Mechanistic Design of Rail Transit Infrastructure Components

Project Summary, Select Findings, and Crosstie Prototyping

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U.S. Department of Transportation
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FTA-Funded Resilient Concrete Crossties and Fastening System Research Program

Objectives

- Develop resilient concrete crosstie design solutions for light, heavy, and commuter rail transit operators

Methodology

- Quantify concrete crosstie and fastening system demands when subjected to rail transit loading environments

Key Parameters to Quantify

- Loading Environment (lateral and vertical wheel/rail loads)
- Crosstie Bending Moments (rail seat and center)
- Rail Displacements (vertical and lateral)

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FTA Project Approach

Paper Study

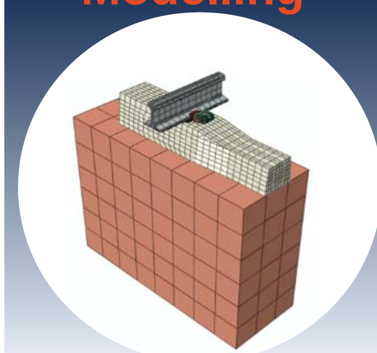
Industry Surveys

Field Data Collection

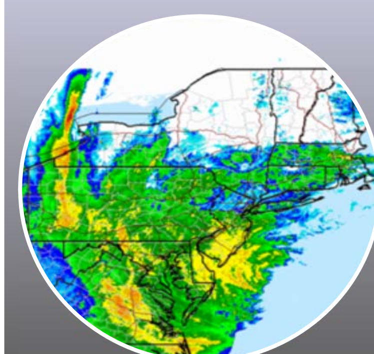
Resilient Concrete Crosstie and Fastening System for Rail Transit

Laboratory Testing

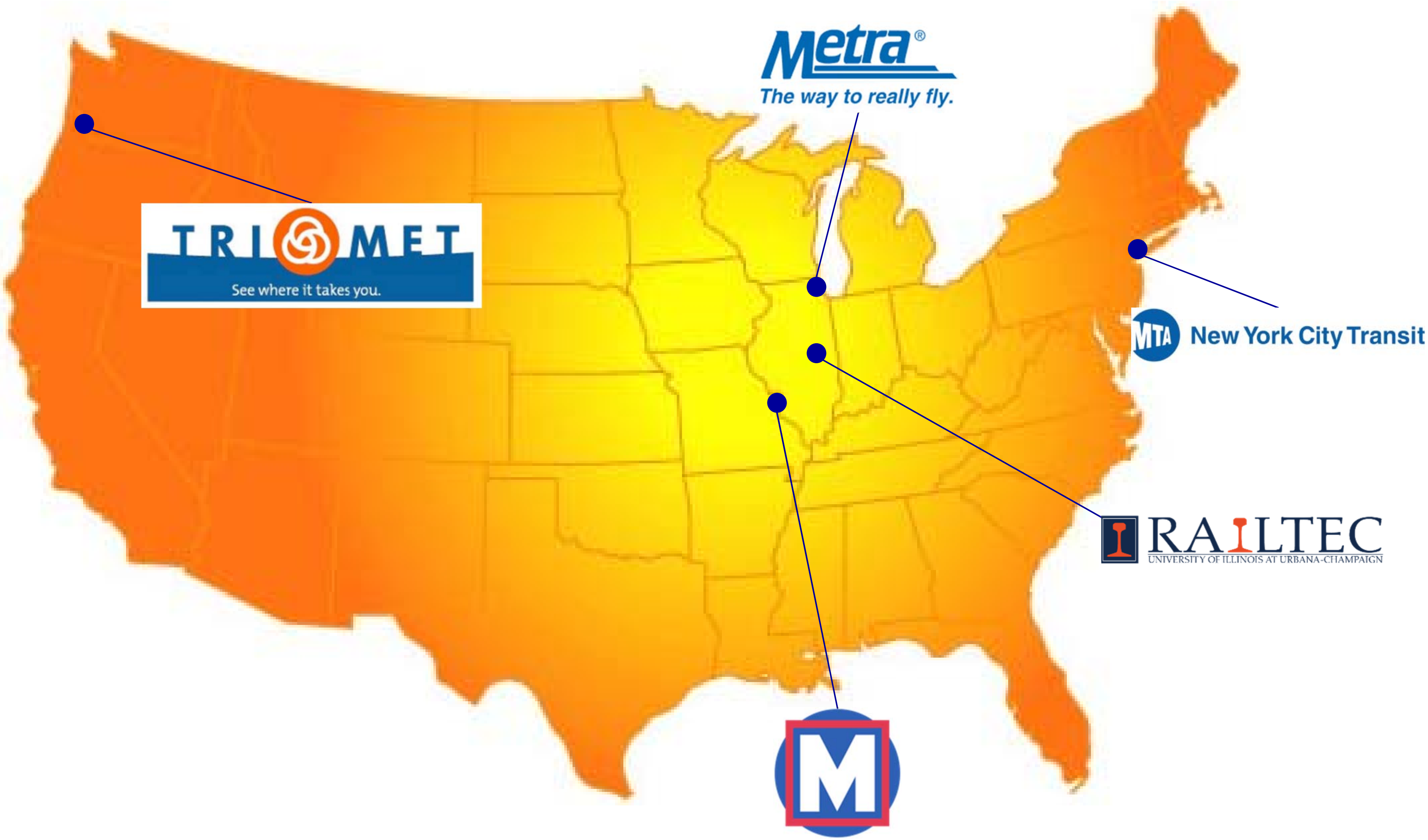
Analytical Modelling



Other Factors

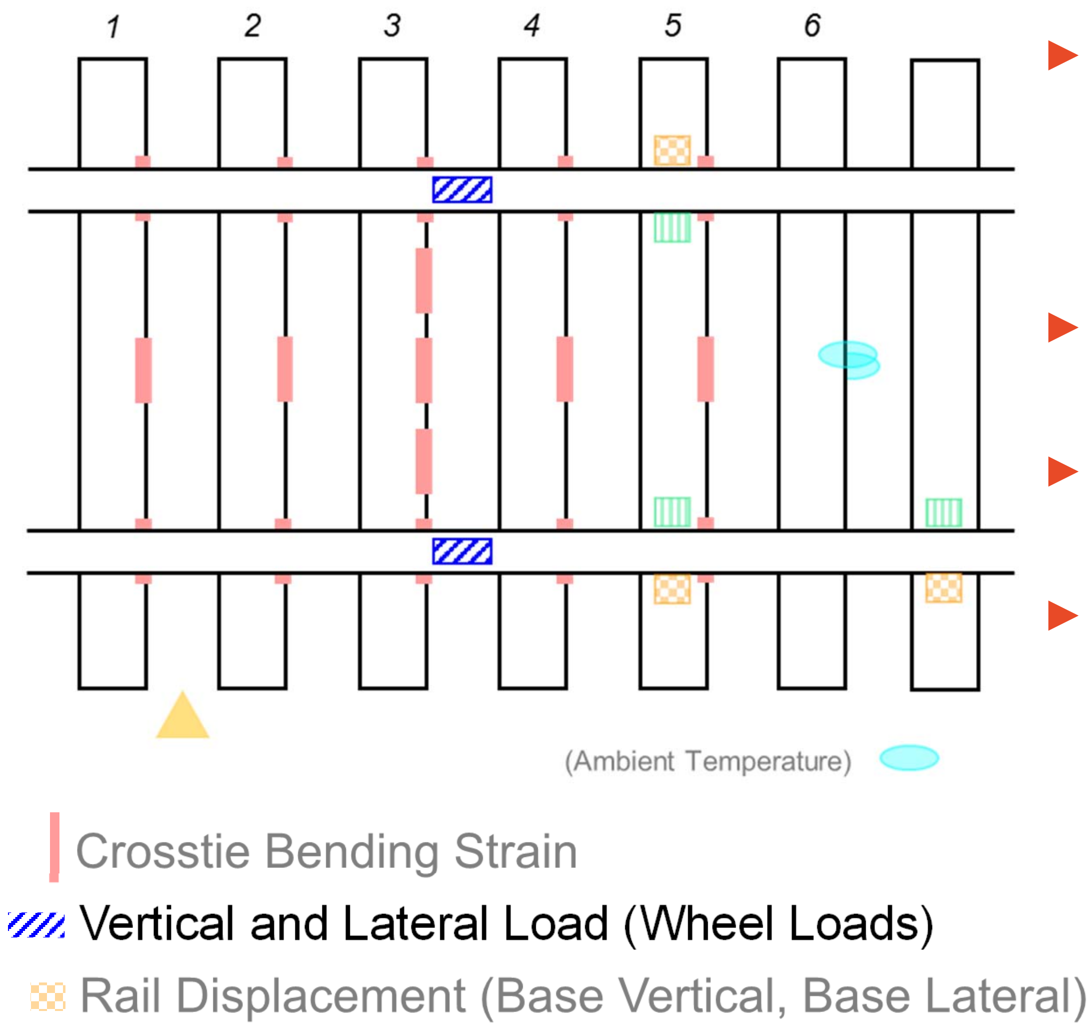


FTA Project Transit Partner Agencies



(Two Sites; Curve & Tangent)

FTA Project Field Instrumentation Map



Metrics to quantify:

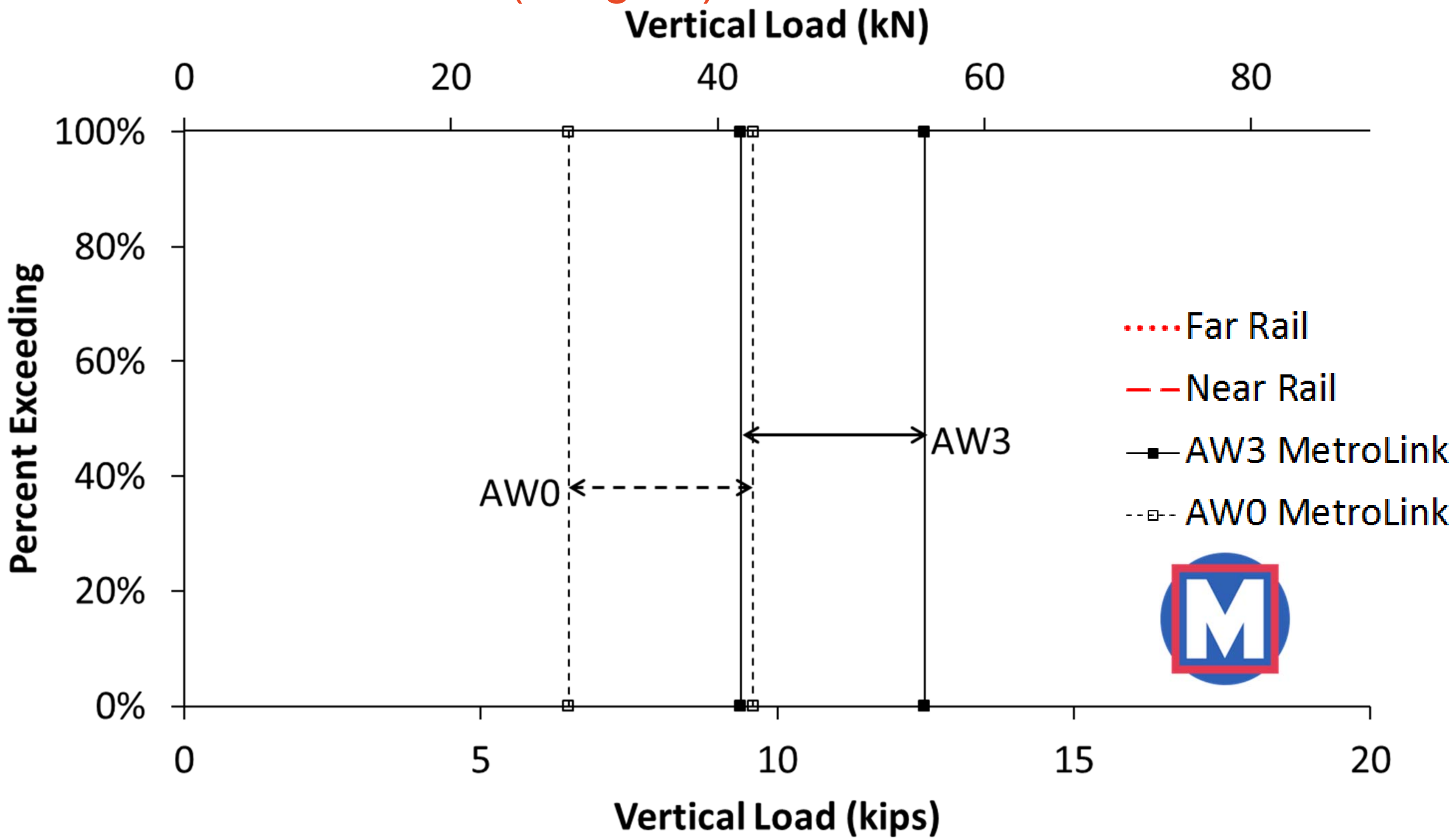
- Vertical and lateral input loads (crosstie and fastening system design, and load environment characterization)
- Crosstie bending strain (crosstie moment design)
- Rail displacements (fastening system design)
- Crosstie temperature gradient

Installation of St. Louis MetroLink Field Site


Installation of St. Louis MetroLink Field Site

Vertical Rail Loads

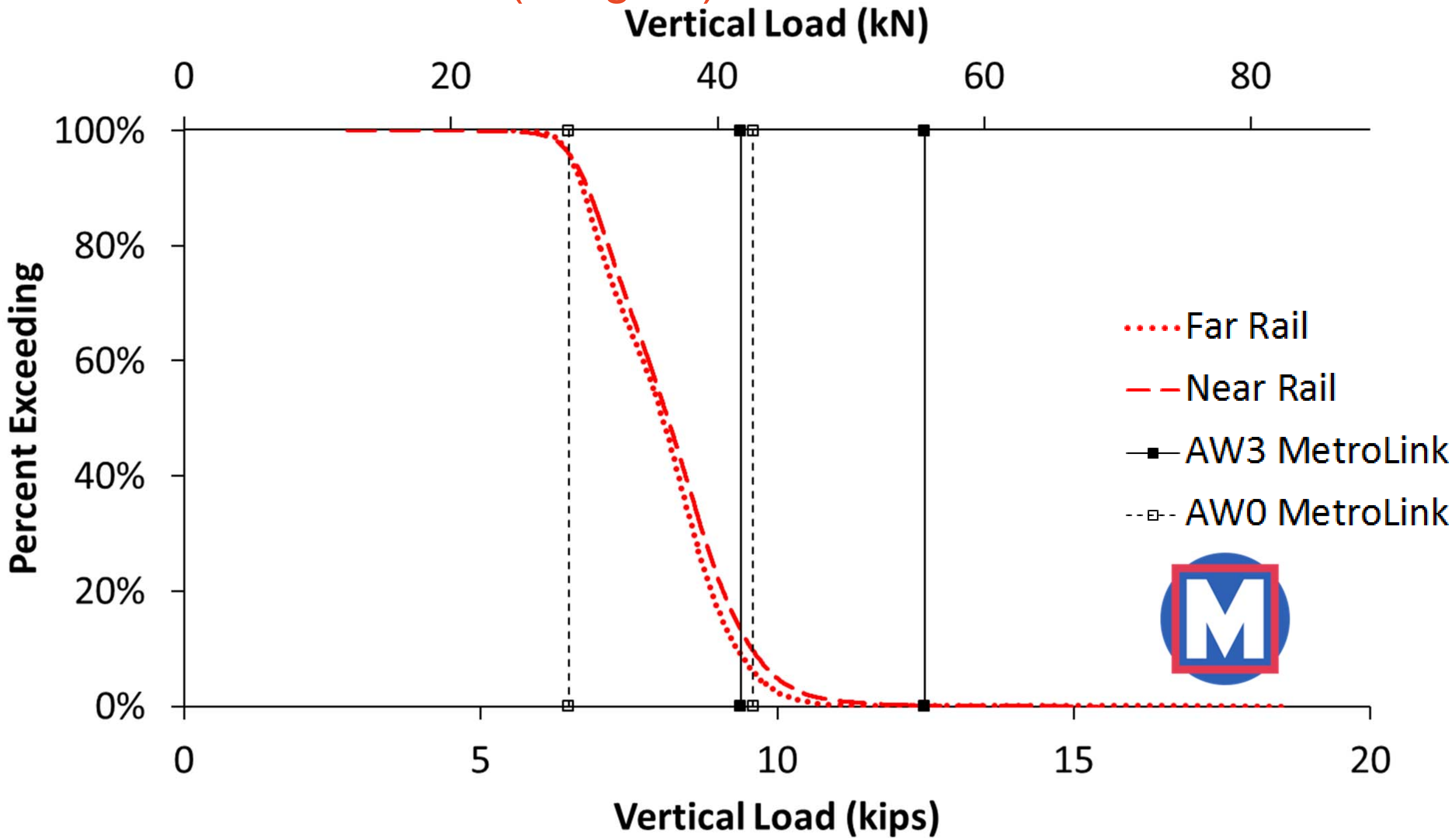
St. Louis MetroLink (Tangent)



- AW0 = Empty Weight
- AW3 = Crush Load

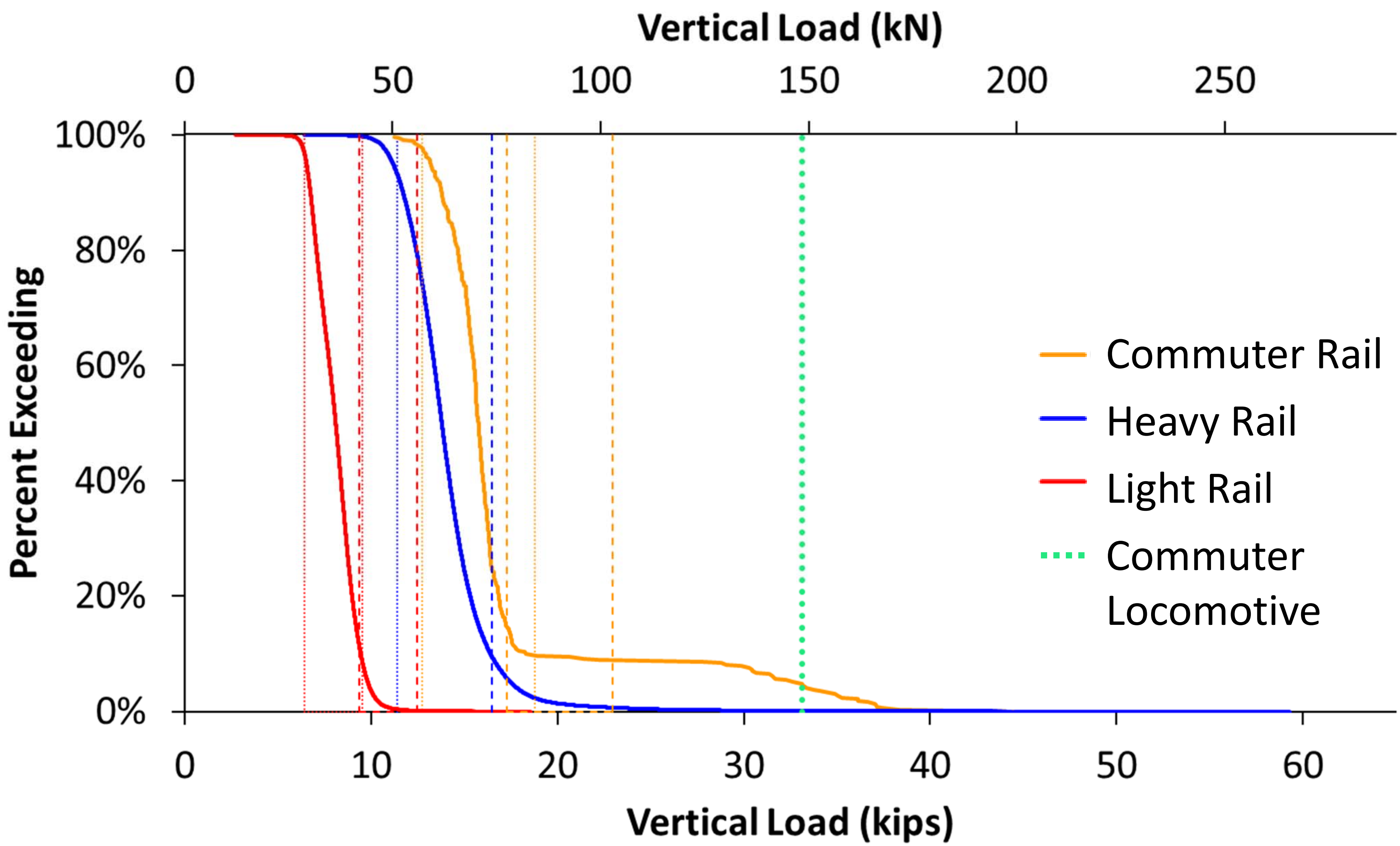
Vertical Rail Loads

St. Louis MetroLink (Tangent)



- AW0 = Empty Weight
- AW3 = Crush Load

Modal Comparison: Vertical Rail Loads



- <0.05% wheel impacts exceed impact factor of 3

Load Data in AREMA Chapter 30 (2018)

Table 30-1-3. AW0 (Empty Load) and AW3 (Crush Load) Axle Loads for Light Rail, Heavy Rail and Commuter Rail Transit Vehicles [8, 9]

Vehicle Type	AW0 Static Wheel Load (kips)			AW3 Static Wheel Load (kips)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Light Rail Vehicle[10]	7.9	4.8	9.1	10.9	6.1	13.0
Heavy Rail Vehicle[11]	9.4	6.8	11.6	12.8	8.1	16.8
Commuter Railcar[12]	10.6	10.6	20.4	20.0	15.2	28.4
Commuter Locomotive[12]	32.7	25.0	37.2	N/A	N/A	N/A

- These values are intended to represent the North American loading regime and are not intended to be used for design



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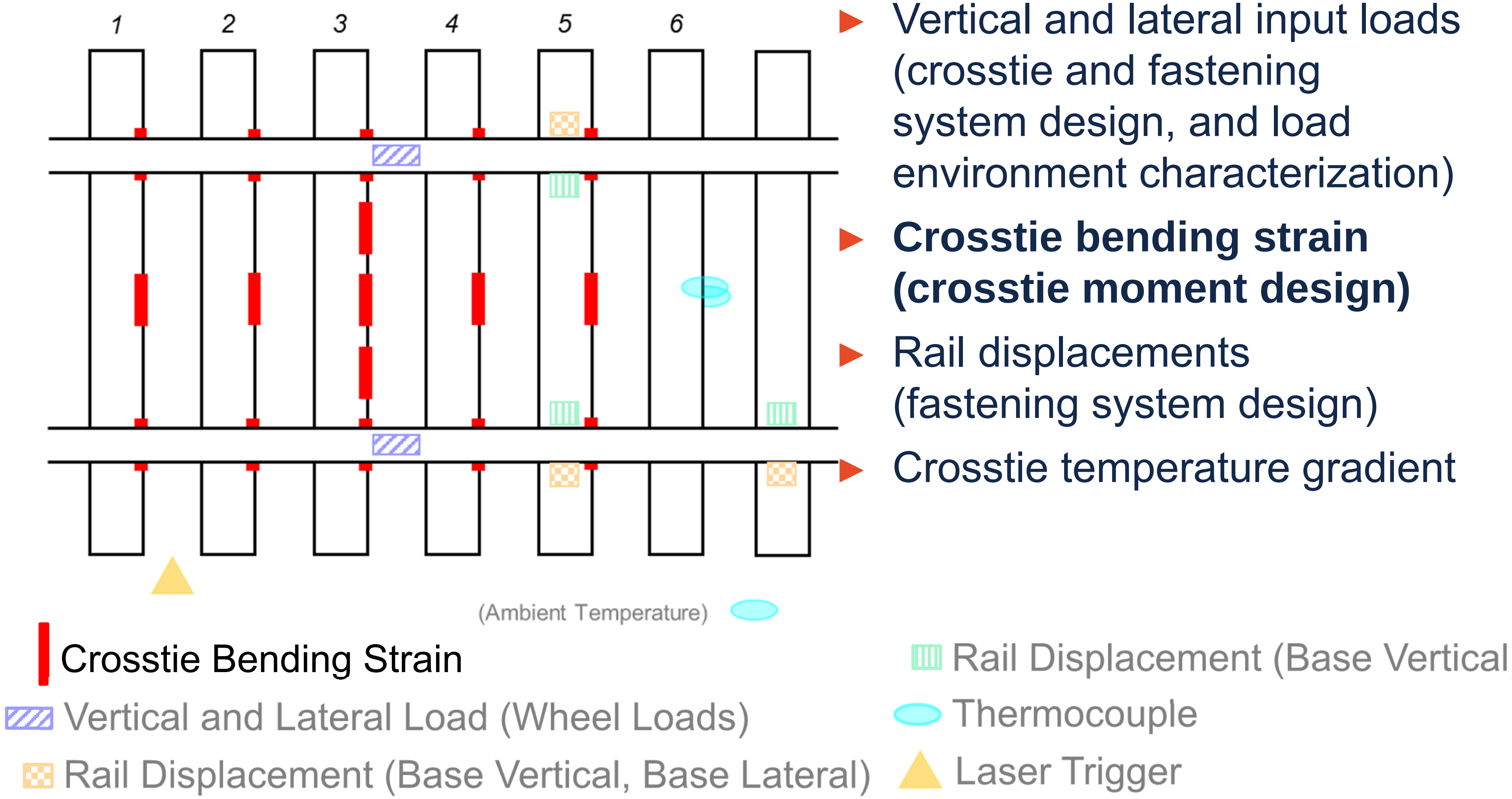

Metrics to quantify:

- Vertical and lateral input loads (crosstie and fastening system design, and load environment characterization)
- **Crosstie bending strain (crosstie moment design)**
- Rail displacements (fastening system design)
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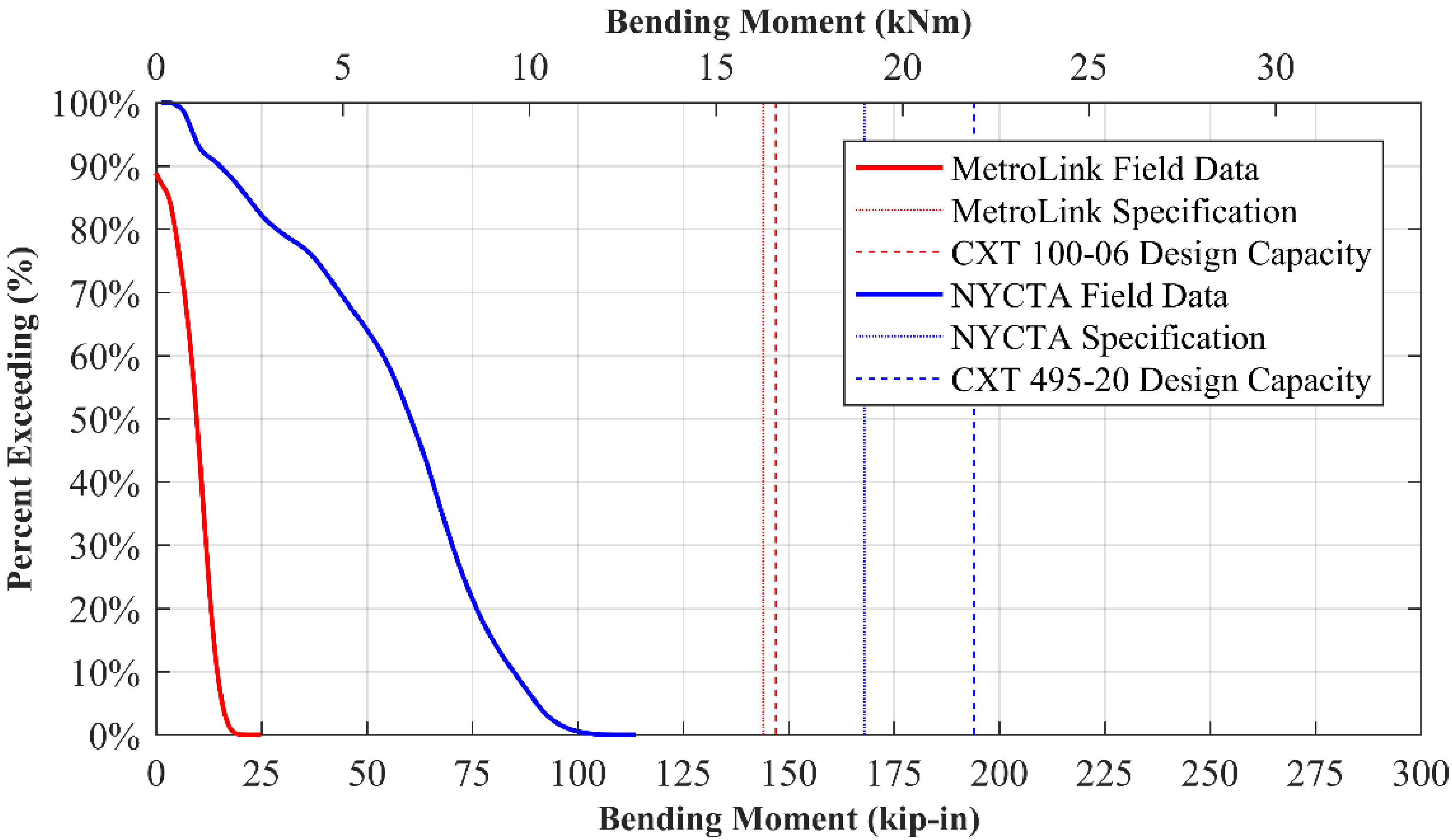
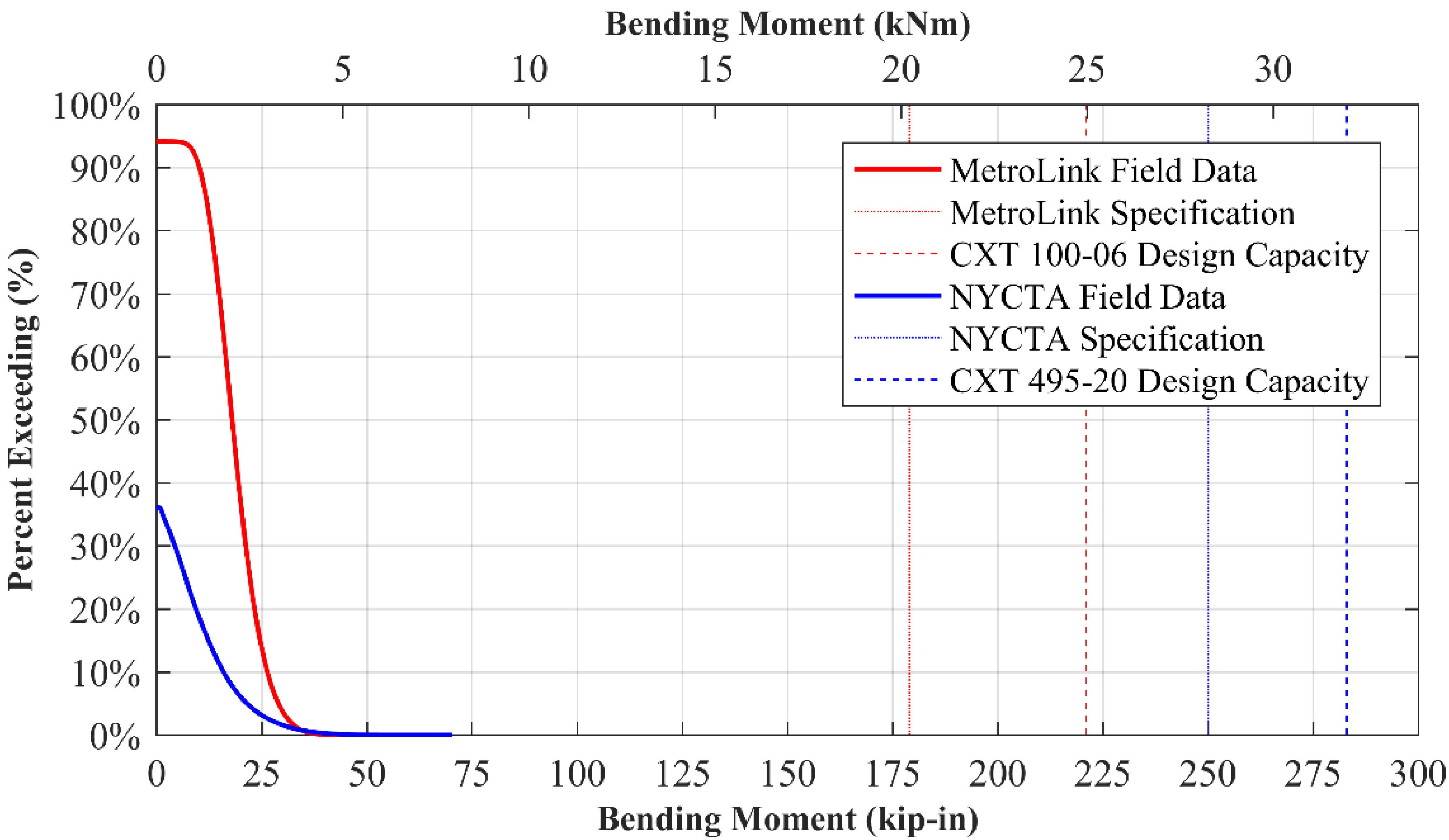
Center Negative (C-) Bending



- Factor of safety is approximately:
  - 6 for the maximum MetroLink C- bending moment measured
  - 2 for the maximum NYCTA C- bending moment measured

Rail Seat Positive (RS+) Bending



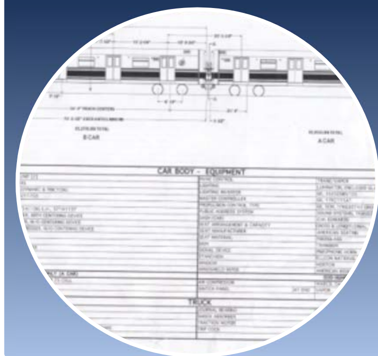
- Factor of safety is greater than:
  - 3 for the maximum MetroLink RS+ bending moment measured
  - 4 for the maximum NYCTA RS+ bending moment measured

Field Experimentation Takeaways

- Loading environment is significantly different at each transit mode
  - Design of any infrastructure component should consider this
- Wheel loads exceeded an impact factor (IF) of 3 rarely (<0.05%)
  - AREMA recommends designing concrete crossties with an IF of 3
- The reserve flexural capacity factors of safety ranged from 2 – 6
- This provides an opportunity to optimize not just the crosstie design but track structure
  - "Savings" from reductions in concrete, steel, & handling could be reallocated into resilient materials (under tie pads, ballast mats, etc.)
- Resilient materials could:
  - Reduce maintenance costs (e.g. increase time between tamping, etc.)
  - Reduce urban pollution (i.e. ground borne noise and vibration, etc.)

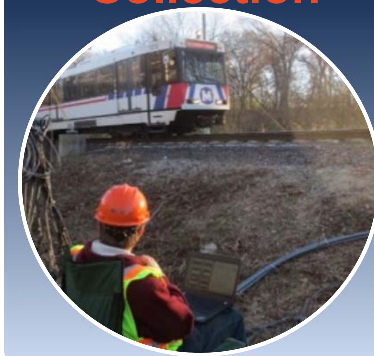
FTA Project Approach

Paper Study



Industry Surveys

Field Data Collection



Resilient Concrete Crosstie and Fastening System for Rail Transit

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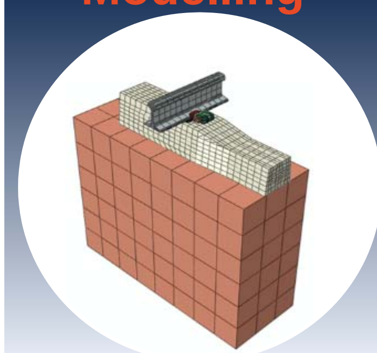

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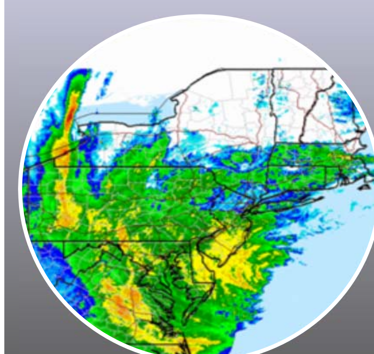
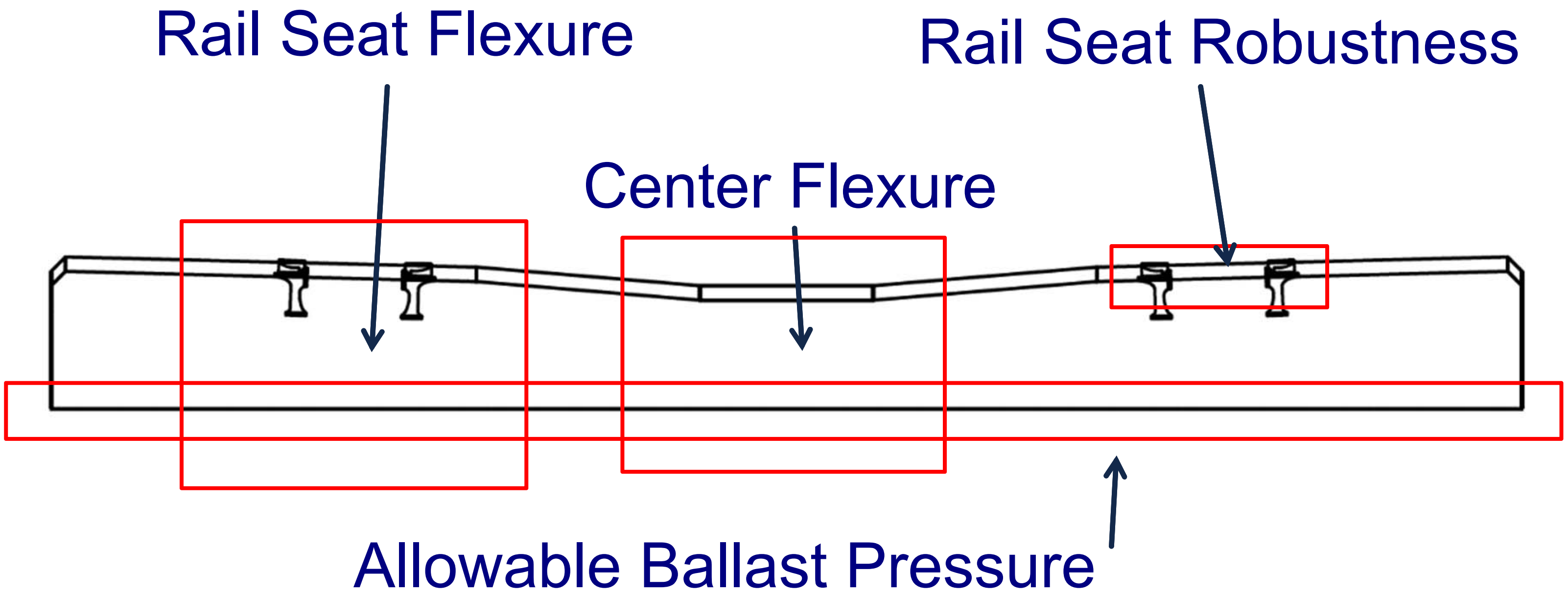


Concrete Crosstie Design Considerations



Initial Prototype Experimentation

Concurrent with Field Data Collection

Purpose:

- Identify how failure modes change varying key parameters
  - Determine a method to ensure a “safe” ultimate failure
- Develop, calibrate, and validate a finite element model

Various Trials

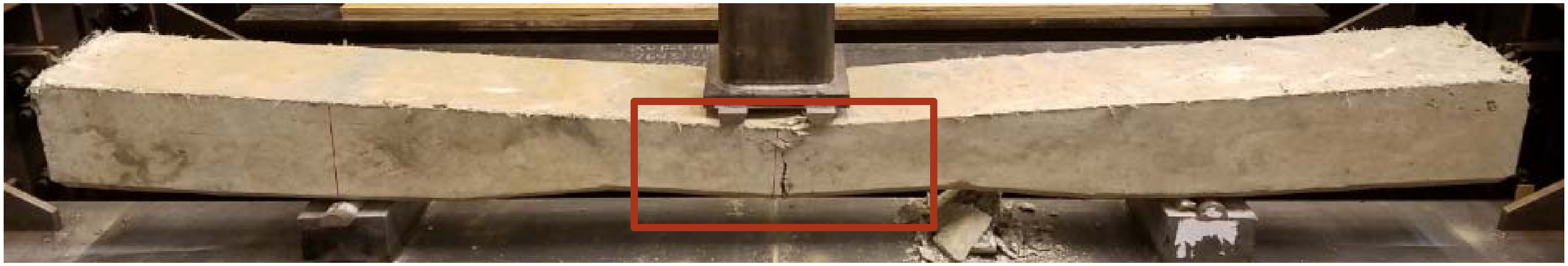
- Prestressing quantity and arrangement
  - *Assist model calibration*
- Synthetic Fibers in Concrete
  - *Quantify failure mode/benefits of fibers*
- Shear and flexural reinforcement
  - *Quantify effect of stirrups on failure mode (shear/flexural)*

Prototype Crosstie Manufacturing

Qualitative Prototype Results

- Standard Crosstie: Failure representative of typical crossties (i.e. shear)

- Fiber Prototype: Failure with more cracks, reduced crack width and non-shear



- Stirrup Prototype: Failure typical

Final Prototype Development

Design Optimization Framework

Establish Target Safety Factors

- RS+ and C- set from field data

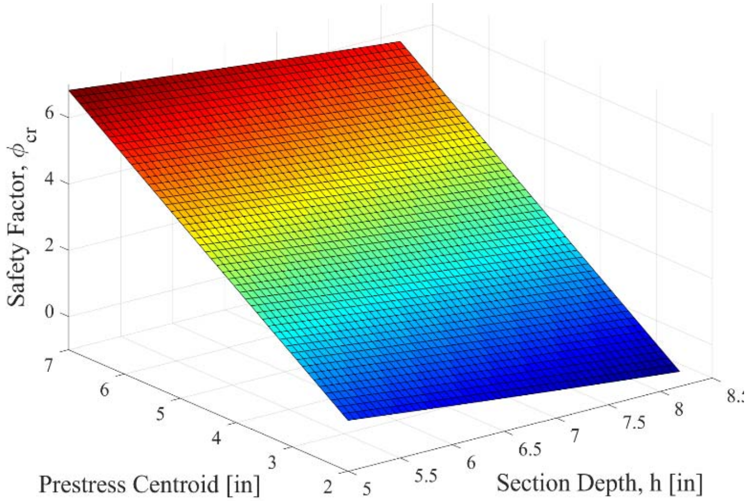
Preliminary Analysis

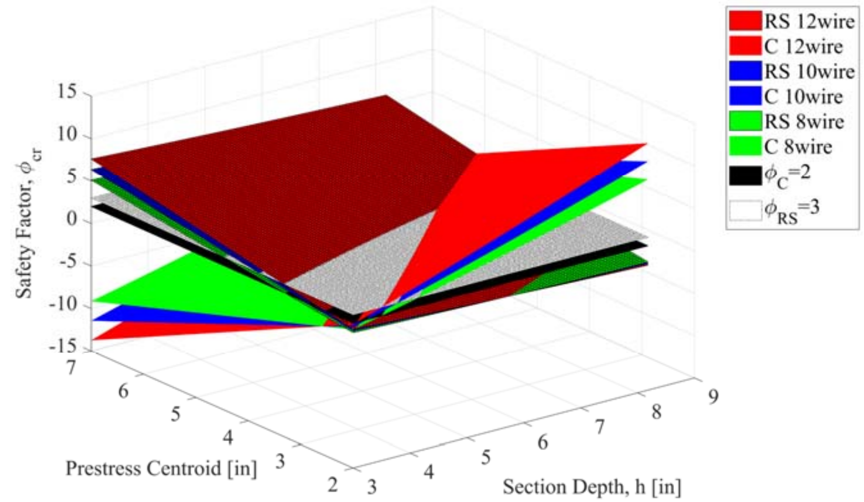
- Calculate cracking moment through section analysis varying:
  - Section depth,
  - Number of wires
  - Eccentricity

Finite Element Analysis

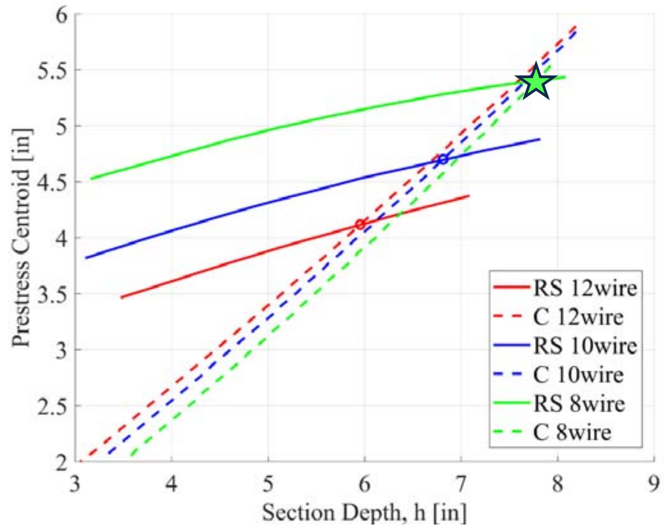
- Run C- and RS+ Simulations
- Quantify cracking and ultimate moments

Preliminary Analysis: Work Flow





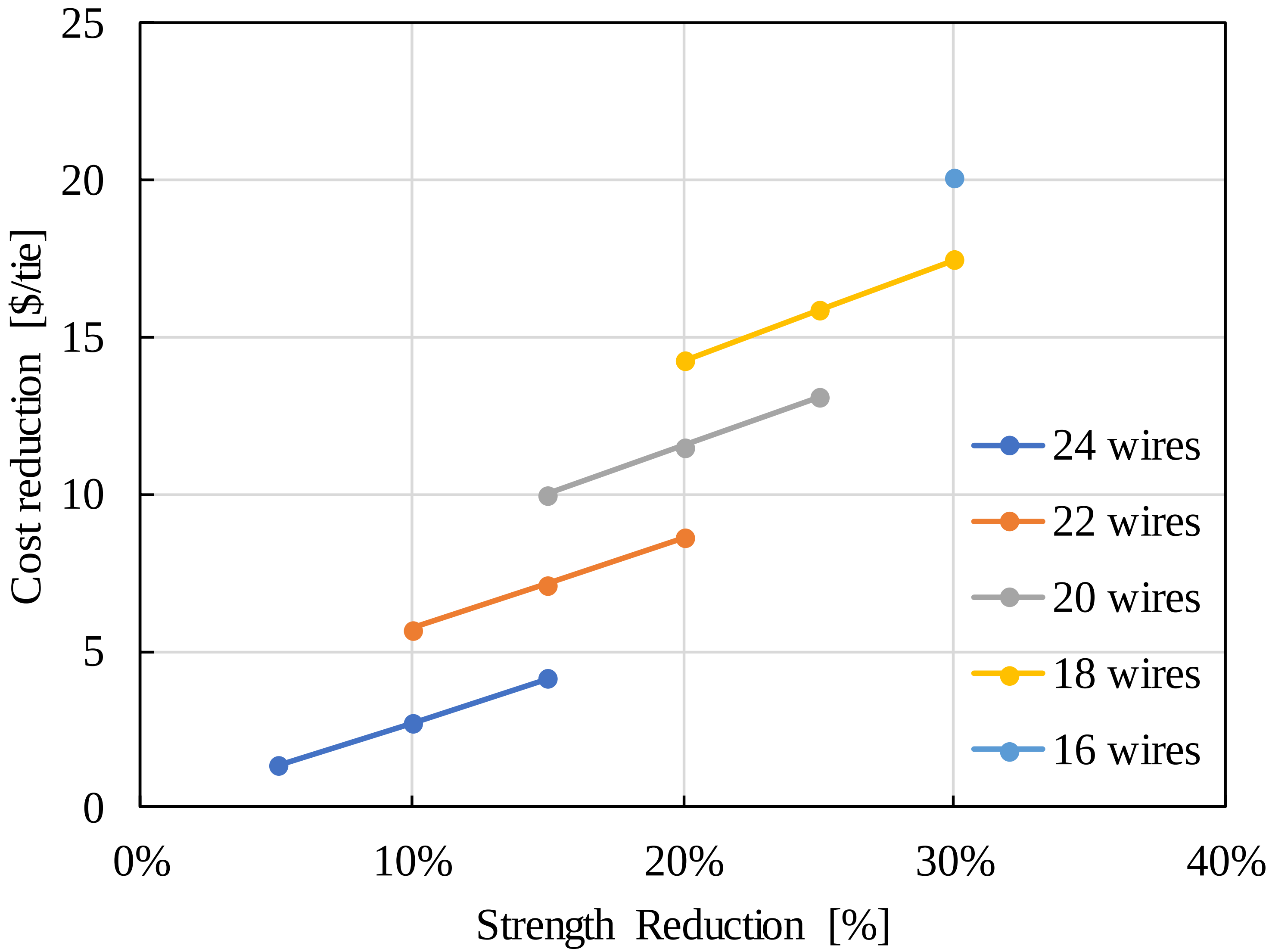
1. Develop safety factor (Ø) surface for RS+ & C-
2. Combine Surfaces & Include Safety Factor planes
3. Plot intersections
   - Intersection will be depth and centroid



First Crack Moment Calculations:

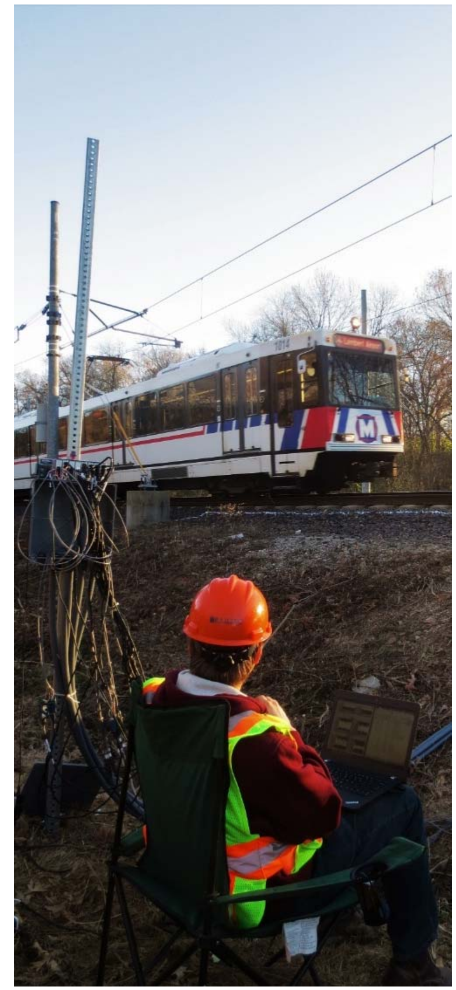
- ACI
  - RS+: 178 kip-in.
  - C-: 56.3 kip-in.
- UIUC FEM
  - RS+: 197 kip-in
  - C-: 89.8 kip-in.

Theoretical Optimization Framework



Path Forward: Installation and Monitoring at MetroLink & Project Dissemination

- Install Prototypes
  - Fall 2018
- Monitor Performance
  - Through Spring 2019
- Project Dissemination
  - Loading Environment
  - Bending Demands
  - Fastener Displacement
  - Design Framework



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Thank you for your attention!

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Rail Transportation and Engineering Center (RailTEC)

U.S. Department of Transportation
Federal Transit Administration

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