Experimentation and Modeling of Concrete Crossties and Fastening Systems

Wheel Rail Interaction Conference

8-9 May 2013

Chicago, IL USA

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Outline

• Background and Research Justification
• RailTEC Concrete Crosstie Research
• Mechanistic Design Introduction
• Key Research Thrust Areas and Summary of Results
  – Laboratory Instrumentation
  – Field Instrumentation
  – Analytical Methods (FEA)
• Future Work
• Acknowledgements
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Concrete Crossties – Overview of Use

• Typical Usage:
  – Freight → Heavy tonnage lines, steep grades, and high degrees of curvature
  – Passenger → High density corridors (e.g. Amtrak’s Northeast Corridor [NEC])
  – Transit applications

• Number of concrete ties in North America*:
  – Freight → 25,000,000
  – Passenger → 2,000,000
  – Transit → Significant quantities (millions)

*Approximate
Fastening System Components

- Rail
- Field
- Gauge
- Insulator
- Clip
- Shoulder
- Rail pad assembly
- Concrete crosstie
Complete System

8-9 ft

56.5 in

8-13 in

6-10 in

Prestress wire or strand

Shoulder insert

Insulator Clip

Tie pad between rail base and rail seat
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Concrete Crosstie and Fastener Research Levels (and Examples)

**Materials**
- Concrete Mix Design
- Rail Seat Surface Treatments
- Pad / Insulator Materials

**Components**
- Fastener Yield Stress
- Insulator Post Compression
- Concrete Prestress Design

**System**
- Finite Element Modeling
- Full-Scale Laboratory Experimentation
- Field Experimentation
## 2012 International Survey Results – Criticality of Problems

<table>
<thead>
<tr>
<th>Problem (higher ranking is more critical)</th>
<th>Average Rank</th>
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<tbody>
<tr>
<td><strong>International Responses</strong></td>
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<tr>
<td>Tamping damage</td>
<td>6.14</td>
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<tr>
<td>Shoulder/fastening system wear or fatigue</td>
<td>5.50</td>
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<tr>
<td>Cracking from center binding</td>
<td>5.36</td>
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<tr>
<td>Cracking from dynamic loads</td>
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<td>Cracking from environmental or chemical degradation</td>
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<td>Derailment damage</td>
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<tr>
<td>Other (e.g. manufactured defect)</td>
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<tr>
<td>Deterioration of concrete material beneath the rail</td>
<td>3.15</td>
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<tr>
<td><strong>North American Responses</strong></td>
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<tr>
<td>Deterioration of concrete material beneath the rail</td>
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Current Design Process

• Found in AREMA Manual on Railway Engineering
• Based largely on practical experience:
  – Lacks complete understanding of failure mechanisms and their causes
  – Empirically derives loading conditions (or extrapolates existing relationships)
• Can be driven by production and installation practices
• Improvements are difficult to implement without understanding complex loading environment
Principles of Mechanistic Design

1. Quantify track system input loads (wheel loads)
2. Qualitatively establish load path (free body diagrams, basic modeling, etc.)
3. Quantify demands on each component
   a. Laboratory experimentation
   b. Field experimentation
   c. Analytical modeling
4. Link quantitative data to component geometry and materials properties (materials decision)
5. Relate loading to failure modes
6. Investigate interdependencies through modeling
7. Establish mechanistic design practices and incorporate into AREMA Recommended Practices
Determining System Input Loads

• Quantitative methods of data collection (Step 1):
  – Wheel Impact Load Detectors (WILD)
  – Instrumented Wheel Sets (IWS)
  – Truck Performance Detectors (TPD)
  – UIUC Instrumentation Plan (FRA Tie BAA)

• Most methods above are used to monitor rolling stock performance and assess vehicle health

• Can provide insight into the magnitude and distribution of loads entering track structure
  – Limitations to WILD: tangent track (still need lateral curve data), good substructure (not necessarily representative of the broader rail network)
Vertical Wheel Loads – Shared Infrastructure

Source: Amtrak – Edgewood, MD (November 2010)
Effect of Traffic Type on Peak Wheel Load

Source: Amtrak – Edgewood, MD (November 2010)
Dynamic Wheel Load Factors

![Graph showing dynamic wheel load factors for various types of rail vehicles and speed factors.](image)

- Freight Cars
- Locomotives
- Passenger Coaches

Source: Amtrak – Edgewood, MD (November 2010)
More than a Dynamic Factor: Impact Factor

Impact Factor (IF) = \frac{\text{Peak Load}}{\text{Static Load}}

Source: UPRR – Gothenburg, NE (January 2010)
So What is Our Design Threshold?

*Need curves for each component / interface and failure mode
Development of Quantitative Loading Model

- Peak Vertical Wheel Load vs. Speed
- Car Type 1
- Car Type 2
- Car Type 3
- Confidence interval

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Development of Quantitative Loading Model

Conceptual Sketch

Locomotives

- 286k Freight Car (Empty)
- 315k Freight Car (Load)

Pass. Coach 1

- 286k Freight Car (Load)
- 315k Freight Car (Empty)

Peak Vertical Wheel Load

Nominal Vertical Wheel Load
Establishment of the Qualitative Load Path

Subscripts:
- b = rail base
- p = pad
- i = insulator clip bearing area
- c = clip
- s = shoulder
- o = insulator post
- t = sleeper

Legend:
- Reaction
- Input Load
- F = Field
- G = Gauge
- B = Base
Rail Seat Load Calculation Methodologies

Wheel Load (kips)

Wheel Load (kN)

Rail Seat Load (kN)

Analysis courtesy of Christopher Rapp
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FRA Tie and Fastening System BAA Objectives and Deliverables

- **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

- **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
Quantification of Lateral Loads Entering the Shoulder Face (Insert)

• Instrumented shoulder face insert
  – Original shoulder face is removed
  – Small beam insert replaces removed section
  – 4-point bending beam experiment
    • Beam strategy is a well-established, successful technology
Transfer of Lateral Load to Shoulder Face

32.5 kip vertical load, 0.5 L/V ratio
Percent of Lateral Load Transferred to Shoulder
Preliminary Data
Full Scale Track Response Experimental System
Full Scale Track Response Experimental System
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Goals of Field Instrumentation

- Lay groundwork for mechanistic design of concrete crossties and elastic fasteners
- Quantify the demands placed on each component within the system
- Develop an understanding into field loading conditions
- Provide insight for future field testing
- Collect data to validate the UIUC concrete crosstie and fastening system FE model
Areas of Investigation

**Rail**
- Stresses at rail seat
- Strains in the web
- Displacements of web/base

**Fasteners/Insulator**
- Strain of fasteners
- Stresses on insulator

**Concrete Crossties**
- Moments at the rail seat
- Stresses at rail seat
- Vertical displacements of crossties
TTCl Field Testing Locations

High-Tonnage Loop (HTL)

5 degree curve spiral
Balance Speed = 33 mph

Tangent
Speeds up to 105 mph

Railroad Test Track (RTT)
Loading Environment

- Track Loading Vehicle (TLV)
  - Static
  - Dynamic
    - Track modulus
- Freight Consist
  - 6-axle locomotive (393k)
  - Instrumented car
  - Nine cars
    - 263, 286, 315 GRL Cars
- Passenger Consist
  - 4-axle locomotive (255k)
  - Nine coaches
    - 87 GRL
Fully Instrumented Rail Seats
Instrumented Low Rail
Field-side Instrumentation

- Vertical Tie Displacement
- Clip Strain
- Base Displacement
- Vertical Web Strain
Gauge-side Instrumentation

Lateral Rail Displacement
Data Acquisition System
Tangent Track (RTT) – Passenger Train
Leading axles of a 10-car freight train (30, 33, and 36t axle loads).
Lateral Loads on Tangent Track (Freight)

Leading axles of a 10-car freight train (30, 33, and 36t axle loads).

- No correlation between lateral loads and train speed on tangent track.
RTT Curved Instrumentation – Train Pass
Lateral Loads Acting on a Curve Track

- Median load is ~5.5 times larger than what was recorded in tangent track.

Leading axles of a 10-car freight train (30, 33, and 36t axle loads).
Global Track Deflections Under Passage of Freight Train
Vertical Displacements of Crossties (HTL)
Effect of Train Speed on Tie Deflection

No significant relationship between train speed and tie deflection
Deflections from train passes do not exceed static response: typically 60% (passenger) and 75% (freight)
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Concrete Crosstie and Fastening System

- Rail
- Pad & Abrasion frame
- Insulator
- Clip
- Shoulder
- Concrete Crosstie
Component Modeling: Validation

- Clip Model

Stress concentration due to support

Mises stress contour (Clamping force = 11.6 kN)

Clamping force-displacement curves
Component Modeling: Concrete Crosstie and Ballast

Static loading of the model

Deformation contour
System Model: Multiple-Tie Modeling

- Track loading vehicle (TLV) applying vertical and lateral loads to the track structure in field
- The symmetric model including 5 crossties

Simplified model: Fastening system were replaced by BCs and pressure

Detailed model with the fastening system
System Modeling: Lateral Load Path

36 Kip Vertical Load

Lateral Load

Lateral Load Path

Friction (F1)

Friction + Insulator Post +Shoulder to Pad

Insulator Post (F2)

Shoulder to Pad (F3)

Force (lb)

L/V Ratio

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Current Research Thrust Areas

• Continued **data analysis** to understand the governing mechanics of the system by investigating the:
  – elastic fastener (clamp) strain response
  – number of ties effected simultaneously
  – bending modes of the crossties
  – pressure magnitude and distribution at the rail seat

• Continued **comparison and validation** of the UIUC tie and fastening system finite element model (Chen, Shin)

• Preparation for **instrumentation trip** (May 2013)
  – Focus on lateral load path by gathering
    • relative lateral tie displacements
    • global lateral tie displacements
    • load transferred to the clip, insulator-post, and shoulder

• Small-scale, **evaluative tests** on Class I Railroads
RailTEC Concrete Tie Research Team

• Previous Personnel
  – 3 Graduate Research Assistants
  – 6 Undergraduate Research Assistants

• Current Personnel
  – 9 Graduate Research Assistants
  – 1 Postdoctoral Researcher
  – 6 Undergraduate Research Assistants
  – 2 Research Engineers
  – 5 Faculty
Acknowledgements

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FRA Tie and Fastener BAA Industry Partners:
Other Supporting Organizations

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AMTRAK

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CN
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U.S. Department of Transportation
Federal Railroad Administration

Amsted RPS
Amsted Rail
GIC

LB Foster
CXT Concrete Ties
HANSON
NORTRAK

PANDROL
vossloh

TCI Transportation Technology Center, Inc.

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