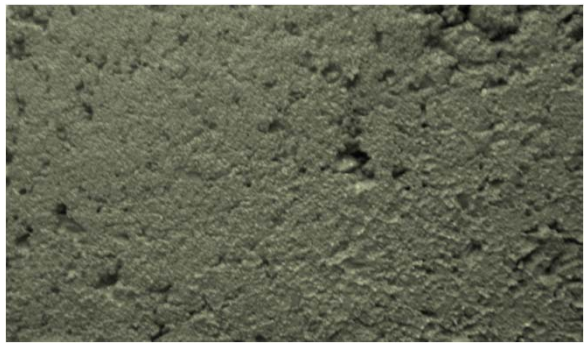
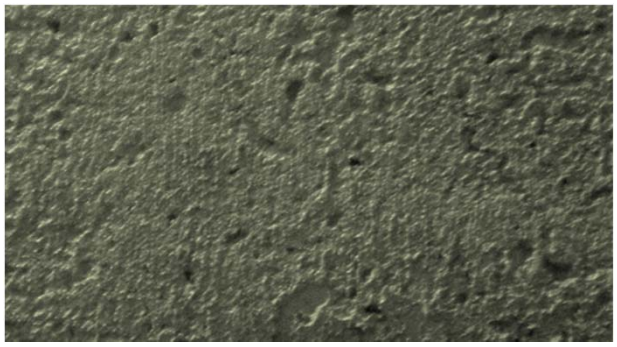
- We want a test that is simple and can examine:
  - Response to vibration
  - Filling ability of the grout (avoid internal voids)
  - Ability of the slip formed concrete to hold a sharp edge (cohesiveness)


12”
12”
12”

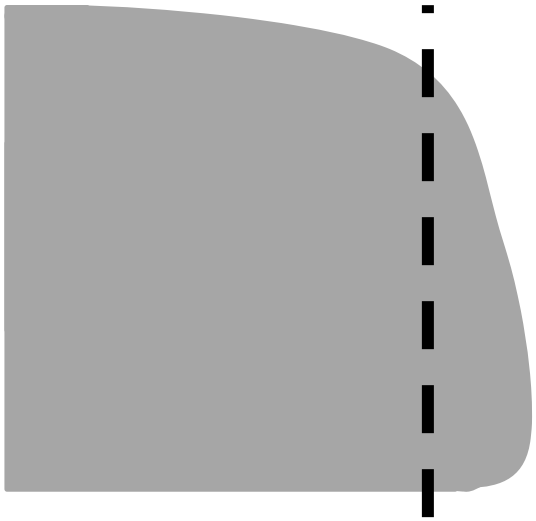
Box Test

- 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

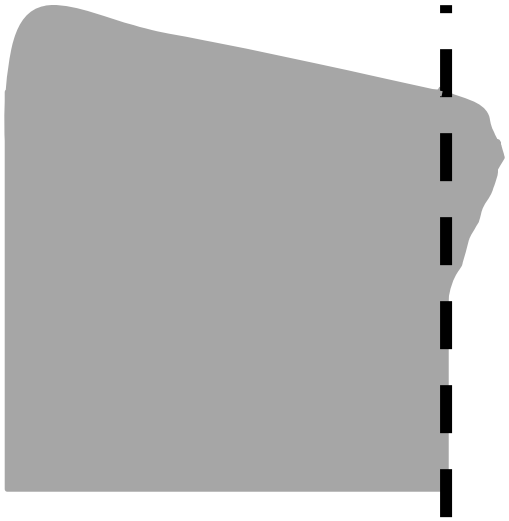
Box Test Ranking Scale

	
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

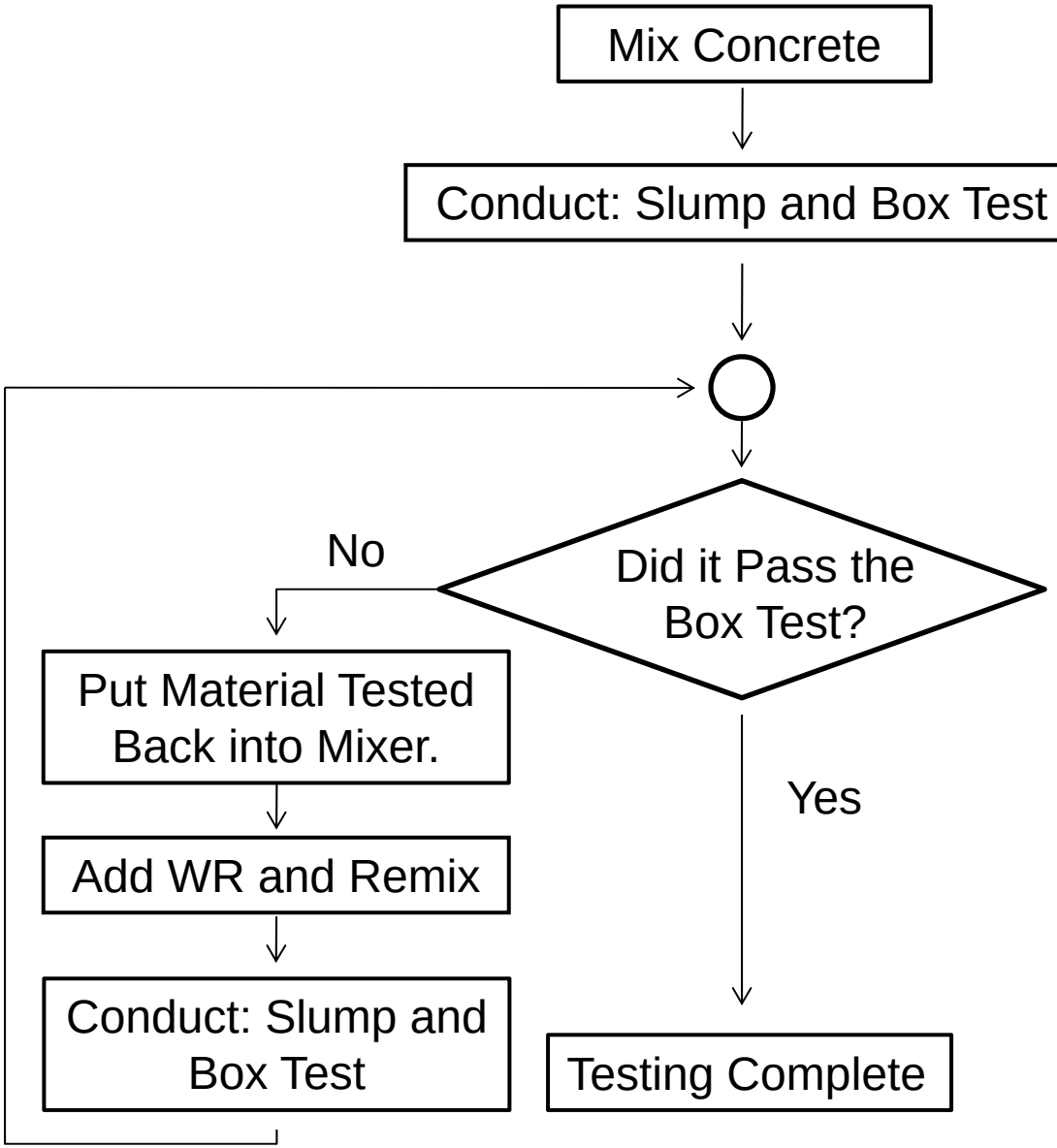


Top Edge Slumping

No Edge Slump

Edge Slump

Evaluating Mixtures with the Box Test



Box Test

- Low amounts of water reducer is good
- High amounts are bad

This technique lets us establish limits!

Validation

- Single Operator +/- 1.5 oz/cwt
- Multi Operator is +/- 2.5 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

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.

How do you find your gradation?

- Shilstone
- 8-18 curves
- Power 45

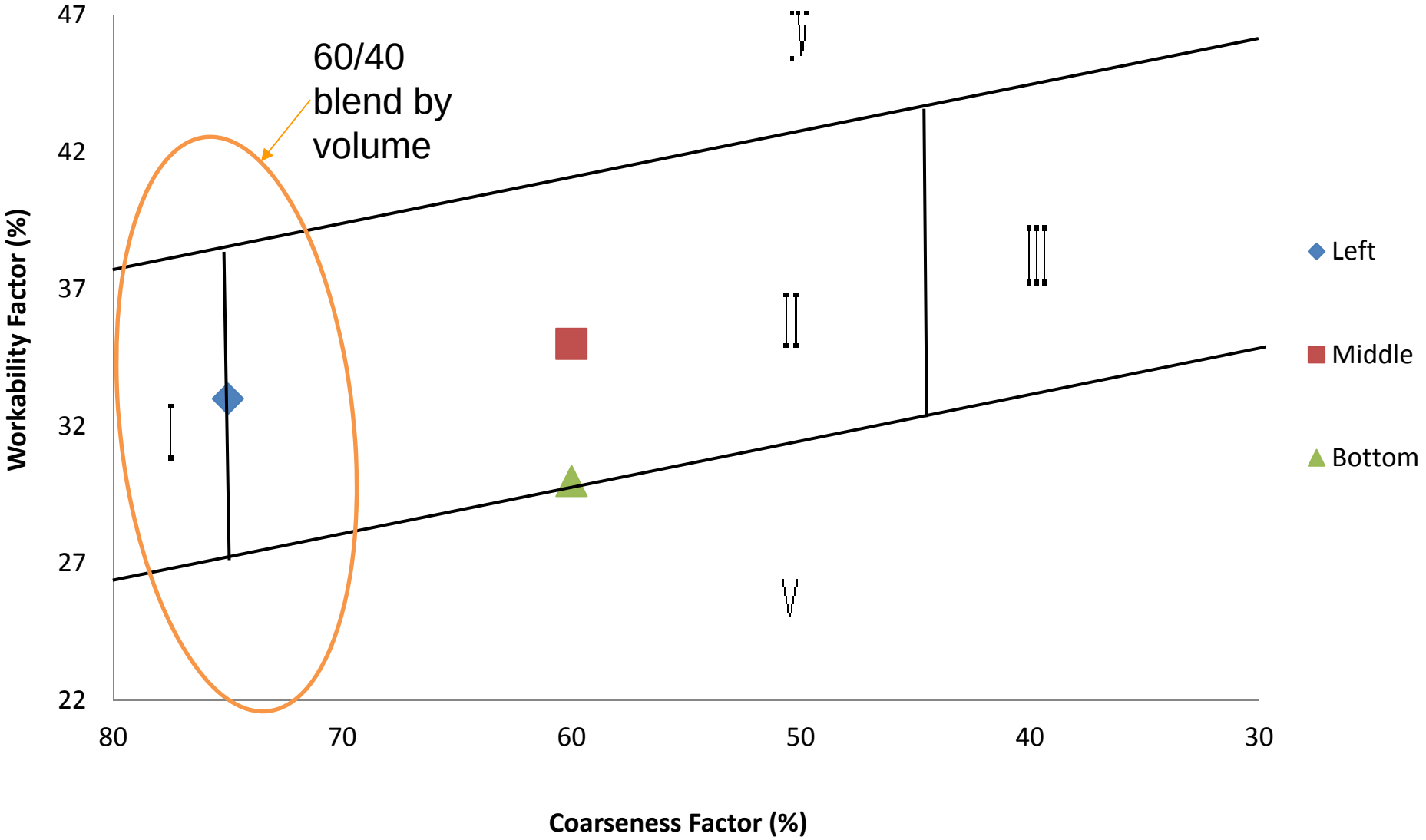
Which one is right?

What do these tools tell you?

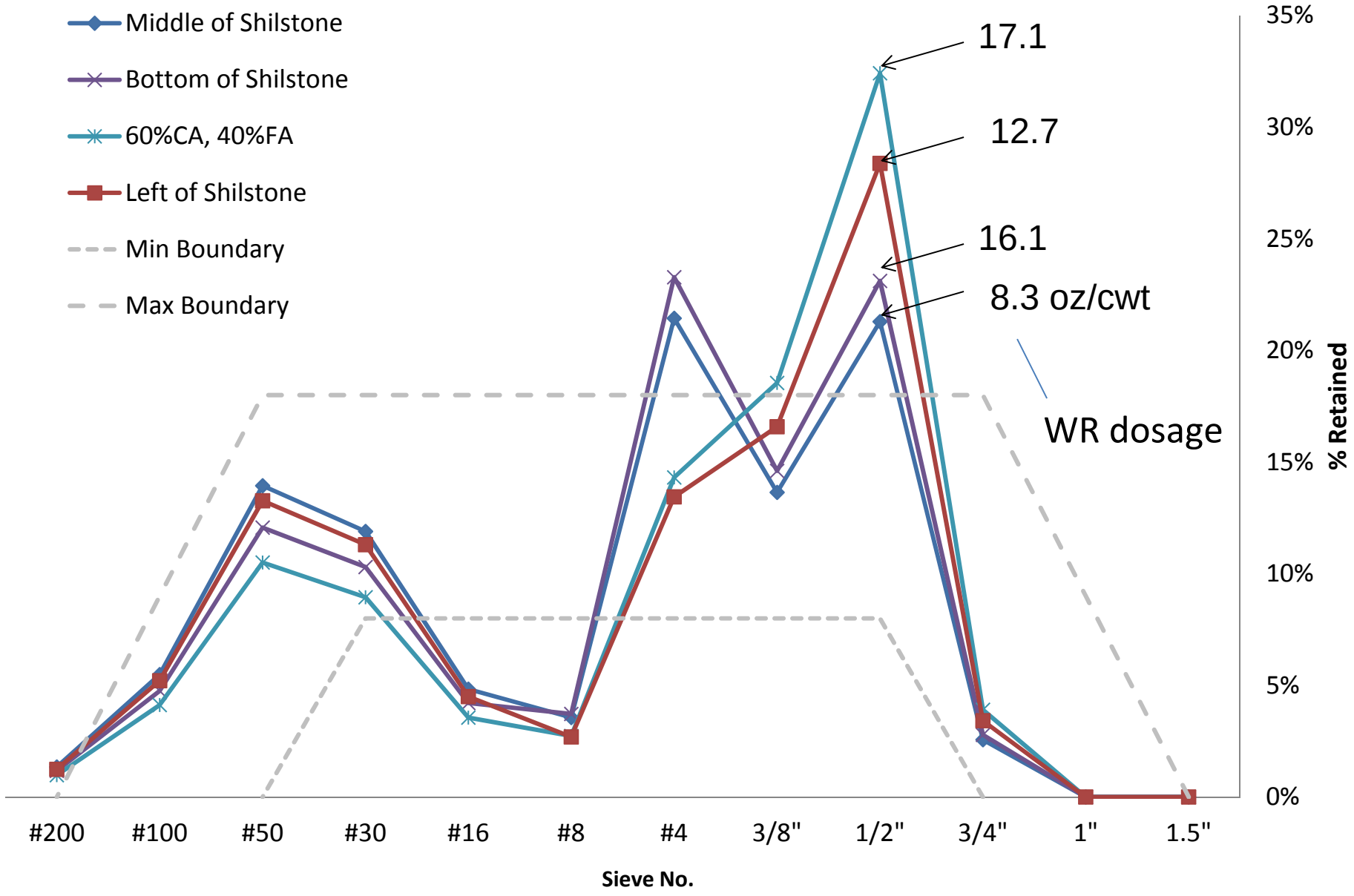
Is one better than the other?

Use of the Box Test to Evaluate Shilstone

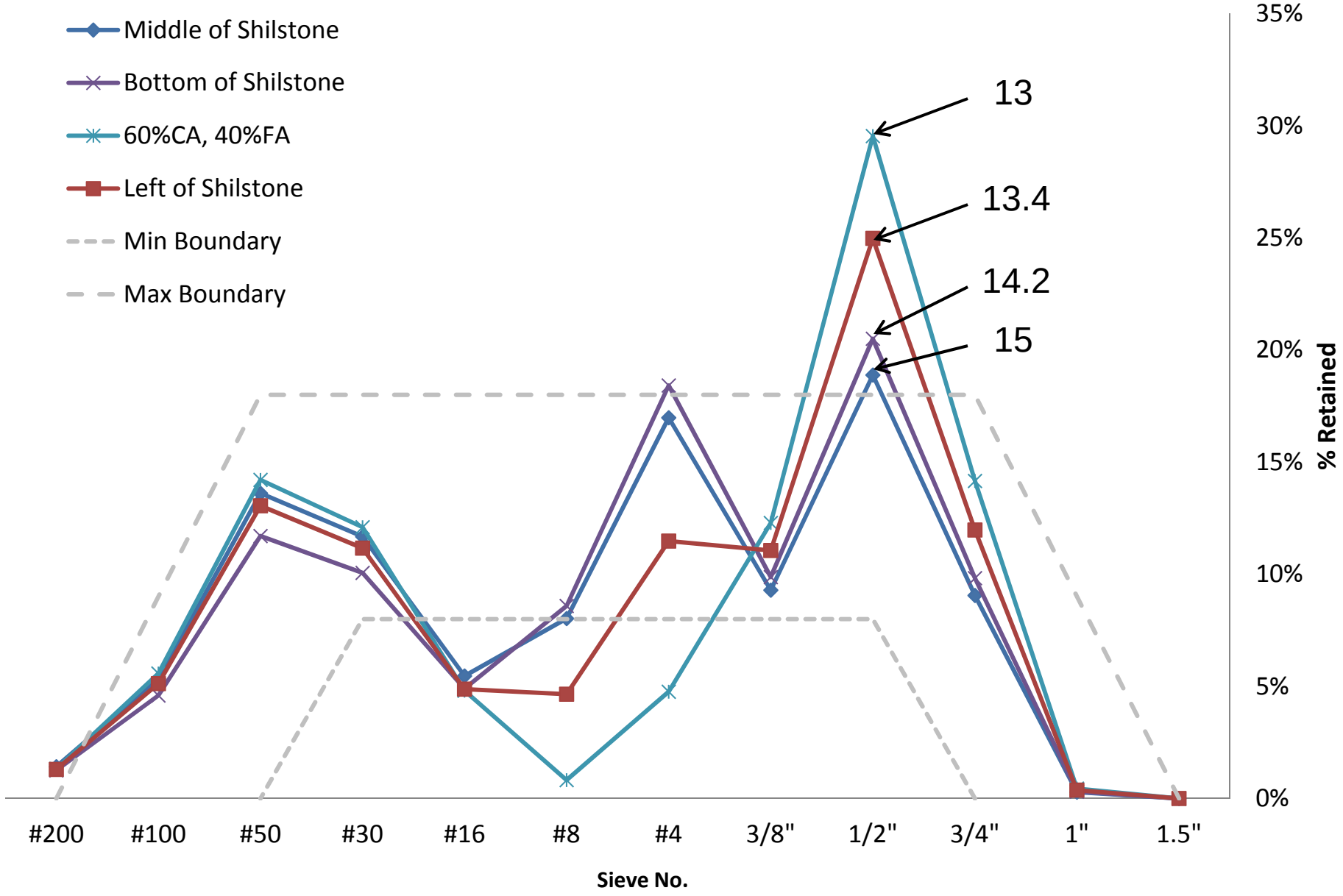
- .45 w/cm
- 5 Sacks total cementitious
- 20% fly ash
- A single sand source
- 3 crushed limestones
  - Limestone A
  - Limestone B
  - Limestone C


60/40
blend by
volume
47
42
37
32
27
22
80
70
60
50
40
30
I
II
III
IV
V
Workability Factor (%)
Coarseness Factor (%)
Left
Middle
Bottom

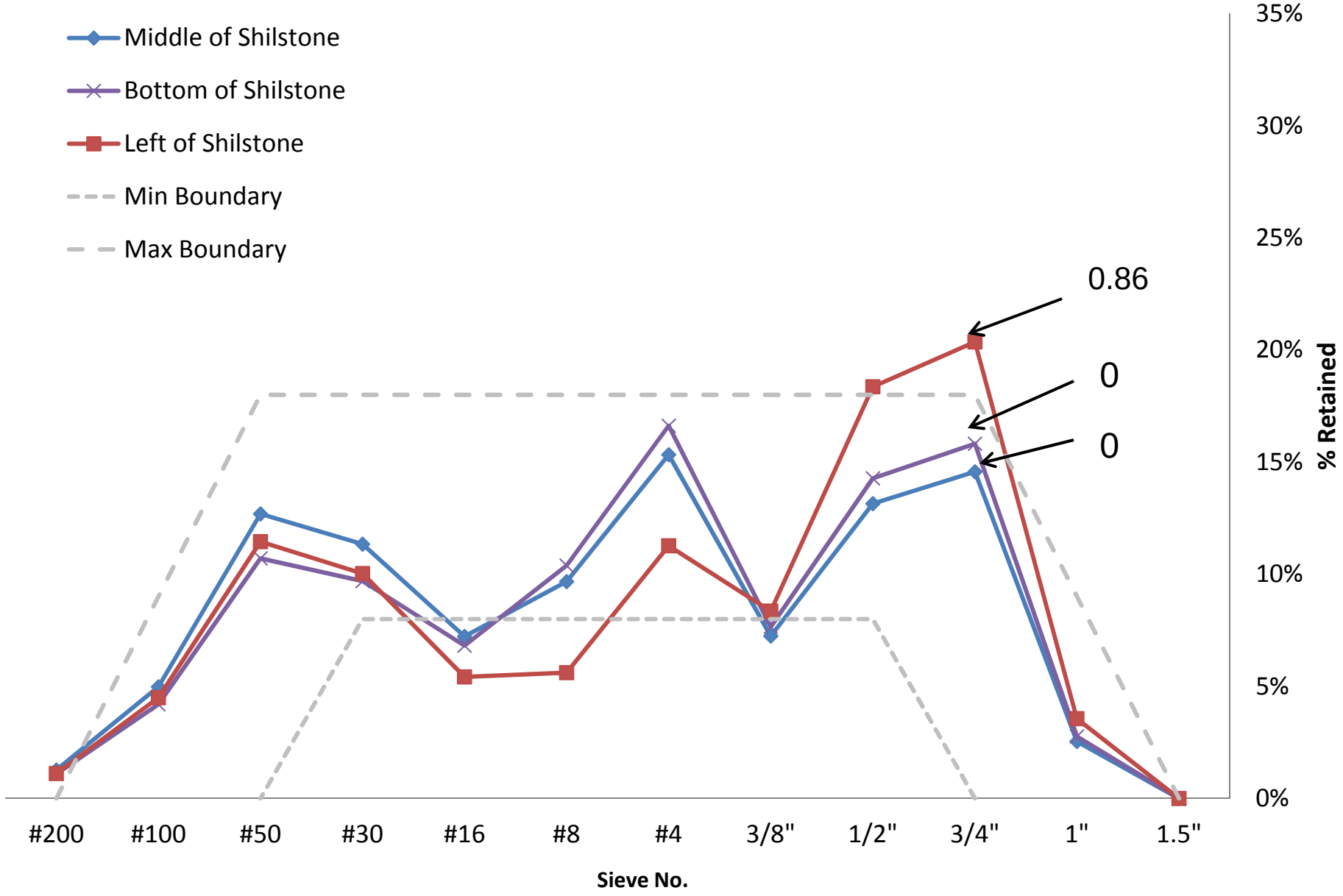
Limestone A & Sand A

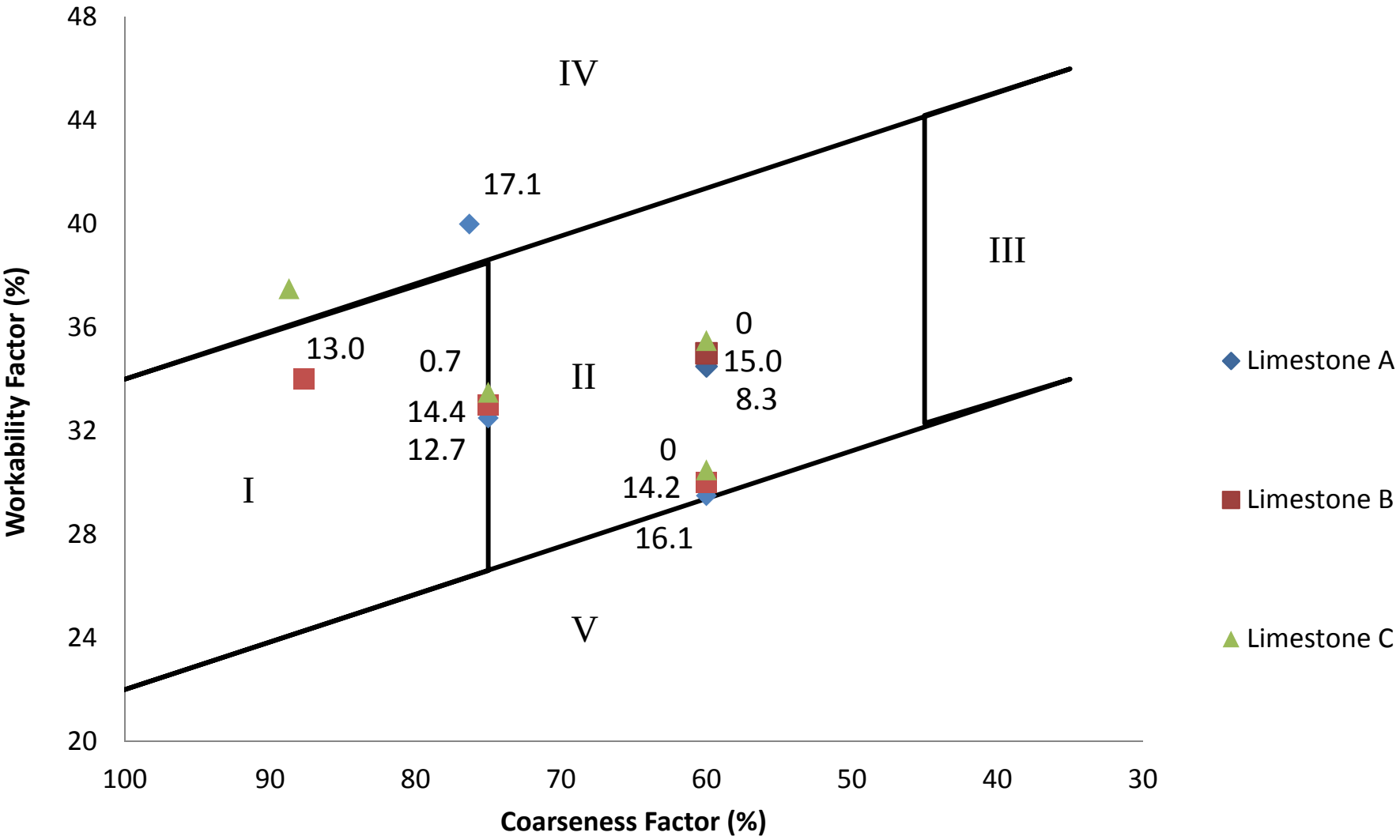


Limestone B & Sand A



Limestone C & Sand A

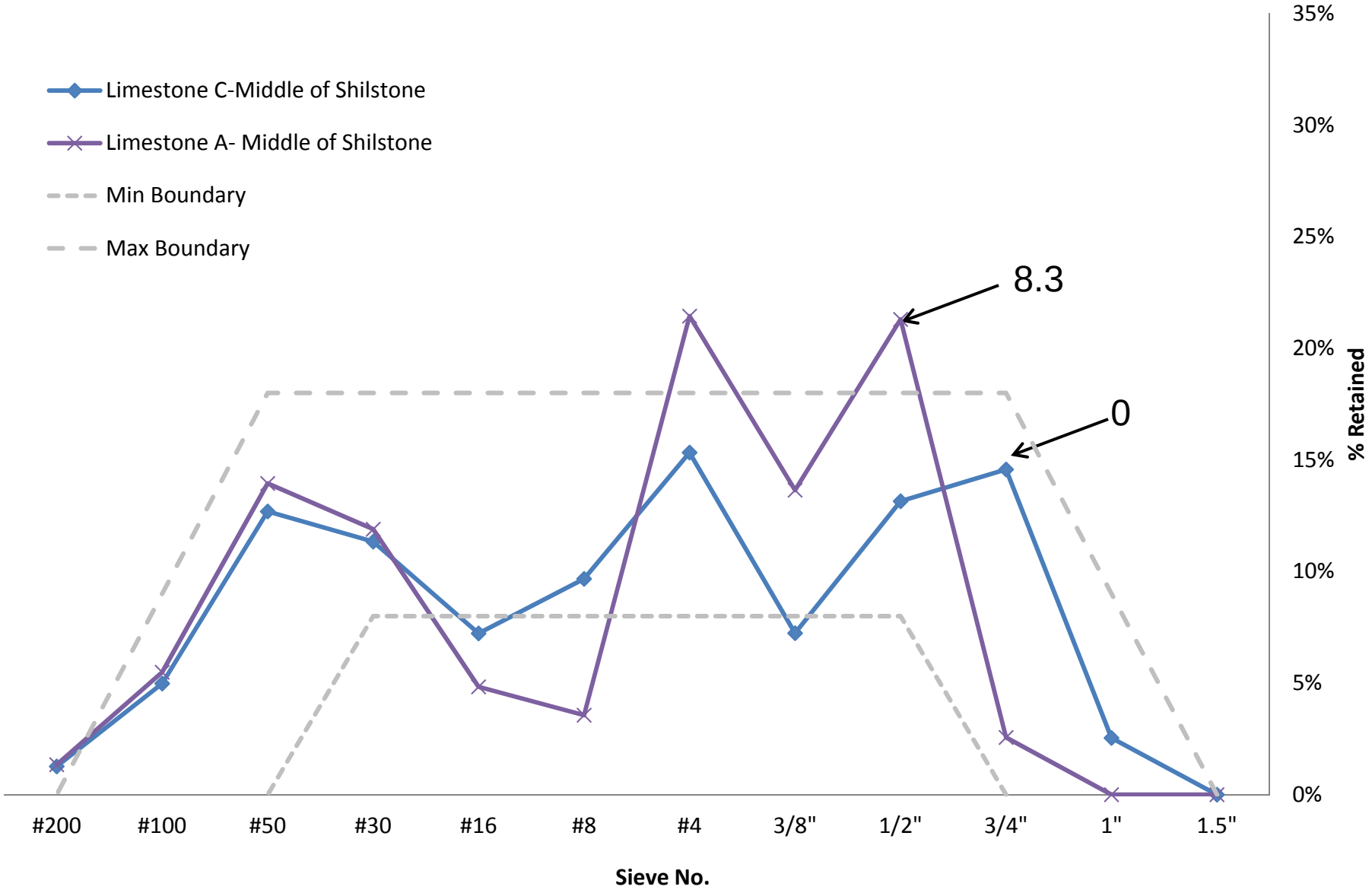



48
44
40
36
32
28
24
20
Workability Factor (%)
100
90
80
70
60
50
40
30
Coarseness Factor (%)
IV
III
II
I
V
17.1
13.0
0.7
14.4
12.7
0
15.0
8.3
0
14.2
16.1
Limestone A
Limestone B
Limestone C

Using the Shilstone Chart alone to proportion your aggregates does not influence performance with these materials.

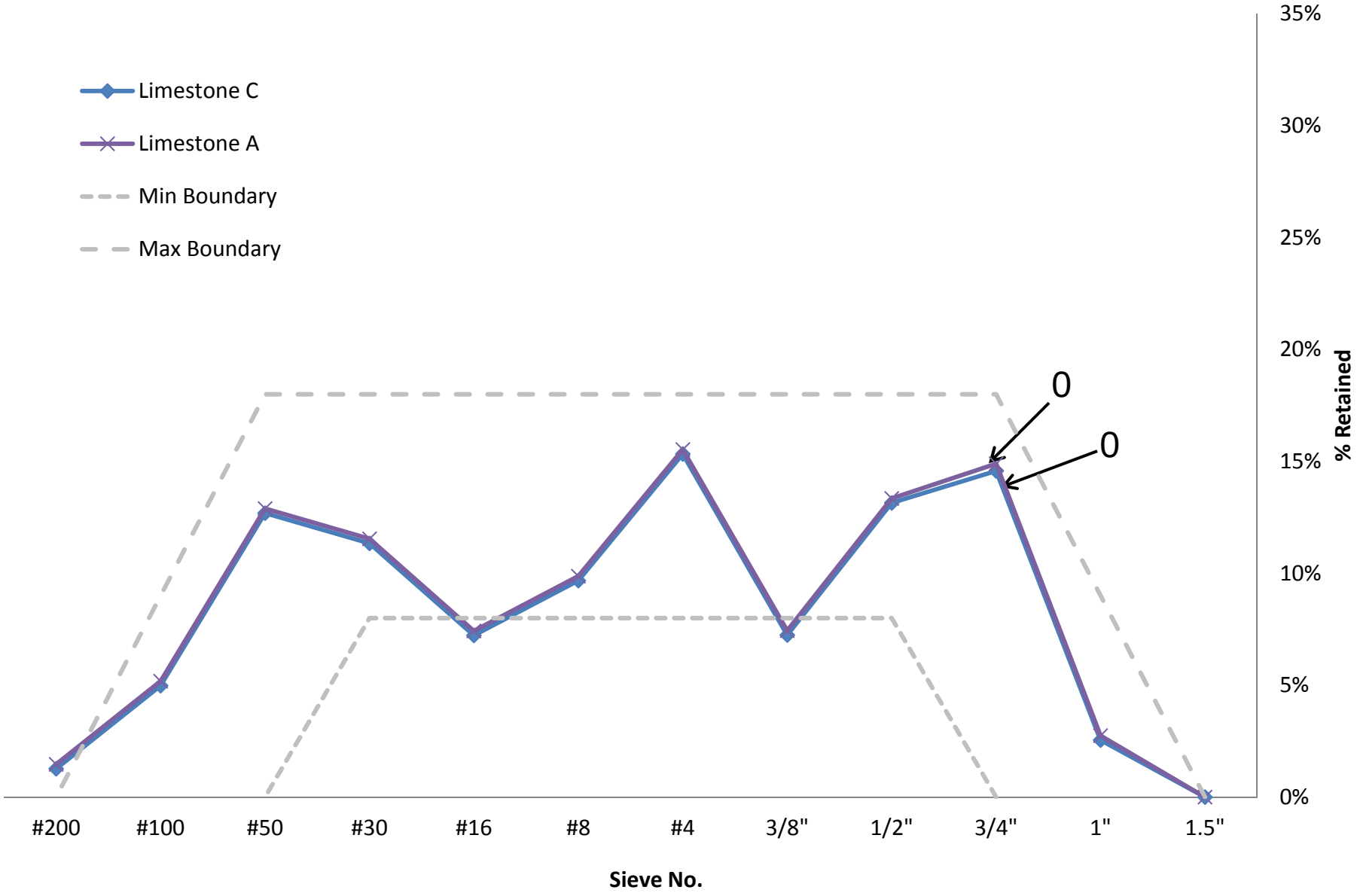
The 8-18 chart seems to provide better guidance.

Does Distribution Really Matter?



We sieved Limestone A to have the exact same gradation as Limestone B.

Yes, Distribution Matters!

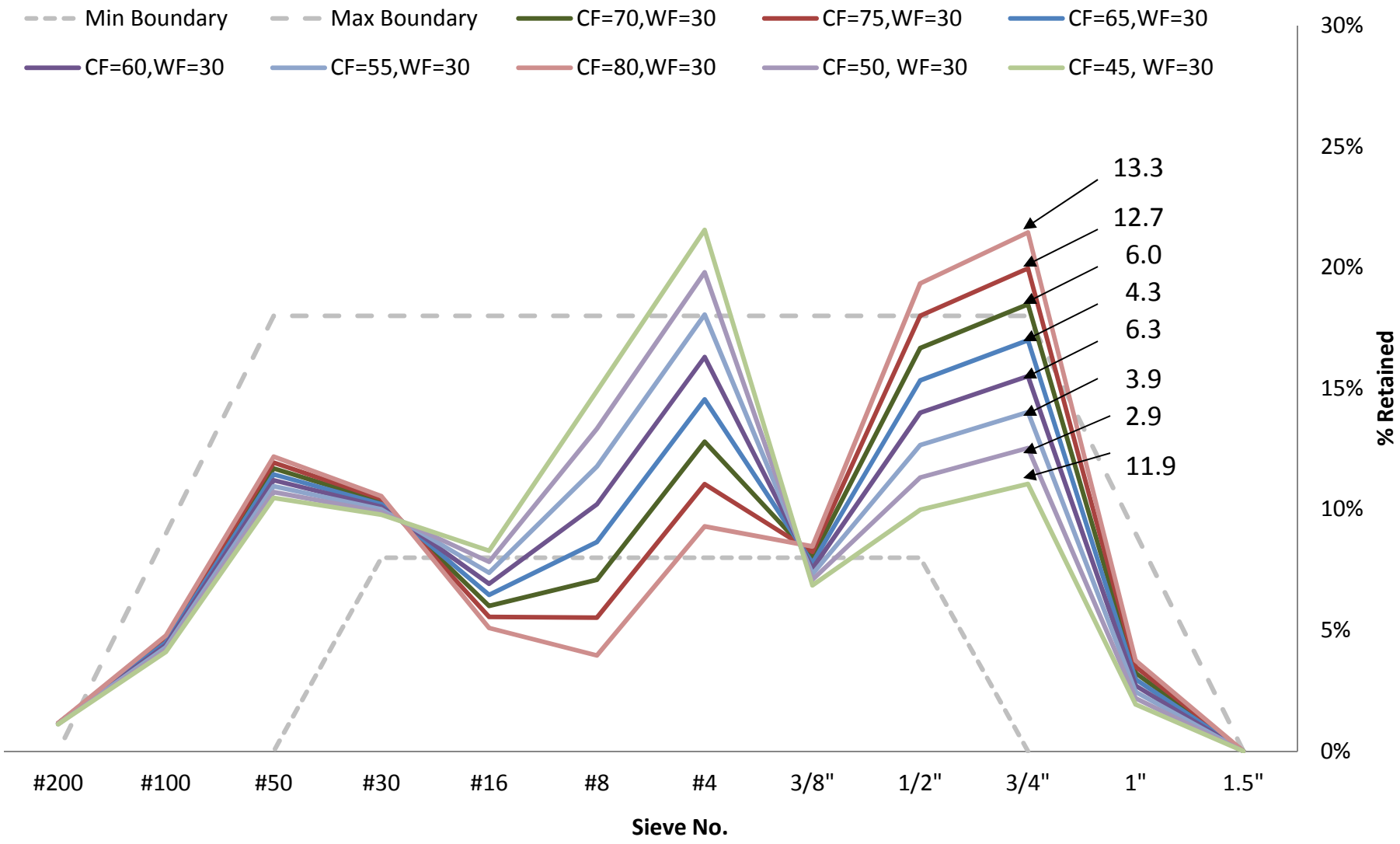


By changing the distribution of aggregates, it changes the workability of the mixture. However the Shilstone method did not accurately predict this (at least for these aggregate combinations).

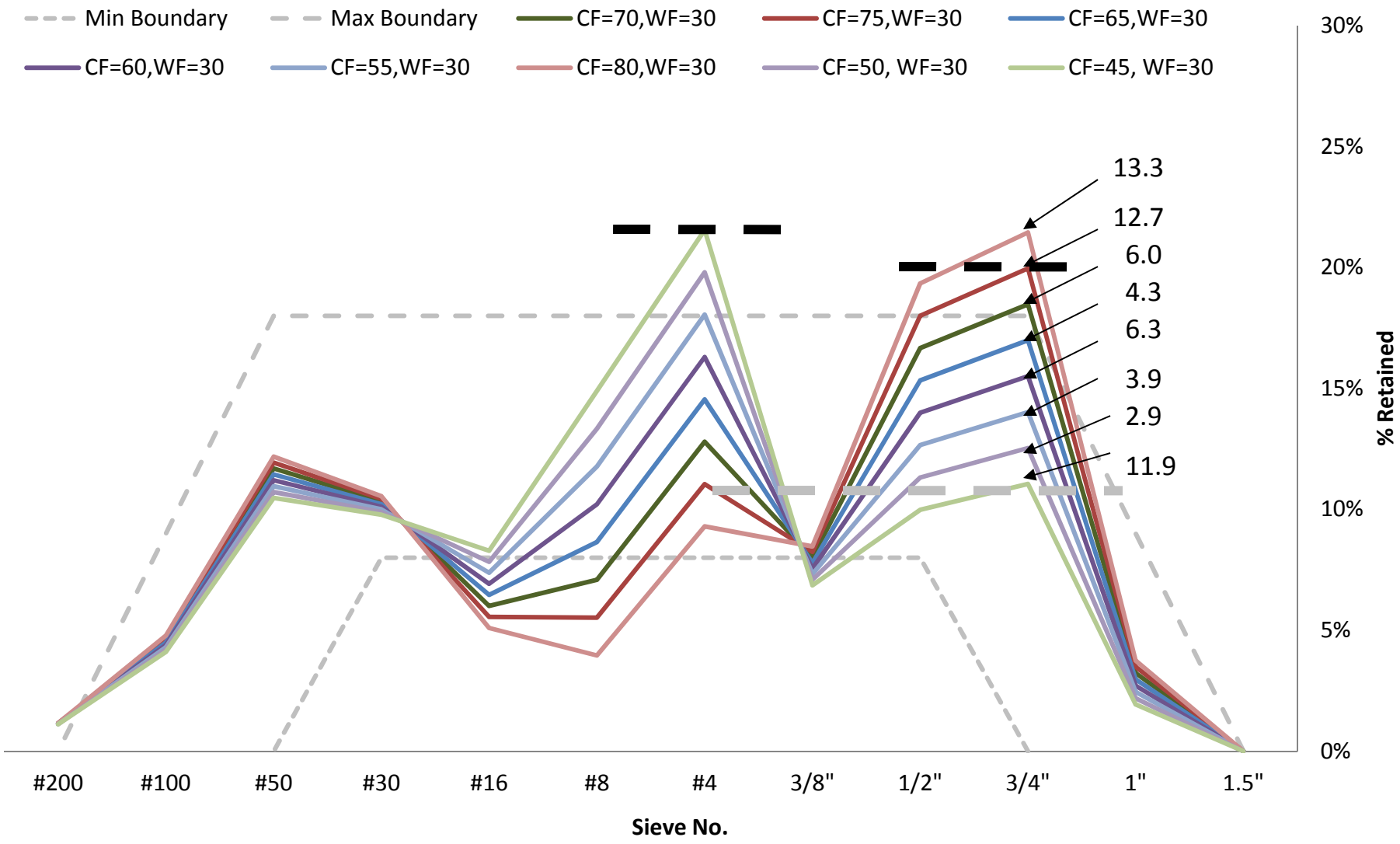
Use of the Box Test to Evaluate Gradations

- .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)

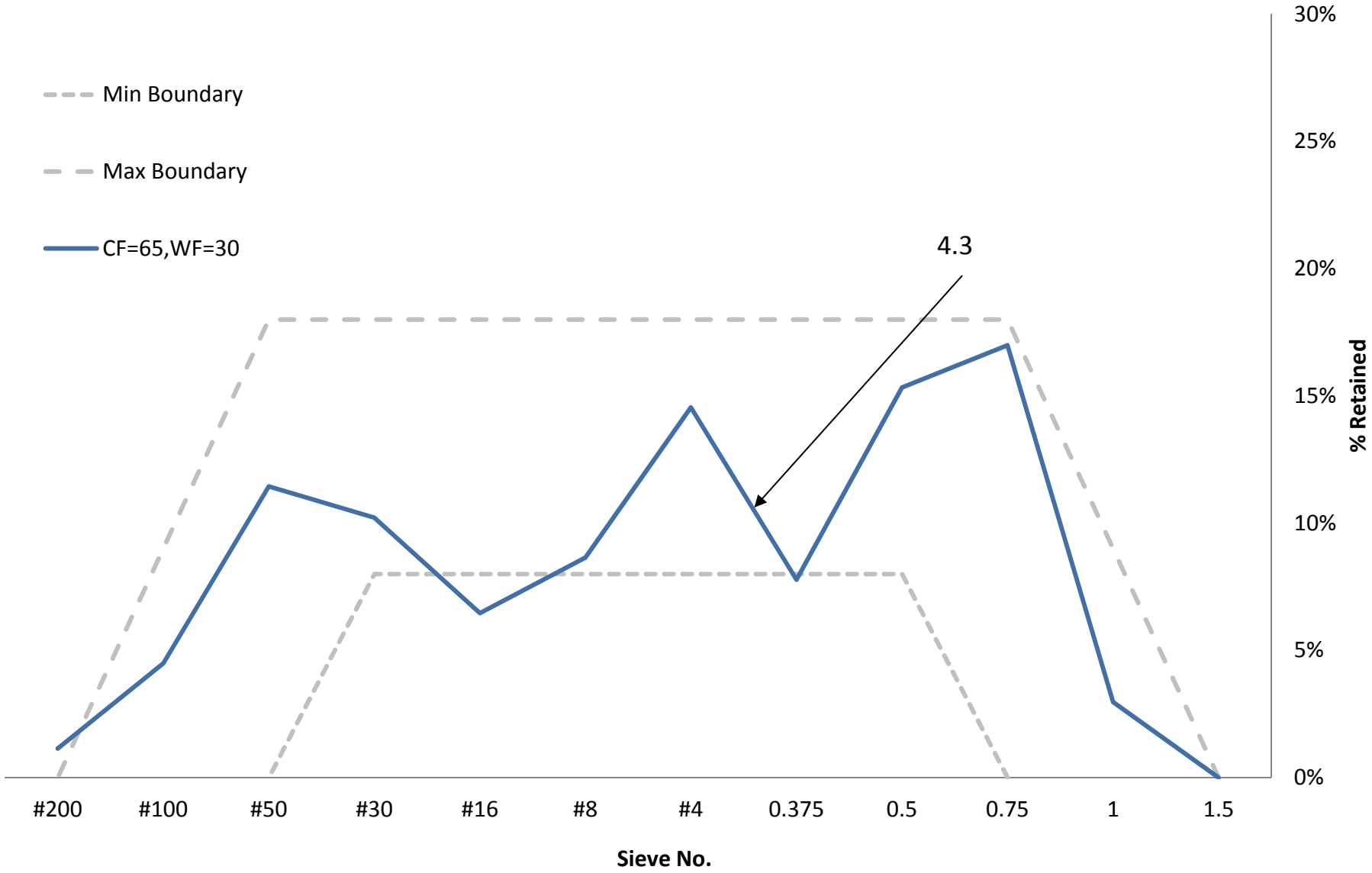
Proportioning of Coarse to Intermediate



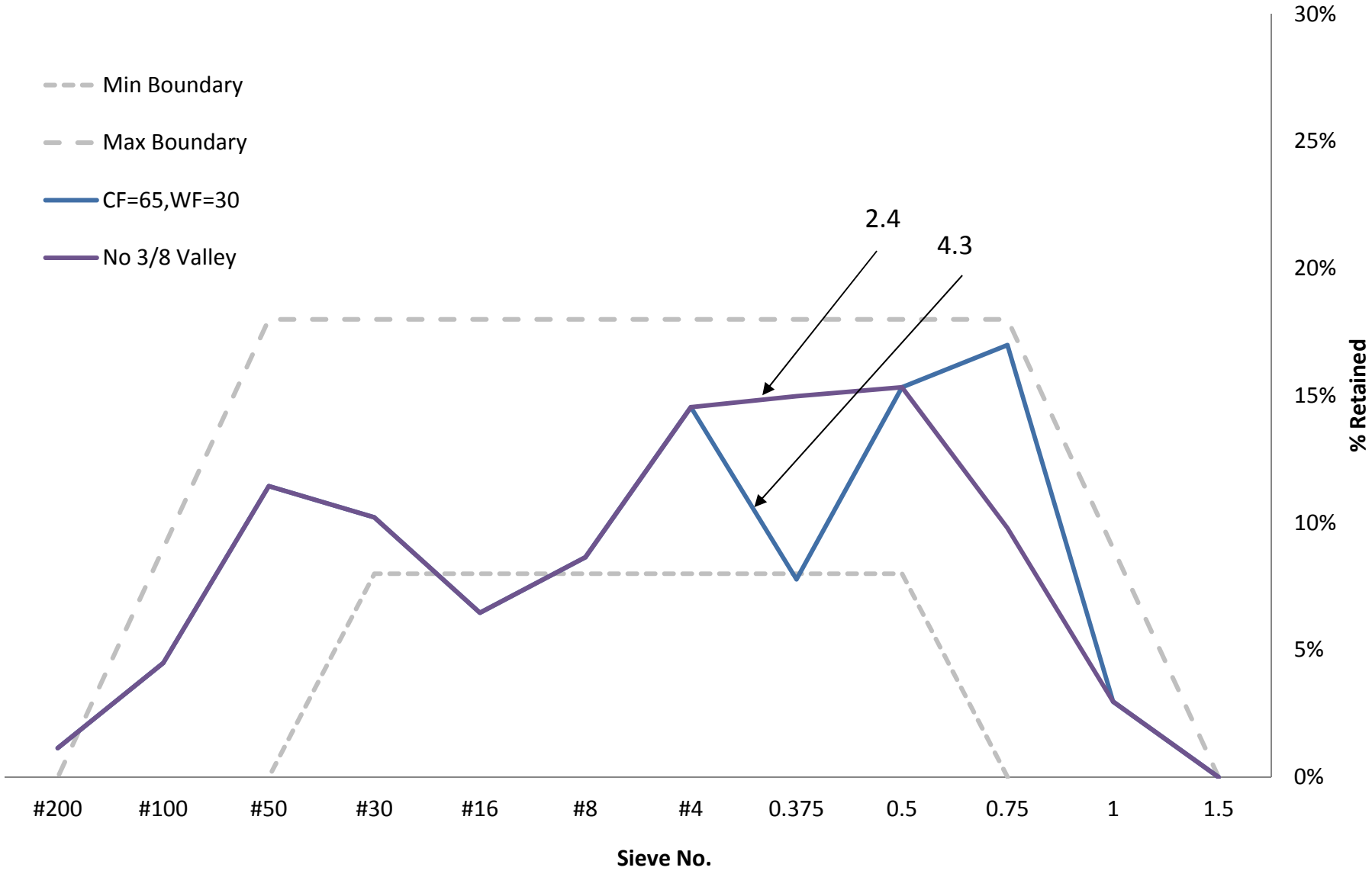
Proportioning of Coarse to Intermediate



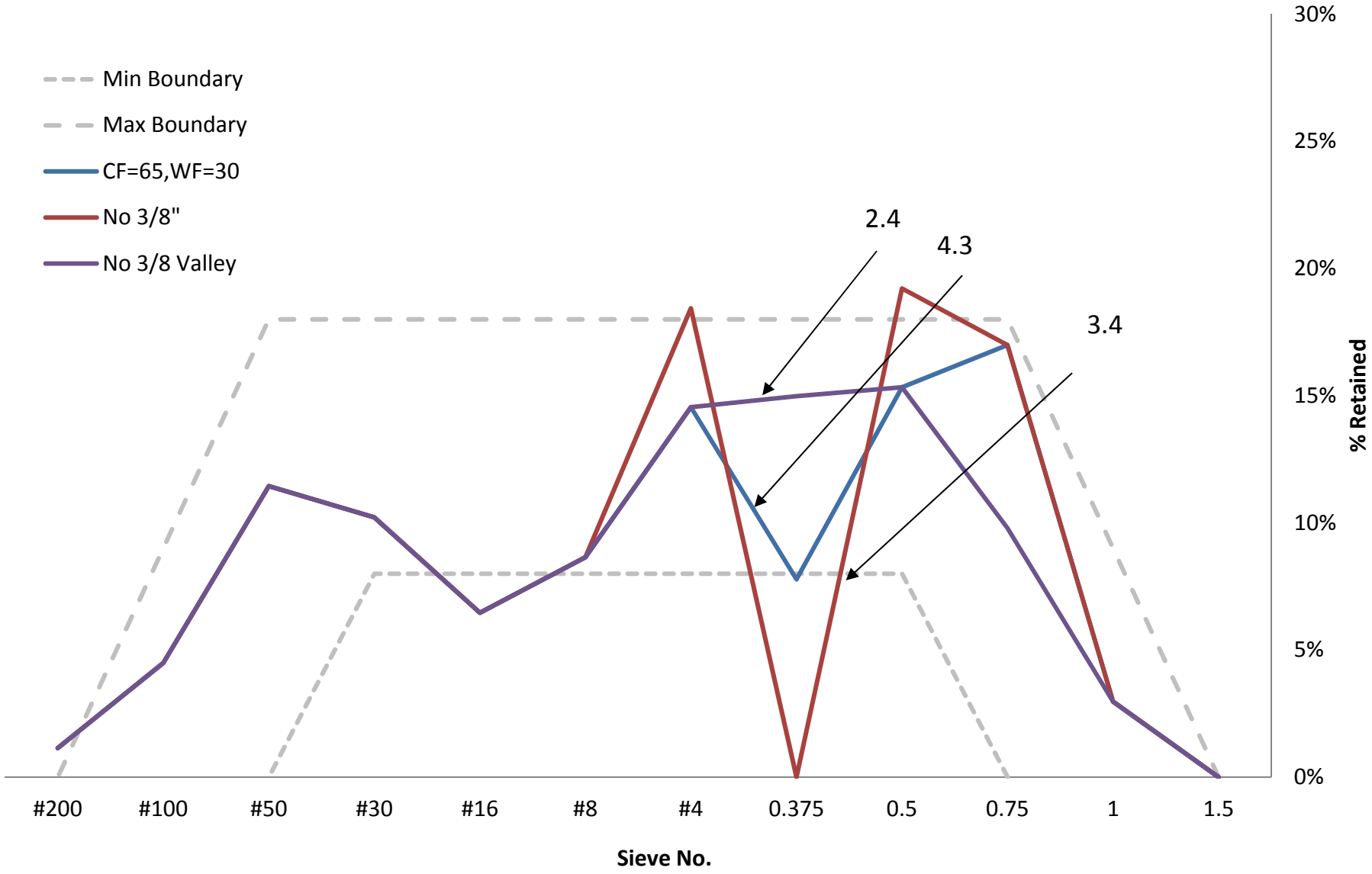
Impacts of a Single Valley



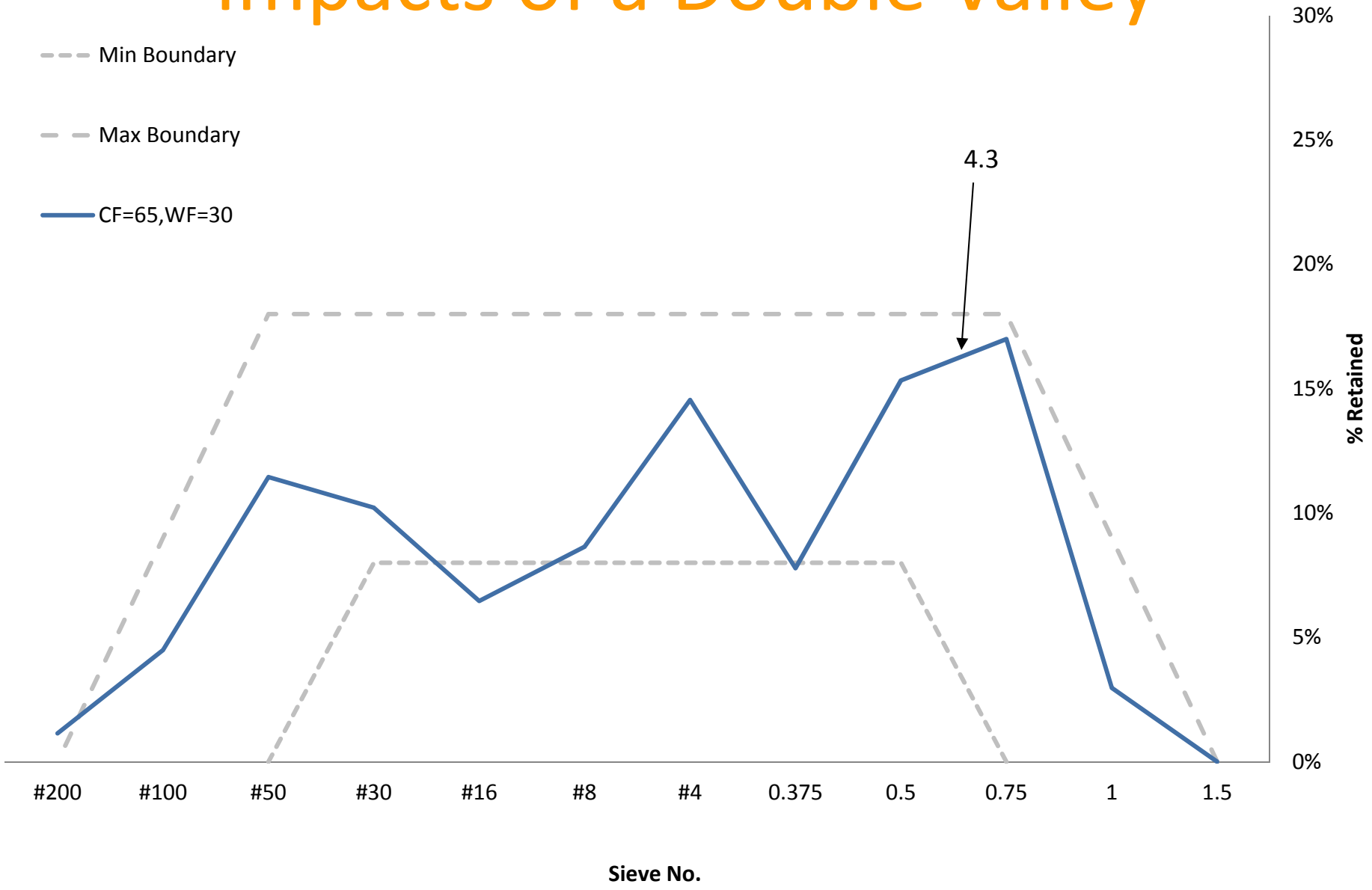
Impacts of a Single Valley



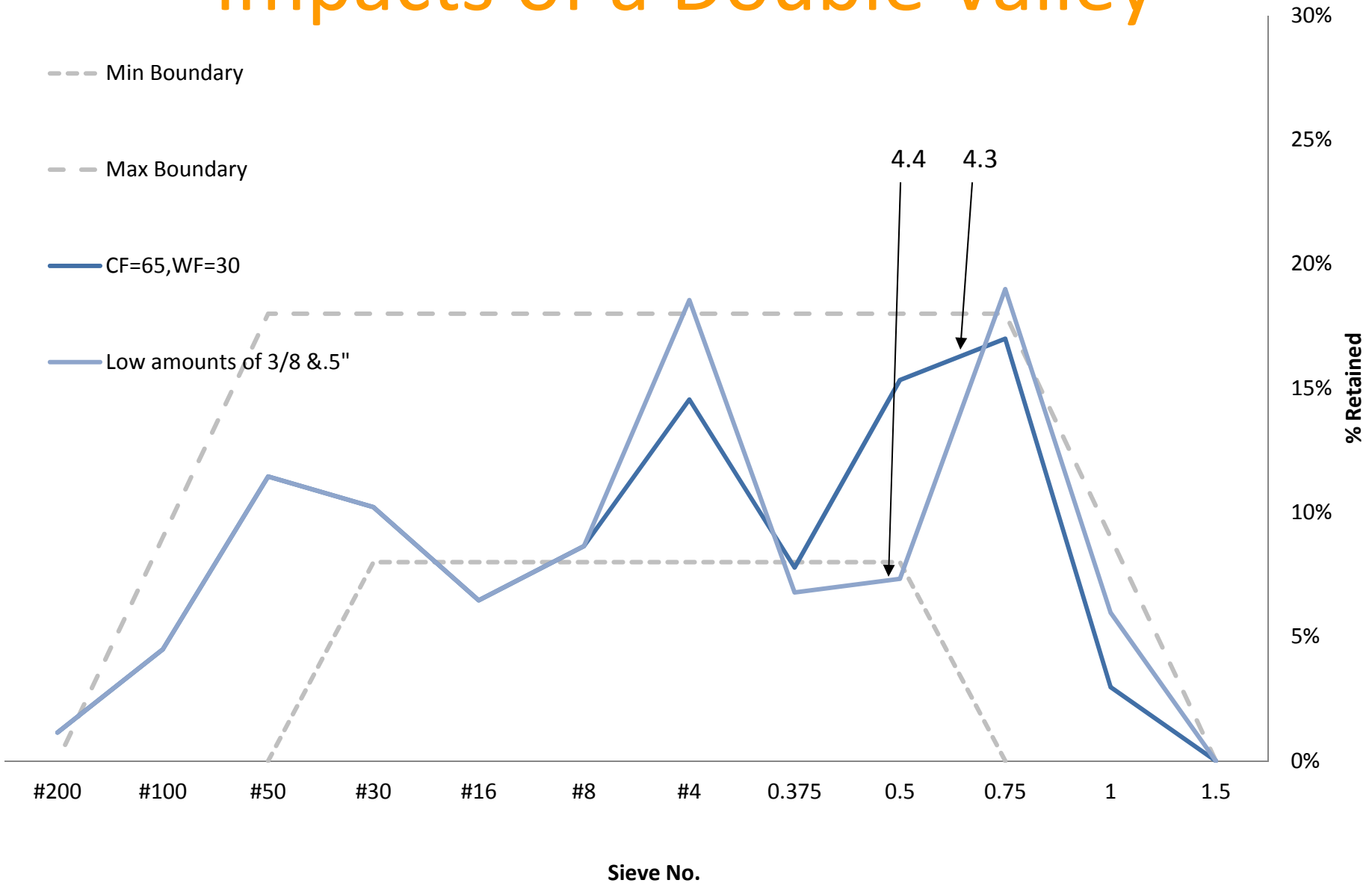
Impacts of a Single Valley



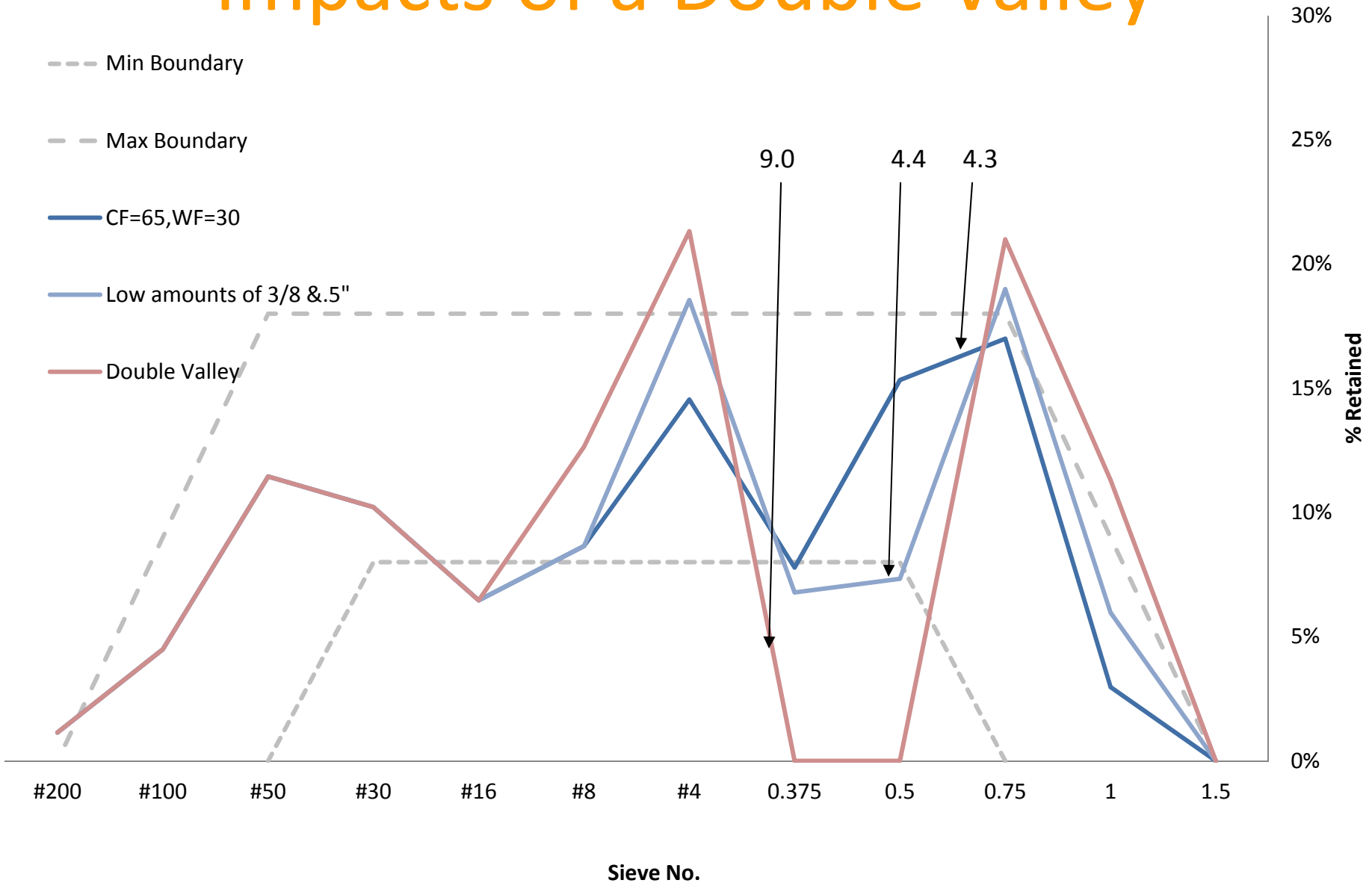
Impacts of a Double Valley



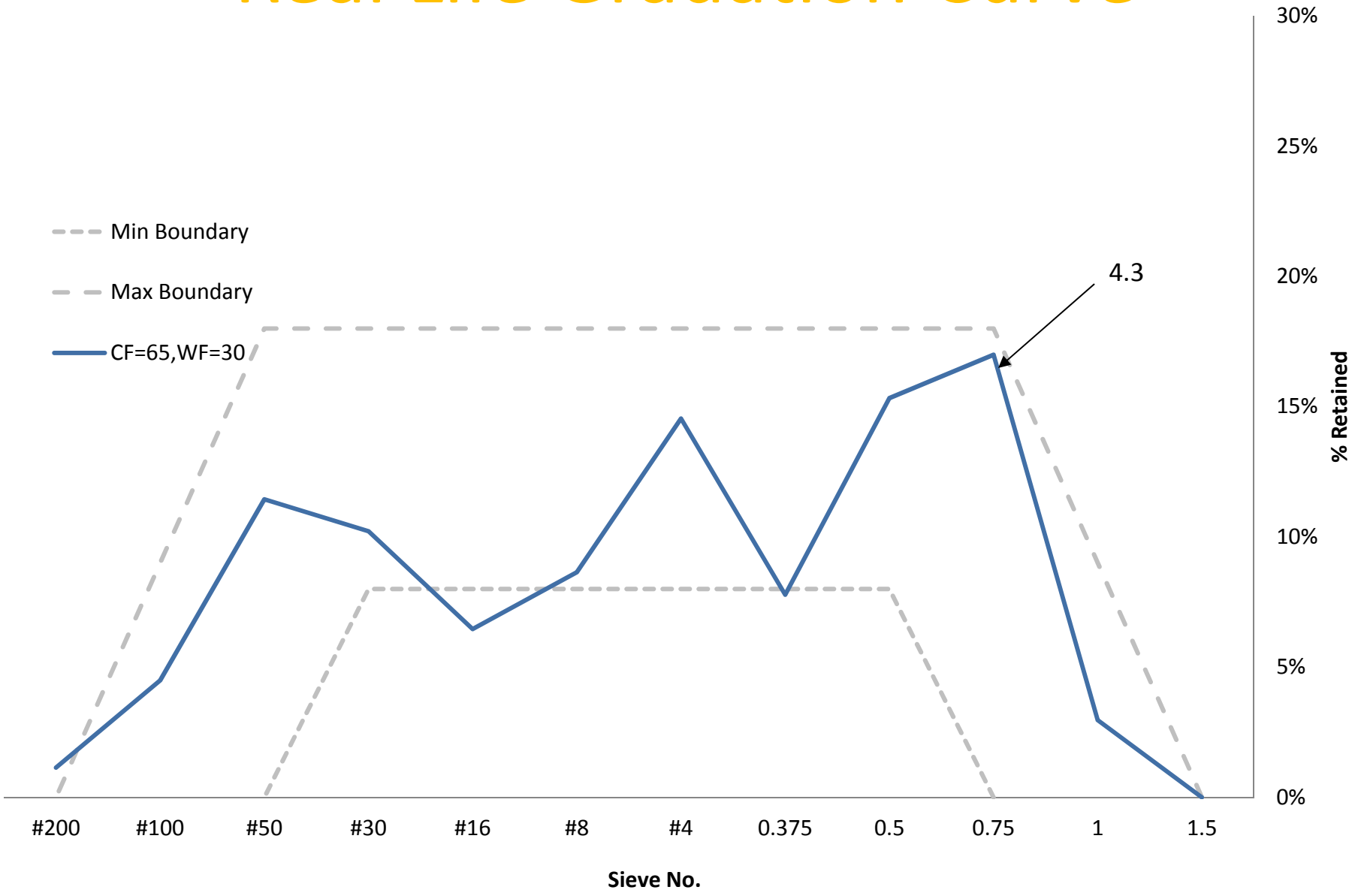
Impacts of a Double Valley



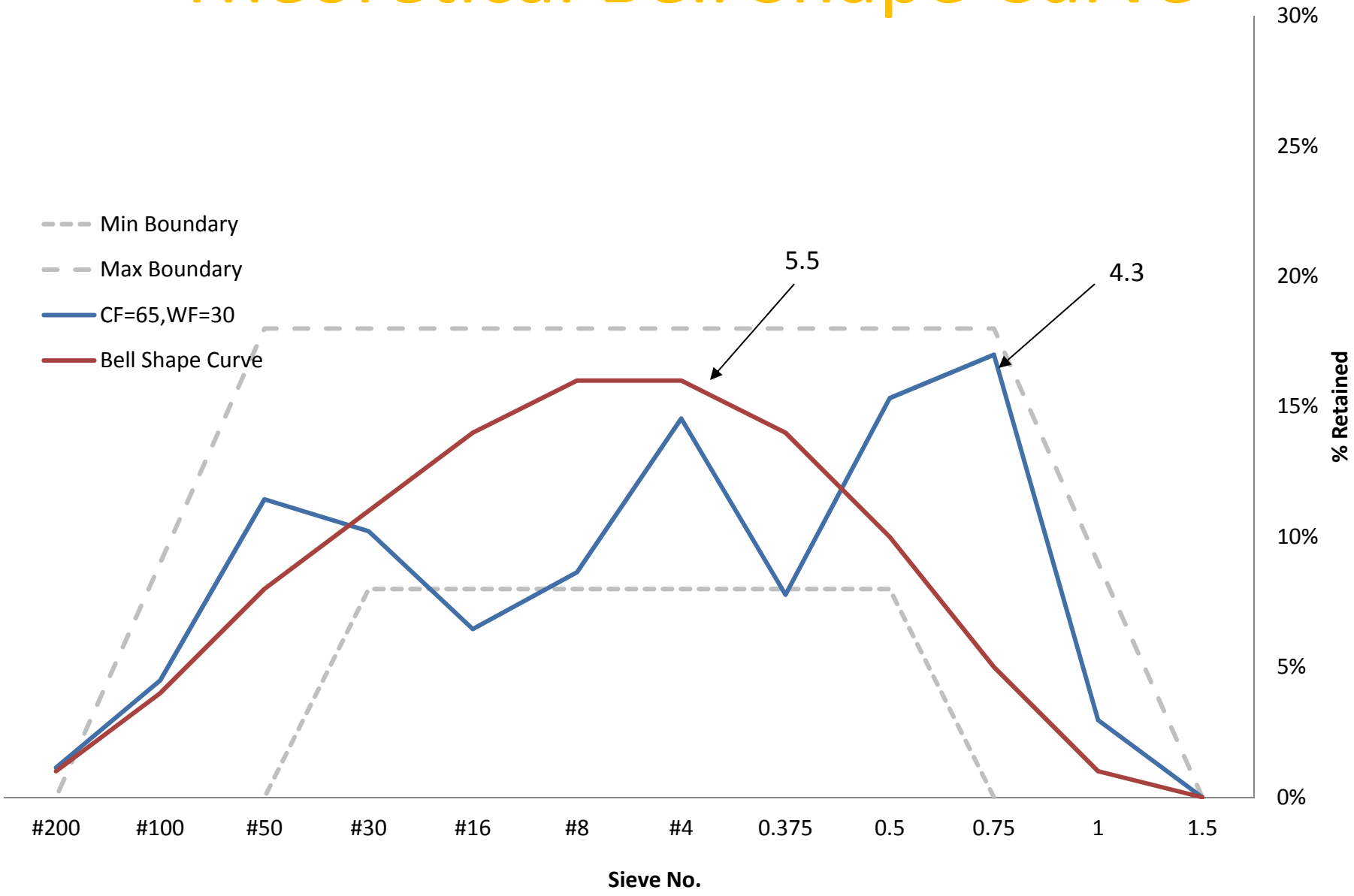
Impacts of a Double Valley



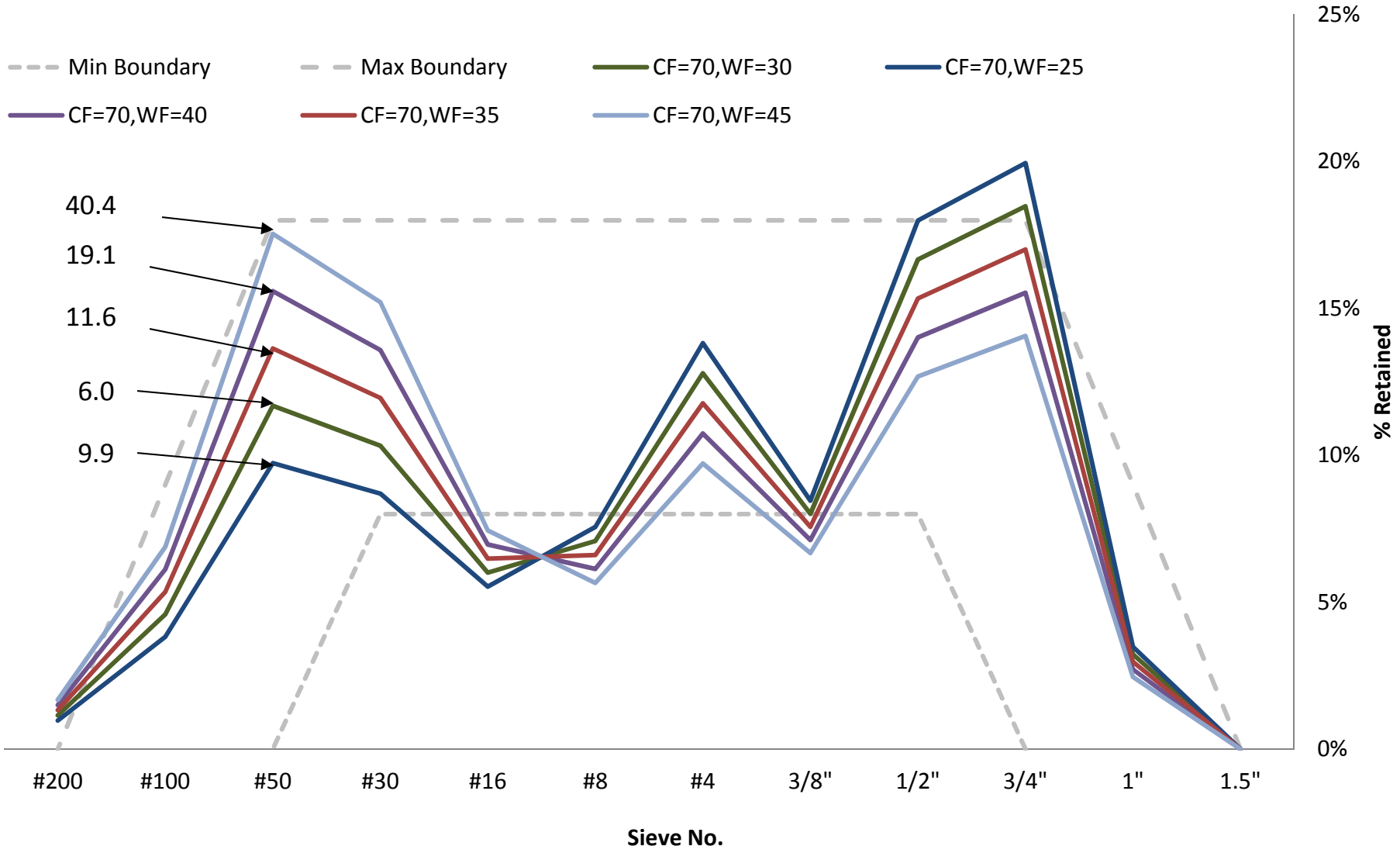
Real Life Gradation Curve



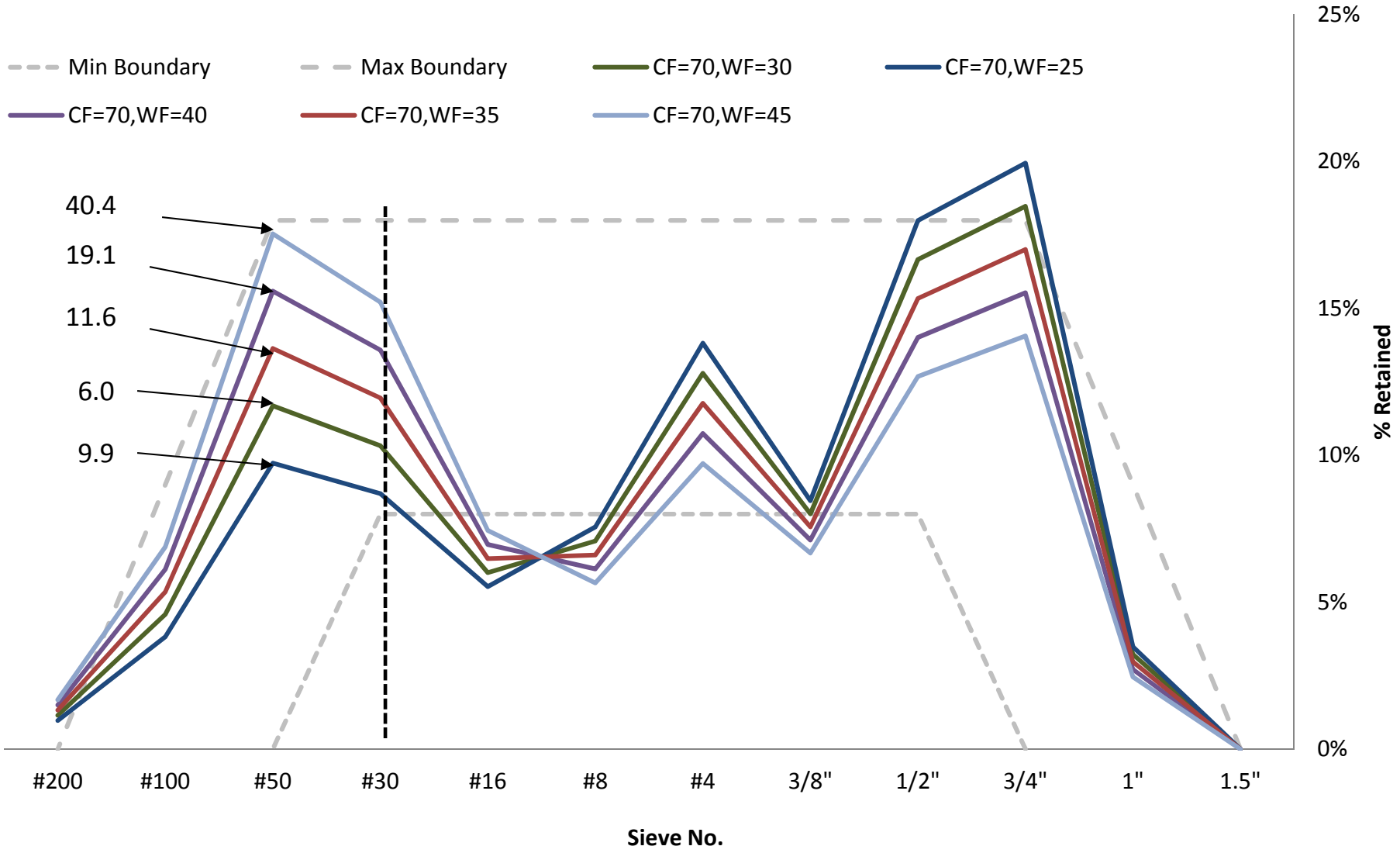
Theoretical Bell Shape Curve

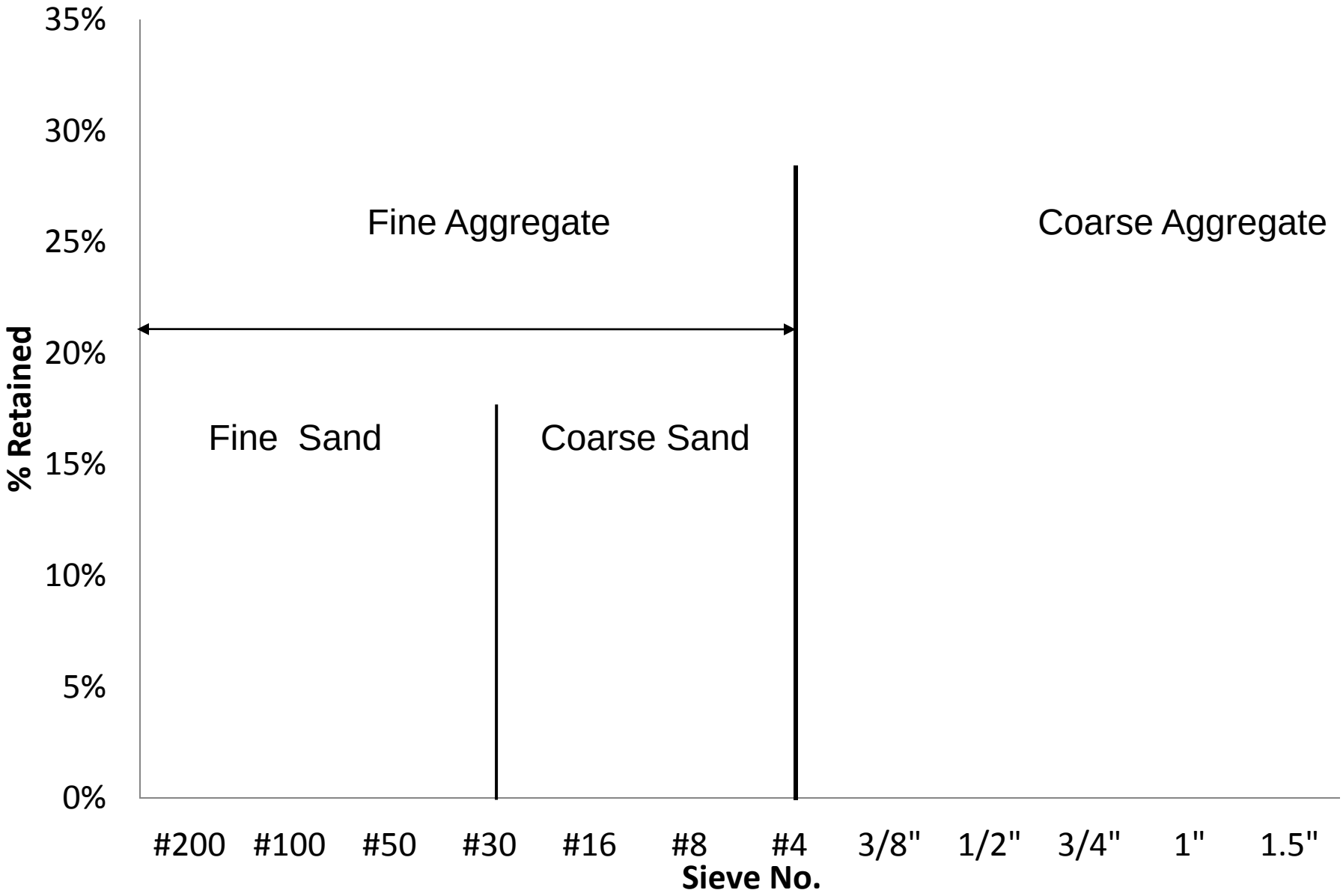


Proportioning of Sand



Proportioning of Sand




35%
30%
25%
20%
15%
10%
5%
0%
% Retained
Fine Aggregate
Coarse Aggregate
Fine Sand
Coarse Sand
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.

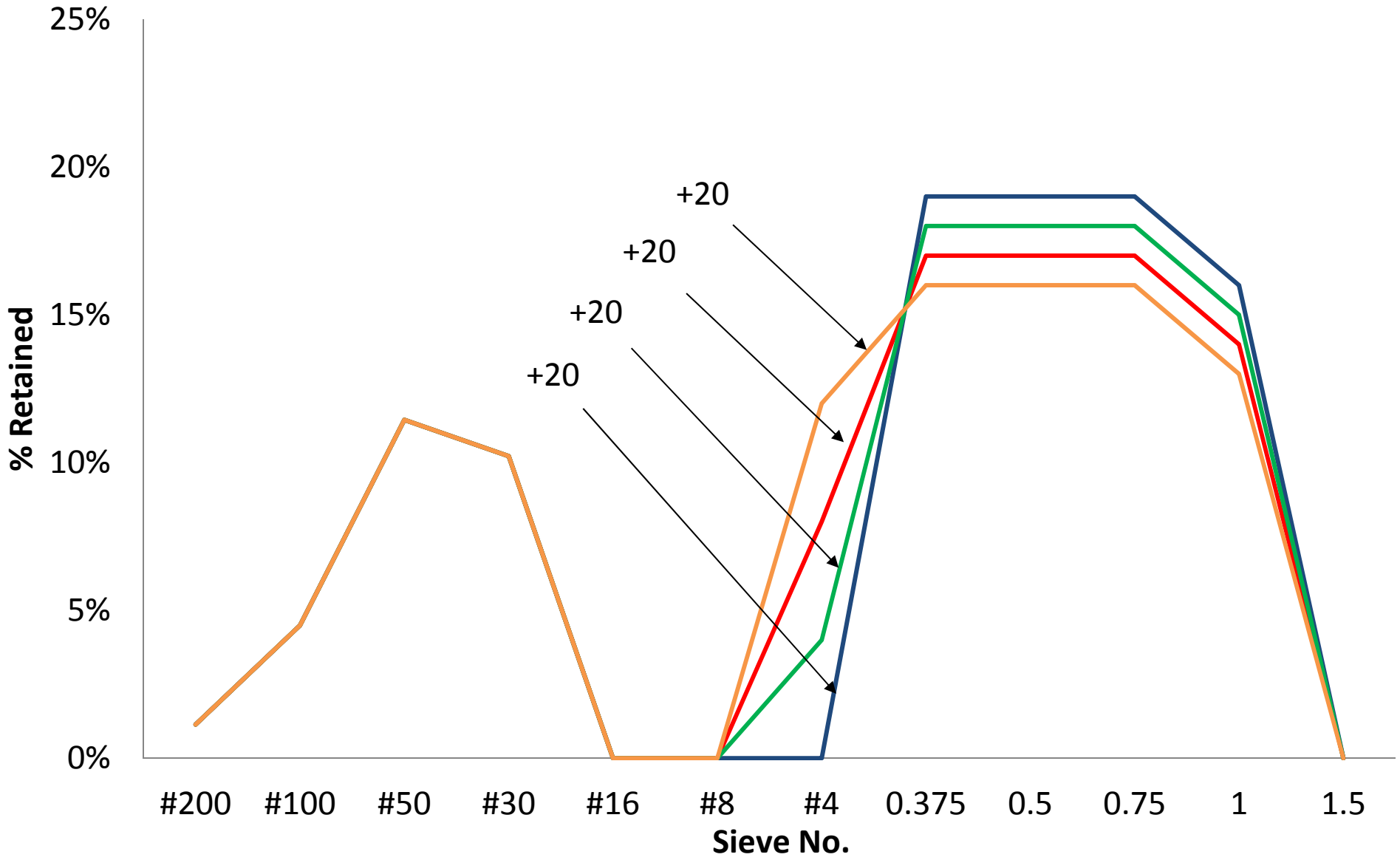
WARNING!!!

- We are about to sieve sand into **CRAZY** gradations and evaluate the subsequent performance
- We are not suggesting that you sieve your sand!
- We did this to better understand the critical characteristics of fine aggregate

Investigation of Coarse Sand

- We are going to remove all of the coarse sand from a mixture and then start to slowly add material on the #4, #8, #16, and #30 to see how the performance changes

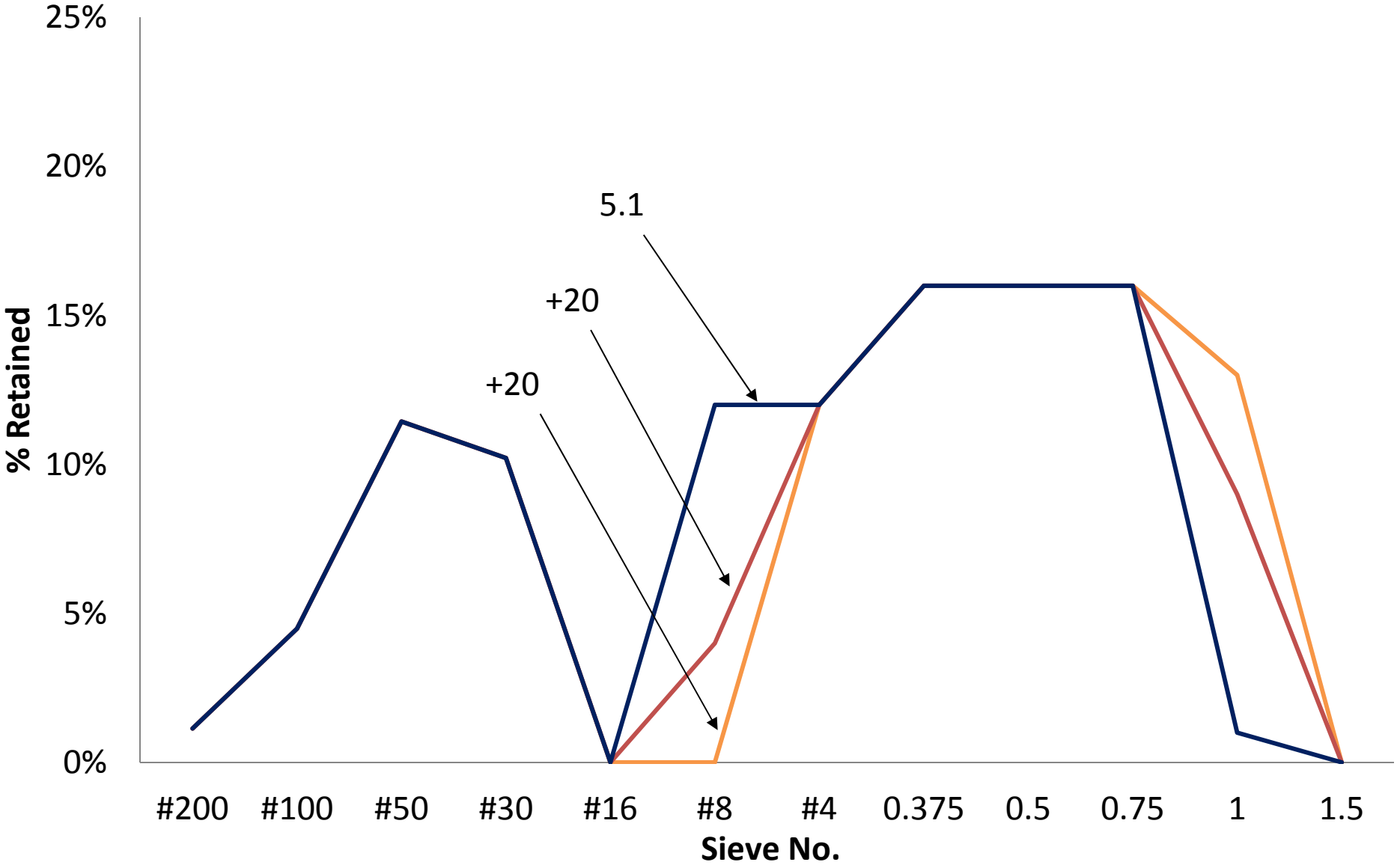
- ACI 302.1R-04 – recommends the sum of #8 and #16 sieve sizes should not be below 13% to help with edge slumping


25%
20%
15%
10%
5%
0%
% Retained
+20
+20
+20
+20
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

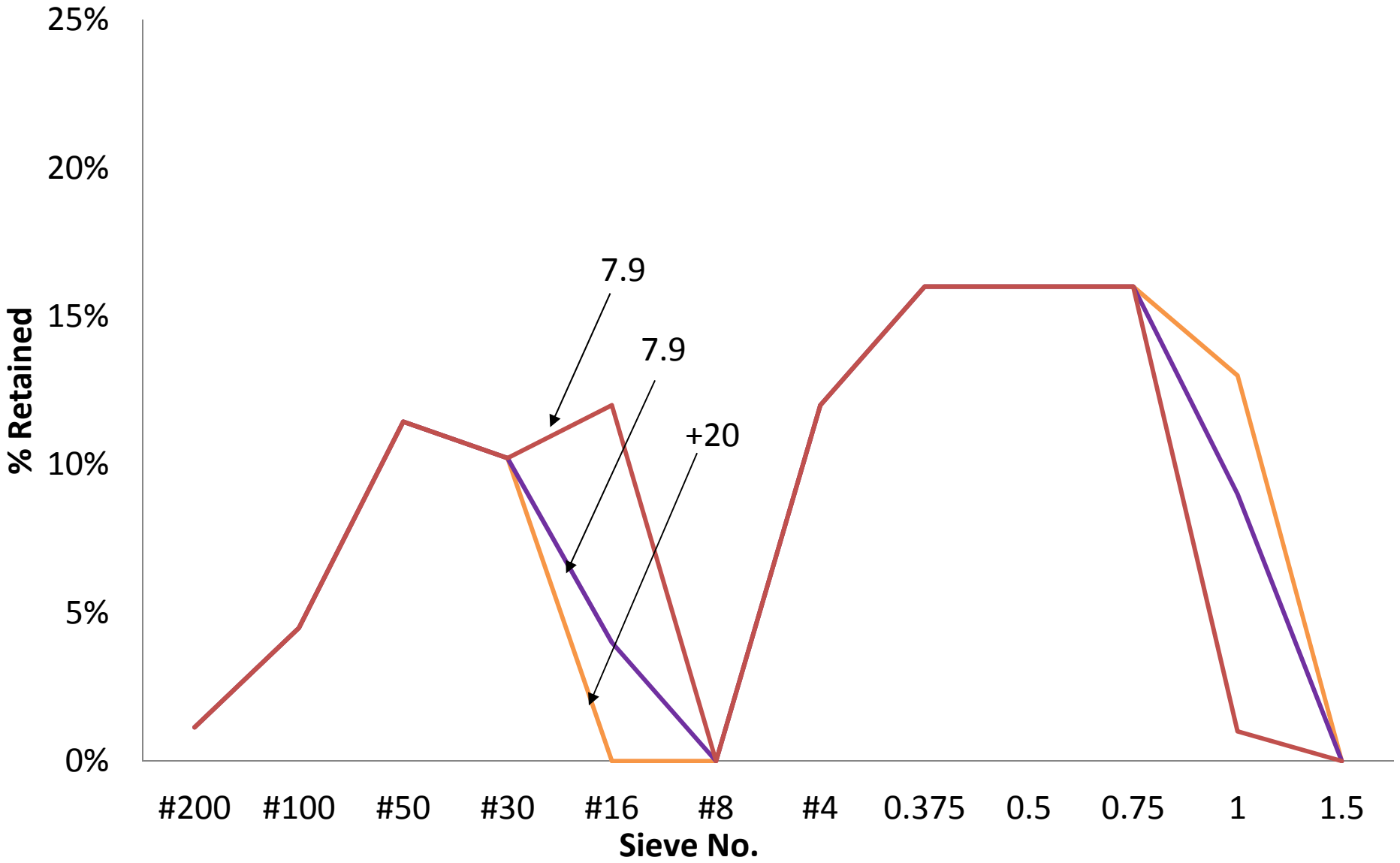
Images of the mixtures

Edge slumping

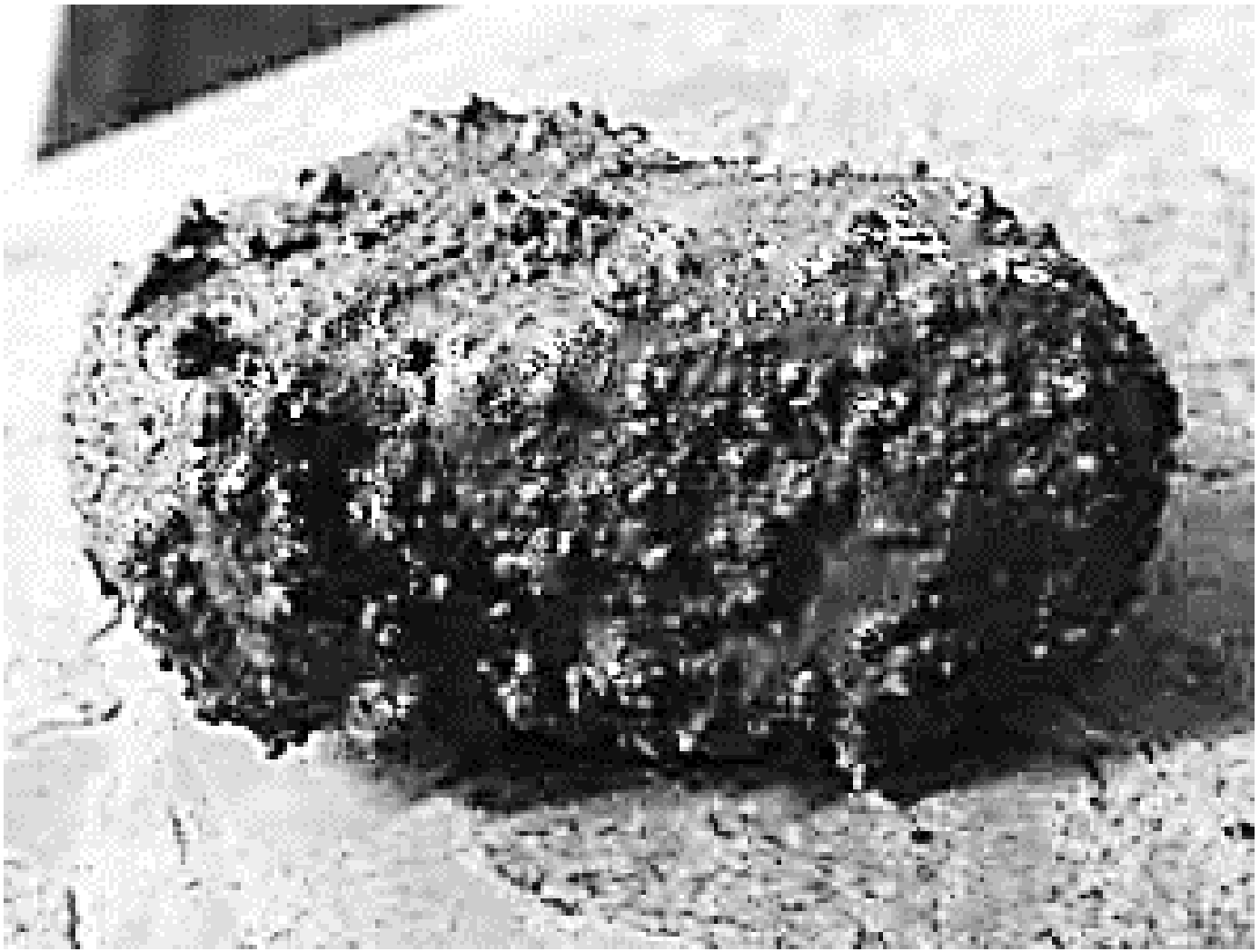
Impacts of #8


25%
20%
15%
10%
5%
0%
% Retained
5.1
+20
+20
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

Impacts of #16



What is happening?

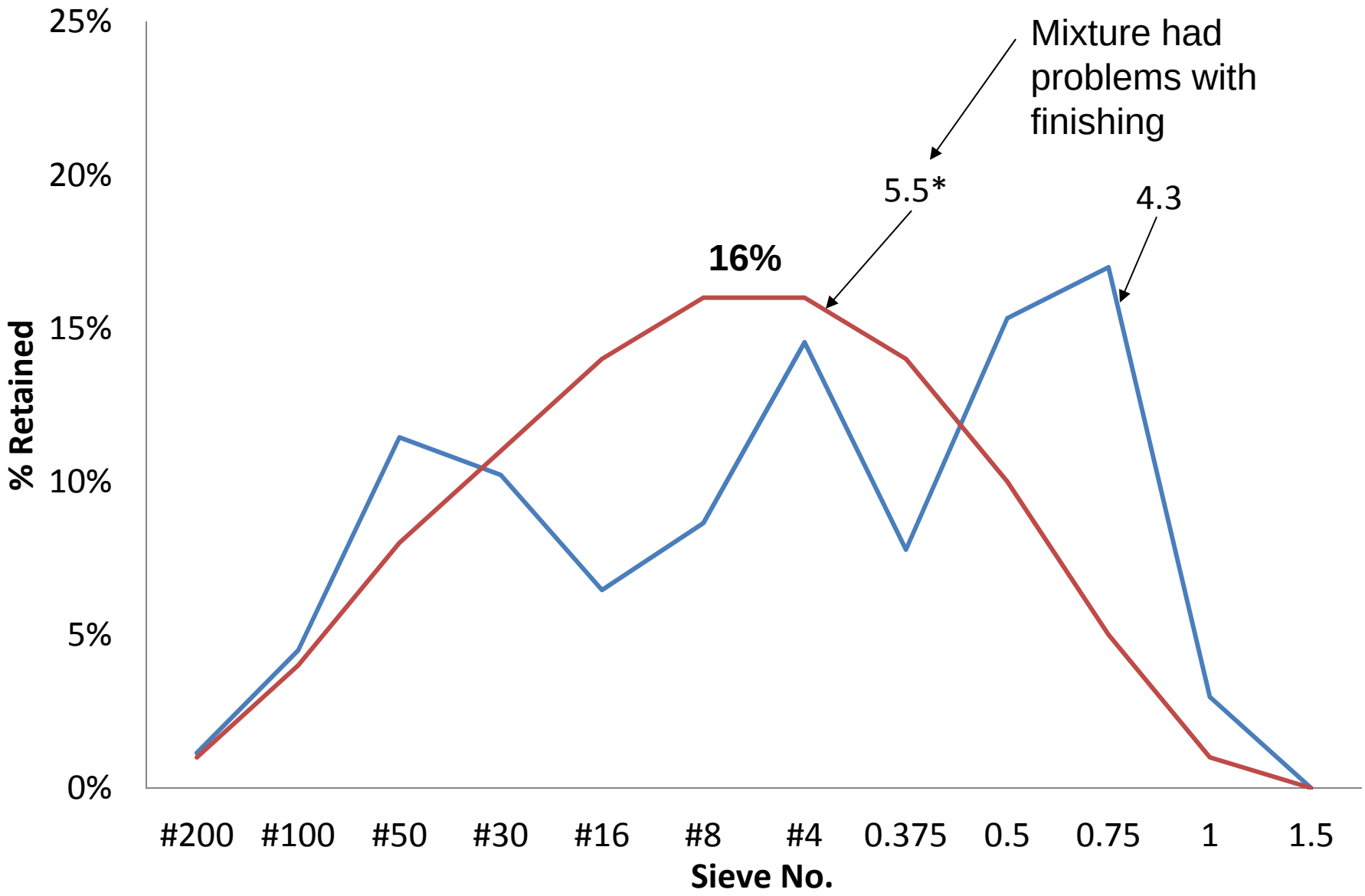


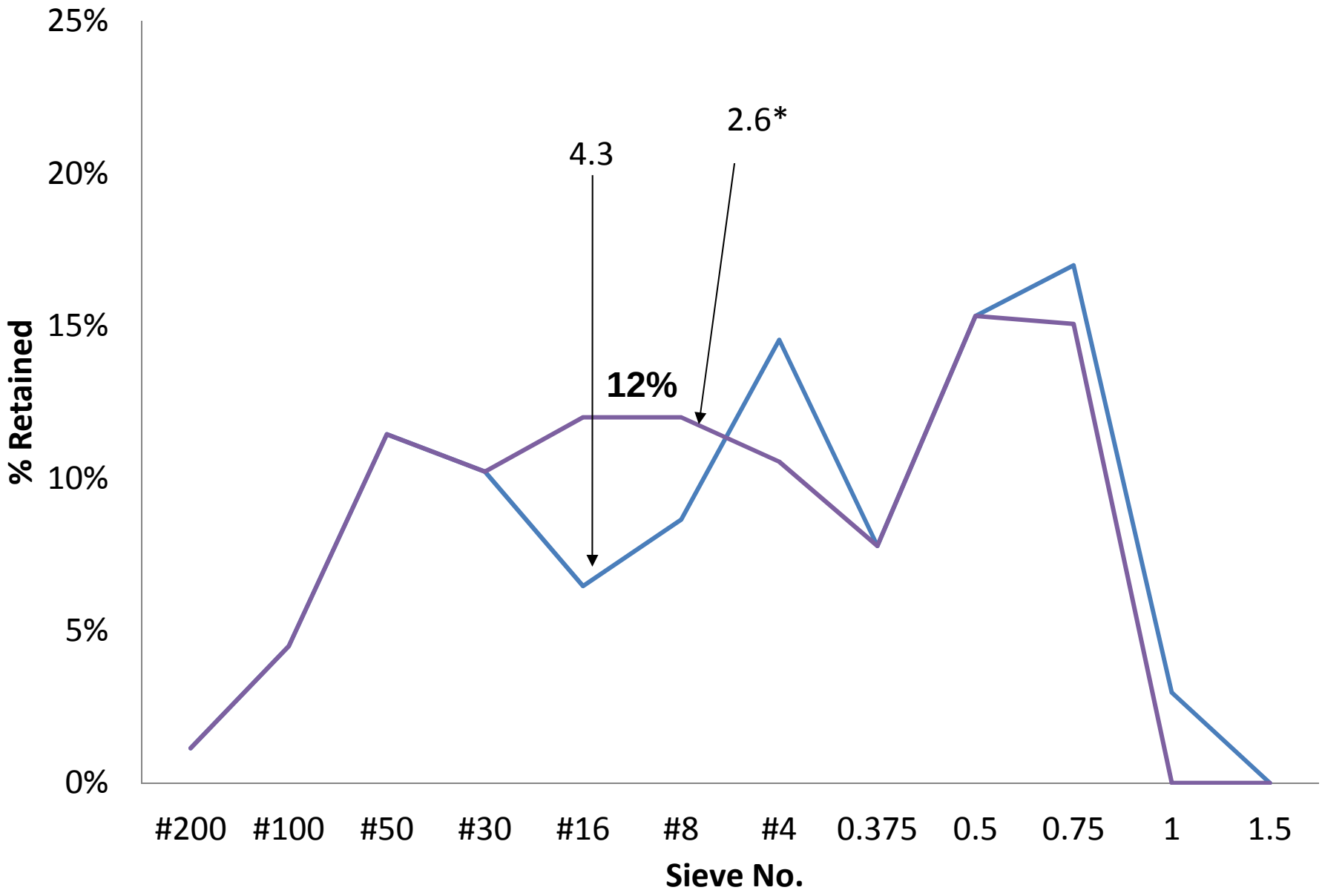
Investigation of Coarse Sand

- The #8 & #16 seems to cling to the coarse aggregate
- These smaller particles help provide more cohesion and internal structure to the mixture
- This is important for edge slumping and response to vibration

Investigation of Coarse Sand

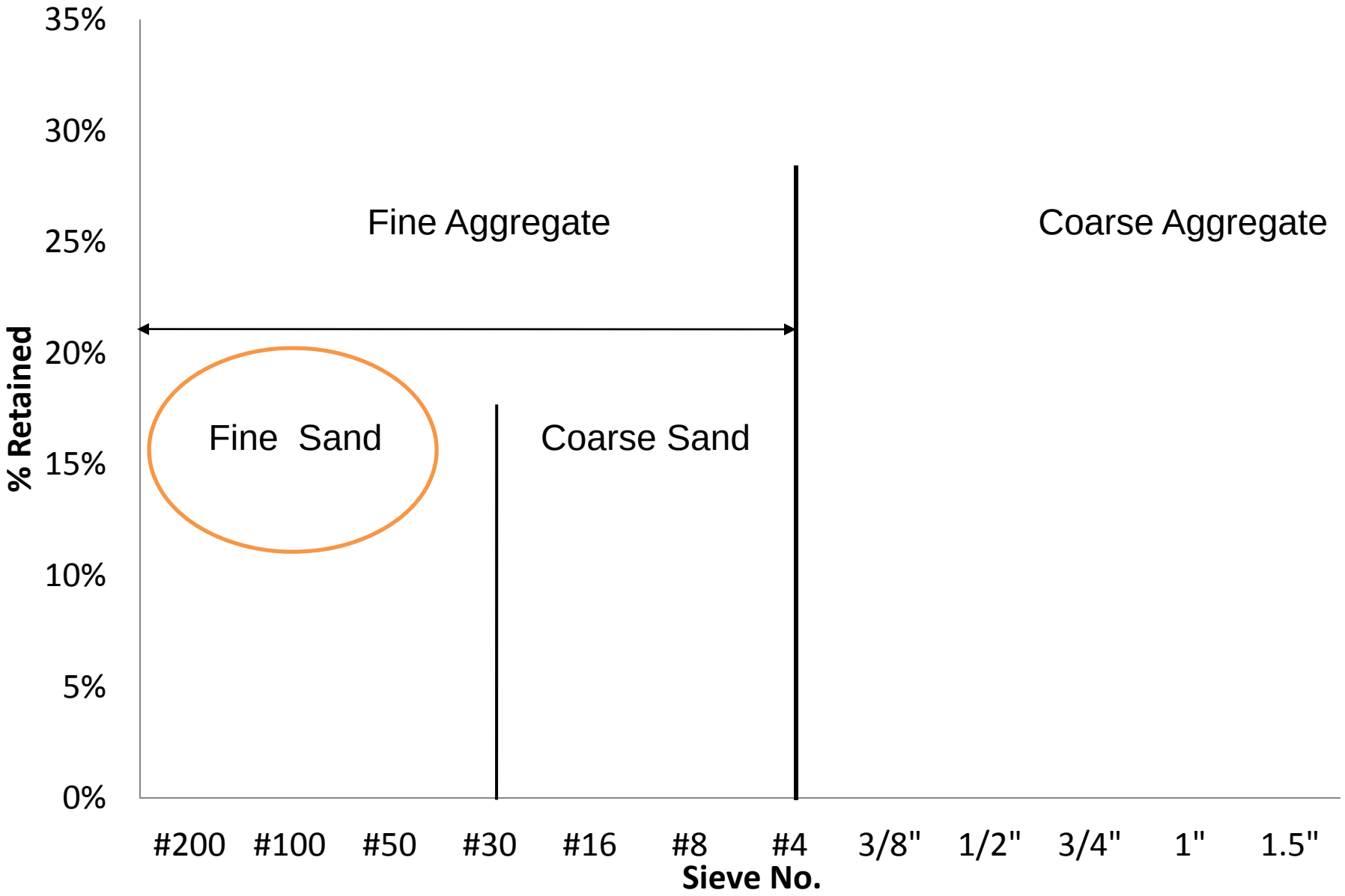
- Can you have too much #8 and #16?


25%
20%
15%
10%
5%
0%
% Retained
Mixture had problems with finishing
5.5*
4.3
16%
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.


25%
20%
15%
10%
5%
0%
% Retained
4.3
2.6*
12%
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

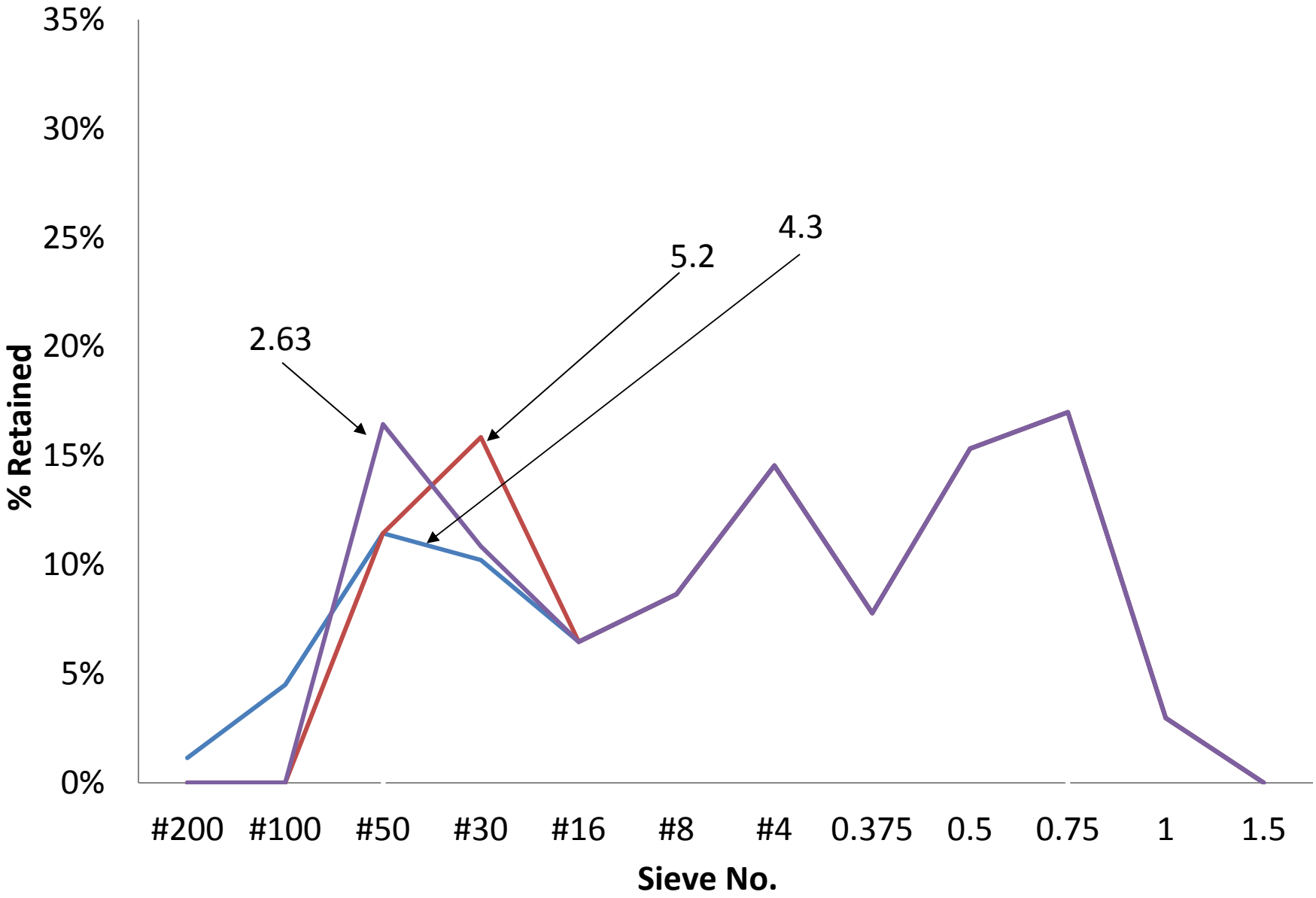
Summary of Coarse Sand

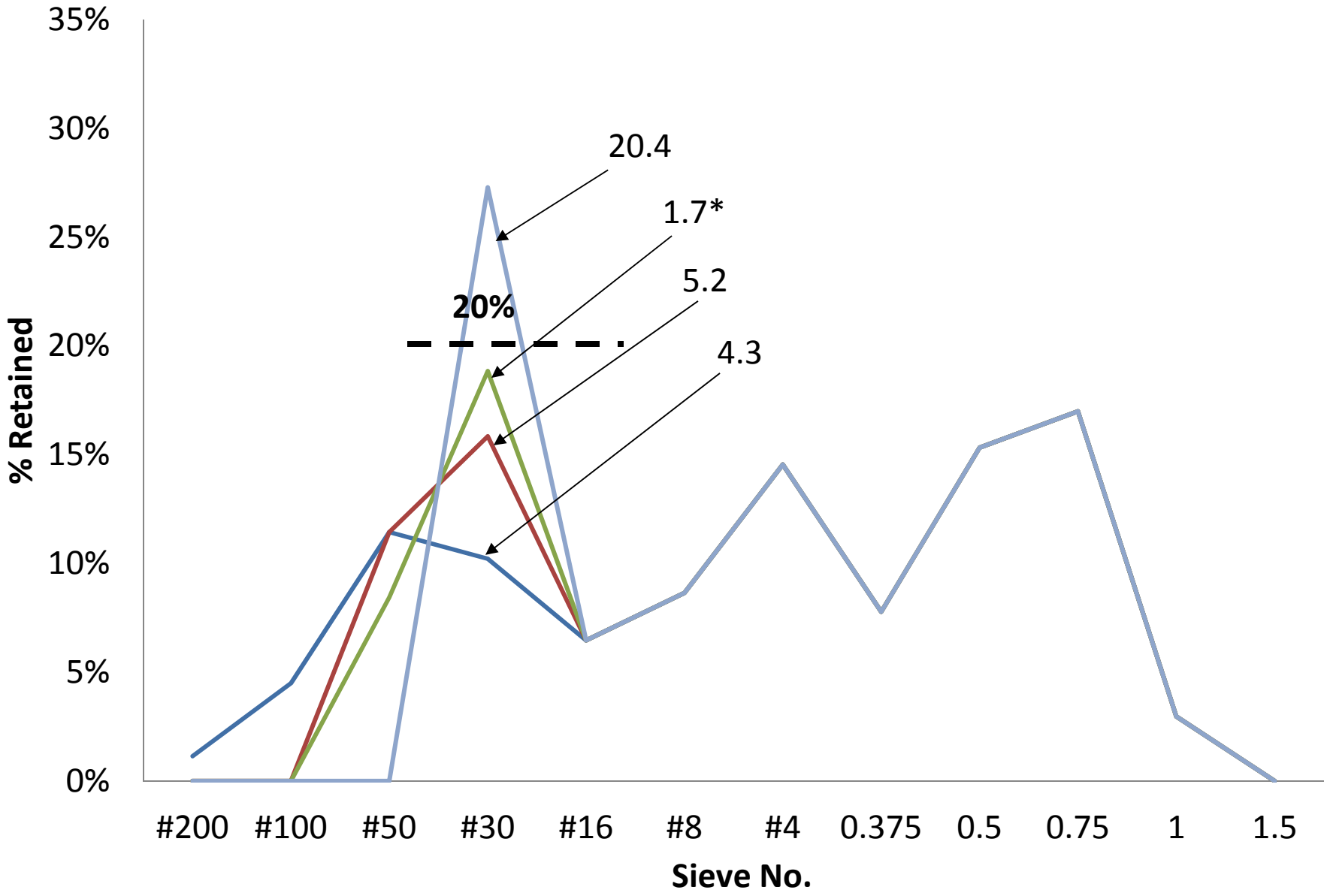
- The #8, #16, and #30 contributes to the edge slumping and response to vibration of the mixture
- A minimum of 15% cumulative retained on the #8-#30 sieve sizes is suggested
- The #8 and #16 should be limited to 12% to minimize finishing issues.


35%
30%
25%
20%
15%
10%
5%
0%
% Retained
Fine Aggregate
Coarse Aggregate
Fine Sand
Coarse Sand
#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
3/4"
1"
1.5"
Sieve No.

Investigation of Fine Sand

- The gradation and volume of aggregates were held constant for sizes greater than #16
- The volume of fine sand (#30 to #200) was held constant
- The distribution was allowed to change


35%
30%
25%
20%
15%
10%
5%
0%
% Retained
2.63
5.2
4.3
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.


35%
30%
25%
20%
15%
10%
5%
0%
% Retained
20.4
1.7*
5.2
4.3
20%
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

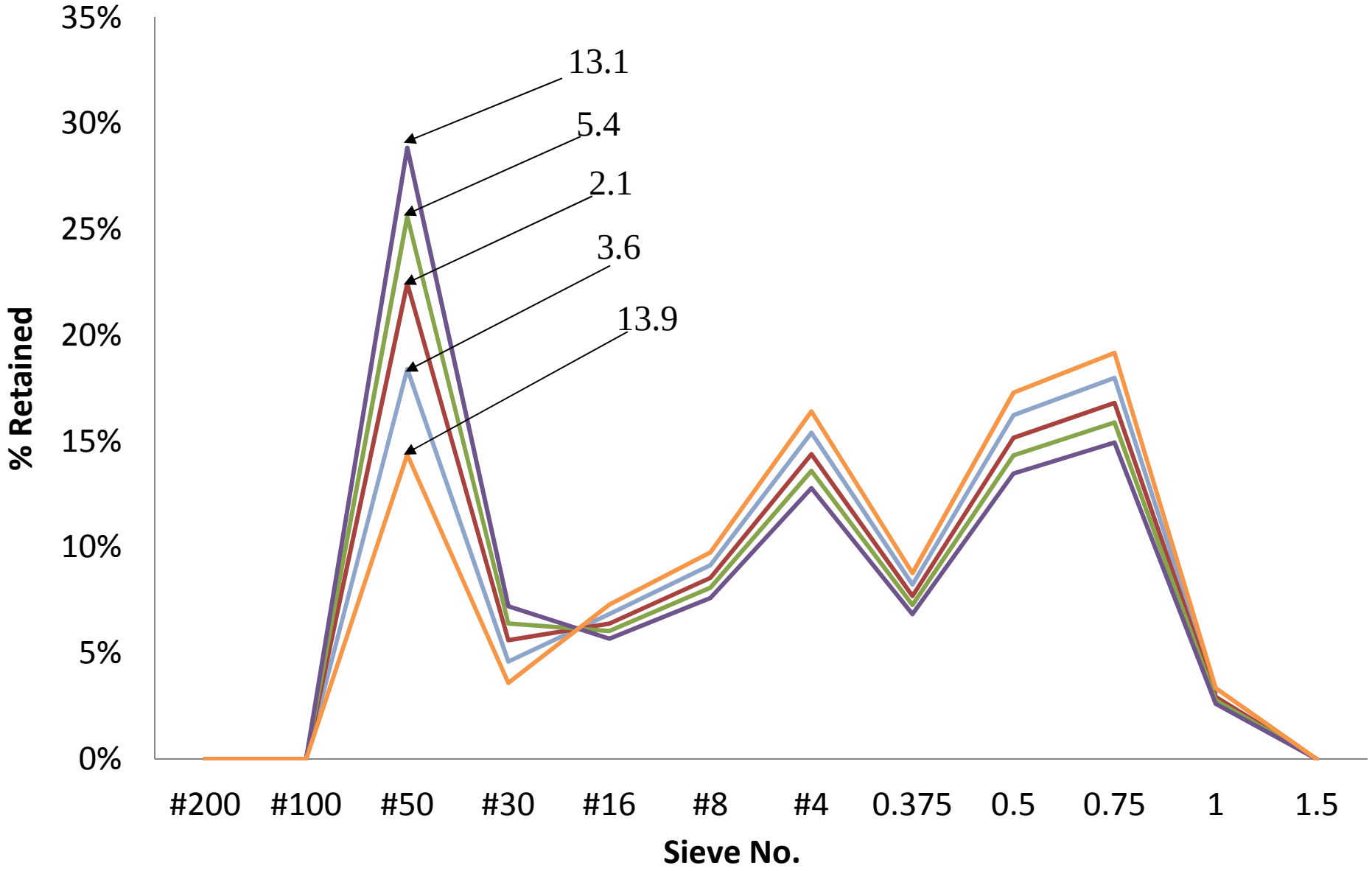
Summary

- Fine sand gradation can vary largely without impacting the workability.
- Mixtures with around 20% retained on the #30 sieve size can cause finishing issues.

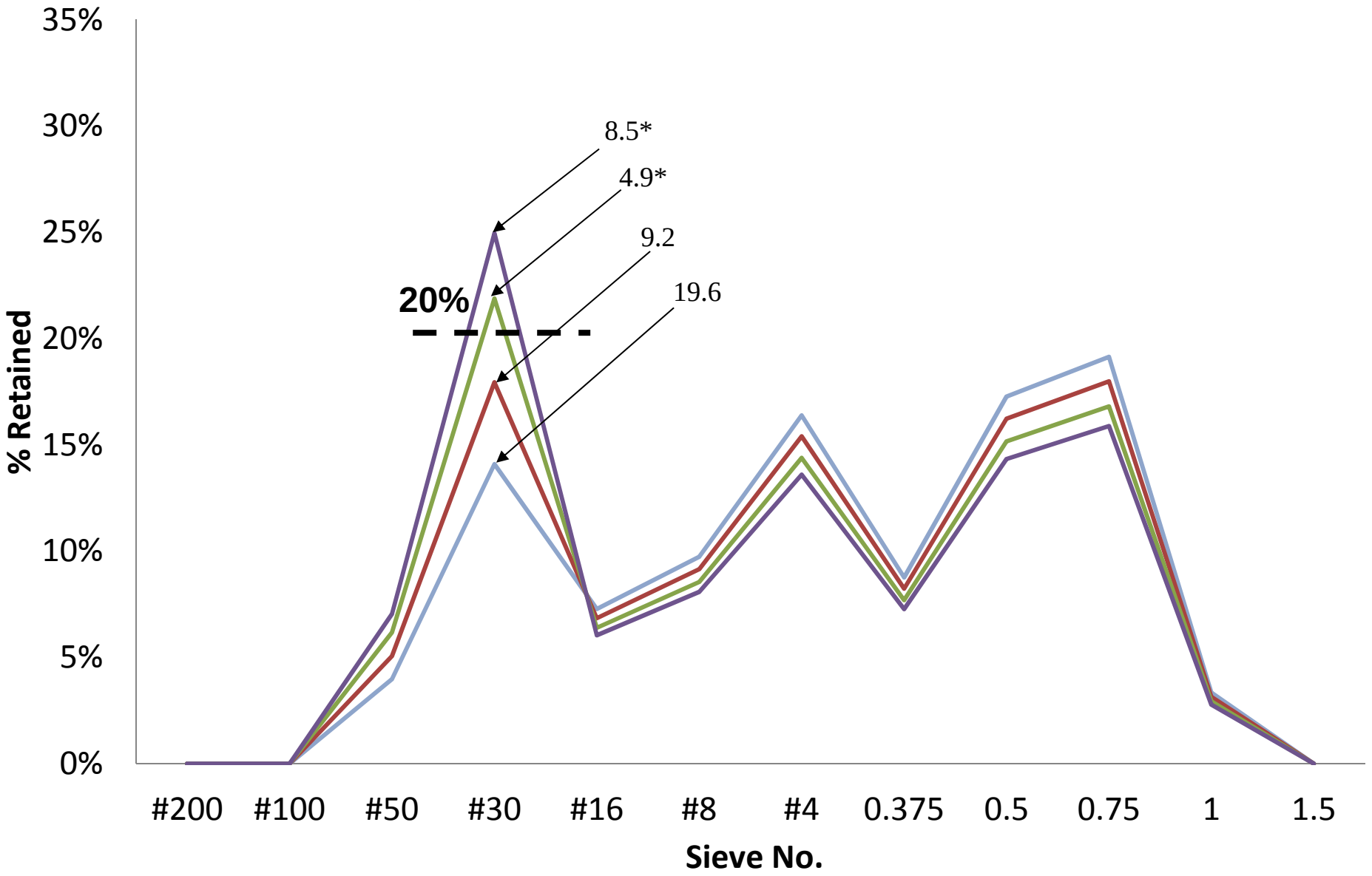
Investigation of Fine Sand

- We are going to hold the gradation of #16 through 1” constant and allow the fine sand (#30 to #200) to vary

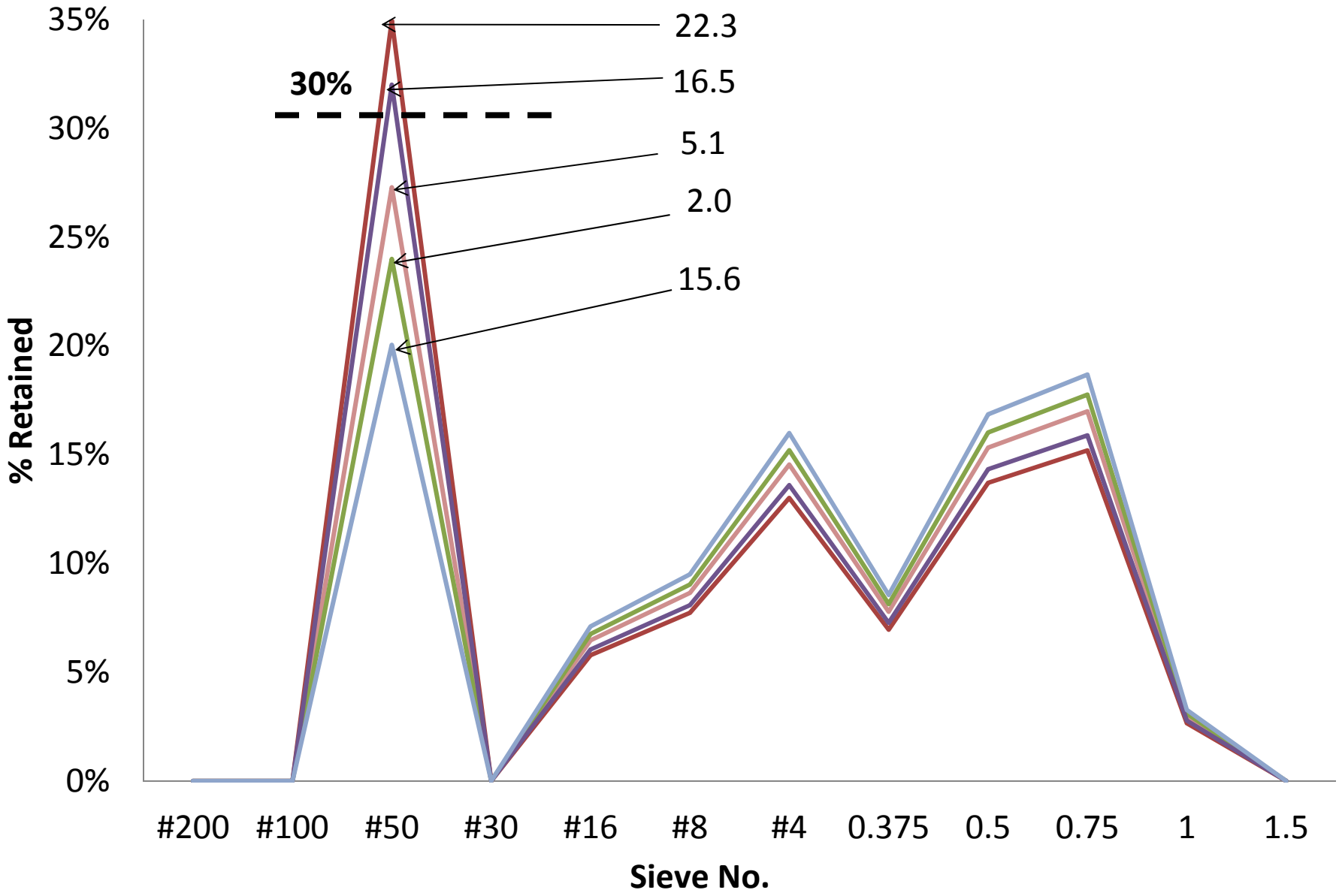
Using 20% #30 & 80% #50



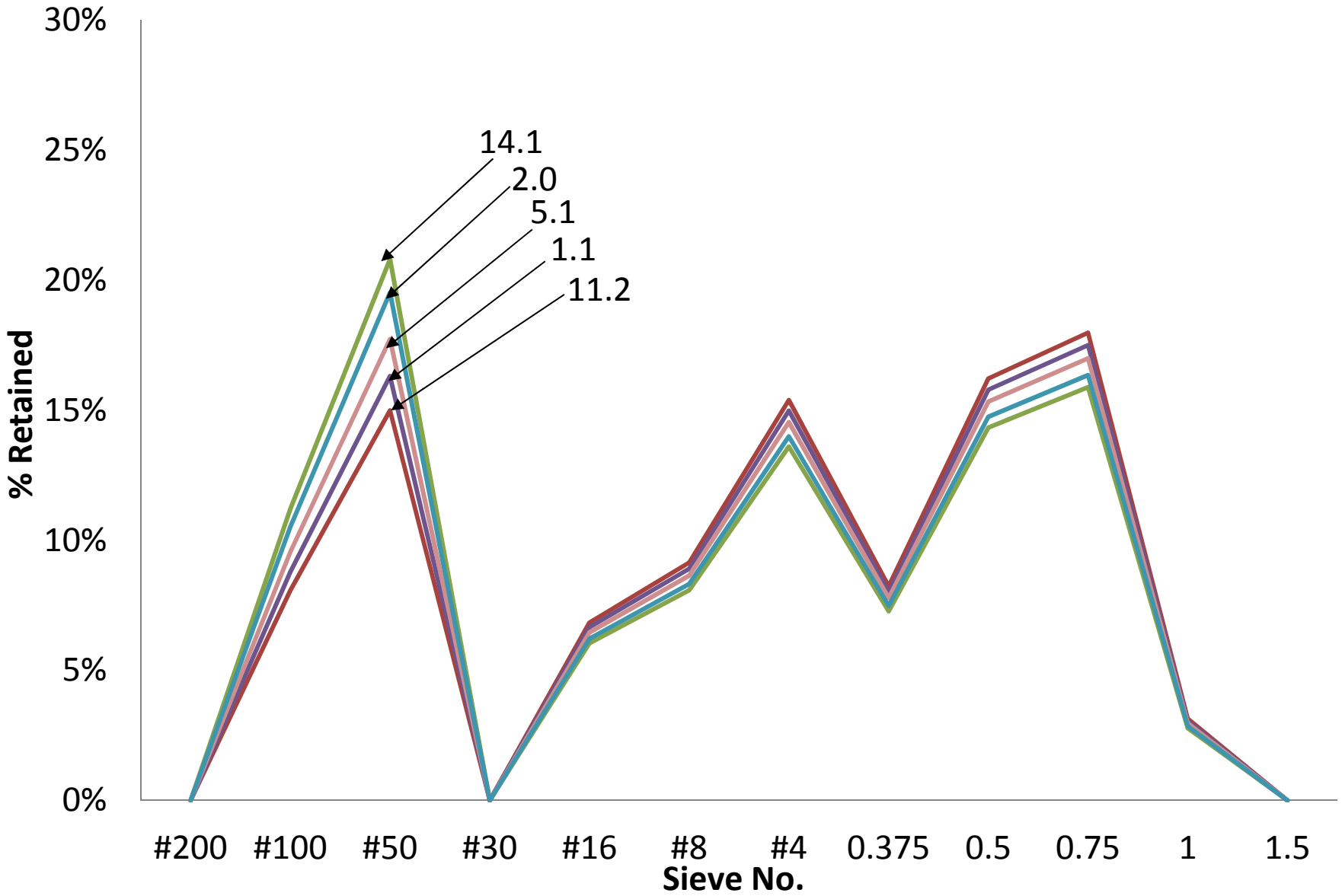
Using 80% #30 & 20% #50

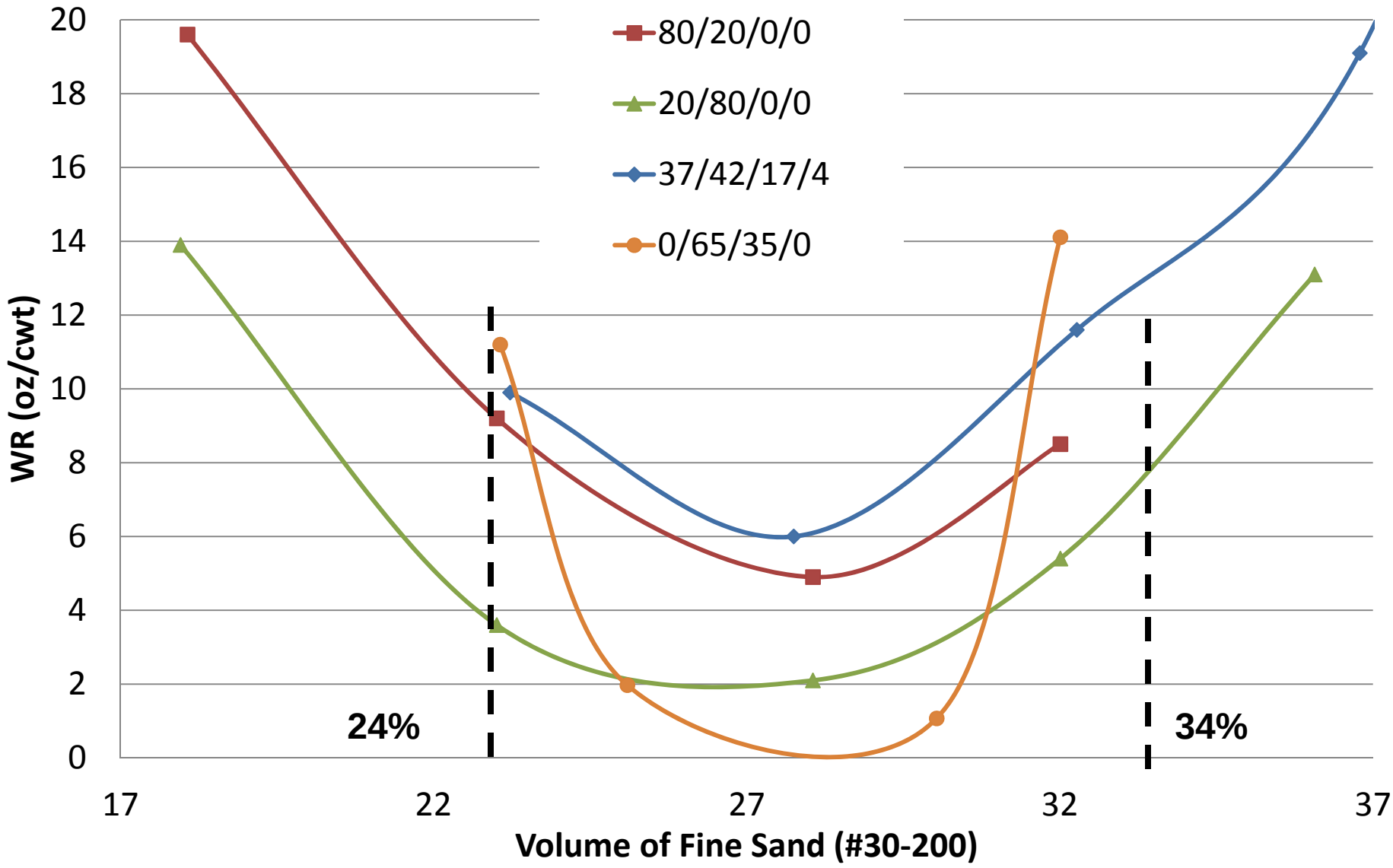


Using Only #50



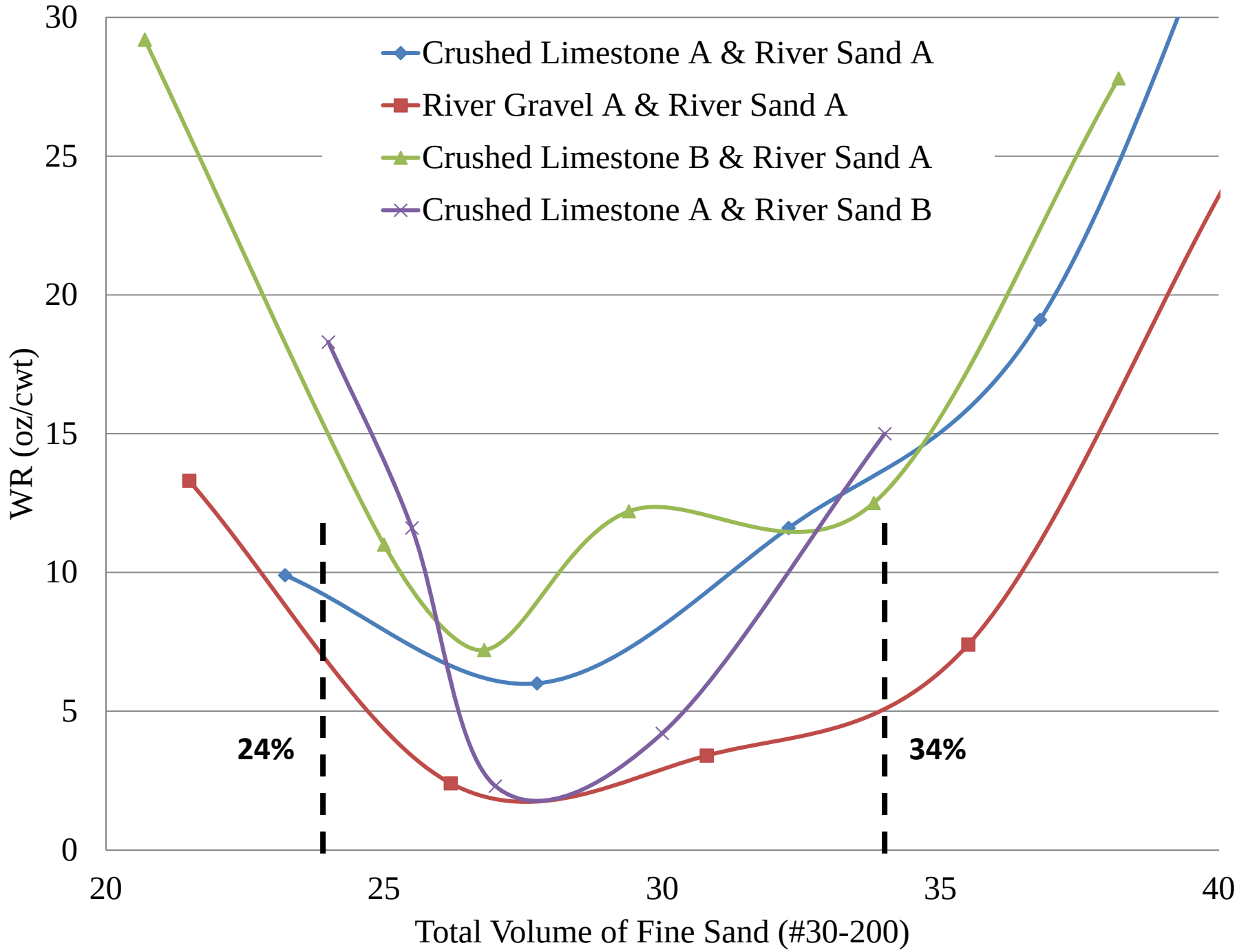
Using 65% #50 & 35% #100




80/20/0/0
20/80/0/0
37/42/17/4
0/65/35/0
WR (oz/cwt)
20
18
16
14
12
10
8
6
4
2
0
17
22
27
32
37
Volume of Fine Sand (#30-200)
24%
34%

Validation with other Aggregates

- Same mixture design as previous
- Vary the sand to coarse and intermediate
- Used 3 different quarries
  - Limestone C
  - Limestone A
  - River Gravel A
- Used River Sand A & B


Crushed Limestone A & River Sand A
River Gravel A & River Sand A
Crushed Limestone B & River Sand A
Crushed Limestone A & River Sand B
WR (oz/cwt)
30
25
20
15
10
5
0
24%
34%
20
25
30
35
40
Total Volume of Fine Sand (#30-200)

Summary

- The distribution of fine sand can vary largely without effecting the workability.
- An aggregate volume between 24% to 34% is recommended for #30 - #200.
- This range was similar for multiple gradations and aggregate sources
- More than 20% retained on the #30 sieve size created finishing issues.

A New Specification for Oklahoma

- We investigated:
  - 5 different coarse aggregates thoroughly
  - Spot checks on 13 different aggregates
  - 3 different sands
  - Over 300 different concrete mixtures
- You put your mixture design in a spreadsheet and it will evaluate if you are within the specification

The *TARANTULA* curve!!!!

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

Excessive amount creates workability issues.

Creates surface finishability problems normally associated with manufactured sands.

Not in Scope of work

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

24-34% of fine sand (#30-200)

20%

20%

20%

16%

10%

12%

4%

4%

30%

25%

20%

15%

10%

5%

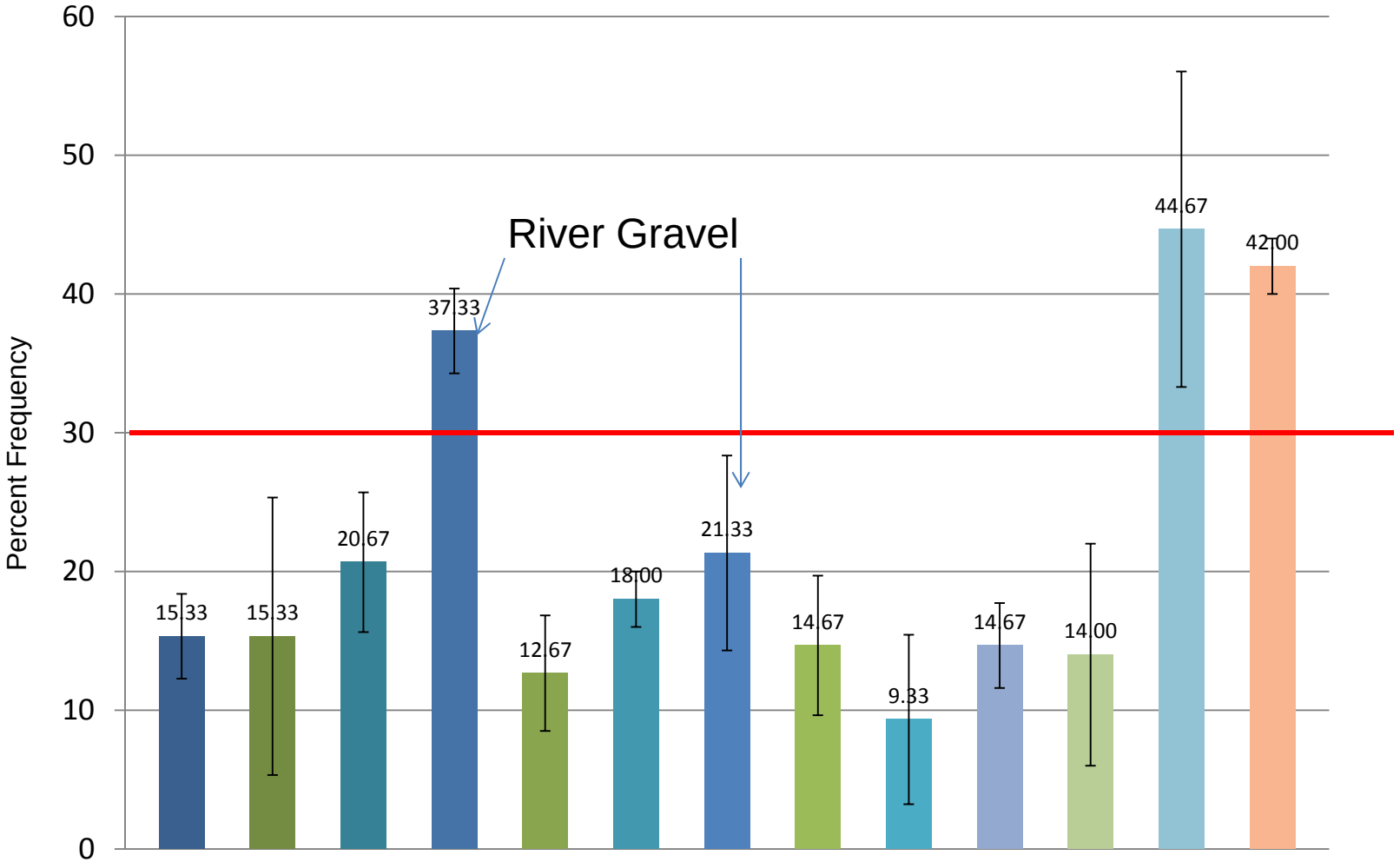
0%

% Retained

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

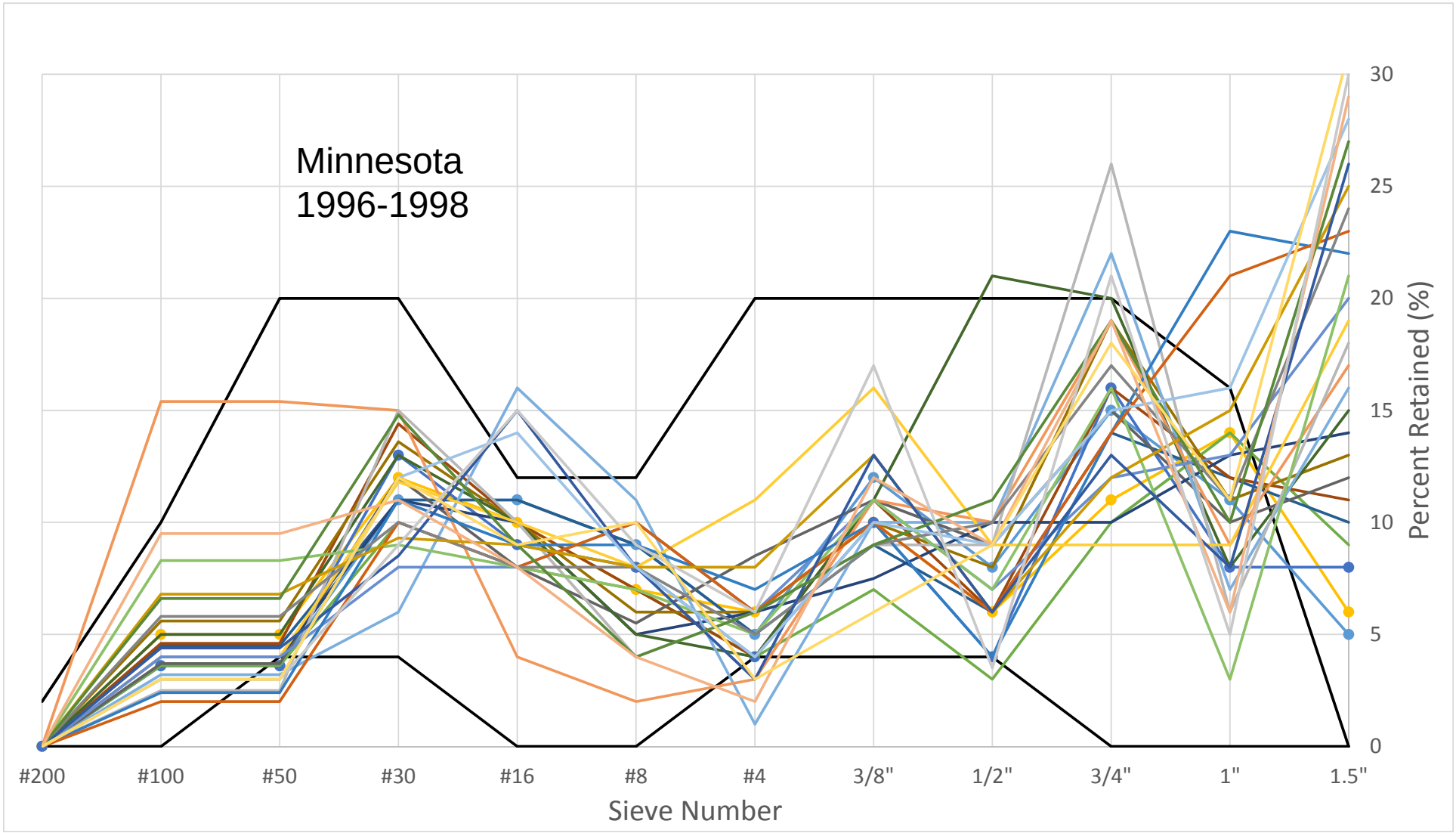
Sieve No.

ASTM D 4791 – ½” 2:1 scale

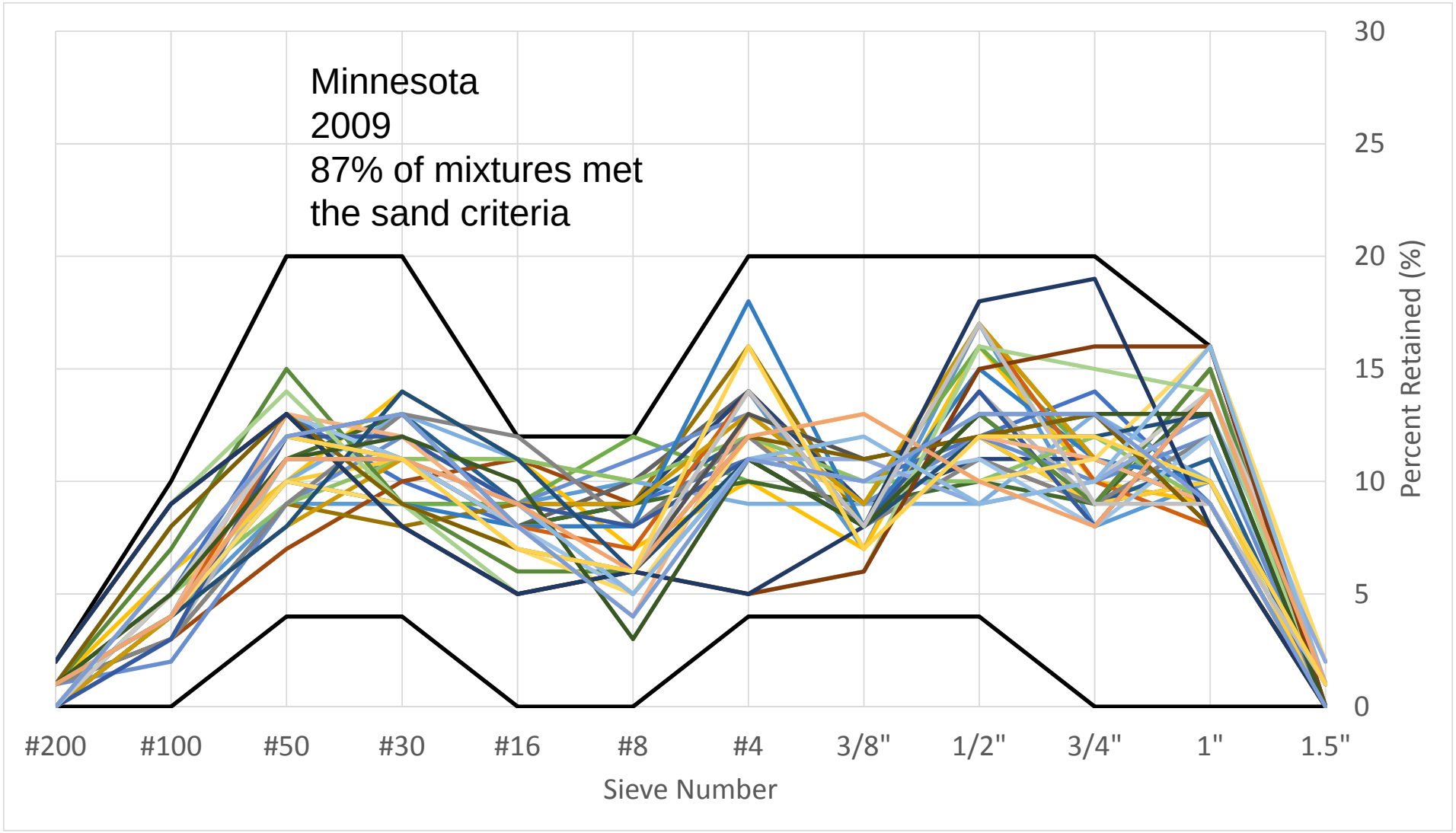


Application

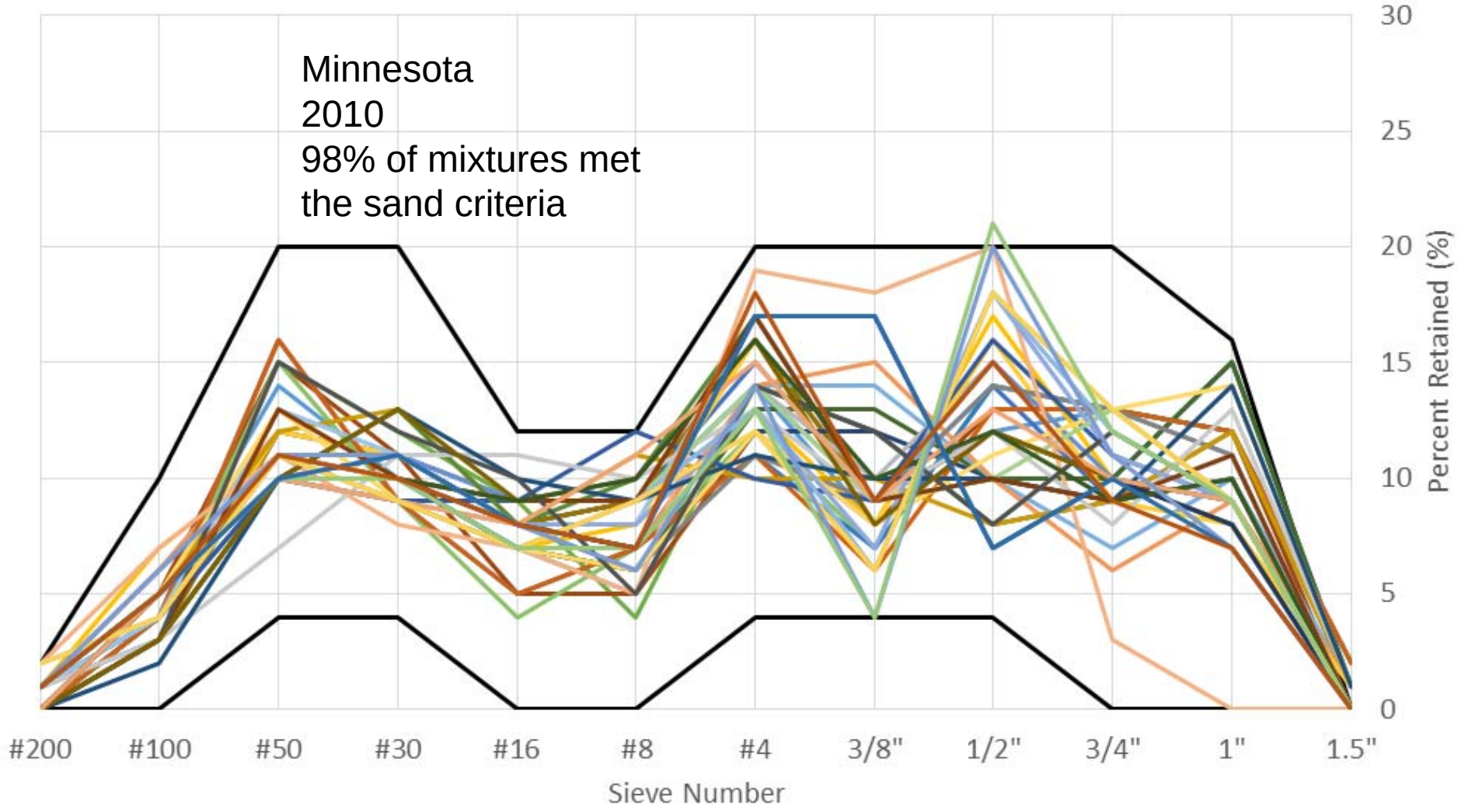
- Five different concrete producers have tried this system and all seen improvements in their concrete
- ***10 lane miles of CRCP for the FHWA hfl project have been placed with this system in Texas with 447 lbs of cementitious/CY.***
- ***The contractor saw a 10% cost savings with a 25% reduction in the carbon footprint!!!!***



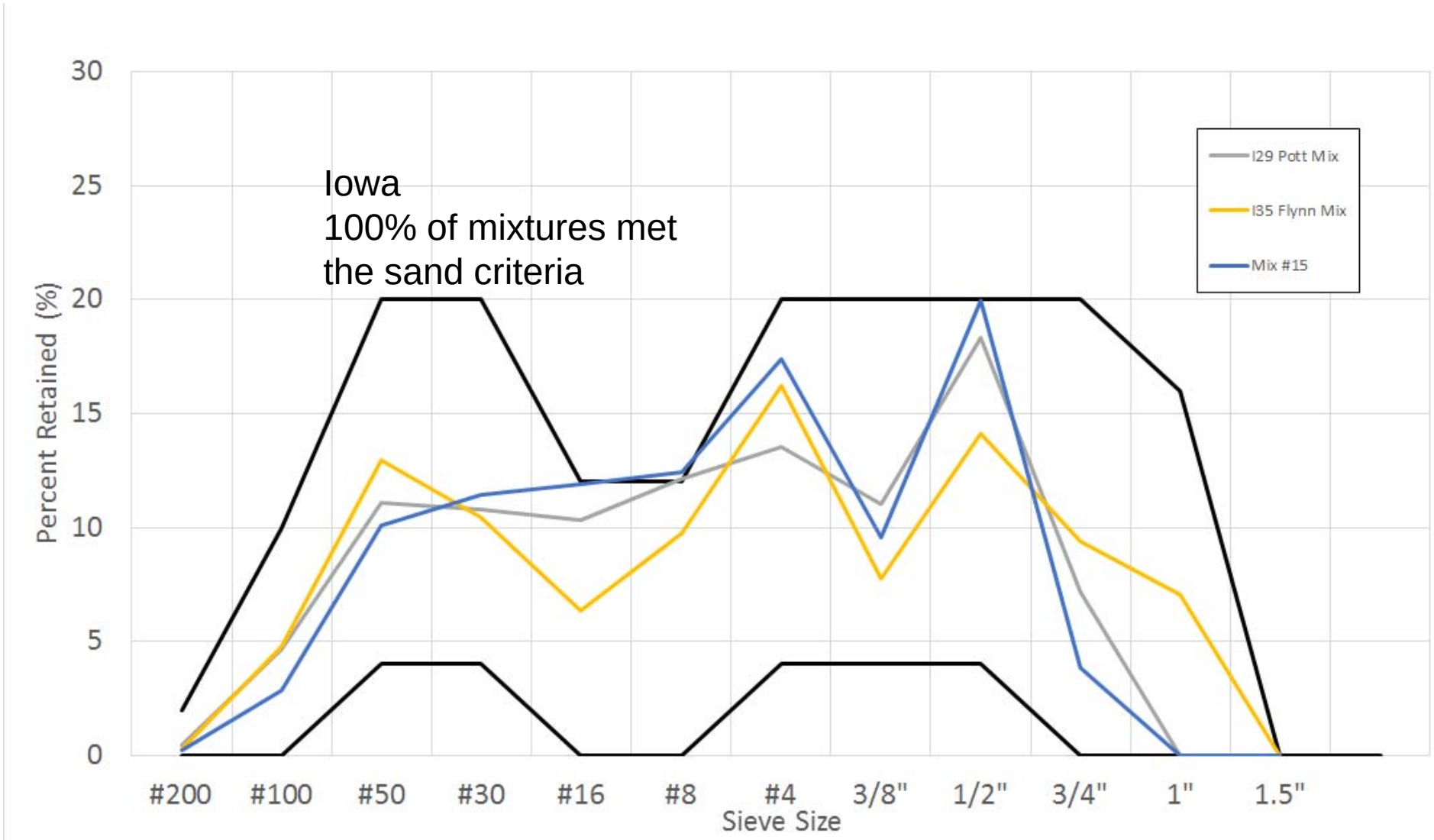
Data from Maria Masten



Data from Maria Masten



Data from Maria Masten



Data from Todd Hansen

Field Concrete

- The contractors are producing mixtures in the field in Minnesota and Iowa 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
- The Tarantula Curve appears to be a good place to start with your mixtures

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

Summary

- The Box Test proved to be a useful test method to evaluate mixtures for concrete pavements
- This test has allowed us great insight into coarse and fine aggregate proportioning
- The Tarantula curve and fine aggregate limits have been used to successfully produce field concrete mixtures

Summary

- Optimized graded concrete mixtures produced in Minnesota and Iowa show good agreement with the specified limits
- It was used in Texas with great contractor savings
- Rough estimates show that this could save Oklahoma over $4 million/year and enough electricity to power 400 homes per year while also producing pavements with improved durability and sustainability

www.optimizedgraded.com

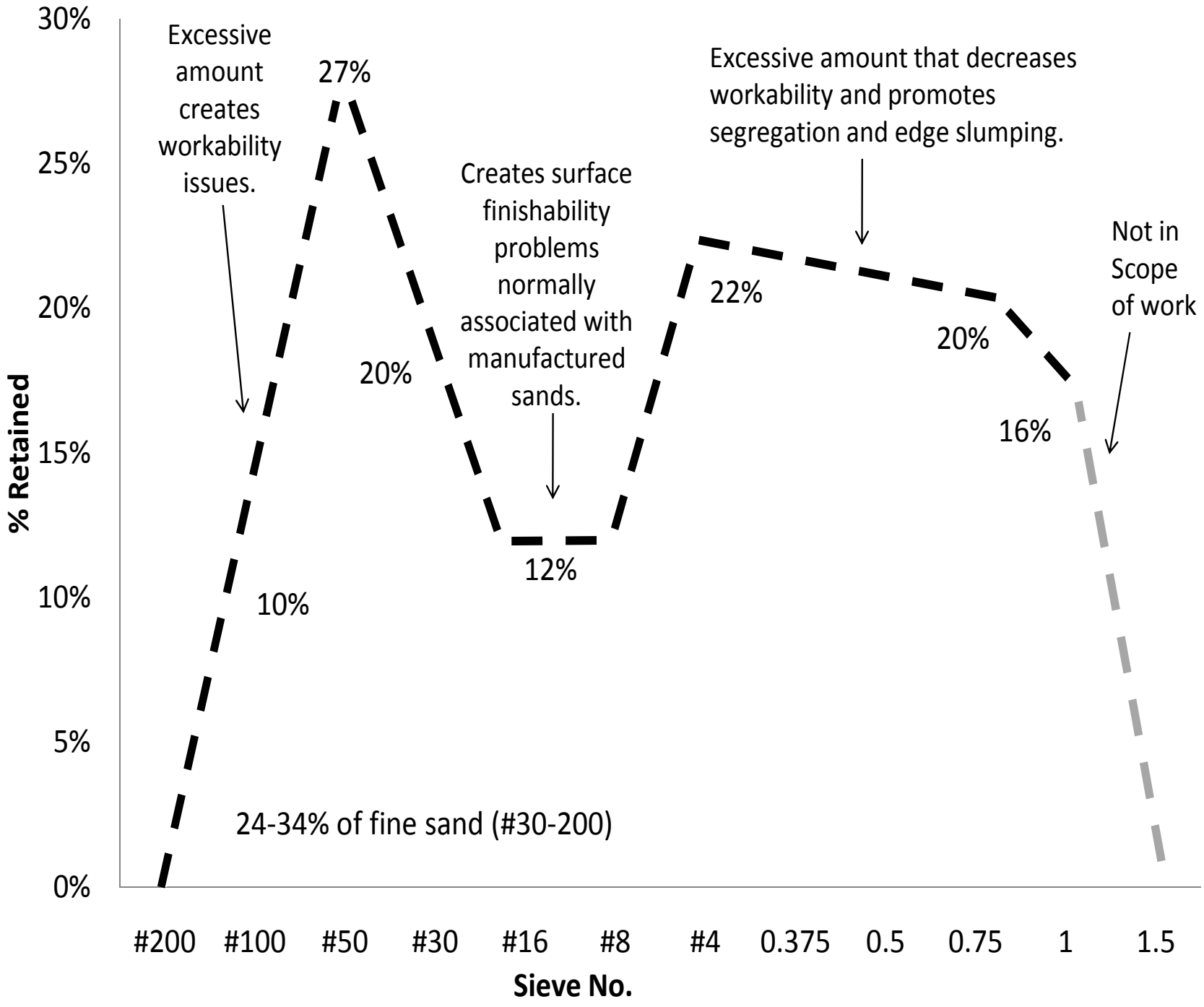
www.tylerley.com

Questions???

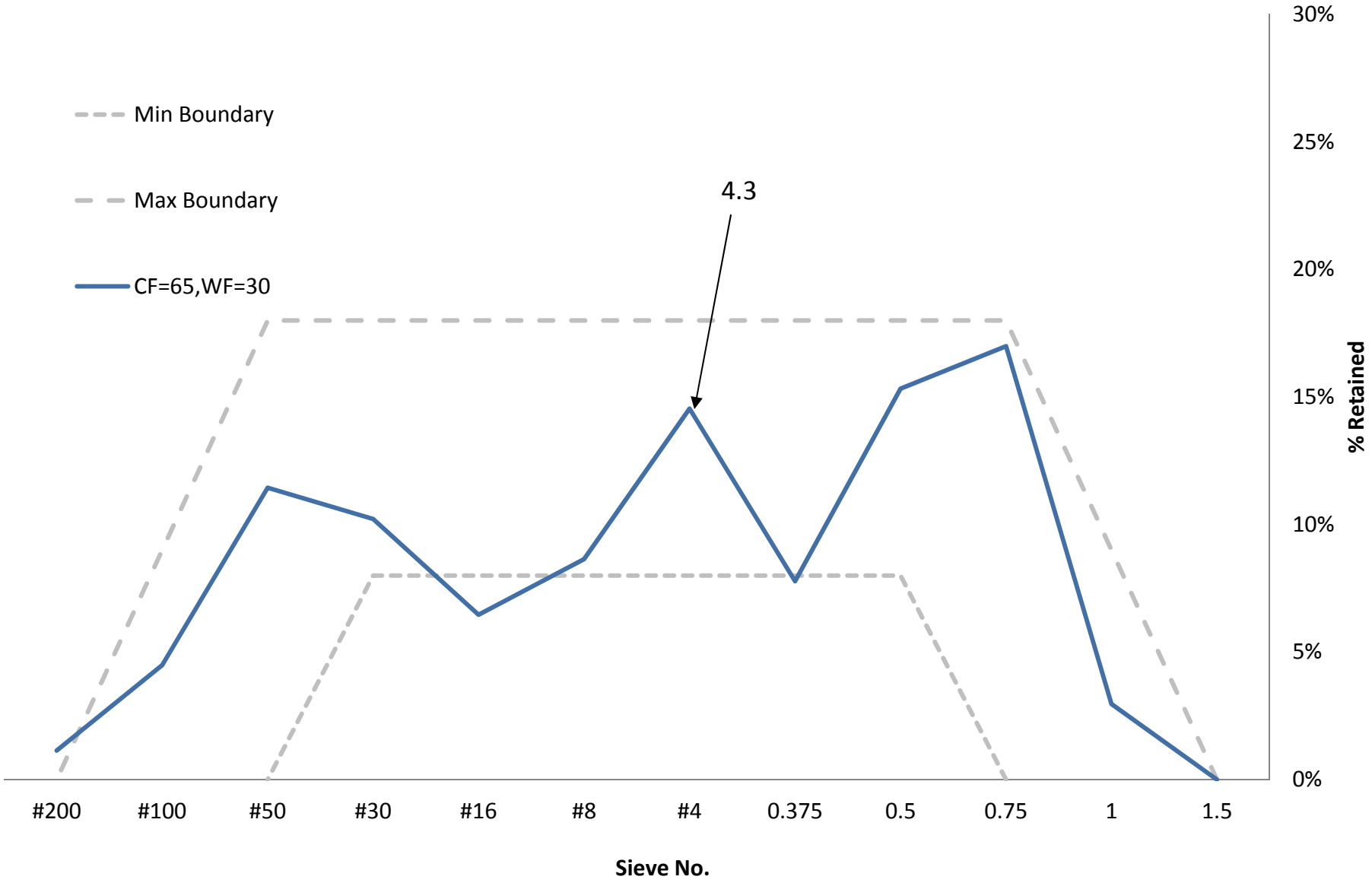
May the Force be with you!!!!

Durability

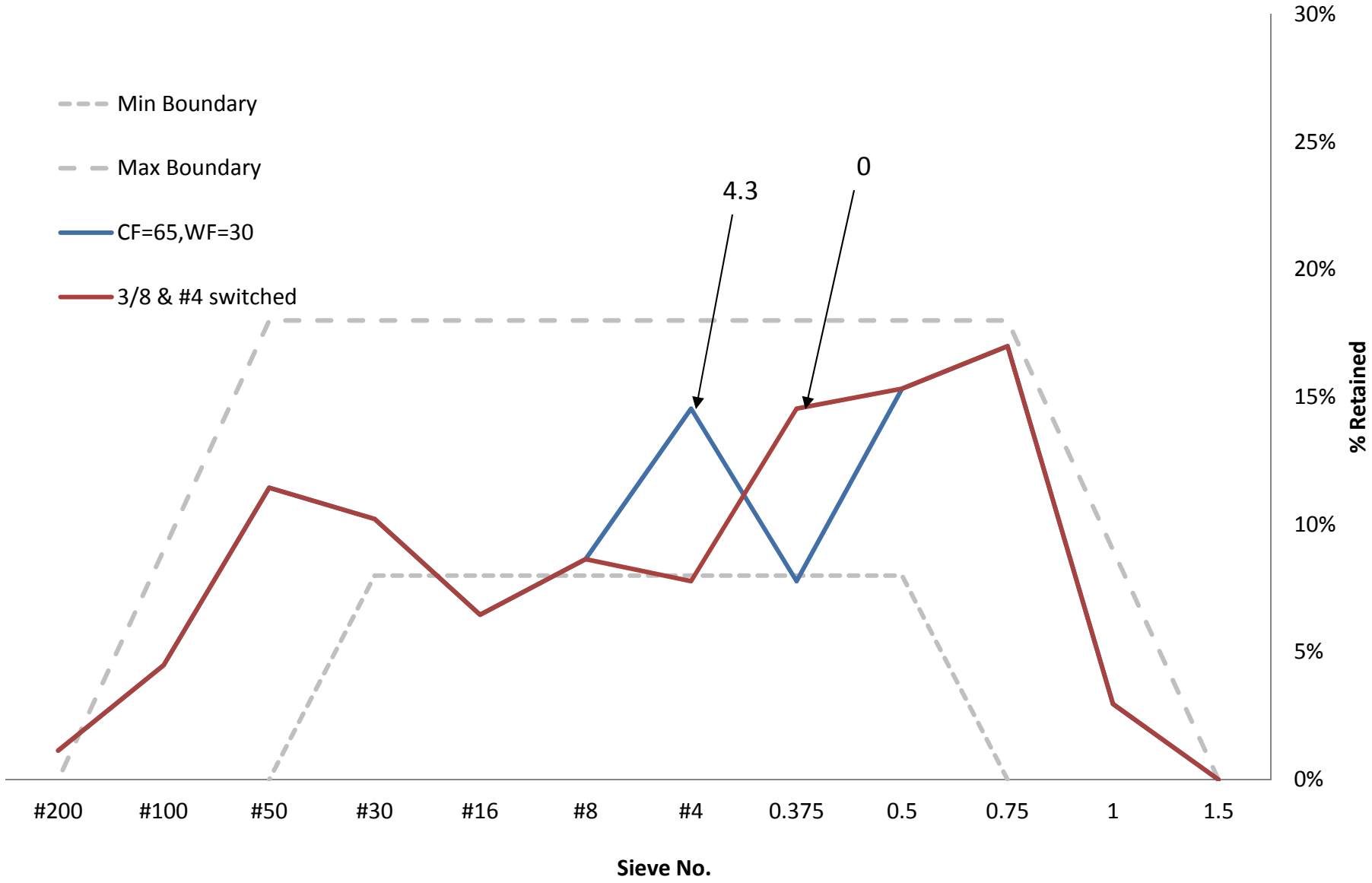
- The mixtures showed satisfactory freeze thaw and shrinkage durability


30%
25%
20%
15%
10%
5%
0%
% Retained
Excessive amount creates workability issues.
27%
20%
Creates surface finishability problems normally associated with manufactured sands.
12%
10%
Excessive amount that decreases workability and promotes segregation and edge slumping.
22%
20%
16%
Not in Scope of work
24-34% of fine sand (#30-200)
#200
#100
#50
#30
#16
#8
#4
0.375
0.5
0.75
1
1.5
Sieve No.

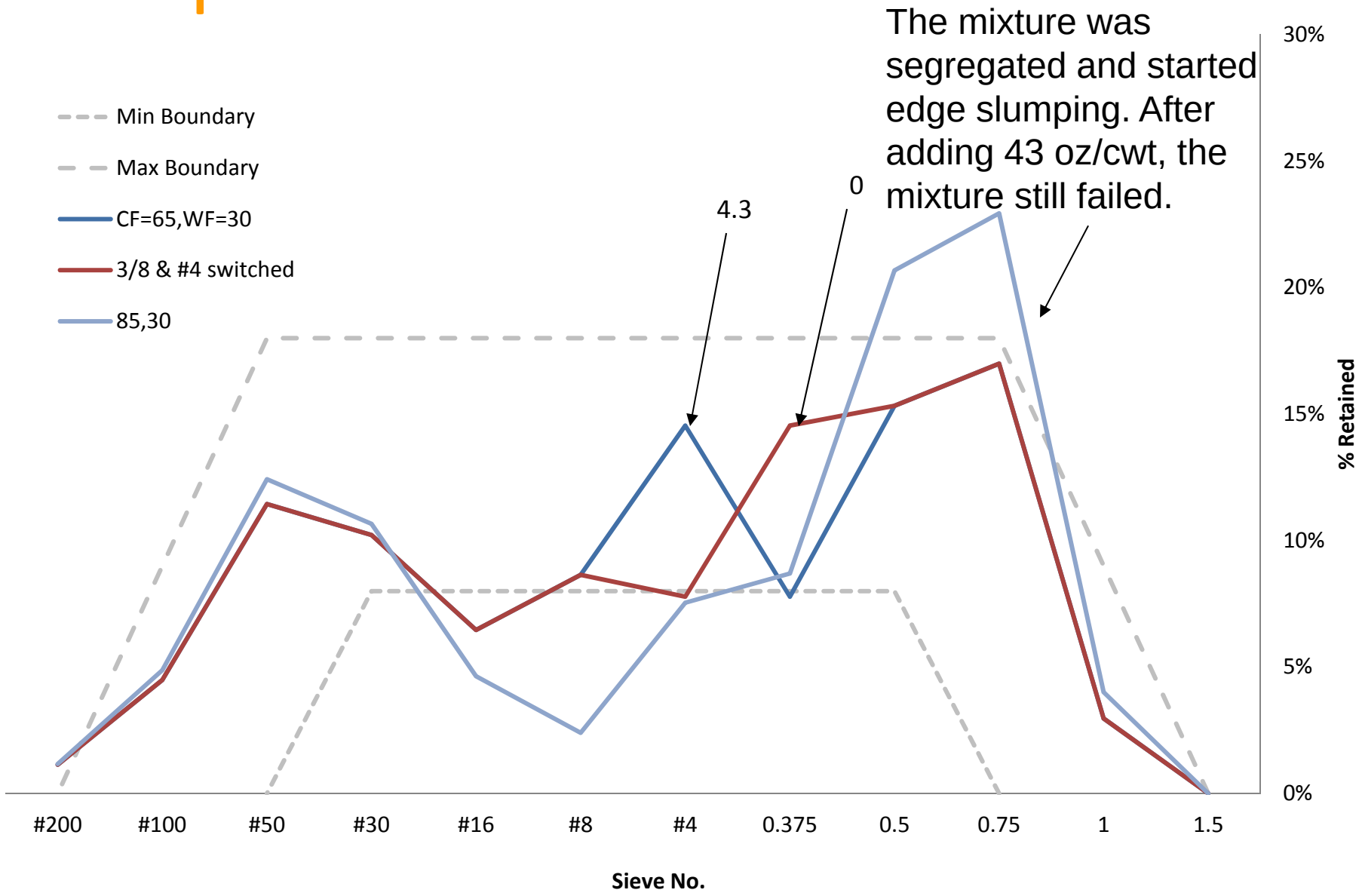
Gap Graded vs Combined Graded



Gap Graded vs Combined Graded



Gap Graded vs Combined Graded



A New Specification for Oklahoma

- Within spec – *470 lbs* of cementitious
  w/20% fly ash replacement
  max w/cm = 0.45
- Out of spec - *564 lbs* of cementitious
  w/20% fly ash replacement
  max w/cm = 0.45