SOLUTIONS FOR THE BUILT WORLD

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

Project Background - General

- 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

- 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

- Outline
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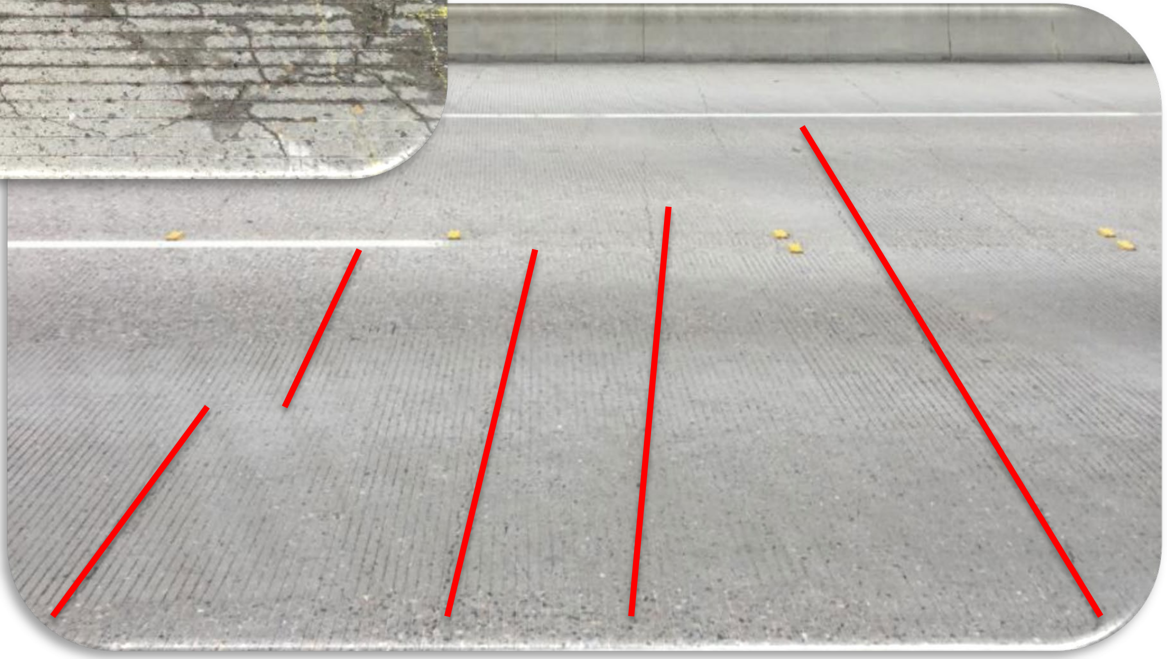
Map cracking



Transverse cracking

Field Investigations – Transverse Cracking

Field Investigation – Transverse Cracking

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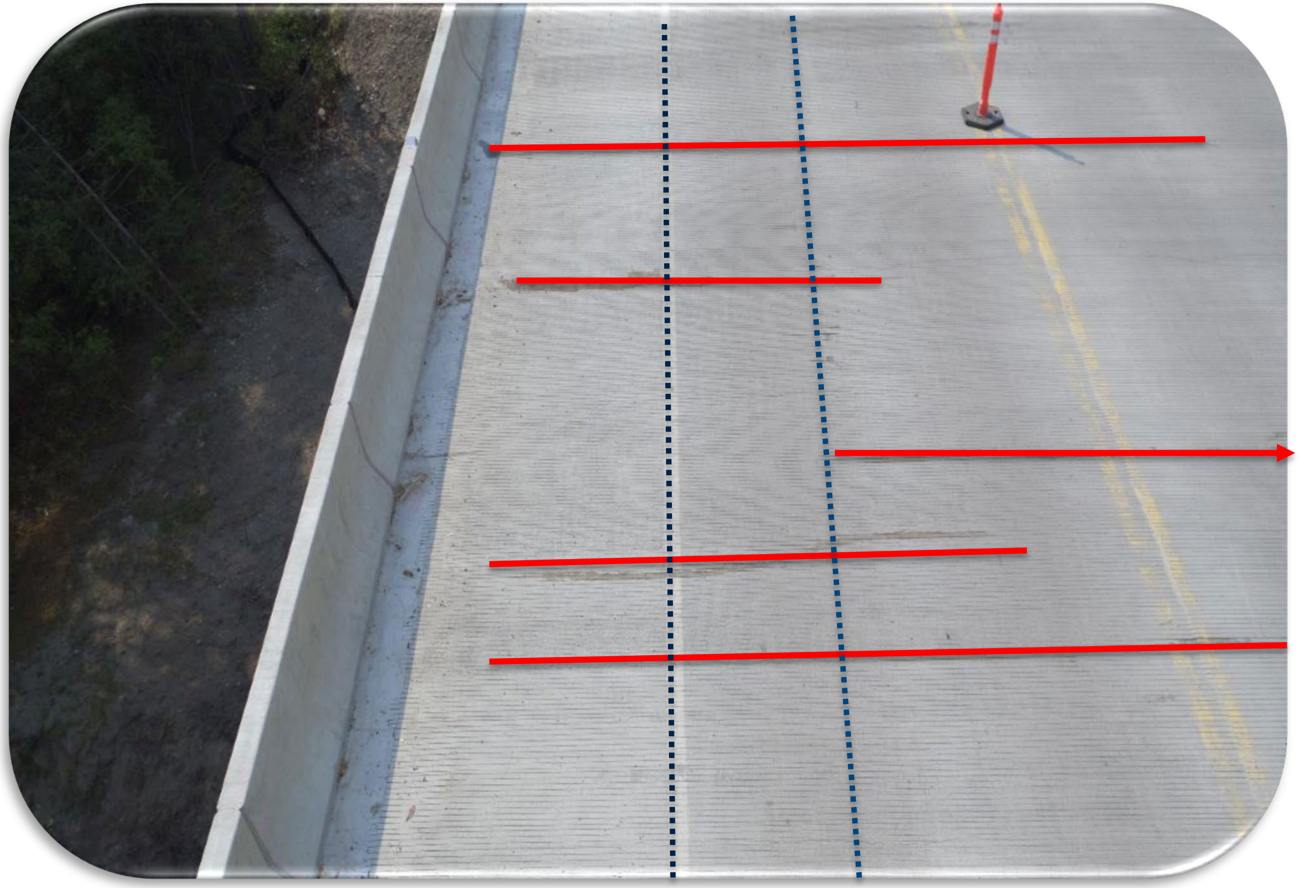

Transverse cracking

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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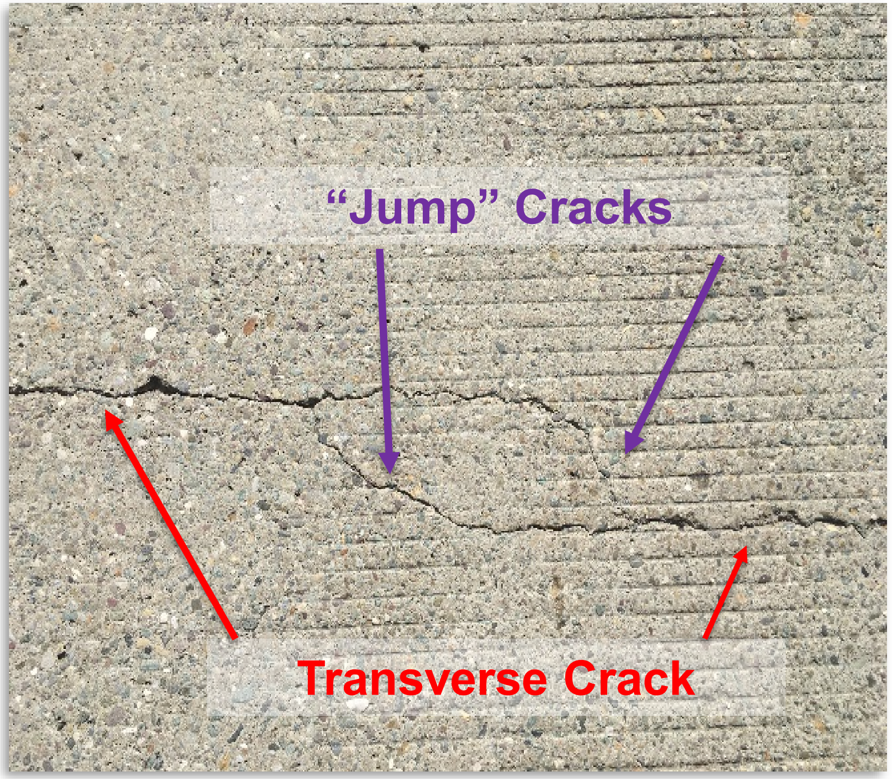

"Jump" cracking

Field Investigation - Characteristic Cracking

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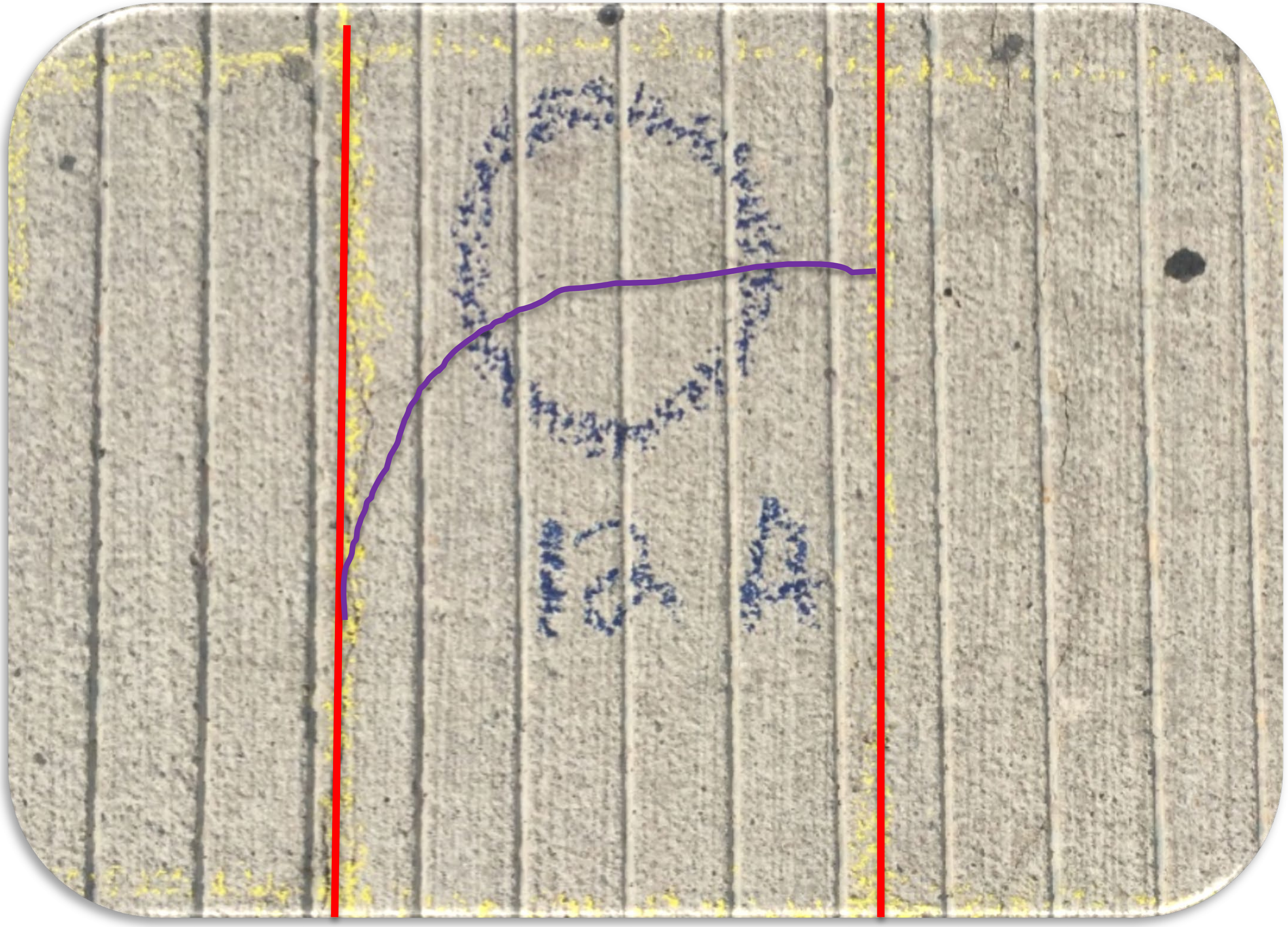

Field Investigation - Characteristic Cracking

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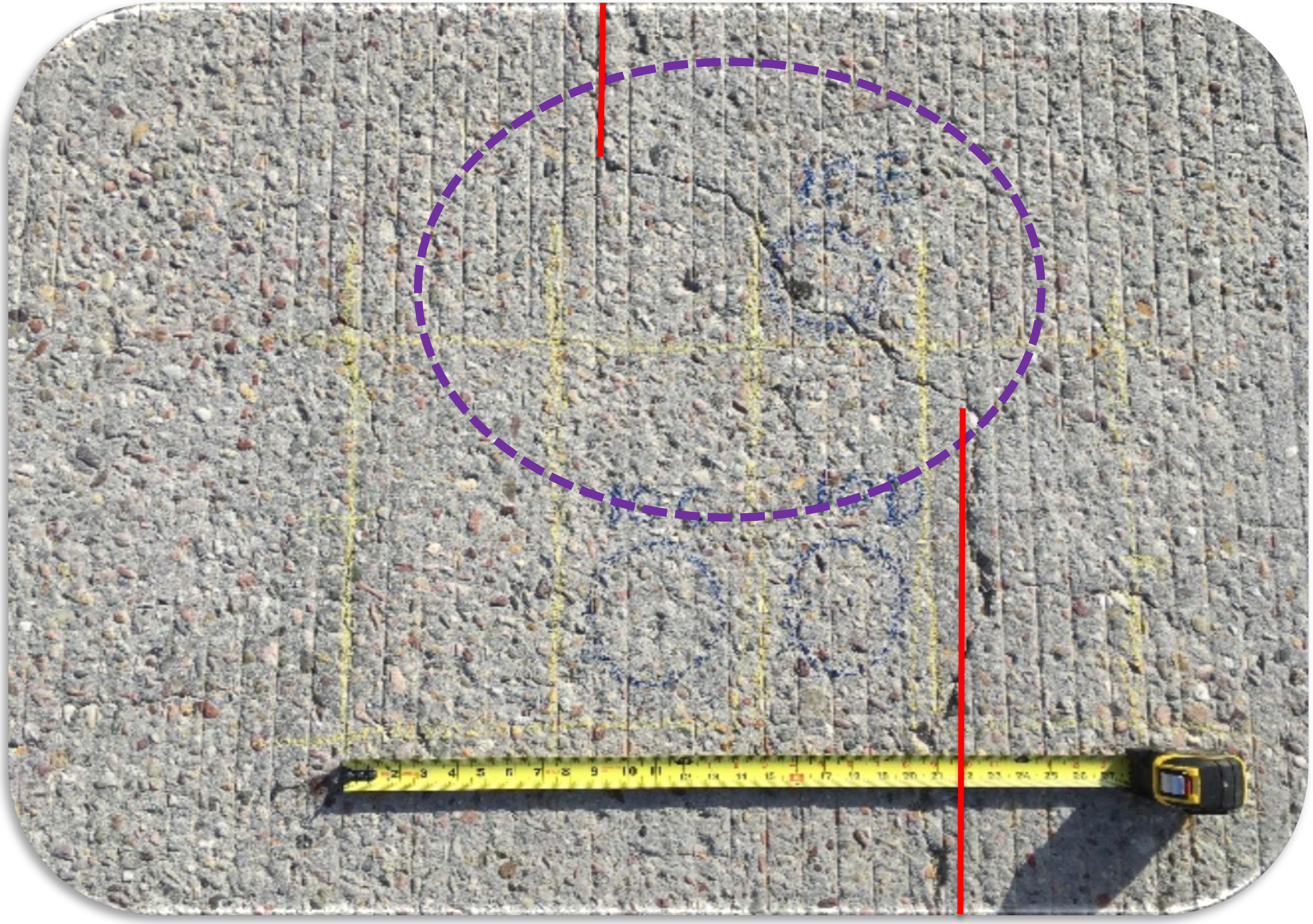
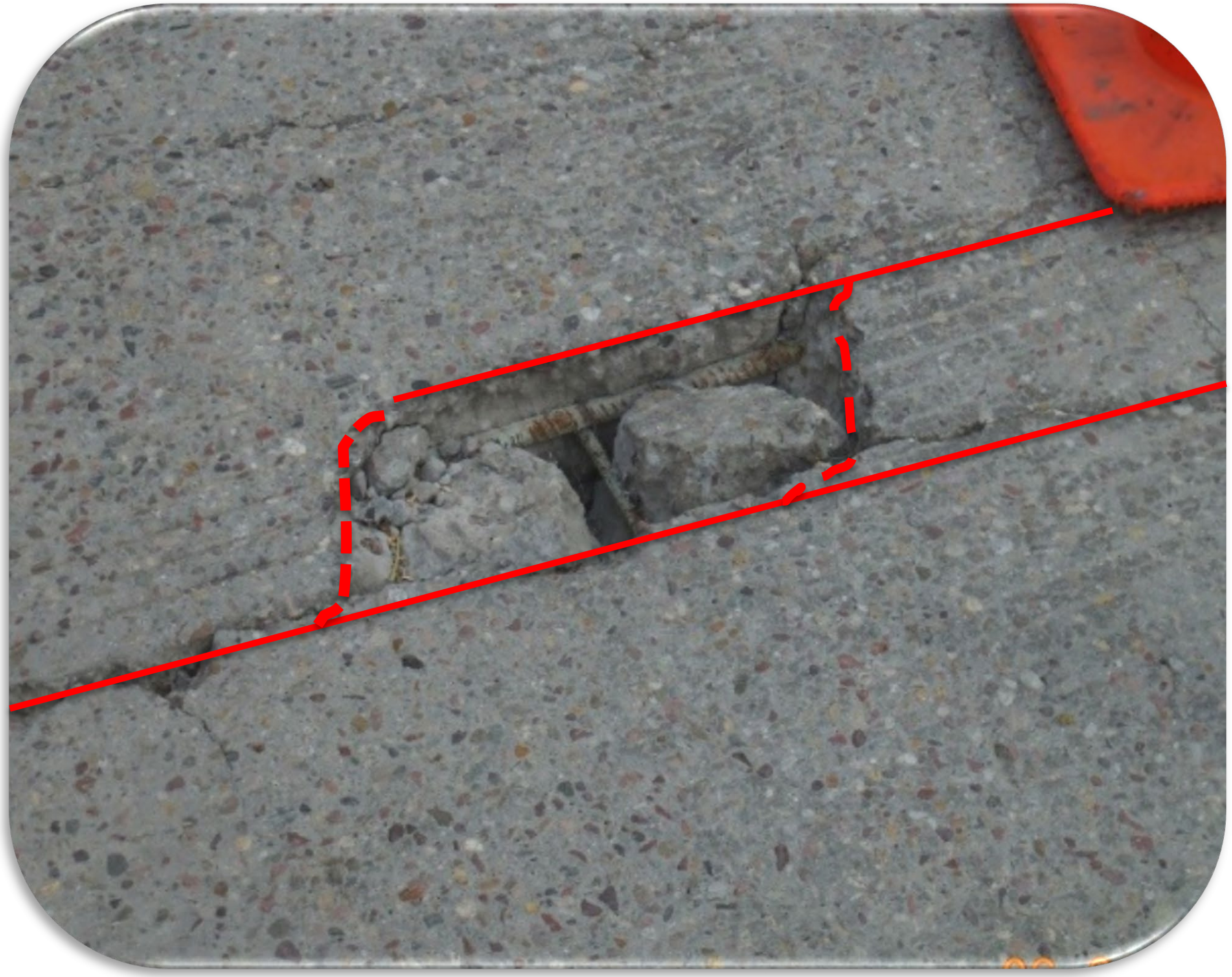


Field Investigation – Deck Penetration

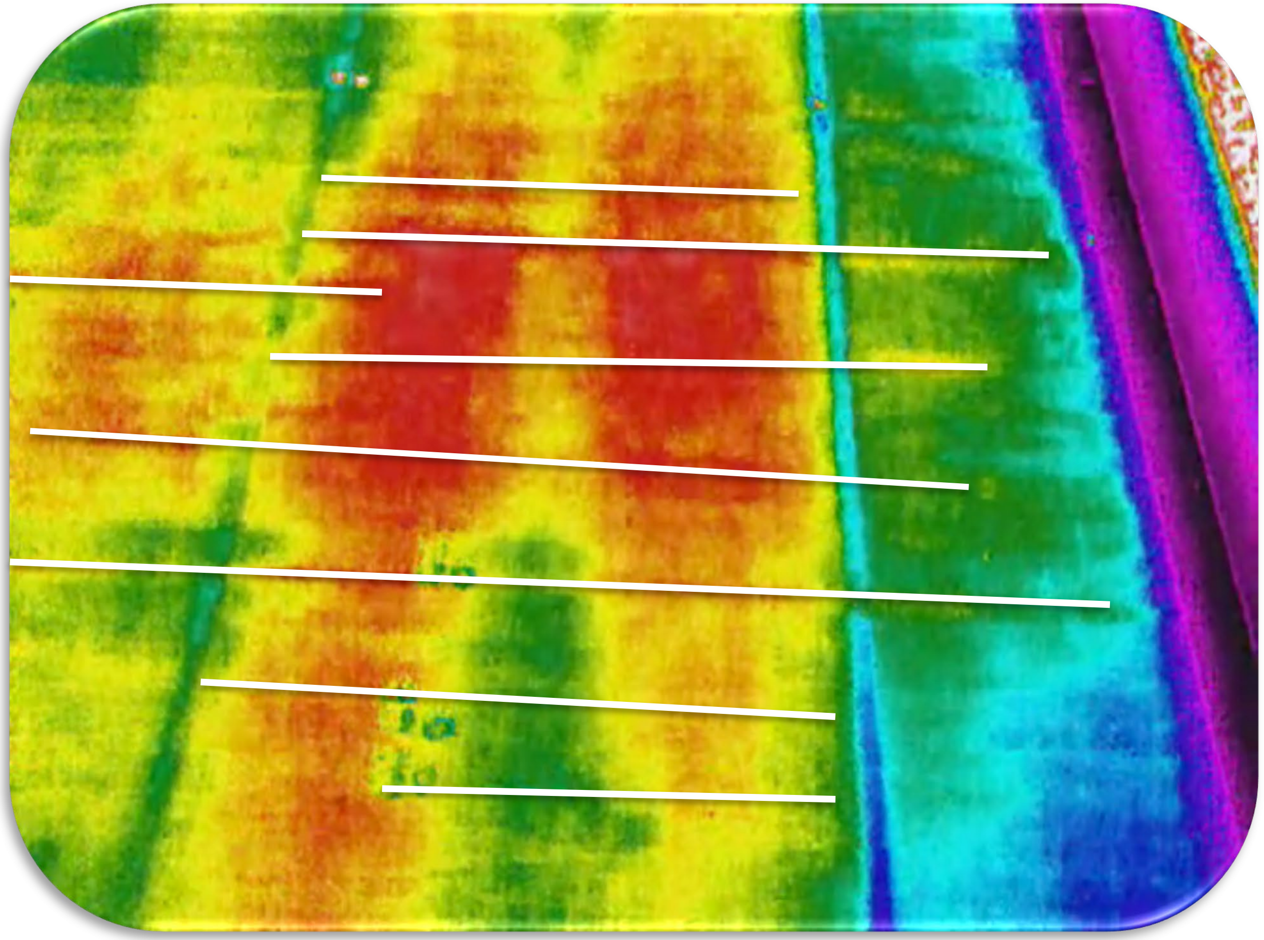


Field Investigation – Cracking

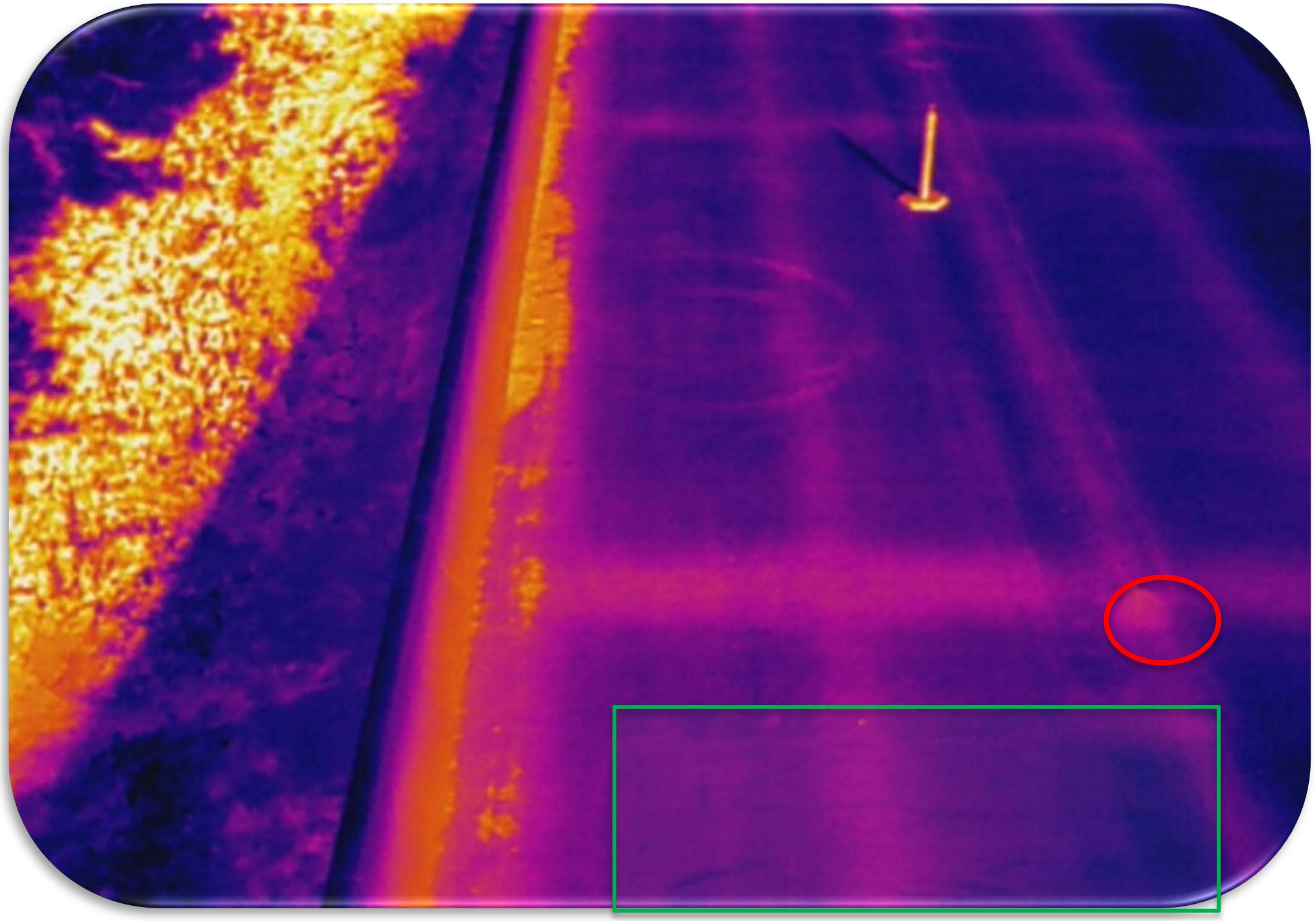
- Transverse crack spacing varied from 2 to 4 feet on most bridges
  - More frequent than typical
- Transverse cracks predominately over transverse bars (GPR)
- Width of transverse cracks were typically 15 to 25 mils
- Plastic shrinkage cracking noted on some decks, most severe on Florence-East MP 10.640 - 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



Field Investigations – Deck Temperatures

- 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

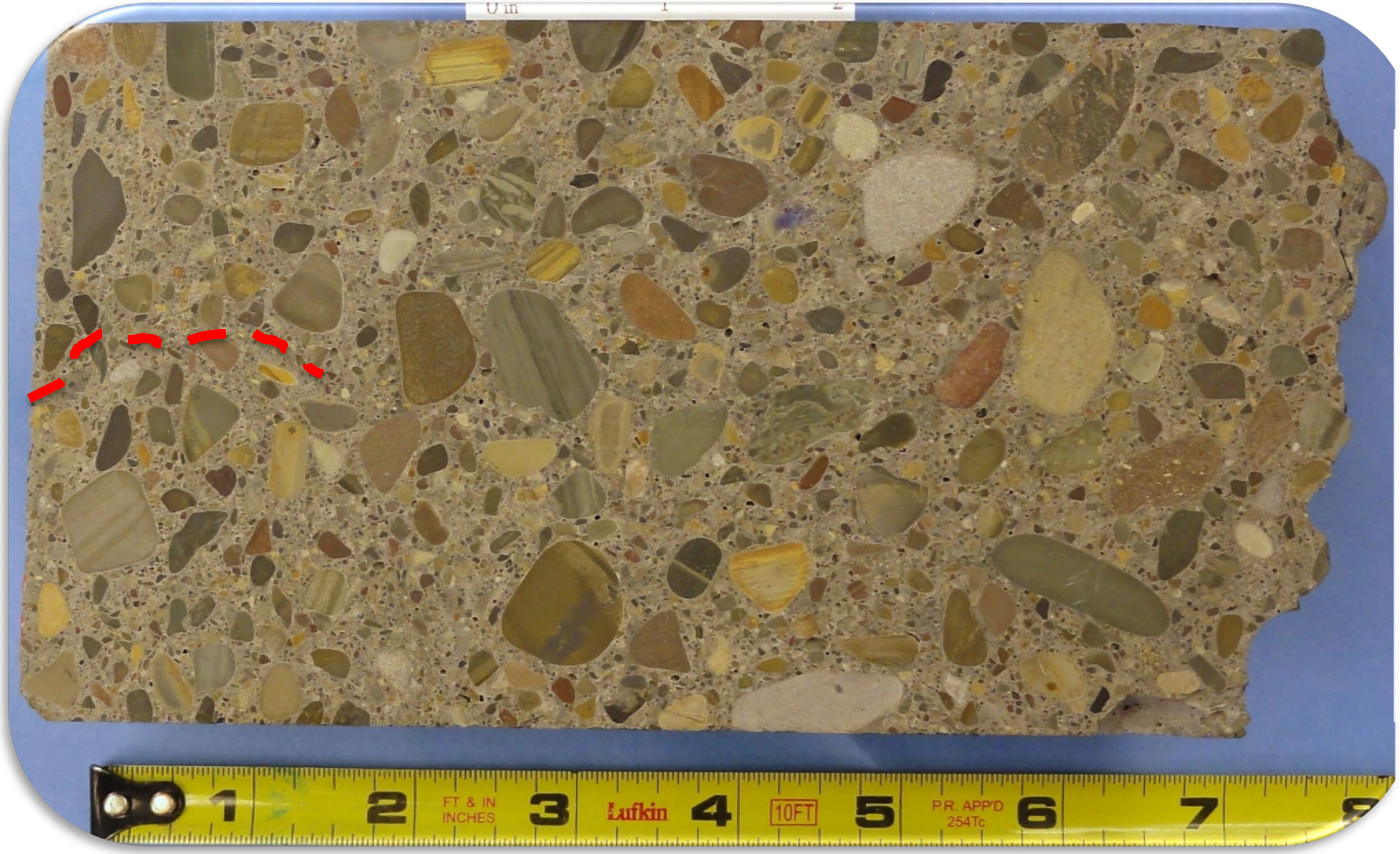
Laboratory Evaluations

Laboratory Evaluations

- 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)

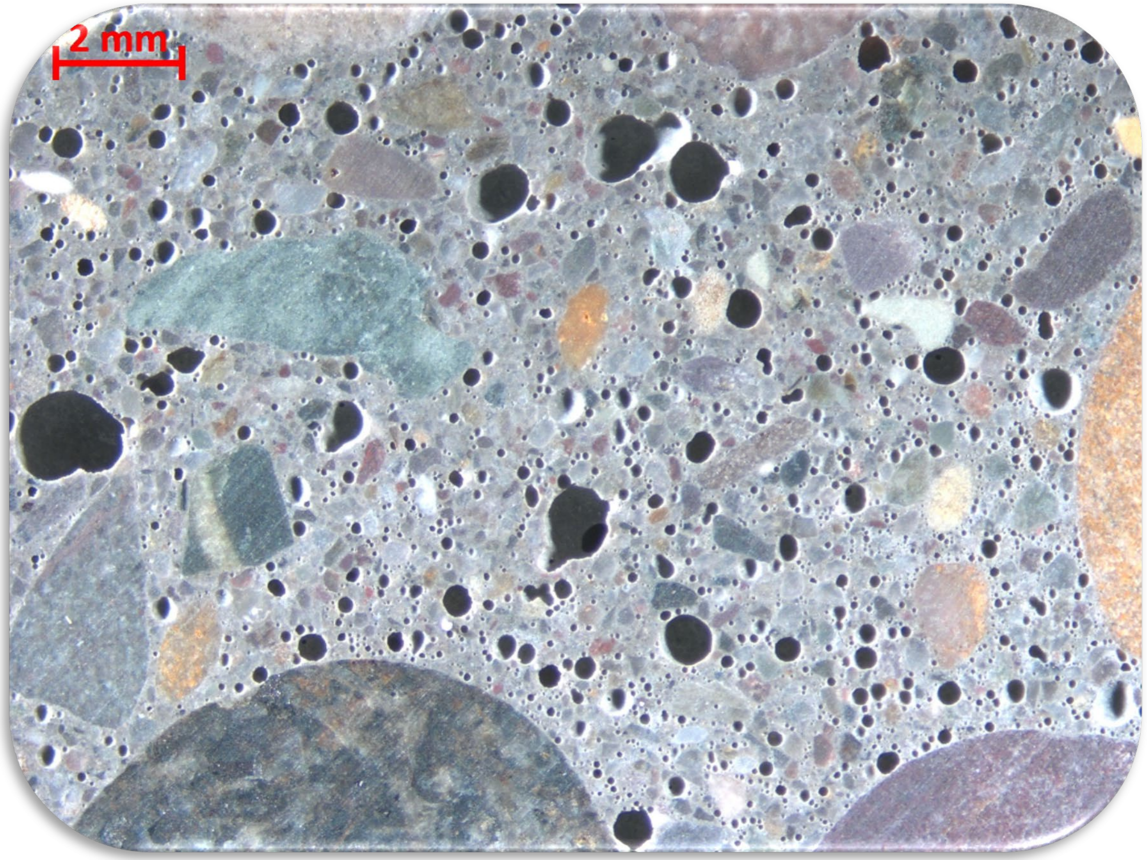
Laboratory Evaluations - Petrography

Laboratory Evaluations - Petrography



Laboratory Evaluations - Petrography

- 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

- Outline
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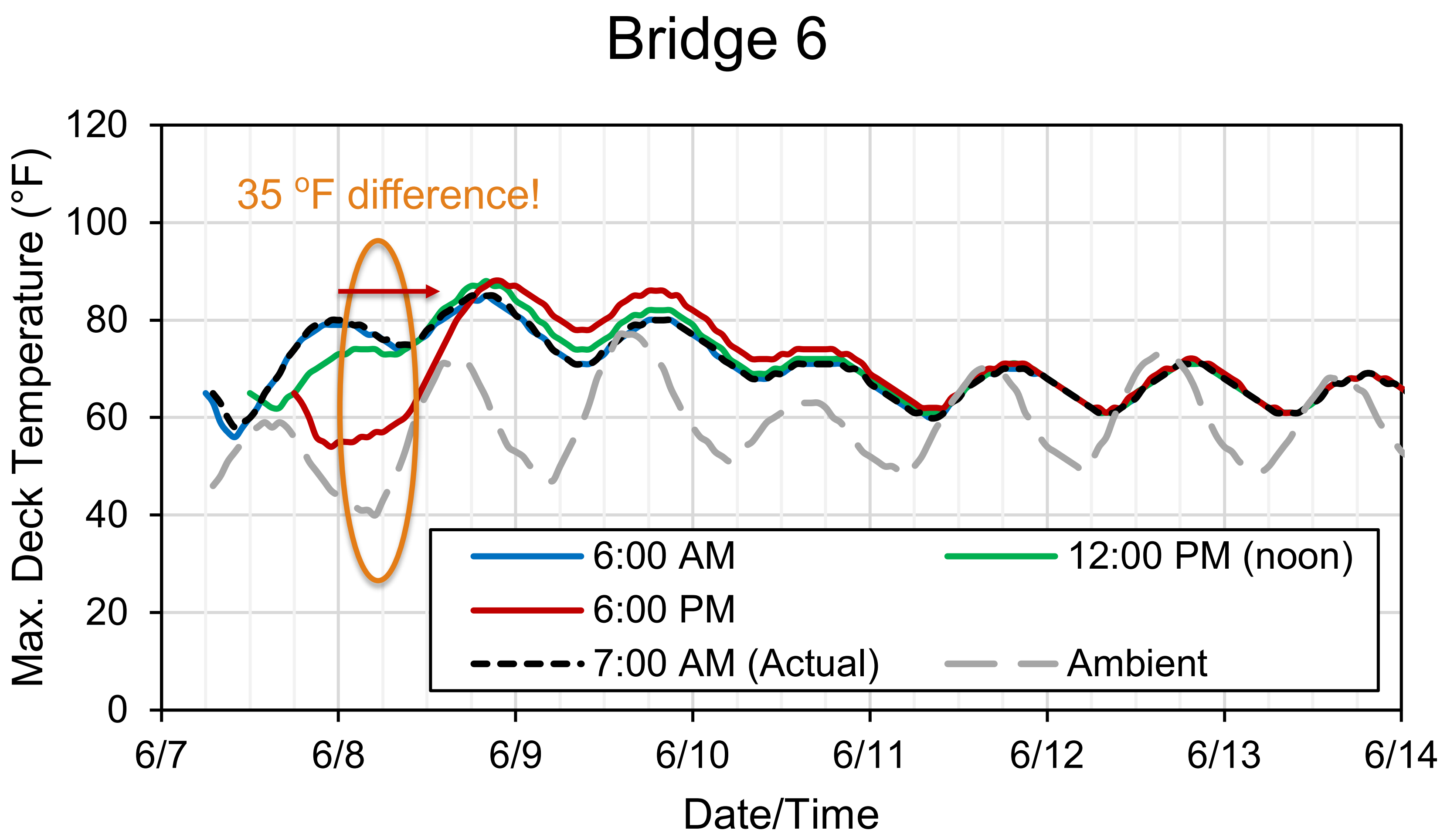
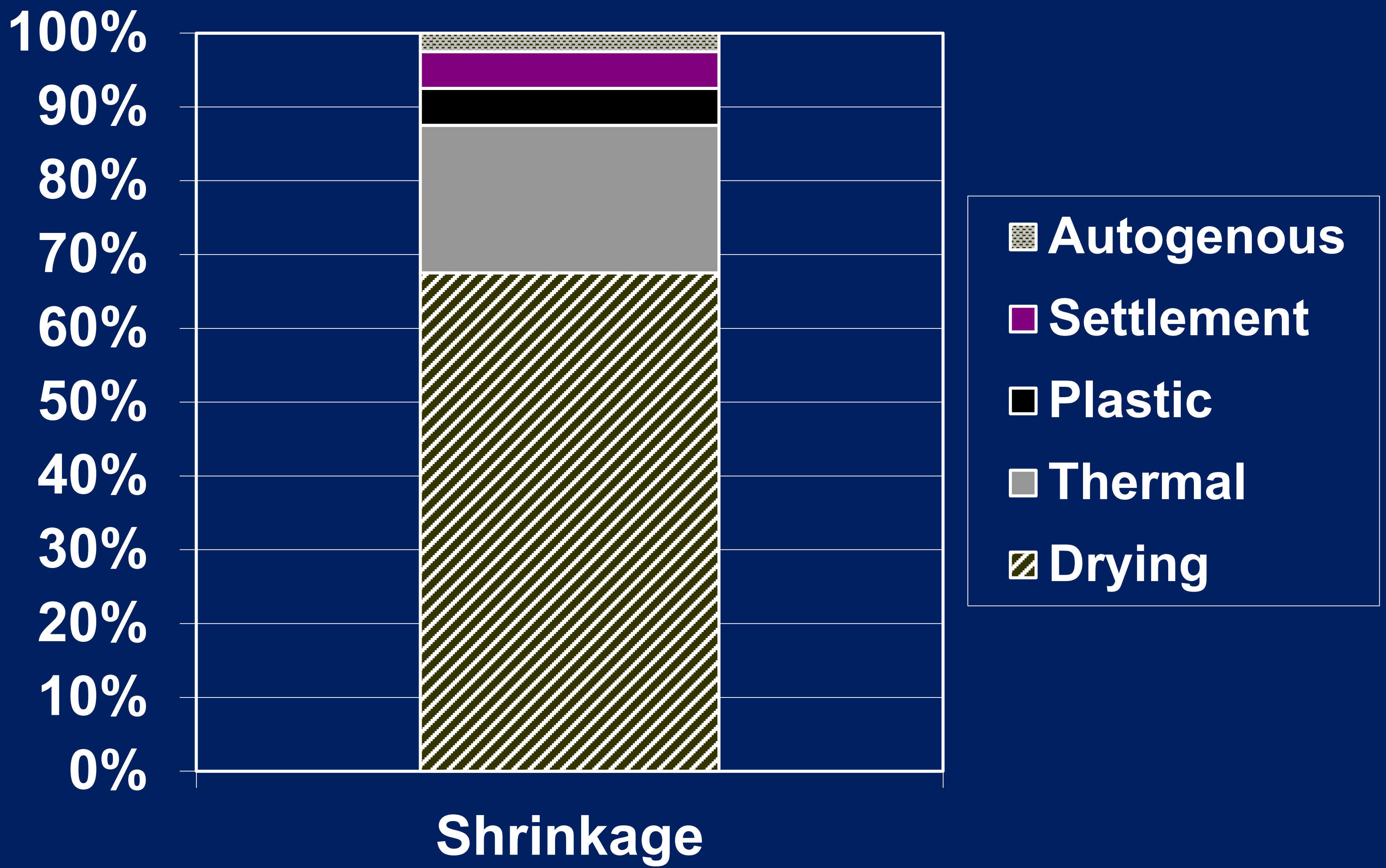
- Laboratory Evaluations
- **Thermal and Stress Modeling**
- Recommendations



Thermal and Stress Modeling

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


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Autogenous
Settlement
Plastic
Thermal
Drying
Shrinkage

Conclusion

- 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 5ºF 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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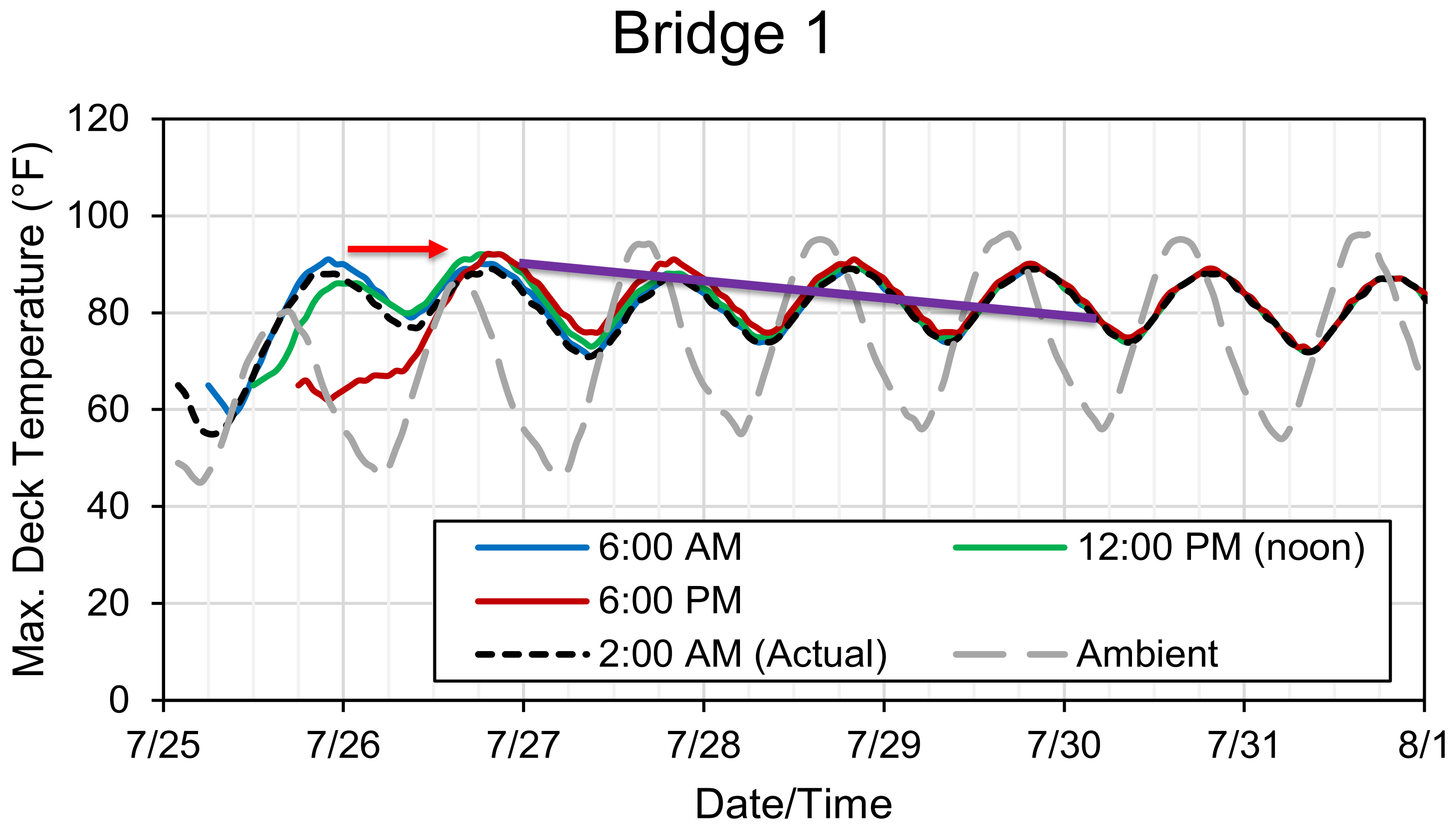

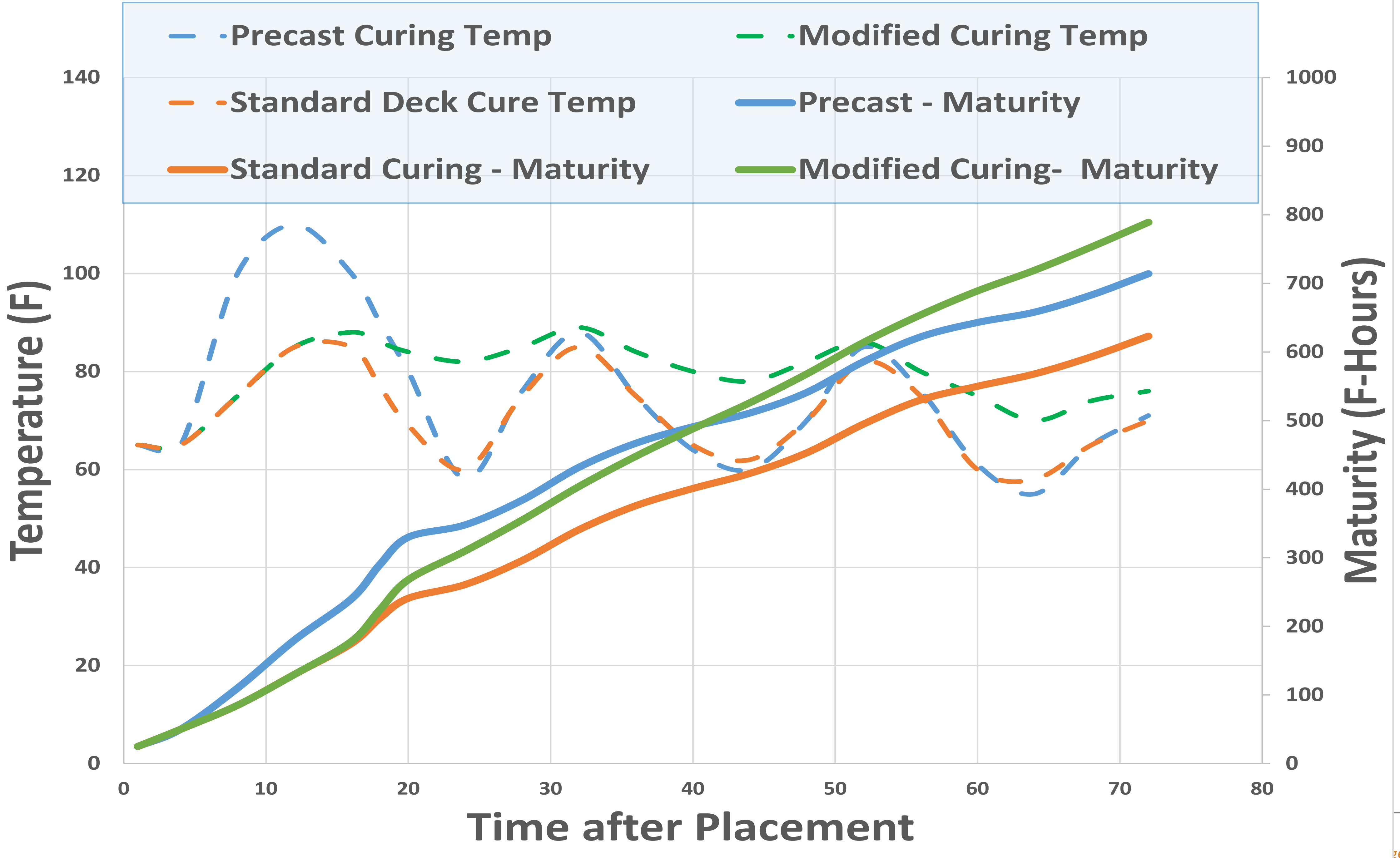

Precast Curing Temp
Modified Curing Temp
Standard Deck Cure Temp
Precast - Maturity
Standard Curing - Maturity
Modified Curing- Maturity
Temperature (F)
Maturity (F-Hours)
Time after Placement
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80

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?

Implementation

- Outline
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- Field Investigation
- Laboratory Evaluations
- Thermal and Stress Modeling
- **Recommendations**

- 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.

Special Thanks!

- **Matt Needham – MDT**
- **Paul Bushnell – MDT**
- **Paul Krauss – WJE**
- **Elizabeth Nadelman - WJE**

Questions?

Thank you very much for the opportunity!