Quantification of Rail Displacement under Light Rail Transit Field Loading Conditions

Joint Rail Conference 2017
Philadelphia, PA
April 6th 2017

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Outline

• Objective and Approach
• Data Collection Overview
• Rail Displacement Results:
  – Curve Site
  – Tangent Site
• Conclusions
• Future work
Objectives and Approach

• **Objectives:**
  
  – *Determine rail displacements under rail transit loading conditions using field data*
  
  – *Evaluate performance of fastening system*: combine field data, developed models and technical specifications of the fastening system provided by manufacturer to assess its level of usage

• **Approach:**

  1. Field Data Collection
  2. Processing of Collected Data
  3. Analysis of Field Results
  4. Comparison with Analytical and Finite Element Models
  5. Evaluation of Fastening System Behavior in Terms of Rail Restraining
Metrics to quantify:

- Crosstie bending strain (crosstie moment design)
- Rail displacements (fastening system design)
- Vertical and lateral input loads (crosstie and fastening system design, and load environment characterization)
- Crosstie temperature gradient

Metrics to quantify:

- Crosstie bending strain (crosstie moment design)
- Rail displacements (fastening system design)
- Vertical and lateral input loads (crosstie and fastening system design, and load environment characterization)
- Crosstie temperature gradient
Data Collection Overview

Rail Restraint

• Desired data:
  – Relative vertical and lateral displacement of rail base with respect to crosstie

• Results:
  – Capture displacement and rotation of rail under each wheel
  – Analyze load and speed effect on rail displacement
  – Curve sites allow more meaningful study: compare results for high and low rail
  – Have a better understanding of train dynamics
Instrumentation Insight
Portable Displacement Measurement Device (PDMD)

- Linear potentiometers fixed to manufactured rapidly-deployable brackets that affix non-permanently to crosstie
- Novotechnik TS-0025 potentiometers
- 6 potentiometers per rail on rail base: horizontal, vertical field and vertical gauge
- Stroke length: $1.1811 \pm 0.000079$ in ($30 \pm 0.002$ mm)
- Manual data collection, small dataset
Partner Agencies

Metra®
The way to really fly.

New York City Transit

RAILTEC
Light Rail Curve Data

Trains in Dataset: 36
18, 19, 20 November 2015 and 17 March 2016

(Curve Site)
MetroLink Curve Location

- Belleville, IL
- Track speed: 45 MPH
- ~80 trains per day (Red Line)
- 900 feet west of Memorial Hospital Station
Curve Geometry
St. Louis MetroLink Curve Site

- **Characteristics:**
  - Curve: 6°00’
    (955 ft. (291 m) radius)
  - Superelevation:
    5.25 in. (133 mm)
  - Balance speed:
    35.4 mph (57 km/h)
- Fastening system: Pandrol Fastclip FC
- Measured speeds
  - From 15 mph (25 km/h) to 46 mph (74 km/h)
- High and low rail instrumented
MetroLink Light Rail Vehicles (LRVs)  
Siemens SD-400 & SD-460

- 2-vehicle (12 axle) trainsets
- Static loads provided by MetroLink engineering staff
- Middle truck unpowered
- AW0 (Unloaded) wheel weights at delivery (kips, one car):

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.6</td>
<td>7.8</td>
<td>7.0</td>
<td>8.0</td>
<td>7.2</td>
<td>9.6</td>
<td>7.4</td>
<td>9.2</td>
<td>6.8</td>
<td>9.2</td>
</tr>
</tbody>
</table>

- Normal Trainset Configuration:
Results
St. Louis MetroLink Curve Site

• The following results were obtained:
  – Horizontal and vertical displacements were analyzed for high and low rail considering displacement due to wheel loads
  – Rail displacement by axle for 12-axle light rail rolling stock
Quantification of Rail Displacement under Light Rail Transit Field Loading Conditions

**Rail Displacement**

**St. Louis MetroLink Curve Site**

<table>
<thead>
<tr>
<th>Displacement</th>
<th>High rail</th>
<th>Low rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>(in)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.381</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.381</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Displacement (in)

Displacement (mm)
Presentation of Results by Axle

• Each MetroLink train consists of a two-car set, so each 6 axles is a ‘repeat’ of the equipment (order aside)

• The following graphs can be compressed by stacking ‘repeat’ axles
Rail Displacements by Axle

St. Louis MetroLink Curve Site

Displacement (in)

Displacement (mm)
Rail Displacements by Axle
St. Louis MetroLink Curve Site

Displacement (in)

Displacement (mm)
Rail Displacements by Axle
St. Louis MetroLink Curve Site

Displacement (in)

Displacement (mm)
Light Rail Tangent Data

Trains in Dataset: 6
8 March 2016
MetroLink Tangent Location

- East St. Louis, IL
- Track speed: 55 MPH
- ~154 trains/day (Red & Blue lines)
- 0.86 miles west of Fairview Heights Station
Track Geometry
St. Louis MetroLink Tangent Site

- Tangent site
- Fastening System: Pandrol Fastclip FC
- Measured speeds
  - From 26 mph (42 km/h) to 52 mph (84 km/h)
- One rail instrumented
Quantification of Rail Displacement under Light Rail Transit Field Loading Conditions

Rail Displacement
St. Louis MetroLink Tangent Site

Displacement (in)

Displacement (mm)

0.015 0 -0.015
0.381 0 -0.381

Displacement (in)

Displacement (mm)

0.015 0 0.000 0.005 0.010 0.015
0.381 0.254 0.127 0.000 -0.127 -0.254 -0.381

(Field) (Gauge)
## Results Summary

<table>
<thead>
<tr>
<th>Maximum Displacement (in(\times10^{-3}))</th>
<th>Curve Site</th>
<th>Tangent Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Rail</td>
<td>Heavy Rail</td>
<td>Commuter</td>
</tr>
<tr>
<td>Horizontal</td>
<td>8.6</td>
<td>-1.7</td>
</tr>
<tr>
<td>Low Rail</td>
<td>10.3</td>
<td>-4.6</td>
</tr>
<tr>
<td>Vertical Gauge</td>
<td>4.2</td>
<td>-11.1</td>
</tr>
<tr>
<td>Vertical Field</td>
<td>11.3</td>
<td>-3.0</td>
</tr>
<tr>
<td>High Rail</td>
<td>7.7</td>
<td>-5.8</td>
</tr>
<tr>
<td>Vertical Field</td>
<td>3.9</td>
<td>-7.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum Displacement (in(\times10^{-3}))</th>
<th>Light Rail</th>
<th>Heavy Rail</th>
<th>Commuter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>2.2</td>
<td>-0.5</td>
<td>---</td>
</tr>
<tr>
<td>Rail A</td>
<td>1.6</td>
<td>-4.2</td>
<td>---</td>
</tr>
<tr>
<td>Vertical Field</td>
<td>1.6</td>
<td>-3.7</td>
<td>---</td>
</tr>
</tbody>
</table>

- Minor displacements under light rail transit revenue service (track equipment not accounted)
- Other rail transit systems to be analyzed to fill in the table
Conclusions

• Horizontal displacement consistently to the field side, resulting in gauge opening

• Larger displacements were found at the curve site

• For curve site:
  – Gauge side alternates positive and negative values
  – Leading axles caused the largest displacements in the system
  – Rotation of the rail found to be towards field side

• For tangent site:
  – Rotation of rail almost negligible
  – Minor lateral displacements due to rocking of LRV
Future Work

- Compare obtained results with working range of fastening system to assess performance
- Expand understanding of speed and load effect on displacements
- Repeat work for different rail transit loading conditions
- Compare with analytical models, Finite Element models, and laboratory experimentation
- Study the effect and contribution of each element of the fastening system to the overall behavior
Acknowledgements

Funding for this research has been provided by:

- Federal Transit Administration (FTA)
- National University Rail Center (NURail Center)

Industry partnership and support has been provided by:

- American Public Transportation Association (APTA)
- New York City Transit (NYCTA)
- Metra (Chicago, Ill.)
- MetroLink (St. Louis, Mo.)
- TriMet (Portland, Ore.)
- Pandrol USA
- Progress Rail Services
- LBFoster, CXT Concrete Ties
- GIC USA
- Hanson Professional Services, Inc.
- Amtrak
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Appendix
Box Plot Background

- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality
Quantification of Rail Displacement under Light Rail Transit Field Loading Conditions

Vertical Rail Loads
St. Louis MetroLink – Curve Location

Vertical Load (kN)

Percent Exceeding

Vertical Load (kips)

- Low Rail
- High Rail
- AW0 MetroLink
- AW3 MetroLink
Vertical Rail Loads
St. Louis MetroLink – Curve Location
Vertical Rail Loads
St. Louis MetroLink – Curve Location

- Low Rail
- High Rail
- AW0 MetroLink
- AW3 MetroLink
Vertical Rail Loads
St. Louis MetroLink – Curve Location

Vertical Load (kN)

Percent Exceeding

- Low Rail
- High Rail
- AW0 MetroLink
- AW3 MetroLink

Vertical Load (kips)
Lateral Rail Loads
St. Louis MetroLink – Curve Location

![Graph showing lateral rail loads for low and high rails. The graph plots lateral load (kN) against percent exceeding, with two curves indicating different rail locations.]
Lateral/Vertical (L/V) Ratios
St. Louis MetroLink – Curve Location

Percent Exceeding

L/V Ratio

Low Rail
High Rail
Vertical Rail Loads
St. Louis MetroLink – Tangent Location

Vertical Load (kN)

Percent Exceeding

- Far Rail
- Near Rail
- AW3
- AW0

Vertical Load (kips)
Vertical Rail Loads
St. Louis MetroLink – Tangent Location

Vertical Load (kN)

Percent Exceeding

Vertical Load (kips)

- Far Rail
- Near Rail
- AW3
- AW0
Vertical Rail Loads
St. Louis MetroLink – Tangent Location
**Vertical Rail Loads**

St. Louis MetroLink – Tangent Location

![Graph showing vertical rail loads](image)
Quantification of Rail Displacement under Light Rail Transit Field Loading Conditions

Lateral Rail Loads
St. Louis MetroLink – Tangent Location

Lateral Load (kN)
-6.7 -4.4 -2.2 0.0 2.2 4.4 6.7 8.9 11.1

Percent Exceeding
100%
80%
60%
40%
20%
0%

Lateral Load (kips)
-1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5

(-) (+)