Concrete Pavement Evaluation and Troubleshooting

Iowa Concrete Lunch and Learn Program
Fall 2023

Dan King, P.E.
deking@iastate.edu

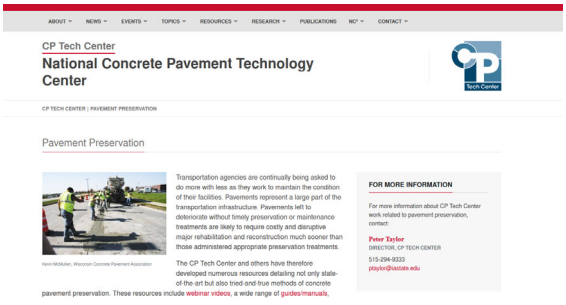
IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center
CP Tech Center

Acknowledgments

- Thanks to Iowa DOT & ICPA for their support of this program
- Special thanks to Jerod Gross, Snyder & Associates

- To learn more, visit the CP Tech Center's "Pavement Preservation" page
  - Topics > Pavement Preservation



https://cptechcenter.org/pavement-preservation/

Outline

- Jointing Review
- Early-Age Cracking
- Other Construction and Early-Age Issues
- Later-Age Troubleshooting

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Jointing Review

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Why is Jointing Important?

- If you place concrete pavements without joints… they will crack!

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Why is Jointing Important?

- If you place concrete pavements without joints… they will crack!

- Old US 20, Moville
  - Built in 1921
  - No joints – pavement cracked on its own

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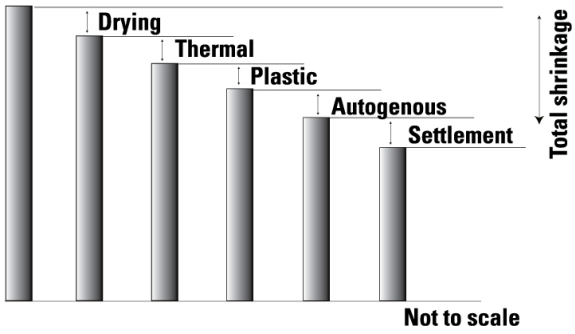
Why Does Concrete Crack at an Early Age?

- Shortly after placement, concrete begins to shrink
  - Decrease in volume as concrete sets due to decreasing concrete temperature and moisture loss
    - Shrinkage due to moisture loss is most significant



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Why Does Concrete Crack at an Early Age?

- If concrete slabs could expand and contract freely, shrinkage wouldn't cause any problems
- However, restraint from the underlying subgrade or subbase causes tensile stresses to develop in the slab as it contracts

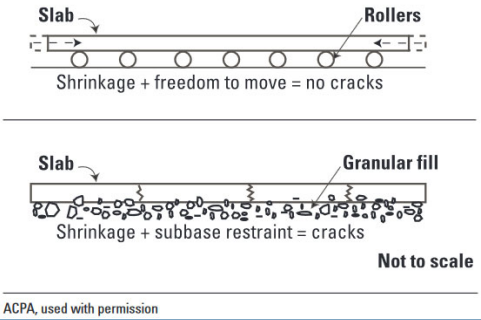

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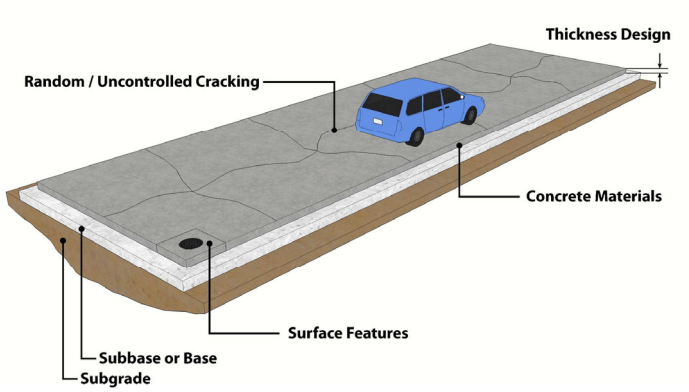
Image: ACPA

Why Does Concrete Crack at an Early Age?

- Concrete gains strength as it hydrates, but eventually these tensile stresses will exceed the concrete strength, and random cracks will develop in the pavement



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What's Wrong with Random Cracks?

- Not every crack in a pavement is a problem, but we'd like to avoid random cracks for a number of reasons:
  - They're ugly
  - They can allow intrusion of water and incompressible materials, which can cause durability and performance issues
  - They can be susceptible to spalling and deterioration
  - They may not be able to transfer heavy traffic loads across the slab, leading to faulting and roughness

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Jointing Concrete Pavements

- We control early-age cracking by sawing control or contraction joints into the pavement
- The saw cut creates a weakened plane that directs the formation of cracks at planned locations

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Images: Iowa DOT, PCA

Jointing Concrete Pavements

- When properly constructed, contraction joints:
  - Control cracking
  - Accommodate slab expansion and contraction
  - Provide load transfer and continuity between slabs
    - With help from dowel bars and tie bars
  - Mitigate curling and warping stresses
  - Allow us to fill or seal the joints to prevent intrusion of water and/or incompressible materials

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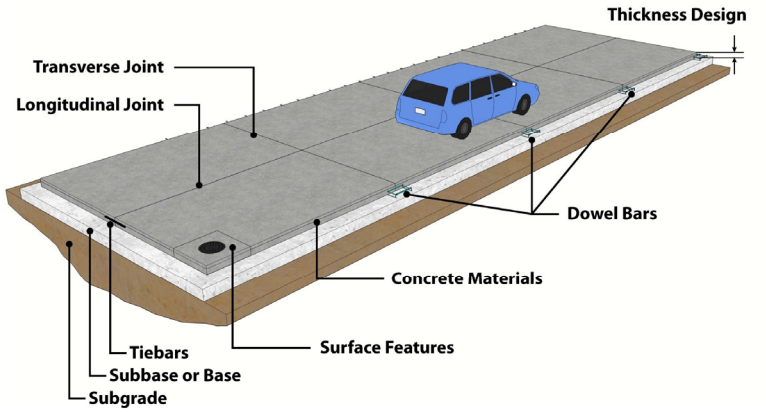
Jointing Concrete Pavements

- To establish a jointing system that meets these needs, we need to saw joints at the correct timing, depth, and spacing



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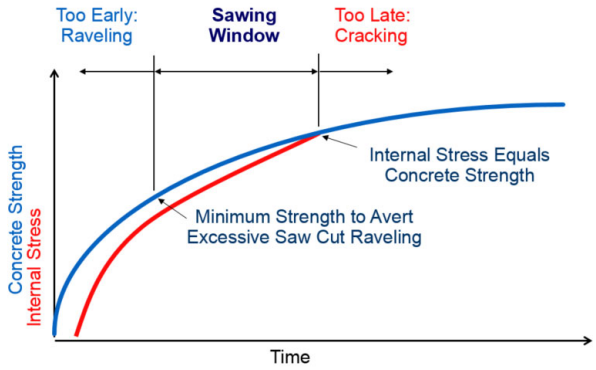
Timing of Joint Sawing

- Joint sawing must be done in the sawing window
  - Period where concrete is strong enough to saw without raveling or spalling, and before tensile stresses exceed strength



- Conventional saws
  - Window starts about 4 to 12 hours after placement
- Early-entry saws
  - Window starts from 1 to 4 hours after placement

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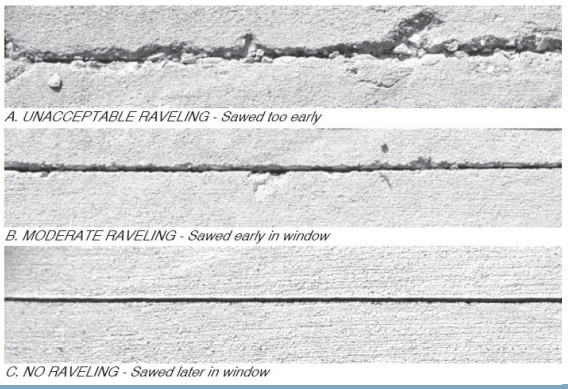
Image: ACPA

Timing of Joint Sawing

- Joint sawing must be done in the sawing window
  - Period where concrete is strong enough to saw without raveling or spalling, and before tensile stresses exceed strength



A. UNACCEPTABLE RAVELING - Sawed too early

B. MODERATE RAVELING - Sawed early in window

C. NO RAVELING - Sawed later in window

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Depth of Joint Sawing

- Joints must be sawed deep enough to weaken the plane and ensure the cracks form at the saw cut locations
- Note differences in specifications for:
  - Transverse vs. longitudinal joints
  - Doweled vs. un-doweled transverse joints
  - Early-entry vs. conventional saws

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Images: Iowa DOT

Depth of Joint Sawing

- Iowa DOT PV-101, SUDAS Figure 7010.101:

Joint Type	Saw Cut Depth		Saw Cut Width	
	Conventional	Early-Entry	Conventional	Early-Entry
Transverse	Undoweled: T/4 ± 1/4” Doweled: T/3 ± 0.25”	1-1/4” ± 1/4”	1/4” ± 1/16”	1/8” to 5/16”
Longitudinal	T/3 ± 0.25”		Not Filled: 1/8” ± 1/16” Filled: 1/4” ± 1/16”	

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Joint Spacing

- Contraction joints must be spaced properly to make sure random cracks don’t form between saw cuts
- Slabs should also be nearly square
- Joint spacing is also important to pavement performance

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Joint Layout

- General joint layout rules of thumb:
  - Transverse joints
    - Maximum spacing (ft) 2x the thickness (inches)
  - Longitudinal joints
    - Typically spaced at lane widths (12 ft) or at third- or quarter-points
    - Avoid slabs 15 ft wide or greater
  - Prevent slab length from exceeding 1.5x slab width
  - Avoid acute angles < 60° and interior corners
  - Match existing joints or cracks
  - Place joints to meet in-pavement structures
  - Allow necessary adjustments to joint locations in the field!

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Early-Age Cracking

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Early-Age Cracking

- Even though we do our best to follow best practices for joint design and construction, we will inevitably run into early-age cracking
- How do we fix these cracks when they occur? How do we prevent them from happening again?

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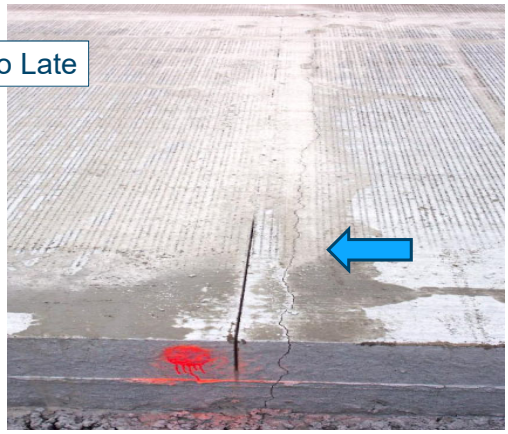
Early-Age Cracking

- Cracking due to joint sawing issues

Too Late



Too Shallow

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R Image: Jerod Gross

Troubleshooting Joint Sawing Issues

- The sawing window is sensitive to many factors:
  - Temperature changes can speed up or delay set time, shifting the window
  - A sharp temperature decrease late in the day or overnight can lead to more slab contraction, narrowing the window
  - Windy, sunny, or dry conditions can lead to a greater amount of evaporation, narrowing the window
  - Concrete mixtures with higher Portland cement contents and higher water contents (greater w/cm) experience more shrinkage, narrowing the window
- Be prepared for changing weather conditions!
  - Both day-to-day and throughout the project

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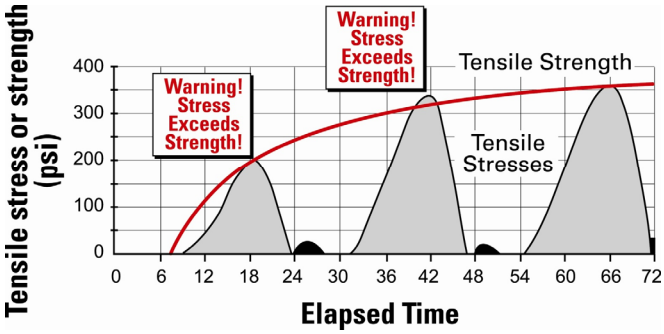
Troubleshooting Joint Sawing Issues

- Contractors typically rely on experience or informal tests like scratching the surface to determine when to begin sawing
- HIPERPAV can be used to anticipate early cracking risk due to temperature and moisture changes

hiperpav.com



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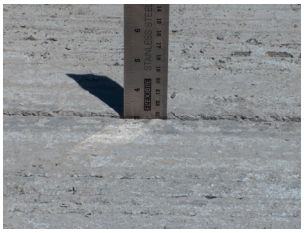
Troubleshooting Joint Sawing Issues

- Verify saw cut depth in the field!
  - If longitudinal joints are shallow, you may have time to re-saw
- Maintain blades and equipment
  - Select proper blade for aggregate type
  - Regularly check for wear and replace blades
  - Check the skid plate on early-entry saws



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Recommended Repairs

- Iowa DOT Construction Manual Appendix 9-6

Defect	Orientation	Location	Description	Dowelled/Undowelled Transverse Joints	Recommended Repair
Plastic Shrinkage	Any	Anywhere	Partial-depth and more than 0.007 in. wide	Either	Do nothing
Uncontrolled Crack	Transverse	Mid-Panel	Full-Depth	Undowelled	Saw/route and seal crack
				Dowelled	Full-Depth Repair or LTR[a]
Uncontrolled Crack	Transverse	Crosses or ends at transverse joint	Full-Depth	Undowelled	Saw & seal crack; Epoxy sawed joint if uncracked
				Dowelled	Full-Depth Repair or If crack jumps from sawcut to edge of slab within 3 feet of edge of slab, stop sawcut, saw & seal crack
Uncontrolled Crack	Transverse	Parallel to & within 5 ft. of joint	Full-Depth	Undowelled	Saw and seal crack Seal joint
				Dowelled	Full-Depth repair to replace crack and joint
Spalled sawcut or uncontrolled crack	Transverse	Anywhere	Spalling; more than 3.0 in wide	Either	Partial-Depth Repair
Uncontrolled Crack	Longitudinal	Relatively parallel to & within 1 ft. of joint; May cross or end at longitudinal joint	Full-Depth	Either	Saw/route & seal the crack or cross-stitch the crack Epoxy sawed joint if uncracked
Uncontrolled Crack	Longitudinal	Relatively parallel to & within wheel path; 1 - 5 ft. from joint	Full-Depth, hairline, or spalled	Either	Remove and replace panel or cross-stitch crack
Uncontrolled Crack	Longitudinal	Relatively parallel to & further than 5 ft. from a longitudinal joint or edge	Full-Depth	Either	Cross-stitch crack
Spalled sawcut or uncontrolled crack	Longitudinal	Anywhere	Spalled	Either	Partial-Depth Repair
Uncontrolled Crack	Diagonal	Anywhere	Full-Depth	Either	Full-Depth Repair
Uncontrolled Crack	Multiple per panel	Anywhere	Two or more full depth cracks dividing panel into 3 or more pieces	Either	Remove and replace panel

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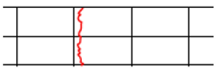
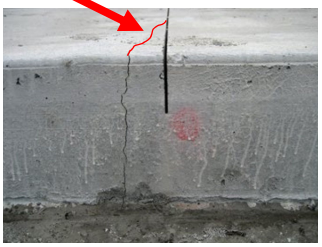
Recommended Repairs

- Transverse cracking within 5 ft of the transverse joint
  - If pavement is un-doweled, route and seal the crack & seal the non-working saw cut with epoxy
  - If pavement is doweled, full depth repair to replace crack and joint
    - Note: if the crack occurs just within 3 feet of the edge of the slab, it's ok to just route and seal





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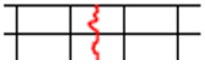
Recommended Repairs

- Transverse cracking – mid-panel
  - If pavement is un-doweled, route and seal the crack
  - If pavement is doweled, consider full depth repair or dowel bar retrofit to provide load transfer



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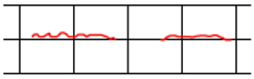
Recommended Repairs

- Longitudinal cracking
  - Within 1 ft of the longitudinal joint: route and seal the crack
  - Between 1 and 5 ft from the longitudinal joint
    - Route and seal
    - Cross-stitch



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Early-Age Cracking

- Cracking due to problems with the joint layout

Excessively wide slab

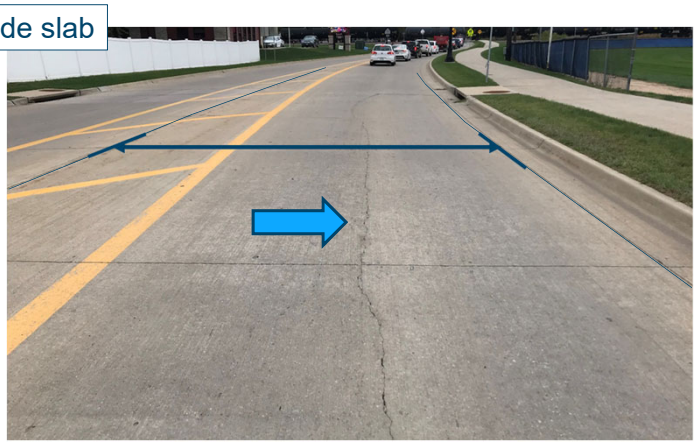

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Image: Jerod Gross

Early-Age Cracking

- Cracking due to problems with the joint layout

Gutterline joint failed to crack

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Image: Steve Mallicoat

Early-Age Cracking

- Cracking due to problems with the joint layout
  - Failure to match joints:

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Images: Jerod Gross

Early-Age Cracking

- Improper placement around manholes, intakes, and other in-pavement structures

vs.

Image: ACPA

Troubleshooting Joint Layout Problems

- Avoid placing slabs 15 ft or wider
- Gradually tapering longitudinal joints at transition areas can help avoid excessively wide slabs

Image: Jerod Gross

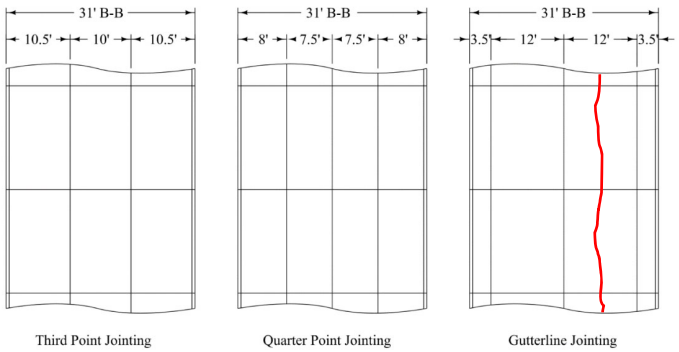
Troubleshooting Joint Layout Problems

- Avoid placing slabs 15 ft or wider
- Gradually tapering longitudinal joints at transition areas can help avoid excessively wide slabs

Image: Jerod Gross

Troubleshooting Joint Layout Problems

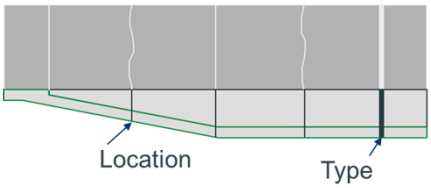
- Gutterline longitudinal joints sometimes fail to crack, especially in pavements less than 9 inches thick
  - Consider third- or quarter-point jointing instead

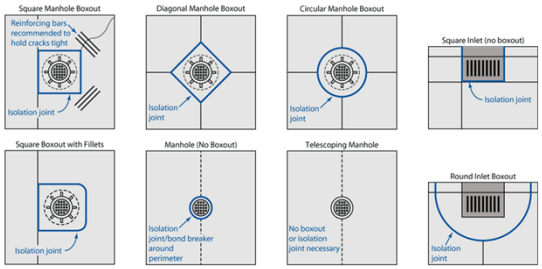


Images: SUDAS

Troubleshooting Joint Layout Problems

- Follow best practices or matching existing joints and cracks and meeting in-pavement structures like manholes and intakes
- Place isolation joints as needed





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R Image: ACPA

Recommended Repairs

- Mid-panel longitudinal cracks may be routed and sealed and/or cross-stitched

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Early-Age Cracking

- What about these hairline cracks?

Plastic shrinkage cracking

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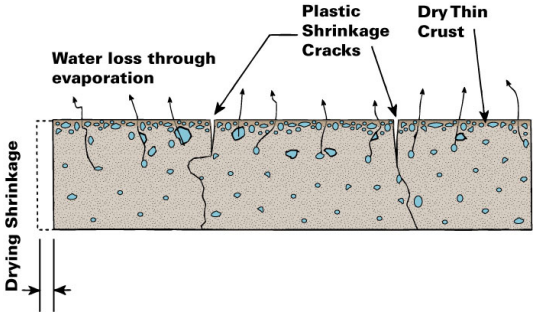
Troubleshooting Plastic Shrinkage Cracking

- Not caused by any sawing problems, but can result from rapid evaporation and shrinkage at the near-surface region
- Prevented by timely and adequate curing
  - Be conscious of hot, dry, and windy conditions



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Recommended Repairs

- No need to route, seal, or patch these hairline cracks as long as they are narrow and shallow
- They can be protected by applying a penetrating surface sealer, or possibly corrected by diamond grinding

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Other Construction and Early-Age Issues

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Tire Tracks

- Sometimes the traveling public gets a little too excited to use the new road…

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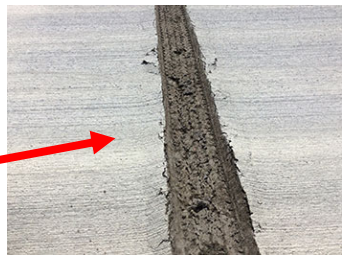
Images: Steve Mallicoat

Troubleshooting Tire Tracks

- The good news is that these tracks rarely pose issues with structural integrity
  - MnROAD study, 2017
    - Deliberate early loading of concrete pavement test sections 2 to 10 hours after placement
    - No indication of structural problems after 5+ years of service
      - Just the functional issue of rough ride at a section loaded after 2 hours



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Recommended Repairs

- Shallow depressions can be corrected with diamond grinding
- Deeper ruts may need to be patched to alleviate roughness
  - Partial depth or full depth

- 24th Street, Ames
  - Paved in 1982
  - Tire tracks have held up well for 40+ years
  - Later diamond grinding did not impact tracks

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Image: Leif Wathne

Recommended Repairs

- Damage to the edge of the slab requires full depth repair

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Image: Steve Mallicoat

Scaling and other Surface Distress

- Iowa and a handful of other Midwestern states have seen an increase in scaling in the last few years
- Usually observed after the first winter

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Images: Peter Taylor

Troubleshooting Scaling

- Known and suspected culprits:
  - Concrete placed relatively late in the year
  - More freeze-thaw cycles and greater exposure to de-icing chemicals in the last few winters
  - Hand-placed concrete with a higher w/cm
  - Inadequate concrete curing
  - Improper surface finishing
    - Turnover and inexperience in the workforce
    - Changes to water demand, bleeding, and setting time due to changes in materials, such as Type IL cement

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Troubleshooting Scaling

- Do not finish extra water into the concrete surface
  - Higher effective w/cm at surface → greater susceptibility to surface distresses

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Images: Jerod Gross

Troubleshooting Scaling

- Beware of misuse of evaporation retarders
  - These products are about 90% water
  - They should not be used as finishing aids or worked into the surface

FOR BEST PERFORMANCE

- Do not apply MasterKure ER 50 as a final finishing aid or work it into the surface of cast-in-place concrete or cementitious repair applications.
- MasterKure ER 50 evaporation reducer is not a curing agent. Concrete treated with this product must still be cured.
- BASF is not responsible for compatibility or results when MasterKure ER 50 evaporation reducer is used with other manufacturers' products.
- MasterKure ER 50 reduces evaporation only while concrete is plastic. It is not a substitute for early curing of hardened concrete, nor does it alter the effectiveness of membrane curing compounds.

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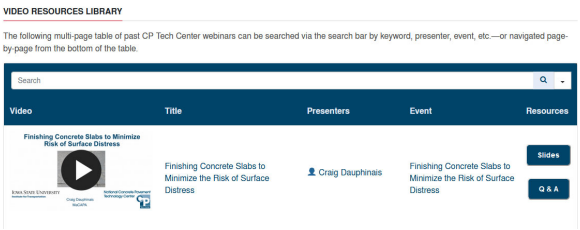
Image: Todd Hanson

New Resources Available from CP Tech Center

- Tech Brief: “Revisiting Concrete Scaling” Tech Brief
  - Published in Summer 2023
- Webinar: “Finishing Concrete Slabs to Minimize Risk of Surface Distress”



https://cptechcenter.org/webinars-and-videos/

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Recommended Repairs

- Monitor the surface distress – if it does not worsen through subsequent winters, it may not be necessary to repair
- Diamond grind to restore texture, ride quality, aesthetics
- Apply a penetrating surface sealer to prevent water from accumulating in depressions or entering the slab

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Other Surface Issues

- Crazing: very shallow cracks appearing at surface; may result from poor curing or from finishing bleed water into the surface
- Popouts: loss of aggregate particles at the surface due to physical or chemical reactions within the aggregates
  - May result from presence of lightweight materials such as chert or shale in the aggregates

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Images: Concrete Construction

Rain Damage

- If the concrete is still plastic, cover it and leave it alone
  - Do not finish rain water into the surface
- Finished texture can often be corrected by diamond grinding
  - See Iowa DOT construction manual 9.53 for more guidelines

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Snow Removal

- If a pavement sits unused or unfinished over the winter, take one of two approaches to snow removal:
  - Leave the snow
  - Clear <u>all</u> of the snow
- Cracking may occur if only the center of the street is cleared and snow is on the inside of the curb and gutter
  - Frost heave, differential settlement → longitudinal cracking

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Image: Steve Mallicoat

Snow Removal

- Frost heave and differential settlement can also lead to cracking if a pavement was finished late in the year and the curb was not backfilled before winter

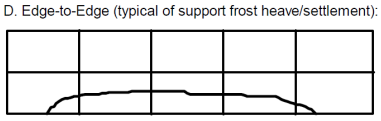

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Image: Jerod Gross

Later-Age Troubleshooting

Later-Age Cracking

- Corner and longitudinal cracking that occur near the pavement edge are often signs of settlement, non-uniform support, and/or inadequate drainage
  - Recommended full depth slab replacement and repair of underlying pavement layers, if possible

Spalling is a sign of vertical displacement

Later-Age Cracking

- Transverse cracking – mid-panel
  - If pavement is doweled, dowel bar retrofit can restore load transfer across the crack

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Image: Iowa DOT

Later-Age Cracking

- When multiple cracks appear in the same slab, full depth repair is the only recommended repair

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Later-Age Cracking

- Misaligned dowel bars and tie bars can lock up joints and lead to spalling, cracking, and delamination
  - Make sure dowel bars are properly anchored and all dowel and tie bars placed at the right location and depth
- Full depth repairs are recommended to restore proper jointing system

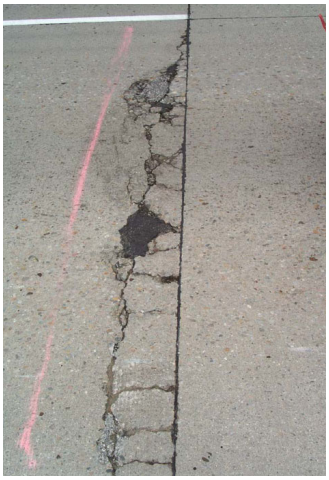

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Image: WSDOT

Joint and Crack Spalling

- What happens if joints or cracks have begun to spall?

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Joint and Crack Spalling

- If the surrounding concrete is still in good condition, consider partial depth repair of spalled joints and cracks

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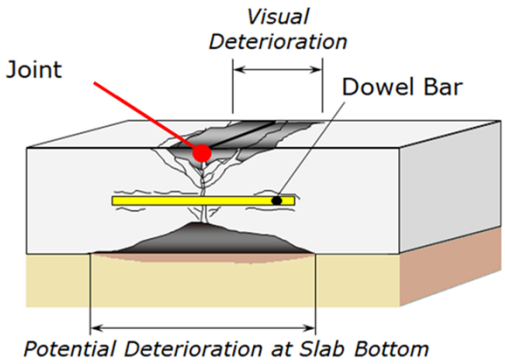
Joint and Crack Spalling

- If the deterioration extends more than halfway through the depth of the slab, full depth repairs are needed



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Images: NHI, APTech

Joint and Crack Spalling

- If the deterioration starts at the joint but continues to a significant distance into the slab, patching is not a long-term solution
  - D-cracking, freeze-thaw, ASR, etc.
  - Overlay or reconstruction will be the most effective treatments in these situations

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Image: APTech

Faulting

- When faulting develops in un-doweled pavements, dowel bar retrofit can restore load transfer
  - In conjunction with diamond grinding, very effective at restoring pavement smoothness

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Bringing it all Together

- Partial depth repair, dowel bar retrofit, and diamond grind all on the same project:

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Good Concrete Practices

- If we use good materials, mixtures, and construction practices up front, it will help us avoid some of these problems – and it will also help make our rehabilitation treatments easier and more effective when problems do occur

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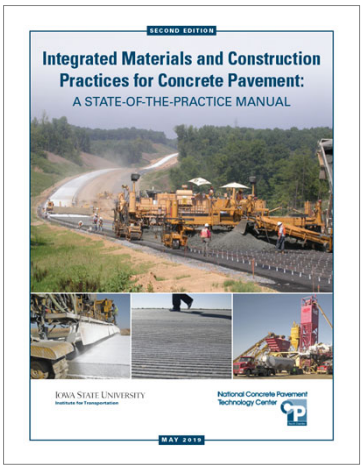
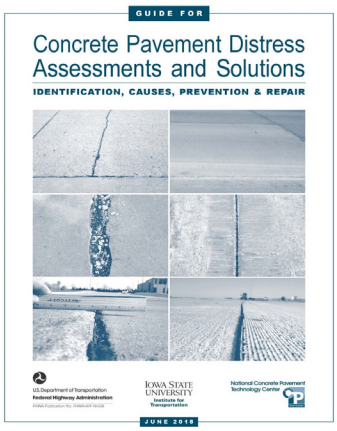
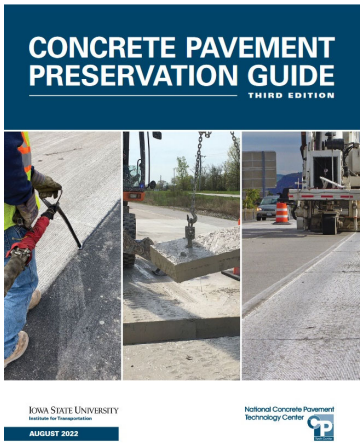
Additional Resources from the CP Tech Center







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