

# Mechanistic design for Concrete Crossties

Application for Amtrak's Shared  
Corridor Application

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2018 International Crosstie and  
Fastening System Symposium





# Concrete Ties – Amtrak's History

Engineering



# Slide Outline

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Engineering

- Timeline of Concrete Tie Manufacture
- Concrete Tie Problems
- Concrete Tie Design Changes
- Elastic Fasteners
- Shoulders
- Tie Pads and Insulators
- Future Considerations



# Timeline of Manufacture

Engineering

- First concrete tie manufactured & installed – 1978
- Manufacturers:
  - Santa Fe San Vel: 1978 to 1983 ~ 1.0 million
  - Lonestar: 1983 to 1986 ~ 0.3 million
  - Rocla: 1990 to 2000 ~ 1.4 million
  - Rocla: 2003 to present ~ 2.3 million
- Total concrete ties purchased to date ~ 5.0 million
- Total concrete ties in track 1056 miles NEC, 2.8 M and 114 miles Harrisburg Line, 300 K



# Concrete Tie Problems

Engineering





Engineering

# Concrete Tie Problems





# Concrete Tie Problems - Operations

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- Amtrak has contracted with HNTB for tie evaluation by qualified inspectors
- Tie evaluation done by walking with Amtrak
- Data accumulated to track trends, identify critical areas, program replacement programs
- CLT used for periodic testing and monitoring
- UIUC is under contract to review and test current tie design and specification



# Concrete Tie Problems –San Vel

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- Approx. 1,000,000 ties manufactured between 1978 to 1983
- Spider cracking with slow progression to failure
- Useful life span of a concrete tie is predicted to be 50 yrs.
- Continuous monitoring and inspection until replacement
- Removed and tested for strength periodically



# Concrete Tie Problems – Lone Star

- Approx. 300,000 ties manufactured between 1982 and 1986
- Cracking first detected in 1986
- Spider cracking with slow progression to failure within a few years
- Attributed to an alkali-silicone reaction (ASR) and low air entrainment
- All ties installed in stretches replaced between 1990 & 1995
- Others similarly afflicted (CSX, LIRR, Transit Systems)



# Concrete Tie Problems – Rocla

Engineering

- Approximately 1,400,000 ties manufactured between 1990 and 2000
- Population of cracking ties & year of first detection:
  - 1990 to 1992: 360,000 ties / cracks detected in 1999 (7+ years from manufacture)
  - 1993 to 1994: 323,000 ties / cracks detected in 2006 (12+ years from manufacture)
  - 1996: 133,000 ties / cracks detected in 2007 (11 years from manufacture)
  - 1997: 118,000 ties / cracks detected in 2001 (4 years from manufacture)
  - 1998 to 1999: 314,000 ties / cracks detected in 2007 (8+ years from manufacture)
- Most ties exhibit hairline cracking with a slow propagation rate
- Some ties exhibit spider cracking with a more rapid propagation rate (predominantly the ties manufactured in 1997)
- Tie cracking attributed to ASR and DEF, result of contamination in the fine aggregate and possible high curing temperatures
- Others similarly afflicted (Metro North, LIRR, MBTA)



# Concrete Tie Design Changes

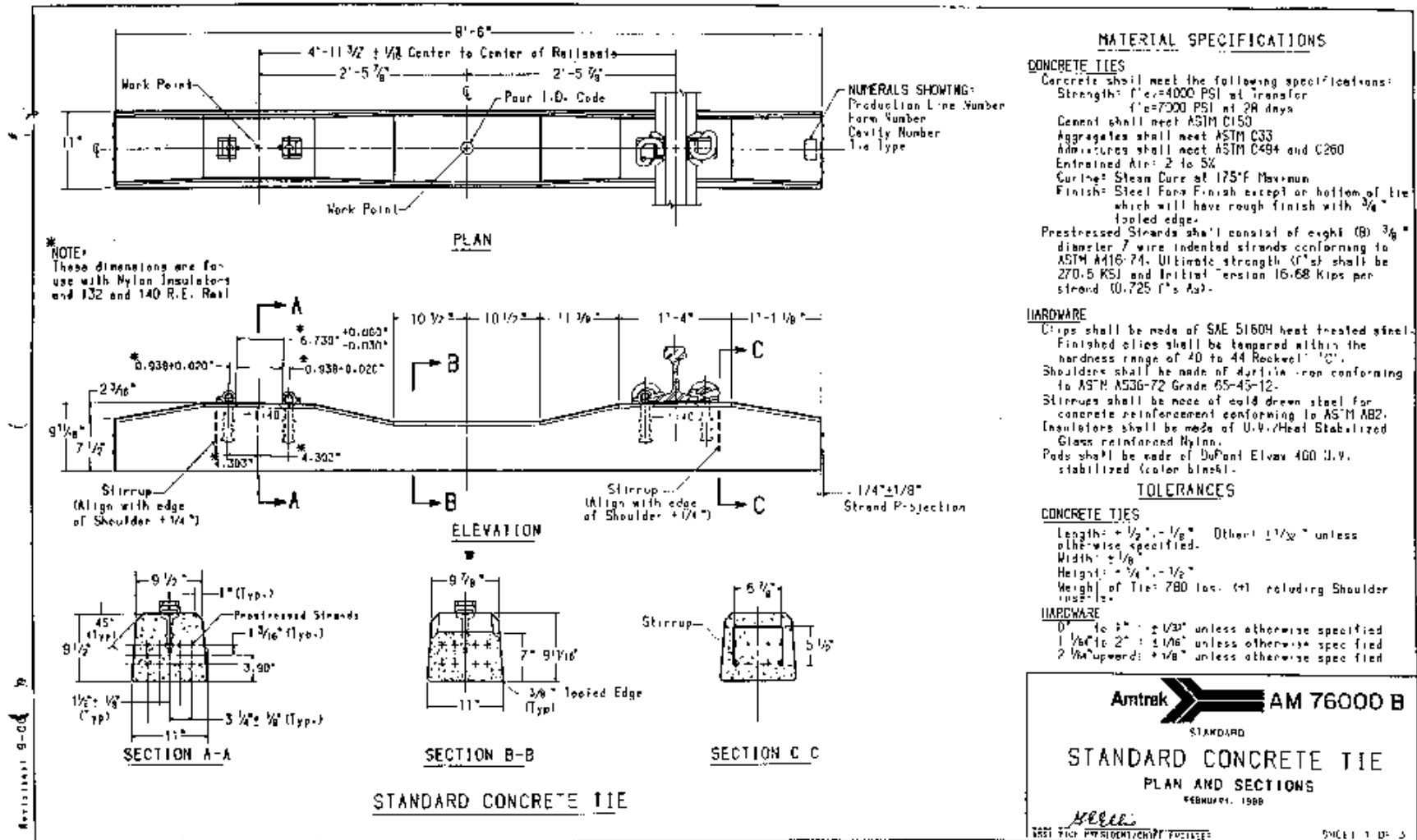
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- Santa Fe San Vel 1978-83
- Lonestar 1983-86
- Rocla 1990-2000
- New Rocla 2003 to present
- New Amtrak Tie 2018-beyond?



# Concrete Tie Design Changes

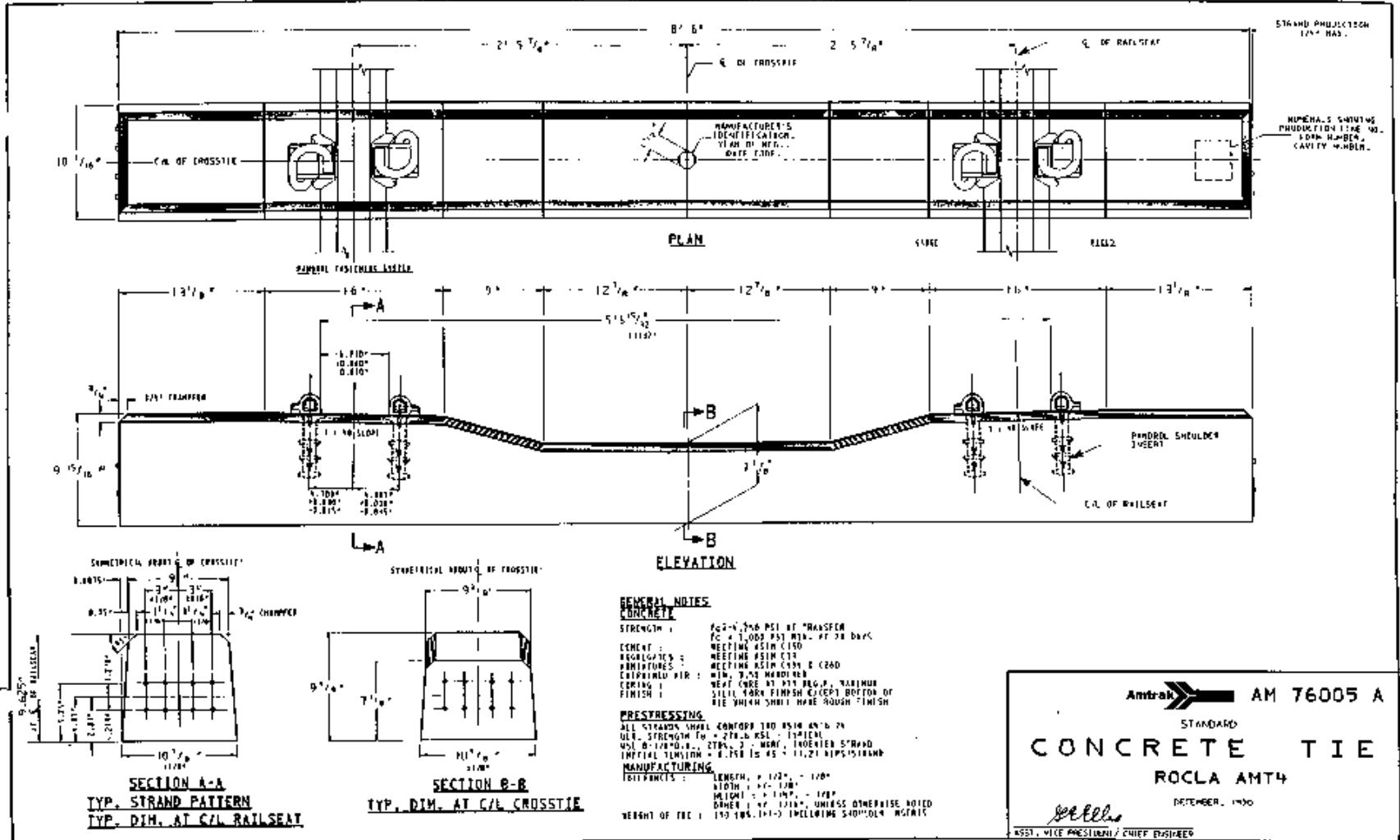
Engineering





# Concrete Tie Design Changes

Engineering

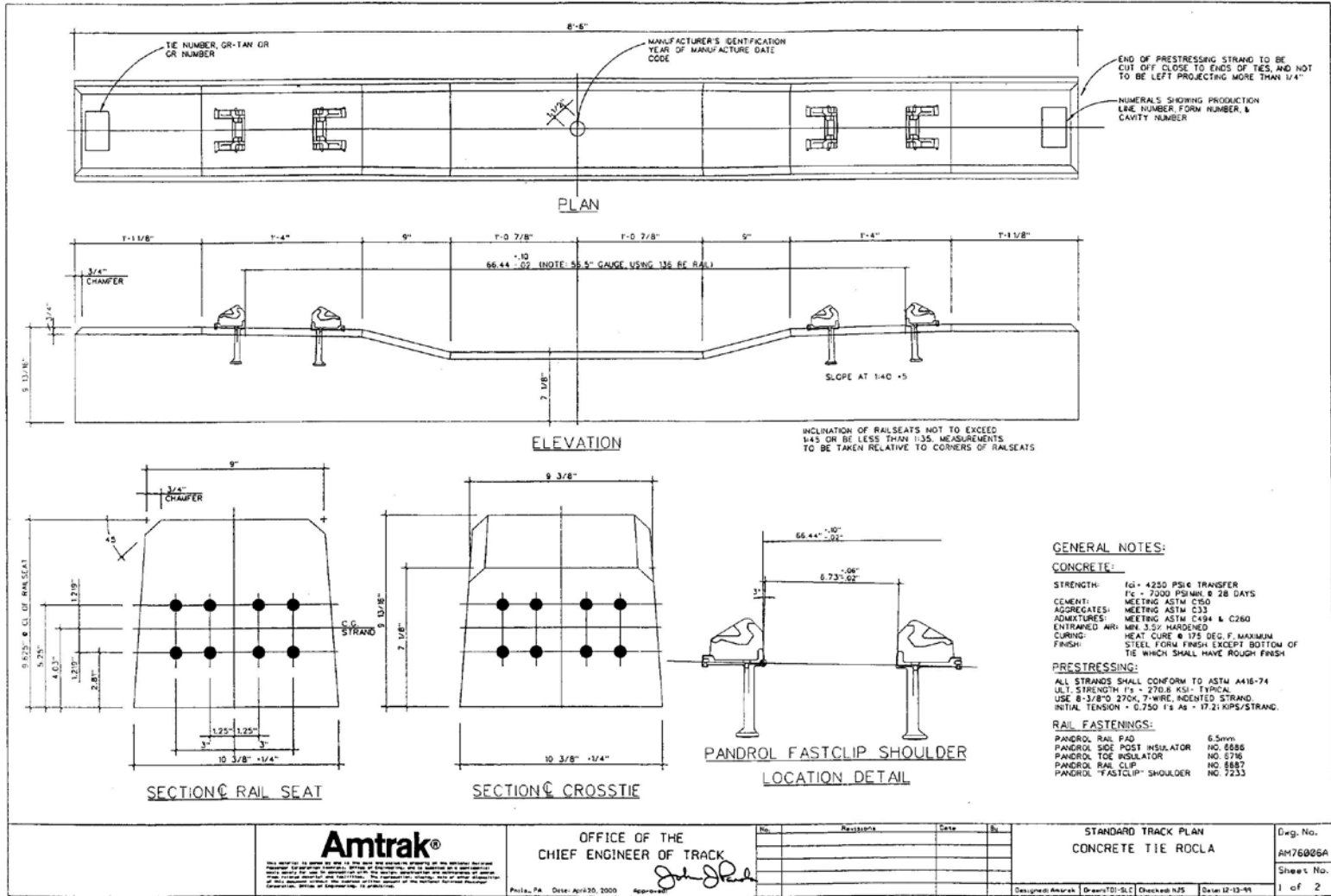






# Concrete Tie Design Changes

Engineering



**Amtrak**

OFFICE OF THE CHIEF ENGINEER OF TRACK

*[Signature]*

PHILA, PA Date: April 20, 2000

No.	Revisions	Date	By

STANDARD TRACK PLAN  
CONCRETE TIE ROCLA

Dwg. No.  
AM76006A  
Sheet No.  
1 of 2

Designed: Amtrak Drawn: TDJ-SLC Checked: NJS Date: 12-13-99



# Past Concrete Tie Design Changes

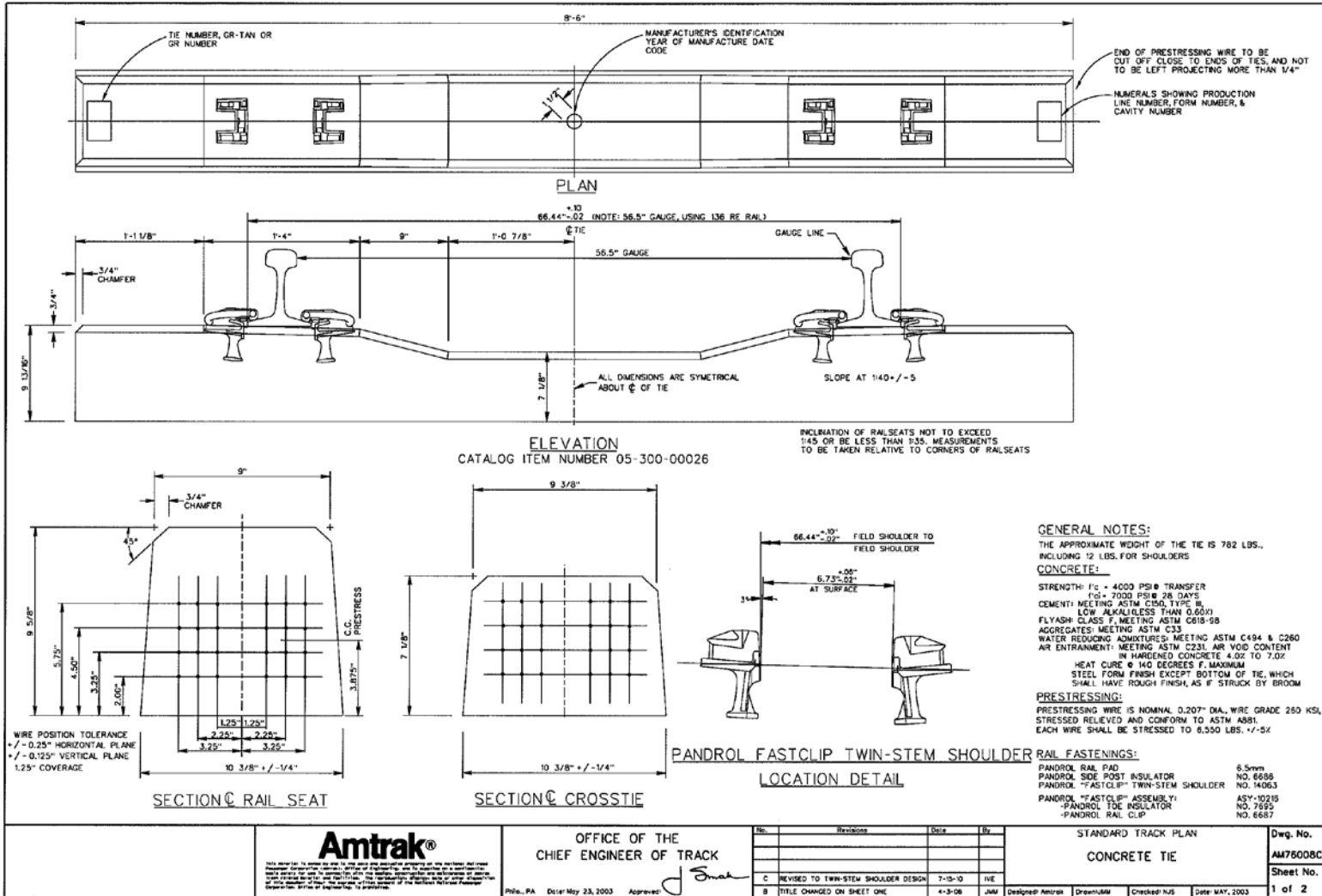
Engineering

- Last major change to Amtrak Tie Specification was in 2003
- Design change from 8 7-strand reinforcing wires to 24 individual indented reinforcing wires to increase tensile strength
- Established tighter limitations on pre-set curing temperatures and new control system installed to closely monitor curing temperatures
- Use of manufactured sand (fine aggregate) to eliminate most all potential reactive contaminants that could contribute to ASR/DEF reactivity
- Use of up to 20% but not less than 15% fly ash in the cementitious portion of the mix for even greater resistance to formation of ASR and DEF
- Additional third party (CTL) testing of materials and hardened concrete
- Increase Q/C process
- Increase air entrainment from 4%-6% to 4%-7%



# Concrete Tie Design Changes

Engineering



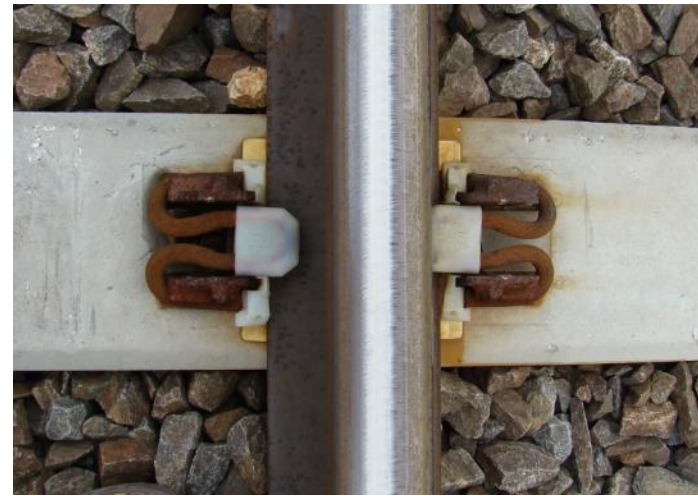




# Elastic Fasteners

Engineering

- 1978-1986 PR 601-A
- 1990- 1995 e 2055
- Mid 1995 to present FastClip

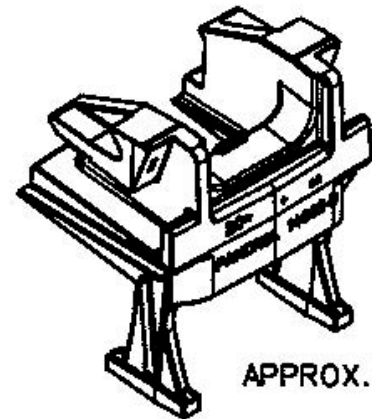
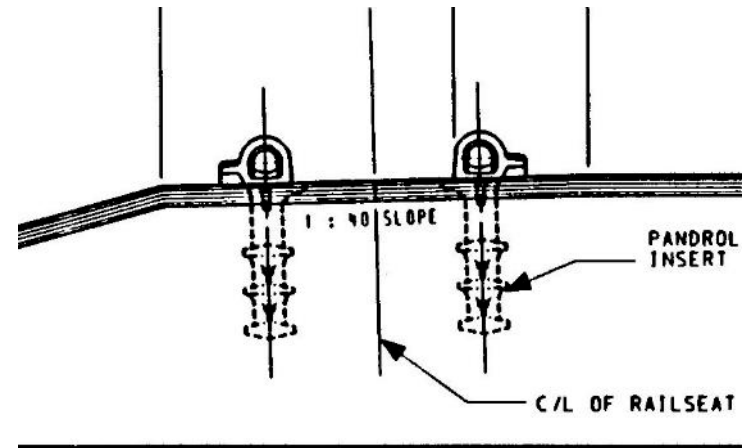




# Cast Shoulders

Engineering

- 1983-1995 Single bi-axial ragged stem
- 2003 Single button stem
- 2010 Double stem FastClip



APPROX. WEIGHT: 3.0 Lbs.



# Tie Pads and Insulators

Engineering

- 5 mm Ohio rubber pad
- 6 1/2 mm irradiated EVA pad
- 6 1/2 mm polyurethane pad (KD, WB)





# Room for Improvements?

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Engineering

- Consider possible tie design change
- Under Tie Pads
- Post Tension Vs Prestress
- Wire placement within the tie
- Fiber Reinforcement
- Geometry changes
- Fastening systems
- Tie Pads and Insulators

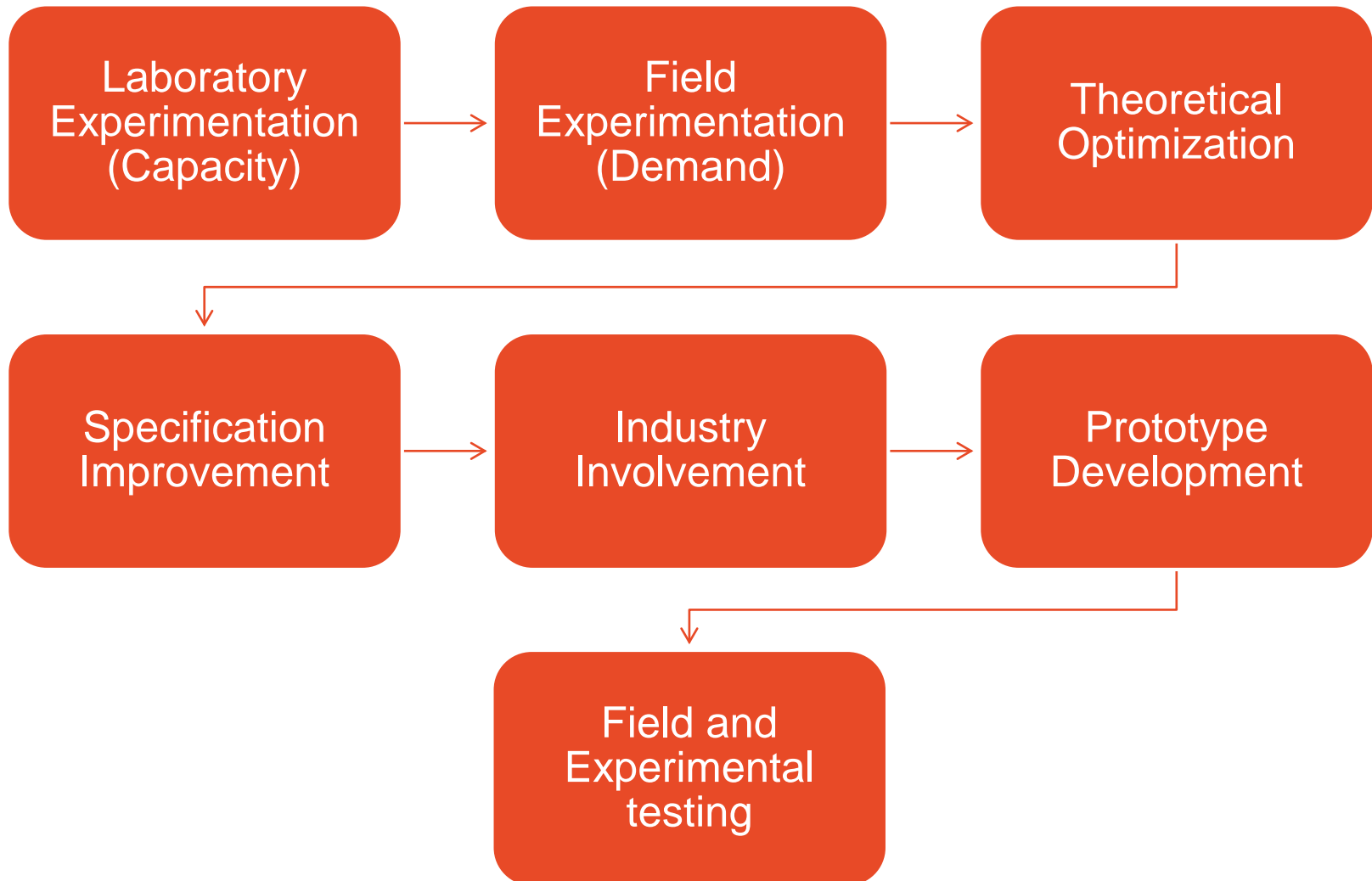


# Future Consideration

Engineering

- Continue third party concrete tie testing
- Continue project with UIUC/RailTEC on new tie design
- Testing with under tie pads
- Compare ride quality data before and after UTP installation
- Data collection technology improvements

# The Mechanistic Approach

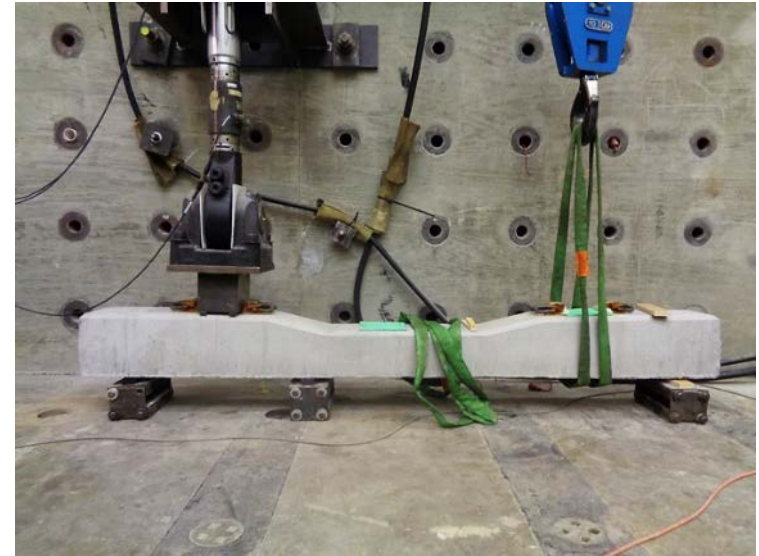


# Laboratory Experimentation



## Overview

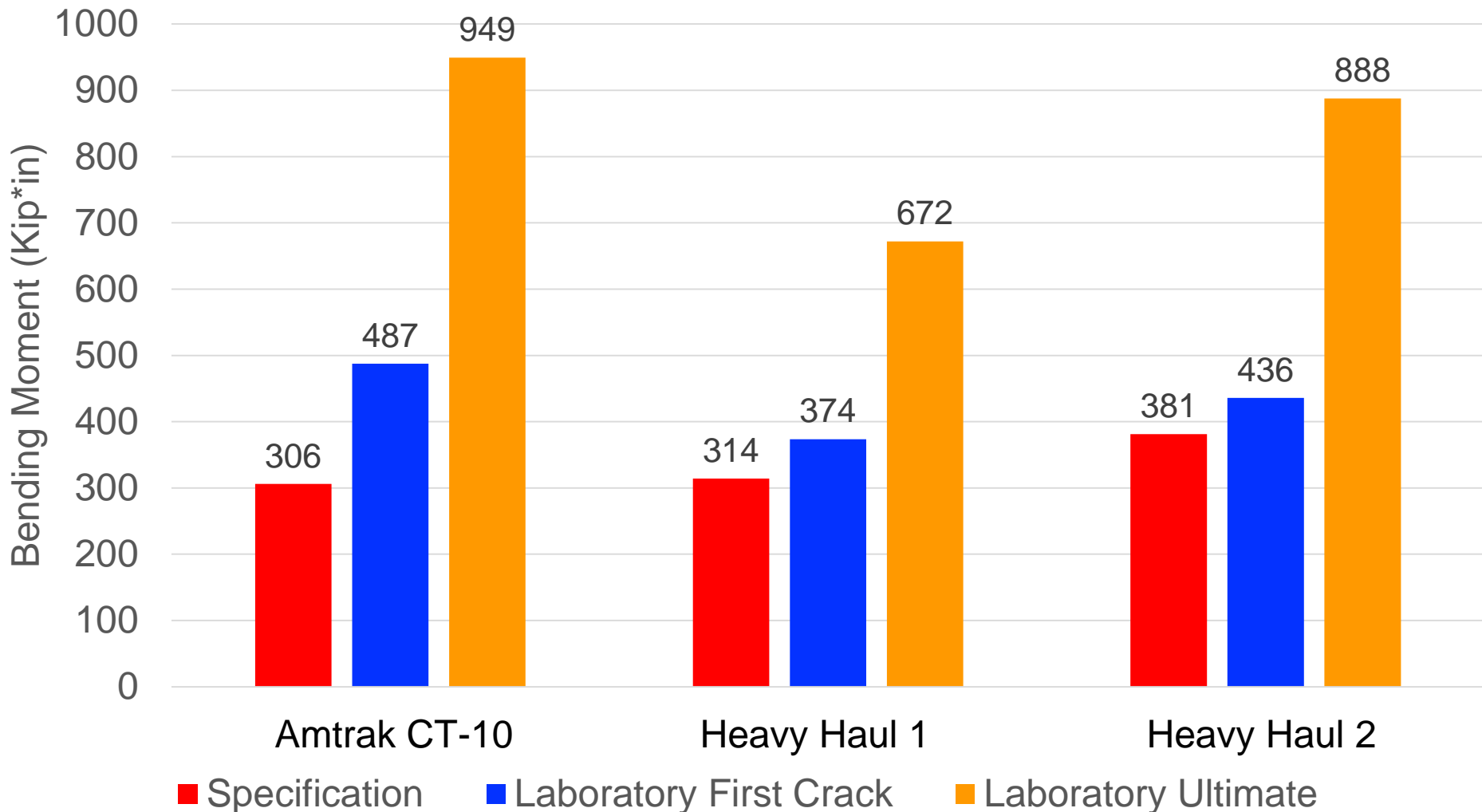
- ▶ Baseline for experimental matrix is the current AREMA design validation sequence of tests (4.9.1)
- ▶ Additional tests (developed at UIUC) were added to facilitate a quantitative comparison of performance
  - Load at first crack
  - Load vs. deflection curves at the center and the rail seat



# Laboratory Experimentation



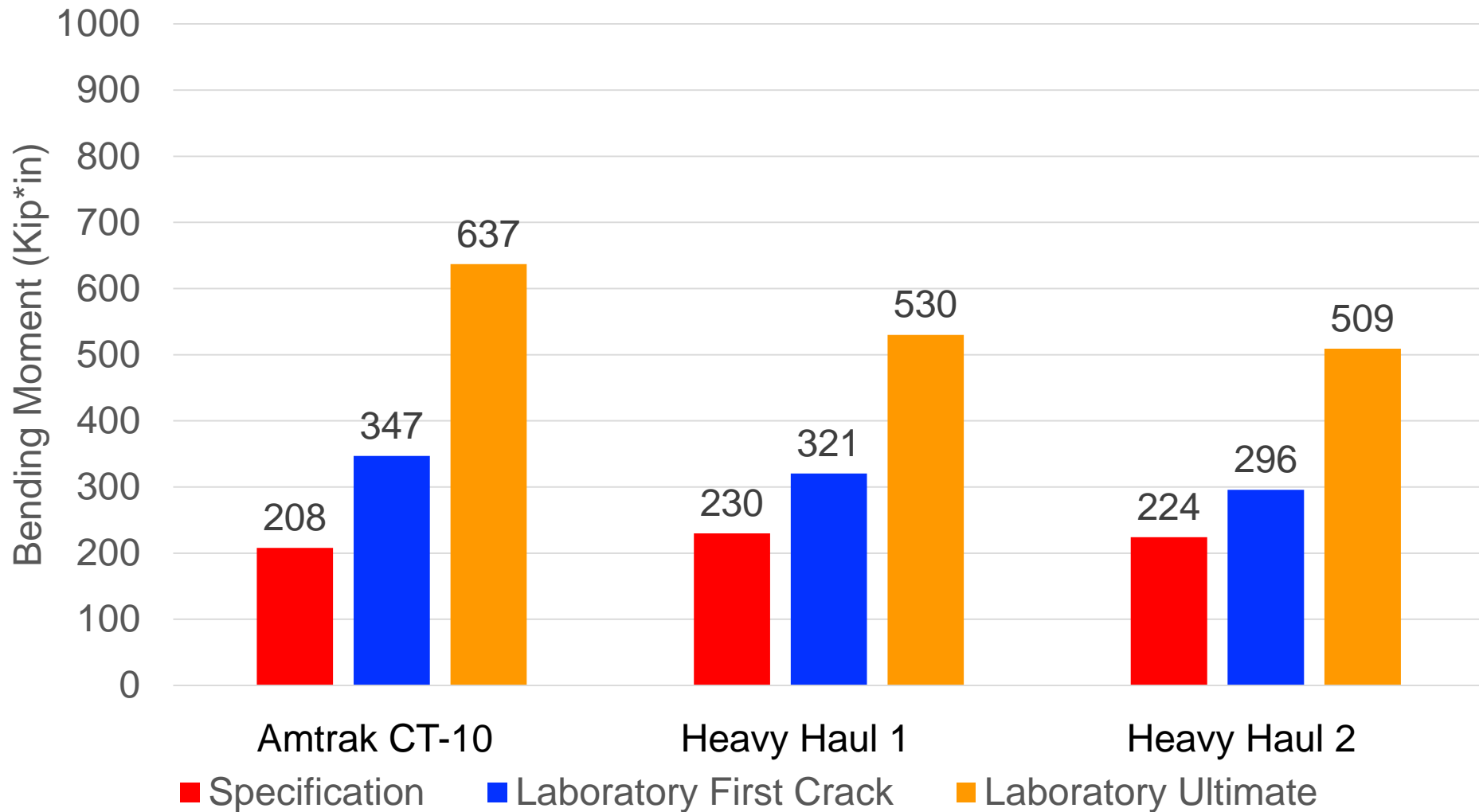
## Rail Seat Positive Testing (RS+)



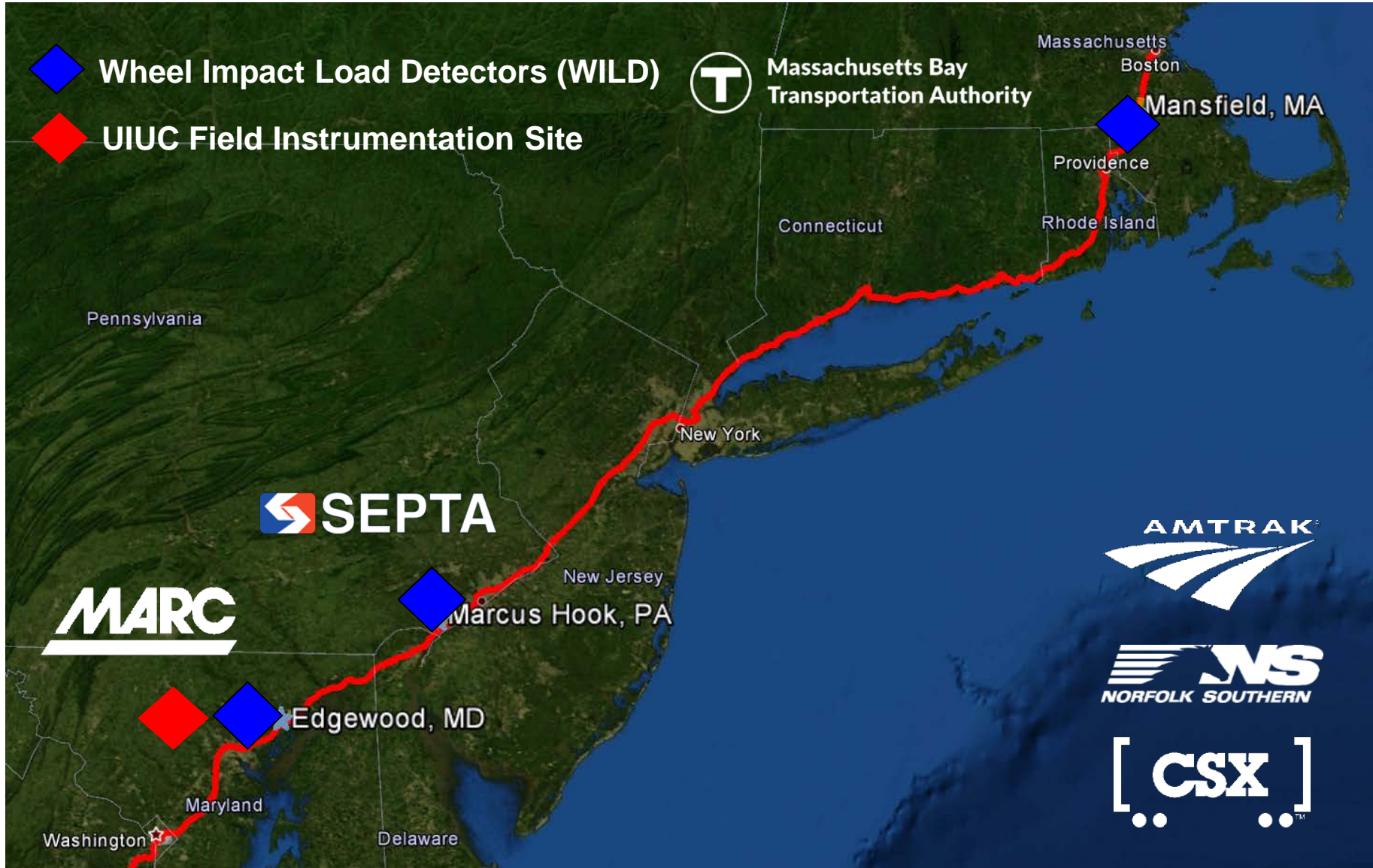
# Laboratory Experimentation



## Center Negative Testing (C-)



# Field Experimentation

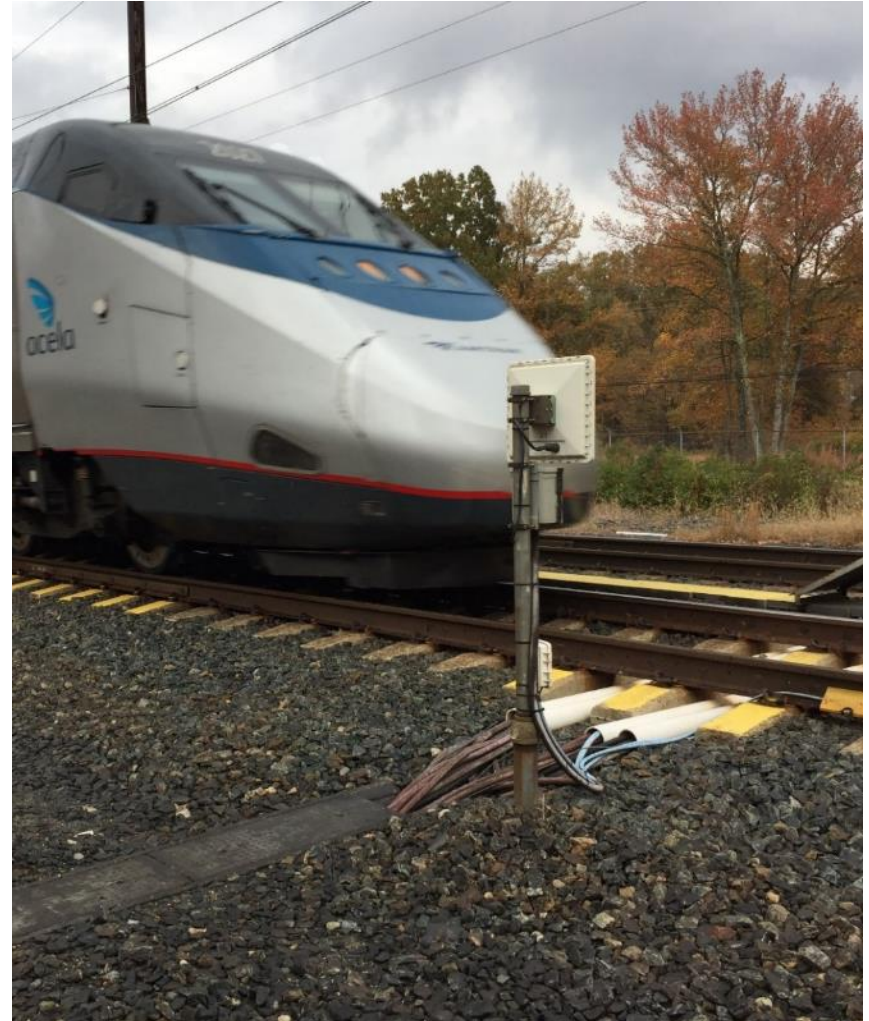


# Field Experimentation



## WILD Results Overview

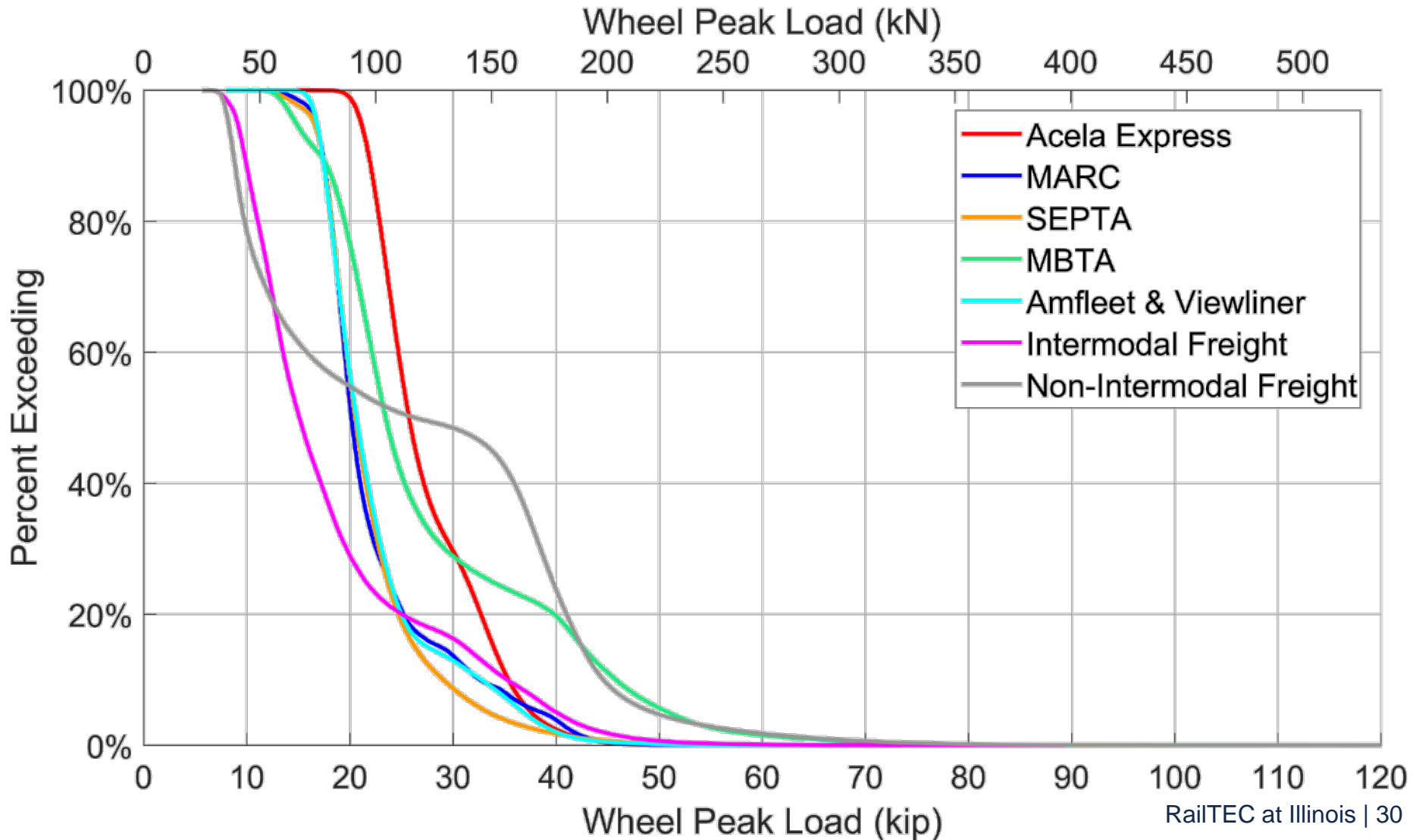
- ▶ Data analyzed from 1 Jan to 30 June 2017
- ▶ Sites:
  - Edgewood, MD
  - Marcus Hook, PA
  - Mansfield, MA
- ▶ 54,156 trains
- ▶ 2,210,687 Axles
- ▶ 36.6 Million Gross Tons (MGT)



# Field Experimentation



## WILD Site Results-Wheel Load Data

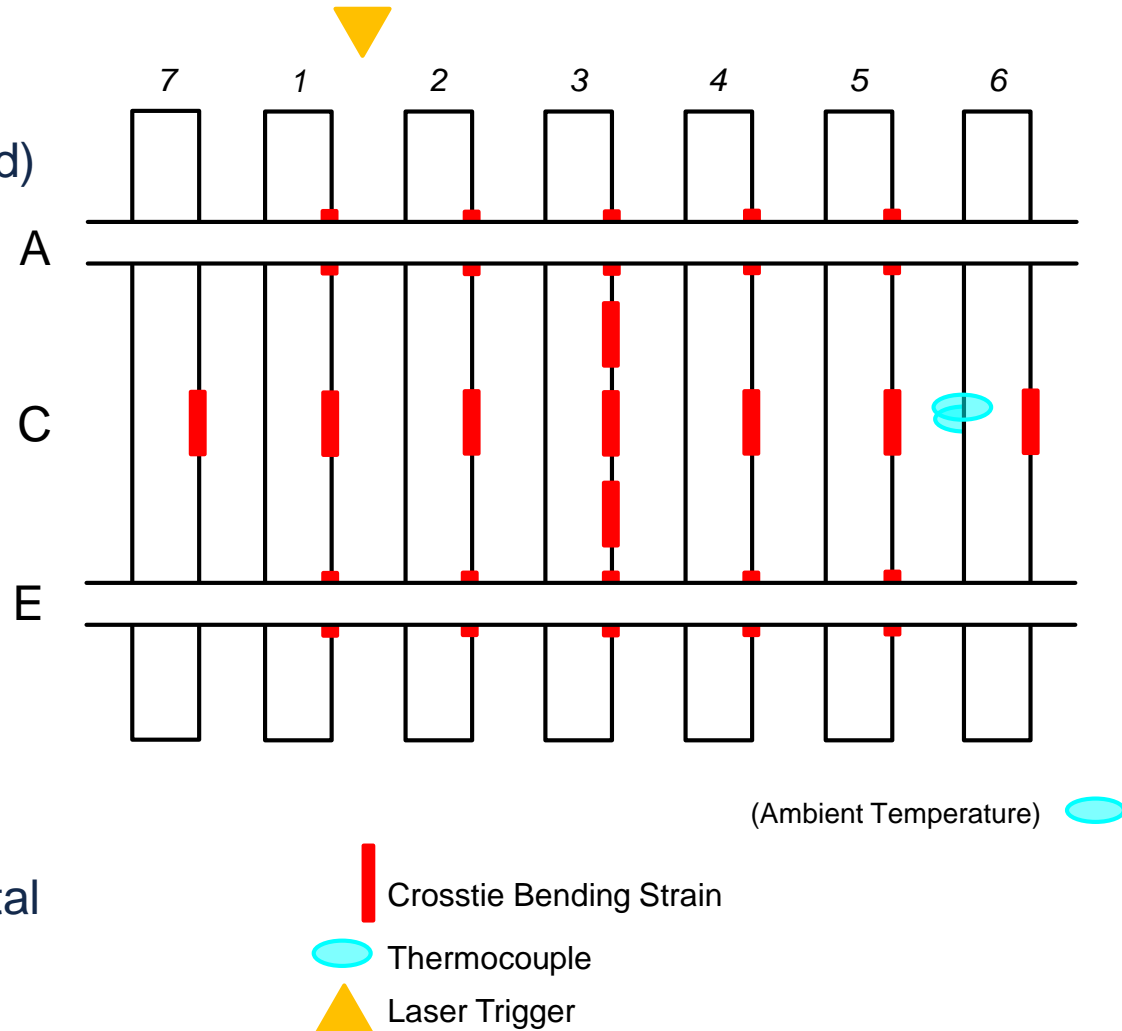


# Field Experimentation



## Instrumented Crossties

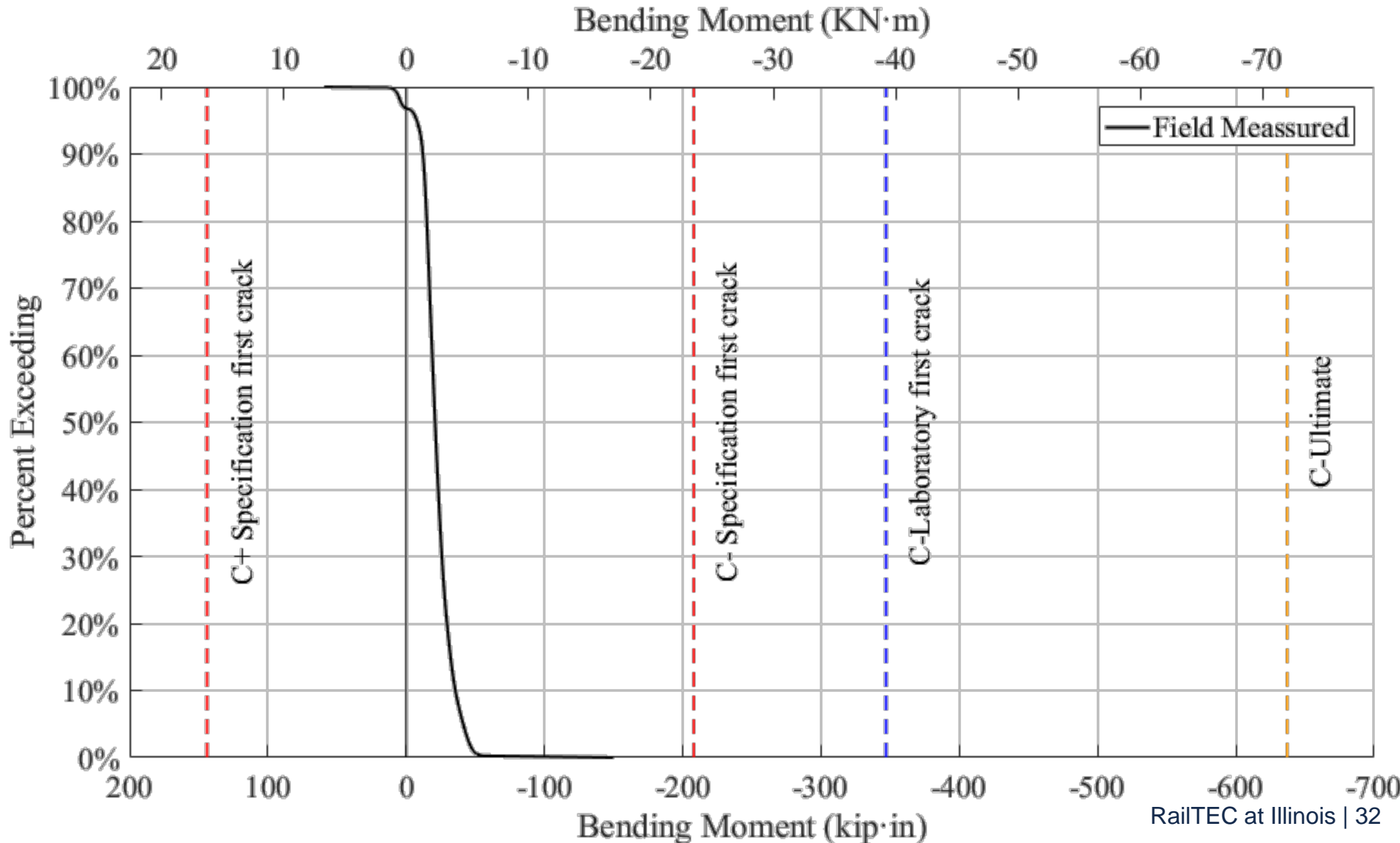
- Site characteristics:
  - Track 2 (typically northbound)
  - Maximum allowable speed: 125 mph (201 km/h)
  - Tangent
  - Grade: 0.1%
- Traffic during data collecting phase:
  - 4,612 trains, 180,362 Axles
  - 13 December 2016 – 17 May 2017
  - 4.5 MGT out of 7.6 MGT total for the same time period.



# Field experimentation



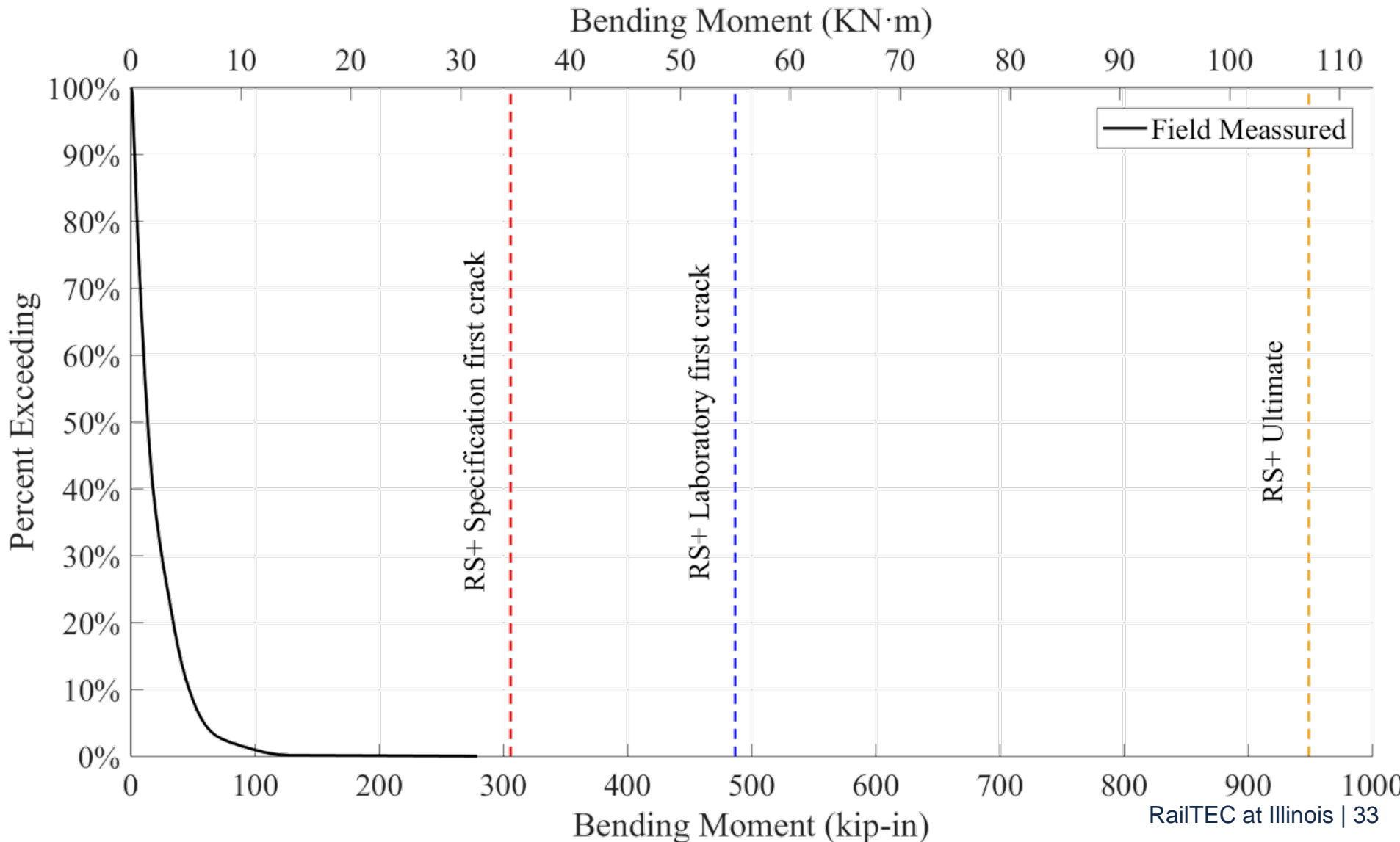
## Instrumented Crossties-Center Bending Moments



# Field experimentation



## Instrumented Crossties-Center Bending Moments

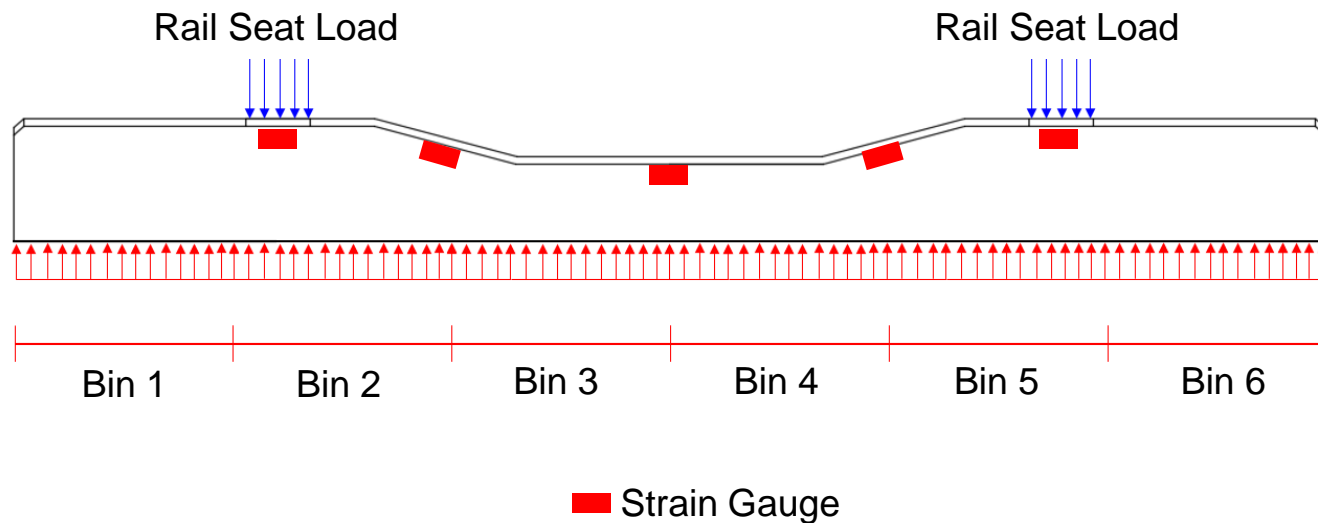


# Field Experimentation



## Support conditions back calculator

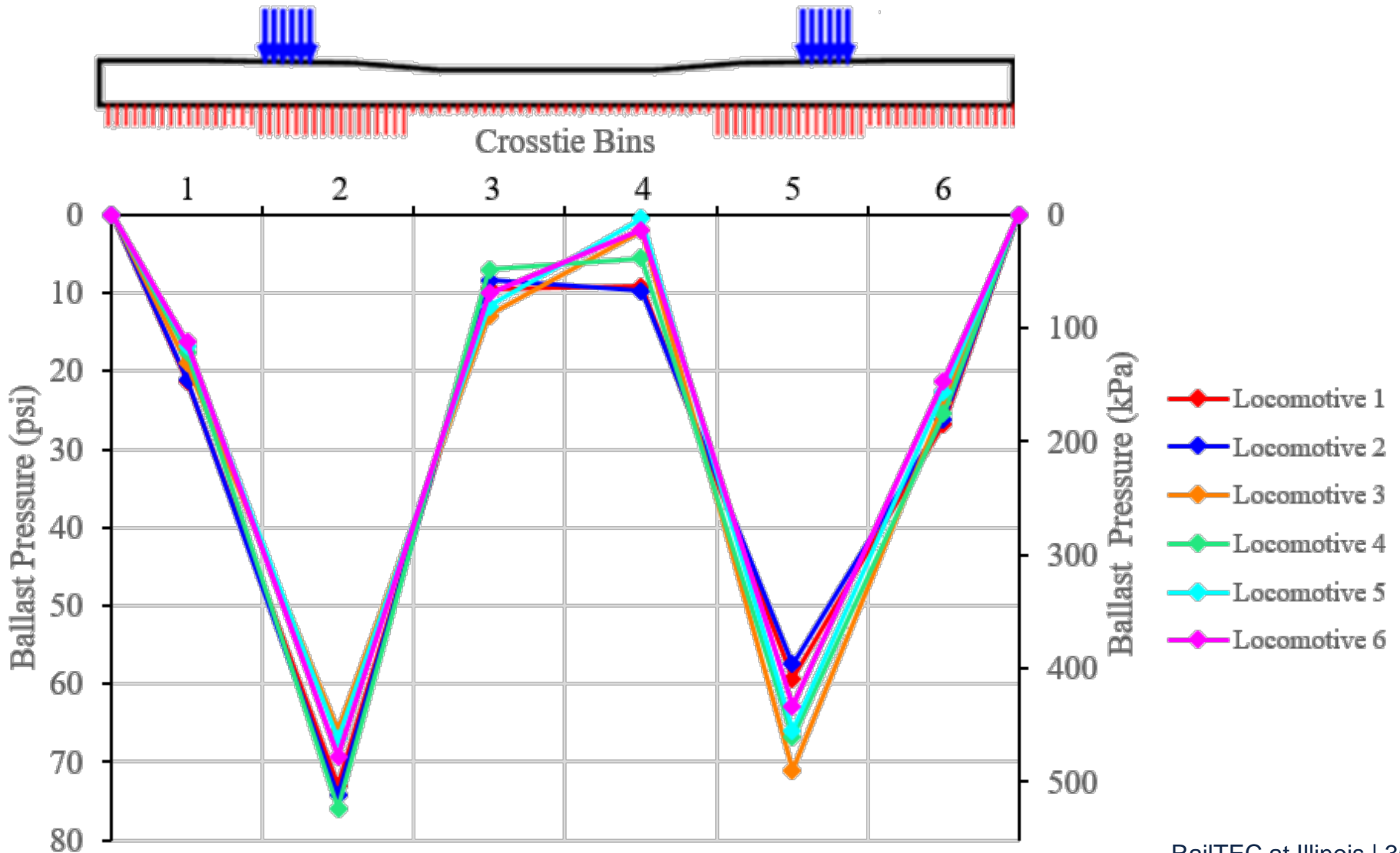
- ▶ Using approach detailed by Gao et al. (2015) support conditions on site were estimated from strain gauge data
- ▶ Known parameters: 5 discrete strain locations and 2 rail seat loads
- ▶ Results are given in terms of percentages of support under 6 discrete bins



# Field Experimentation



## Support conditions back calculator

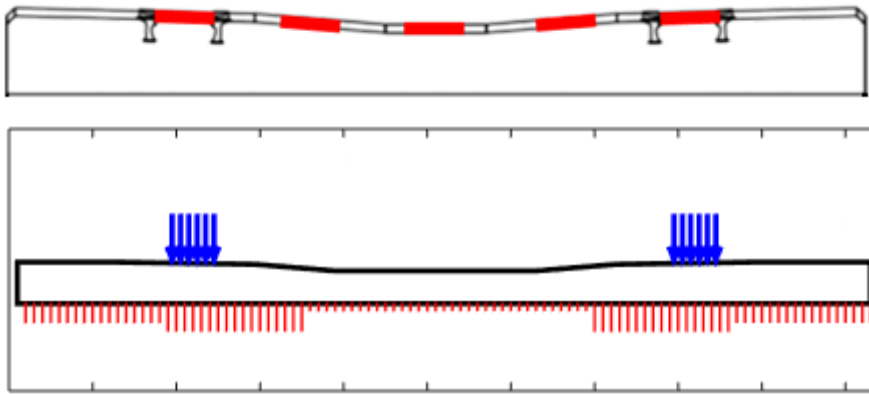


# Field Demand Estimation

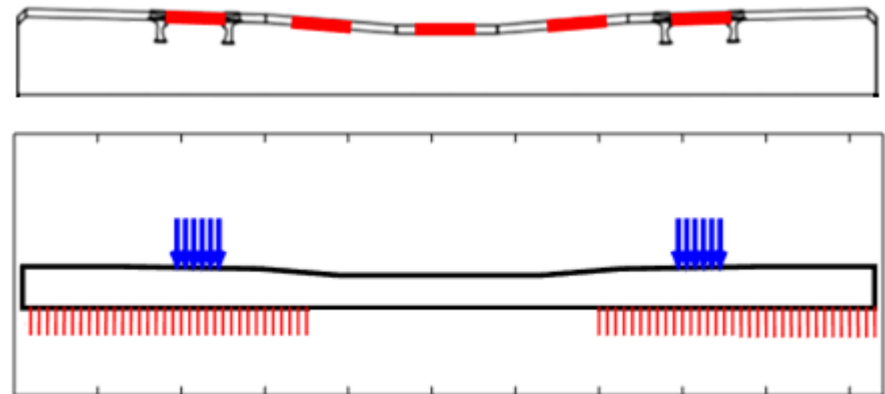


## Potential Variability in Support Conditions

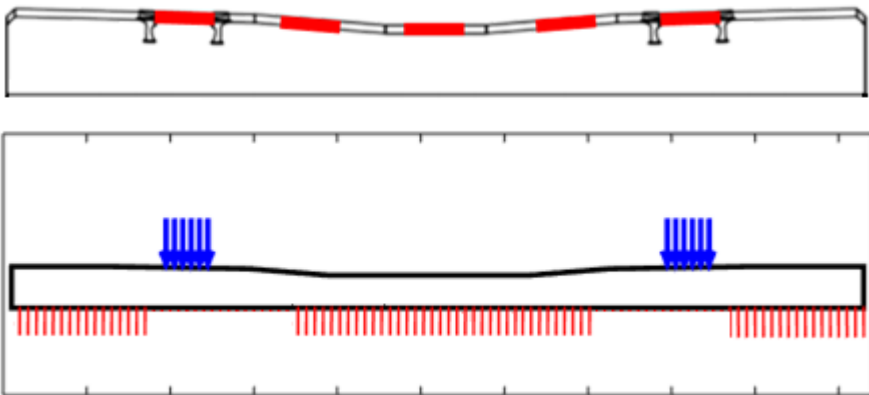
Good Rail Seat support



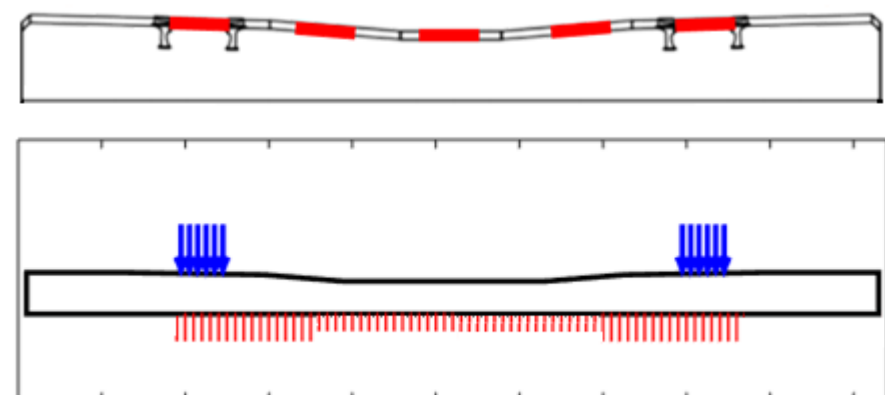
Lack of Center Sup.



Lack of Rail Seat Support



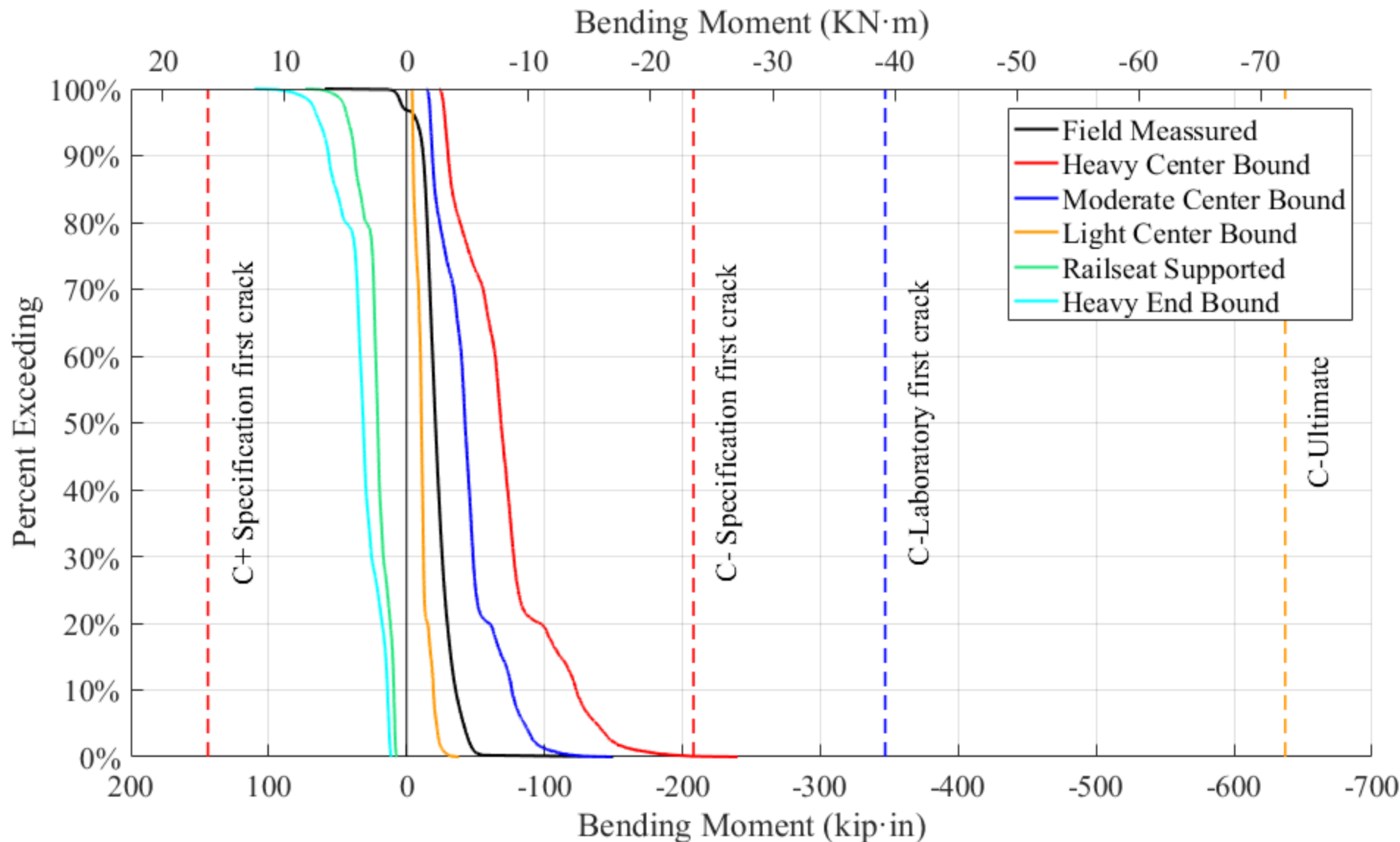
Moderate Center Binding



# Field Demand Estimation



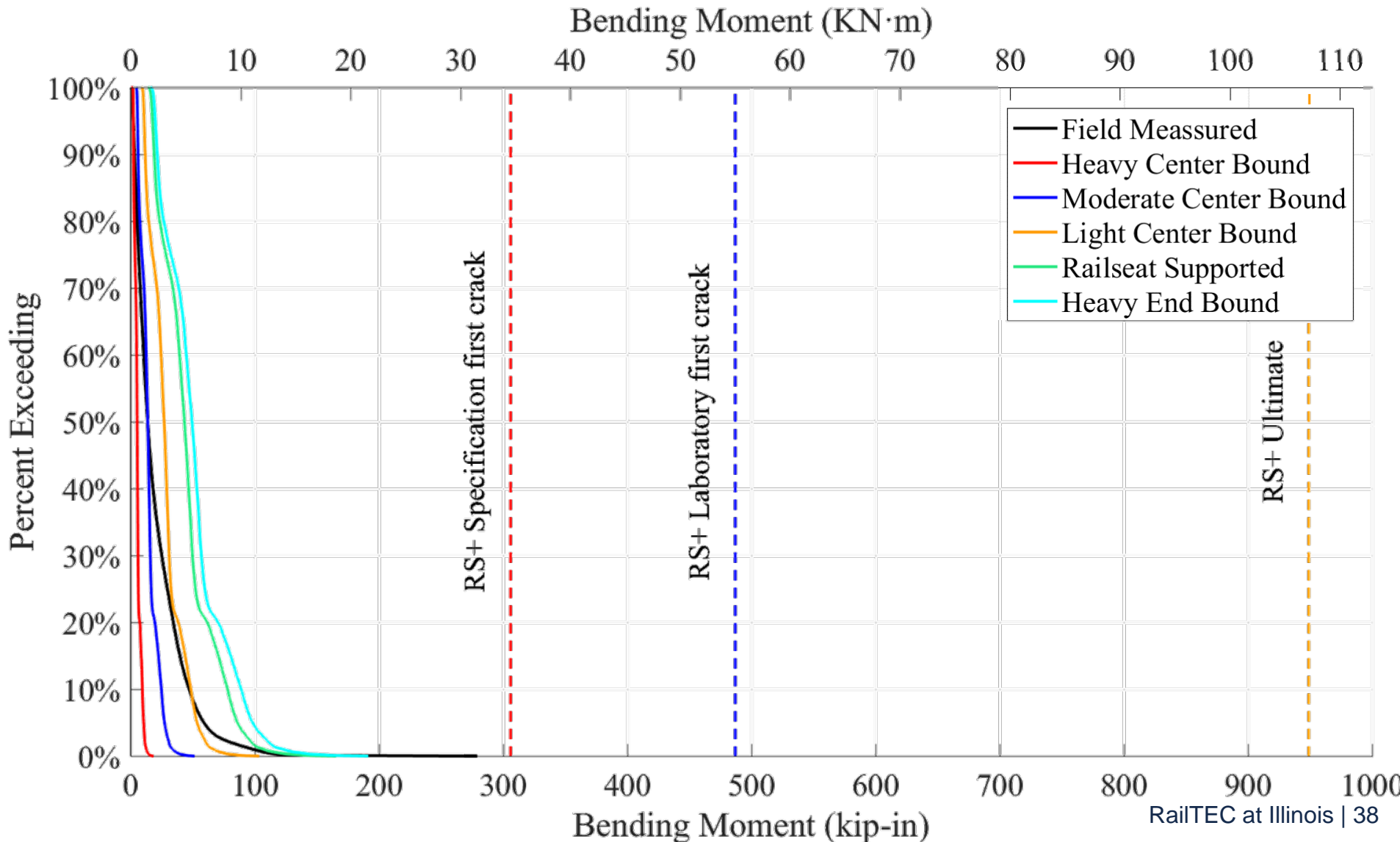
## Extrapolated Center Demand



# Field Demand Estimation



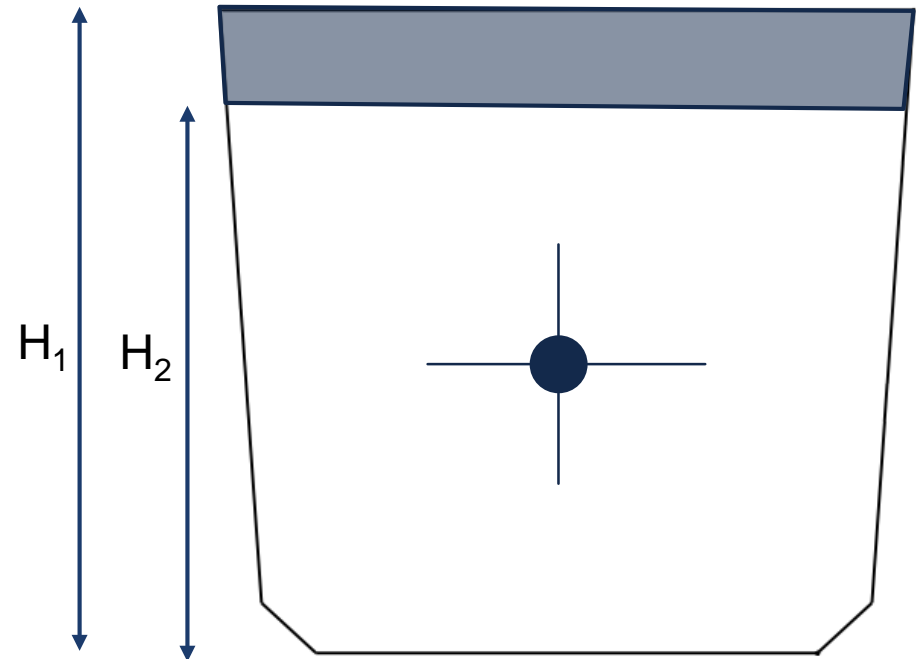
## Extrapolated Rail Seat Demand



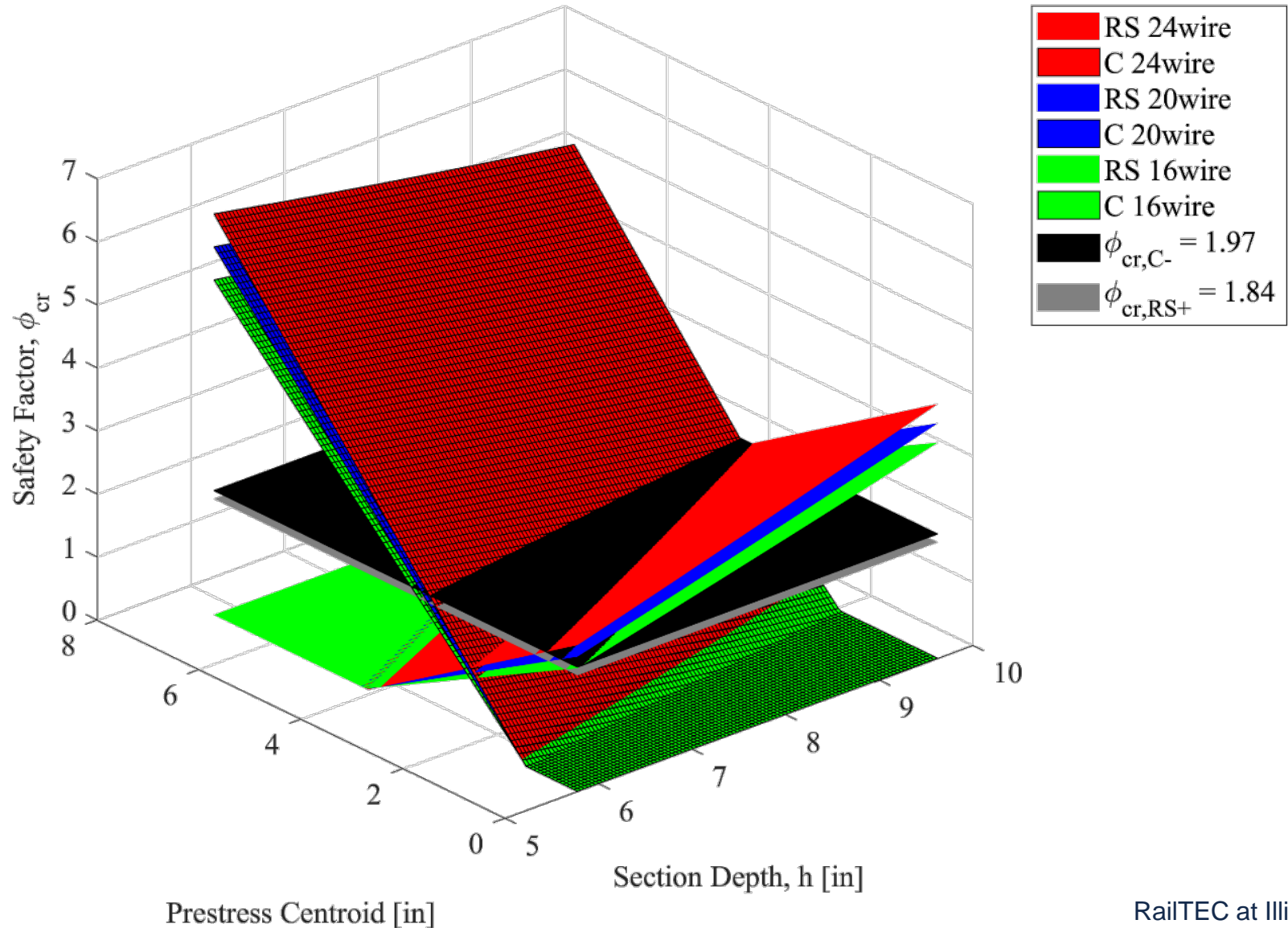
# Theoretical Optimization Framework



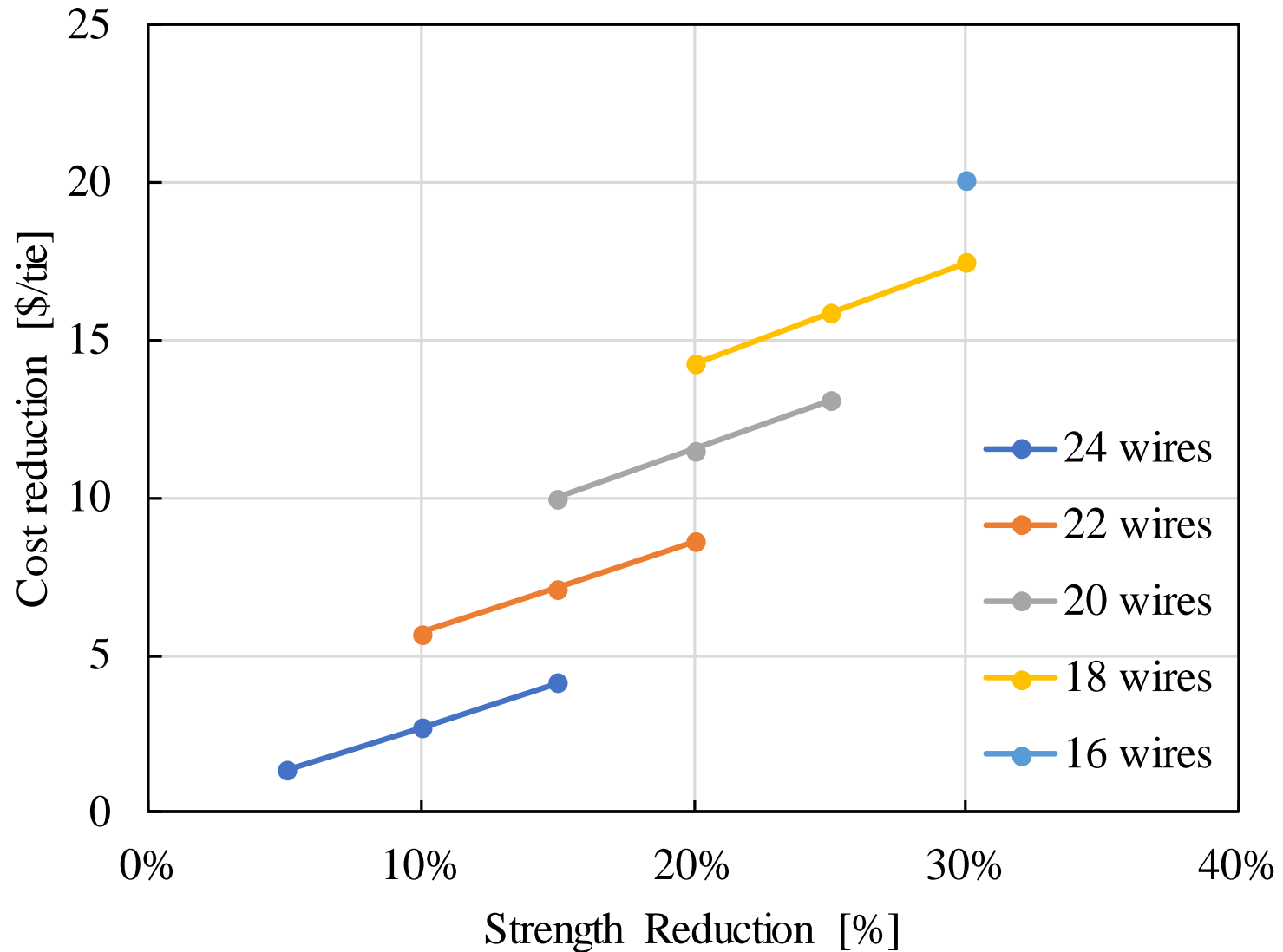
- ▶ Analysis tool for optimization of current design
- ▶ Reduces capacity to field measured values
- ▶ Maximizes cost reduction
- ▶ Constrains
  - Use of same form
    - Reduce depth
    - Reduce wires
- ▶ Best suited for reusing forms for different projects
- ▶ Theoretical model in development



# Theoretical Optimization Framework



# Theoretical Optimization Framework



# Practical Optimization Development



- ▶ Reducing capacity is not appealing
- ▶ It limits the potential increases in weight, capacity or speeds
  
- ▶ Quantifying the reserve capacity for handling future increased demand is more appealing
  
- ▶ Optimization is based around the objective of getting same capacity with less or the same amount of materials
  
- ▶ Two approaches
  - Incremental optimization of the current design
  - Clean slate design



# Practical Optimization Development



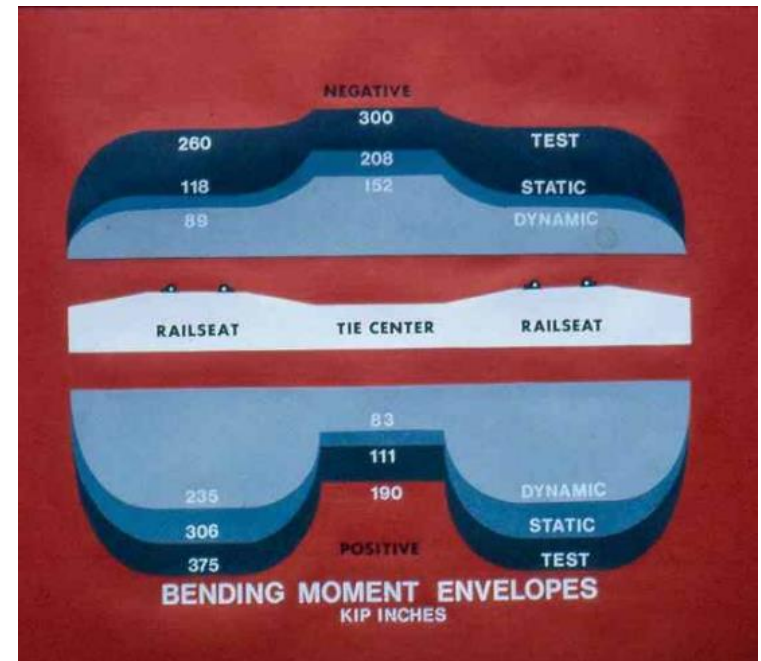
- ▶ Two approaches
  - Incremental optimization of the current design
    - Same demand
    - Same cross section
    - Optimization of reinforcement



Center Negative (C-)	Rail Seat Positive (RS+)
208 kip-in	306 kip-in

- Clean slate design
  - Balanced capacity
  - Optimized cross section
  - New technologies

Center Negative (C-)	Rail Seat Positive (RS+)
<b>245 kip-in</b>	306 kip-in



# Future of the project and Conclusions



- ▶ Laboratory Testing of prototypes
  - Both incremental updates and clean slate updates
- ▶ Specification improvement
  - Changes in materials specification
  - Standardized test
  - Material screening procedures
- ▶ Field deployment of prototypes
  - In-revenue service
  - TLM Compatibility evaluation



# Acknowledgements



Concrete Crosstie  
Manufacturers

Fastening System  
Manufacturers



PANDROL



vossloh

**Progress Rail**  
*A Caterpillar Company*

# Thank you for your attention!



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Rail Transportation and Engineering Center (RailTEC)**



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