



Breaking the Cycle of Surface Scaling on Concrete Flatwork

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SIMPSON GUMPERTZ & HEGER

Engineering of Structures
and Building Enclosures

Learning Objectives

1. Understand the causes of surface scaling on concrete formwork.
2. Identify factors leading to the recent onset of scaling issues, including weather, construction practices, materials, competition, pricing, specifications, expectations, and supervision.
3. Recognize common strategies for avoiding concrete surface scaling.
4. Discuss ideas for avoiding and mitigating these effects.

Our recent experience...



Our Experience – Common Causes

- Low entrained air content
- Overworked surface
- Poor curing
- Poor specification
- Early exposure
- Deicing salt attack
- A combination of the above (over 50% of the time)

Key things to remember today...

- Everyone is annoyed, exasperated, and frustrated by this problem.
- We are going to ask you to relax your preconceptions:
 - There are many concrete “diseases” with scaling symptoms – it has to be properly diagnosed and responsibility is different for each
 - If there are “n” people in the room, each knows the “n-1” people responsible for the problem
- Spoiler Alert: There isn't one thing happening and there isn't one solution.

Bottom Line

None of us wants:

- Rework
- Money-loser projects
- Delays to users
- Added maintenance
- Claims/disputes



What is scaling?

Scaling – What is it & why does it happen ?

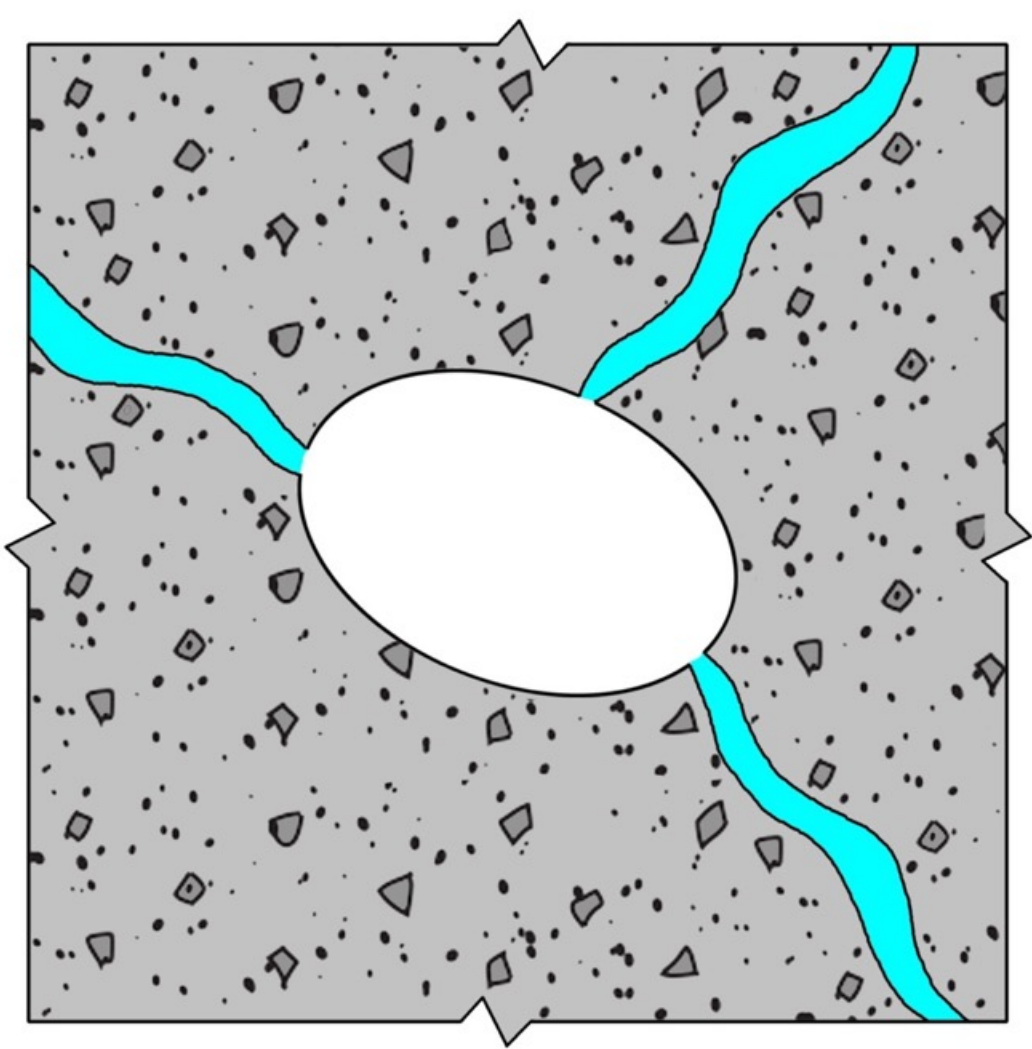


PCA: “...caused by the expansion of water due to freezing and thawing cycles and the use of deicing chemicals; however properly specified, produced, finished, and cured quality concrete need not suffer this type of deterioration.”

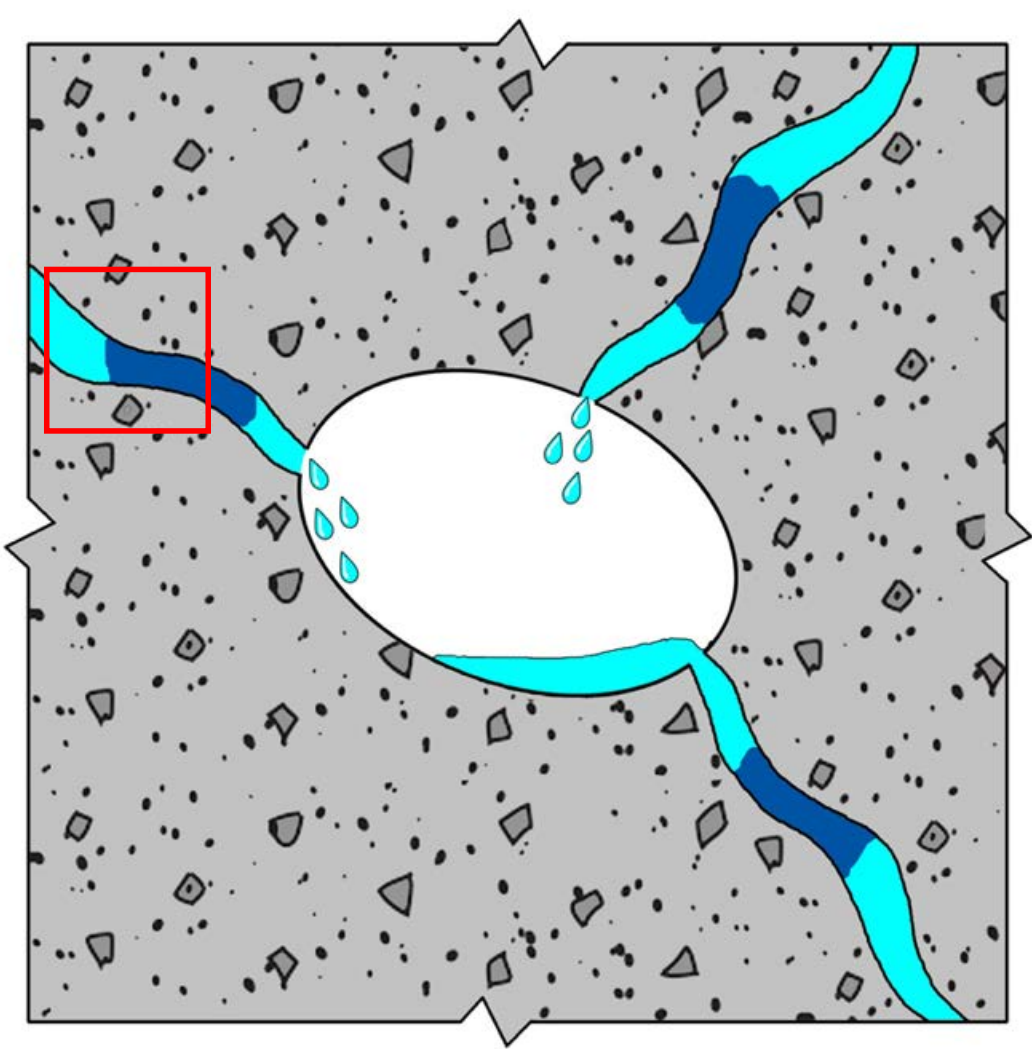
Scaling at the microscopic level...

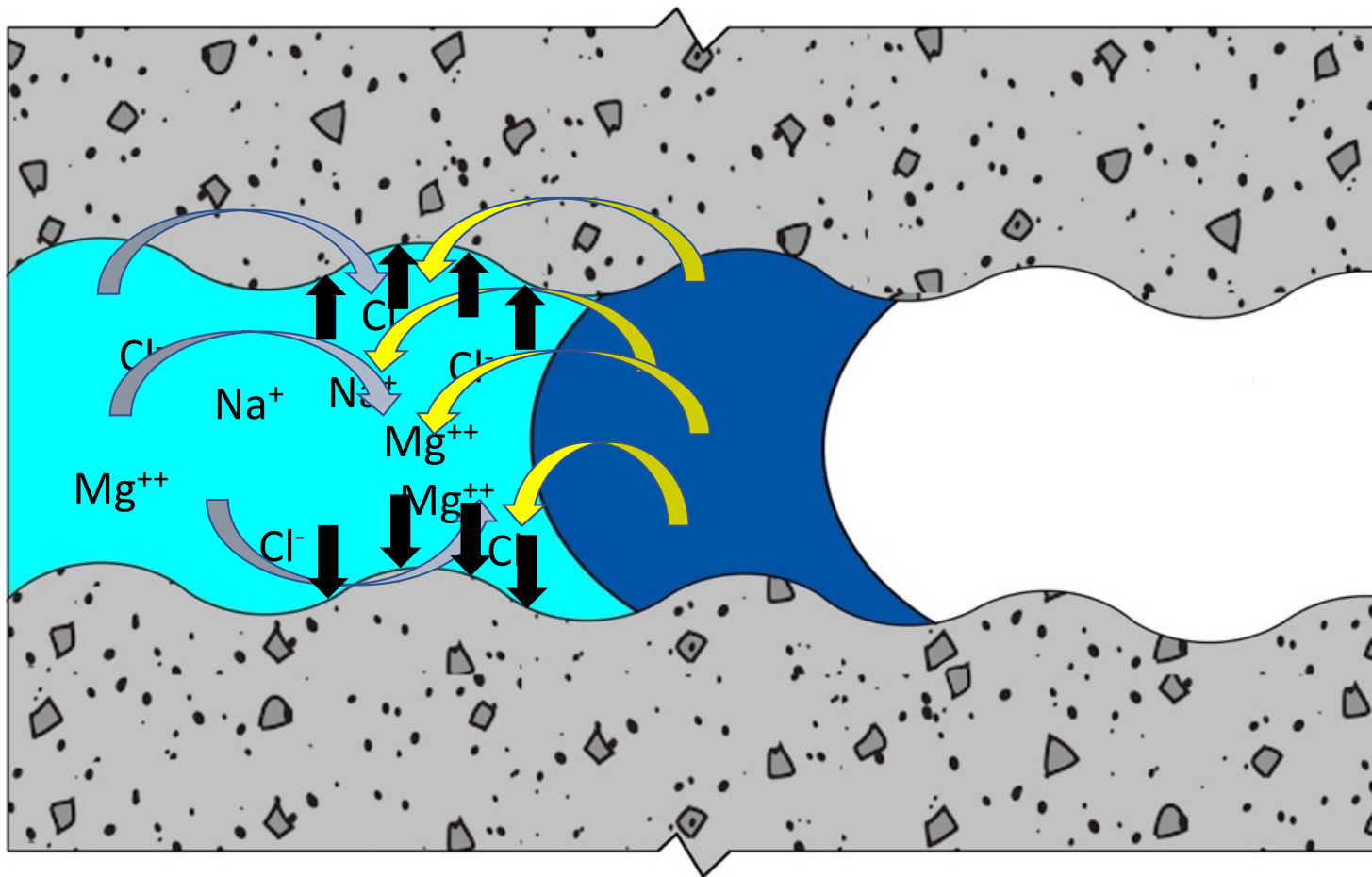


Mechanism...



Mechanism...





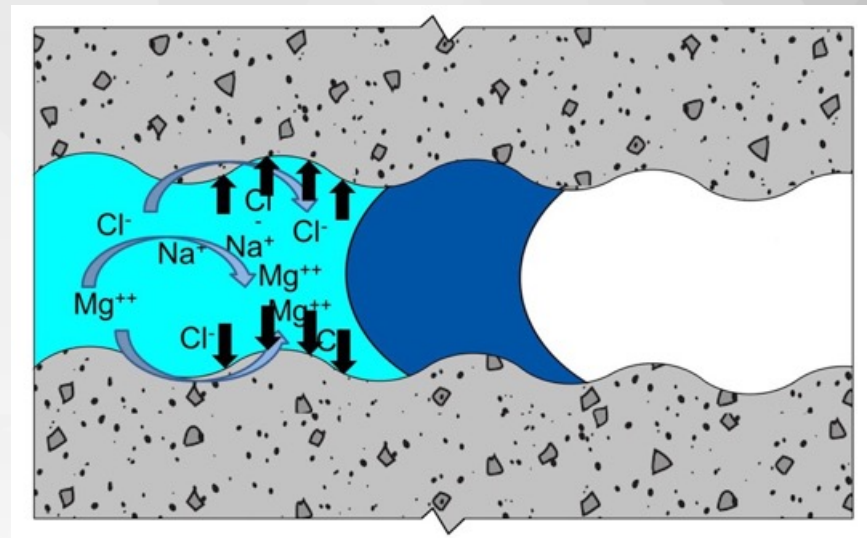
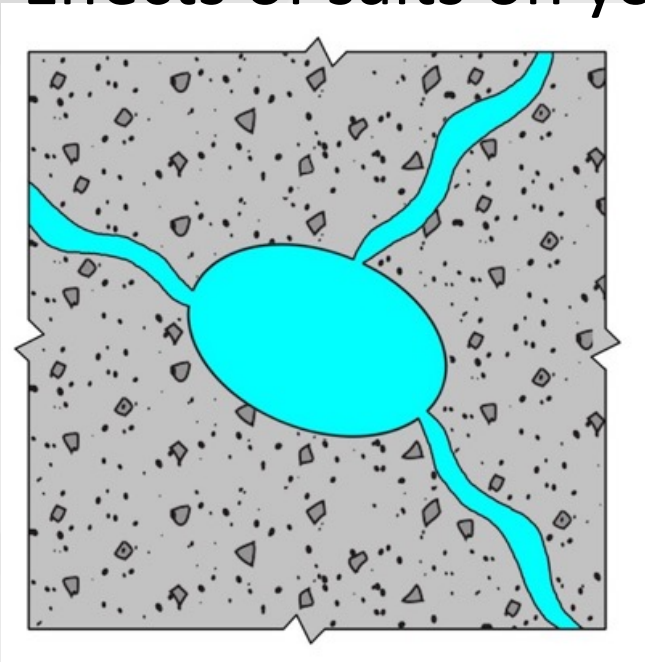
Two types of scaling

- Exposure of young or “green” concrete to aggressive conditions
- Freezing and thawing of non-durable concrete



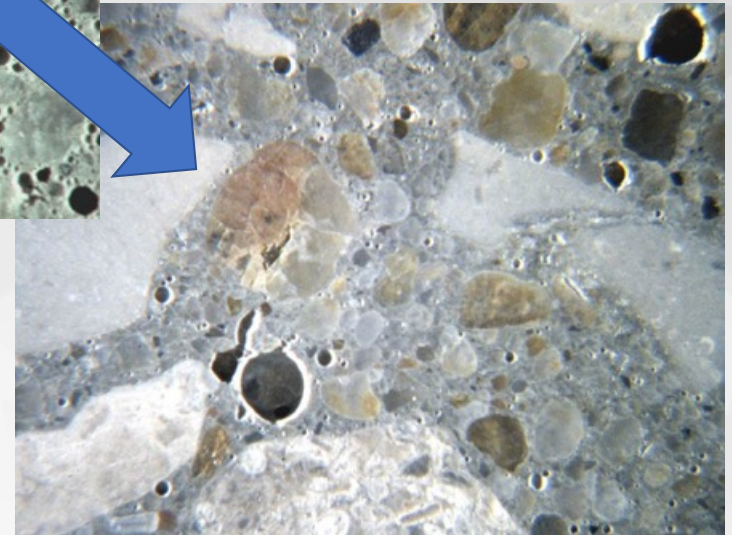
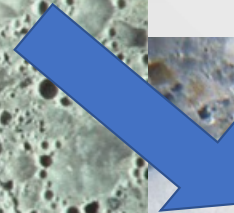
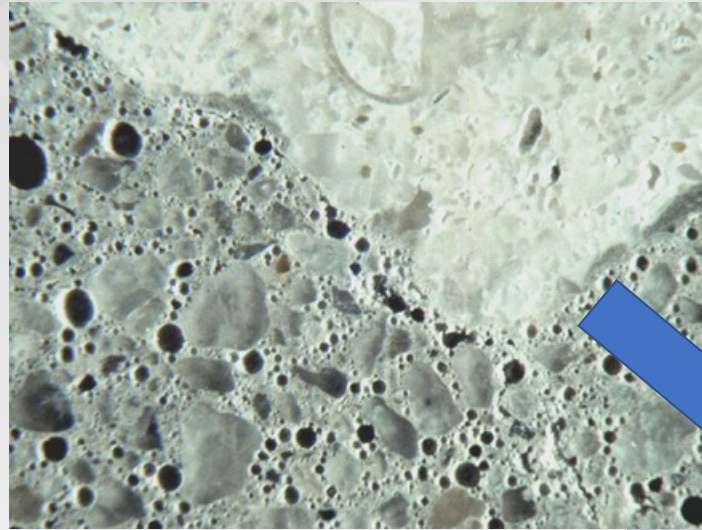
Early-age exposure scaling is caused by...

- Freezing of concrete that still contains placement water
- Effects of salts on young (weak) concrete



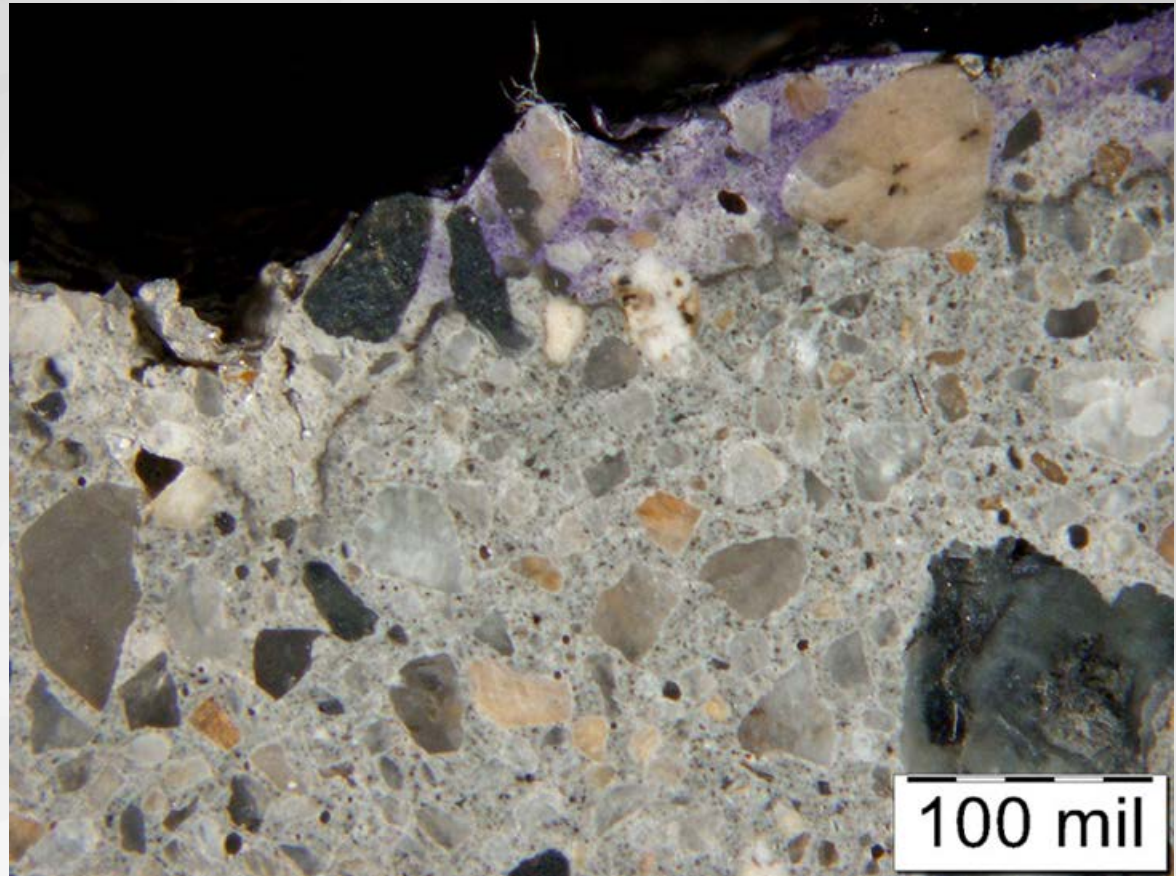
Non-durable concrete is caused by...

- Lack of entrained air



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- High w/cm



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- Low hydration



Non-durable concrete is caused by...

- Lack of entrained air
- High w/cm
- Low hydration
- Low strength

Table 4.2.3.1b—Requirements by freezing-and-thawing exposure class

Exposure Class	Minimum \bar{f}_c ,* MPa (psi)	Maximum w/cm [†]	Air content	Limits on cementitious materials
F0	No restriction	No restriction	No restriction	No restriction
F1	25 (3500)	0.50	Table 4.2.3.2.4	No restriction [‡]
F2	25 (3500)	0.45	Table 4.2.3.2.4	No restriction [‡]
F3a [§]	32 (4500)	0.45**	Table 4.2.3.2.4	Table 4.2.3.1c [‡]
F3b [¶]	32 (4500)	0.45**	Table 4.2.3.2.4	No restriction [‡]

*The minimum average compressive strength that should be achieved before initial exposure to freezing and thawing.

[†]The maximum w/cm for the in-place concrete to provide adequate restriction of freezable water in the properly-cured concrete.

[‡]High cementitious material replacement for portland cement frequently results in lower rates of strength gain. Care should be taken to ensure that adequate curing (moisture, temperature, and time) is provided so that the minimum \bar{f}_c is achieved before initial exposure to freezing and thawing.

[§]Hand-finished surfaces.

[¶]Formed and machine-finished surfaces.

**A lower w/cm may be needed when corrosion is of concern (ACI 318-14).

But don't count out the environment...

- Early freezes
- Aggressive chemicals
- Saturation



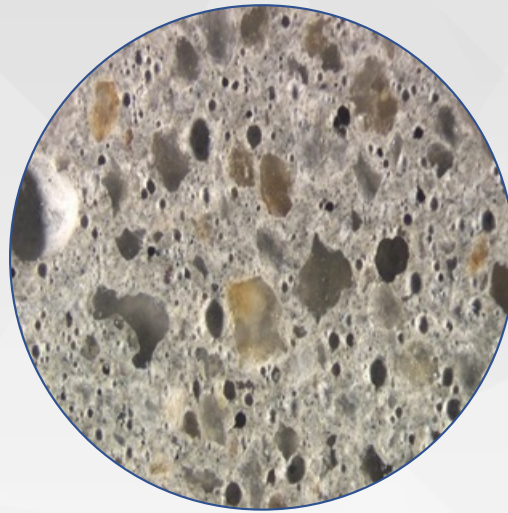
So what is going on?

So what is going on?

- Many things are in play
 - There are many mechanisms that all manifest as scaling
 - There are lots of different people and steps involved
 - You have to investigate to find out which one or who
- Likely contributors:
 - Exposure
 - Finishing
 - Deicing salts
 - Materials
 - Specifications
 - Curing
 - Economics

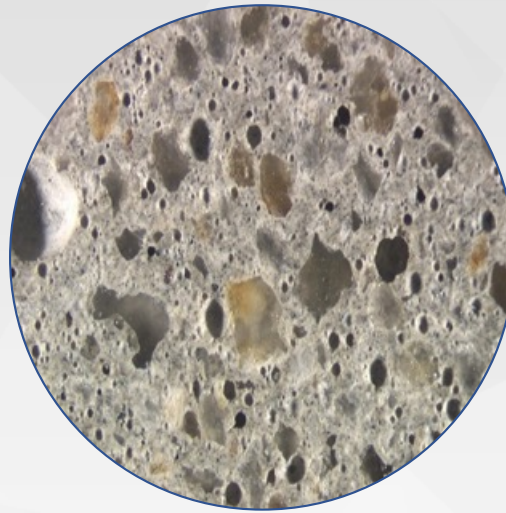
Framing the discussion...

- We have always had concrete



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- We have always had winter



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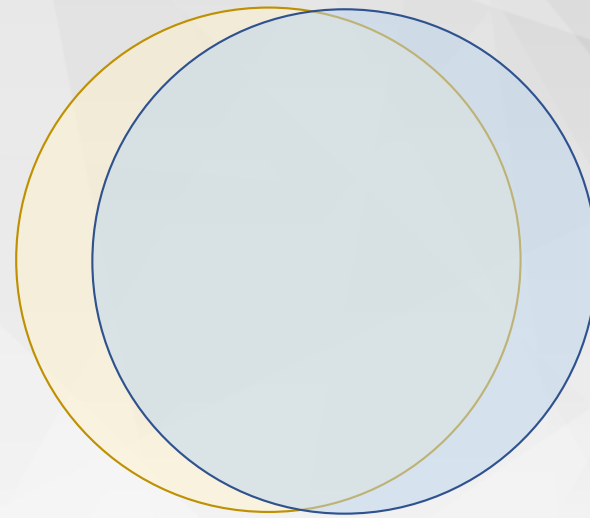
Concrete



Exposure

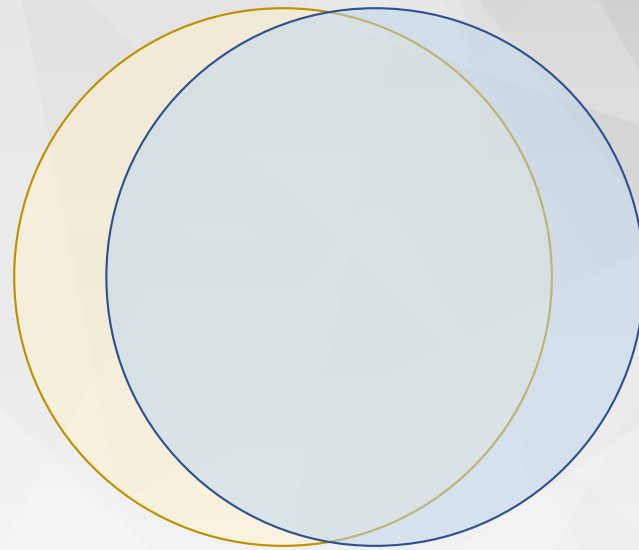
Framing the discussion...

- We have always had concrete
- We have always had winter
- It worked pretty well in the past



Exposure...

- Later construction seasons



Exposure...

- Later construction seasons



Late season requirements...

- 500 psi required before FIRST freeze (more for harsher exposure)
- Concrete has to lose excess moisture before it freezes
- 3,500 psi before repeated cycles
- 4,500 psi before repeated cycles with deicers (Per ACI)
- “Green” concrete is especially vulnerable to deicing salts
- Protection recommended if the concrete is exposed early in life

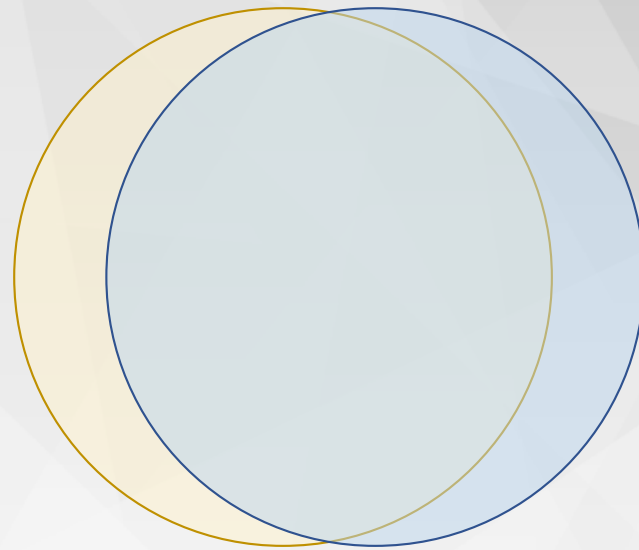
Late season requirements...

- We are seeing late placements, with distress clearly correlating to the placement season
- But...economic advantages to late season placements means we have to balance risk and reward



Exposure...

- Later construction seasons
- Changes in the weather



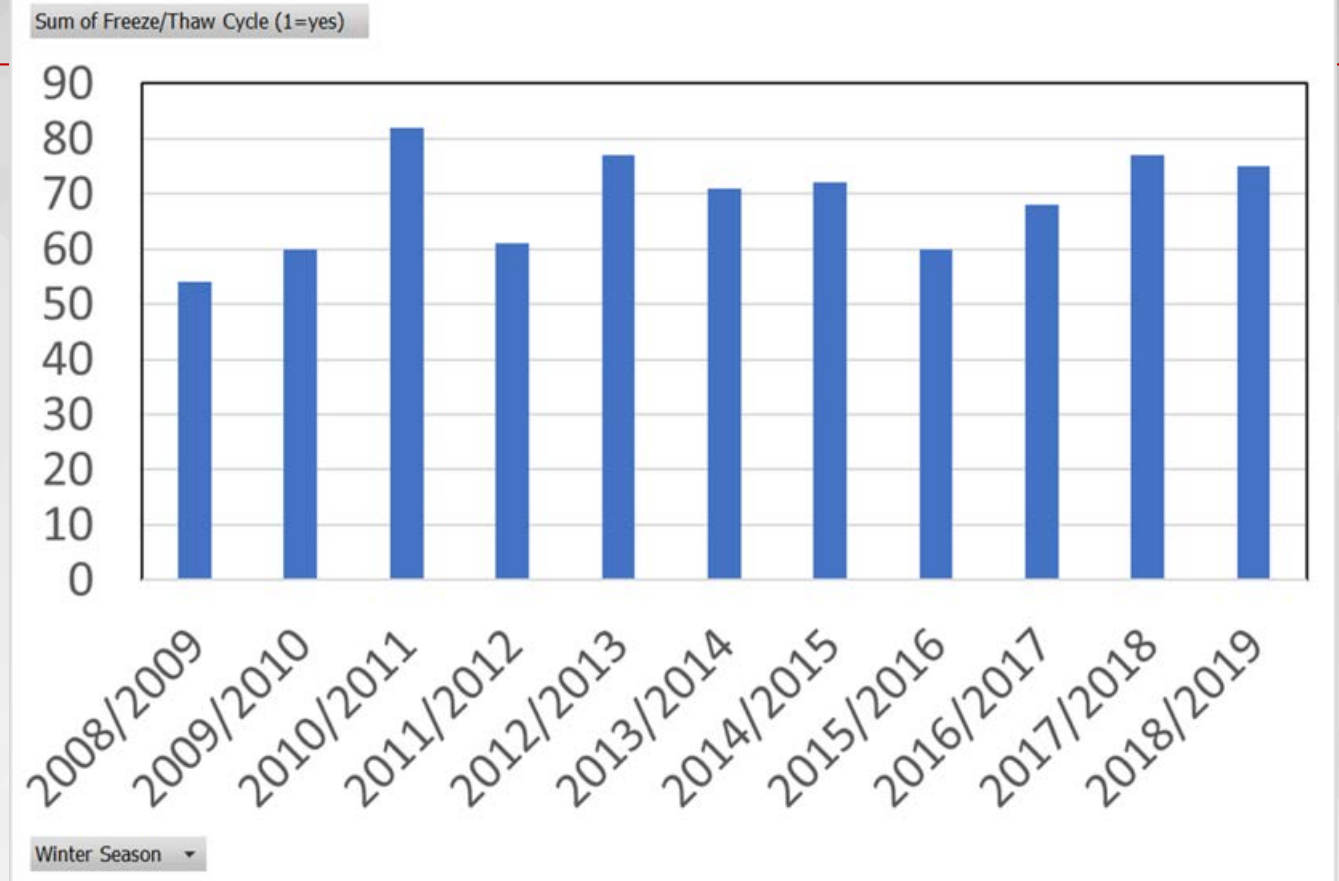
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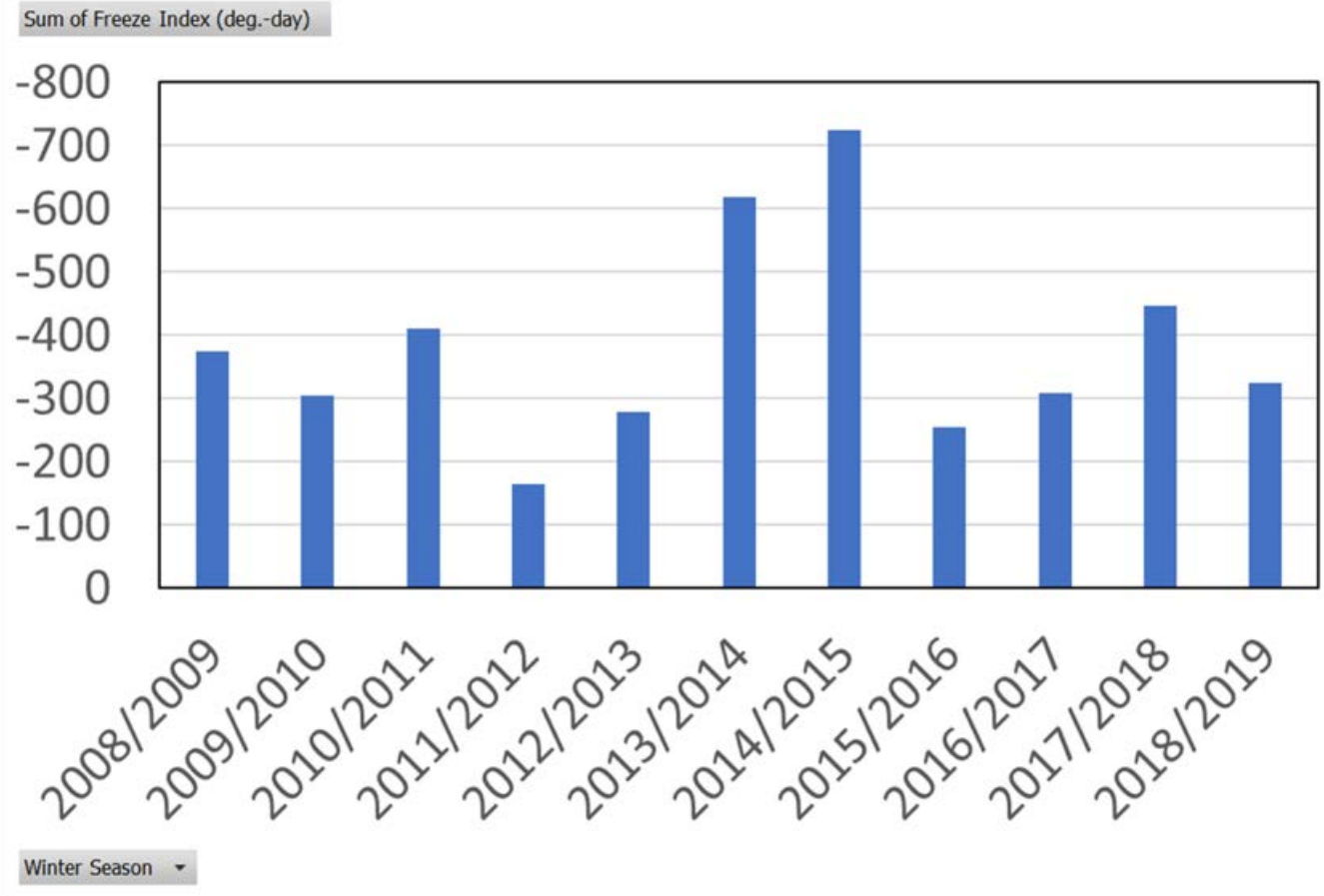
Exposure...

- Number of cycles?



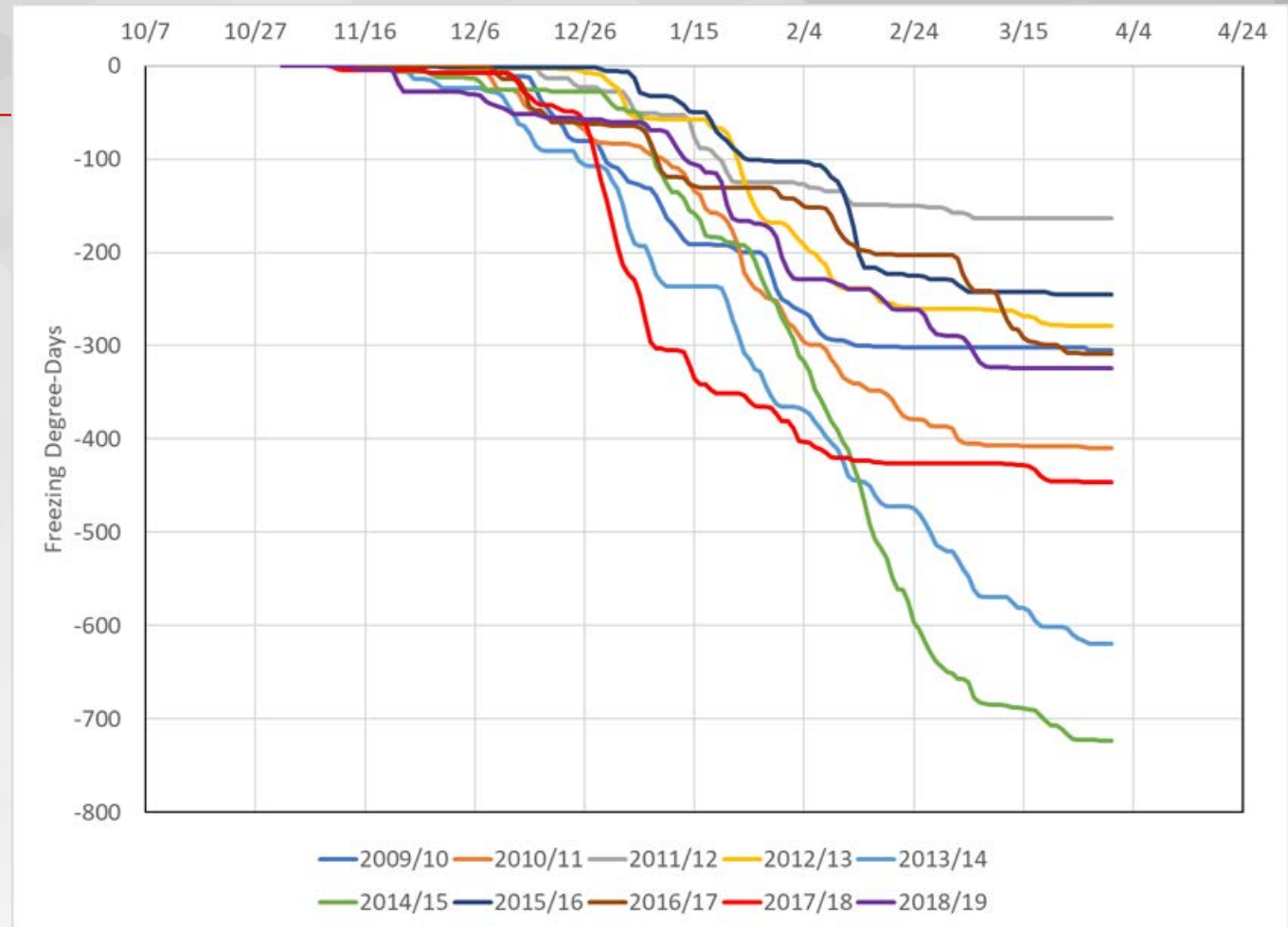
Exposure...

- Number of cycles?
- Severity of winter?



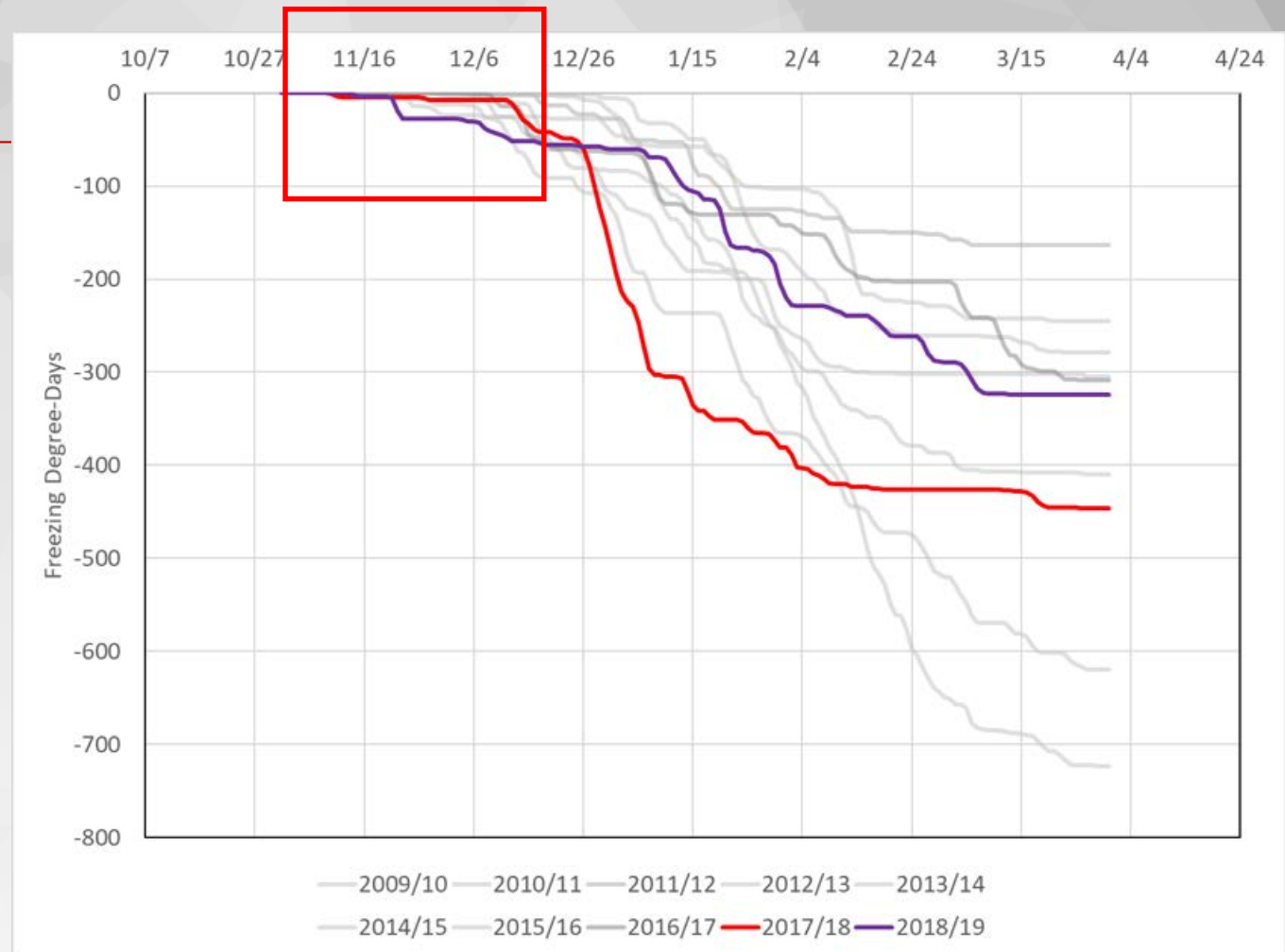
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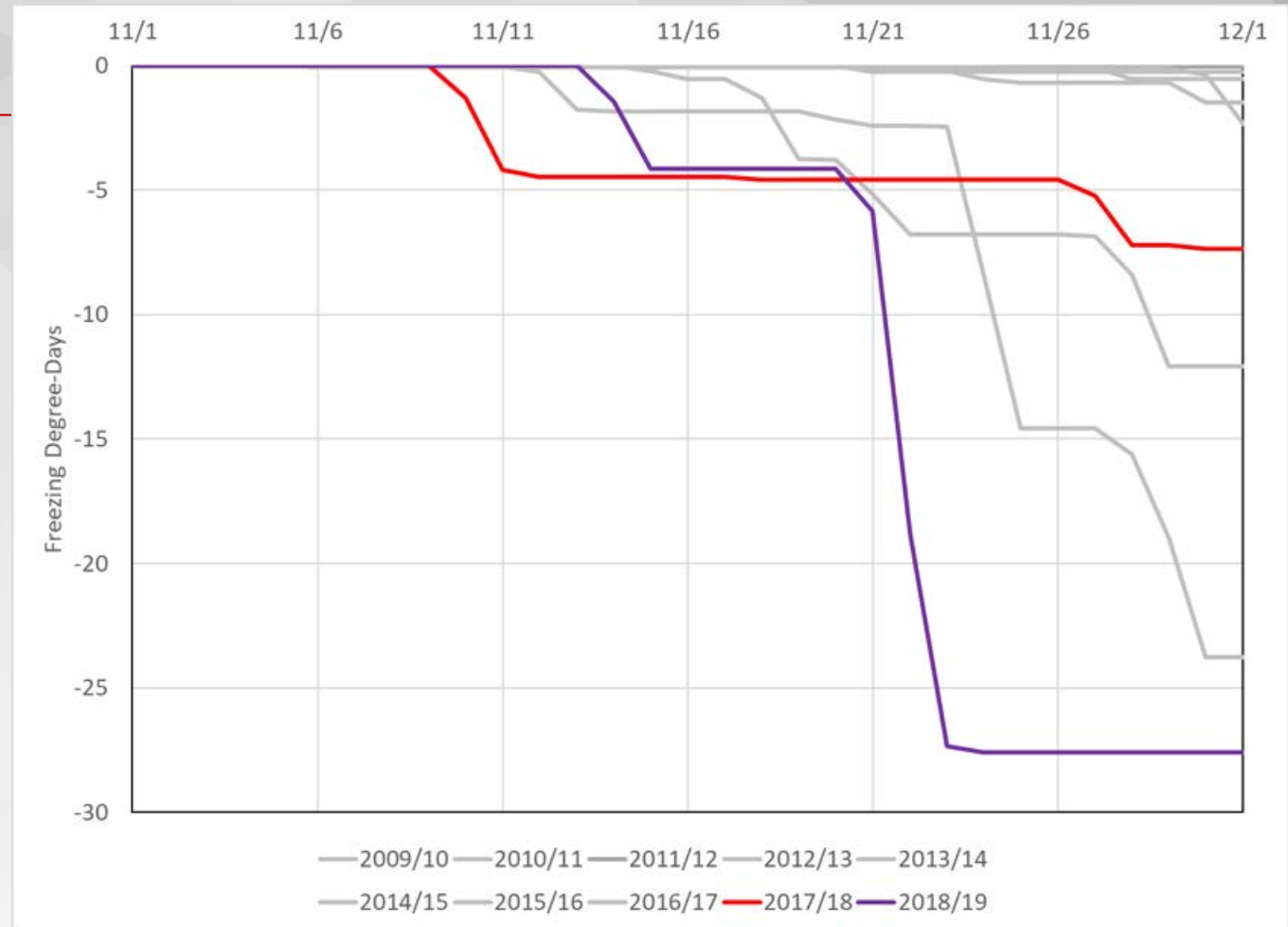
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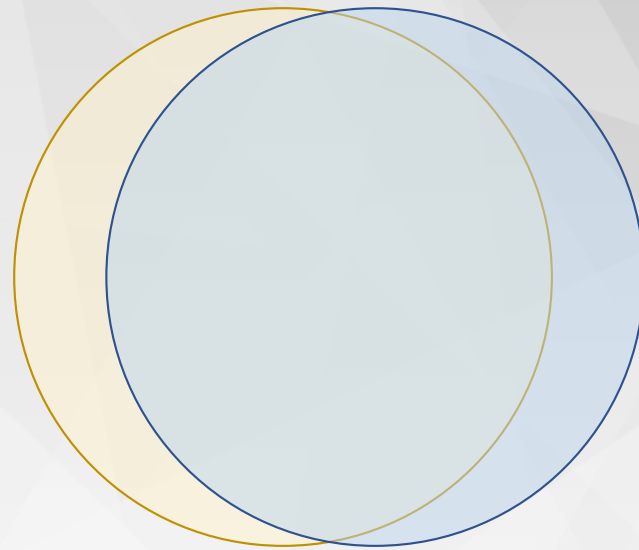
Exposure...

- Number of cycles?
- Severity of winter?
- Timing of first freeze?



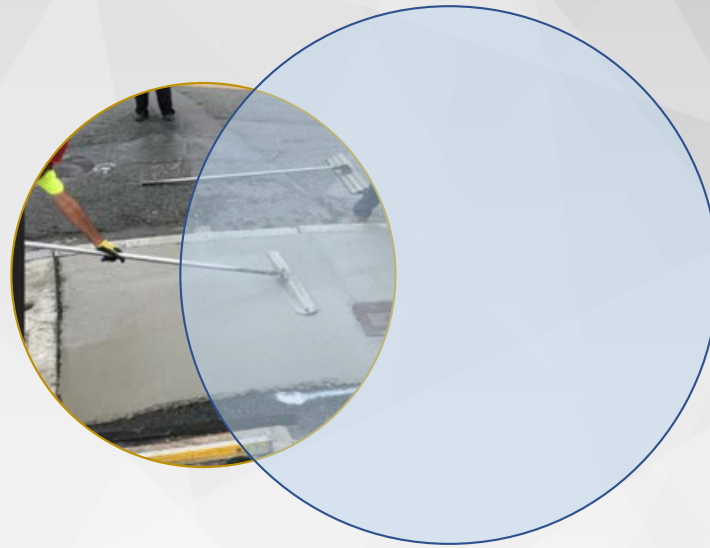
Finishing...

- The finisher is usually the first one blamed...
- Sometimes it is warranted...
- We aren't "finishing it the same way we always have..."



Finishing...

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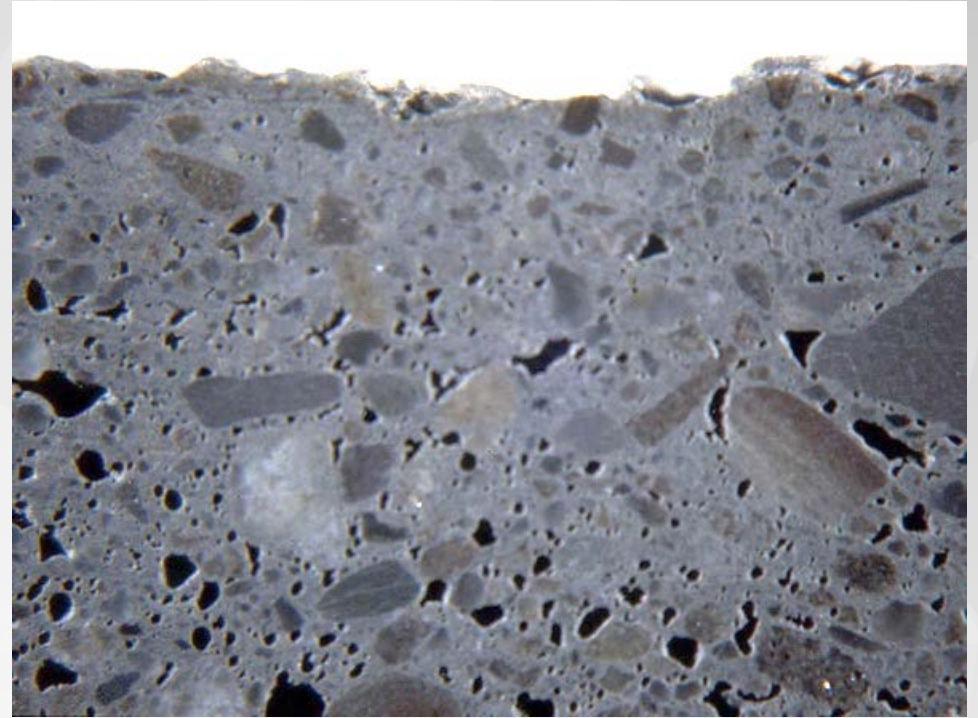
Finishing...

- Isn't being done "the same way we always have..."
 - Changes in concrete
 - Labor changes
 - Economics
- And sometimes it isn't being done correctly...



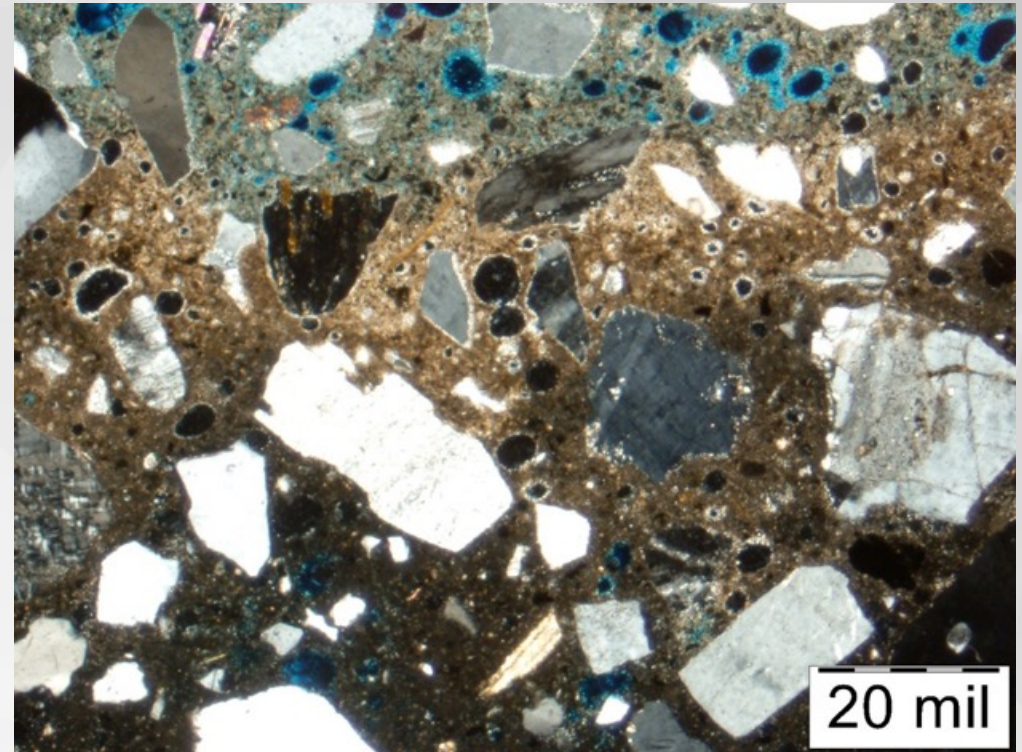
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- Can remove air from the near-surface.



Finishing...

- Isn't being done "the same way we always have..."
 - Changes in concrete
 - Labor changes
 - Economics
- And sometimes it isn't being done correctly...
- Can remove air from the near-surface.
- Can trap bleed water.



Finishing...what about certification?

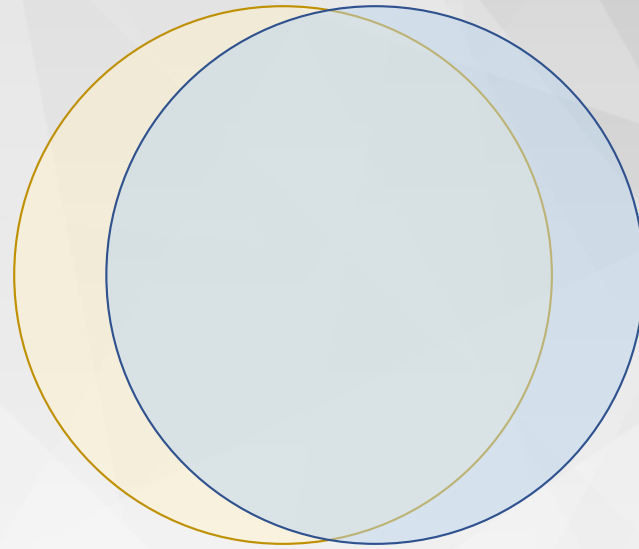
- ACI Flatwork finisher certification exists
- It doesn't exactly cover sidewalks
- Not a bad idea, but...
- Has associated costs
 - Actual time and money
 - Potential for "beta error"
- Only means you know how to do it "correctly", not that you will
- Needs incentives, such as pay factors, and oversight to make it worthwhile



PCA trowel photo – used with permission

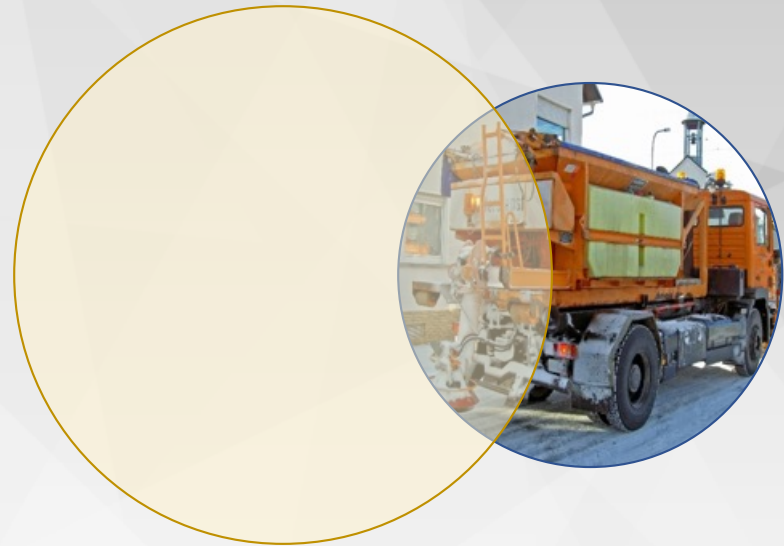
De-icing...

- De-icing is known to exacerbate the problem
- De-icing has changed over the years
 - More emphasis on clear paths of travel
 - New materials
 - Pre-treatment of salt and pre-application of brines



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- De-icing is known to exacerbate the problem
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De-icing...

- Is sometimes clearly associated with damage patterns, sometimes not...
- Note that concrete should be able to survive deicing salts, but our testing hasn't evolved to address changes in de-icing technology...



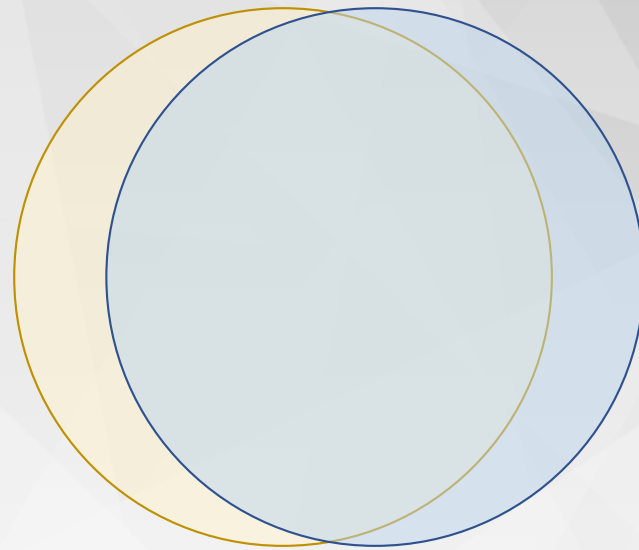
De-icing – when can I first apply them?

- Sometime between now and never.
- Industry does not have a definitive answer.
 - “1 to 3 months”
 - “1 year”
 - After the first freeze-thaw cycle.
 - “After a period of drying”
- Most of these are UNREALISTIC
- Our recommendation:
 - Best bet is to not de-ice for the first winter
 - More realistically, do not de-ice until 2 to 3 months
 - Protect the concrete with a silane or siloxane sealer
 - Read the bag for application rates



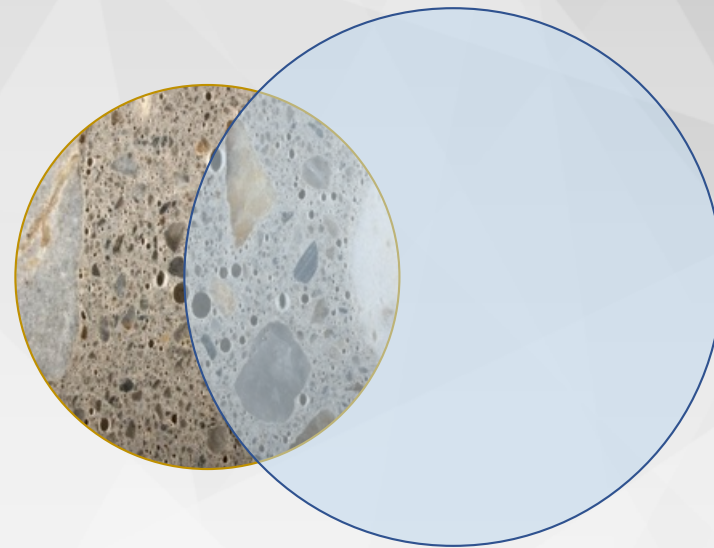
Materials...

- Changes in cements
- Changes in admixtures
- Changes in pozzolans



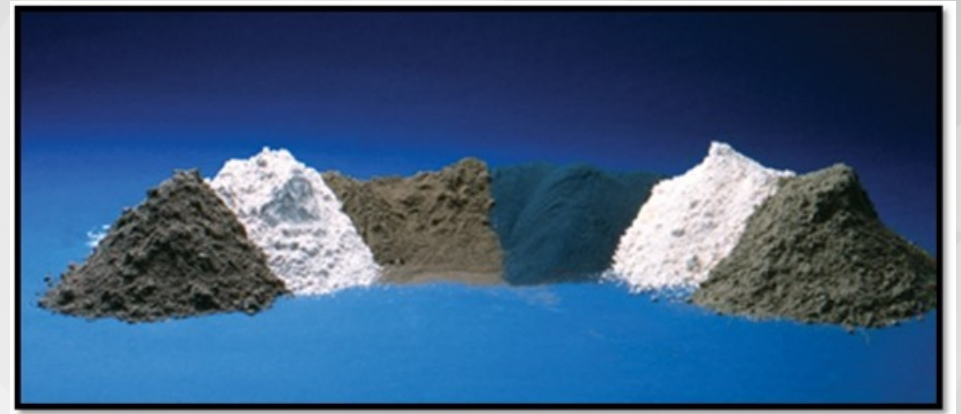
Materials...

- Changes in cements
- Changes in admixtures
- Changes in pozzolans



Materials

- Cements are finer
- SCMs are common, we are even seeing blends of three
- SCM sources are in flux
- These change
 - Finishing “feel”
 - Timing of finishing
 - Bleed
 - Strength gain



Material effects include...

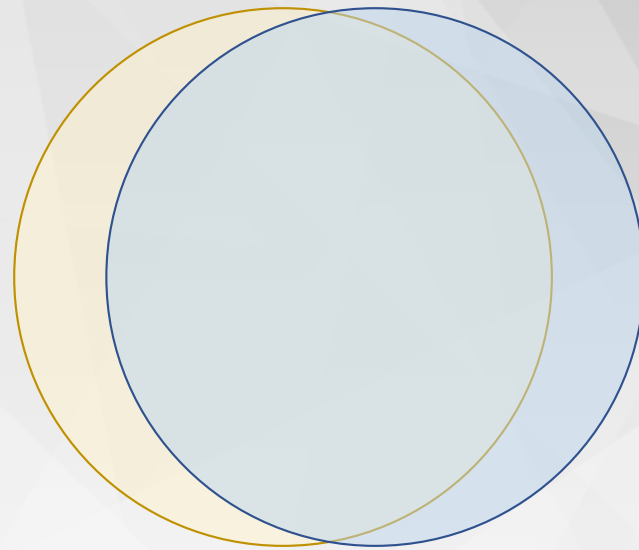
- Air-entrainers are different now; typically see synthetics
- Interactions with other admixtures, particularly polycarboxylates
- Sensitivity to process
- These changes don't make the concrete "bad", they make it different



PCA photograph – used with permission

Specifications...

- Sidewalks are often an afterthought
- Not really ACI 318, not really AASHTO...
- Often unrealistic curing
- Haphazardly enforced
- Weak on testing
- Haven't been updated to reflect current practice



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- Sidewalks are often an afterthought
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- Weak on testing
- Haven't been updated to reflect current practice

Nominal maximum aggregate size, in.*	Air content, percent	
	Exposure Class F1	Exposure Classes F2 and F3
3/8	6	7.5
1/2	5.5	7
3/4	5	6
1	4.5	6
1-1/2	4.5	5.5
2 [†]	4	5
3 [†]	3.5	4.5

*See ASTM C33 for tolerance on oversize for various nominal maximum sizes.
†Tolerances apply to total mixture. When testing concretes, however, particles larger than 1-1/2 in. are removed by sieving and air content of the sieved fraction (tolerance on air content as determined by the air content of total mixture) is computed from the air content of the material passing the 1-1/2 in. sieve in accordance with ASTM C456.

Specifications...

	Strength (psi)	w/cm	Air	SCM Limits
ACI 201.2-01	4,000	0.45	4.5-7.5	[no mention]
ACI 201.2-16	4,500	0.45*	4.5-7.5	Max. limits given
Mass. Building Code	3,500	-	4.5-7.5	[no mention]
AASHTO (LRFD Bridge)	4,000	0.45	4.5-7.5	[no mention]
Typical DOT	4,000	-	5.0-6.0	Min./Max limits given
ACI 318-95	4,500	0.45	4.5-7.5	Max. limits given
ACI 318-14	5,000	0.40	4.5-7.5	Max. limits given
City of Boston	4,000	-	5.5-7.5	None allowed

- All for wet, with deicer exposure

Specifications...

To think about

- Recommendations are based on prior testing and have evolved; have your specifications kept up?
- Deicing technology has changed; does what worked before work now?

Concerns

- Finishability challenges
- Hot weather protection
- Curing becomes more important
- Cost: labor and materials

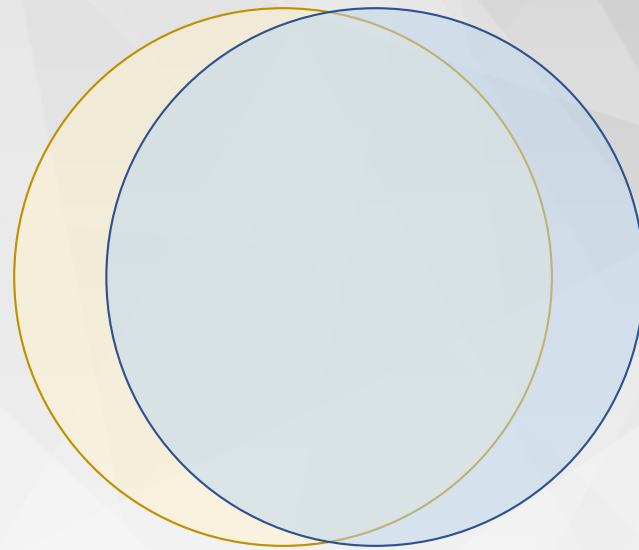
Specifications

- Check your testing requirements and frequency
 - Owners
 - Contractors
 - Producers
- Enforce your testing requirements to level the field
- Testing is only as good as the tester
- But remember, the in-situ concrete isn't tested



Curing...

- Is critical to performance
- Provides for hydration and reaction of the cement in the near-surface concrete



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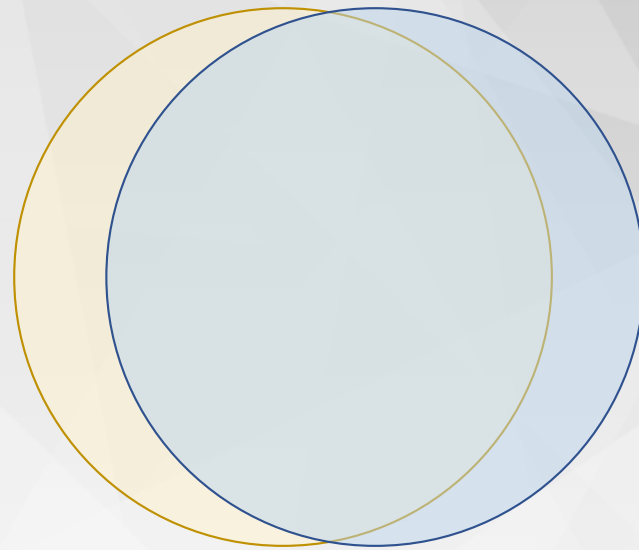
Curing

- Absolutely necessary for good concrete
- Absolutely impractical for miles of sidewalk when you have to keep businesses open
- Curing compounds are a mixed bag
 - Help early
 - Can interfere with later coatings
 - New cure/seals look promising



Economics...

- Are the driver of the entire system
- Critical to staying competitive in the market
- Affect finishing, curing, materials, exposure, time to first exposure...



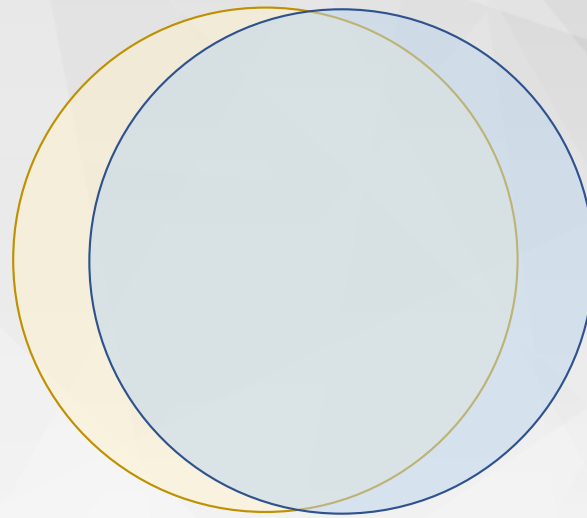
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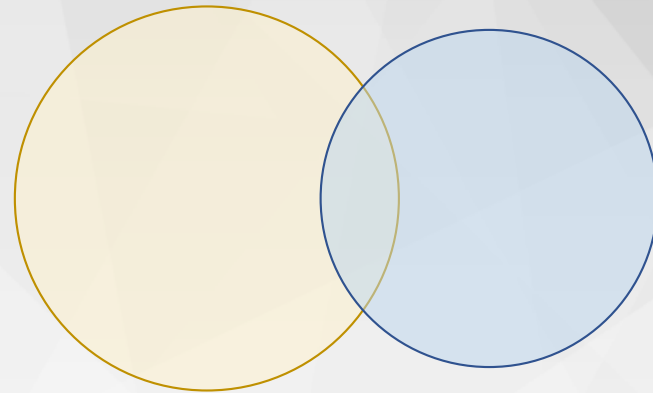
Maybe a combination...

- We have always had concrete
- We have always had winter
- It worked pretty well in the past



Maybe a combination...

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Maybe multiple things changed...

Let's collect our thoughts

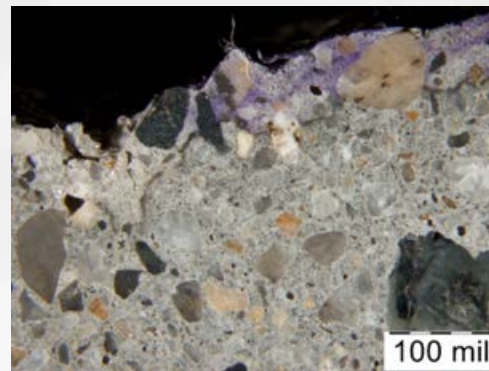
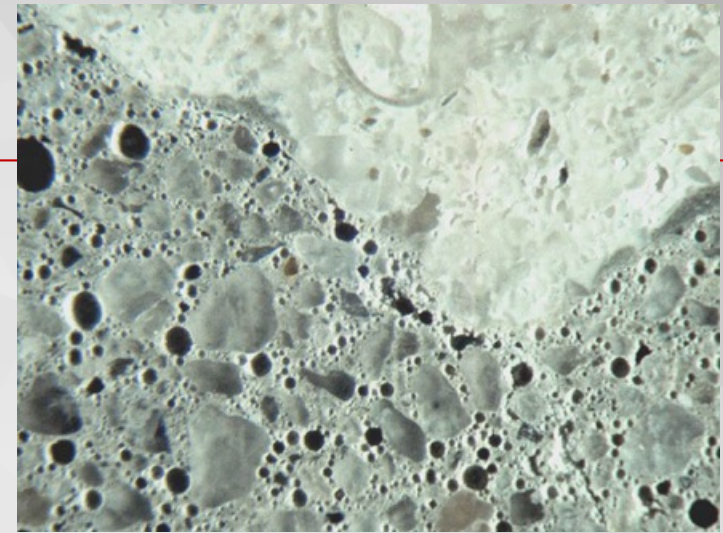
So far, we have learned...

- There is a lot going on here
- It is a systems-level problem, not an item-level problem
- As a system-level problem, there is a real question of system “robustness”
- Different types of problems manifest in a similar way, making them hard to tell apart



Likely contributors...

- Exposure
- Finishing
- Deicing salts
- Materials
- Specifications
- Curing
- Economics



**So how do we move
forward?**

Let's look at some options...

- Group by when they get implemented
- Realize that different ones are appropriate for different projects – you need to balance cost, risk, and reward
 - Late-season placement at the entrance to a signature building?
 - June placement at the dumpster pad?

Before construction...

- Specifications – materials, testing, curing, sealers...
 - Make sure that all are bidding to the same expectations and requirements – this may take some education and time
 - Probably want 0.40 w/cm; 5,000 psi strength, 5.0-8.0% air
 - Probably an acrylic/silane-based cure and seal
 - Probably want to test the concrete often – maybe even core
 - Pre-qualify concretes
- Planning – timing, crews, suppliers, expectations...
 - Start testing mixes, maybe with updated tests that reflect today's practices and deicers
- Payment factors – to reinforce & reward doing it the right way, all the time

During construction...

- Use proper techniques and best practices
 - Incent and motivate the workers
 - Certification of finishers – maybe, but that won't solve problem if finishers don't want it to, and runs risk to the labor force
- Inspection, testing, and monitoring
 - Hold everyone to the same standards
 - Testing for what matters is not so straightforward
 - “Keeps honest people honest” and levels the playing field
- Protect and cure
 - Prevent early exposure
 - Give the concrete a chance to succeed

Avoiding scaling – after construction...

- Control the exposure
 - Choose your deicer carefully
 - Apply as recommended, and to minimum extent required
 - Consider alternates to early salting
 - Remove excess and rinse as often as you can
- Consider sealers
 - Provide additional margin, especially for concrete cast late in season
 - Benefits likely outweigh the costs

Wrap up...

A multi-phase issue with many contributors...

- Everyone owns a bit, and everyone can help improve the situation
- Requires a cooperative response
- Adjust the way we think about it – they are big \$, and big impact
- Need to recognize the economics of the projects
 - Maintain an even field with uniform expectations, testing, and enforcement
 - Incent all parties – share risk and reward
- We can be successful if we all do our part!



Questions?

This concludes The American Institute of Architects
Continuing Education Systems Course



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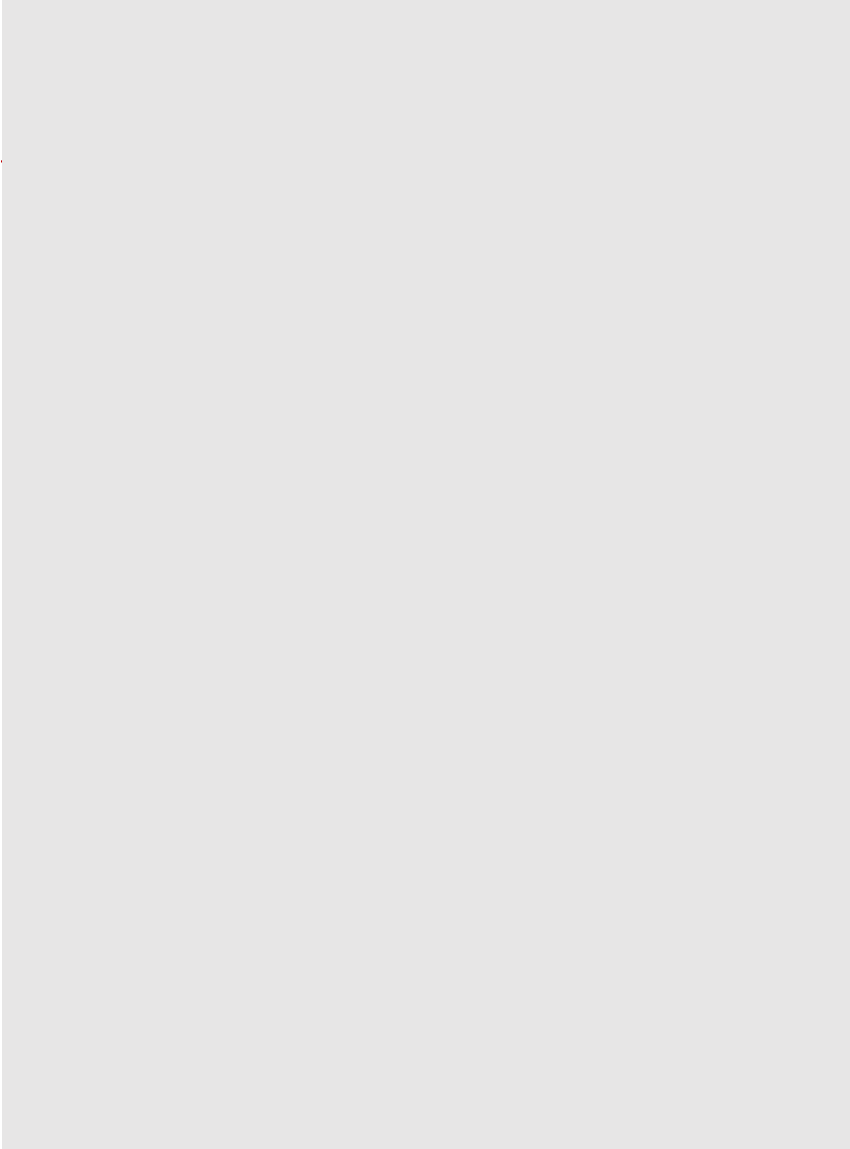


Brett Holland
rbholland@sgh.com









SECTION BREAK

Option 1

1. Keep this photo as your background image.
2. Delete this text box when finished.

Option 2

1. Insert new, full-bleed photo to replace this background image.
2. Send new image to background.
 1. Right click on photo.
 2. Hover over “Send to Back” to open sub-menu.
 3. Click on “Send to Back” in sub-menu.
3. Delete this text box when finished.

ACI 201, ACI 318 and AASHTO – Where does concrete flat work fit?

Durable concrete is...

ACI 201.2R-16 Exposure Classes

Knowing your Exposure Class
(ACI 201 and 318, which are the

Table 4.2.3.1a—Freezing-and-thawing exposure classes

Exposure Class	Severity	Condition
F0	Not applicable	Concrete not exposed to freezing conditions
F1	Moderate	Concrete exposed to freezing and thawing conditions, but very low probability of concrete being near saturation at time of exposure ^a
F2	Severe	Concrete exposed to freezing and thawing conditions, with a high probability of concrete being near saturation at time of exposure, but no deicing chemical exposure ^b
F3	Very severe	Concrete exposed to freezing and thawing conditions as well as deicing chemicals ^c

^aExamples are vertical surfaces above the level of snow accumulation or horizontal elevated floors in areas protected from direct exposure to moisture.

^bExamples are: vertical surfaces below the level of snow accumulation; vertical surfaces with sufficient moisture exposure to allow the concrete to be near saturation prior to freezing; retaining walls or other vertical elements with one side exposed to moisture; and slab-on-ground that is not protected from freezing.

^cExamples are: vertical surfaces that may have deicing-chemical-contaminated snow piled against them; sidewalks or pavements that receive deicing chemicals; and concrete that received frequent exposure to seawater as well as freezing-and-thawing conditions.

Durable concrete is...and

Designing your concrete mixture to meet the freeze-thaw durability requirements of ACI 201

Table 4.2.3.2.4—Recommended air contents

Nominal maximum aggregate size, in. (mm)	Air content, percent*	
	Exposure Class F1	Exposure Class F2 and F3
3/8 (9.5)	7	7.5
1/2 (12.5)	7	7
3/4 (19)	6.5	7
1 (25)	6.5	6.5
1-1/2 (37.5)	6	6.5
2 (50)	6	6
3 (75)	5	5.5

*Field tolerance on air content is recommended as $\pm 1/2$ percent. Air content recommendations are based on 18 percent air in the paste portion of the concrete with a Vinsol resin air-entraining agent (from an analysis of work by Klieger [1952]). Mixture proportions based on guidance in ACI 211.1 for angular coarse aggregates along with the maximum w/cm values from Table 4.2.3.1b were used to determine the air content recommendations. Mixtures using rounded aggregates will require approximately 1 percent less air due to the lower paste contents associated with rounded aggregates.

Table 4.2.3.1b—Requirements by freezing-and-thawing exposure class

Exposure Class	Minimum \bar{f}_c , ¹ MPa (psi)	Maximum w/cm ²	Air content	Limits on cementitious materials
F0	No restriction	No restriction	No restriction	No restriction
F1	25 (3500)	0.50	Table 4.2.3.2.4	No restriction ³
F2	25 (3500)	0.45	Table 4.2.3.2.4	No restriction ³
F3a ⁴	32 (4500)	0.45**	Table 4.2.3.2.4	Table 4.2.3.1c ¹
F3b ⁴	32 (4500)	0.45**	Table 4.2.3.2.4	No restriction ¹

¹The minimum average compressive strength that should be achieved before initial exposure to freezing and thawing.

²The maximum w/cm for the in-place concrete to provide adequate restriction of freezable water in the properly-cured concrete.

³High cementitious material replacement for portland cement frequently results in lower rates of strength gain. Care should be taken to ensure that adequate curing (moisture, temperature, and time) is provided so that the minimum \bar{f}_c is achieved before initial exposure to freezing and thawing.

⁴Hand-finished surfaces.

⁵Formed and machine-finished surfaces.

**A lower w/cm may be needed when corrosion is of concern (ACI 318-14).

Table 4.2.3.1c—Cementitious materials limitations for Exposure Class F3b

Cementitious materials	Maximum percent of total cementitious materials by mass ¹
Fly ash or other pozzolans conforming to ASTM C618	25
Slag conforming to ASTM C989/C989M	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50 ¹
Total of fly ash or other pozzolans and silica fume	35 ¹

¹The total cementitious materials also include ASTM C150/C150M, ASTM C595/C595M, ASTM C845/C485M, and ASTM C1157/C1157M cements.

The maximum percentage should include:

- (a) Fly ash or other pozzolans in Type IP blended cement, ASTM C595/C595M or ASTM C1157/C1157M
- (b) Slag used in the manufacture of an IS blended cement, ASTM C595/C595M or ASTM C1157/C1157M
- (c) Silica fume, ASTM C1240, present in a blended cement

²Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of total mass of the cementitious materials.

Durable concrete is considering the enhanced freeze-thaw durability requirements of ACI 201

CODE			COMMENTARY	
Table 19.3.2.1—Requirements for concrete by exposure class				
Exposure class	Maximum $w/cm^{(1,2)}$	Minimum f'_c , psi	Additional requirements	Limits on cementitious materials
			Air content	
F0	N/A	2500	N/A	N/A
F1	0.55	3500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete	N/A
F2	0.45	4500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete	N/A
F3	0.40 ⁽³⁾	5000 ⁽³⁾	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete	26.4.2.2(b)

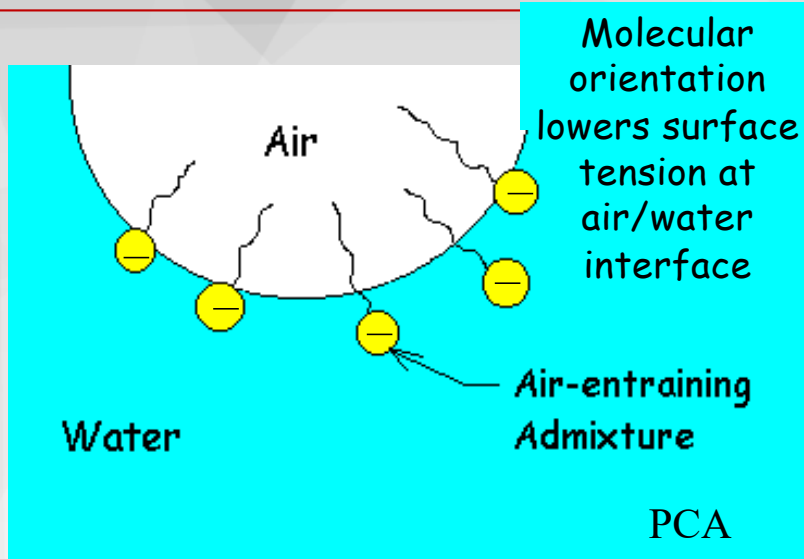
Table 19.3.3.1—Total air content for concrete exposed to cycles of freezing and thawing

Nominal maximum aggregate size, in.	Target air content, percent	
	F1	F2 and F3
3/8	6.0	7.5
1/2	5.5	7.0
3/4	5.0	6.0
1	4.5	6.0
1-1/2	4.5	5.5
2	4.0	5.0
3	3.5	4.5

Durable concrete is considering AASHTO Requirements

- Limits w/cm to 0.45
- Requires providing a minimum 30 day drying period after curing before allowing the use of deicers.

Why Air-Entrainment Important?

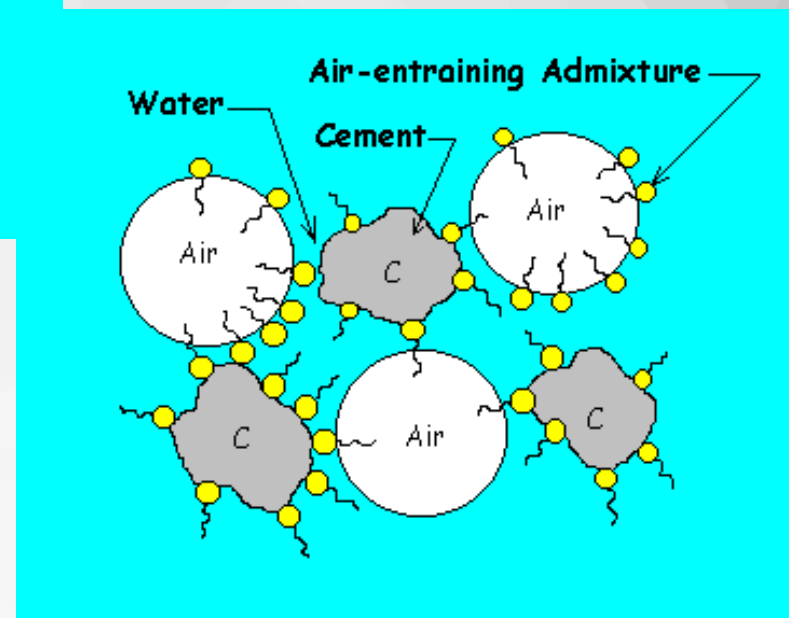


PCA

Acts at Air-Water Interface

- Entrained air voids (~0.05-1mm) remain stable throughout hydration and remain after setting

- AEA's are surfactants.
- Non-polar chain molecule, with a -ve charge at one end
- Cause water to foam during mixing



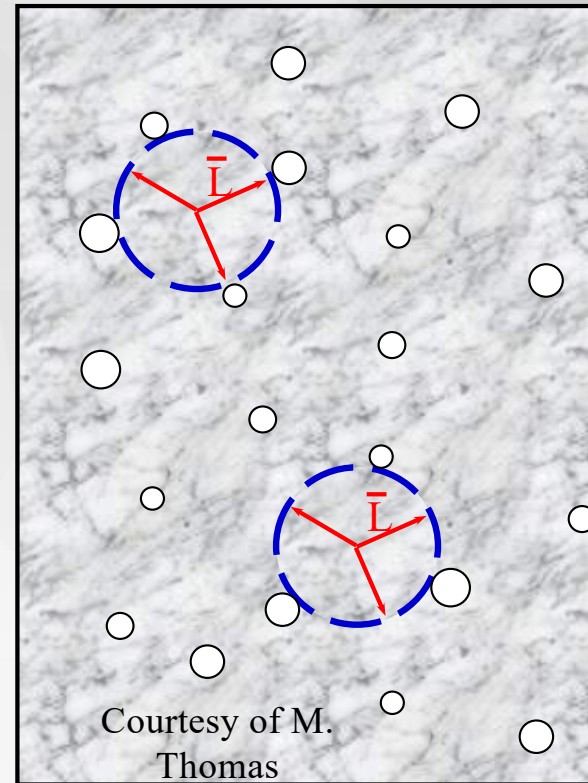
Characteristics of Frost Resistant Air Void System

ASTM C 457

- Spacing factor ≤ 0.008 in (0.203 mm)
- Specific surface ≥ 600 in²/in³ (24 mm²/mm³)
- Voids per linear inch: 1.5 - 2 times the percentage of air

Air Void Spacing & Volume

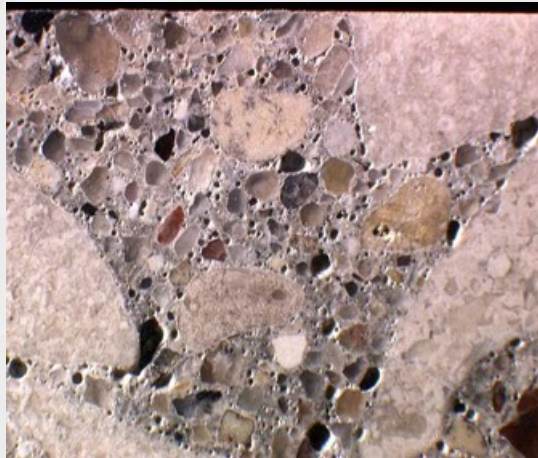
- **Spacing factor (\bar{L}):** the maximum distance of any point in the the cement paste from the periphery of an air void.
- **Specific surface:** the surface area of a quantity of air voids that have a total volume of 1 in³ (16 cm³).



Air-Entraining Admixtures (AEAs)

- 4 Categories:
 1. Wood Derived Products: Vinsol[®] resin, Tall oil, Wood rosin (Less available)
 2. Synthetic Materials: Alky-aryl sulfonates and sulfates (Now most common)
 3. Vegetable Acids: Coconut fatty acids, Alkanolamine salt
 4. Miscellaneous: Alkali/alkanolamine acid salts, Animal tallows
- Must pass ASTM C 260

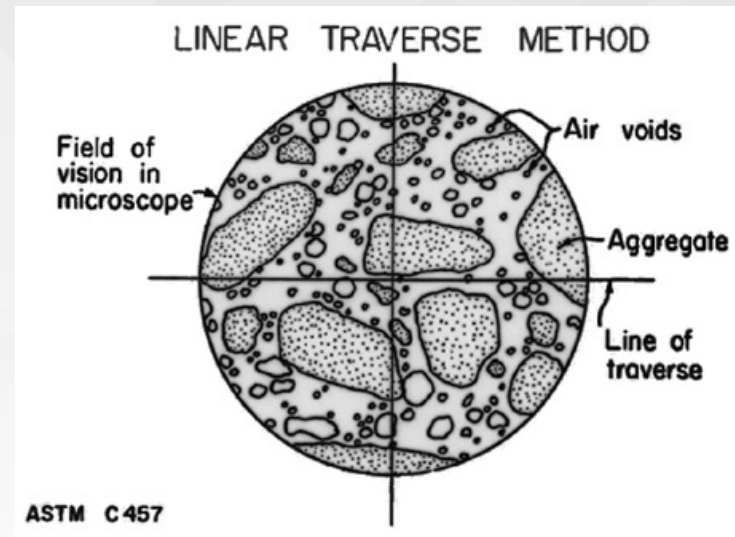
Measuring Air in Hardened Concrete

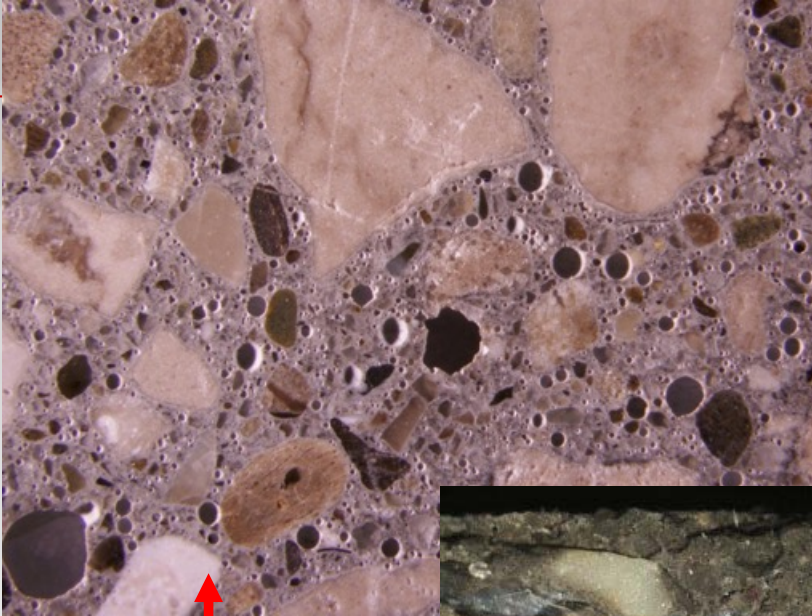


- ASTM C 457 provides 2 methods

A: Linear Traverse Method

B: Point Count Method





Good Air



Low Air



Low Air in the Surface Region (Overfinishing)

What's Different Now?

Batching and Transporting Durable Concrete

- Batch to meet the ACI design requirements for air and w/cm
- Know how your AEA's perform
- Slump;
 - <3-in. (75mm),
 - >6-in. (150mm)
- Temperature
- Quality Control Testing (more on this later)

Placing Finishing and Curing Durable Concrete

- Placement/ Pumping
- Consolidation
- Finishing
- Curing



Quality Control

Concrete materials

Cement

- Admixture dosage based on cement content
- Higher fineness requires higher dosage
- Alkalies increase air entrainment

Supplementary Cementitious Materials

- Fly ash, silica fume may increase dosages 2 – 6 times
- Be careful for unburned carbon in fly ash

Aggregates

- Increased sand content helps air entrainment
- Ultra fines (< #200) harmful

Admixtures

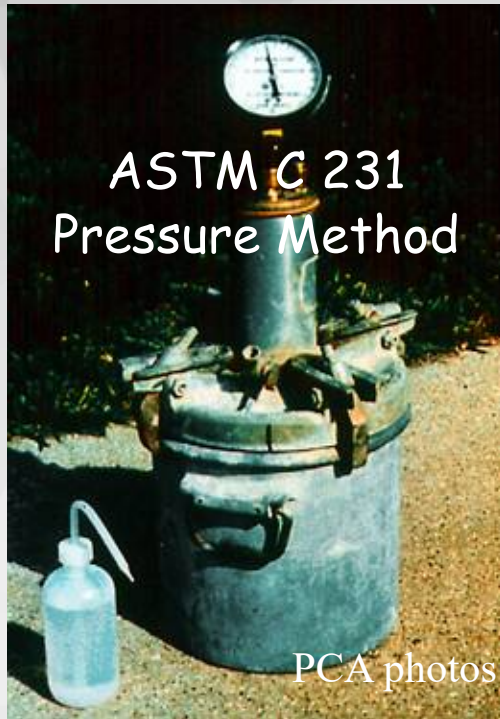
- Compatibility should be examined
- Added separately to mixtures
- Some superplasticizers affect spacing factor

QC Testing of Materials and Concrete; Submittals



Measuring and Monitoring Air Content in the Field

PCA photos



ASTM C 138
Gravimetric
Method



Measure total air volume in a sample compacted in a standard way.
Cannot distinguish between entrained and entrapped air.
Does not consider effects placing/finishing operations.

Avoid early-age exposure by...

- Avoid placing flatwork after September
- It can be done but you have to understand the risks



What can I do about freeze-thaw scaling?

- Confirm the cause and determine the extent
 - Good investigation, including a hands-on survey; use a chain drag and hammer
 - More survey = fewer surprises = more certainty
 - Remove samples and test (petrography, NOT strength)
- Determine the response
 - How deeply is the concrete affected?
 - How widely is the concrete affected?
 - How much do I have to spend?
 - How do I combine these needs?
 - Do I just fix what is bad today or slow/stop it in the future?

Conclusions

- We can improve the odds and achieve scaling resistant flatwork
- We need to consider life-cycle cost
- If we do not want to lose the market to asphalt we need a cooperative response to minimize this problem

Scaling Notes Conclusions

- Freezing scaling is caused by water, and made worse by de-icing salts
- Nothing protects saturated concrete, so let it dry
- Use a sealer or membrane
- Avoid placing late in season, if you do, use a sealer!!
- Repair is hard - it will never be the same
- Use a durable concrete

CODE

TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. w/cm^*	Min. f'_c , psi	Additional minimum requirements	
			Air content	Limits on cementitious materials
F0	N/A	2500	N/A	N/A
F1	0.45	4500	Table 4.4.1	N/A
F2	0.45	4500	Table 4.4.1	N/A
F3	0.45	4500	Table 4.4.1	Table 4.4.2
			Cementitious materials†—types	

TABLE 4.4.1 — TOTAL AIR CONTENT FOR CONCRETE EXPOSED TO CYCLES OF FREEZING AND THAWING

Nominal maximum aggregate size, in.*	Air content, percent	
	Exposure Class F1	Exposure Classes F2 and F3
3/8	6	7.5
1/2	5.5	7
3/4	5	6
1	4.5	6
1-1/2	4.5	5.5
2 [†]	4	5
3 [†]	3.5	4.5

*See ASTM C33 for tolerance on oversize for various nominal maximum size designations.

†Air contents apply to total mixture. When testing concretes, however, aggregate particles larger than 1-1/2 in. are removed by sieving and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is computed from value measured on the sieved fraction passing the 1-1/2 in. sieve in accordance with ASTM C231.