Resilient Concrete Crosstie and Fastening System Designs for Light Rail, Heavy Rail, and Commuter Rail Transit Infrastructure

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Matthew V. Csenge, Marcus S. Dersch, J. Riley Edwards
Outline

• Background and Problem Statement
• Mission and Approach
• Rail Transit Vehicle, Infrastructure, and System Characteristics
• Rail Transit Vehicle Weight and Wheel Loads
• Rail Transit Vehicle Impact Factors
• Field Data Collection
• Future Work
Background and Problem Statement

- Rail transit systems have unique loading conditions due to the variety of vehicles used from system to system.
- Limited research has been conducted to understand the type and magnitude of loads in rail transit systems.
- Aging rail transit infrastructure assets need to be well maintained or replaced to keep the system in a “state of good repair.”
Project Mission

Characterize the desired performance and resiliency requirements for concrete crossties and fastening systems, quantify their behavior under load, and develop resilient infrastructure component design solutions for concrete crossties and fastening systems for rail transit operators.
Project Approach

- Paper Study
- Industry Surveys
- Field Data Collection
- Laboratory Experimentation
- Environmental Factors and Special Circumstances

Resilient Concrete Crosstie and Fastening System for Rail Transit Infrastructure
# Rail Transit Definitions and System Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Light Rail (Tram)</th>
<th>Heavy Rail (Metro)</th>
<th>Commuter Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (prs/h)</td>
<td>6,000 – 20,000</td>
<td>10,000 – 60,000</td>
<td>8,000 – 45,000</td>
</tr>
<tr>
<td>Exclusive ROW</td>
<td>40% – 90%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Overhead/diesel</td>
<td>Third rail/overhead</td>
<td>Overhead/third rail/diesel</td>
</tr>
<tr>
<td>Area Coverage</td>
<td>Central business district</td>
<td>Mostly central business district</td>
<td>Mostly suburban coverage</td>
</tr>
<tr>
<td>Station Spacing</td>
<td>0.25-1 mi (0.4-1.6 km)</td>
<td>0.5-2 mi (0.8-3.2 km)</td>
<td>2-5 mi (3.2-8 km)</td>
</tr>
<tr>
<td>Frequency</td>
<td>5-20 minutes</td>
<td>5-20 minutes</td>
<td>0.5-3 hours</td>
</tr>
<tr>
<td>Speed</td>
<td>20-55 mph (32-88 km/h)</td>
<td>50-80 mph (80-129 km/h)</td>
<td>30-125 mph (48-201 km/h)</td>
</tr>
</tbody>
</table>

Example
Rail Transit Vehicle Weight and Wheel Loads

- Quantify Static Wheel Loads
- Estimate Impact Factors
- Quantify In-Service Loads
- Design Prototype Transit Crosstie
Rail Transit Vehicle Weight Definitions

• AW0: Empty vehicle operating weight
• AW1 (Seated Load)
  – Fully seated passenger load + AW0
• AW2 (Design Load)
  – Standing passenger load at 4/m² + AW1
• AW3 (Crush Load)
  – Standing passenger load at 6/m² + AW1
• AW4 (Structural Design Load)
  – Standing passenger load at 8/m² + AW1
Rail Transit Vehicle Weight Definitions

- **AW0**: Empty vehicle operating weight
- **AW1** (Seated Load)
  - Fully seated passenger load + AW0
- **AW2** (Design Load)
  - Standing passenger load at 4/m² + AW1
- **AW3** = Maximum Passenger Capacity × Average Passenger Weight + AW0
- **AW4** (Structural Design Load)
  - Standing passenger load at 8/m² + AW1
Resilient Concrete Crosstie and Fastening System Designs for Rail Transit Infrastructure

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Rail Transit Vehicle Weight Definitions

- Rail transit vehicle information
  - National Transit Database (NTD) Revenue Vehicle Inventory
  - Vehicle datasheets

- These sources provided data for:
  - 100% of light rail vehicles (2,072 of 2,072)
  - 85% of heavy rail vehicles (9,781 of 11,474)
  - 72% of commuter railcars (4,353 of 6,047)
  - 91% of commuter locomotives (674 of 738)
Rail Transit Vehicle Weight Definitions

• Average passenger weight
  – 155 lbs (70 kg) per passenger is currently used in the Light Rail Design Handbook*
  – Smith and Schroeder (2013) took quantitative and statistical approach to the best way to account for the growth in rider size and weight over the last 30-40 years

\[
\text{Total Car Weight} = 199 \text{ lbs } \times \text{Seat Cap.} + 106 \text{ lbs } \times \text{ft}^2 \text{ stand space} + \text{Car Weight}
\]

– 195 lbs (88.5 kg) is used as average passenger weight to simplify calculation

Light Rail, Heavy Rail, and Commuter Rail Vehicle Wheel Load Distribution

Wheel Load (kN)

Wheel Load (kips)

Percent Exceeding

Light Rail AW0
Heavy Rail AW0
Commuter Railcar AW0
Commuter Rail Locomotive AW0

Light Rail AW3
Heavy Rail AW3
Commuter Railcar AW3
Commuter Rail Locomotive AW0
Resilient Concrete Crosstie and Fastening System Designs for Rail Transit Infrastructure

Light Rail, Heavy Rail, and Commuter Rail Vehicle Wheel Load Distribution

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Imperial Units</th>
<th></th>
<th>Metric Units</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AW0 Wheel Load (kips)</td>
<td>AW3 Wheel Load (kips)</td>
<td>AW0 Wheel Load (kN)</td>
<td>AW3 Wheel Load (kN)</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Average</td>
<td>Minimum</td>
</tr>
<tr>
<td>Light Rail</td>
<td>4.8</td>
<td>9.1</td>
<td>7.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Heavy Rail</td>
<td>6.8</td>
<td>11.6</td>
<td>9.4</td>
<td>8.1</td>
</tr>
<tr>
<td>Commuter Railcar</td>
<td>10.6</td>
<td>20.4</td>
<td>10.6</td>
<td>15.2</td>
</tr>
<tr>
<td>Commuter Rail Locomotive</td>
<td>25.0</td>
<td>37.2</td>
<td>32.7</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- This data is balloted for inclusion in the American Railway Engineering and Maintenance-of-way Association (AREMA) Manual for Railway Engineering
Rail Transit Vehicle Impact Factors

- Quantify Static Wheel Loads
- Estimate Impact Factors
- Quantify In-Service Loads
- Design Resilient Transit Crosstie
Rail Transit Vehicle Impact Factor

- Impact factor is defined as a percentage increase over static vertical loads intended to estimate the dynamic effect of wheel and rail irregularities.
- AREMA recommends an impact factor of 200%, which indicates the design load is three times the static load, equivalent to an impact load factor of 3.
- The same impact factor of three applies to both freight railroads and rail transit systems.
- Data from a wheel impact load detector (WILD) site on Amtrak’s Northeast Corridor between New York City and Washington DC were analyzed to determine optimum design impact factors.
Peak Load vs. Nominal Wheel Load for Commuter Railcars

Nominal Wheel Load (kN)

Peak Load = Static Load

Impact Factor (IF)
- IF = 1
- IF = 2
- IF = 3
- IF = 4

Peak Load vs. Nominal Wheel Load for Commuter Railcars
Peak Load vs. Nominal Wheel Load for Commuter Locomotives

Nominal Wheel Load (kN)

Peak Load = Static Load

Impact Factor (IF)

- IF = 4
- IF = 3
- IF = 2
- IF = 1

Nominal Wheel Load (kips)

Peak Load (kips)

Nominal Wheel Load (kN)

Peak Load (kN)
Impact Factor Conclusions

- Impact factor of 3 considers 98.9% of nominal commuter railcar wheel loads at the location analyzed.
- Impact factor of 2 considers 99.9% of nominal commuter locomotive wheel loads at the location analyzed.
- Different types of rail vehicles can impart higher or lower impact loads on the track.
  - These data will be further compared to field data collected during this project.
Field Data Collection

- Quantify Static Wheel Loads
- Estimate Impact Factors
- Quantify In-Service Loads
- Design Resilient Transit Crosstie
Purpose of Field Data Collection

• Field experimentation is used to quantify the in-service demands placed on the track system across loading conditions and environments

• 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)
Partner Agencies

Field Instrumentation Timeline
MetroLink: Fall ‘15, Winter ‘16
NYCT: Spring ‘16
Metra: Summer ‘16
TriMet: TBD
Instrumentation Map

- Crosstie Bending Strain
- Vertical and Lateral Load (Wheel Loads)
- Rail Displacement (Base Vertical, Base Lateral)
- Rail Displacement (Base Vertical)
- Thermocouple
- Laser Trigger

(Top Temperature)
(Base Temperature)
(Ambient Temperature)
Automated Data Acquisition System

- Automated data collection systems have been deployed at MetroLink and New York City Transit sites using National Instruments (NI) Compact DAQ (cDAQ) equipment.

- Laser sensor triggers data collection every time a train passes the site.

- Thermocouple data is recorded every 5 minutes, 24 hours per day.

- A third system will be installed at the Metra site in summer 2016.
Preliminary Data

- Automated DAQ system collects an average of:
  - 154 train data files per day at the MetroLink site
    - Tangent location
    - Maximum operating speed: 55 mph (88 km/h)
    - Deployed on March 18, 2016
  - 88 train data files per day at the New York City Transit site
    - Curve location: 3.6° (485 m radius)
    - Maximum operating speed: 30 mph (48 km/h)
    - Deployed on April 25, 2016
MetroLink Light Rail Vehicles
Siemens SD-400 & SD-460

- 2-vehicle (12 axle) trainsets
- Traction motor and gearbox locations:

• Normal trainset configuration:
Box Plot Background

- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality
Light Rail Vertical Loads

Vertical Wheel Load (kips) vs. Axle

- Rail A
- Rail B

*data from 1,963 trains
Field Data Collection Conclusions

- Automated data collection systems can be deployed at remote locations and will run reliably for long durations.
- In-service wheel loads may be up to 1.5 times more than the static wheel load for a rail transit vehicle.
- Large amounts of data collected at automated sites requires automated or semi-automated data processing.
Future Work

• Further expand the understanding of vehicle and infrastructure characteristics for rail transit systems

• Incorporate field data to evaluate the effectiveness of dynamic factor models and rail seat load models for light rail and heavy rail systems

• Install automated data collection system on commuter rail transit system (Metra, Chicago, IL, USA)
2016 International Crosstie & Fastening System Symposium

- Co-organized by: RailTEC, AREMA Committee 30 (Ties), Railway Tie Association (RTA)

- Three day conference with presentations, discussions, and a technical tour

- 14-16 June 2014 – Sessions on UIUC campus in Champaign, IL

- 15 June 2014 – Technical tour to UIUC’s Research and Innovation Laboratory (RAIL)
  - NDT Corp. Demonstration Outside RAIL

- Keynote address by David Connell, UPRR VP Engineering Retired

- Draft program released

- To date:
  - 38 presentations accepted
  - 14 supporters
  - Registration open
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- Pandrol USA
- Progress Rail Services – Fastening Solutions
- LBFoster
- GIC Inc.
- Hanson Professional Services, Inc.
- Amtrak

FTA Industry Partners:

U.S. Department of Transportation
Federal Transit Administration

NURail Center

AMERICAN PUBLIC TRANSPORTATION ASSOCIATION

New York City Transit

Metra®

The way to really fly.

Progress Rail Services

A Caterpillar Company

Hanson Professional Services, Inc.

Amtrak

LBFoster

CXT Concrete Ties
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Contact Information

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

Xiao (Sean) Lin  
Graduate Research Assistant  
xiaolin4@illinois.edu

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

Yu Qian  
Research Engineer  
yuqian1@illinois.edu

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

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