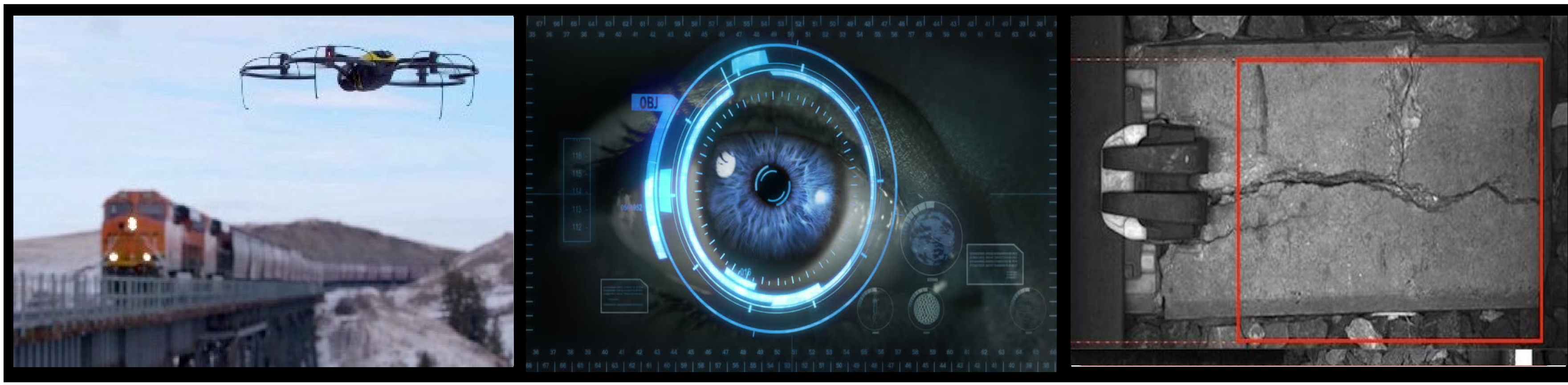
Railroad Infrastructure 4.0:

Development and Application of an Automatic Ballast Support Condition Assessment System



The 3rd Workshop on Railway Operation for Safety and Reliability

November 29, 2018

Yu Qian, Ph.D.

Assistant Professor

University of South Carolina

UNIVERSITY OF SOUTH CAROLINA

Biography

Current Position:

- Assistant Professor
  Department of Civil & Environmental Engineering
  University of South Carolina

Education:

- Ph.D., Civil Engineering
  University of Illinois at Urbana-Champaign (2014)
- M.S., Theoretical and Applied Mechanics
  University of Illinois at Urbana-Champaign (2013)
- M.S.(Honor), Civil Engineering
  University of Kansas (2009)
- B.S., Civil Engineering
  Huazhong University of Science & Technology (2008)
- B.S., Construction Management
  Wuhan University (2008)

The State of South Carolina

South Carolina: One of the 13 Original US Colonies.

(http://en.wikipedia.org/wiki/Hong Kong)

(https://en.wikipedia.org/wiki/Richland_County,_South_Carolina)

The University of South Carolina

The **University of South Carolina** (established in 1801) is a public university in Columbia, South Carolina, United States, with seven satellite campuses. Its main campus covers over 359 acres (145 ha) in downtown Columbia.

Outline

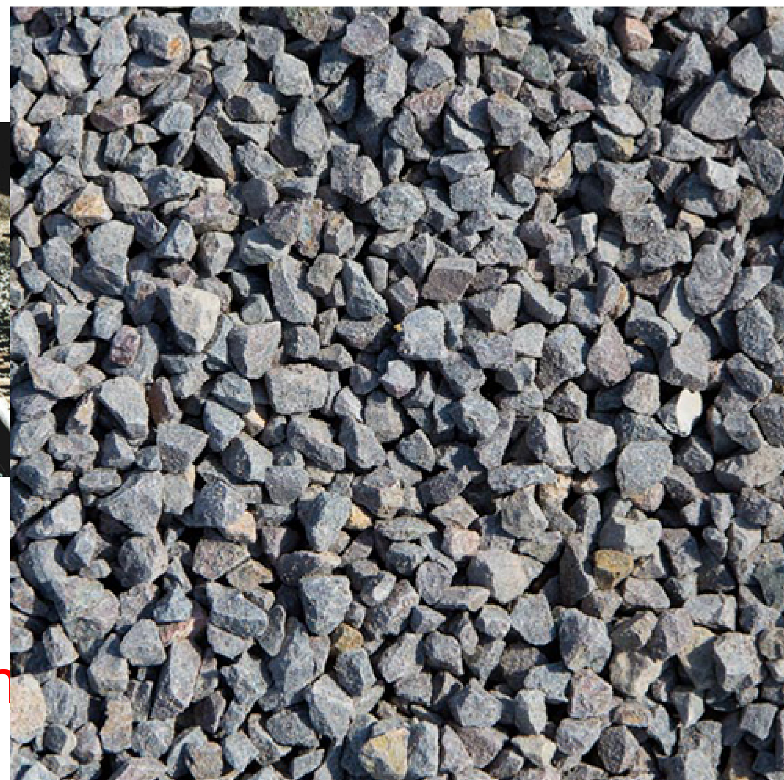
- Motivation
- Approach
- Laboratory validation
- Field Application
- Future Development

Railroad Ballast

- Typically “uniformly” graded unbound aggregates
- Similar to highway base course
- **NOT a continuous medium**

(FRA)

Lateral stability

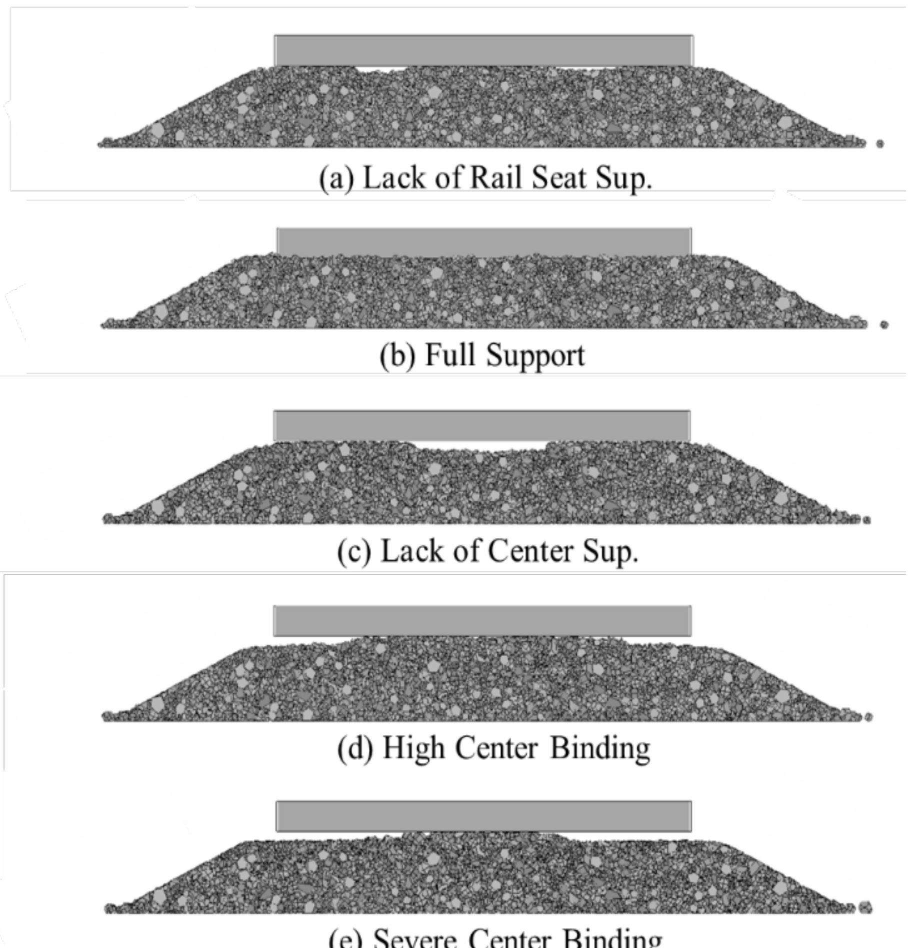


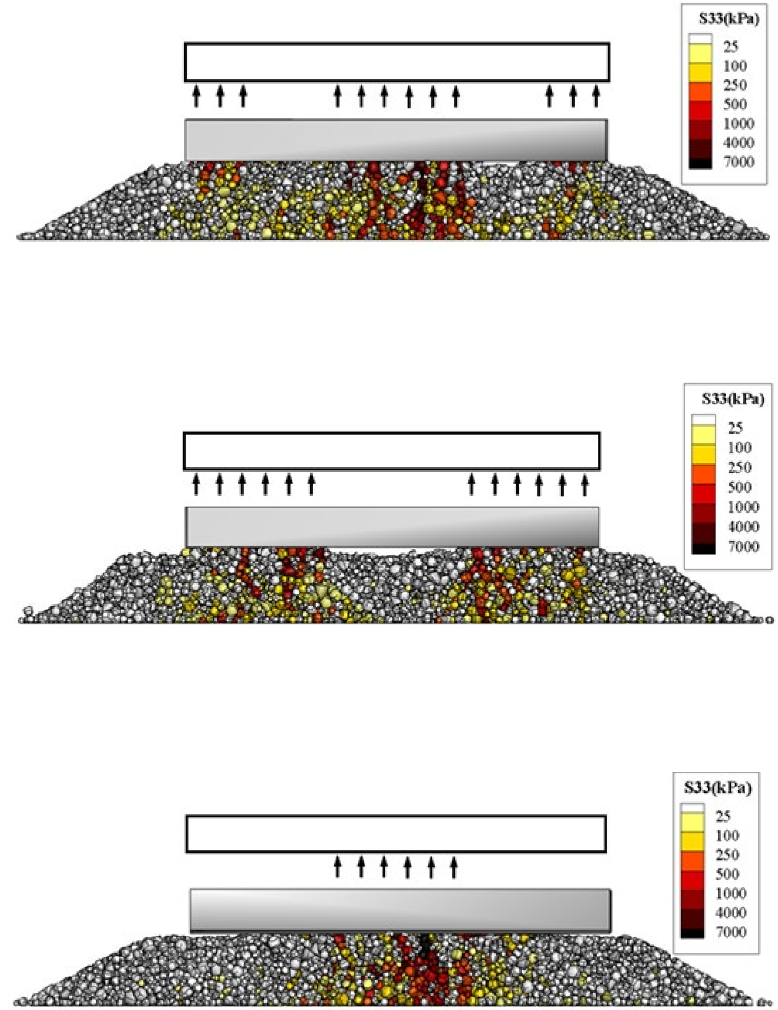
(KTX)

Ballast flying

Th niform

Ballast Support Issue





(Courtesy of Bin Feng & Wenting Hou)

Ballast Support Issue

How to detect different support conditions in the field?

Ballast Support Issue

How to reasonably detect different support conditions in the field?

Ballast Support Condition Detection

- **Problems**: 1) Destructive Test

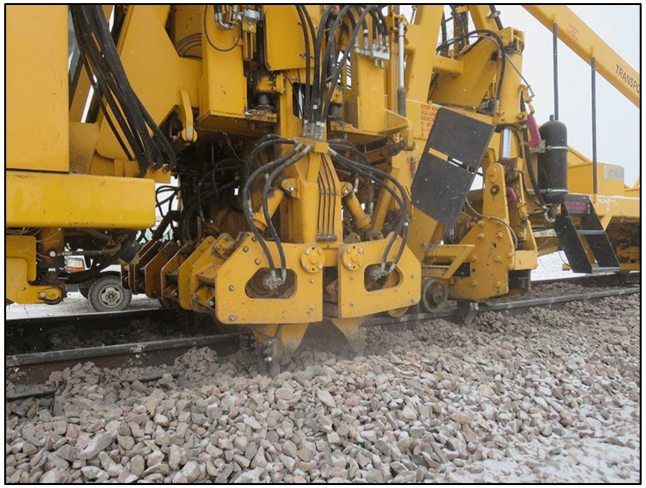
  2) High Failure Rate

  3) Unreliable Results

  4) Expensive in terms of time and labor

Research Objectives

- **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

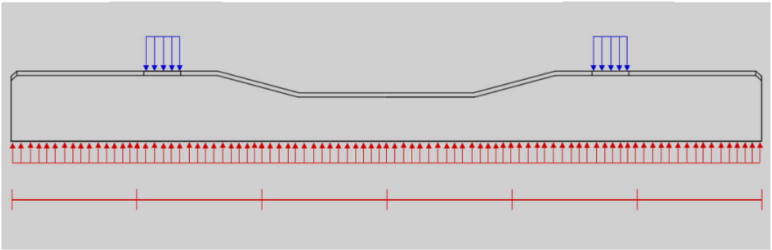


Support Condition Back-Calculator Facts

2-D Crosstie Bending Model

Optimization Algorithm

Laboratory Validation



2-D Crosstie Bending Model

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  - Each bin consists a percentage of total reaction force
- 9 model inputs:
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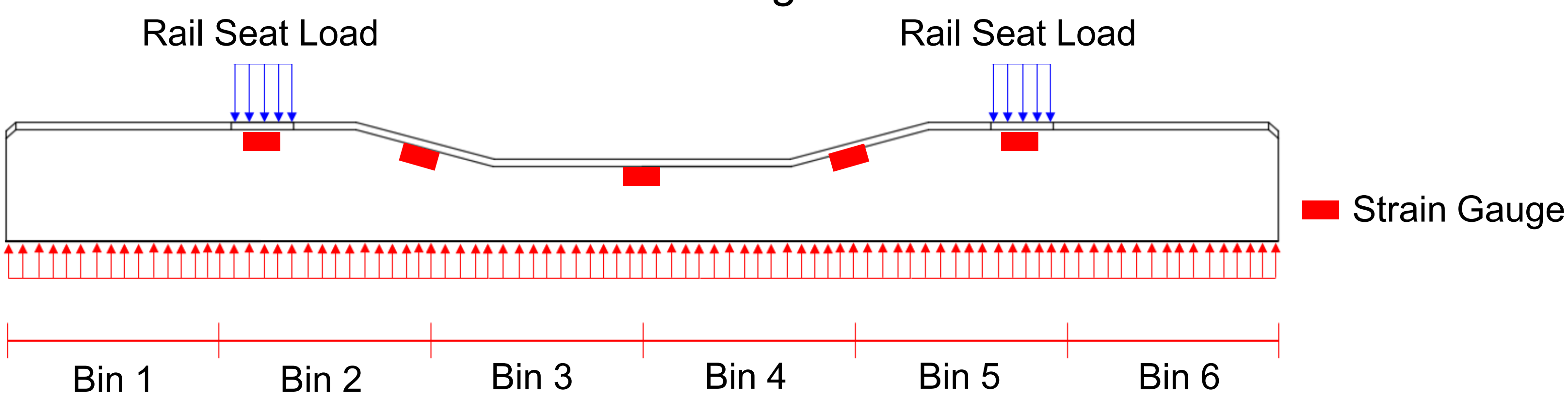

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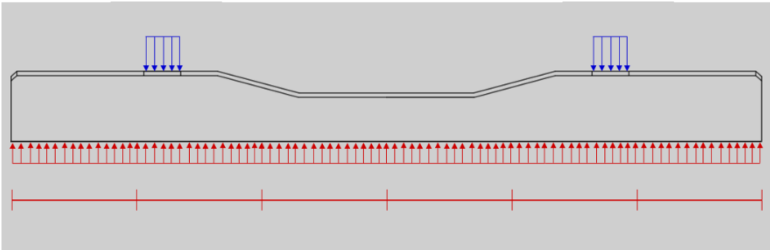
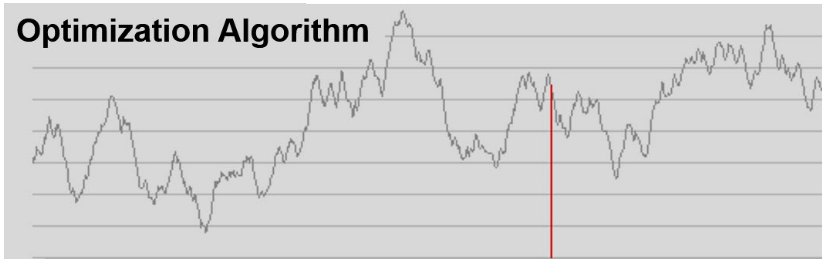


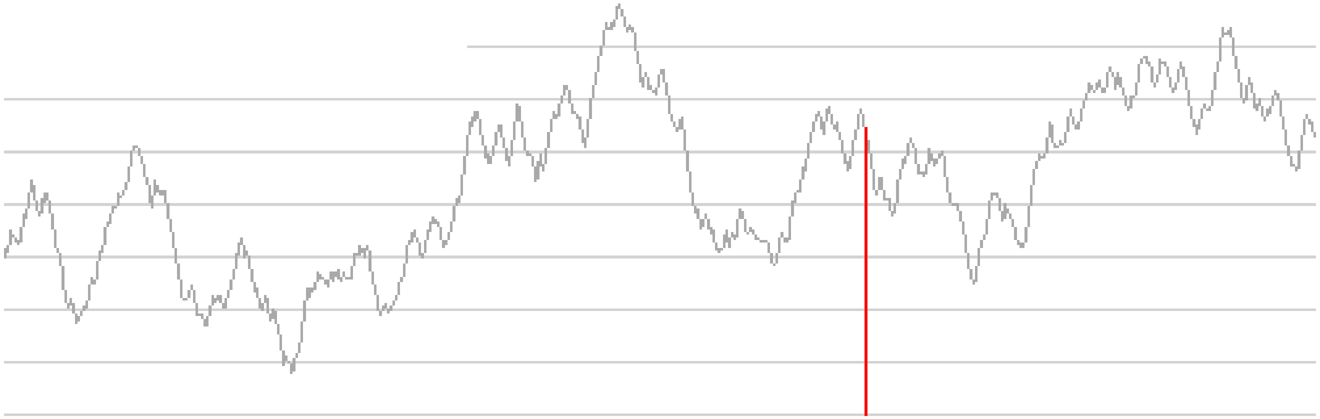
Optimization Algorithm



Laboratory Validation

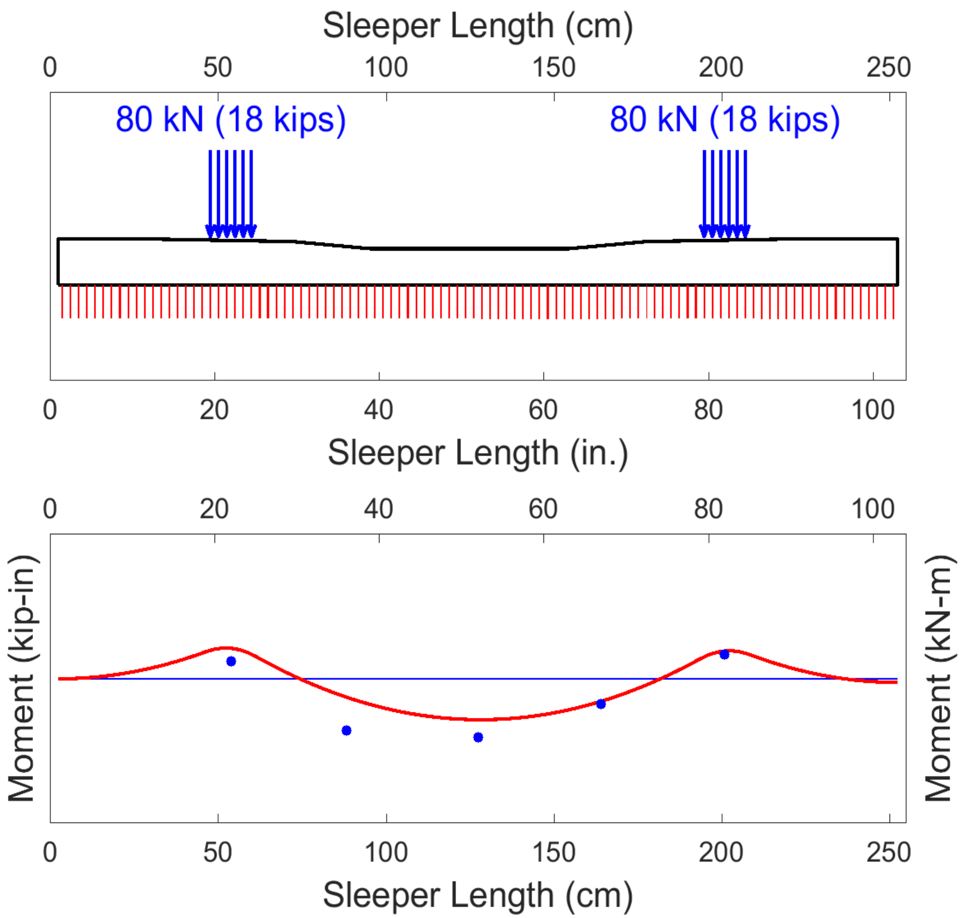
Optimization Algorithm: *Simulated Annealing*

- **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



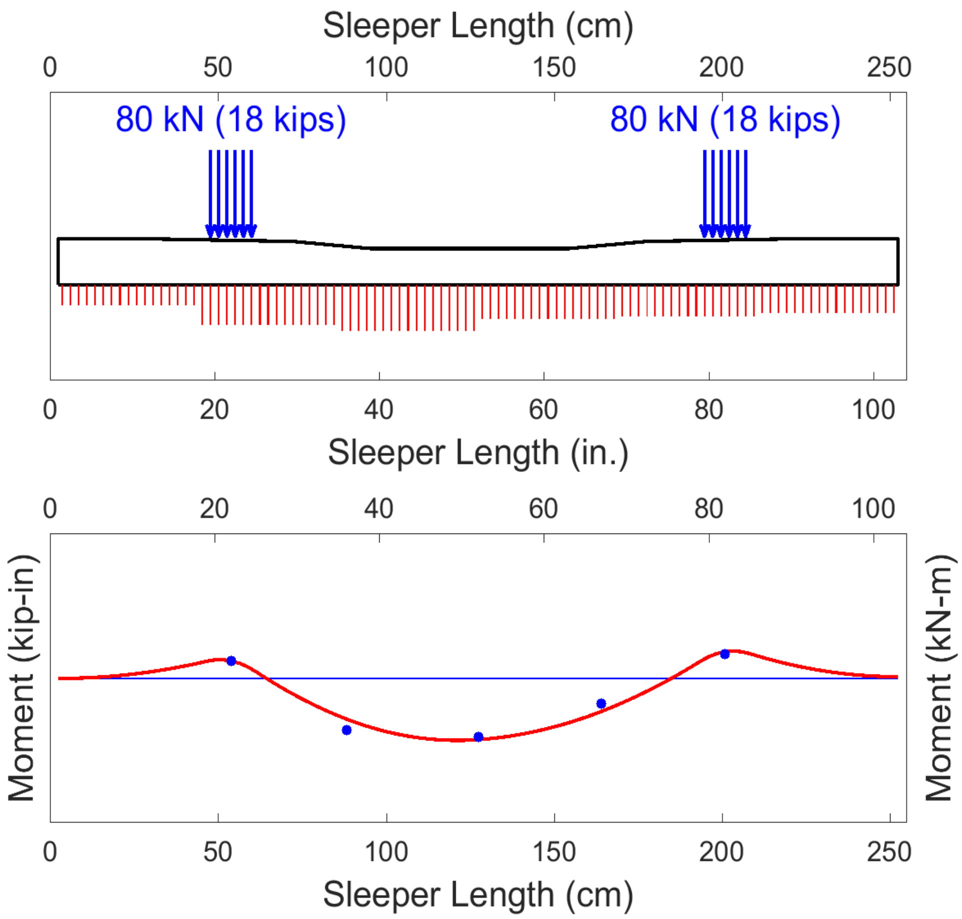
Wikipedia: Simulated Annealing

2-D Crosstie Bending Model



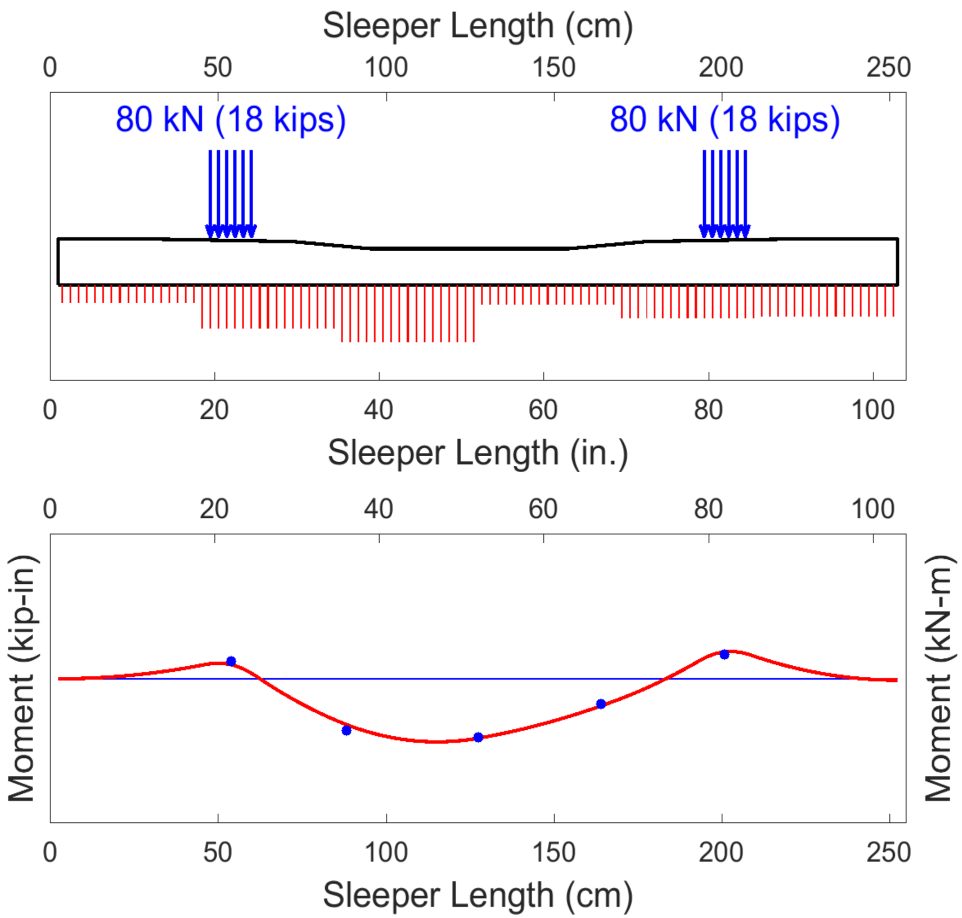
Initial condition, iteration step 0

2-D Crosstie Bending Model



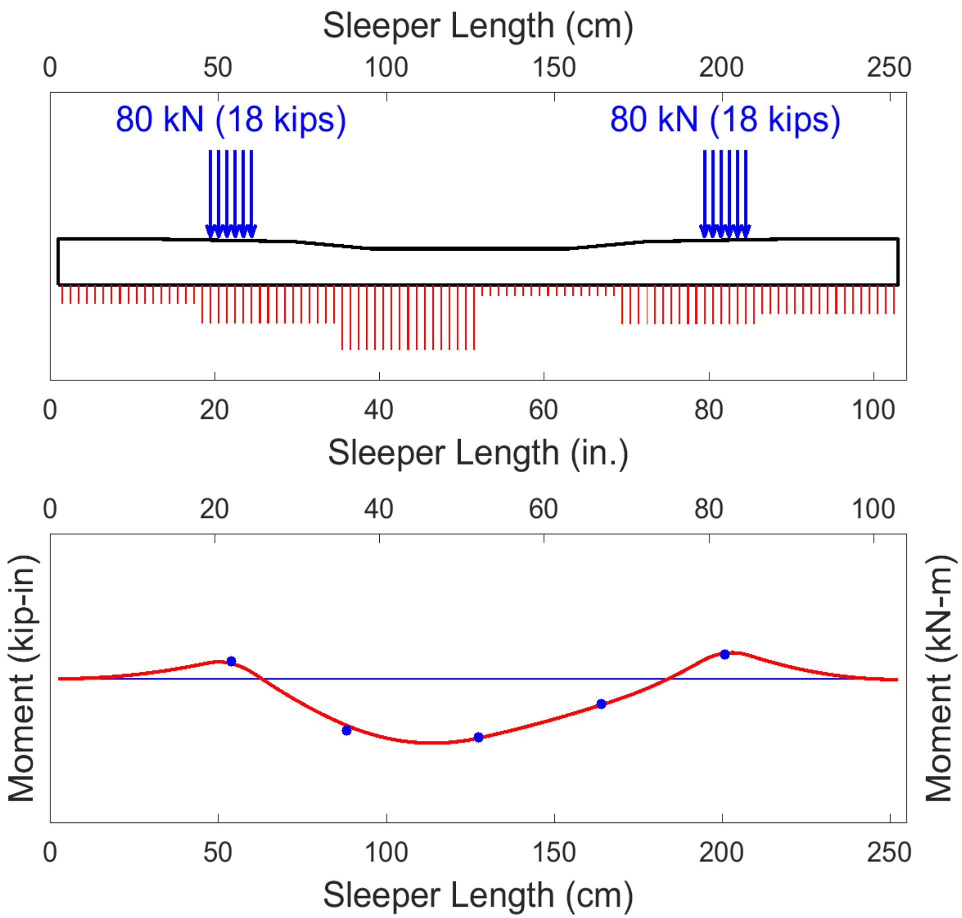
Initial condition, iteration step 100

2-D Crosstie Bending Model



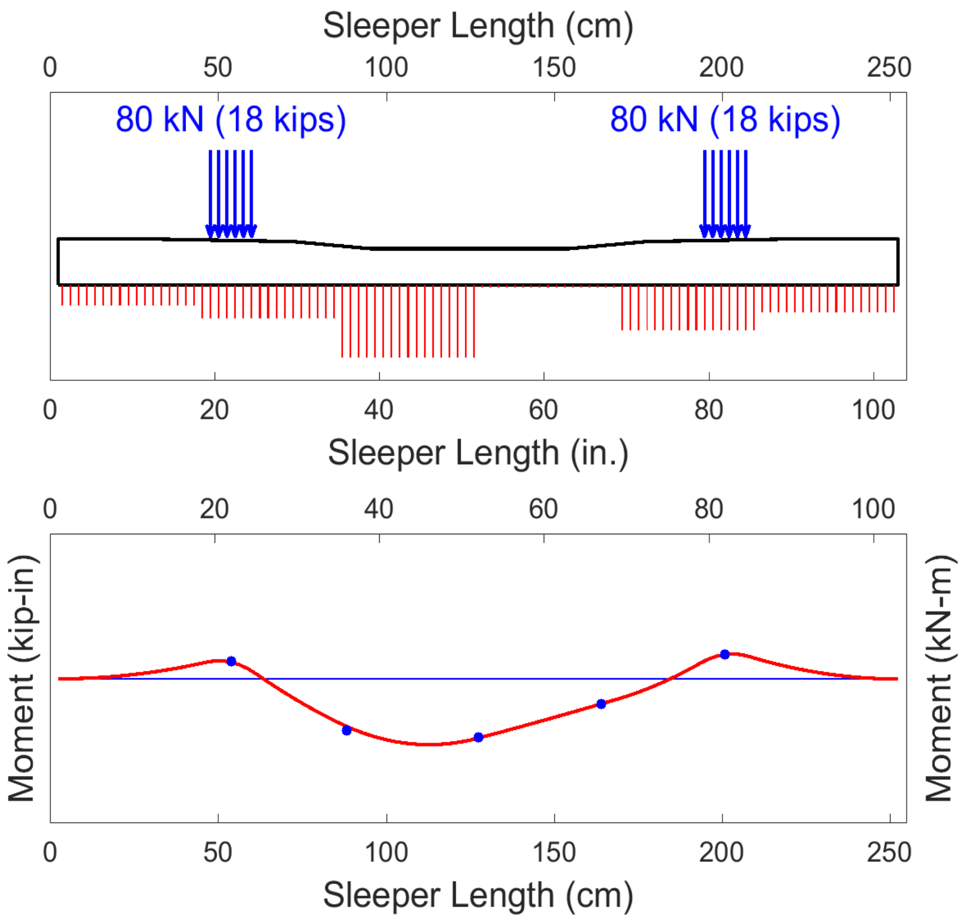
Initial condition, iteration step 200

2-D Crosstie Bending Model



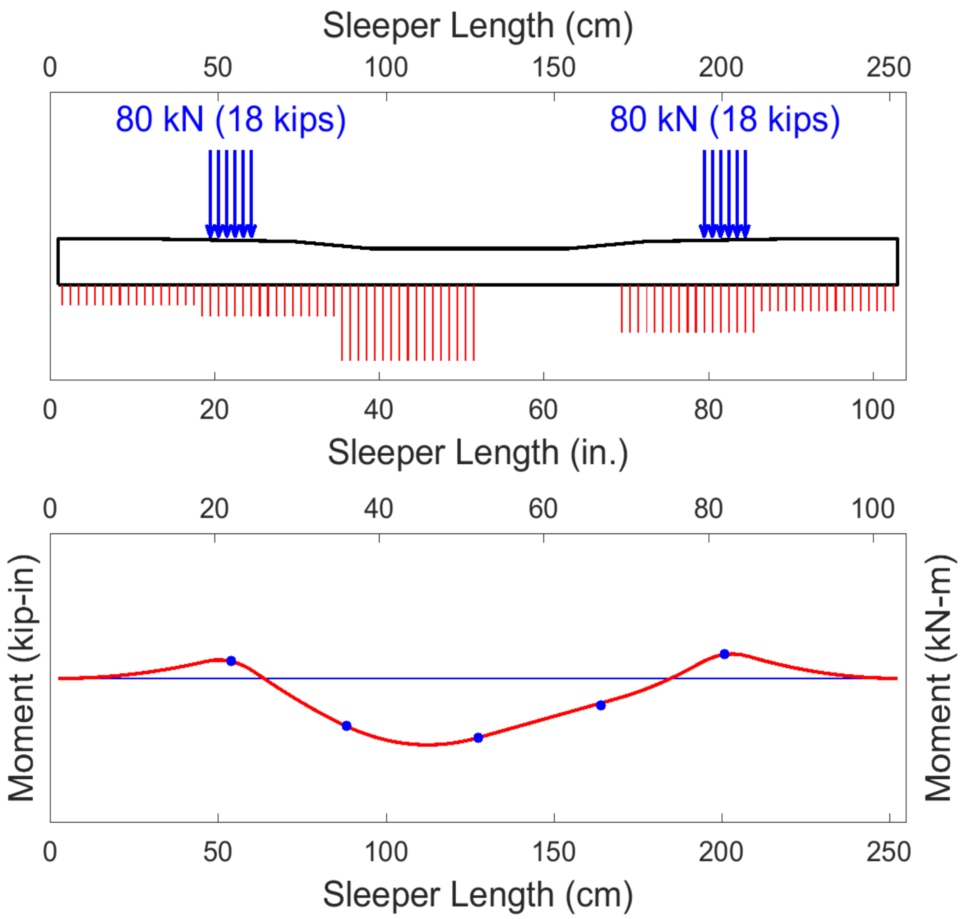
Initial condition, iteration step 300

2-D Crosstie Bending Model



Initial condition, iteration step 400

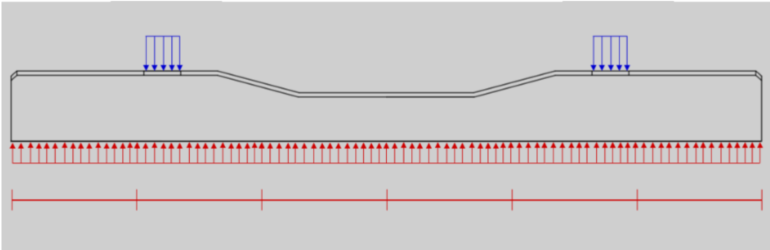
2-D Crosstie Bending Model



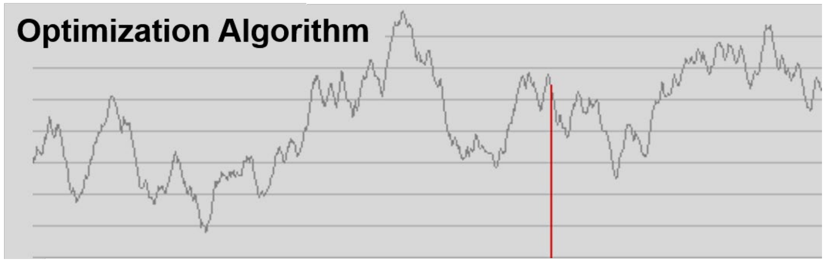
Initial condition, iteration step 550

Support Condition Back-Calculator Facts

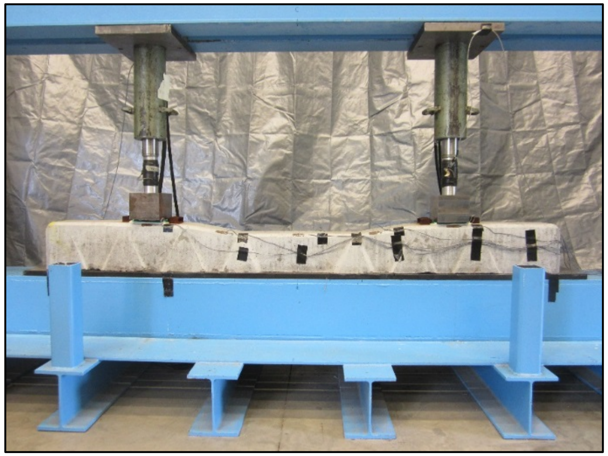
2-D Crosstie Bending Model



Optimization Algorithm

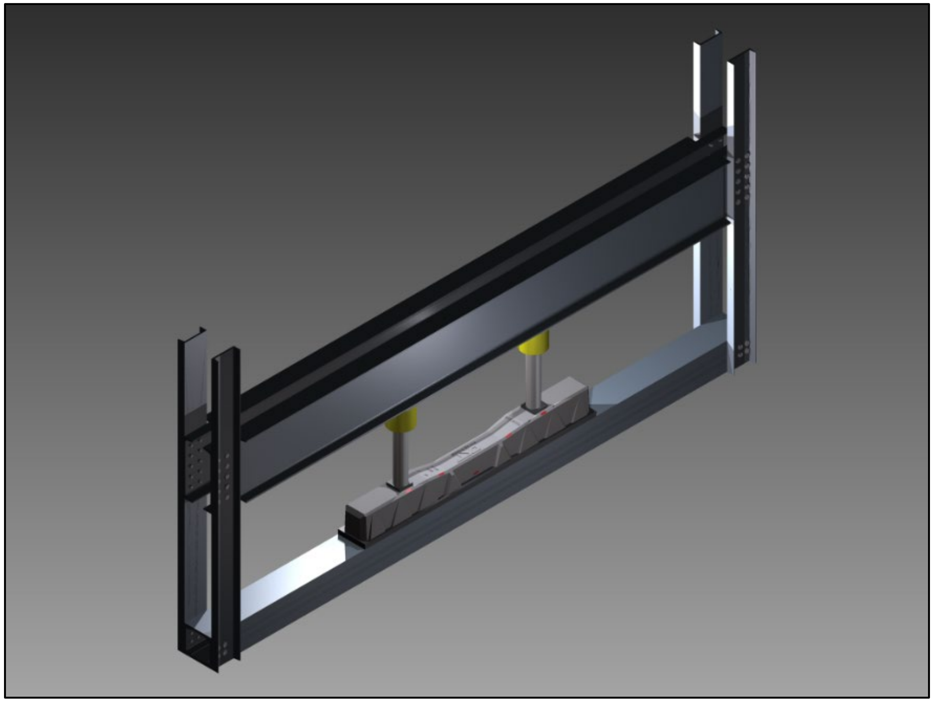


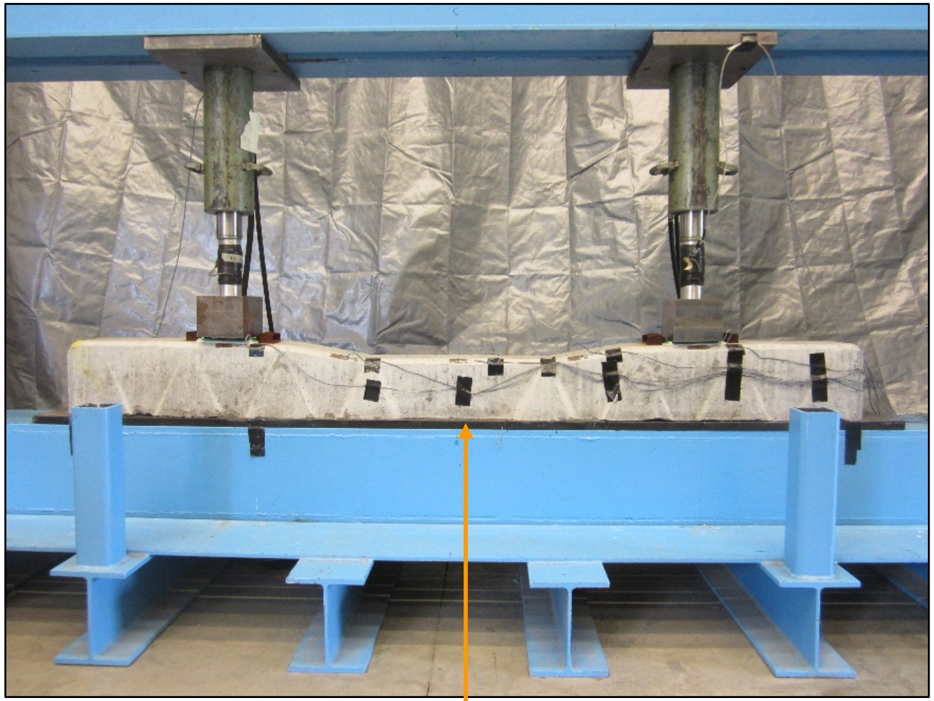
Laboratory Validation



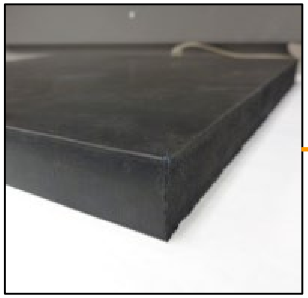
Laboratory Experimentation Equipment

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



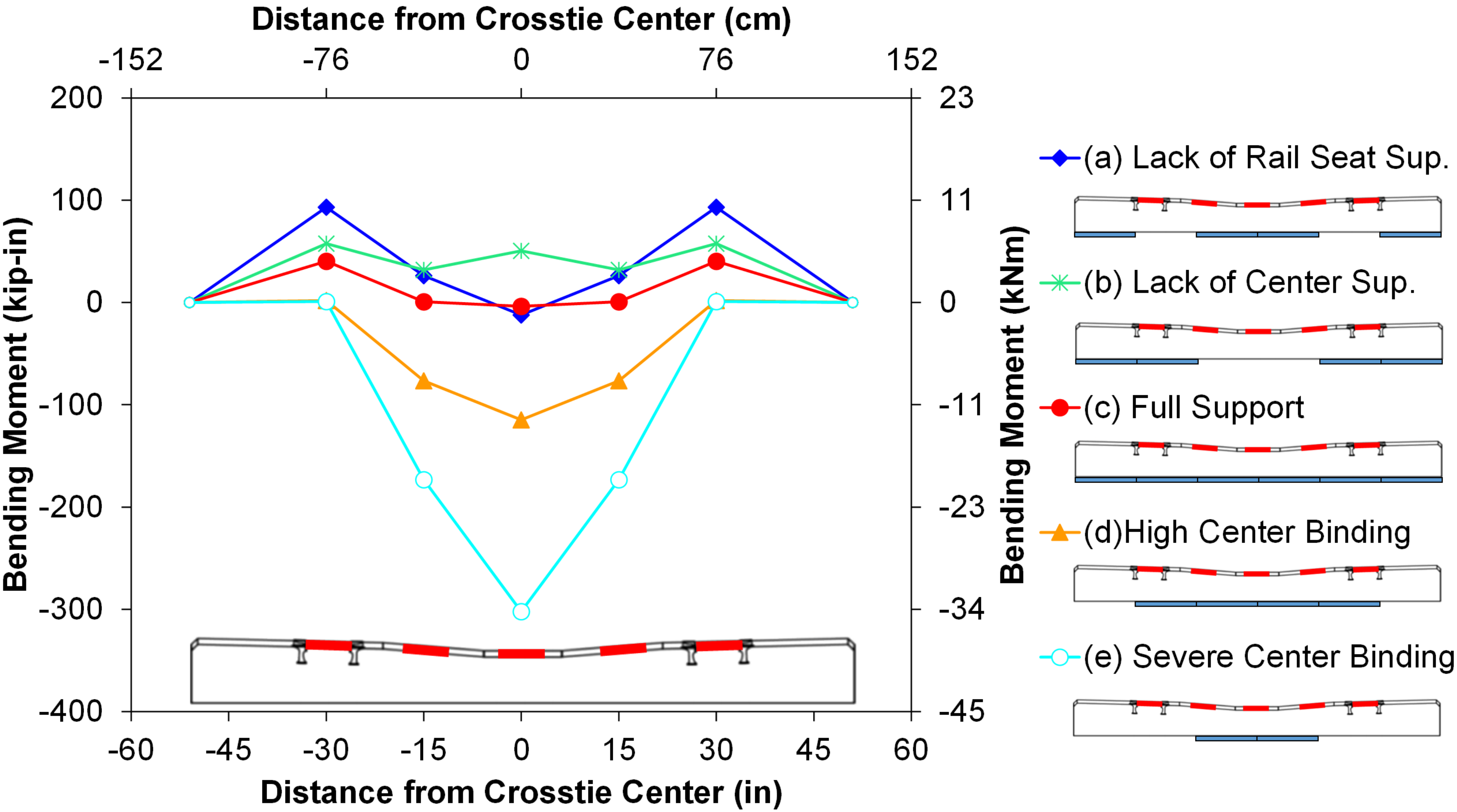


- Supporting rubber pads



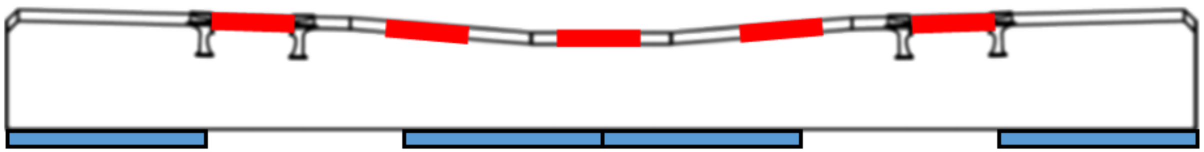
Influence of Support Condition on Crosstie Bending Moments

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

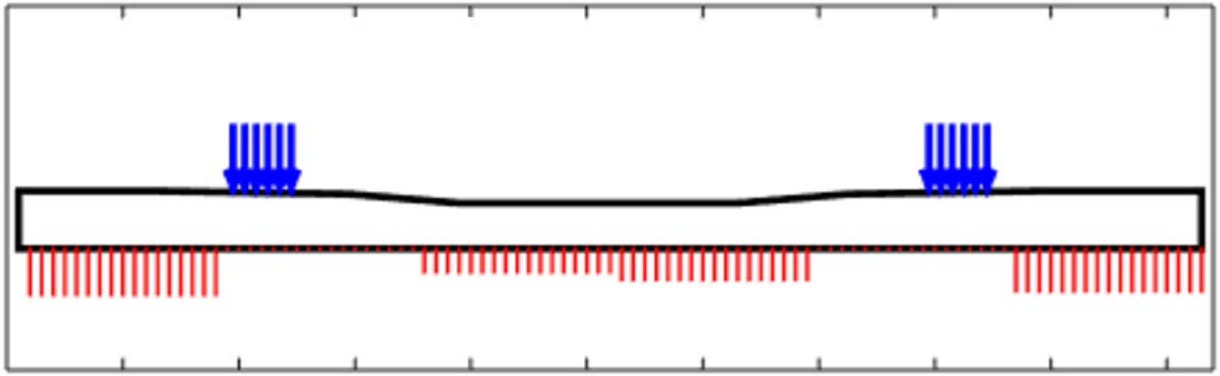


Lab Setup and Back-Calculator Result:
Lack of Rail Seat Support

Lab Setup

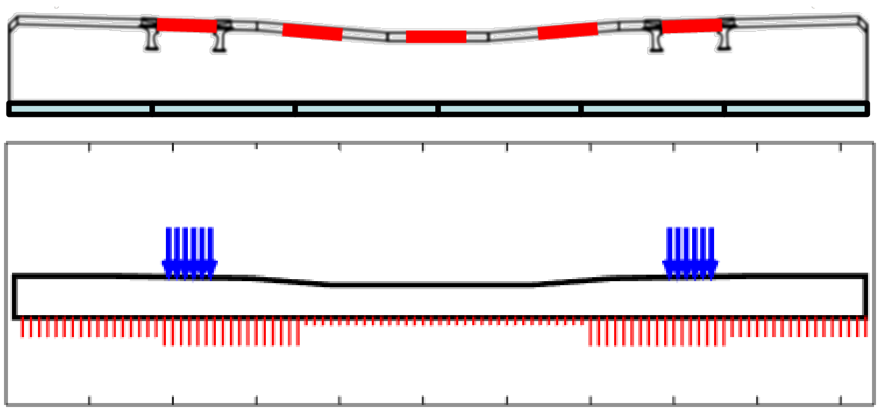


Back-Calculator Result

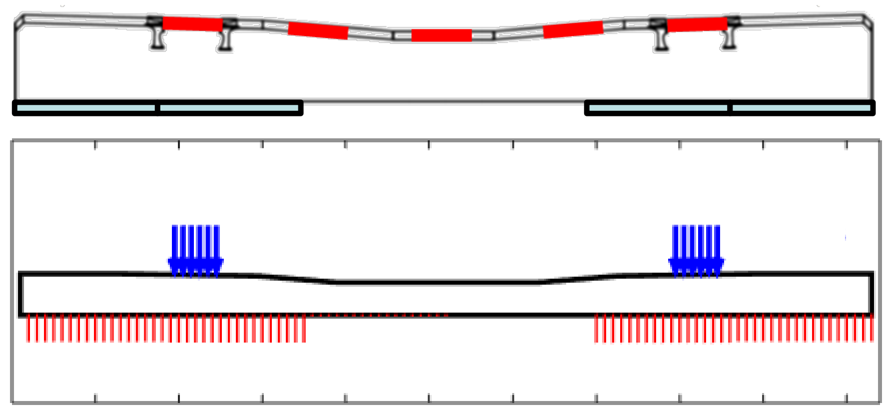


Comparison between Lab Support Conditions and Back-Calculator Results

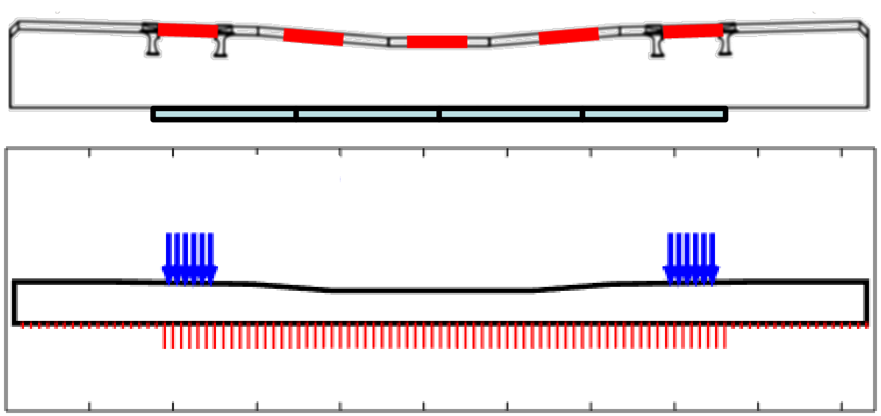
Full Support



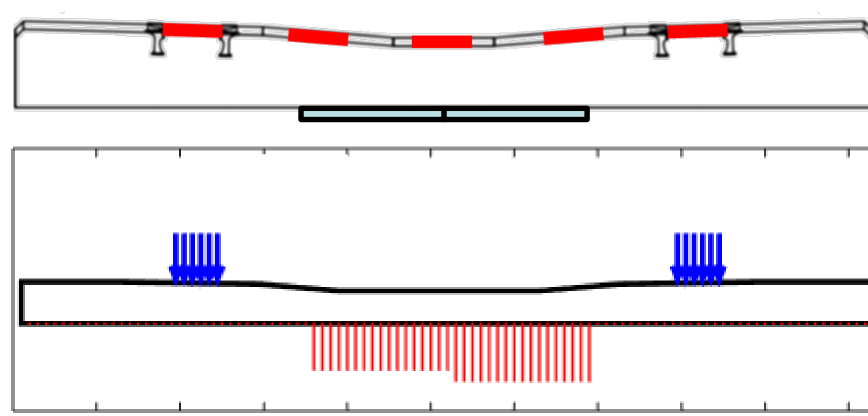
Lack of Center Support



Light Center Binding

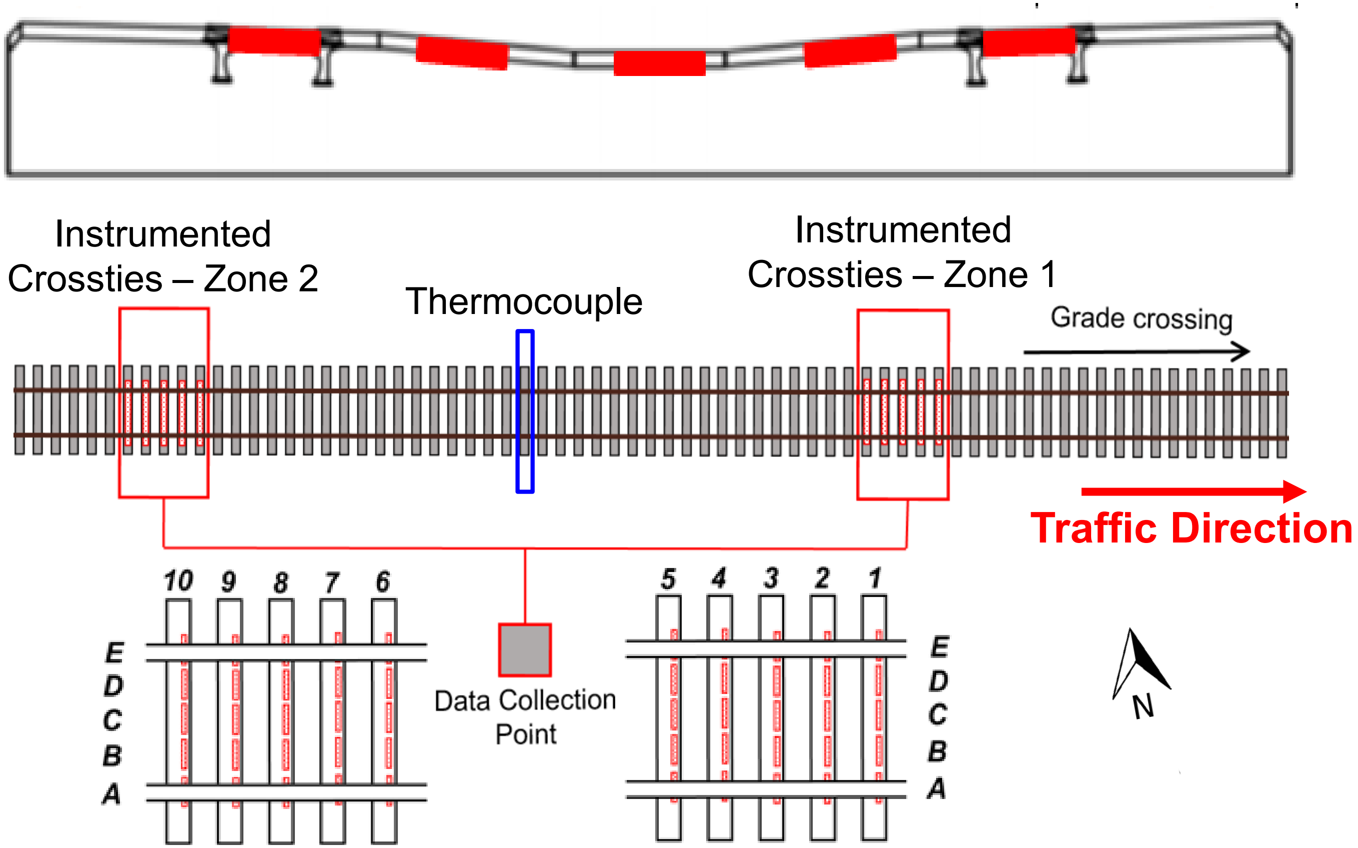


High Center Binding



Field instrumentation Site Layout

- 50 surface strain gauges installed on 10 crossties



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

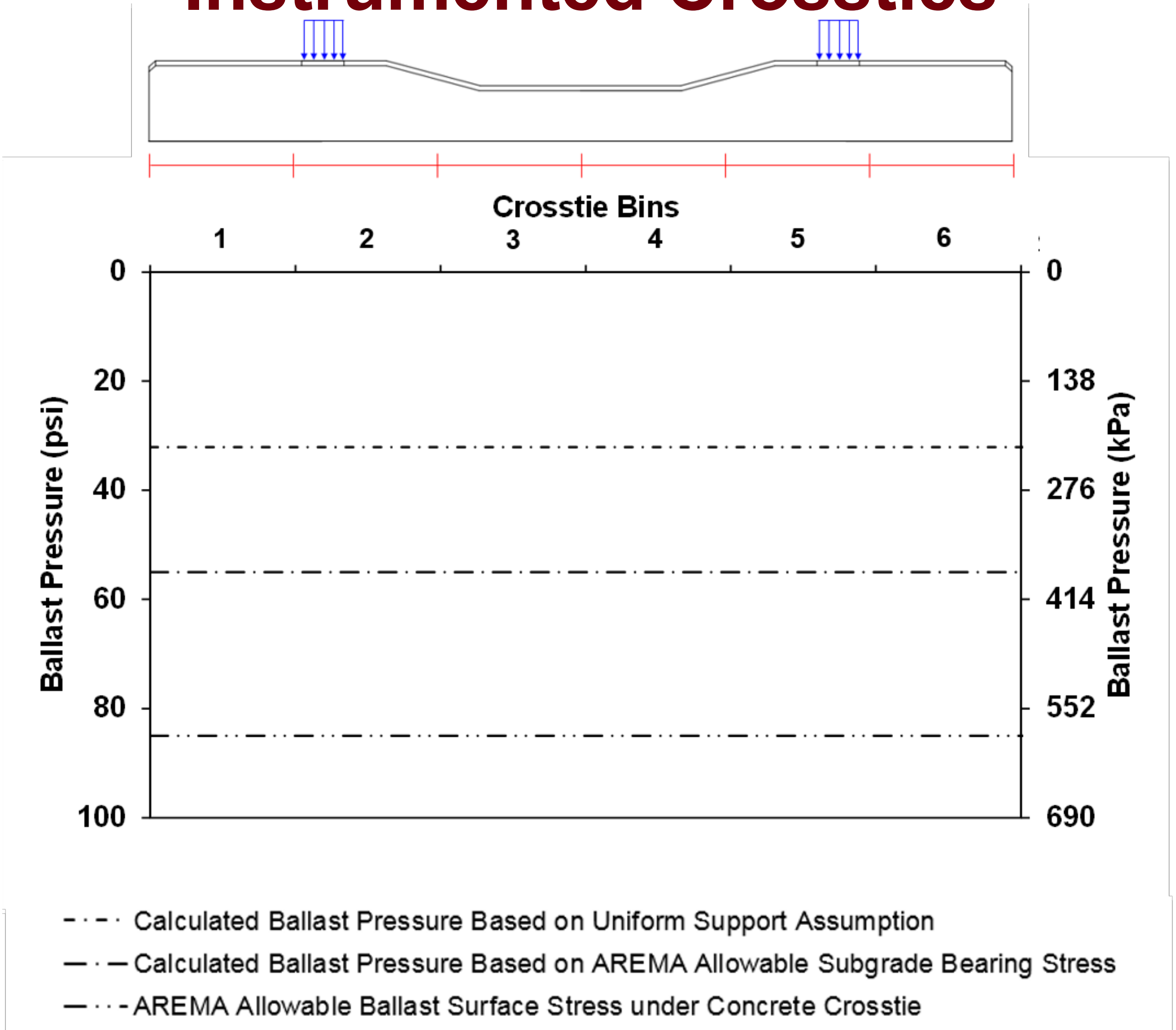
Ballast Pressure Limit States

- 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**

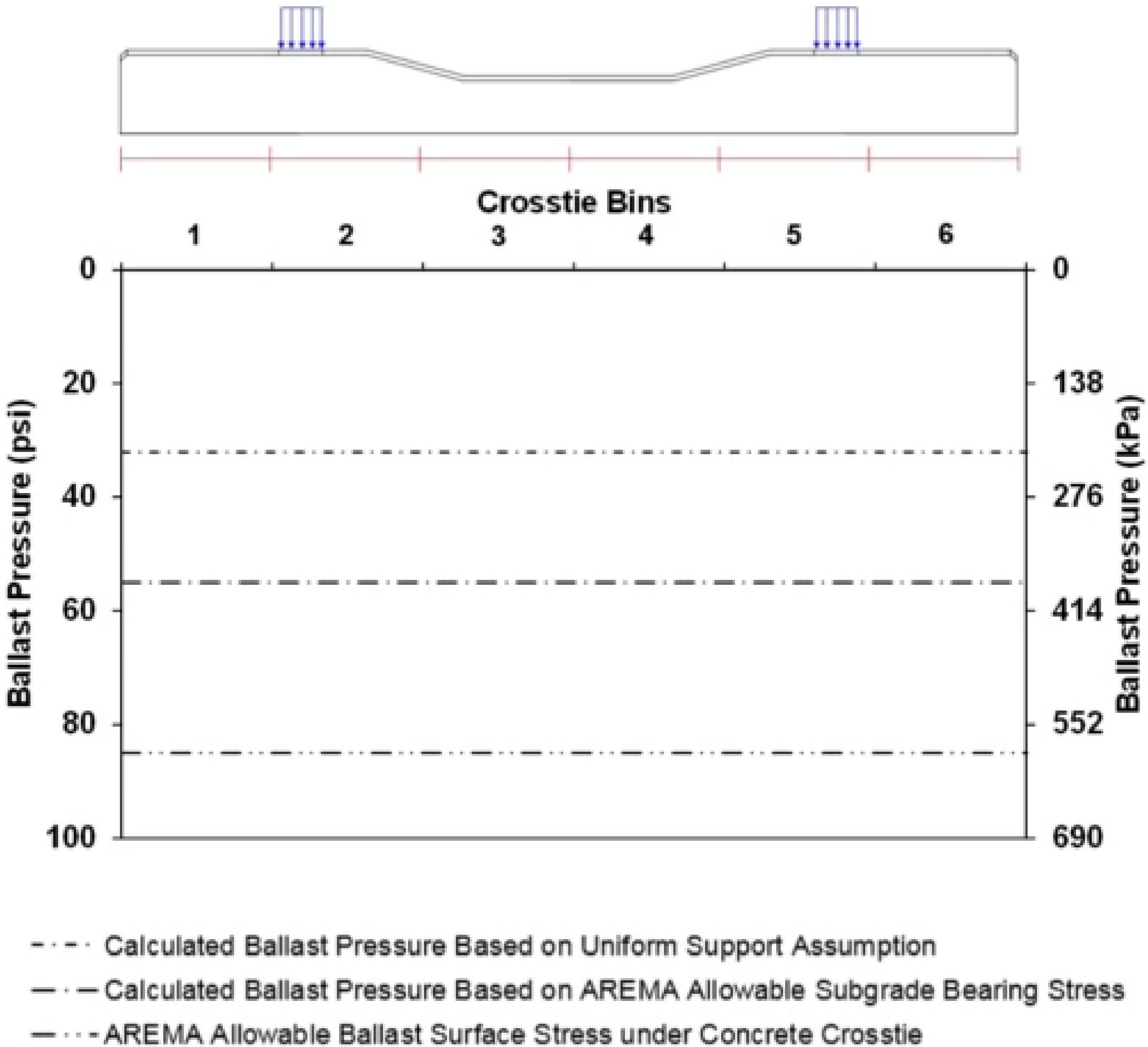
$$h = \left(\frac{16.8p_a}{p_c}\right)^{4/5}$$

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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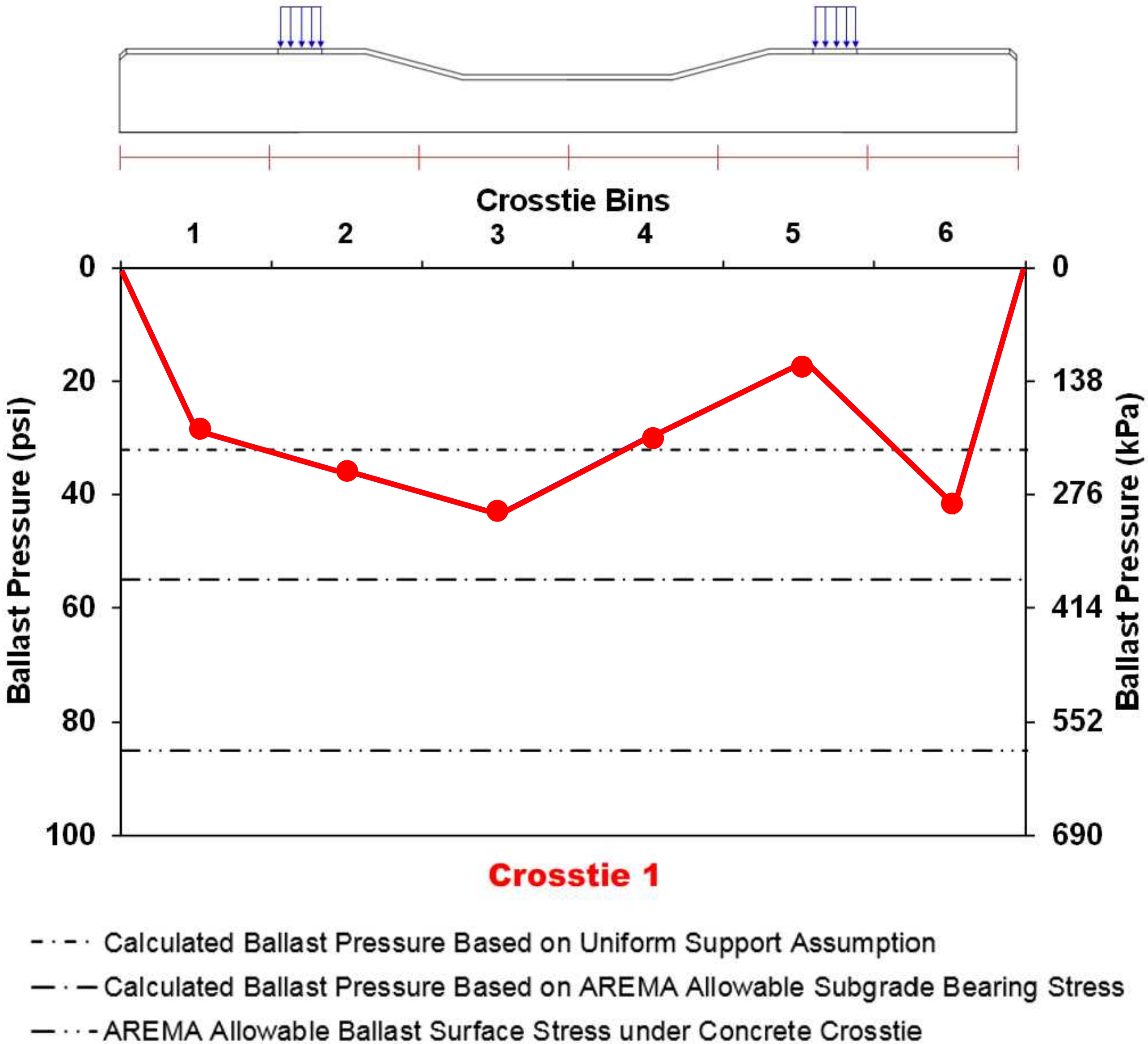

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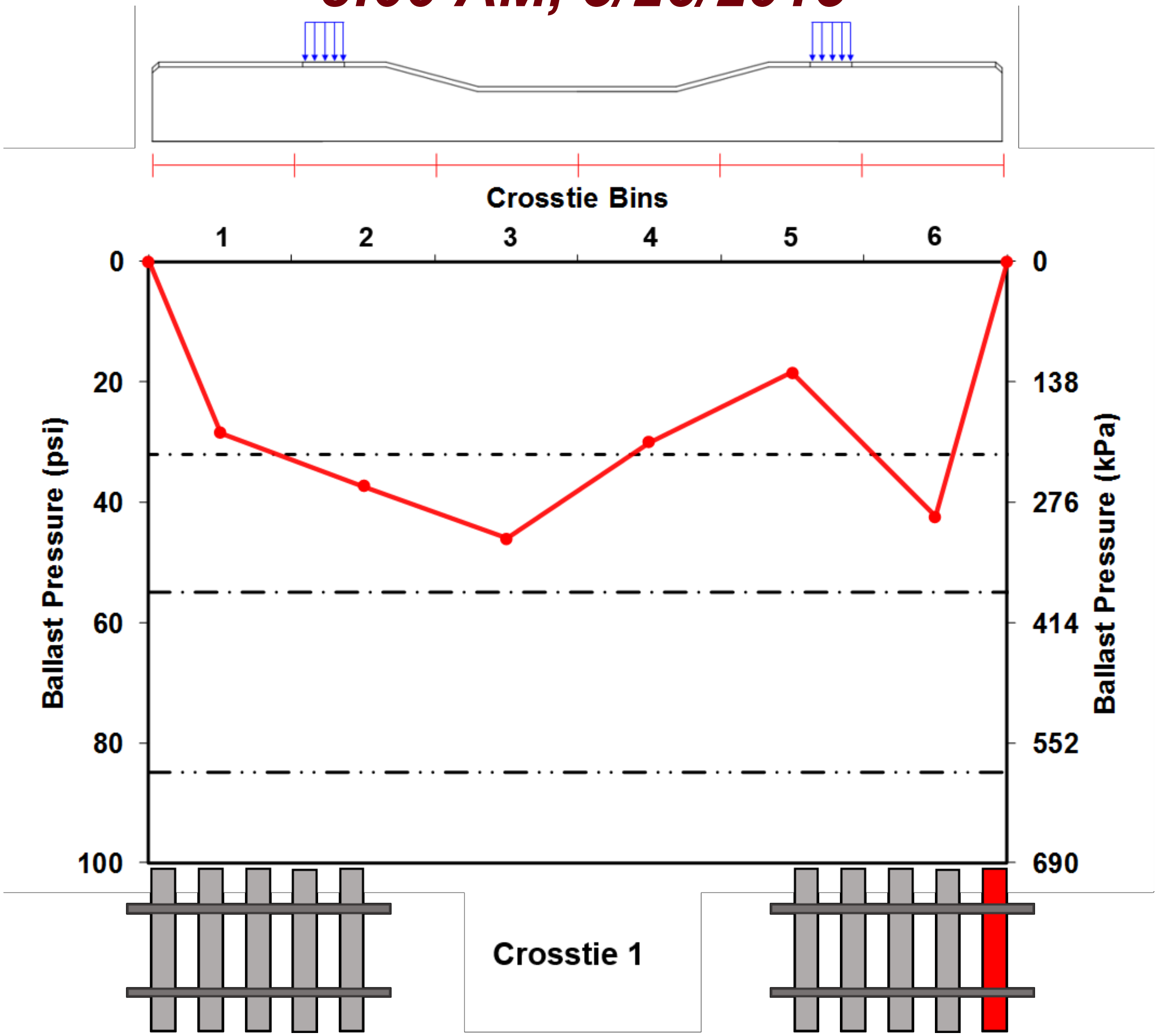

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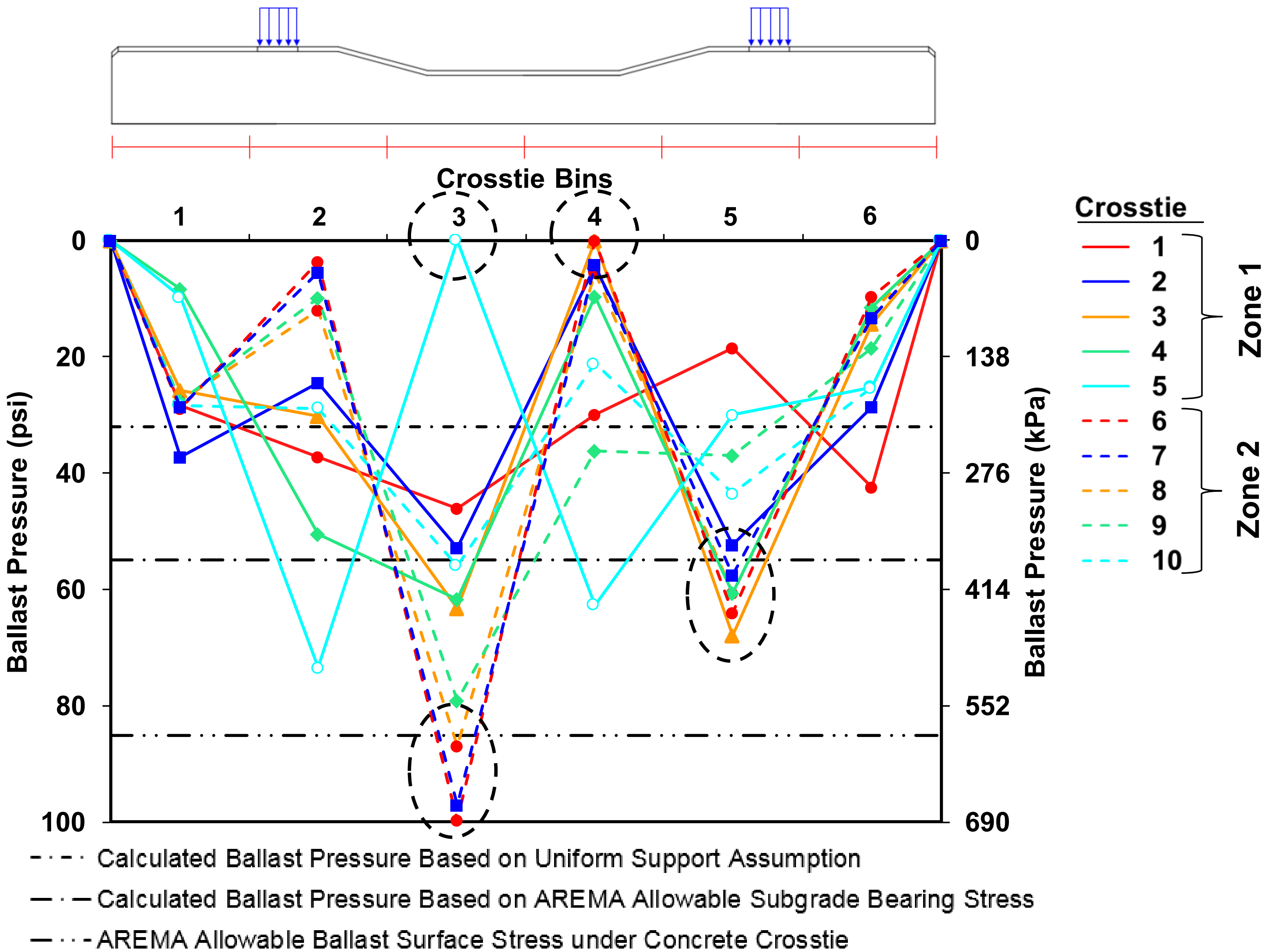
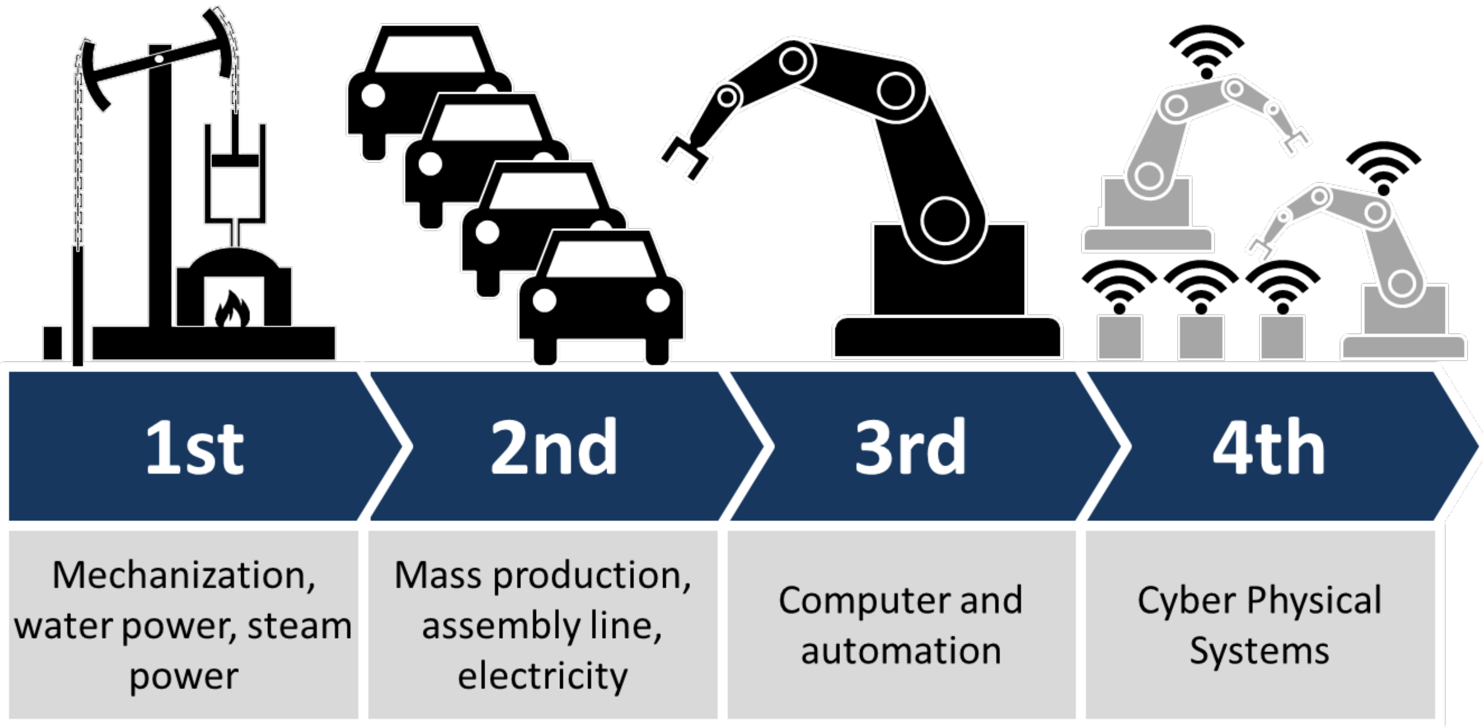


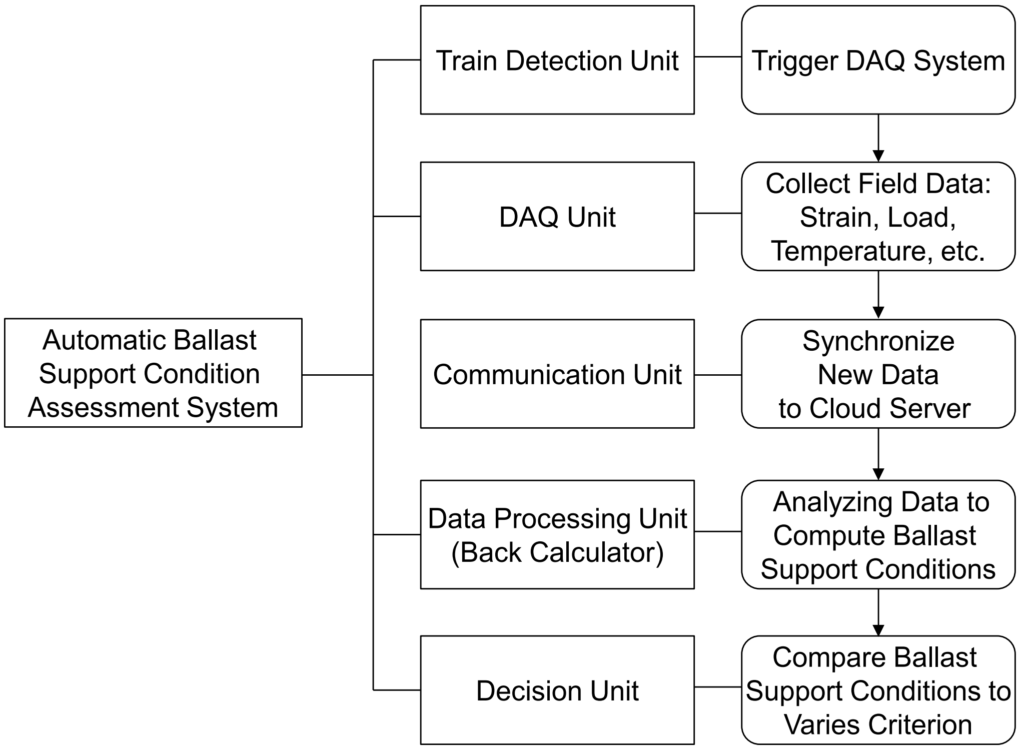
What is Railroad 4.0?

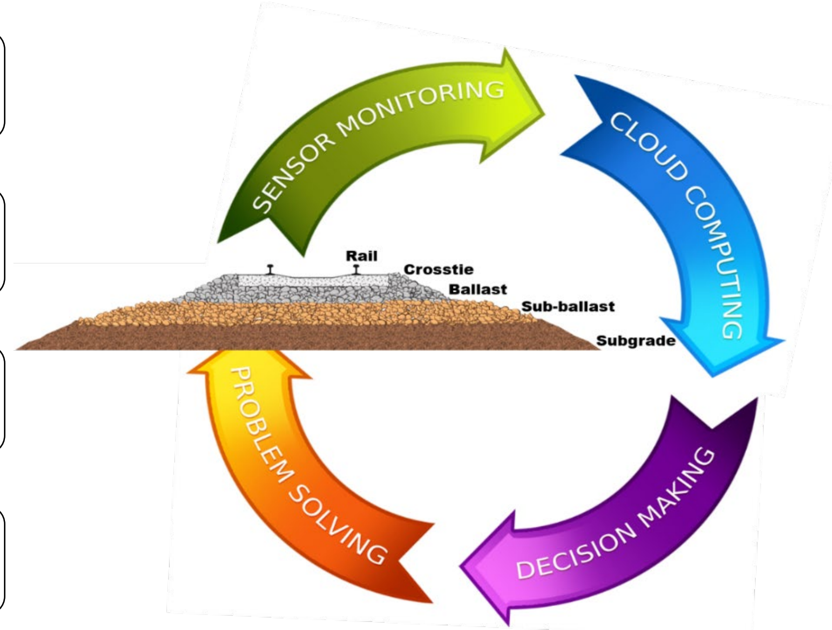


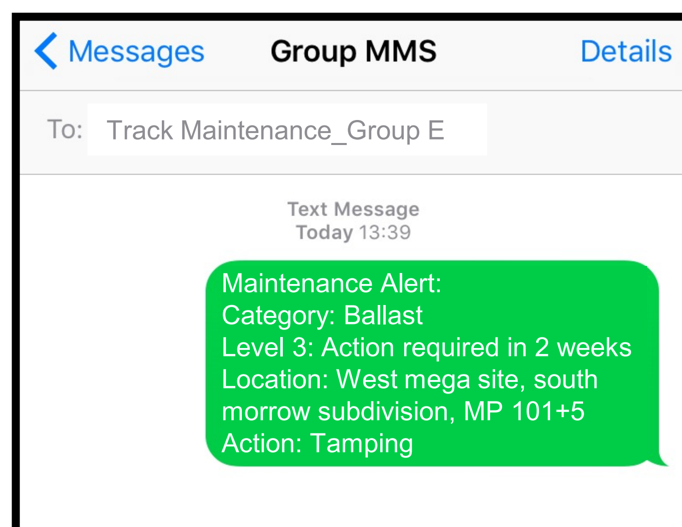
Industry 4.0 is the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of things and cloud computing. (Wikipedia)

Railroad Infrastructure 4.0 is the current trend of automation and data exchange in railroad infrastructure . It includes cyber-physical systems, the Internet of things and cloud computing.

Automatic Track Support Condition Assessment System





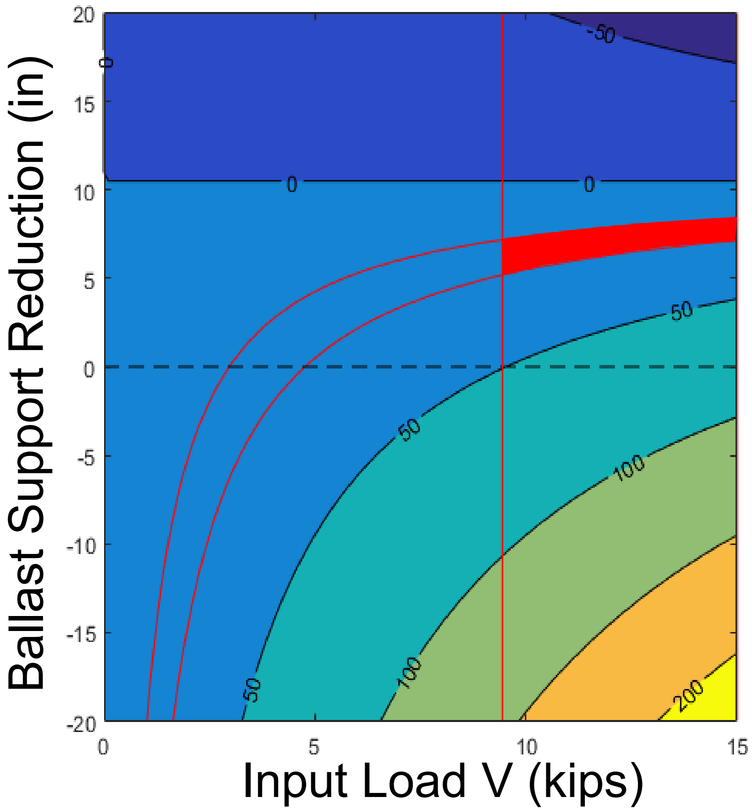


Notify User with simple "go" or "no go"

Automatic Track Support Condition Assessment System







U.S. Department of Transportation
Federal Transit Administration

Canga et al. (2017) *JRC*
Canga et al. (2017) *APTA*
Canga et al. (2018) *AREMA*
Canga et al. (2018) *CBM*

AMTRAK

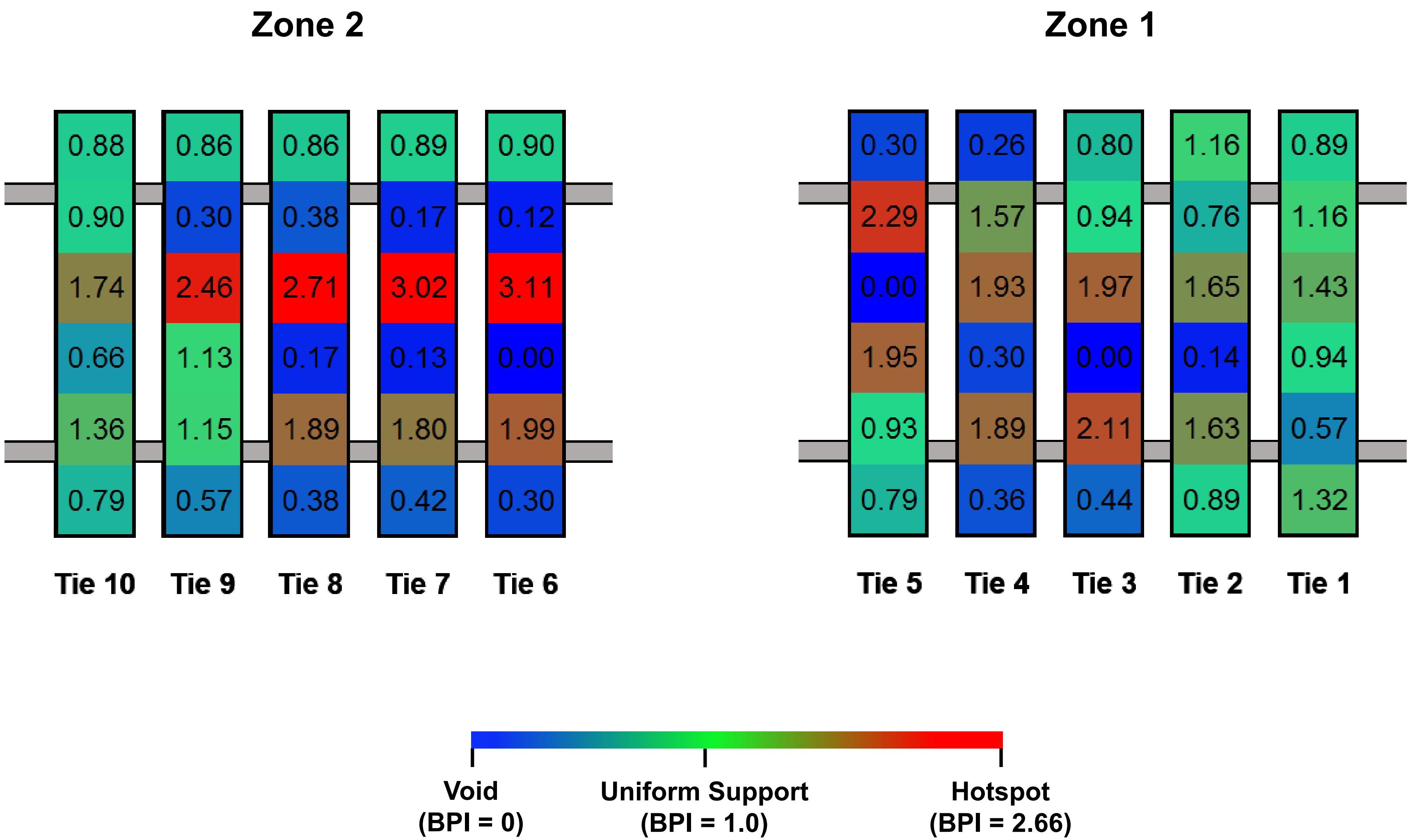
Ballast Pressure Index (BPI)

- 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

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

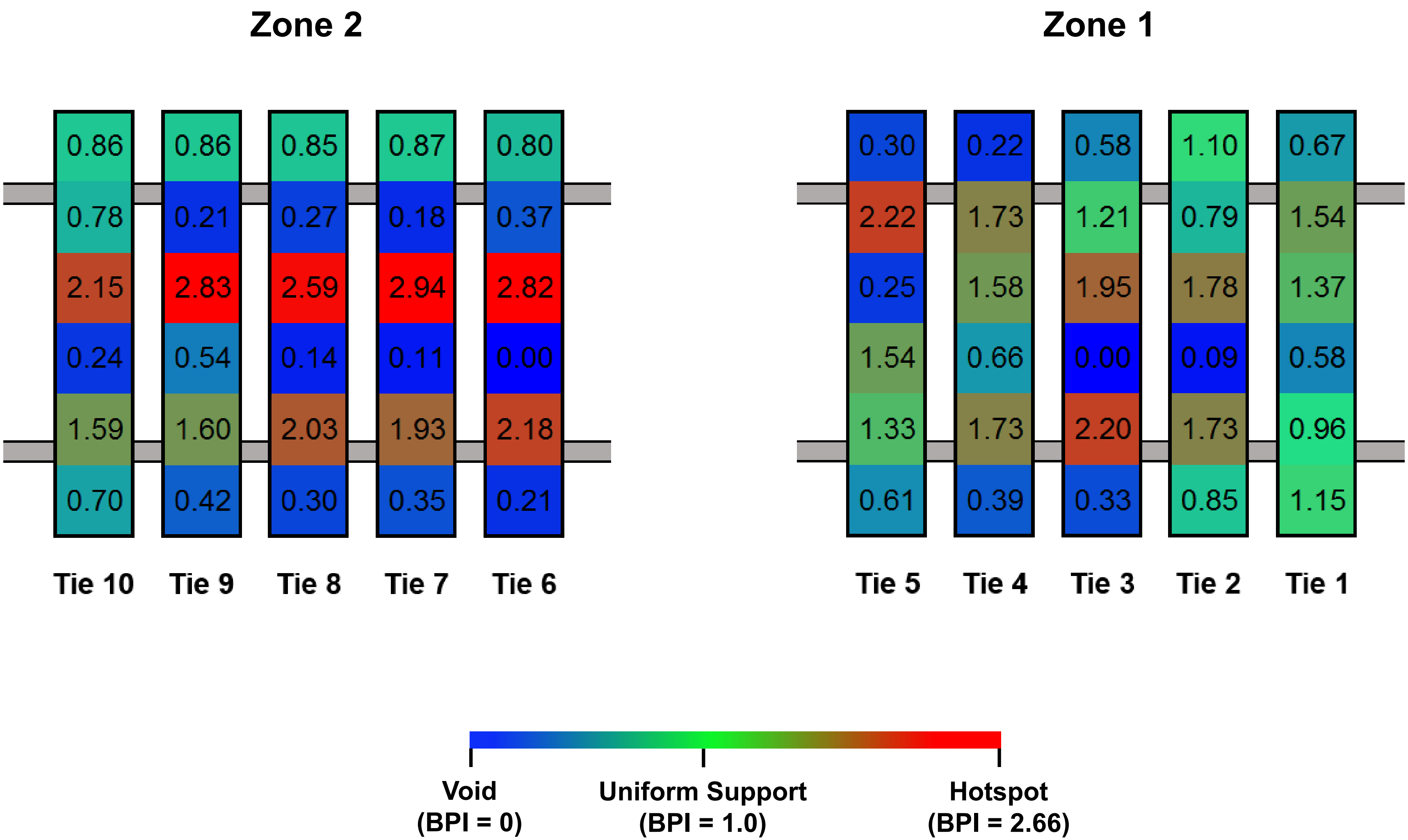
Where, BPI = Ballast Pressure Index
P_c = Pressure calculated from back-calculator
P_u = Pressure based on assumed uniform support

Ballast Pressure Index for Loaded Axle:
8:00 AM, 5/26/2015

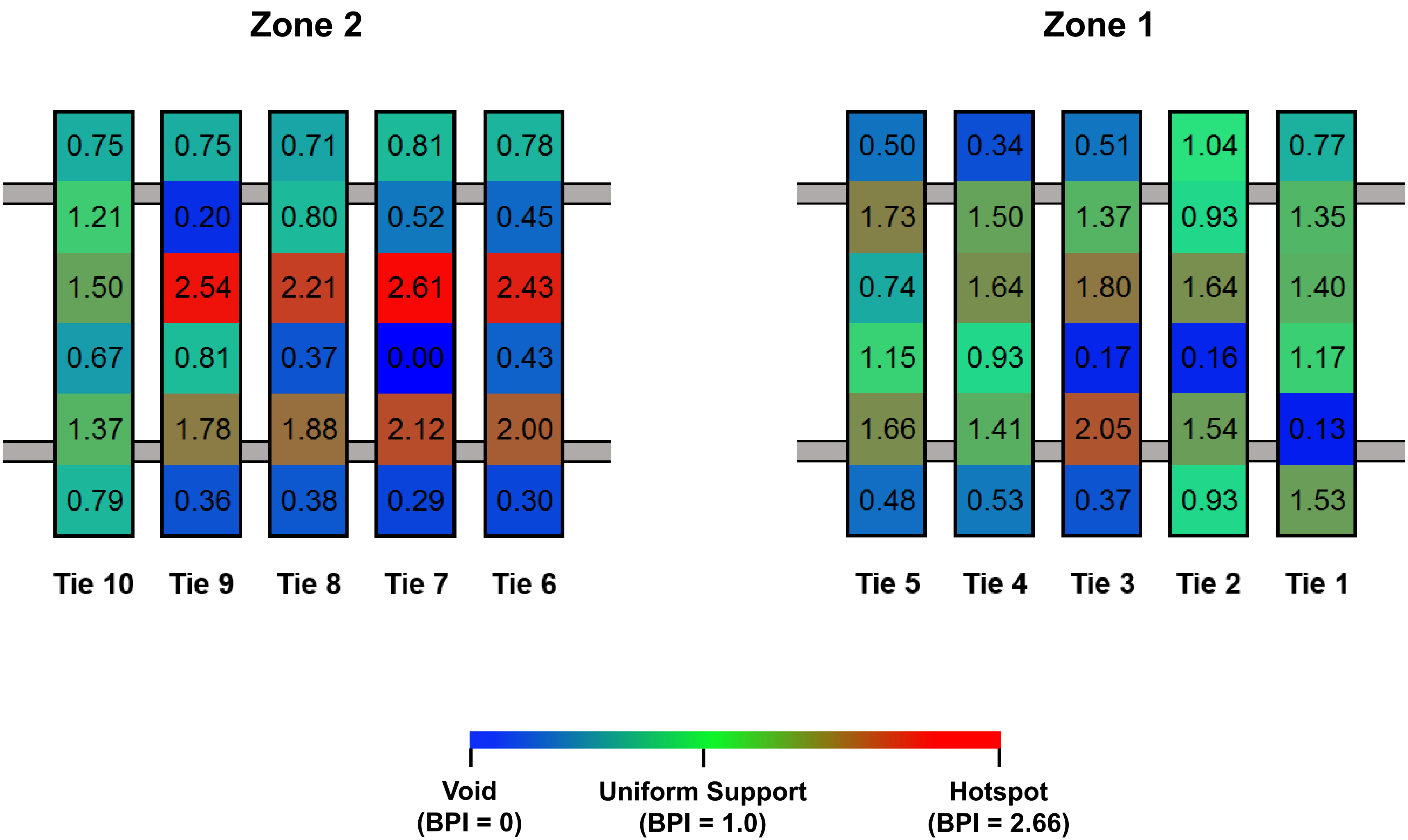


Ballast Pressure Index for Loaded Axle:

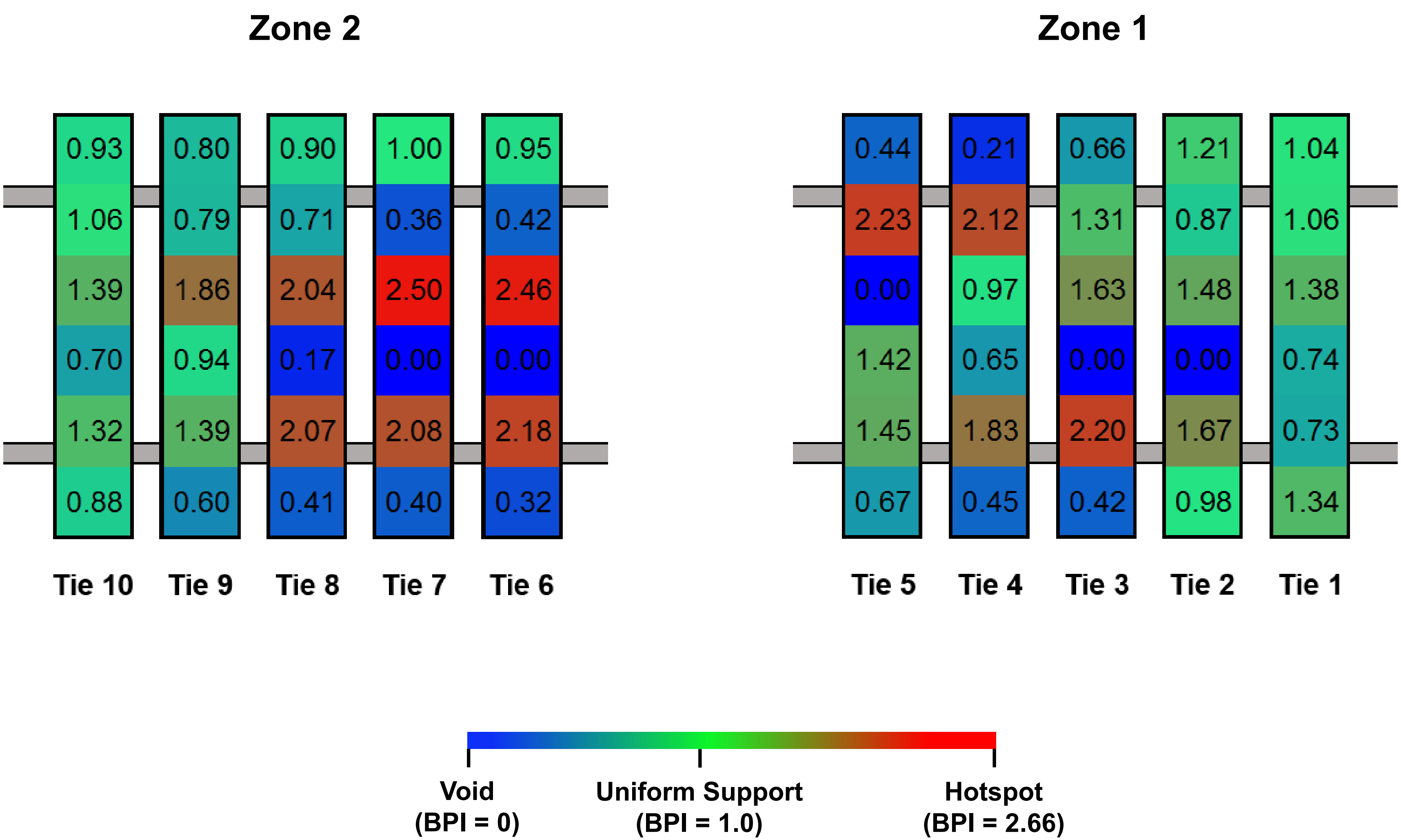
8:00 AM, 7/8/2015



Ballast Pressure Index for Loaded Axle:
8:00 AM, 8/14/2015

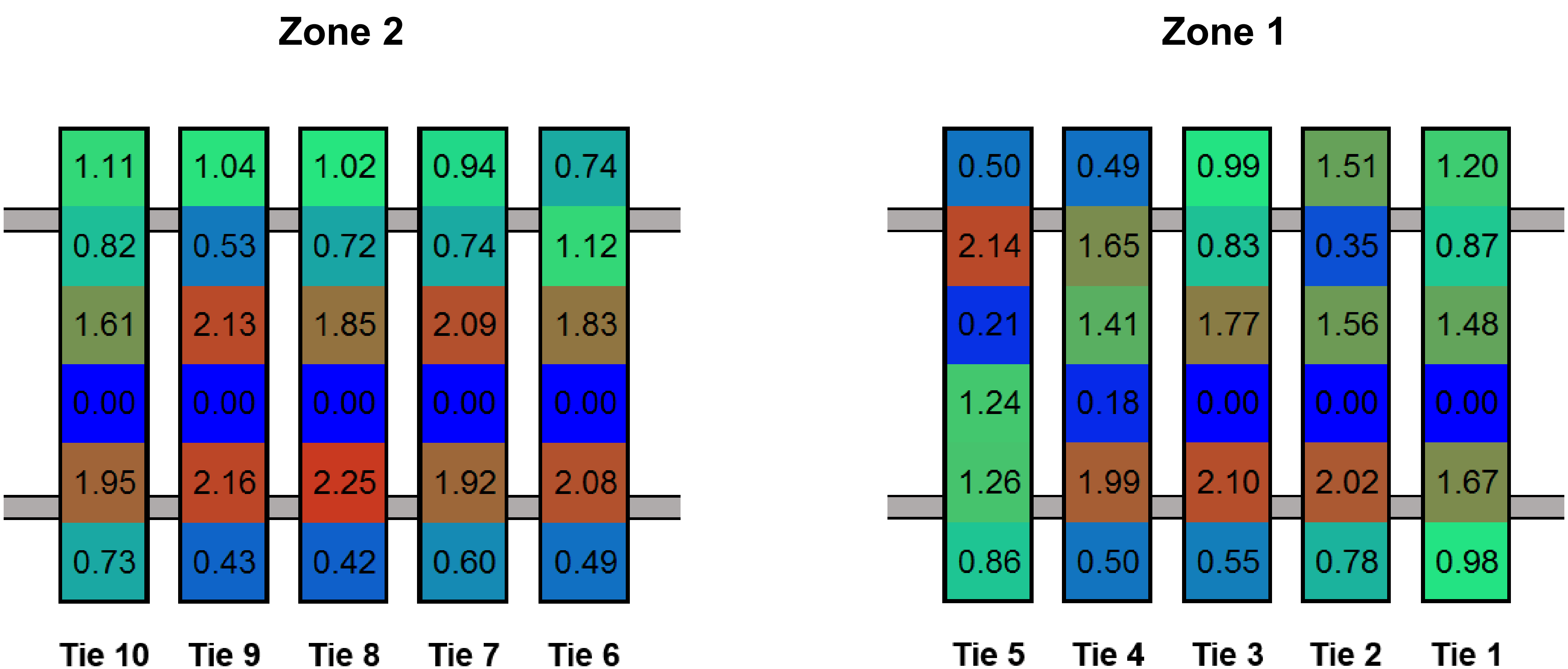


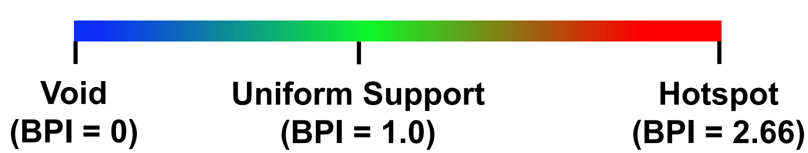
Ballast Pressure Index for Loaded Axle:
10:00 AM, 8/14/2015



Ballast Pressure Index for Loaded Axle:

1:00 PM, 8/14/2015





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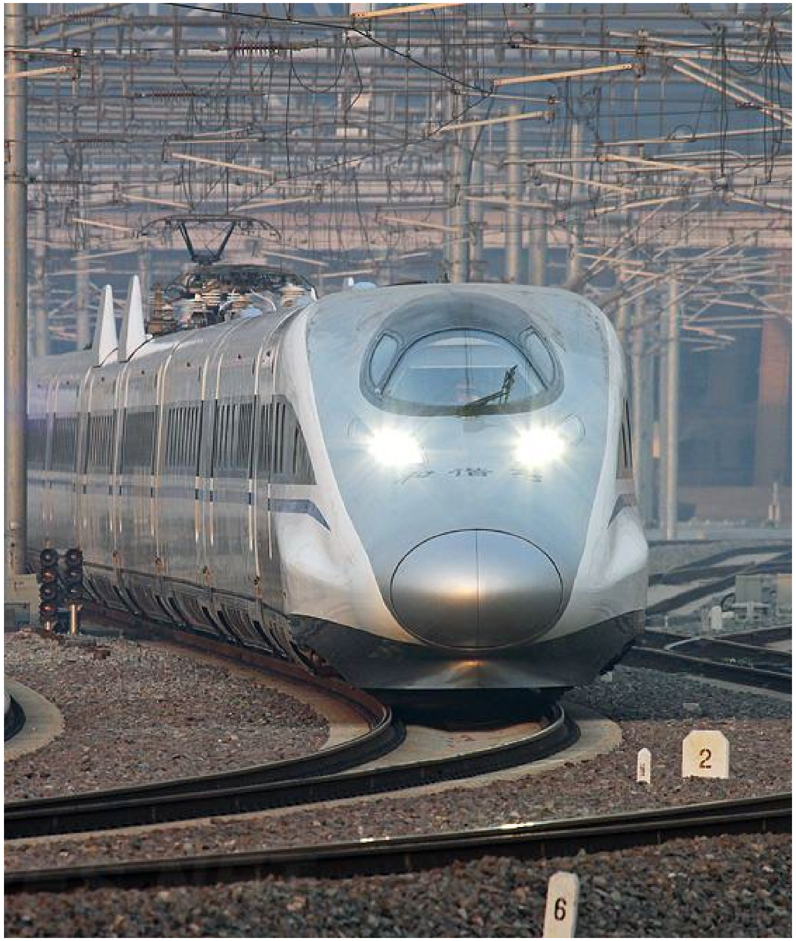

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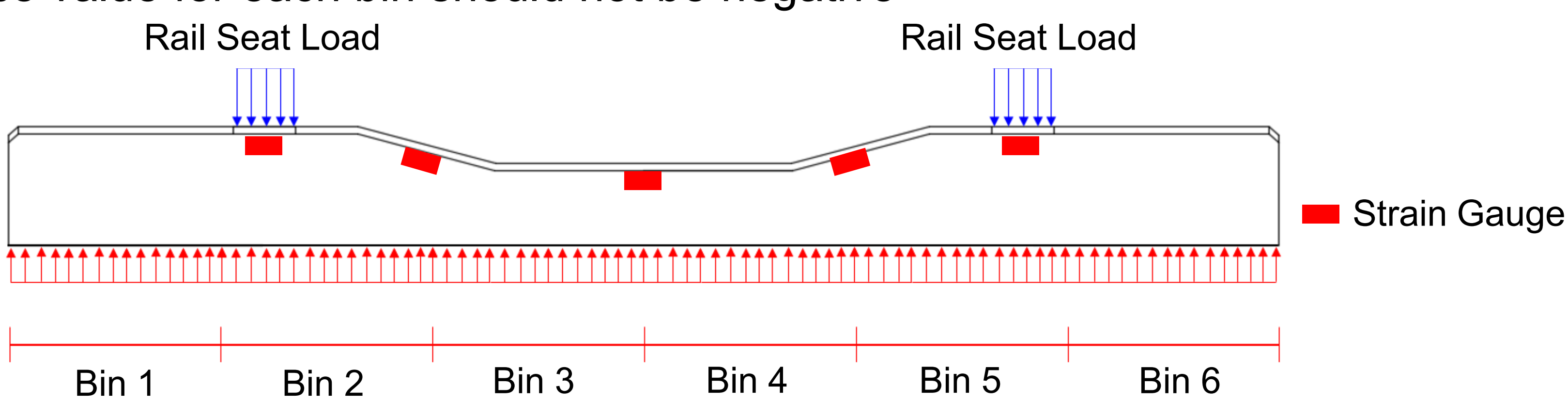

2-D Crosstie Bending Model

- Crosstie divided into ∞ bins of equal width:
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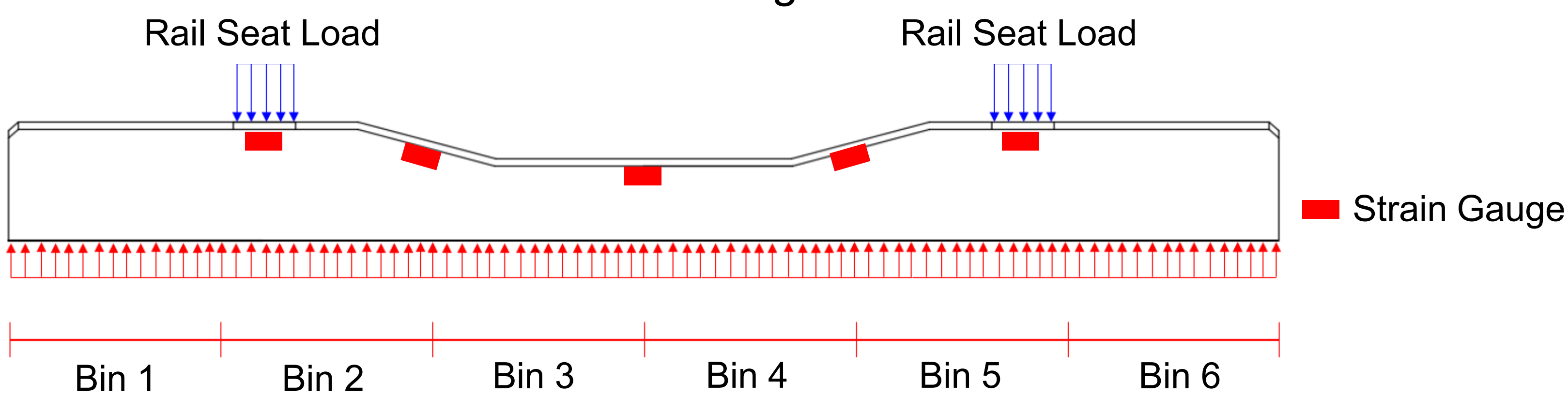
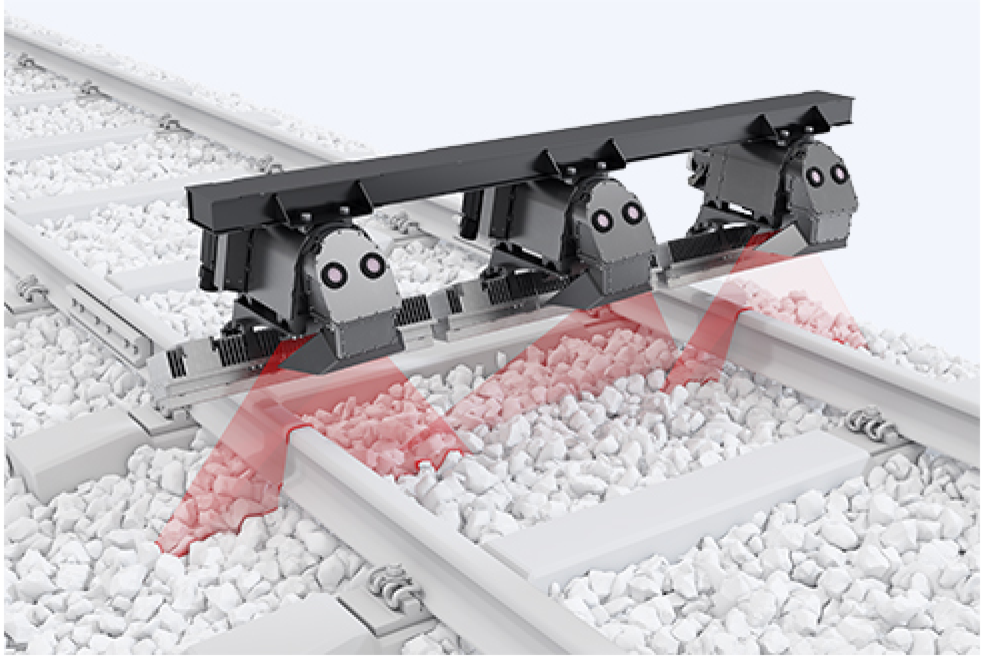


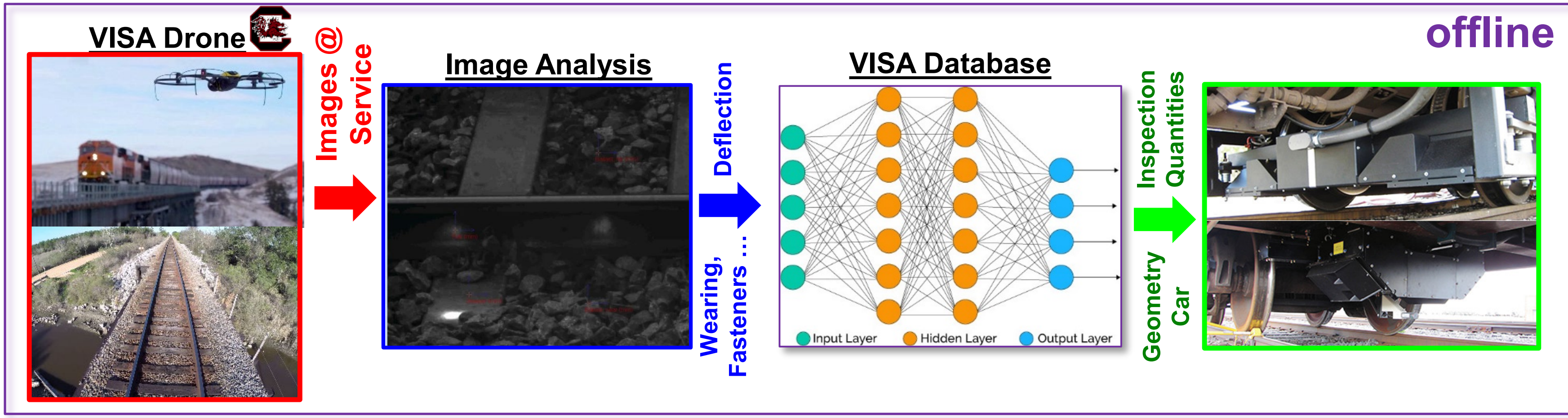
Methods to Measure Surface Strain



Infinite number of surface strain measure by laser beam

Able to back-calculate crosstie stiffness and input load as long as the number of bins is smaller than the number of the surface strain

Methods to Measure Surface Strain



Data Acquisition – What You Can See

Methods to Measure Surface Strain

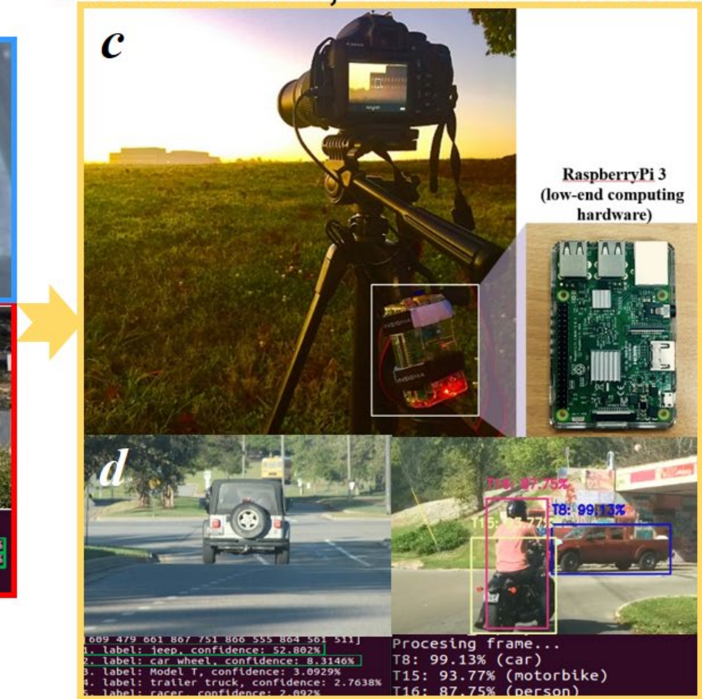
Data Acquisition – What Drones Can See

Application in High Speed Rail

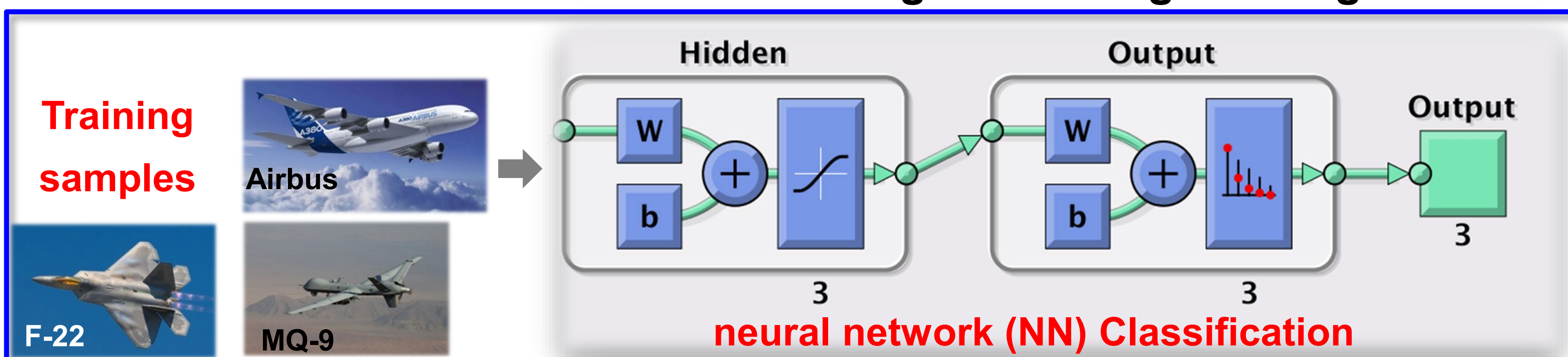
Related Experience

Deep Learning & Automatic Target Recognition (ATR) Algorithms

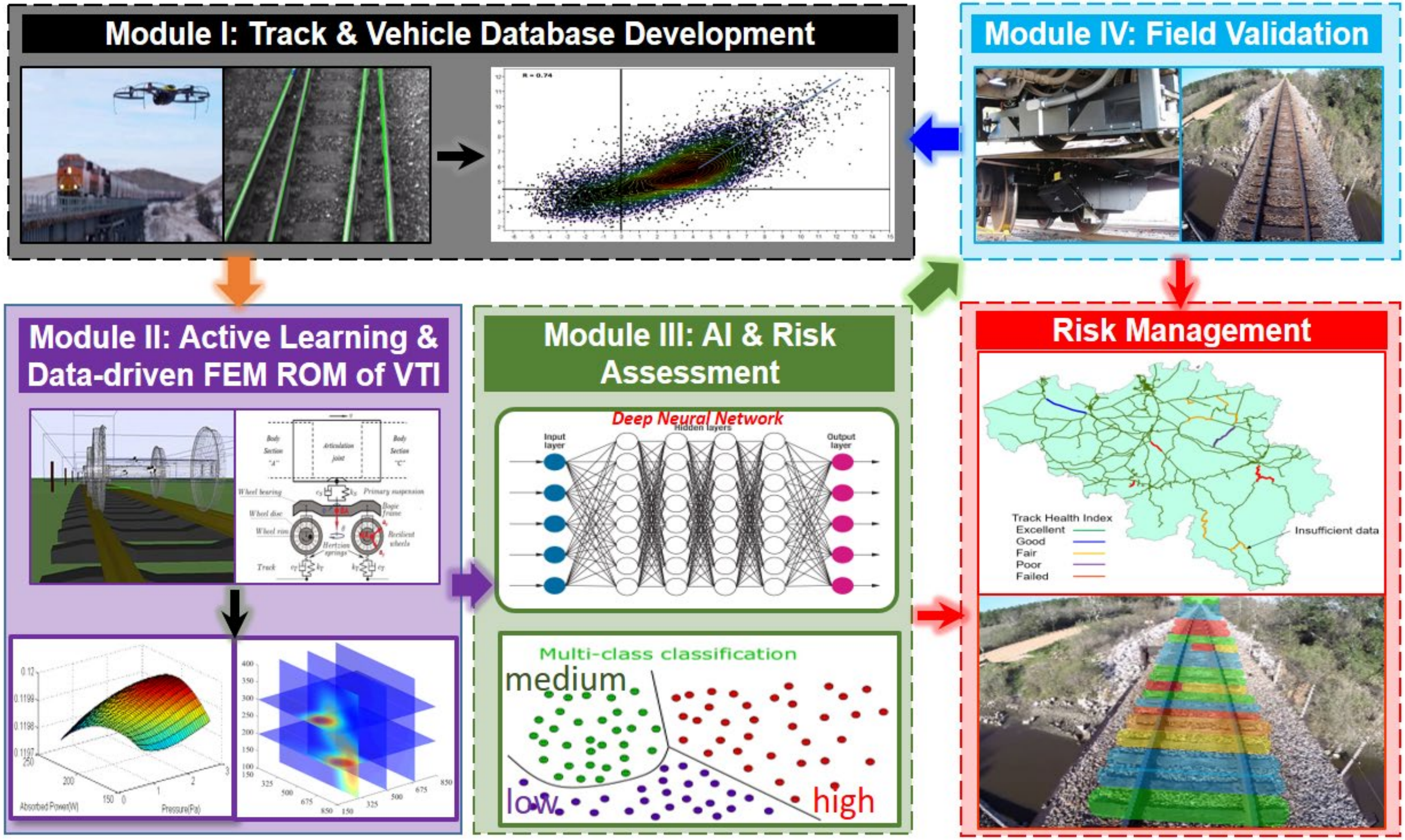
Computing Platform & Fieldable ATR, Threat Assessment



Feature Selection & Machine Learning-based Target Recognition



Extended Track Inspection Framework



intelligent **R**isk **A**ssessment and **P**rediction **S**ystem

Contact Information

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Email: yuqian@sc.edu