UIUC FRA Crosstie and Fastening System BAA 2014-2: Investigation of Deteriorated Crossties and Support Conditions

Experimental Matrix Development

FRA and FTA Crosstie and Fastening System Research Program
Industry Partners (IP) Meeting
Tucson, AZ
4 November 2015
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Outline

• Project Introduction
• Motivation for Research
  – FRA Accident Database
  – Literature Review
  – Industry Survey
• Laboratory Experimentation
  – Equipment
  – Experimental Matrix
• Expected Industry Impact
• Preliminary Conclusions
Current FRA Concrete Crosstie Research at UIUC

- Prior FRA-funded concrete crosstie research at UIUC focused on new track components and optimal track geometry and support conditions.

- Current project focuses on degraded components and sub-optimal track conditions:
  - Component level
  - System level

- Laboratory experiments, field experiments, finite element modeling (FEM), expert opinion, and literature review are used to maximize impact on:
  - CFR 213 (Track Safety Standards)
  - AREMA Chapter 30 (Ties)
  - Crosstie manufacturers
  - Railroads
  - Researchers

FRA BAA 2014-2
Objectives and Deliverables

- **Program Objectives**
  - Determine common failure types and quantify the common track conditions in repeat failure locations
  - Quantify the effect worn/degraded track conditions have on critical track component’s stress state via conducting:
    - Laboratory experimentation
    - Finite Element Modeling (FEM) parametric studies incorporating poor support conditions

- **Program Deliverables**
  - Improved mechanistic design recommendations for concrete crossties and fastening systems in the US
  - Proposed revisions to AREMA Recommended Practices
  - Improved safety due to increased strength of critical infrastructure components and revisions to FRA Track Safety Standards, CFR 213
  - Industry outreach and workforce development
FRA Accident Database Analysis

- Performed analysis of 10 years of accident data from the FRA accident database, from 2004 to 2013, filtering for the following accident causes:
  - **T001** Roadbed settled or soft
  - **T105** Insufficient ballast section
  - **T110** Wide gage (due to defective or missing crossties)
  - **T111** Wide gage (due to defective or missing spikes or other rail fasteners)
  - **T205** Defective or missing crossties
  - **T206** Defective spikes or missing spikes or other rail fasteners (use code T111 if results in wide gage)

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Overview of Track-caused Derailments

*This analysis considers only main lines of Class 1 railroads*
Track-caused Derailment Analysis

All Crosstie Types

Severity (average number of cars derailed per accident)

- Defective fastening system
- Insufficient ballast section
- Defective crossties
- Wide gage due to defective fastening system
- Roadbed settled or soft
- Wide gage due to defective crossties

Average frequency for all track, roadbed and structures related accidents

*This analysis considers only main lines of Class I railroads

Frequency (total number of accidents from 2004 to 2013)

Concrete Crossties

Severity (average number of cars derailed per accident)

- Defective fastening system
- Roadbed settled or soft
- Wide gage due to defective crossties
- Insufficient ballast section

Average frequency for all accidents caused by the plotted conditions

*This analysis considers only main lines of Class I railroads with concrete crossties

Average cars derailed for all accidents caused by the plotted conditions

Frequency (total number of accidents from 2004 to 2013)
Understanding the Accident Causes

• **Roadbed settled or soft:**
  - Weak subgrade offering poor track support
  - Poor drainage areas affecting track stiffness and removal of excess water

• **Wide gage due to defective or missing crossties:**
  - Rail cant deficiency (e.g. rail seat deterioration)
  - Cracked crossties (e.g. center cracking, rail seat cracking, etc.)
  - Missing crossties

Development of Initial Experimental Matrix

- Literature Review
- Industry Survey
- FRA Accident Database
- Expert Opinion

Initial Laboratory Experimental Matrix
Literature Review

- Volpe report on 2013 derailment of CSX freight train on Metro-North tracks in Bronx, NY

- Caused by combination of degraded track conditions caused derailment as presented within report:
  - Poor drainage
  - High temperature induced rail to push under insulator
  - Center bound and worn crossties

- Accident cause reported to FRA as *T110 Wide Gage* (due to defective or missing crossties)


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Development of Initial Experimental Matrix

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Initial Laboratory Experimental Matrix
## Industry Survey

### Content and Audience

- **Mission:** quantify common failure types and understand research needs

- **Objectives:**
  - Develop criticality ranking of specific track superstructure problems and FRA accident codes
  - Pairing track problems that could lead to derailments when combined
  - Identify laboratory tests that are relevant to the industry

- **14 survey respondents**, all industry experts in one of the following categories:
  - Railway infrastructure owner, operator, or maintainer
  - Academic, industry, or institutional researcher
  - Concrete crosstie or fastening system manufacturer

## Industry Survey Results

### Criticality Ranking of Problems

<table>
<thead>
<tr>
<th>Problem (higher rank is more critical)</th>
<th>Average Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail seat deterioration and other forms of rail cant deficiency</td>
<td>4.57</td>
</tr>
<tr>
<td>Worn or missing shoulder</td>
<td>4.14</td>
</tr>
<tr>
<td>Worn or missing insulator</td>
<td>3.79</td>
</tr>
<tr>
<td>Missing clip</td>
<td>3.71</td>
</tr>
<tr>
<td>Center negative crosstie bending</td>
<td>3.43</td>
</tr>
<tr>
<td>Missing rail pad</td>
<td>3.36</td>
</tr>
<tr>
<td>Fouled ballast</td>
<td>3.21</td>
</tr>
<tr>
<td>Insufficient depth of ballast</td>
<td>3.00</td>
</tr>
<tr>
<td>Weak subgrade</td>
<td>3.00</td>
</tr>
<tr>
<td>Concrete crosstie with deteriorated bottom</td>
<td>2.93</td>
</tr>
<tr>
<td>Rail seat positive crosstie bending</td>
<td>2.45</td>
</tr>
</tbody>
</table>
### Survey Results

**Criticality of FRA Accident Codes**

<table>
<thead>
<tr>
<th>FRA Accident Code (higher rank is more critical)</th>
<th>Average Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide gage due to defective or missing crossties (T110)</td>
<td>4.33</td>
</tr>
<tr>
<td>Wide gage due to defective or missing spikes or other rail fasteners (T111)</td>
<td>4.25</td>
</tr>
<tr>
<td>Defective or missing crossties (T205)</td>
<td>3.64</td>
</tr>
<tr>
<td>Defective spikes or missing rail fasteners (T206)</td>
<td>3.42</td>
</tr>
<tr>
<td>Roadbed settled or soft (T001)</td>
<td>3.25</td>
</tr>
<tr>
<td>Insufficient ballast section (T105)</td>
<td>3.00</td>
</tr>
</tbody>
</table>

- **Fouled ballast**
- **Rail seat deterioration**

### Survey Results

**Ranking of Paired Problem**

- Votes indicate the number of survey respondents that considered that the problem pair could lead to a derailment

<table>
<thead>
<tr>
<th>Problem Pair (there were 14 survey takers)</th>
<th>Votes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail seat deterioration and other forms of rail cant deficiency Worn or missing shoulder</td>
<td>11</td>
</tr>
<tr>
<td>Worn or missing insulator Worn or missing shoulder</td>
<td>11</td>
</tr>
<tr>
<td>Center negative crosstie bending Concrete crosstie with deteriorated bottom</td>
<td>10</td>
</tr>
<tr>
<td>Missing clip Worn or missing shoulder</td>
<td>10</td>
</tr>
<tr>
<td>Rail seat deterioration and other forms of rail cant deficiency Missing clip</td>
<td>9</td>
</tr>
</tbody>
</table>
Survey Results

Essay Question on Laboratory Experiments

• Out of 14 survey respondents:

  – 6 would like to see different support conditions and center negative crosstie bending tested in a laboratory

  – 4 would like to see cracked crossties tested in a laboratory

  – 3 would like to see wet ballast tested in a laboratory

Development of Initial Experimental Matrix

- Literature Review
- Industry Survey
- FRA Accident Database
- Expert Opinion

Initial Laboratory Experimental Matrix
Development of Initial Experimental Matrix

- Literature Review
- Industry Survey
- FRA Accident Database
- Expert Opinion

Initial Laboratory Experimental Matrix

Experimental Variables

**Support Conditions**

- **Support conditions**
  - Proper support
  - Center binding
  - Rail seat positive

- **Cases were based on:**
  - Field conditions
  - Expert opinion
  - Industry partners feedback on draft experimental matrix
Experimental Variables

Crosstie Cracking

- All cracks were generated with a severe center binding condition, with rail seat load of 20 kips applied at both rail seats

• Cracks along the crosstie span were approximately symmetric about the center
• Cracks closed up after unloading (indication of prestressing members)
• Cracks were deeper than the first level of prestress (e.g. AREMA failure for center negative test)
• Cracked crossties are not classified as failed ties according to CFR 213

Defining Failed Concrete Crossties

- FRA – CFR 213 (Track Safety Standards)
  - Broken through or deteriorated to the extent that prestressing material is visible;
  - Deteriorated or abraded at any point under the rail seat to a depth of ½ inch or more;
  - Configured with less than two fasteners on the same rail;
  - […]

- AREMA Chapter 30 (Ties)
  - Various standardized laboratory tests
    • Crack beyond first level of presstress for center negative test

- Railroads (Specific Track Maintenance Standards)
  - Various thresholds for different railroads
Experimental Matrix

- Matrix was executed five times to account for variability
- 12 combinations of support conditions and crosstie health variation

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Support Condition</th>
<th>Crosstie Condition</th>
<th>Purpose</th>
<th>Vertical Load Applied to Each Rail Seat Simultaneously</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>kips</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Healthy Crotie</td>
<td>Baseline - Healthy Crotie, Full Support</td>
<td>0-20</td>
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<tr>
<td>2</td>
<td>2</td>
<td>Healthy Crotie</td>
<td>Healthy Crotie, Light Center Binding</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Healthy Crotie</td>
<td>Healthy Crotie, Moderate Center Binding</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Healthy Crotie</td>
<td>Healthy Crotie, Severe Center Binding</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Healthy Crotie</td>
<td>Healthy Crotie, High Impact Loads (Rail Seat Positive)</td>
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</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Healthy Crotie, Newly Tamped</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Deep Cracks, Full Support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>Deep Cracks, Light Center Binding</td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>3</td>
<td>Deep Cracks, Moderate Center Binding</td>
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<td>11</td>
<td>5</td>
<td>Deep Cracks, High Impact Loads (Rail Seat Positive)</td>
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</tr>
<tr>
<td>12</td>
<td>6</td>
<td>Deep Cracks, Newly Tamped</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurement Devices

- **Surface Strain Gauges**
  - Calculation of bending moments

- **Linear Potentiometers**
  - Measurement of vertical displacements
  - Estimation of crosstie shape
Laboratory Experimentation Equipment

- Loading frame

- Supporting rubber pads

Expected Industry Impact

<table>
<thead>
<tr>
<th>Impact</th>
<th>Railroads</th>
<th>FRA - CFR 213</th>
<th>AREMA Chapter 30</th>
<th>Crosstie Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consensus on definition of failed concrete crossties</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Input on expected crosstie bending moments</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Input on expected concrete crosstie deflections and gage widening effect based on crosstie shape</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimation of crosstie support conditions based on bending moment measurements and cracking observation</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Preliminary Conclusions and Path Forward

- **Wide gage due to defective or missing crossties** and **Roadbed settled or soft** are two of the most common track related accident causes in the US for both timber and concrete crossties.

- Industry Survey results indicated the need for research on
  - Crosstie support conditions
  - Crosstie cracking

- Results from this project will guide future experimentation using the **Track Loading System (TLS)** at UIUC.

TLS at RailTEC’s RAIL

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  - Hanson Professional Services, Inc.
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  - TTX Company
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  - Hailing Yu and Ted Sussmann
- RailTEC Team
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