Measuring Concrete Crosstie Rail Seat Pressure Distribution with Matrix Based Tactile Surface Sensors (MBTSS)

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Outline

• Overview of FRA Concrete Crosstie and Fastening System BAA
• Current Objectives of Experimentation with MBTSS
• Pulsating Load Testing Machine (PLTM) at UIUC
• Sensor Layout and Data Representation
• Experimentation at UIUC
  – Rail Pad Test
  – Fastening Clip Test
• Conclusions
• Future Work
• Acknowledgements
FRA Concrete Crosstie and Fastening System BAA

- **Program Objectives**
  - Conduct comprehensive international literature review and state-of-the-art assessment for design and performance
  - Conduct experimental laboratory and field testing, leading to improved recommended practices for design
  - Provide mechanistic design recommendations for concrete crossties and fastening system design in the US

- **Select Program Deliverables**
  - Improved mechanistic design recommendations for concrete crossties and fastening systems in the US
  - Improved safety due to increased strength of critical infrastructure components
  - Centralized knowledge and document depository for concrete crossties and fastening systems
FRA Tie and Fastener Program Structure

**Inputs**
- Comprehensive Literature Review
- International Tie and Fastening System Survey
- Loading Regime (Input) Study
- Rail Seat Load Calculation Methodologies
- Involvement of Industry Experts

**Outputs/Deliverables**
- Data Collection
- Document Depository
- Groundwork for Mechanistic Design
- International Survey Report
- Load Path Map
- Parametric Analysis
- State of Practice Report
- Validated Tie and Fastening System Model

**Outputs/Deliverables**
- Modeling
- Laboratory Study
- Field Study

**Improved Recommended Practices**
Current Objectives of Experimentation with MBTSS

- Measure magnitude and distribution of pressure at the concrete crosstie rail seat
- Gain better 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
Pulsating Load Testing Machine (PLTM)

- Housed at the Advanced Transportation and Research Engineering Laboratory (ATREL)
- Owned by Amsted RPS
- Used for Full Scale Concrete Tie and Fastening System Testing
- Following AREMA Test 6 – Wear and Abrasion
- Three 35,000 lb. actuators: two vertical and one horizontal
  - Ability to simulate various Lateral/Vertical (L/V) ratios
Pulsating Load Testing Machine (PLTM)
MBTSS Placement (Profile)

- Pad Assembly (0.007 in.)
- BoPET (0.007 in.)
- PTFE (0.006 in.)
- MBTSS (0.004 in.)

MBTSS Layers

Data Acquisition Handle
MBTSS Placement (Plan)
Visual Representation of Data

- Data visually displayed as color 2D or 3D images
- Force and pressure are calculated at each sensing point
- Standard color scale applied to all data

Sample 2D MBTSS Output

Sample 3D MBTSS Output
Experimentation at UIUC

• Laboratory experimentation to measure effect of \( \frac{L}{V} \) ratio on pressure distribution in the rail seat varying:
  – Rail pad assembly
  – Fastening clip

• Attempt to simulate range of field loading inputs in the laboratory using the PLTM
Rail Pad Test

- **Objective:** gain understanding of effect of pad modulus on rail seat pressure distribution
- Bound the experiment by using low and high modulus pads
- Two rail pad types with same dimensions and geometry
  - Thermoplastic Vulcanizate (TPV - lower modulus)
  - Medium-Density Polyethylene (MDPE – higher modulus)
- Concrete rail seat and fastening system held constant
- Identical loading conditions
  - 32.5 kip vertical load
  - Lateral load varies based on respective L/V ratio

<table>
<thead>
<tr>
<th>Material</th>
<th>Shore Hardness</th>
<th>Flexural Modulus, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPV</td>
<td>86 (A)</td>
<td>15,000*</td>
</tr>
<tr>
<td>MDPE</td>
<td>60 (D)</td>
<td>120,000</td>
</tr>
</tbody>
</table>

*Approximate flexural modulus based on a TPV with a similar Shore Hardness of 87A
### Rail Pad Test Results

<table>
<thead>
<tr>
<th>L/V Ratio</th>
<th>0.25</th>
<th>0.44</th>
<th>0.48</th>
<th>0.52</th>
<th>0.56</th>
<th>0.60</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contact Area (in²)</strong></td>
<td>28.8</td>
<td>27.9</td>
<td>27.3</td>
<td>25.8</td>
<td>24.0</td>
<td>21.3</td>
</tr>
<tr>
<td>% of Rail Seat</td>
<td>85</td>
<td>82</td>
<td>80</td>
<td>76</td>
<td>71</td>
<td>63</td>
</tr>
<tr>
<td>Peak Pressure (psi)</td>
<td>2,139</td>
<td>2,573</td>
<td>2,800</td>
<td>2,925</td>
<td>3,162</td>
<td>3,400</td>
</tr>
</tbody>
</table>

### TPV

- **Contact Area (in²)**: 20.1
- % of Rail Seat: 59
- Peak Pressure (psi): 3,213

### MDPE

- **Contact Area (in²)**: 19.3
- % of Rail Seat: 57
- Peak Pressure (psi): 3,469
Average Pressure Distribution for TPV Rail Pad

Pressure (psi) vs. Distance from Gauge Edge of Sensor on Rail Seat (in.).

Legend:
- L/V Ratio: 0.60 (red), 0.56 (blue), 0.52 (orange), 0.48 (green), 0.44 (cyan), 0.25 (magenta).

Gauge: FIELD

Pressure (psi) vs. Distance from Gauge Edge of Sensor on Rail Seat (in.).

Legend:
- L/V Ratio: 0.60 (red), 0.56 (blue), 0.52 (orange), 0.48 (green), 0.44 (cyan), 0.25 (magenta).

Gauge: FIELD
Average Pressure Distribution for MDPE Rail Pad

- Pressure (psi) on the y-axis.
- Distance from Gauge Edge of Sensor on Rail Seat (in.) on the x-axis.

Legend:
- L/V Ratio
  - 0.60: Red
  - 0.56: Blue
  - 0.52: Orange
  - 0.48: Green
  - 0.44: Cyan
  - 0.25: Magenta

Gauge vs. Field comparison.
### Rail Pad Test Results (cont.)

- **Two-Part Pad Assembly**
  - Poly Pad
  - Nylon 6-6 Abrasion Frame

- **32.5 kip vertical load**

- **Lateral load varies based on respective L/V ratio**

<table>
<thead>
<tr>
<th>L/V Ratio</th>
<th>Contact Area (in²)</th>
<th>% of Rail Seat</th>
<th>Peak Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.24</td>
<td>24.9</td>
<td>80</td>
<td>2,550</td>
</tr>
<tr>
<td>0.44</td>
<td>24.0</td>
<td>77</td>
<td>2,821</td>
</tr>
<tr>
<td>0.48</td>
<td>23.9</td>
<td>77</td>
<td>2,877</td>
</tr>
<tr>
<td>0.52</td>
<td>23.9</td>
<td>77</td>
<td>2,990</td>
</tr>
<tr>
<td>0.56</td>
<td>23.4</td>
<td>75</td>
<td>3,201</td>
</tr>
<tr>
<td>0.60</td>
<td>23.4</td>
<td>75</td>
<td>3,325</td>
</tr>
</tbody>
</table>
Average Pressure Distribution for Two-Part Pad Assembly
Rail Pad Comparison at 0.52 L/V

- Load Applied:
  - 32.5 kip vertical
  - 16.9 kip lateral

<table>
<thead>
<tr>
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<th>Contact Area (in²)</th>
<th>Peak Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPV</td>
<td>25.8</td>
<td>2,925</td>
</tr>
<tr>
<td>MDPE</td>
<td>19.0</td>
<td>3,721</td>
</tr>
<tr>
<td>Two-Part Pad Assembly</td>
<td>23.9</td>
<td>2,990</td>
</tr>
</tbody>
</table>
Clip Test

- **Objective**: gain preliminary understanding of effect of clip geometry on pressure distribution
- Rail pad material held constant
- Identical loading conditions
  - 32.5 kip vertical load
  - Lateral load varies based on respective L/V ratio

<table>
<thead>
<tr>
<th></th>
<th>Clip A</th>
<th>Clip B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Toe Load, lbs</td>
<td>4,750</td>
<td>5,500</td>
</tr>
<tr>
<td>Spring Rate*, lb/in</td>
<td>8,223</td>
<td>6,286</td>
</tr>
</tbody>
</table>

*Value based on manufacturer’s design toe load at a given deflection
## Clip Test Results

### Clip A
- **Contact Area (in²)**
  - 0.25: 28.4
  - 0.44: 26.6
  - 0.52: 23.6
  - 0.60: 16.6
- **% of Rail Seat**
  - 0.25: 84%
  - 0.44: 78%
  - 0.52: 70%
  - 0.60: 49%
- **Peak Pressure (psi)**
  - 0.25: 2,188
  - 0.44: 2,327
  - 0.52: 2,872
  - 0.60: 3,809

### Clip B
- **Contact Area (in²)**
  - 0.25: 27.6
  - 0.44: 24.5
  - 0.52: 21.0
  - 0.60: 17.2
- **% of Rail Seat**
  - 0.25: 81%
  - 0.44: 72%
  - 0.52: 62%
  - 0.60: 51%
- **Peak Pressure (psi)**
  - 0.25: 2,744
  - 0.44: 3,067
  - 0.52: 3,385
  - 0.60: 4,083

### Pressure (psi) Scale
- 0 1000 2000 3000 4000
Average Pressure Distribution for Clip B

Pressure (psi) vs. Distance from Gauge Edge of Sensor on Rail Seat (in.)

L/V Ratio:
- 0.60
- 0.52
- 0.44
- 0.25

Gauge vs. Field Comparison

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Conclusions from Testing

• **Effect of L/V Ratio**
  – Lower L/V ratios distribute the pressure over a larger contact area
  – Higher L/V ratios cause a concentration of pressure on the field side of the rail seat
    • Results in higher peak pressures

• **Rail Pad Test**
  – Lower modulus rail pads distribute rail seat loads over a larger contact area
    • Reduces peak pressure values
    • Mitigates highly concentrated loads at this interface
  – Higher modulus rail pads distribute rail seat loads in more highly concentrated areas
    • Possibly leads to localized crushing of the concrete surface
  – Two-Part Pad Assembly
    • Maintains relatively consistent contact area under increasing L/V ratios
    • Peak pressures similar to the lower modulus TPV pad
Conclusions from Testing (cont.)

- **Fastening Clip Test**
  - Design of the clip component of the fastening system affects the shape of the pressure distribution on the rail seat
  - Minimal differences in peak pressures and contact areas of pressure distribution between the two clips tested in the experiment
Future Work with MBTSS

- Field testing at TTC in Pueblo, CO to understand pressure distribution varying track and loading conditions
  - Instrument high and low rail seats of a crosstie to compare varying track geometries
  - Instrument consecutive rail seats to see load transfers between crossties
  - Continue pad modulus testing within bounded experiments
- Continue testing common North American fastening systems
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Questions / Comments

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