Early-Age Bridge Deck Cracking: Case Study

Todd Nelson, Elizabeth Nadelman, Paul Krauss
Early-Age Bridge Deck Cracking: Case Study

- Project Background
- Investigation
- Thermal Modeling
- Recommendations
Early-Age Bridge Deck Cracking: Case Study

- Severe early-age transverse cracking noted on a large number of bridge decks in Montana
- Early-age transverse cracking led to deck penetrations in three bridge decks
- Decks were only 1 to 9 years old
Bridge Locations

- Outline
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Typical Distress

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Early-Age Bridge Deck Cracking: Case Study

- Performed investigation to determine cause of cracking and to make recommendations for mitigation and prevention
Early-Age Bridge Deck Cracking: Case Study

- Field Investigations
  - Detailed investigation of four bridges
  - Comparative investigations of eight additional bridges
    - Crack mapping
    - Delamination survey
    - Concrete coring
    - Impulse response
    - Infrared thermography
    - Drone
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- **Laboratory Evaluations**
  - Petrography
  - Mechanical property evaluation
  - Thermal property evaluation (COTE)
  - Chloride ion content
  - X-ray diffraction of efflorescence

- **Modeling – Sensitivity Analysis**
Characteristic Cracking

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Map cracking

Transverse cracking
Characteristic Cracking

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Transverse cracking
Characteristic Cracking

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“Jump” cracking
Characteristic Cracking

- Crack progression:
  1. Transverse cracks develop early
  2. Cracks progress over time
  3. Closely-spaced transverse cracks can “jump”
  4. Holes may develop at jumps
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**Modeling**

- Temperature model: ConcreteWorks
- Stress model: Mathcad tool based on Zuk (1961)\(^1\)

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

- Used ConcreteWorks to simulate peak temperature-time histories for 3 bridge decks
  - Deck geometry based on drawings
  - Heat generation simulated based on mix designs and cement compositions
  - Ambient temperature, wind speed, solar radiation based on historic records (NCDC)
  - Assumed placement temperature of 65 degrees F based on available batch ticket information
Temperature Model

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Bridge 6

35 °F difference!
Temperature Model

- Project Background
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**Bridge 1**

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Max. Deck Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:00 AM</td>
<td>80</td>
</tr>
<tr>
<td>12:00 PM (noon)</td>
<td>70</td>
</tr>
<tr>
<td>6:00 PM</td>
<td>60</td>
</tr>
<tr>
<td>2:00 AM (Actual)</td>
<td>50</td>
</tr>
<tr>
<td>Ambient</td>
<td>40</td>
</tr>
</tbody>
</table>

**Bridge 2**

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Max. Deck Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:00 AM</td>
<td>85</td>
</tr>
<tr>
<td>12:00 PM (noon)</td>
<td>75</td>
</tr>
<tr>
<td>6:00 PM</td>
<td>65</td>
</tr>
<tr>
<td>4:00 AM (Actual)</td>
<td>55</td>
</tr>
<tr>
<td>Ambient</td>
<td>45</td>
</tr>
</tbody>
</table>
Temperature Model

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**Bridge 6**

Placing concrete in late afternoon shifts peak temp. difference to Day 2 or 3.
Stress analyses were performed using Mathcad, based on first-principles model by Zuk (1961)

- Developed for composite bridge decks
- Calculate free strain in each segment due to temperature change and/or shrinkage
- Calculate stresses generated by compatibility along interfaces

Modifications:

- Creep was implicitly modeled by reducing the elastic modulus of concrete.
Stress Model

- Sensitivity Analysis
  - Autogenous shrinkage
  - Drying shrinkage
  - Temperature changes in deck and girder
  - Compressive strength of deck concrete
  - Thickness of deck
  - Girder spacing
Stress Model

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Sensitivity Analysis: Key Findings

- High sensitivity to tensile stresses caused by early-age temperature drops
- 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
Simulations also performed for “realistic” temperature distributions

- Assumed top 1/3 of deck is cooled 10 degrees F relative to interior
  - Simulated tensile stresses reached up to 130 psi at 3 days (after cooling)
  - Steeper substantial gradients may have existed in actual deck
Simulations also performed for “realistic” temperature distributions

- Simulations also performed assuming uniform drying shrinkage of 500 microstrain
  - Simulated tensile stresses reached up to 590 psi
Simulations also performed for “realistic” temperature distributions

- Tensile capacity of the concrete may be exceeded by “realistic” thermal and shrinkage effects
- Simulated stresses generally correlated with observed crack severity
Recommendations

- Curing recommendations to limit thermal cracking
  - Move pour times to later afternoon
  - After peak hydration, apply insulation

- Recommendations implemented on 2 new bridge decks in late 2016 and 3 new bridge decks in 2017
  - DOT reports little to no transverse cracking observed (typically over bents, if observed)
Recommendations

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- **Recommendations**
Additional recommendations for reducing early-age shrinkage cracking:

- Immediately fog mist placements until wet curing media is in place
- Limit cementitious material contents to 600 lb/yd$^3$ or less
- Limit silica fume replacement to 5%
- Specify w/cm between 0.42 and 0.45
Recommendations

- Additional recommendations for design:
  - Increase design thickness of decks to 8 inches minimum
  - Modify specifications to require staggering of top and bottom transverse reinforcing mats
Conclusions

- Early-age thermal effects can generate significant thermal stresses in bridge decks.

- Risk of cracking may be reduced by:
  - Pouring concrete in late afternoon
  - Applying insulation to the deck after peak hydration
Questions?

Thanks for attending!