Lateral Load Path Analysis

FRA Concrete Tie and Fastener BAA – Industry Partners Meeting
Incline Village, NV
7 October 2013
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Outline

- Background
- Purpose of lateral force measurement
- Defining the lateral load path
- Lateral force measurement technology
- Preliminary results and conclusions
- Future work
Overall Project Deliverables

**Mechanistic Design Framework**
- Literature Review
- Load Path Analysis
- International Standards
- Current Industry Practices
- AREMA Chapter 30

**Finite Element Model**
- Laboratory Experimentation
- Field Experimentation
- Parametric Analyses

**I – TRACK**
- Statistical Analysis from FEM
- Free Body Diagram Analysis
- Probabilistic Loading

Lateral Load Path Analysis
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
  – 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

- Vert. load
- Lat. Load
- Bearing forces
- Frictional forces
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
Laboratory Proof of Concept

- Instrumented shoulder face insert tested on Pulsating Load Testing Machine (PLTM) at UIUC
- Lateral load: 1,800 lbf (8 kN) to 18,000 lbf (80 kN)
- Varied L/V ratio from 0.1 to 0.5
- Dynamic loading at 3 Hz
- Representative loading conditions
  - Sharp curvature
  - Demanding conditions
Preliminary Laboratory Conclusions

- Percentage of lateral load transferred into shoulder depends on stiffness at insulator-shoulder interface
- Lower coefficients of friction between concrete crosstie and rail pad result in increased lateral load through post
- Successful laboratory testing results make LLED a viable way to measure lateral load in the field
Field Experimentation
Map of Instrumentation Technologies

Rail seat with all measurement technologies

Lateral Load Evaluation Device (LLED)
Tangent Track
Track Loading Vehicle (TLV)
V = 40 kip (177.9 kN)
L = Variable
Lateral Load Path Analysis

Lateral Load Transfer

Force (lbf)

0

1,000

2,000

3,000

4,000

5,000

6,000

Force (kN)

0

3

6

9

12

15

18

21

24

27

40 kips

4 kips
Lateral Load Path Analysis

Lateral Load Transfer

Force (lbf) vs. Force (kN)

- 40 kips
- 8 kips

Diagram showing lateral load transfer with force values on the y-axis and force values on the x-axis.
Lateral Load Path Analysis

Lateral Load Transfer

Force (lbf) vs. Force (kN)

- Force (lbf): 0, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000
- Force (kN): 0, 3, 6, 9, 12, 15, 18, 21, 24, 27

- 40 kips
- 12 kips
Lateral Load Path Analysis

Lateral Load Transfer

- Force (lbf) vs. Force (kN)
- Force values: 0, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000 (kips)
- Force values: 16, 40, 24, 21, 18, 15, 12, 9, 6, 3, 0 (kN)

Diagram shows a concentrated load transfer with forces labeled as 16 kips and 40 kips.
Lateral Load Transfer

- Force (kN)
- Force (lbf)

- 40 kips
- 20 kips
Lateral Load Path Analysis

Lateral Load Transfer

Force (lbf) vs. Force (kN)

- Force (lbf): 0, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000
- Force (kN): 0, 4, 8, 12, 16, 20, 24, 28

Notices:
- 40 kips
- 22 kips
Lateral Load Path Analysis

Lateral Load Transfer

Force (lbf) vs. Force (kN)

- 0 kips
- 4 kips
- 40 kips

Graph showing lateral load transfer with force in kips and kN on the y-axis.
Lateral Load Path Analysis

Lateral Load Transfer

Force (lbf) vs. Force (kN)

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

0 6 12 18 24 27

40 kips
8 kips
Lateral Load Path Analysis

Lateral Load Transfer

Force (lbf) vs. Force (kN)

- Force (lbf): 0, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000
- Force (kN): 0, 6, 12, 18, 24, 30, 36

- 40 kips
- 12 kips
Lateral Load Transfer

<table>
<thead>
<tr>
<th>Force (lbf)</th>
<th>0</th>
<th>1,000</th>
<th>2,000</th>
<th>3,000</th>
<th>4,000</th>
<th>5,000</th>
<th>6,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (kN)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
</tr>
</tbody>
</table>

- 40 kips
- 16 kips
Lateral Load Transfer

Force (lbf) vs. Force (kN)

- Force (lbf) Range: 0 to 6,000
- Force (kN) Range: 0 to 27

Key Points:
- 40 kips (green arrow)
- 20 kips (red arrow)
- A higher lateral stiffness leads to more load being carried by that particular rail seat.

<table>
<thead>
<tr>
<th>Rail Seat</th>
<th>Lateral Stiffness (lbf/in)</th>
<th>Max. Force (lbf)</th>
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</thead>
<tbody>
<tr>
<td>S</td>
<td>192,498</td>
<td>7,828</td>
</tr>
<tr>
<td>E</td>
<td>155,369</td>
<td>5,582</td>
</tr>
<tr>
<td>U</td>
<td>146,322</td>
<td>4,632</td>
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</table>
Lateral Load Restraint
Distribution within Fastening System
Lateral Load Restraint

Tangent Track, TLV

Lateral Input Load

Estimated Friction Forces

Sum of Lateral Bearing Forces

L/V Ratio

Force (lbf)

Force (kN)
Lateral Load Restraint
Curved Track (High Rail), Passenger and Freight Runs

FREIGHT CONSIST (Peak values)

PASSENGER CONSIST (Peak values)
Lateral Load Restraint
Curved Track (Low Rail), Passenger and Freight Runs

FREIGHT CONSIST (Peak values)

PASSENGER CONSIST (Peak values)
Preliminary Field Conclusions

• 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 stiffness of the fastening system plays an important role in transferring the lateral load into the shoulder

• As the L/V ratio increases:
  – Lateral bearing restraint forces increase
  – Lateral frictional restraint forces decrease
Future work

• Measurement of lateral load on revenue service track
• Further laboratory testing
  – Continued tests on PLTM
  – Full-scale track loading system (under construction)
  – Component experiments to better understand the thresholds of plastic damage
• Investigation of alternative component materials
• Application of measurement technology on different fastening systems
Acknowledgements

Funding for this research has been provided by the
- Association of American Railroads (AAR)
- 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, Harold Harrison, UIUC Machine Shop
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