Top 10 Findings and Outcomes
FRA Crosstie and Fastening System
BAA 2010-1 Research Program

2 April 2015
Riley Edwards, Marcus Dersch, and Yu Qian
FRA Crosstie and Fastening System Research Program – Select Impacts

1. Quantification of wheel loads
2. Development of technique for measuring lateral forces
3. Quantification of rail seat pressures
4. Development of revised crosstie bending analysis methodology
5. Development of full-scale laboratory setup (RAIL)
6. Performance modeling tools
7. Mechanistic design framework for ties/fasteners
8. Additions and Revisions to AREMA Chapter 30 (Ties)
9. Industry outreach
10. Workforce development (student education and career placement)
1. Quantification of Peak Wheel Loads

- Freight Locomotives
- Intermodal Freight Cars
- Passenger Coaches
- Passenger Locomotives
- Other Freight Cars

10 kips ≈ 45 kN
Comparison of Dynamic Wheel Load Factors

- Talbot
- Indian Railways
- Eisenmann
- ORE/Birmann
- German Railways
- South African Railways
- Clarke
- WMATA
- Sadeghi

**Graph Details:**
- **Y-axis:** Dynamic Factor, $\phi$
- **X-axis:** Speed (mph)

**Legend:**
- Freight Cars
- Locomotives
- Passenger Coaches

**Conversion Note:**
10 mph $\approx$ 16 kph
2. Successful Development of Lateral Force Measurement Technology

- Development and testing of Lateral Load Evaluation Device (LLED)
  - Original shoulder face is removed
  - Insert designed as a beam and optimized to replace removed section and maintains original geometry
  - Measures bending strain of beam under 4-point bending
Lateral Load Data – Sample Field Results

- Force (lbf)
- Force (kN)
- 0
- 1,000
- 2,000
- 3,000
- 4,000
- 5,000
- 6,000
- 0
- 6
- 12
- 18
- 24
- 27

- 20 kips
- 40 kips

Crossties and Fastening Systems – State of the Program Address
3. Quantifying Rail Seat Pressure Magnitude and Distribution

Rail

Pad/Abrasion Plate
- BoPET: 0.007"
- PTFE: 0.006"
- Sensor: 0.004"
- PTFE: 0.006"
- BoPET: 0.007"

Gauge
Field

Matrix Based Tactile Surface Sensor

Cast-in Shoulders
Concrete Crosstie

MBTSS Setup

Concrete Crosstie
Rail Seat Pressure Distribution Data

% Initial Contact Area

3:  62%
11: 58%

Unloaded

Increasing Pressure

40 kips

20 kips
## Rail Pad Assemblies - Pressure Distribution

Loading: 32.5kip (145kN) vertical, 16.9kip (75kN) lateral (0.52 L/V Force Ratio)

<table>
<thead>
<tr>
<th>Contact Area: $\text{in}^2 (\text{cm}^2)$</th>
<th>Max Pressure: psi (kPa)</th>
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<tbody>
<tr>
<td>25.8 (166)</td>
<td>2,925 (20,000)</td>
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<tr>
<td>19.0 (123)</td>
<td>3,721 (25,600)</td>
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<tr>
<td>23.9 (154)</td>
<td>2,990 (20,600)</td>
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Pulsating Load Testing Machine (PLTM)
4. Development of Revised Crosstie Bending Moment Analysis Method

- Cracking from dynamic loads and center cracking considered critical problems in North America and Internationally
- Current AREMA analysis methodology reviewed and found to be insufficient
- Proposed changes to AREMA Chapter 30:
  - Improve clarity of analysis methodology
    - Accepted as of October 2014
  - Increase center moment capacity to reduce center negative cracks
    - To be discussed further during Spring 2015
## Comparison of International Bending Moment Analysis Methods

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<tr>
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<th>AREMA C30.4</th>
<th>UIC 713R</th>
<th>AS 1085.14</th>
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<tr>
<td>Rail Seat Load kips (kN)</td>
<td>62.1 (276.2)</td>
<td>66.4 (295.4)</td>
<td>53.3 (237.1)</td>
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<tr>
<td>Rail Seat Positive kip-in (kN-m)</td>
<td>300 (33.9)</td>
<td>224 (25.3)</td>
<td>280 (31.6)</td>
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<tr>
<td>Rail Seat Negative kip-in (kN-m)</td>
<td>-159 (-18.0)</td>
<td>-112 (-12.7)</td>
<td>-187 (-21.1)</td>
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<tr>
<td>Center Positive kip-in (kN-m)</td>
<td>141 (15.9)</td>
<td>209 (23.6)</td>
<td>112 (12.7)</td>
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<tr>
<td>Center Negative kip-in (kN-m)</td>
<td>-201 (-22.7)</td>
<td>-299 (-33.8)</td>
<td>-240 (-27.1)</td>
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</table>
Comparison Between Current and Proposed ($M_C$-)

![Graph showing comparison between current and proposed crosstie spacing and bending moment](image-url)
5. Development and Use of a Full-Scale Track Loading System
6. Performance Modeling Tools

- Crosstie and fastening system finite element model (FEM)
  - Quantify effect of design modifications to components
    - Geometry, material properties, tolerances, etc.
  - Quantify effect of system modifications:
    - Tie spacing, etc.

- I-TRACK design software
  - User friendly (compared to FEM)
  - Quickly quantify effect of:
    - Design change already studied by FEM
      - Component geometry, material, etc.
    - Load applied to rail (vertical and lateral)
Development and Validation of Crosstie and Fastener Finite Element (FE) Model

- Development of both multiple-tie and single-tie models
- Validated with laboratory and field data
- Ability to run parametric analyses
Development of Simplified Design Software (I-TRACK)

- Software based on statistical analyses of the UIUC FE model
- A neural network model was developed to predict track components responses based on user defined inputs
I-TRACK Preliminary Project Phases

- The development of I-TRACK follows a systematic process. The project was divided in 3 phases, which add additional complexity and analysis capabilities.

- Goal: expedite the development of I-TRACK, test the model accuracy and functionalities on a continuous basis, and provide interim utility to end users.

Phase I: I-TRACK Version 1.0

- Vertical Wheel Load
- Lateral Wheel Load
- Clip Young’s Modulus
- Insulator Young’s Modulus
- Rail Pad Young’s Modulus
- Track Vertical and Lateral Deflection
- Clamping Force
- Clip Max Stress
- Rail Base Lateral Translation
- Abrasion Frame Lateral Translation
- Rail Seat Load
- Max Rail Seat Pressure
7. Mechanistic Design Framework

- Design approach utilizing forces measured in track structure and properties of materials that will withstand or transfer them
- Uses responses (e.g. contact pressure, relative displacement) to optimize component geometry and materials requirements
- Based on measured and predicted response to load inputs that can be supplemented with practical experience
- Requires thorough understanding of load path and distribution
- Allows load factors to be used to include variability due to location and traffic composition
- Used in other engineering industries (e.g. pavement design, structural steel design, geotechnical)
Mechanistic Component Design Example

1. Define Load Inputs
2. Define Design Criteria
3. Component Design
4. System Verification
## 8. Changes to AREMA Chapter 30 (Ties)

- **Multiple proposed changes to AREMA Chapter 30 (5 Total)**
- **Driven by students funded on this project (and through IPs)**

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<tr>
<th>Proposed Ballot Title</th>
<th>Description of Ballot</th>
<th>Lead Student</th>
<th>Status</th>
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<tr>
<td>Addition of Rail Seat Load Distribution</td>
<td>Introduce language characterizing the loading environment at the rail seat, which may affect crosstie failure mechanisms associated with Rail Seat Deterioration (RSD).</td>
<td>Matthew Greve</td>
<td>PASSED</td>
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<td>Amendments to Loading Environment</td>
<td>Update section 1.2 Load Environment, which covers wheel to rail loads of North American freight and passenger traffic. Revisions are intended to update the load table currently provided in AREMA using modern traffic data.</td>
<td>Andrew Scheppe</td>
<td>PASSED</td>
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<td>Addition of Lateral Load Distribution</td>
<td>Add language to the proposed sections stating that lateral load distribution may not mimic vertical load distribution as previously hypothesized. Also, that fastening system design (e.g. friction, stiffness) will have an effect on lateral load distribution.</td>
<td>Brent Williams</td>
<td>PASSED</td>
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<td>Crosstie Flexural Capacity Analysis Method</td>
<td>Update sections on flexural analysis of concrete crossties to address issues with current analysis process and introduce new and improved method of analysis.</td>
<td>Henry Wolf</td>
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9. Industry Outreach: Papers, Posters, and Presentations

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<th>Year</th>
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Total 54 61 24
## RailTEC Crosstie Journal Articles

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<tr>
<td>2012</td>
<td>American Concrete Institute (ACI) Materials</td>
<td>RSD Mechanisms</td>
<td>Zeman</td>
<td>In Press</td>
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<td>2013</td>
<td>Transportation Research Record (TRR)</td>
<td>Rail Seat Pressures</td>
<td>Rapp</td>
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<td>2013</td>
<td>ASTM Advances in Civil Engineering Materials</td>
<td>SSART Abrasion</td>
<td>Shurpali</td>
<td>Final Internal Review</td>
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<td>Journal of Rail and Rapid Transit (JRRT)</td>
<td>Small and Large Scale Abrasion Research</td>
<td>Kernes</td>
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<td>Comparison of Dynamic Factors</td>
<td>Van Dyk</td>
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International Crosstie and Fastening System Symposia (2012 and 2014)

- Co-organized by: AREMA Committee 30 (Ties), Railway Tie Association (RTA)
- **2014 Event: 140 total attendees**
- Focus → state of the art in timber, concrete, and composite crosstie and fastening system design, performance, research, modeling, and inspection
- Presentations available at: http://railtec.illinois.edu/Crosstie/2014/presentation.php
- THANKS FOR SPONSORSHIP from INDUSTRY PARTNERS!
10. Our role in Rail Workforce Development...

RailTEC Tie and Fastener Team in June 2014
Industry Placement

• Crosstie Manufacturer
  – Mauricio Gutierrez: GIC
  – Ryan Kernes: GIC

• Fastening System Manufacturer
  – Thiago Bizarria: Vossloh Fastening Systems
  – Brandon Van Dyk: Vossloh Fastening Systems

• Rail Engineering Design Firm
  – Chris Rapp: Hanson Professional Services
  – Andrew Scheppe: Hanson Professional Services
  – Amogh Shurpali: BARSYL

• Academia/Research
  – Moochul Shin: Western New England University
UIUC FRA Crosstie and Fastening System BAA 2014-2: Investigation of Deteriorated Crossties and Support Conditions

3 Year Research Program
2015 - 2017
Riley Edwards, Bassem Andrawes, Marcus Dersch, Yu Qian, and Josué César Bastos
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
Resilient Concrete Crosstie and Fastening System Designs for Light Rail, Heavy Rail, and Commuter Rail Transit Infrastructure

Funded by:
Federal Transit Administration (FTA)

Rail Transportation and Engineering Center (RailTEC)

University of Illinois at Urbana-Champaign

2.5 Year Program 2015 - 2017
FTA Research Project
Objectives and Deliverables

• **Program Objectives**
  
  – Conduct extensive literature review regarding current design practices and needs
  
  – Quantify the loads entering rail transit infrastructure:
    
    • Laboratory and field experimentation
    
    • Finite Element Modeling (FEM)
  
  – Develop mechanistic design recommendations for crossties and fasteners

• **Program Deliverables**
  
  – Quantification of loading conditions for rail transit
  
  – Improved mechanistic design recommendations for concrete crossties and fastening systems for rail transit
  
  – Proposed revisions to AREMA Recommended Practices for rail transit
Acknowledgements

FRA Tie and Fastener BAA Industry Partners:

FTA Tie and Fastener Industry Partners:
Acknowledgements

Funding for this research has been provided by:
- Federal Transit Administration (FTA)

Industry Partners:
- New York City Transit (New York, NY)
- TriMet (Portland, OR)
- Metra (Chicago, IL)
- MetroLink (St. Louis, MO)
- National Railway Passenger Corporation (Amtrak)
- Amsted RPS, Inc.
- Pandrol USA
- GIC
- Hanson Professional Services, Inc.
- CXT Concrete Ties, Inc., LB Foster Company
- American Public Transportation Association (APTA)
Other Supporting Organizations

- BNSF
- Union Pacific
- Building America
- AMTRAK
- Norfolk Southern
- CSX
- CN
- CP
- U.S. Department of Transportation
- Federal Railroad Administration
- RPS
- GIC
- LB Foster
- Hanson
- Nortrax
- Pandrol
- Vossloh
- TCI
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