Best Construction and Maintenance Practices for Long-Term Durability

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National Concrete Pavement Technology Center
Tech Center

Construction and Longevity

Construction and Longevity

- Choosing the right ingredients and the right recipe are important to make a great meal…

Construction and Longevity

- …but everything still needs to be cooked properly!

Construction and Longevity

- Mix design and proportioning are important for achieving long-term durability, but the construction process just as crucial to making sure a concrete structure meets its design goals

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Image: ACI

Steps to Long Life

Target performance
Workability – response to handling / vibration as needed
Durability – survive the environment
Strength – enough

Design Levers
Gradation – Tarantula Curve
Paste Volume – Fill void space + a bit
Cementitious – w/cm, SCMs
Admixtures – AVS, flow, bleed rate

Batching
Uniformity – Water control
– Cementitious blending
– Adjustments for incoming variability
Mixing – Time and energy

Transport
Mixing – equipment used
Workability
– Time and weather
– Added water / admixtures
Segregation – mixture

Placement
Workability – Time and equipment
Air-void-system – pumping, vibration, finishing
Uniformity – Handling and vibration

Finishing
Surface – air, bleeding, weather, setting time, smoothness
Curing – methods, duration
Sawing – Timing, equipment

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Construction Practices are Critical to Longevity

- Disruptions in delivery and placement can lead to cold joints:

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Image: Structural Guide

Construction Practices are Critical to Longevity

- Over-vibration can lead to surface defects and segregation:

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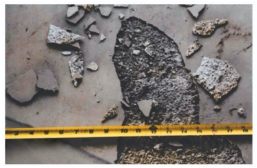
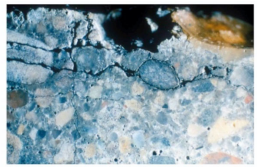
L Image: Minnich

Construction Practices are Critical to Longevity

- Improper finishing can lead to delamination and scaling:





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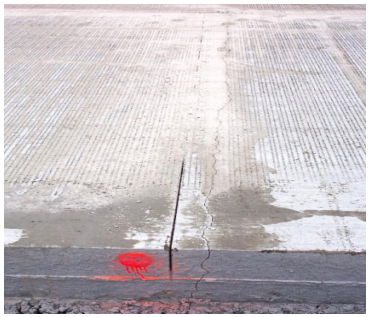
Images: PCA

Construction Practices are Critical to Longevity

- Late joint sawing can lead to random cracking:



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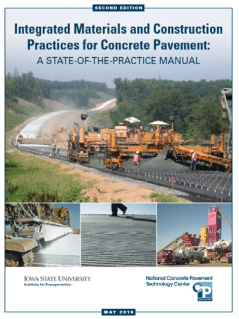
CP Tech Center Programs

- Integrated Materials and Construction Practices Manual:



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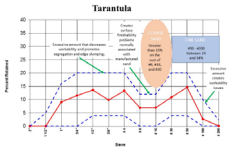
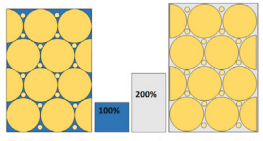
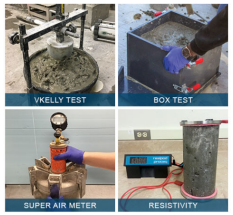
CP Tech Center Programs

- Performance Engineered Concrete Paving Mixtures (PEM)
  - Developing better tools to design, specify, and measure important properties of concrete pavement mixes





Adding intermediate aggregates → less paste is required



L Image: Oklahoma State University

CP Tech Center Programs

- Next steps:
  - Performance Centered Concrete Construction
    - Addressing everything between the batch plant and the grade that influences concrete durability and performance
      - Batching
      - Transport
      - Handling
      - Placement
      - Consolidation
      - Finishing
      - Curing
      - Sawing

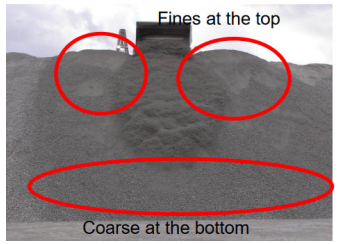
Tech Center

Batching

- The batching and mixing process can introduce significant variability to concrete production
  - Dry batch vs. central batch
  - Timing and uniformity of addition of materials, admixtures

Batching

- Things to watch for handling aggregates:
  - Segregation
  - Moisture content



Batching

- Variations in aggregate gradation and moisture content from mix-to-mix can cause swings in concrete uniformity and workability
  - If this causes difficulty with placement, consolidation, finishing, etc., it can lead to durability problems down the line

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Batching

- How can we address variability that stems from the batching process?
  - Monitor aggregate moisture contents and make mix adjustments
  - Test early and often for concrete uniformity and report back to the plant
  - Can we develop better testing tools to measure uniformity?
    - Long-term goal: integrate them in real-time with the construction process

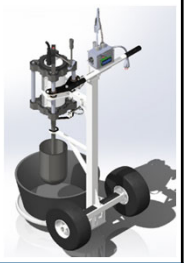

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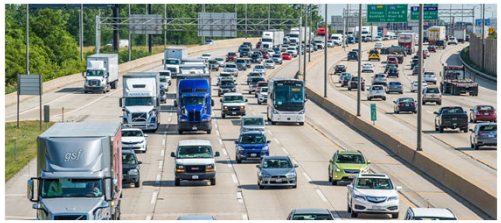
Image: Minnich

Transport

- Timing and consistency of delivery from the plant to the site can be affected by:
  - Weather
  - Traffic
  - Site Conditions
  - Workforce



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Transport

- Potential downstream effects of disruptions in transportation:
  - Varying workability and uniformity
  - Mix can fall out of temperature specification
  - Need for water and admixture additions on-site
  - Changes to pump pressure, vibration frequency
  - Cold joints in structures
  - Paving machine stops and starts

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Transport

- New QC tools can help producers and contractors keep track of adjustments made in transport and when arriving on-site
- Eventually, better sensors and test methods could be integrated with mixing and placement processes to allow for automated adjustments

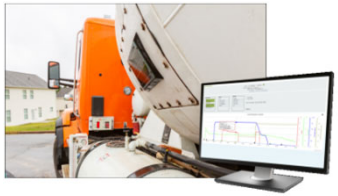

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Image: Command Alkon

Handling and Placement

- Workability of the concrete delivered to the project site needs to meet the needs of each placement method
- Aim for uniform delivery and avoid mishandling concrete in ways that change the properties of the material delivered to the site – segregation, air content, water content, etc.

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Image: PCA

Placement

- Make sure standing water is moved or displaced from inside forms and that forms will not absorb water
- Use best practices to avoid segregation
  - Don't allow concrete to pile up so that you're forced to spread it out by hand across the deck/grade, into corners, etc.

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Image: PCA

Pavements and Slabs on Ground

- Subgrade and subbase preparation
  - Ensure stable, adequate, and uniform support
    - Settlement cracking can drive future durability issues
  - Moisten subgrade to prevent absorption of mix water
- Follow best practices for installation of vapor retarders and insulation to prevent moisture damage to floor coverings

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Pumping

- Pumping has developed into one of the most common methods for concrete placement
- Common to observe a loss of air content after pumping
  - 0.5% to 1% is common – but it's sometimes worse
  - Factors that appear to worsen air loss:
    - Higher pump pressures
    - Flowable mixtures
    - Vertical boom configurations
    - Sharp elbows in the boom configuration
  - Smaller (entrained) air bubbles should be more resilient
  - Current research working toward a better understanding of this phenomenon

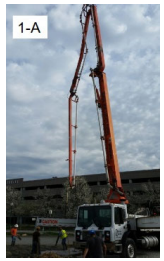


Image: NRMCA

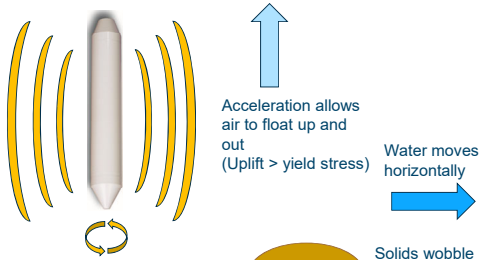
Consolidation

- Proper consolidation is needed to ensure durable concrete in-place
- How much do we need?
  - Enough to achieve sufficient embedment and bond between concrete and reinforcement
  - Enough to eliminate voids and release entrapped air
  - Not so much that the entrained air is knocked out
- Vibration is the most widely-used consolidation method

Image: Baker Concrete

Vibration

- Vibration energy is a function of:
  - Frequency
  - Amplitude
  - Duration
  - Spacing
- The energy you need to impart depends on:
  - Workability
  - Air void system



Shaft oscillates in a circle sending out P and S waves

Acceleration allows air to float up and out (Uplift > yield stress)

Water moves horizontally

Solids wobble And maybe rotate

Vibration

- Consequences of under-vibration
  - High entrapped air content
  - Honeycombing
- Consequences of over-vibration
  - Removal of entrained air
  - Separation of water from aggregate
    - Segregation
    - Excessive bleed water
    - Surface discoloration
    - Surface defects

Vibration

- Standard workability tests like the slump cone don't always give us good insight into how a concrete mix responds to vibration
- VKelly test:
  - A better measure of uniformity and workability under vibration
  - Currently developed for paving mixtures

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Air Void System

- The air void system can be affected by nearly every stage of the construction process:
  - Transport
  - Handling
  - Pumping
  - Vibration
  - Finishing
- If the air void system isn't dialed in, it can also disrupt batching and the construction process!

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Air Void System

- Remember what we want from our air void system
  - Small, uniform, well-distributed air bubbles that help protect against freeze-thaw damage and scaling
- Testing at both the plant and project site can help detect problems and allow for timely adjustments at the plant
  - Behind the paving machine, after pumping…

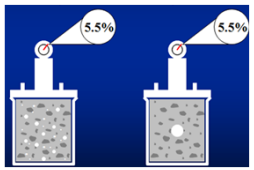

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Image: FHWA

Air Void System

- The Super Air Meter provides insight into the distribution of our air void system beyond total air content
- Future: will it be possible to make real-time, non-destructive air content measurements and make rapid adjustments?

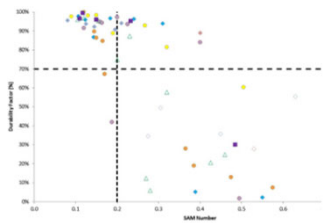

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Image: Oklahoma State University

Finishing

- Proper finishing in flatwork, exterior concrete, and pavements is important to achieve a durable, long-lasting surface

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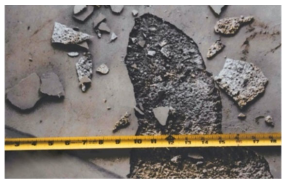
Images: PCA, The Constructor

Finishing

- Delamination or scaling may result from:
  - Finishing while bleed water is present at the surface
  - Hard troweling of air-entrained concrete
  - Overworking the surface



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Images: PCA

Finishing

- Pavements
  - Things are working best when:
    - Finishing is mostly achieved by the paving machine
    - Finishers are focused primarily on correcting minor imperfections and voids
    - No water is added to the surface to finish
  - Real-time smoothness monitoring

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Curing

- Curing has a significant influence on the final properties of concrete
  - Strength
  - Shrinkage
  - Surface properties
  - Transport properties
  - Durability

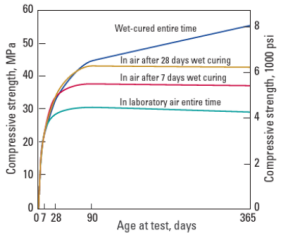

FIGURE 17-1. Effect of wet curing time on strength gain of concrete (Gonnerman and Shuman 1928).

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Curing

- What do we need to do?
  - Keep the concrete wet and warm (but not too warm) to allow hydration to proceed to its fullest extent
  - Prevent evaporation of moisture from exposed surfaces
  - Ensure complete and uniform coverage
- Things to watch out for:
  - Harsh weather conditions, e.g. cold, wind, sun
  - Changing weather patterns

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Curing

- Durability issues that may result from insufficient curing:
  - Plastic shrinkage and drying shrinkage cracking
  - Undesirable surface properties (e.g. scaling, crazing, dusting, abrasion resistance)
  - Susceptibility to freeze-thaw damage and other distresses driven by water infiltration like ASR

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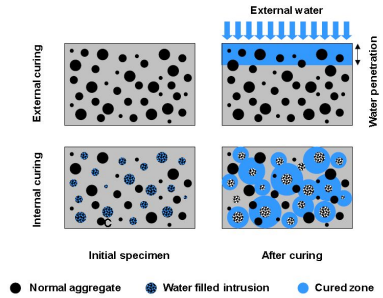
Internal Curing

- Introduction of additional moisture to assist with curing from within the mix



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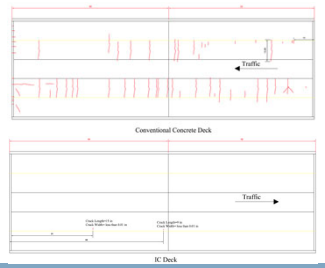
Internal Curing

- Promising results reducing shrinkage cracking in bridge decks
- Reduction in temperature and moisture gradients in pavements



Ohio DOT Test Project: 1-year Review

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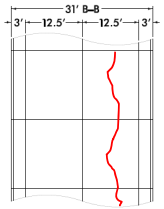
Internal Curing

- Most projects in the U.S. to date have used expanded lightweight fine aggregate
- Recent work is evaluating use of super absorbent polymers

Joint Sawing

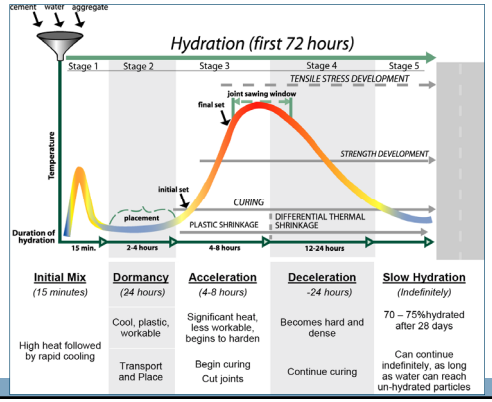
- Joints are where exterior concrete slabs and pavements are most susceptible to infiltration of water and de-icing chemicals
- It's crucial to saw cut joints at the proper time and depth to ensure good performance and durability of the system



Gutterline Jointing

Joint Sawing

- Sawing window:



Joint Sawing

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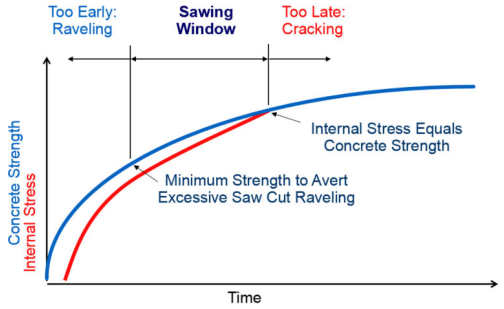
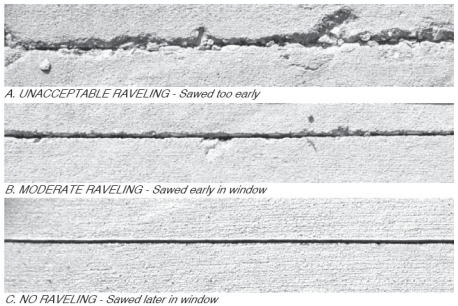


Image: ACPA

Joint Sawing

- Raveling:



A. UNACCEPTABLE RAVELING - Sawed too early

B. MODERATE RAVELING - Sawed early in window

C. NO RAVELING - Sawed later in window

Joint Sawing

- Be conscious of how weather and mix factors affect the sawing window
  - Weather can be unpredictable, and some mixes may be more susceptible to changes depending on the conditions
  - Hour-to-hour and day-to-day
- Weather:
  - Rising and falling temperatures
  - Sunny/cloudy
  - Wind
  - Humidity
- Mix:
  - Cementitious content and composition
    - SCMs, etc.)
  - Water demand
  - High early strength

Joint Sawing

- HIPERPAV
  - Software designed to help predict susceptibility to early age cracking based on mix design factors, weather conditions

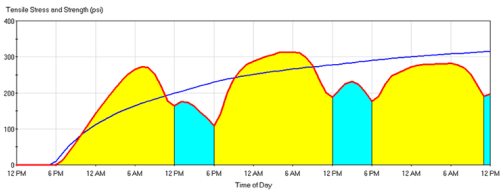


Image: FHWA

Next Steps and Future Goals

- With a better understanding of how our construction processes affect the concrete mix, we can:
  - Gain insight into the variability introduced at each stage in concrete batching, transport and placement
  - Use measurements at the plant and at the job site to make real-time adjustments during the project
  - Leverage improved tools and technologies to create a feedback loop between production and construction

Next Steps and Future Goals

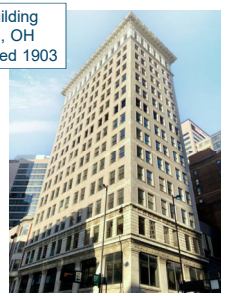
- Develop the best practices, guidance, and tools to make sure our durable concrete mix designs become durable concrete structures in-place:

Maintenance and Longevity

Maintenance and Longevity

- Designed and constructed correctly, concrete buildings and infrastructure are capable of fulfilling very long-term service life

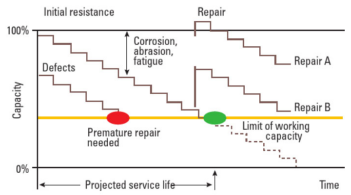
Ingalls Building
Cincinnati, OH
Constructed 1903

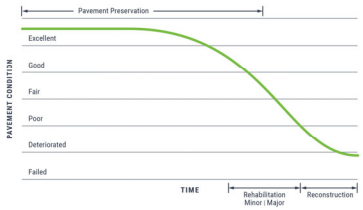


Old US 20, Moville, IA
Constructed 1921

Maintenance and Longevity

- Regular maintenance can go a long way to ensure that concrete meets or even exceeds its design life
- Timely maintenance and rehabilitation can also help make sure that early problems don't compromise the life of a structure





L Image: PCA

Concrete Structures

- Corrosion of reinforced concrete

R Image: NRMCA

Concrete Structures

- Corrosion culprits: chlorides, carbonation, and time

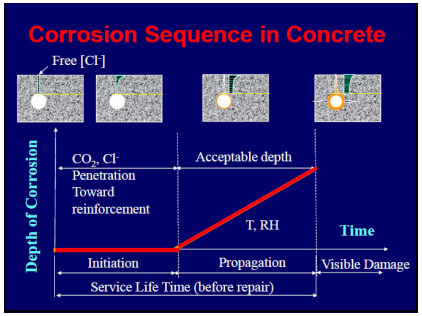


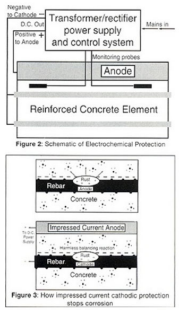
Image: Dr. Kejin Wang

Concrete Structures

- As a structure ages, carbonates, etc., there are proactive measures that can be taken to delay the onset of corrosion
- Keep water and chlorides out!
  - Penetrating surface sealers
  - Water repellant coatings
  - Overlays
  - Seal cracks

Concrete Structures

- Preservation of structures already experiencing corrosion damage is possible through several methods:
  - Corrosion inhibitors
  - Cathodic protection
  - Electrochemical chloride migration



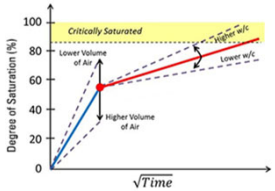
Images: Concrete Society UK

Pavements and Exterior Concrete

- Concrete structures and surfaces exposed to the elements face some of the harshest durability challenges
  - Moisture
  - Freeze-thaw cycles
  - De-icing chemicals

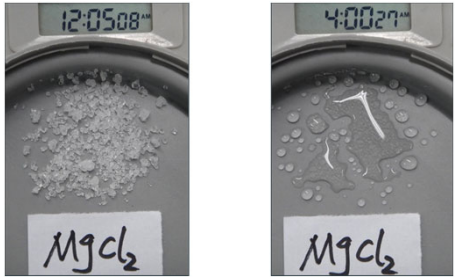
Protection from Water and De-icing Salts

- Freeze-thaw damage occurs when concrete becomes critically saturated and temperatures drop below freezing
- Exposed joint faces are most susceptible to saturation
- Infiltration of de-icing chemicals will also occur at joints



Protection from Water and De-icing Salts

- De-icing chemicals are an issue for multiple reasons:
  - They like to hang onto water and keep the concrete saturated



Protection from Water and De-icing Salts

- De-icing chemicals are an issue for multiple reasons:
  - They directly react with calcium hydroxide within the concrete microstructure itself to produce oxychlorides
    - Expansion nearly 3× greater than that of water freezing!

$$3Ca(OH)_2 + CaCl_2 + 12H_2O \rightarrow CaCl_2 \cdot 3Ca(OH)_2 \cdot 12H_2O$$

Calcium Oxychloride

Maintenance Practices

- Joints are where exterior concrete slabs and pavements are most susceptible to infiltration of water and de-icing chemicals
- Properly designing and proportioning the mixture is critical to reducing the susceptibility of concrete to joint deterioration
- Even if you have a pavement that is susceptible to this type of damage, or starting to experience it, there are maintenance and preservation activities to repair, slow, and prevent further damage

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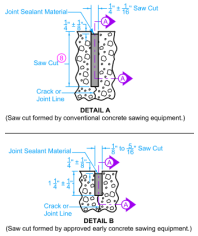
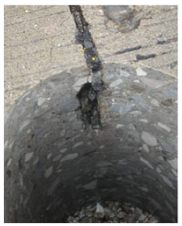
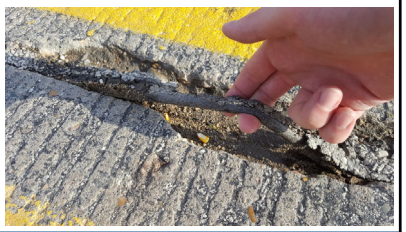
Joint Sealing/Filling

- It's never too late to clean out and seal (or re-seal) joints
- joint sealing vs. filling with hot pour asphalt sealant
- Backer rod is no longer recommended







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Joint Rehabilitation

- Before joint deterioration gets too bad…

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Image: Dale Harrington

Joint Rehabilitation

- …it can still be repaired and restored through partial depth patching

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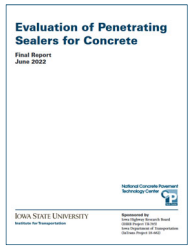
Surface Sealers

- Another option when pavements appear susceptible to joint deterioration is to apply a breathable, penetrating surface sealer Laboratory test protocol for evaluating the suitability of surface sealers for pavement joints published this year:



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Winter Maintenance

- Concrete can stand up to de-icing challenges when we use a good mix, good construction practices, and proper maintenance
- One thing to keep in mind: what about the first winter?
  - Concrete placed before the fall should be fine
  - What about late season placements in climates where temperatures start to drop in the fall?
    - Curing and hydration can slow quite a bit in the short-to-medium term
    - Mixes with greater SCM replacement rates are generally more sensitive to falling temperatures

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Winter Maintenance

- Options for the first winter
  - Less harsh de-icing treatments
    - Sand (if possible)
    - Stick to sodium chloride (“regular salt”)
    - More judicious applications: less brine and pre-treatment
  - Apply a penetrating sealer to the surface/joints
    - Be mindful of application temperature

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