Outline

- Objective and Approach
- Flexural Behavior Results
- Temperature Effect Results
- Conclusions
- Future Work
Objectives and Approach

- **Objectives:**
  - Understand the flexural behavior of crossties under rail transit loading conditions using field data collected under revenue service
  - Study the variability of moments as a function of rolling stock wheel loads
  - Use the bending moment characterization of transit systems for crosstie redesign

- **Approach:**
  1. Field Data Collection
  2. Processing of Measured Strains
  3. Analysis of Data
  4. Design Related Information

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**

- **Instrumentation:**
  - Crosstie Bending Strain
  - Vertical and Lateral Load (Wheel Loads)
  - Rail Displacement (Base Vertical, Base Lateral)
  - Rail Displacement (Base Vertical)
  - Thermocouple
  - Laser Trigger
  - (Ambient Temperature)
Crosstie Specifications

Rail Transit System

Crosstie Manufacturer

<table>
<thead>
<tr>
<th>Model</th>
<th>CXT 100-06</th>
<th>CXT 495-20</th>
<th>CXT 497s</th>
<th>CXT 505s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>8' 3&quot;</td>
<td>8' 6&quot;</td>
<td>8' 6&quot;</td>
<td>8' 6&quot;</td>
</tr>
<tr>
<td>Tie Spacing</td>
<td>30&quot;</td>
<td>24&quot;</td>
<td>24&quot;</td>
<td>24&quot;</td>
</tr>
</tbody>
</table>

Design Capacity

- **Center Negative Spec.**
  - Design: 147 kip-in
  - Spec.: 144 kip-in

- **Rail Seat Positive Spec.**
  - Design: 221 kip-in
  - Spec.: 179 kip-in

Data Processing Overview

Crosstie Bending

- **Desired data:**
  - Crosstie bending strains due to transit loads

- **Motivation of study and objective of data analysis:**
  - Understand revenue service bending moments
  - Determine the support conditions for crossties
  - Calibrate FE model with field data
  - Assess the capacity and design of the manufacturer and the specifications given by rail transit agencies
Partner Agencies

Light Rail Tangent Data

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

(Tangent Site)
Center Negative Bending
St. Louis MetroLink

Bending Moment (kNm)

Percent Exceeding

Bending Moment (kip-inches)

- Crosstie 1
- Crosstie 2
- Crosstie 3
- Crosstie 4
- Crosstie 5
- Combined
Center Negative Bending
St. Louis MetroLink

![Graph showing bending moment distribution for different crossties and a combined analysis.]

Rail Seat Bending
St. Louis MetroLink – Gauge A

![Graph showing bending moment distribution for different crossties and a combined analysis.]

Rail Seat Bending
St. Louis MetroLink – Gauge A

Bending Moment (kNm)

Percent Exceeding

Bending Moment (kip-inches)

-2 0 2 4 6 8 10 12 14 16 18 20

100%

80%

60%

40%

20%

0%

-20 0 20 40 60 80 100 120 140 160 180

Crosstie 1
Crosstie 2
Crosstie 3
Crosstie 4
Crosstie 5
Combined

Rail Seat Bending
St. Louis MetroLink – Gauge E

Bending Moment (kNm)

Percent Exceeding

Bending Moment (kip-inches)

-2 0 2 4 6 8 10 12 14 16 18 20

100%

80%

60%

40%

20%

0%

-20 0 20 40 60 80 100 120 140 160 180

Crosstie 1
Crosstie 2
Crosstie 3
Crosstie 4
Crosstie 5
Combined
Rail Seat Bending
St. Louis MetroLink – Gauge E

Average Bending Moments
St. Louis MetroLink
Bending Moment
St. Louis MetroLink

Partner Agencies
Heavy Rail Curve Data

Trains in Dataset: 2,245
From 26 April 2016
to 30 June 2016

Center Negative Bending
MTA New York City Transit
Center Negative Bending
MTA New York City Transit

Bending Moment (kNm)

Percent Exceeding

0 2 4 6 8 10 12 14 16 18 20 22

0 20 40 60 80 100

-Crosstie 1
-Crosstie 2
-Crosstie 3
-Crosstie 4
-Crosstie 5
-Combined

Bending Moment (kip-inches)

Partner Agencies

Metra
The way to really fly.

New York City Transit
RAILTEC
Commuter Rail Tangent Data

Trains in Dataset: 5
From 4 August 2016
to 5 August 2016

Center Negative Bending
Chicago Metra

Immediately after tamping activity
Center Negative Bending

Chicago Metra

Immediately after tamping activity

Rail Seat Bending

Chicago Metra – Gauge A

Immediately after tamping activity
**Rail Seat Bending**

**Chicago Metra – Gauge A**

Immediately after tamping activity

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**Rail Seat Bending**

**Chicago Metra – Gauge E**

Immediately after tamping activity
Rail Seat Bending
Chicago Metra – Gauge E

Immediately after tamping activity

Average Bending Moments
Chicago Metra

Immediately after tamping activity
Bending Moment

Chicago Metra

Bending Moment (kNm)

Immediately after tamping activity

Center Negative Bending Comparison

Bending Moment (kNm)
Center Negative Bending Comparison

Bending Moment (kNm)

Bending Moment (kip-inches)

Percent Exceeding

- Light Rail (St. Louis MetroLink)
- Heavy Rail (NYCTA)
- Freight and Commuter (Metra)
- MetroLink Specification
- NYCTA Specification
- AREMA Recommendation
- CXT 100 Design Capacity
- CXT 495-20 Design Capacity
Center Negative Bending Comparison

**Rail Transit Concrete Crosstie Flexural Behavior**

**Slide 35**

**Rail Transit Concrete Crosstie Flexural Behavior**

**Slide 36**
rail transit concrete crosstie flexural behavior

slide 37

Crosstie Reserve Capacity
Center Negative Bending Moment

<table>
<thead>
<tr>
<th>Percentile Bending Moment</th>
<th>Reserve Design Capacity</th>
<th>Design Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light Rail</td>
<td>Heavy Rail</td>
</tr>
<tr>
<td>Minimum</td>
<td>82.48</td>
<td>10.86</td>
</tr>
<tr>
<td>Average</td>
<td>12.96</td>
<td>2.96</td>
</tr>
<tr>
<td>90%</td>
<td>9.25</td>
<td>1.93</td>
</tr>
<tr>
<td>95%</td>
<td>8.74</td>
<td>1.83</td>
</tr>
<tr>
<td>99%</td>
<td>8.05</td>
<td>1.71</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.55</td>
<td>1.51</td>
</tr>
</tbody>
</table>

- Max recorded center bending moment (25 kip-inches) for light rail could be increased by a factor of 5.6 without reaching the design moment for the crosstie or the agency specifications.
- Max center bending moment found for heavy rail is 112 kip-inches, providing potential reserve capacity of 1.5.
- Max recorded center bending moment on commuter rail shared corridor:
  - 45 kip-inches for commuter rail rolling stock (potential reserve capacity 4.5)
  - 83 kip-inches for freight trains (potential reserve capacity of 2.4)

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rail seat bending comparison

Bending Moment (kNm)

<table>
<thead>
<tr>
<th>Percent Exceeding</th>
<th>Bending Moment (kip-inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>0</td>
</tr>
<tr>
<td>90%</td>
<td>0</td>
</tr>
<tr>
<td>80%</td>
<td>5</td>
</tr>
<tr>
<td>70%</td>
<td>10</td>
</tr>
<tr>
<td>60%</td>
<td>15</td>
</tr>
<tr>
<td>50%</td>
<td>20</td>
</tr>
<tr>
<td>40%</td>
<td>25</td>
</tr>
<tr>
<td>30%</td>
<td>30</td>
</tr>
<tr>
<td>20%</td>
<td>35</td>
</tr>
<tr>
<td>10%</td>
<td>40</td>
</tr>
<tr>
<td>0%</td>
<td>45</td>
</tr>
</tbody>
</table>

- Light Rail (St. Louis MetroLink)
- Commuter (Metra)
- MetroLink Specification
- AREMA Recommendation
- CXT 100 Design Capacity
## Rail Seat Bending Comparison

![Bending Moment Comparison Graph](image)

### Crosstie Reserve Capacity

**Rail Seat Bending Moment**

<table>
<thead>
<tr>
<th>Percentile Bending Moment</th>
<th>Reserve Design Capacity</th>
<th>Design Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light Rail</td>
<td>Heavy Rail</td>
</tr>
<tr>
<td>Minimum</td>
<td>43.11</td>
<td>---</td>
</tr>
<tr>
<td>Average</td>
<td>7.50</td>
<td>---</td>
</tr>
<tr>
<td>90%</td>
<td>5.41</td>
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<tr>
<td>95%</td>
<td>4.95</td>
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</tr>
<tr>
<td>99%</td>
<td>4.16</td>
<td>---</td>
</tr>
<tr>
<td>Maximum</td>
<td>2.15</td>
<td>---</td>
</tr>
</tbody>
</table>

- Max recorded rail seat positive bending moment **(62 kip-inches)** for light rail could be increased by a factor of **2.2** without reaching the design moment for the crosstie or the agency specs.
- Data for heavy rail could not be obtained.
- Max recorded center bending moment on commuter rail shared corridor:
  - **84 kip-inches** for commuter rail rolling stock (potential reserve capacity of **3.6**)
  - Data for freight has not been obtained.
Bending Moments Conclusions

- Flexural reserve capacity was quantified for the three rail transit systems (light, heavy, and commuter rail)
- Check for maintenance-of-way equipment loads, as these can be the governing loads (especially for light rail)
- Potential reserve capacity for center negative bending moment is generally higher than rail seat positive bending moment
- Relevant variability of bending moments in heavy rail, changing support conditions hugely affect moment distribution
- Low center bending moments in commuter rail for data after tamping of track (restoration of support conditions)
- Future work:
  - Data set for commuter rail and freight to be expanded
  - Rail seat bending moments on heavy rail to be studied

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
Data Processing Overview
Crosstie Temperature Gradient

- Desired data:
  - Temperature gradient of crosstie

- Motivation of study and objective of data analysis:
  - Quantify the difference in temperature between top and bottom of crosstie and understand the effect of temperature differential on crosstie support conditions
  - Study how environmental conditions affect to temperature of crosstie
  - Relate temperature and bending moment distribution in concrete crossties

- Advantage of automated data collection
  - Daily and seasonal variations to be considered

Environmental conditions cause differential temperature between top and bottom of crosstie

- Differential strain at top and bottom of crosstie (curl)

- Curl affects to crosstie support conditions
  - Upward curl: lack of center support due to (+) gradient
  - Downward curl: center binding due to (-) gradient
Temperature Gradient Effect

- Environmental conditions cause differential temperature between top and bottom of crosstie
- **Differential strain at top and bottom** of crosstie (curl)
- Curl affects to crosstie support conditions
  - **Upward curl**: lack of center support due to (+) gradient
  - **Downward curl**: center binding due to (-) gradient

Partner Agencies

![Map of Partner Agencies](image)
Light Rail Temperature Data

From 7 March 2016 to 22 August 2016

Temperature Distribution
St. Louis MetroLink

- Current data batch from 7 March 2016 to 22 August 2016
Temperature Distribution
St. Louis MetroLink

- 19 March 2016 to 2 April 2016 (1250 trains during this time)
- Limited range to study variation and relation with bending moments

Temperature and Bending Moment
St. Louis MetroLink

- Noticeable relation between variation in gradient and in bending moment
- Positive center bending moments would be reached for hotter part of the day
Temperature and Bending Moment
St. Louis MetroLink

- Noticeable relation between variation in gradient and in bending moment
- Positive center bending moments would be reached for hotter part of the day
Temperature and Bending Moment
St. Louis MetroLink

- Scatter plot of Temperature Gradient vs Center Bending Moment (in abs. value)
- Consistent linear relation gradient/ bending moment for the 5 different ties

Temperature and Bending Moment
St. Louis MetroLink

- Trendlines to define relation, slope of 1 kip-in/°F (0.063 kN-m /°C)
- Relation between moment and gradient has same slope for all ties
Partner Agencies

Heavy Rail Temperature Data

From 25 April 2016 to 12 September 2016
Temperature Distribution
MTA New York City Transit

• Current data batch from 25 April 2016 to 12 September 2016

Temperature Distribution
MTA New York City Transit

• 4 May 2016 to 18 May 2016 (937 trains during this time)
• Selected in order to compare with bending moments
Similar to previous plot, relation between gradient variation and variation in bending moment.
Similar to previous plot, relation between gradient variation and variation in bending moment

Scatter plot of Temperature Gradient vs Center Bending Moment (in abs. value)

Bigger difference due to higher variability in center bending moments for NYCTA
Temperature and Bending Moment

MTA New York City Transit

- Approximate slope of 1 kip-in/°F (0.063 kN-m/°C)
- Bigger difference due to higher variability in center bending moments for NYCTA

Temperature Results and Conclusions

- Similar behavior of temperature data for both sites and crossties, suggesting similar moment/gradient value (~ 1 kip-in/°F [0.063 kNm/°C])
- Ambient temperature consistently similar to temperature at bottom of tie
- Top of crosstie temperature more variable and sensitive to solar radiation
- The bending moment variation captured is due to the changing support conditions of the crossties due to curl
- Effect of temperature gradient on bending moments due to train loads is studied
Overall Flexural Conclusions

• Potential reserve capacity in center bending moment and rail seats is found in the three different light rail transit systems analyzed
• Rail seats bending moments on curve sites should be the focus of additional study
• Top of crosstie very sensitive to temperature variation due to solar radiation
• Curl due to temperature gradient between top and bottom affects support conditions
• Variation of bending moments inferred by rolling stock varies linearly with curl

Future Work

• Expand data sets, mostly for commuter rail to study:
  – Variations on smaller sets as they increase
  – Seasonal variation effect on temperature and bending moment due to increase of input loads
• Analysis of crossties’ intermediate gauges
• Comparison of different crossties under same loading conditions and different systems performance
• Compare results with lab tests, analytical models, and FEM models
• Understand bending moments under transit rail loading conditions to undertake new design of crossties
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 Inc.
  - Hanson Professional Services, Inc.
  - Amtrak

- Special thanks to Union Pacific for providing access to their Geneva Subdivision for field instrumentation

Contact Information

Alvaro E. Canga Ruiz
Graduate Research Assistant
cangaru2@illinois.edu

Aaron A. Cook
Graduate Research Assistant
aacook2@illinois.edu

Matthew V. Csenge
Manager of Experimentation
csenge2@illinois.edu

Marcus S. Dersch
Senior Research Engineer
mdersch2@illinois.edu

Yu Qian
Research Engineer
yuqian1@illinois.edu

J. Riley Edwards
Senior Lecturer and Research Scientist
jedward2@illinois.edu