Mechanistic Design of Concrete Crossties for Rail Transit Systems

Project Objectives and Update

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

Bonita Springs, FL

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U.S. Department of Transportation
Federal Transit Administration

RAILTEC
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Outline

- Background and Problem Statement
- Mission and Approach
- Vehicle Weight and Wheel Loads
- Field Data Collection
  - Partner Agencies
  - Locations and Site Layouts
  - Vehicle Types
  - Instrumentation Overview
  - Automated DAQ System
- Path Forward and Future Work

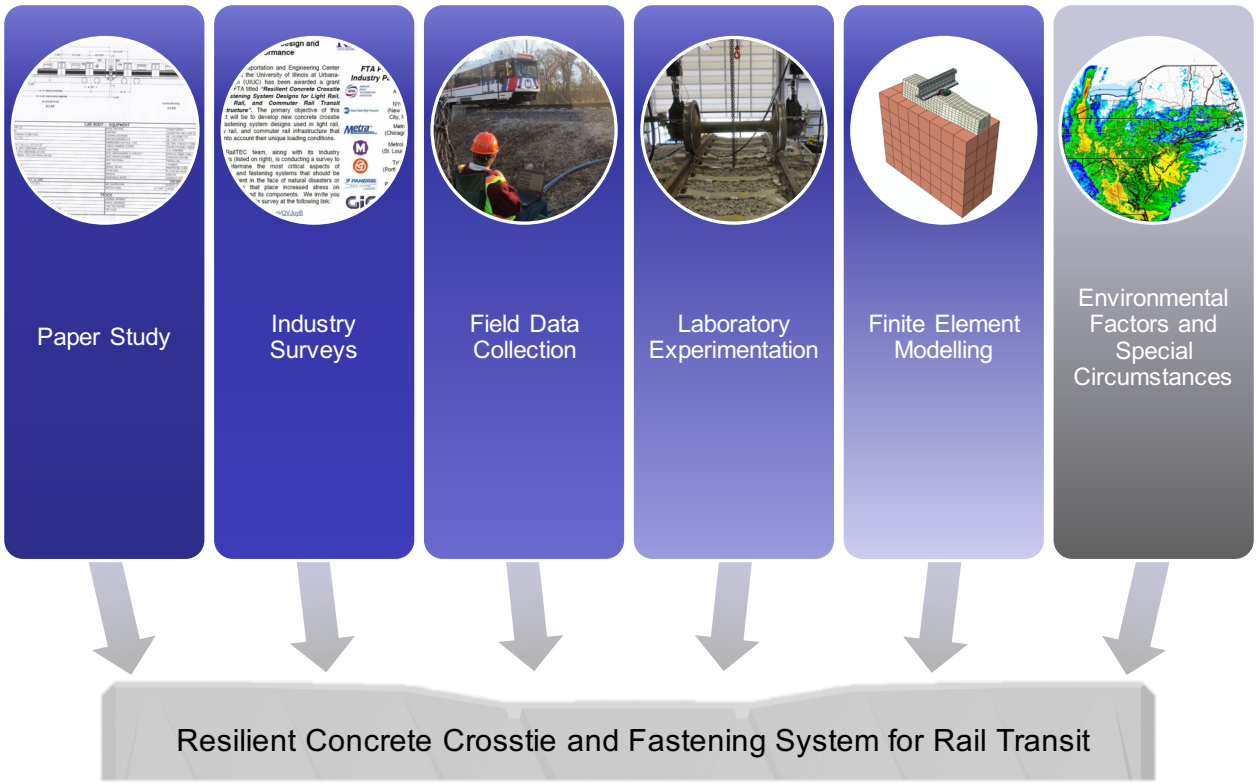
Background and Problem Statement

- 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” – a USDOT Strategic Goal

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



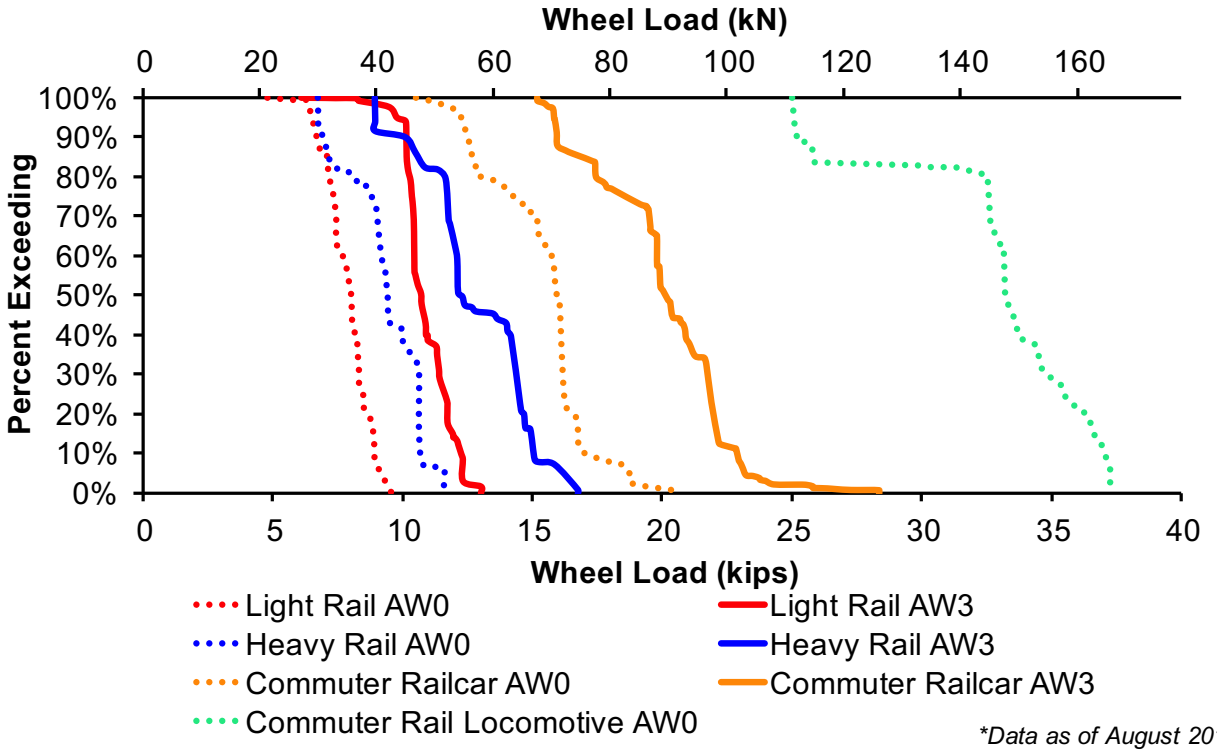
Rail Transit Vehicle Weight Definitions

- **AW0 (Empty Load)**
  - Empty vehicle weight, ready to operate
- AW1 (Seated Load)
  - Crew and fully seated passenger load + AW0
- AW2 (Design Load)
  - Standing passenger load at $4/m^2$ + AW1
- **AW3 (Crush Load)**
  - **Maximum passenger capacity × average passenger weight + AW0**
- AW4 (Structural Design Load)
  - Standing passenger load at $8/m^2$ + AW1

Rail Transit Vehicle Weight Quantification

- AW0 and AW3 weights were calculated for rail transit vehicles operating within the United States as of August 2015
  - National Transit Database (NTD) Revenue Vehicle Inventory
  - Vehicle datasheets
  - 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)
- 195 lbs. (88.5 kg) per person was used as average passenger weight for AW3 calculations based on multiple sources, including Federal Aviation Administration (FAA) standards
- Data tabulated and balloted for inclusion in the AREMA Manual for Railway Engineering

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



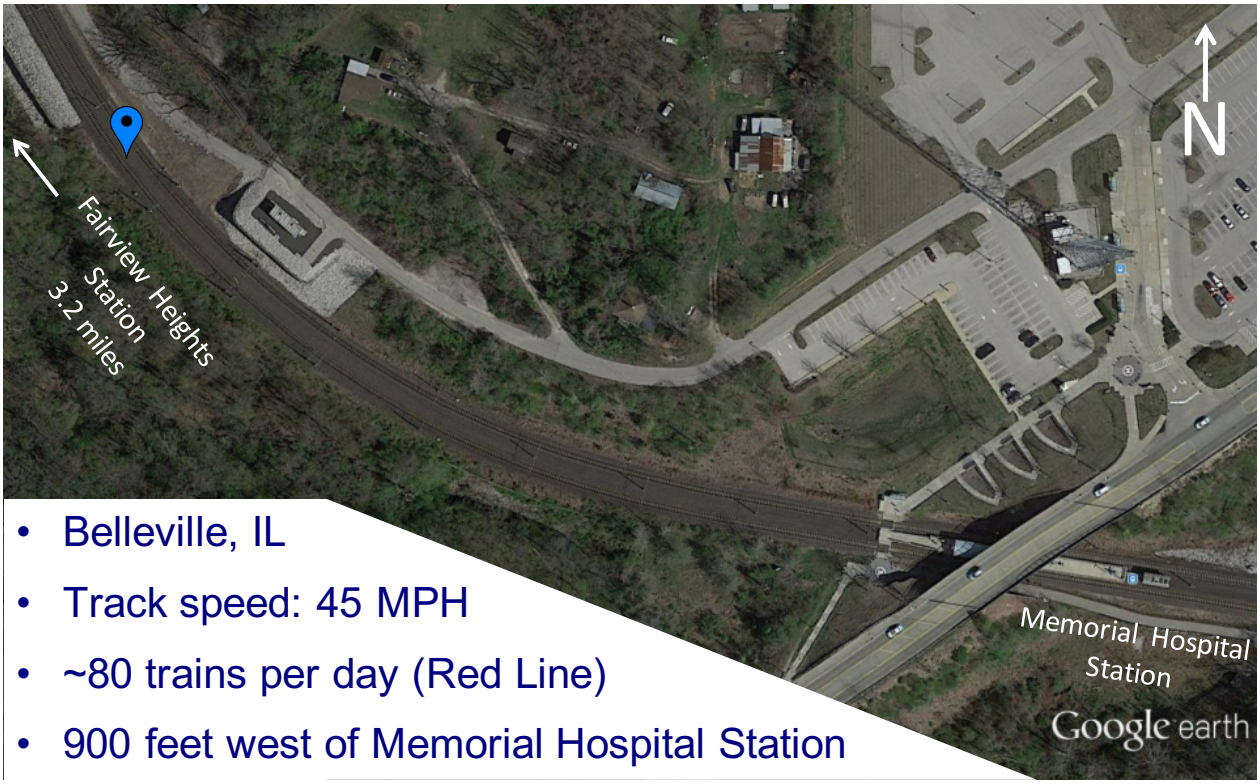
*Data as of August 2015

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:
  - **Vertical and lateral input loads** (crosstie and fastening system design, and load environment characterization)
  - **Rail displacements** (fastening system design)
  - **Crosstie bending strain** (crosstie moment design)
    - Temperature gradient-induced curl

Partner Agencies

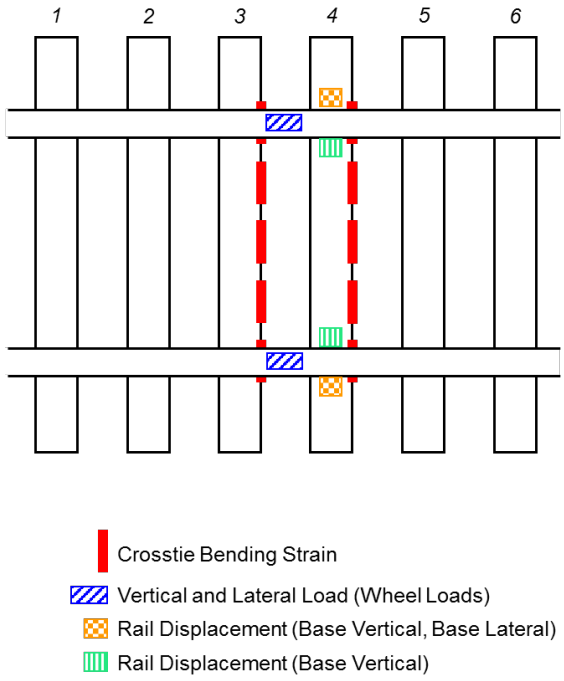
MetroLink Curve Location



- Belleville, IL
- Track speed: 45 MPH
- ~80 trains per day (Red Line)
- 900 feet west of Memorial Hospital Station

Field Instrumentation Map

MetroLink Curve Site



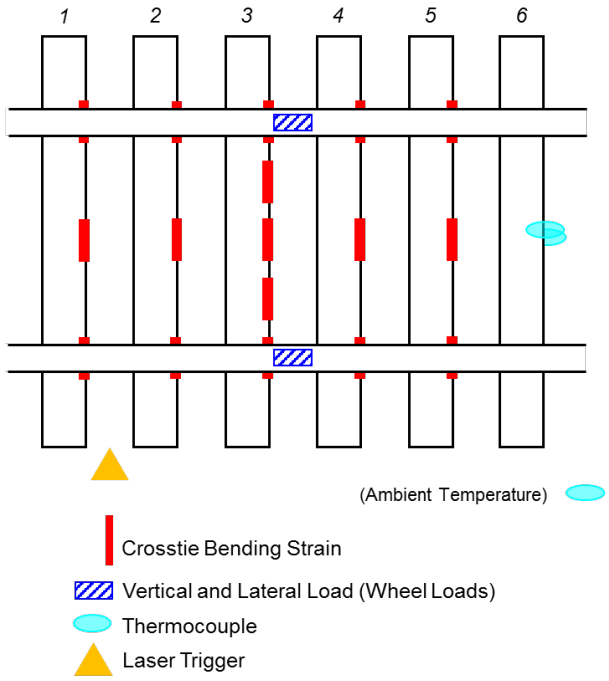
- Site characteristics:
  - Track 1 (westbound/inbound)
  - Maximum allowable speed: 45 mph (72 km/h)
  - Curve: 6°00' (955 ft. (291 m) radius)
  - Superelevation: 5.25 in. (133 mm)
  - Grade: -1.0% (directional traffic)

MetroLink Tangent Location

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

Field Instrumentation Map

MetroLink Tangent Site



- Site characteristics:
  - Track 1 (westbound/inbound)
  - Maximum allowable speed: 55 mph (88.5 km/h)
  - Tangent
  - Grade: -0.27% (directional traffic)

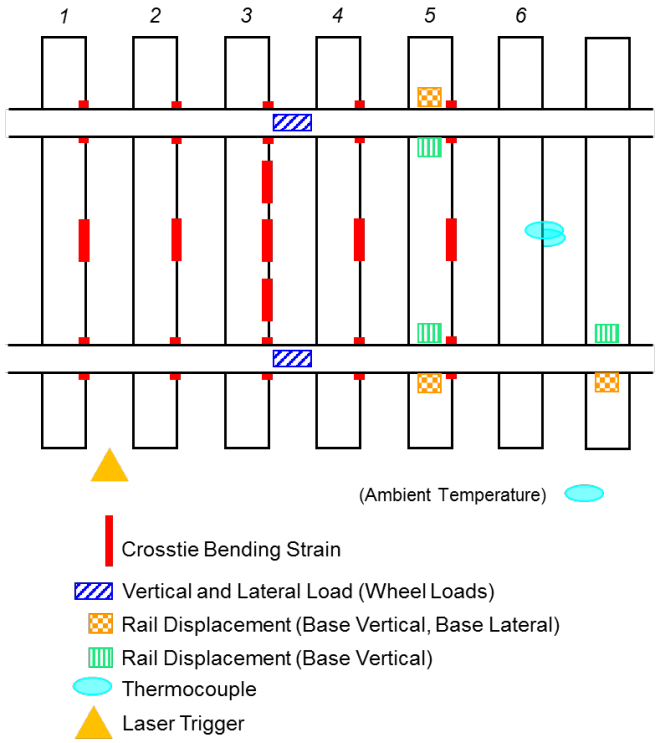
NYCTA Location

New York City Transit

- Far Rockaway, NY
- Track speed: 30 MPH
- ~80 trains/day (A service)
- Located on the eastern leg of Hammels Wye

Field Instrumentation Map

NYCTA Site



- Site characteristics:
  - Track 1 (southbound/outbound)
  - Maximum allowable speed: 30 mph (48 km/h)
  - Curve: 3°37.5' (1,580.6 ft. (481.8 m) radius)
  - Superelevation: 2 in. (50.8 mm)
  - Grade: 2.28% (directional traffic)

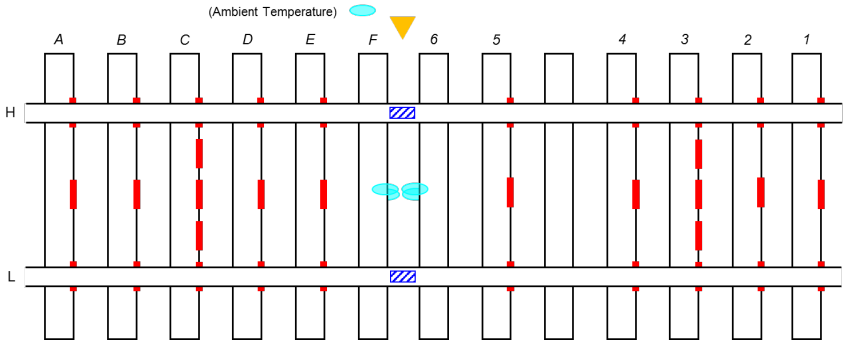
New York City Transit

Metra Location

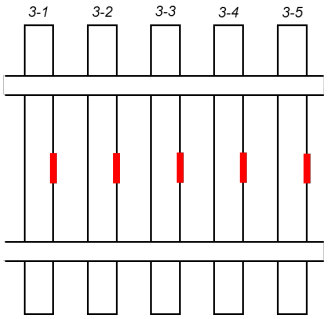
- Elburn, IL
- Track speed 60-70 MPH
- ~50 trains/day (UP West Line)
- 450 feet east of La Fox Station

Field Instrumentation Map

Metra Site



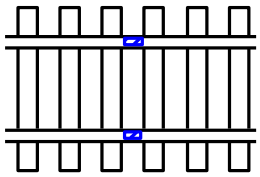
Crosstie Bending Strain
Vertical and Lateral Load (Wheel Loads)
Thermocouple
Laser Trigger



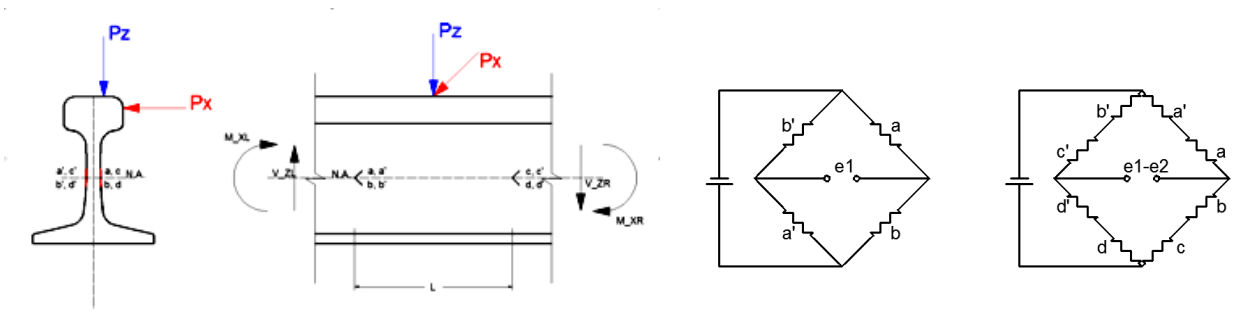
- Site characteristics:
  - Tracks 2 and 3
  - Maximum allowable speed:
    Track 2: 70 mph (112 km/h)
    Track 3: 60 mph (96 km/h)
  - Tangent
  - Grade: 0.31%

Instrumentation Overview

Vertical and Lateral Wheel Loads

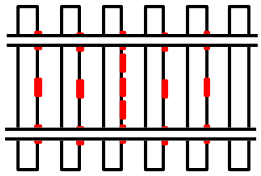


- **Desired data**:
  - Vertical and lateral loads at the wheel-rail interface and rail seat
- **Instrumentation description and methodology:**
  - Industry standard strain gauge bridges applied to rail web and flange, similar to a wheel impact load detector (WILD) site
  - Based on previous UIUC field instrumentation, one instrumented crib per rail to approximate wheel loads throughout whole test section



Instrumentation Overview

Crosstie Bending



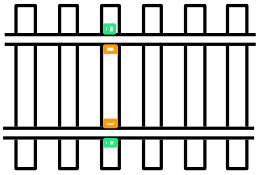
- **Desired data**:
  - Crosstie center bending strains
- **Instrumentation description and methodology:**
  - Surface strain gauges mounted along the chamfer of the crosstie
  - Based on previous UIUC research, gauges will be placed at rail seats and center of crossties to account for most critical design moments
  - Intermediate gauges placed between rail seats and center will allow for more precise back-calculation of support conditions

Center and intermediate gauges

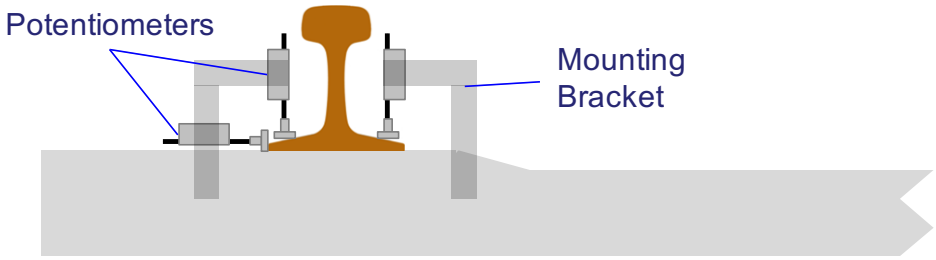
Rail seat gauge

Instrumentation Overview

Rail Restraint

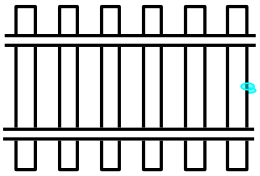


- **Desired data**:
  - Vertical and lateral rail base displacements
- **Instrumentation description and methodology:**
  - Linear potentiometers fixed to manufactured rapidly-deployable brackets that affix non-permanently to crosstie
  - Displacements measured at rail seats with instrumentation to:
    - Calculate rail rotation and translation



Instrumentation Overview

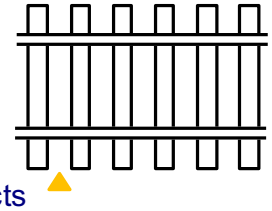
Thermocouples



- **Desired data**:
  - Temperature differential from top to bottom of crosstie
  - Ambient conditions also monitored
- **Instrumentation description and methodology:**
  - Thermocouples affixed to the chamfer and side, just above the base of crosstie
  - Based on previous UIUC research, temperature gradients can induce “curl” in crossties
    - This can have an effect on the bending moments recorded throughout the day

Instrumentation Overview

Laser Distance Sensor



- **Desired data**:
  - Train presence detection
- **Instrumentation description and methodology:**
  - Laser distance sensor mounted next to the track detects change in distance when an object crosses its beam
  - Pattern and magnitude of recorded signal helps determine if a data collection was triggered by a passing train or a false trigger, such as track workers, animals, etc., and even which track the train was on

Automated Data Acquisition System

- Automated data collection systems have been deployed on MetroLink (tangent site), NYCTA, and Metra
  - Use National Instruments (NI) Compact DAQ (cDAQ) equipment
- Laser sensors triggers data collection every time a train passes the site
- Thermocouple data is recorded every 5 minutes, 24 hours per day

Automated Data Collection Statistics

- **MetroLink Tangent Site**
  - Deployed on March 18, 2016
    - *Approximately 26,000 revenue trains' of data to date*
- **NYCTA Site**
  - Deployed on April 25, 2016
    - *Approximately 11,000 revenue trains' of data to date*
- **Metra Site**
  - Deployed on September 22, 2016
    - *Approximately 1,100 revenue trains' of data to date*

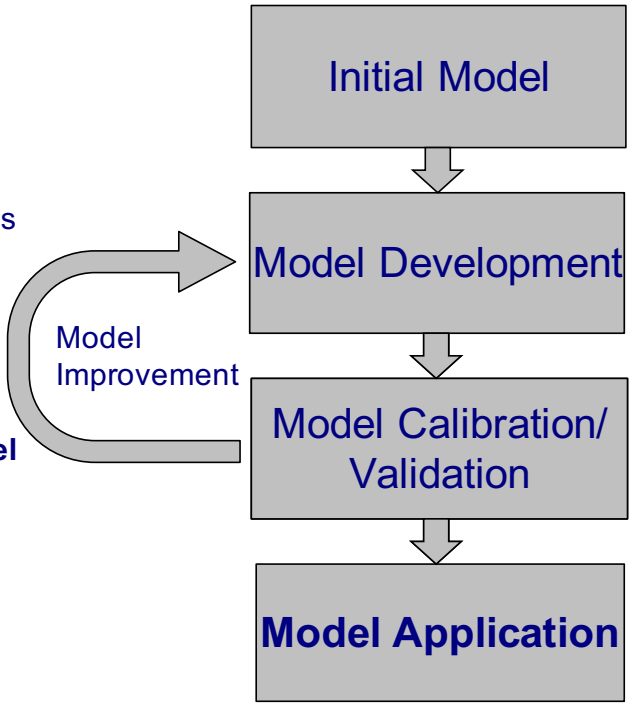
**Additional non-revenue trains have been recorded at most sites, but have not yet been processed or included in these numbers*

Laboratory Experimentation

- Primary goal is to develop a prototype crosstie for rail transit
- Data collected at field sites will be used to inform laboratory experimentation on prototype components
- Specific area of research focus: Under tie pads (UTPs)

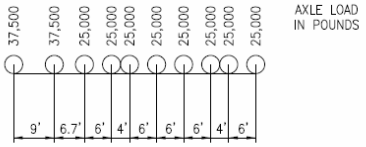
Finite Element (FE) Modelling

- Initial Model
  - Start with previously developed material models
- Model Development
  - Recreate lab/field setup with similar load and support conditions
- Model Calibration/Validation
  - Displacement/strain calibration
- **Model Application**
  - **Parametric Studies:**
    - **Reduction of prestress level**
    - **Reduction in number of prestress wires**
    - **Loss of section due to abrasion**
  - **Optimize Crosstie Design**

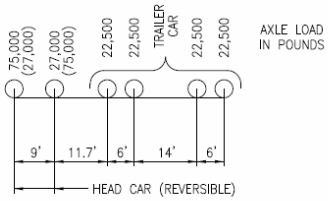


Immediate Path Forward

- 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
- Investigate seasonal and other long-term variation
- Investigate wheel loads of maintenance vehicles used on transit properties



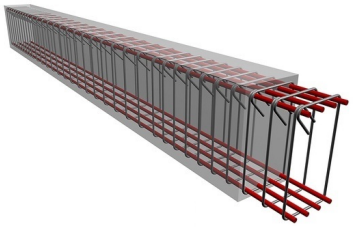
LOADING DIAGRAM 2 – MAINTENANCE TRAIN



LOADING DIAGRAM 3 – MAINTENANCE CAR WITH/WITHOUT TRAILER CAR

Future Work

- Finite element experimentation investigating reduced levels of prestress or conventionally reinforced concrete for rail transit crossties
- Materials experimentation investigating fiber-reinforced concrete for crossties
- Laboratory experimentation with prototype crossties
- Investigation and testing of corrosion mitigation strategies for rail and fastening systems for systems using electric traction power



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Amtrak
Hanson
Pandrol USA
GIC
LBFoster CXT Concrete Ties

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