Effect of Lateral Load on Rail Seat Pressure Distributions

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Outline

- FRA Project Objectives
- RSD Background
- Equipment Overview
- Pressure Distribution Relation to RSD
- Field Data Analysis
  - Load Distribution Progression
  - Contact Areas vs. L/V
  - Pressure Comparison
- Conclusions
- Future Work
FRA Project Objectives

• Expand knowledge of international practices and standards for concrete crosstie and fastening system design

• Improve understanding of vertical and lateral load paths within track superstructure

• Develop recommendations for conventional component and interface design based on findings

• Provide framework for mechanistic design approach for concrete crossties and fastening systems
Overall Project Deliverables

**Mechanistic Design Framework**
- Literature Review
- Load Path Analysis
- International Standards
- Current Industry Practices
- AREMA Chapter 30

**I-TRACK**
- Statistical Analysis from FEM
- Free Body Diagram Analysis
- Probabilistic Loading

**Finite Element Model**
- Laboratory Experimentation
- Field Experimentation
- Parametric Analyses
Current Objectives of Experimentation with Matrix Based Tactile Surface Sensors (MBTSS)

- Measure magnitude and distribution of pressure at the concrete crosstie rail seat
- Improve understanding of how load from wheel/rail interface is transferred to rail seat
- Compare pressure distribution on rail seats:
  - Under various loading scenarios
  - Under various fastening systems
- Identify regions of high pressure and quantify peak values
Rail Seat Deterioration Background

- Rail Seat Deterioration (RSD) is the degradation of concrete directly underneath the rail pad, resulting in track geometry problems.
- Surveys conducted by UIUC report that North American Class I Railroads and other railway infrastructure experts ranked RSD as one of the most critical problems associated with concrete crosstie and fastening system performance.
- Potential RSD mechanisms as determined through research at UIUC:
  - Abrasion
  - Crushing
  - Freeze-thaw
  - Hydraulic pressure cracking
  - Hydro-abrasive erosion
MBTSS Equipment

• Hardware and software by Tekscan, Inc.
• Components:
  – Sensor
  – Data acquisition handle
  – I-Scan software
Equipment Preparation and Protection

- Sensors trimmed to fit rail seat
- BoPET and PTFE layered on each side of sensor to protect from shear and puncture damage
- Plastic sleeves and plastic bags to protect sensor tabs from puncture and debris between experiments
- Plastic sleeves to protect data acquisition handles during experimentation
Sensor Installation

- Rail
- Pad/Abrasion Plate
  - BoPET: 0.007”
  - PTFE: 0.006”
  - Sensor: 0.004”
  - PTFE: 0.006”
  - BoPET: 0.007”
- Cast-in Shoulders
- Concrete Crosstie
- MBTSS Setup
  - Matrix Based Tactile Surface Sensor
  - Field
MBTSS Laboratory Testing Overview

- First used in railroad applications by University of Kentucky on timber crossties
- Laboratory experimentation with Pulsating Load Testing Machine (PLTM)
  - Two 35,000 lb (156 kN) vertical actuators
  - One 35,000 lb (156 kN) lateral actuator
- Ability to simulate various L/V force ratios by varying loads
- Proven feasibility for use on concrete crosstie rail seats
- Laboratory experimentation performed varied:
  - Rail pad materials, geometry, and type
  - Fastening clip type
Field Experimentation Overview

- Field instrumentation at the Transportation Technology Center, Inc. (TTCI) in Pueblo, CO
- MBTSS used with multiple instrumentation technologies to better understand:
  - Tangent vs curved track
  - Effect of reduced contact area
  - Role of individual crosstie support conditions
  - Lab experiments vs in-service conditions
  - Static vs dynamic loading environments
July 2012 Field Instrumentation

- Initial installation of various instrumentation technologies (e.g. MBTSS, strain gauges, potentiometers) to capture loads and behavior of various aspects of the concrete sleepers and fastening systems

- Successes:
  - Proof of feasibility for field applications
  - Effect of lateral load on longitudinal distribution
  - Guidance for future field instrumentation

- Limitations:
  - Limited number of rail seats
  - Did not capture vertical tie displacement
  - Lateral load path affected by protective layers
May 2013 Field Instrumentation

- Collected data from 8 MBTSS sensors simultaneously
  - Separation from lateral load instrumentation
  - Effect of individual crosstie support conditions
  - Capture of entire distribution of wheel-rail load
TTC Field Testing Locations

High Tonnage Loop (HTL)
5° Curve: Balance Speed of 33 mph

Railroad Test Track (RTT)
Tangent: Speed up to 105 mph
Load Input: Track Loading Vehicle (TLV)

- Modified railcar with instrumented wheelset on hydraulic actuators
- Can apply known and controlled loads to track structure
- L/V force ratio testing:
  - Vertical loads ranging from 0 to 40,000 lbs (178 kN)
  - Lateral loads ranging from 0 to 22,000 lbs (97.8 kN)
Mapping Rail Seat Pressure Distributions

Increasing Vertical Load Magnitudes

Unloaded

Increasing Pressure

5 kips

0 kips
Mapping Rail Seat Pressure Distributions

Increasing Vertical Load Magnitudes

10 kips

Unloaded

Increasing Pressure
Increasing Vertical Load Magnitudes

Unloaded

Increasing Pressure

20 kips

0 kips

Mapping Rail Seat Pressure Distributions
Mapping Rail Seat Pressure Distributions

Increasing Vertical Load Magnitudes

30 kips

0 kips

Unloaded

Increasing Pressure

30 kips

0 kips

Unloaded
Mapping Rail Seat Pressure Distributions

Increasing Vertical Load Magnitudes

Unloaded

Increasing Pressure

40 kips

0 kips
Mapping Rail Seat Pressure Distributions

Increasing L/V Force Ratio

% Initial Contact Area

3: 100%

11: 100%

Unloaded

Increasing Pressure
Mapping Rail Seat Pressure Distributions

Increasing L/V Force Ratio

<table>
<thead>
<tr>
<th>% Initial Contact Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>3: 101%</td>
</tr>
<tr>
<td>11: 100%</td>
</tr>
</tbody>
</table>

40 kips

4 kips
Mapping Rail Seat Pressure Distributions

Increasing L/V Force Ratio

% Initial Contact Area
3: 101%
11: 101%
Mapping Rail Seat Pressure Distributions

Increasing L/V Force Ratio

% Initial Contact Area

3: 101%

11: 101%
Mapping Rail Seat Pressure Distributions

Increasing L/V Force Ratio

% Initial Contact Area
3: 84%
11: 79%

Unloaded
Increasing Pressure

40 kips
16 kips

1 2 3 4 A
9 10 11 12 P
Increasing L/V Force Ratio

% Initial Contact Area
3: 62%
11: 58%
Mapping Rail Seat Pressure Distributions

Changing Load Location

<table>
<thead>
<tr>
<th>% Initial Contact Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: N/A</td>
</tr>
<tr>
<td>9: 83%</td>
</tr>
</tbody>
</table>

40 kips

20 kips

Unloaded

Increasing Pressure
Mapping Rail Seat Pressure Distributions

Changing Load Location

40 kips

20 kips

% Initial Contact Area
2: 68%
10: 62%
Mapping Rail Seat Pressure Distributions

Changing Load Location

% Initial Contact Area
3: 62%
11: 58%
Changing Load Location

40 kips
20 kips

% Initial Contact Area
4: 73%
12: 69%

Mapping Rail Seat Pressure Distributions

Changing Load Location

40 kips
20 kips

% Initial Contact Area
4: 73%
12: 69%

Mapping Rail Seat Pressure Distributions
Mapping Rail Seat Pressure Distributions

Changing Load Location

% Initial Contact Area

A: N/A
P: 86%

40 kips

20 kips

Unloaded
Increasing Pressure
Mapping Rail Seat Pressure Distributions

TLV Varying Lateral Load at RTT

40,000 lb (178 kN) Vertical Load

Percent of Initial Contact Area vs. L/V Force Ratio

1 2 3 4 A

9 10 11 12 P
Mapping Rail Seat Pressure Distributions

TLV Varying Lateral Load at RTT

20,000 lb (88.9 kN) Vertical Load

Percent of Initial Contact Area vs. L/V Force Ratio
Effect of Increased L/V Force Ratio

Pressure (psi) vs. L/V Force Ratio (Constant 40 Kip Vertical Load)

- Maximum Pressure
- Average Pressure
- Uniform Pressure

Pressure (MPa) vs. L/V Force Ratio (Constant 40 Kip Vertical Load)
Conclusions

- Rail seat load distribution is highly nonuniform, even between adjacent crossties.
- Rail base rotation at “threshold” L/V force ratio can lead to significant load concentration on field side of rail seat.
  - Loss of up to 54% of initial contact area.
- The behavior of the load distribution under increasing L/V force ratios is affected by the magnitude of vertical load.
  - Further analysis required to establish confident relationship between V and “threshold” L/V force ratio.
- Average and maximum pressure are affected by reduction of contact area.
  - 71% increase in average pressure.
  - 98% increase in maximum pressure.
- Lateral force plays a more significant role than vertical force in RSD mechanisms because of its effect on contact area.
Future Work

• Further analysis of 2013 Field Instrumentation data:
  – Effect of individual crosstie support conditions on wheel load and rail seat load distributions
  – Effect of train weight and speed (relative to balancing speed of a curve) on load distribution

• Additional experimentation:
  – Comparison of full-scale laboratory loading frame to field and current laboratory experimentation
  – Define relationship between vertical load and “threshold” L/V
  – Controlled analysis of effect of crosstie support conditions
  – Further analysis of nonuniform load distribution and maximum pressure
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Questions & Comments

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Appendix
Sensor Technology

- Pressure sensitive ink printed in rows and columns to form matrix
- Each intersection creates a sensing point
- As force is applied the resistivity decreases resulting in a higher output to software
- Our sensors:
  - 44 x 44 “sensel” (sensor cell) matrix
  - Each sensel is 0.22 x 0.22 in (5.59 x 5.59 mm)
  - 100 Hz maximum data collection rate
  - Outputs 0-255 “raw sum” scale

MBTSS Limitations

- Protective sleeves required to prevent shear and puncture damage to sensor
  - Sleeves alter friction and lateral load path in system
- Input load needed to correlate raw sum units to engineering units
- 100 Hz maximum data collection rate limits reliability of data from train operations at higher speeds
- I-Scan software unstable if too much data is processed without program restart
  - Problem identified with large installations
Effect of Distribution Factor

40,000 lb (178 kN) Vertical, 20,000 lb (88.9 kN) Lateral Load