Choosing and Designing the Right Concrete Pavement Mix

Winter 2026 Iowa Concrete Lunch & Learn

Dan King, PhD, PE
deking@iastate.edu

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center
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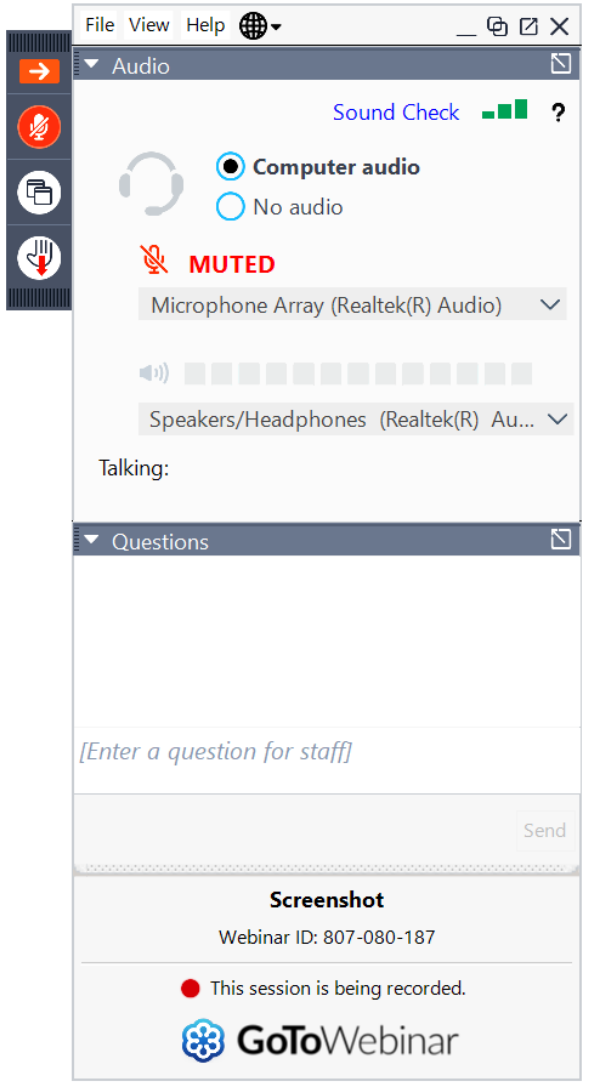

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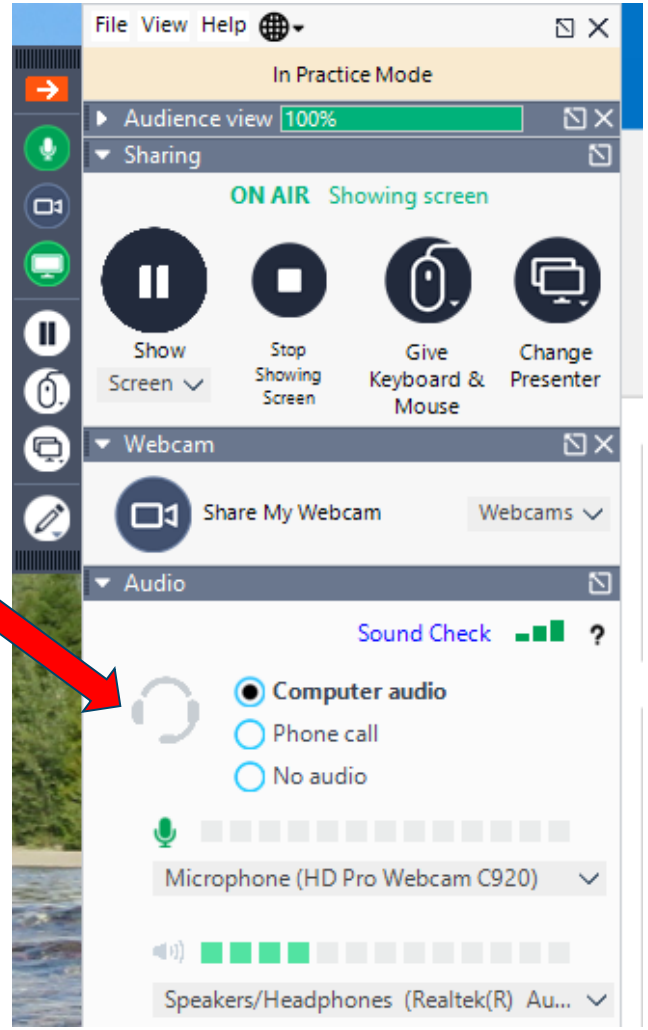

Housekeeping

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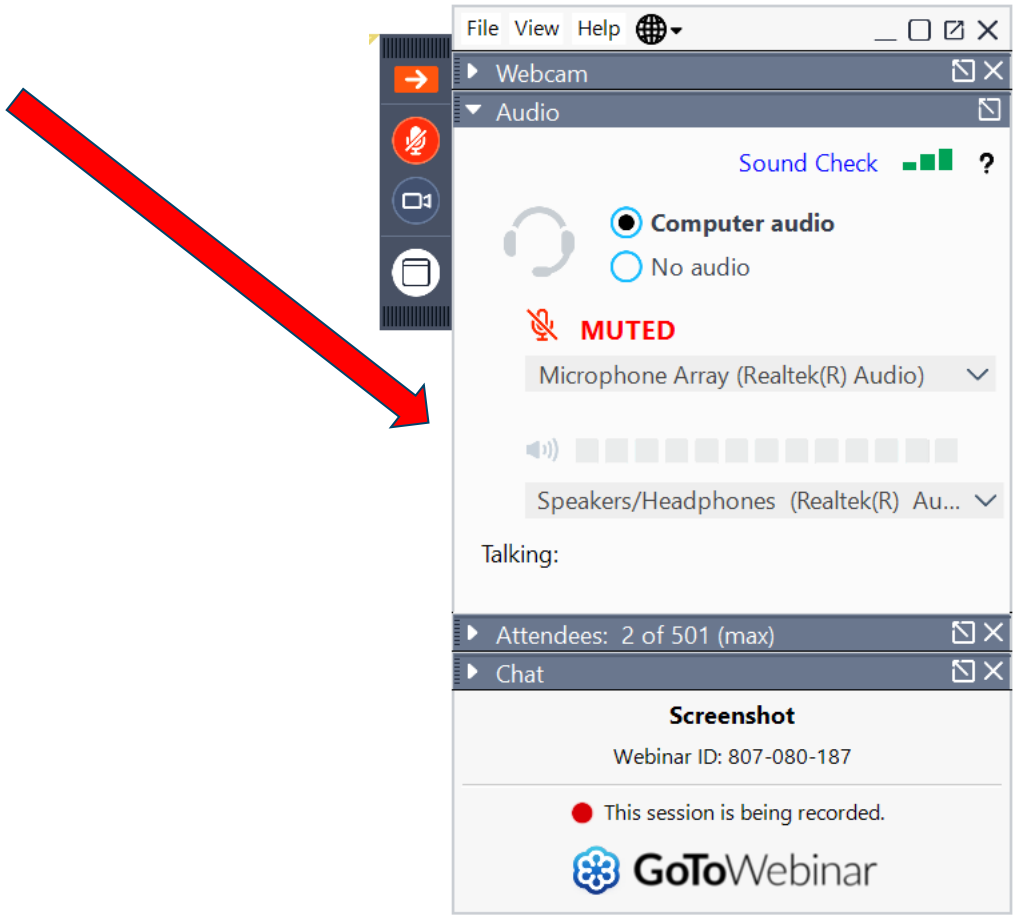

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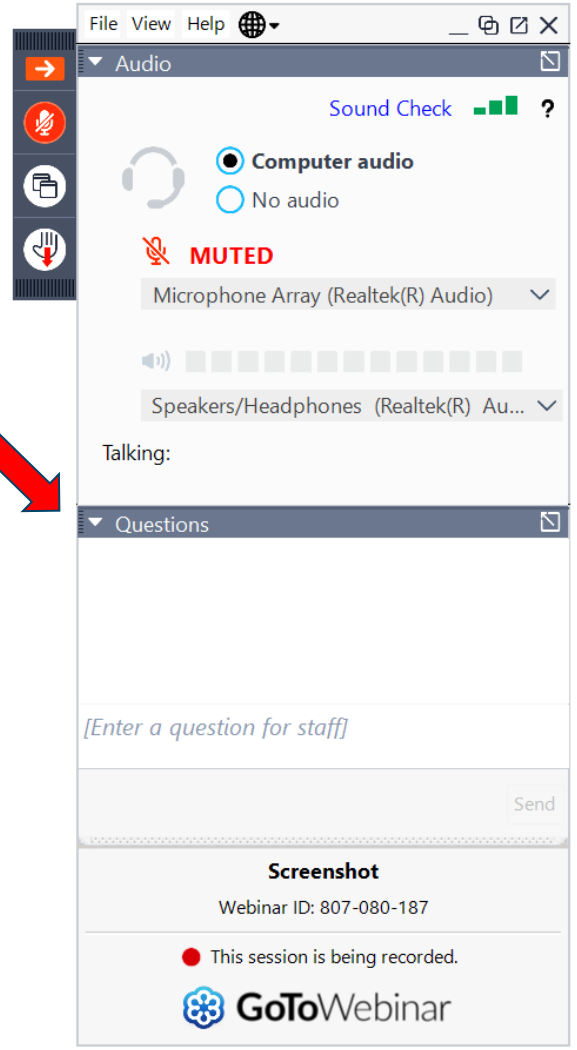
- Everyone is muted
- If you have questions, type them here
- We will compile all of the questions after the webinar is finished and post a full Q&A online
- A link to download a pdf of the slides is included under the “Handouts” tab
- PDHs will be sent out to all attendees after the webinar



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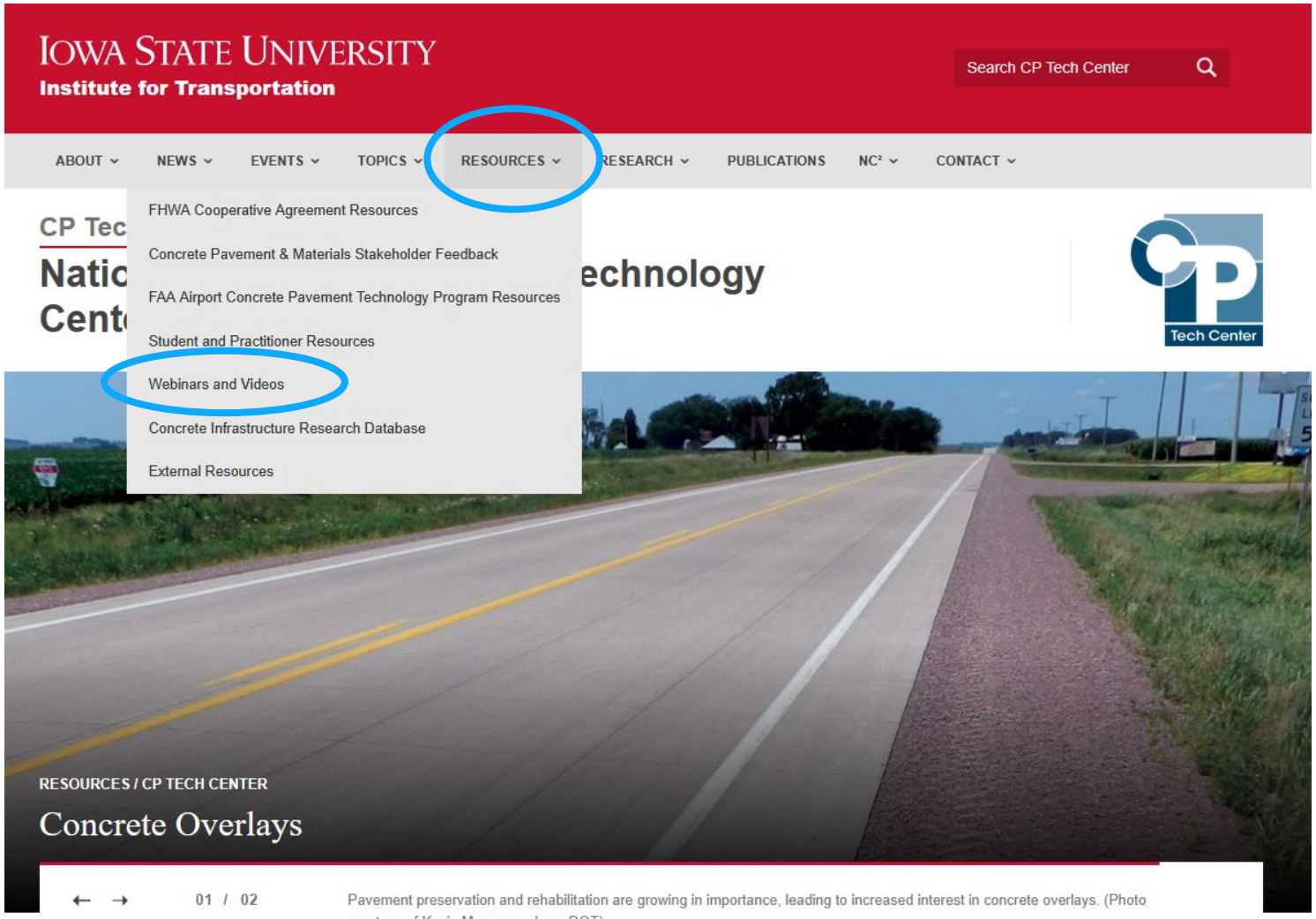

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Search

Video	Title	Presenters	Event	Resources
	Not Your Grandfather's Concrete	Peter Taylor Matt Fonte	Concrete Pavement Technology Tuesday	Slides Q & A
	Pavement Design for Designers & Non-Designers and Why You Should Care	Eric Ferrebee Jim Mack	Concrete Pavement Technology Tuesday	Slides Q & A
	Performance Engineered Mixtures for PCC Pavements	Peter Taylor Christian Olmoz	New and Evolving Technologies Webinar	Slides Q & A

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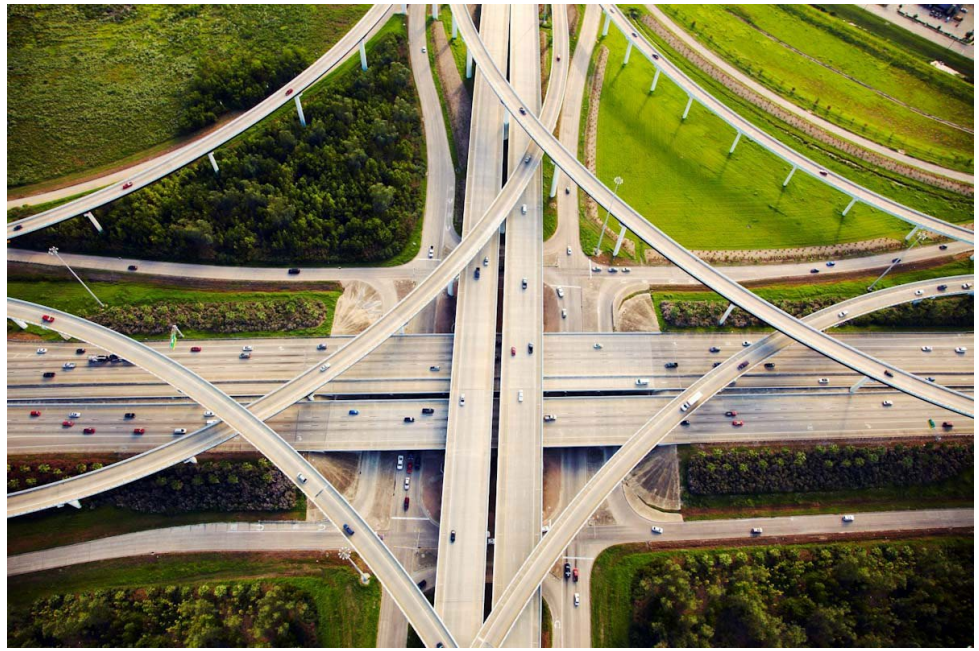
Acknowledgments

- Thanks to Iowa DOT & ICPA for supporting this program
- Lee Shepard, ICPA
- Todd Hanson, Iowa DOT
- Jerod Gross, Snyder & Associates, Inc.
- King’s Material, Cedar Rapids

Introduction

- Concrete is the world's most widely-used building material, and we deploy it in a huge variety of ways



Introduction

- We design and proportion concrete based on what we need for a given placement method and the performance requirements for the structure

Concrete Pavements

- What are some of the key construction and performance goals for concrete pavements?
  - Ease of placement
  - Strength to carry traffic loads
  - Long-term durability

Image: ACPA

Concrete Pavements

- What are some of the properties that we need to consider when we design and proportion the mixture to meet these goals?
  - Workability
  - Transport (permeability)
  - Strength
  - Cold weather resistance
  - Shrinkage
  - Aggregate stability

Concrete Pavements in Iowa

- Iowa builds more concrete pavements than almost anywhere in the U.S., and we have a great suite of mix specifications and design tools to meet our needs

Concrete Pavements in Iowa

- That being said, we frequently experience change!
  - In the 1990s, changes in aggregate availability caused workability problems that led to some early durability failures
  - In the 2000s, we realized that an over-emphasis on strength and under-emphasis on durability left some pavements prone to damage from freeze-thaw and de-icing chemicals
  - Most recently, changes to cement and SCMs has led to challenges with concrete workability and finishing

Concrete Pavements in Iowa

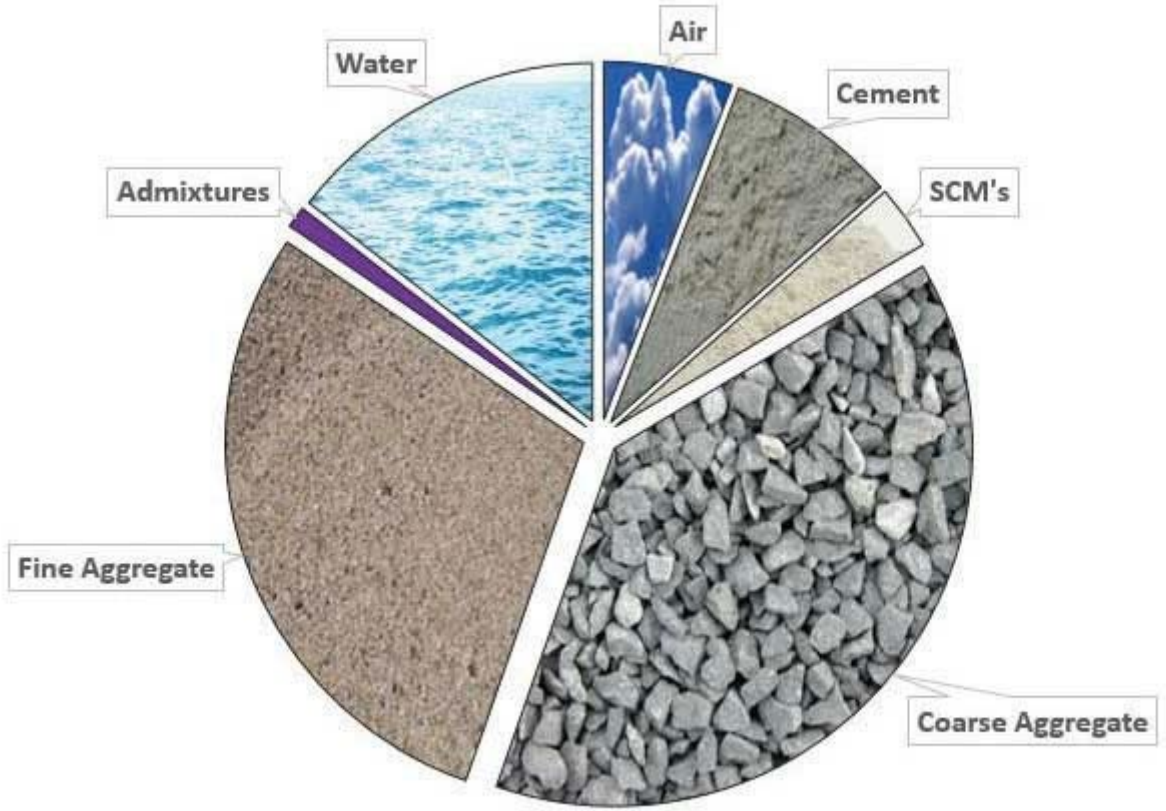
- We have made – and continue to make – changes to our concrete mix specifications to adapt to these changes and further improve the performance of our pavements

Today's Presentation

- Key principles of mix design and proportioning
- Choosing and designing the right mix for pavements

Concrete Materials

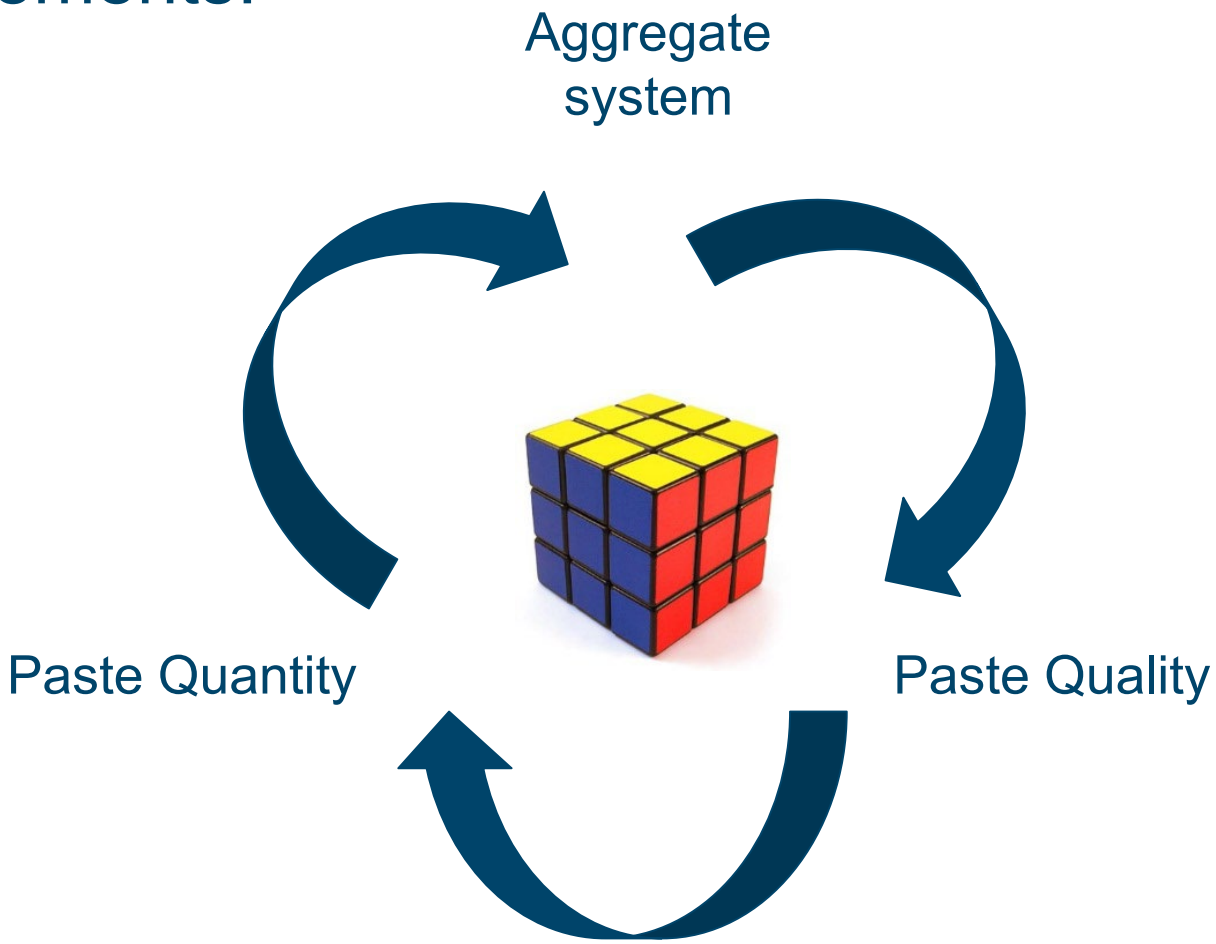
- How do we design and proportion these materials to meet our design goals?



L Image: Construction Specifications Institute

Mix Design & Proportioning

- Three key elements:



Mix Design & Proportioning

- How these elements fit into our design goals:

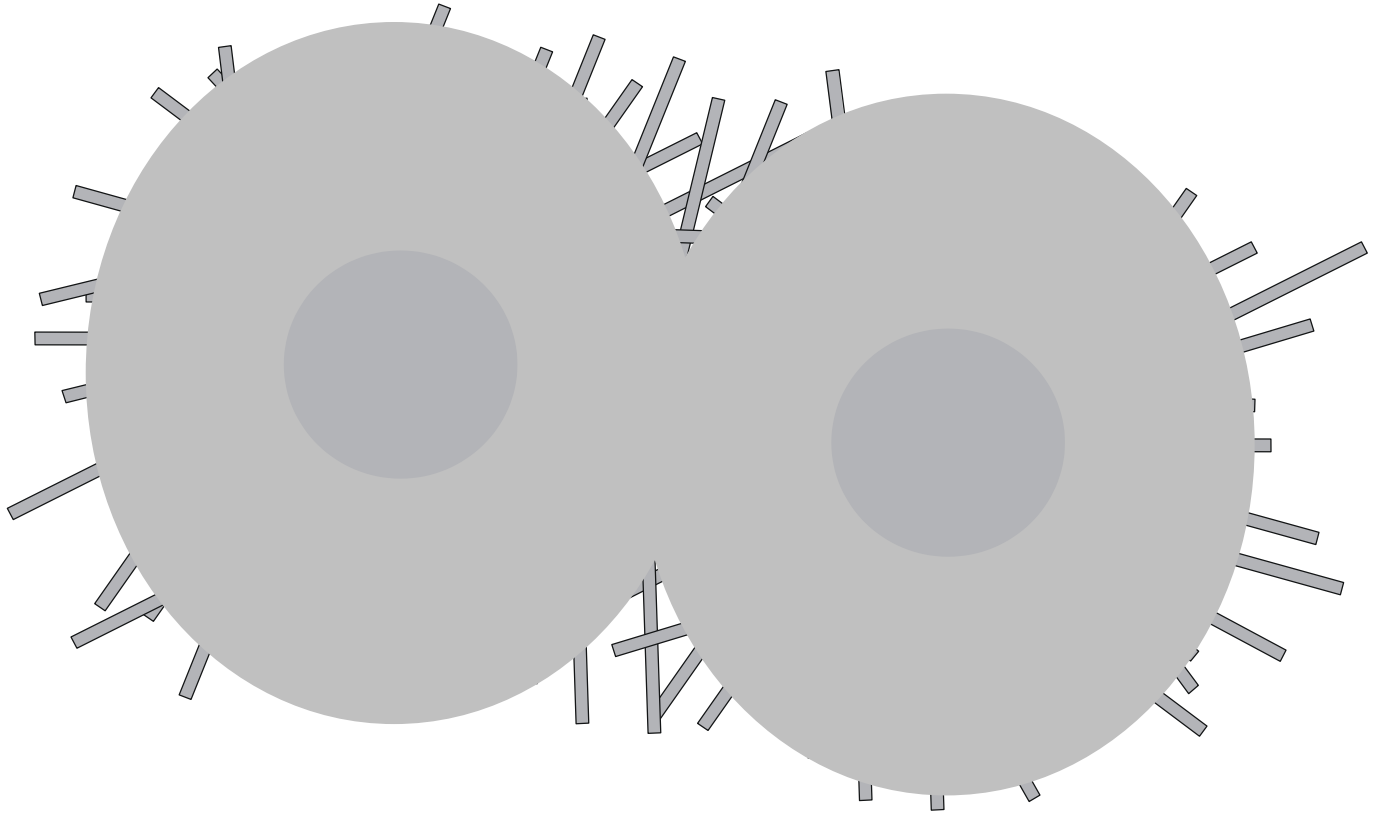
		Workability	Transport	Strength	Cold weather	Shrinkage	Aggregate stability
Aggregate System	Type, gradation	✓✓	-	-	-	-	✓✓
Paste quality	Air, w/cm, SCM type and dose	✓	✓✓	✓✓	✓✓	✓	✓
Paste quantity	Vp/Vv	✓	-	-	-	✓✓	-

Step 1: Paste Quality

- The paste phase is the combination of our cementitious materials, water & air
  - Cementitious materials
    - Portland cement
    - SCMs
  - Water-to-cementitious ratio (w/cm)
  - Air void system

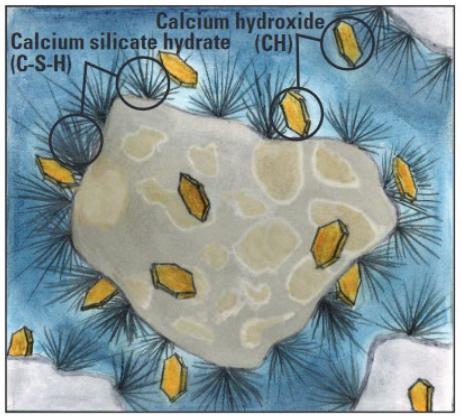
Step 1: Paste Quality

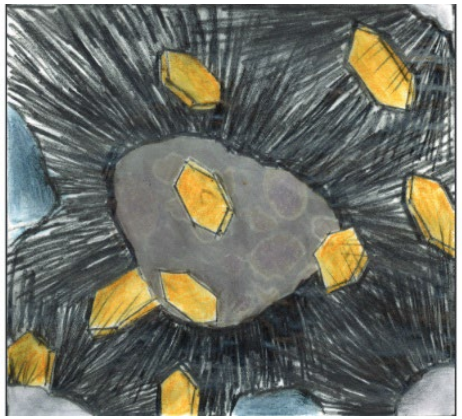
- Portland cement reacts with water in a series of irreversible hydration reactions that lead concrete to set and gain strength

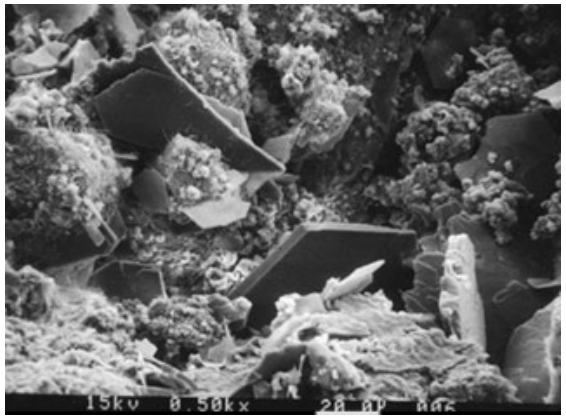


Step 1: Paste Quality

- These reactions create a number of hydration products
  - Calcium silicate hydrate (C-S-H) is a gel that grows out from cement grains and binds the mixture into a dense solid
    - It is the most abundant and desirable hydration product
    - More C-S-H → stronger, less permeable concrete
  - Calcium hydroxide (CH) is a water-soluble crystal that can be a source of durability issues, such as ASR



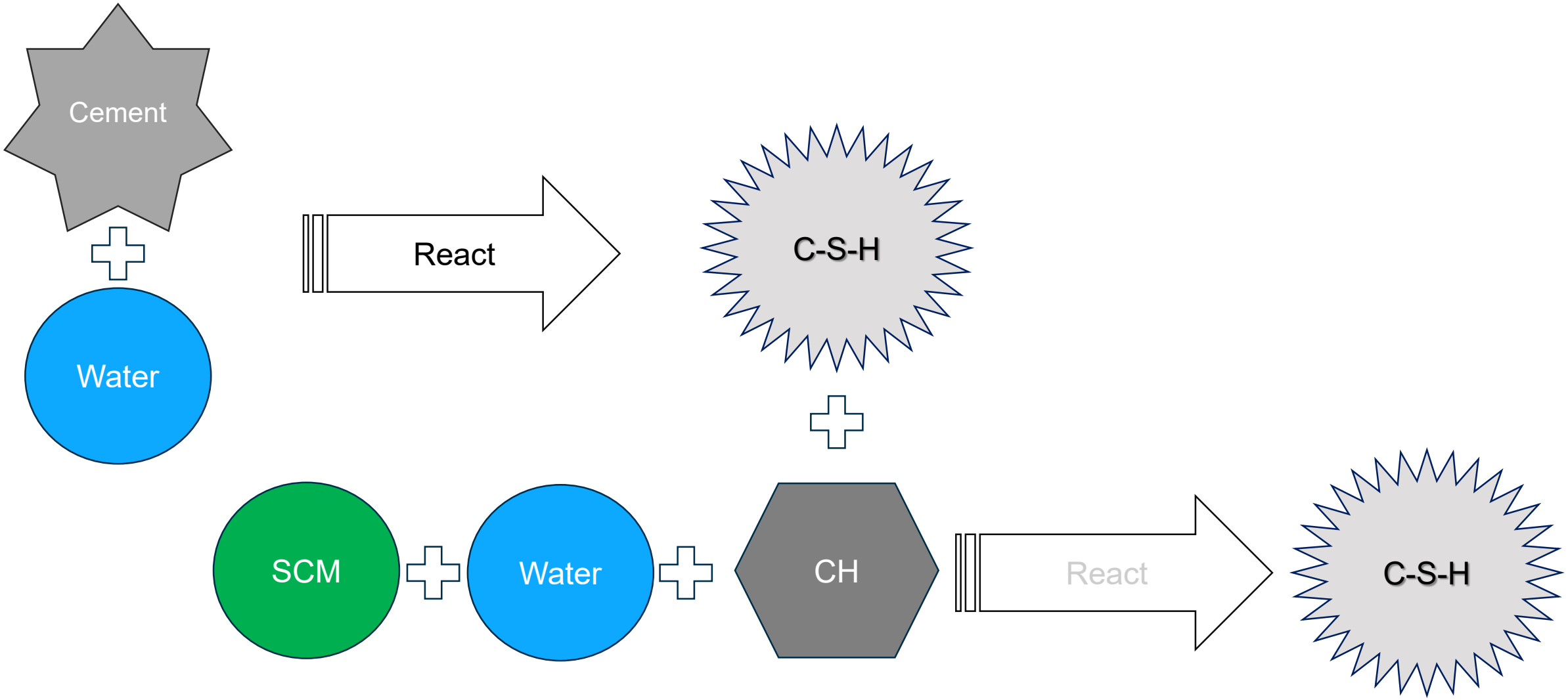




Step 1: Paste Quality

- Replacing some of the cement in our mix with supplementary cementitious materials (SCMs), such as fly ash and slag, can enhance many desirable concrete properties:
  - Workability
  - Long-term strength
  - Long-term durability
- They achieve these goals by spurring pozzolanic reactions to convert CH into additional C-S-H

Step 1: Paste Quality



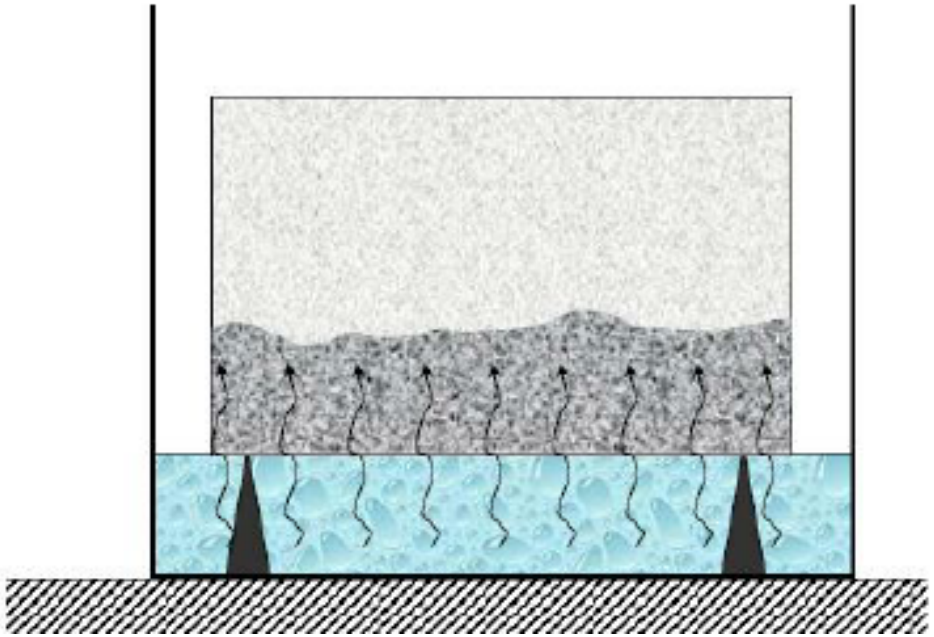
Step 1: Paste Quality

- Reactions between SCMs and CH are secondary reactions, so replacing cement with SCMs initially slows strength gain
- From 7 to 28 days and beyond, strength and permeability are greatly improved thanks to the production of more C-S-H
- The reduction in CH mitigates the potential for durability issues, such as ASR and reactions with de-icing chemicals

Product	Typical Replacement Rate
Class F fly ash	15% to 25%
Class C fly ash	15% to 40%
Slag cement	25% to 50%
Silica fume	5% to 15%

Step 1: Paste Quality

- Concrete is porous at the microscopic level
  - Capillaries: space between hydrated cement grains
  - Taking steps to reduce capillary pore space also helps make stronger, less permeable concrete



Images: Todd Hanson, Iowa DOT

Step 1: Paste Quality

- Water-to-cementitious ratio (w/cm)
  - Lower w/cm → stronger, less permeable concrete

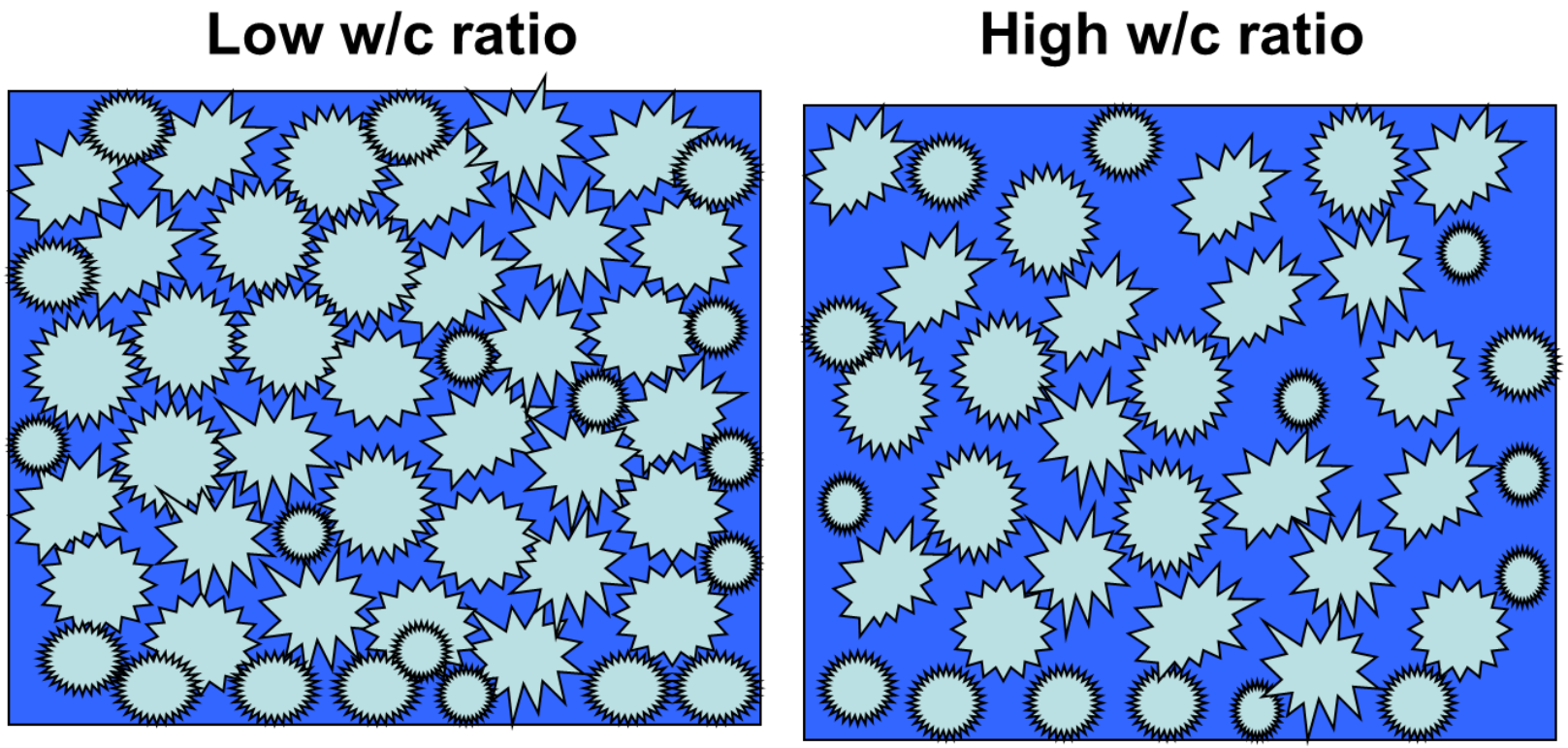


Image: Todd Hanson, Iowa DOT

Step 1: Paste Quality

- A maximum w/cm of 0.45 is a traditional limit for exterior concrete placed in freeze-thaw climates to ensure durability
  - Pavements exposed to harsh conditions and de-icing chemicals can benefit from an even lower w/cm
- Water content is also important to workability
  - Depending on the construction method, increasing w/cm makes concrete easier to place and finish
  - In slipform paving, a too-high w/cm can lead to edge slump

Step 1: Paste Quality

- Air void system
  - Protects concrete against freeze-thaw damage
  - Minimum 5% air content in-place (behind the paver)
  - Voids must be well-distributed throughout the concrete

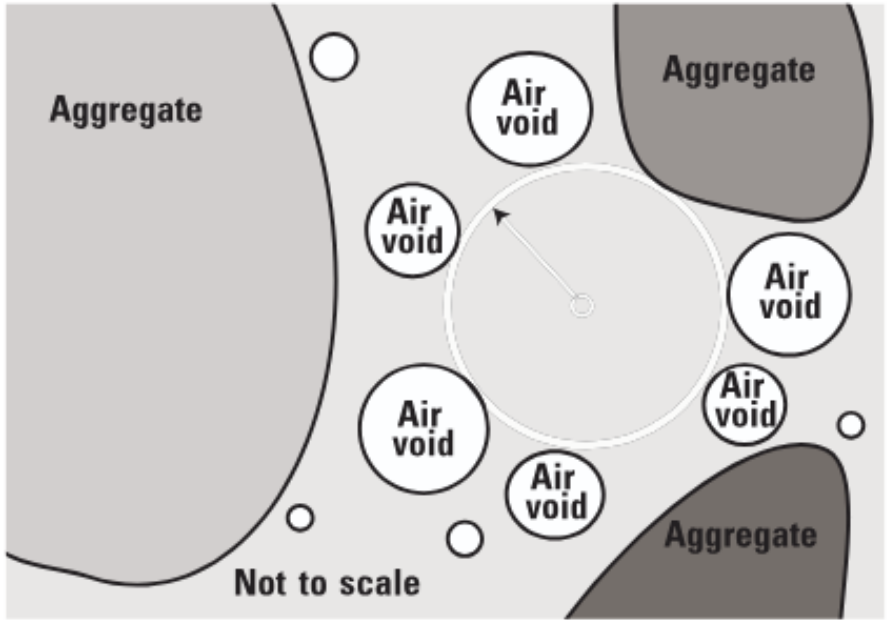


Image: Celik Ozyildirim, VTRC

Step 2: Aggregate System

- Aggregates strongly influence workability and durability
- ASTM C33 describes physical and durability requirements
- Iowa DOT IM 409 classifies aggregate durability based on:
  - Clay content
  - Salt susceptibility
  - Pore system, i.e. freeze-thaw durability

DURABILITY CLASS	QUALITY	TEST LIMITS	TEST METHOD
Class 2	Salt susceptibility quality Secondary Pore Index	Max. 4.5 Max. 30	Iowa 223 Iowa 219
Class 3	Salt susceptibility quality Secondary Pore Index	Max. 1.5 Max. 25	Iowa 223 Iowa 219
Class 3i	Salt susceptibility quality Secondary Pore Index	Max. 1.0 Max. 20	Iowa 223 Iowa 219

More durable

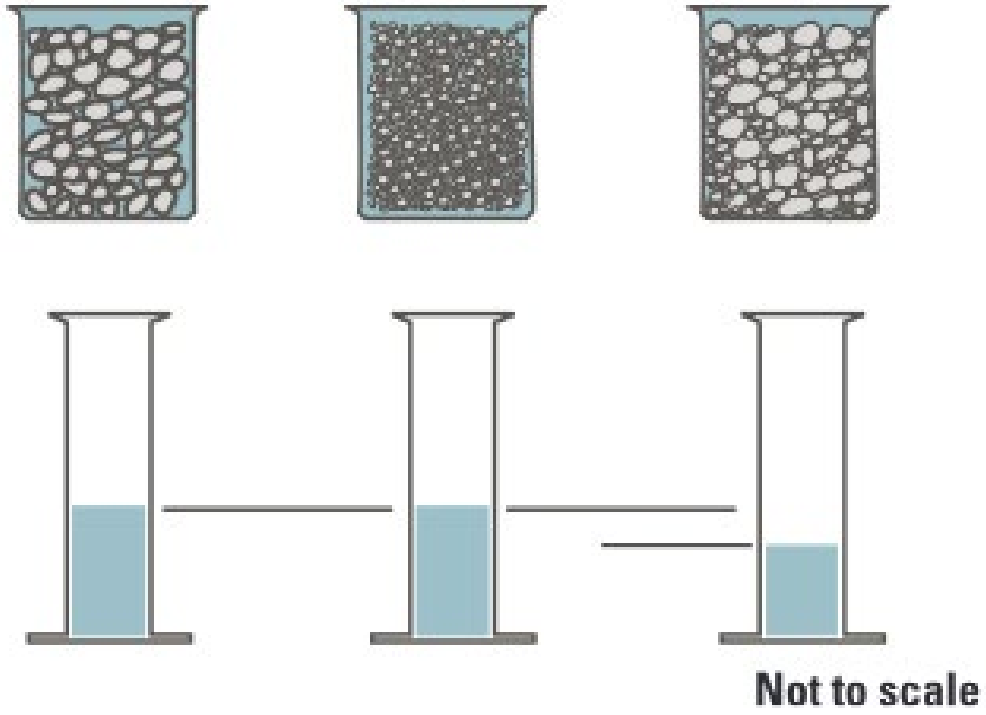
Step 2: Aggregate System

- Well-graded aggregate systems can enhance workability and durability
  - A balanced variety of aggregate sizes helps minimize the amount of void space that needs to be filled by paste
  - Traditionally, mixes contain one coarse aggregate and one fine aggregate, but adding one or more intermediate sizes can improve the gradation

Image: Todd Hanson, Iowa DOT

Step 2: Aggregate System

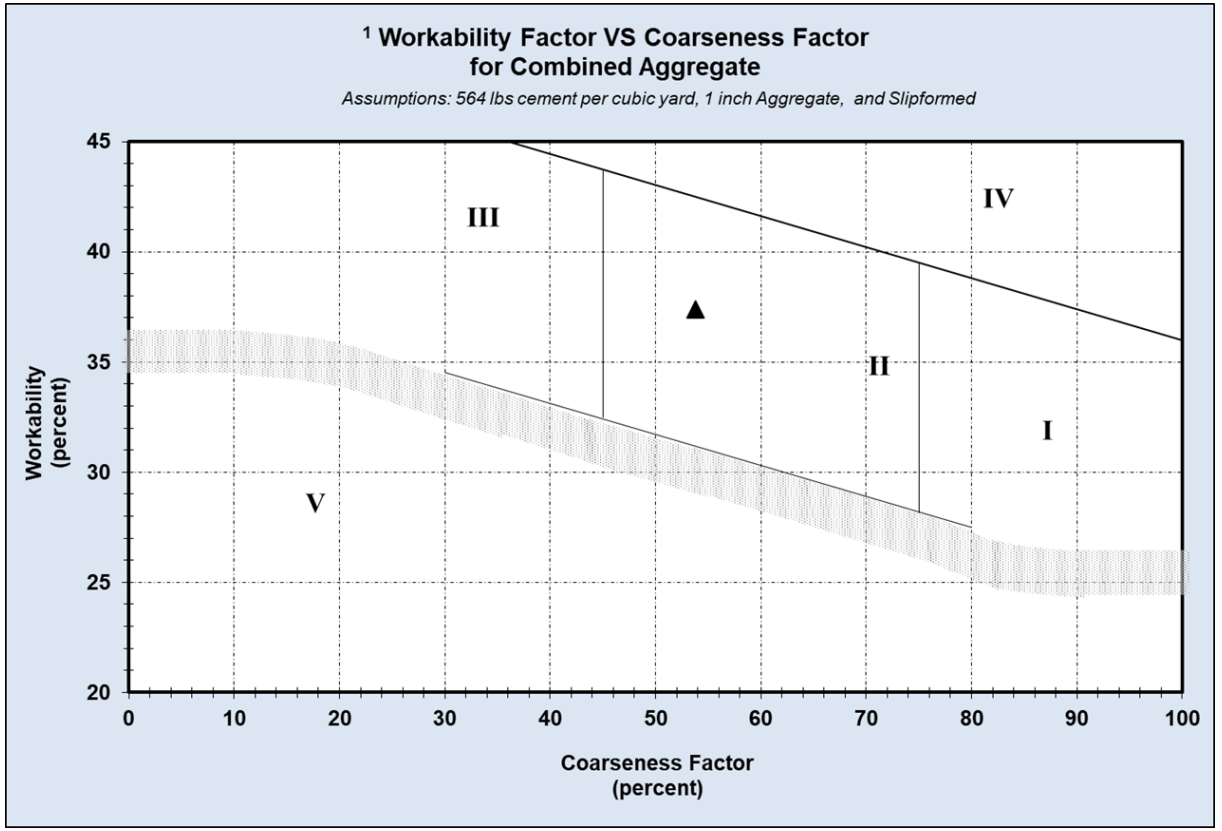
- Effect of grading on water demand and paste content:



L Image: ACA, R Image: Todd Hanson, Iowa DOT

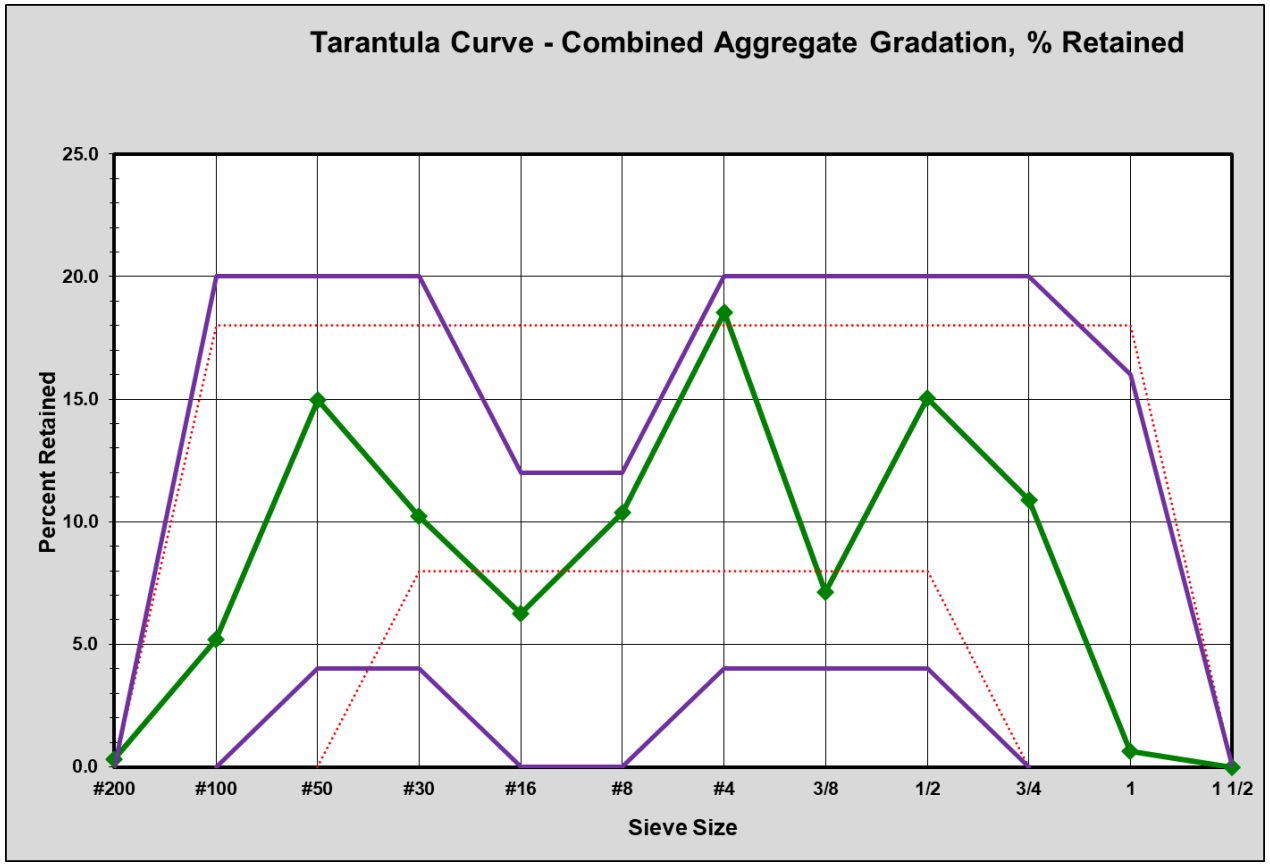
Step 2: Aggregate System

- Tools for evaluating a combined aggregate gradation:
  - Iowa DOT uses the Shilstone coarseness/workability chart:



Step 2: Aggregate System

- Tools for evaluating a combined aggregate gradation:
  - The tarantula curve is a newer tool that is very useful:

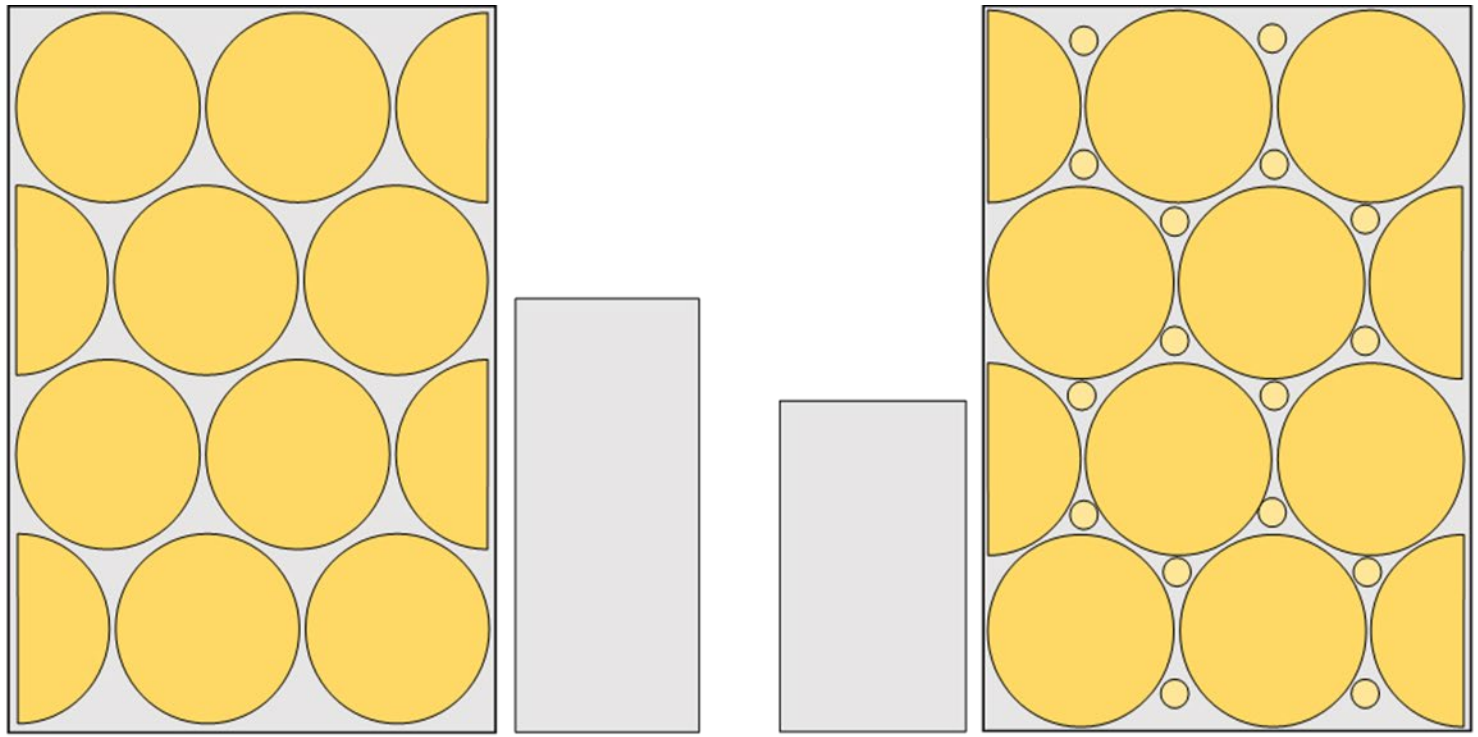


Step 3: Paste Quantity

- We want to select a paste content (e.g. total cementitious content) that is optimized to meet our goals
  - Enough paste to achieve sufficient workability to make the concrete easy to place and finish
  - But not too much, because excessive paste can:
    - Increase permeability and decrease durability
    - Increase drying shrinkage and risk of early-age cracking
    - Increase costs and carbon emissions
  - Remember that more cement doesn't always mean stronger! (especially in the long run)

Step 3: Paste Quantity

- How do we determine the optimal amount of paste?
  - It depends on our workability targets and the void space



Changing gradation affects amount of paste needed

Step 3: Paste Quantity

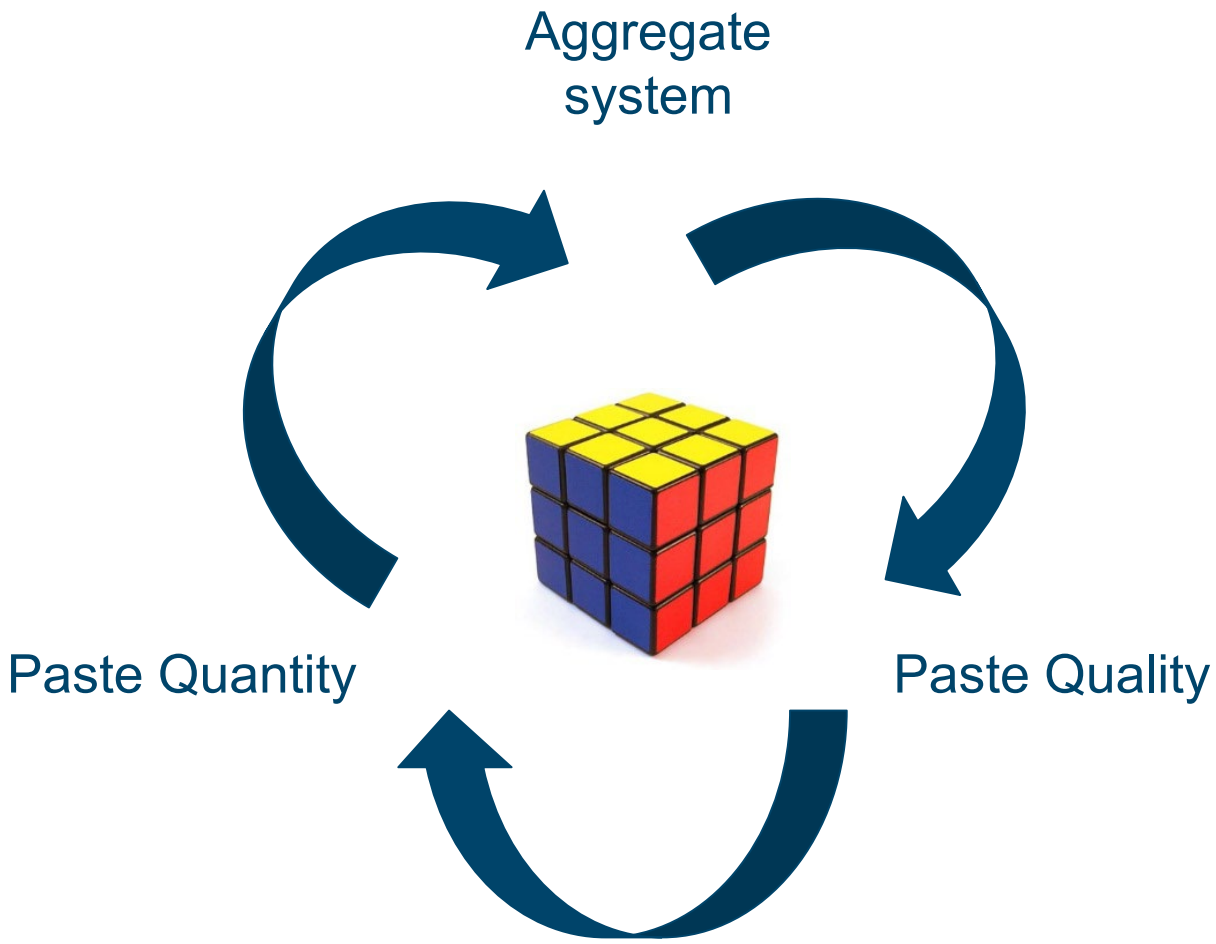
- Required workability depends on the placement method
  - Slipform paving
    - A slump of 0.5 to 1.5 inches generally works well
    - We can use a leaner mix (less paste relative to voids)

Step 3: Paste Quantity

- Required workability depends on the placement method
  - Fixed form paving and hand placements
    - A slump of 3 to 5 inches generally works well
    - More paste (relative to voids) helps achieve the desired workability and eases consolidation and finishing

Mix Design & Proportioning

- Review:



Iowa Paving Mix Specifications

- In Iowa, we specify Class C concrete mixtures for pavements
  - Iowa DOT IM 529 & Iowa SUDAS 7010:

	C-4	C-4WR	C-3	C-3WR	QM-C	C-SUD
Coarse Aggregate Proportion	50%	50%	55%	55%	User-designed gradation	User-designed or 55% Coarse, 45% Fine
Fine Aggregate Proportion	50%	50%	45%	45%		
Intermediate Aggregate Proportion	n/a	n/a	n/a	n/a		
Cementitious Material Content (Volume)	11.8%	11.2%	11.4%	10.8%	10.6%	10.6%
Maximum SCM Content	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Class C fly ash: 35%, Class F fly ash: 25%, Slag: 35%, Total: 40%
Design w/cm	0.43	0.43	0.43	0.43	0.40	0.40
Maximum w/cm	0.488	0.45	0.488	0.45	0.435	0.42

Iowa Paving Mix Specifications

- In Iowa, we specify Class C concrete mixtures for pavements
  - Iowa DOT IM 529 & Iowa SUDAS 7010:

	C-V47B	QM-C	CV-SUD
Coarse Limestone Proportion	30%	User-designed gradation	User-designed or 45% Coarse, 55% Class V
Class V Aggregate Proportion	70%		
Cementitious Material Content	11.3%	10.6%	11.4%
Maximum SCM Content	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Class C fly ash: 35%, Class F fly ash: 25%, Slag: 35%, Total: 40%
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Maximum w/cm	0.488	0.435	0.42

What Mix Should I Specify?

- We generally do not recommend specifying C-3 and C-4 mixes for pavements, because the maximum w/cm is too high (0.488)

	C-4	C-4WR	C-3	C-3WR	QM-C	C-SUD
Coarse Aggregate Proportion	50%	50%	55%	55%	User-designed gradation	User-designed or 55% Coarse, 45% Fine
Fine Aggregate Proportion	50%	50%	45%	45%		
Intermediate Aggregate Proportion	n/a	n/a	n/a	n/a		
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What Mix Should I Specify?

- C-3WR or C-4WR mixes are good everyday options for concrete pavements and parking lots

	C-4	C-4WR	C-3	C-3WR	QM-C	C-SUD
Coarse Aggregate Proportion	50%	50%	55%	55%	User-designed gradation	User-designed or 55% Coarse, 45% Fine
Fine Aggregate Proportion	50%	50%	45%	45%		
Intermediate Aggregate Proportion	n/a	n/a	n/a	n/a		
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Design w/cm	0.43	0.43	0.43	0.43	0.40	0.40
Maximum w/cm	0.488	0.45	0.488	0.45	0.435	0.42

Features of C-3WR and C-4WR Mixes

- Pre-determined proportions of coarse and fine aggregates
  - C-3WR: 55% coarse & 45% fine
  - C-4WR: 50% coarse & 50% fine
  - No intermediate aggregate
  - Users do not need to analyze or optimize the gradation
- About 566 to 587 lbs/cy total cementitious content
  - Batch weights are calculated from the SG of the materials
- Water reducing admixtures help provide workability and maintain strength while keeping the max w/cm down at 0.45

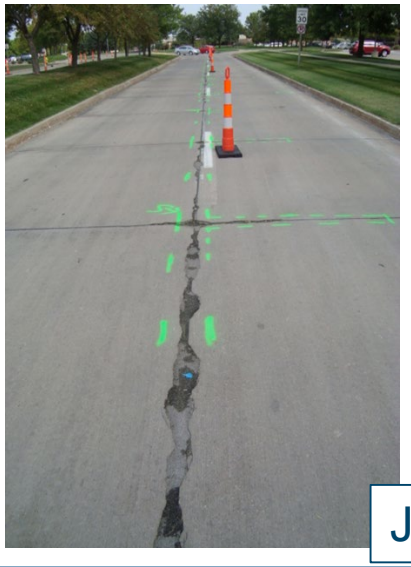
Features of C-3WR and C-4WR Mixes

- Because the aggregate gradations are not optimized, the total cementitious content is higher than for other mixes
  - Ensures there's enough paste to overcome the possibility of a poor combined gradation
  - In some markets, intermediate aggregates are not available
- The additional paste and higher maximum w/cm also make these mixes easier to place and finish when doing fixed form paving or hand placements

Limitations of C-3WR and C-4WR Mixes

- Many concrete pavements made from C-3WR and C-4WR mixes have performed very well over the years
- That said, they are not optimized for workability or durability, and issues have popped up over the years, especially if or when the pavements are placed at or above the maximum w/cm

Vibrator trails



Joint deterioration

L Image: Bob Steffes

What Mix Should I Specify?

- Iowa DOT developed the QM-C specification in the 1990s to optimize gradations, improve workability, and improve quality

	C-4	C-4WR	C-3	C-3WR	QM-C	C-SUD
Coarse Aggregate Proportion	50%	50%	55%	55%	User-designed gradation	User-designed or 55% Coarse, 45% Fine
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Maximum w/cm	0.488	0.45	0.488	0.45	0.435	0.42

Features of QM-C Mixes

- The aggregate proportions are designed and optimized according to the Shilstone coarseness/workability chart
- QM-C mixes usually contain an intermediate aggregate in addition to coarse and fine aggregates
  - Pea gravel
  - Limestone chip
  - Usually at a relative proportion of 5 to 15%
- About 555 lbs/cy total cementitious content
- Maximum w/cm of 0.435
- Usually contain water-reducing admixtures

Features of QM-C Mixes

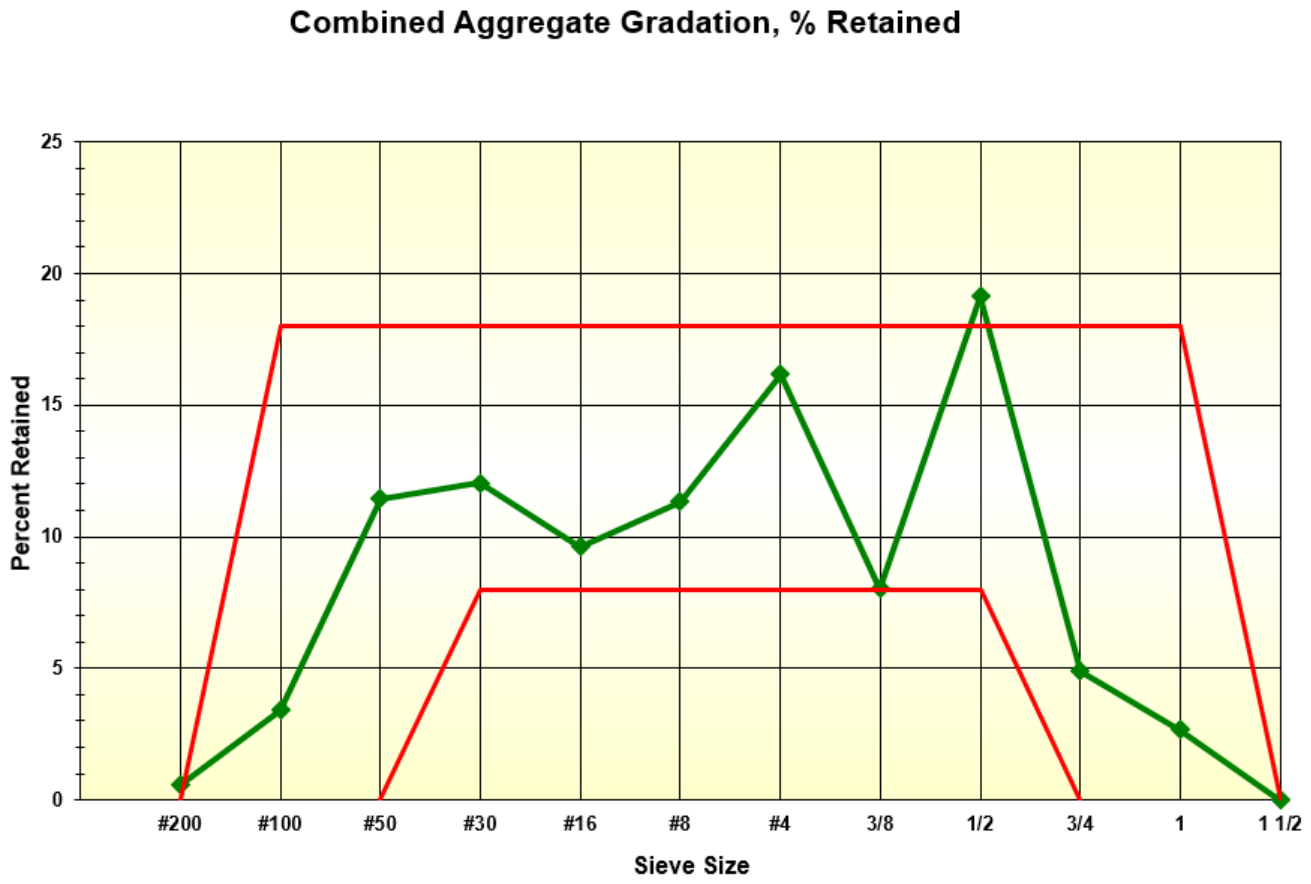
- Analyzing a combined gradation:

	% Total Aggregate	A Number	Producer & Location
% Coarse	44.5	A85006	MM Ames Mine
% Interm.	15.2	A85006	MM Ames Mine
% Fine	40.3	A77534	MM Saylorville
Total	100.0		

						(dependent on MIX DESIGN)		
Sieve Size	% Passing Coarse	% Passing Intermediate	% Passing Fine	% Passing (Combined Agg)	% Retained (Combined Agg	% Passing Paste	% Passing (Combined Tot)	% Retained (Combined Tot)
1 1/2"	100.0	100.0	100.0	100.0	0.0	100.0	100.0	0.0
1"	94.0	100.0	100.0	97.3	2.7	100.0	98.1	1.9
3/4"	83.0	100.0	100.0	92.4	4.9	100.0	94.7	3.4
1/2"	40.0	100.0	100.0	73.3	19.1	100.0	81.5	13.3
3/8"	22.0	100.0	100.0	65.3	8.0	100.0	75.9	5.6
#4	14.0	25.0	97.0	49.1	16.2	100.0	64.7	11.2
#8	5.0	0.7	88.0	37.8	11.3	100.0	56.8	7.9
#16	4.2	0.7	65.0	28.2	9.6	100.0	50.1	6.7
#30	3.4	0.8	36.0	16.1	12.0	100.0	41.8	8.4
#50	2.5	0.8	8.5	4.7	11.4	100.0	33.8	7.9
#100	1.7	0.9	0.9	1.3	3.4	100.0	31.5	2.4
#200	0.9	0.9	0.4	0.7	0.6	100.0	31.1	0.4
#325	-	-	-	-	-	96.5	29.5	1.5
Liquid	-	-	-	-	-	65.4	20.0	9.5
					100.0			100.0

Features of QM-C Mixes

- Analyzing a combined gradation:



Features of QM-C Mixes

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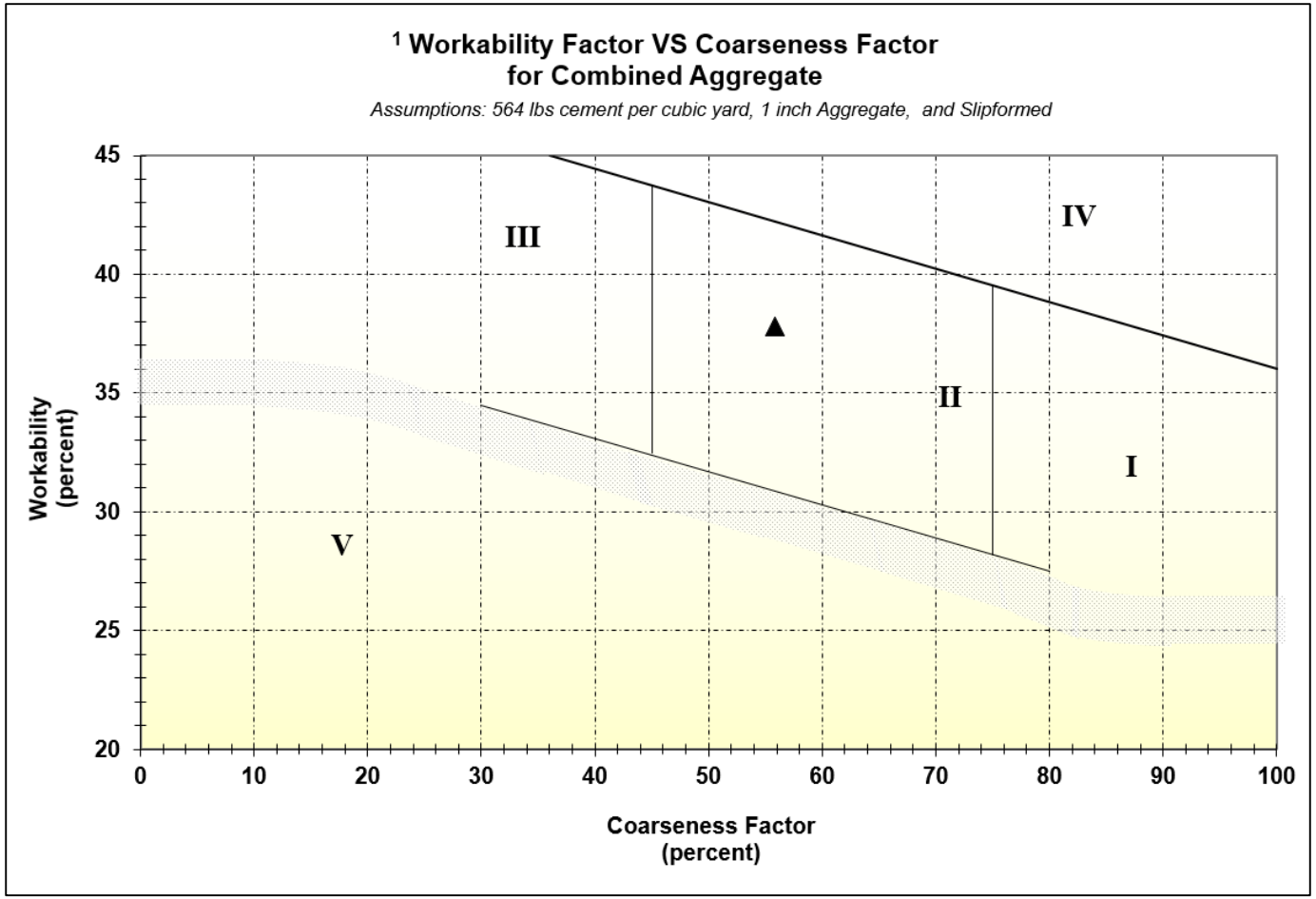


Features of QM-C Mixes

- These mixes are used on large DOT mainline paving projects
  - The specification also includes contractor QC testing requirements that are not required for other types of work
- Optimizing the gradation helps improve workability and allows for a reduction in total cementitious content
- The lower maximum w/cm (0.435) helps improve durability
- The implementation of the QM-C specification over the last 25+ years has been highly successful, and has served as a model for other state DOTs

What Mix Should I Specify?

- The C-SUD specification was developed in the 2010s to provide an option for enhanced durability on city streets

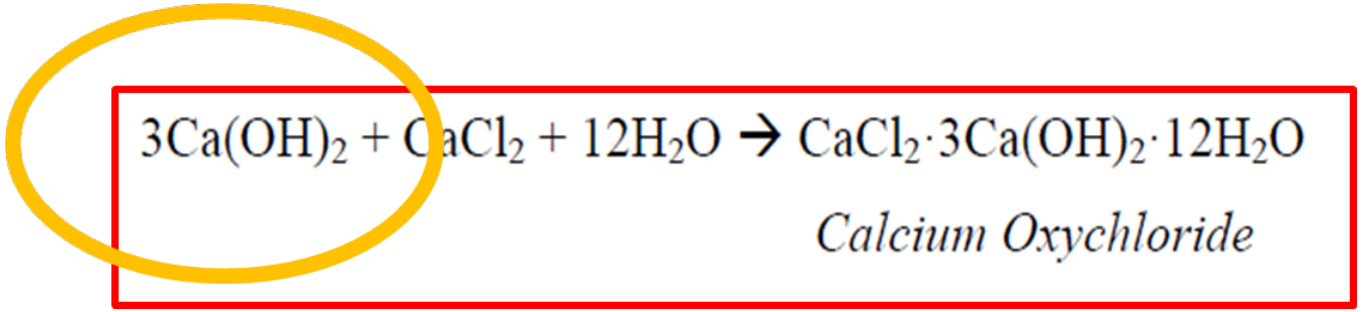
	C-4	C-4WR	C-3	C-3WR	QM-C	C-SUD
Coarse Aggregate Proportion	50%	50%	55%	55%	User-designed gradation	User-designed or 55% Coarse, 45% Fine
Fine Aggregate Proportion	50%	50%	45%	45%		
Intermediate Aggregate Proportion	n/a	n/a	n/a	n/a		
Cementitious Material Content (Volume)	11.8%	11.2%	11.4%	10.8%	10.6%	10.6%
Maximum SCM Content	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Fly ash: 20%, Slag: 35%, Total: 50%	Class C fly ash: 35%, Class F fly ash: 25%, Slag: 35%, Total: 40%
Design w/cm	0.43	0.43	0.43	0.43	0.40	0.40
Maximum w/cm	0.488	0.45	0.488	0.45	0.435	0.42

Features of C-SUD Mixes

- C-SUD uses QM-C mix features as a starting point
  - Optimized aggregate proportions
  - Reduction in total cementitious content
- C-SUD then adds a few other features which are designed to further enhance durability when it's needed
  - An even lower maximum w/cm (0.42)
  - Higher allowable fly ash replacement rate
    - 35% Class C fly ash
    - 25% Class F fly ash

Features of C-SUD Mixes

- These changes are specifically designed to improve durability for city streets that receive the heaviest de-icing treatments and where drainage may not be as favorable as on state highways
  - Lower maximum w/cm further reduces permeability
  - Fly ash provides protection from de-icing attack
    - Class F fly ash is more pozzolanic than Class C fly ash, so less is needed to achieve the same effect



C-SUD Experience to Date

- Upwards of 1 million SY of pavements with C-SUD mixes have been paved since 2015, with excellent performance to date
- There can be some challenges when paving with C-SUD mixes

Limitations of C-SUD Mixes

- SCMs like fly ash and slag slow down initial strength gain
  - Class F fly ash slows set time more than Class C fly ash
- Using higher replacement rates allowed by C-SUD can delay saw cutting and time to reach opening strength
  - These effects are exacerbated at colder temperatures

Limitations of C-SUD Mixes

- C-SUD mixes are generally not as workable or easy to finish for fixed form paving or hand placements
  - C-SUD (and QM-C) mixes are optimized for slipform paving
  - These mixes are leaner and less “creamy” thanks to the reduced paste content and lower w/cm
  - Mixes with higher SCM contents can also be “stickier”
  - These effects may be exacerbated in hot temperatures

Limitations of C-SUD Mixes

- These issues have been reported when hand finishing with C-SUD mixes since they were first introduced in 2015
- The recent introduction of Type IL (portland limestone) cement may be making hand placement and finishing with C-SUD even a bit more challenging:
  - Increased water demand and reduced bleeding
  - Changes to finishing, curing, setting time, and sawing
  - Changing behavior with water-reducing admixtures

Addressing Workability Concerns

- Some cities specify C-SUD mixes for mainline paving and allow C-3WR or C-4WR mixes to be used for handwork
  - This is also how Iowa DOT handles QM-C projects
- Other cities would still like to use C-SUD mixes for handwork for improved durability at areas like turn lanes, intersections, roundabouts, and larger patches

C-SUDHW Mixes

- A new C-SUDHW mix is under development to provide a higher durability solution that is more suitable for hand placements
- This mix has not yet been added to Iowa DOT or SUDAS specifications, but key features include:
  - Higher total cementitious content (593 lbs/cy, about 11.3%) to provide more paste to ease placement and finishing
  - Maintain a lower maximum w/cm (0.435), though with a bit more room to add water than allowed by C-SUD
  - Allow up to 25% fly ash
  - Require use of water-reducing admixture

C-SUDHW Mixes

- ICPA, Iowa DOT & CP Tech Center collaborated with several cities to test out this mix in 2025:
  - Altoona
  - Ames
  - Ankeny
  - Cedar Rapids
  - Iowa City
  - West Des Moines
- Let us know if you'd like to try a C-SUDHW mix in 2026!

C-SUDHW Mixes

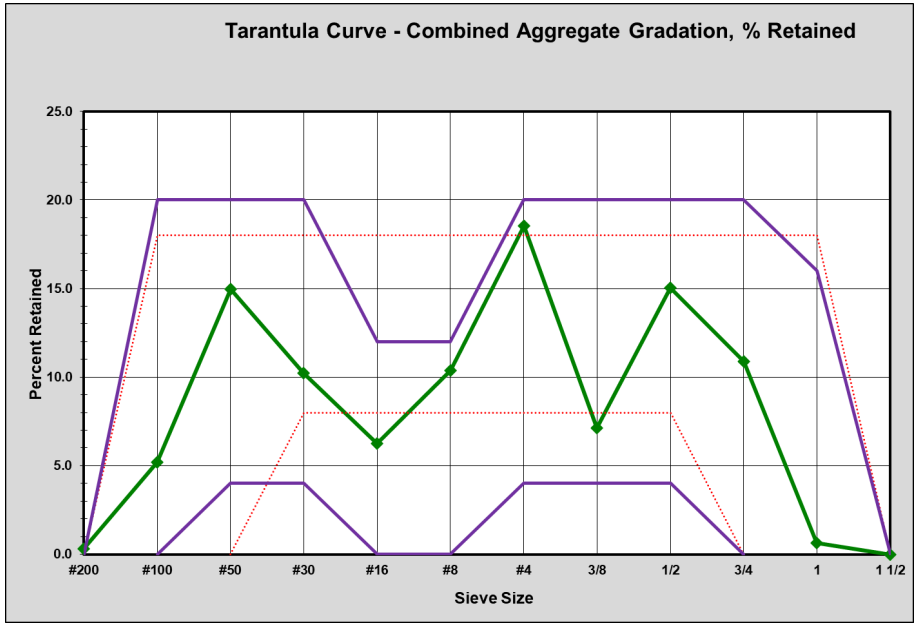
- Feedback from contractors so far:
  - “Works fine”
  - “Finished like C-4”
  - “Sealed up nice, no curb issues at 3 inch slump”
  - “Definitely more cream”
  - “Closed up nicely, very little working”
  - “Water reducer did its job”
- ICPA has been collecting cylinders at each project and testing for strength and resistivity – results so far have been good

Troubleshooting

- Even with all of the available options, we can still encounter challenges preparing pavement mixes and during construction
- Workability suggestions:
  - Use water reducing admixtures to avoid increasing water content beyond the maximum w/cm
  - Allow concrete producers and contractors to adjust admixture dosage rates during construction
    - Iowa DOT IM 403: “dosage rates may be adjusted, within manufacturers range limits, to improve workability for the conditions on the project”

Troubleshooting

- Workability suggestions (continued):
  - Perform trial batches to identify any unforeseen issues when using new cements or SCMs
  - Analyze combined gradations using the tarantula curve
  - Even if an intermediate aggregate is not available, consider adjusting the relative proportions of coarse and fine aggregates from the C-SUD default of 55% coarse and 45% fine



Troubleshooting

- Set time suggestions:
  - Remember that Class F fly ash slows down set time more than Class C fly ash, but that not as much Class F fly ash is needed to achieve the same durability performance
  - In cold weather:
    - Don’t remove SCMs from the mix, but consider reducing SCM content back to typical limits
    - Consider increasing total cementitious content to help get the mix “kicked off” a bit faster
      - The C-SUDHW specification could help here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