Rail Transit Loading Conditions

FRA and FTA Crosstie and Fastening System Research Program
Industry Partners (IP) Meeting
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Outline

• Field Quantification of Wheel-Rail Loads
  • Light Rail
  • Heavy Rail
  • Commuter Rail
• Discussion of Lateral to Vertical (L/V) Ratios
• Summary of Rail Transit Loading Conditions
Typical Field Instrumentation Map

- 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

<table>
<thead>
<tr>
<th>Crosstie Bending Strain</th>
<th>Rail Displacement (Base Vertical)</th>
<th>Thermocouple</th>
<th>Laser Trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical and Lateral Load (Wheel Loads)</td>
<td>Rail Displacement (Base Vertical, Base Lateral)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Partner Agencies

- Metra
- New York City Transit
- RAILTEC
Light Rail Curve Data

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

Vertical Rail Loads
St. Louis MetroLink (Curve)
Vertical Rail Loads
St. Louis MetroLink (Curve)
Vertical Rail Loads
St. Louis MetroLink (Curve)
Lateral Rail Loads
St. Louis MetroLink (Curve)

Lateral to Vertical (L/V) Ratios
St. Louis MetroLink (Curve)
Partner Agencies

Light Rail Tangent Data

Trains in Dataset: 2,245
From 18 March 2016
to 26 April 2016

(Tangent Location)
Vertical Rail Loads
St. Louis MetroLink (Tangent)

Vertical Load (kN)

Percent Exceeding

0% 20% 40% 60% 80% 100%

Vertical Load (kips)

Far Rail
Near Rail
AW3 MetroLink
AW0 MetroLink

St. Louis MetroLink (Tangent)
Vertical Rail Loads
St. Louis MetroLink (Tangent)
Vertical Rail Loads
St. Louis MetroLink (Tangent)

Lateral Rail Loads
St. Louis MetroLink (Tangent)
Lateral to Vertical (L/V) Ratios
St. Louis MetroLink (Tangent)

Box Plot Background

- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality
- 50% of Data are within the box

Bending Moment

<table>
<thead>
<tr>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
</tbody>
</table>

Median

IQR

Q1 (25th Percentile)

Q3 (75th Percentile)

Min (within fences)

Max (within fences)

Upper inner fence (Q3+1.5×IQR)

Lower inner fence (Q1-1.5×IQR)

Outliers
Vertical Wheel Loads
St. Louis MetroLink (Tangent)

Lateral Wheel Loads
St. Louis MetroLink (Tangent)
Partner Agencies

Heavy Rail Curve Data

Trains in Dataset: 2,245
From 26 April 2016
to 30 June 2016
### Vertical Rail Loads

**MTA New York City Transit (Curve)**

- **Low Rail**
- **High Rail**
- **AW0 NYCTA**
- **AW3 NYCTA**

```
Vertical Load (kN)
```

- Percent Exceeding
  - 1.0%
  - 0.8%
  - 0.6%
  - 0.4%
  - 0.2%
  - 0.0%

- Vertical Load (kips)
  - 0
  - 10
  - 20
  - 30
  - 40
  - 50
  - 60
  - 70

### Lateral Rail Loads

**MTA New York City Transit (Curve)**

- **Low Rail**
- **High Rail**

```
Lateral Load (kN)
```

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

- Lateral Load (kips)
  - -15
  - -10
  - -5
  - 0
  - 5
  - 10
  - 15
  - (-)
  - (+)
Lateral to Vertical (L/V) Ratios
MTA New York City Transit (Curve)

Percent Exceeding

Low Rail
High Rail

Vertical Wheel Loads
MTA New York City Transit (Curve)

Vertical Load (kips)

Axle
“Compressing” the Previous Chart

- Each NYCTA train consists of 4 two-car sets, so each 8 axles is a ‘repeat’ of the equipment (order aside)
- The last chart can be compressed by stacking ‘repeat’ axles
Lateral Wheel Loads
MTA New York City Transit (Curve)

Axle

Lateral Load (kips)

High Rail
Low Rail

MTA New York City Transit
Partner Agencies

Commuter Rail Tangent Data

Trains in Dataset: 5
From 4 August 2016 to 5 August 2016
Vertical Rail Loads
Chicago Metra (Tangent)

Vertical Load (kN)

Percent Exceeding

Vertically Ratio of Rail Load

- Near Rail
- Far Rail
- AW0 Metra Locomotive
- AW0 Metra Coach
- AW3 Metra Coach

Preliminary Data – Recalibration Planned

Vertical Load (Kips)
Vertical Rail Loads
Chicago Metra (Tangent)

Vertical Load (kN)

0 40 80 120 160 200 240

Percent Exceeding

0% 20% 40% 60% 80% 100%

Vertical Load (Kips)

Near Rail
Far Rail
AW0 Metra Locomotive
AW0 Metra Coach
AW3 Metra Coach

Preliminary Data – Recalibration Planned
Lateral Rail Loads
Chicago Metra (Tangent)

Lateral Load (kN)

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

-13.3 -11.1 -8.9 -6.7 -4.4 -2.2 0.0 2.2 4.4 6.7 8.9 11.1 13.3

-3 -2 -1 0 1 2 3

Near Rail
Far Rail

Preliminary Data – Recalibration Planned

Lateral to Vertical (L/V) Ratios
Chicago Metra (Tangent)

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

-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1

Near Rail
Far Rail

Preliminary Data – Recalibration Planned
**Vertical Wheel Loads**

**Chicago Metra (Tangent)**

- Locomotives
- Coaches

**Preliminary Data – Recalibration Planned**

**Lateral Wheel Loads**

**Chicago Metra (Tangent)**

- Near Rail
- Far Rail

**Preliminary Data – Recalibration Planned**
Lateral Wheel Loads
Chicago Metra (Tangent)

Modal Comparison:
Vertical Wheel Loads
Modal Comparison: Vertical Wheel Loads

Commuter Rail*
Heavy Rail
Light Rail

*Preliminary Data – Recalibration Planned
Modal Comparison: Vertical Wheel Loads

- Preliminary Data – Recalibration Planned
**Modal Comparison: Lateral Loads**

**Tangent Locations**

- Preliminary Data – Recalibration Planned

**Modal Comparison: Lateral Loads**

**Curve Locations**
Modal Comparison: L/V Ratios

Tangent Locations

- Preliminary Data – Recalibration Planned

Modal Comparison: L/V Ratios

Curve Locations

- Heavy Rail
- Light Rail
### Vertical Load Percentiles for Each Mode

<table>
<thead>
<tr>
<th>Percentile Vertical Load</th>
<th>Light Rail (Tangent) kips (kN)</th>
<th>Heavy Rail (Curve) kips (kN)</th>
<th>Commuter Rail* (Tangent) kips (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>2.7 (12.2)</td>
<td>6.4 (28.5)</td>
<td>11.2 (49.9)</td>
</tr>
<tr>
<td>50%</td>
<td>8.1 (36.0)</td>
<td>13.8 (61.4)</td>
<td>15.8 (70.1)</td>
</tr>
<tr>
<td>90%</td>
<td>9.4 (42.0)</td>
<td>16.4 (72.9)</td>
<td>18.3 (81.3)</td>
</tr>
<tr>
<td>95%</td>
<td>9.8 (43.8)</td>
<td>17.5 (77.8)</td>
<td>32.6 (145.2)</td>
</tr>
<tr>
<td>99%</td>
<td>10.7 (47.5)</td>
<td>21.1 (93.8)</td>
<td>37.1 (165.0)</td>
</tr>
<tr>
<td>Maximum</td>
<td>18.6 (82.6)</td>
<td>59.3 (263.9)</td>
<td>44.9 (199.7)</td>
</tr>
</tbody>
</table>

| Sample Size (Wheel Passes) | 53,880 | 143,680 | 372 |
| Max. AW0                  | 9.59 (42.6) | 11.4 (50.6) | 18.7 (83.5) |
| Max. AW3                  | 12.5 (55.5) | 16.6 (74.0) | 23.1 (103.0) |

*Preliminary Data – Recalibration Planned

### Impact Factor Percentiles for Each Mode

<table>
<thead>
<tr>
<th>Percentile Impact Factor</th>
<th>Light Rail (Curve)</th>
<th>Light Rail (Tangent)</th>
<th>Heavy Rail (Curve)</th>
<th>Commuter Rail* (Tangent, Coaches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0.47 – 0.91</td>
<td>0.22 - 0.42</td>
<td>0.39 - 0.56</td>
<td>0.49 - 0.88</td>
</tr>
<tr>
<td>50%</td>
<td>0.70 – 1.35</td>
<td>0.65 - 1.25</td>
<td>0.83 - 1.21</td>
<td>0.68 - 1.23</td>
</tr>
<tr>
<td>90%</td>
<td>0.90 – 1.72</td>
<td>0.76 - 1.46</td>
<td>0.99 - 1.44</td>
<td>0.73 - 1.33</td>
</tr>
<tr>
<td>95%</td>
<td>0.94 – 1.82</td>
<td>0.79 - 1.52</td>
<td>1.05 - 1.54</td>
<td>0.76 - 1.37</td>
</tr>
<tr>
<td>99%</td>
<td>1.02 – 1.97</td>
<td>0.86 - 1.65</td>
<td>1.27 - 1.85</td>
<td>0.79 - 1.44</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.14 – 2.19</td>
<td>1.49 - 2.86</td>
<td>3.57 - 5.21</td>
<td>0.96 - 1.74</td>
</tr>
</tbody>
</table>

Impact Factor = \( \frac{\text{Dynamic Load}}{\text{Static Load}} \)

Static load is compared to Min. AW0 and Max. AW3

*Preliminary Data – Recalibration Planned
Impact Factor Comparison Chart

- MetroLink Curve Low Estimate
- MetroLink Tangent Low Estimate
- NYCTA Curve Low Estimate
- Metra Tangent Coaches Low Estimate
- MetroLink Curve High Estimate
- MetroLink Tangent High Estimate
- NYCTA Curve High Estimate
- Metra Tangent Coaches High Estimate
- AREMA Recommended Impact Factor

*Preliminary Data – Recalibration Planned
Impact Factor Comparison Chart

Lateral Load Percentiles for Each Mode

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Light Rail (Curve)</th>
<th>Light Rail (Tangent)</th>
<th>Heavy Rail (Curve)</th>
<th>Commuter Rail* (Tangent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-2.3 (-10.4)</td>
<td>-1.2 (-5.4)</td>
<td>-10.5 (-46.8)</td>
<td>-1.9 (-8.8)</td>
</tr>
<tr>
<td>50%</td>
<td>2.6 (11.5)</td>
<td>0.1 (0.5)</td>
<td>2.4 (10.5)</td>
<td>-0.1 (-0.6)</td>
</tr>
<tr>
<td>90%</td>
<td>5.2 (22.9)</td>
<td>0.6 (2.7)</td>
<td>5.7 (25.6)</td>
<td>0.4 (1.7)</td>
</tr>
<tr>
<td>95%</td>
<td>5.7 (25.4)</td>
<td>0.8 (3.6)</td>
<td>6.5 (29.1)</td>
<td>0.6 (2.6)</td>
</tr>
<tr>
<td>99%</td>
<td>6.4 (28.4)</td>
<td>1.3 (5.7)</td>
<td>7.9 (35.0)</td>
<td>0.9 (4.2)</td>
</tr>
<tr>
<td>Maximum</td>
<td>6.7 (29.7)</td>
<td>2.4 (10.4)</td>
<td>12.0 (53.5)</td>
<td>2.1 (9.5)</td>
</tr>
</tbody>
</table>

Sample Size (Wheel Passes) | 120 | 26,690 | 143,680 | 372

*Preliminary Data – Recalibration Planned
Rail Load Data Conclusions

- Instrumentation has successfully captured wheel-rail loading data from 3 rail transit modes at 4 field sites
- At both curve locations, the high rail experiences the largest load in 99% of cases while the low rail experiences the absolute maximum load
- In comparing tangent locations, the L/V ratio varies more for lighter equipment (light rail vs. commuter rail), but this difference is not as distinct for curve sites
- Impact Factors for differ between modes; for example, between heavy and light rail the impact factor is:
  - 2.7 times greater at maximum load
  - 1.7 times greater at 99th percentile load

Path Forward

- Analyze extreme cases to understand better the environment leading to high wheel loads
- Study the influence of speed on vertical & lateral loads
- Use field data to evaluate the effectiveness of dynamic factor models and rail seat load models for light, heavy, and commuter rail systems
- Further study of L/V ratios and track/train dynamics
- Perform analysis of seasonal variation
- Recalibration and further collection of Metra data
- Further investigation of maintenance-of-way equipment loading conditions and their influence on design
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