Concrete Crossties Flexural Behavior Analysis under Light Rail Transit Loading Conditions



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Outline

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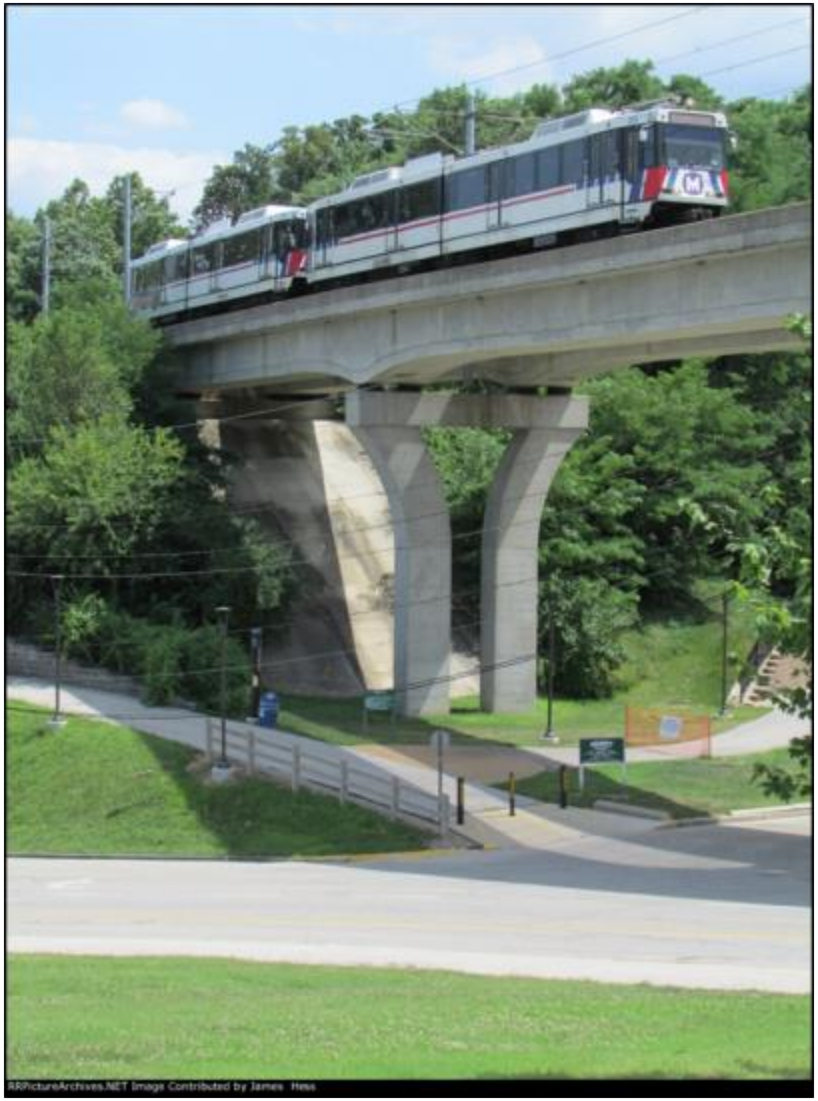
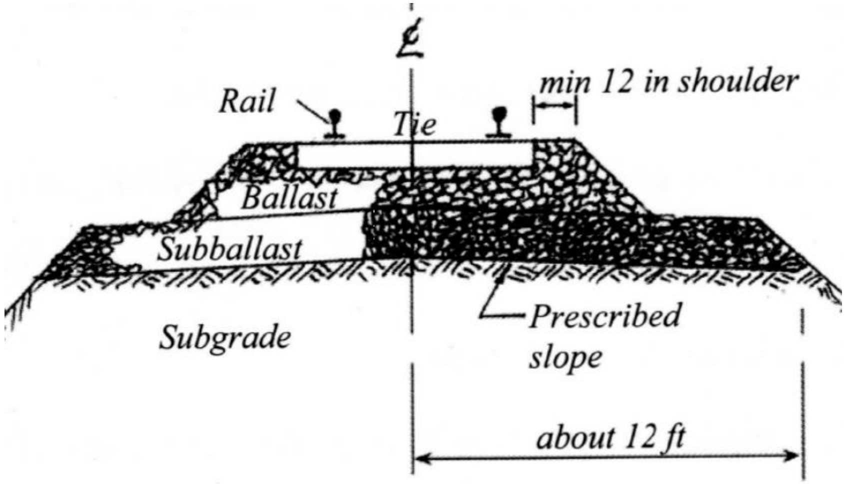
- Problem Statement
- Objective and Approach
- Flexural Behavior Results
- Conclusions
- Future Work



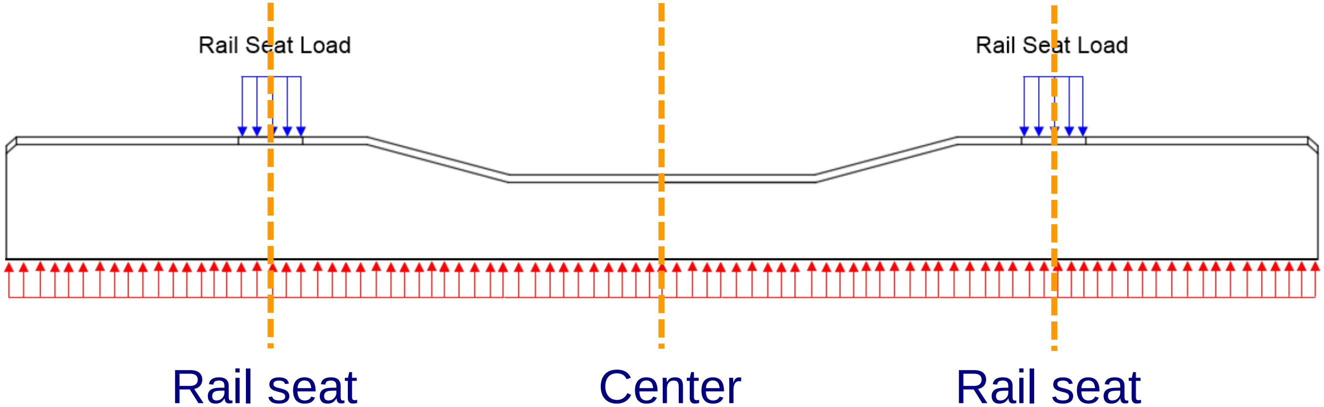
Background

- **Light rail** is a commonly used mode of public transit in North America for in-city transportation
- **Ballasted track** is the most frequent superstructure system used in railroads worldwide - **simple and efficient**
- **Concrete** is 2nd most used material for crossties in the US (~5 % of total) after timber – provides higher **system resiliency** and **longer** expected **life cycle**
- Current design methodologies are based on practical experience
- **Rail transit load** environment has **not** been **studied** in depth



Problem Statement

- Crossties behave as beams – flexural behavior governs
- **Mechanistic design approach of concrete crossties** is proposed by researchers at the University of Illinois
- Consider in service loads, real **field loading conditions** using field data collection as fundamental tool
- **Flexural performance** of crosstie largely dependent on **support conditions (ballast reaction)**
- Traditional design approach to limit crack opening in critical cross sections (C- and RS+)

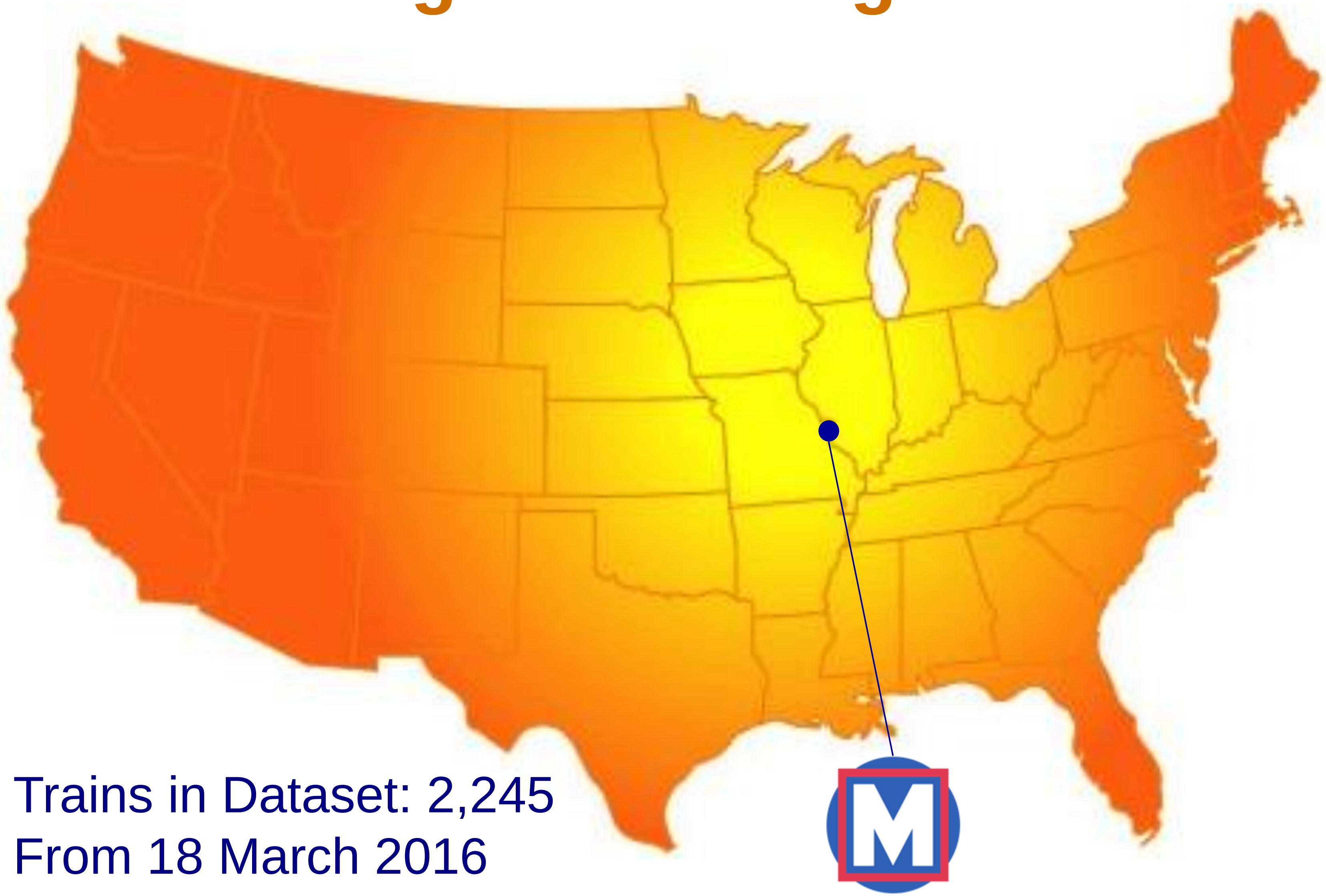


Objectives and Approach

- **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*

Partner Agencies

Light Rail Tangent Data

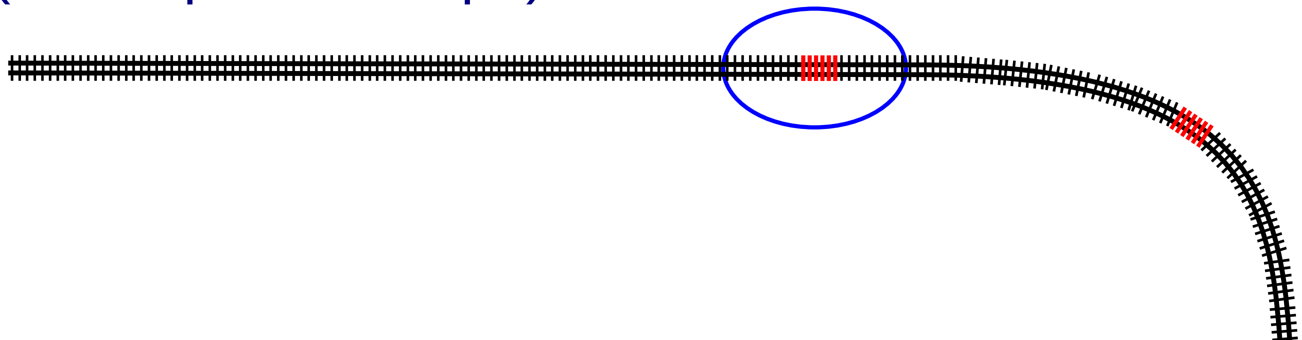


Trains in Dataset: 2,245
From 18 March 2016
to 26 April 2016

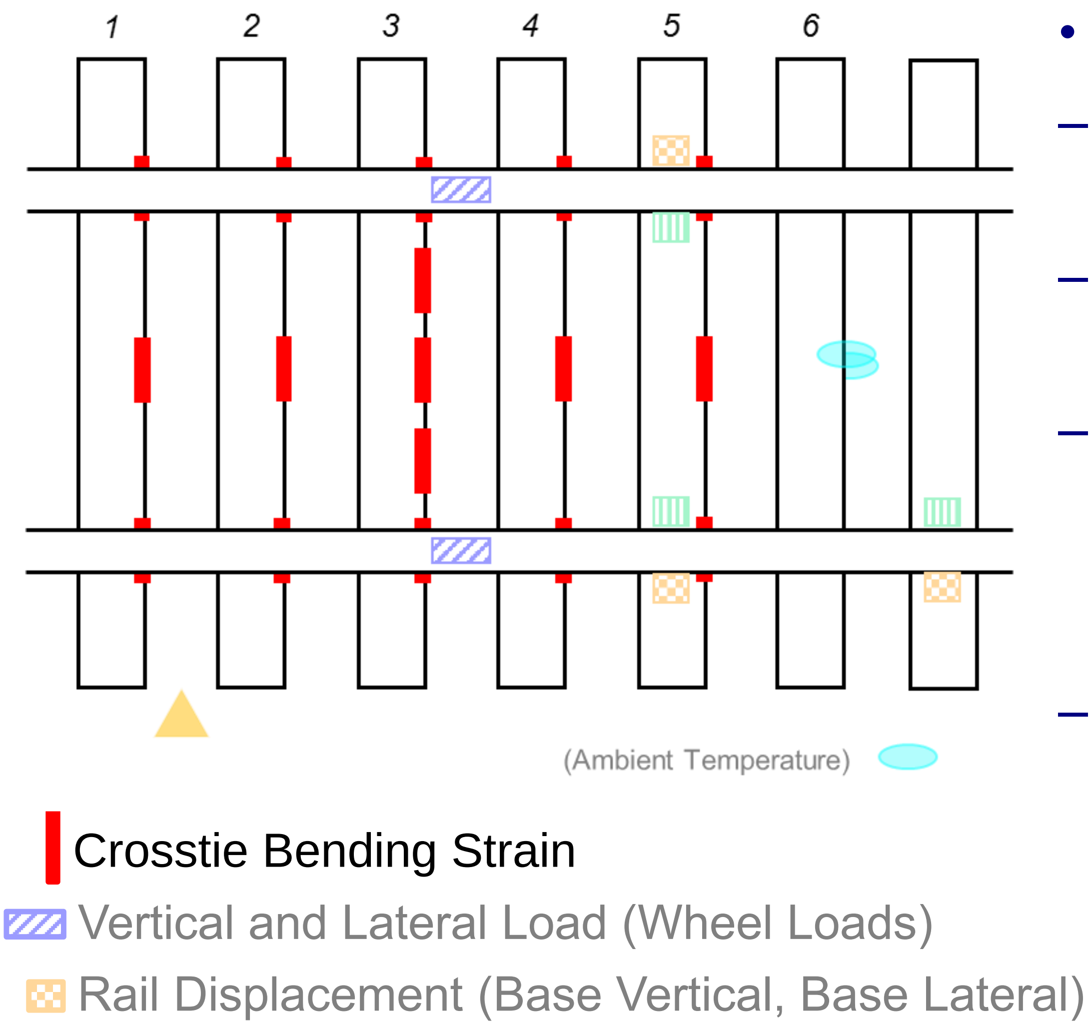
Track Geometry

St. Louis MetroLink Tangent Site

- Light rail system
- Tangent site
- Located in East St. Louis, IL
- Automated data collection
  (~154 trains/day (Red & Blue lines))
- Prestressed concrete crosstie: LB Foster CXT 100-06
  - Design capacity: C- 147 kip-in; RS+ 221 kip-in
- Measured speeds range from 26 mph to 52 mph
  (track speed 55 mph)



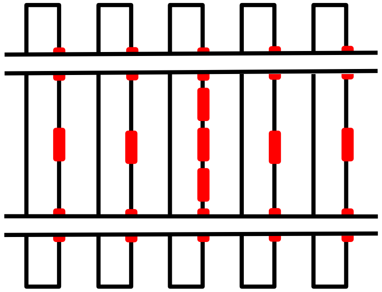
Typical Field Instrumentation Map



- 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 Bending



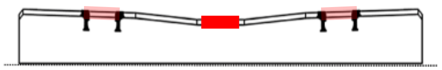
- **Desired data**:
  - Crosstie bending strains due to transit loads
- **Data collection and objective of data analysis:**
  - Surface strain gauges mounted along the chamfer of the crosstie
  - Understand revenue service bending moments and determine the support conditions for crossties
  - Assess the capacity and design of the manufacturer and the specifications given by rail transit agencies

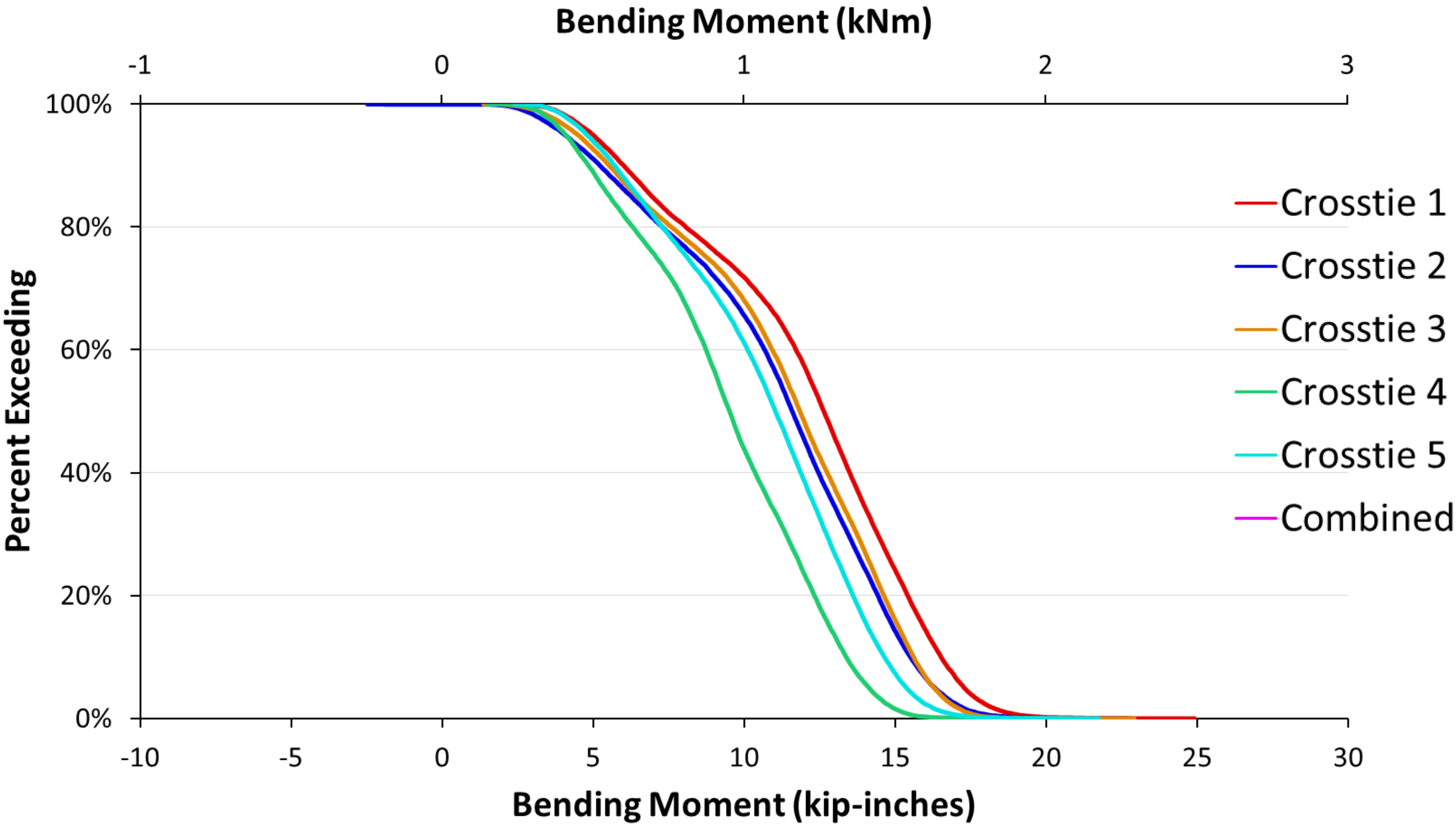
Center and intermediate gauges

Rail seat gauge

Center Negative Bending

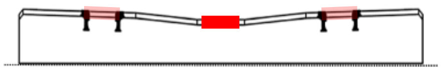
St. Louis MetroLink

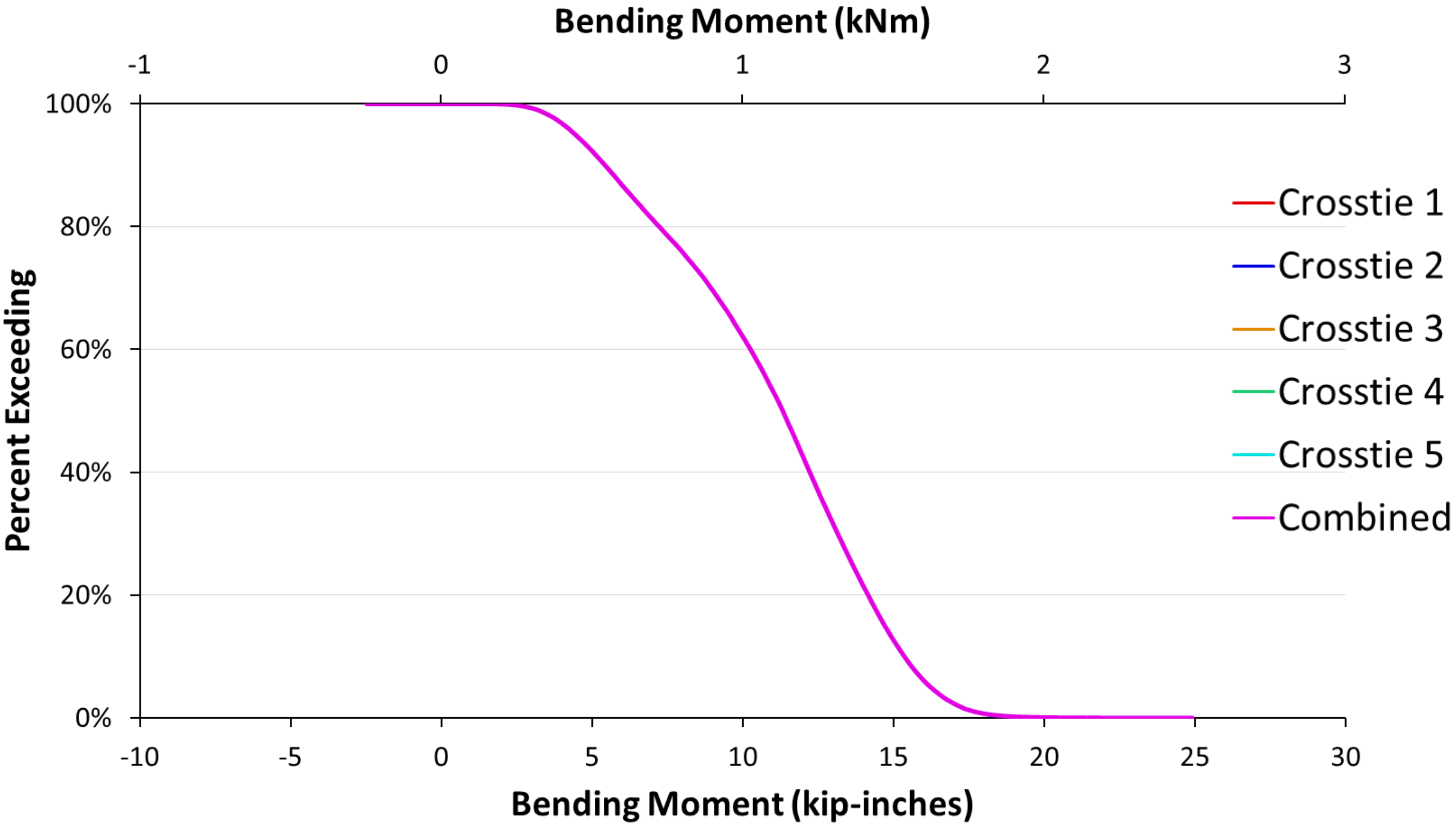




Center Negative Bending

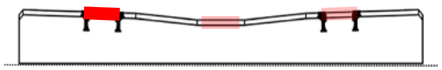
St. Louis MetroLink

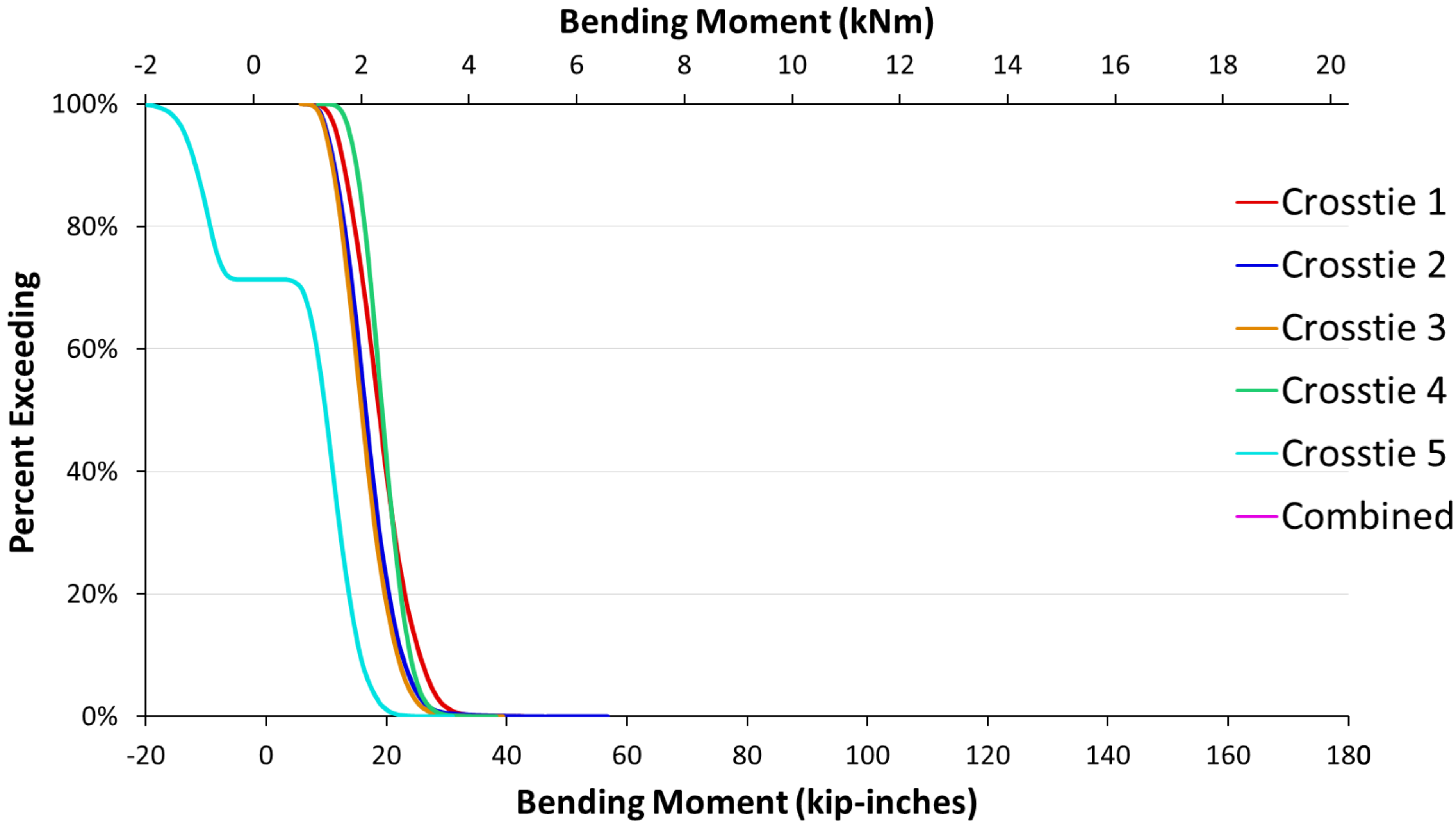




Rail Seat Bending

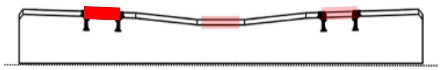
St. Louis MetroLink – Gauge A

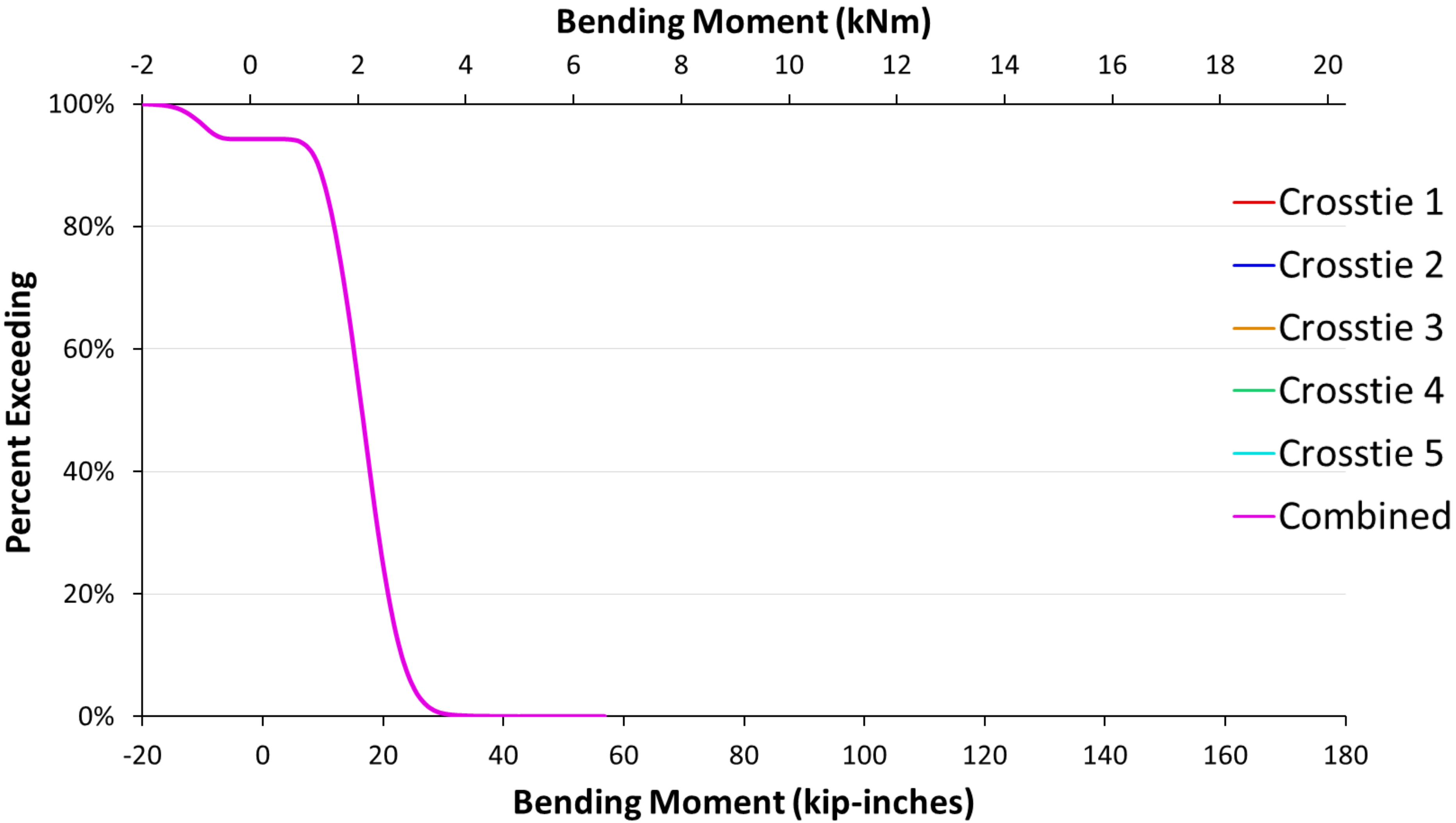




Rail Seat Bending

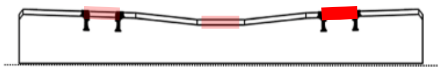
St. Louis MetroLink – Gauge A

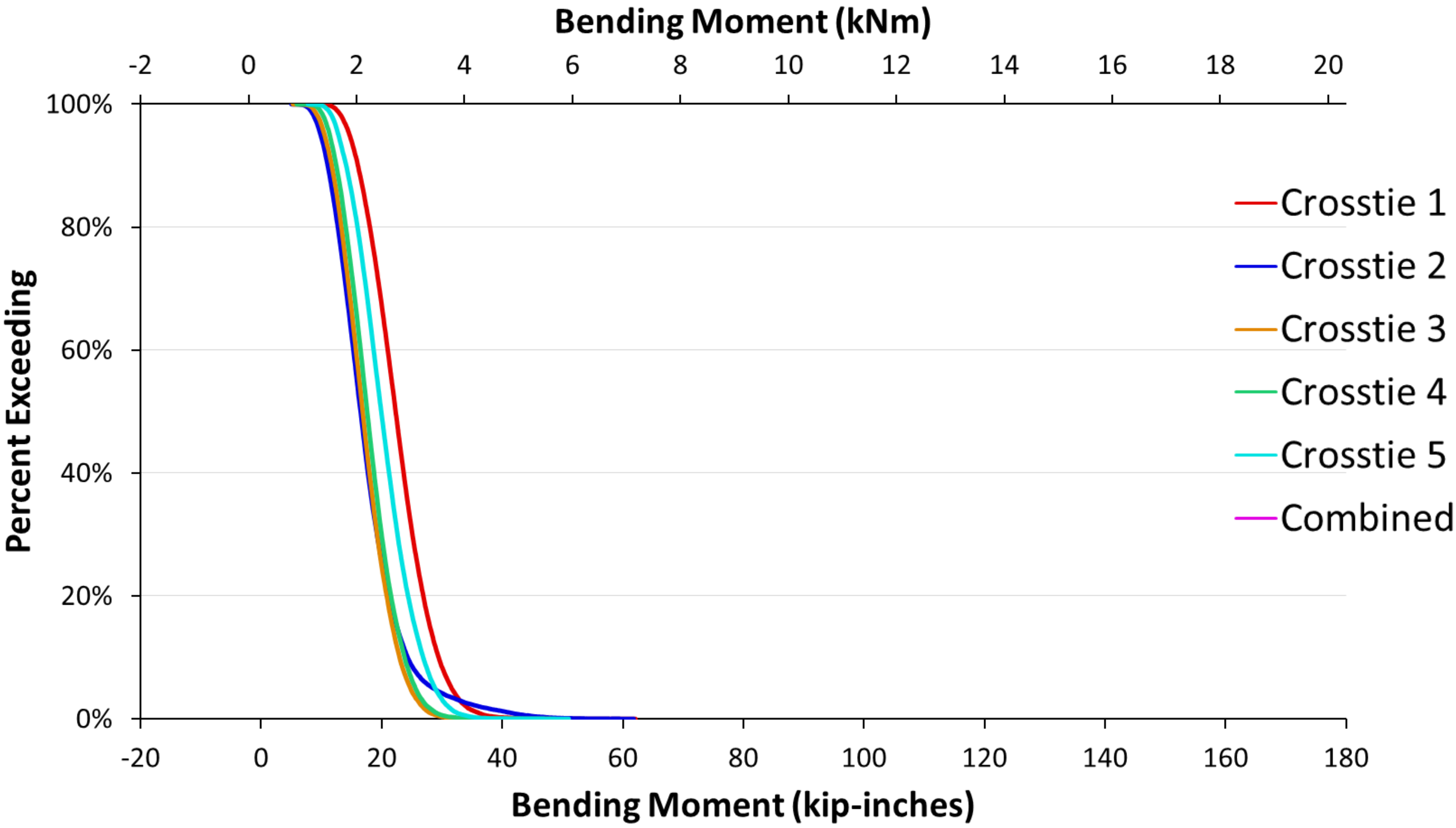




Rail Seat Bending

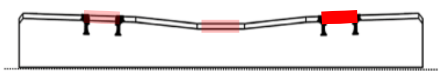
St. Louis MetroLink – Gauge E

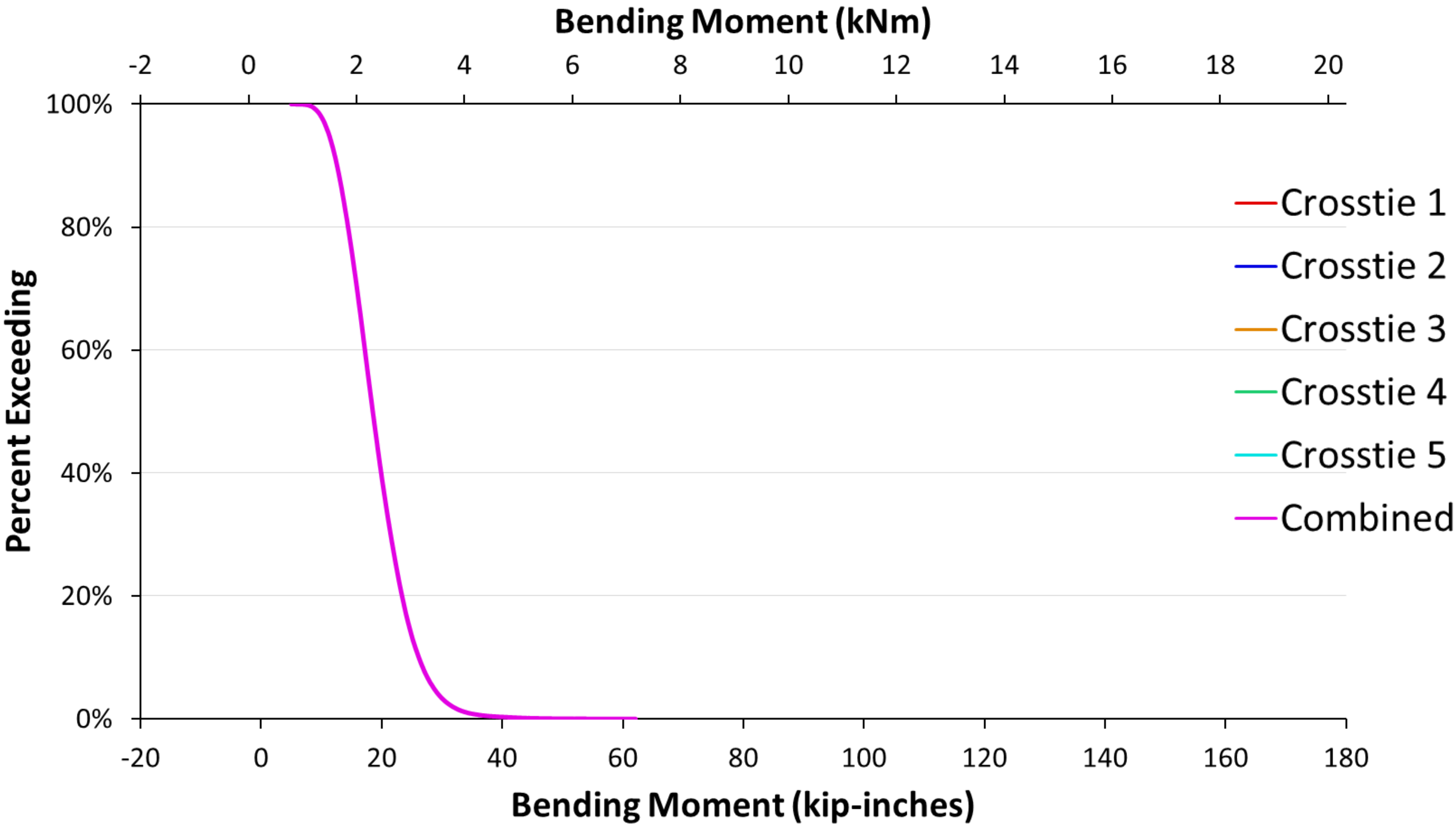




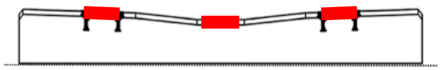
Rail Seat Bending

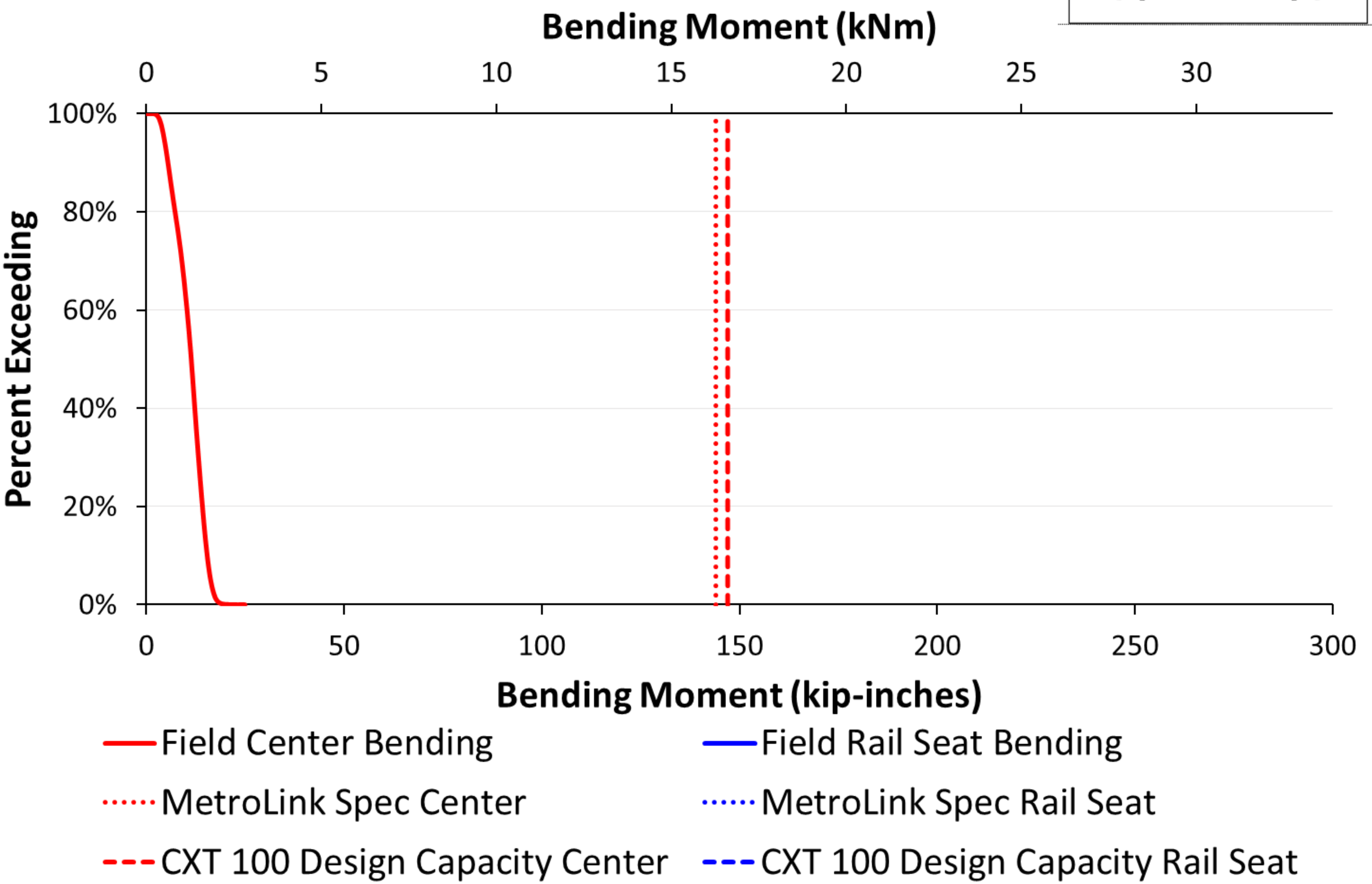
St. Louis MetroLink – Gauge E





Design Capacity Comparison





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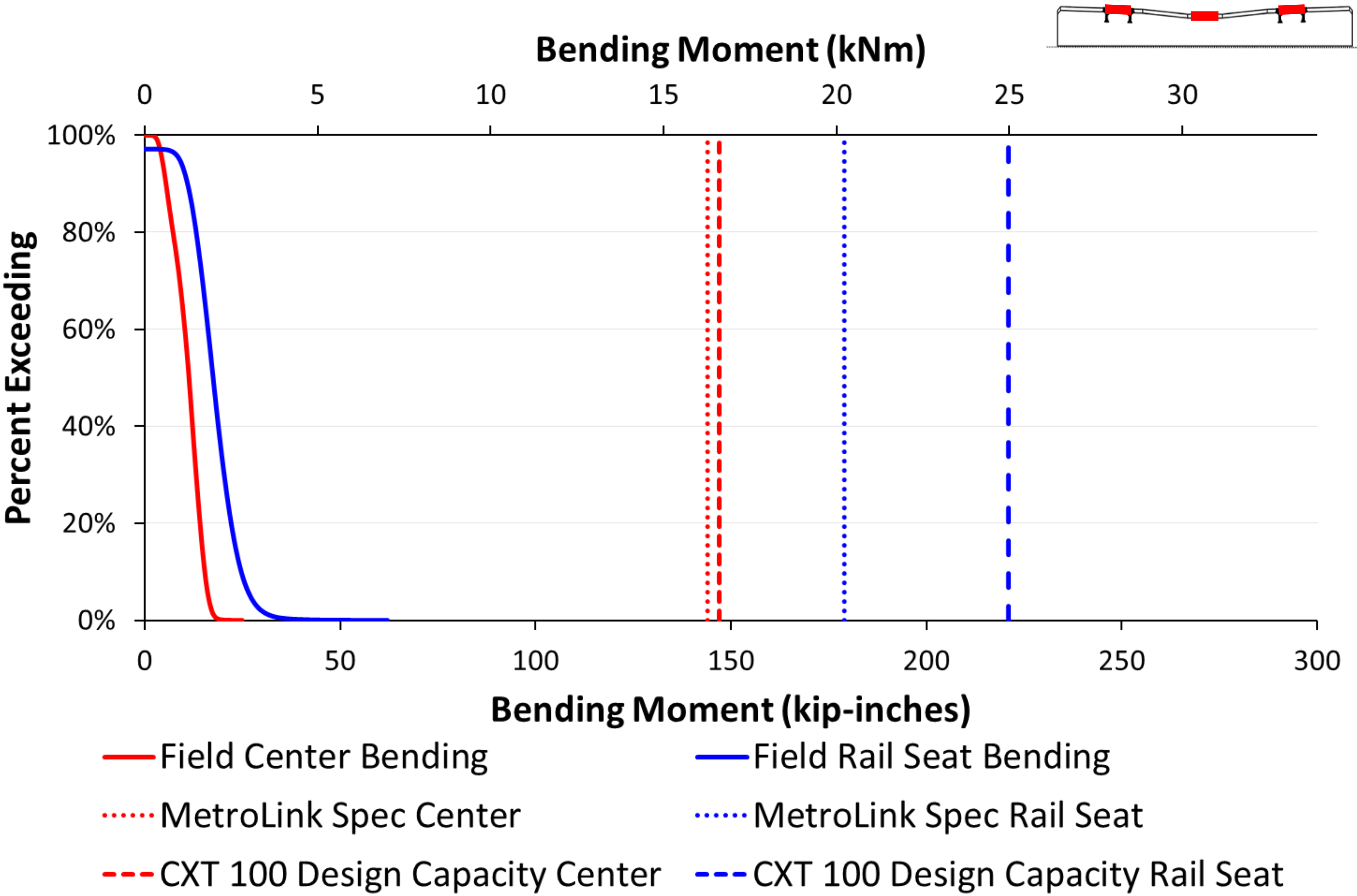


Crosstie Reserve Capacity

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

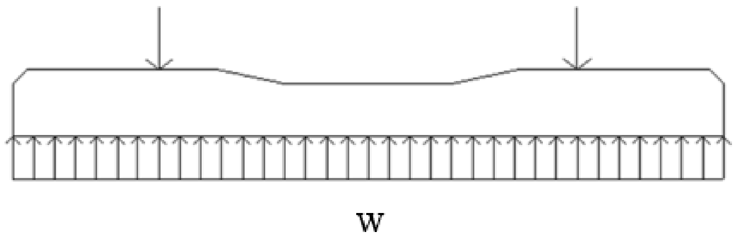
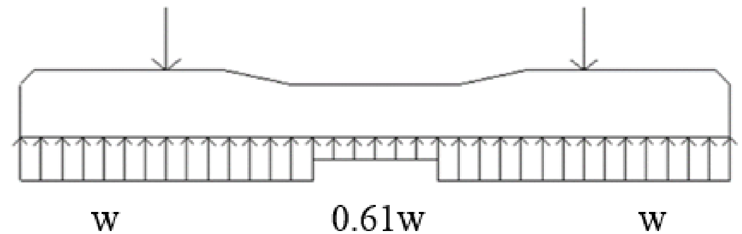
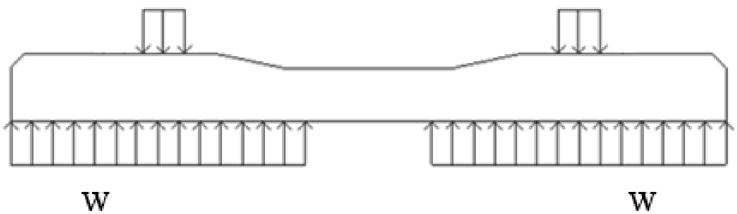
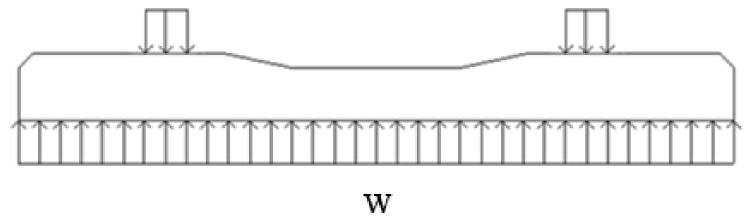
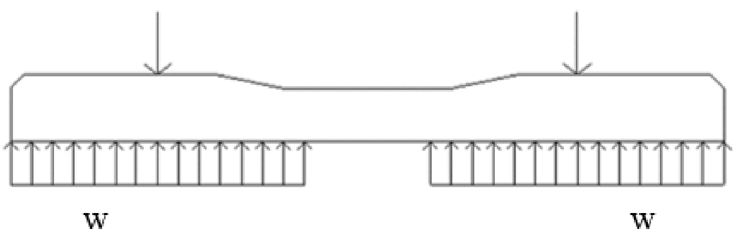
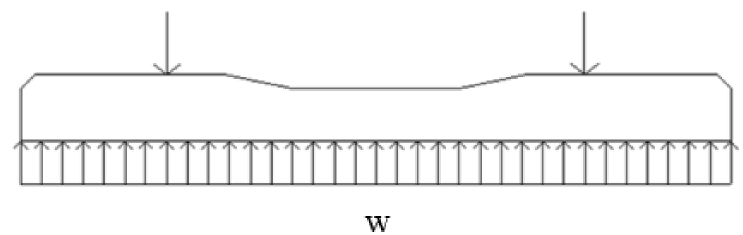
Percentile Bending Moment	Center Negative	Rail Seat Positive
Minimum	82.48	43.11
Average	12.96	7.50
90%	9.25	5.41
95%	8.74	4.95
99%	8.05	4.16
Maximum	5.55	2.15

- Max recorded center bending moment (**25 kip-inches**) could be increased by a factor of **5.6** without reaching the design moment for the crosstie or the agency specifications
- Max recorded rail seat positive bending moment (**62 kip-inches**) defines a potential reserve capacity of **2.2**.

Comparison with Design Standards

- Large amount of field data collected
  - 2245 train passes
  - 12 axles per train
  - 5 different ties
  - Dynamic input loads
- Field results compared with capacity required by design standards to understand current design procedures' accuracy
- Current design standards use different assumptions: support conditions, rail seat load considerations
- Analyzed standards:
  - AREMA
  - Euronorm (EN) / International Union of Railways (UIC)
  - Australian Standard (AS)

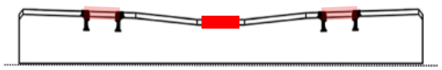
Comparison with Design Standards

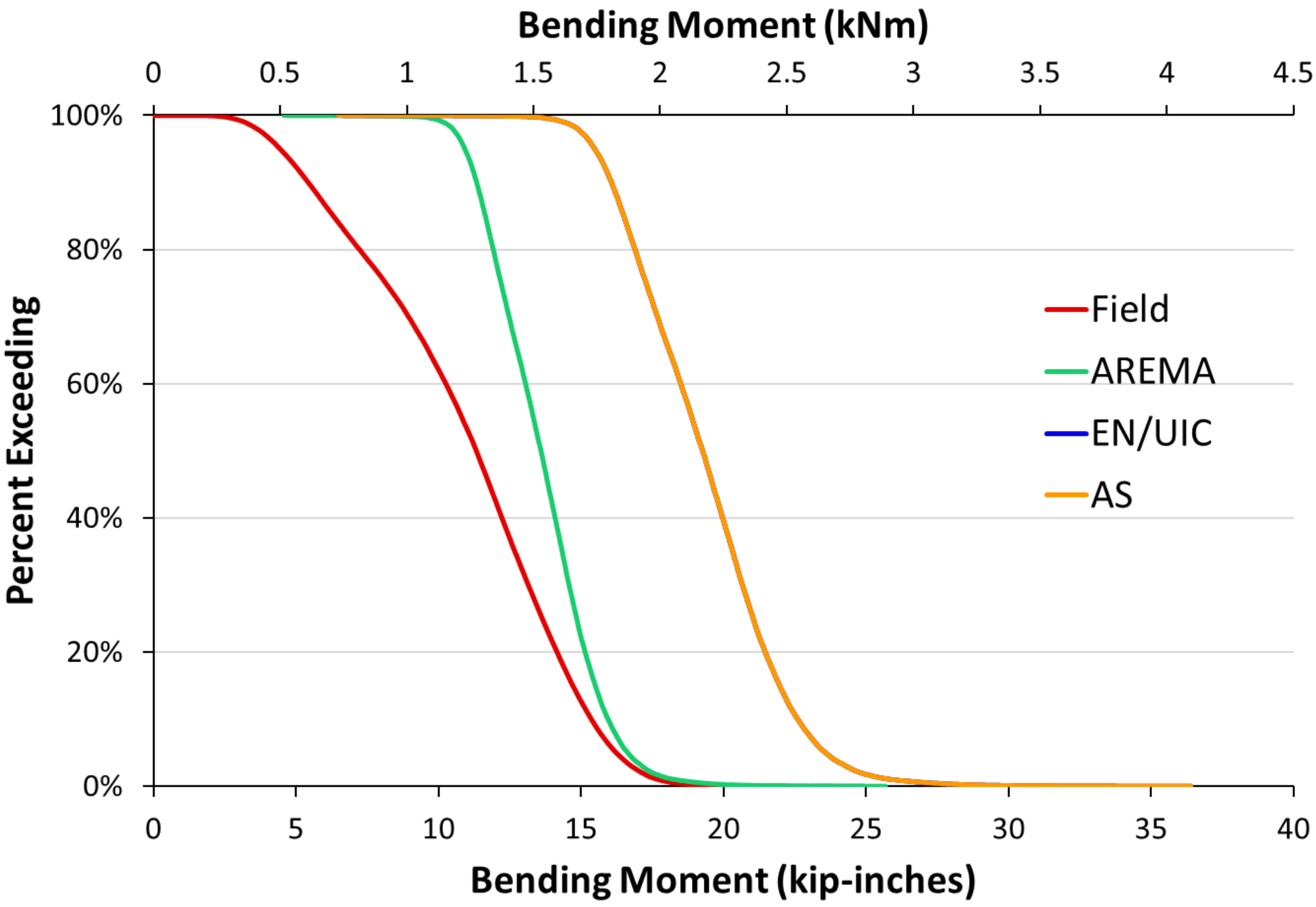
	Rail Seat Positive (RS+)	Center Negative (C-)
AREMA*	 (a)	 (b)
EuroNorm/ UIC	 (c)	 (d)
Australian Standard	 (e)	 (f)

*Methodology used until 2016

Comparison with Design Standards

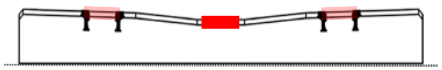
Center Negative Bending Moment

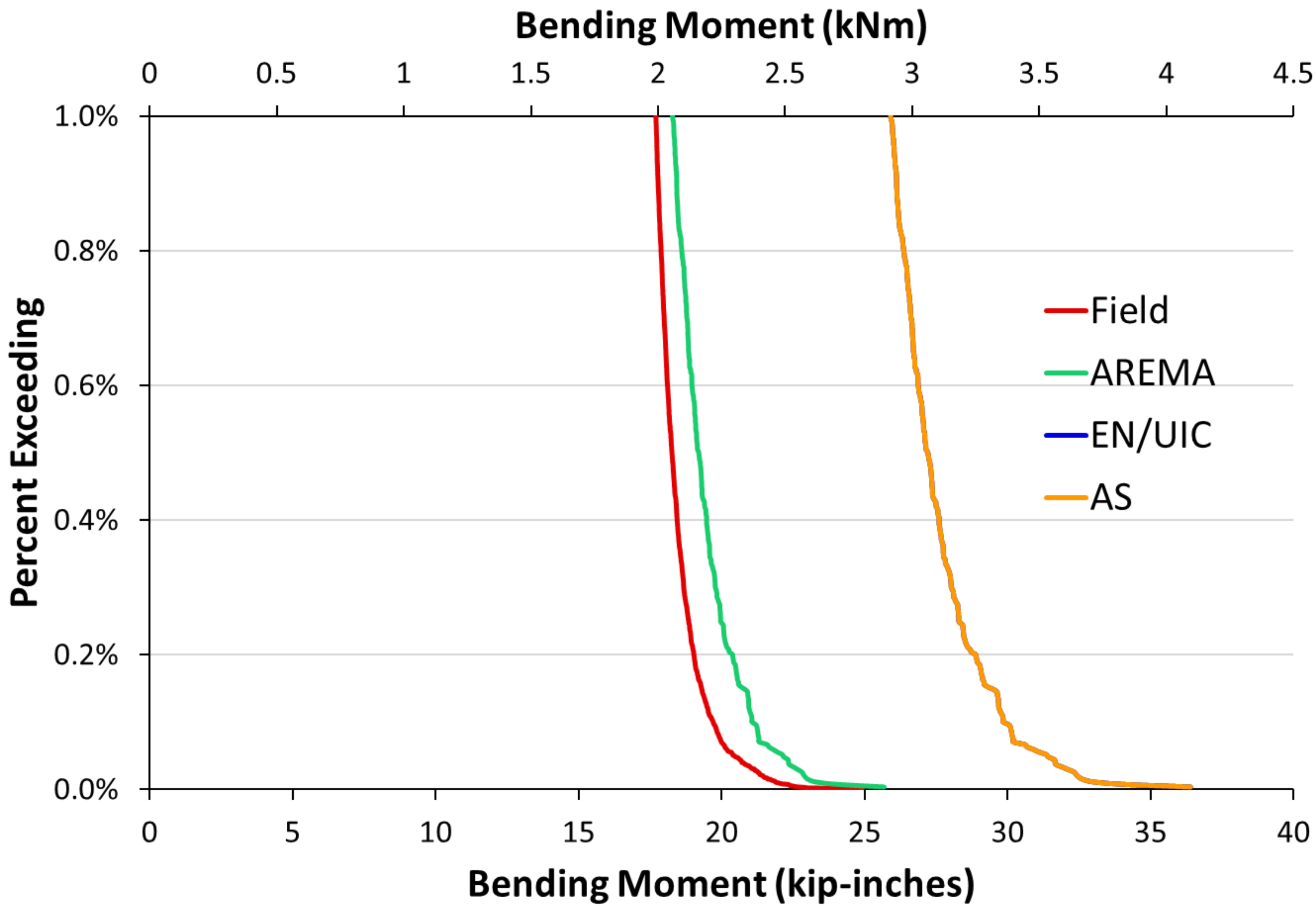




Comparison with Design Standards

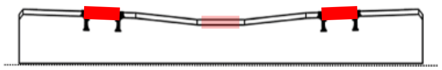
Center Negative Bending Moment

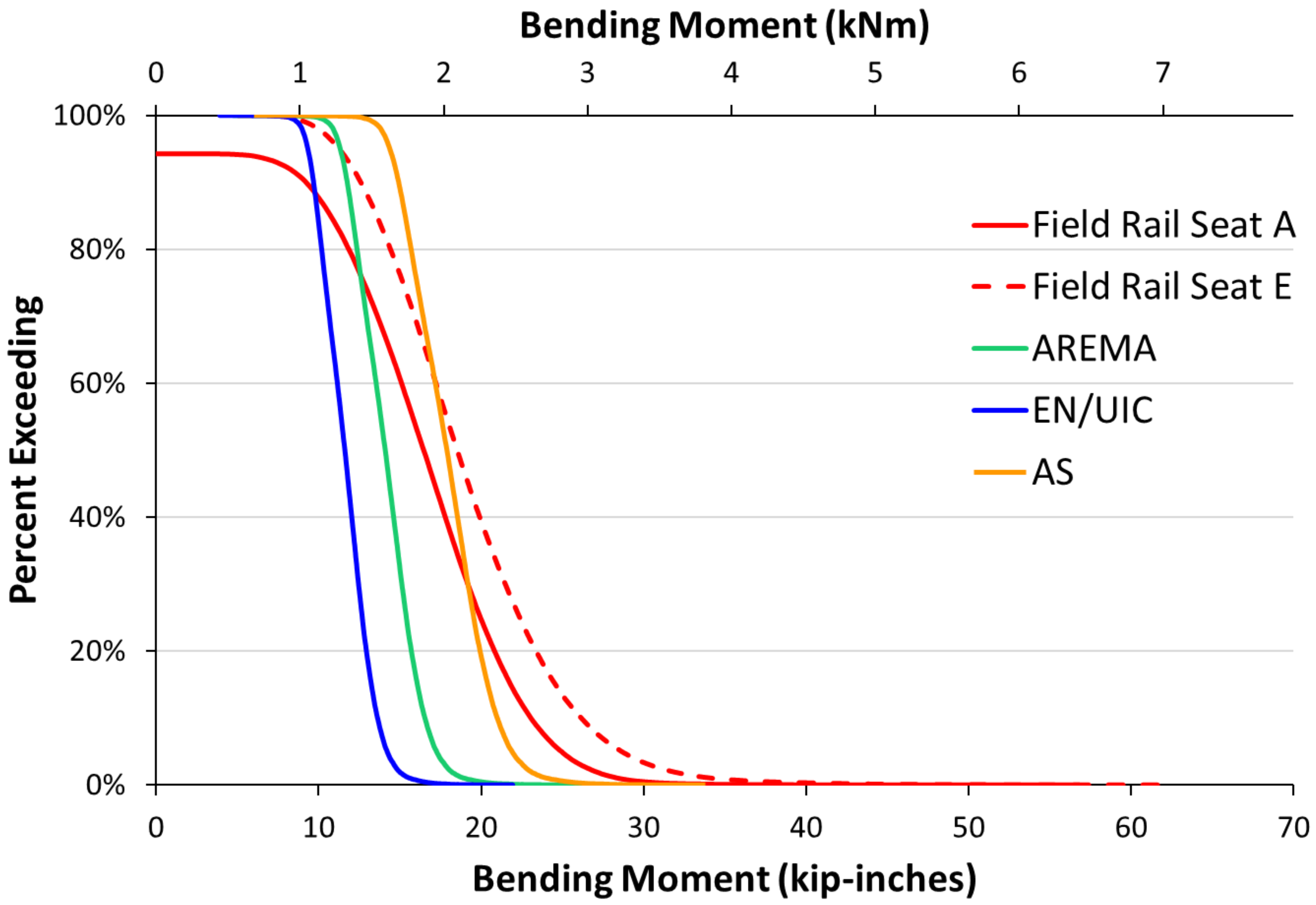




Comparison with Design Standards

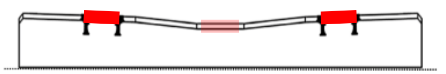
Rail Seat Positive Bending Moment

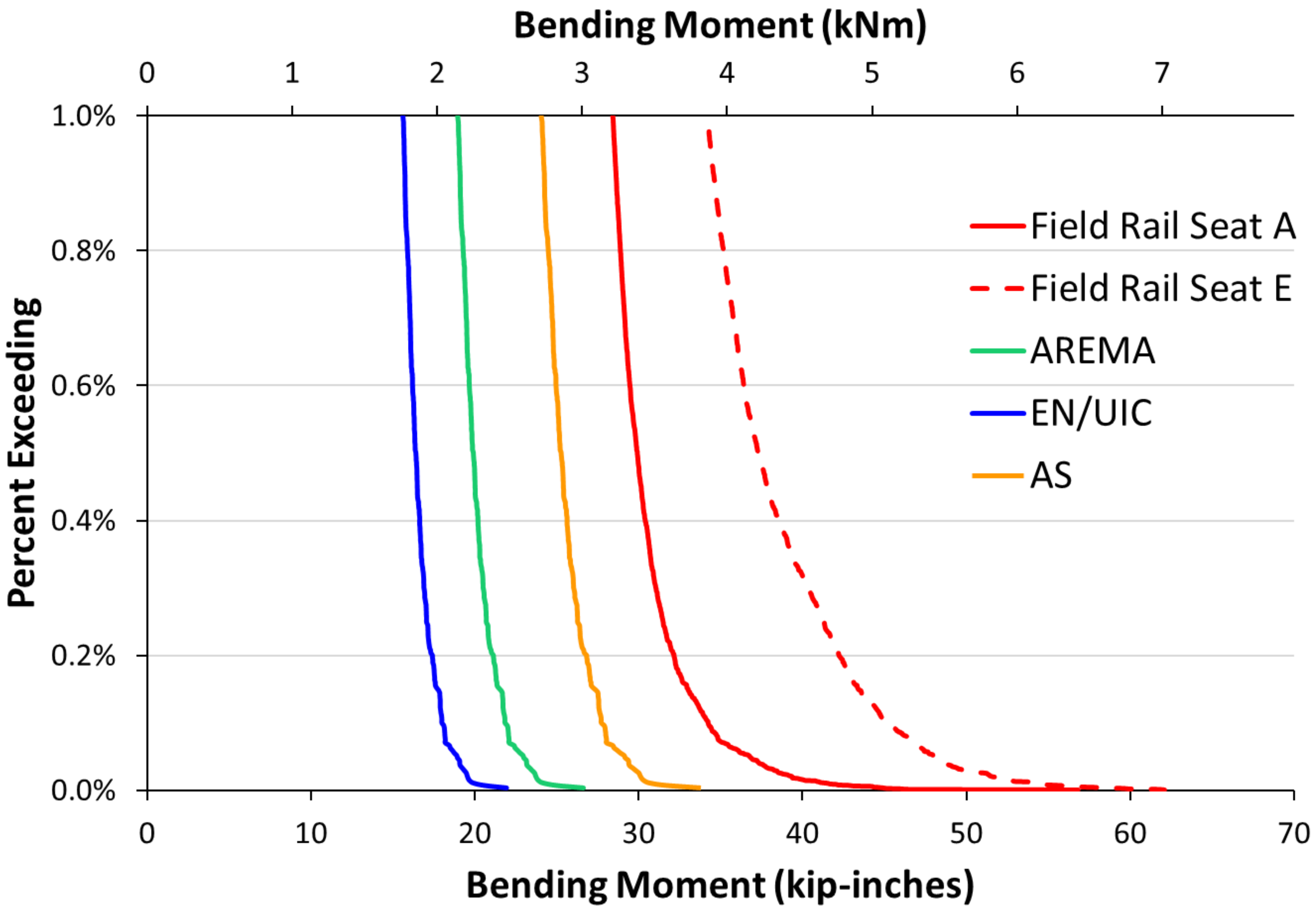




Comparison with Design Standards

Rail Seat Positive Bending Moment





Bending Moments Conclusions

- Flexural reserve capacity was quantified for a light rail transit system (only revenue service, equipment not accounted)
- For current in-service design, excessive **potential reserve capacity** is found when compared to design capacity
- **Minor variability in support conditions** was observed between consecutive crossties
- Potential reserve capacity for center negative bending moment (5.6) is generally higher than for rail seat positive bending moment (2.2)
- Using field measured dynamic loads, analytical design approach used by standards do not match the on-site measured bending moments:
  - Overdesign for C-
  - **Lack of capacity** for **RS+**

Future Work

- Observe seasonal and environmental variations in track behavior (automated data collection)
- Bound support condition variability of the system
- Derive new analytical models that match better field results – propose new design assumptions
- Develop track monitoring tools to assess need for maintenance (resurfacing due to deteriorated support)
- Calibrate FE model with real field data
- Use this information to develop prototype

Acknowledgements

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NURail Center

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