Evaluation of Performance of Bridge Deck with UHPC and LMC Overlays through Accelerated Structural Testing

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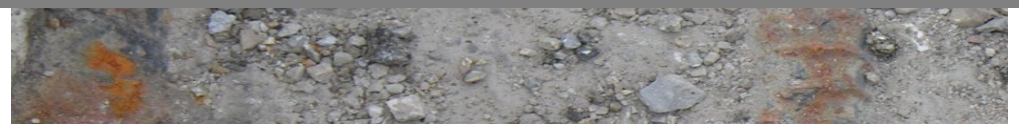
OF NEW JERSEY

Significance of Understanding Bridge Deck Performance

- Concrete decks, due to their more direct exposure to environmental and traffic loads, deteriorate faster than other bridge components.
- Relationships between numerous factors and deck performance have been examined in the field, but are not well defined. Those include:
  - traffic load,
  - climatic conditions,
  - maintenance practices,
  - age,
  - reinforcement type and protective layers,
  - supporting superstructure, etc.
- How we can develop more comprehensive understanding of bridge deck performance in a relatively short time?



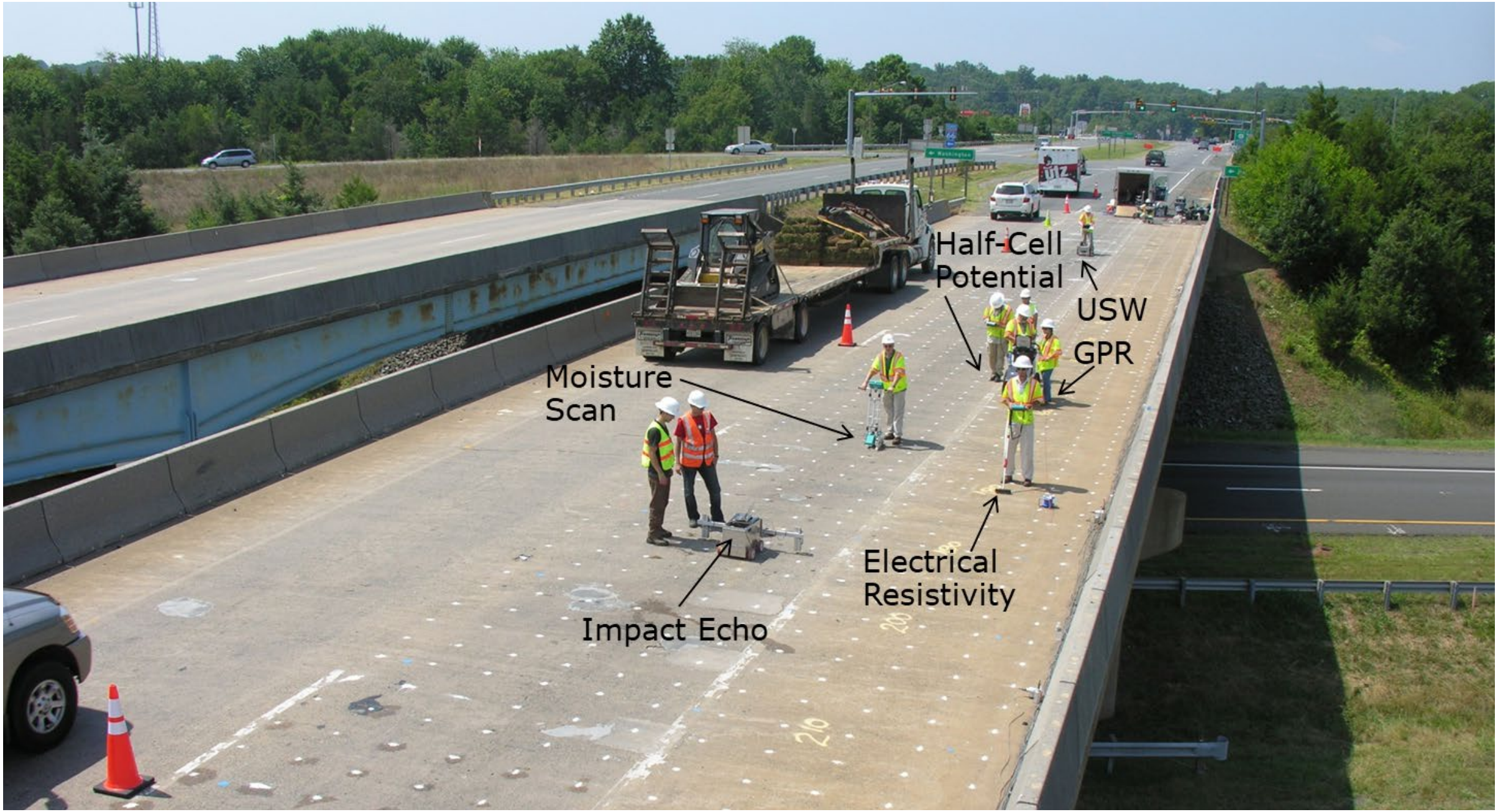
Outline

- Bridge deck condition assessment and performance monitoring by nondestructive evaluation (NDE) technologies
  - Accurate and quantifiable condition assessment
  - Capturing of deterioration progression through periodical NDE surveys
  - Identification of primary causes of deterioration
- Description of the BEAST facility for accelerated testing
- Results of the accelerated performance evaluation of bare and overlaid bridge decks
  - Importance of baseline measurements
  - Capturing of deterioration and defect formation progression
  - Comparison of performance of bare and overlaid decks

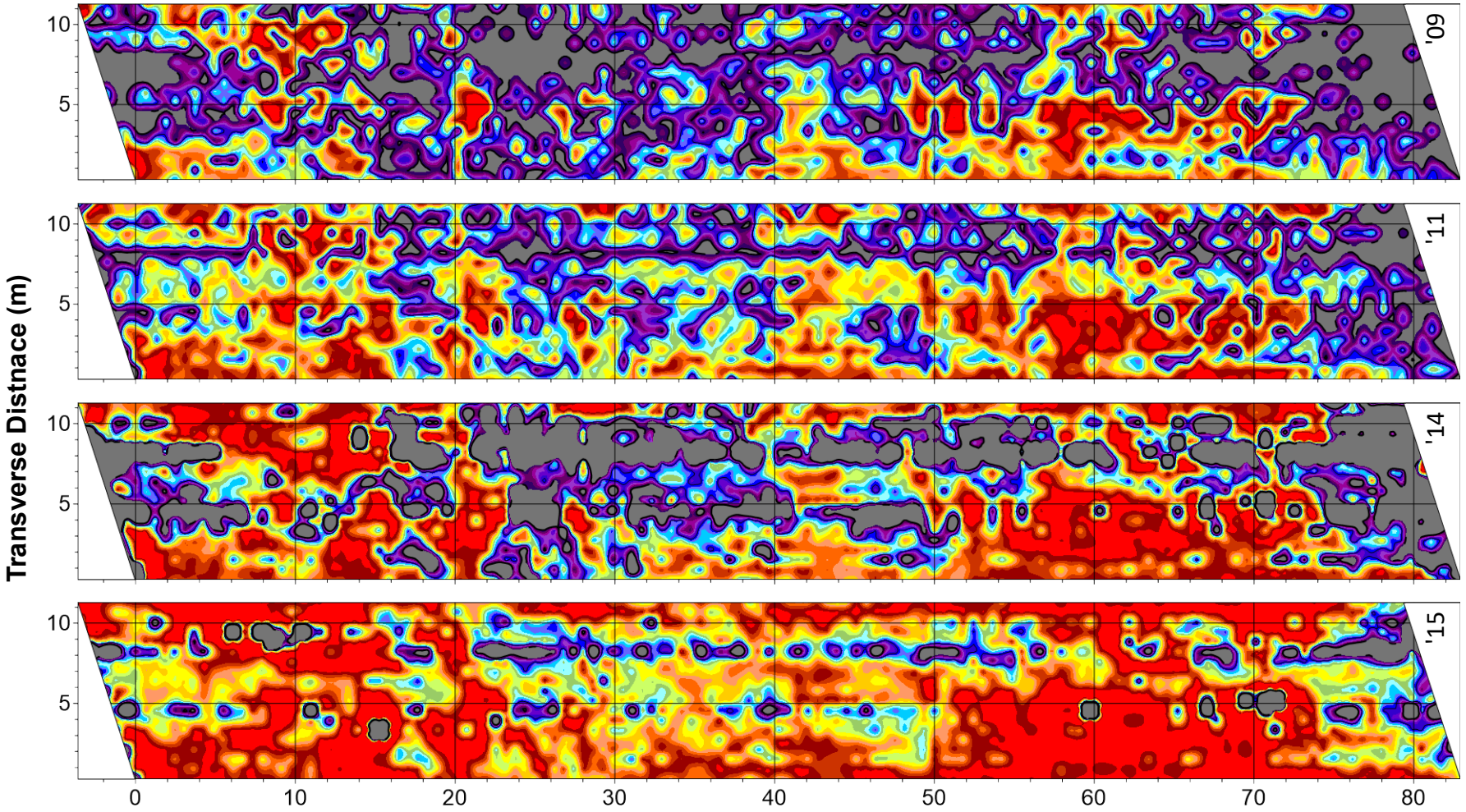
Bridge Deck Condition Assessment and Monitoring by Nondestructive Evaluation (NDE) Technologies

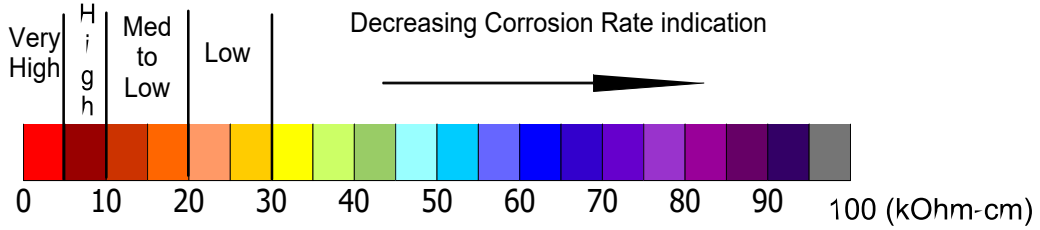
Reinforced Concrete Deterioration and Defect Types of Primary Interest

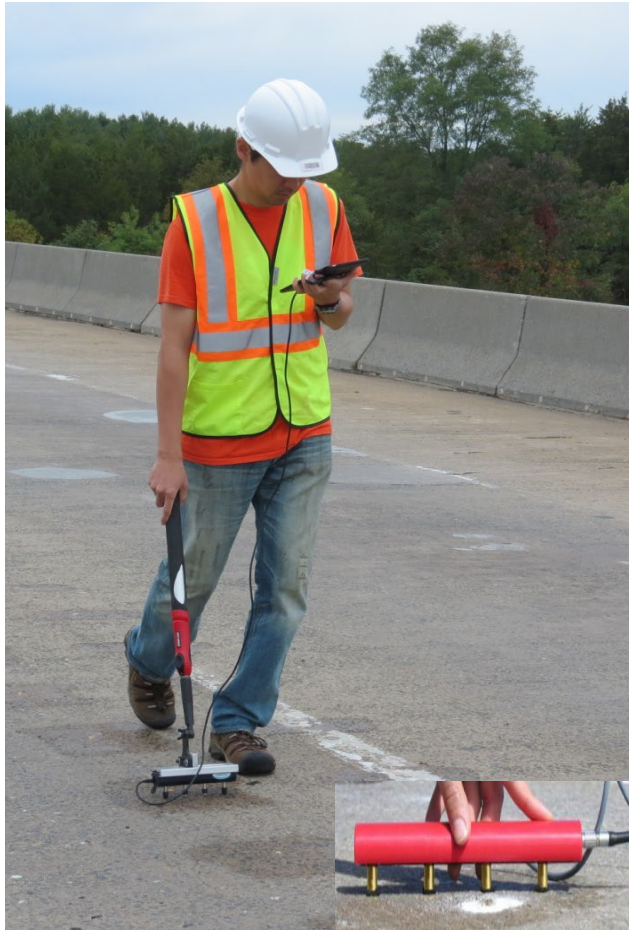
Manual NDE Data Collection on Bridge Deck (Haymarket Bridge, VA)



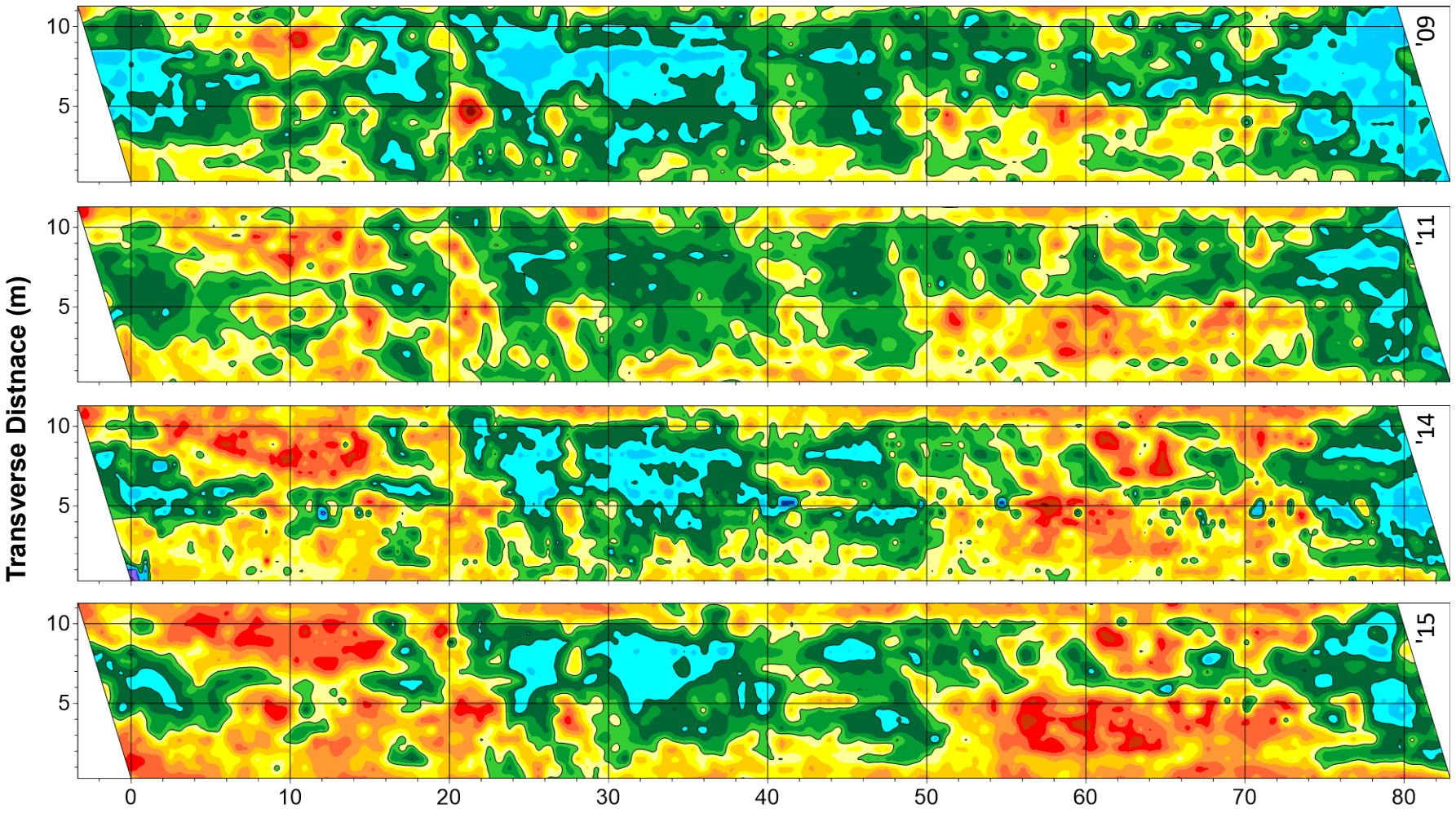
Electrical Resistivity Maps for Haymarket Bridge 2009-2015

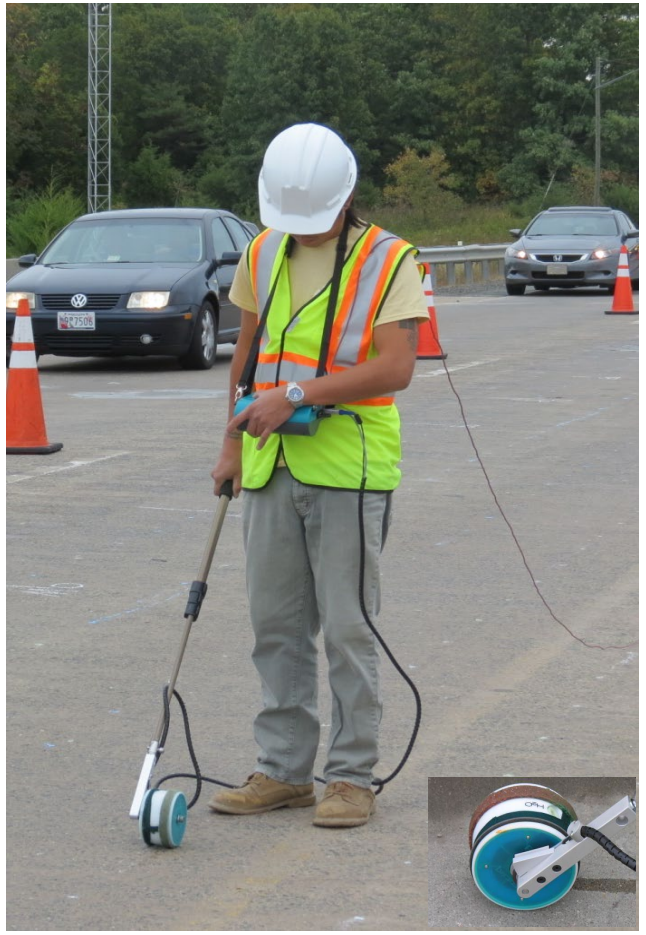




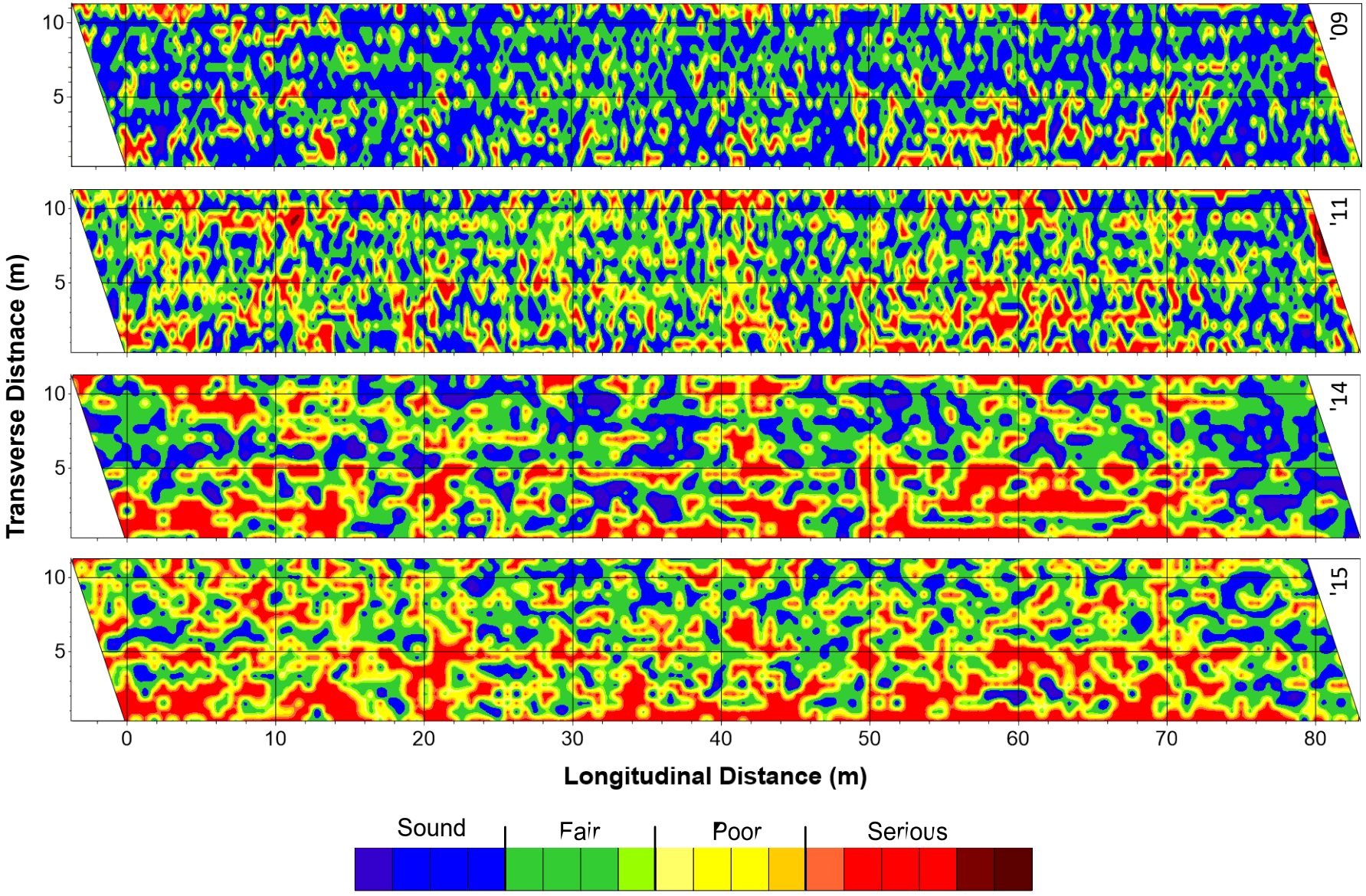


Half-Cell Potential Maps for Haymarket Bridge 2009-2015

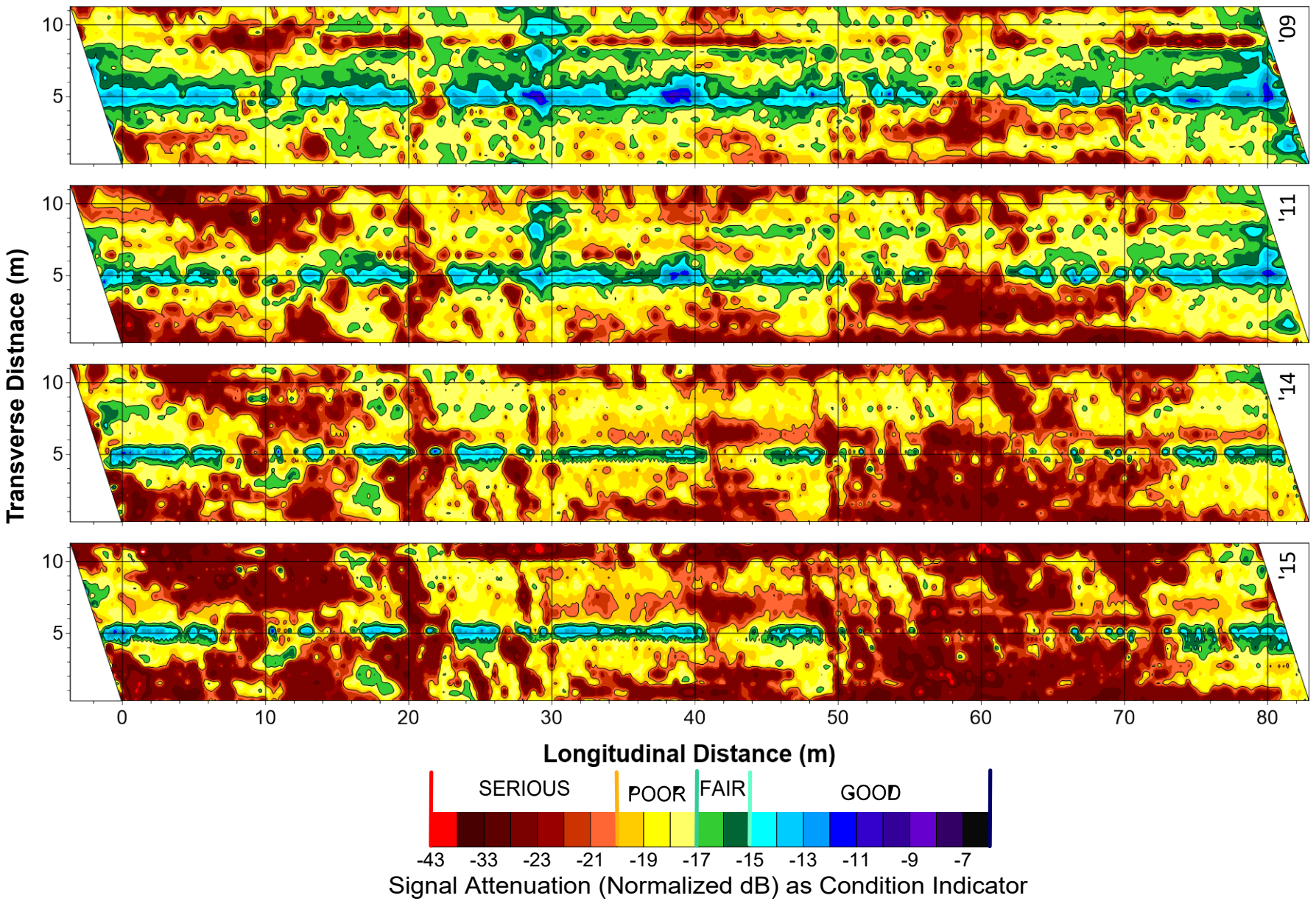




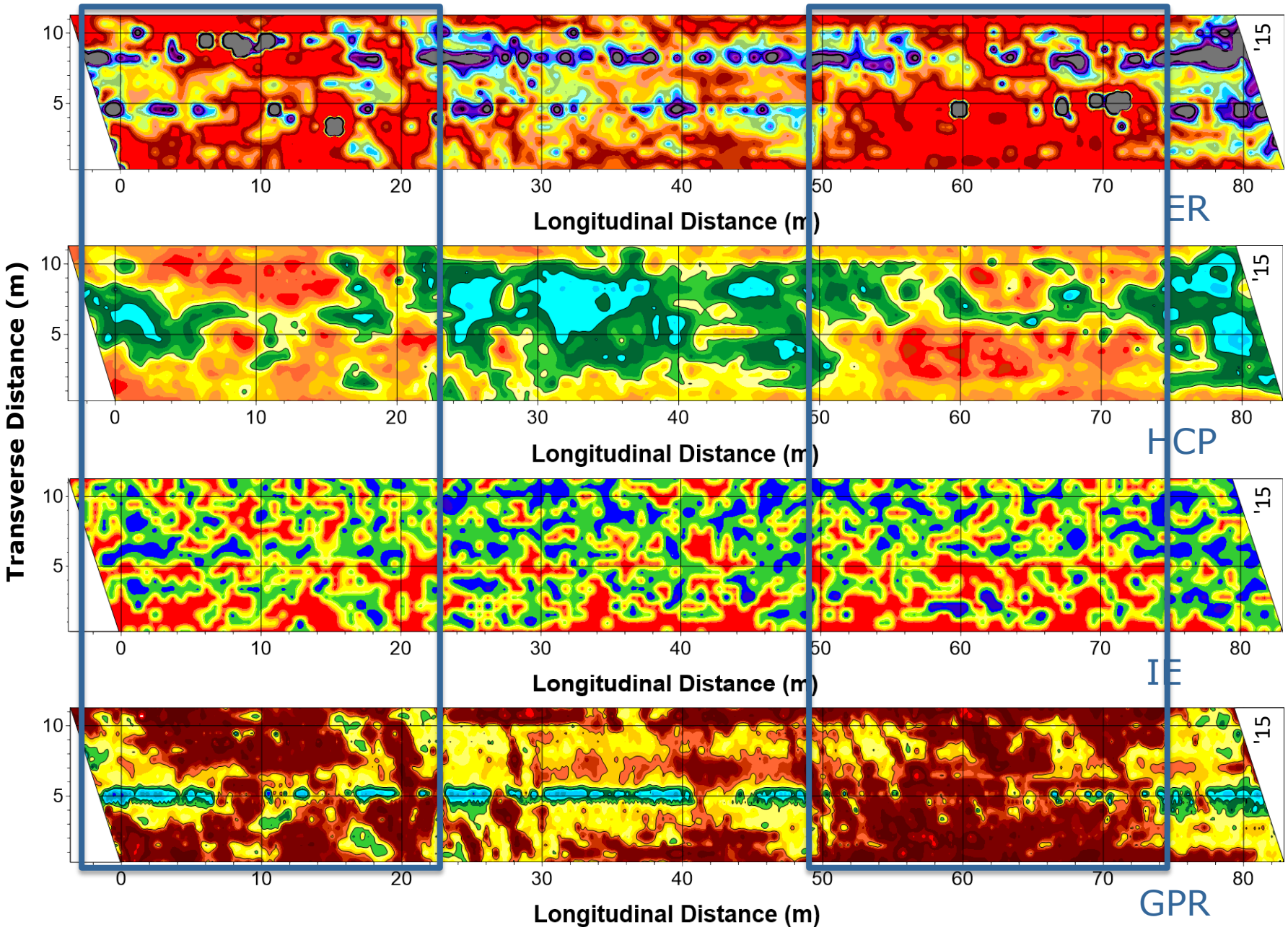
Impact Echo Delamination Maps for Haymarket Bridge 2009-2015



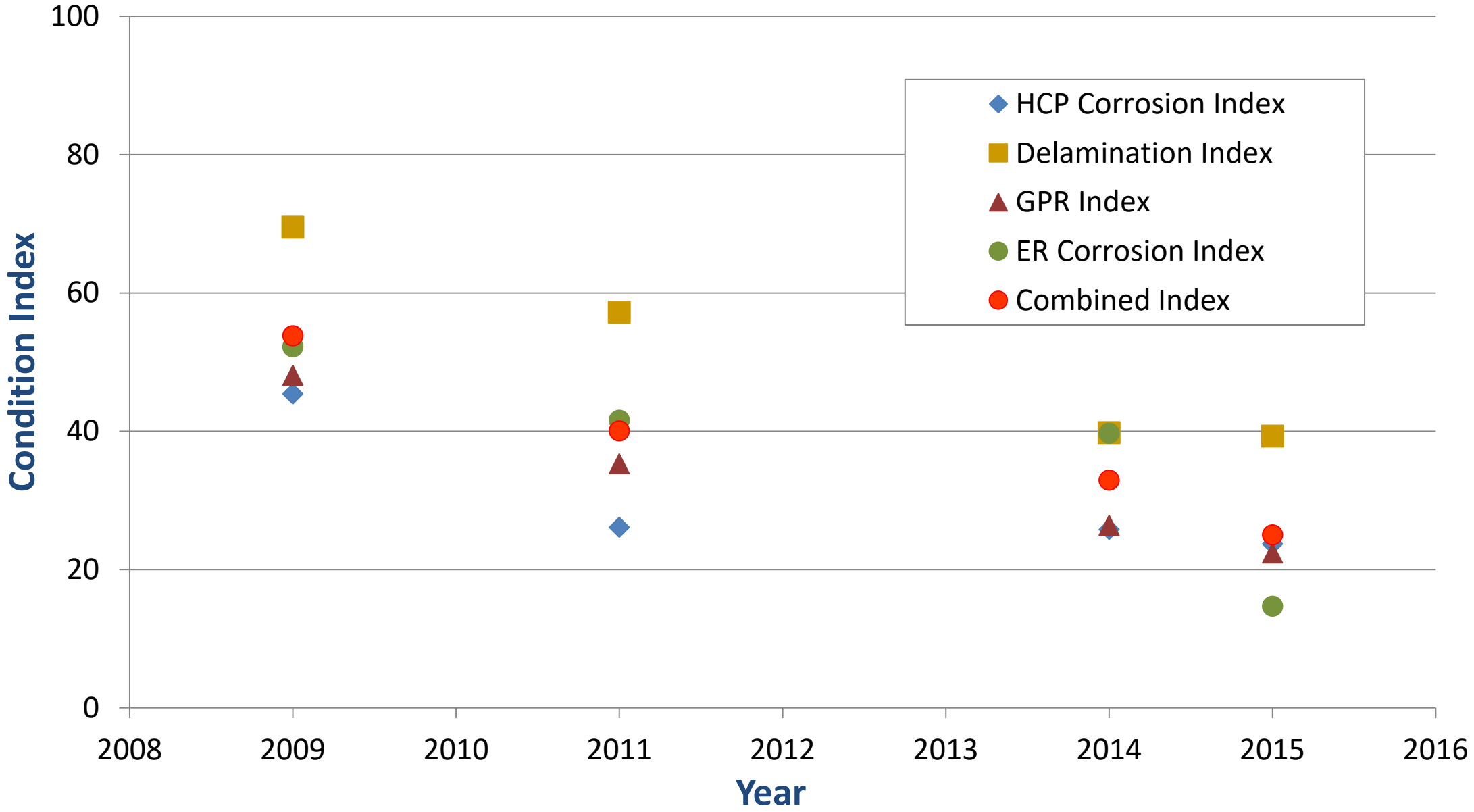
GPR Maps for Haymarket Bridge 2009-2015



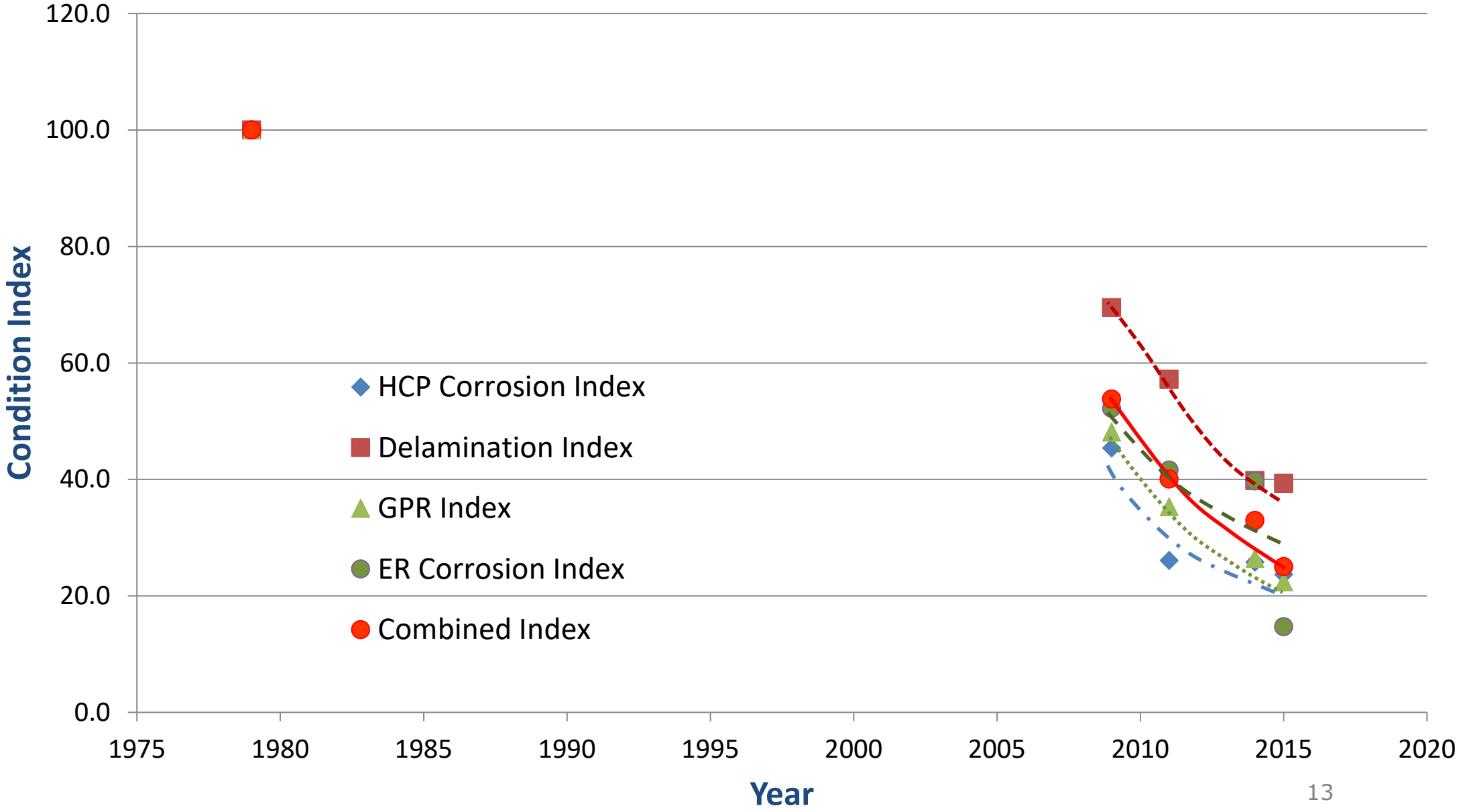
Comparison of NDE Technology Results for 2015



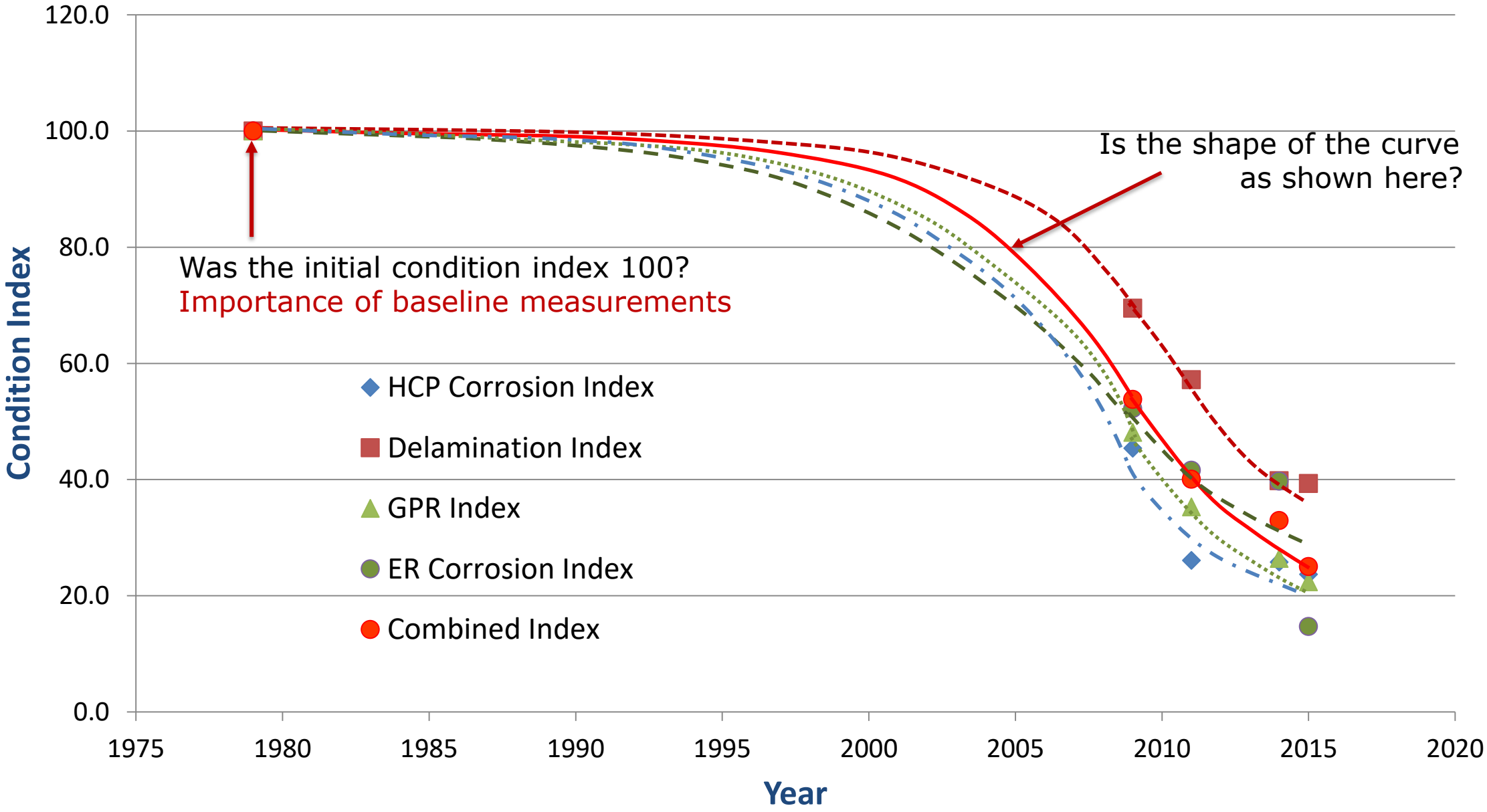
Condition Deterioration Progression 2009-2015



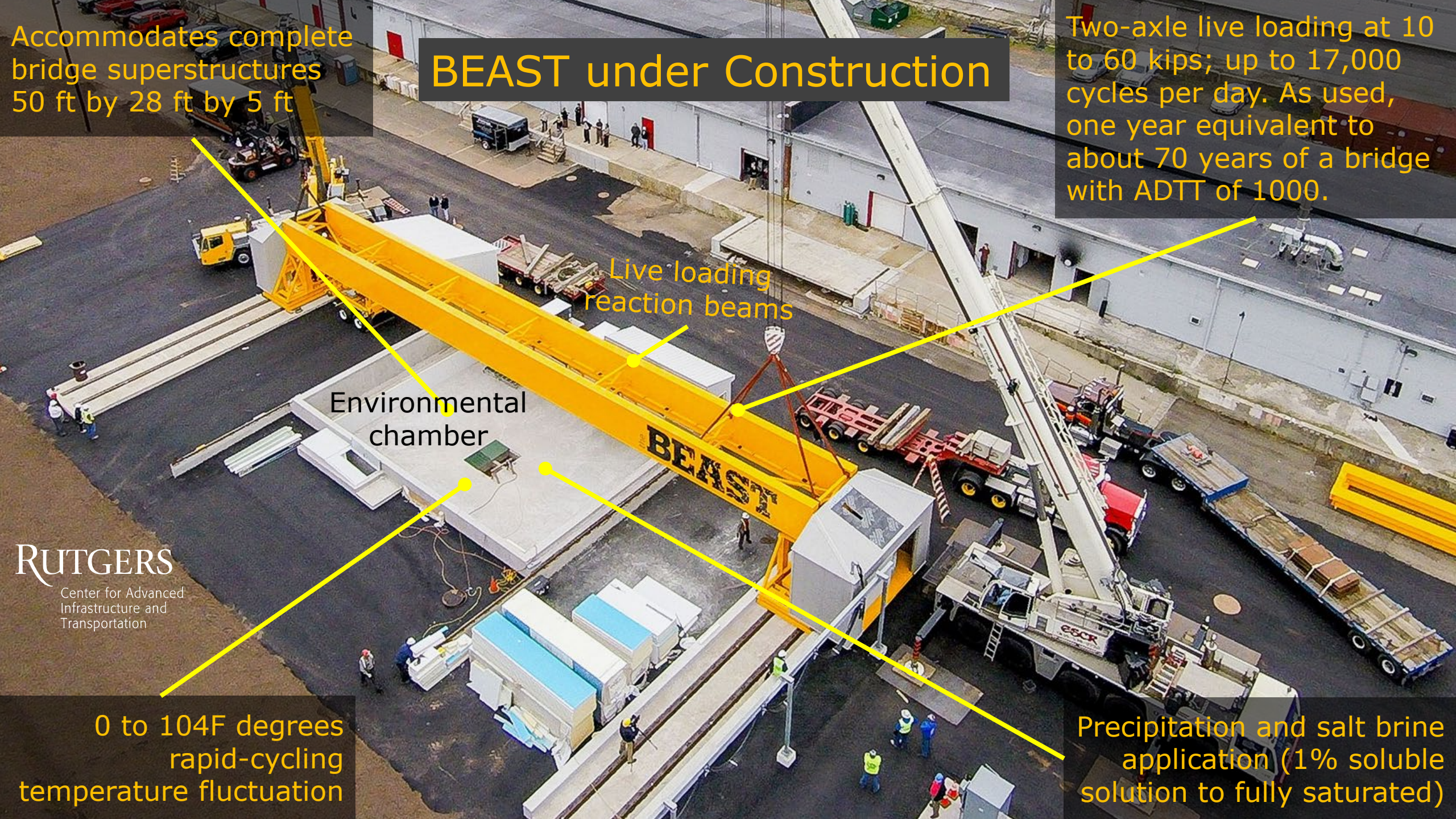
Condition Index Degradation Curves for Four NDE Technologies – Haymarket Bridge



Condition Index Degradation Curves for Four NDE Technologies – Haymarket Bridge



BEAST (Bridge Evaluation and Accelerated Structural Testing) Facility Description


BEAST under Construction
Accommodates complete bridge superstructures 50 ft by 28 ft by 5 ft
Two-axle live loading at 10 to 60 kips; up to 17,000 cycles per day. As used, one year equivalent to about 70 years of a bridge with ADTT of 1000.
Live loading reaction beams
Environmental chamber
BEAST
RUTGERS
Center for Advanced Infrastructure and Transportation
0 to 104F degrees rapid-cycling temperature fluctuation
Precipitation and salt brine application (1% soluble solution to fully saturated)

Results of the Performance Evaluation of Bare and Overlaid Concrete Decks

Bridge Deck Performance Evaluation Projects

- Phase 1 – Performance of Bare Concrete Bridge Decks – 2.05 million live loading passes
- Phase 2 – Performance of Overlaid Concrete Bridge Decks – 3.2 million live loading passes
  - Bare deck from Phase 1 hydrodemolished down to the top rebar level
  - Half of the deck overlaid with an UHPC (ultra high performance concrete) and half with an LMC (latex modified concrete) overlay
- Funded by FHWA – Long Term Bridge Performance Program

BEAST - Test Sample Steel Superstructure

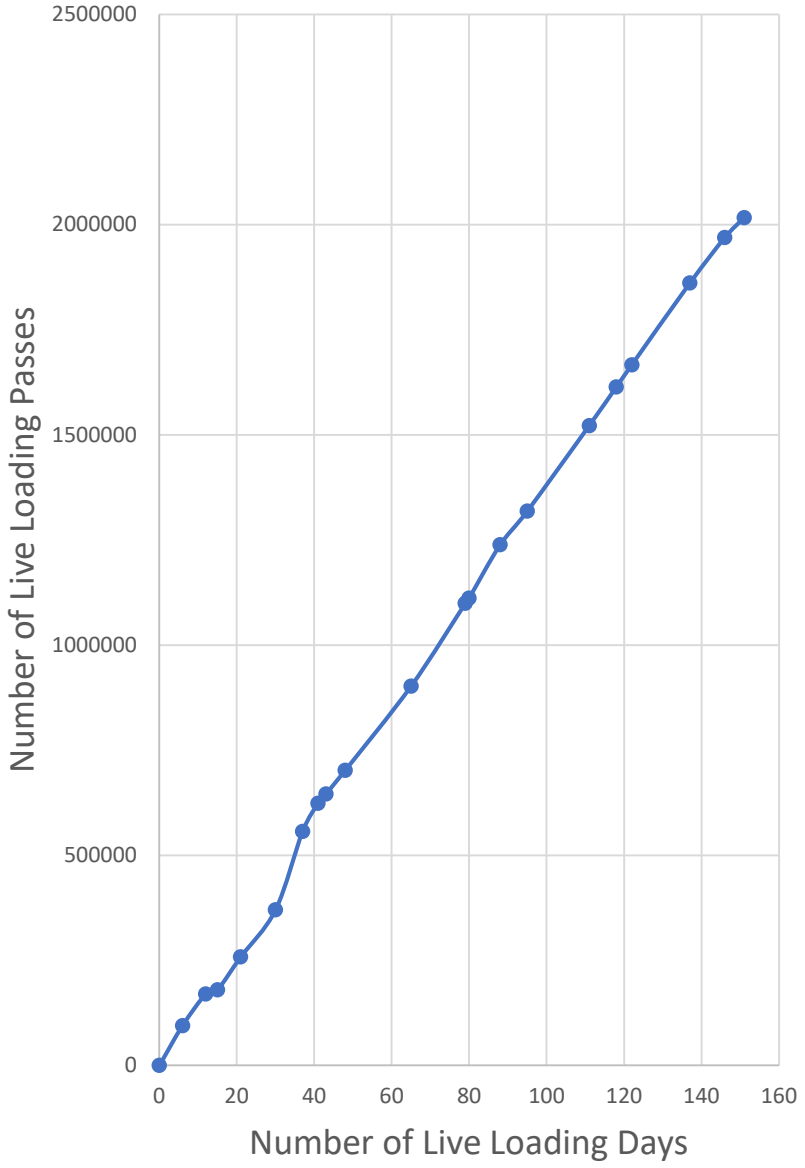
BEAST – Finished Deck with NDE Data Collection Grid

1ft by 1 ft
(30 cm by 30 cm)

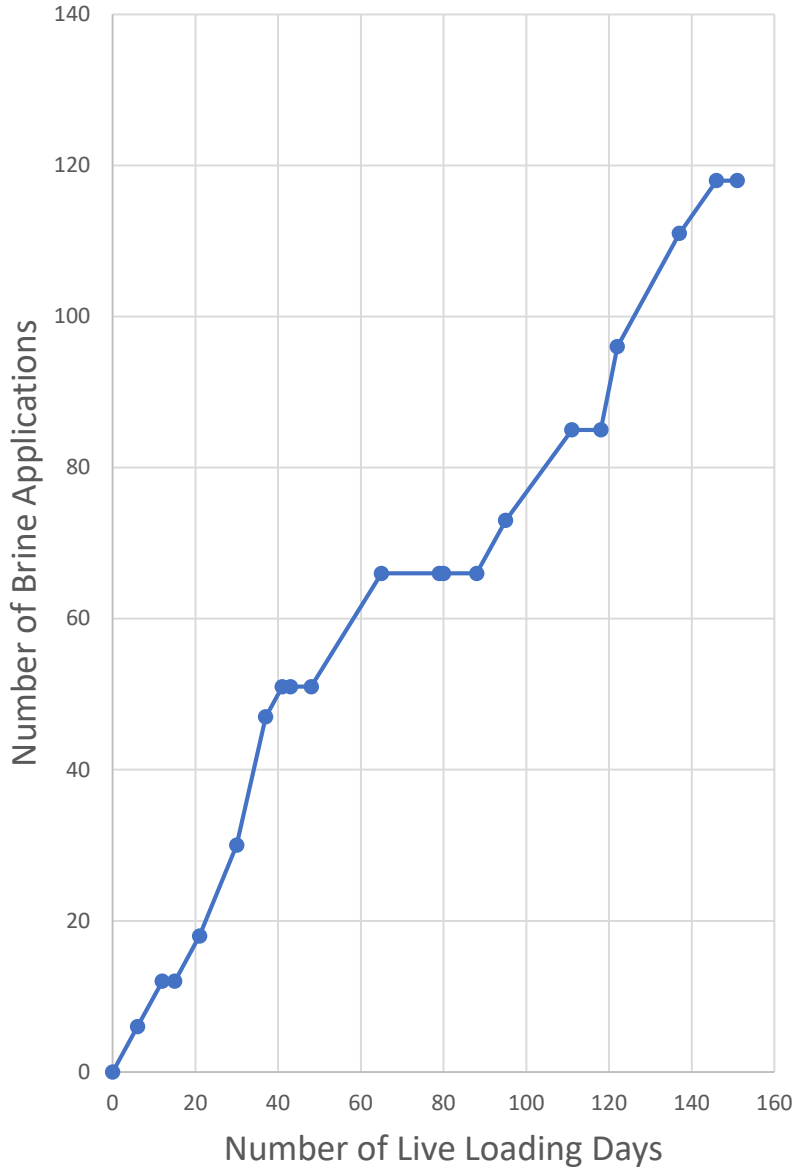
BEAST – Loading Frame and Environmental Chamber

Phase 1 (Bare Deck) Uninterrupted BEAST Operation

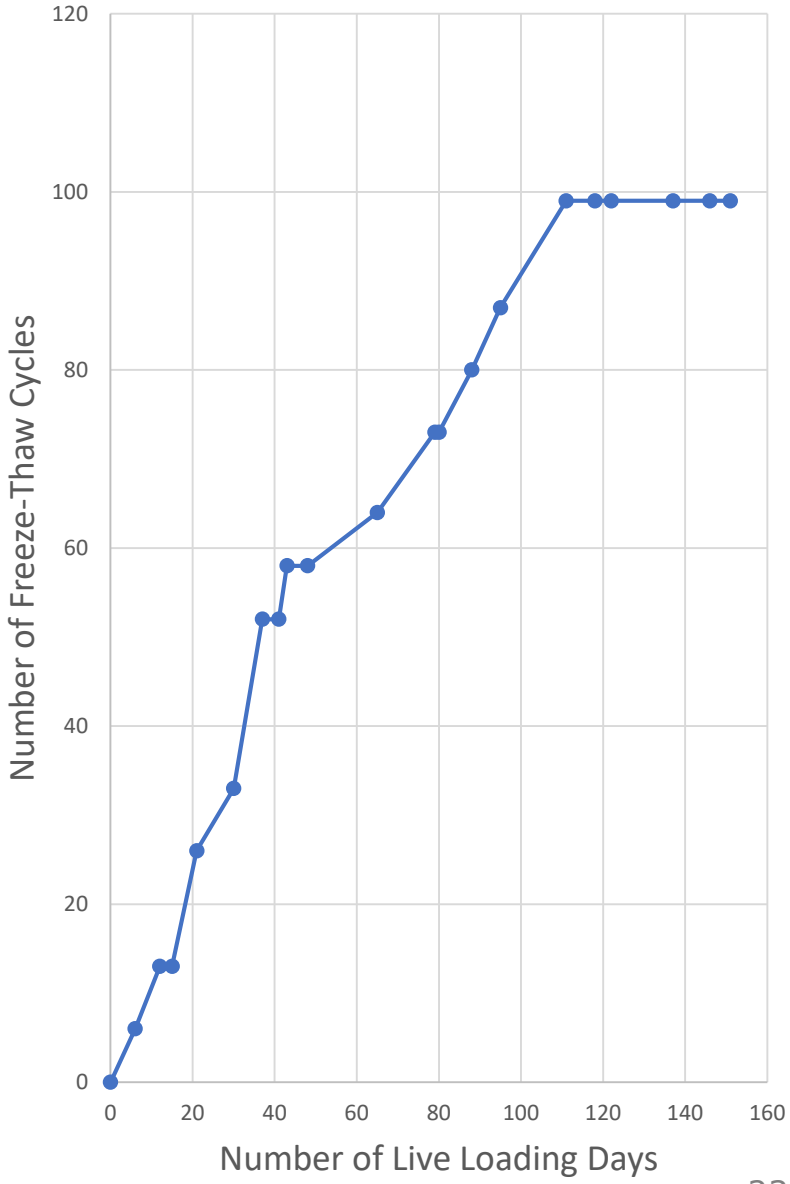
Cumulative Live Loading Passes



Cumulative Brine Applications

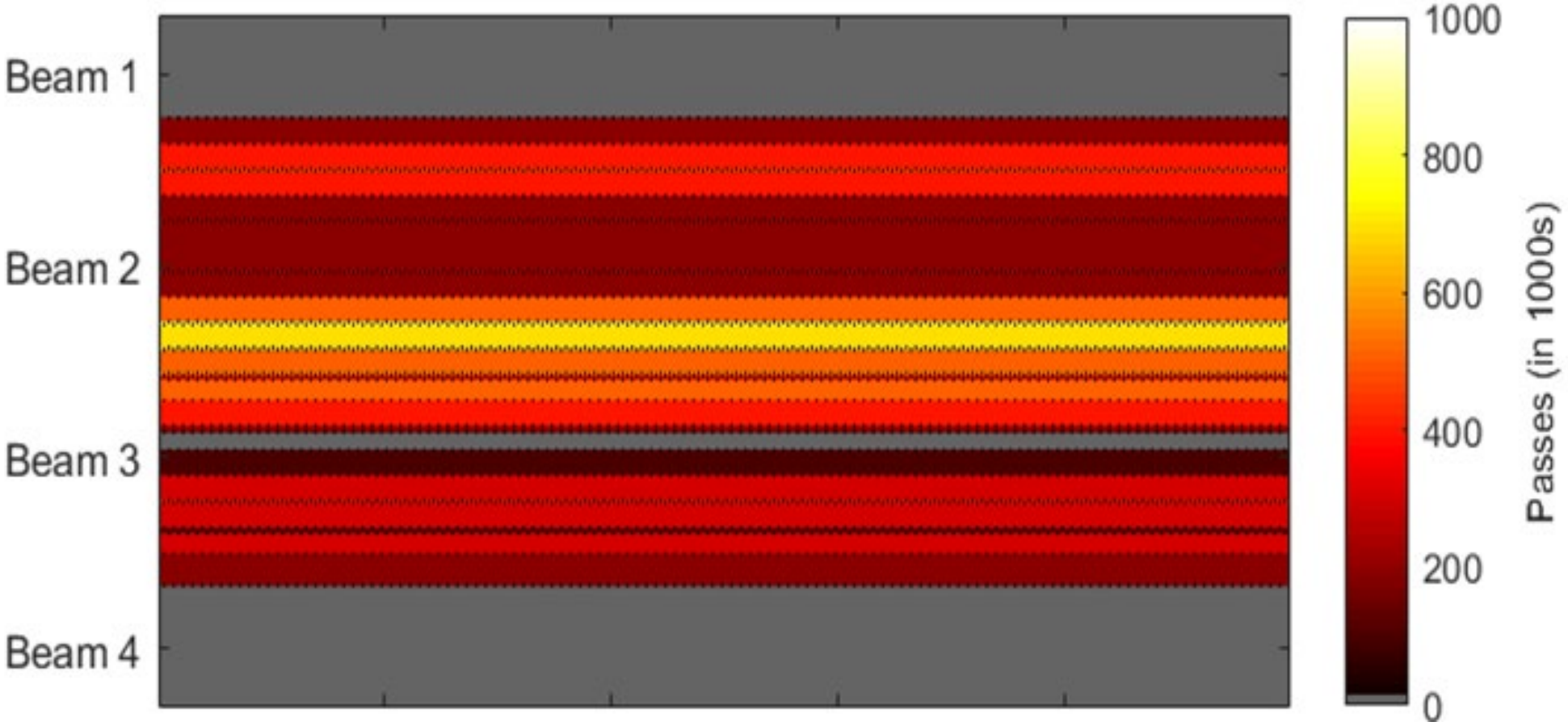


Cumulative Freeze-Thaw Cycles



Spatial Distribution of Live Loading Passes

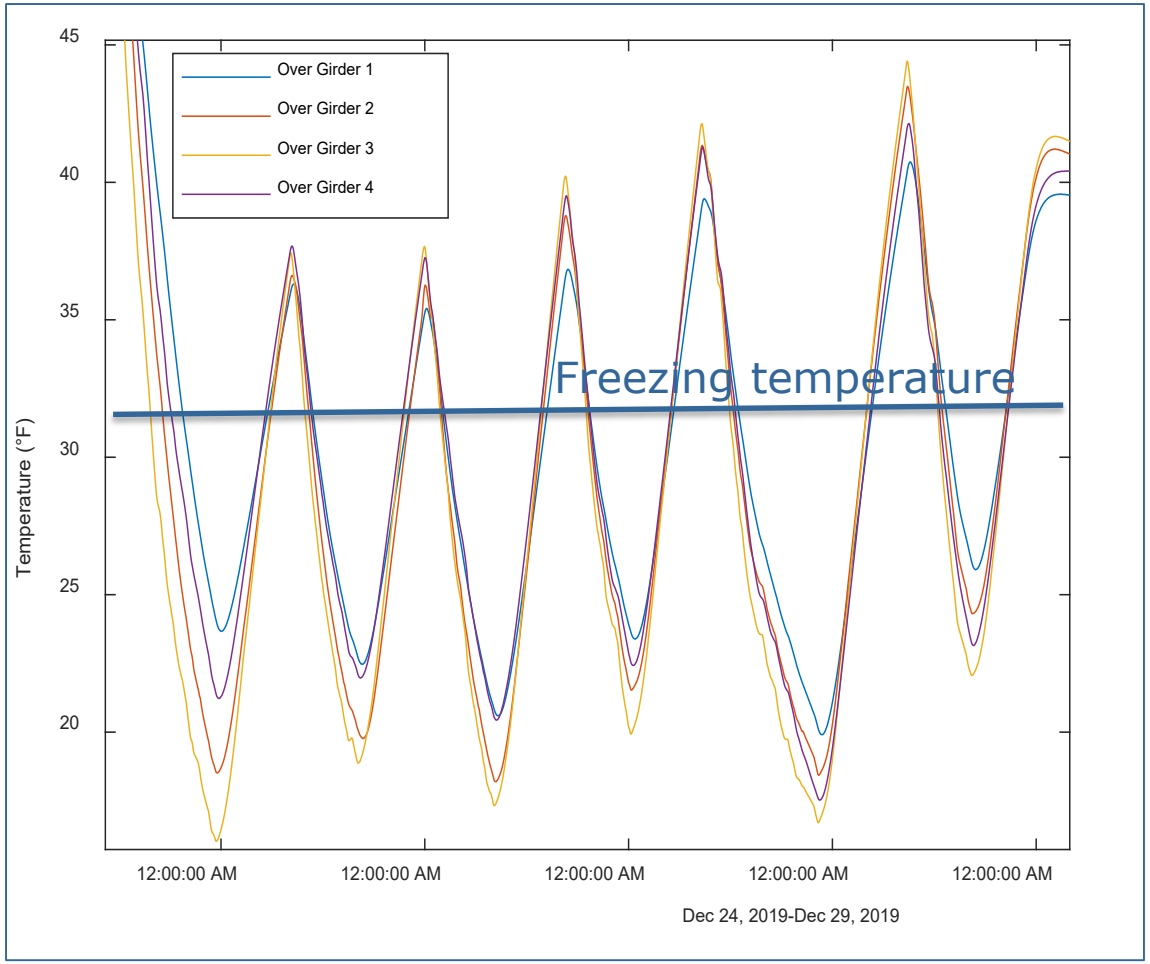
Over 1.5 million passes of 50,000 lb live load in total for seven load paths.



Environmental Loading

- Heating/cooling mode is cycled every 8 hours
- Room temperature fluctuates 0-80^{0}F, to achieve 20-40^{0}F cycle at the deck's top reinforcement level
- 30 gal of 6% salt brine applied at the end of each heating cycle
- Close to 100 heating/cooling cycles and over 4500 gal of salt brine applied

Typical Deck Response to Temperature Cycling



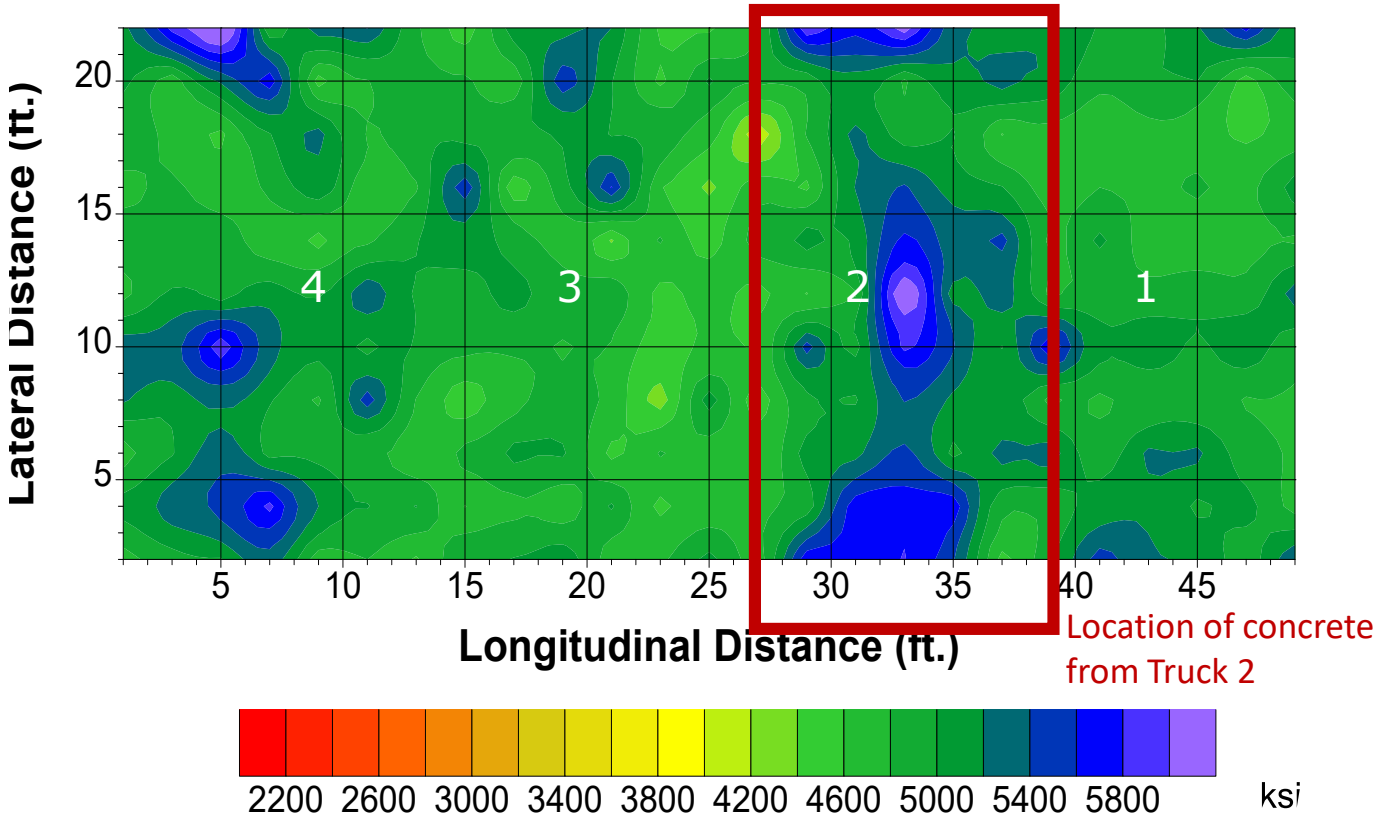
*Temperatures recorded at top reinforcing layer

BEAST – Primary NDE Data Collection Methods

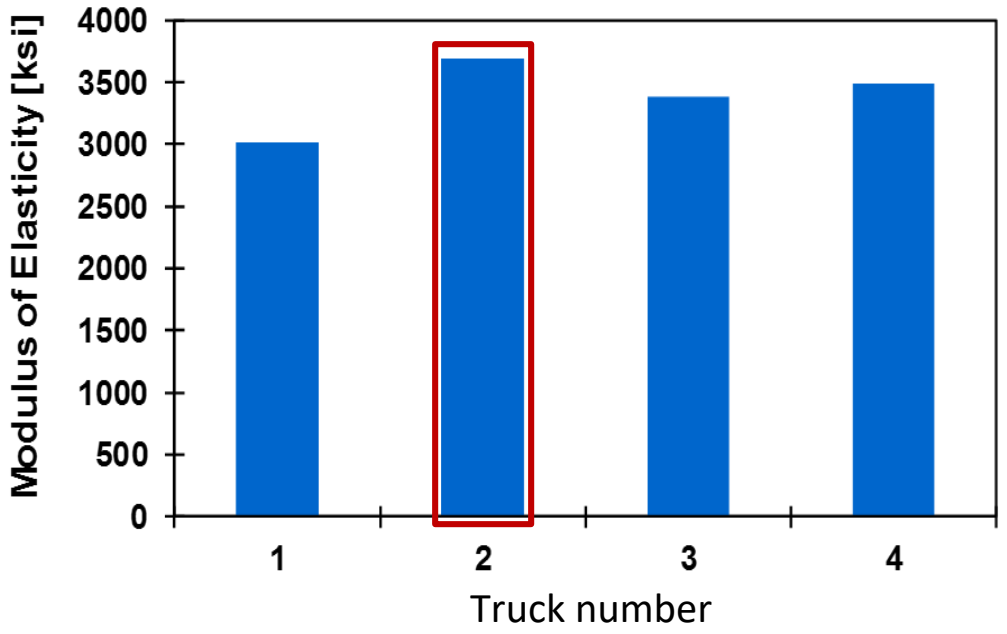
- Electrical Resistivity (ER)
- Half-Cell Potential (HCP)
- Ground Penetrating Radar (GPR)
- Impact Echo (IE)
- Ultrasonic Surface Waves (USW)
- Ultrasonic Tomography (UST)

BEAST – Concrete Modulus after 28 Days

Modulus of elasticity from USW (28 days)



Modulus of elasticity as per ASTM C469 (28 days)

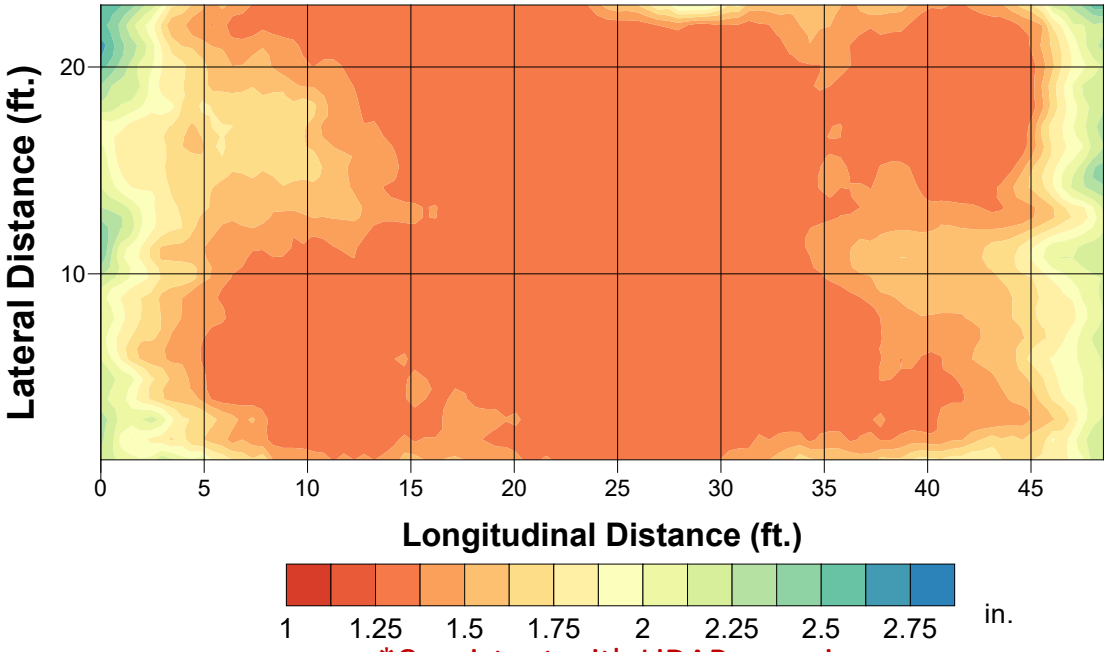


BEAST – Deck Concrete Cover Thickness

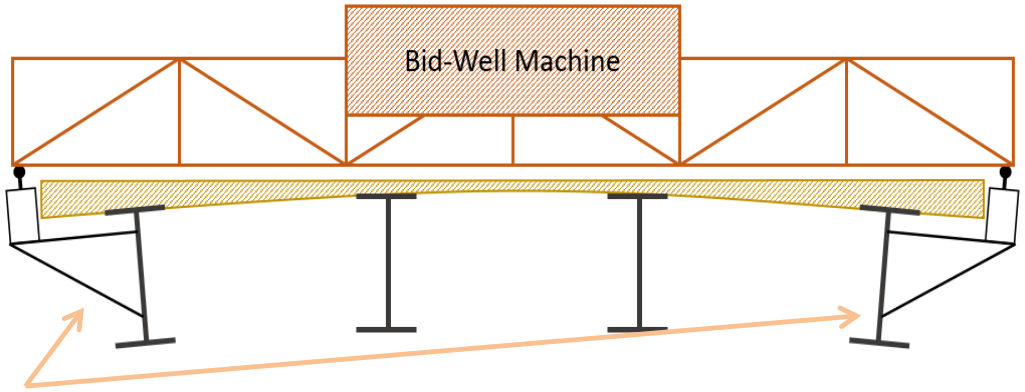
Use of Bid-Well automated screeding machine resulted in 1.25 inch concrete cover in the mid-span region (instead of 2 in.)

Deformation of structure due to bid-well weight caused uneven thickness

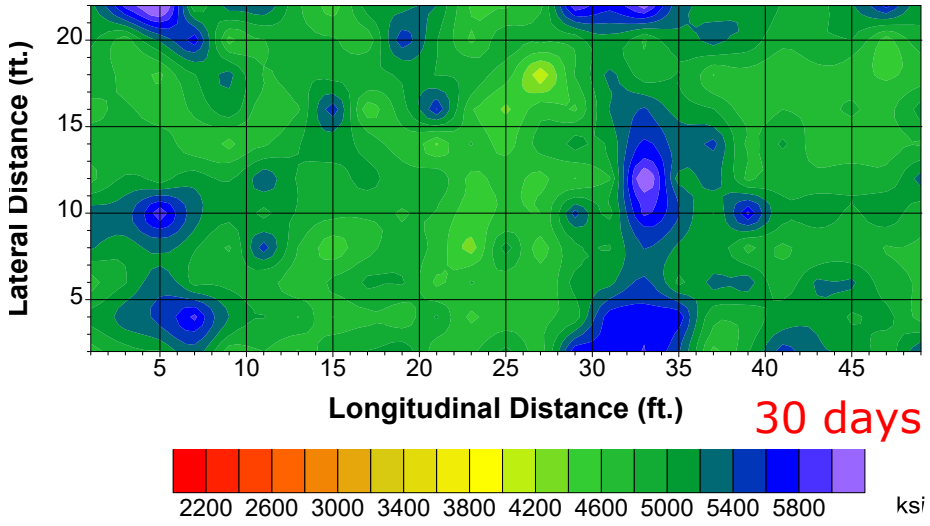
GPR Obtained Concrete Cover*



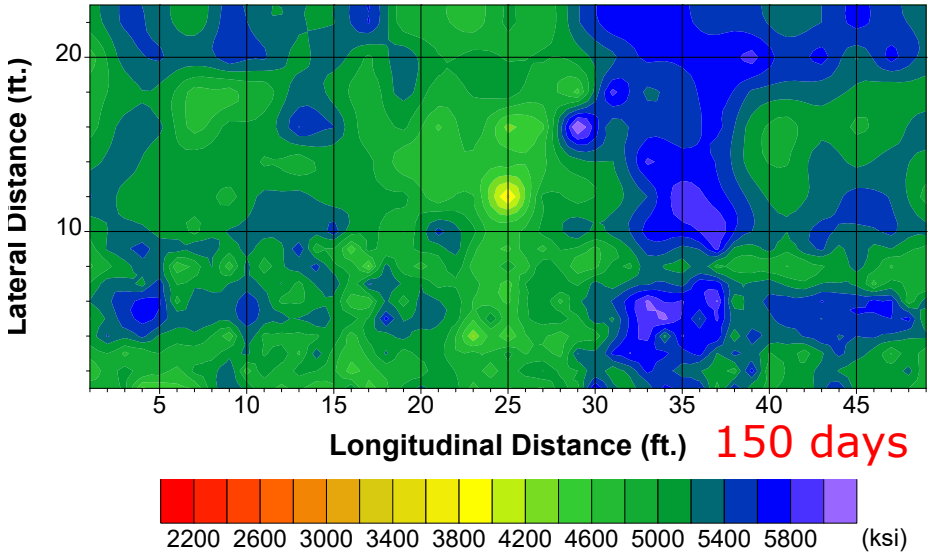
*Consistent with LiDAR scanning



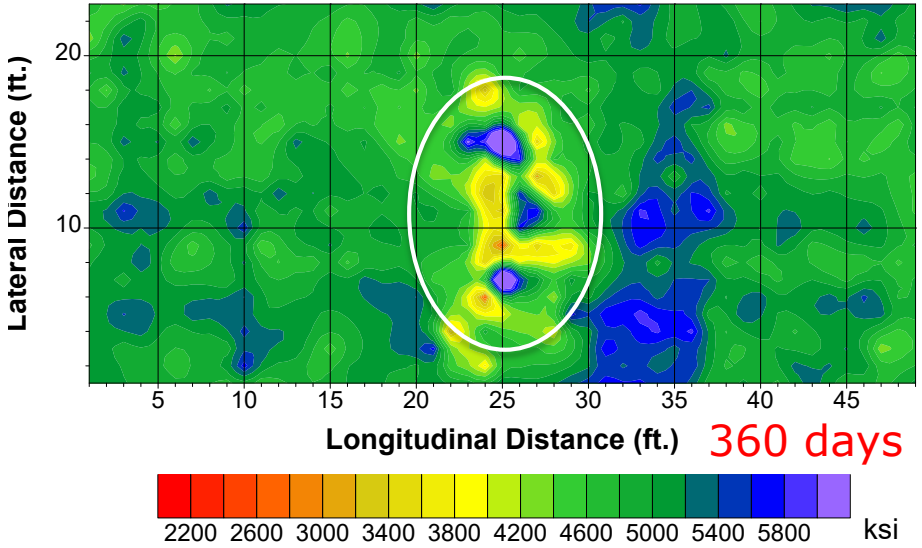
Modulus Evaluation by Ultrasonic Surface Waves



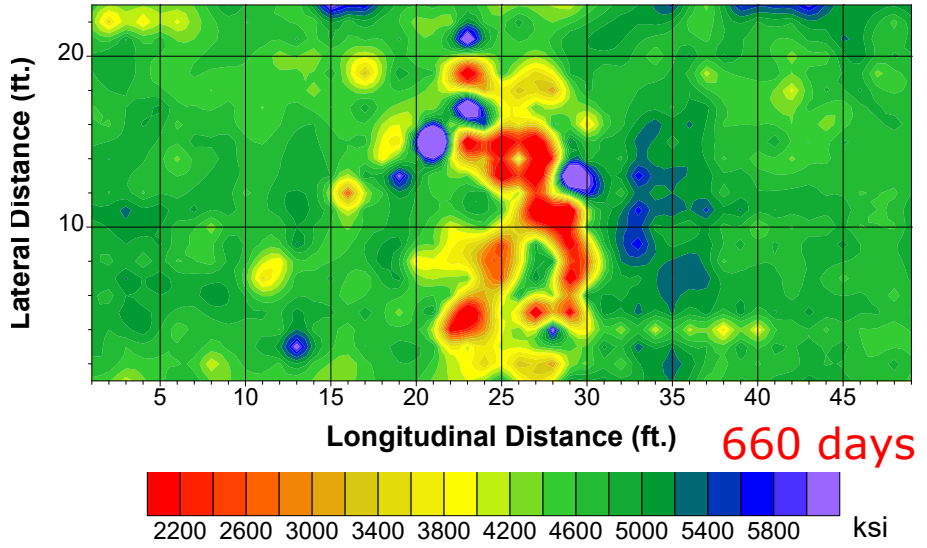
Average 4987.2 ksi, StDev 361.0 ksi



Average 5100.0 ksi, StDev 268.7 ksi

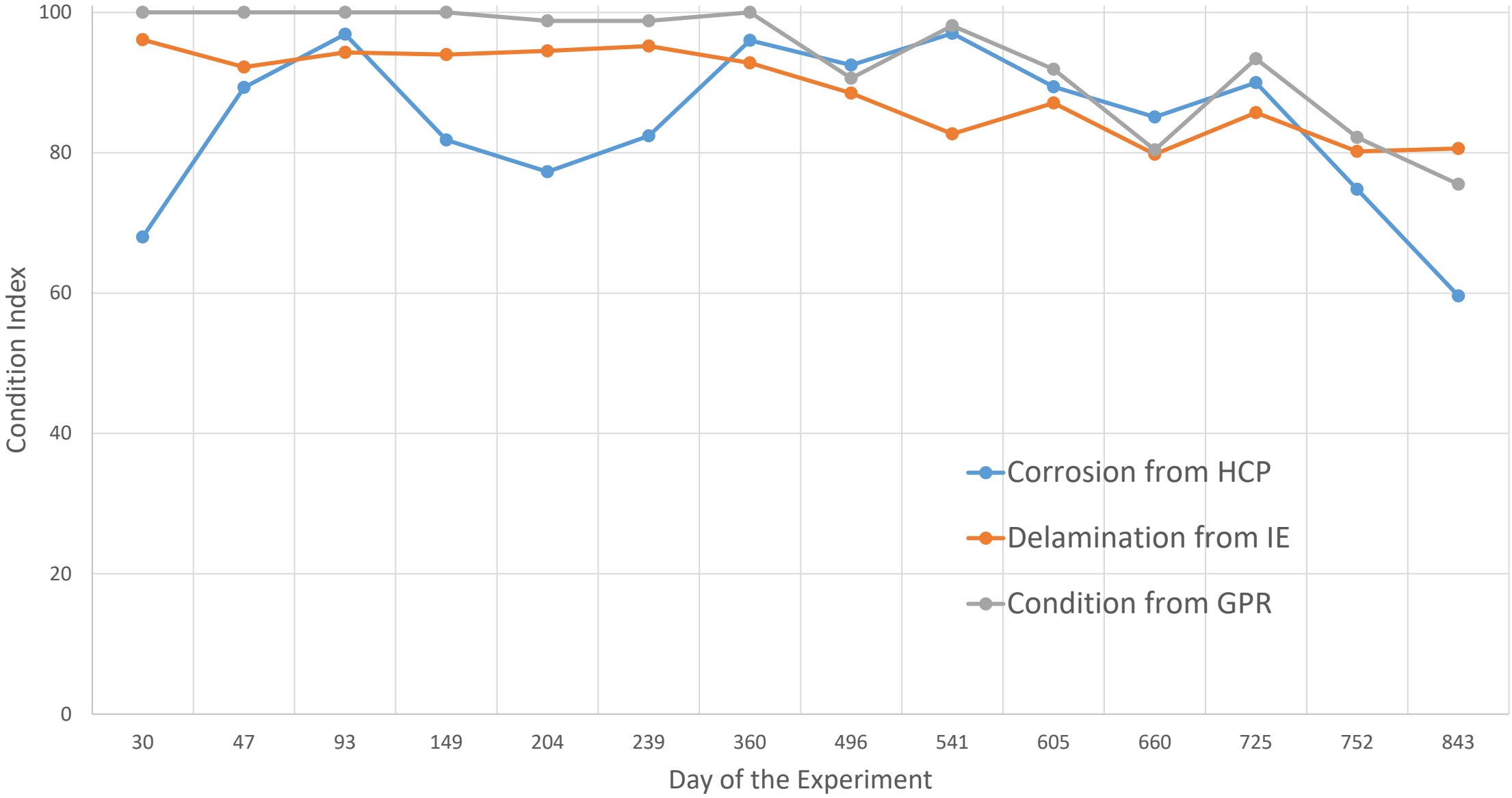


Average 4909.2 ksi, StDev 466.8 ksi

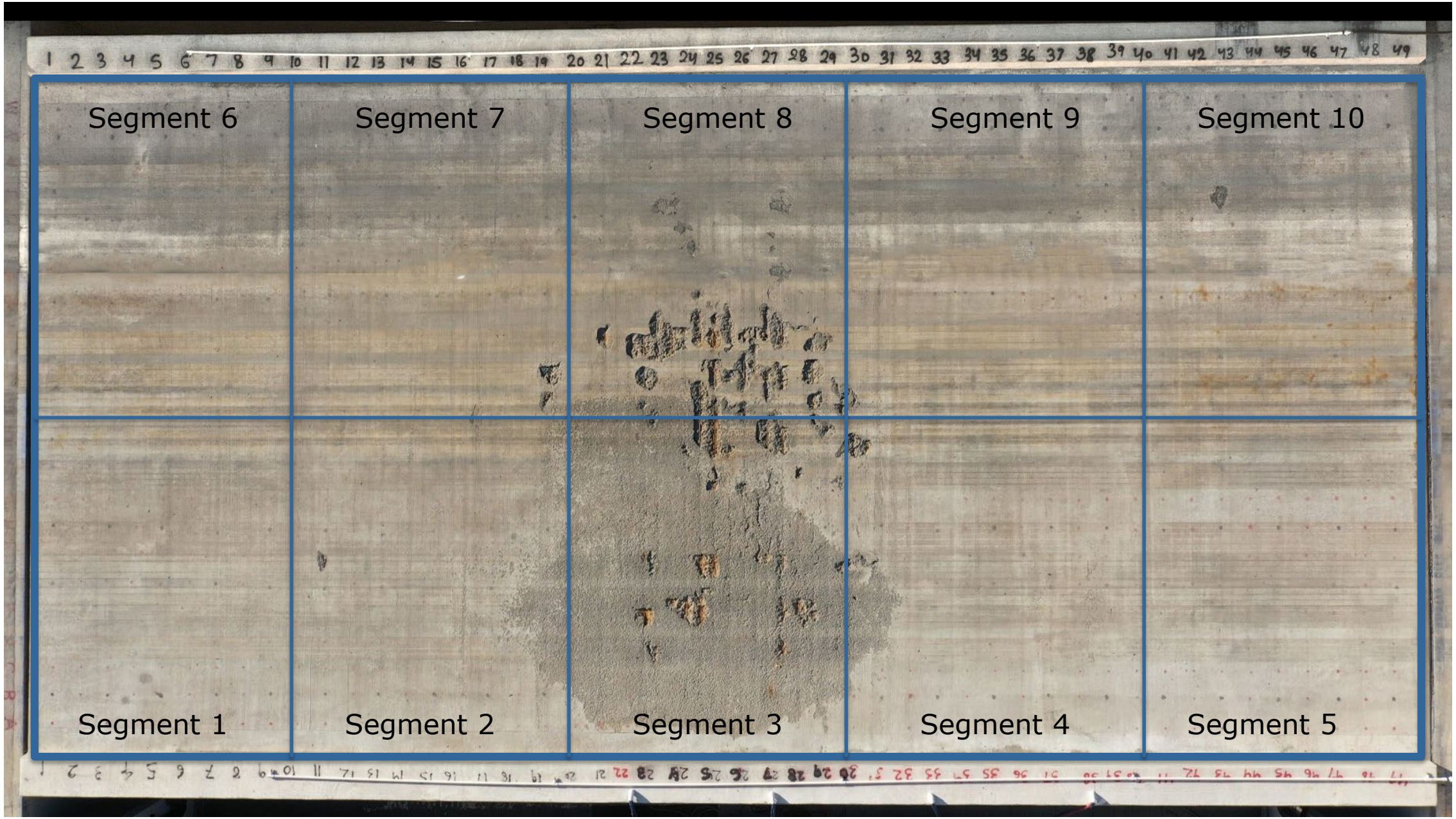


Average 4588.9 ksi, StDev 801.7 ksi

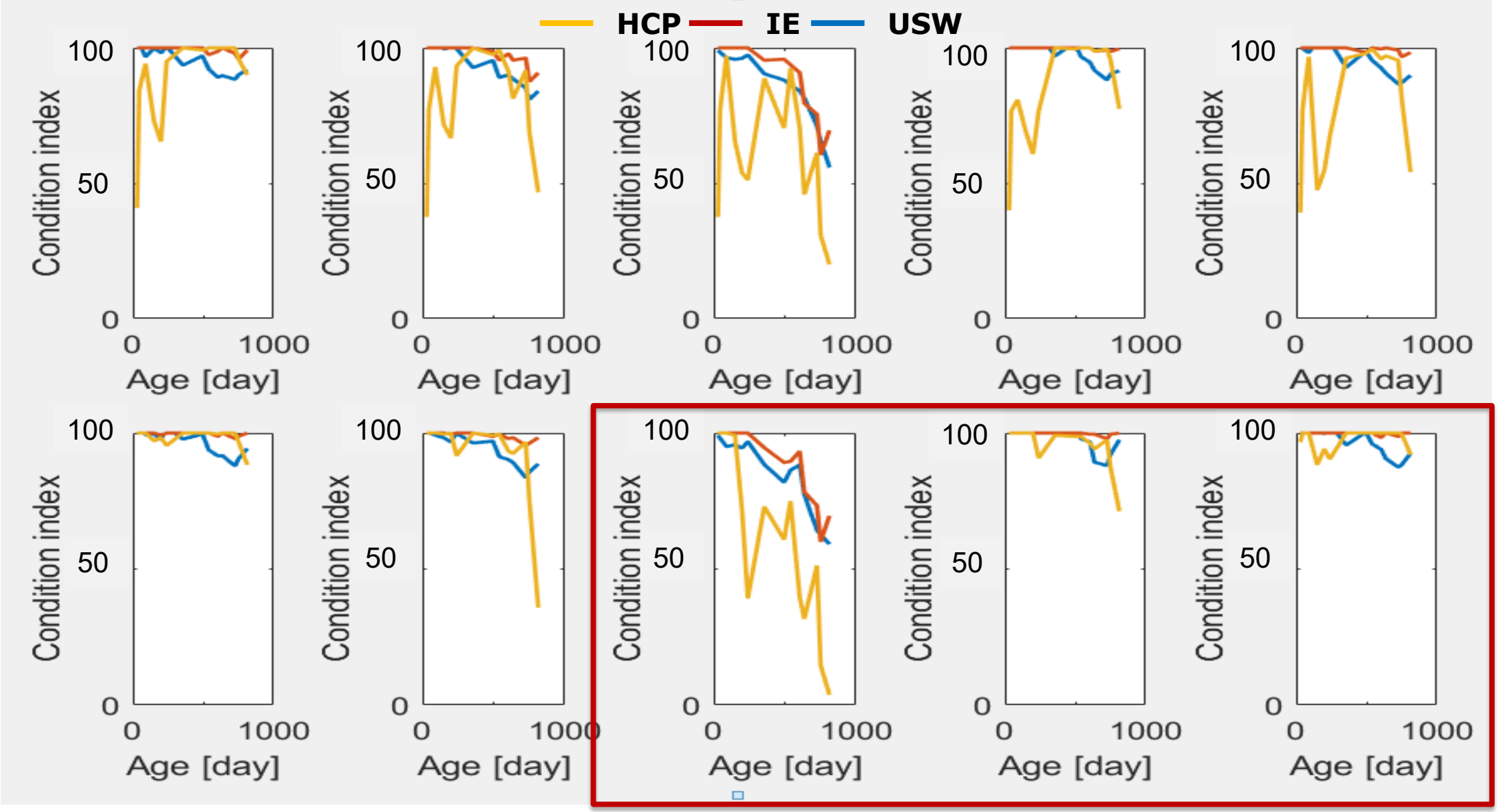
Condition (Deterioration) Curves from HCP, IE and GPR



Bridge Deck Segmentation

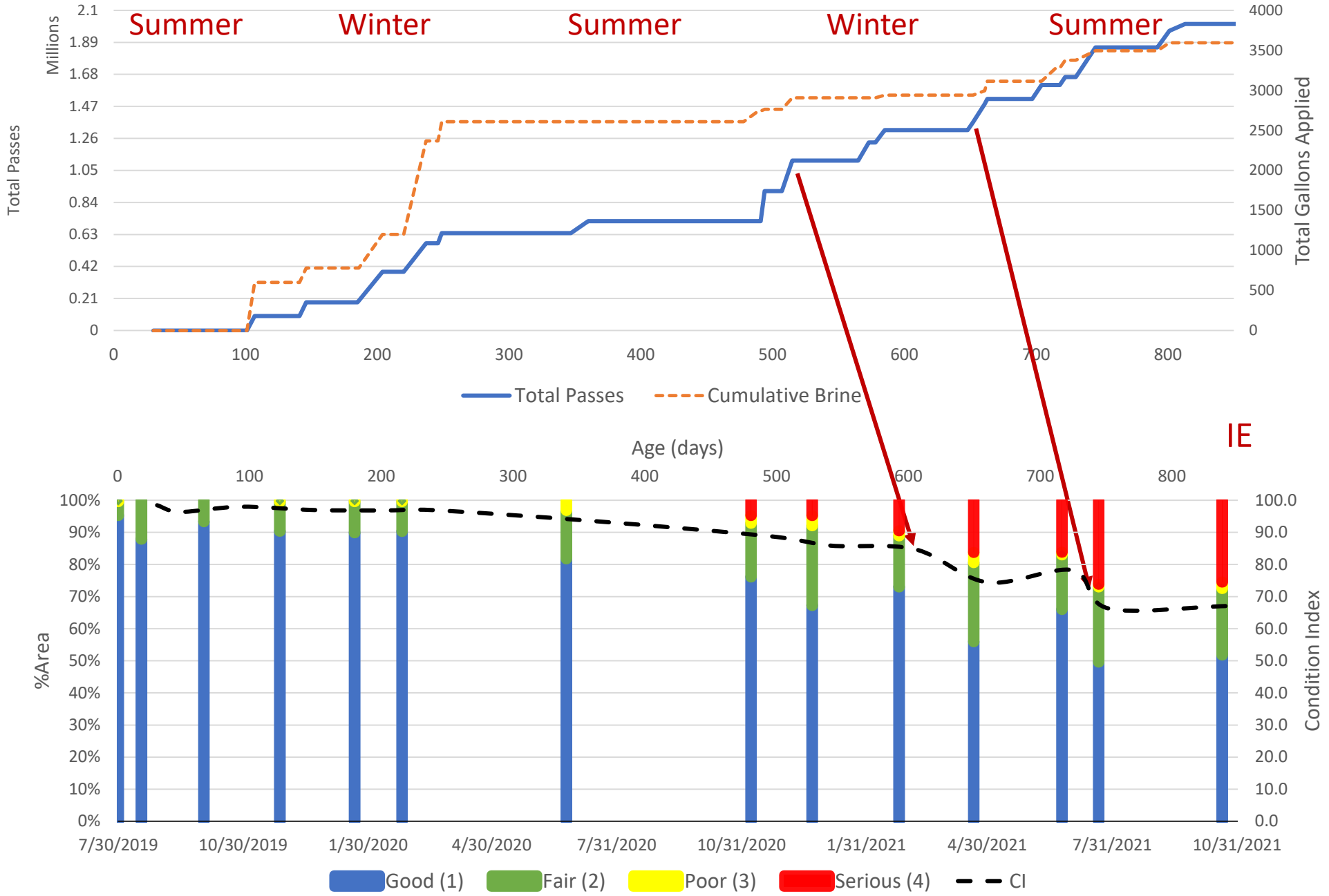


Deterioration Curves for Corrosion, Delamination, and Concrete Quality Degradation for Deck Segments



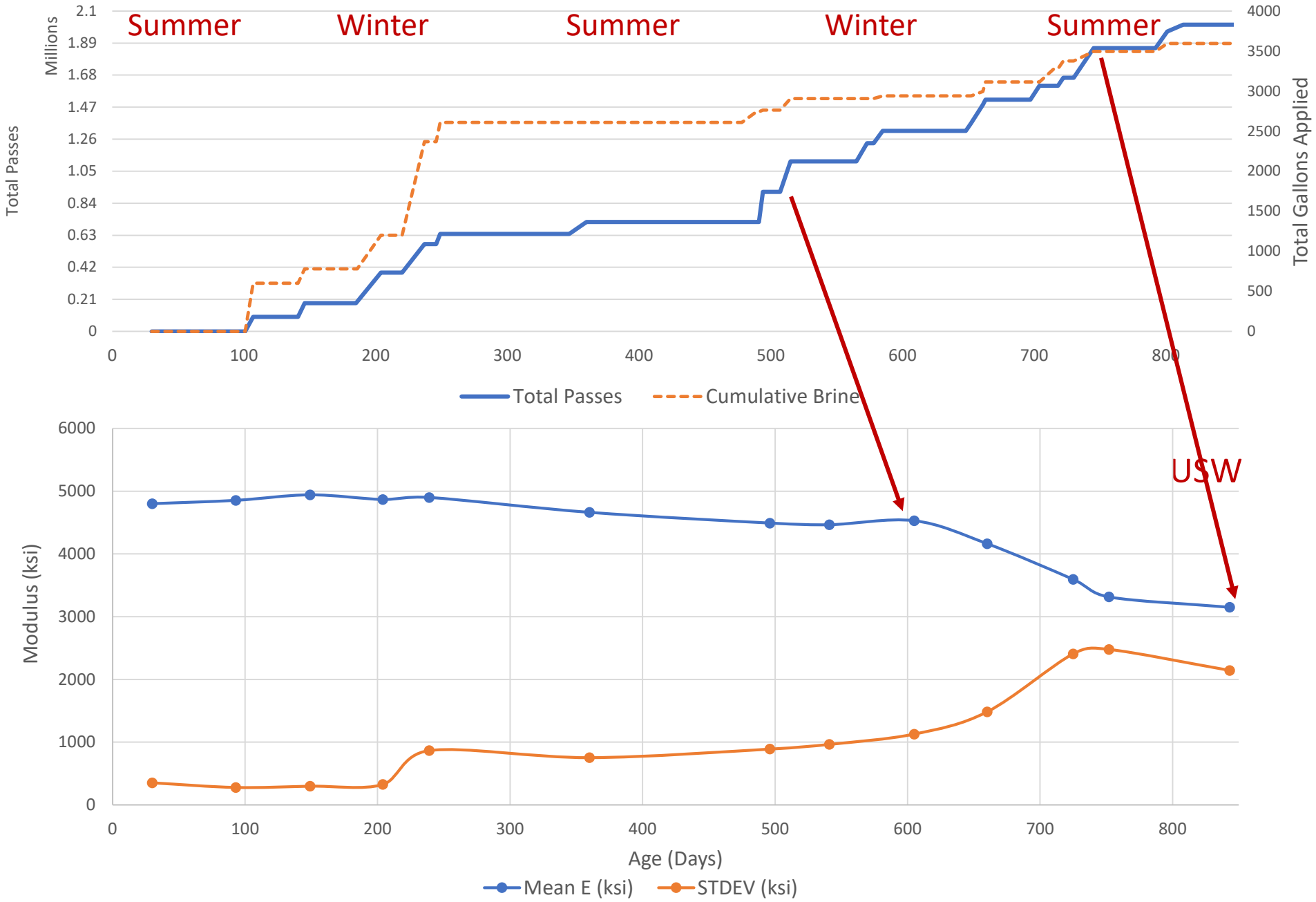
Live and Environmental Loading Vs. Delamination from IE Results

20-30 ft Deck Section



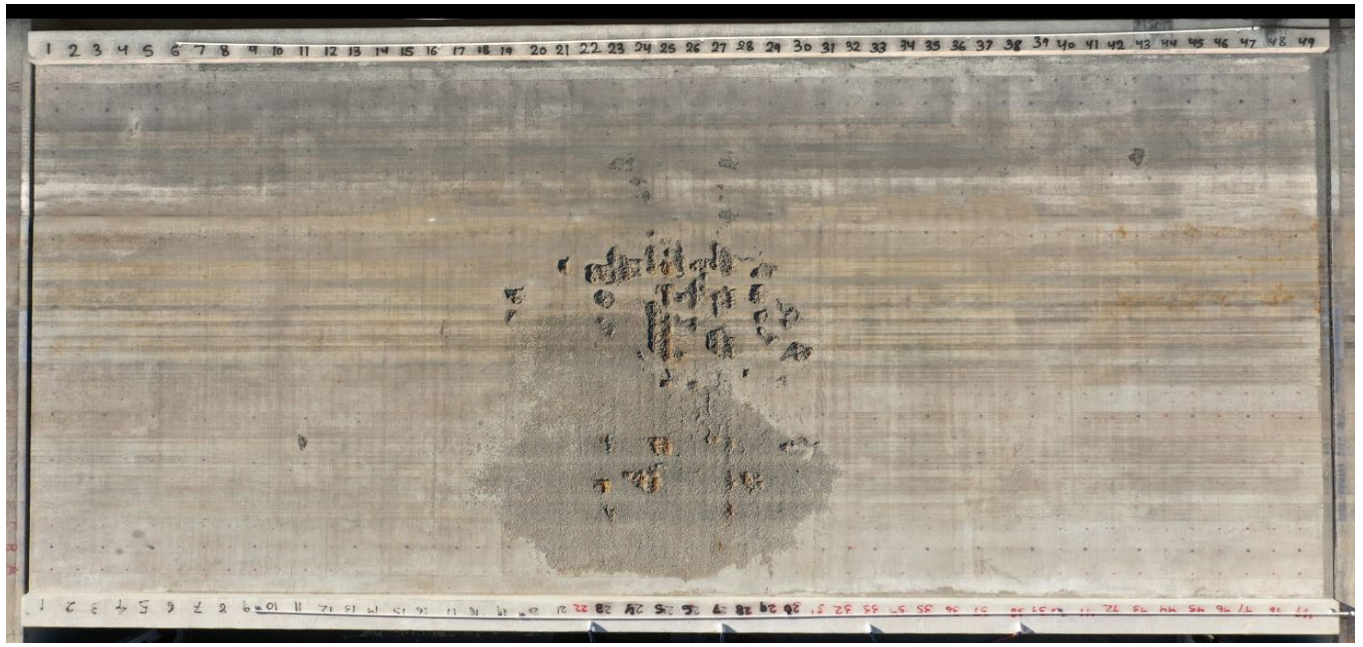
Live and Environmental Loading Vs. Concrete Quality from USW Results

20-30 ft Deck Section



BEAST – Comparison of Bare and Overlaid Deck Performance

Bare Deck after 2.05M Live Load Passes

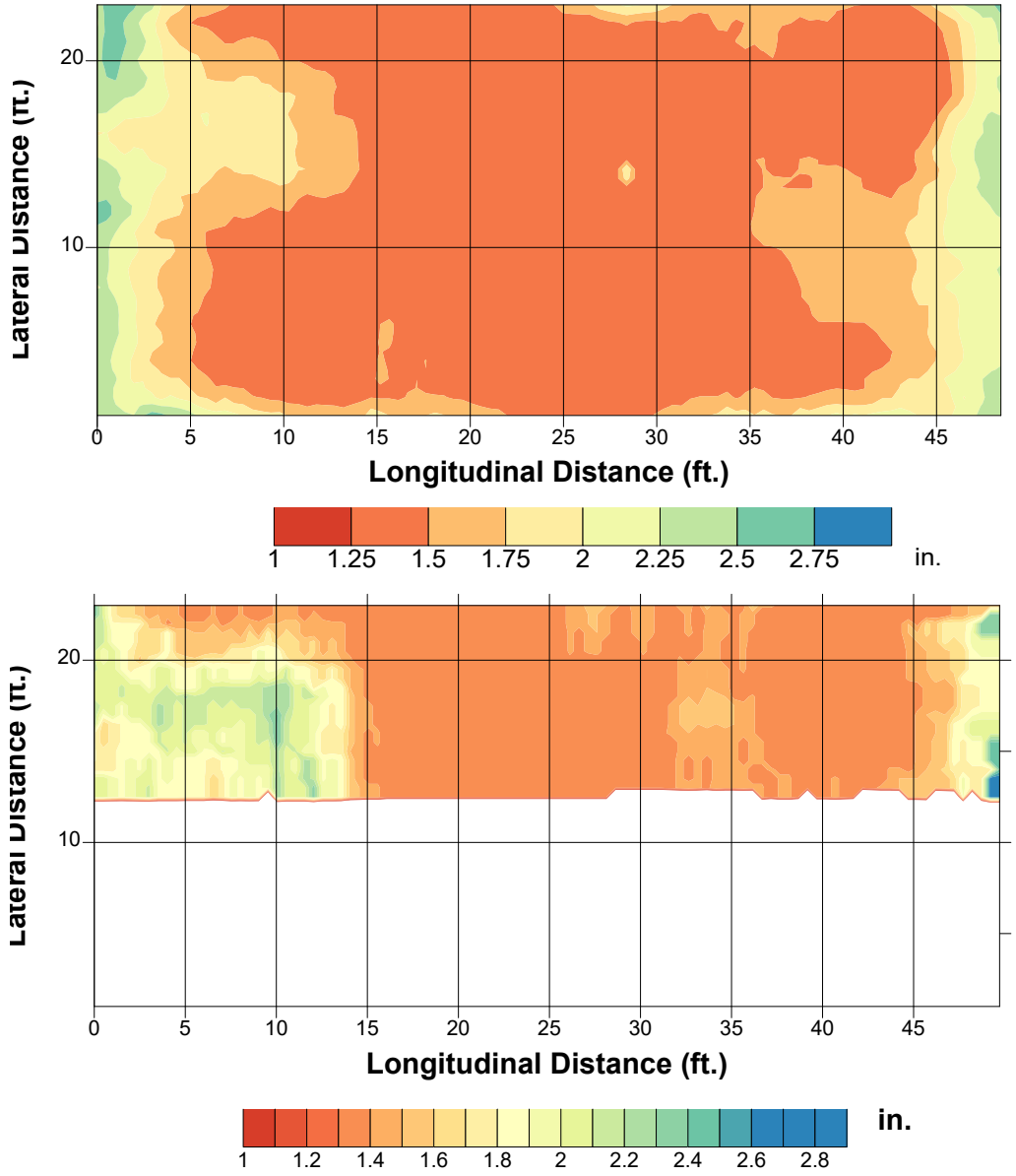


LMC Overlay

Overlaid Deck after 2.6M Live Load Passes

UHPC Overlay

Comparison of Concrete Cover Thickness of Bare and Overlaid Decks



Bare deck

Middle section 1.25 in – to 1.5 in

Overlaid deck (LMC side)

Middle section 1.3 in – to 1.6 in

Comparison of Bare (2.05M LLP) and Overlaid Deck (3.0M LLP) Performance

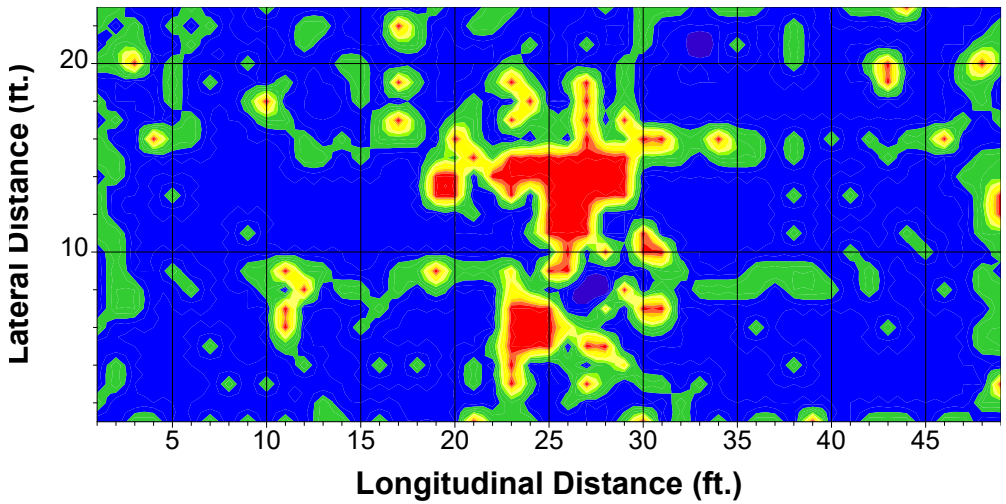
Delamination map from impact echo

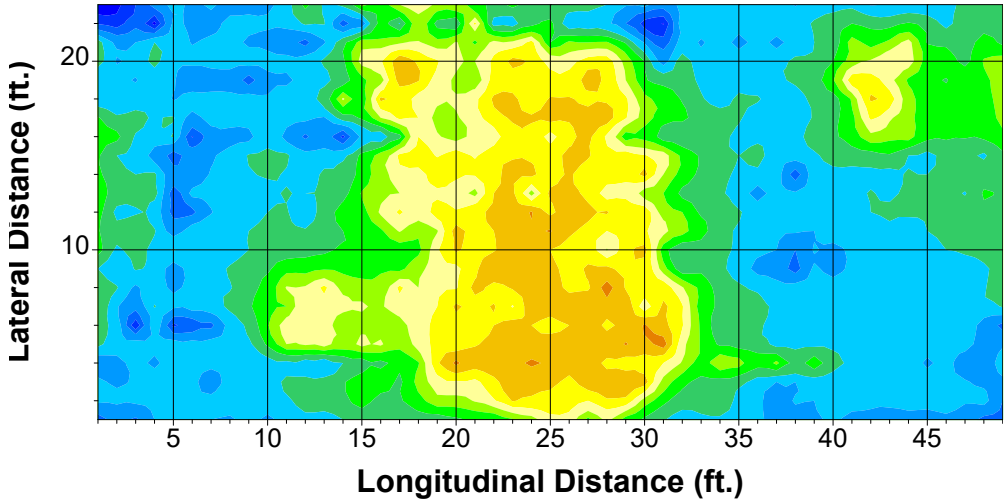
Corrosion activity from half-cell potential

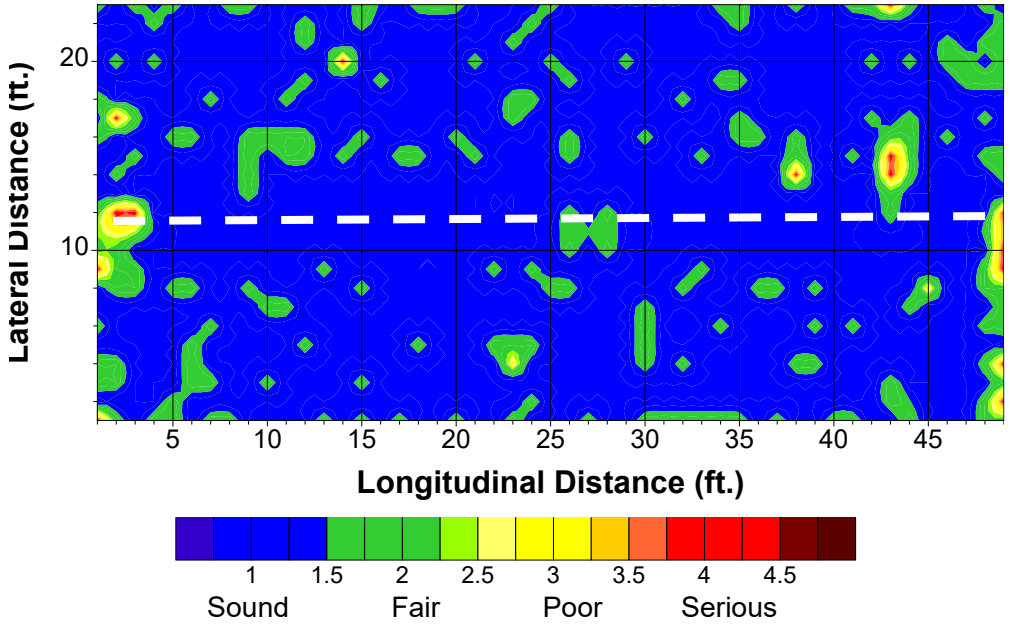
Bare Deck

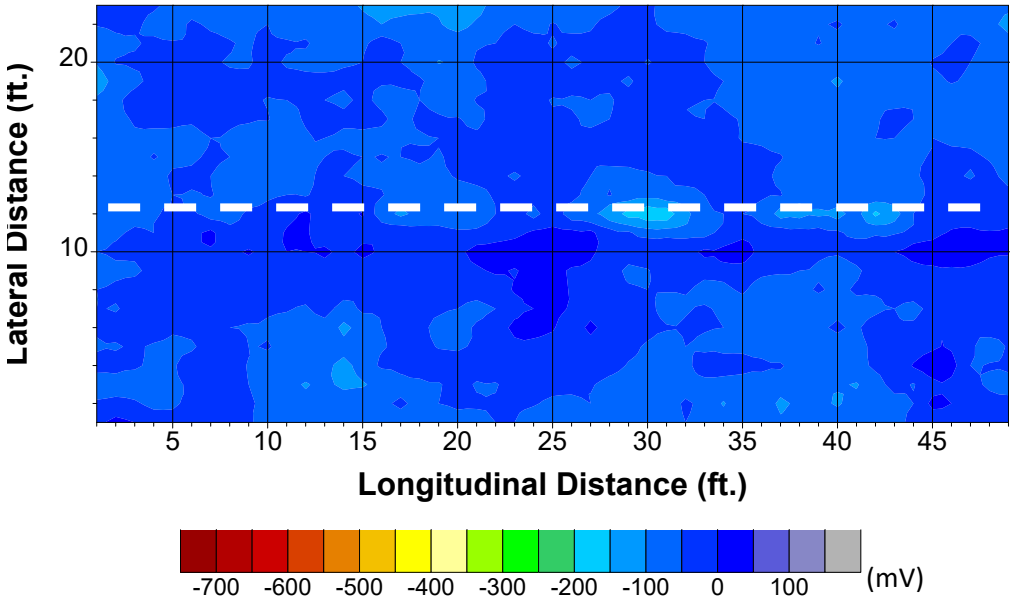
LMC Overlaid Deck

UHPC Overlaid Deck







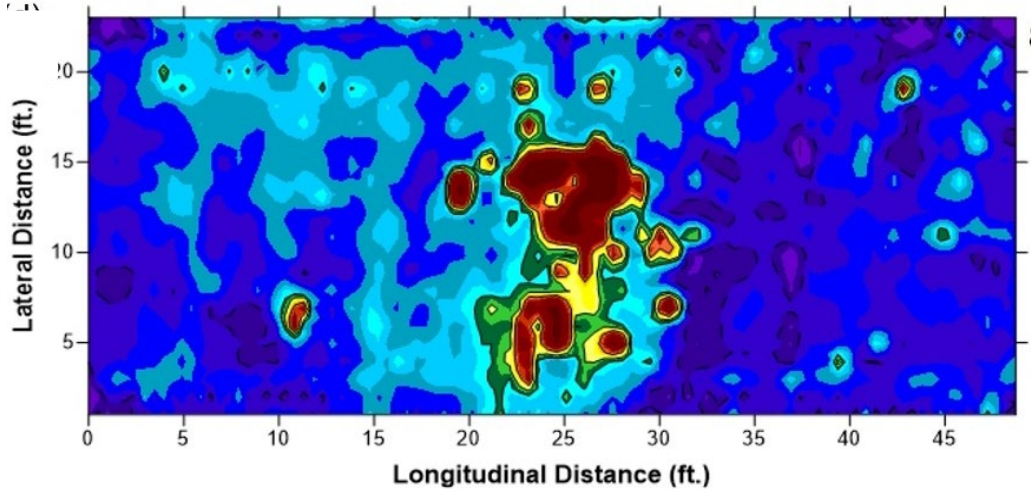


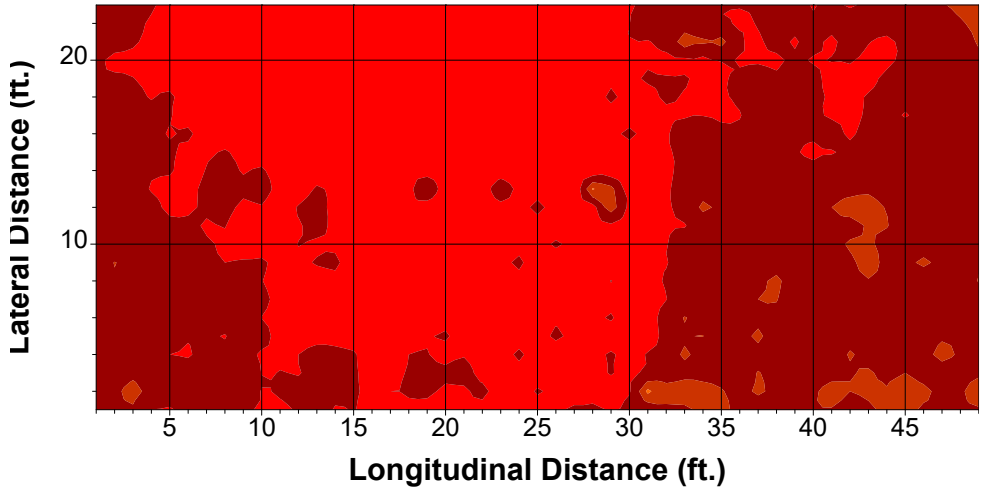
Comparison of Bare (2.05M LLP) and Overlaid Deck (3.0M LLP) Performance

GPR based condition map

Corrosive environment from ER

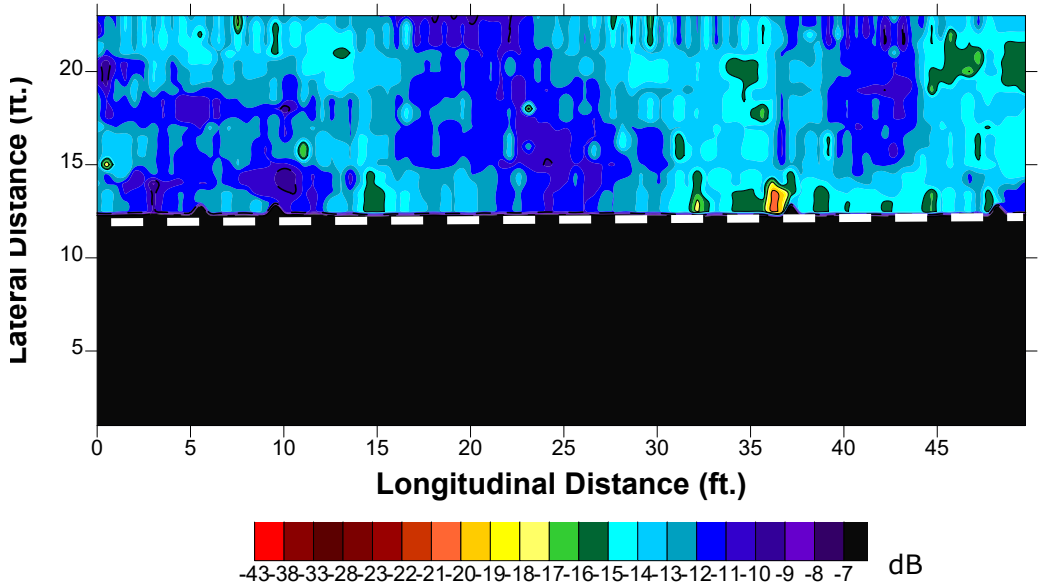
Bare Deck

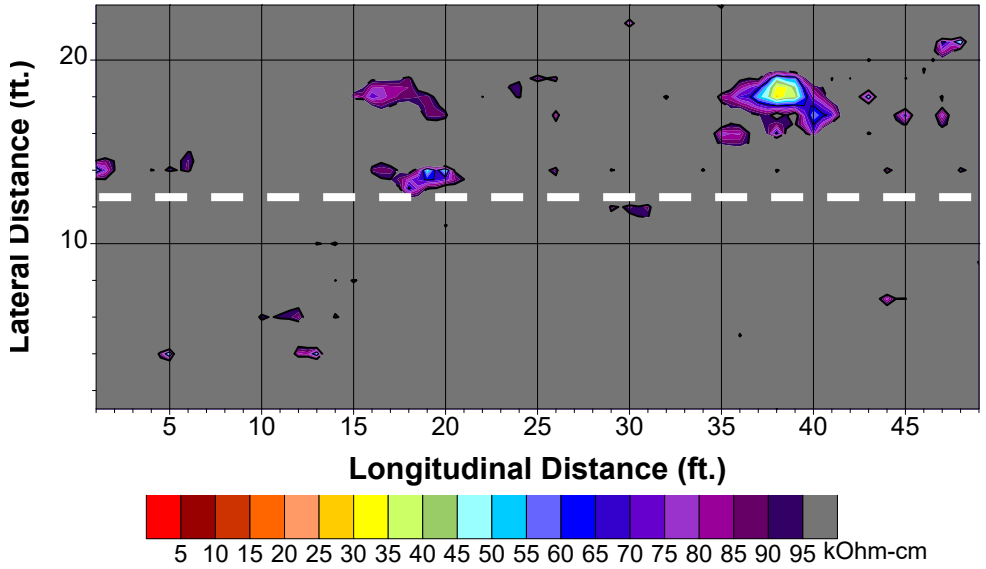




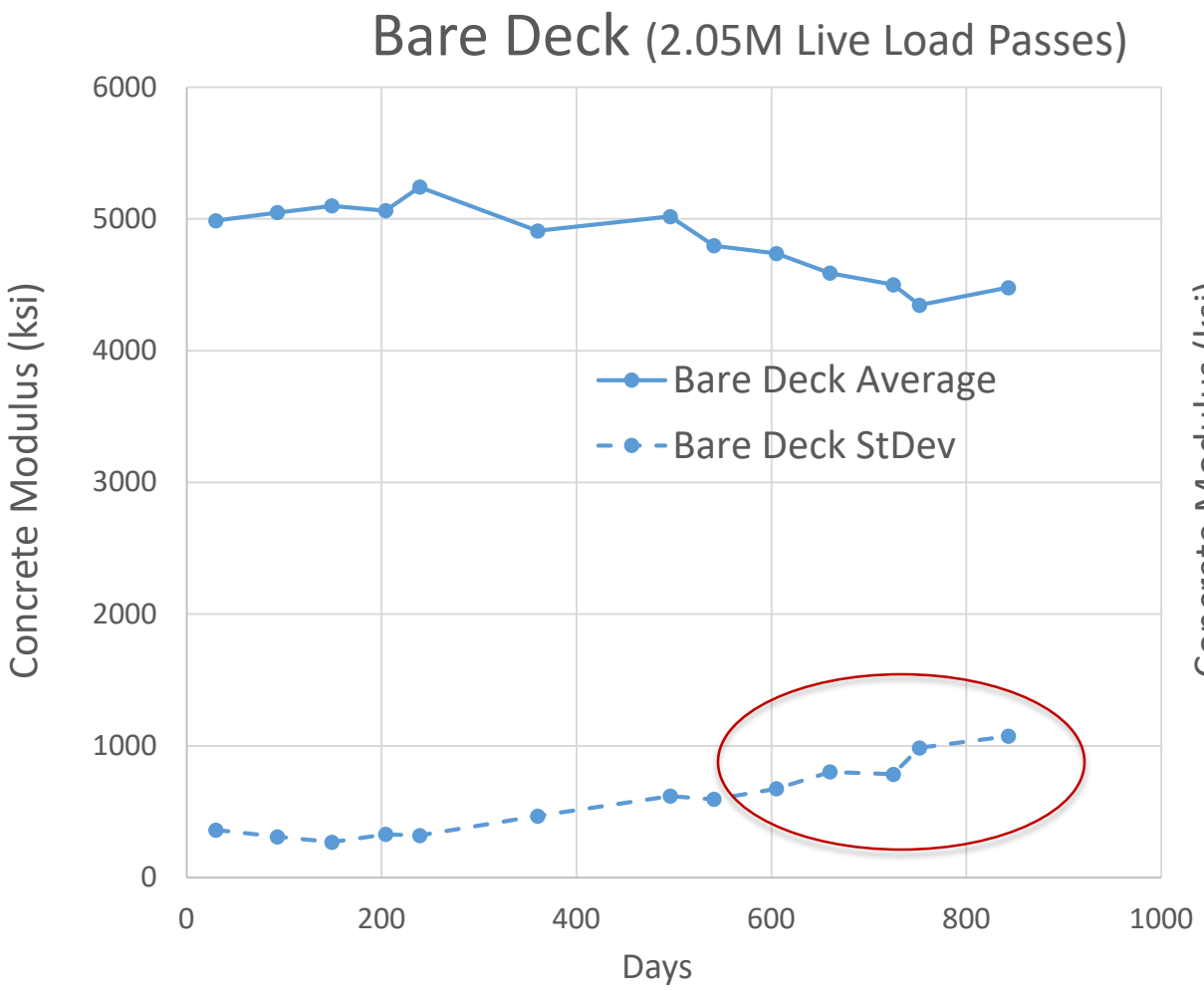
LMC Overlaid Deck

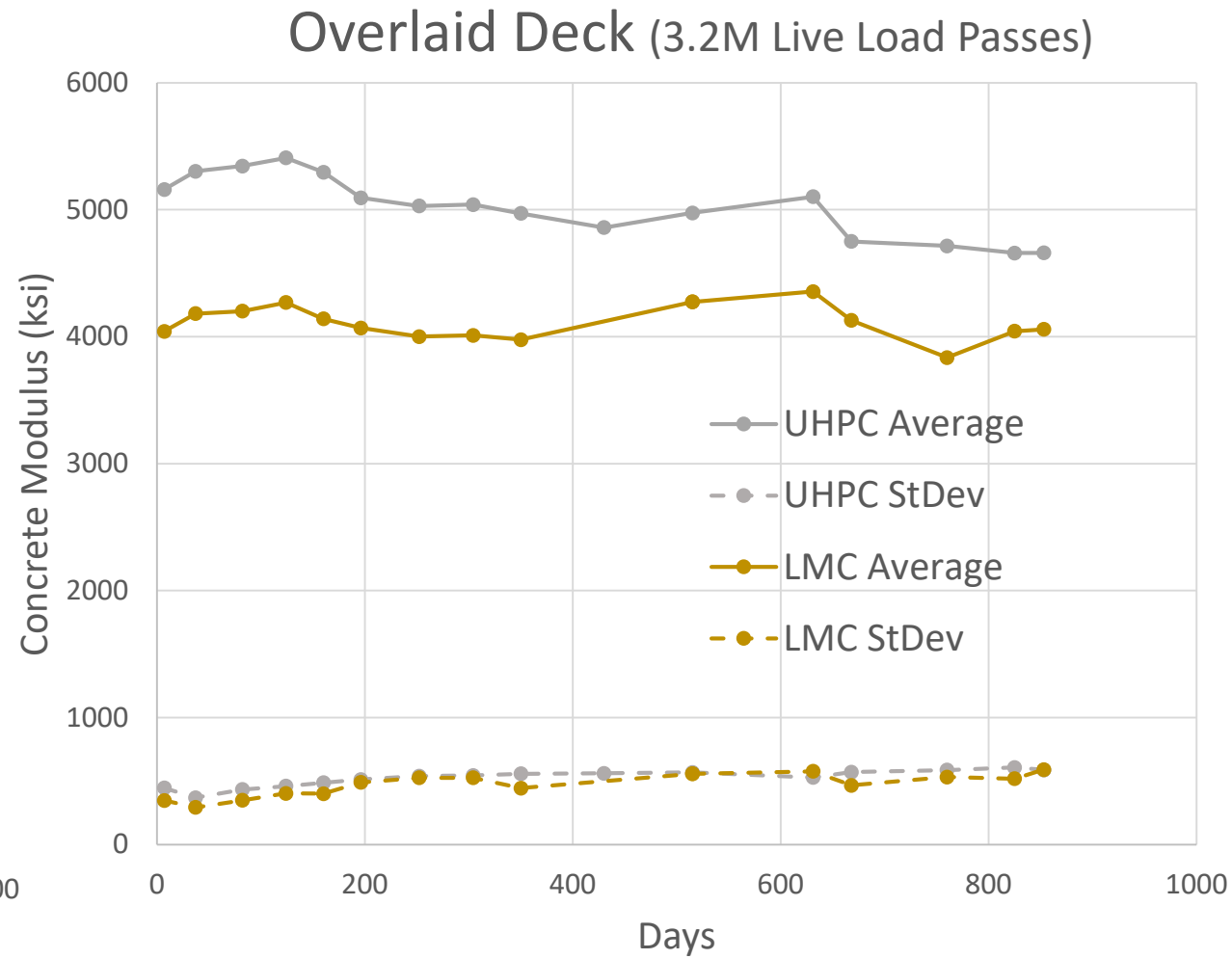
UHPC Overlaid Deck



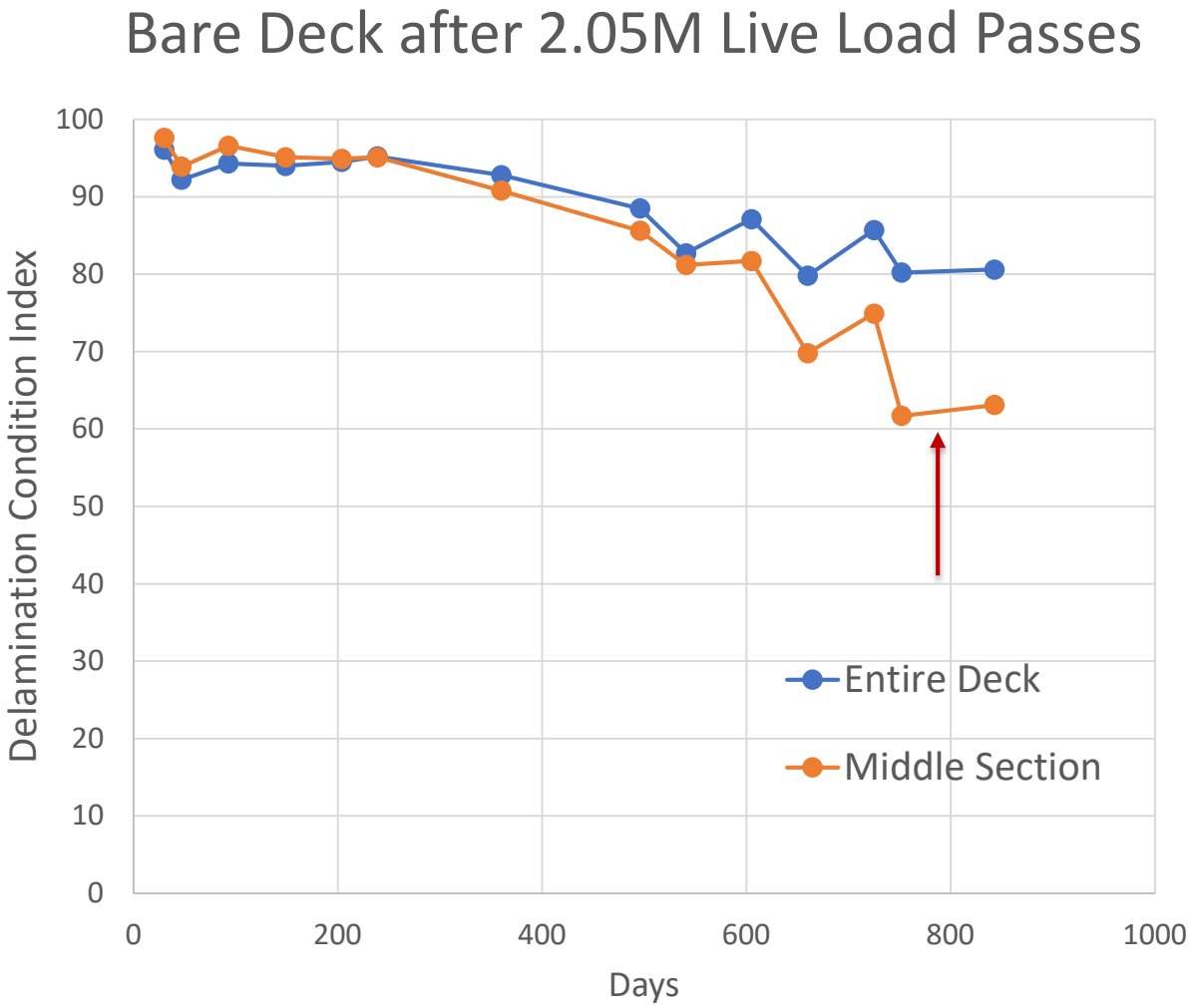


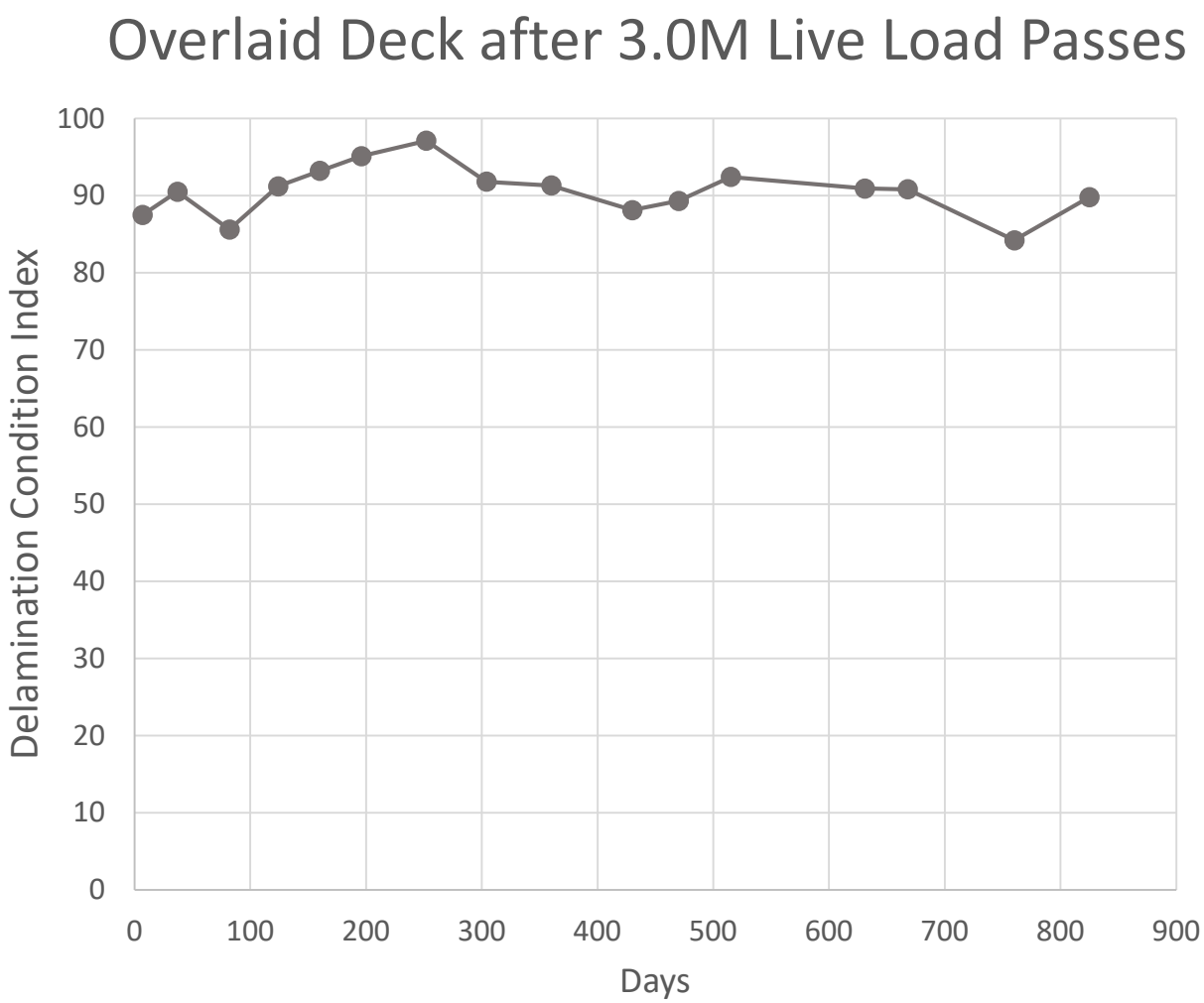
Comparison of Performance of Bare and Overlaid Decks
Concrete Modulus from USW





Comparison of Performance of Bare and Overlaid Decks
Delamination Condition Index from Impact Echo





Conclusions

- UHPC and LMC overlaid decks have shown significantly better performance than bare decks. Even with 60% more live loading cycles, there was lower concrete quality degradation, and far less signs of corrosion and delamination.
- Accelerated structural testing opens opportunities for much faster development of fundamental understanding of deterioration mechanisms and deterioration progression in bridges, in particular in concrete bridge decks.
- Evaluation is done at rates thirty or more times faster than on the majority (90 percent) of real bridges.
- Obtained data enable development of more realistic deterioration and predictive models, critical for effective bridge management.
- BEAST opens opportunities for rapid performance evaluation of:
  - New materials
  - New designs
  - Condition monitoring and assessment systems
  - Maintenance and rehabilitation procedures, etc.

Thank you!

Acknowledgments

- Federal Highway Administration – Long-Term Bridge Performance Program
- New Jersey Department of Transportation
- Seong-Hoon Kee (Dong-A University), Sherif Farrag and John Braley (Rutgers University)