Rail Transit Concrete Crosstie Flexural Behavior

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

Bonita Springs, FL

26 October 2016

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U.S. Department of Transportation
Federal Transit Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

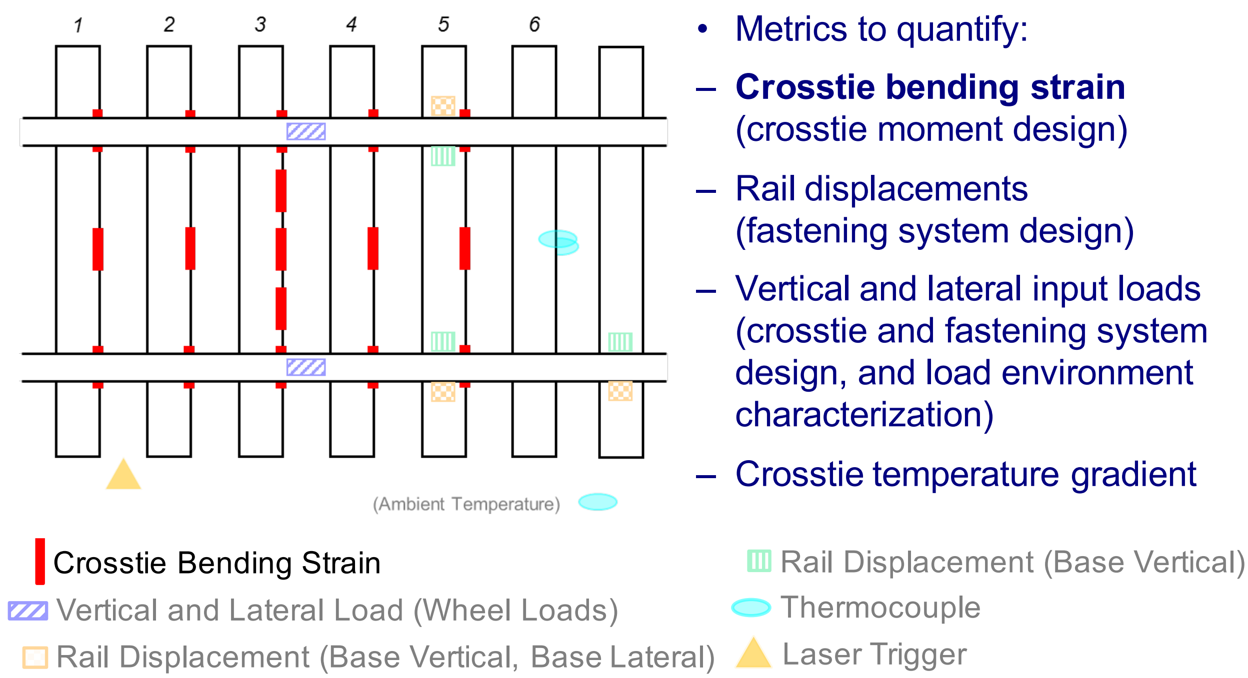
Outline

- 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



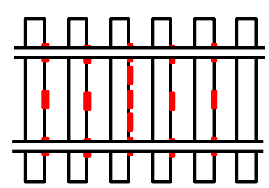
- Metrics to quantify:
  - **Crosstie bending strain** (crosstie moment design)
  - Rail displacements (fastening system design)
  - Vertical and lateral input loads (crosstie and fastening system design, and load environment characterization)
  - Crosstie temperature gradient

Crosstie Specifications

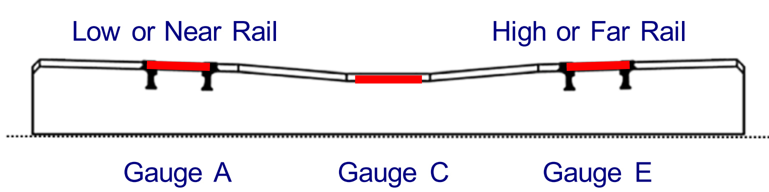
Rail Transit System			M	MTA New York City Transit	Metra® The way to really fly.	
Crosstie Manufacturer			LBFoster CXT Concrete Ties	LBFoster CXT Concrete Ties	LBFoster CXT Concrete Ties	LBFoster CXT Concrete Ties
Model			CXT 100-06	CXT 495-20	CXT 497s	CXT 505s
Length			8’ 3”	8’ 6”	8’ 6”	8’ 6”
Tie Spacing			30”	24”	24”	24”
Design Capacity	Center Negative	Spec.	144 kip-in	168 kip-in	203 kip-in	230 kip-in
		Design	147 kip-in	194 kip-in	203 kip-in	230 kip-in
	Rail Seat Positive	Spec.	179 kip-in	250 kip-in	300 kip-in	300 kip-in
		Design	221 kip-in	283 kip-in	330 kip-in	381 kip-in

Data Processing Overview

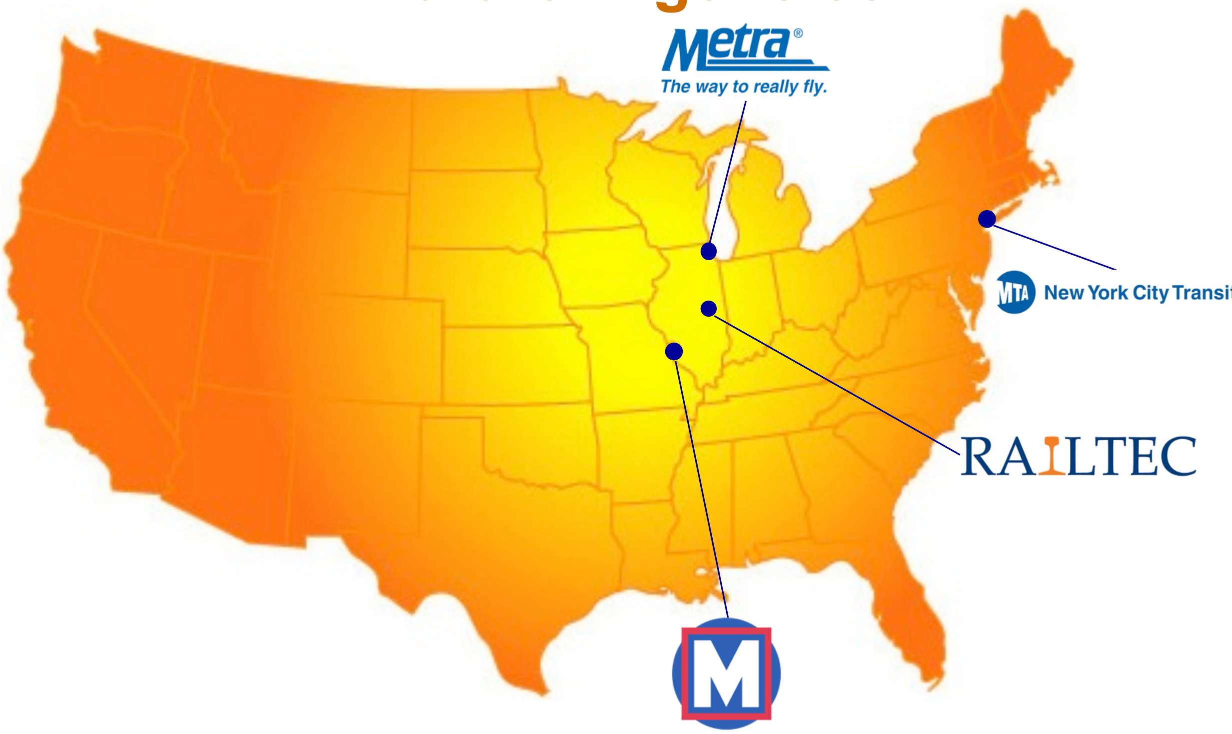
Crosstie Bending



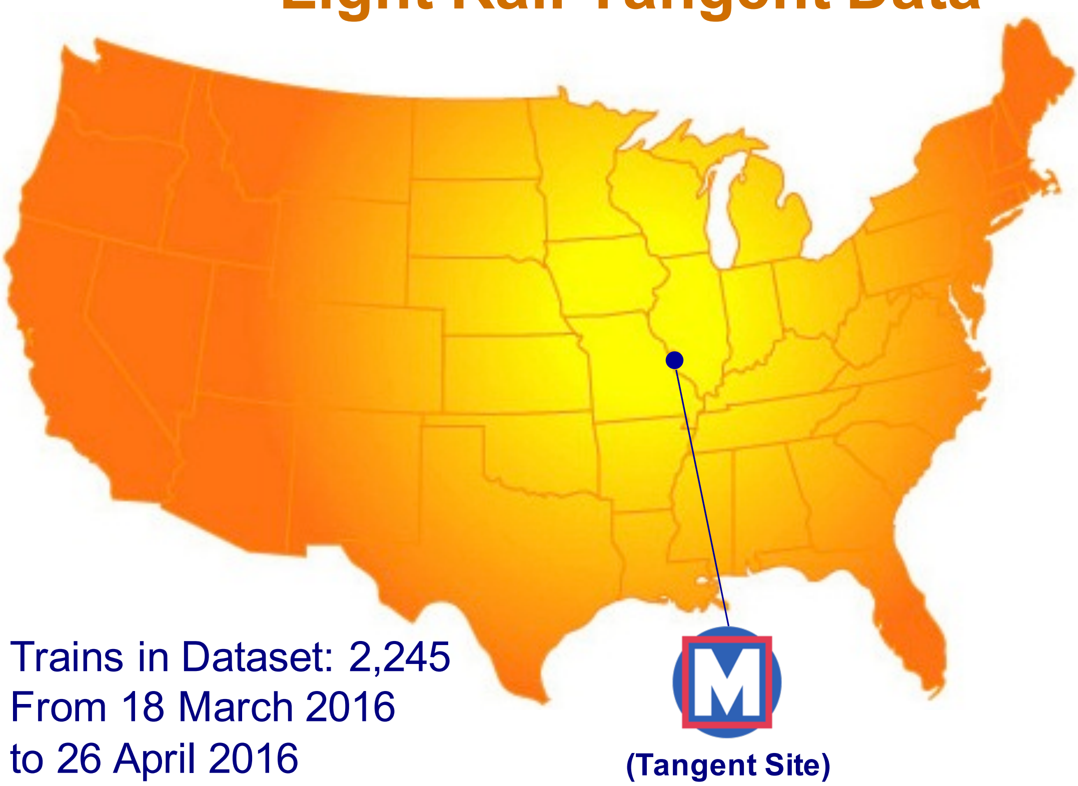
- **Desired data**:
  - Crosstie bending strains due to transit loads
- **Motivation of study and objective of data analysis:**
  - Understand revenue service bending moments
  - Determine the support conditions for crossties
  - Calibrate FE model with field data
  - Assess the capacity and design of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



Partner Agencies



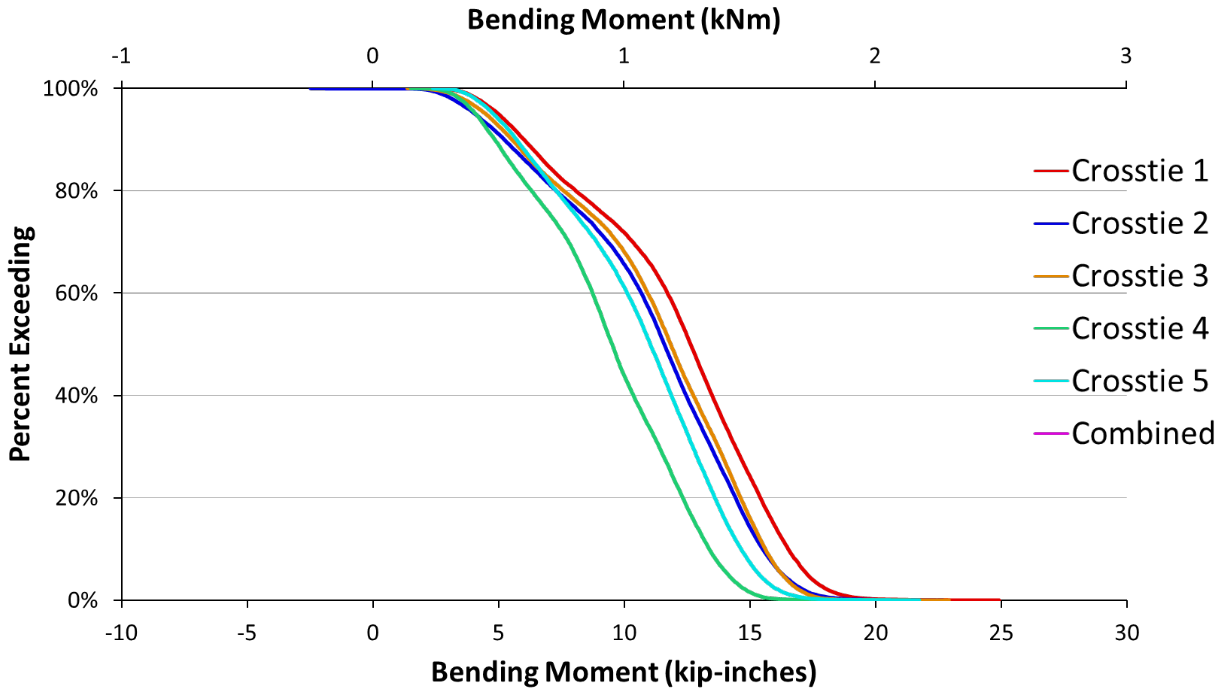
Light Rail Tangent Data



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

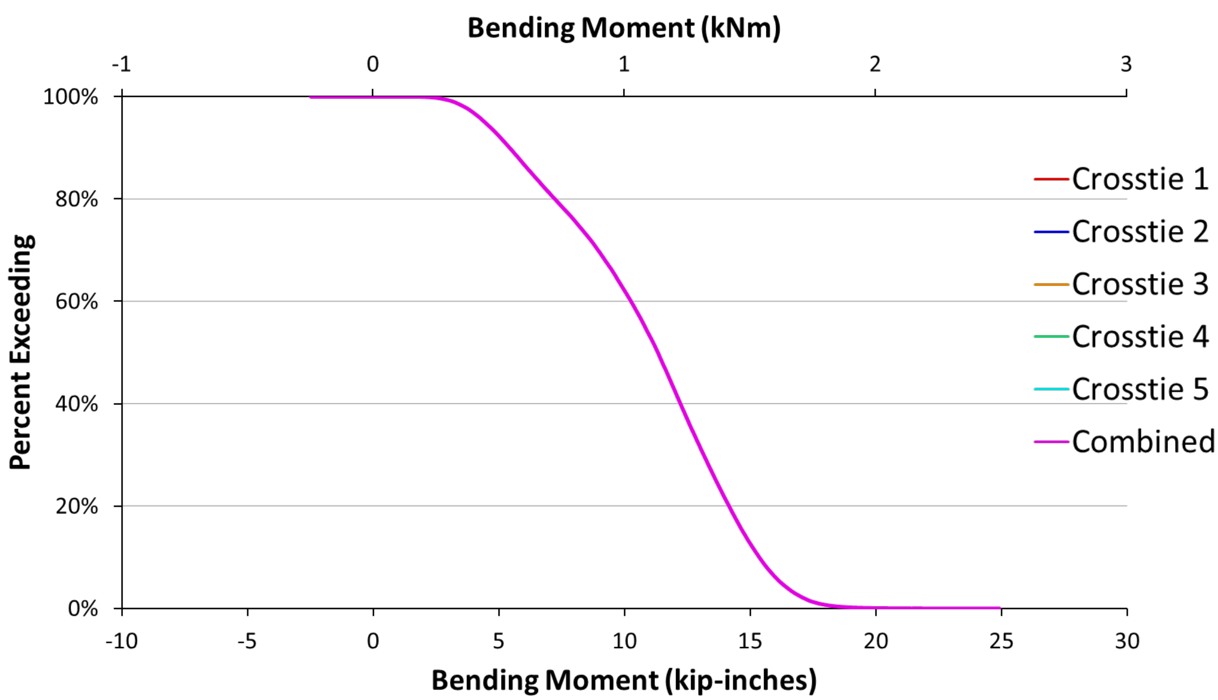
Center Negative Bending

St. Louis MetroLink



Center Negative Bending

St. Louis MetroLink



Center Negative Bending

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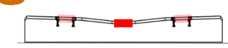
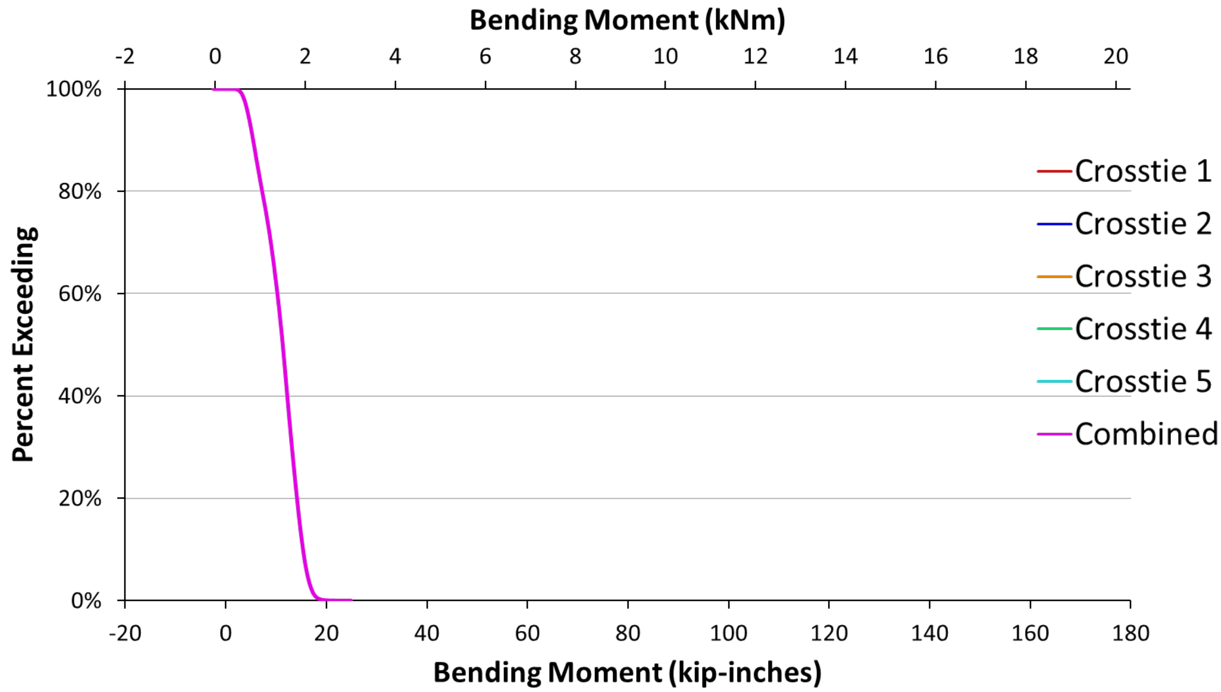
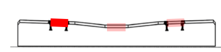
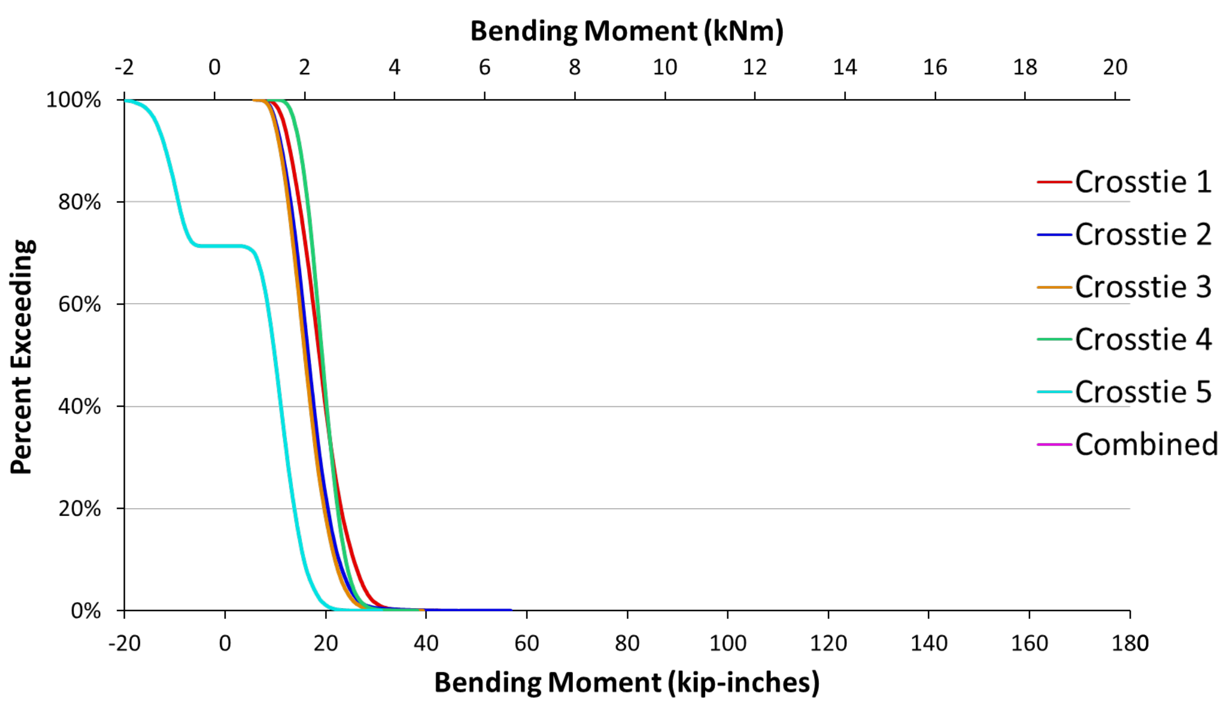




Rail Seat Bending

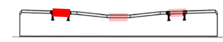
St. Louis MetroLink – Gauge A

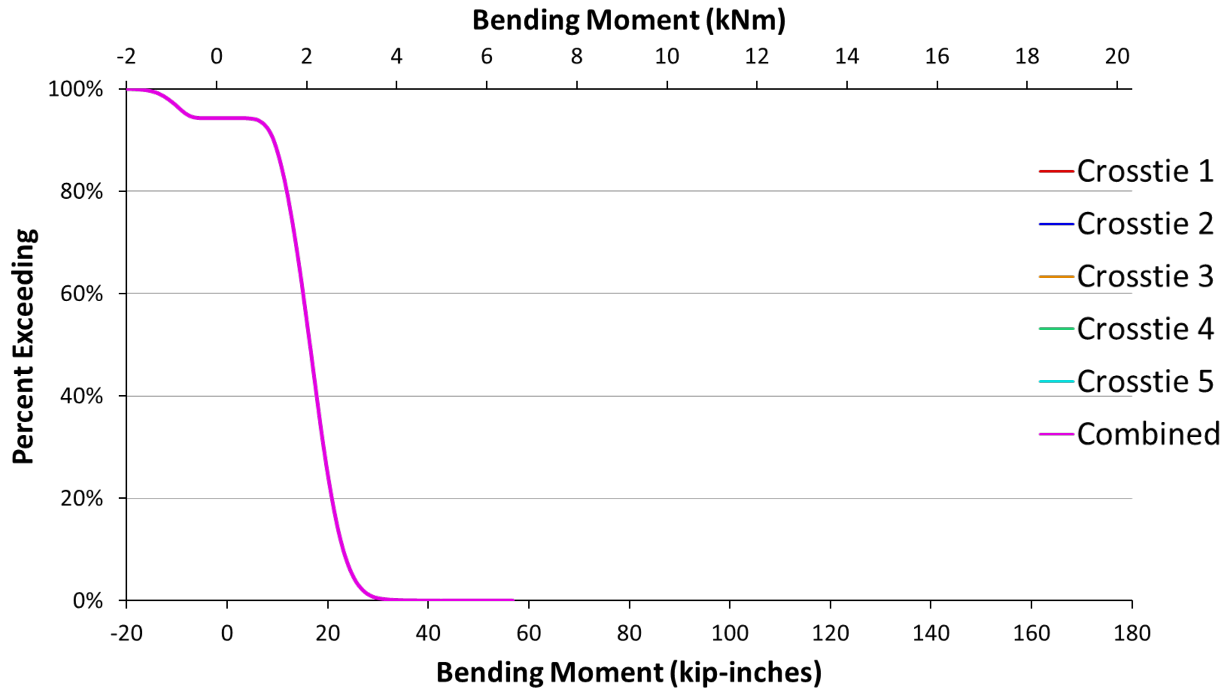




Rail Seat Bending

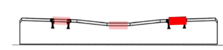
St. Louis MetroLink – Gauge A

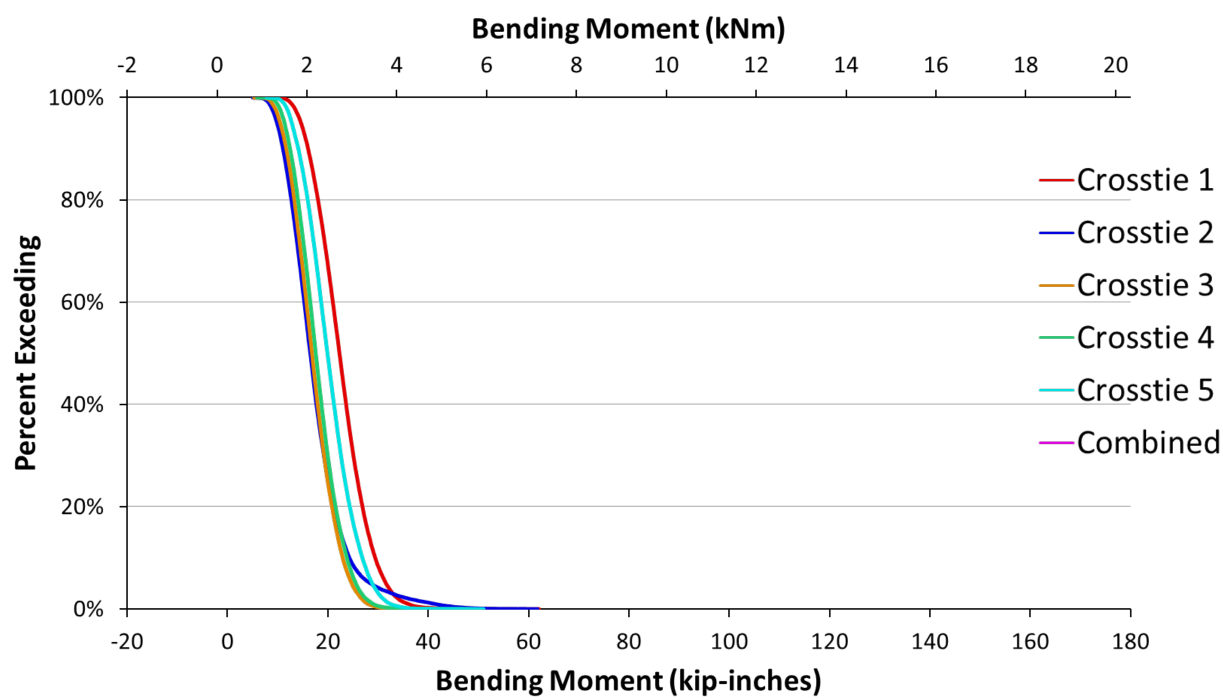




Rail Seat Bending

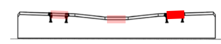
St. Louis MetroLink – Gauge E

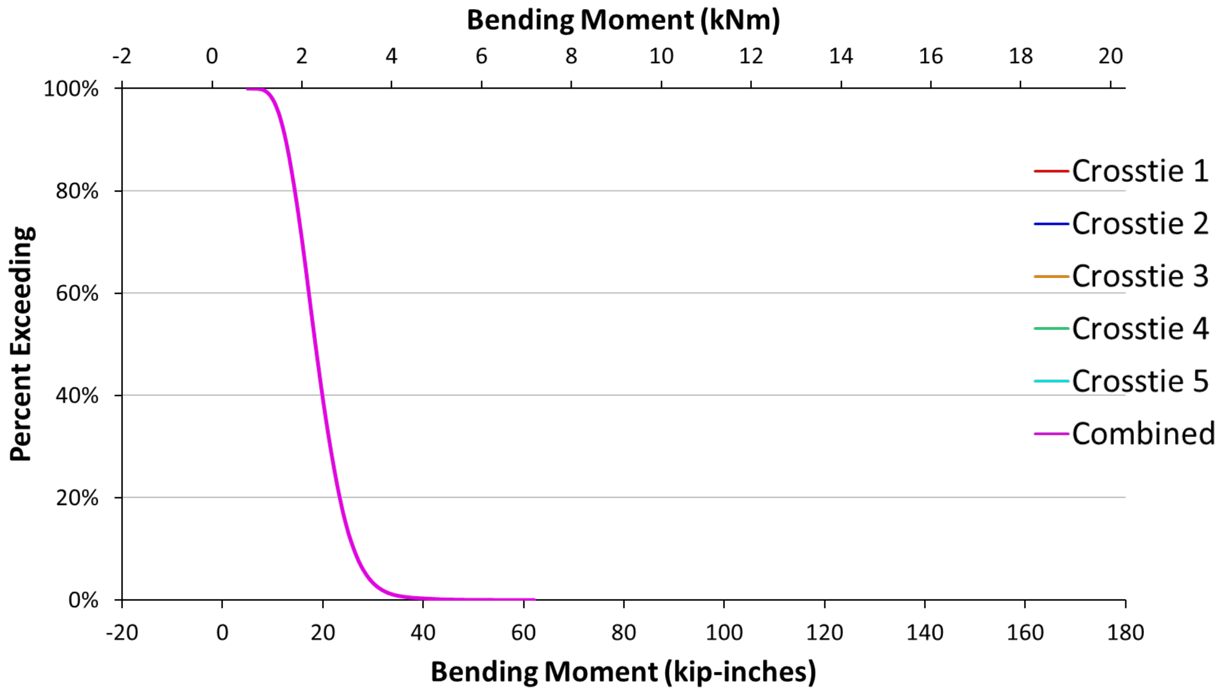




Rail Seat Bending

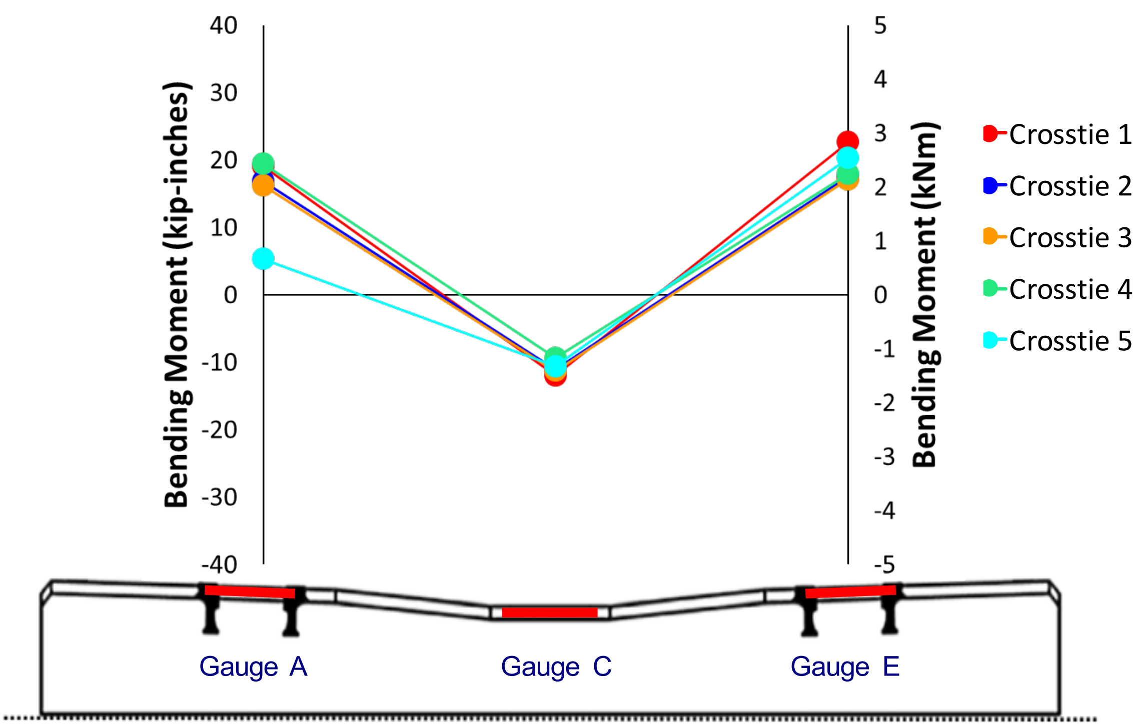
St. Louis MetroLink – Gauge E





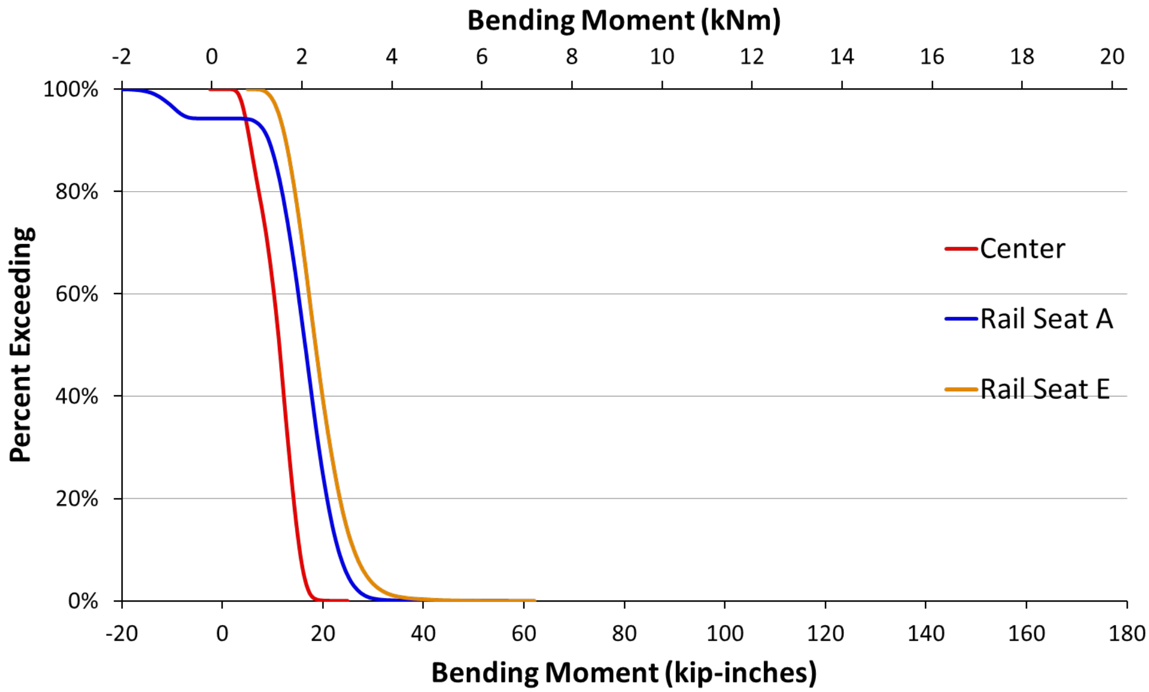
Average Bending Moments

St. Louis MetroLink



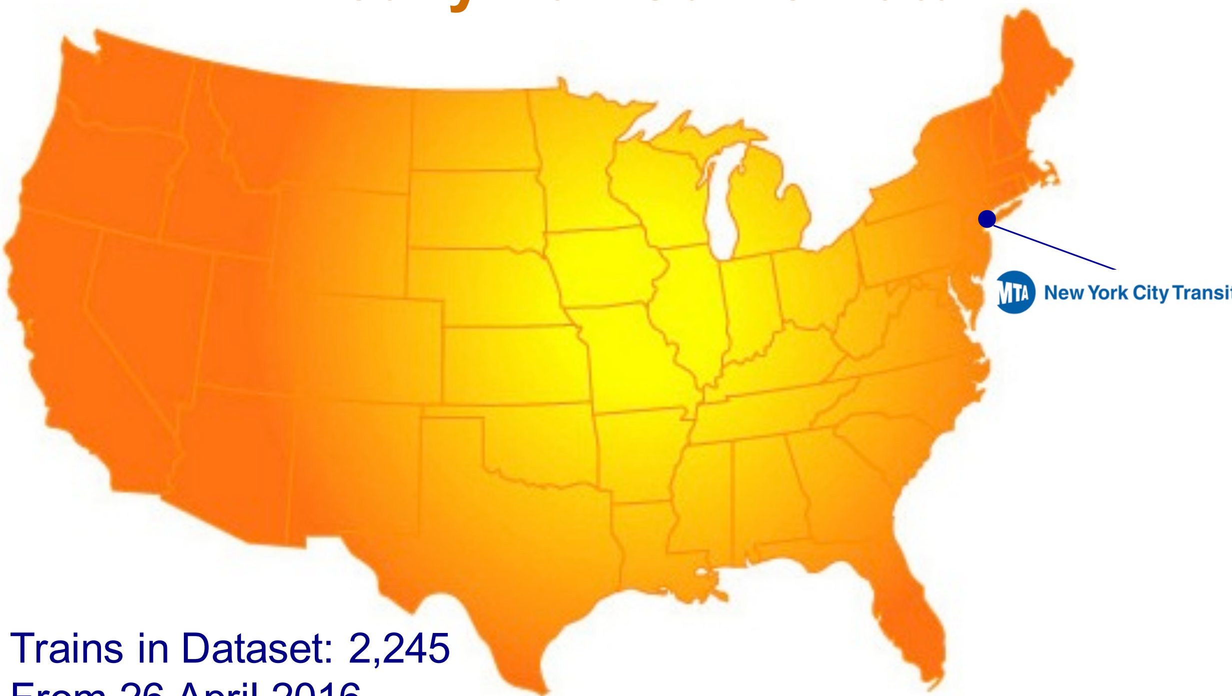
Bending Moment

St. Louis MetroLink



Partner Agencies

Heavy Rail Curve Data

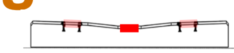


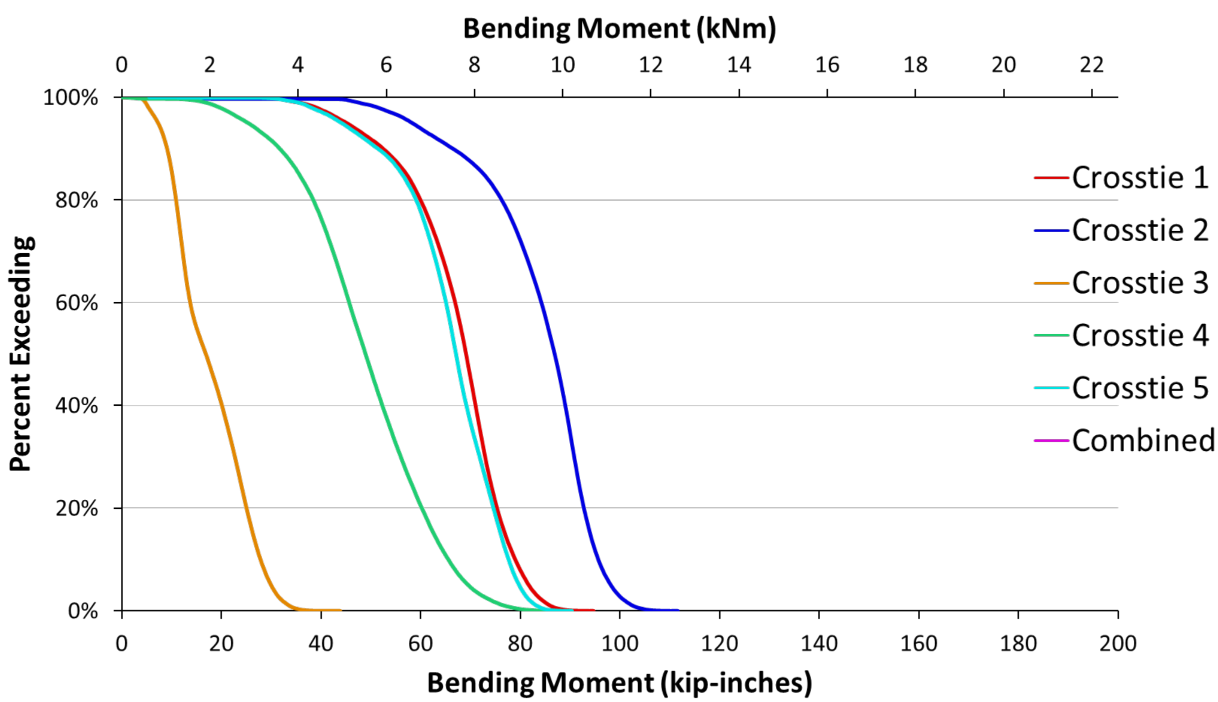
Trains in Dataset: 2,245
From 26 April 2016
to 30 June 2016

New York City Transit

Center Negative Bending

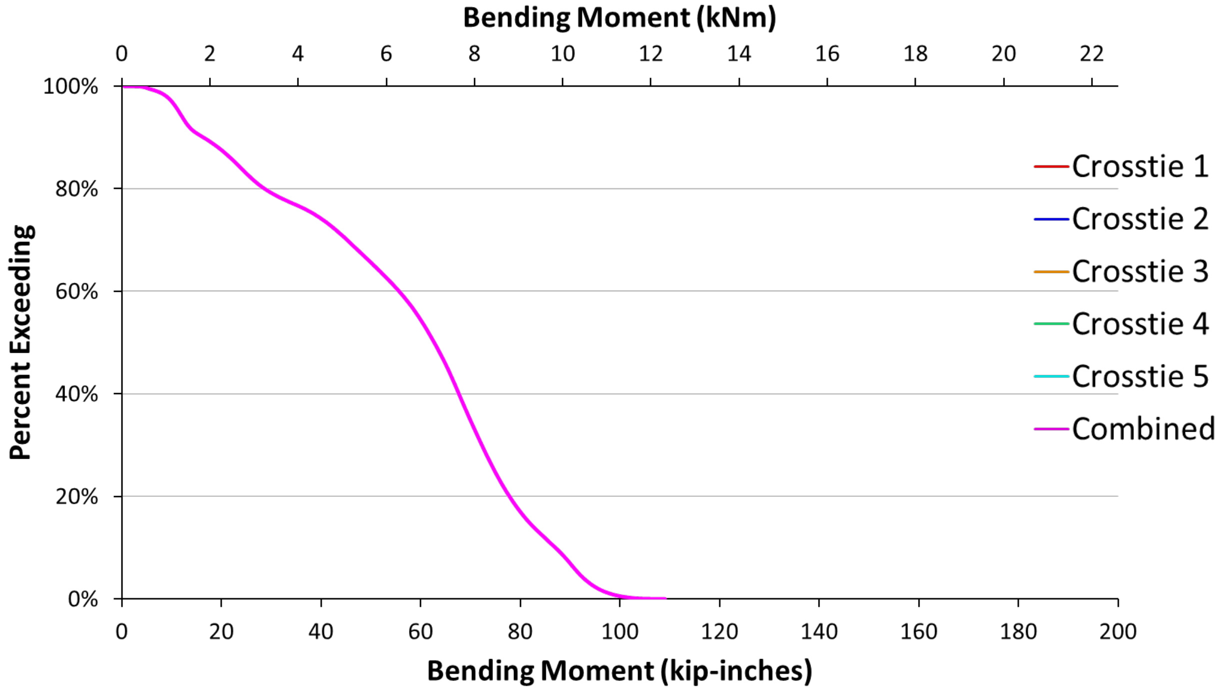
MTA New York City Transit





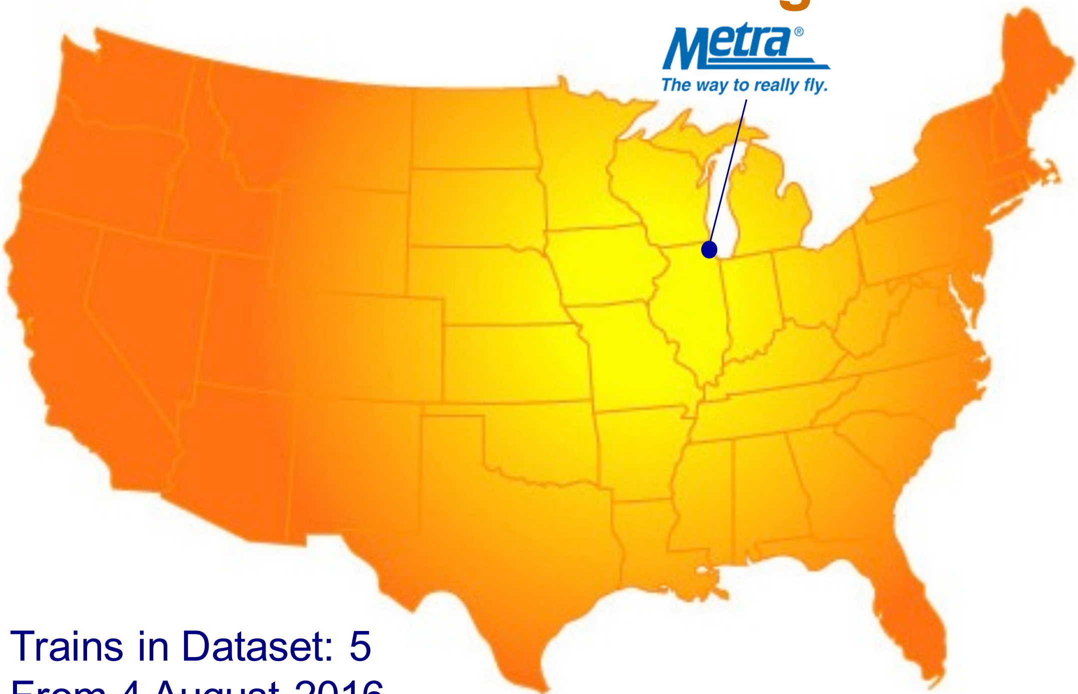
Center Negative Bending

MTA New York City Transit



Partner Agencies

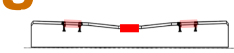
Commuter Rail Tangent Data

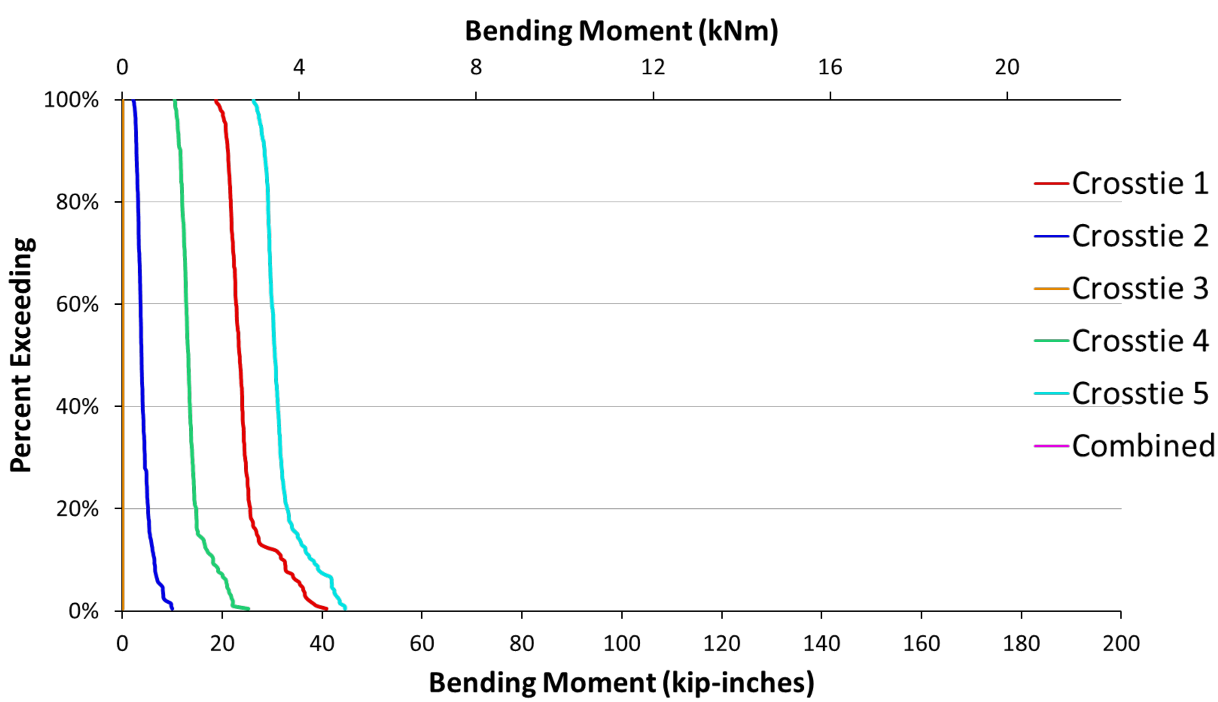


Trains in Dataset: 5
From 4 August 2016
to 5 August 2016

Center Negative Bending

Chicago Metra

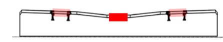


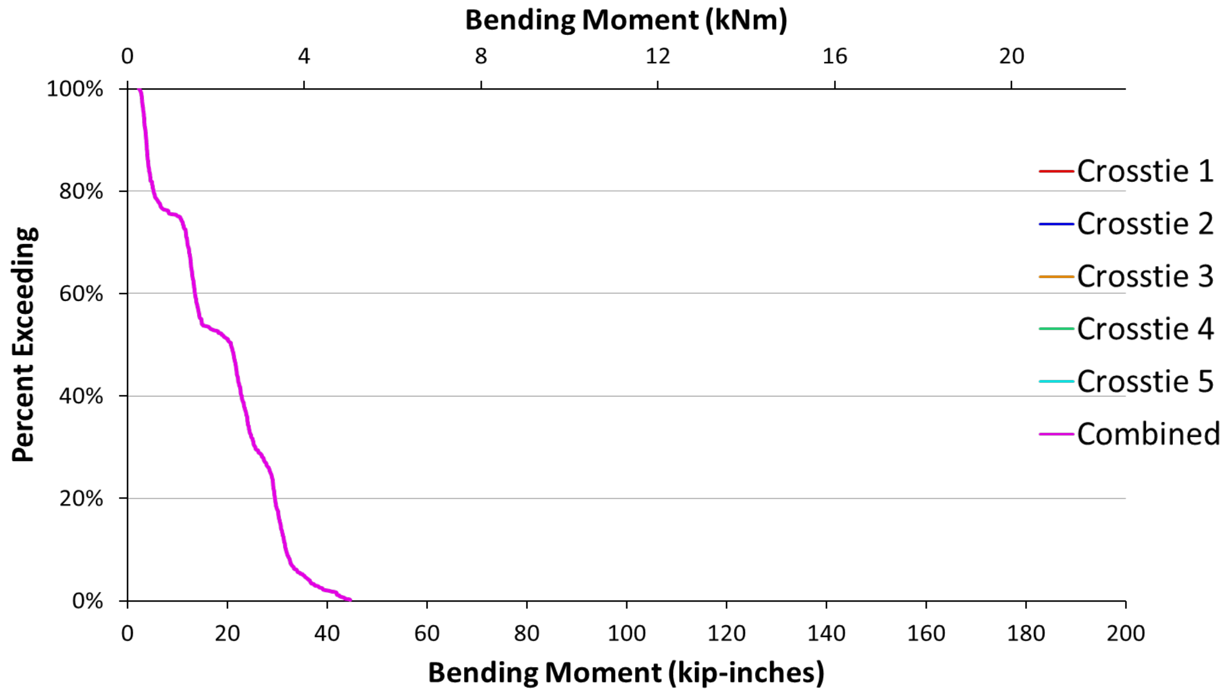


Immediately after tamping activity

Center Negative Bending

Chicago Metra

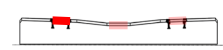


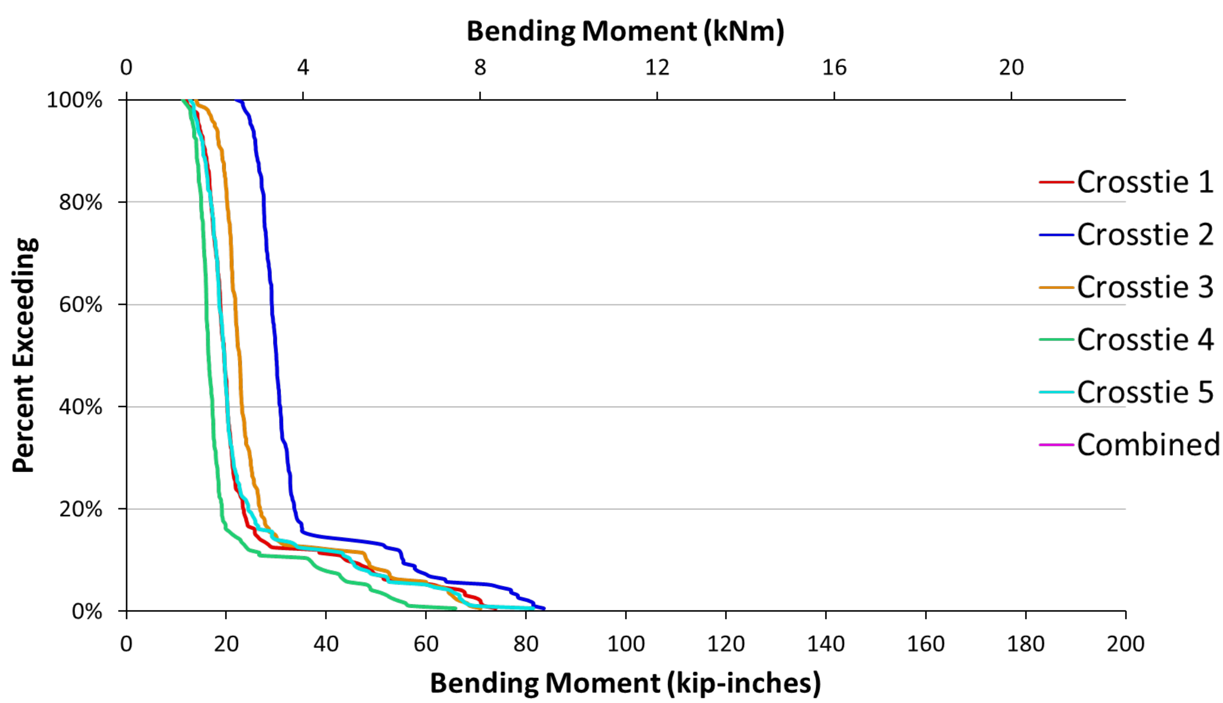


Immediately after tamping activity

Rail Seat Bending

Chicago Metra – Gauge A

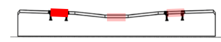


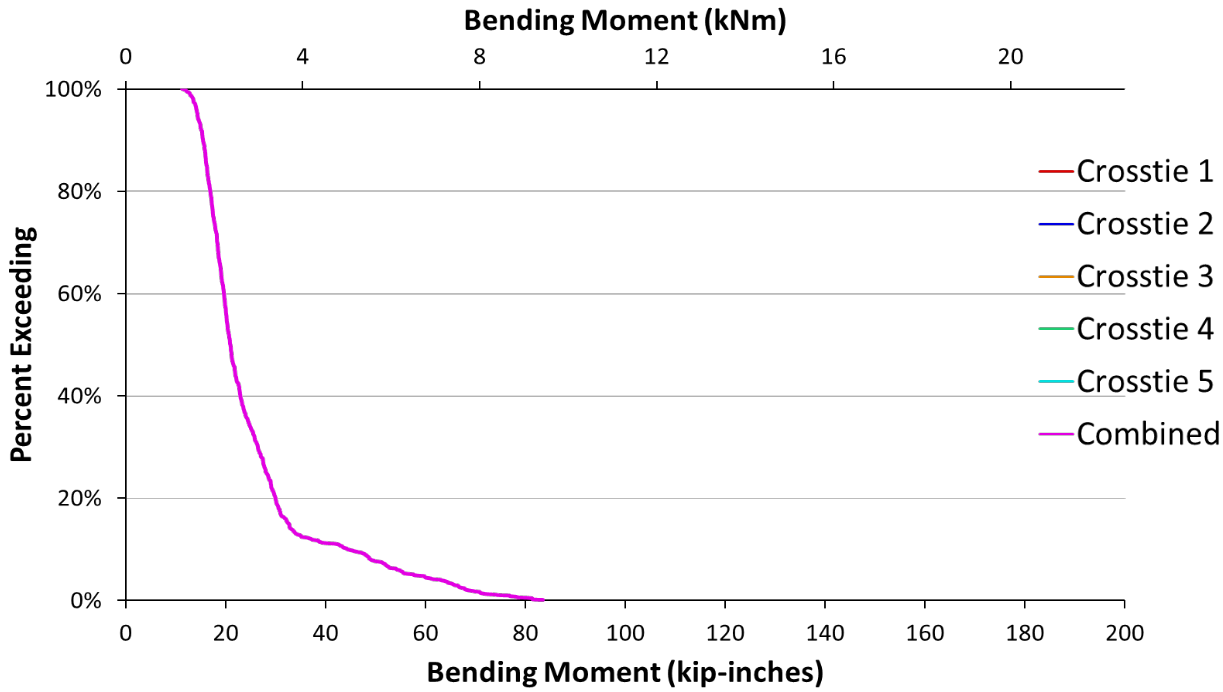


Immediately after tamping activity

Rail Seat Bending

Chicago Metra – Gauge A

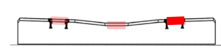


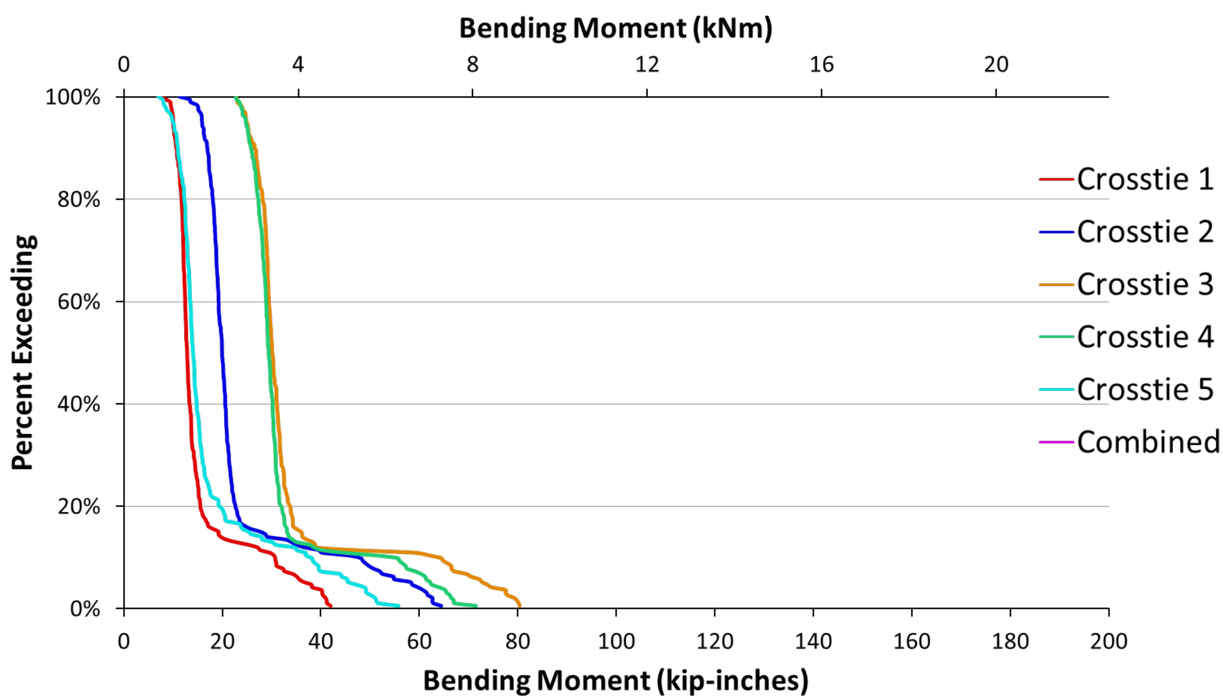


Immediately after tamping activity

Rail Seat Bending

Chicago Metra – Gauge E

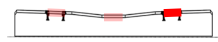


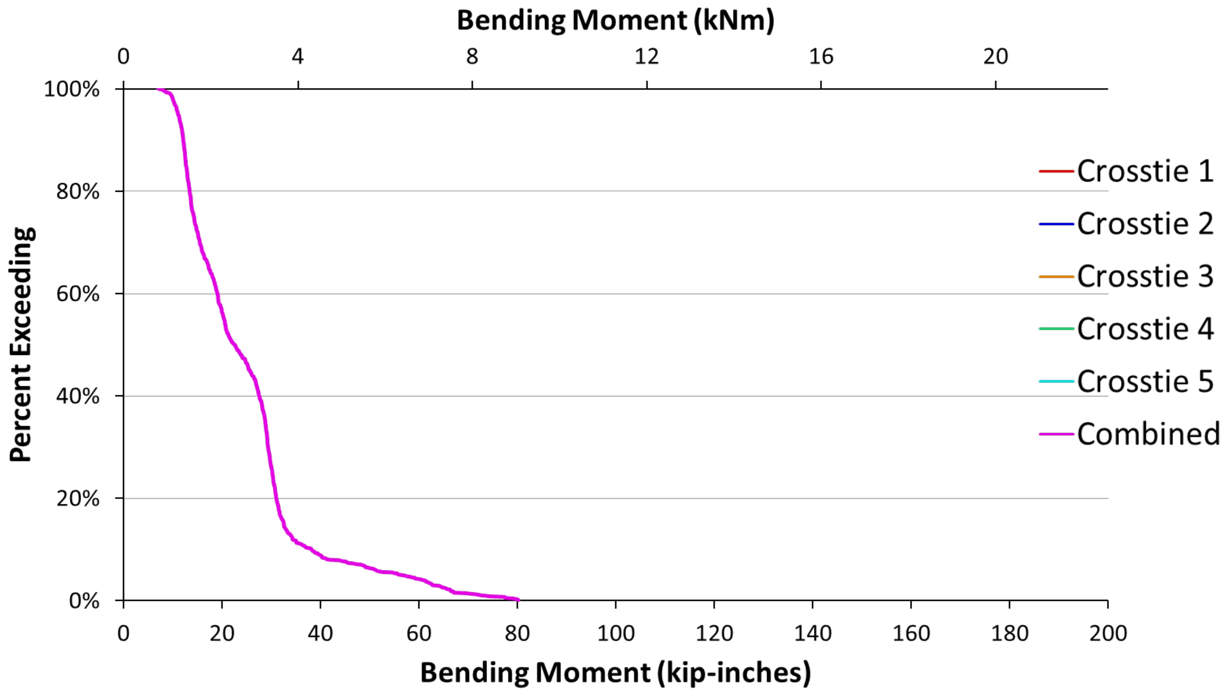


Immediately after tamping activity

Rail Seat Bending

Chicago Metra – Gauge E

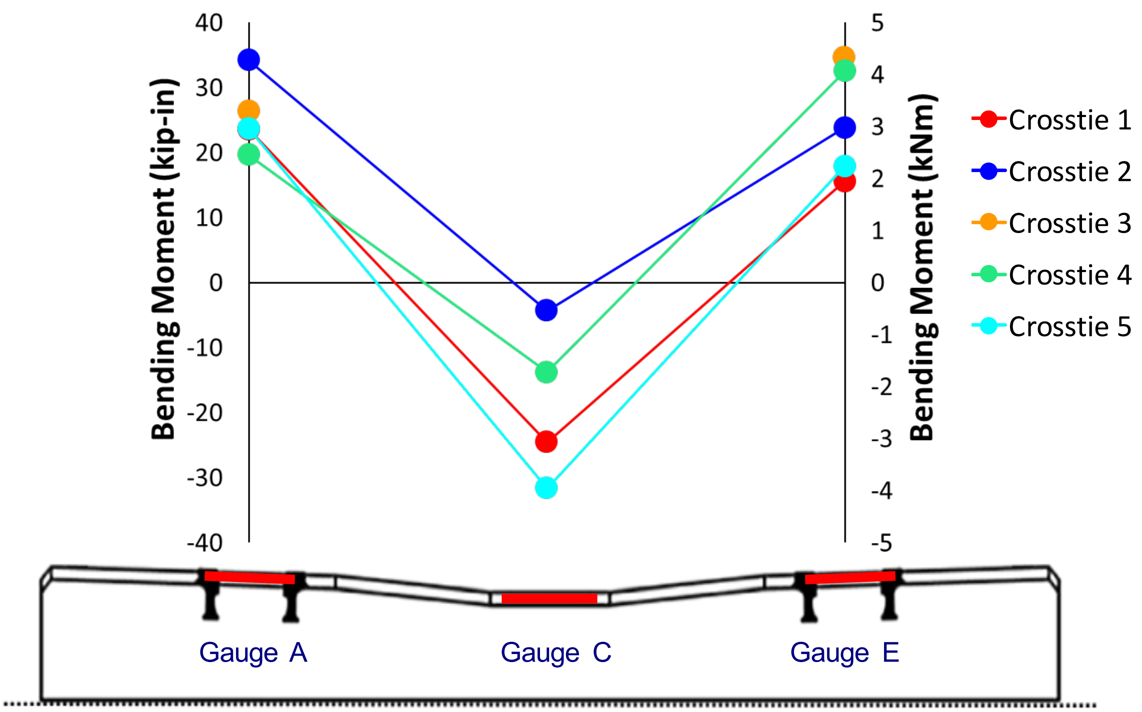




Immediately after tamping activity

Average Bending Moments

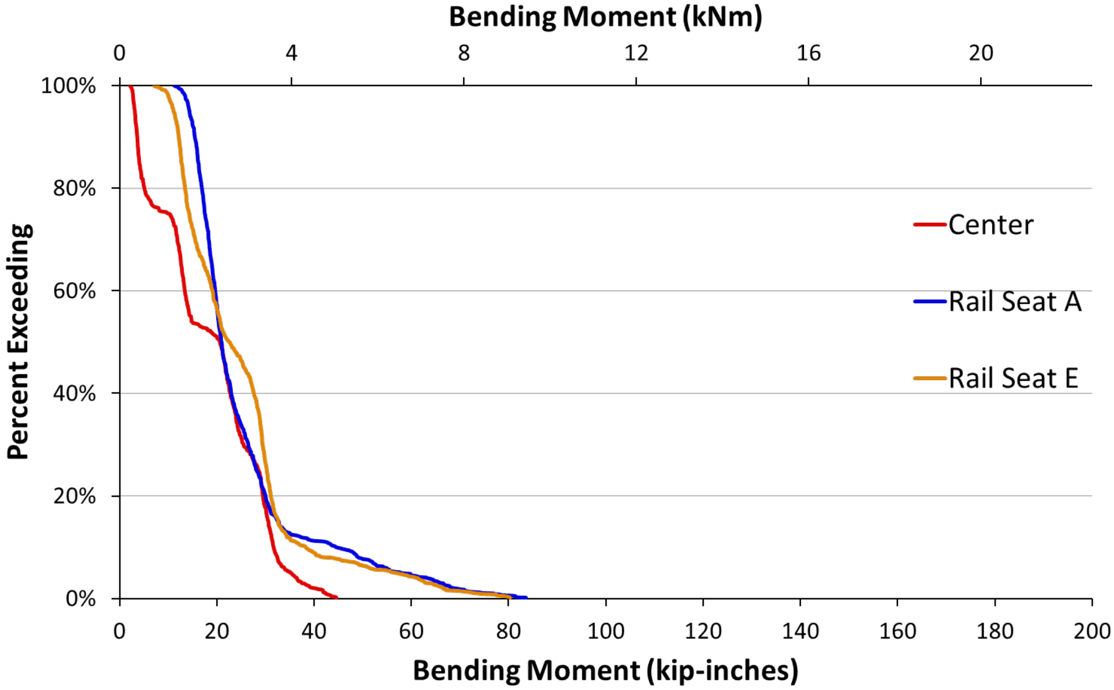
Chicago Metra



Immediately after tamping activity

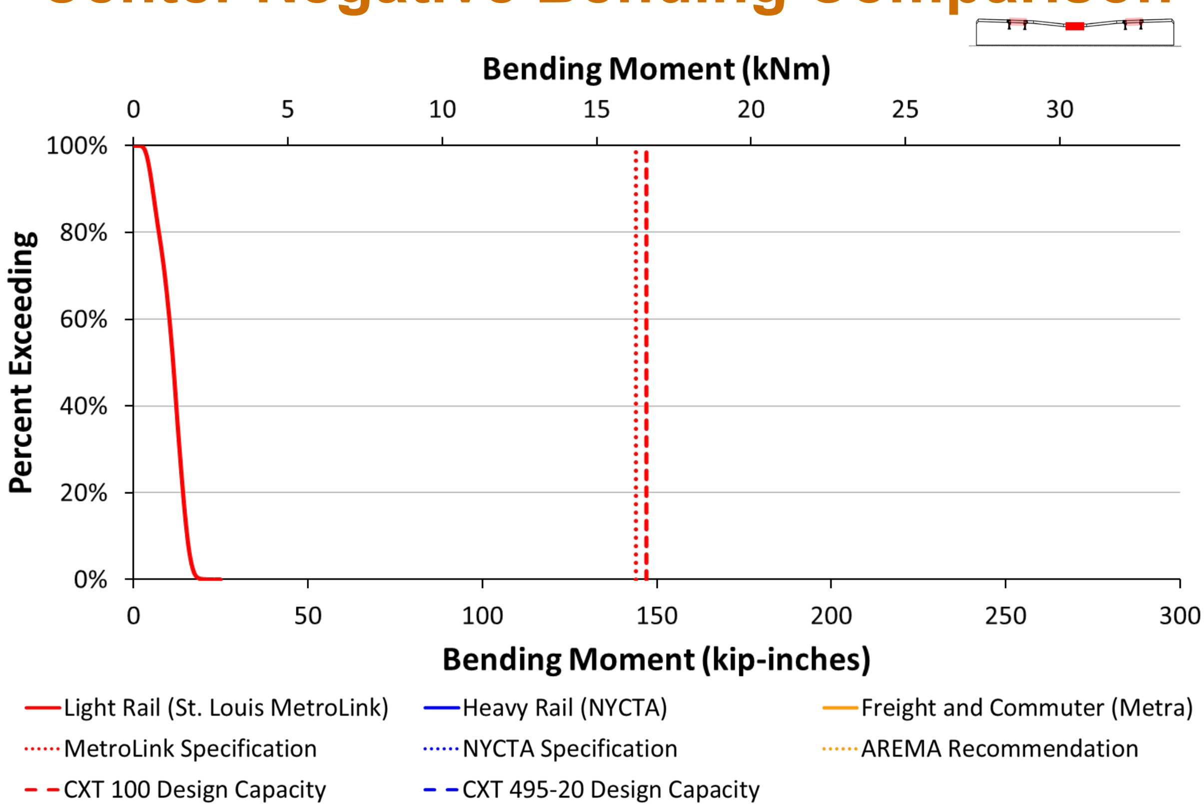
Bending Moment

Chicago Metra



Immediately after tamping activity

Center Negative Bending Comparison



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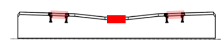
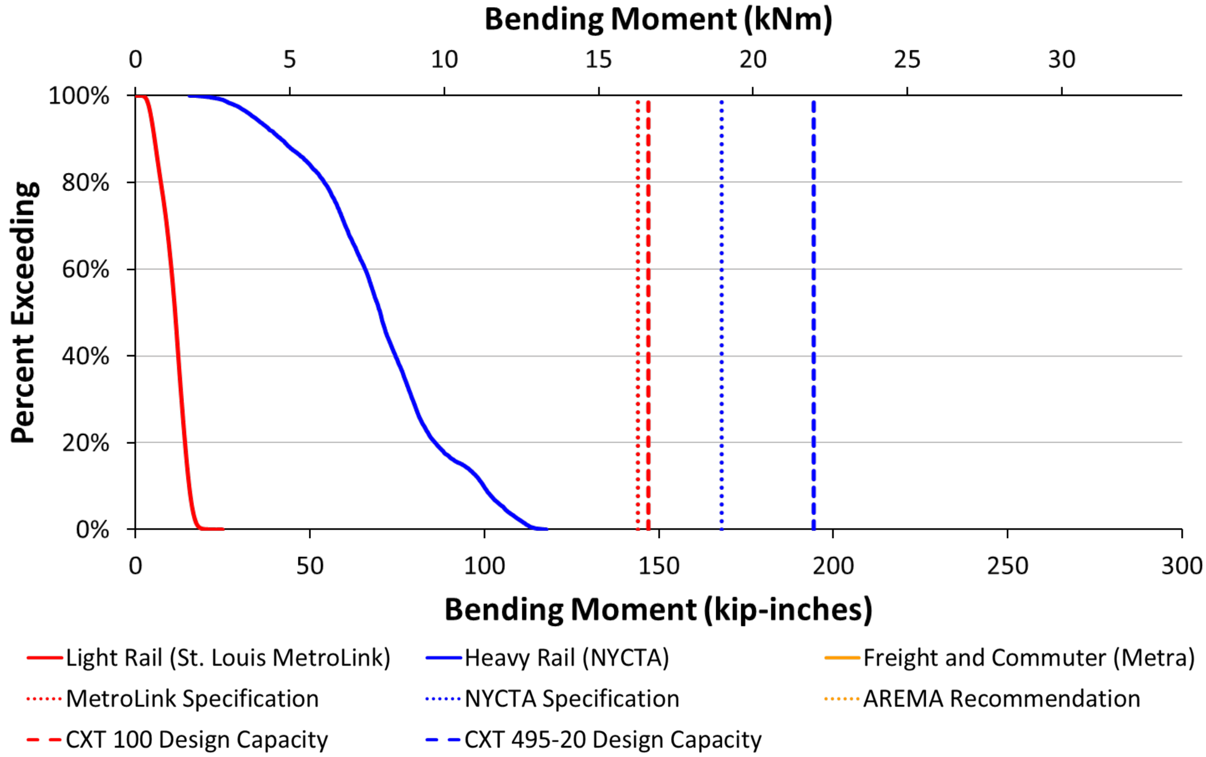
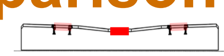
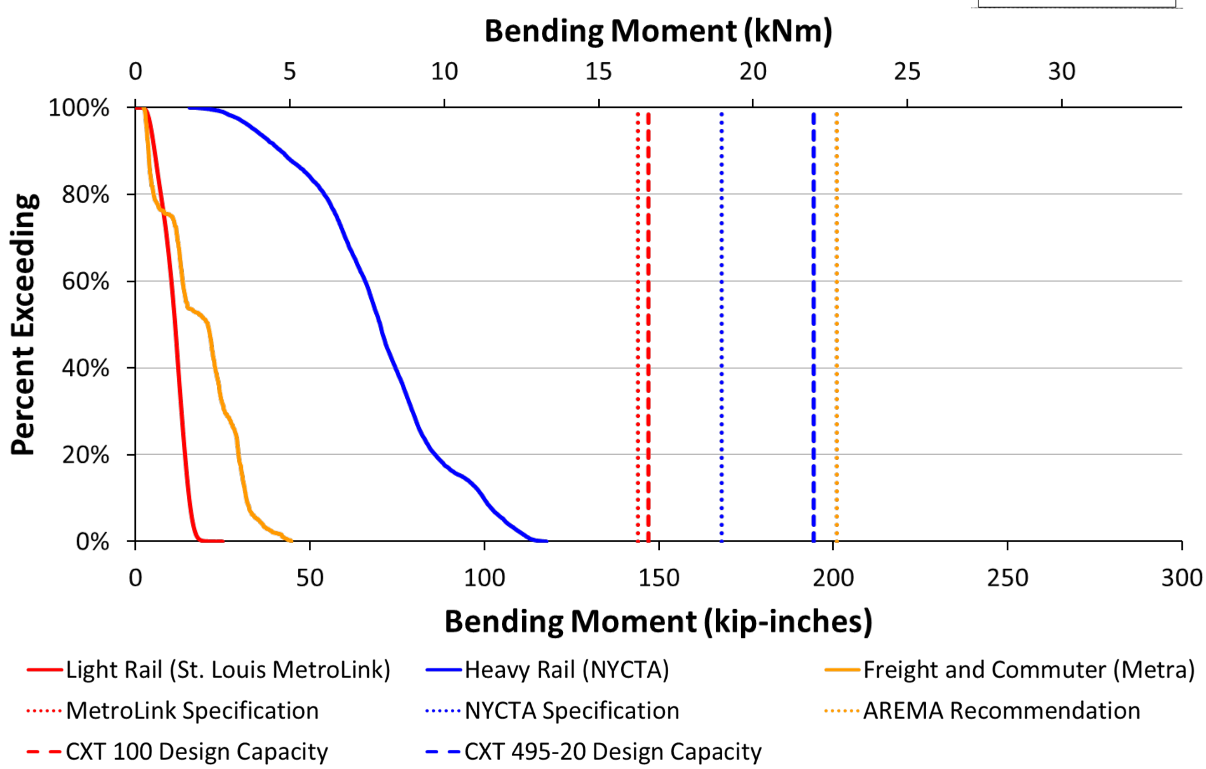




Center Negative Bending Comparison





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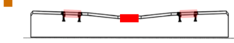

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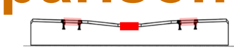


Crosstie Reserve Capacity

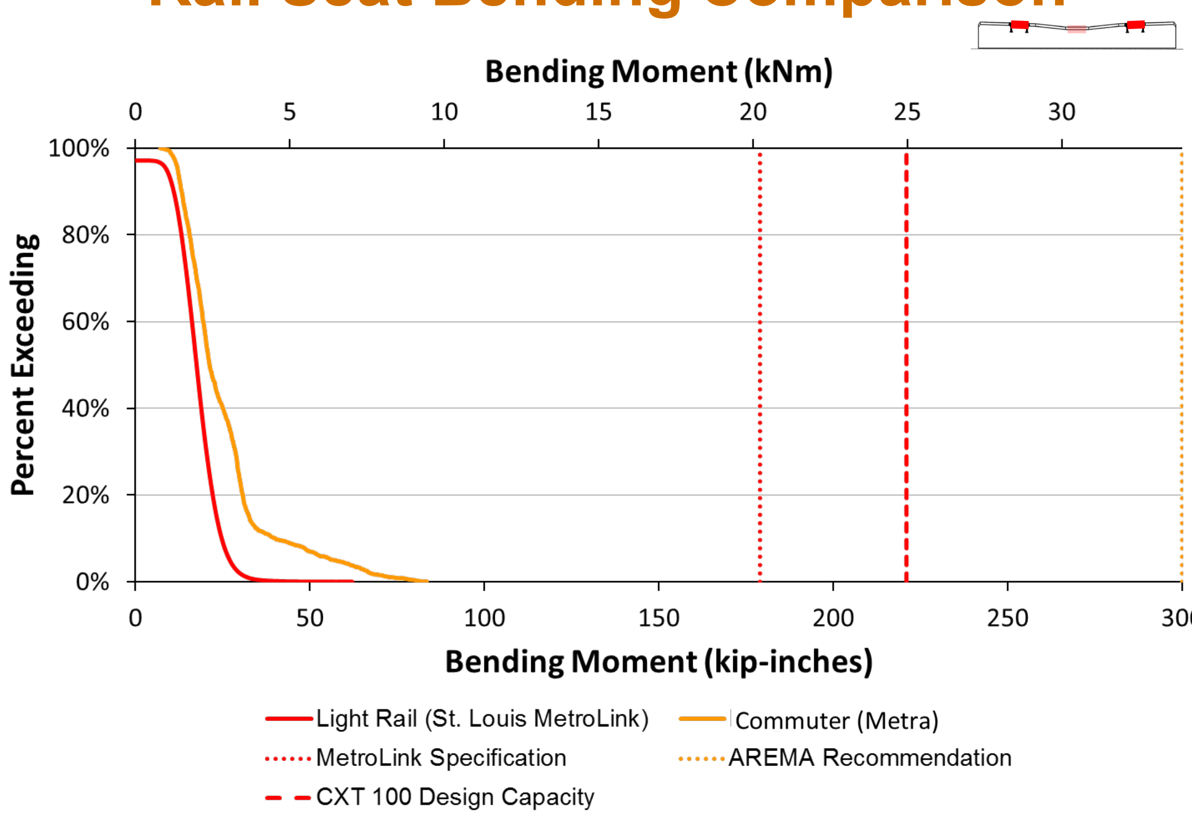
Center Negative Bending Moment

$$\text{Reserve Design Capacity} = \frac{\text{Design Capacity}}{\text{Measured Bending Moment}}$$

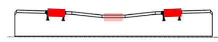
Percentile Bending Moment	Light Rail	Heavy Rail	Commuter Rail	Freight
Minimum	82.48	10.86	90.82	71.05
Average	12.96	2.96	10.84	9.08
90%	9.25	1.93	6.34	4.90
95%	8.74	1.83	5.69	4.55
99%	8.05	1.71	4.73	3.80
Maximum	5.55	1.51	4.51	2.43

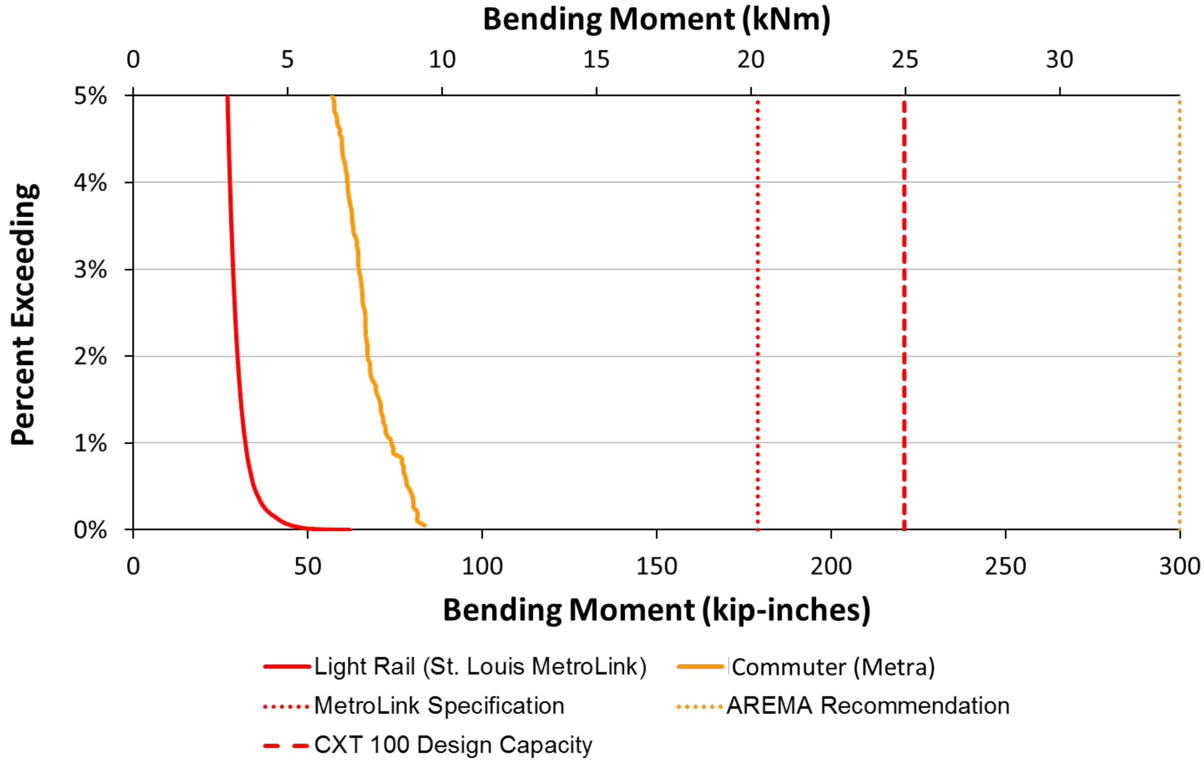
- Max recorded center bending moment (**25 kip-inches**) for light rail could be increased by a factor of **5.6** without reaching the design moment for the crosstie or the agency specifications
- Max center bending moment found for heavy rail is **112 kip-inches**, providing potential reserve capacity 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**)

Rail Seat Bending Comparison



Rail Seat Bending Comparison





Crosstie Reserve Capacity

Rail Seat Bending Moment

$$\text{Reserve Design Capacity} = \frac{\text{Design Capacity}}{\text{Measured Bending Moment}}$$

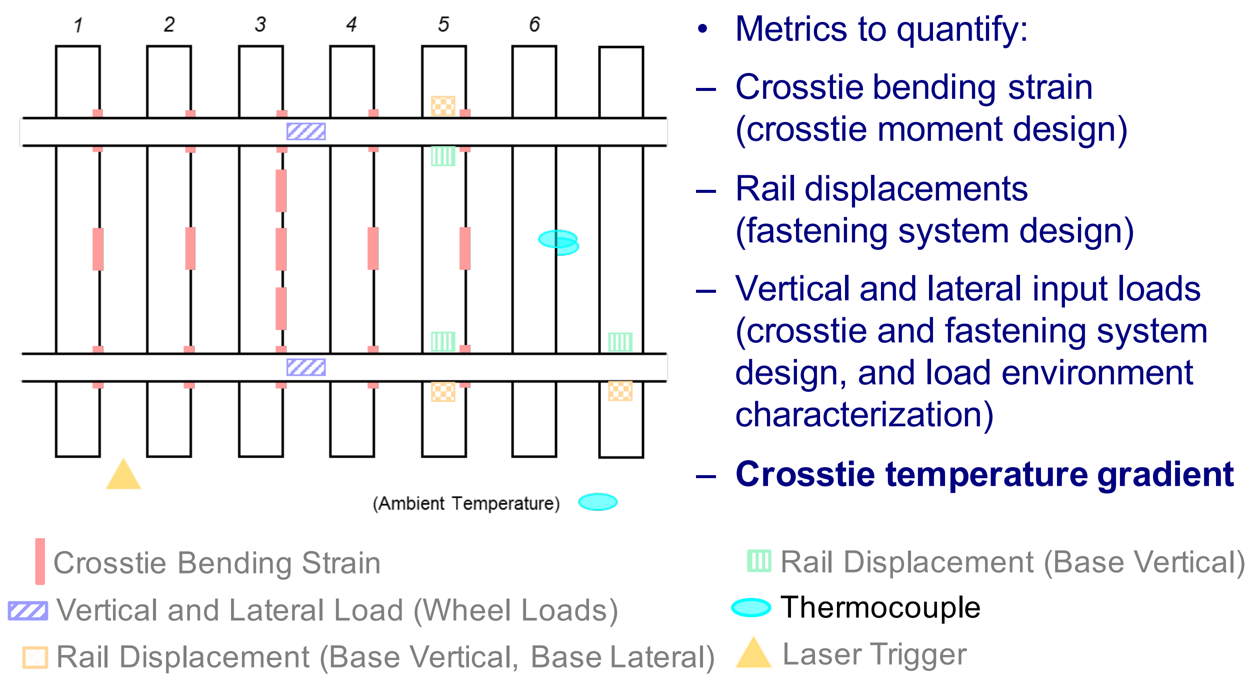
Percentile Bending Moment	Light Rail	Heavy Rail	Commuter Rail	Freight
Minimum	43.11	---	42.45	---
Average	7.50	---	11.90	---
90%	5.41	---	7.48	---
95%	4.95	---	5.24	---
99%	4.16	---	4.05	---
Maximum	2.15	---	3.59	---

- 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

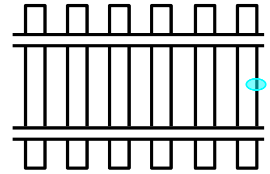
Typical Field Instrumentation Map



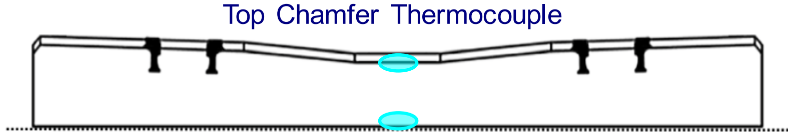
- Metrics to quantify:
  - Crosstie bending strain (crosstie moment design)
  - Rail displacements (fastening system design)
  - Vertical and lateral input loads (crosstie and fastening system design, and load environment characterization)
  - **Crosstie temperature gradient**

Data Processing Overview

Crosstie Temperature Gradient

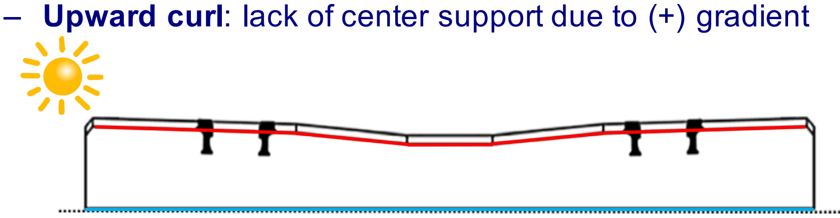


- **Desired data**:
  - Temperature gradient of crosstie
- **Motivation of study and objective of data analysis:**
  - Quantify the difference in temperature between top and bottom of crosstie and understand the effect of temperature differential on crosstie support conditions
  - Study how environmental 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

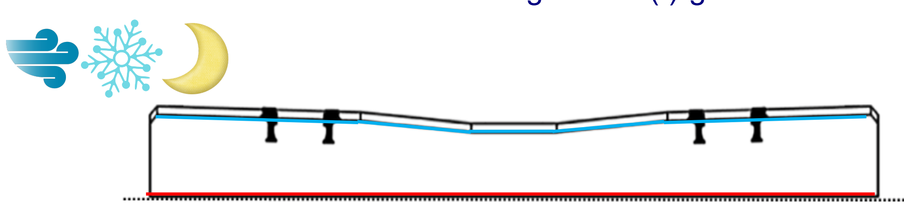


Temperature Gradient Effect

- 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

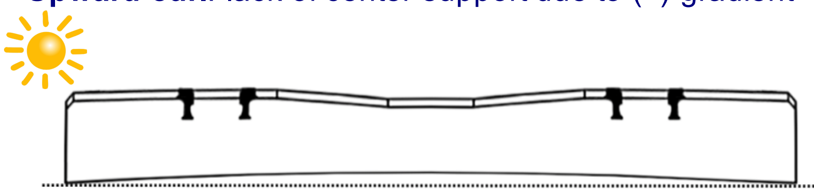


  - **Downward curl**: center binding due to (-) gradient

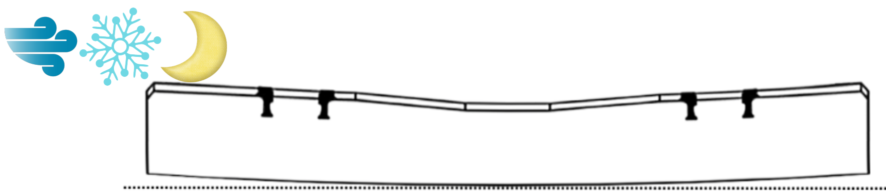


Temperature Gradient Effect

- 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

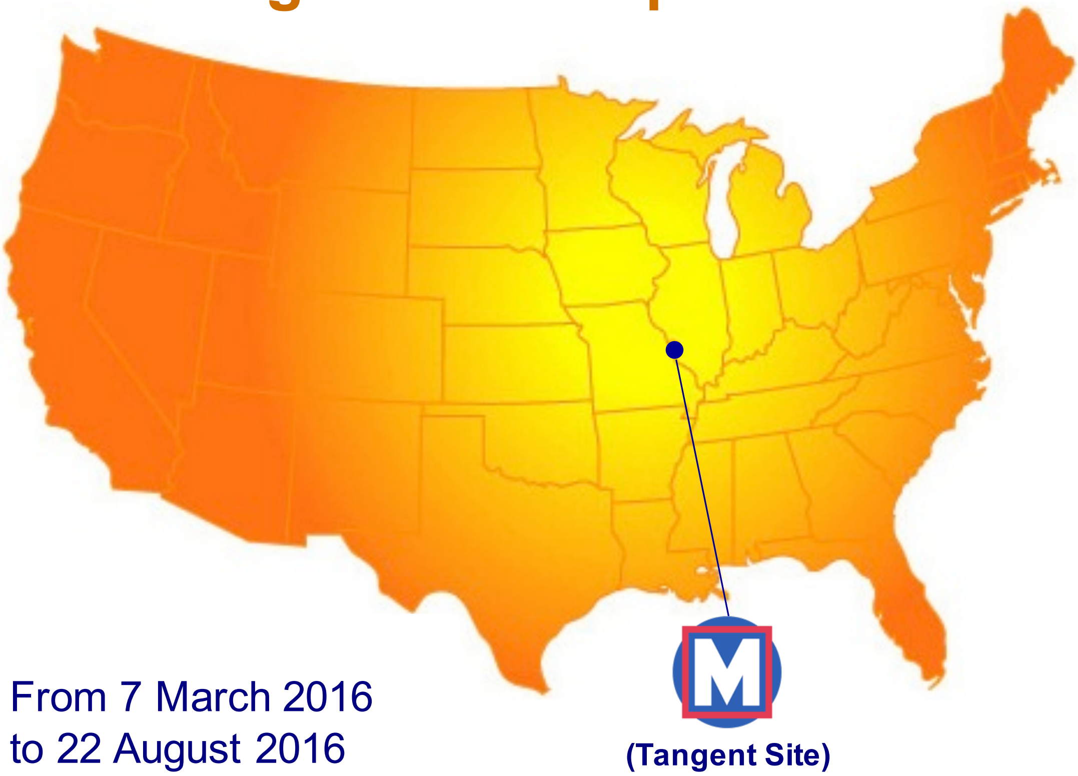


  - **Downward curl**: center binding due to (-) gradient



Partner Agencies

Light Rail Temperature Data

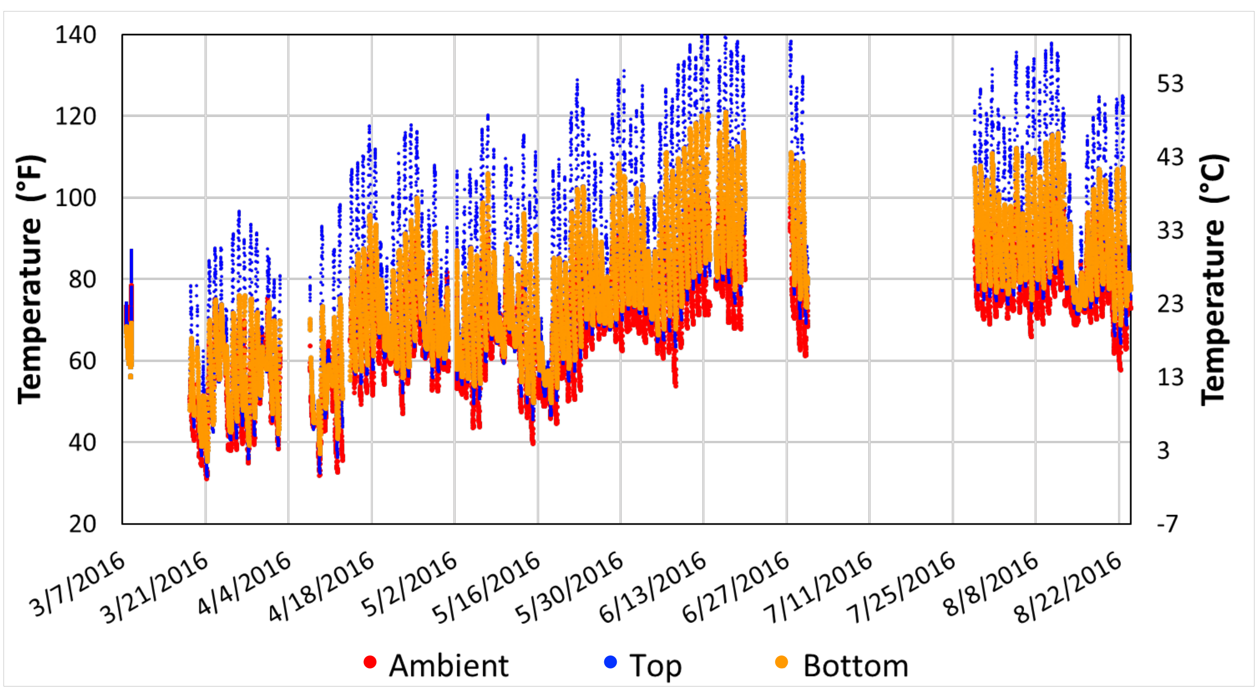


From 7 March 2016
to 22 August 2016

Temperature Distribution

St. Louis MetroLink

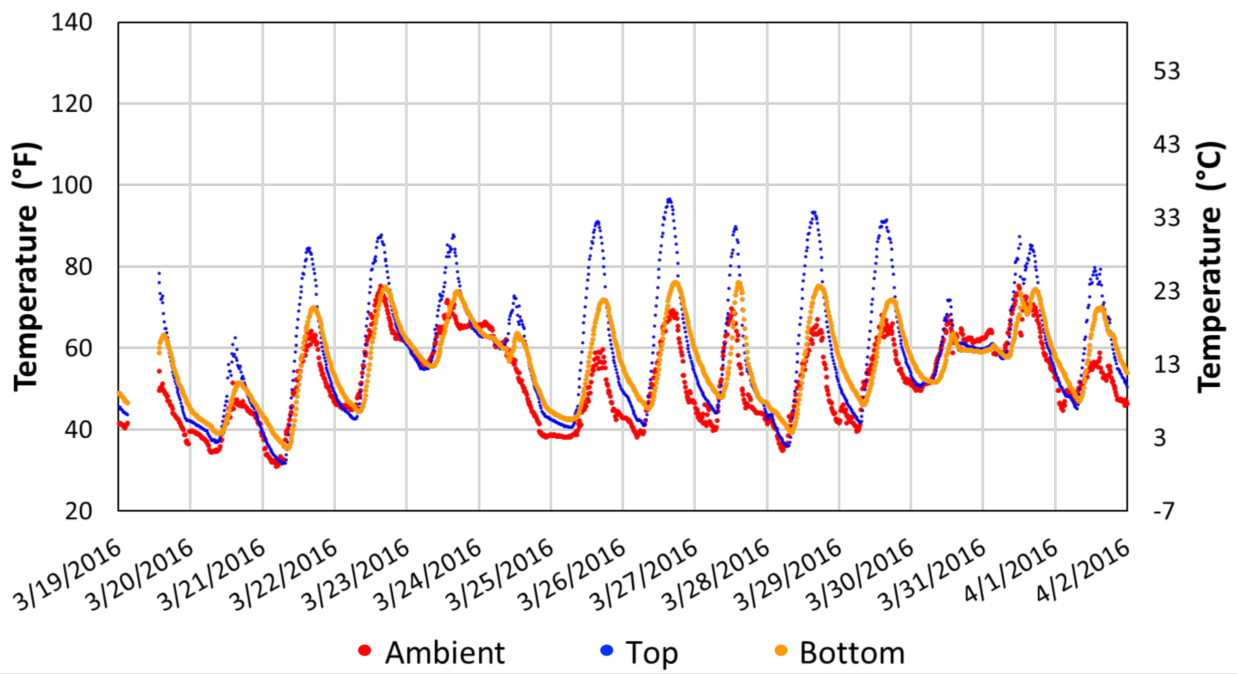
- Current data batch from 7 March 2016 to 22 August 2016



Temperature Distribution

St. Louis MetroLink

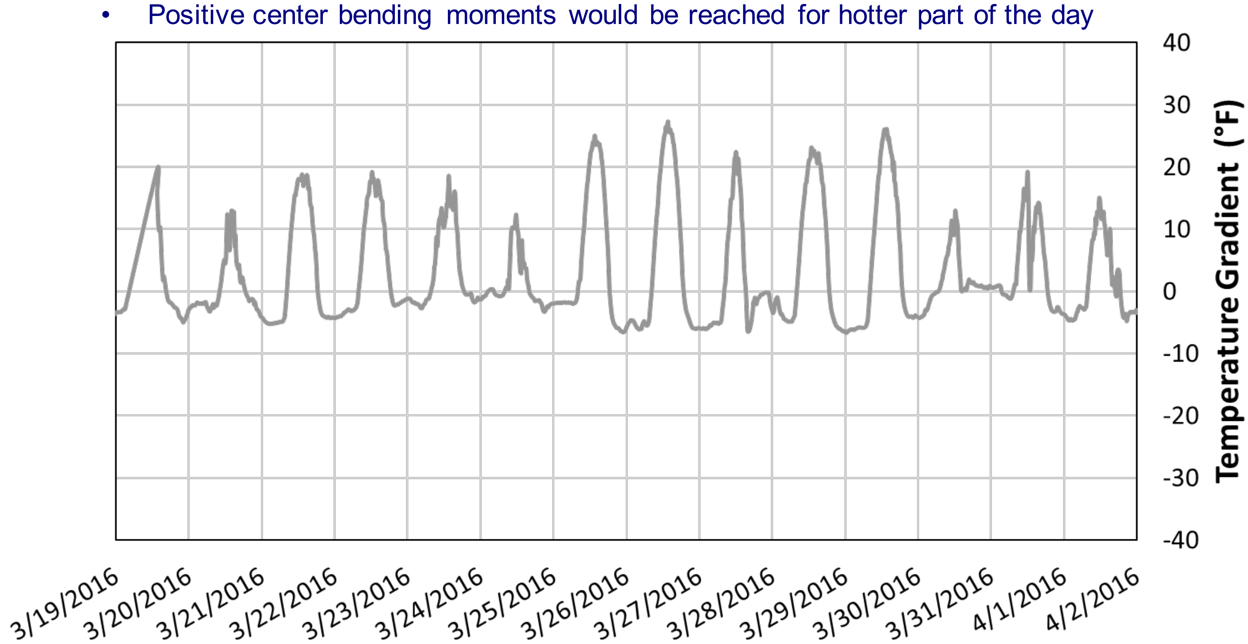
- 19 March 2016 to 2 April 2016 (1250 trains during this time)
- Limited range to study variation and relation with bending moments



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



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St. Louis MetroLink

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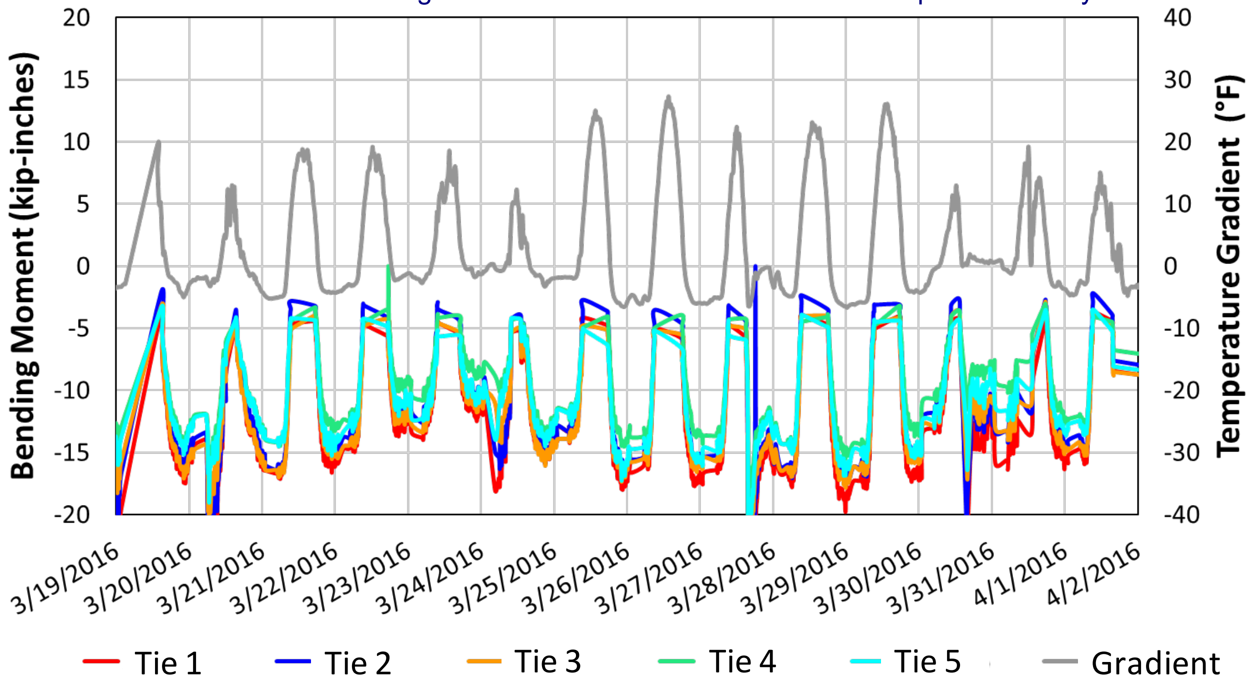

Temperature and Bending Moment

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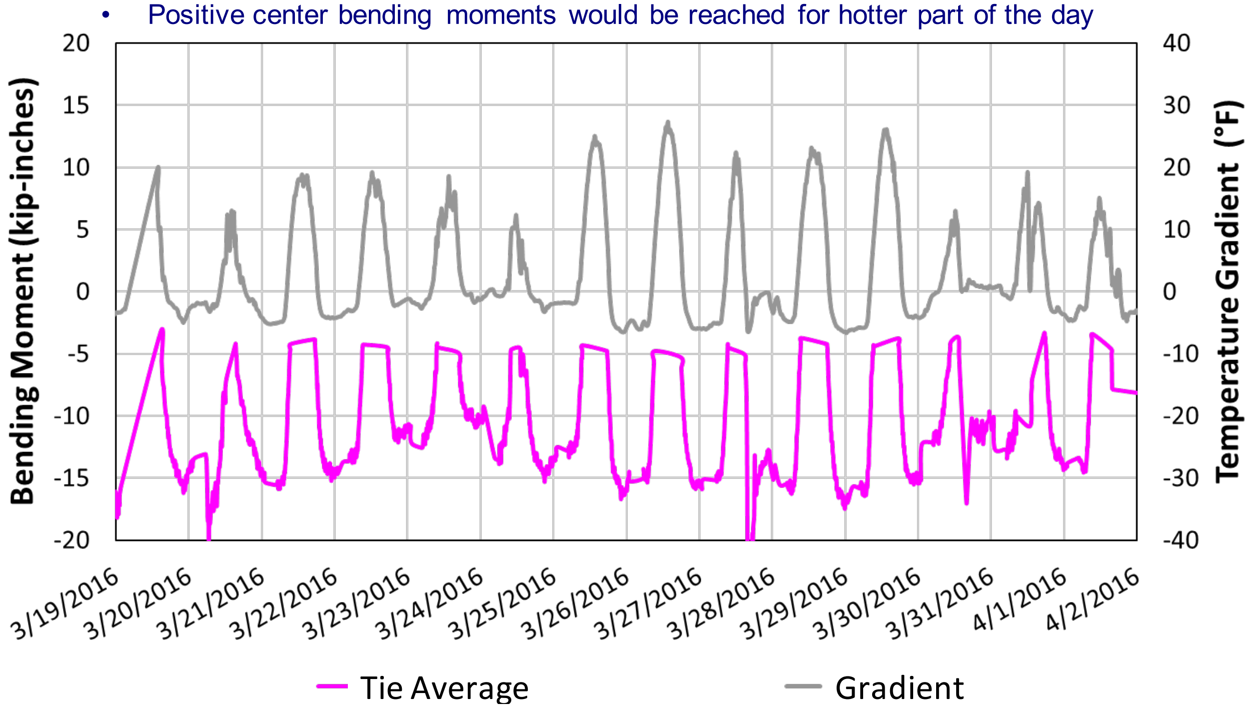
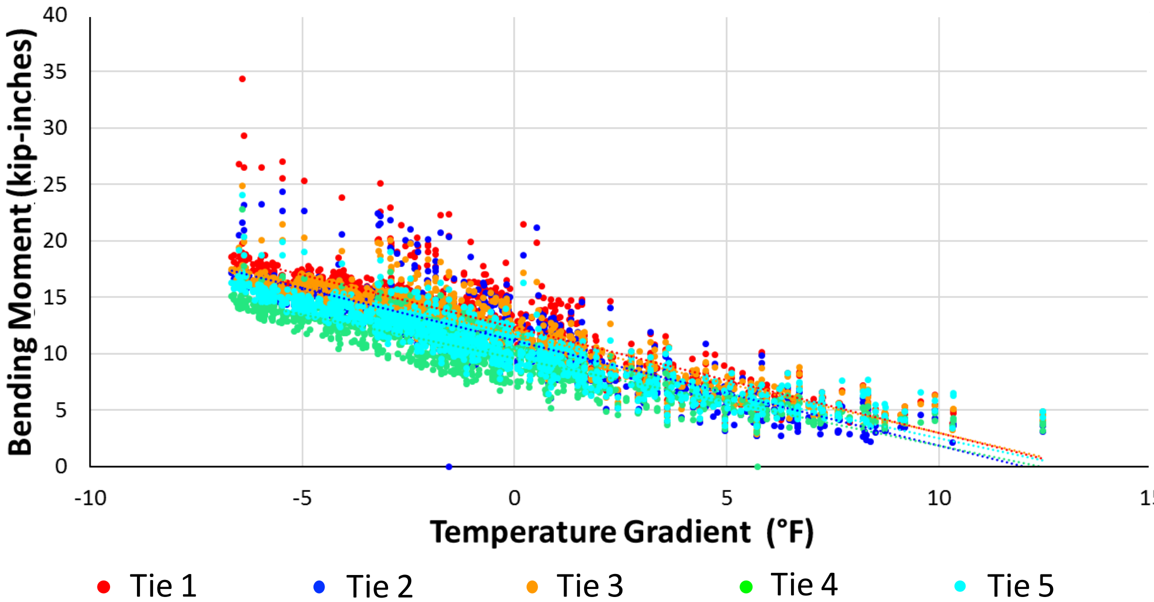


Temperature and Bending Moment

St. Louis MetroLink

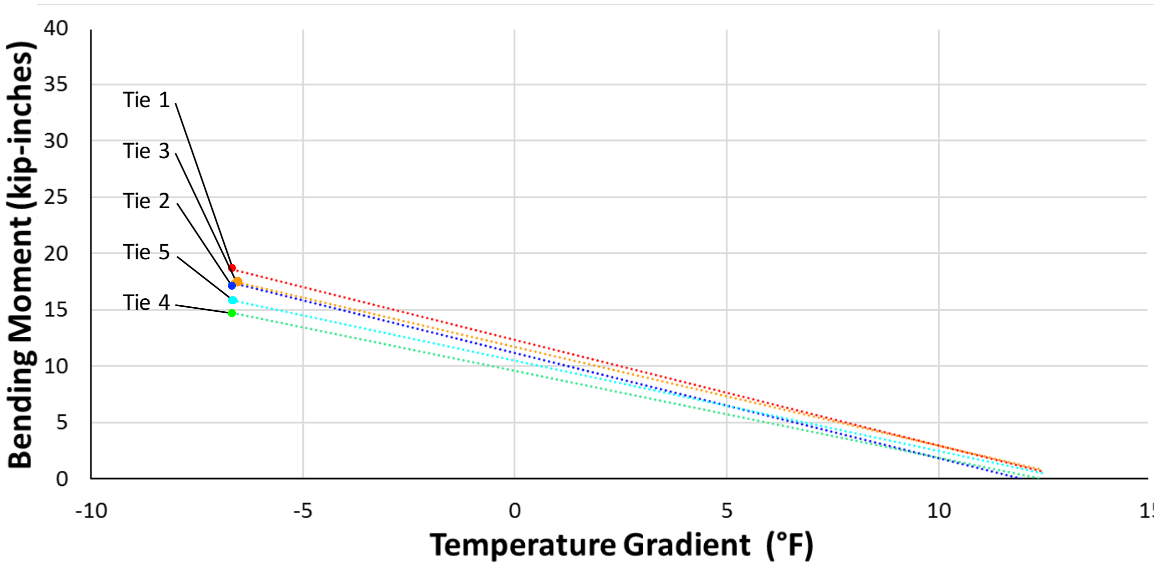
- Scatter plot of Temperature Gradient vs Center Bending Moment (in abs. value)
- Consistent linear relation gradient/ bending moment for the 5 different ties



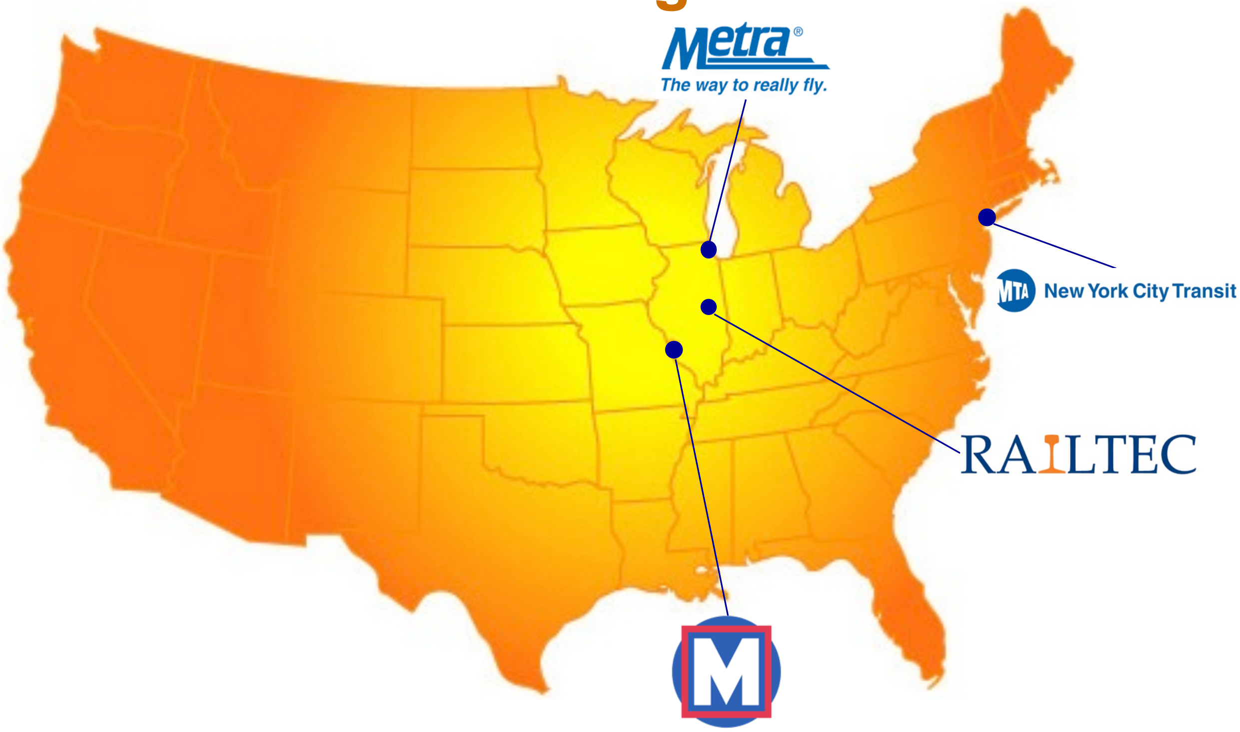
Temperature and Bending Moment

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

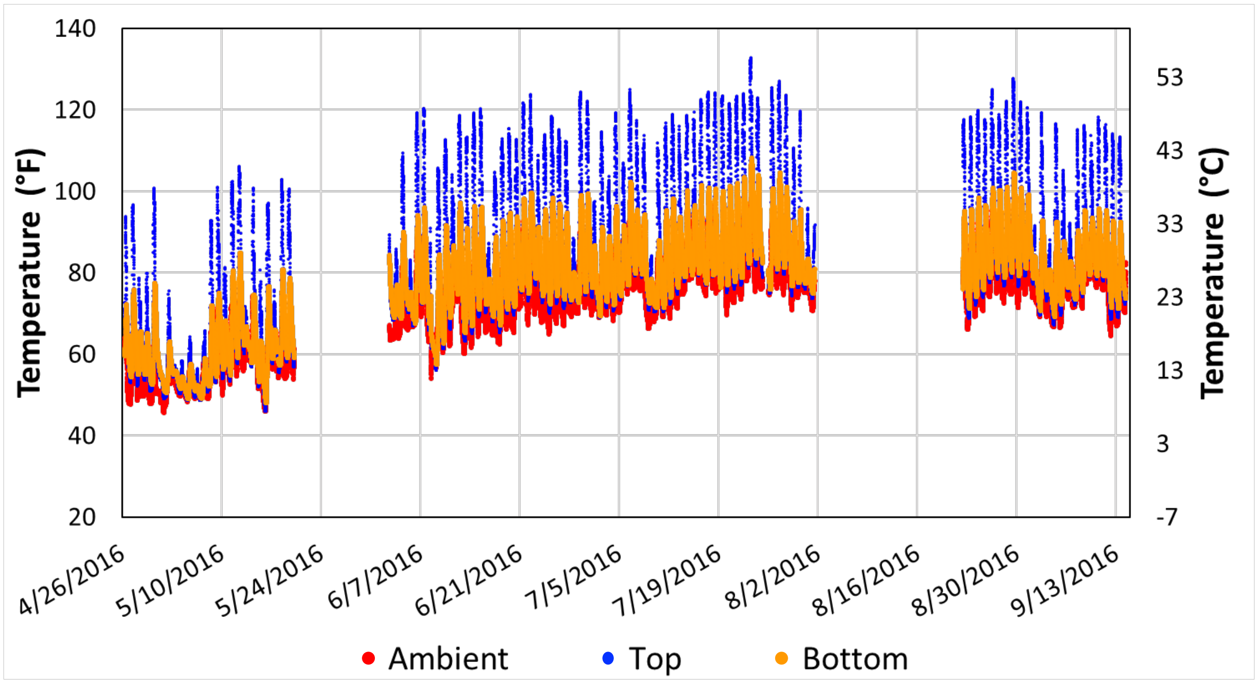
From 25 April 2016
to 12 September 2016

Temperature Distribution

MTA New York City Transit

New York City Transit

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

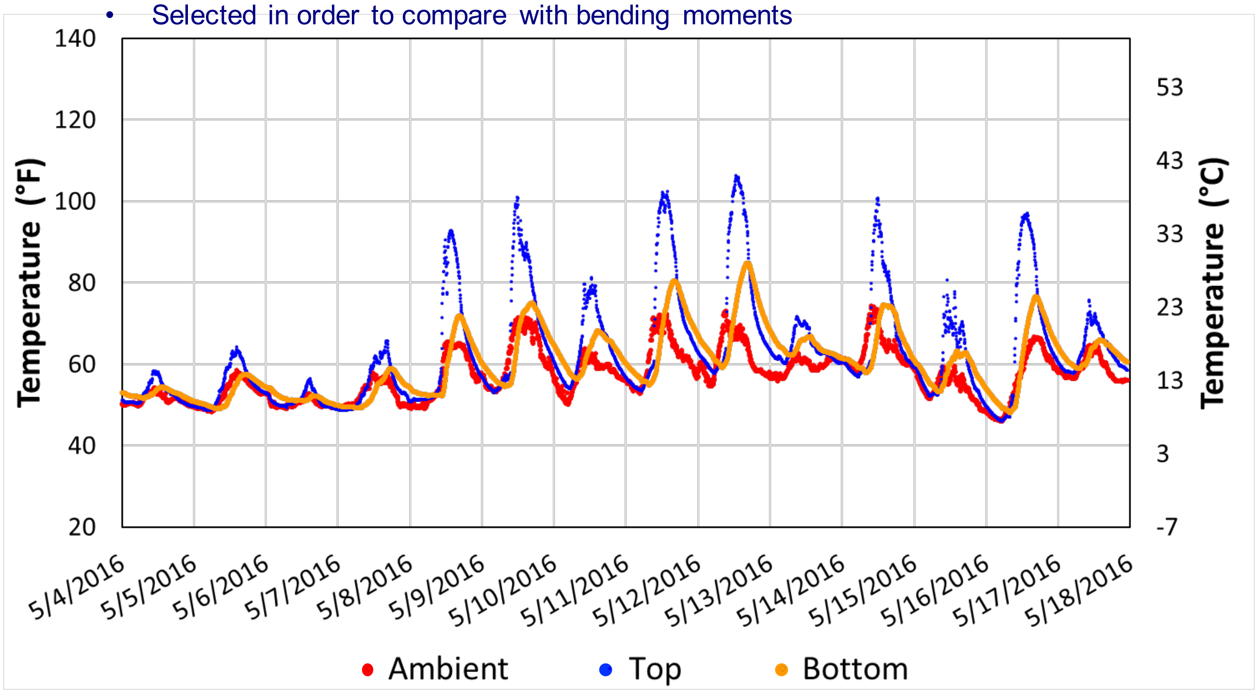


Temperature Distribution

MTA New York City Transit

New York City Transit

- 4 May 2016 to 18 May 2016 (937 trains during this time)
- Selected in order to compare with bending moments

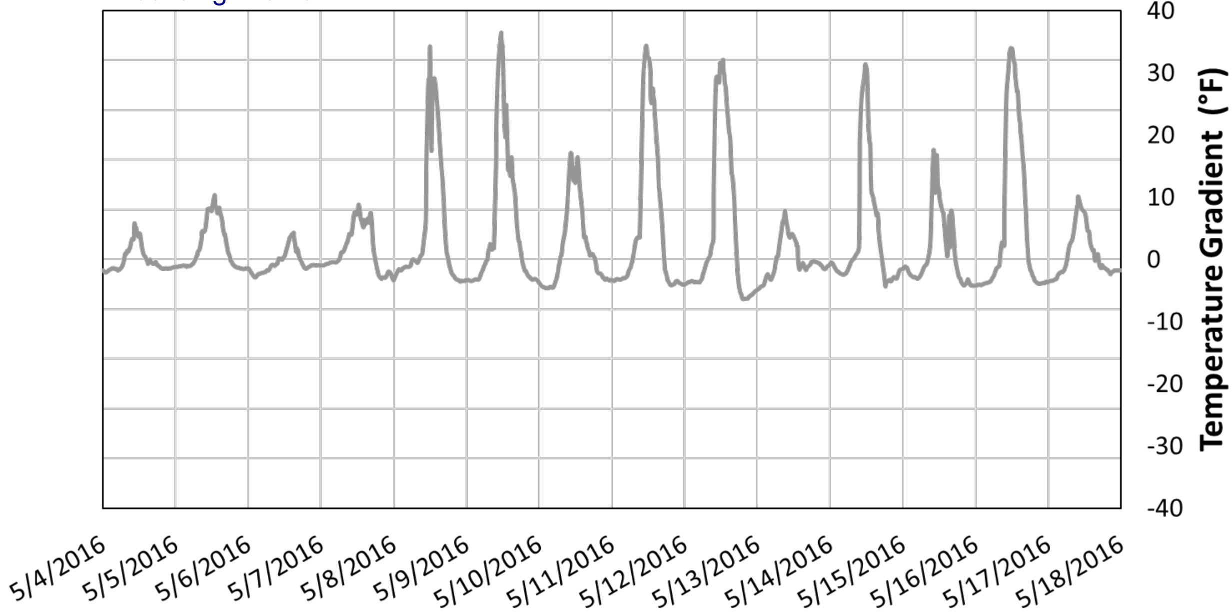


Temperature and Bending Moment

New York City Transit

MTA New York City Transit

- Similar to previous plot, relation between gradient variation and variation in bending moment

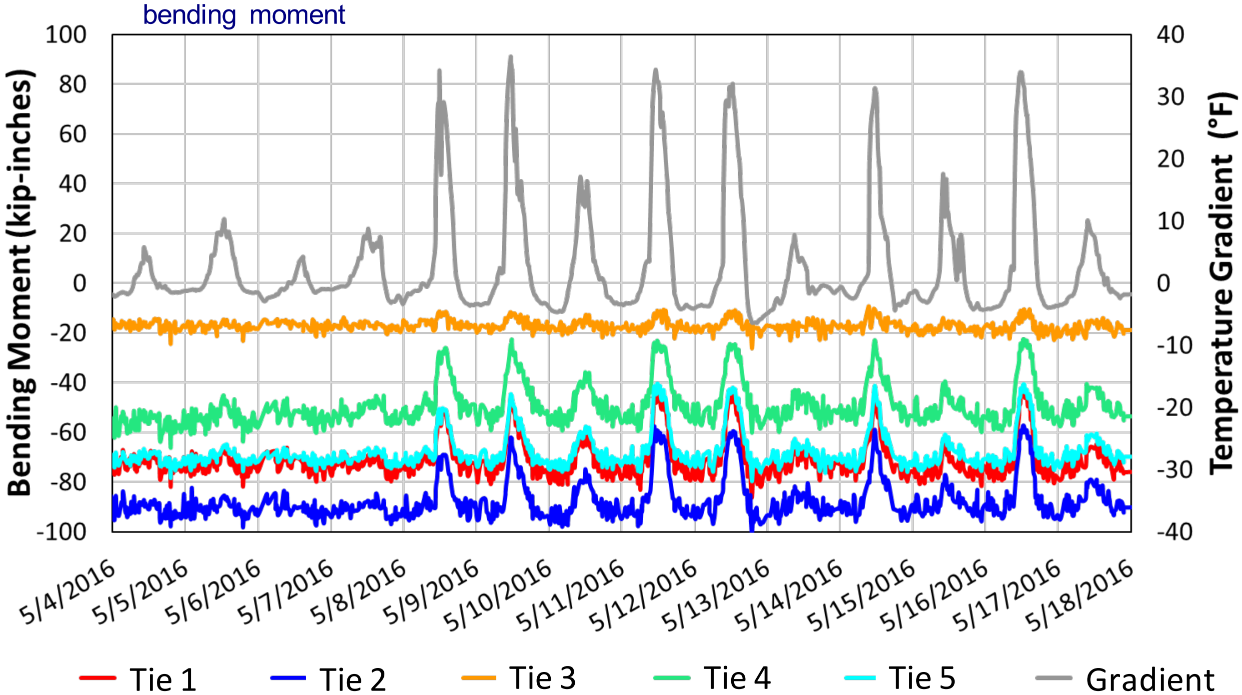


Temperature and Bending Moment

New York City Transit

MTA New York City Transit

- Similar to previous plot, relation between gradient variation and variation in bending moment

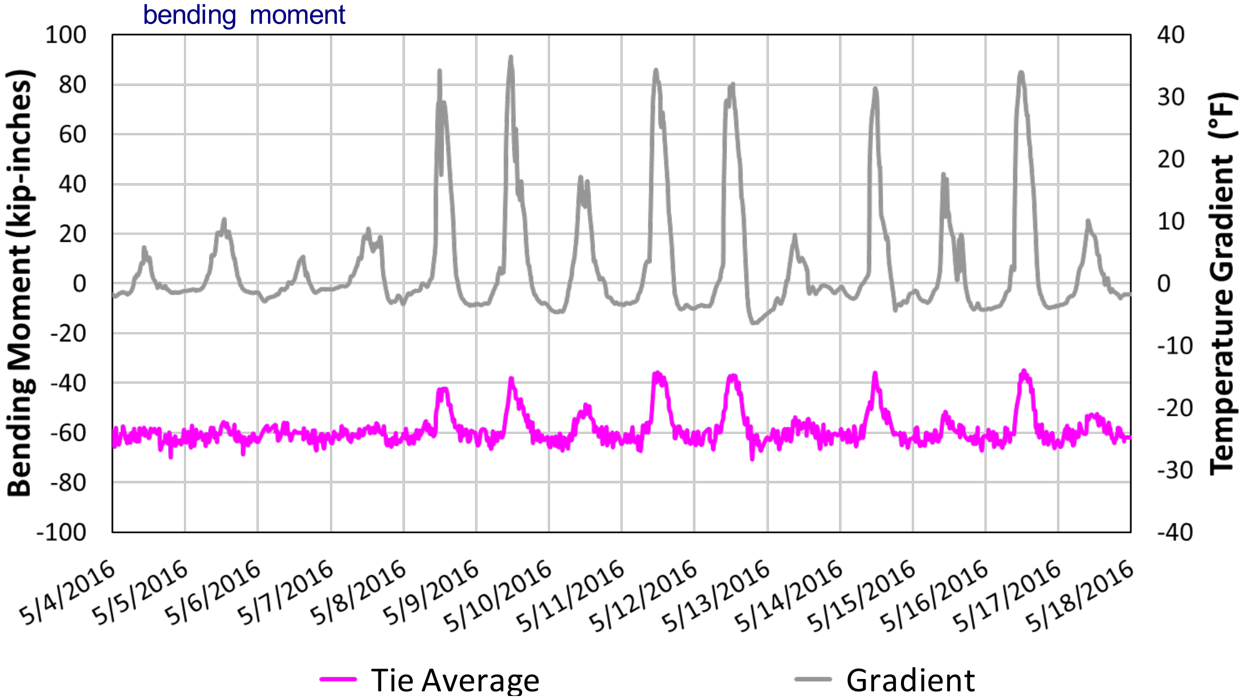


Temperature and Bending Moment

New York City Transit

MTA New York City Transit

- Similar to previous plot, relation between gradient variation and variation in bending moment

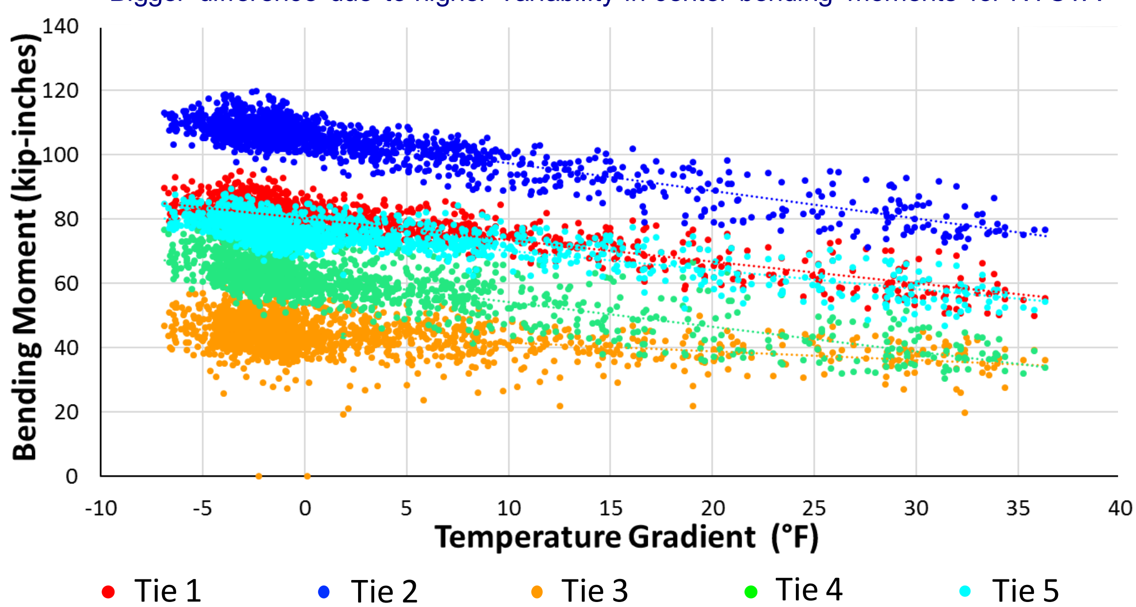


Temperature and Bending Moment

New York City Transit

MTA New York City Transit

- Scatter plot of Temperature Gradient vs Center Bending Moment (in abs. value)
- Bigger difference due to higher variability in center bending moments for NYCTA

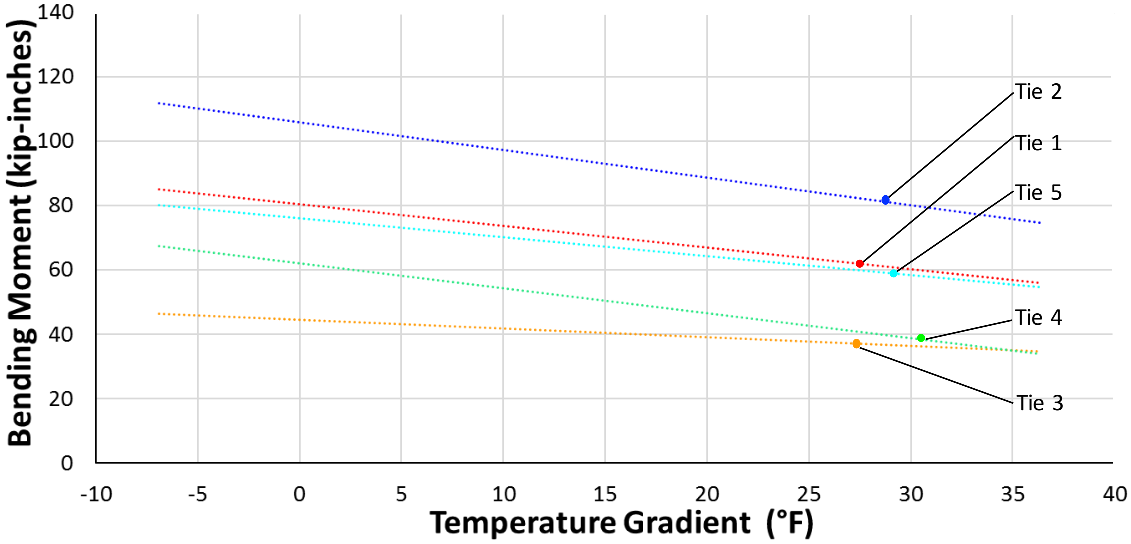


Temperature and Bending Moment

New York City Transit

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

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