Nondestructive Estimation of Concrete Crosstie Support Conditions Using Field Bending Moments

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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**
  - Field Implementation
    - Quantification of ballast pressure
    - Application of Ballast Pressure Index (BPI)
    - Crosstie curling behavior
- Preliminary conclusions
- Future work
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*
Comparison between Lab Support Conditions and Back-Calculator Results

- Full Support
- Lack of Center Support
- Light Center Binding
- High Center Binding
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
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: \textbf{32 psi}
- AREMA allowable ballast pressure under concrete crossties: \textbf{85 psi}
- Ballast pressure calculated based on AREMA allowable subgrade bearing stress (25 psi) using Talbot equation: \textbf{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

- - - - Calculated Ballast Pressure Based on Uniform Support Assumption
- - - - Calculated Ballast Pressure Based on AREMA Allowable Subgrade Bearing Stress
- - - - AREMA Allowable Ballast Surface Stress under Concrete Crosstie
Distribution of Ballast Pressure under Loaded Axle:

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

8:00 AM, 5/26/2015

Ballast Pressure (psi) vs. Ballast Pressure (kPa)

- Calculated Ballast Pressure Based on Uniform Support Assumption
- Calculated Ballast Pressure Based on AREMA Allowable Subgrade Bearing Stress
- AREMA Allowable Ballast Surface Stress under Concrete Crosstie
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
Nondestructive Estimation of Concrete Crosstie Support Conditions Using Field Bending Moments

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

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Legend:
- Void (BPI = 0)
- Uniform Support (BPI = 1.0)
- Hotspot (BPI = 2.66)
Nondestructive Estimation of Concrete Crosstie Support Conditions Using Field Bending Moments

Ballast Pressure Index for Loaded Axle:

8:00 AM, 7/8/2015

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Ballast Pressure Index Colors:
- Void (BPI = 0)
- Uniform Support (BPI = 1.0)
- Hotspot (BPI = 2.66)
Nondestructive Estimation of Concrete Crosstie Support Conditions Using Field Bending Moments

Ballast Pressure Index for Loaded Axle:

8:00 AM, 8/14/2015

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Ballast Pressure Index (BPI):
- Void (BPI = 0)
- Uniform Support (BPI = 1.0)
- Hotspot (BPI = 2.66)
Nondestructive Estimation of Concrete Crosstie Support Conditions Using Field Bending Moments

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

**Zone 2**

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- **Void** (BPI = 0)
- **Uniform Support** (BPI = 1.0)
- **Hotspot** (BPI = 2.66)
Nondestructive Estimation of Concrete Crosstie Support Conditions Using Field Bending Moments

Ballast Pressure Index for Loaded Axle: 1:00 PM, 8/14/2015

Zone 2

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<td>0.78</td>
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</tbody>
</table>

Legend:
- Void (BPI = 0)
- Uniform Support (BPI = 1.0)
- Hotspot (BPI = 2.66)
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

• Future work
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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- BNSF Railway
- National Railway Passenger Corporation (Amtrak)
- Progress Rail Services
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- TTX Company

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