Analysis of the Lateral Load Path in Concrete Crosstie Fastening Systems

Joint Rail Conference
Colorado Springs, CO
3 April 2014
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Outline

• Background
• Purpose of lateral force measurement
• Lateral force measurement technology
• Crosstie-to-crosstie distribution
• Dynamic forces during train runs
• Results and conclusions
• Future work
Background

• 25 million concrete crossties are in use on North American heavy haul freight railroads

• **Industry trends:**
  – Many variations in fastening system design and performance
  – Fastening system components are failing earlier than their design life
    • Crushing, abrasion, fracturing
  – Increasing heavy axle loads (HAL) and traffic volumes
  – Shared infrastructure with both HAL and high speed rail (HSR)

• **Industry need:**
  – Fastening systems that economically withstand increasingly demanding loading conditions
    • Minimizing maintenance procedures allows for increased operating efficiency and capacity
Purpose of Lateral Force Measurement

• **Quantify lateral loading conditions to aid in the mechanistic design of fastening systems**

• Understand demands on fastening system components under loading conditions known to generate failures

• Gain understanding of the lateral load path by:
  – Quantifying forces and stresses acting on the insulator and shoulder
  – Quantifying the distribution of lateral forces in fastening system

• e.g. Bearing on shoulder, frictional resistance from rail pad assembly or clip, etc.

• Understanding the causes of variation on lateral load distribution among adjacent crossties
Defining the Lateral Load Path

- Vertical Wheel Load
- Lateral Wheel Load
- Bearing Forces
- Frictional Forces

- Rail
- Clip
- Rail Pad Assembly
- Shoulder
- Concrete Crosstie
- Insulator
Lateral Force Measurement Methodology

• 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
    • Measuring bending strain is a proven technique
Tie-to-Tie Lateral Load Distribution

- Force (lbf)
- Force (kN)

0 1,000 2,000 3,000 4,000 5,000 6,000

0 6 12 18 24 27

Analysis of the Lateral Load Path
Tie-to-Tie Lateral Load Distribution

- Force (lbf)
- Force (kN)

- 40 kips
- 4 kips

- Analysis of the Lateral Load Path
Tie-to-Tie Lateral Load Distribution

![Graph showing lateral load distribution with forces in kips and kN. The graph includes a diagram of a structure with forces applied at different points, indicating 40 kips at one location and 8 kips at another.](image)
Tie-to-Tie Lateral Load Distribution

Force, $F$ (lbf)

Force, $F$ (kN)

40 kips
12 kips

Analysis of the Lateral Load Path
Tie-to-Tie Lateral Load Distribution

Force, $F$ (lbf)

Force, $F$ (kN)

40 kips

16 kips

Analysis of the Lateral Load Path
Tie-to-Tie Lateral Load Distribution

![Diagram showing the distribution of force between ties with force values marked at 0, 1,000, 2,000, 3,000, 4,000, 5,000, and 6,000 kips on the y-axis. The x-axis shows force in kN and lbf, with values at 0, 6, 9, 12, 15, 18, 21, 24, and 27 kips. The diagram includes a representation of the load path with arrows indicating the forces applied to the ties.]

- Force, $F$ (lbf)
- Force, $F$ (kN)
Tie-to-Tie Lateral Load Distribution

- Force, $F$ (kN)
- Force, $F$ (lbf)

40 kips

4 kips
Tie-to-Tie Lateral Load Distribution

Force, F (lbf)

40 kips
8 kips

Force, F (kN)
Tie-to-Tie Lateral Load Distribution

Force, $F$ (lbf)

0 1,000 2,000 3,000 4,000 5,000 6,000

Force, $F$ (kN)

0 6 12 18 24 30 36 42

40 kips

12 kips

$F$
Tie-to-Tie Lateral Load Distribution

Force, $F$ (lbf) vs. Force, $F$ (kN)

- Force, $F$ (lbf) scale:
  - 40 kips
  - 16 kips

- Force, $F$ (kN) scale:
  - 27
  - 24
  - 21
  - 18
  - 15
  - 12
  - 9
  - 6
  - 3
  - 0

The graph illustrates the lateral load distribution with bars indicating forces in kips and kN.
Tie-to-Tie Lateral Load Distribution

Force, F (lbf)

Force, F (kN)

40 kips

20 kips

F

Tie-to-Tie Lateral Load Distribution

Force, $F$ (kips)

Force, $F$ (kN)

0

40 kips

4 kips

F

Analysis of the Lateral Load Path
Tie-to-Tie Lateral Load Distribution

The graph illustrates the distribution of lateral forces in a tie-to-tie path. The forces are measured in kips (kip) and kN (kilo-Newtons). The graph shows that the total force is divided into two parts: one of 40 kips (approximately 177 kN) and another of 8 kips (approximately 35 kN) at the bottom. The total force at the top is 48 kips (approximately 212 kN).
Tie-to-Tie Lateral Load Distribution

Force, $F$ (kips)

40 kips

12 kips

Force, $F$ (kN)
Tie-to-Tie Lateral Load Distribution

Force, $F$ (lbf)

Force, $F$ (kN)

40 kips

16 kips

Analysis of the Lateral Load Path
Analysis of the Lateral Load Path

Tie-to-Tie Lateral Load Distribution

Force, F (lbf)

Force, F (kN)

0 1,000 2,000 3,000 4,000 5,000 6,000

0 6 12 18 24 27

40 kips

20 kips

F
Lateral Loads Within Fastening System
Curved Track (High Rail), Passenger and Freight Peak Loads

![Graph showing lateral loads and speed relationship for different types of load (passenger, freight)].

- Lateral Wheel Load (Freight)
- Shoulder Response, F (Freight)
- Passenger

Force, $F$ (lbf) vs. Speed (mph)
Lateral Loads Within Fastening System
Curved Track (Low Rail), Passenger and Freight Peak Loads

Force, F (lbf)

Force, F (kN)

Lateral Wheel Load (Freight)

Shoulder Response, F (Freight)

Passenger

Passenger

Speed (mph)
Challenges with Lateral Load Resistance

- Lateral loads appear to be primarily distributed among three crossties
  - Vertical load is distributed to five or more crossties based on previous research conducted at UIUC
- Lateral loads entering the shoulder appear to be primarily influenced by the lateral wheel load
  - However, lower L/V ratios at the same lateral input load magnitude result in slightly higher loads entering the shoulder, assumed to be due to friction
  - Stress on insulator can reach >17,000 psi
- Lateral loads are significantly higher from passing freight trains than from passenger trains
- L/V ratio not sufficient for describing force distribution at crosstie and fastening system
Failed insulators are often seen on heavy haul lines in sharp curvature
  – High lateral fastening system forces the likely cause

Unequal vertical and lateral load distributions coupled with high lateral forces may cause critical loading scenarios within fastening systems
Analysis of the Lateral Load Path

Rail Seat Lateral to Vertical Reaction Ratio (RSR)

\[
\text{L/V Force Ratio} = \frac{L_{\text{input}}}{V_{\text{input}}}
\]

\[
\text{RSR} = \frac{L_{\text{reaction}}}{V_{\text{reaction}}}
\]
Rail Seat Lateral to Vertical Reaction Ratio (RSR)

• Given:
  – Lateral bearing load is distributed to three crossties
  – Vertical bearing load is distributed to five crossties

• A 0.5 L/V Force Ratio applied directly over Tie B will result in a 0.25 RSR Ratio at the rail seat of Tie B and a 0.31 RSR at the rail seat of adjacent Ties A and C

• Adjacent fastening systems may have to withstand higher load ratios than what is applied at the WRI

• Future research will investigate threshold RSR values (i.e. what RSR values are associated with failure)
Future work

• Lateral load measurement on revenue service track
  – What are lateral load magnitudes and distribution under demanding field conditions?
  – What are the effects of varying track geometry?

• Full-scale laboratory testing
  – What are the effects of varying component tolerances?
  – How does lateral track stability affect lateral fastening system forces?

• Component-level laboratory testing
  – What are the thresholds of plastic damage?
  – How do alternative material properties affect load transfer and distribution in the fastening system?
Acknowledgements

- Funding for this research has been provided by:
  - Association of American Railroads (AAR) Technology Outreach Program
  - Federal Railroad Administration (FRA)
- Industry Partnership and support has been provided by
  - Union Pacific Railroad
  - BNSF Railway
  - National Railway Passenger Corporation (Amtrak)
  - Amsted RPS / Amsted Rail, Inc.
  - GIC Ingeniería y Construcción
  - Hanson Professional Services, Inc.
  - CXT Concrete Ties, Inc., LB Foster Company
  - TTX Company
- For assistance with research and lab work
  - Andrew Scheppe, UIUC Machine Shop, Harold Harrsion
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