Overview of UIUC’s Concrete Cross-tie and Fastening System Laboratory Study

2012 Joint Rail Conference
17-19 April 2012 • Philadelphia, PA.

Sihang Wei, Daniel A. Kuchma, J. Riley Edwards, Marcus S. Dersch
Outline

• Introduction
• Instrumentation plan overview
• Preliminary laboratory test
  – Built up load cell feasibility study
  – Partial instrumentation plan feasibility study
• Rail displacement laboratory study
• Conclusion
Introduction

• Overall laboratory instrumentation objectives:
  – Develop instrumentation plan to measure forces at critical interfaces (pad-tie, insulator-clip, insulator-rail, etc.) prior to field testing
  – Guide field instrumentation
  – Provide model validation
Role of Lab Instrumentation

Lab
- Validate model assumptions
- Understand and quantify the influence of factors that affect the flow of forces

Lab-Field
- Develop field instrumentation plan
- Develop test load conditions

Lab-Analysis
- Confirm assumptions in FEM analysis
- Supply insight on undocumented behaviors
Areas of Investigation

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

Fasteners/ Insulator
- Strain of fasteners
- Stresses on insulator

Concrete Crossties
- Internal strains
  - Midspan
  - Rail Seat
- Stresses at rail seat
- Global displacement of the tie
Instrumentation Plan

- Rail deformation measurement (strain gauges)
- Deflection measurement (LVDT/potentiometers)
- Load transfer measurement (load cells & concrete embedment strain gauges)
Rail Deformation Measurement

• Strain gauge locations:
  - Lateral built-up load cell – moment & shear force
  - Vertical gauges – lateral wheel load
  - Chevron pattern – vertical wheel load
  - Transverse gauges – bending at rail base
Built-up Load Cell

Curvature:
\[ \phi = \frac{\varepsilon}{d} \]

Moments:
\[ M_{XL} = EI \rho_{XL} = EI \left( \frac{\varepsilon_a + \varepsilon_{a'}}{2} \right) \cdot \frac{1}{d_t} = EI \left( \frac{\varepsilon_b + \varepsilon_{b'}}{2} \right) \cdot \frac{1}{d_b} \]

Shear force:
\[ \Delta V_Z = V_{ZL} - V_{ZR} = (M_{XL} - M_{XR}) \cdot \frac{1}{L} \]
Vertical Gages

\[ P_X \propto V \text{ (shear force)} \]

\[ V = \frac{\partial M}{\partial x} = \frac{M_B - M_A}{d} \text{ (independent of } P_Z, x_1, y_1) \]

\[ M_A = \left( \frac{EI}{c} \right) \varepsilon_A , \quad M_B = \left( \frac{EI}{c} \right) \varepsilon_B \]

\[ P_X = V = \frac{M_B - M_A}{d} = \left( \frac{EI}{cd} \right) (\varepsilon_B - \varepsilon_A) \]

\[ P_X \propto (\varepsilon_B - \varepsilon_A), \]

where \[ \varepsilon_A = \frac{(\varepsilon_a - \varepsilon_{a'})}{2} \]

\[ \varepsilon_B = \frac{(\varepsilon_b - \varepsilon_{b'})}{2} \]
Chevron Gages

\[ P_Z = V_{ZL} - V_{ZR} \]

\[ V_{ZL} = \frac{EI}{(1 + \nu)Q} \varepsilon_1, \quad V_{ZR} = \frac{EI}{(1 + \nu)Q} \varepsilon_2 \]

\[ \varepsilon_1 = \varepsilon_a - \varepsilon_b + \varepsilon_{a'} - \varepsilon_{b'}, \quad \varepsilon_2 \]

\[ = \varepsilon_c - \varepsilon_d + \varepsilon_{c'} - \varepsilon_{d'} \]

\[ P_Z = \frac{EI}{(1 + \nu)Q} (\varepsilon_1 - \varepsilon_2) \]
Transverse Gauges

Curvature:
\[ \phi = \frac{\varepsilon}{t} \]
\( t \) – thickness of rail base

Moments:
\[ M_{XL} = EI\phi = EI\frac{\varepsilon}{t} \]
Displacement Measurement

- Lateral disp. of the rail head ($Dx_2$)
- Lateral disp. of the rail base ($Dx_1$)
- Vertical disp. of the rail base ($Dz_1$)
Rigid Body Displacements

Total vertical displacement:

\[ Dz1 \]

Vertical displacement of the rail (due to \( Pz \)):

\[ DPz = \frac{Pz}{E} \]

Rotating angle:

\[ \theta = \arctan \frac{y_{2'} - y_{1'}}{x_{2'} - x_{1'}} - \arctan \frac{y_2 - y_1}{x_2 - x_1} \]

Old: \((x_1, y_1) (x_2, y_2)\)

New: \((x_{1'}, y_{1'}) (x_{2'}, y_{2'})\)

Rotating center:

\[ Lc = \frac{Dz1}{\theta} \]
Lateral Load Transfer

- To measure the load transfer between the rail base and the cast-in shoulder
Vertical Rail Seat Load Transfer

• Plan: Install concrete embedment strain gauges in rail seat area to measure the load transfer from rail base to concrete tie

• 3x3 or 2x2 strain gauge patterns are planned to use to measure the uneven stress distribution
Built up Load Cell Feasibility Study  
(Aug. 2011)

- **Objective**: Test feasibility of built up load cell
- **Strategy**: Utilize eight strategically located strain gauges on the rail
- **Test**: Simple 3-point bending test with loads ranging from 0 to 32,500 pounds
- **Results**:
  - Strains remained linear
  - In elastic range

Test setup at Newmark Lab, UIUC
Preliminary Partial Instrumentation Plan
Feasibility Study
(Sep. 2011)

- **Objective**: Test feasibility of built up load cell & strain gauged clips while fully assembled
- **Strategy**: Utilize 20 strategically located strain gauges on rail & clips
- **Test**: Applied load to single rail seat on a fully supported tie at an L/V of 0.25 & 0.52 with static & dynamic loads ranging from 0 to 32,500 pounds
- **Results**:
  - Strains behaved non-linear at clips
  - Residual strains in system
  - Strains in gauge clip greater than field clip
Field Side Clip Strains

Strains recorded from the gauges on the clip at field side
using percentage of max load (L/V=52%)
Gauge Side Clip Strains

Strains recorded from the gauges on the clip at gauge side using percentage of max load (L/V=52%).
Rail Displacements Laboratory Study
(spring 2012)

SLTM test set up at ATREL, UIUC
Rail Displacements

\[ \frac{P_x}{P_z(L/V)} = 0.5 \]

Graph showing rail displacements with time on the x-axis and displacement in inches on the y-axis. The graph includes three lines:
- Dx2 Lateral Rail Head
- Dz1 Vertical Rail Base
- Dx1 Lateral Rail Base

The graph indicates displacement values for different points, such as:
- \( P_z = 5k \)
- \( P_z = 10k \)
- \( P_z = 15k \)
- \( P_z = 20k \)
- \( P_z = 25k \)
- \( P_z = 30k \)

The graph shows how the rail displacements change with time for each load level.
Rail Displacements

<table>
<thead>
<tr>
<th>Pz (kips)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>25</th>
<th>20</th>
<th>15</th>
<th>10</th>
<th>5</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dx1</td>
<td>0</td>
<td>0.003255</td>
<td>0.003534</td>
<td>0.003255</td>
<td>0.002976</td>
<td>0.002697</td>
<td>0.00186</td>
<td>0.00186</td>
<td>0.001953</td>
<td>0.002418</td>
<td>0.00279</td>
<td>0.00372</td>
<td>0.000837</td>
</tr>
<tr>
<td>Dz1</td>
<td>0</td>
<td>0.002883</td>
<td>0.006324</td>
<td>0.007905</td>
<td>0.008928</td>
<td>0.00930</td>
<td>0.009114</td>
<td>0.009393</td>
<td>0.009207</td>
<td>0.008649</td>
<td>0.007161</td>
<td>0.005394</td>
<td>0.000651</td>
</tr>
<tr>
<td>Dx2</td>
<td>0</td>
<td>0.016089</td>
<td>0.022506</td>
<td>0.025947</td>
<td>0.029574</td>
<td>0.032271</td>
<td>0.034224</td>
<td>0.032736</td>
<td>0.031341</td>
<td>0.030039</td>
<td>0.028458</td>
<td>0.024459</td>
<td>0.002604</td>
</tr>
</tbody>
</table>
Rail Displacements & Stress distribution

Assumption:
Rigid body motion

Limitations:
Neglected bending action of rail web & base

Check Results:
Rail pad deflection (tip): $\Delta T = 0.009\,\text{in}$
Rail pad thickness: $T = 0.3\,\text{in}$
Strain: $\varepsilon = \Delta T / T = 0.009 / 0.3 = 0.03$
Total vertical reaction:
\[
R_v = \varepsilon \times E \times W \times L / 2
\]
\[
= 0.03 \times 345 \times 6 \times 1.844 / 2
\]
\[
= 57.2\,\text{kips} \approx 1.9 \times (30\,\text{kips})
\]
\[
= 1.9P_z
\]

Learning:
Need to consider bending behavior of rail web/base in future work

$L = 1.844\,\text{in}$
$W = 6\,\text{in}$
Summary

• Three laboratory studies have been performed thus far
  1) Built up load cell feasibility
  2) Preliminary partial instrumentation plan feasibility
  3) Rail displacement laboratory study
• Each study has guided this project’s instrumentation plan
• Laboratory setup variability between field conditions
  – Support conditions
  – No “lateral” constraint from short rail piece
  – Loading conditions
Summary (cont.)

• Laboratory studies allow us to:
  – Refine instrumentation plan
  – Develop detailed studies within controlled variables
  – Validate laboratory finite element model
  – Study pressure distribution under different L/V ratio & different support conditions
  – Study the effect of dynamic load
  – Compare results to field investigation
  – Make recommendations to refine lab tests in future
Acknowledgements

Funding for this research has been provided by the Federal Railroad Administration (FRA)

Industry Partnership and support has been provided by
- Union Pacific (UP) 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

For assistance in instrumentation preparation:
- Harold Harrison, Jacob Henschen, Thomas Frankie
Questions?