Clamping Force & Concrete Crosstie Bending Behavior Analysis

FRA Tie and Fastener BAA - Industry Partners Meeting
Incline Village, NV
7 October 2013
Sihang Wei, Daniel Kuchma
Outline

• Project Objectives

• Clamping Force Analysis
  • Introduction
  • UIUC clip instrumentation
  • Clamping force calculation methodology
  • Change of clamping force due to wheel load
  • Clip strain diagram
  • Conclusions

• Concrete Crosstie Bending Behavior Analysis
  • Introduction
  • UIUC concrete crosstie instrumentation
  • Bending moment at rail seats and center
  • Conclusions
Overall Project Deliverables

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

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

**Finite Element Model**
- Laboratory Experimentation
- Field Experimentation
- Parametric Analyses
Objectives of Clamping Force Analysis Experimentation

- Define the components of the clamping force vector
- Determine the range that the components of clamping force may vary under the following operating conditions:
  - Clip installation
  - Tangent and curvature
  - Low speed and higher speed
  - Round wheels and wheels with irregularities
- Determine how the change in clamping force effects the load path in the system
Clamping Force and Concrete Crosstie Bending Behavior Analysis

Background

• Clamping force as defined by manufacturer is the force applied by the clips vertically relative the rail seat
• Clamping force and clip behavior is examined in detail using finite element analysis
• Laboratory experimentation was used to validate the boundary conditions within the system model
• Clamping force as defined by the manufacturer is calculated via:

\[ R = D \times K \]

where,
R: Clamping force
D: Vertical displacement at clip tip
K: Stiffness of clip toe

For “Amsted RPS UAB2000”
R = 2,375 lbs (expected)
K = 8,223 lbs/in
Clamping Force Components

- Clamping force can be broken into two components
  - Normal force (N)
  - Tangential force (T)
- Normal force is
  - The component of the clamping force normal to the clip toe
  - Affected by the rail base rotation and rail pad assembly compression
- Tangential Force is
  - The component of the clamping force tangential to the clip toe
  - Affected by the rail base lateral translation and frictional interface between the clip and insulator
UIUC Clip Instrumentation and Force Calculation Methodology

- Clip strains were measured using strain gauges:
  - Four (4) on each clip
  - One (1) on both flat portions of clip, top and bottom
- Rail base vertical displacement, near the clip toe was measured using a potentiometer
- Change of force for each toe was calculated using the following methodology

\[
\Delta N = D_G \cdot (1250\text{lbs} / 0.289\text{in})
\]

\[
\Delta T = \left(\frac{-e_t + e_b}{2} - \frac{\Delta Nd(t / 2)\cos\varphi}{EI}\right) \cdot \frac{EI}{d(t / 2)\sin\varphi}
\]

- Where:
  - \(D_G\) is the gage side rail base vertical displacement
  - \(e_t\) is the strain measured at the top of the clip
  - \(e_b\) is the strain measured at the bottom of the clip
  - \(d\) is the distance from clip contact to strain gauge
Laboratory Experimentation Results: Change in Normal and Tangential Clamping Force Under Load

- An experiment was performed to investigate the change in clamping force components under varying load.
- The gage-side normal and tangential clamping force components showed greater changes than the field-side components.
- Gage-side clamping force components to be investigated in the field experimentation.

\[ \Delta NF/G: \text{Change of normal force at field/gauge side} \]
\[ \Delta TF/G: \text{Change of tangential force at field/gauge side} \]
Instrumented Clips
Change in Clamping Force

- **ΔN**: change in normal force
- **ΔT**: change in tangential force

<table>
<thead>
<tr>
<th>Force (lbs)</th>
<th>S</th>
<th>E</th>
<th>U</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
<td>20</td>
<td>20</td>
<td>-20</td>
</tr>
</tbody>
</table>

40 kips

20 kips
Change in Clamping Force

ΔN: change in normal force
ΔT: change in tang. force

40 kips
20 kips
Change in Clamping Force

- ΔN: change in normal force
- ΔT: change in tangential force

Force (lbs):
- S: 150 kips
- E: 100 kips
- U: 150 kips
- W: 0 kips

40 kips
20 kips
Change in Clamping Force

\( \Delta N: \) change in normal force

\( \Delta T: \) change in tangential force

- **20 kips**
- **40 kips**
Change in Clamping Force

$\Delta N$: change in normal force
$\Delta T$: change in tang. force

Force (lbs)

- S
- E
- U
- W

40 kips
20 kips
Change in Clamping Force

ΔN: change in normal force
ΔT: change in tang. force

40 kips
20 kips
Change of Clamping Force Under Dynamic Load

Location: **Tangent**

Equipment: **Freight**

Speed: **2 mph**

- **EG_N**
- **EG_T**
- **SG_N**
- **SG_T**
- **UG_N**
- **UG_T**
- **WG_N**
- **WG_T**

xG_N/T
x: location (E, S, U, W)
N/T: normal/tangential force
Change of Clamping Force Under Dynamic Load

Location: Curve  Equipment: Freight  Speed: 2 mph

- Normal force
- Tangential force

Axle #

xG_N/T
x: location (E, S, U, W)
N/T: normal/tangential force
Change of Clamping Force Under Dynamic Load

Location: **Tangent**  
Equipment: **Freight**  
Speed: **70 mph**

due to flat spot on wheel

<table>
<thead>
<tr>
<th>Location</th>
<th>Equipment</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Freight</td>
<td>70 mph</td>
</tr>
<tr>
<td>S</td>
<td>Freight</td>
<td>70 mph</td>
</tr>
<tr>
<td>U</td>
<td>Freight</td>
<td>70 mph</td>
</tr>
<tr>
<td>W</td>
<td>Freight</td>
<td>70 mph</td>
</tr>
</tbody>
</table>

xG_N/T  
x: location (E, S, U, W)  
N/T: normal/tangential force
Strain Diagram After Installation (Actual)

- The inner and outer calculated surface strain distributions shown in blue
- The inner and outer calculated surface strain values are listed in black
- The inner and outer recorded surface strain values are listed in red
- Recorded strain is very close to calculated strain
- Resulting clamping force components: $N = 2740$ lbs, $T = -140$ lbs

- Comparing with yielding strain of steel:

$$e_y = \frac{f_y}{E} = \frac{183 \text{ksi}}{23000 \text{ksi}} = 7957 \text{ms}$$
Strain Diagram After Installation

- Yielding strain: \( e_y = \frac{f_y}{E} = \frac{183\text{ksi}}{23000\text{ksi}} = 7957\text{ms} \)

- The strain distribution for inner and outer surface are shown below for case
  \( N = 2500 \text{ lbs}, \)
  \( T = 0 \text{ lbs} \) (assuming no tangential force)
Strain Diagram due to Typical Wheel Load

- Yielding strain: \( e_y = \frac{f_y}{E} = \frac{183\text{ksi}}{23000\text{ksi}} = 7957\text{ms} \)

- The strain distribution for inner and outer surface are shown below for case 
  \( N + \Delta N = 2500\text{ lbs} + 200\text{ lbs}, \)
  \( T + \Delta T = 0\text{ lbs} + 200\text{ lbs} \)
Strain Diagram Due to Impact Load

- Yielding strain: \( e_y = f_y / E = 183\text{ksi} / 23000\text{ksi} = 7957\text{ms} \)

- The strain distribution for inner and outer surface are shown below for case
  \( N + \Delta N = 2500\text{ lbs} + 400\text{ lbs}, \)
  \( T + \Delta T = 0\text{ lbs} + 200\text{ lbs} \)
Conclusions from Clamping Force Analysis

Experimentation

- Clamping force can be represented by two orthogonal forces
  - Normal and tangential

- The clamping force of a clip will not vary significantly when it is positioned two ties from the applied load

- The normal and tangential components of the clamping force do not change significantly under typical train operation

- Impact loads can impart significant strain into the clip

- The initial strain during installation may approach yield limit

- A more conservative design could be accomplished by closing up the gap between the two clip toes
Objectives of Crosstie Bending Behavior Analysis

Experimentation

- Determine support conditions below crossties
- Determine the bending moments at the crosstie rail seats and the crosstie center when subject to:
  - Static and dynamic loads
  - Varying load magnitude (empty – 315 kips)
Background: Previous Research on Support Conditions

Sleeper/ballast contact patterns:
(a) central void, (b) single hanging, (c) double hanging,
(d) triple hanging, and (e) side-central voids

Kaewunruen & Ramennikov, 2007
- Strains measured at the top and bottom of both rail seats and the crosstie center
- Bending moments can then be calculated at both rail seats and crosstie center
Crosstie Bending Moment Calculation Methodology

\[
M(\text{railseat1}) = (e_{S2} - e_{S1})EI_{12} / d_{12}
\]
\[
M(\text{center}) = (e_{S4} - e_{S3})EI_{34} / d_{34}
\]
\[
M(\text{railseat2}) = (e_{S6} - e_{S5})EI_{56} / d_{56}
\]

Where,
\(e\): strain recorded from concrete surface gauge #1~#6
\(E\): elastic modulus of concrete, 4500 ksi
\(I\): moment of inertia at each location
\(d\): the distance between the upper and lower gauges at each location
Instrumentation Location (Full Map)

- Rail Displacement Fixture
- Rail Longitudinal Displacement/Strains
- Pad Assembly Longitudinal Displacement
- Pad Assembly Lateral Displacement
- Insulator Longitudinal Displacement
- Insulator Vertical Displacement
- Steel Rods
- Vertical Web Strains
- Vertical and Lateral Circuits
- Shoulder Beam Insert (Lateral Force)
- Embedment Gages, Vertical Circuit, Clip Strains
- Crosstie Surface Strains
- MBTSS
Instrumented Crossties
Concrete Crosstie Design Cracking Moment

From CXT $f'c(28d)=11,730$ psi
Using $f'c=11,000$ psi

Positive: top in compression
Negative: top in tension

- Mid-point
  - positive: $196.8$ k-in
  - negative: $-256.8$ k-in

- Rail-seat
  - positive: $405.6$ k-in
  - negative: $-219.6$ k-in
Bending Moments Under Static Load: Rail Seats E and U and Crosstie Center E-U

- Design rail seat cracking moments
  - positive: 405.6 k-in
  - negative: -219.6 k-in
- Design tie center cracking moment
  - positive: 196.8 k-in
  - negative: -256.8 k-in
Clamping Force and Concrete Crosstie Bending Behavior Analysis

**Bending Moments Under Dynamic Load: Rail Seat C by Car Type**

- **Design rail seat cracking moments**
  - positive: 405.6 k-in
  - negative: -219.6 k-in

- Due to flat spot on wheel

- Car Weight: 44 kips
- Car Weight: 260 kips
- Car Weight: 286 kips
- Car Weight: 315 kips

**Graph:**
- Y-axis: Moments (kips-in)
- X-axis: Speed (mph)
- Data points for different car weights and speeds.
Bending Moments Under Dynamic Load: Crosstie Center C-S by Car Type

- Design tie center cracking moment
  - positive: 196.8 k-in
  - negative: -256.8 k-in

Car Weight: 44 kips
- Car Weight: 260 kips
- Car Weight: 286 kips
- Car Weight: 315 kips
Discussion on Support Length

"Newly tamped track" in UIC

- As crosstie support length is reduced, the resulting rail seat moment is reduced

- Reduced support length
Conclusions from Bending Behavior Analysis Experimentation

- Bending moments recorded during dynamic train runs are larger than those recorded during static tests.
- In general, the recorded bending moment increased as the nominal car weight increased.
- Impact loads can significantly effect the crosstie bending moments.
- Bending moments recorded in field do not approach the cracking limit.
- Low bending moments at rail seat may be due to a short support length in the field.
Future Work

• Clip Performance
  – Effect of cyclic loading on tangential and normal components of clamping force
  – Effect of repeated impact load on tangential and normal component of clamping force

• Crosstie Performance
  – Rail seat vertical load will be analyzed via concrete embedment strain gauges cast below the rail seat
  – Rail seat vertical load and concrete crosstie bending behavior will be compared
  – More detailed analysis of the effect of support conditions on concrete crossties bending
Acknowledgements

U.S. Department of Transportation

Federal Railroad Administration

• Funding for this research has been provided by the 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

FRA Tie and Fastener BAA
Industry Partners:
Questions?

Sihang Wei
Graduate Research Assistant
Department of Civil and Environmental Engineering
University of Illinois, Urbana-Champaign
Email: wei22@illinois.edu