SOLUTIONS FOR THE BUILT WORLD

Early-Age Bridge Deck Cracking: Case Study

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Early-Age Bridge Deck Cracking: Case Study

- **Outline**
- Project Background
- Investigation
- Thermal Modeling
- Recommendations

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- 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

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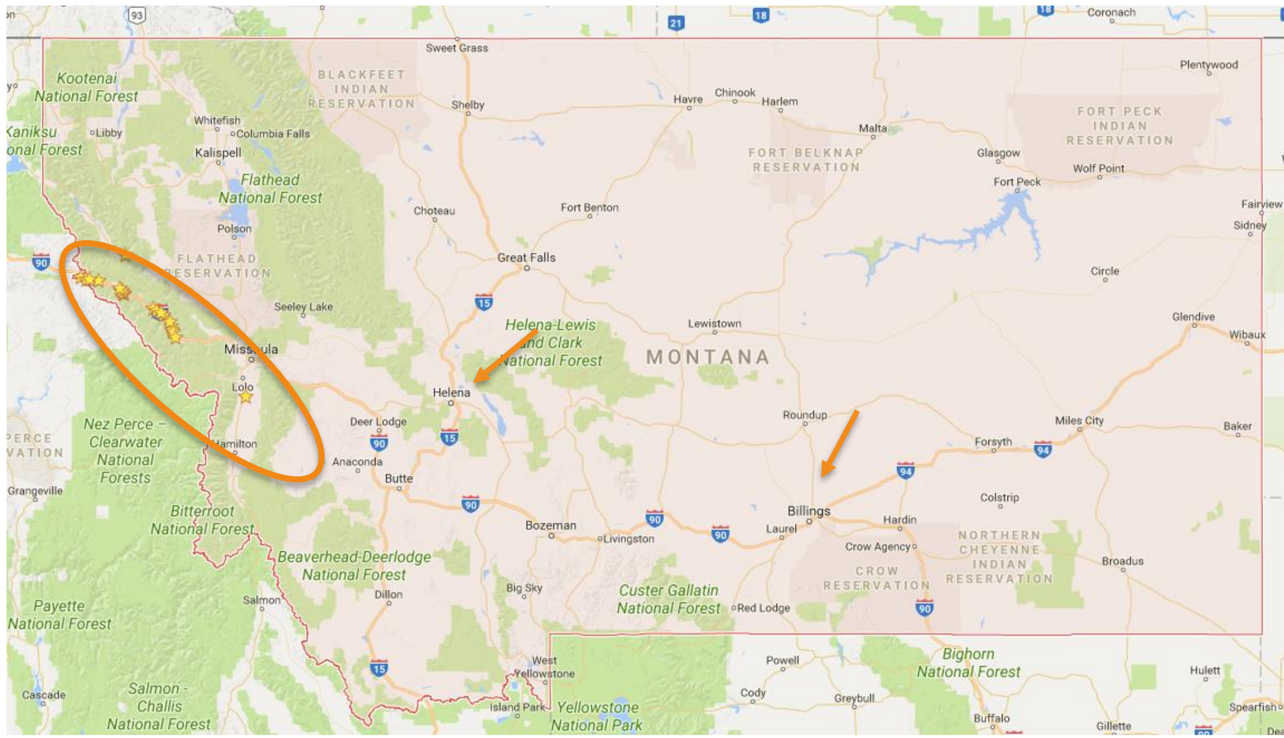

Bridge Locations

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Typical Distress

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- Performed investigation to determine cause of cracking and to make recommendations for mitigation and prevention

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- Field Investigations
  - Detailed investigation of four bridges
  - Comparative investigations of eight additional bridges
    - Crack mapping
    - Delamination survey
    - Concrete coring
    - Impulse response
    - Infrared thermography
    - Drone

Early-Age Bridge Deck Cracking: Case Study

- 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

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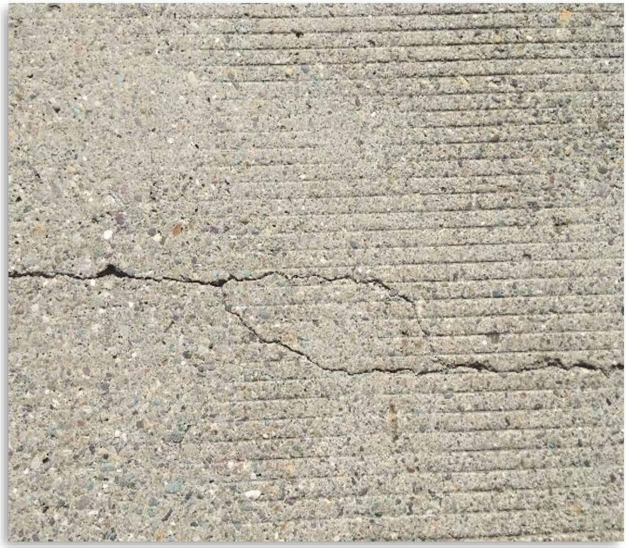

"Jump" cracking

Characteristic Cracking

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- 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

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- 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

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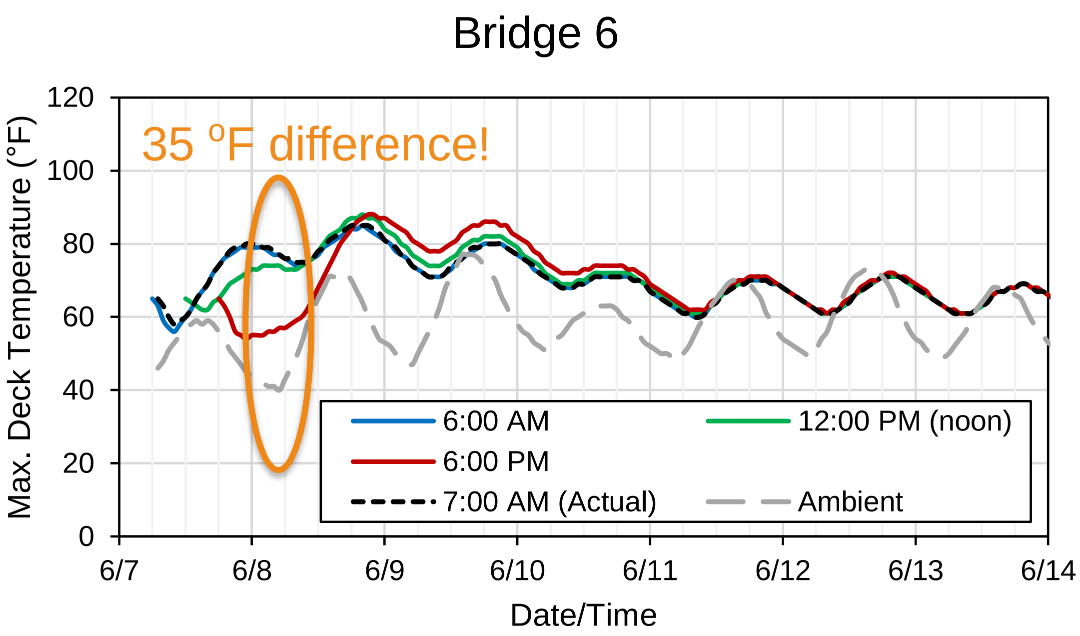

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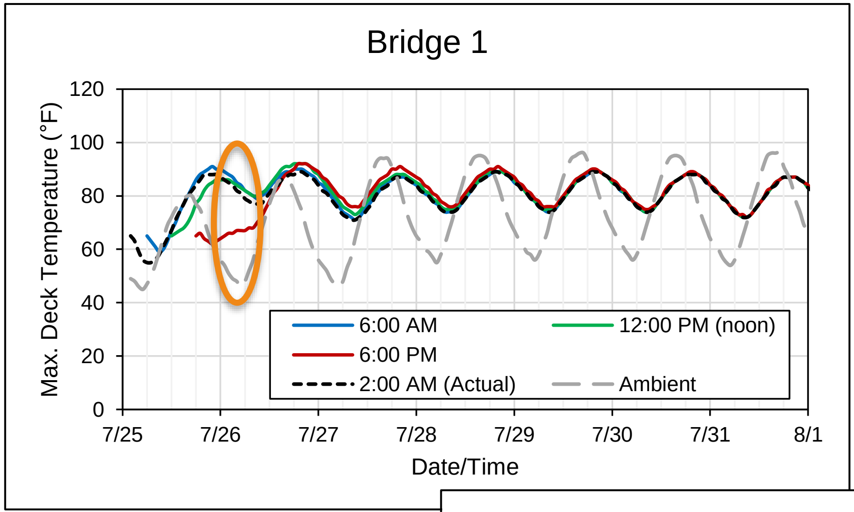

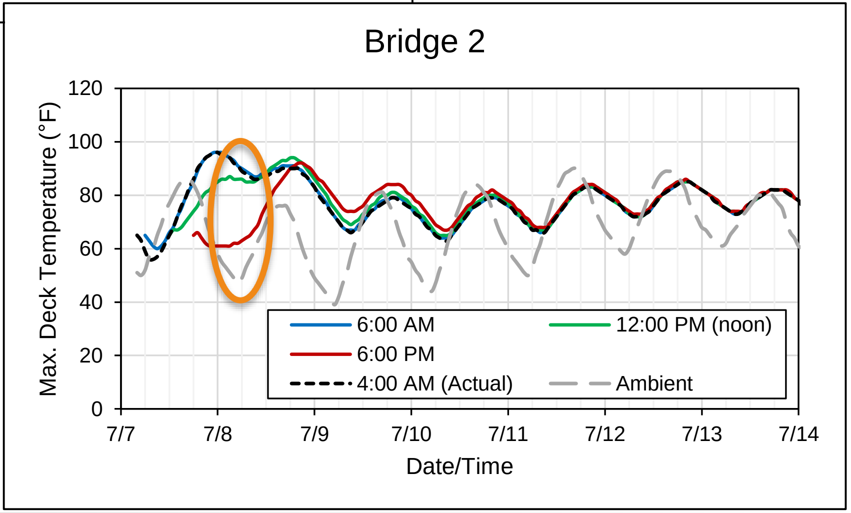

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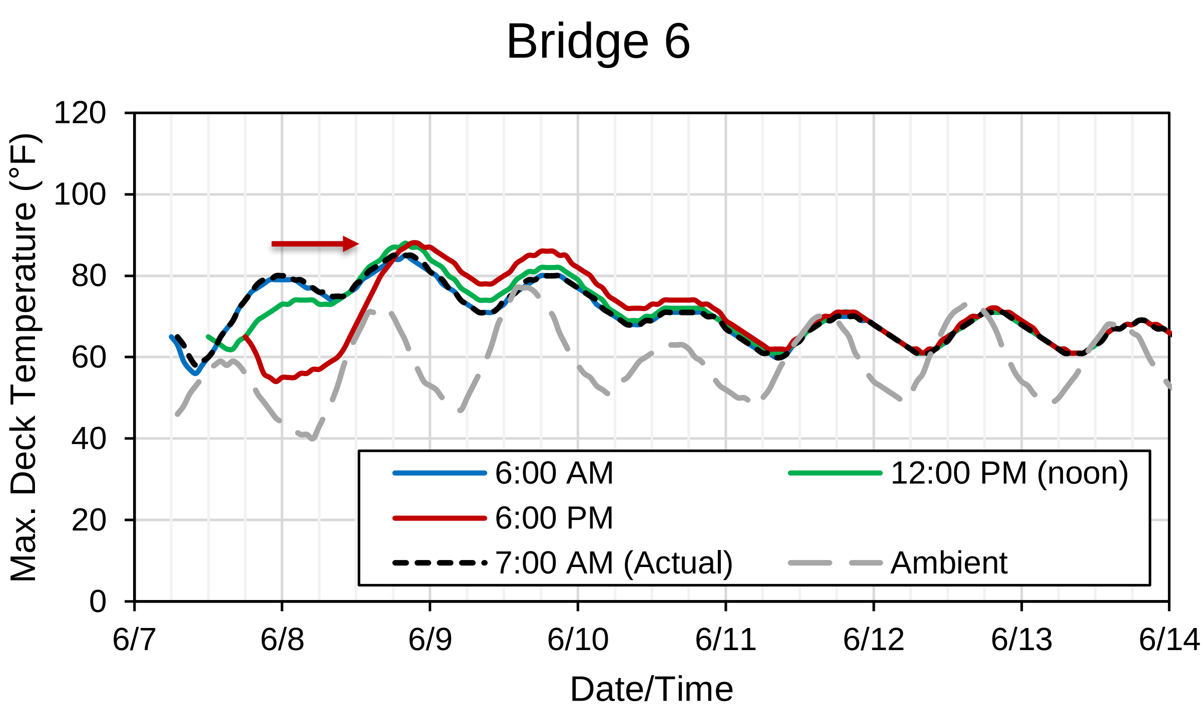

Placing concrete in late afternoon shifts peak temp. difference to Day 2 or 3.

Stress Model

- 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

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

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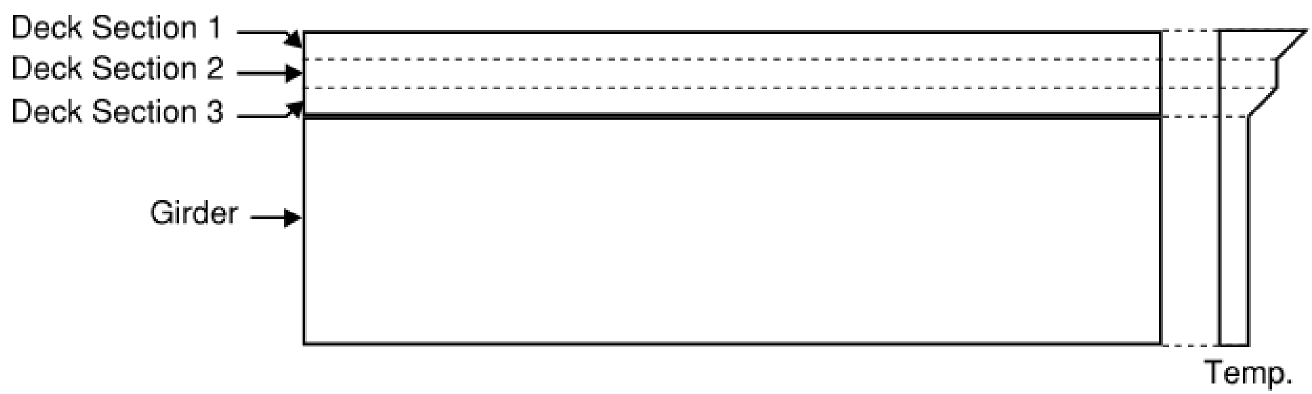
- Modifications:



- 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

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  - **Autogenous shrinkage**
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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

Stress Model

- 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

Stress Model

- 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**

Stress Model

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- 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

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- 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)

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- 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!