Crosstie and Elastic Fastener Field Experimentation for Mechanistic Design

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Outline

- Introduction
  - Components
  - Purpose for Research
  - Project Structure
- Field Experimentation
  - Objectives
  - Instrumentation Strategy
  - Testing at Transportation Technology Center (TTC)
- Experimental Results and Preliminary Findings
  - Vertical Load Path
  - Lateral Load Path
- 3D Finite Element Model
- Future Work
General Assembly

Rail

Field

Gauge

Concrete crosstie

Rail pad assembly

Shoulder

Clip

Insulator

Clip

Insulator

Shoulder
Common Concrete Crosstie and Fastener Failures

- Rail seat positive flexural cracking
- Center negative flexural cracking
- Prestress wire bond loss
- Broken shoulder
- Rail seat deterioration
- Insulator post wear
- Fastener fatigue
- Pad wear
FRA Tie and Fastener Project Structure

**Inputs**

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

**Modeling**

**Laboratory Study**

**Field Study**

**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

Improved Recommended Practices

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*Indianapolis, IN*
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/tie center
- Stresses at rail seat
- Vertical/Lateral displacements of crossties
Field Instrumentation Locations (TTC)

- High Tonnage Loop (HTL)
  - Curve (~5°)
  - Design balance speed of 30 mph
  - Safelok I Fasteners
Field Instrumentation Locations (TTC)

- Railroad Test Track (RTT)
  - Tangent
  - Safelok I Fasteners
Loading Environment

- **Track Loading Vehicle (TLV)**
  - Static
  - Dynamic

- **Track Loading A-Frame**
  - Vertical: 0 - 50 kip
  - Lateral: 0 - 10 kips

- **Freight Consist**
  - 6-axle locomotive (393k)
  - Ten cars
    - Empty, 263, 286, 315
    - GRL Cars
  - FAST Train

- **Passenger Consist**
  - 4-axle locomotive (255k)
  - Nine coaches
    - 87 GRL
Full Instrumentation
Field Testing of the Crosstie Fastener System

Vertical and Lateral Crosstie Displacement

Vertical and Lateral Web Strain
Fully Instrumented Rail Seat

Instrumented Clip

Lateral Rail Displacement

Lateral Pad Displacement

Longitudinal Pad Displacement
Lateral Shoulder Load Instrumentation

- Instrumented shoulder face insert
  - Original shoulder face is removed, grinded away
  - Insert designed as a beam and optimized to replace removed section
  - Measures bending strain of beam under 4-point bending

- Measuring bending strain is a proven technique
Rail Seat Pressure Distribution Instrumentation

MBTSS Setup

Rail

Pad/Abrasion Plate
- Mylar: 0.007”
- Teflon: 0.006”
- Sensor: 0.004”
- Teflon: 0.006”
- Mylar: 0.007”

Matrix Based Tactile Surface Sensor

Cast-in Shoulders

Concrete Crosstie

Gauge

Field
Select Experimental Results

- Vertical Loading Path
  - Crosstie Support Conditions
  - Rail Seat Loads
  - Vertical Load Distribution
  - Rail Seat Pressure Distribution

- Lateral Loading Path
  - Lateral Rail Loads (Tangent and Curve)
  - Lateral Shoulder Loads
Crosstie Support Variability: Vertical Crosstie Displacement - HTL

- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Low rail: weak support (slack or gap in support system)
- Modulus according to Kerr ranges from 3,600 – 10,000+ lb/in^2

![Graph showing vertical tie displacement vs. vertical load for different cases: U, W, S, E, G, C.](image)

- High Rail
- Low Rail

Low Rail: weak support (slack or gap in support system)
Crosstie Support Variability: Vertical Crosstie Displacement - HTL with 10 kip zero

- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Subgrade modulus ranges from 6000 – 12,900 lb/in^2
- Range is only 6000 – 7,800 lb/in^2 if rail seat C is discarded
Rail Seat Load Variability:
Vertical Rail Seat Load - HTL

- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Rail seat load transfer percentages range from 42 – 94%

Diagram showing vertical applied rail load (kips) vs. vertical rail seat load (kips) with different rail sections labeled High Rail and Low Rail.
Vertical Strain Distribution in the Rail

- Curve track
- Static vertical loads of 40 kips applied
- Static lateral load of 20 kips applied
- Vertical distribution of load among 5 – 7 crossties

Strain (µϵ)

- Field
- Gauge

-400 -300 -200 -100 0 100 200 300 400

1 2 3 4 5 6 7

40kips 20kips
Vertical Load Distribution at Rail Seat

- Curve track
- Static vertical loads of 40 kips applied
- Vertical distribution of load among 3 – 5 crossties
# Rail Seat Pressure Distributions Under Varying L/V Force Ratios

<table>
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<tr>
<th>L/V Force Ratio</th>
<th>0.0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.55</th>
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<td>Rail Seat 3F</td>
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<td>(Far Rail)</td>
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<tr>
<td>Gauge Sides of Rail Seats 3N and 3F</td>
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<tr>
<td>Rail Seat 3N</td>
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<tr>
<td>(Near Rail)</td>
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</tbody>
</table>

Pressure

Unloaded

Increasing Pressure
Rail Rotation under Varying Lateral Load

40 Kip Vertical Load

Percent of Initial Contact Area

L/V Force Ratio

0 0.1 0.2 0.3 0.4 0.5 0.6

1N 2N 2F 3N 3F 4N 4F 5N
Lateral Loads Acting on Tangent Track

*Leading axles of a 9-car freight train (263, 286, 315 GRL Cars).
Lateral Loads Acting on Curved Track

- Median loads can be 4 times larger than loads on tangent track.
Lateral Loads Acting on Curved Track

- Highest loading demands
- Twice as high as high rail at low speeds
Analysis of Lateral Load Distribution

Location: RTT
Equipment: TLV

V = 40 kip (177.9 kN)
L = 20 kip (89 kN)

L/V = 0.5
Distribution of Lateral Loads

20 kip (89 kN)
Distribution of Lateral Loads

20 kip (89 kN)
Distribution of Lateral Loads

20 kip (89 kN)
Distribution of Lateral Loads

- 20 kip (89 kN)
Distribution of Lateral Loads

20 kip (89 kN)
Distribution of Lateral Loads

20 kip (89 kN)
Findings and Potential Design Considerations

**Vertical loading**
- Measured static loads had a distributed response over 5-7 crossties at the wheel rail interface, and as low as 3 crossties at the rail seat.
- Vertical loading demands were highest at higher speeds on high rail.
- Rail seat forces are highly dependent on the stiffness of the substructure and support conditions and range from 20% to 90% of the wheel-rail load.
- Design of crossties and fastening systems should incorporate probabilistic loading conditions (wide variations of loading inputs).

**Lateral loading**
- Static lateral loads were distributed over 3 rail seats (approximately half of the load distribution area compared to vertical loads).
- On average, loads were found to be 3-6 times higher on curved track than on tangent track.
- Design should consider transfer of lateral loads and the potential for use of specialized components on curves.
Future Work

- Continue analysis of data to understand the governing mechanics of the system by investigating the:
  - Factors that determine vertical and lateral load distribution
  - Bending moments of the crossties
  - Pressure magnitude and distribution at the rail seat
  - Stresses and displacements in the fastening system
- Complete construction and begin experimentation with full scale track loading system at UIUC
- Complete validation of the UIUC finite element model using field and laboratory results
- Develop a simplified design tool to facilitate mechanistic design of concrete crossties and fastening systems
- Small-scale, evaluative experimentation on Class I Railroads
Modeling of Concrete Sleeper and Fastening System

- Rail
- Concrete Sleeper
- Insulator
- Clip
- Pad & Abrasion frame
- Shoulder
Multiple-Crosstie Modeling

- Model is validated using field data from TTC experiments
- Both global model and sub-model are used to provide accurate representation of interaction of multiple crosstie systems
- Objective for sub-model technique: Have identical or similar global behaviors (load distribution, displacement) in both models
Full-Scale Track Loading System (Under Construction)
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