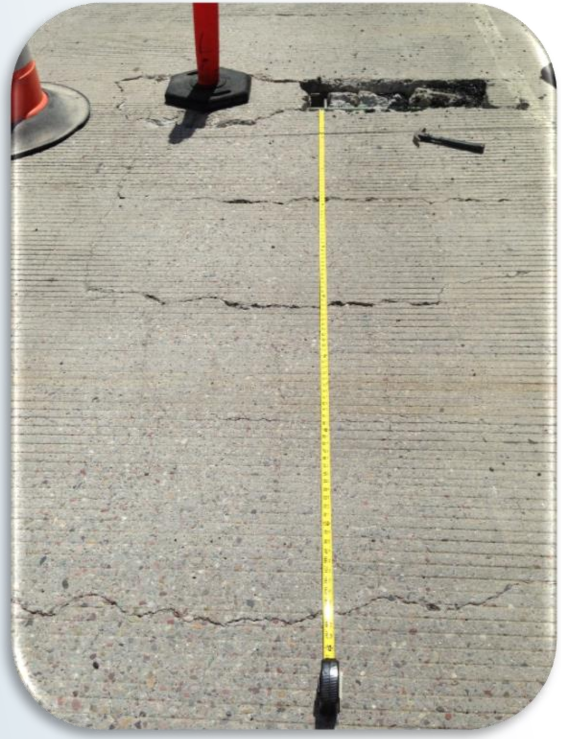
# Long Term Monitoring of Bridge Decks in Montana

**Todd Nelson, P.E.**
Associate Principal
Wiss Janney Elstner Associates

# The Problem

- Closely spaced transverse cracks on numerous bridges in western Montana
- In some cases, through deck penetrations developed
- Young bridge decks < 8 years
- Mostly in the alpine regions

# The Problem

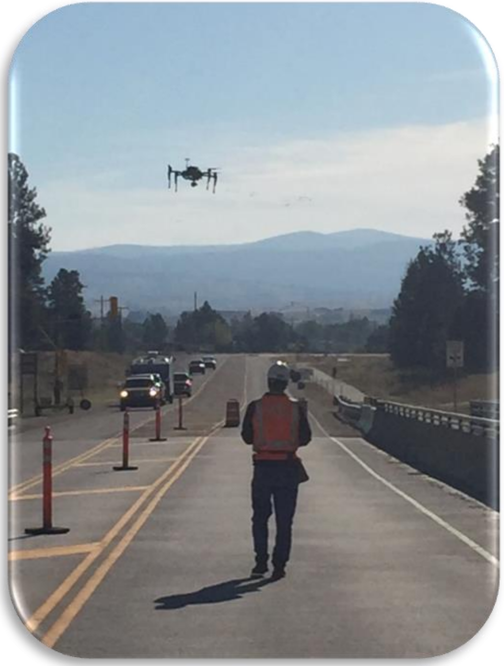


# The Investigation

- Construction Document and Literature Review
- Field Inspections
- **Instrumentation**
- Laboratory Testing
- Finite Element Modeling (FEM)

# Field Inspections

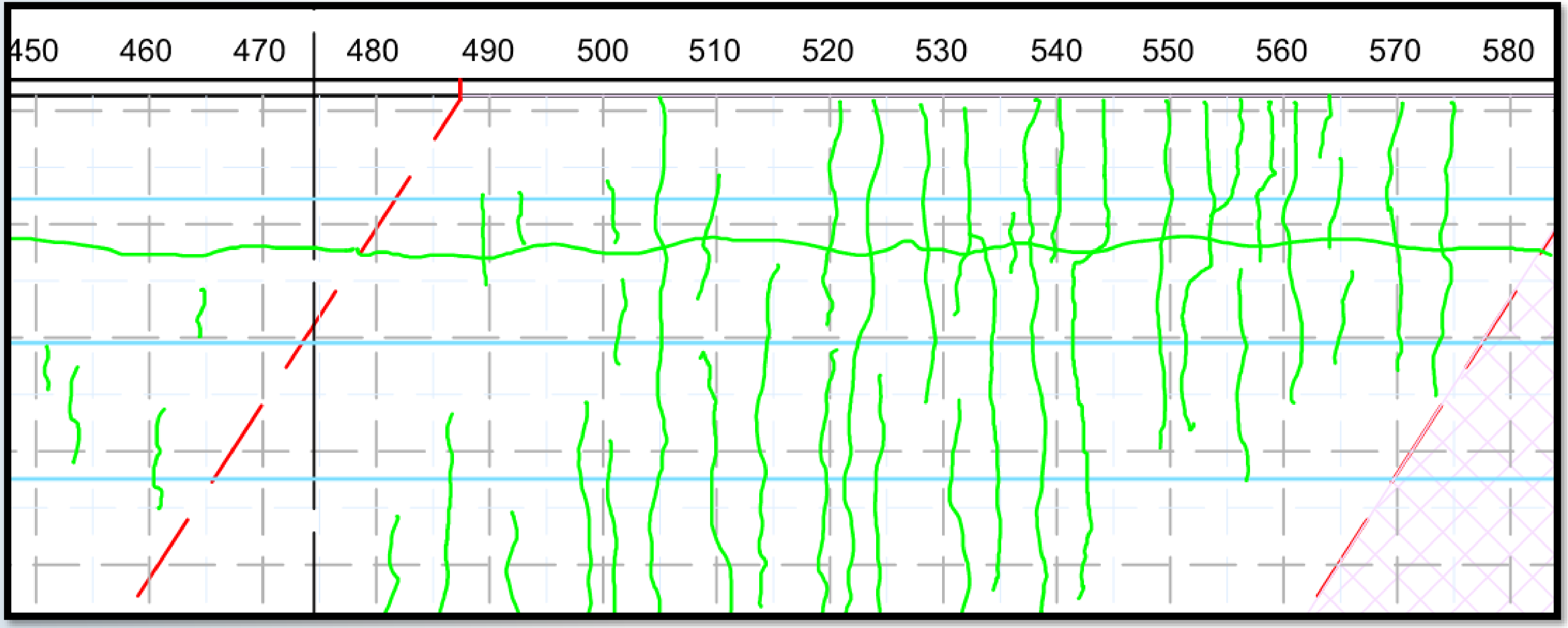
- 14 bridge decks inspected
  - Crack mapping – density/severity
  - Delamination survey
  - Ground penetrating radar
  - Infrared thermography
  - Drone survey
  - Concrete core extraction
  - Bridge deck documentation



# Field Inspections

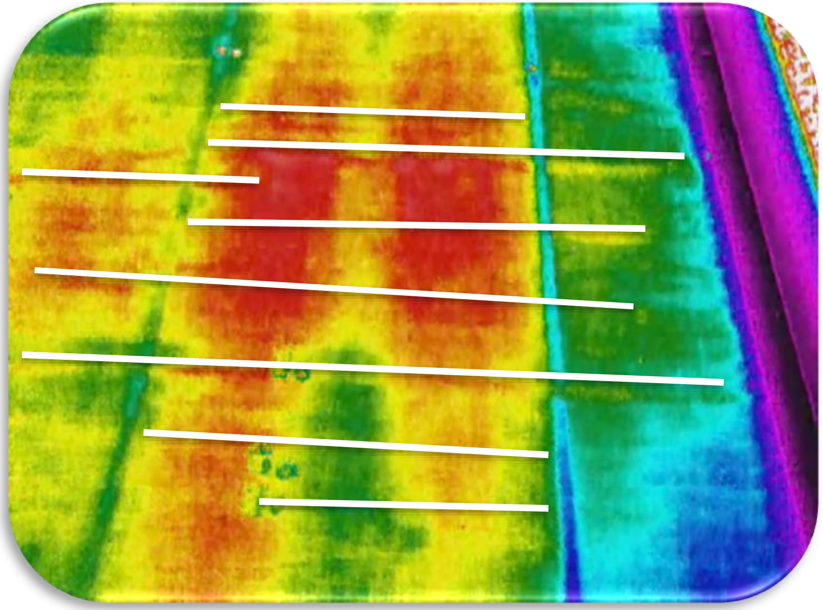
- Overall Visual Rating = 3
- Transverse cracks at 3 to 4 feet
- Crack width 20 to 30 mils

| Crack density (ft/ft2) | Crack Severity (mil*ft/ft2) |
|---|---|
| 0.19 | 3.87 |
| 0.14 | 2.45 |
| 0.17 | 3.15 |


450
460
470
480
490
500
510
520
530
540
550
560
570
580

# Field Inspections – IR/Drones

- Drone survey with infrared thermography (IR)
- IR could pick up cracks as tight as 5 mils
- Cracking density but not cracking severity



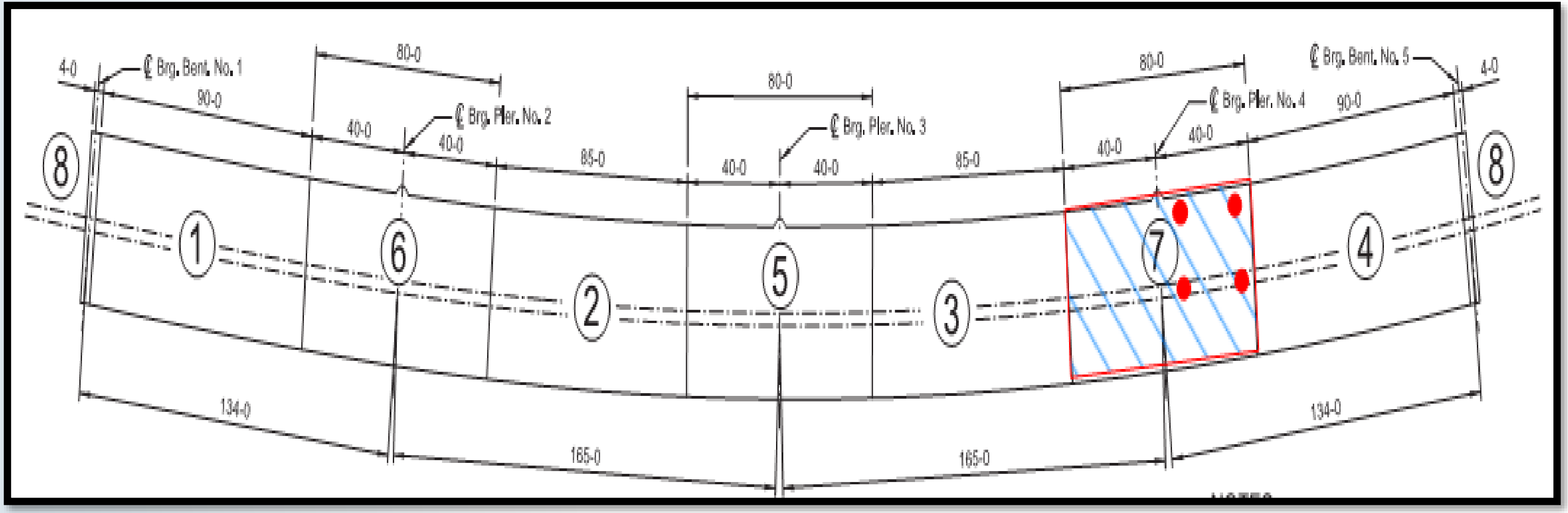
# Field Inspections - Summary

- No delamination found
- Transverse cracks align with reinforcing steel
- Most transverse cracks are full thickness
- The following factors did not yield any consistent trends in the development of transverse cracking severity: bridge bearing type, span length, span bearing type, placement location, and placement length.
- Very early age and late age development of transverse cracks

# Instrumentation

- Assess the impact of environmental changes on the internal deck temperatures, relative humidity (RH), and strains.
- Instrumentation:
  - Strain (vibrating wire SG's)
  - Temperature
  - Relative Humidity (resistive)
  - Ambient conditions
    – temperature, relative humidity, wind speed, and solar radiation

# Instrumentation



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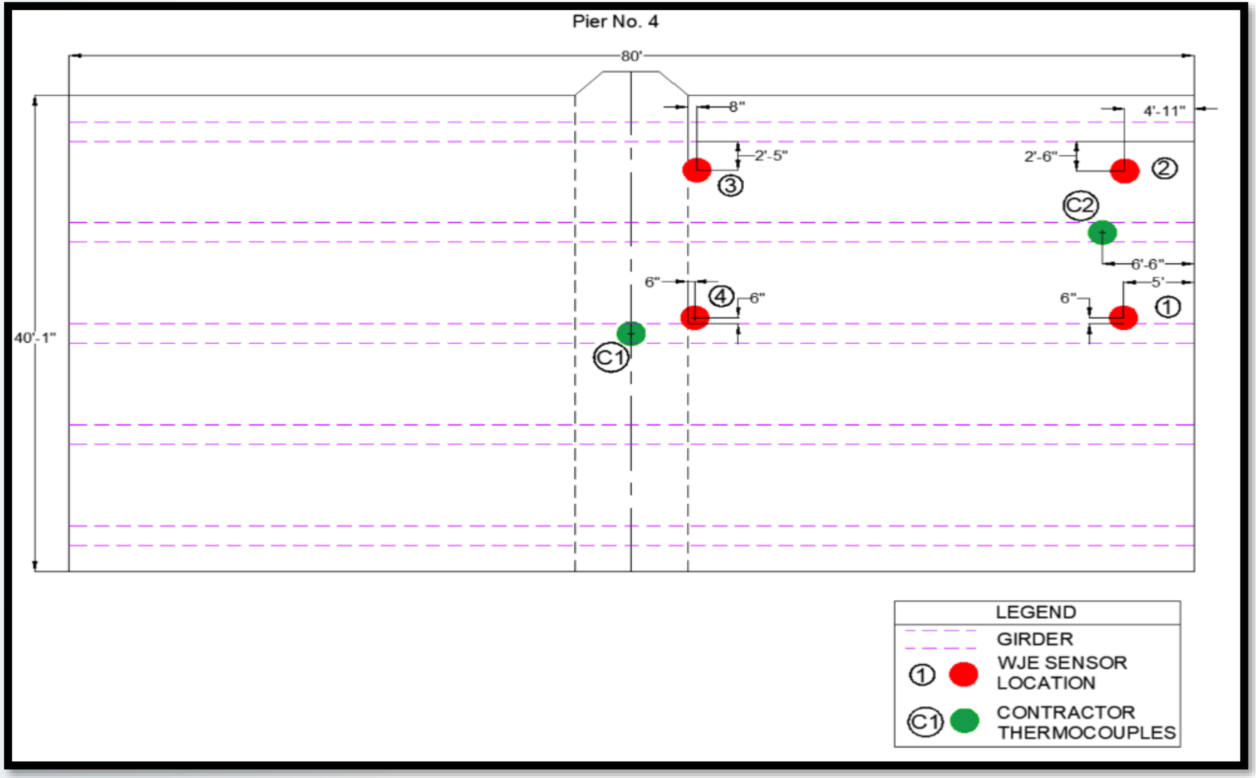
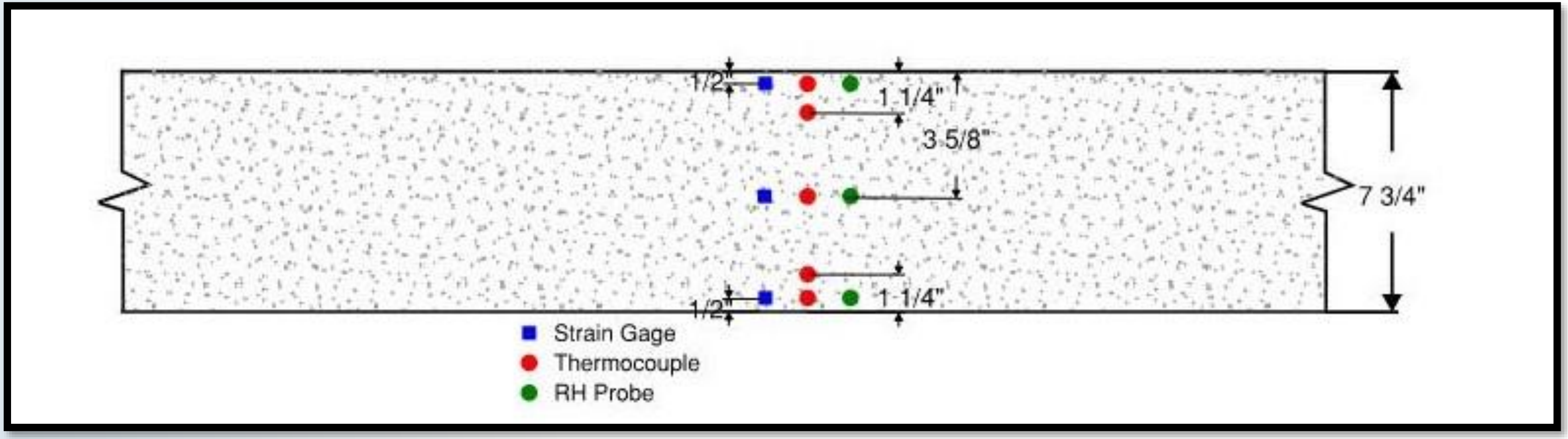
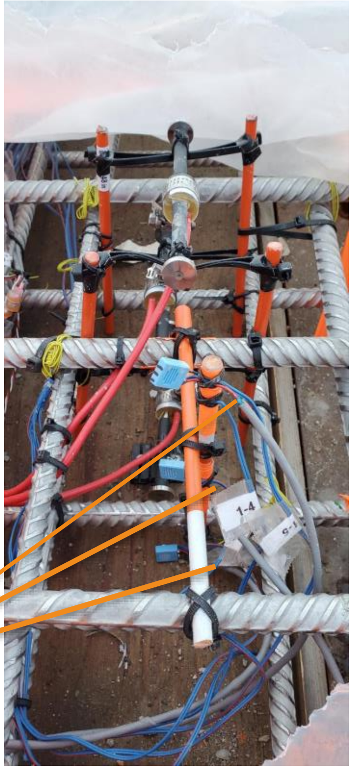


# Instrumentation



# Instrumentation

Vibrating wire strain gages



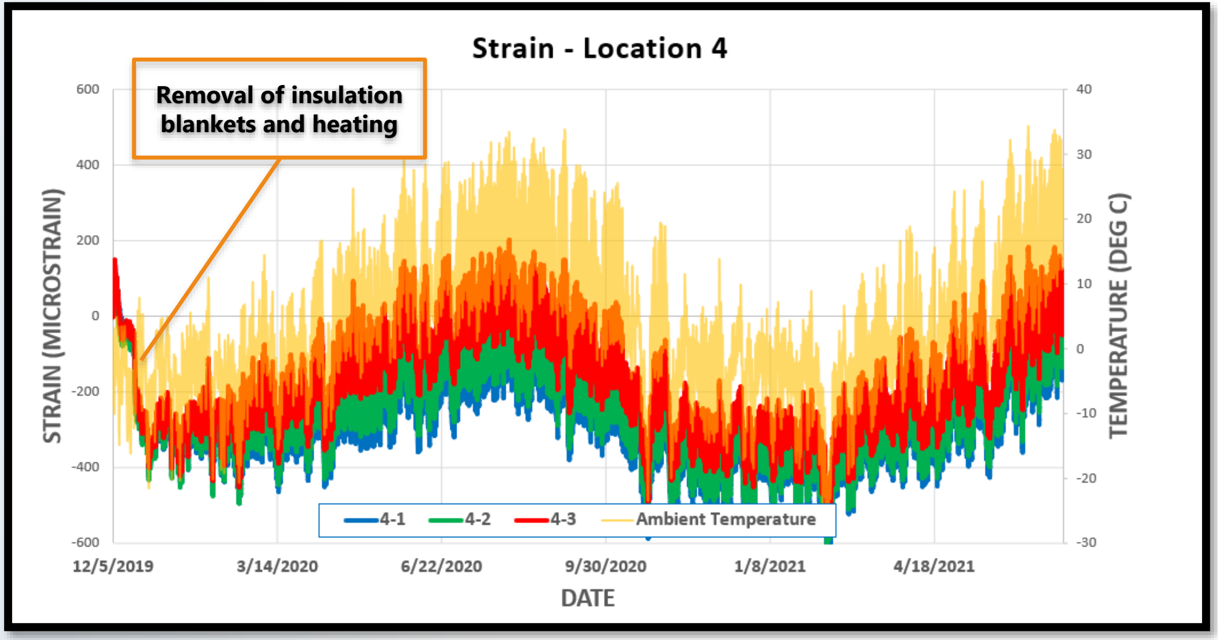
RH Sensors

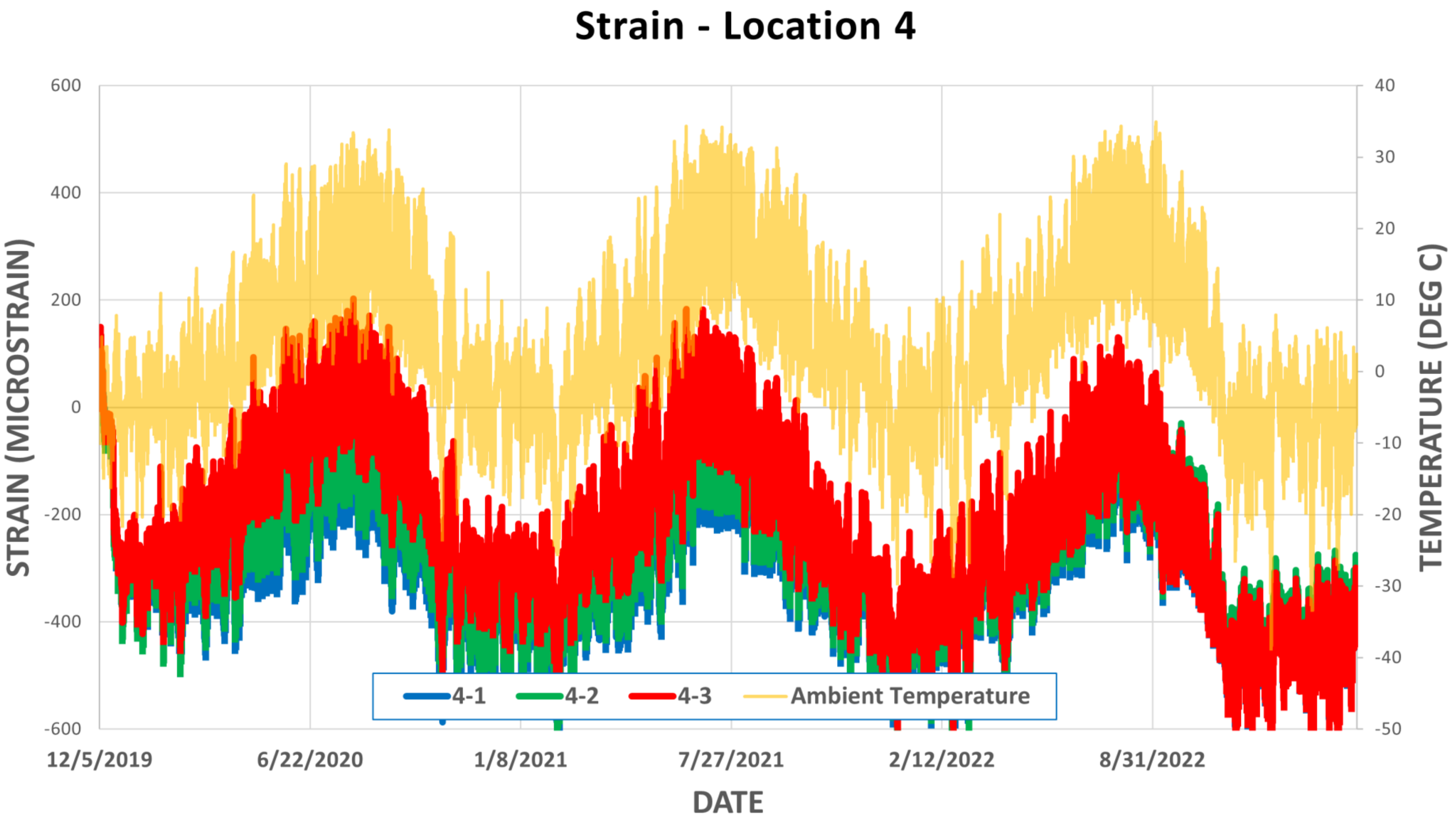
Thermocouples

# Instrumentation


# Instrumentation - Strain

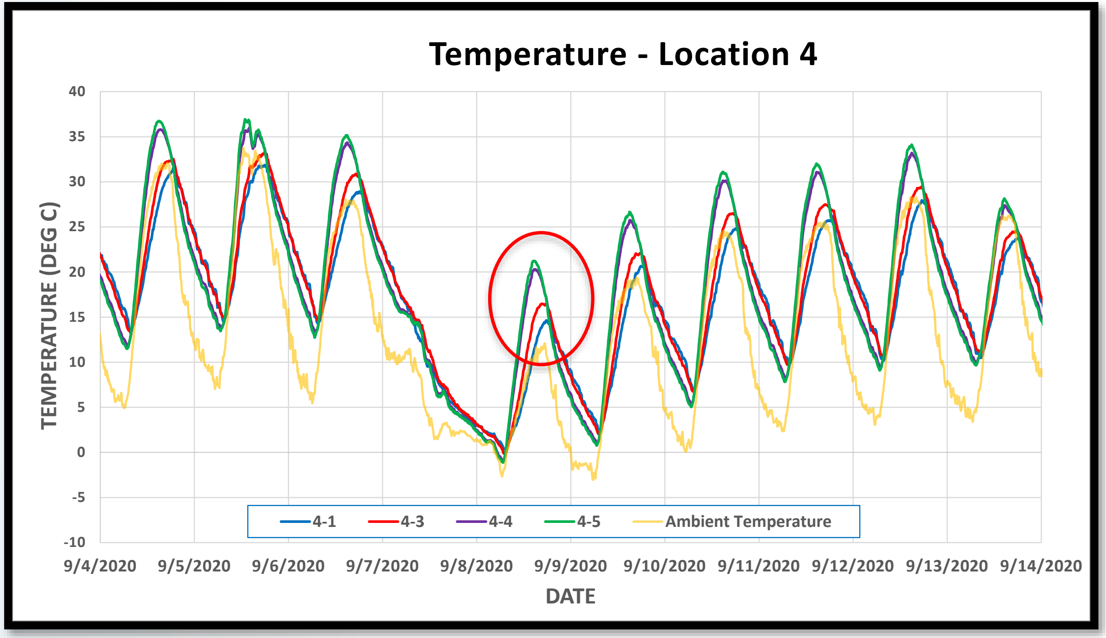
- Compressive strain developed in deck after removal of insulation and heating




Strain - Location 4
STRAIN (MICROSTRAIN)
600
400
200
0
-200
-400
-600
TEMPERATURE (DEG C)
40
30
20
10
0
-10
-20
-30
-40
-50
12/5/2019
6/22/2020
1/8/2021
7/27/2021
2/12/2022
8/31/2022
DATE
4-1
4-2
4-3
Ambient Temperature

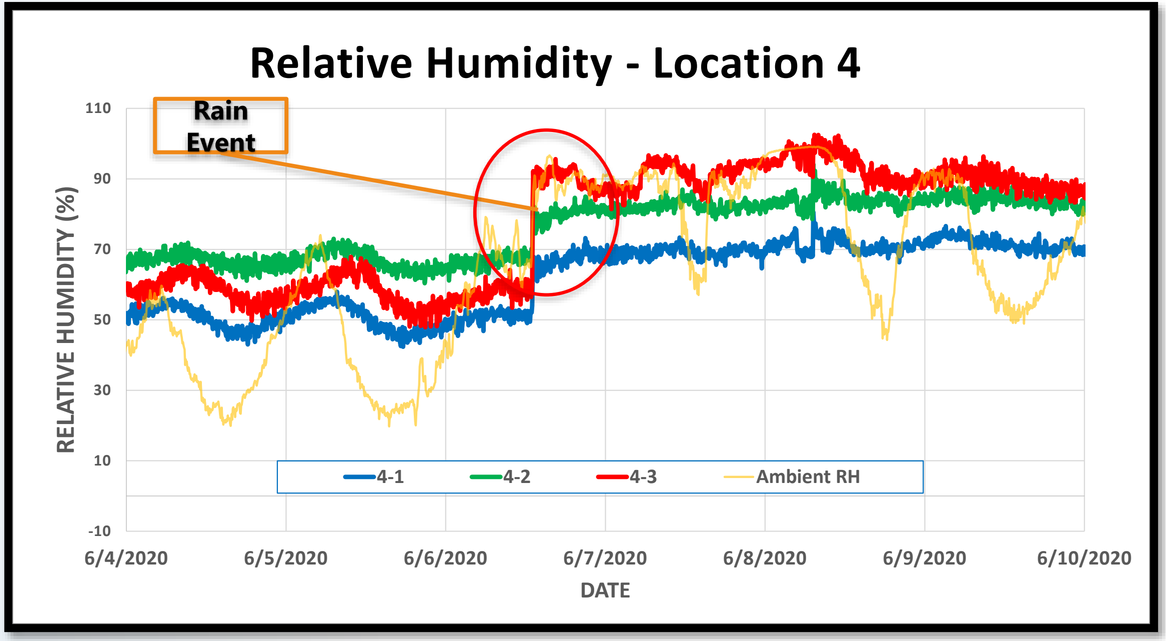
# Instrumentation - Temperature

- Large daily temperature changes observed (ΔT=55 to 60˚F)
- Temperature gradient within the deck, 20F



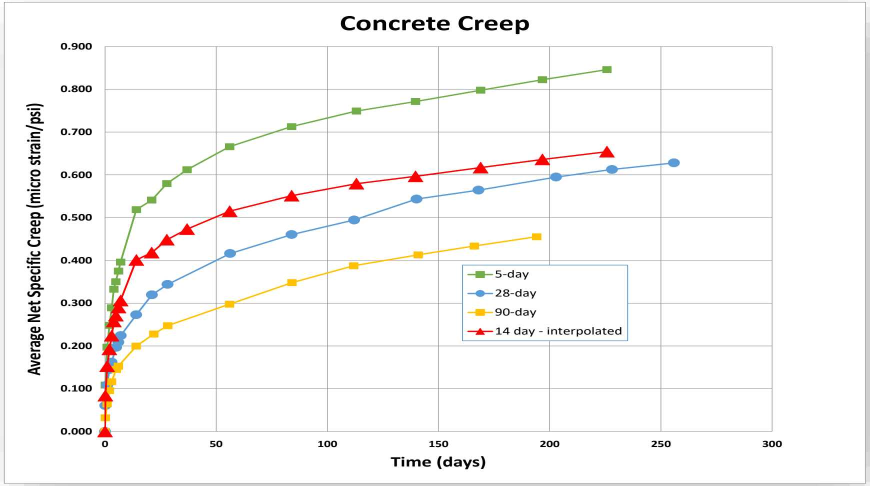
# Instrumentation - Relative Humidity

- Large daily RH changes observed, increase from 20 to 100 % within 24 hours - RH gradient within the deck up to 30% RH



# Laboratory Testing

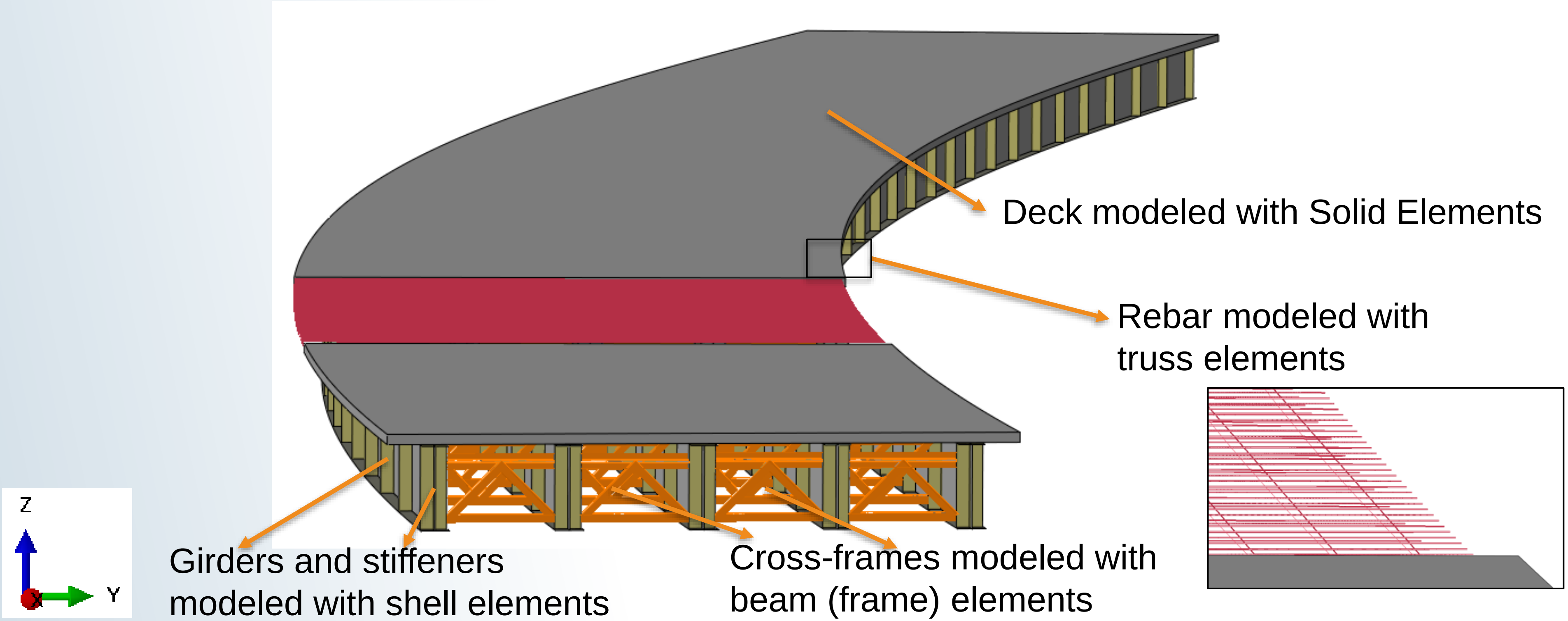
- Mix designs were tested in the laboratory for the following:
  - Compressive, splitting, MoE, and flexural strength versus maturity
  - Drying shrinkage (varying moist cure durations)
  - Creep (various loading ages)
  - Coefficient of thermal expansion



# Finite Element Modeling (FEM)

- Full scale, 3D Model of bridge deck created in Abaqus/CAE 2020
- Same bridge as instrumentation
- 4-span bridge, 5 steel plate girders with 7.75″ composite deck
- FE model included full-length deck geometry, girders, and lateral braces

# Finite Element Modeling (FEM)

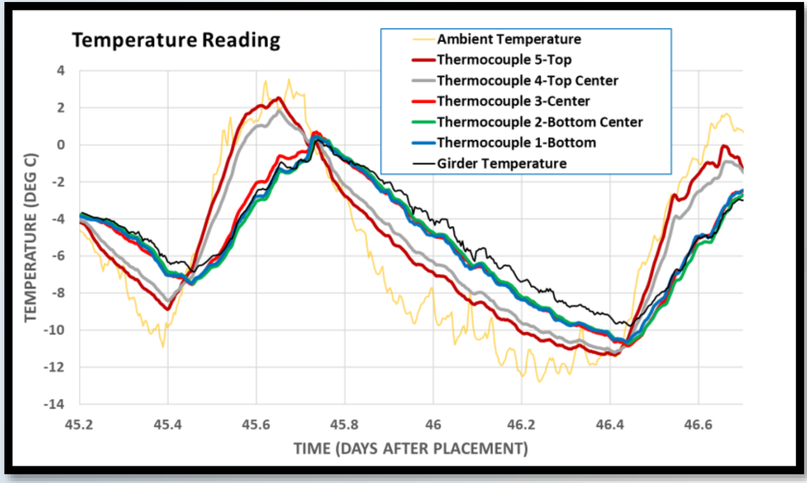


# Finite Element Modeling (FEM) - Scenarios

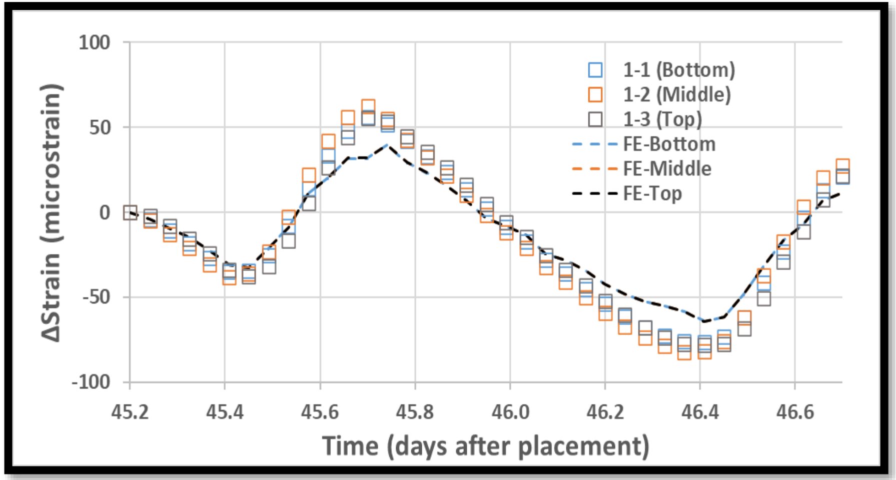
- Later-age Analyses (typically >90 days after placement)
- Early-age Analyses (4 hours to 14 days after placement)
- Factors investigated:
  - Drying shrinkage
  - Temperature histories (sharp drop or increase)
  - Relative humidity (moisture) histories (sharp drop or sharp increase)
  - Length of wet-curing time with summer and winter placements
  - Sensitivity on deck thickness and girder restraint

# Finite Element Modeling (FEM) - Validation

- Model was validated against field strain gauge data
  - The goal was to verify the global FE model trend VS. actual field behavior




**Temperature input for FE Model**

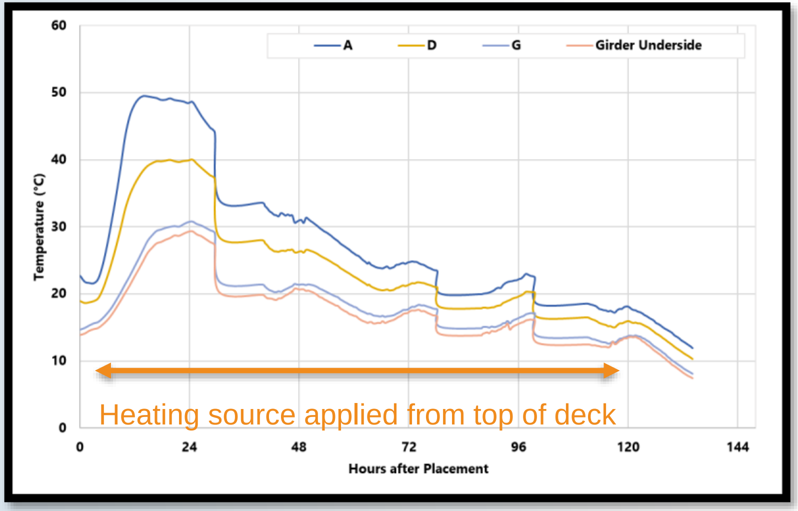



Strain output from FE Model against field-measured strain data

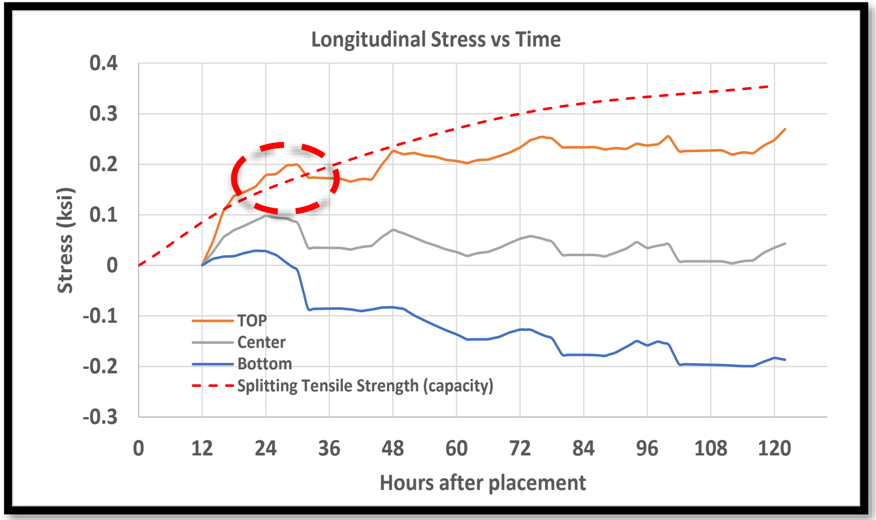
# FEM - Early-age Winter Placement

## Heating from top of the deck

### Winter placement temperature

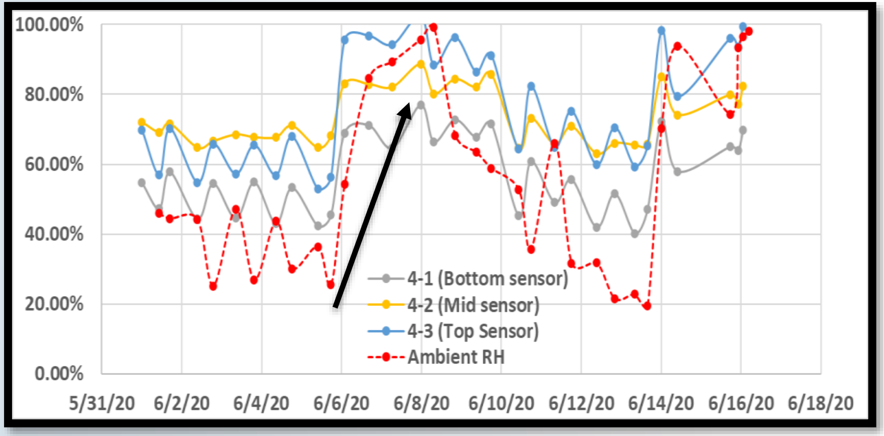



### Average Resultant Longitudinal Stress vs time

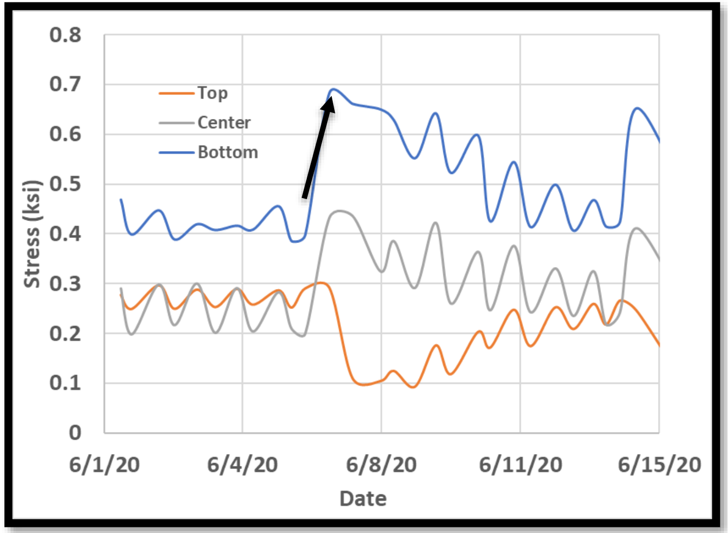


# FEM - Later-age Moisture Gradient

## Recorded Relative Humidity from the Field




## Stress vs time




- Higher RH gradient existed after rain event.
- Increase in tensile stresses at the bottom of the deck ~300 psi

# Finite Element Modeling (FEM) - Summary

- Drying shrinkage can contribute up to 300 psi in tensile stress
- Large temperature rises can create an increase in tensile stress by as much as 400 psi, underside of deck
- Large changes in relative humidity can create an increase in tensile stress by as much as 300 psi, underside of deck
- Winter curing, heating from below is preferred to heating from the top

# WJE's Recommendations

- Three primary goals of recommendations:
  1. Reduction in drying shrinkage
  2. Reduction in thermal gradients
  3. Reduction in moisture gradients

Reduction in volumetric movement

# WJE's Recommendations

- Mixture Proportions
  - w/cm of 0.42 to 0.45
  - Limit total cementitious to 600 lb./yd$^3$ or less
  - Use of slag cement and fly ash
  - Lower plastic concrete temperatures to < 75F
  - Optimized aggregate gradation, likely needed for reduction in cementitious content
  - Larger top sized aggregate

# WJE's Recommendations

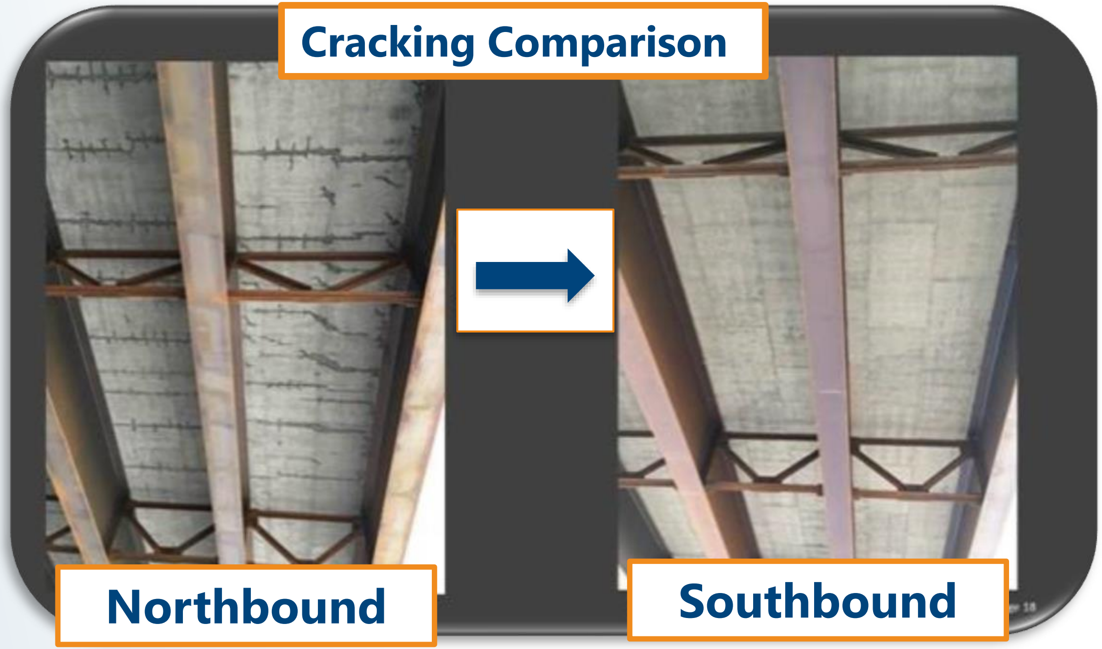
- <u>Design and Construction Practices</u>
  - Summer curing:
    - Installation of insulated blankets after peak hydration
    - Removal of insulation blankets after 4 to 5 days
  - Winter curing:
    - Heat cure from underside is preferable and provides additional pre-compression benefit
  - Reduction in moisture gradient - installation of thin-polymer overlays at later ages ~ 6 to 9 months after construction

# WJE's Recommendations

- <u>Design and Construction Practices</u>
  - Increase design thickness of decks to 8 inches minimum
  - Modify specifications to require staggering of top and bottom transverse reinforcing mats

# WJE's Recommendations

- Cracking comparison, before and after WJE's recommendations



# Thank you!

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