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TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Aggregate Sustainability—Applications

April 25, 2024

2:00 – 3:30 PM



PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.



Purpose Statement

This webinar will focus on aggregate optimization for concrete mix designs as well as reclaimed asphalt pavement and recycled concrete aggregate applications and how each impacts sustainability of aggregates.

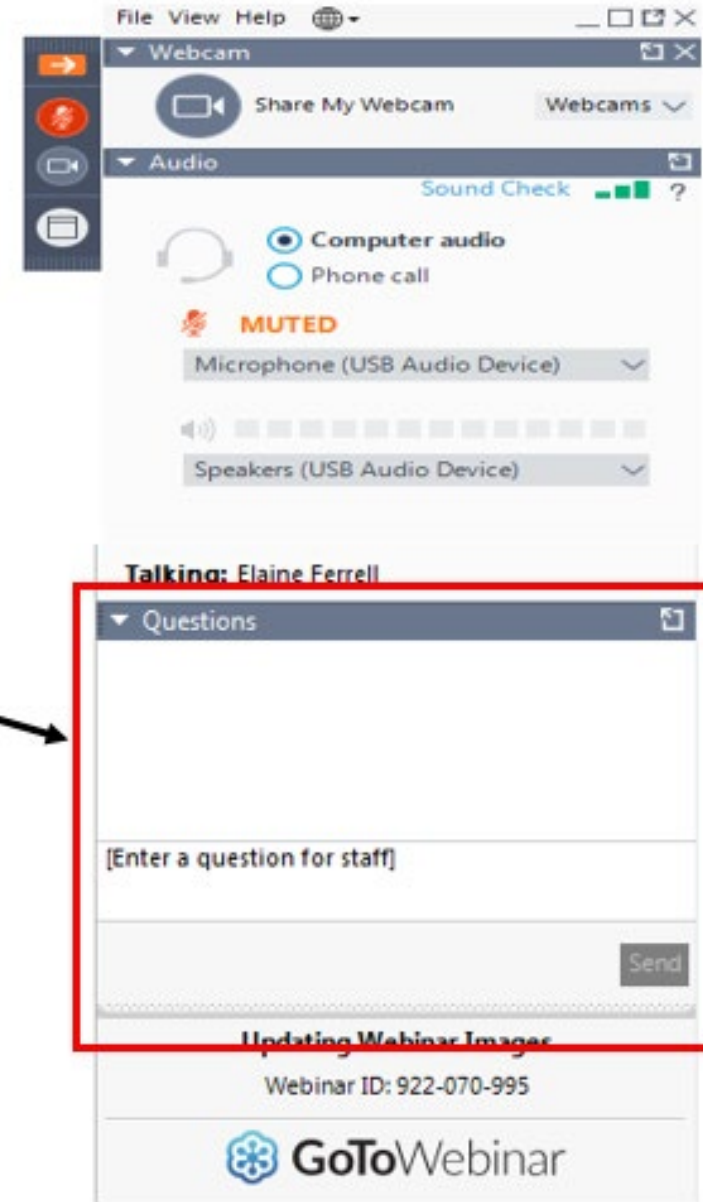
Learning Objectives

At the end of this webinar, you will be able to:

- (1) Use RCA as a replacement for natural aggregates in concrete mixtures
- (2) Lower the embodied greenhouse gases in concrete and improve duration by utilizing improved aggregate optimization
- (3) Identify potential Surface Aggregate Classification A RAP aggregates

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters



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*New Jersey Institute of
Technology*



Sheng Hu
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Texas A&M University



Edith Arambula Mercado
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Texas A&M University

Aggregate Optimization for Concrete Mix Design

James W Mack



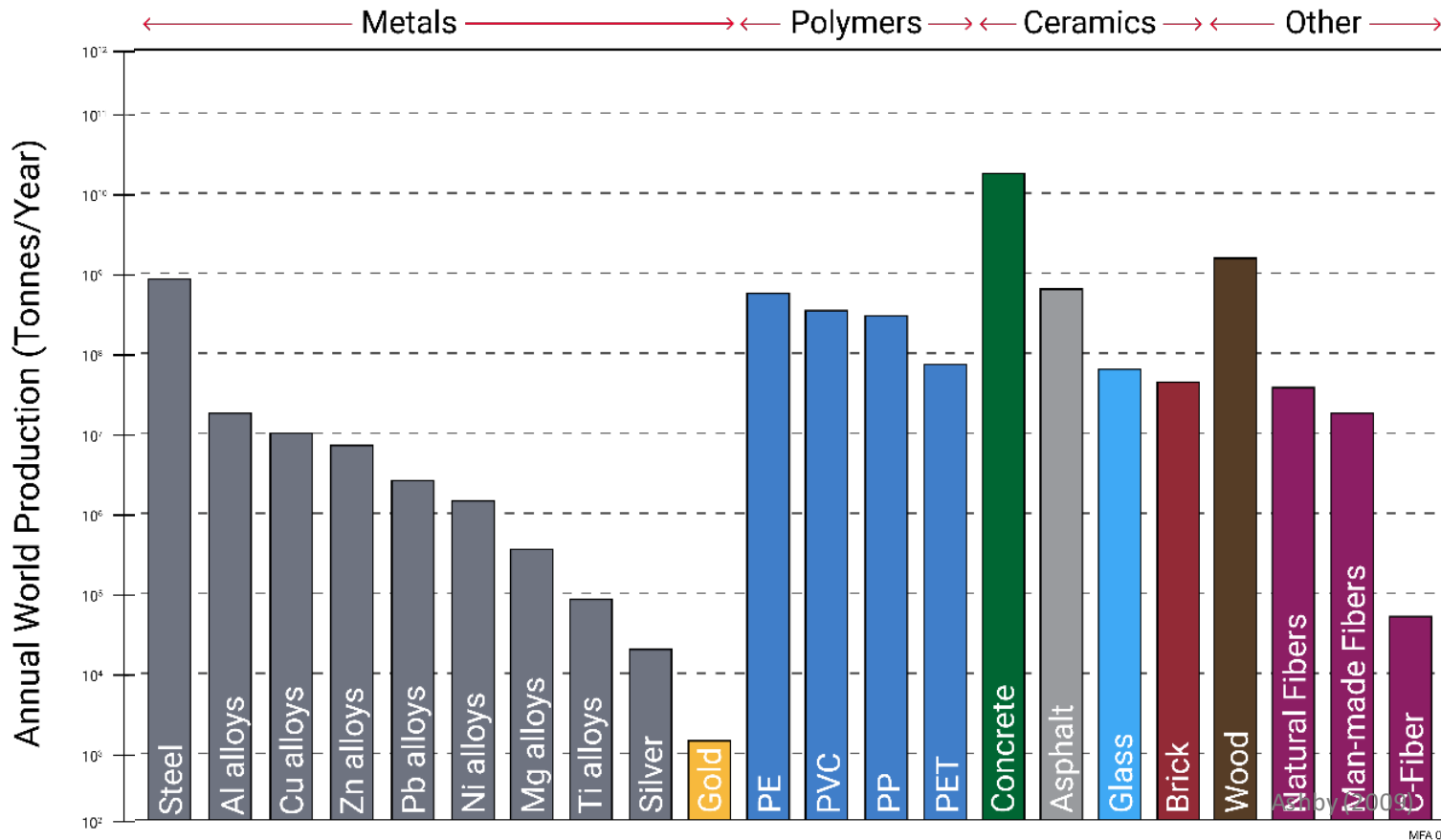
TRB Webinar: Aggregate Sustainability, Part 2—Applications
April 25, 2024

Today's Discussion

- Why are we looking at this?
- Concrete & CO₂
- Tarantula Curve for Aggregate Optimization

Concrete is the most used construction material, and has a CO2 footprint to match

Yearly production of different types of construction materials



Log Scale: Each step is a 10x increase

Concrete's usage is 10x's more than any other construction material

- Cement/Concrete production is ~6 to 8% of the Global carbon emissions.
 - U.S. Cement Industry Global GHG Contribution = 0.17% CO2eq
- In the U.S., about 66.9 M Tonnes of CO2 were emitted in 2019 from cement production.
 - U.S. Cement Industry U.S. GHG Contribution = 1.25% CO2eq

Concrete will continue to play a critical role in a low-carbon economy. There are no substitutes for its cost effectiveness, strength & resilience

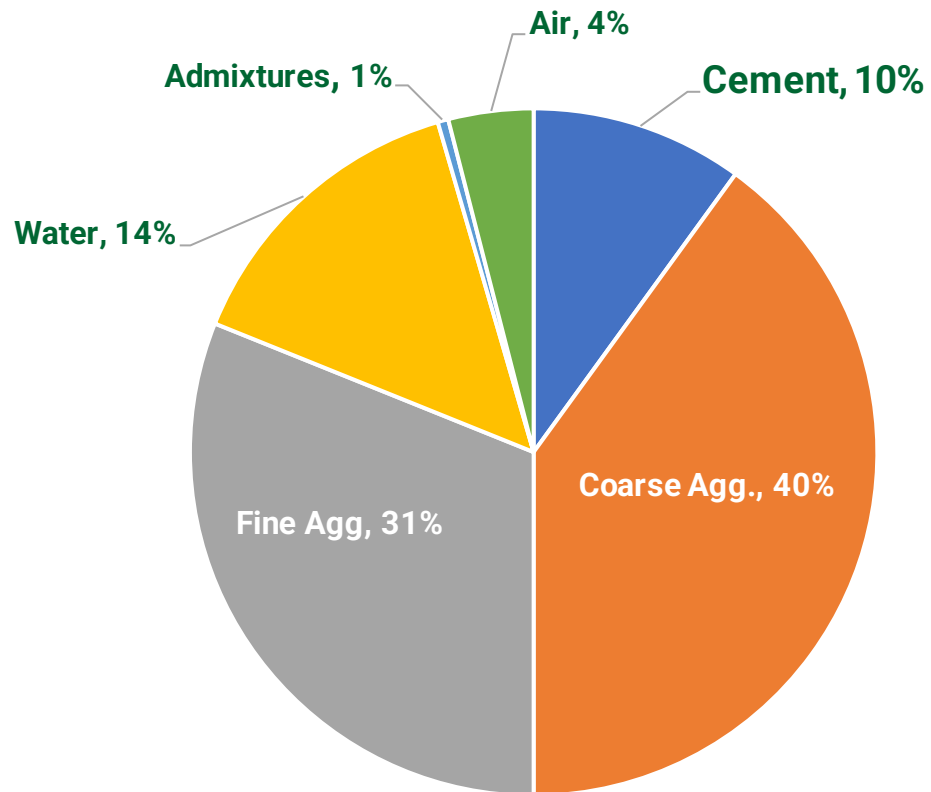
Sources:

1. EPA, FacilityLevel Information on Greenhouse Gas Tools (FLIGHT) database (2019)
2. Global Alliance for Building and Construction, 2018 Global Status report, IEA

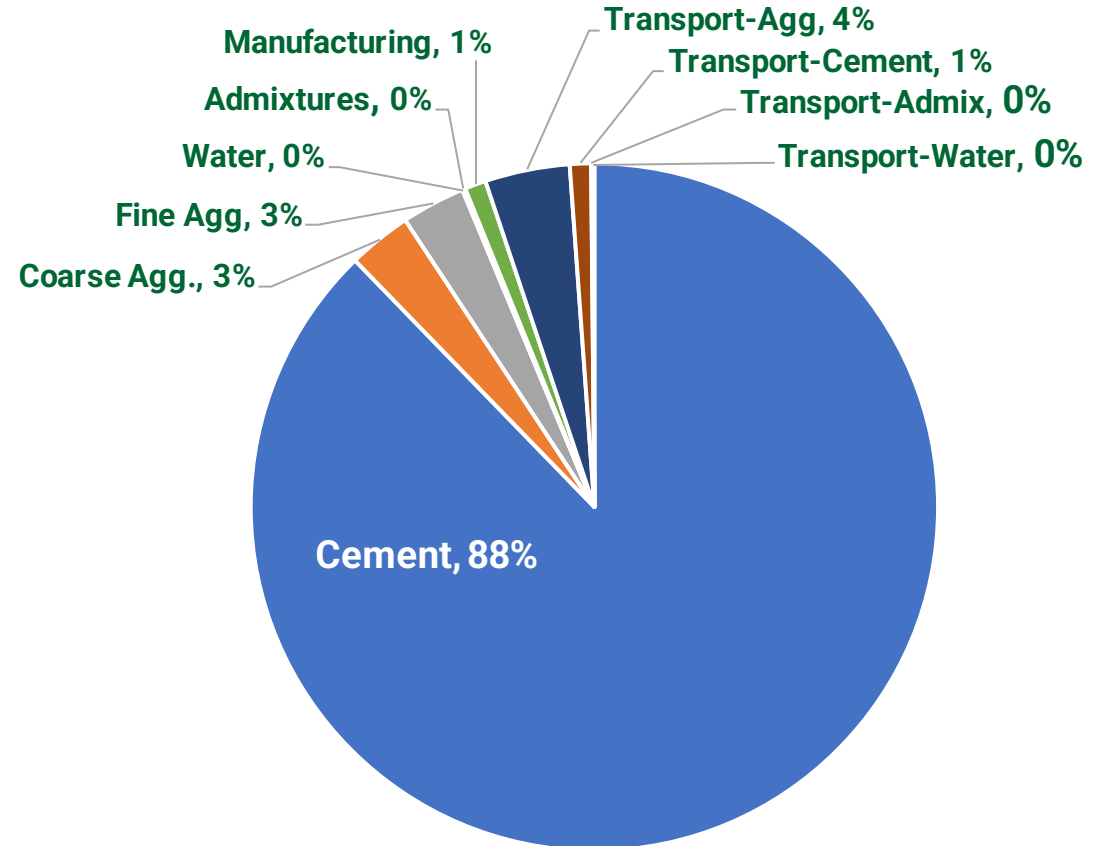
Many Items Impact a Concrete's Carbon Footprint

CO2 footprint from Cement ~75 to 90% of the total Mix GWP

Volume



Embodied CO2



Levers to Reduce Concrete CO₂

- **Use of Type IL cement**

Type IL cement is a Portland-limestone cement containing more than 5% but less than or equal to 15% by mass of limestone

- **Alternative & Blended Cements**

The use of low CO₂ clinker and blended cements

- **Supplementary Cementitious Materials (SCMs)**

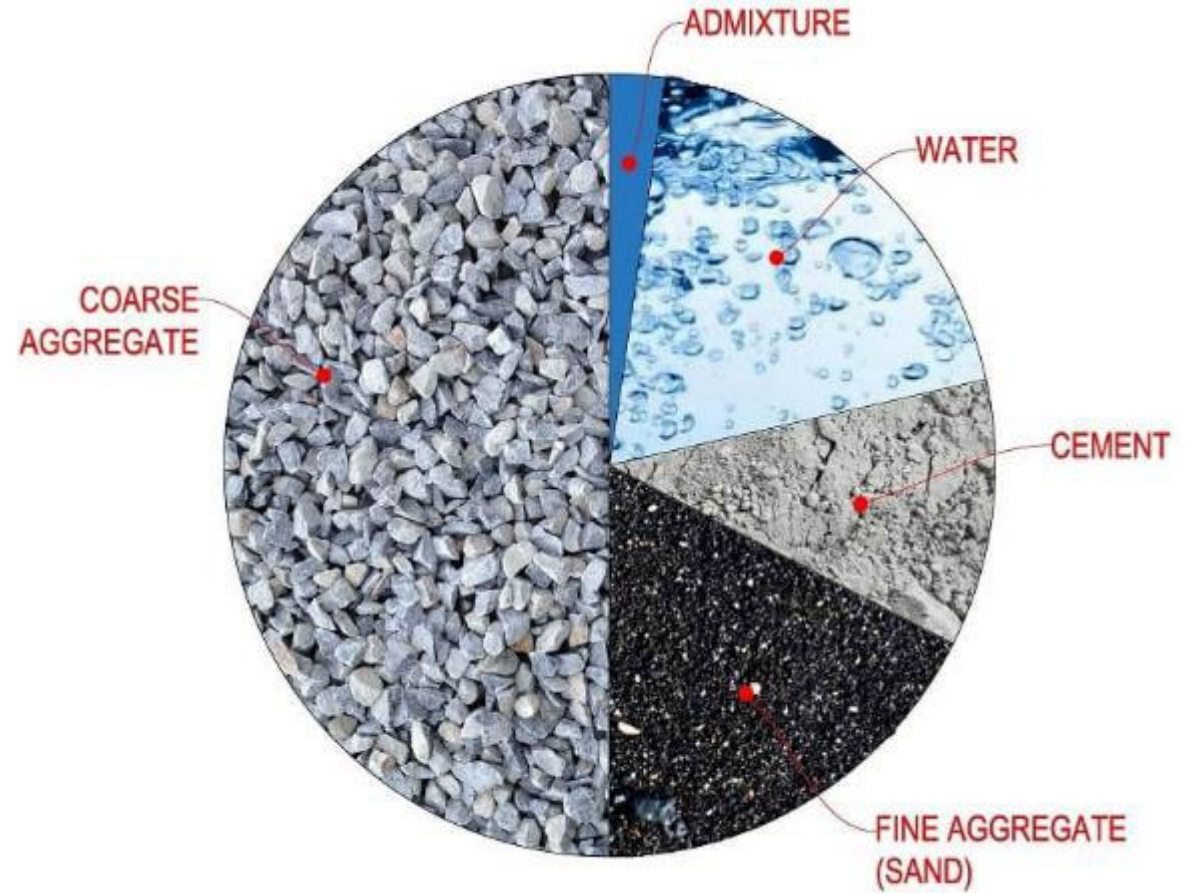
Fly Ash, Slag, other pozzolans to reduce the amount of cement in the concrete

- **Aggregate Optimization**

Use Well Graded Mixes to reduce paste and improve workability & durability

- **In-situ / Fresh Concrete Carbon Capture**

Technologies that inject Liquid CO₂ into the fresh concrete during batching or use CO₂ curing to capture & store CO₂ permanently



Optimizing concrete mixes using these tools allows the Industry to create low carbon ready-mix concrete such CX's **Vertua**[®] brand of low carbon concrete

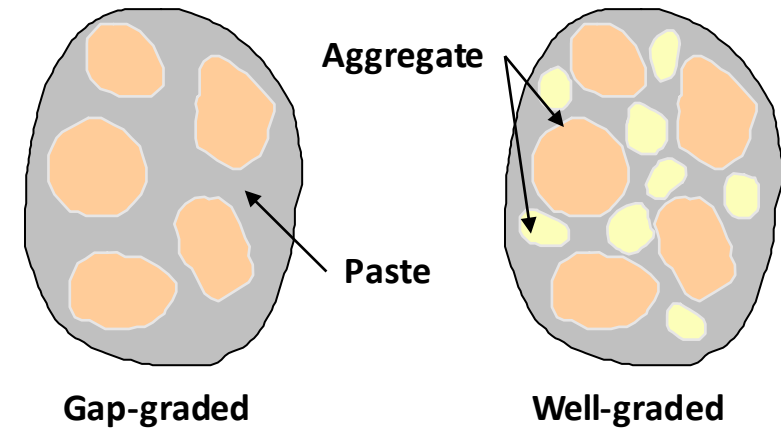
Approximate Reduction in CO2 for the Various Levers

Actual Amount of Reduction depends on Mix parameters, requirements, etc.

Technology	~ % Reduction in CO2
Use of Type IL cement	7 to 8%
Blended Cements	} Low SCM – 20%
Supplementary Cementitious Materials (SCMs)	
Aggregate Optimization	14%
In-situ / Fresh Concrete Carbon Capture	5%

Aggregate Optimization

- Historically most concrete's use a "Gap-graded" mixes
- The goal of aggregate optimization is to increase the aggregate volume and decrease the paste content:
 - Lower cement contents (~ +/- 10%)
 - Reduced water demand
 - Decreased shrinkage
 - Increased concrete density
 - Improves durability
 - Improves workability
 - Improved response / flow due to vibration



Tarantula curve Intro

Tyler Ley, PE, PhD

> 96K subscribers
> 9.5M views



www.youtube.com/tylerley

Desired Properties in a Concrete Mix

- **Strength**—The ability to carry the mechanical loads.
- **Aggregate stability**—The tendency for some aggregates to undergo alkali aggregate reaction or d-cracking.
- **Durability / Permeability / Transport**—The ability to resist penetration by fluids and chemicals. The ability to resist effects of freezing and thawing as well as the deicing chemicals applied (where necessary).
- **Shrinkage**—The tendency to lead to random cracking or warping of the slabs, particularly in drier regions.
- **Workability**—While this is primarily a concern for the contractor, experience has shown that mixtures placed with the wrong workability are more likely to be short lived.

WORKABILITY = Most Important
If the concrete cannot be placed, nothing else matters

Aggregates make up 75% of the volume of a concrete mixture

To have workable and high quality concrete, you need to understand your aggregates.

All these mixes are the same on paper

- 1850 lbs coarse
 - 1250 lbs sand
 - 445 lbs cement
 - 180 lbs fly ash
 - 250 lbs water
-
- Each has a different aggregate gradation (aka particle size distribution)

Deficient Fine Sand



Excessive fine sand



Just right...



Excessive Intermediate



Excessive Coarse



Aggregates make up 75% of the volume of a concrete mixture

To have workable and high quality concrete, you need to understand your aggregates.

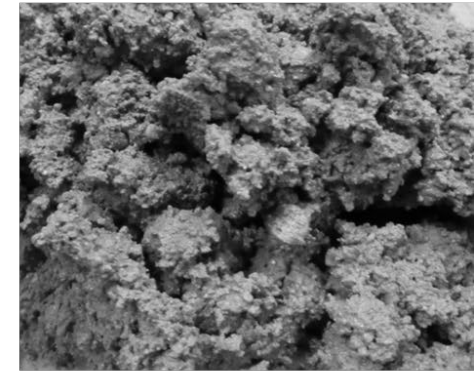
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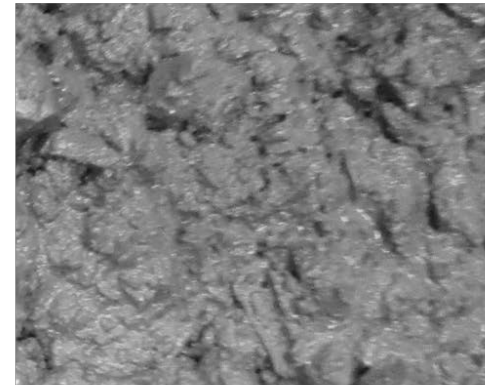
Deficient Fine Sand



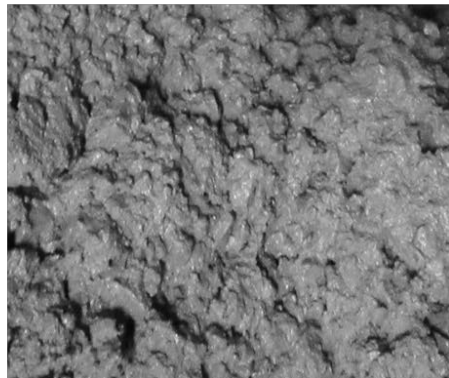
Excessive fine sand



Just right...



Excessive Intermediate



Excessive Coarse

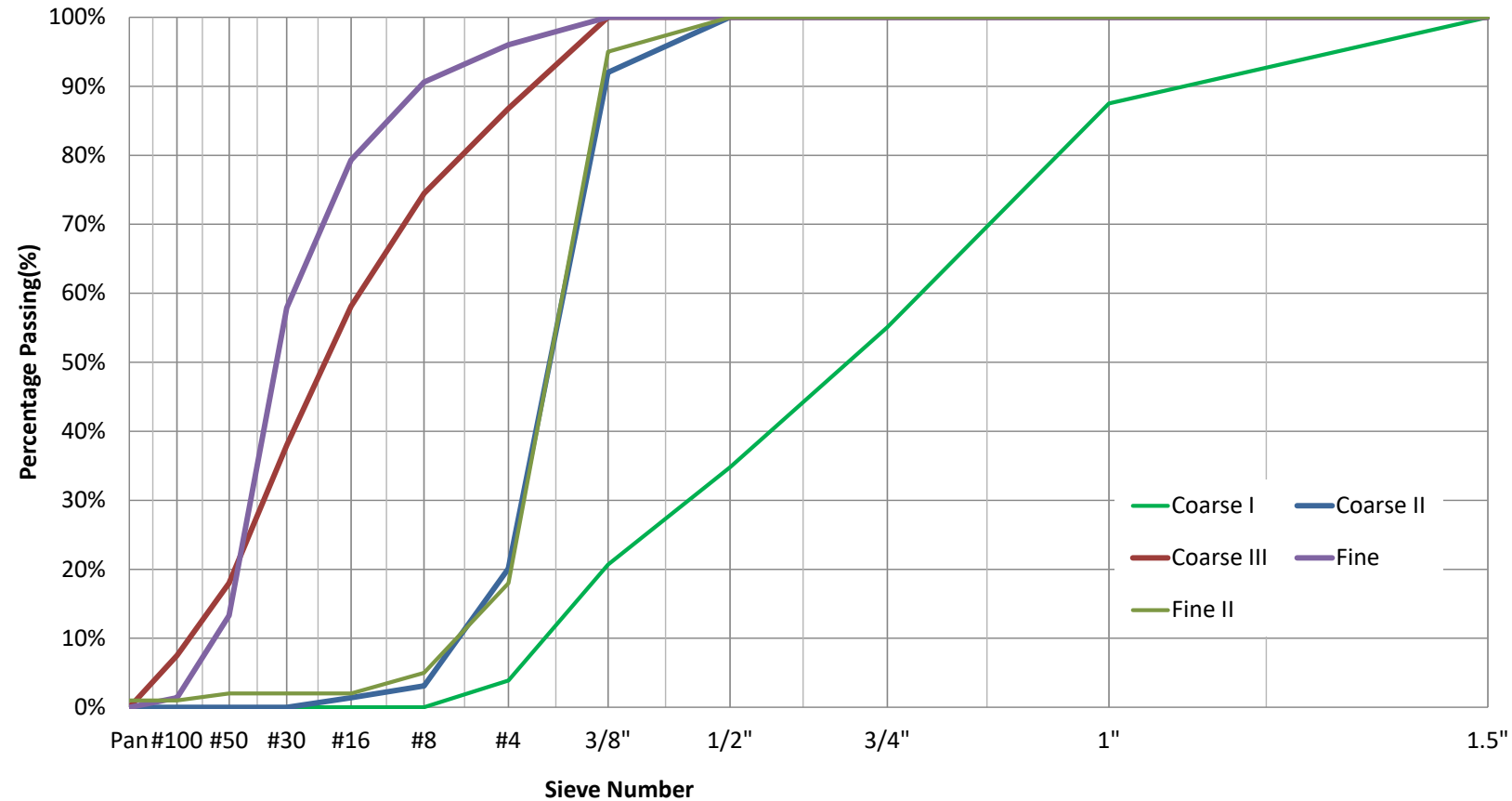


Aggregates make up 75% of the volume of a concrete mixture

To have workable and high quality concrete, you need to understand your aggregates.

All these mixes are the same on paper

- 1850 lbs coarse
- 1250 lbs sand
- 445 lbs cement
- 180 lbs fly ash
- 250 lbs water
- Each has a different aggregate gradation (aka particle size distribution)



Question: "How to Combine the Aggregate Gradations to make the Concrete Mixture more Workable?"

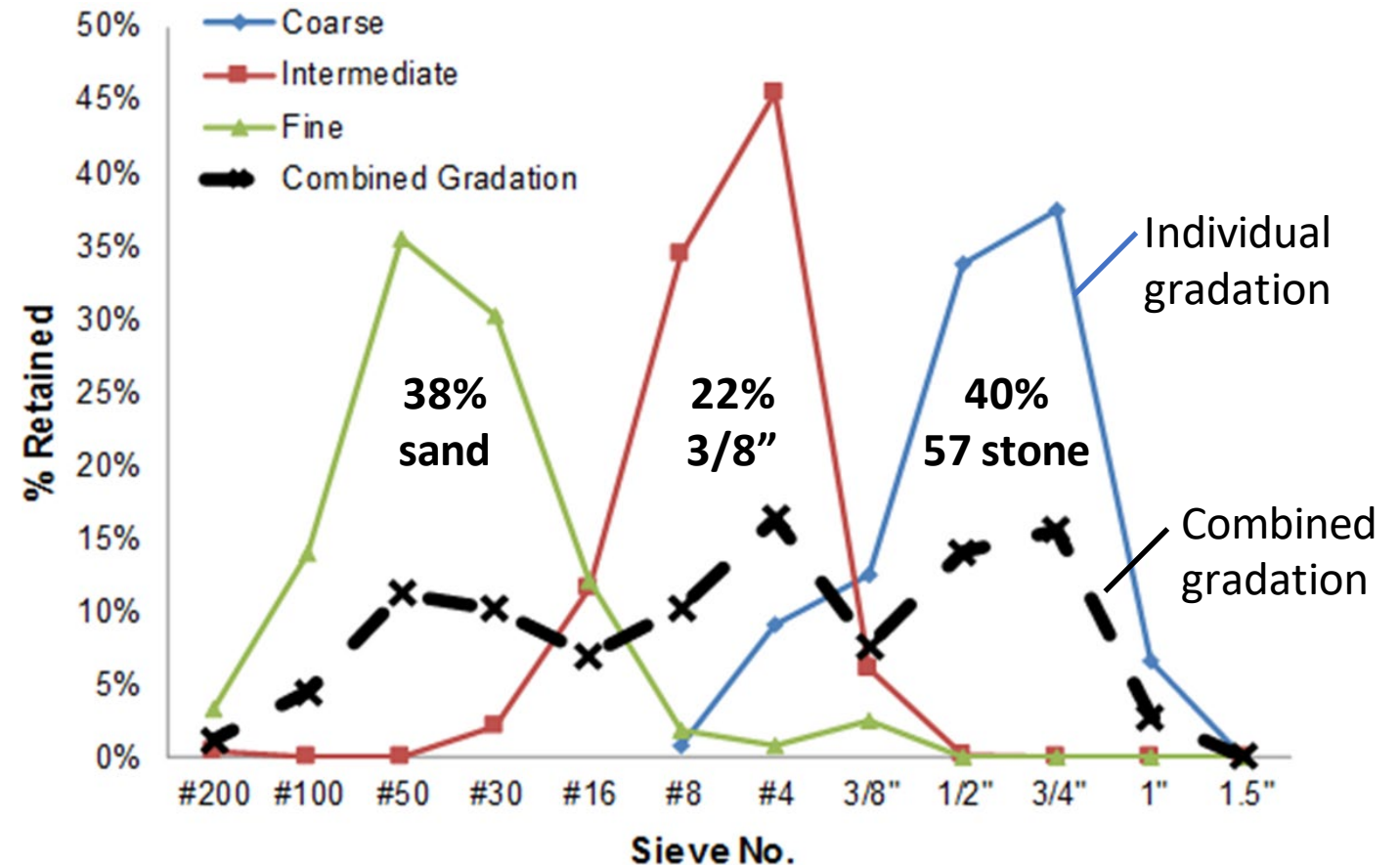
How much of each size of material to use?

How much paste is needed?

What makes a mix workable?

If the mix is more workable, can paste can be removed?

What happens to other properties (shrinkage, strength, etc.)



The Solution - the “Tarantula Curve” for Mix Proportioning

Evaluates and Improves the distribution of the Aggregate System



1 Plot / adjust the Combined Gradation Curve so that it falls within the “Tarantula” boundary

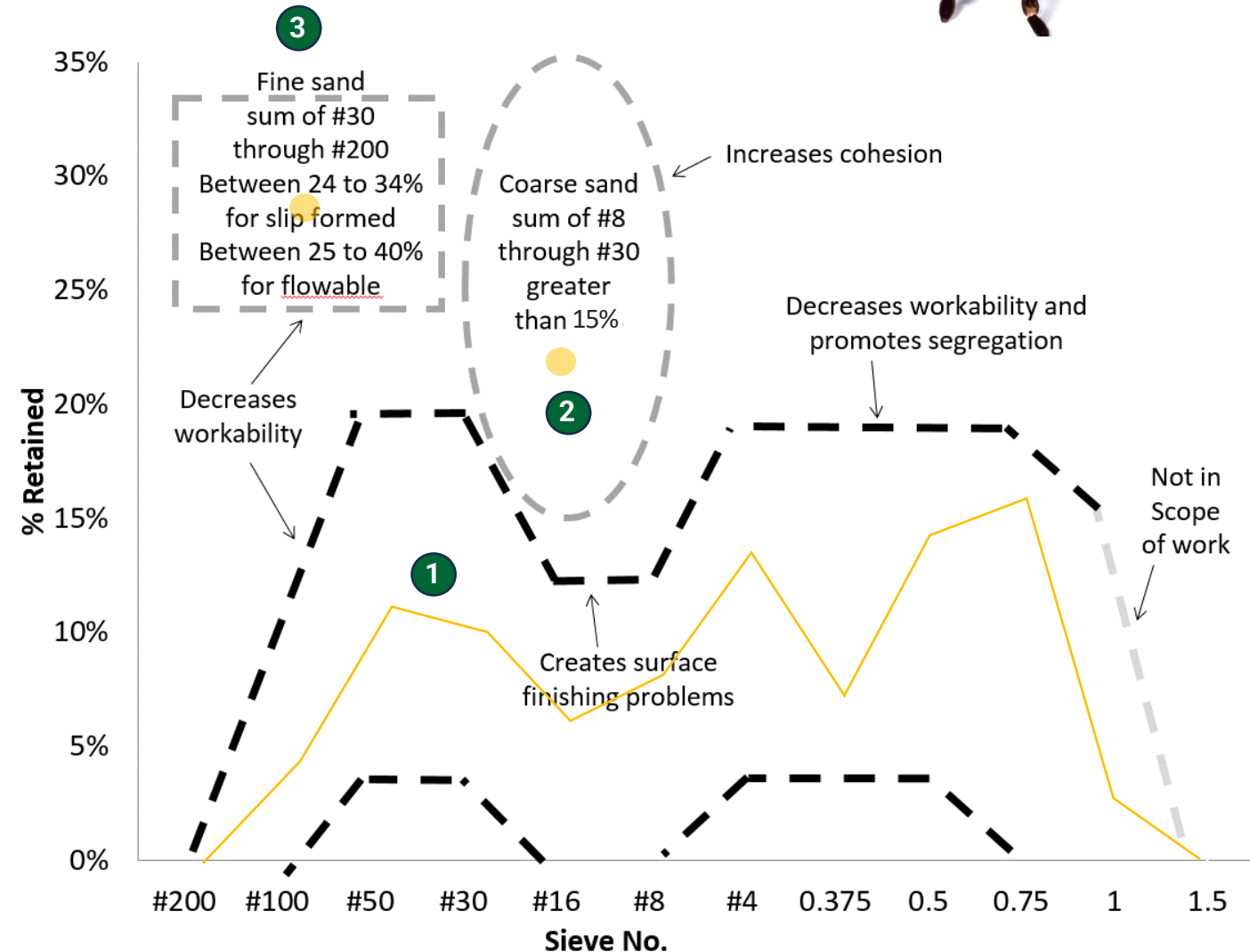
- Typically need at least 3 different aggregates sizes (coarse, intermediate, and fine)

2 Coarse sand is important for finishing and cohesion.

- The limits and sum of the #8, #16, and #30 help determine this

3 Distribution of fine sand effects workability but amount can vary largely widely

- Sum of #30 - #200 sieves
- Between 25% to 40% for flowable concrete
- Between 24% to 34% for slip formed (slip forming needs more cohesion)



Example Cost and CO2 Savings

Original Mix Designs

Material	lbs/Cy	Adjust	Unit Cost \$/ton	Estimated Price	CO2eq/ton	CO2eq
CA 1	1762		\$ 37.00	\$ 32.60	5.00	4.41
MA - 1	0		\$ 38.00	\$ -	5.00	-
RM sand	1423		\$ 22.00	\$ 15.65	4.50	3.20
WATER	234		\$ 1.00	\$ 0.12		-
CEMENT	454		\$ 110.00	\$ 24.97	922.00	209.29
F FA	110		\$ 90.00	\$ 4.95	-	-
Air	2%		Est. Mix Price	\$ 78.29		
Total Cementitious	564				CO2 (matrls only)	216.90
w/c ratio	0.41					
Volume, ft3	27.01					
Paste %	25.0					

Optimized (Recommended) Mix Designs

Material	lbs/Cy	Adjust	Unit Cost \$/ton	Estimated Price	CO2eq/ton	CO2eq
CA 1	1597		\$ 37.00	\$ 29.54	5.00	3.99
MA - 1	355		\$ 38.00	\$ 6.75	5.00	0.89
RM sand	1350		\$ 22.00	\$ 14.85	4.50	3.04
WATER	206		\$ 1.00	\$ 0.10		-
CEMENT	400		\$ 110.00	\$ 22.00	922.00	186.71
F FA	99		\$ 90.00	\$ 4.46	-	-
Air	2%		Est. Mix Price	\$ 77.70		
Total Cementitious	499				CO2 (matrls only)	194.62
w/c ratio	0.41					
Volume, ft3	27.01					
Paste %	22.0					

Reduction in Cost = \$0.59/CY

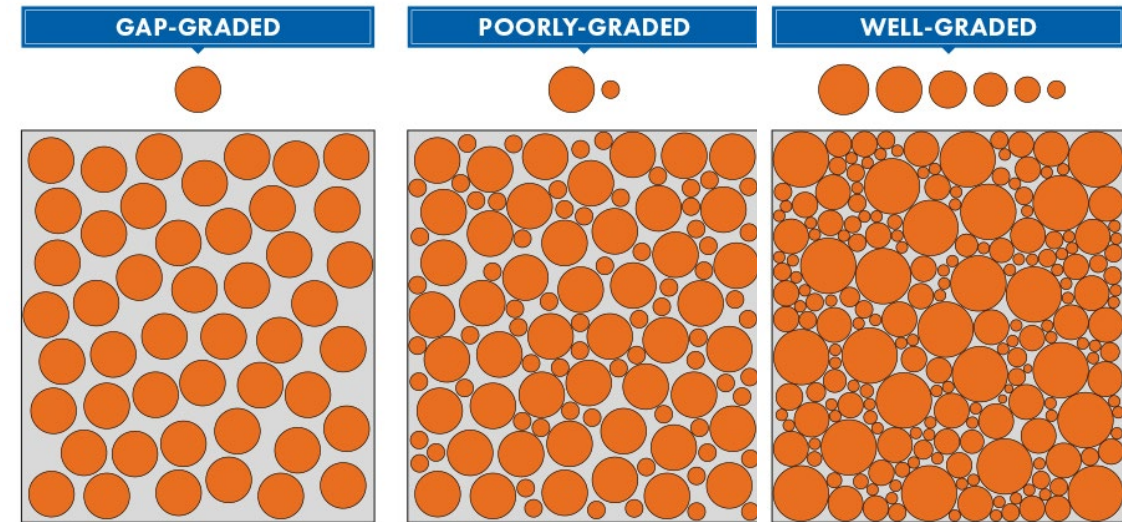
Reduction in CO2 = 11.3%

Reduction of 54 lbs. Cement

The Tarantula Curve Works on 2 Basic Principles

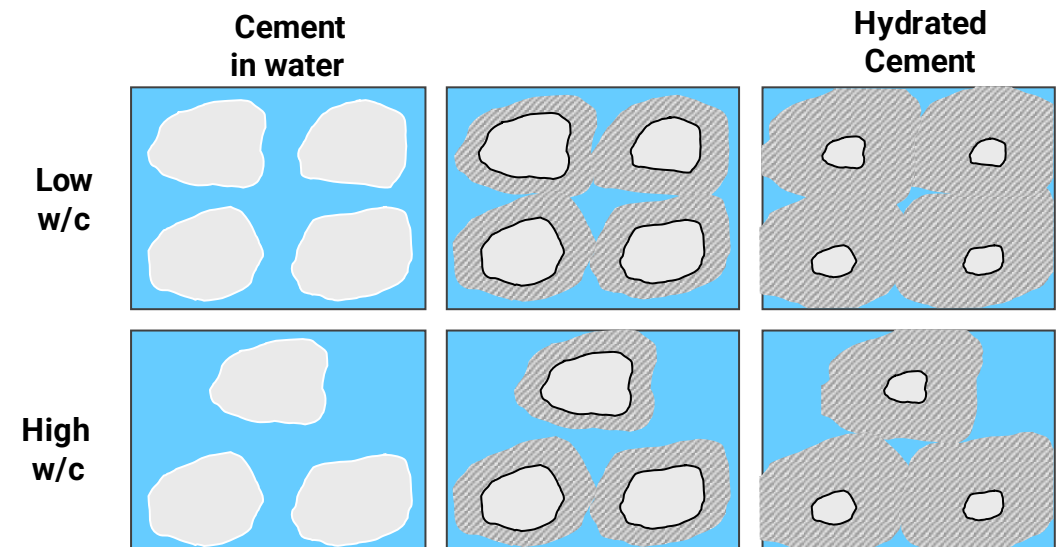
1. Cement Paste is the costliest, least sustainable, & weakest part

- » Increase the aggregate volume / decrease the paste volume
 - Less permeable, higher strengths, improved durability, improved workability
- » Requires 3+ aggregates - combo of coarse (#57 or #67), medium (#89), & fine (sand)



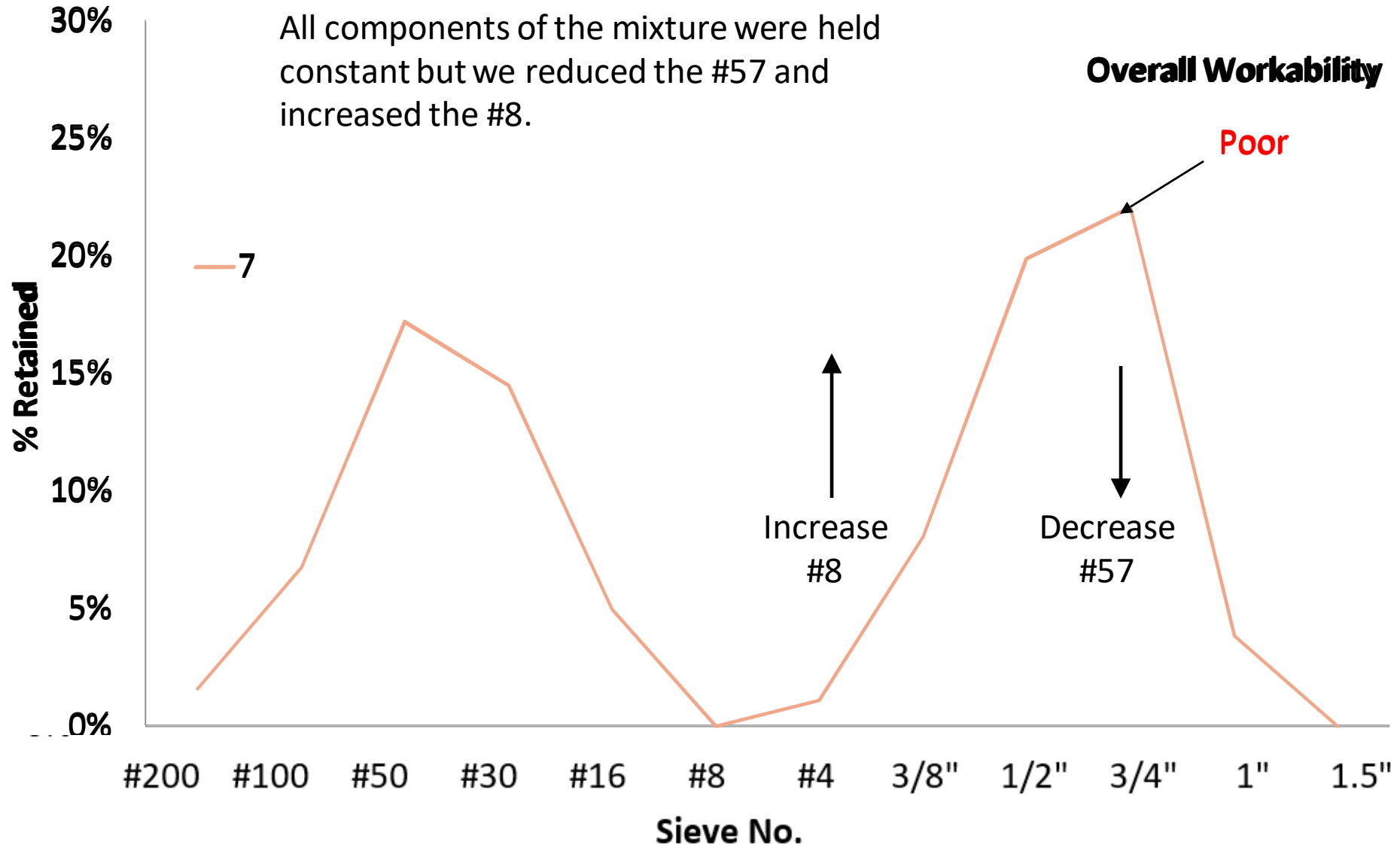
2. Strength is controlled by water / cement (w/c) ratio

- » Its not about the amount of cement – its how close the cement grains are
 - Standard practice to increase strength is increase cement content and keep water constant (e.g. ~32-35 gals)
- » Better to reduce the water content & keep cement constant.
 - May require more admixtures to maintain workability.



How Gradation impacts the Performance

Coarse Aggregate – Limestone A



How Gradation impacts the Performance Coarse Aggregate – Limestone A

As long as the % retained is not more than the maximum boundary limit of 20% on $\frac{3}{4}$ " to #4 sieve size = good performance in the concrete.

As soon as go above the limit, there is a decrease in the workability and an increase in segregation.

High Coarse



Moderate Amount



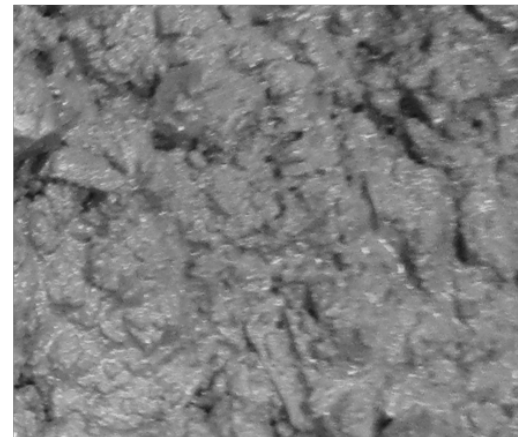
High Intermediate



Excessive Coarse



Sufficient Amount

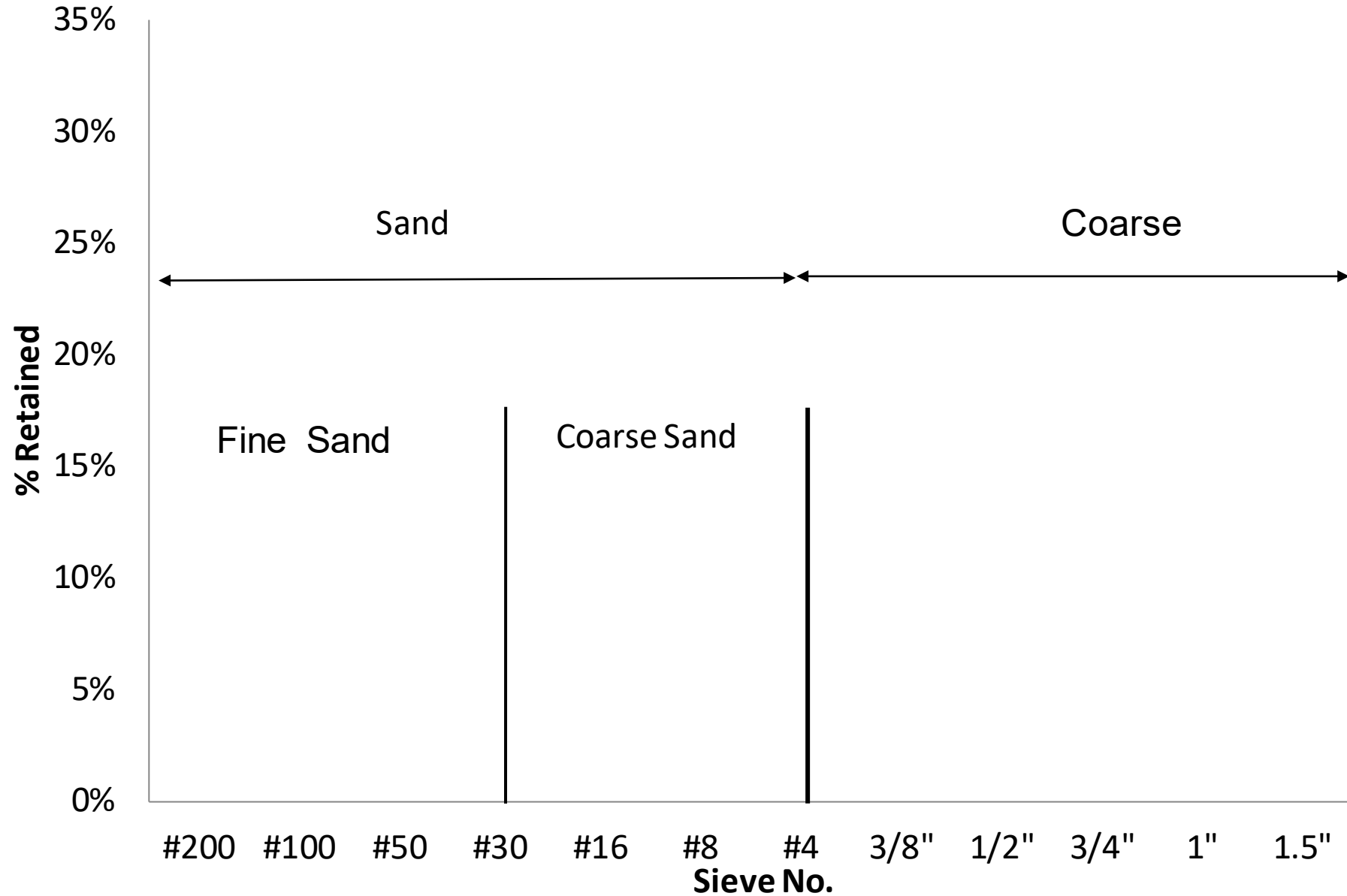


Excessive Intermediate



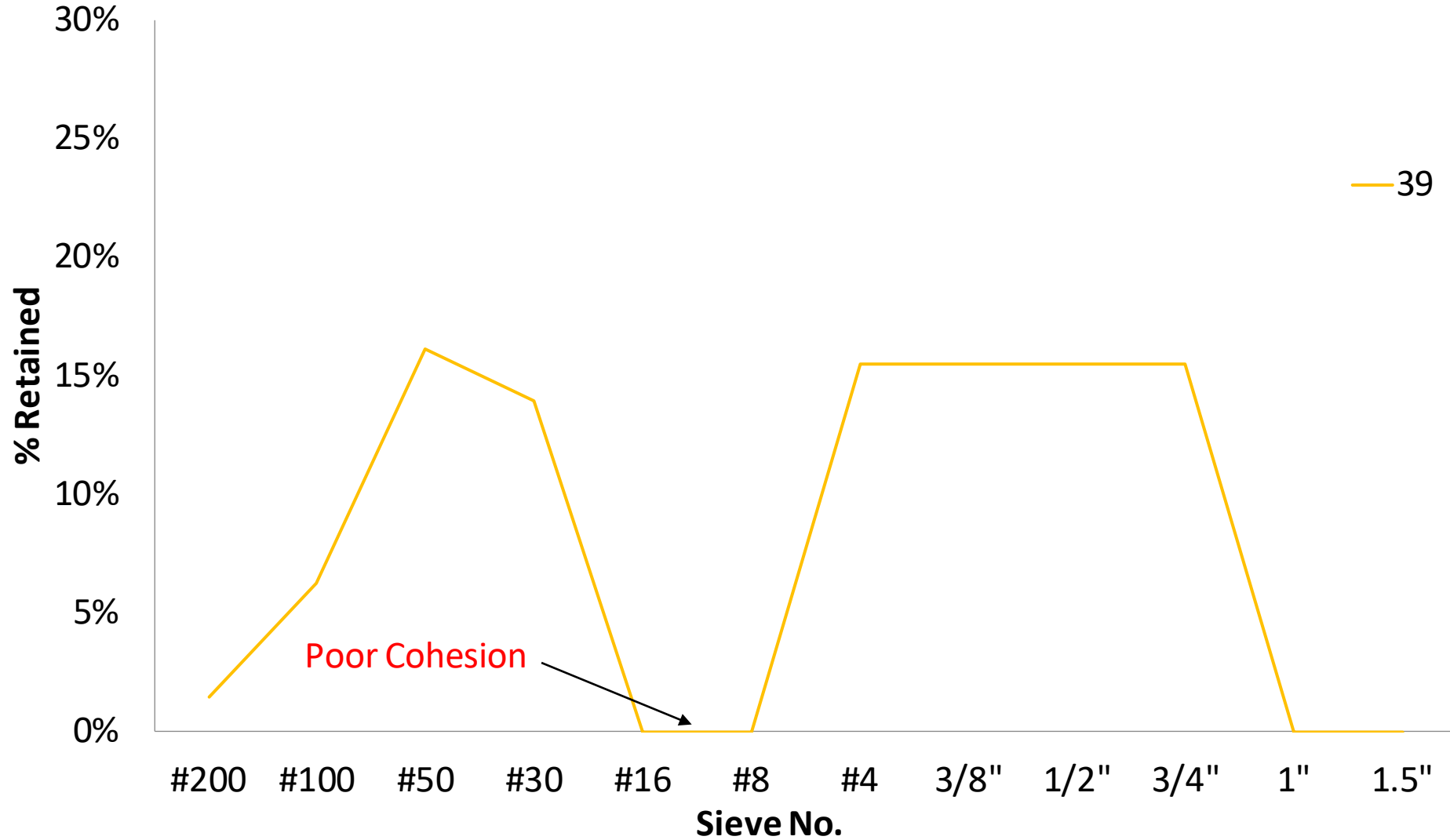
How Gradation impacts the Performance

Fine Aggregate



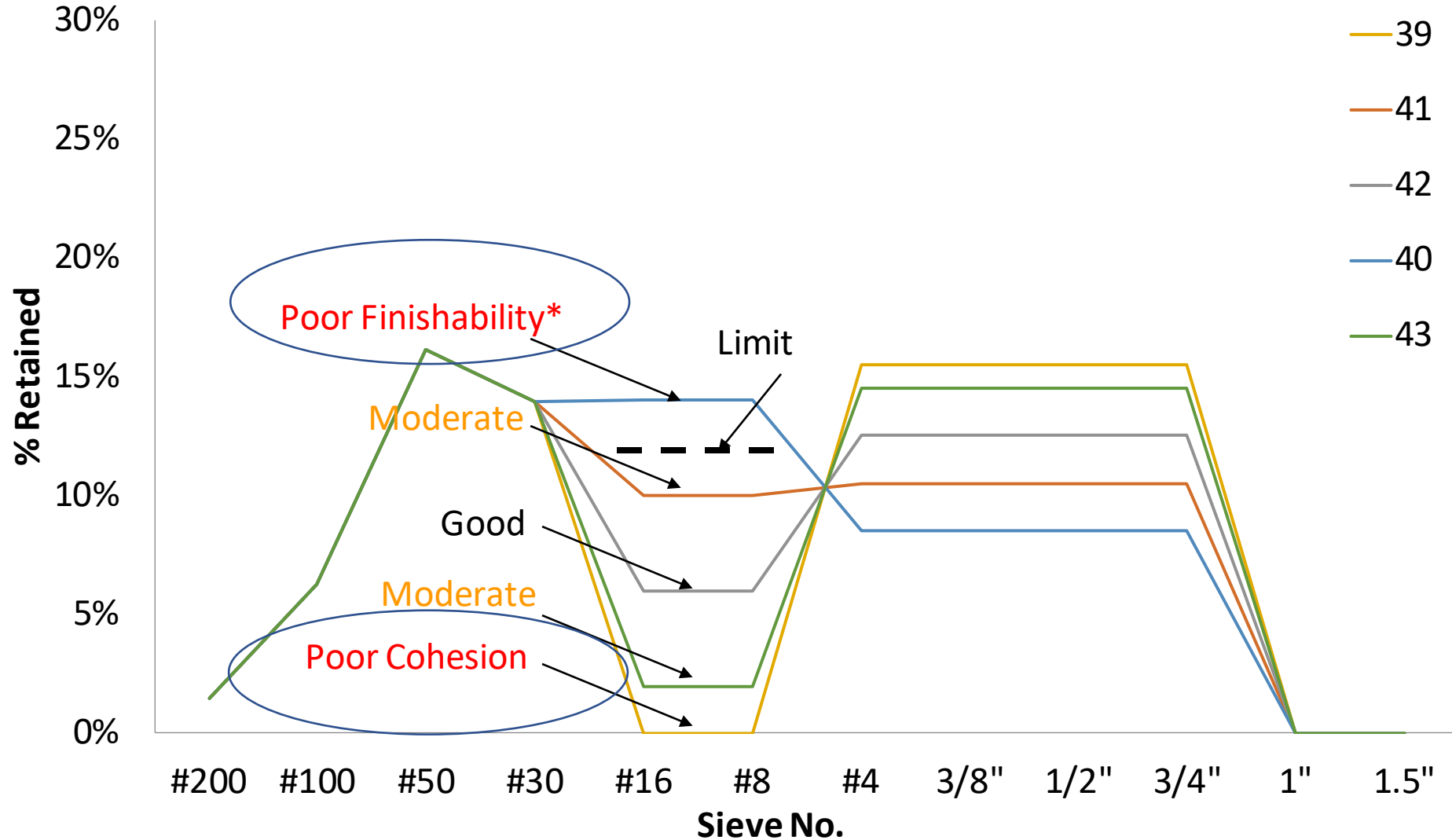
How Gradation impacts the Performance

Fine Aggregate – Coarse Sand



How Gradation impacts the Performance

Fine Aggregate – Coarse Sand



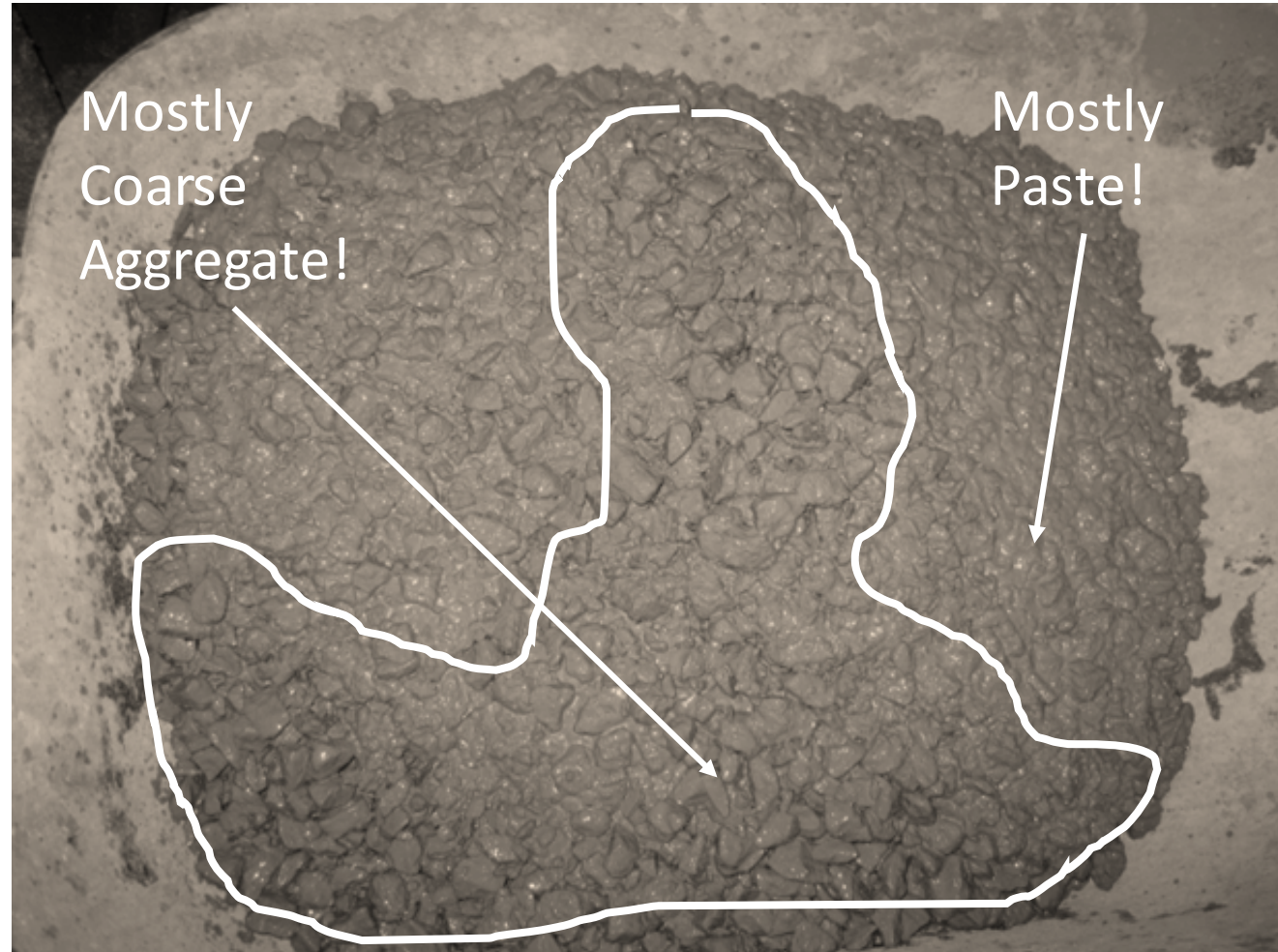
How Gradation impacts the Performance

Fine Aggregate – Coarse Sand

The coarse sand is important for finishing and cohesion

For cohesion, a minimum of 15% retained on the #8-#30 sieve sizes was needed.

The limits and sum of the #8, #16, and #30 help determine this.



How Gradation impacts the Performance

Fine Aggregate – Coarse Sand

The coarse sand is important for finishing and cohesion

Finishability issues created a maximum boundary limit on # 8 & #16 of 12% on each sieve size.

0 Passes



8 Passes

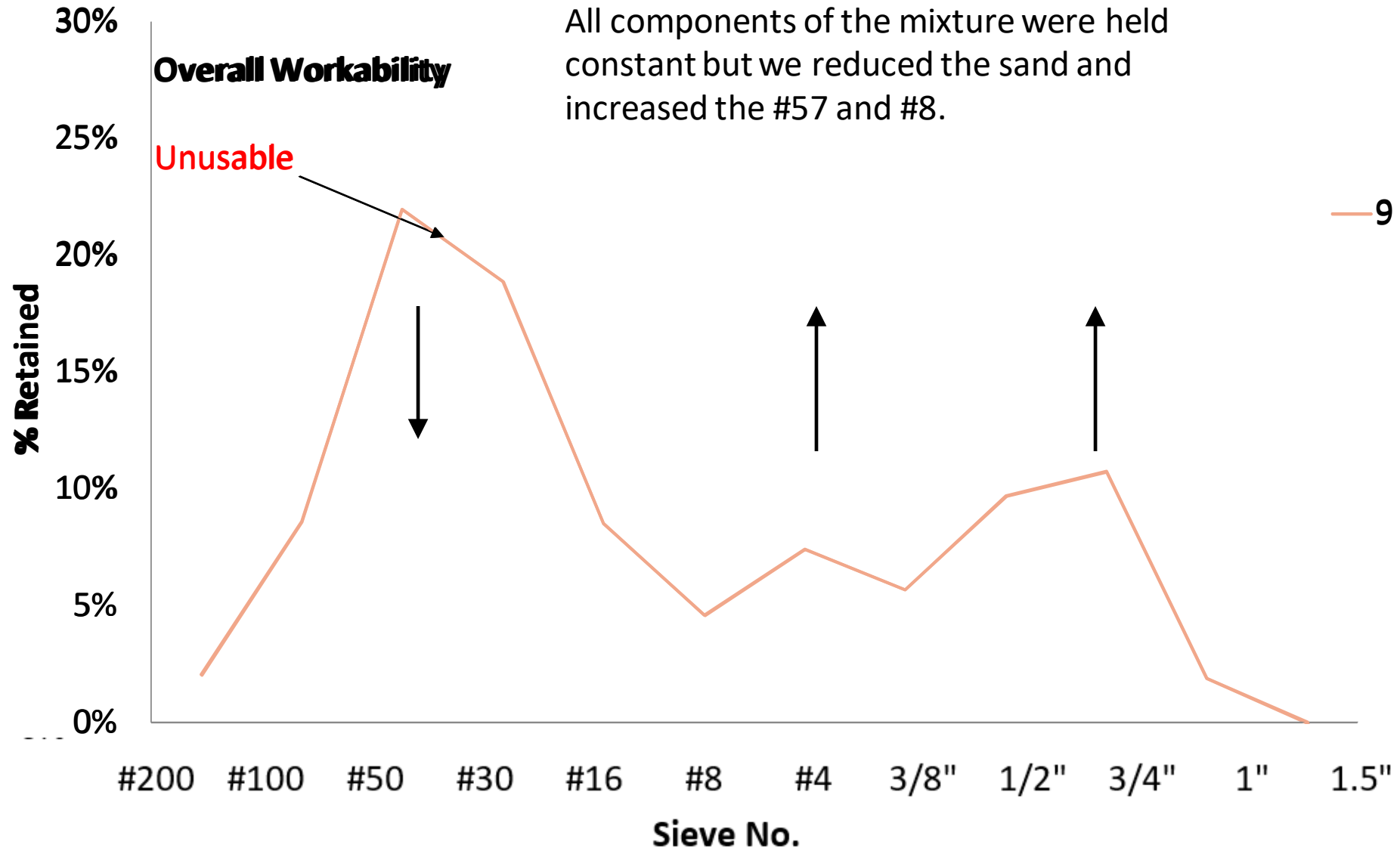


18 Passes



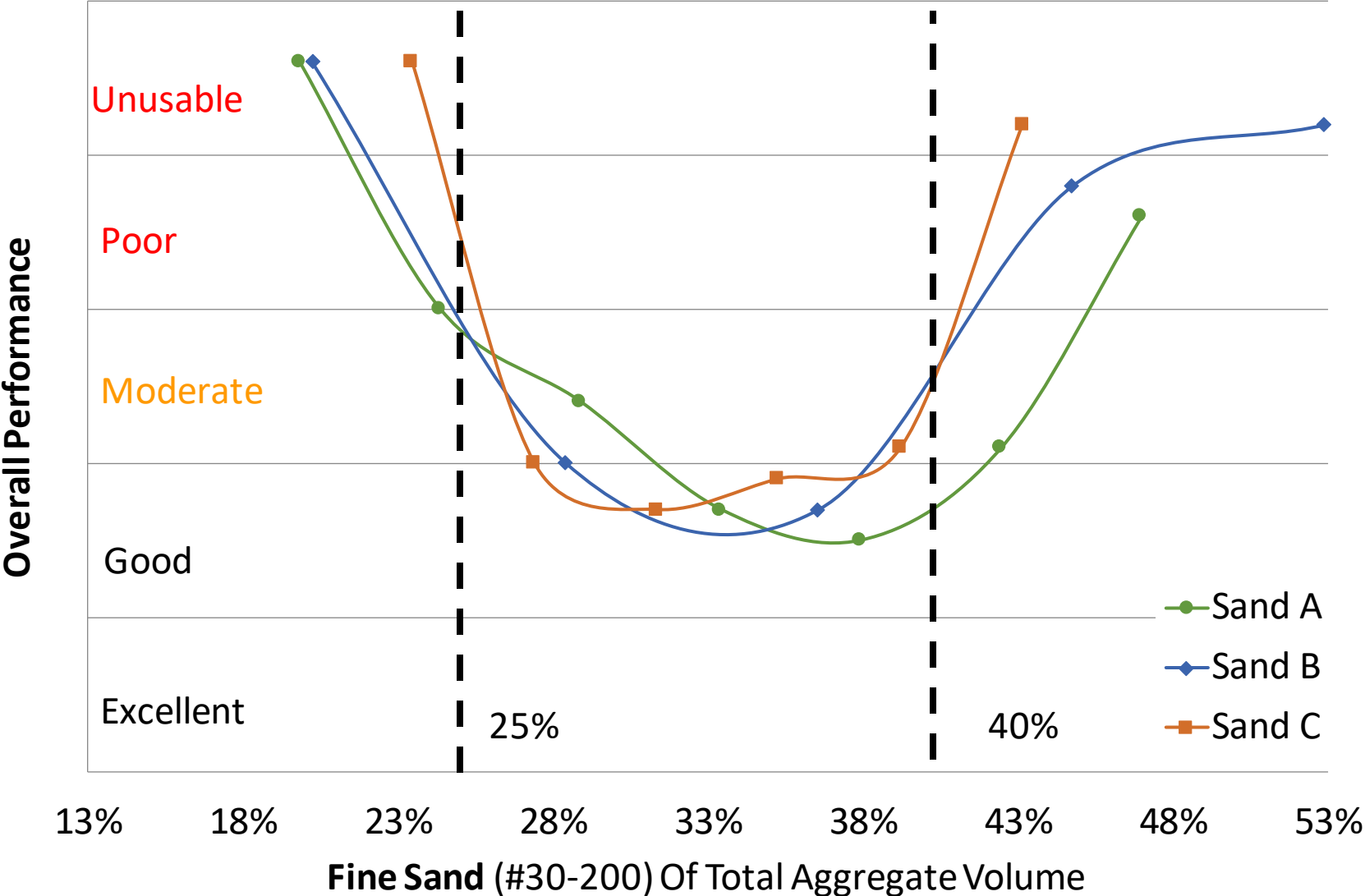
How Gradation impacts the Performance

Fine Aggregate – Fine Sand



How Gradation impacts the Performance

Fine Aggregate – Fine Sand



How Gradation impacts the Performance

Fine Aggregate – Fine Sand

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

Excessive Sand



Sufficient Sand



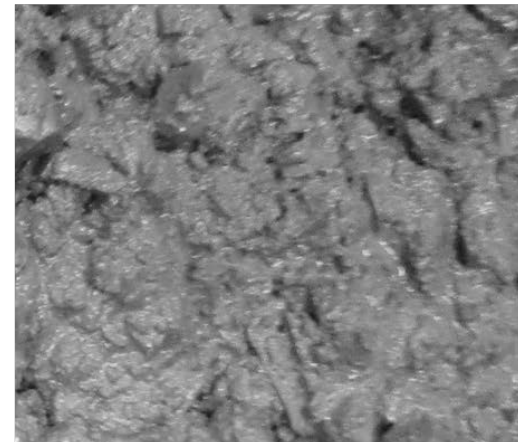
Deficient Sand



Excessive Sand



Sufficient Sand



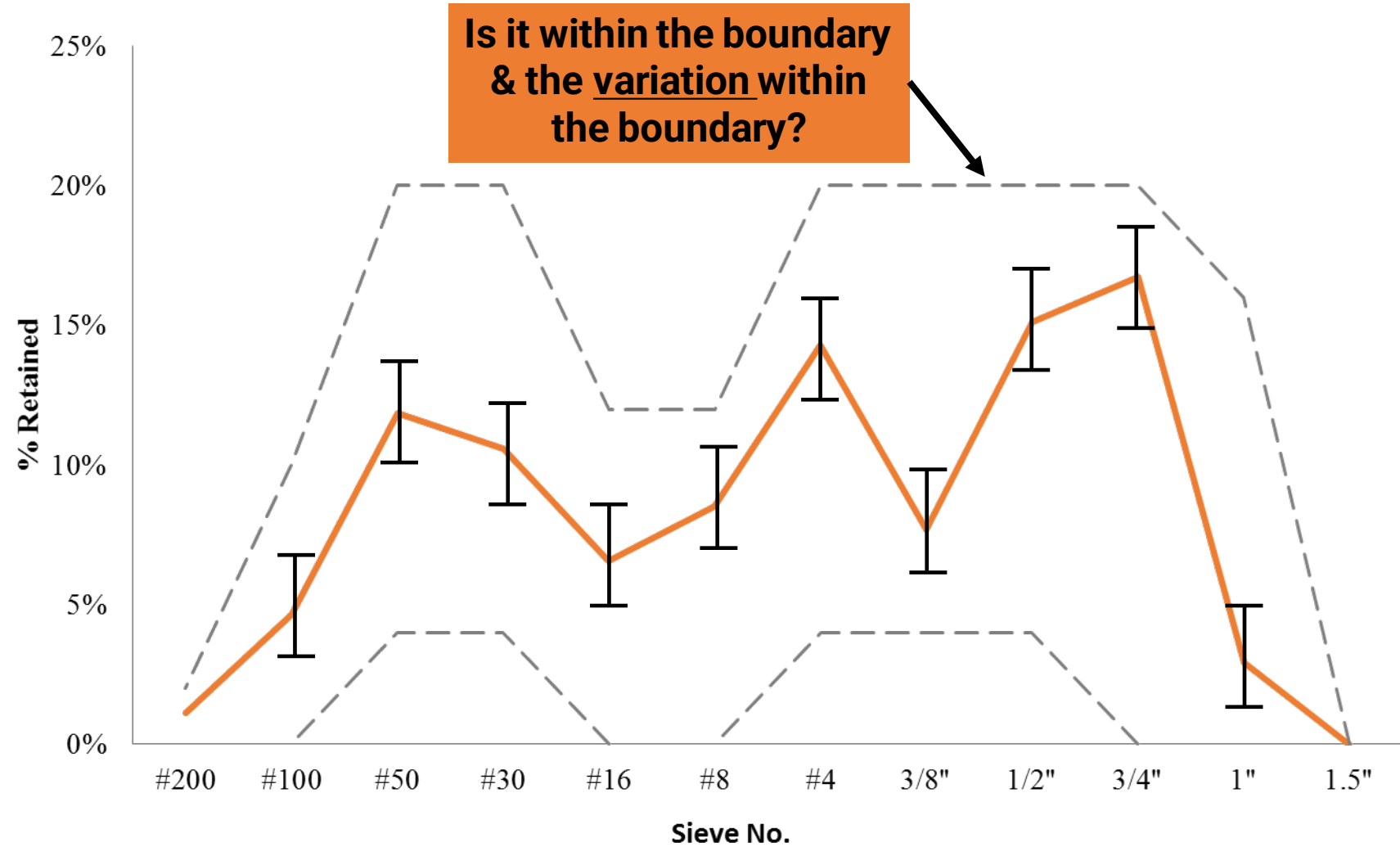
Deficient Sand



How Gradation impacts the Performance

Checking the Mix

Is the proposed the proposed combined aggregate gradation within the boundary?



How Gradation impacts the Performance

Checking the Mix

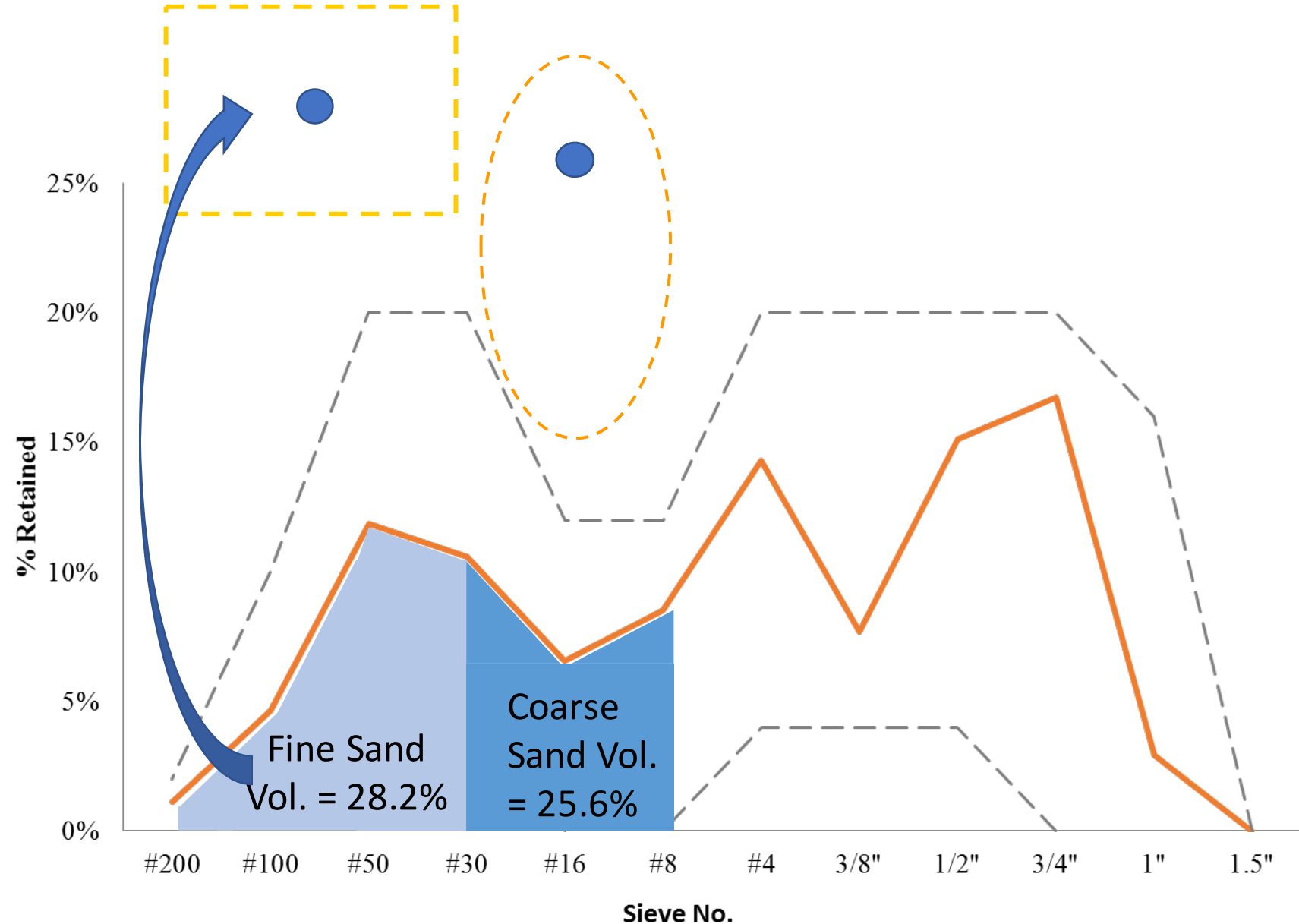
Is the proposed the proposed combined aggregate gradation within the boundary?

Coarse Sand Volume in the Oval?

$$\begin{aligned} \text{CS\%} &= \#8 + \#16 + \#30 \\ &= 8.1\% + 6.3\% + 11.2\% \\ &= 25.6\% > 15\% \end{aligned}$$

Find Sand Volume in the Square?

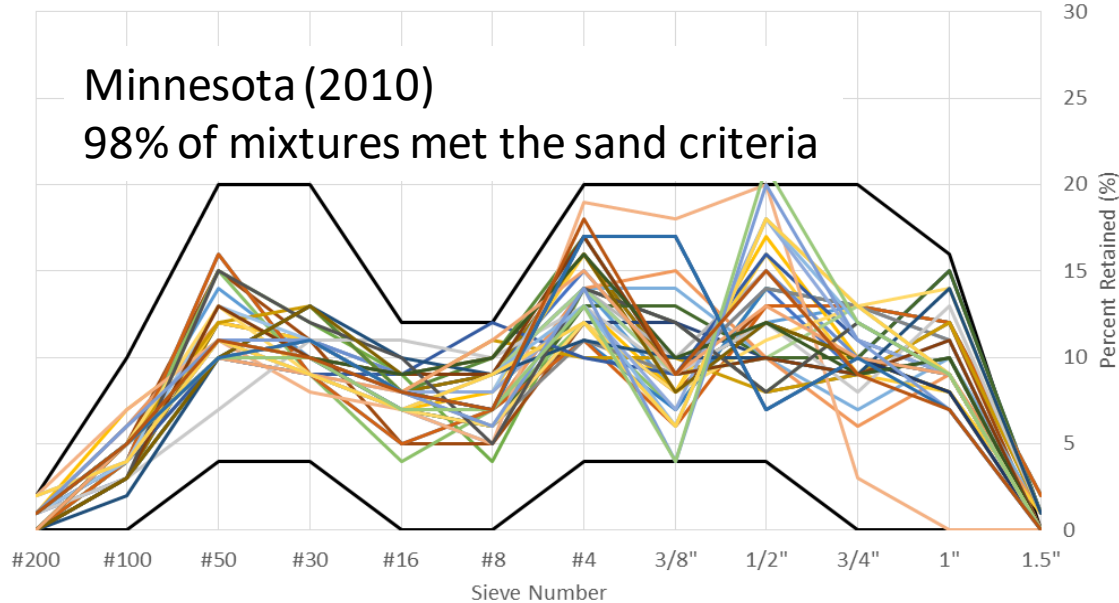
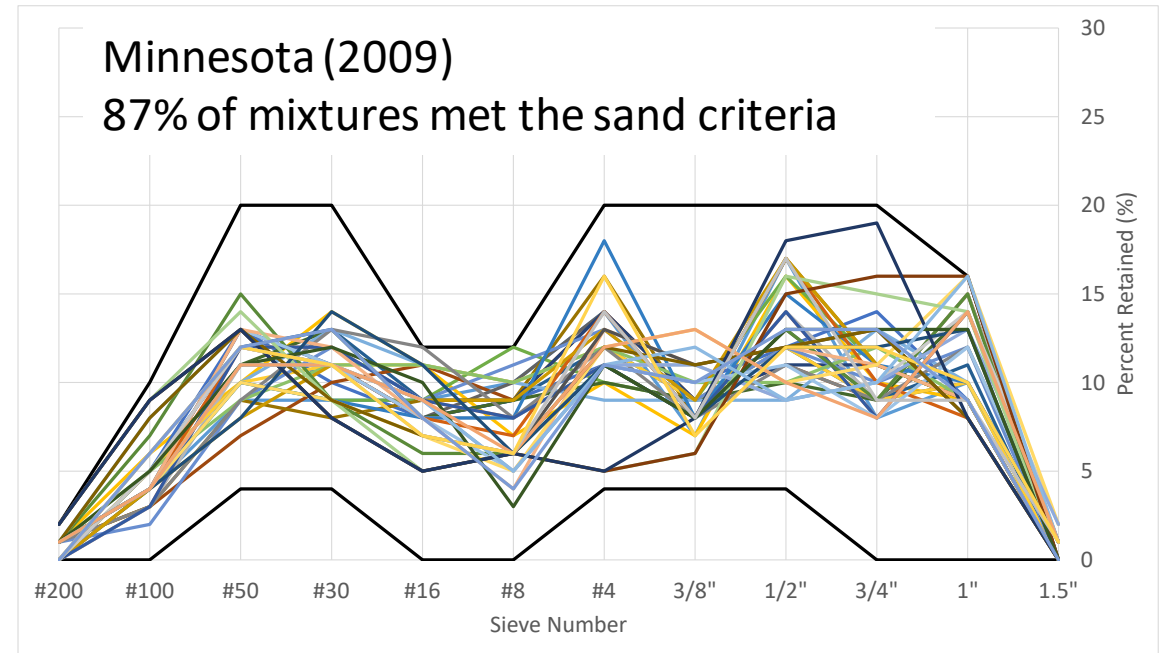
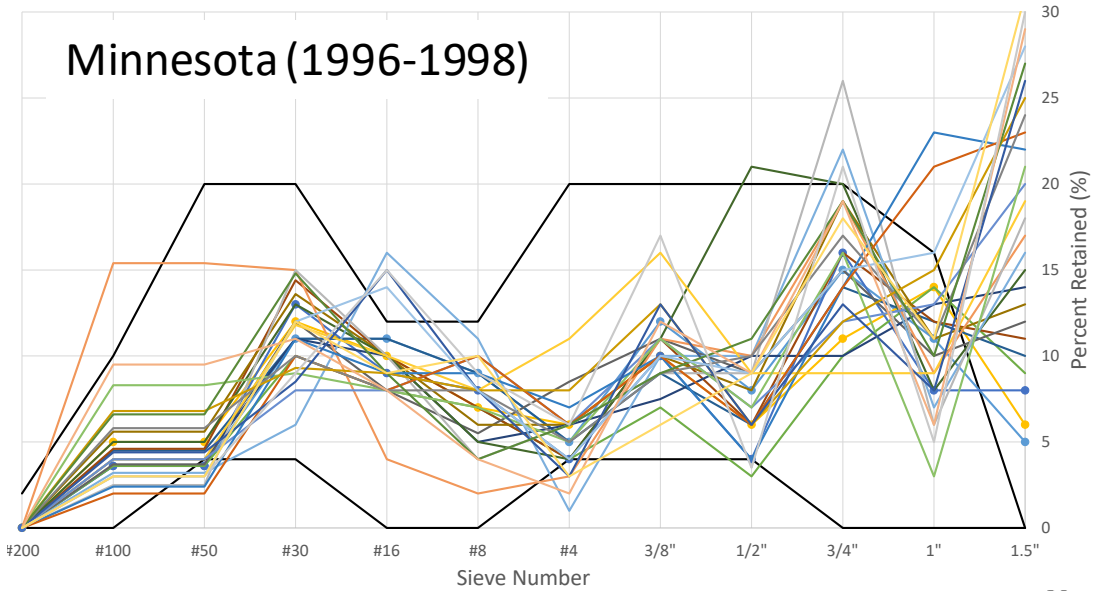
$$\begin{aligned} \text{FS\%} &= \#30 + \#50 + \#100 + \#200 \\ &= 11.2\% + 12.1\% + 4.0\% + 0.9\% \\ &= 28.2\% \end{aligned}$$



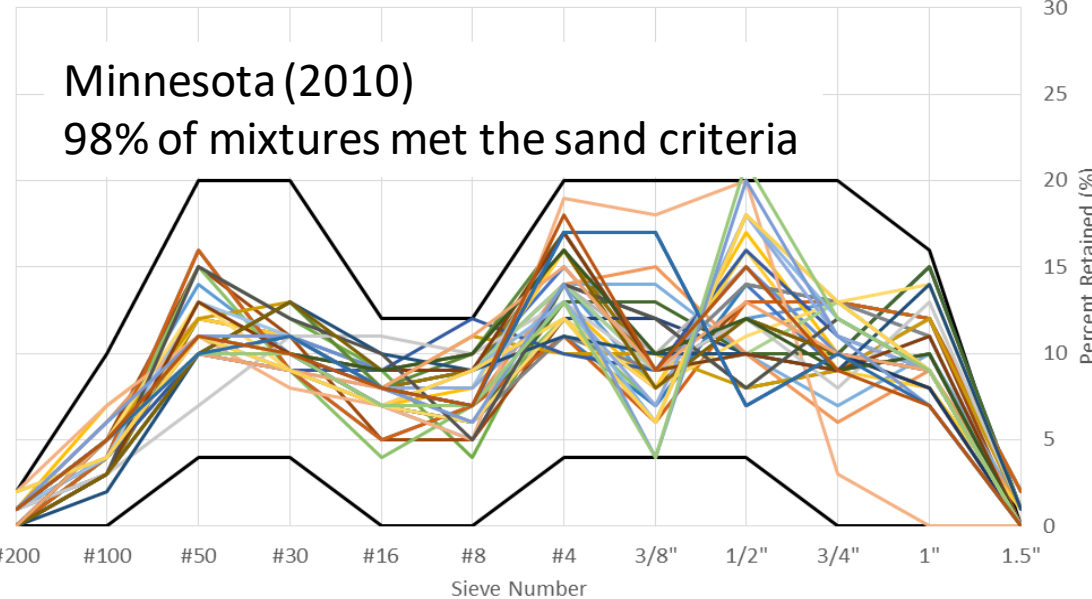
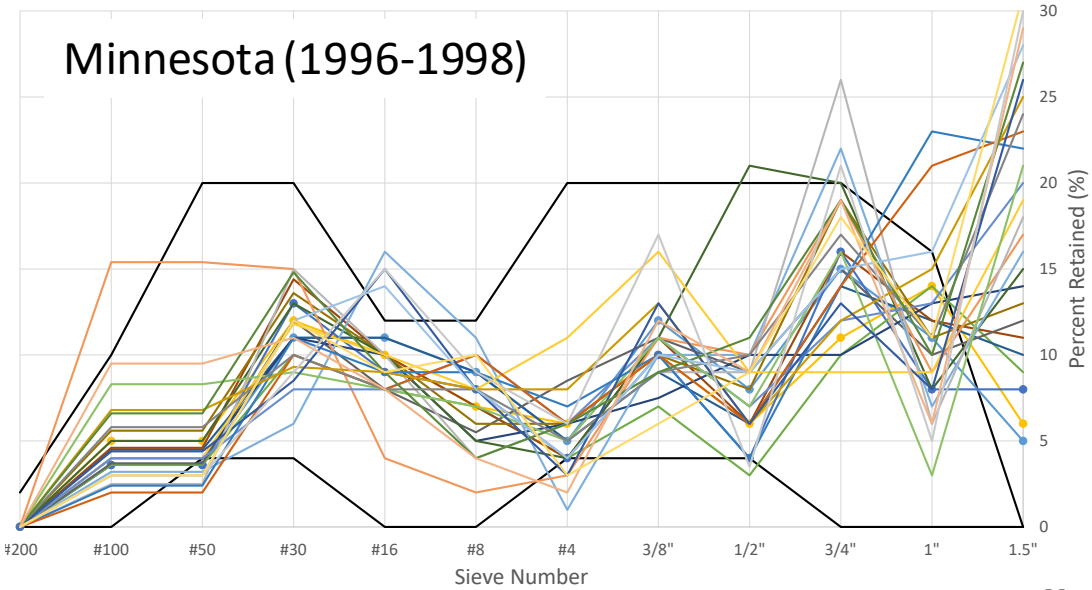
Does This Work?

- States that specify Optimized Gradation
 - Colorado
 - Minnesota
 - Idaho
 - Kansas
 - Oklahoma
 - Pennsylvania
 - Iowa
 - Wisconsin
 - and many more....

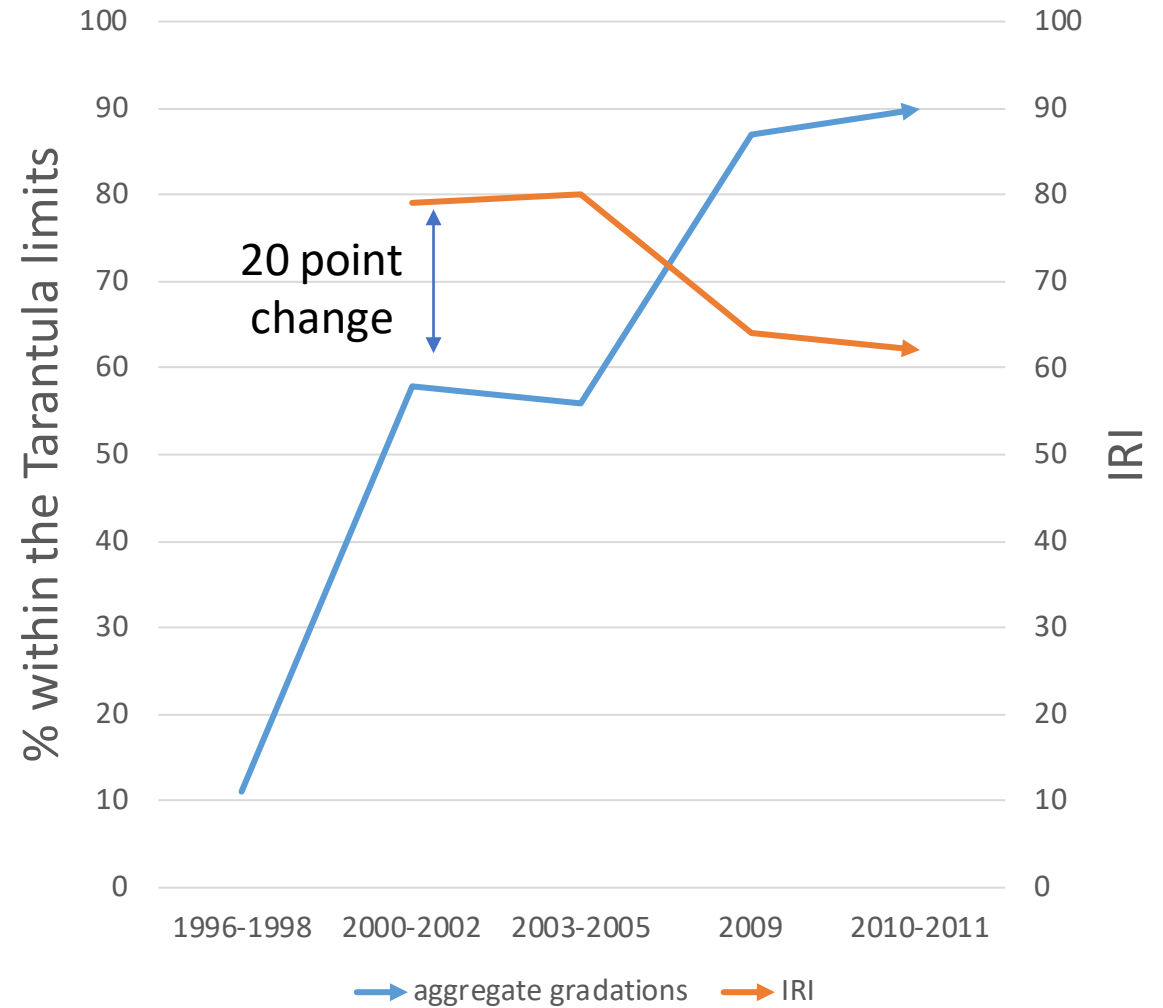
Does This Work?



Does This Work?



Minnesota Pavement Mixtures from 1996 - 2011




Data from Maria Masten, MnDOT

Alturki and Ley 2017

Sources of Information

Tarantula Curve

Home The Box Test Tarantula Curve Publications Aggregate Contact Us



Our Motto

"We are uncovering the black magic of concrete mixture design one mixture at a time."

Welcome to tarantulacurve.com

This website was developed by the civil engineering research team at Oklahoma State University under the direction of Tyler Ley and Dan Cook. The focus of the website started out to advance aggregate proportioning through gradation, but has turned into much more than that. Now, the focus has been to advance the knowledge of concrete materials, basic mixture design principles, and most importantly, optimized graded

<http://www.tarantulacurve.com/>
www.youtube.com/tylerley

Spreadsheet

http://www.tarantulacurve.com/uploads/1/6/3/9/16391330/_ogcp_spreadsheet.xlsx

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CP Tech Center

National Concrete Pavement Technology Center



CP TECH CENTER | CONCRETE MIXTURE PROPORTIONING

Concrete Mixture Proportioning



Concrete pavement owners care most about a pavement's long-term performance—its durability and strength. Contractors care more about its constructability—its workability, setting, and early strength that constrain when their next phase of work can begin. Both care about their bottom line.

No one-size-fits-all concrete recipe exists. Mixture proportioning is the iterative process of determining how much of which ingredients available in a given locale can most economically produce the best concrete matching pavement requirements.

The following CP-Tech-Center-curated collection of resources is not comprehensive, but it does represent the current state of concrete mixture proportioning research and best practice. See also the

FOR MORE INFORMATION

For more information about CP Tech Center work related to concrete mixture proportioning, contact:

Peter Taylor
DIRECTOR, CP TECH CENTER
515-294-9333
ptaylor@iastate.edu

<https://cptechcenter.org/mix-proportioning/>
<https://cptechcenter.org/performance-engineered-mixtures-pem/>

Spreadsheet

<https://intrans.iastate.edu/app/uploads/2019/03/Mixture-proportioning-2021-06.xlsx>

A photograph of the Golden Gate Bridge in San Francisco, viewed from a low angle looking across the water. The bridge's towers and suspension cables are visible. The entire image is overlaid with a semi-transparent teal color.

Thank You

jamesw.mack@cemex.com

Ph: 713-598-6669

TRB Webinar

Surface Aggregate Classification of Reclaimed Asphalt Pavements

Texas A&M Transportation Institute

Sheng Hu

April 2024

Outline

- Introduction
- Skid Resistance and Surface Aggregate Classification (SAC)
- Dynamic Friction Tester (DFT) for Skid Resistance Evaluation
- DFT Measurements on Reclaimed Asphalt Pavement (RAP) Aggregate and Mix
- Preliminary DFT-based SAC Criteria for RAP
- Pilot Implementation
- Q/A

Introduction

- Pavement skid resistance is crucial for safety
- TxDOT aims to halve fatal crashes by 2035, with zero fatalities by 2050



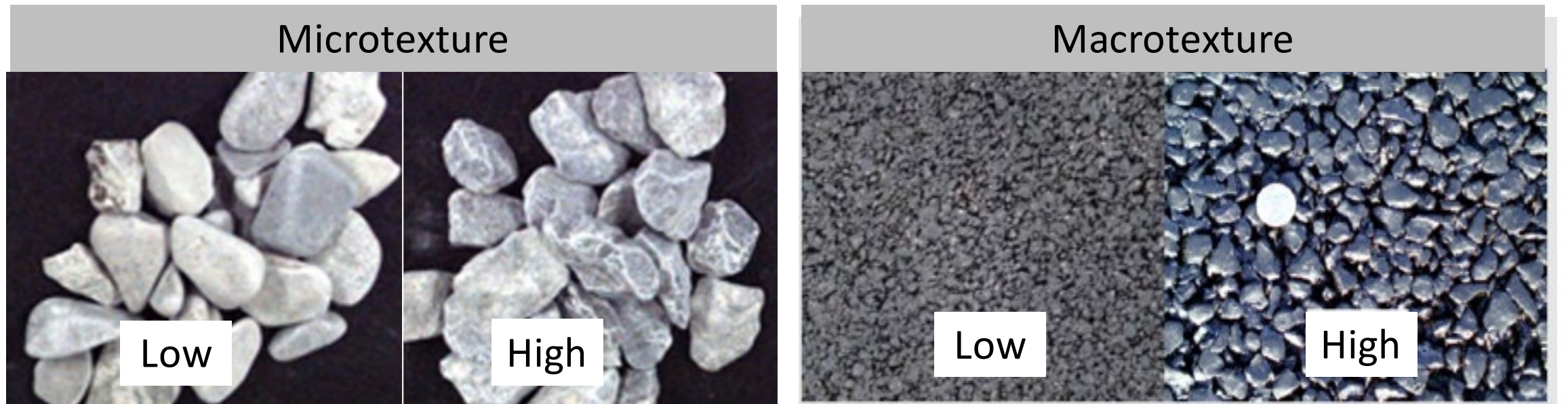
Introduction

- SAC-A aggregate demand increasing significantly
- TxDOT and asphalt industry promote RAP usage, but current specs only allow to use RAP as SAC-B
- Objective: Assess RAP's potential as SAC-A



Skid Resistance and SAC

- Skid resistance links to Microtexture and Macrotexture
 - Microtexture: Influenced by aggregate type
 - Macrotexture: Influenced by mix type



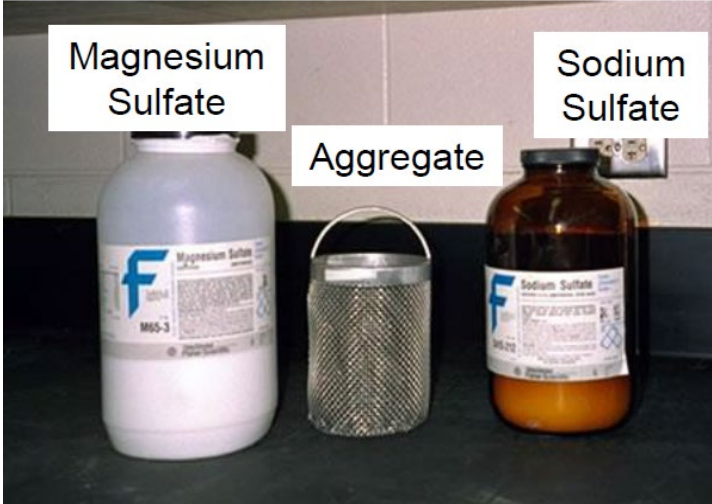
Skid Resistance and SAC

- Current SAC for Aggregate
 - Indirect measurement of aggregate skid resistance

Property	Test Method	SAC A	SAC B	SAC C
Acid Insoluble Residue, % Minimum	Tex-612-J	55	---	---
5-Cycle Mg Sulfate Soundness, % Maximum	Tex 411-A	25	30	35

Will not be included in the TxDOT 2024 specification

Acid Insoluble Residue



Skid Resistance and SAC

- Current SAC for Mix (Blended Aggregate)
 - One SP-C Mix with 53.4% SAC-A Aggregate

Class (A) Rock (Y/N):		SAC-A	SAC-B	SAC-B				RAP
		No	Yes	No	No	No		
Sieve Size:		Individual Ret., %	Individual Ret., %	Individual Ret., %	Individual Ret., %	Individual Ret., %	Individual Ret., %	Individual Ret., %
Passing	Retained							
-	1"		0.0	0.0	0.0			0.0
1"	3/4"		0.0	0.0	0.0			0.0
3/4"	1/2"		7.6	0.0	0.0			0.0
1/2"	3/8"		7.8	2.8	0.0			0.6
3/8"	No. 4		11.2	14.8	0.3			4.8
No. 4	No. 8		0.3	6.5	4.3			5.2
No. 8	No. 16		0.1	0.3	7.8			2.4
No. 16	No. 30		0.1	0.3	4.5			1.6
No. 30	No. 50		0.3	0.1	2.9			1.4
No. 50	No. 200		0.1	0.1	3.5			2.4
No. 200	Pan		0.5	0.3	3.7			1.6
Total:			28.0	25.1	27.0			19.9
Percent of plus No. 4			26.6	17.6	0.3			5.4
Percent of plus No. 8:			26.9	24.1	4.6			10.5
Percent of plus No. 4 from class (A) Rock:			26.6	Percent of plus No. 8 from class (A) Rock:			26.9	
Total Percent of plus No. 4			49.8	Total Percent of plus No. 8:			66.1	
Percent of plus No. 4 from class (A) Rock:			53.4	Percent of plus No. 8 from class (A) Rock:			40.7	

Fiscal Year	Skid Number	Skid Test Date
2019	28.6	5/6/2019
2019	23.0	5/6/2019
2019	28.1	5/6/2019
2019	30.3	5/6/2019
2019	31.0	5/6/2019
2019	36.4	5/6/2019
2019	24.8	5/6/2019
2019	25.1	5/6/2019
2019	29.0	5/6/2019
2019	22.3	5/6/2019
2019	27.5	5/6/2019
2019	27.1	5/6/2019
2019	24.4	5/6/2019
2019	30.5	5/6/2019
2019	26.2	5/6/2019
2019	30.4	5/6/2019
2019	31.1	5/6/2019
2019	28.0	5/6/2019
2019	25.4	5/6/2019
2019	19.1	5/6/2019

Skid Resistance and SAC

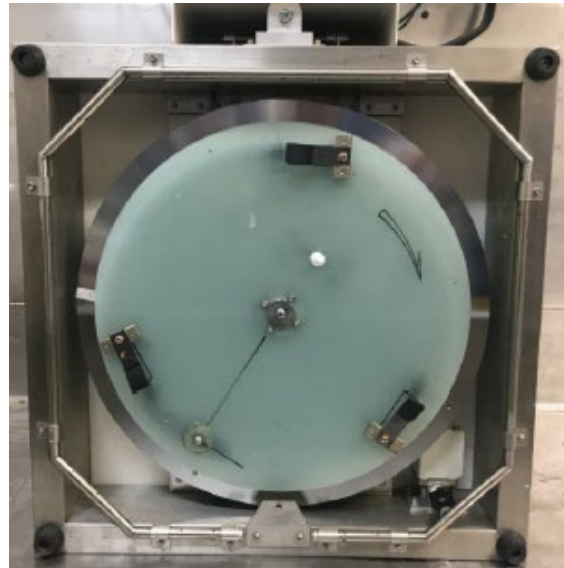
- Current SAC for Mix (Blended Aggregate)
 - One SP-D Mix with 100% SAC-A Aggregate

		SAC-A	SAC-A	SAC-A	Sand		
Class (A) Rock (Y/N):		Yes	Yes	Yes	No		
Sieve Size:		Individual Ret., %	Individual Ret., %	Individual Ret., %	Individual Ret., %	Individual Ret., %	Individual Ret., %
Passing	Retained						
-	3/4"	0.0	0.0	0.0	0.0		
3/4"	1/2"	0.0	0.0	0.0	0.0		
1/2"	3/8"	4.8	0.0	0.0	0.0		
3/8"	No. 4	28.1	6.5	1.4	0.0		
No. 4	No. 8	12.4	2.7	7.3	0.0		
No. 8	No. 30	3.3	0.5	12.7	0.0		
No. 30	No. 50	0.3	0.0	2.8	0.0		
No. 50	No. 200	0.4	0.1	2.8	8.3		
No. 200	Pan	0.9	0.2	3.1	1.7		
Total:		50.0	10.0	30.0	10.0		
Percent of plus No. 4		32.9	6.5	1.4	0.0		
Percent of plus No. 8		45.2	9.2	8.6	0.0		
Percent of plus No. 4 from class (A) Rock:		40.7		Percent of plus No. 8 from class (A) Rock:		63.1	
Total Percent of plus No. 4		40.7		Total Percent of plus No. 8		63.1	
Percent of plus No. 4 from class (A) Rock:		100.0		Percent of plus No. 8 from class (A) Rock:		100.0	

Fiscal Year	Skid Number	Skid Test Date
2016	32.0	7/18/2016
2016	30.0	7/18/2016
2016	28.0	7/18/2016
2016	27.0	7/18/2016
2016	30.0	7/18/2016
2016	35.0	7/18/2016
2016	33.0	7/18/2016
2016	36.0	7/18/2016
2016	38.0	7/18/2016
2018	20.6	6/20/2018
2018	19.4	6/20/2018
2018	19.6	6/20/2018
2018	19.6	6/20/2018
2018	24.4	6/20/2018
2018	21.6	6/20/2018
2018	34.7	6/21/2018
2018	38.0	6/21/2018
2018	36.1	6/21/2018

DFT for Skid Resistance Evaluation

- DFT: direct measurement of skid resistance
 - Measures a friction value on wet surface (ASTM E1911)
 - Spinning disk with 3 rubber sliders contacting surface



DFT for Skid Resistance Evaluation

- Maryland DOT used DFT to measure aggregate friction

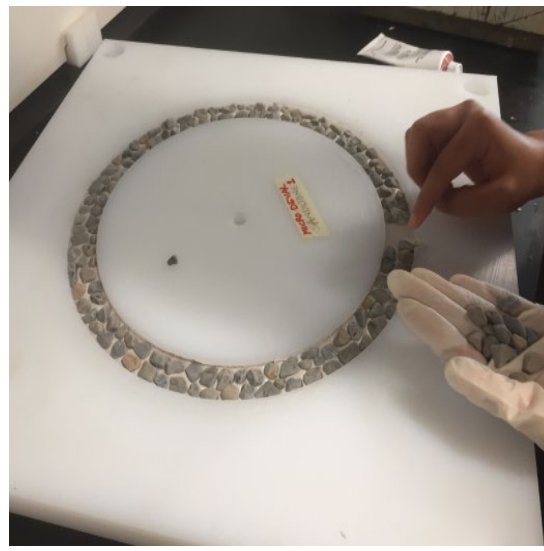


Dynamic Friction Value Categories	
Category	DFV
HDFV I	50
HDFV II	45
HDFV III	40
SDFV IV	30
SDFV V	25
LDFV VI	20

H: High; S: Standard; L: Low

DFT for Skid Resistance Evaluation

- Richard Izzo's group at TxDOT Material & Tests Division (MTD) established its own test procedure
 - Micro-Deval polishing aggregates: 10500 revolutions (105 minutes)
 - Fabricate an aggregate ring: passing 3/8" sieve and retaining on 1/4" sieve
 - Run DFT on the aggregate ring



DFT for Skid Resistance Evaluation

- Presentation at TxDOT 2020 Short Course (Richard Izzo)
 - Conducted over 800 DFT tests since 2016
 - Evaluated more than 100 raw aggregate sources
 - Calculated blended DFT values for HMA mixes

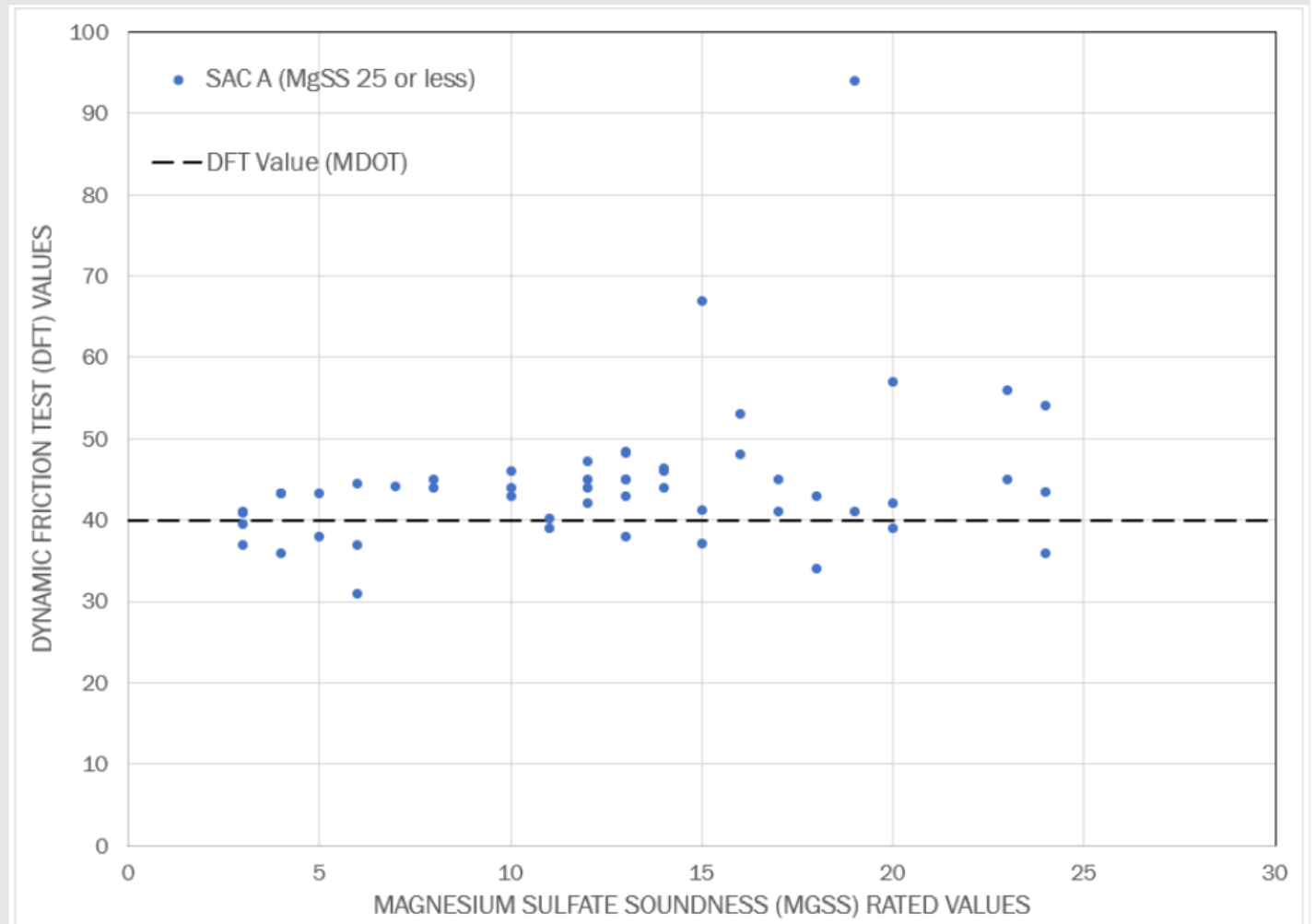
AGGREGATE	# SOURCES
LIMESTONE	47
DOLOMITE	13
GRAVEL (LIMESTONE & GRAVEL)	6
GRAVEL (GRAVEL & LIMESTONE)	30
SANDSTONE	3
IGNEOUS	16
LIGHTWEIGHT	1

AGGREGATE	ITEM 344 -SUPERPAVE SP-C (SAC A)	
	+#4 STOCKPILE	DFT VALUE
STOCKPILE 1	19.3	43
STOCKPILE 2	22.3	43
STOCKPILE 3	4.9	27
STOCKPILE 4	0.1	27
RAP	2.8	30
+#4 SAC A (50% MINIMUM)	84%	
DFT BLEND VALUE	39	

AGGREGATE	ITEM 341 TYPE D - SAC B		ITEM 341 TYPE D - SAC B	
	+#4 STOCKPILE	DFT VALUE	+#4 STOCKPILE	DFT VALUE
STOCKPILE 1	13.3	36	20.9	30
STOCKPILE 2	14.1	36	10.6	30
STOCKPILE 3	0.3	30	0.1	30
STOCKPILE 4	0	30	0	30
RAP	5.5	30	3	30
DFT BLEND VALUE	35		30	

DFT for Skid Resistance Evaluation

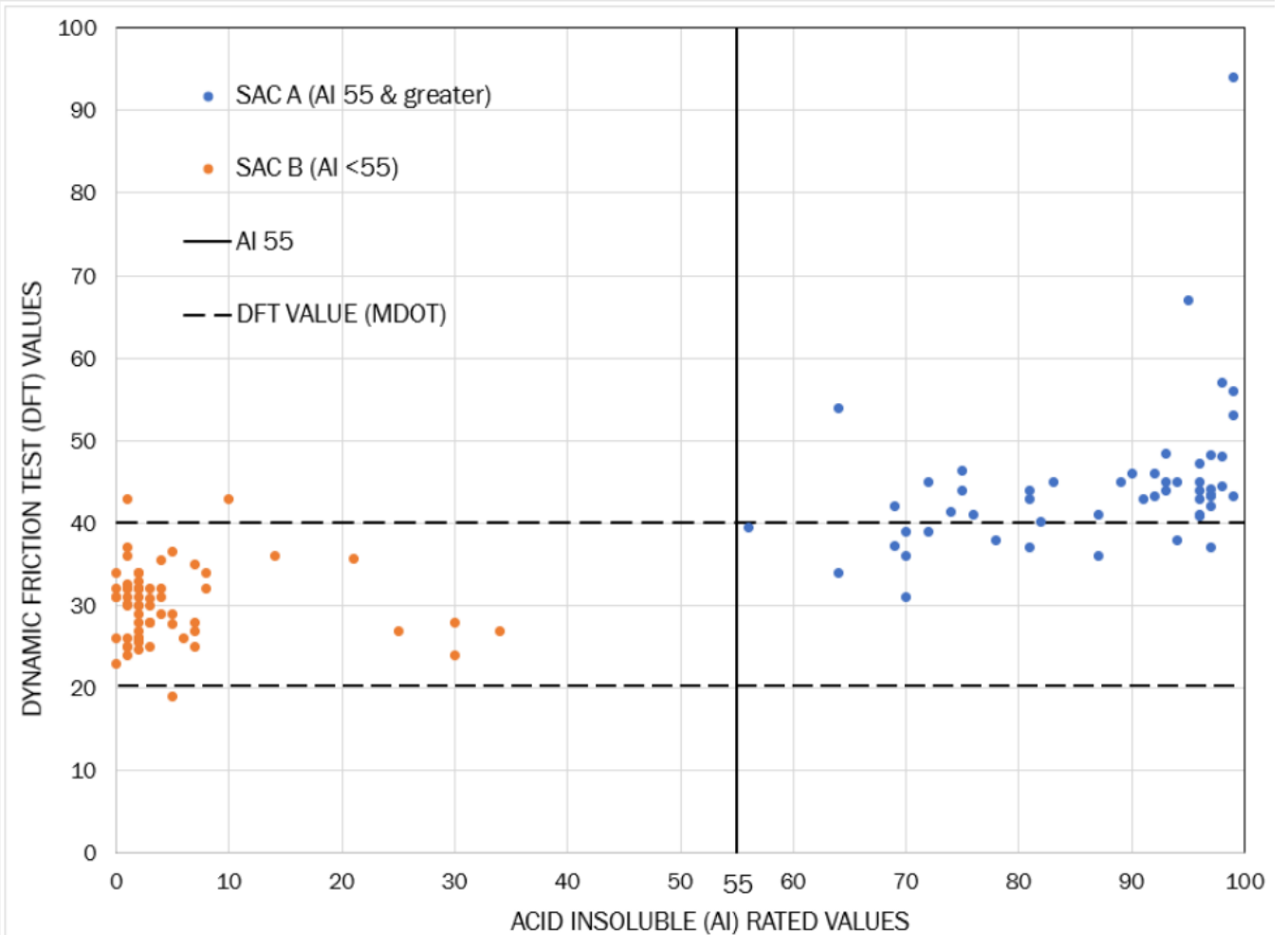
- DFT values of individual aggregate sources, not blended values.
- All material codes combined – Dolomite, Gravel, Igneous, Lightweight, Limestone, and Sandstone.
- Poor correlation/trend of Soundness to DFT Value for SAC A sources.
- Soundness not a strong indicator of friction for SAC A sources.



Richard Izzo, 2020 TxDOT Short Course

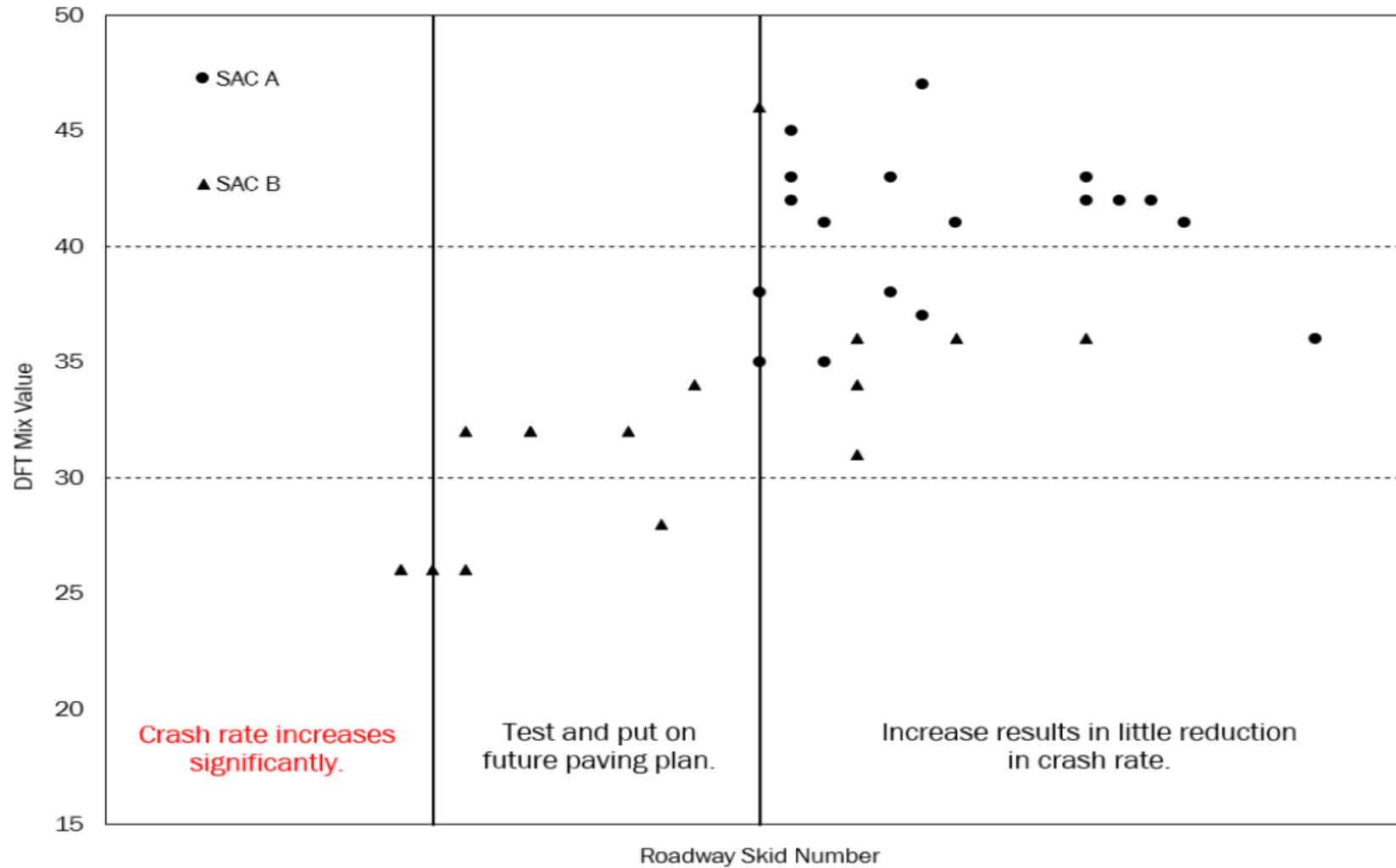
DFT for Skid Resistance Evaluation

- DFT value compared with acid insoluble for SAC A and SAC B sources.
- All material codes combined – Dolomite, Gravel, Igneous, Lightweight, Limestone, and Sandstone.
- Generally, a high AI > 55 will produce a higher DFT Value.
- DFT does a good job differentiating aggregate sources with lower AI values.



Richard Izzo, 2020 TxDOT Short Course

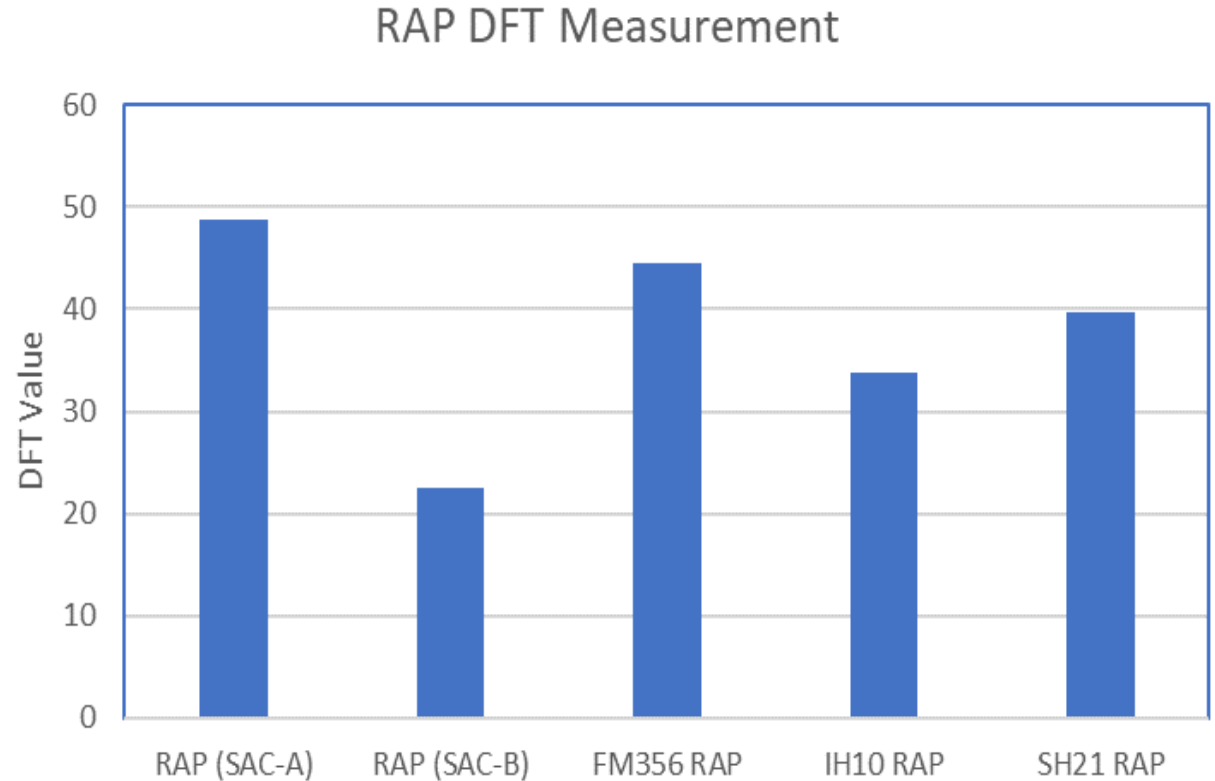
DFT for Skid Resistance Evaluation



Richard Izzo, 2020 TxDOT Short Course

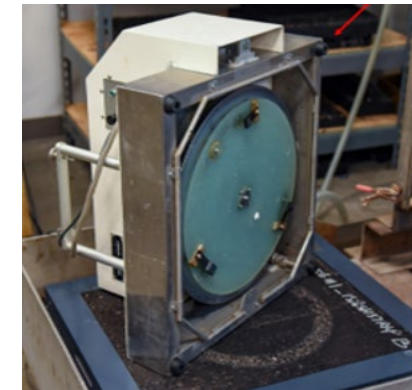
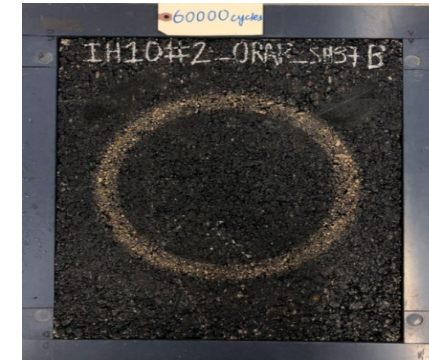
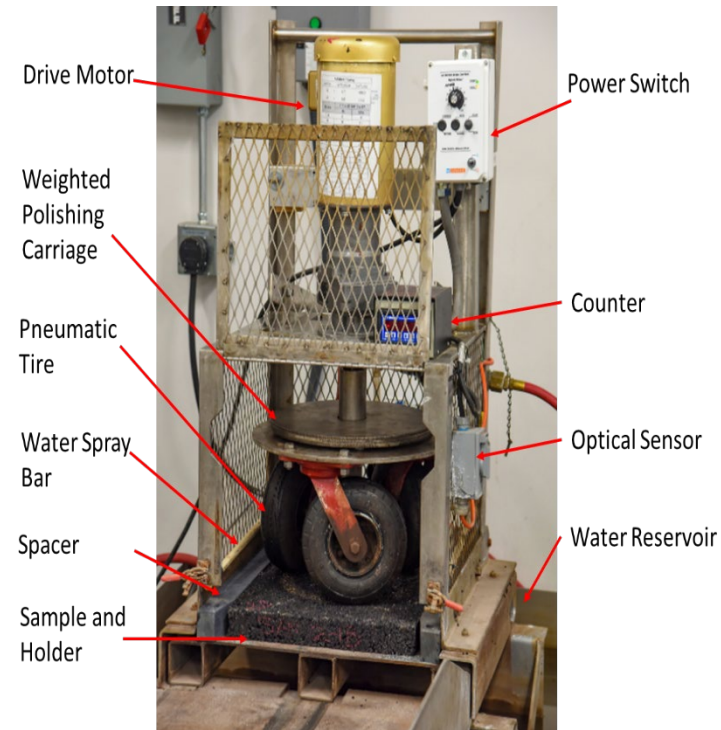
DFT Measurement on RAP and Mix

- DFT on RAP Aggregate
 - Ignition oven test
 - Micro-Deval polishing aggregates: 10,500 revolutions (105 minutes)
 - RAP aggregate ring: passing 3/8" sieve and retaining on 1/4" sieve
 - Run DFT on the ring



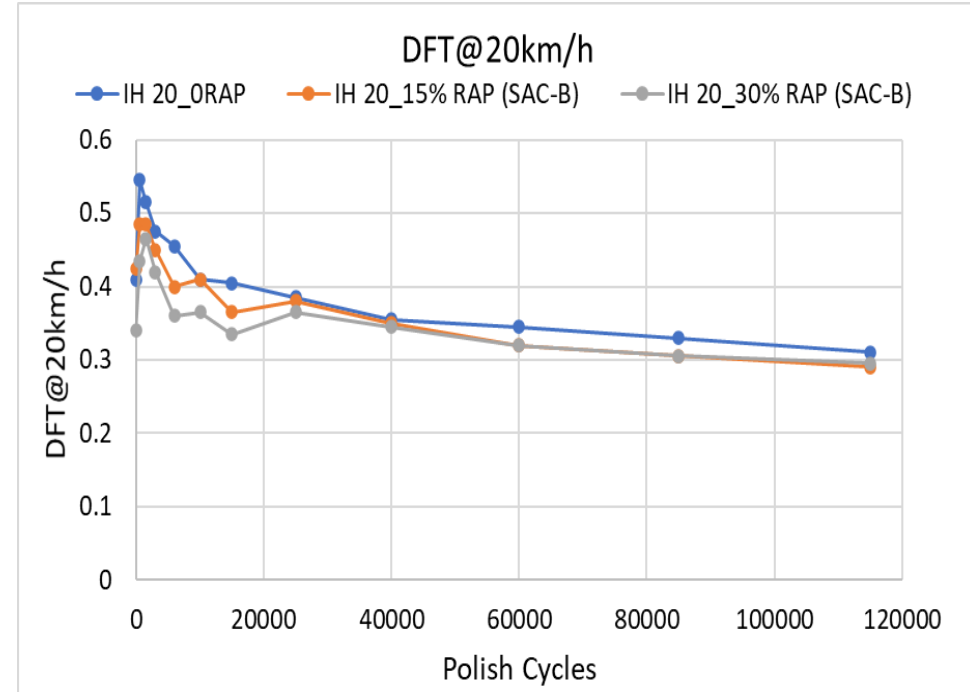
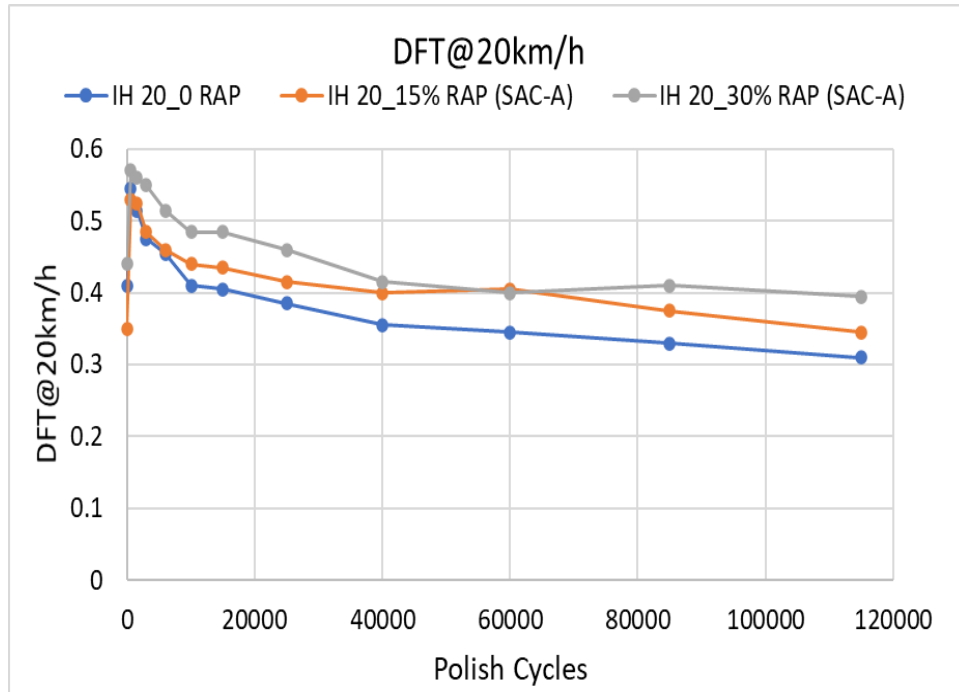
DFT Measurement on RAP and Mix

- DFT on Mix Slab



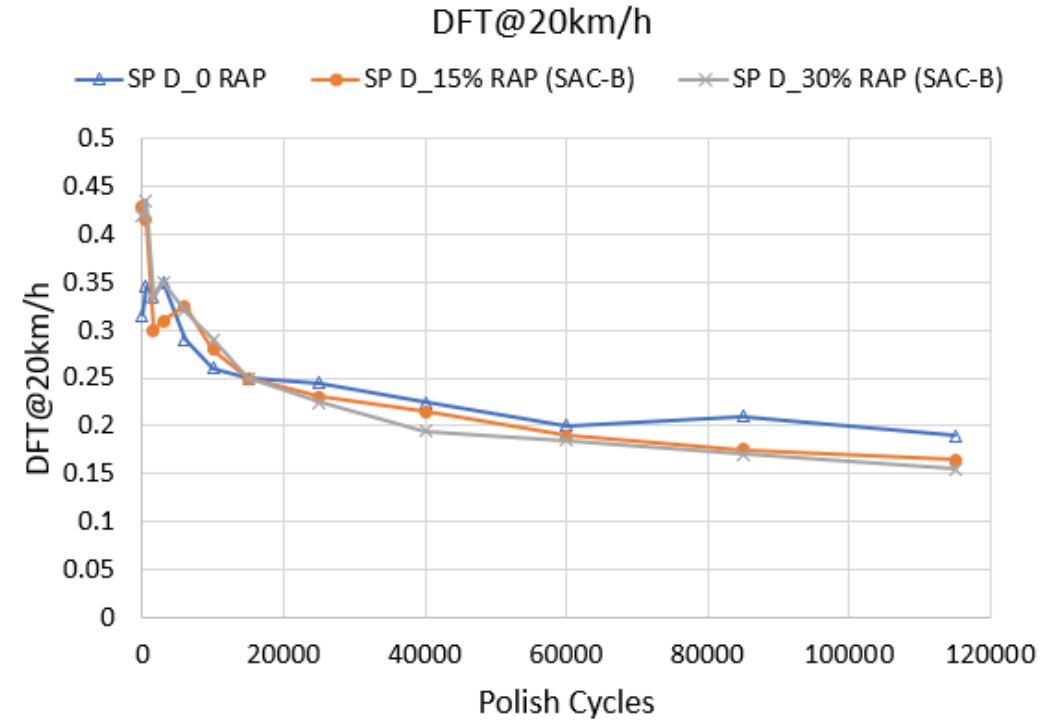
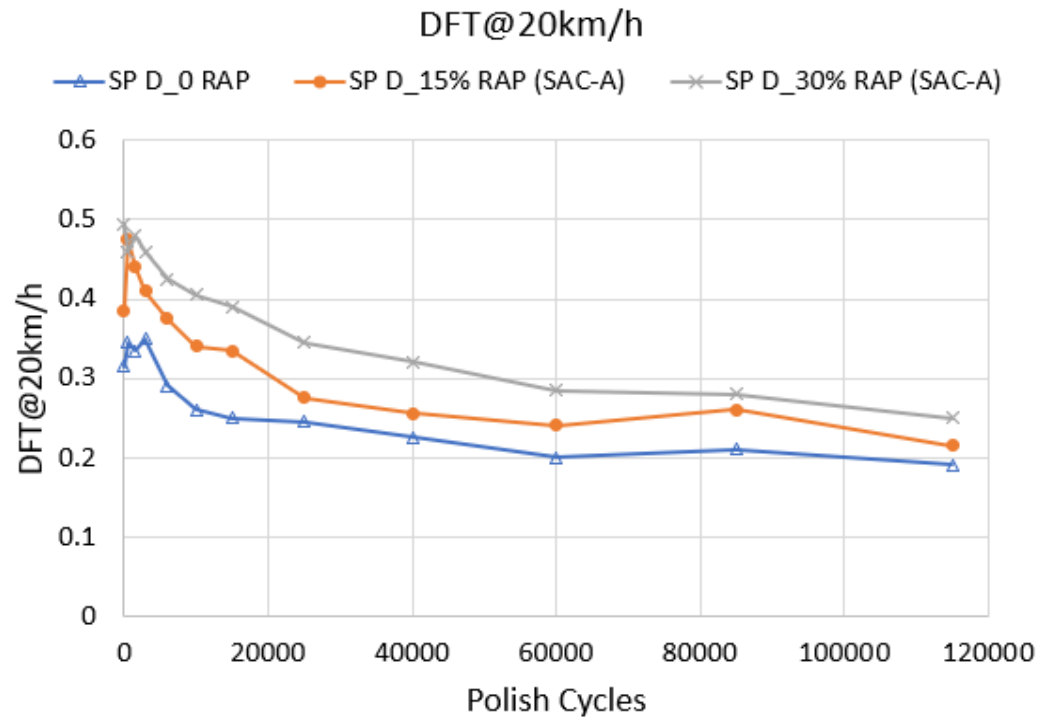
DFT Measurement on RAP and Mix

- RAP Impact on Mix Slab DFT



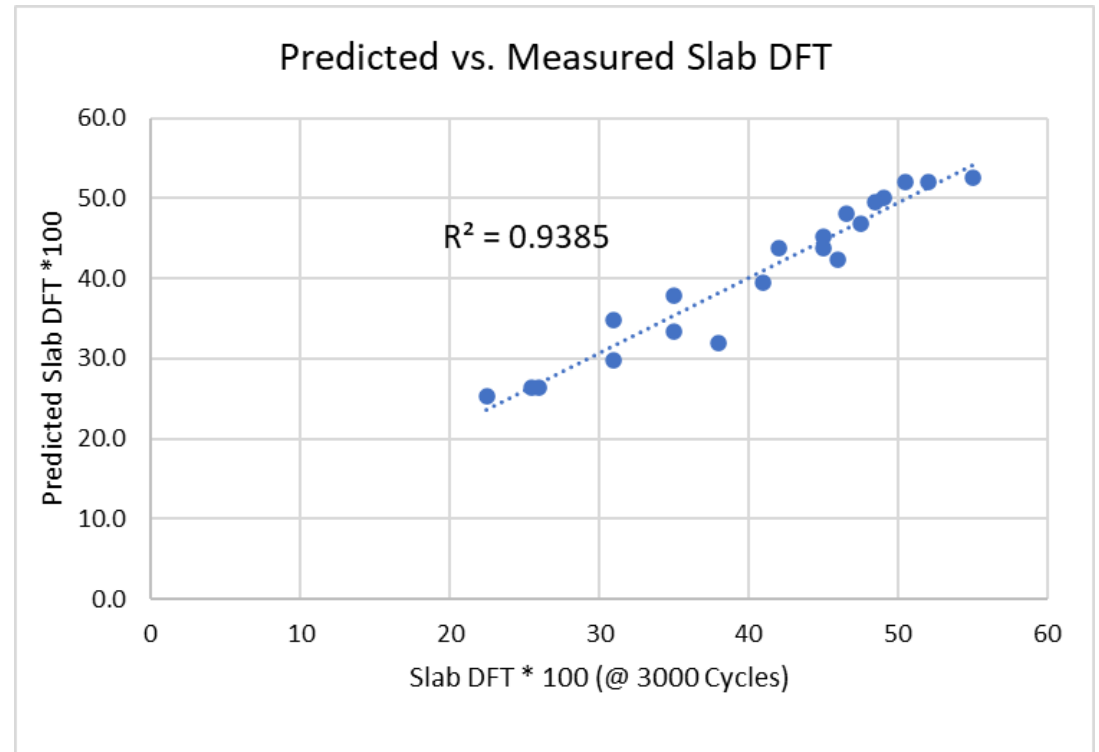
DFT Measurement on RAP and Mix

- RAP Impact on Mix Slab DFT



Preliminary DFT-based SAC Criteria for RAP

Mixture Name	Slab DFT * 100 (@ 3000 Cycles)	Blended DFT * 100 (AMD, +#4)	Macro-MPD, mm
FM 356_0 RAP	49	41.8	0.748
FM 356_15% RAP (SAC-A)	52	42.8	0.661
FM 356_30% RAP (SAC-A)	50.5	42.8	0.641
FM 356_15% RAP (SAC-B)	46.5	40.7	0.865
FM 356_30% RAP (SAC-B)	45	38.5	0.537
IH 20_0 RAP	47.5	32	0.682
IH 20_15% RAP (SAC-A)	48.5	33.5	0.730
IH 20_30% RAP (SAC-A)	55	35.1	0.694
IH 20_15% RAP (SAC-B)	45	31.2	0.473
IH 20_30% RAP (SAC-B)	42	30.4	0.408
IH 10_0 RAP	26	29.3	0.513
IH 10_15% RAP (SAC-A)	31	31.1	0.500
IH 10_30% RAP (SAC-A)	38	32.2	0.460
IH 10_15% RAP (SAC-B)	25.5	29.3	0.772
IH 10_30% RAP (SAC-B)	22.5	28.7	0.473
SP D_0 RAP	35	33.4	0.775
SP D_15% RAP (SAC-A)	41	34.2	0.653
SP D_30% RAP (SAC-A)	46	35.7	0.657
SP D_15% RAP (SAC-B)	31	31.8	0.462
SP D_30% RAP (SAC-B)	35	31	0.460



$$DFT_{\text{Slab}} = 1.896 * DFT_{\text{Blended}} - 0.221 + G$$

G, Gradation Adjusting Factor

Superpave C, -0.07; Superpave D, -0.033; Type D, 0.082

Preliminary DFT-based SAC Criteria for RAP

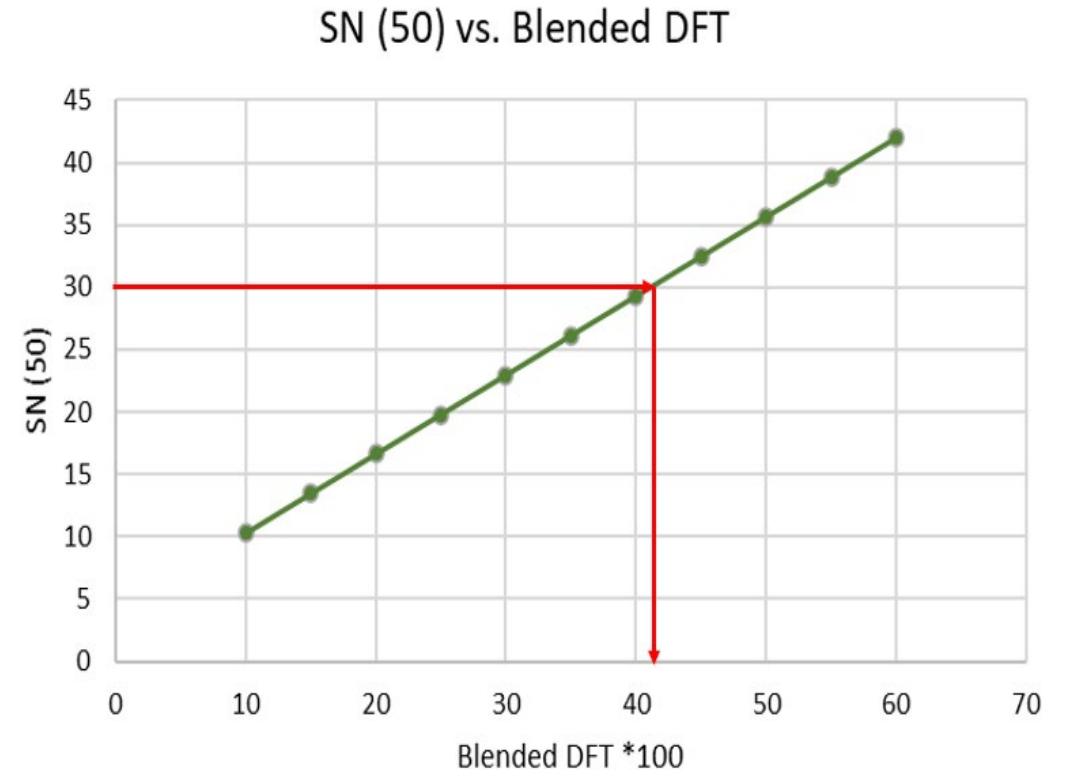
- SN is a function of mixture microtexture (DFT) and macrotexture (measured by circular track meter [CTM] in mean profile depth [MPD])
- ASTM E1960, International Friction Index (IFI)

$$S_p = 14.2 + 89.7 MPD$$

$$IFI = 0.081 + 0.732 DFT_{20} \exp(-40/S_p)$$

- TxDOT 0-6746, 2017

$$SN(50) = 4.81 + 140.32(IFI - 0.045)e^{\frac{-20}{S_p}}$$



Preliminary DFT-based SAC Criteria for RAP

- Preliminary recommendation

Property	Test Method	SAC A
<i>DFT *100 (After Micro-Deval), min</i>	<i>ASTM E1911 TxDOT Aggregate Ring</i>	<i>43</i>

RAP Aggregate

Property	Method	SAC A
<i>Plus #4 from SAC A, % min</i>	<i>Use the determined SAC of RAP aggregate</i>	<i>50</i>
<i>DFT_{Blended} *100, min</i>	<i>Use the determined RAP DFT value for the blended DFT Calculation</i>	<i>43</i>

RAP Mix

Pilot Implementation

- Select 3 field projects with milled RAP
- Evaluate RAPs using both traditional SAC aggregate tests and DFT
- Design the mixes using the SAC-A RAPs
- Construct field test sections with the SAC-A RAPs
- Monitor and measure field skid number and DFT friction
- Verify and adjust the preliminary SAC-A RAP criteria
- Training workshops

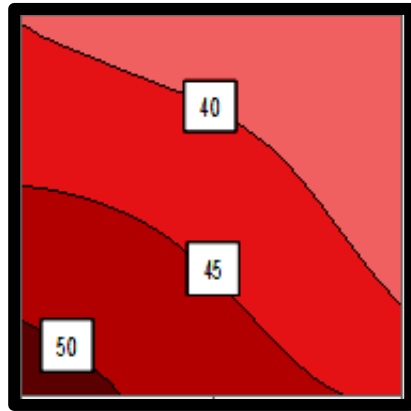
Acknowledgements

- TxDOT Project Management Team:
 - Kevin Pete, Tom Schwerdt, Richard Izzo, Edward Morgan, Enad Mahmoud, Jefferey Perabo, Michael Dawidczik, Jim Grissom, Lacy Peters, Aldo Madrid, Jenny Li
- TTI Research Team:
 - Fujie Zhou, Tom Scullion, Emmanuel Fernando
- UT Tyler:
 - Mena Souliman

Q/A

Thank You All!

USING RECYCLED CONCRETE AGGREGATES IN CONCRETE MIXTURES



Matthew P. Adams, Ph.D., FACI

**J.A. Reif, Jr., Department of Civil and Environmental Engineering
New Jersey Institute of Technology**

TRB Webinar on Aggregate Sustainability
Webinar
25 April 2024

PRESENTATION OVERVIEW

Interest and Use



- Cost
- Sustainability
- Feasibility



Properties



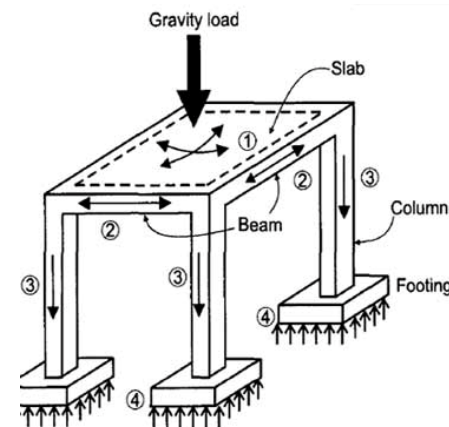
- Aggregates
- Concrete with RCA
- Mechanical properties
- Durability properties



Design



- Available specifications
- Design guidelines
- Design tools



Conclusions



- Research needs



PRESENTATION OVERVIEW

Interest and Use

- Cost
- Sustainability
- Feasibility



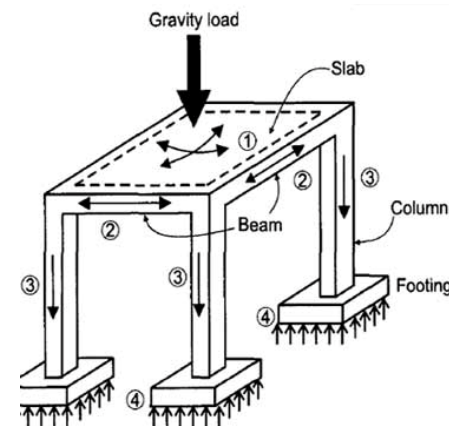
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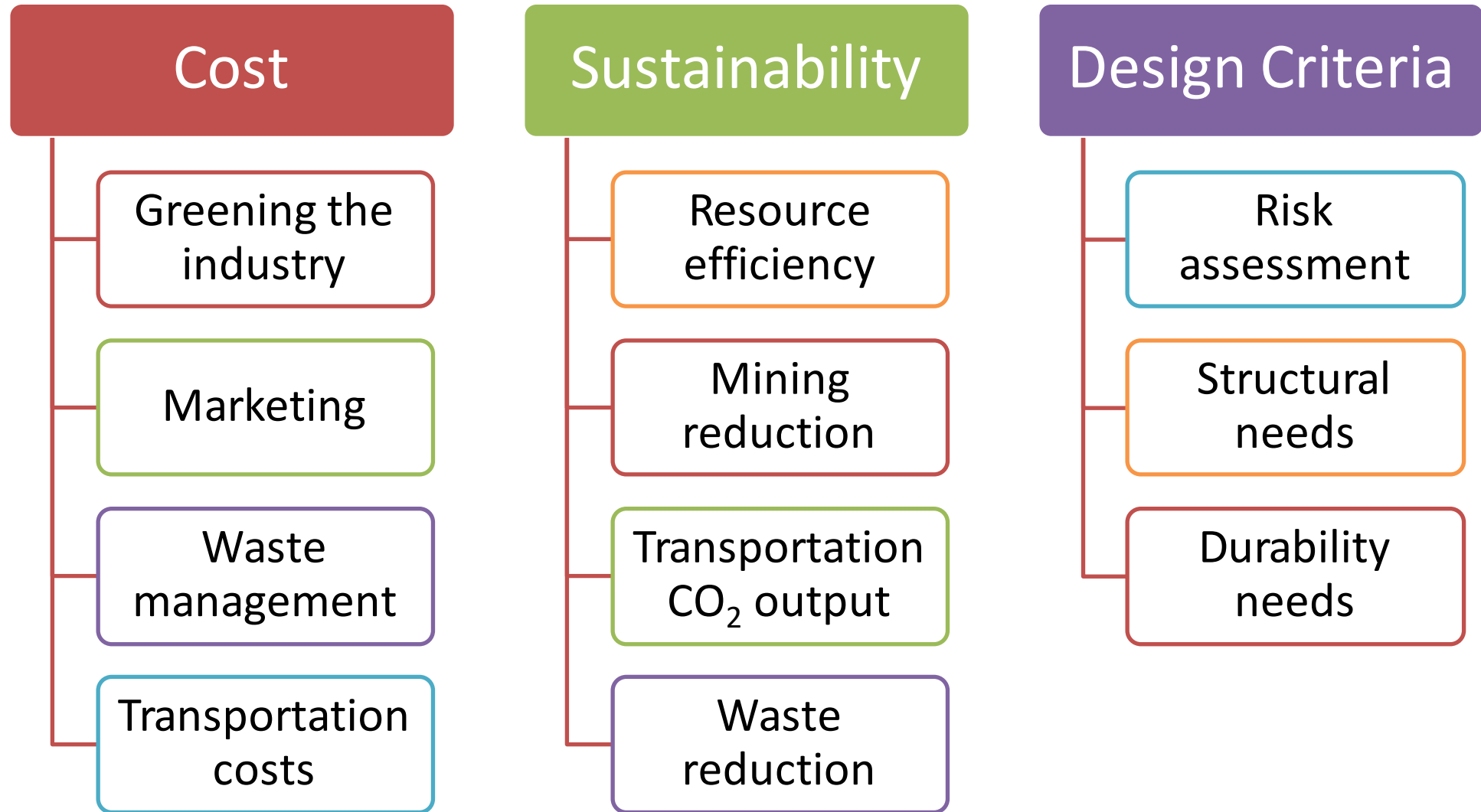


Conclusions

- Research needs



CONSIDERATIONS FOR USING RECYCLED CONCRETE



COST CONSIDERATIONS



- Waste management
 - Costs of shipping waste to landfills can be reduced
- Transportation
 - RCA sources may be more readily available than natural aggregates in urban areas
- Processing costs
 - Startup costs can be considerable
 - Need to remove steel, brick, asphalt, other contaminants



GLOBAL WARMING POTENTIAL CONSIDERATIONS



- Low impact on CO₂e / GWP
- Highly dependent on travel distance and processing
- Industry Average GWP:
 - Crushed Aggregate: 0.00372 lb CO₂e / lb of aggregate
 - RCA: 0.0012 lb CO₂e / lb of aggregate
- May be more impactful in 10 years

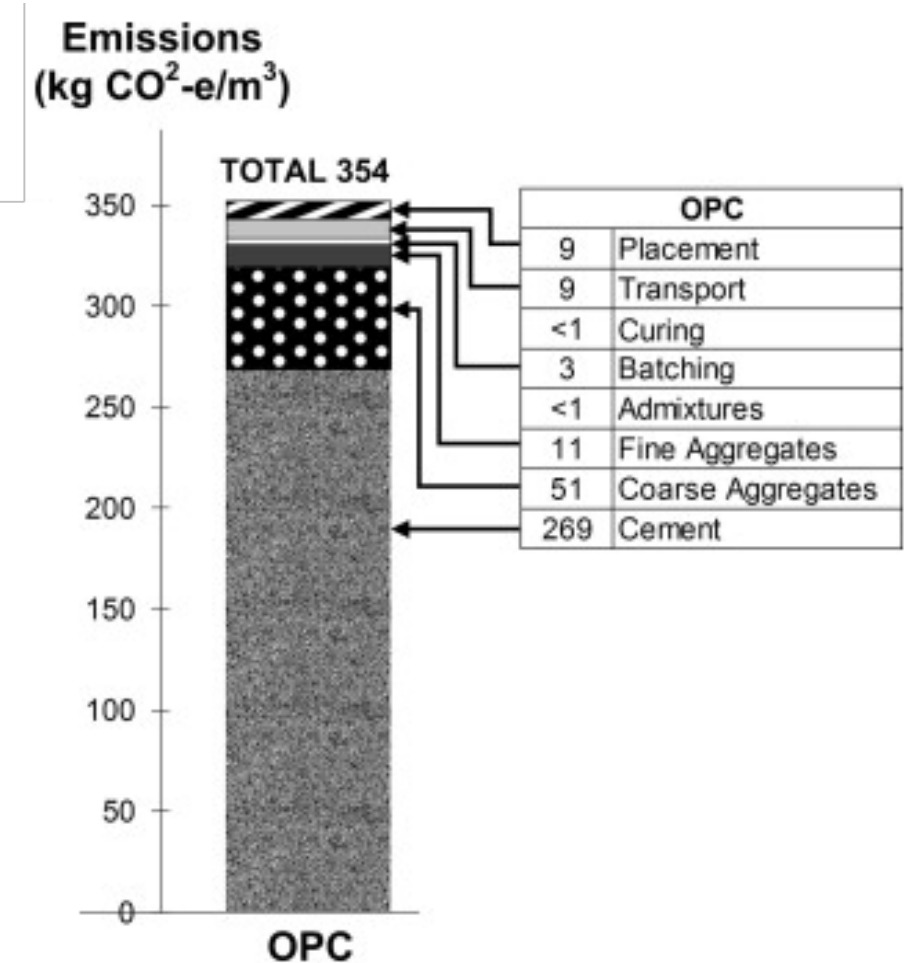


Image courtesy: Turner and Collins 2013

COST CONSIDERATIONS

- Spend \$1.45 M / year on disposing of waste concrete
- Cost analysis showed benefit to reusing vs. waste over 10 year period
 - Fill does not consume all waste
 - Can they use it as an aggregate replacement for sidewalks?



SUSTAINABILITY CONSIDERATIONS



- Resource efficiency – Toronto case study



SUSTAINABILITY CONSIDERATIONS



- Resource efficiency – Toronto case study
 - Estimated concrete aggregate needs: 66million tons / year
 - 1.36 billion tons required 2010-2030
 - Estimated capacity of mines in the greater Toronto area before 2030:
 - 1.09 billion ton capacity
 - Deficit of 27 million tons



DESIGN CONSIDERATIONS



- Risk assessment
 - Life-expectancy
 - Risk if damage occurs
 - Variability in materials
- Strength requirements
 - Can we produce good material?
- Durability requirements
 - Does your material fit the requirements if used in a different environment?



FEASIBILITY CONSIDERATIONS



Access to Space



Processing
Equipment



Material Access

PRESENTATION OVERVIEW

Interest and Use



- Cost
- Sustainability
- Feasibility



Properties



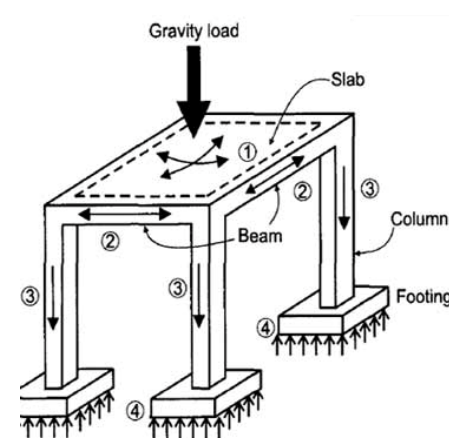
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Design



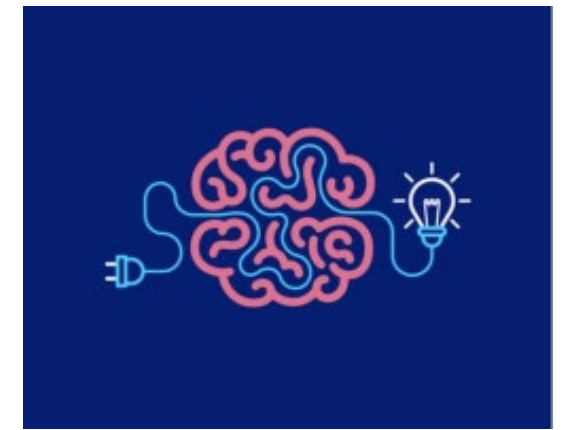
- Available specifications
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Conclusions



- Research needs





WHAT IS RCA?



- Concrete is demolished
- Large pieces of steel and other impurities are removed



- Crushed to 12 in size chunks
- Remaining steel is removed using a magnet



- Crushed down to usable sizes
- Stored for use



- Graded for specific applications

RCA PARTICLE COMPOSITION



Original natural
fine aggregate

Original natural
coarse aggregate



Adhered mortar



- Determine history and performance of parent concrete
- Was it:
 - Air entrained?
 - ASR reactive?
 - In a chloride rich environment?

A large, 3D-rendered golden letter 'H' with a metallic sheen and shadows. Below the 'H' is a thick red horizontal bar. Underneath the bar, the word 'HISTORY' is written in a bold, black, sans-serif font.

IMPACT OF ADHERED MORTAR CONTENT



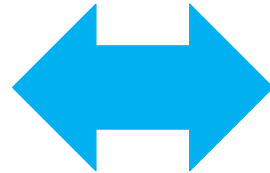
Workability



Permability



Strength



Shrinkage



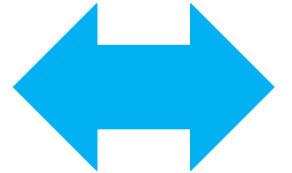
Cracking
Resistance



Abrasion



Corrosion
resistance



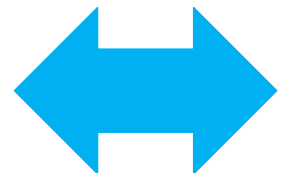
Alkali-Silica
Reactivity



Soundness

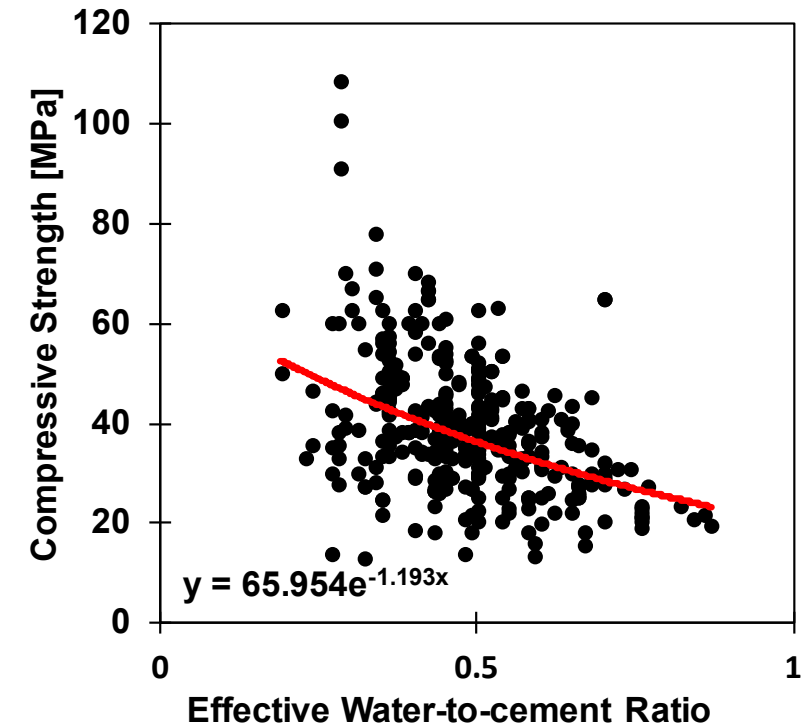
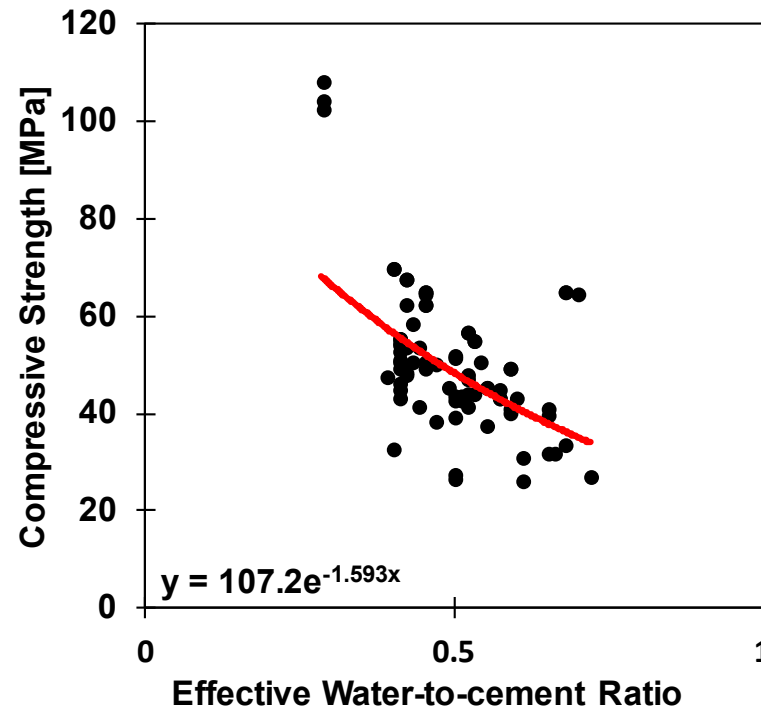
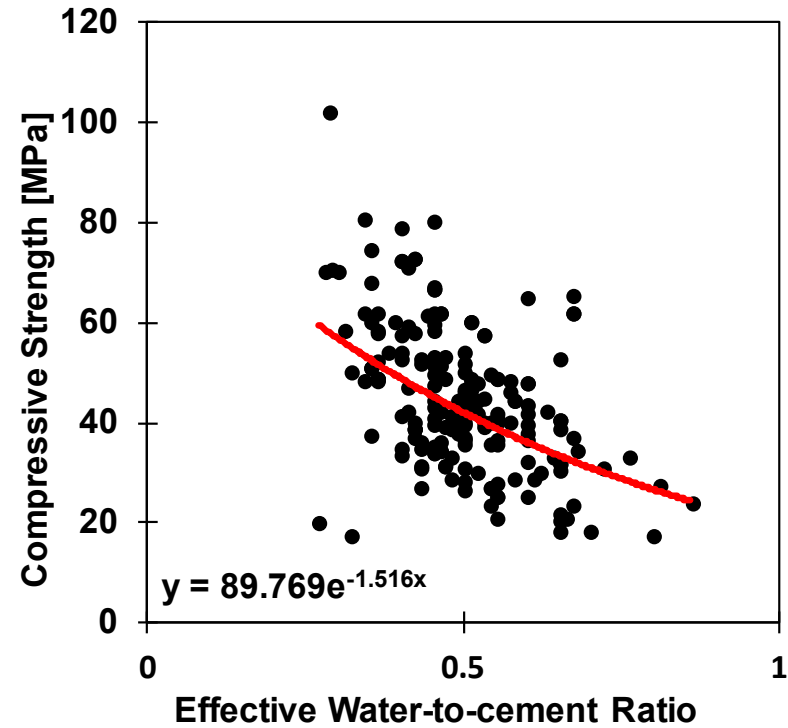


Freeze-Thaw
Resistance





IMPACT ON COMPRESSIVE STRENGTH



0% RCA

45 MPa mean f'_c

10-20% RCA

50 MPa mean f'_c

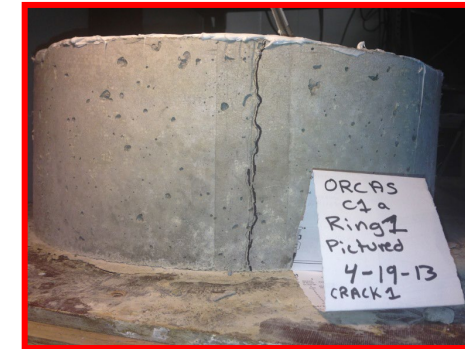
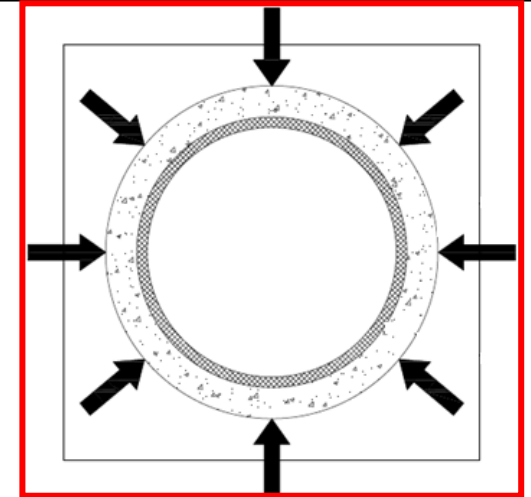
80-100% RCA

40 MPa mean f'_c

IMPACT ON DRYING SHRINKAGE



Free Shrinkage
Measures total propensity for volume change

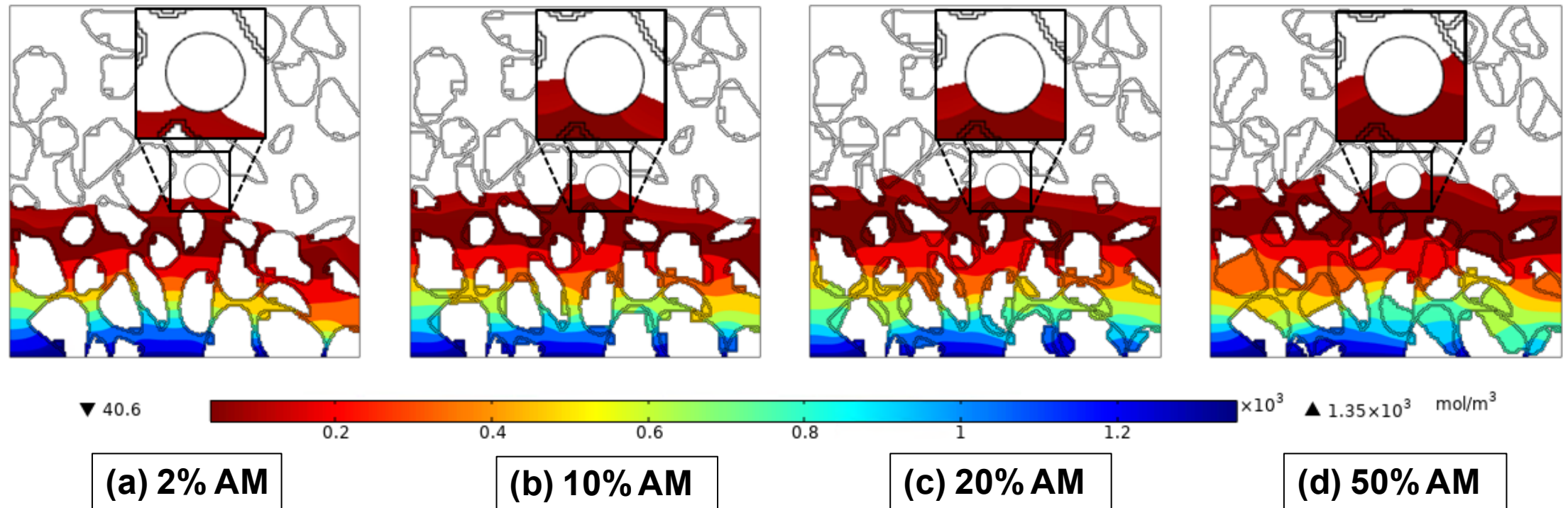


Restrained Shrinkage
Measures resistance to cracking under volume change

IMPACT ON CORROSION RESISTANCE

- Chloride content reached critical chloride value
- Chloride moved faster in higher AM contents

Chloride content that reached critical chloride value after 360 days



PRESENTATION OVERVIEW

Interest and Use



- Cost
- Sustainability
- Feasibility



Properties



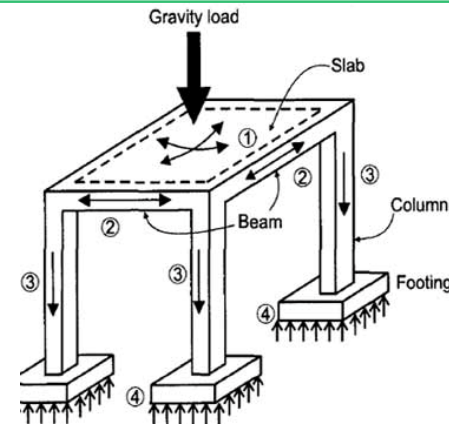
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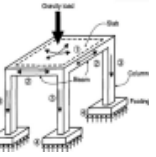
Conclusions



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AVAILABLE SPECIFICATIONS

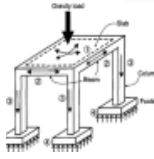


- ASTM says to treat RCA as if it were a natural aggregate
- ACI has a “state of the art” report published in 2001....
- ACI 318 – 24 now allows for the use of RCA but requires it to meet the requirements of ASTM C33

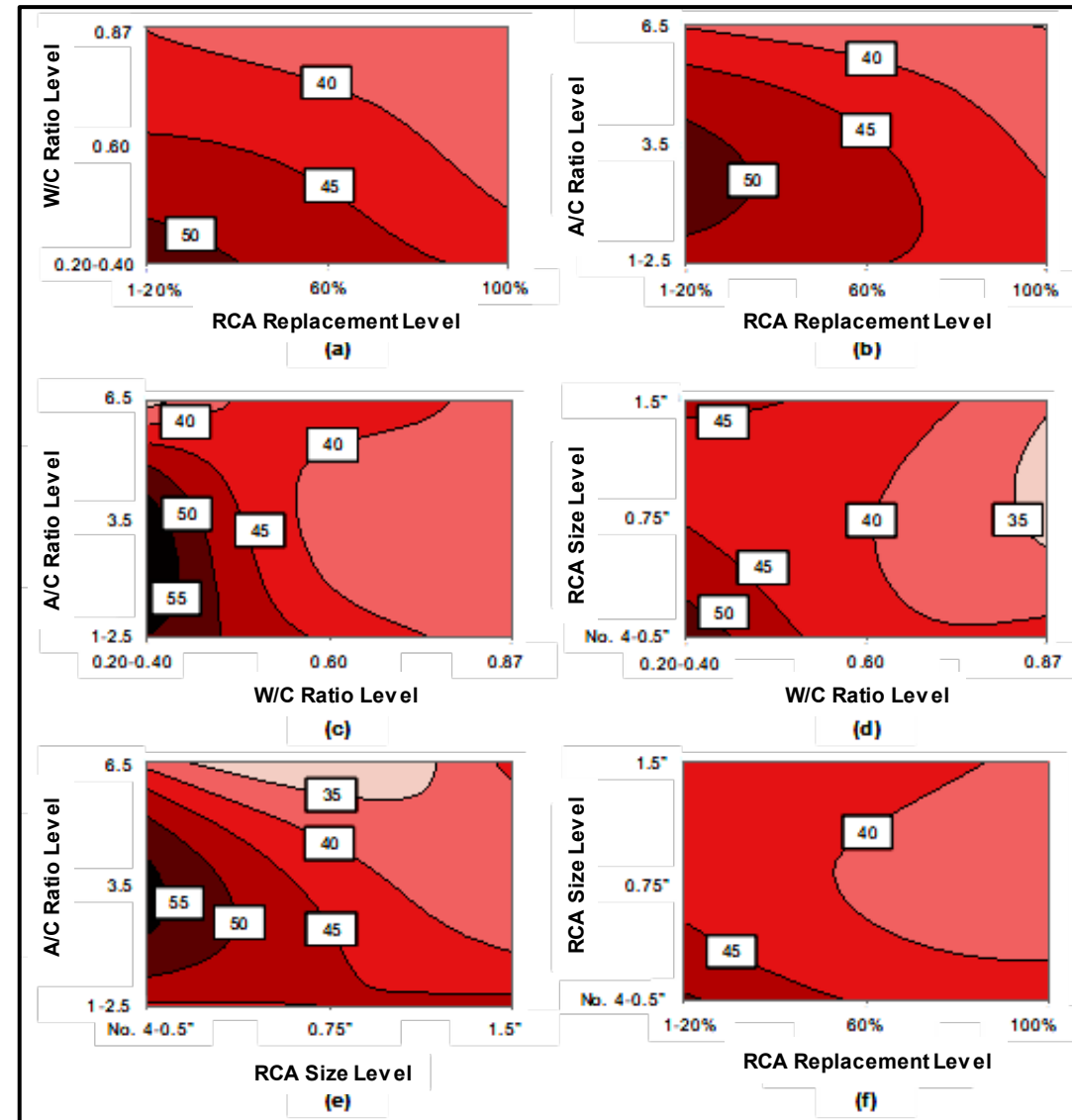


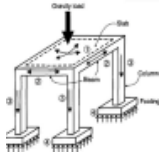
American Concrete Institute
Always advancing

UNDERSTANDING THE TRENDS OF RCA COMPRESSIVE STRENGTH THROUGH CONTOUR PLOTS



- Bivariate relationships can estimate RCA strength for given two factors
- The responses of compressive strengths (MPa) was used to develop the RCA mixture design method





NJIT MIXTURE DESIGN PROCEDURE

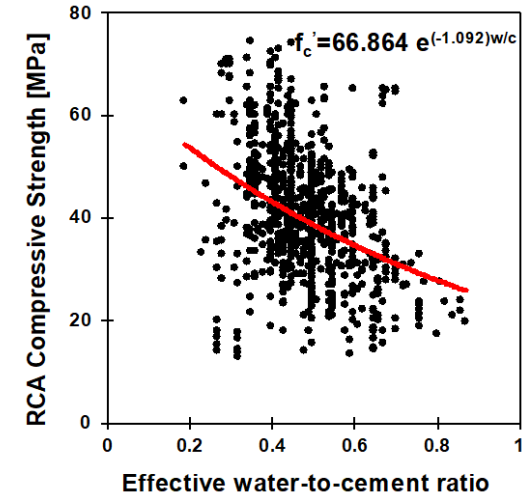
Step 1: Target RAC Strength

Specified f_c'	St.D.
$f_c' < 21$ MPa	2.32 MPa
$21 \leq f_c' \leq 35$ MPa	3.97 MPa
$f_c' > 35$ MPa	9.32 MPa

Target Strength $f_{c',req} = f_c' + \delta k^*$

Note: k^* can be taken as 1.645 based on 5% defective

Step 2: Determining W/C ratio

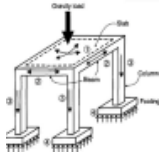


Step 4: Determining A/C ratio

RCA Replacement	A/C Ratio		
	1.0-2.5	2.6.-3.5	3.6-6.5
1-20%	45 MPa	45 MPa	40 MPa
21-60%	50 MPa	45 MPa	35 MPa
61-100%	35 MPa	35 MPa	30 MPa

Step 3: Determining RCA replacement

W/C Ratio	RCA Replacement		
	1-20%	21-60%	61-100%
0.20-0.40	50 MPa	45 MPa	40 MPa
0.41-0.60	45 MPa	40 MPa	35 MPa
0.61-0.87	40 MPa	35 MPa	35MPa



NJIT MIXTURE DESIGN PROCEDURE CONT'D

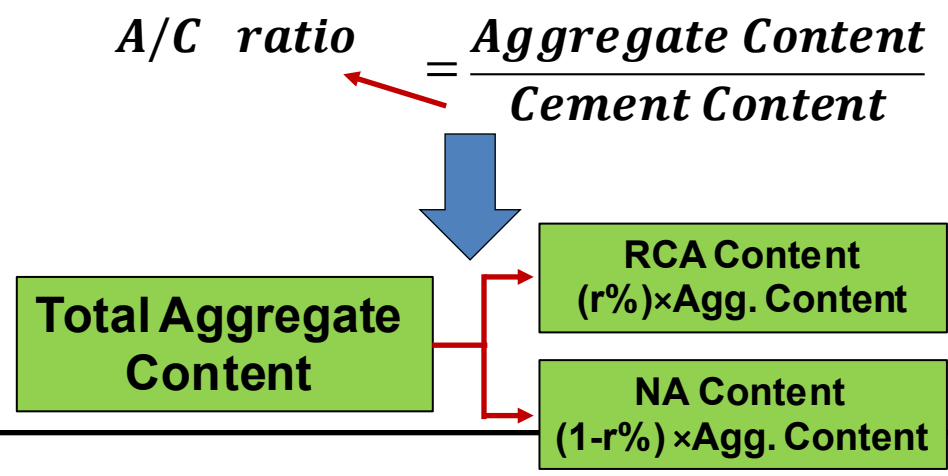
Step 5: Final Selection for A/C according to the correct W/C

W/C Ratio	A/C Ratio		
	1.0-2.5	2.6.-3.5	3.6-6.5
0.20-0.40	55 MPa	35 MPa	35 MPa
0.41-0.60	55 MPa	40 MPa	35 MPa
0.61-0.87	35 MPa	40 MPa	35 MPa

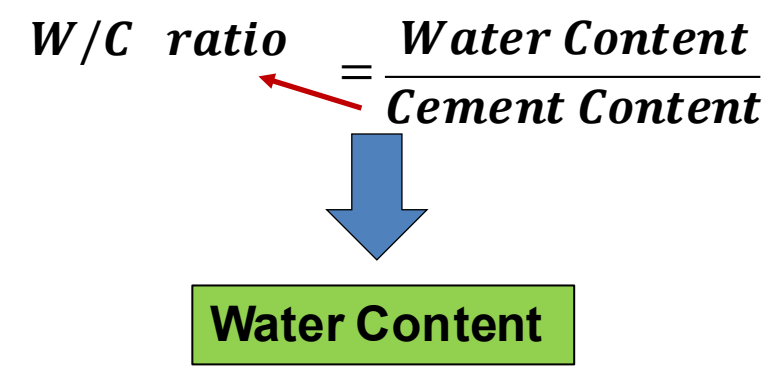
Step 6: Minimum Requirement for Cement Content (ref: ACI 302)

Nominal maximum Aggregate size [in.]	Cementing Materials [lb/yd ³]
1 – ½	470
1	520
¾	540
½	590
¾	610

Step 8: Determining Aggregate Content



Step 7: Determining Water Content



PRESENTATION OVERVIEW

Interest and Use



- Cost
- Sustainability
- Feasibility

Properties



- Aggregates
- Concrete with RCA
- Mechanical properties
- Durability properties

Design

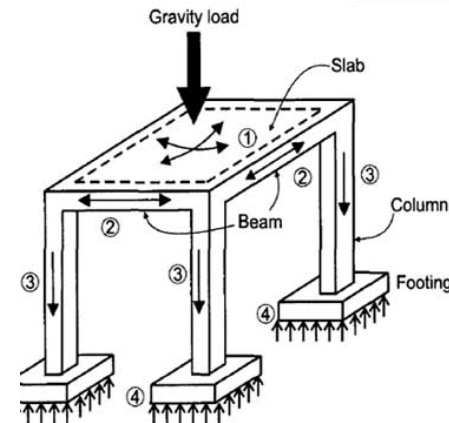


- Available specifications
- Design guidelines
- Design tools

Conclusions



- Research needs





- Understand how to properly classify aggregates.
 - i.e. come up with a modification to ASTM C33 which specifies aggregates for construction

- Understand the role of aggregates on chloride and CO₂ migration

- Field testing to understand how durability tests line up with actual performance



- Suitable normal-strength concrete mixtures can be developed using recycled concrete aggregates
- Care must be taken to properly assess the history and quality of RCA
- Useful and reliable for marginal or non-structural applications

ACKNOWLEDGEMENTS

- Dr. Anuruddha Jayasuriya
- Dr. Jin Fan
- Dr. Matthew Bandelt
- Dr. Jason Ideker
- Dr. Burkan Isgor
- Dr. Tengfei Fu

THANK YOU



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May 2, 2024

TRB Webinar: Highly Modified
Asphalt Development and
Applications

June 23-26, 2024

2nd International Roadside Safety
Conference



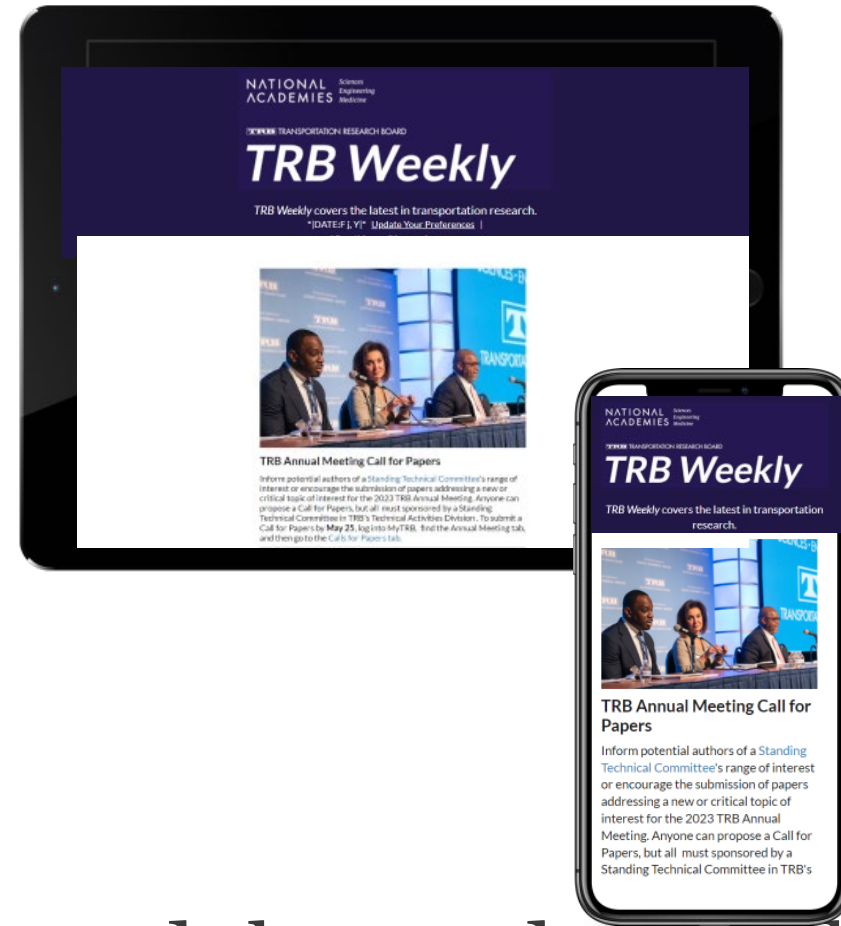
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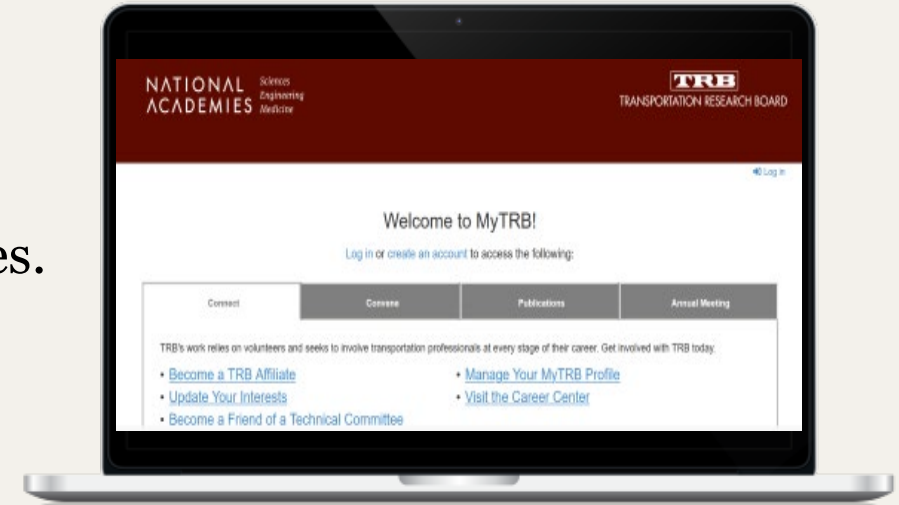


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