Curing Methods to Mitigate Early-Age Bridge Deck Cracking

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Curing Methods to Reduce Early Age Deck Cracking

- Montana DoT Case Study: *Curing Methods to Mitigate Early Age Cracking*
- Project Background
- Field Investigations
- Laboratory Evaluations
- Thermal and Stress Modeling
- Curing Recommendations
In 2016, MDT communicated to WJE that severe transverse cracking was noted on a number of bridge decks in western Montana.

In three bridges, cracking led to deck penetrations (holes in the deck).

Concrete decks were only 1 to 9 years old.

MDT and FHWA commissioned WJE in early 2016 to investigate the problem.
Project Background – MDT Documentation

- Outline
- **Project Background**
- Field Investigation
- Laboratory Evaluations
- Thermal and Stress Modeling
- Recommendations
Project Background – Distress Reported by MDT
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Field Investigation

- Detailed investigation of four bridges
  - Crack mapping
  - Delamination survey
  - Infrared thermography
  - Drone (photographs, thermographic imagery, and video)
  - Ground penetrating radar
  - Concrete coring

- Comparative investigations of eight additional bridges
Field Investigation – Types of Cracking

- Map cracking
- Transverse cracking
Field Investigations – Transverse Cracking
Field Investigation – Transverse Cracking

Transverse cracking
Field Investigation – Transverse Cracking

Transverse cracking - Underside
Field Investigation - Characteristic Cracking

- Hypothesis on crack progression:
  1. Transverse cracks develop, likely early – to be investigated further
  2. Transverse cracks progress over time
  3. Closely-spaced transverse cracks form “jump” cracks
  4. Continued volumetric movement and traffic loading - widen and ravel transverse and “jump” cracks
  5. Deck penetrations may develop at “jump” cracks with the right conditions:
     - Deck penetrations more prone to occur with top and bottom mats aligned
     - The more closely spaced the transverse cracks, the more likely deck penetrations will occur
Field Investigation - Characteristic Cracking

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“Jump” Cracking

- Transverse Crack
- “Jump” Cracks
Field Investigation - Characteristic Cracking

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Field Investigation - Characteristic Cracking

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Field Investigation – Deck Penetration
Field Investigation – Cracking

- Transverse crack spacing varied from 2 to 4 feet on most bridges
  - More frequent than typical
- Transverse cracks predominately over transverse bars (GPR)
- Width of transverse cracks were typically 15 to 25 mils
- Plastic shrinkage cracking noted on some decks, most severe on Florence-East MP 10.640 - 1 year old and contained silica fume concrete.
- Longitudinal cracking noted, but not significant
Field Investigation – Drone Photographs
Field Investigation – Infrared Thermography
Field Investigation – Infrared Thermography
Concrete deck surface and underside temperatures were measured

- Surface temperatures varied from 42 F to 104 F
- Underside temperatures varied from 40 to 58 F
- Very high temperature swings! Fairly unique to Montana
- Relevant to subsequent thermal analysis and modeling
Lab Evaluation

- 42 Cores were extracted from the field
- Petrographic Analyses (ASTM C856)
- Physical Properties
  - Compressive Strength (ASTM C42)
  - Splitting Tensile Strength (ASTM C469)
  - Thermal property evaluation (COTE)
- Others (Chloride ion content, x-ray diffraction, SEM)
Laboratory Evaluations - Petrography
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- All transverse and “jump” cracks appeared to have initiated very early – cracks propagate around aggregates
- No signs of internal distress
- Air void system is good for freeze/thaw durability
- Aggregates are sound
- W/cm ratios were adequate, occasionally slightly elevated
Thermal and Stress Modeling

- Thermal and stress modeling on three bridges
  - Temperature model: ConcreteWorks
  - Stress model: Mathcad tool based on Zuk (1961)\(^1\)

- Why?
  - Have a better understanding of early age temperature changes and gradients and associated stresses
  - Sensitivity analysis – curing options, daily temperature changes, concrete temperatures, placement times, deck thickness, etc.
  - Results to help guide recommendations

\(^1\)Zuk, W. “Thermal and Shrinkage Stresses in Composite Beams,” *Journal of the American Concrete Institute*, (1961): 327-340.
Thermal and Stress Modeling

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- Recommendations

Bridge 6

Max. Deck Temperature (°F)

35 °F difference!

Date/Time


6:00 AM
6:00 PM
12:00 PM (noon)
7:00 AM (Actual)
Ambient
Sensitivity Analysis: Key Findings

- High sensitivity to tensile stresses caused by early-age ambient temperature drops and corresponding drop in peak hydration temperatures

- Stresses due to thermal gradients (e.g., cooling of deck surfaces) are greater magnitude than stresses due to uniform temperature changes

- Strains due to temperature generally larger than strains due to autogenous shrinkage for bridges investigated

- Drying shrinkage may be significant at later ages
Transverse cracks are likely initiated at early ages
- Driven by early age temperature gradients

Cracks continue to propagate

“Jump” cracks occur with tightly spaced transverse cracks

Deck penetrations occur under right conditions
- Deck penetrations more prone to occur with top and bottom mats aligned
- The more closely spaced the transverse cracks, the more likely deck penetrations will occur
- Driving lanes and under wheel paths more susceptible
Recommendations

- Goals of recommendations?
  - Reduce early age temperature gradient and associated stresses
  - Reduce autogenous shrinkage
  - Reduce the potential for early age and long term drying shrinkage
  - Maintain low permeability concrete
  - Maintain durability and service life
  - Work with MDT to achieve practical implementation
Specific Recommendations

- **Curing**
  - Immediately fog mist placements until wet curing media is in place
  - Contractor to measure evaporation rate
  - Apply wet-curing methods immediately after finishing
    - Pre-Wet burlap, cotton blankets, but no plastic!
  - Why is this important?
Specific Recommendations

- Curing
  - Application of insulation blankets shortly after peak hydration temperatures
  - Contractor to monitor concrete temperatures
  - When concrete temperatures are within 5°F of ambient and vertical temperatures through deck thickness are uniform - remove insulation
  - Minimum of 72 hours old (or 96 hours old if concrete contains silica fume), remove all curing and allow deck to dry.
  - After the surface has dried, white-pigmented curing compounds may be applied.
Specific Recommendations

- **Placement Times**
  - Move placement times to afternoon
    - Based on modeling, late afternoon likely best
  - Prevents peak hydration temperatures to occur during peak ambient temperatures
  - Moves peak concrete temperature to 2 to 3 days later - concrete has higher tensile strength
Specific Recommendations

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**Bridge 1**

![Graph showing temperature variations over time for Bridge 1]

- **Max. Deck Temperature (°F)**
- **Date/Time**
  - 6:00 AM
  - 12:00 PM (noon)
  - 6:00 PM
  - 2:00 AM (Actual)
- **Ambient**

**Graph Details**

- Temperature data from 7/25 to 8/1
- Variation in temperature over different times of the day and night
Additional Recommendations

- **Mixture Proportions Recommendations**
  - Reduce plastic concrete temperatures < 75F
  - Limit silica fume replacement to 5%
  - Specify w/cm between 0.42 and 0.45
  - Limit cementitious material contents to 600 lb./yd^3 or less
  - Optimized gradation and crushed aggregates

- Why are these important?
WJE’s recommendations implemented on approximately 24 new bridge decks since early 2017

- MDT reports a decrease transverse cracking.
- WJE briefly inspected one new deck placed in the Helena area (built in summer of 2017), approximately three weeks after placement – transverse cracks were difficult to find (very tight) and spaced far apart.
- Additional research initiated in 8/2019 to evaluate bridges constructed with recommendations, instrument new bridge decks to capture actual early age temperatures and strains, and perform additional detailed modeling and laboratory evaluations.
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Questions?

Thank you very much for the opportunity!