R&T UPDATE
Concrete Pavement Research & Technology

WHAT TO DO WHEN FACED WITH EARLY-AGE CRACKING

If uncontrolled early-age cracking is experienced on a concrete paving project, the cause(s) must be determined immediately and the contractor and agency team must take action to minimize/eliminate the cause(s) or their effects before proceeding any further with paving. Early-age cracking is any cracking that may develop within the first 7 days after concrete placement. However, some cracking may initiate at the bottom of the slab and not become visible until days or weeks pass. So sixty (60) days is generally the outer limit for cracking to be considered "early-age." The following are types of early-age cracking:

1. Plastic shrinkage cracking
2. Random cracking (no orientation)
3. Longitudinal cracking (top-down or bottom-up, which may occur early but appear later)
4. Transverse cracking (top-down or bottom-up)
5. Corner cracking
6. Cracks just ahead of sawing (pop-off cracks)
7. Sympathy cracks
8. Settlement cracks over dowel bars or tie bars
9. Re-entrant cracks.

Some cracking may have an obvious cause and corrective actions are simple and quick to avert further problems. However, other cracking may result from marginal conditions and correcting one marginal condition may resolve an immediate problem, but may not reduce the cracking potential substantially for subsequent paving. It is important to identify as many marginal conditions as possible and rectify as many that are under the control of the design engineer or the contractor.

Investigating Early Cracking

The process of investigating early-age cracking, for which the obvious cause is not readily apparent, involves additional steps:

1. Gather relevant information.
2. Work through an iteration of logical steps to pinpoint one or more causes. This involves a process of elimination, starting with one obvious factor verified by field results (e.g. changing a component or proportion in the concrete mixture). As the process of elimination continues, additional steps may require more rigorous data evaluation, coring, and/or laboratory testing. FHWA's HIPERPAV software is a very helpful analysis tool for determining early-age concrete properties and the potential for cracking.
3. Identify whether the cracking manifests as isolated or systematic (widespread) occurrences. If the cracking is systematic, a thorough review of all design features and key construction procedures will likely be needed.

When confronted with an early-age cracking situation, begin to document the conditions immediately. The back page of this R&T Update outlines a list of relevant information that aids in the evaluation and reduction of risk. The tables provided inside this R&T Update list the factors that may influence the development of different crack formations, and potentially helpful investigative techniques.

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Guideline for Primary Pavement Factors Relating to Early-Age Crack Formations

Primary Paving Factor or Consideration	Sub-Factor	Plastic Shrinkage Cracking	Random Cracking (No Orientation)	Longitudinal Cracking	Transverse Cracking (Partial or Full Width)	Corner Cracking	Pop-off Cracks (Just ahead of saw)	Late Cracking (7 to 60 days after paving)	Sympathy Cracks	Settlement Cracks (over tiebars or dowels)	Re-entrant Cracks
Applied Loads	**Public or Construction Vehicles**	Not applicable	Not applicable	Early loading by traffic or equipment - particularly along free slab edges	Not applicable	Early loading by traffic or equipment	Not applicable	Not generally applicable	Not applicable	Not applicable	Not applicable
Concrete Mixture	**Aggregate - Coarse Fraction**	Dry concrete mixture from concrete aggregates not saturated surface dry at mixing	Dry concrete mixture from concrete aggregates not saturated surface dry at mixing	Dry concrete mixture from concrete aggregates not saturated surface dry at mixing	Dry concrete mixture from concrete aggregates not saturated surface dry at mixing	Not generally applicable unless other crack formations are also present	Not generally applicable	Not generally applicable	Not generally applicable	Not generally applicable	Not generally applicable
Concrete Mixture	**Aggregate - General Condition**	Poor aggregate gradation (gap gradation requires more paste and causes more shrinkage)	Poor aggregate gradation (gap gradation requires more paste and causes more shrinkage)	Poor aggregate gradation (gap gradation requires more paste and causes more shrinkage)	Poor aggregate gradation (gap gradation requires more paste and causes more shrinkage)	Not generally applicable unless other crack formations are also present	Not generally applicable	Not generally applicable	Not generally applicable	Not generally applicable	Not generally applicable
Concrete Mixture	**Aggregate - Sand Fraction**	Sand may be too fine; Sand angularity may cause harsh finishing (i.e. manufactured sands)	Sand may be too fine; Sand angularity may cause harsh finishing (i.e. manufactured sands)	Sand may be too fine; Sand angularity may cause harsh finishing (i.e. manufactured sands)	Sand may be too fine; Sand angularity may cause harsh finishing (i.e. manufactured sands)	Not generally applicable unless other crack formations are also present	Not generally applicable	Not generally applicable	Not generally applicable	Not generally applicable	Not generally applicable
Concrete Mixture	**Material Combinations (incl. supplementary cementing materials and admixtures)**	Incompatibility leads to delayed set and/or higher concrete shrinkage	Incompatibility leads to delayed set and/or higher concrete shrinkage	Incompatibility leads to delayed set and/or higher concrete shrinkage	Incompatibility leads to delayed set and/or higher concrete shrinkage	Not generally applicable unless other crack formations are also present	Not generally applicable	Not generally applicable	Not generally applicable	High-slump concrete for fixed form paving; or, delay in setting time	Not generally applicable
Curing	**Quality**	Inadequate curing (either late or poor coverage) to protect against prevailing conditions	Inadequate curing (either late or poor coverage) to protect against prevailing conditions	Inadequate curing (either late or poor coverage) to protect against prevailing conditions	Inadequate curing (either late or poor coverage) to protect against prevailing conditions	Inadequate curing (either late or poor coverage) to protect against prevailing conditions	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Finishing	**Timing**	Delayed; causing overworking of surface	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Joints	**Design Dimensions and/or Locations**	Not applicable	Joint spacing too long by design	Slabs too wide in relation to thickness and length; too many lanes ties together; excessive edge restraint during fill-in lane placement	Slabs too long in relation to thickness and width	Dimensions too long, causing excessive curling and warping stresses	Skewed joints increase risk of this formation	Dimensions too long, causing excessive curling and warping stresses	Joints in paved lane do not match joints in adjacent lane; or, different joint cracking patterns in adjacent lanes	Not applicable	Stress-riser due to odd-shaped panels; or, cracks from interior corners box-out corners
Joints	**Dowels and/or Tiebar Placement**	Not applicable	Not applicable	Not applicable	Misaligned or bonded dowels in adjacent transverse joints prevent cracked joint functioning (joints with misaligned bars must be cracked)	Dowel bars and/or tiebars too close to each other at corner - prevents joint corner relaxation causing crack	Not applicable	Misaligned or bonded dowels in adjacent transverse joints prevent cracked joint functioning (joints with misaligned bars must be cracked)	Not applicable	Shallow dowel or tiebar placement	Not applicable
Joints	**Saw Cut Depth**	Not applicable	Too shallow; either poor saw set-up or subbase bonding altered effective section	Too shallow; either poor saw set-up or subbase bonding altered effective section	Too shallow; either poor saw set-up or subbase bonding altered effective section	During paving grout penetrates transverse joints in previously-placed lanes preventing joint closure	Not applicable	Not applicable	Joints match in location but not in type (e.g. isolation vs. contraction)	Not applicable	Not applicable
Joints	**Saw Cut Timing**	Not applicable	Late sawing for prevailing conditions	Late sawing for prevailing conditions	Late sawing for prevailing conditions	Not applicable	Late sawing for prevailing conditions; sawing into the direction of the wind	Not applicable	Cracks form across fill-in lane from transverse joints in the adjacent lanes (paved previously)	Not applicable	Not applicable
Subbase	**Interface condition**	Not applicable	Slab to subbase bonding; friction against rough base surface; penetration of concrete into voids of open-graded subbase	Slab to subbase bonding; friction against rough base surface; penetration of concrete into voids of open-graded subbase	Slab to subbase bonding; friction against rough base surface; penetration of concrete into voids of open-graded subbase	Not generally applicable	Not applicable	Slab to subbase bonding; friction against rough base surface; penetration of concrete into voids of open-graded subbase	Not applicable	Not applicable	Not applicable
Subbase	**Presence of cracks/Joints**	Not applicable	Reflection cracking from working subbase cracks or joints (only where bonding or high friction exists)	Reflection cracking from working subbase cracks or joints (only where bonding or high friction exists)	Reflection cracking from working subbase cracks or joints (only where bonding or high friction exists)	Not applicable	Not applicable	Reflection cracking from working subbase cracks or joints (only where bonding or high friction exists)	Not applicable	Not applicable	Not applicable
Subbase	**Stability**	Not applicable	Not applicable	Differential support condition created by 1) frost heaving, 2) soil settling, or 3) expansive soils	Poor stability causes excessive deflection under load, raising curling stresses	Poor stability causes excessive deflection under load, raising curling stresses	Not applicable	Differential support condition created by 1) frost heaving, 2) soil settling, or 3) expansive soils	Not applicable	Not applicable	Not applicable
Weather	**Dry Conditions**	High rate of evaporation from surface; Risk increases with warm air temperature, high wind, or low humidity	Excessively hot conditions during paving (+100 deg. F)	Excessively hot conditions during paving (+100 deg. F)	Excessively hot conditions during paving (+100 deg. F)	Not generally applicable	High winds	Not applicable	Not applicable	Not applicable	Not applicable
Weather	**Wet Conditions**	Temperature drop due to sudden cold front prior to rain	Temperature drop due to sudden cold front or rain shower	Temperature drop due to sudden cold front or rain shower	Temperature drop due to sudden cold front or rain shower	Not generally applicable	High winds	Not applicable	Not applicable	Not applicable	Not applicable

Investigation Techniques for Early-Age Cracking

Investigative Factor/Technique	Test(s)	Plastic Shrinkage Cracking	Random Cracking (No orientation)	Longitudinal Cracking	Transverse Cracking (Partial or Full Width)	Corner Cracking	Pop-off Cracks (Just ahead of saw)	Late Cracking (after 7 to 60 days after paving)	Sympathy Cracks	Settlement Cracks (over tiebars or dowels)	Re-entrant Cracks
Crack Orientation	**Crack map**	Not applicable	Draw map ASAP; denote changes over time using multiple colors	Draw map ASAP; denote changes over time using multiple colors	Draw map ASAP; denote changes over time using multiple colors	Not applicable	Not applicable	Early -age bottom up cracking becomes visible	Draw map ASAP; denote changes over time using multiple colors	Not applicable	Not applicable
Crack Orientation	**Coring**	Core typical cracks to denote crack depth	Obtain cores through subbase to check slab/subbase bonding	Obtain cores through cracks to check depth of cracking & aggregate breakage	Obtain cores through cracks to check depth of cracking & aggregate breakage	Obtain cores through cracks to check depth of cracking & aggregate breakage	Not applicable	Not applicable	Not applicable	Check dowel depths using cover meter, GPR, or magnetic imaging device	Not applicable
Material Quality	**Curing Compound**	Check quality and application rate of curing compound	Check quality and application rate of curing compound	Check quality and application rate of curing compound	Check quality and application rate of curing compound	Check quality and application rate of curing compound	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Material Quality	**Cement & Admixtures**	Review mixture design	Review mixture design	Review mixture design	Review mixture design	Not applicable	Not applicable	Review mixture design	Not applicable	Review mixture design	Not applicable
Material Quality	**Aggregates**	Examine the sand gradation for fineness; Evaluate combined gradation for quality	Examine the sand gradation for fineness; Evaluate combined gradation for quality	Examine the sand gradation for fineness; Evaluate combined gradation for quality	Examine the sand gradation for fineness; Evaluate combined gradation for quality	Not applicable	Not applicable	Examine the sand gradation for fineness; Evaluate combined gradation for quality	Not applicable	Not applicable	Not applicable
Joint Function	**Dowel Lubrication**	Not applicable	Not applicable	Not applicable	Perform pullout testing	Perform pullout testing	Not applicable	Perform pullout testing	Not applicable	Not applicable	Not applicable
Joint Function	**Crack (or Joint) open and closure movement**	Not applicable	Install studs and monitor crack movement using Demec Gauge or equivalent	Install studs and monitor crack movement using Demec Gauge or equivalent	Install studs and monitor crack movement using Demec Gauge or equivalent	Not applicable	Not applicable	Install studs and monitor crack movement using Demec Gauge or equivalent	Install studs and monitor movement using Demec Gauge (if old joint/crack questionable)	Not applicable	Not applicable
Slab-Subbase Bonding / Interaction	**Push-Off Test**	Not applicable	Cast large specimen on available exposed subbase or remove concrete to create isolated test slab. Jack against test slab and measure resistance to 1) initiate movement and 2) develop constant movement rate.	Cast large specimen on available exposed subbase or remove concrete to create isolated test slab. Jack against test slab and measure resistance to 1) initiate movement and 2) develop constant movement rate.	Cast large specimen on available exposed subbase or remove concrete to create isolated test slab. Jack against test slab and measure resistance to 1) initiate movement and 2) develop constant movement rate.	Not applicable	Not applicable	Cast large specimen on available exposed subbase or remove concrete to create isolated test slab. Jack against test slab and measure resistance to 1) initiate movement and 2) develop constant movement rate.	Not applicable	Not applicable	Not applicable

Relevant Information to Collect

1. **Design Information**
   a. Pavement thickness as designed
   b. Pavement thickness as constructed
   c. Joint spacing – transverse & longitudinal
   d. Base type
2. **Concrete Mix Information**
   a. Cement type and source
   b. Cement grind history – Fresh grind/ Not-fresh grind
   c. Supplementary cementitious materials – Type C or F fly ash source, slag source and content
   d. Cement content
   e. Aggregate Data
      - Gradation – uniform/gap, well-graded or other
      - Coarse aggregate type, source and amount
      - Coarse aggregate coefficient of thermal expansion
      - Fine aggregate type, source and amount

   f. Admixture manufacturer(s), type(s) and dosage(s)
3. **Environmental Information**
   a. Weather and temperature conditions for three (3) days prior to paving and 14 days after
   b. Hot/cold weather precautions taken
   c. Rainfall history during and up to three (3) days after concrete paving
4. **Construction Information**
   a. Paving history – start time, finish time, and curing time
   b. Method used for minimizing bond to stabilized base
   c. Base surface condition
   d. Fresh concrete temperature
   e. Concrete curing method
      - Curing compound type and rate of application (if used)

   f. Timing and depth of saw cutting
      - Transverse joint – As specified and actual range
      - Longitudinal joint – As specified and actual range

   g. Dowel alignment verification results
   h. Early-age loading history
5. **Other Relevant Information**
   a. Concrete temperature history or maturity data may be particularly helpful.
   b. Develop crack maps, including crack width(s). Note the ambient temperature during the survey.
   c. Update maps regularly (every day or every few days) to determine if cracking is progressive.

Summary

There is always some risk of early cracking, but many measures can reduce these risks. Prior planning and immediate action minimize the negative effects of contributing factors.

For more information see publications:

- “Early Cracking of Concrete Pavement,” TB016P, ACPA, Skokie, IL, 2002.
- “Best Practices for Airport Portland Cement Concrete Pavement Construction,” Innovative Pavement Research Foundation, Washington, DC, 2003.

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