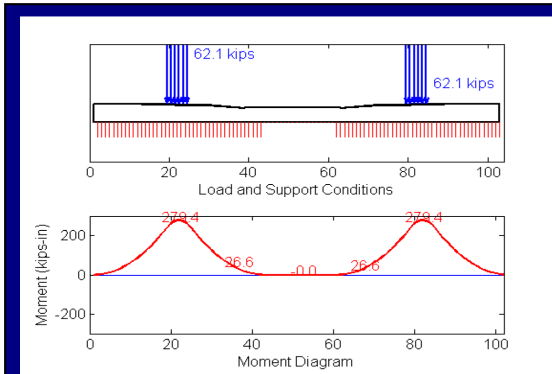
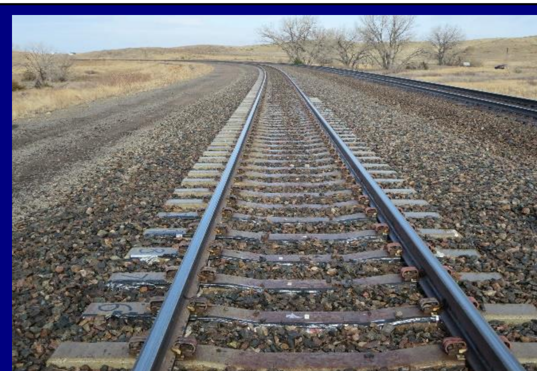
Nondestructive Estimation of Concrete Crosstie Support Conditions Using Field Bending Moments





2017 TRB Annual Meeting

Washington, D.C.

10 January, 2017

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RAILTEC

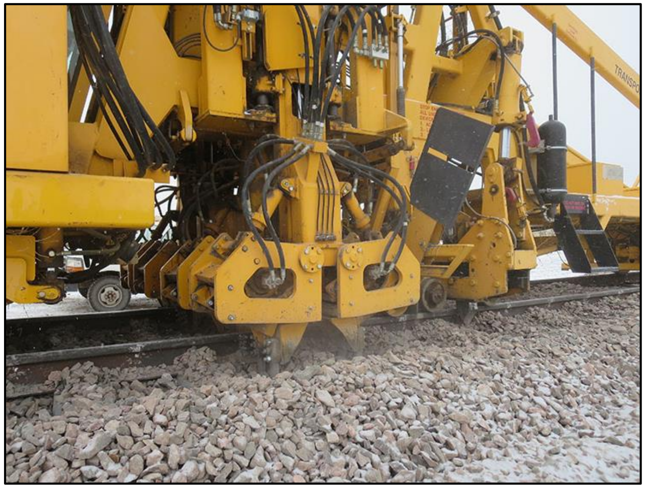
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Problem statement and research objective
- Support condition back-calculator facts
- Field Implementation
  - Quantification of ballast pressure
  - Application of Ballast Pressure Index (BPI)
  - Crosstie curling behavior
- Preliminary conclusions
- Future work

Problem Statement and Research Objective

- **Objective:** Develop a non-intrusive method to quantify support conditions and their variation over time/tonnage
- **Purpose:** Provide rail industry with a tool to better prioritize surfacing
- **Challenge:** It is inherently difficult to quantify the pressure distribution at the crosstie-ballast interface
- **Approach:** Back-calculate ballast support conditions from measured concrete crosstie bending moments



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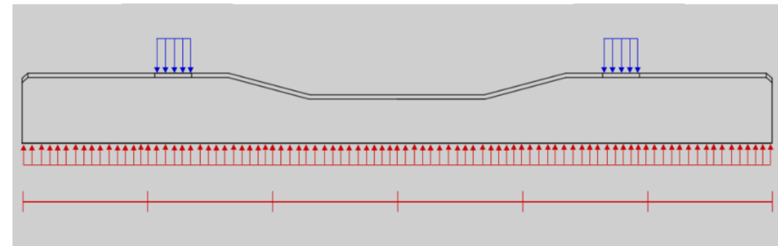
Support Condition Back-Calculator Facts

2-D Crosstie Bending Model

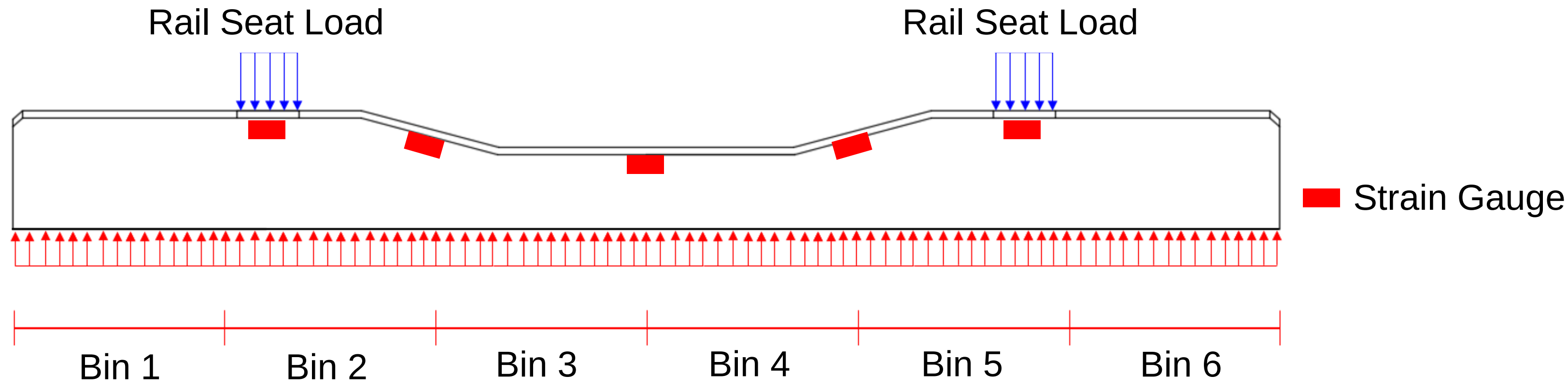


Optimization Algorithm

Laboratory Validation

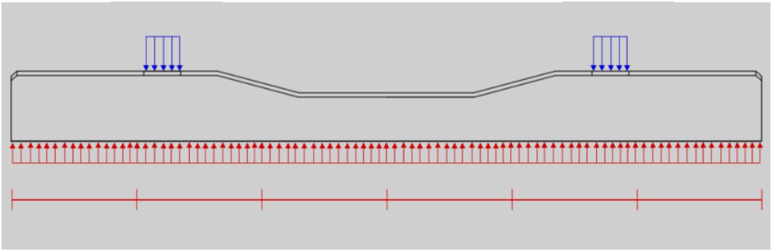
2-D Crosstie Bending Model

- Crosstie divided into 6 bins of equal width:
  - Each bin consists a percentage of total reaction force
- 9 model inputs:
  - Known bending moments from 7 locations (5 from strain gauges, 2 from end conditions)
  - 2 approximated rail seat loads (from load cell, WILD, or rail-mounted strain gauges)
    - Rail seat load is assumed to be uniformly distributed across rail seat
- 2 boundary conditions:
  - Force equilibrium (all bins should sum to approximately 100%)
  - Force value for each bin should not be negative

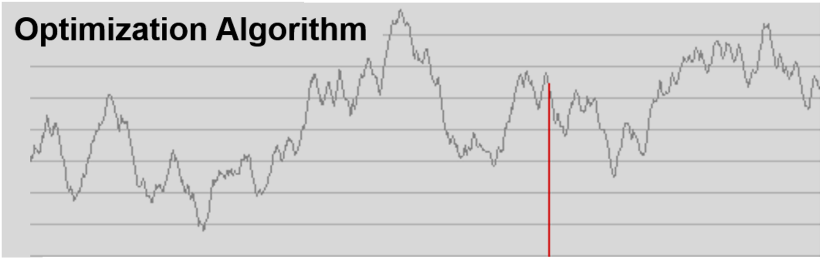


Support Condition Back-Calculator Facts

2-D Crosstie Bending Model



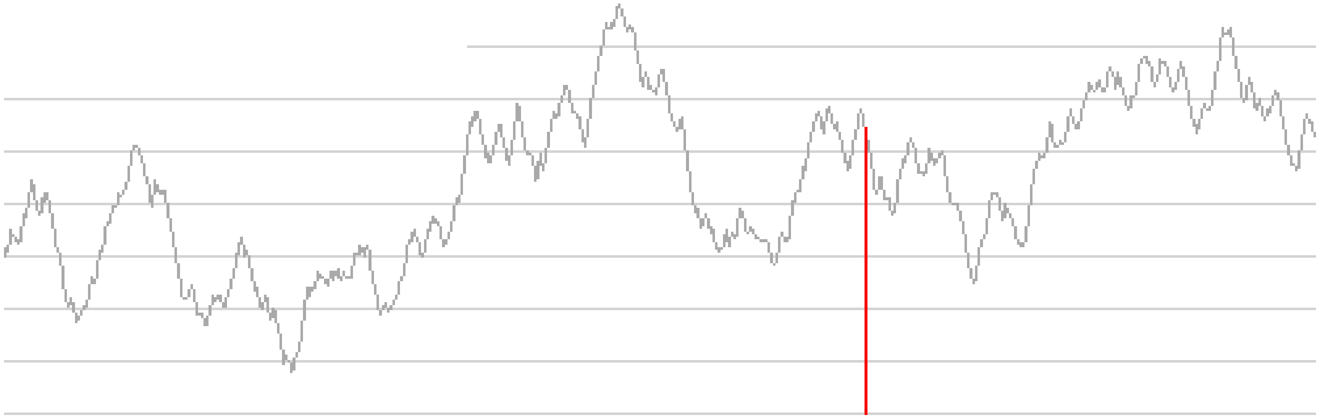
Optimization Algorithm



Laboratory Validation

Optimization Algorithm:
Simulated Annealing

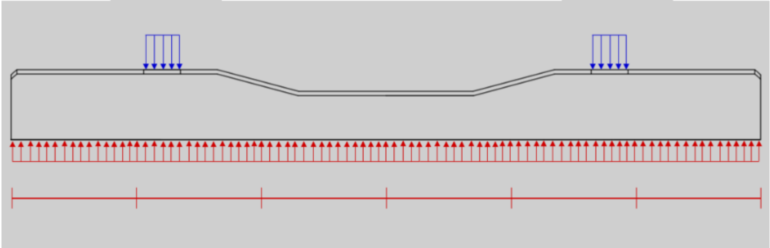
- **Definition:**
  - A probabilistic technique for approximating the global optimum of a given function
- **Benefits:**
  - Has a probability of accepting a “worse” solution
  - Pareto distribution is chosen as random variable generator
  - Avoids stopping at a local optimum



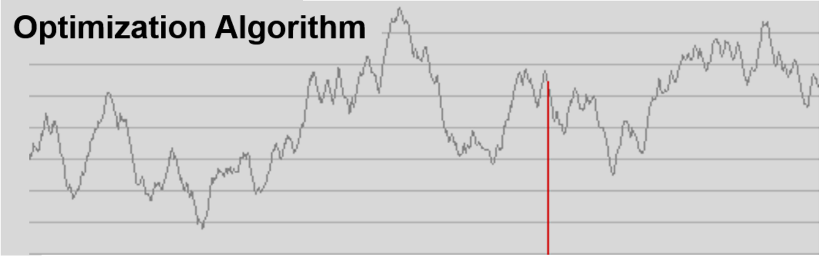
Wikipedia: Simulated Annealing

Support Condition Back-Calculator Facts

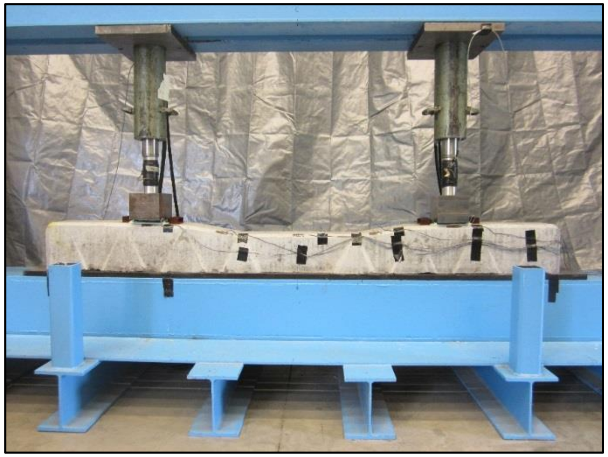
2-D Crosstie Bending Model



Optimization Algorithm

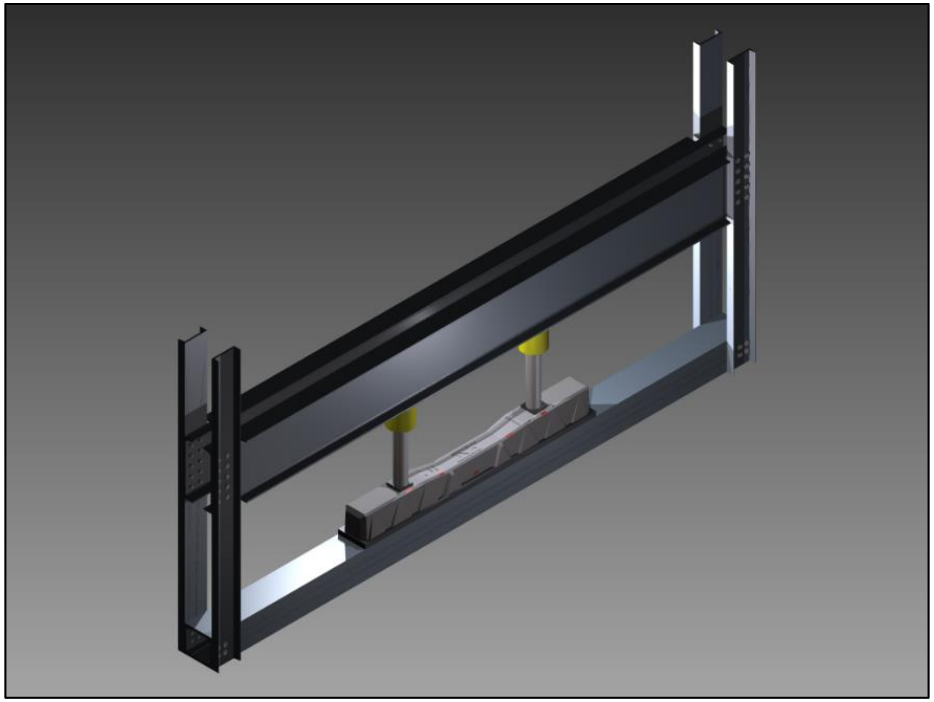


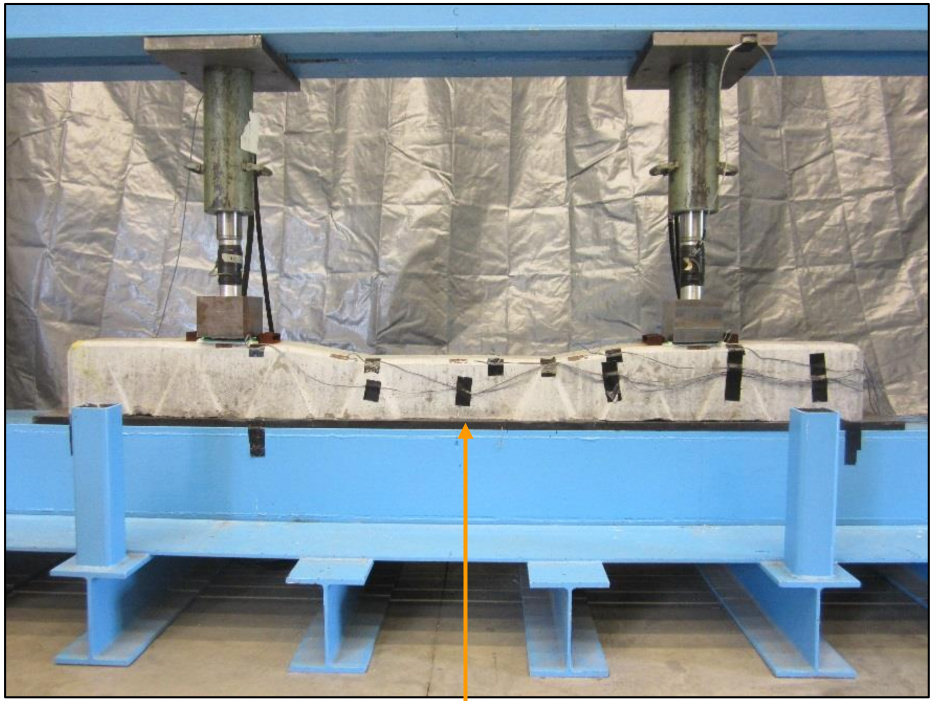
Laboratory Validation



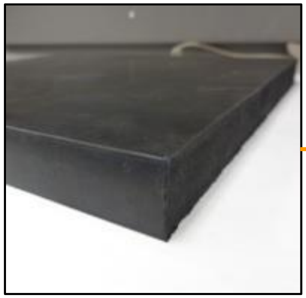
Laboratory Experimentation Equipment

- Loading frame - Static Load Testing Machine (SLTM) at RAIL



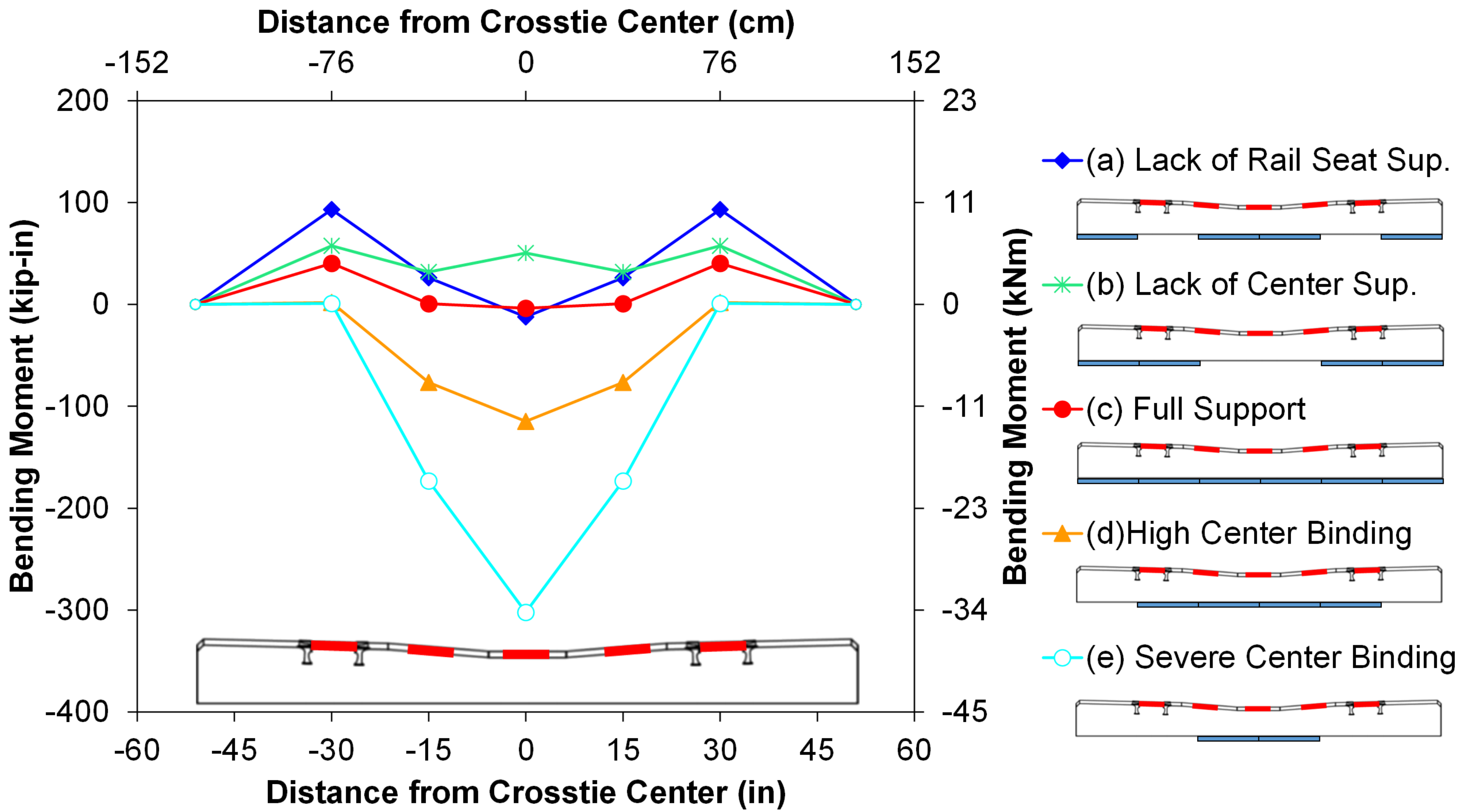


- Supporting rubber pads



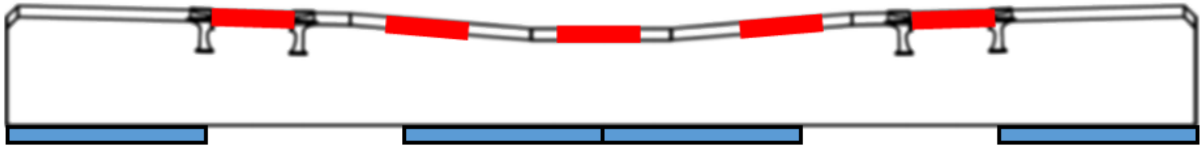
Influence of Support Condition on Crosstie Bending Moments

Rail Seat Load: 10 kips (44.5 kN), Healthy Crosstie

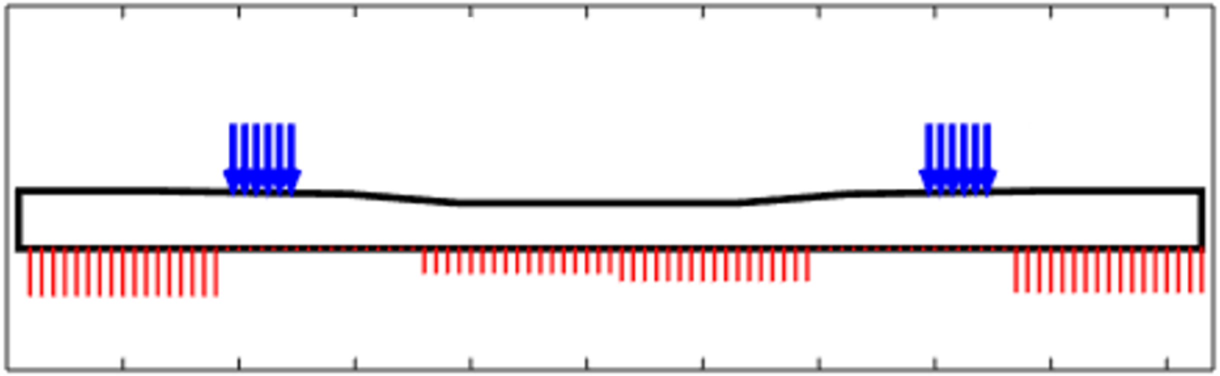


Lab Setup and Back-Calculator Result:
Lack of Rail Seat Support

Lab Setup

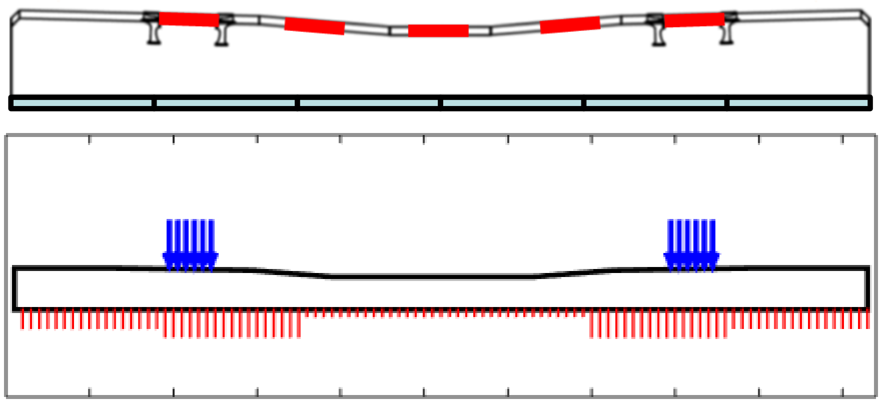


Back-Calculator Result

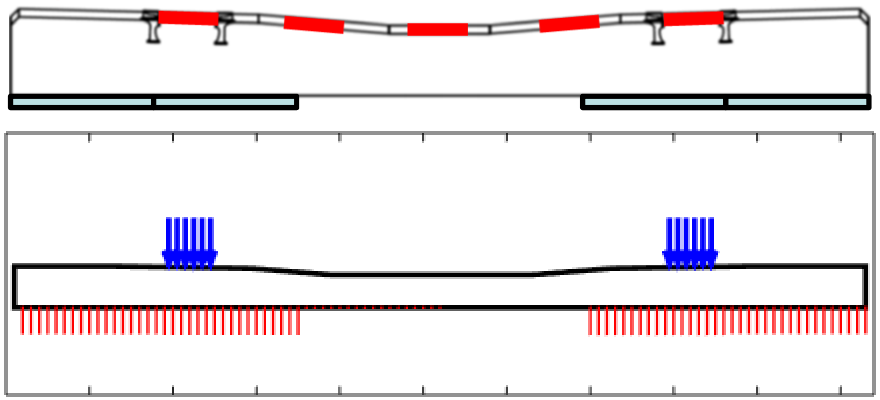


Comparison between Lab Support Conditions and Back-Calculator Results

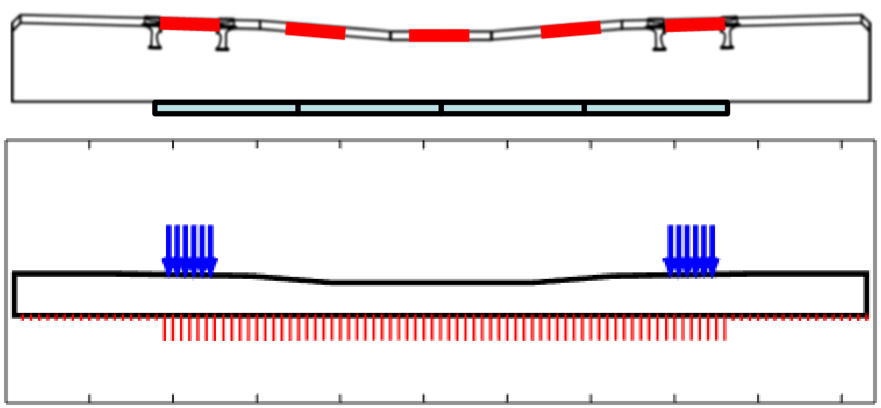
Full Support



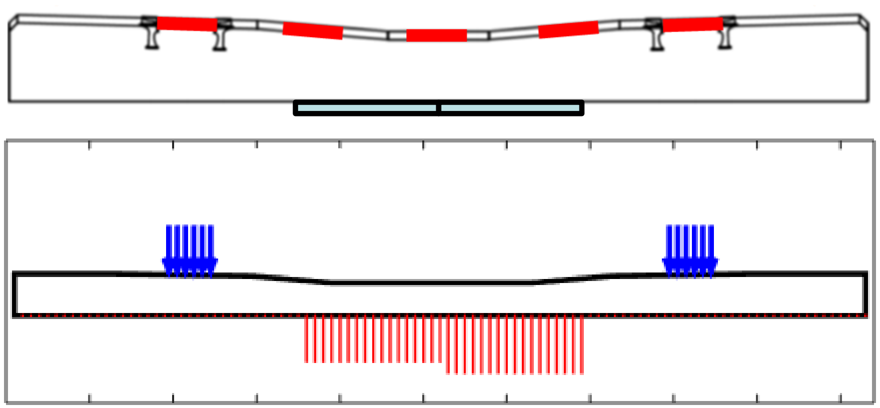
Lack of Center Support



Light Center Binding



High Center Binding



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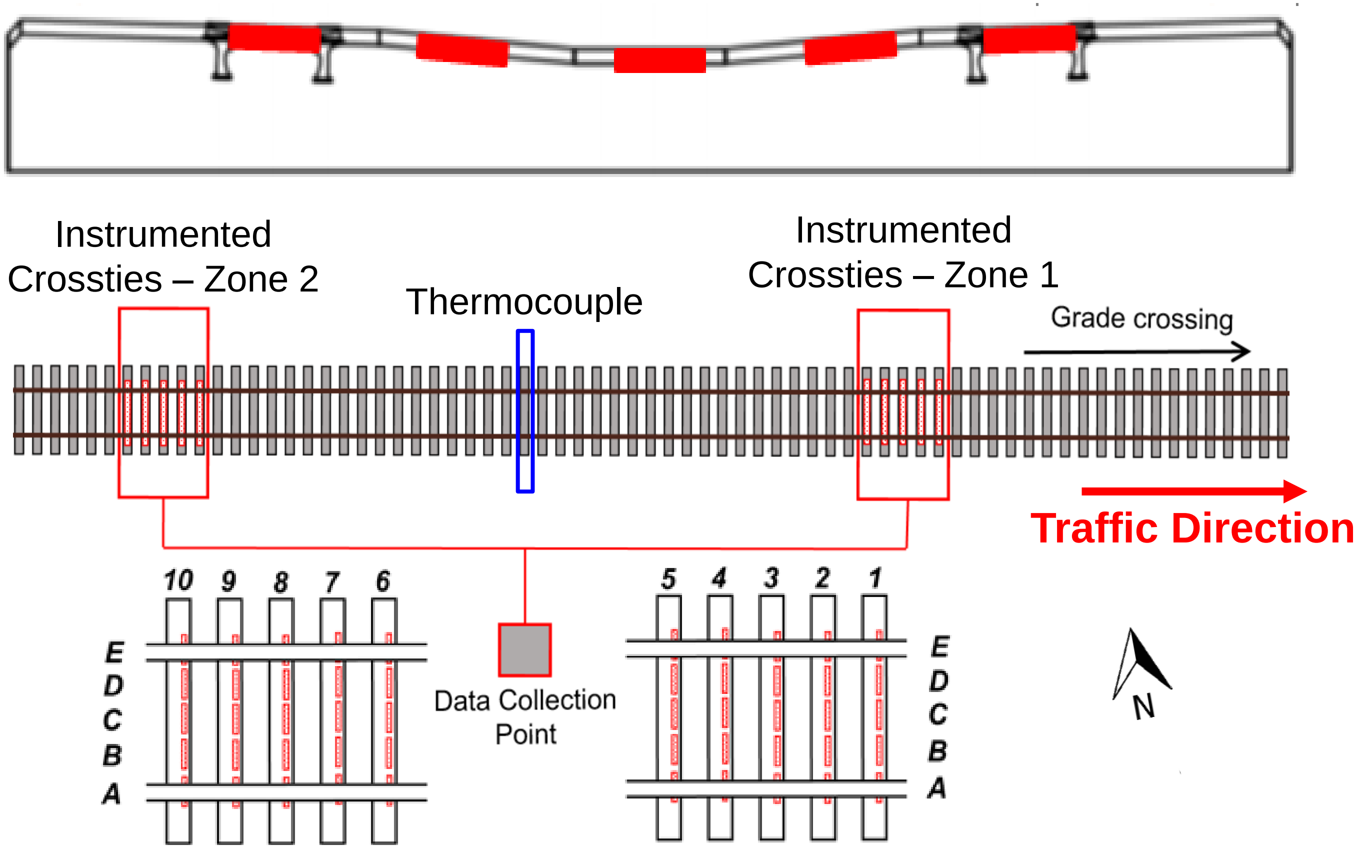
Field instrumentation Site Layout

- 50 surface strain gauges installed on 10 crossties



- Nearby Wheel Impact Load Detector (WILD) site provides wheel load data

Ballast Pressure Limit States

- Ballast pressure calculated based on uniform reaction assumption: **32 psi**
- AREMA allowable ballast pressure under concrete crossties: **85 psi**
- Ballast pressure calculated based on AREMA allowable subgrade bearing stress (25 psi) using Talbot equation: **55 psi**

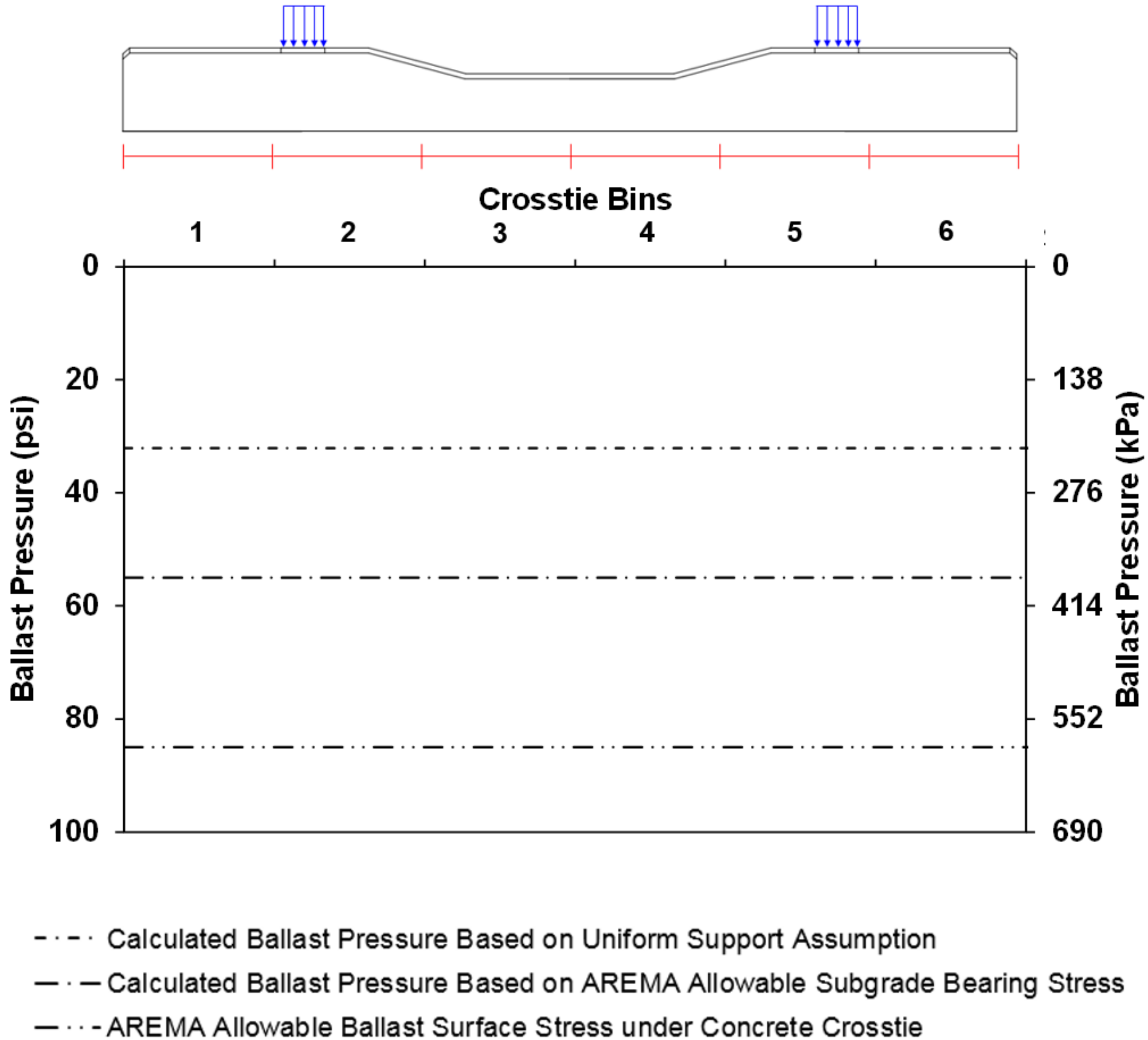
$$h = \left(\frac{16.8 p_a}{p_c}\right)^{4/5}$$

Where, h = Support ballast depth

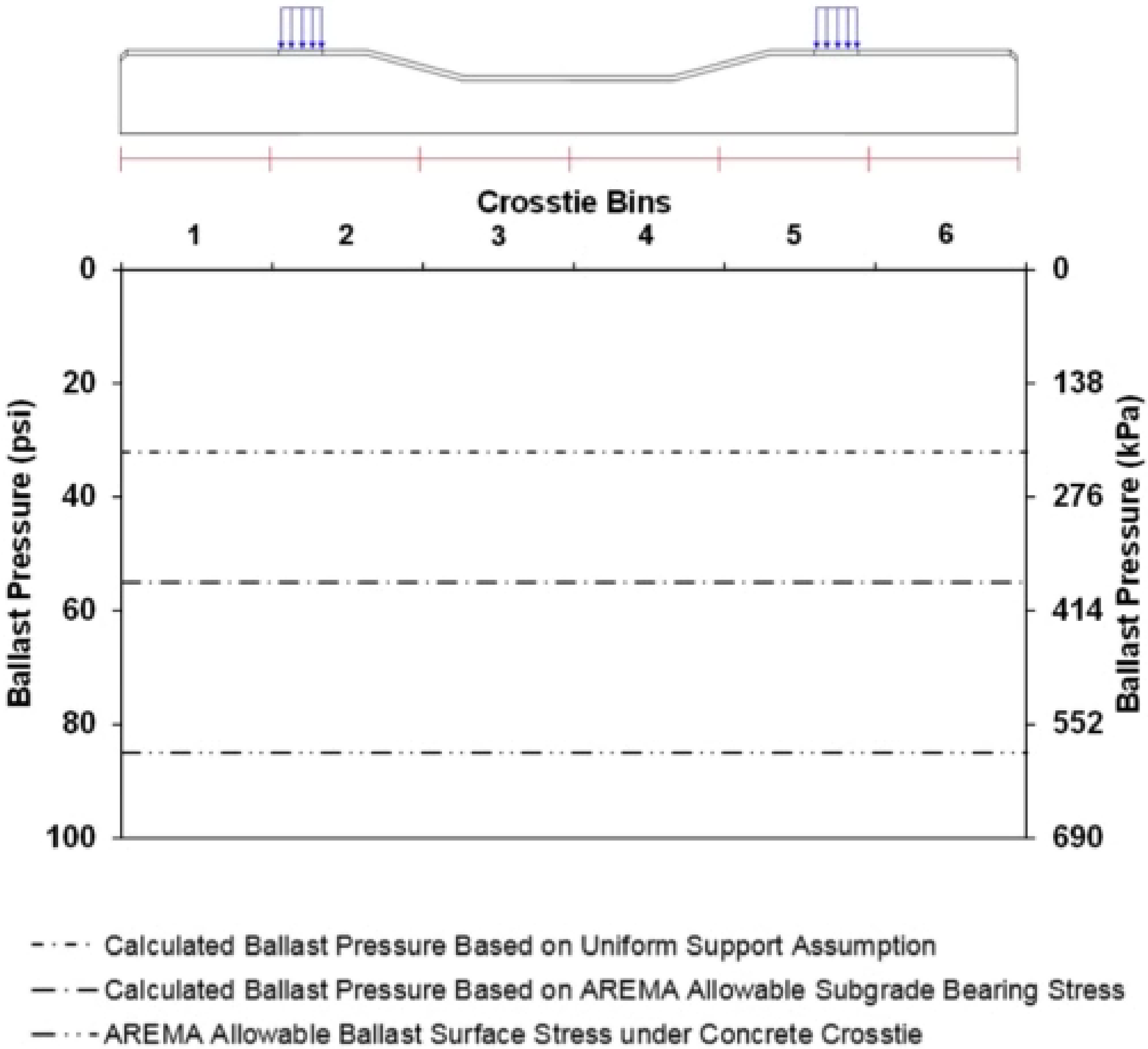
p_a = Stress at bottom of tie (top of ballast)

p_c = Allowable subgrade stress

Distribution of Ballast Pressure for Instrumented Crossties



Distribution of Ballast Pressure under Loaded Axle: *8:00 AM, 5/26/2015*



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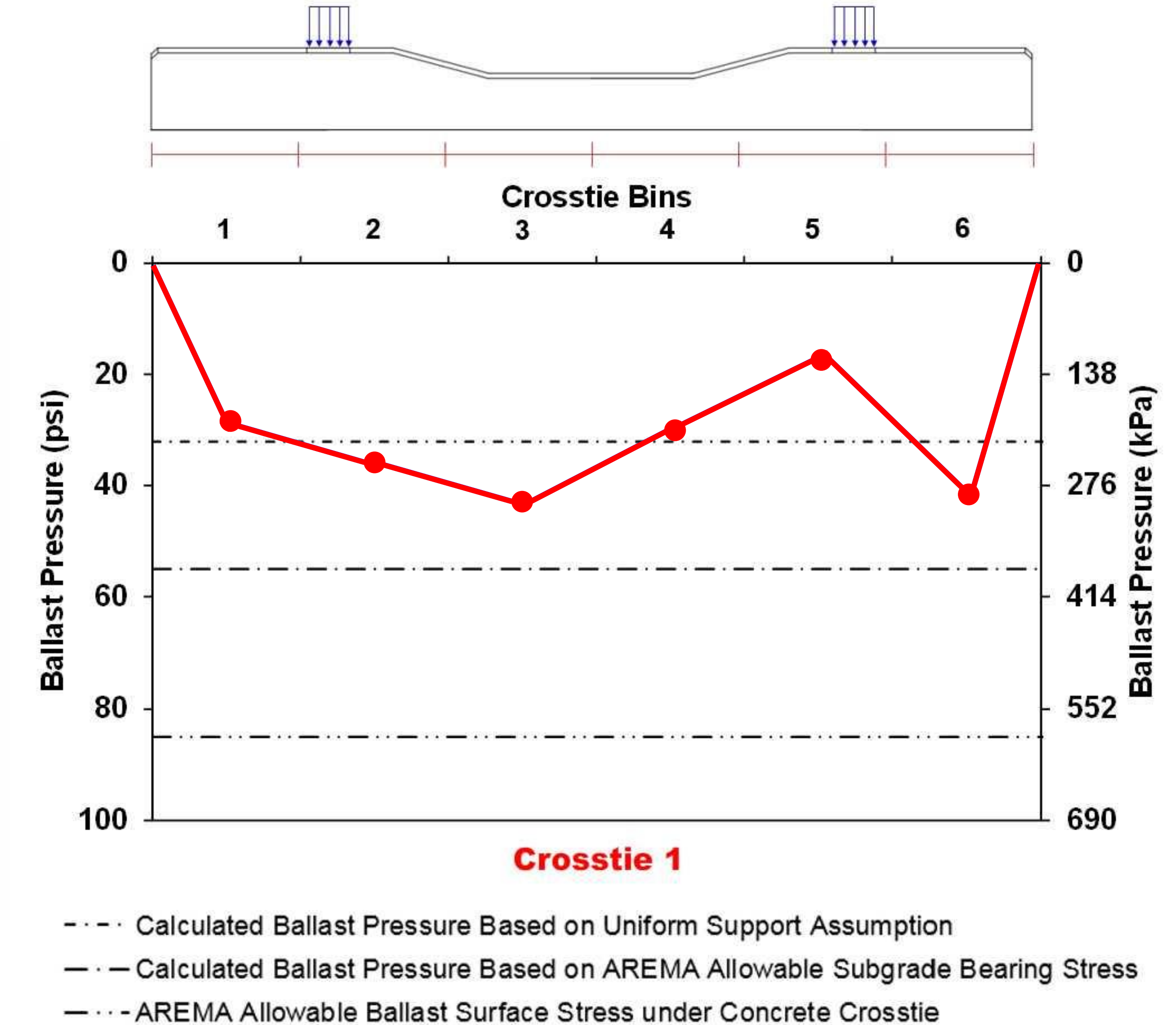

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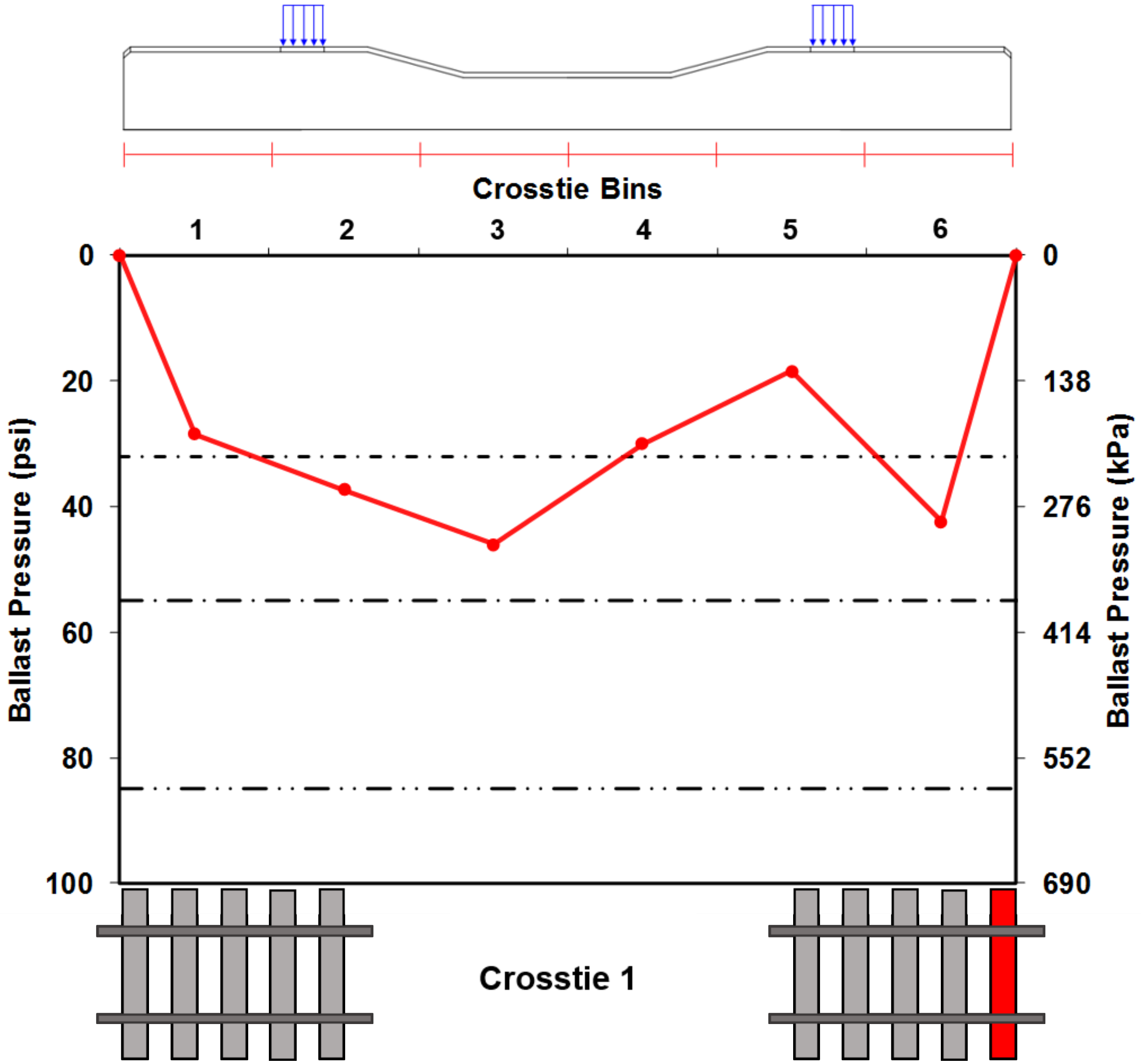

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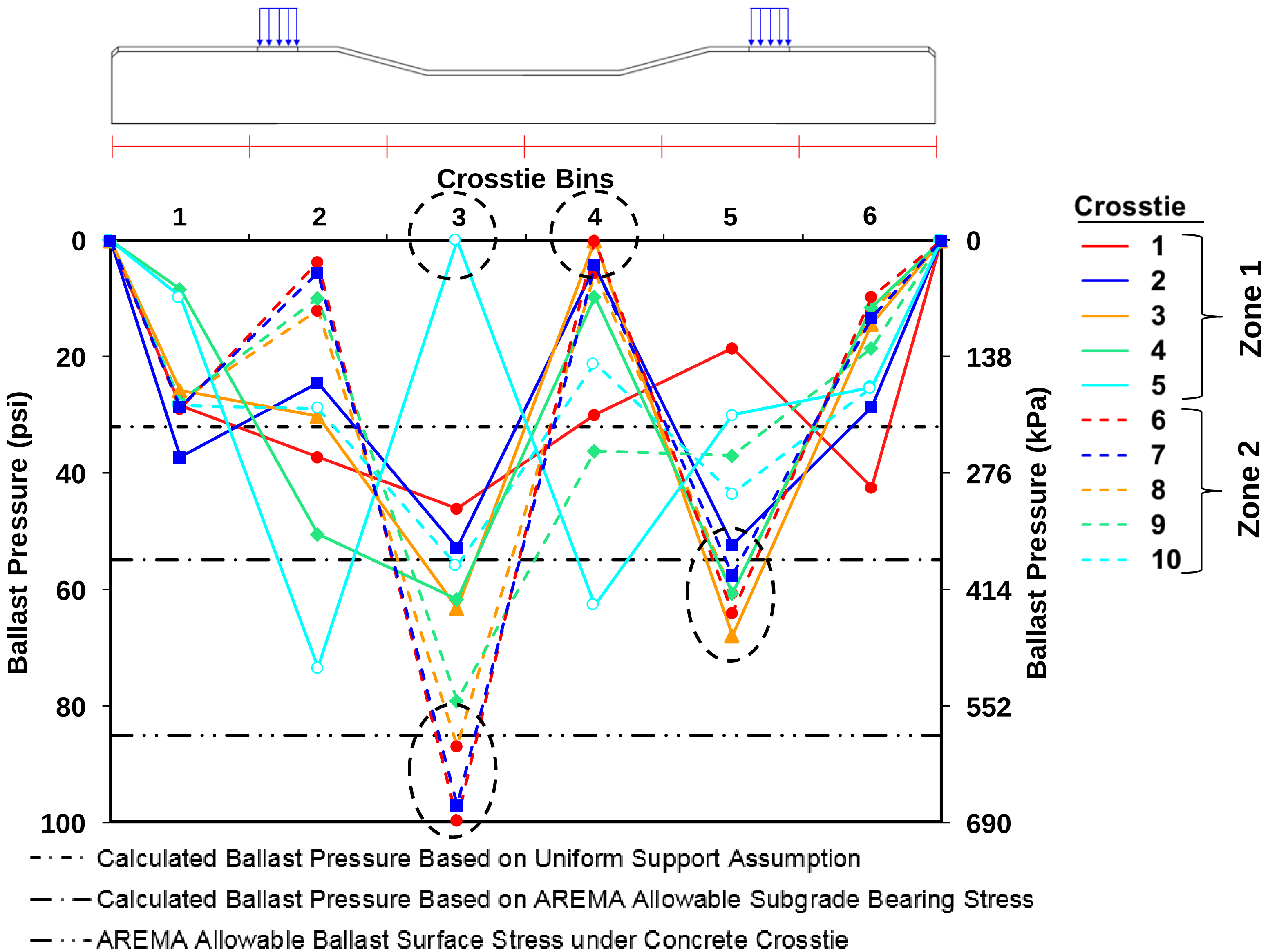


Ballast Pressure Index (BPI)

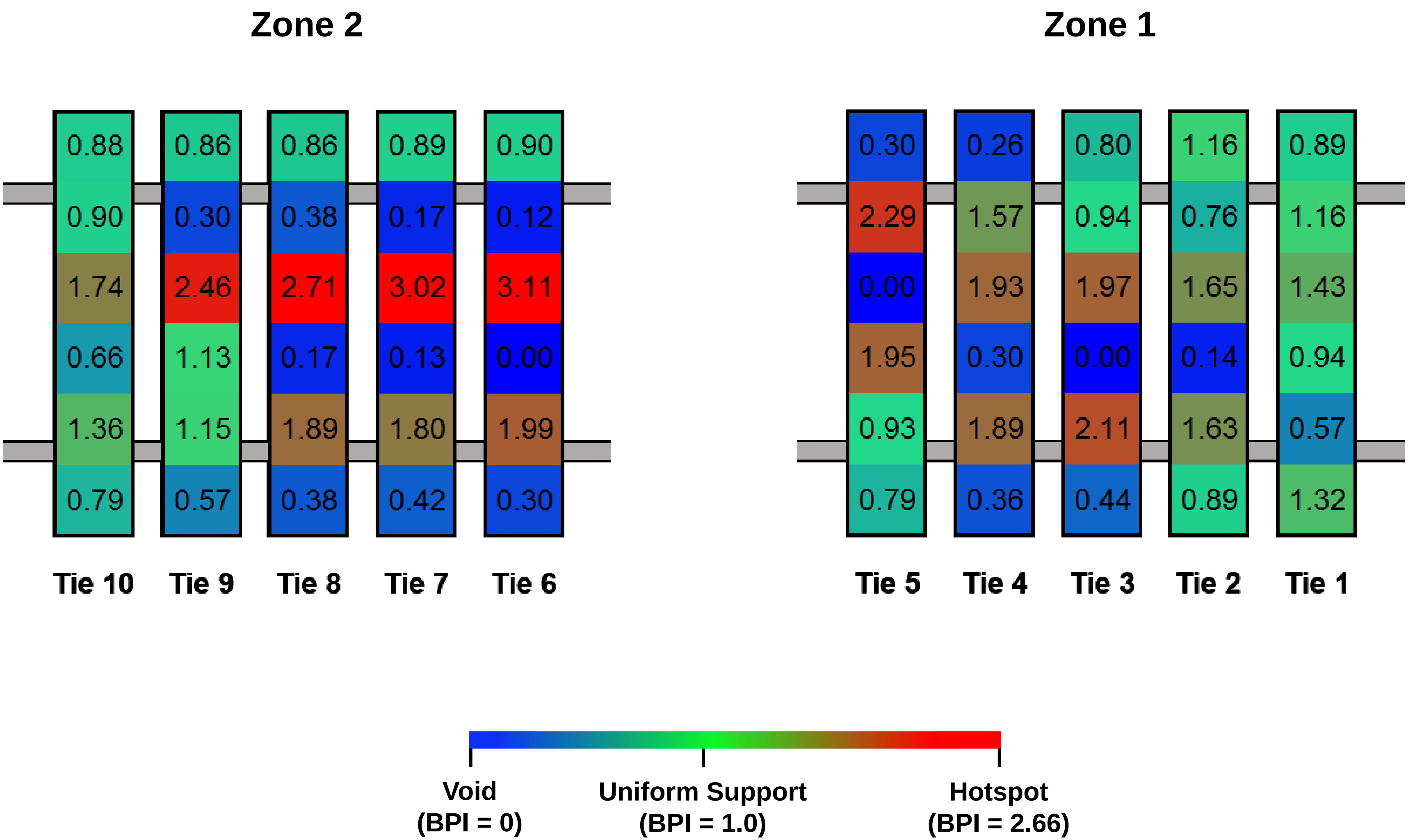
- A quantifiable value which estimates the uniformity of ballast distribution below a crosstie
- Ballast Pressure Index (BPI) is defined as the calculated ballast pressure, normalized to the theoretical, uniform ballast pressure within each bin

$$BPI = \frac{P_c}{P_u}$$

Where, BPI = Ballast Pressure Index
P_c = Pressure calculated from back-calculator
P_u = Pressure based on assumed uniform support

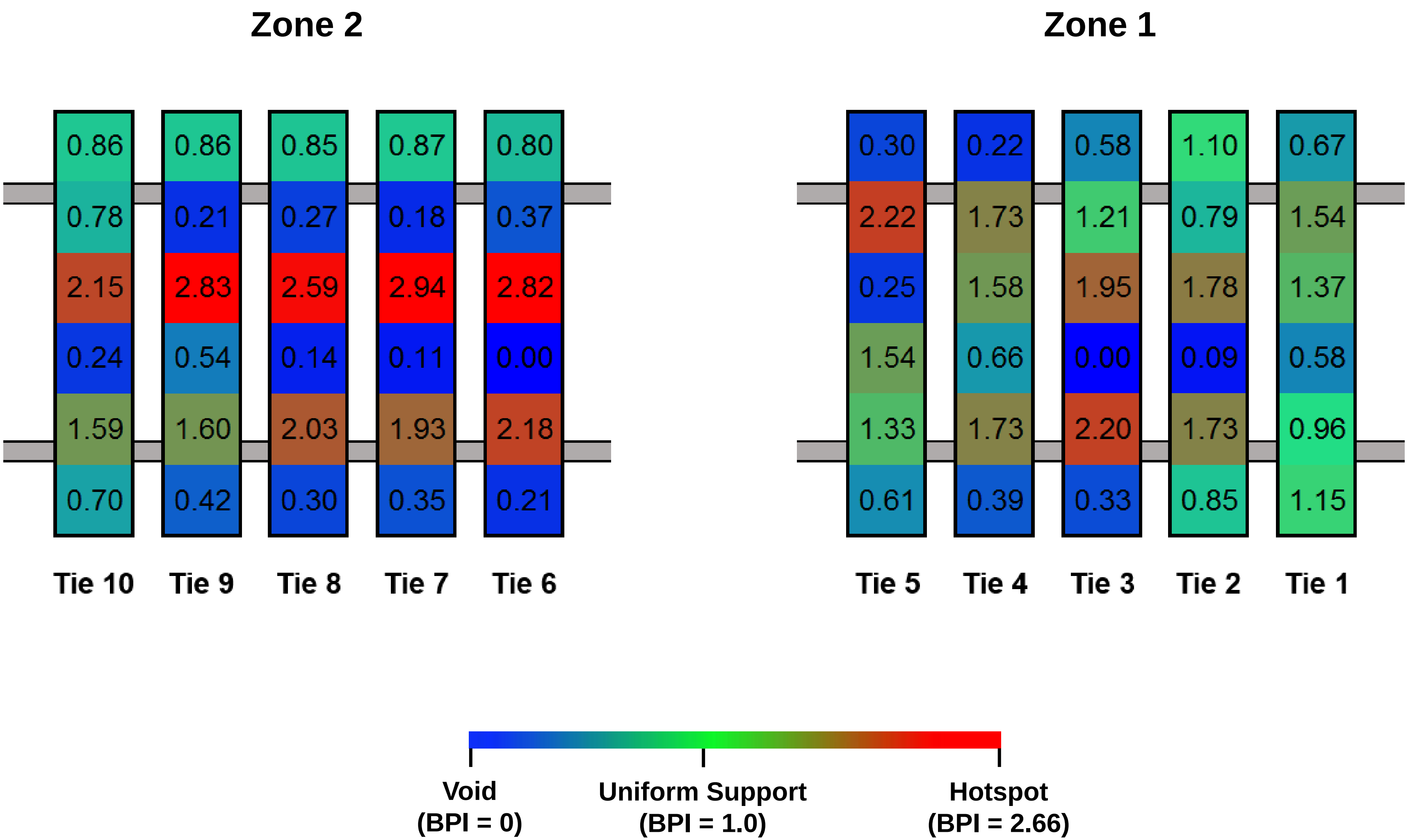
Ballast Pressure Index for Loaded Axle:

8:00 AM, 5/26/2015



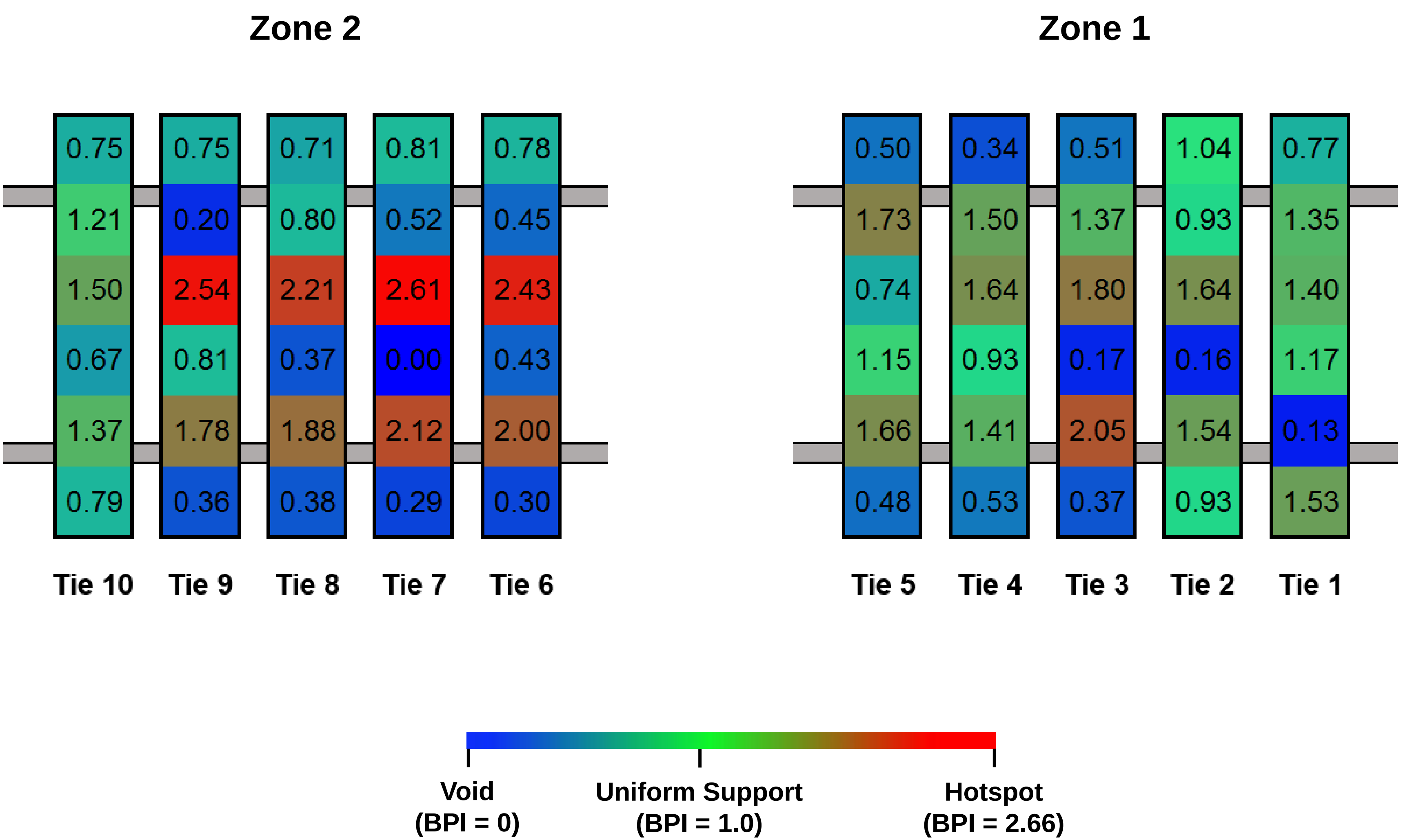
Ballast Pressure Index for Loaded Axle:

8:00 AM, 7/8/2015



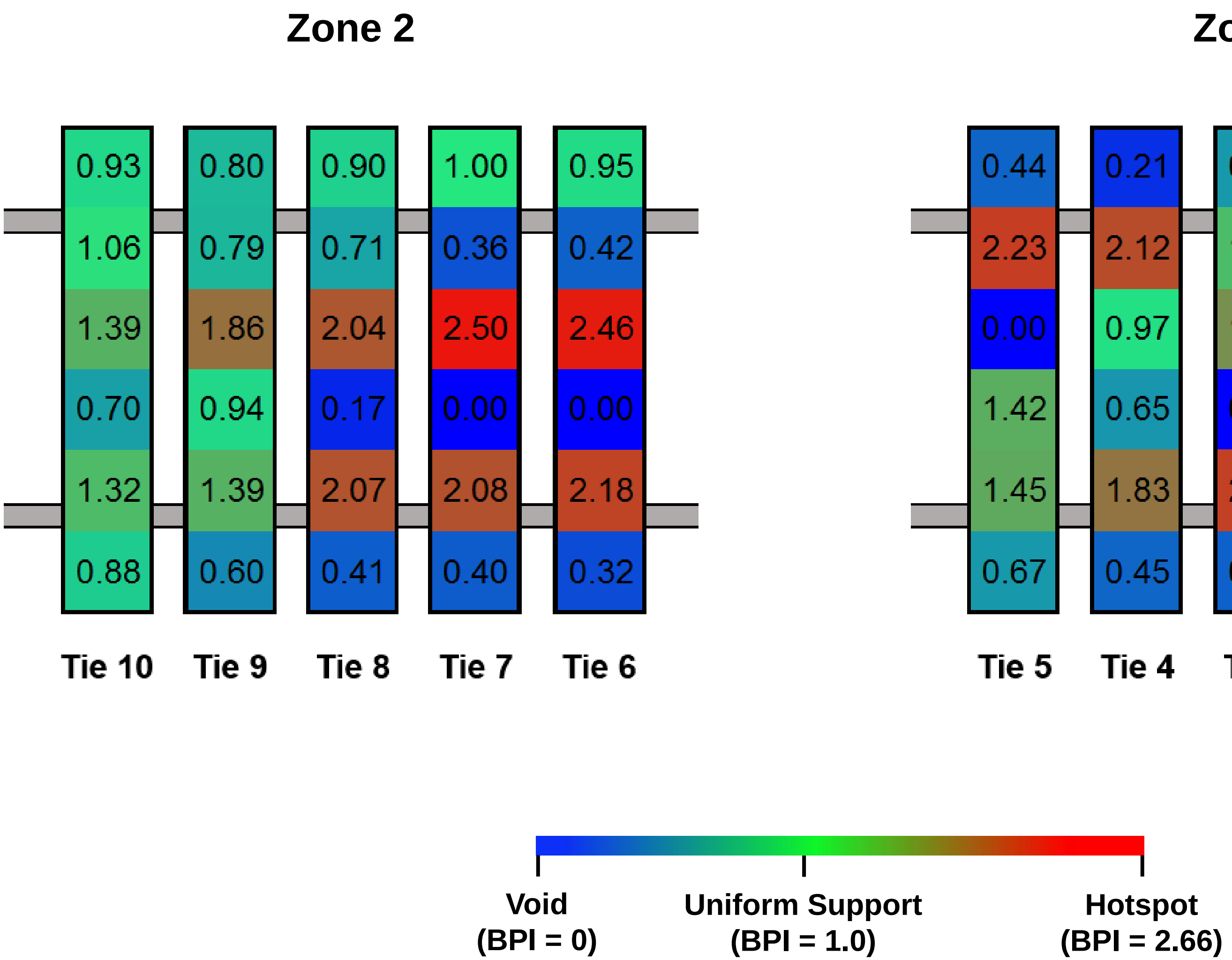
Ballast Pressure Index for Loaded Axle:

8:00 AM, 8/14/2015



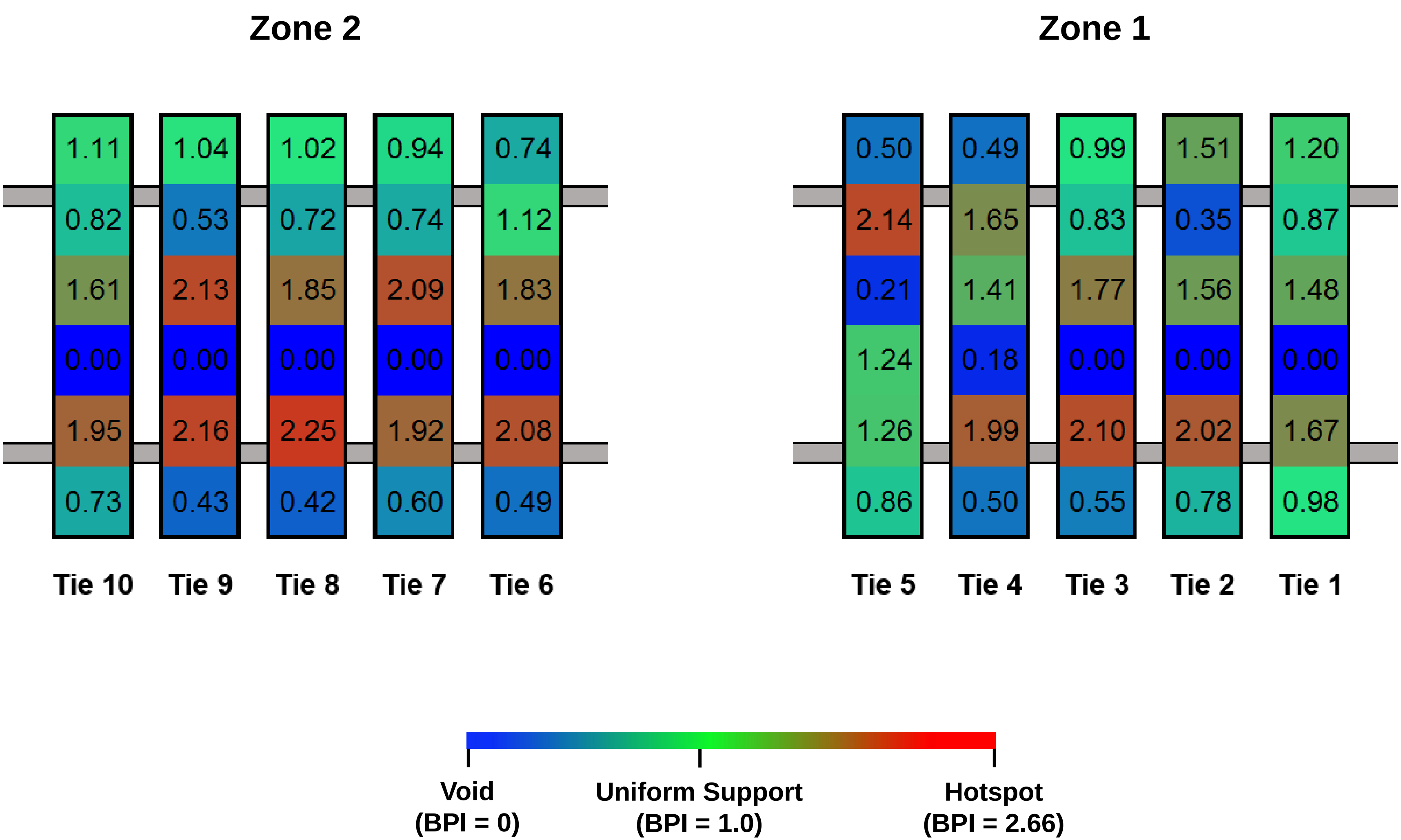
Ballast Pressure Index for Loaded Axle:

10:00 AM, 8/14/2015

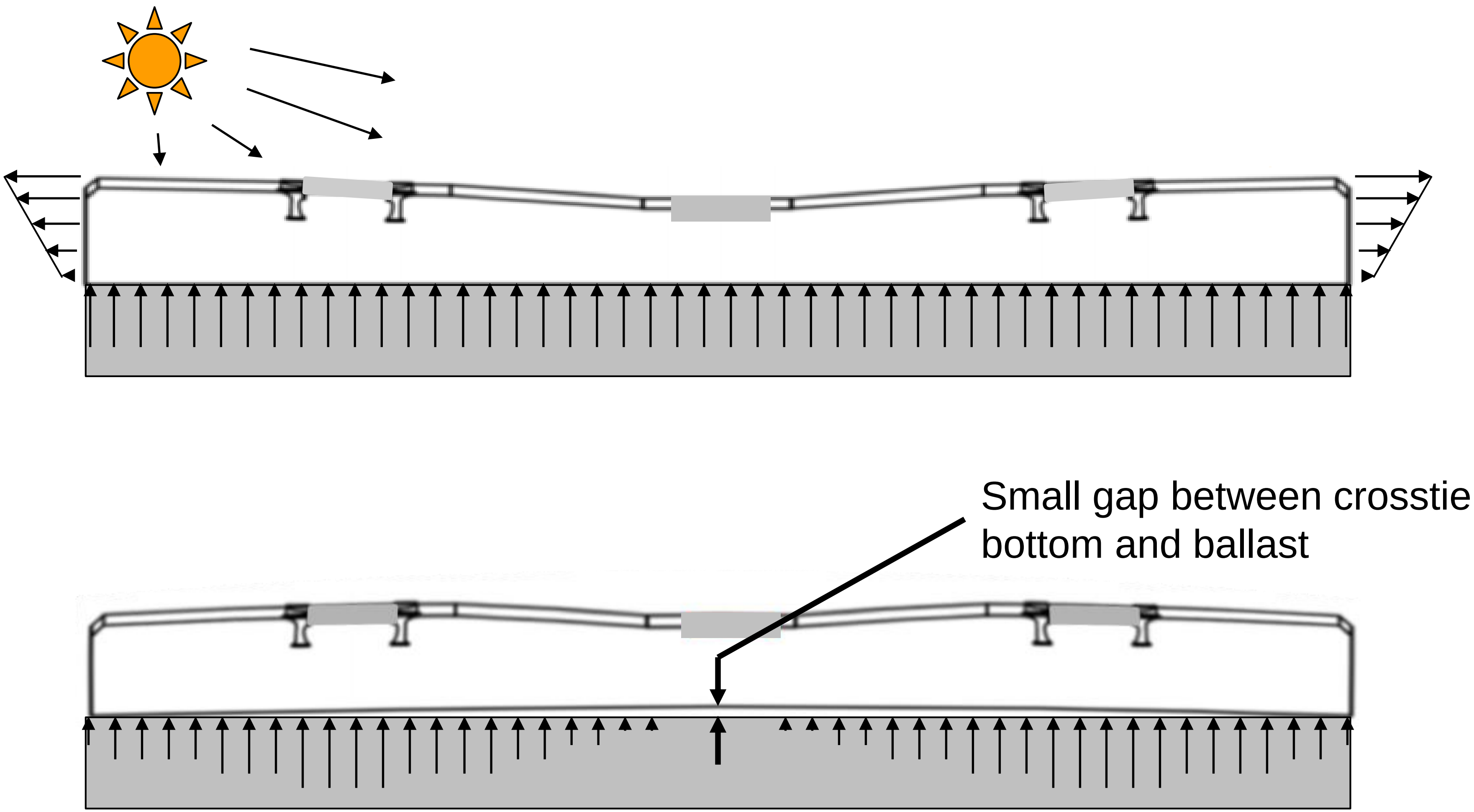


Ballast Pressure Index for Loaded Axle:

1:00 PM, 8/14/2015



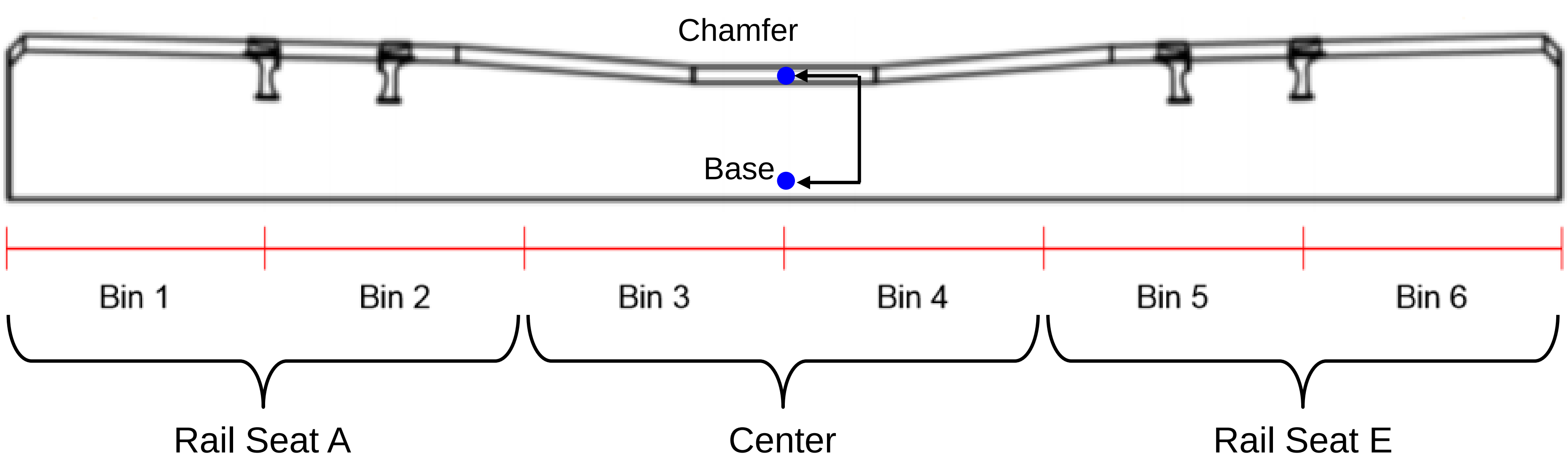
Crosstie Curling due to Temperature Gradient



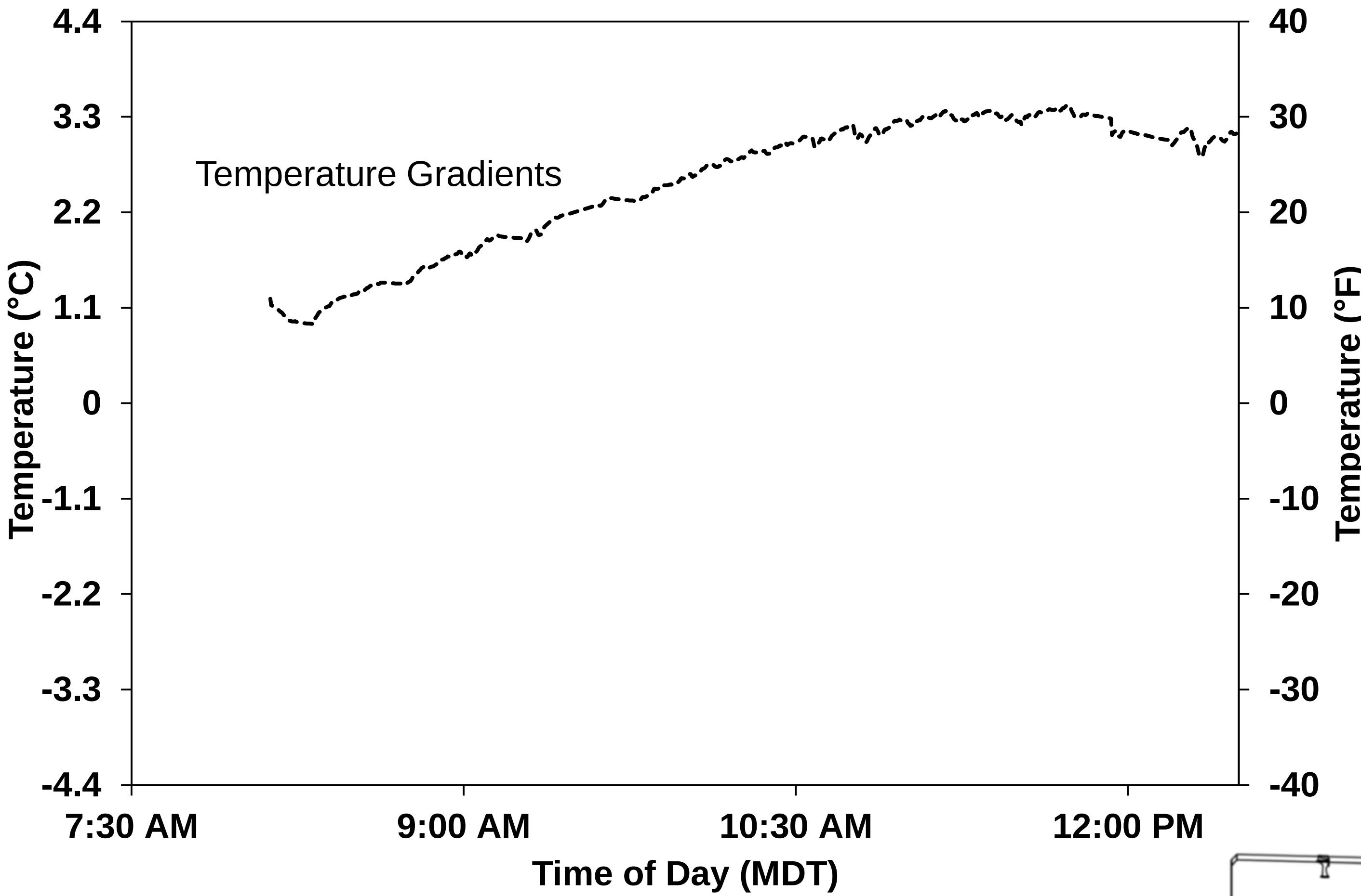
- Investigate the ballast redistribution using support condition back-calculator

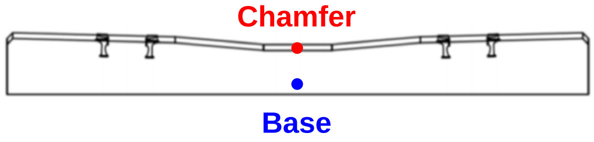
Curling Behavior Investigation

- 2 thermocouples installed on the crosstie:
  - Chamfer temperature
  - Ballast/Base temperature
- Crosstie divided into three regions: Rail Seat A, Center, and Rail Seat E

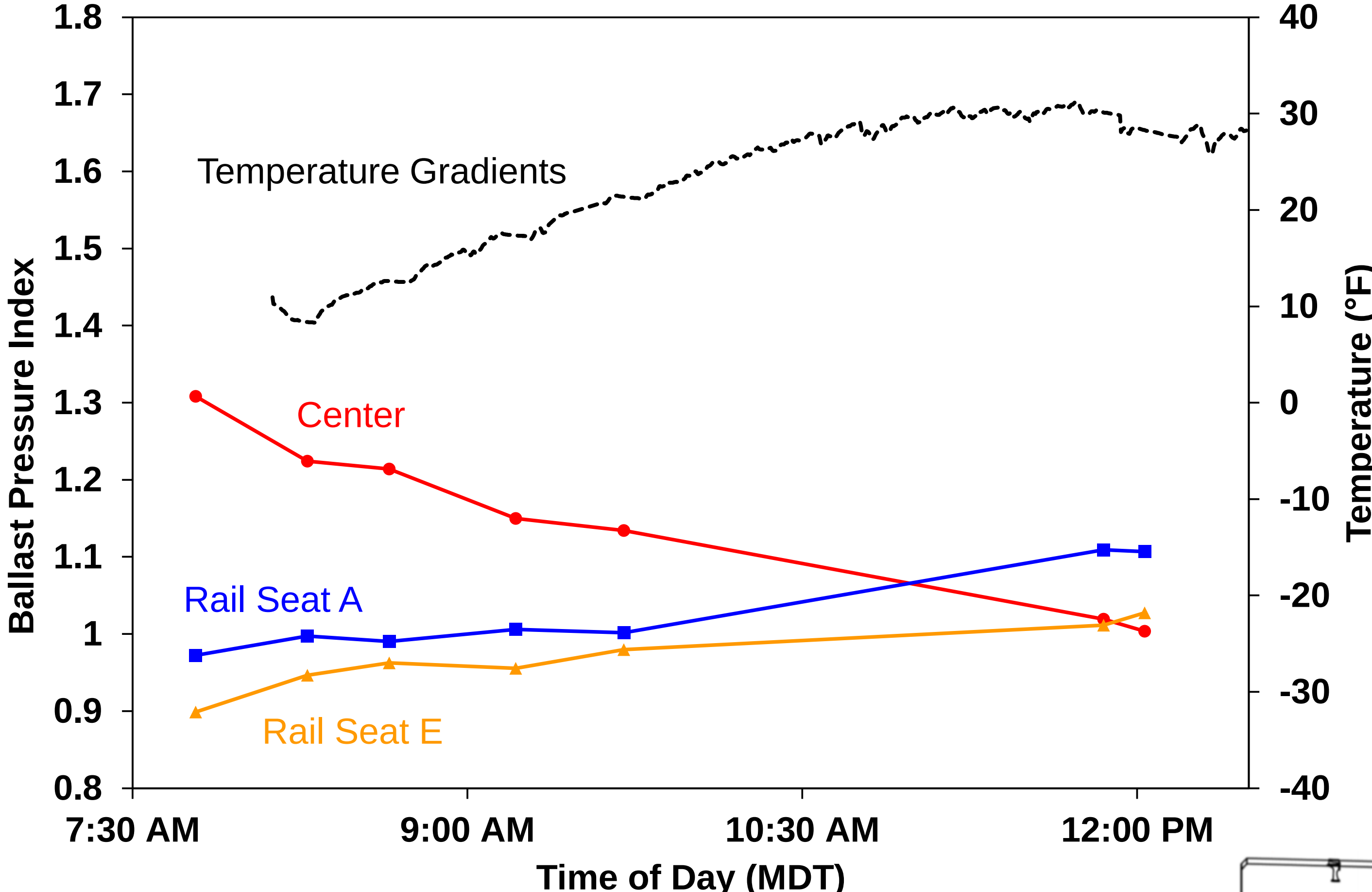


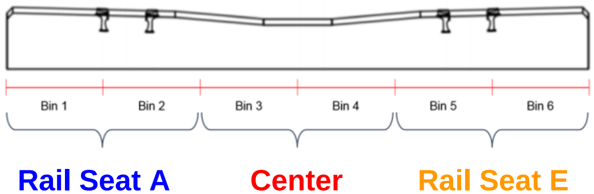
Measured Temperatures and Temperature Gradients:
Crosstie 3, Morning of 9/17/2015





Ballast Pressure Index and Temperature Gradients:
Crosstie 3, Morning of 9/17/2015





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Preliminary Conclusions

- Back-calculator was validated in the laboratory
- Back-calculator can provide quantitative assessment of ballast support conditions
- Ballast Pressure Index (BPI) can be used to estimate the uniformity and variability of ballast pressure
- Ballast pressures below crossties within the field test site were highly variable
  - Allowable subgrade bearing stress and ballast surface stress were exceeded at times, thus indicating the potential for accelerated ballast deterioration
  - Effect of temperature gradient on ballast pressure redistribution was quantified

Future Work

- Continue collecting field data to monitor the ballast behavior
  - Installed rail strain gauge to monitor wheel loads
  - Installed automated data collection system
  - Investigate effect of tonnage on ballast deterioration rate
- Compare ballast pressure distributions on different sites under different traffic
- Determine feasibility of quantifying support through crosstie displacement

Acknowledgements

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