Experimentation and Modeling of Concrete Crossties and Fastening Systems

Wheel Rail Interaction Conference

8-9 May 2013

Chicago, IL USA

J. Riley Edwards and Brandon Van Dyk

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Background and Research Justification
- RailTEC Concrete Crosstie Research
- Mechanistic Design Introduction
- Key Research Thrust Areas and Summary of Results
  - Laboratory Instrumentation
  - Field Instrumentation
  - Analytical Methods (FEA)
- Future Work
- Acknowledgements

Outline

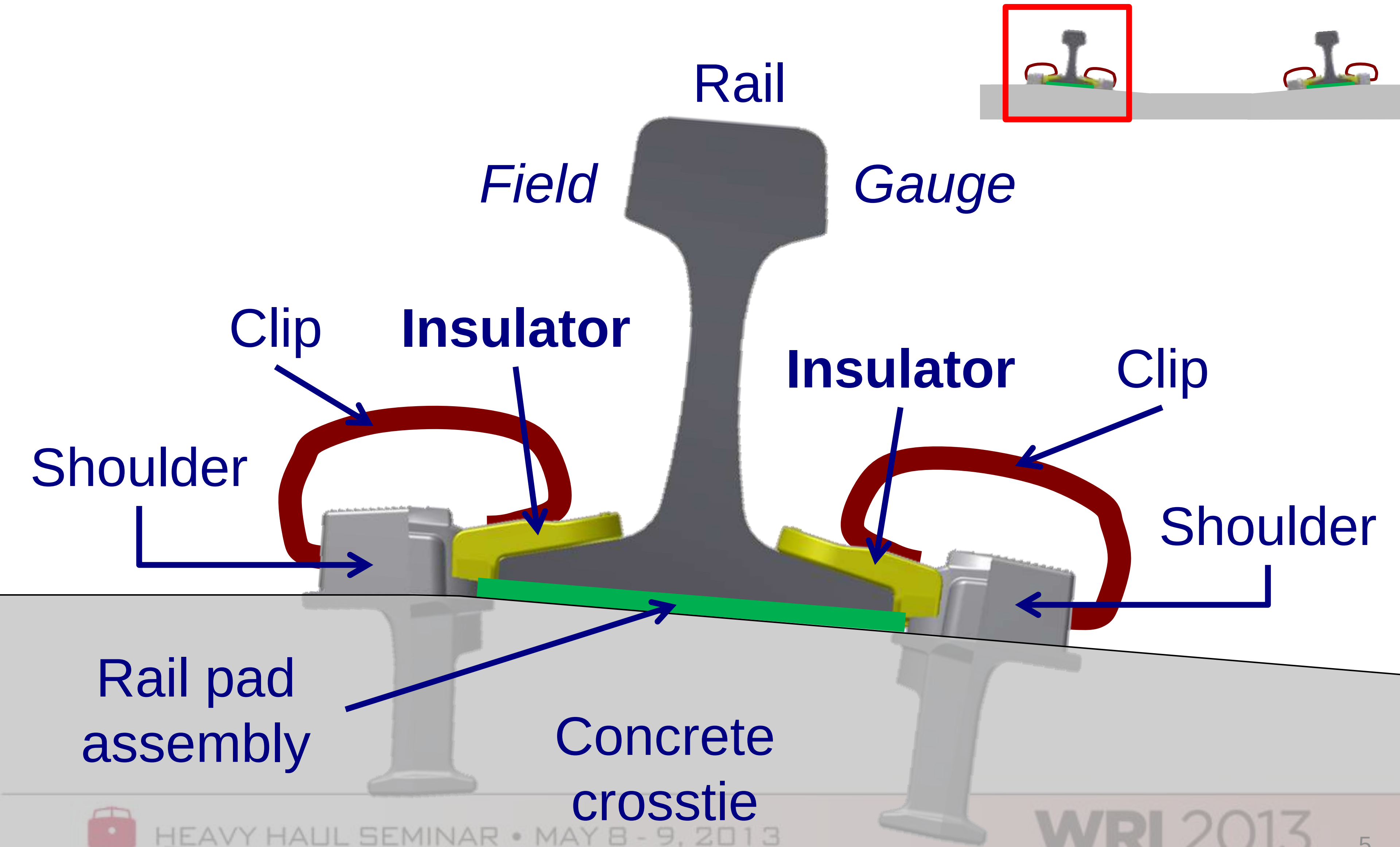
- **Background and Research Justification**
- RailTEC Concrete Crosstie Research
- Mechanistic Design Introduction
- Key Research Thrust Areas and Summary of Results
  - Laboratory Instrumentation
  - Field Instrumentation
  - Analytical Methods (FEA)
- Future Work
- Acknowledgements

Concrete Crossties – Overview of Use

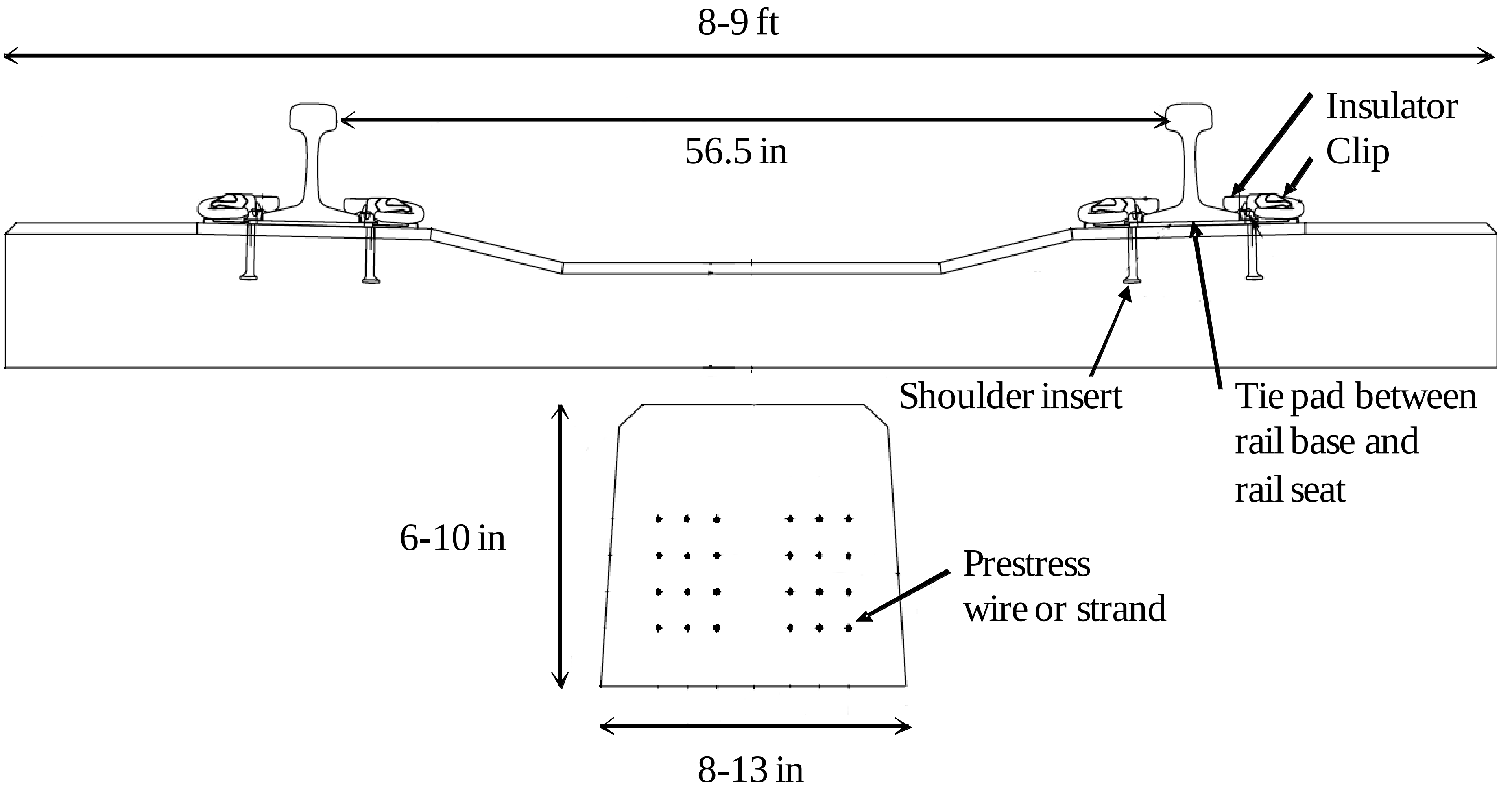
- Typical Usage:
  - Freight → Heavy tonnage lines, steep grades, and high degrees of curvature
  - Passenger → High density corridors (e.g. Amtrak's Northeast Corridor [NEC])
  - Transit applications
- Number of concrete ties in North America*:
  - Freight → 25,000,000
  - Passenger → 2,000,000
  - Transit → Significant quantities (millions)

**Approximate*

Fastening System Components



Complete System



Outline

- Background and Research Justification
- **RailTEC Concrete Crosstie Research**
- Mechanistic Design Introduction
- Key Research Thrust Areas and Summary of Results
  - Laboratory Instrumentation
  - Field Instrumentation
  - Analytical Methods (FEA)
- Future Work
- Acknowledgements

Concrete Crosstie and Fastener Research Levels (and Examples)

Materials

- Concrete Mix Design
- Rail Seat Surface Treatments
- Pad / Insulator Materials

Components

- Fastener Yield Stress
- Insulator Post Compression
- Concrete Prestress Design

System

- Finite Element Modeling
- Full-Scale Laboratory Experimentation
- Field Experimentation

2012 International Survey Results – Criticality of Problems

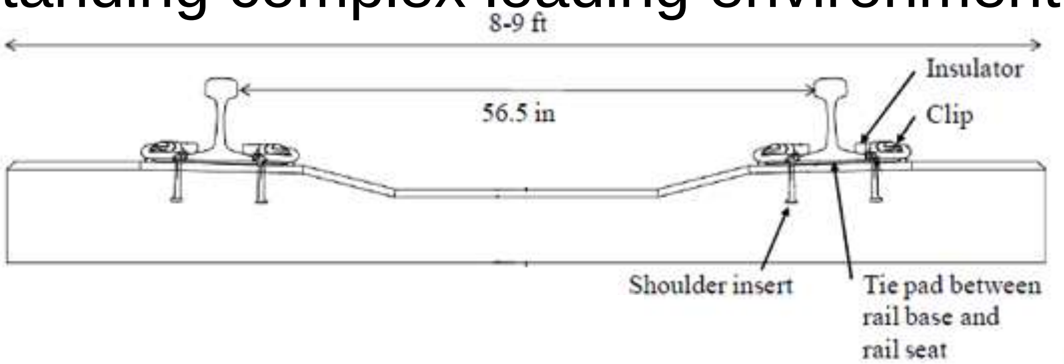
Problem (higher ranking is more critical)	Average Rank
International Responses	
Tamping damage	6.14
Shoulder/fastening system wear or fatigue	5.50
Cracking from center binding	5.36
Cracking from dynamic loads	5.21
Cracking from environmental or chemical degradation	4.67
Derailment damage	4.57
Other (e.g. manufactured defect)	4.09
Deterioration of concrete material beneath the rail	3.15
North American Responses	
Deterioration of concrete material beneath the rail	6.43
Shoulder/fastening system wear or fatigue	6.38
Cracking from dynamic loads	4.83
Derailment damage	4.57
Cracking from center binding	4.50
Tamping damage	4.14
Other (e.g. manufactured defect)	3.57
Cracking from environmental or chemical degradation	3.50

Outline

- Background and Research Justification
- RailTEC Concrete Crosstie Research
- **Mechanistic Design Introduction**
- Key Research Thrust Areas and Summary of Results
  - Laboratory Instrumentation
  - Field Instrumentation
  - Analytical Methods (FEA)
- Future Work
- Acknowledgements

Current Design Process

- Found in AREMA Manual on Railway Engineering
- Based largely on practical experience:
  - Lacks complete understanding of failure mechanisms and their causes
  - Empirically derives loading conditions (or extrapolates existing relationships)
- Can be driven by production and installation practices
- Improvements are difficult to implement without understanding complex loading environment



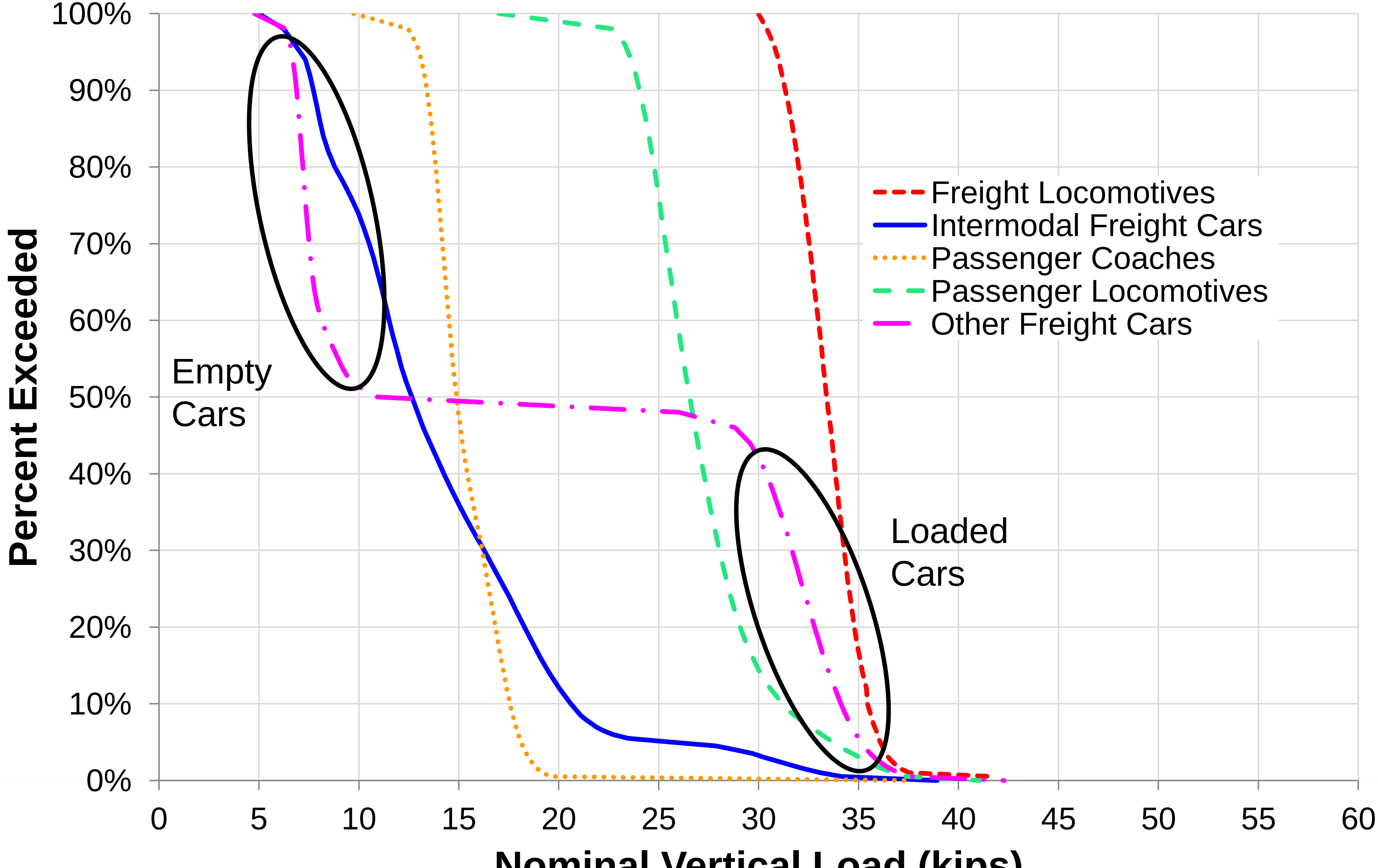
Principles of Mechanistic Design

1. Quantify track system input loads (wheel loads)
2. Qualitatively establish load path (free body diagrams, basic modeling, etc.)
3. Quantify demands on each component
    a. Laboratory experimentation
    b. Field experimentation
    c. Analytical modeling
4. Link quantitative data to component geometry and materials properties (materials decision)
5. Relate loading to failure modes
6. Investigate interdependencies through modeling
7. Establish mechanistic design practices and incorporate into AREMA Recommended Practices

Determining System Input Loads

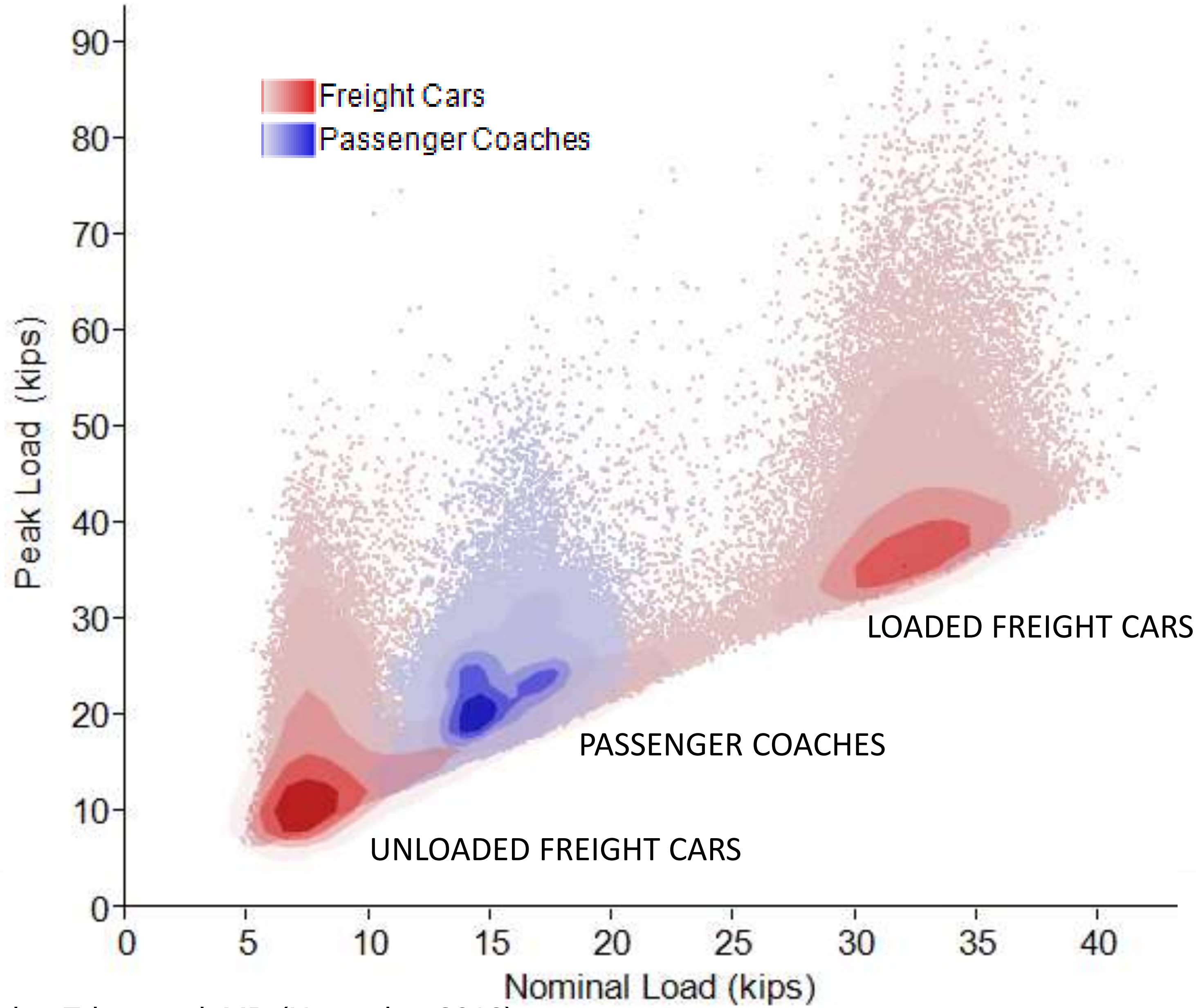
- Quantitative methods of data collection (Step 1):
  - Wheel Impact Load Detectors (WILD)
  - Instrumented Wheel Sets (IWS)
  - Truck Performance Detectors (TPD)
  - UIUC Instrumentation Plan (FRA Tie BAA)
- Most methods above are used to monitor rolling stock performance and assess vehicle health
- Can provide insight into the magnitude and distribution of loads entering track structure
  - Limitations to WILD: tangent track (still need lateral curve data), good substructure (not necessarily representative of the broader rail network)

Vertical Wheel Loads – Shared Infrastructure



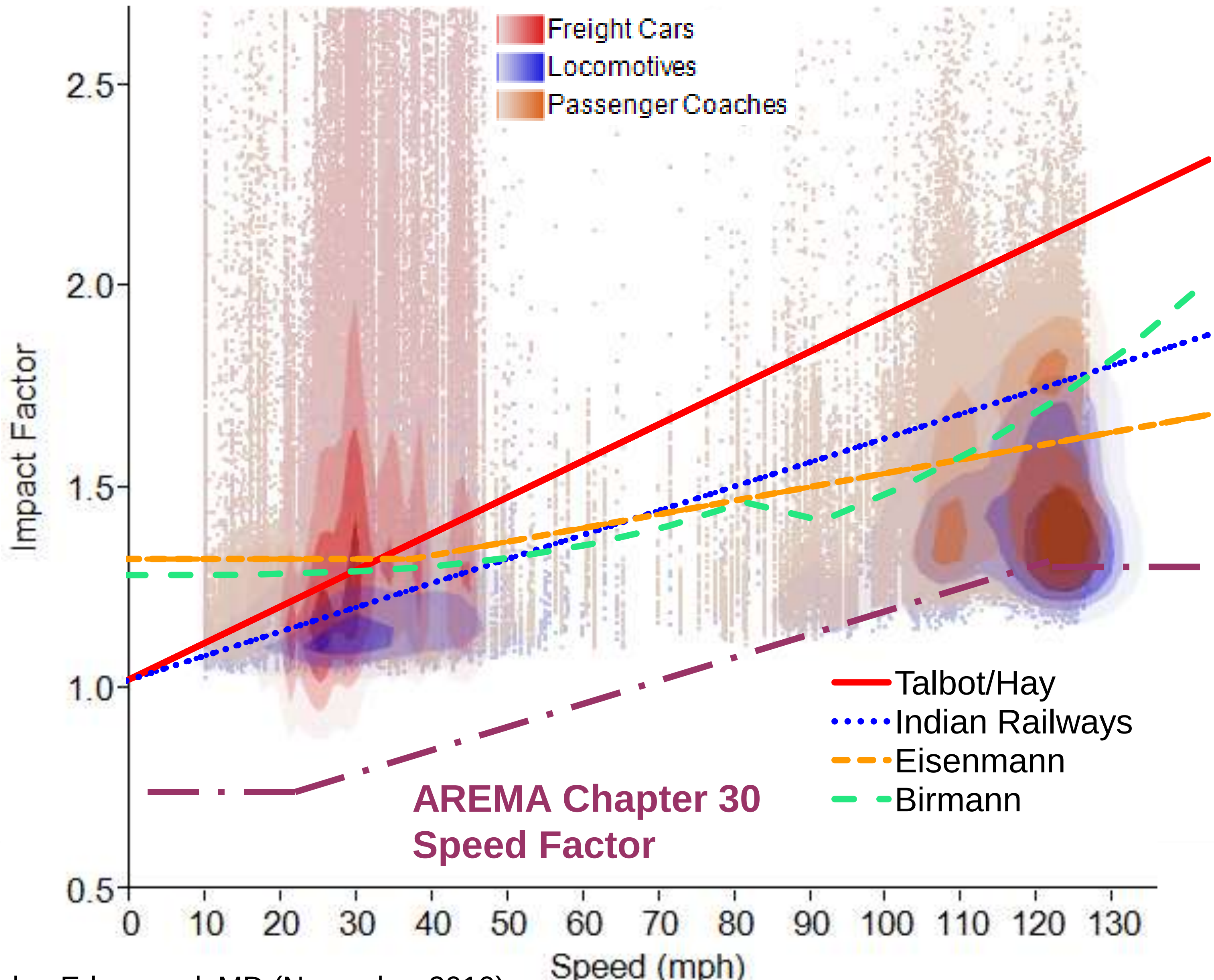
Source: Amtrak – Edgewood, MD (November 2010)

Effect of Traffic Type on Peak Wheel Load



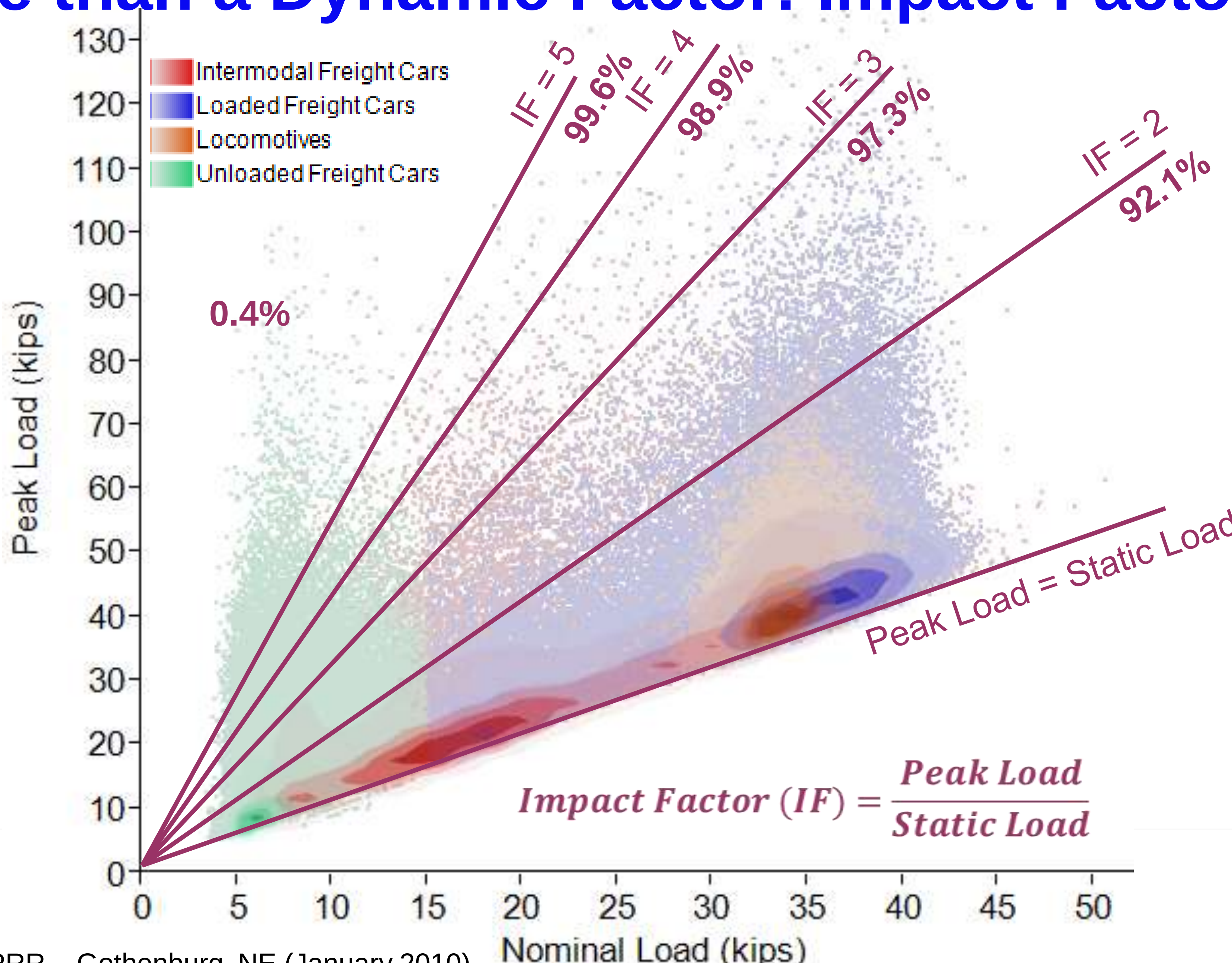
Source: Amtrak – Edgewood, MD (November 2010)

Dynamic Wheel Load Factors



Source: Amtrak – Edgewood, MD (November 2010)

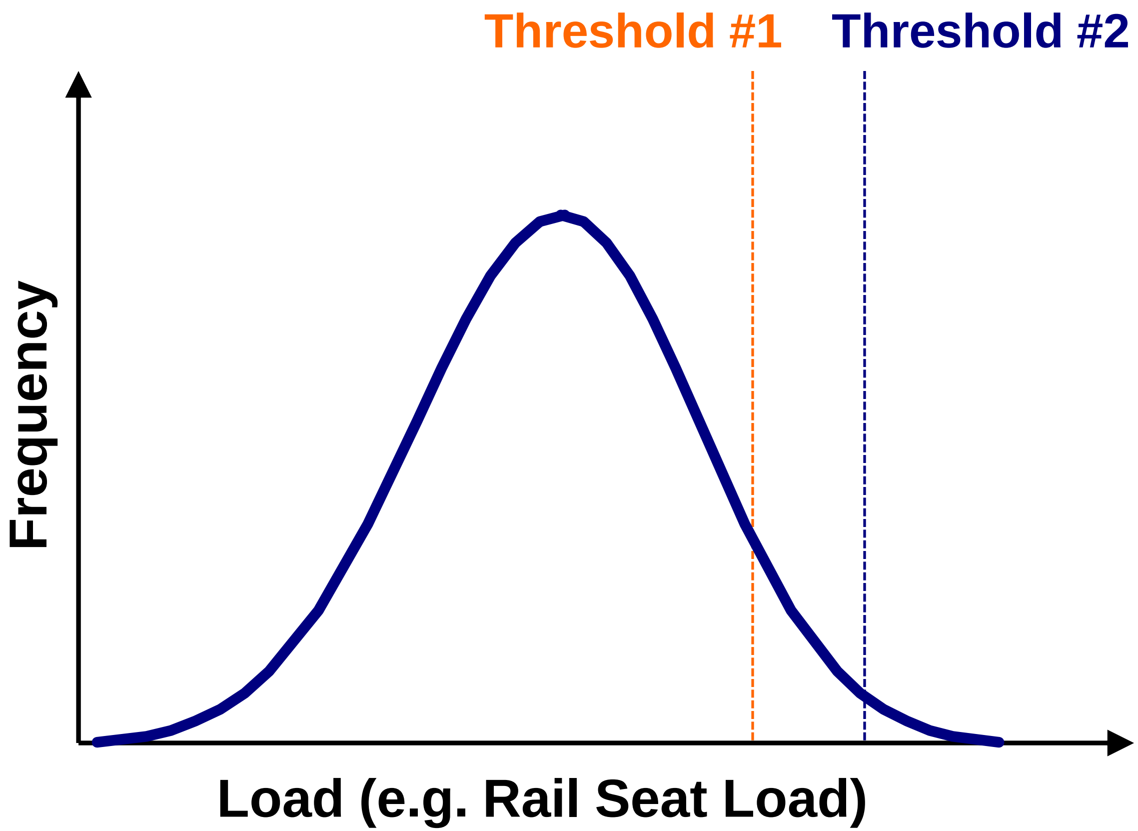
More than a Dynamic Factor: Impact Factor



$$Impact\ Factor\ (IF) = \frac{Peak\ Load}{Static\ Load}$$

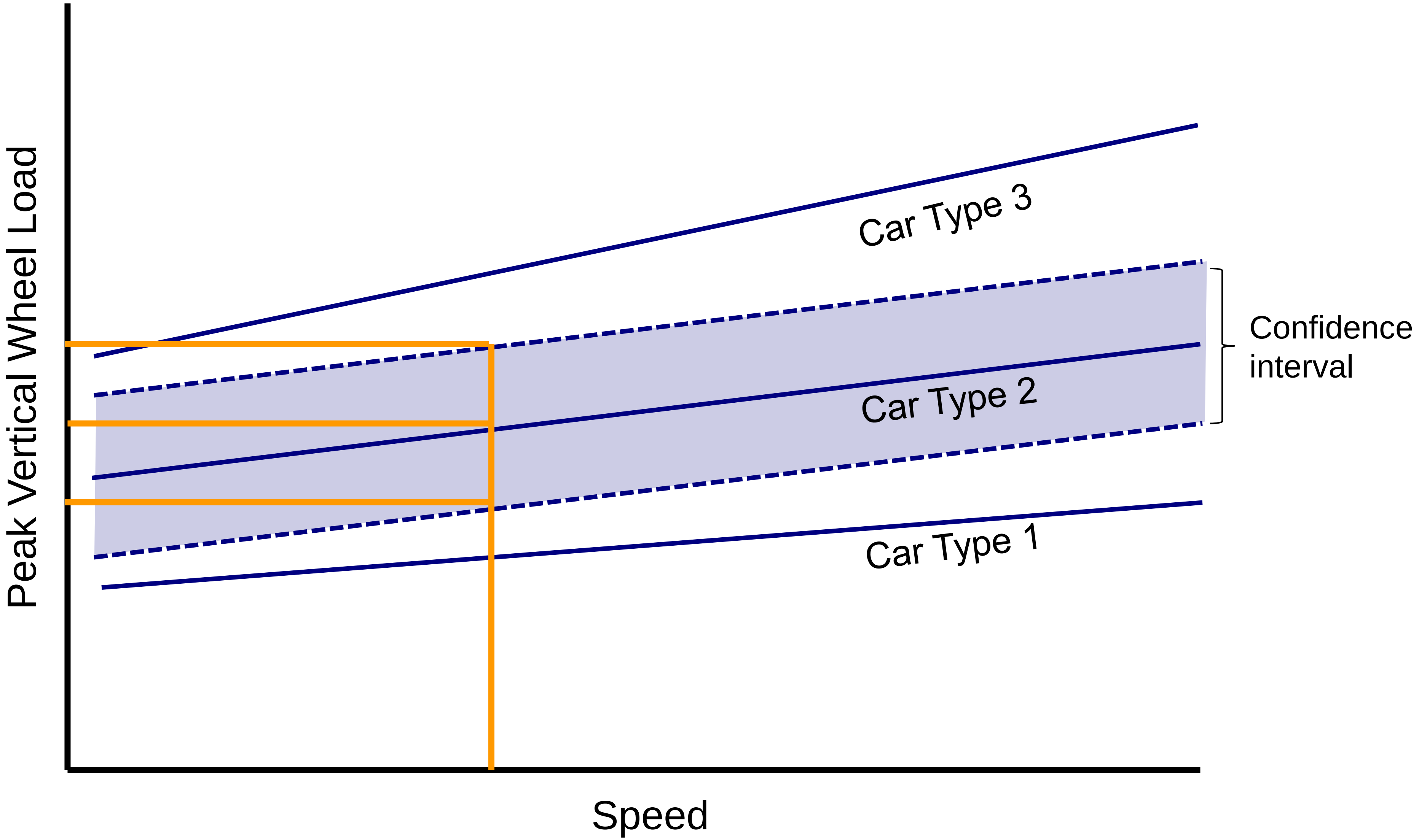
Source: UPRR – Gothenburg, NE (January 2010)

So What is Our Design Threshold?

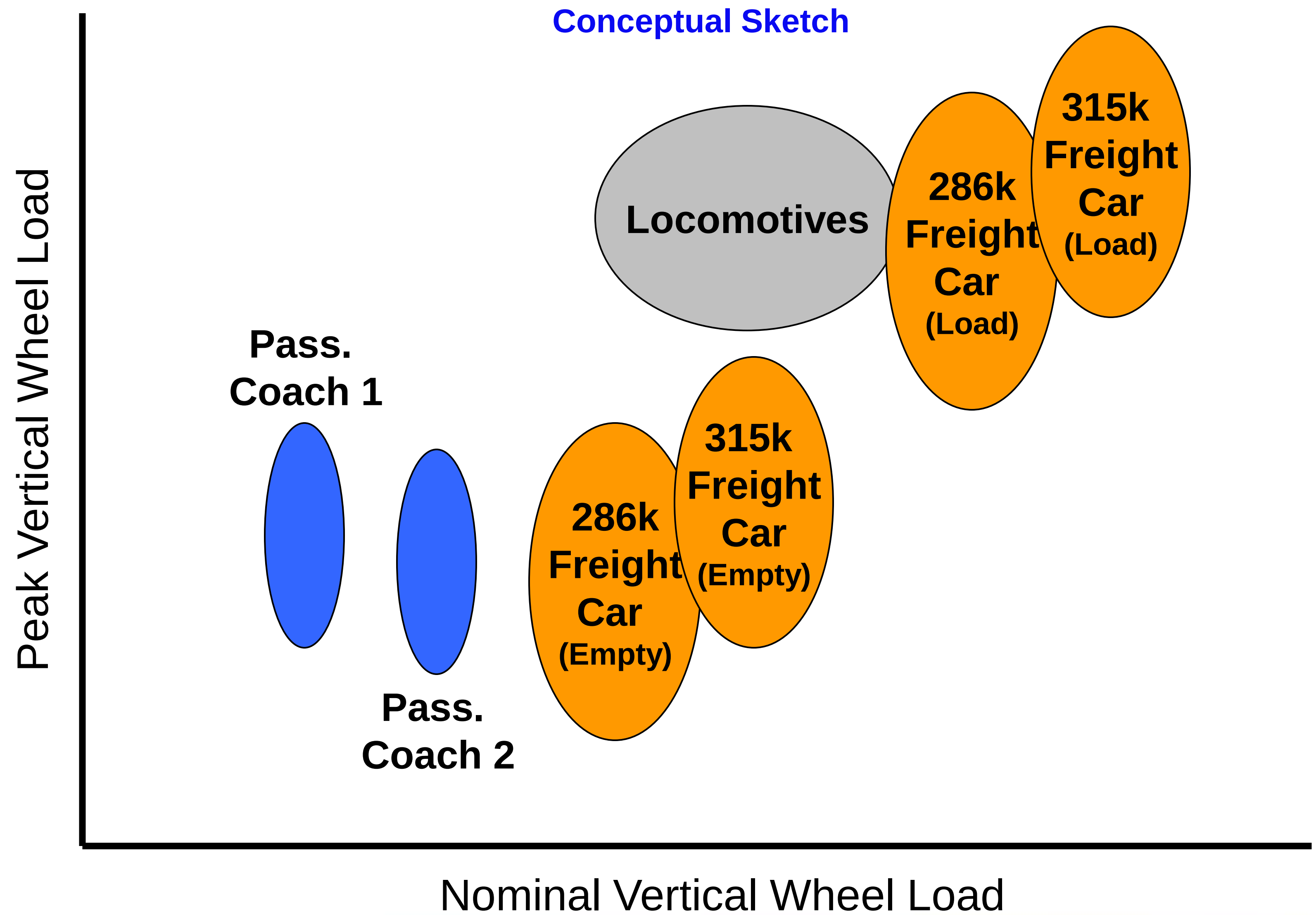


***Need curves for each component / interface and failure mode**

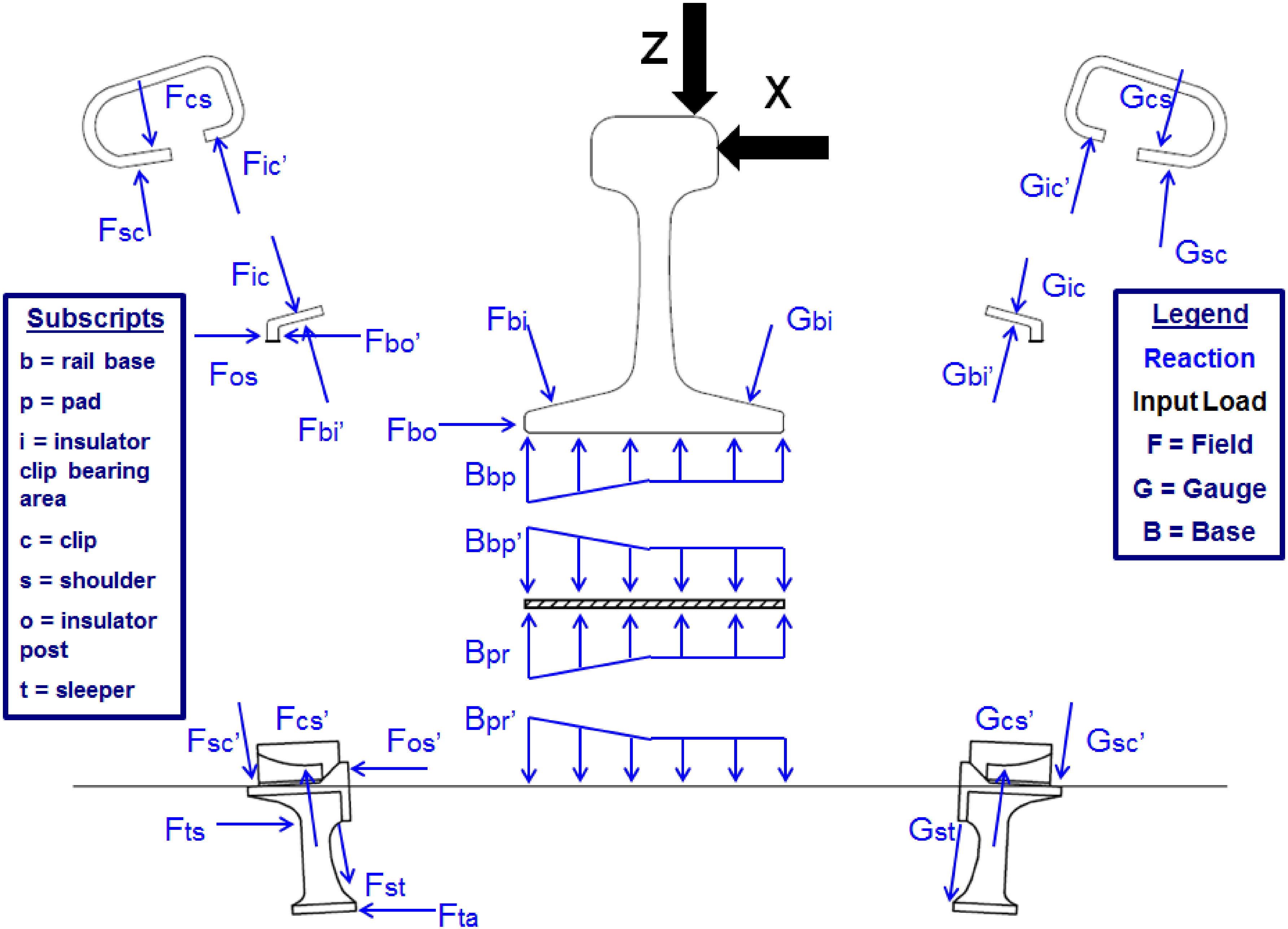
Development of Quantitative Loading Model



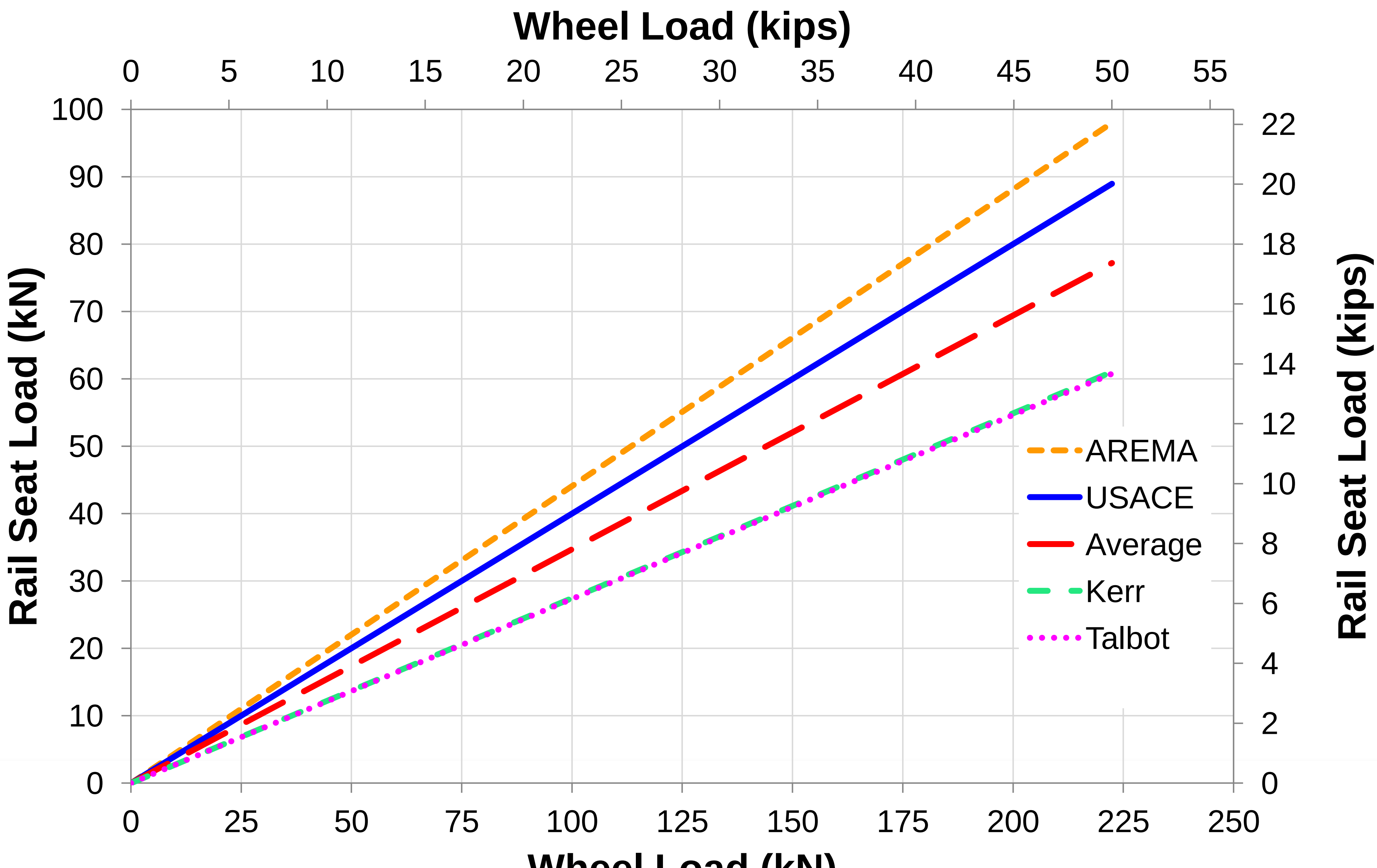
Development of Quantitative Loading Model



Establishment of the Qualitative Load Path



Rail Seat Load Calculation Methodologies



Analysis courtesy of Christopher Rapp

Outline

- Background and Research Justification
- RailTEC Concrete Crosstie Research
- Mechanistic Design Introduction
- Key Research Thrust Areas and Summary of Results
  - **Laboratory Instrumentation**
  - Field Instrumentation
  - Analytical Methods (FEA)
- Future Work
- Acknowledgements

FRA Tie and Fastening System BAA Objectives and Deliverables

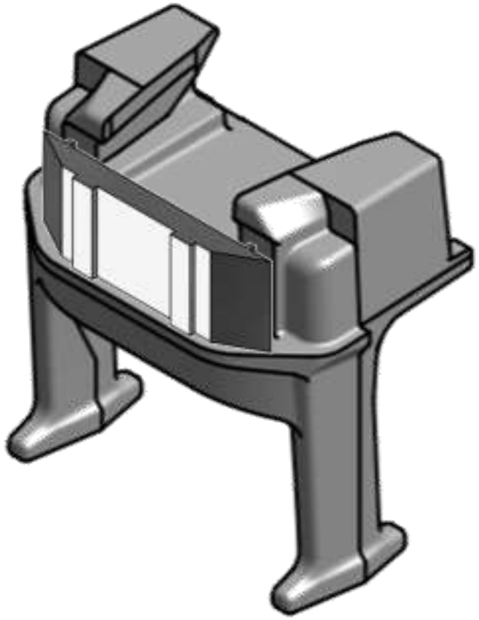
U.S. Department of Transportation
Federal Railroad Administration

FRA Tie and Fastener BAA Industry Partners:

- **Program Objectives**
  - Conduct comprehensive international literature review and state-of-the-art assessment for design and performance
  - Conduct experimental laboratory and field testing, leading to improved recommended practices for design
  - Provide mechanistic design recommendations for concrete crossties and fastening system design in the US
- **Program Deliverables**
  - Improved mechanistic design recommendations for concrete crossties and fastening systems in the US
  - Improved safety due to increased strength of critical infrastructure components
  - Centralized knowledge and document depository for concrete crossties and fastening systems

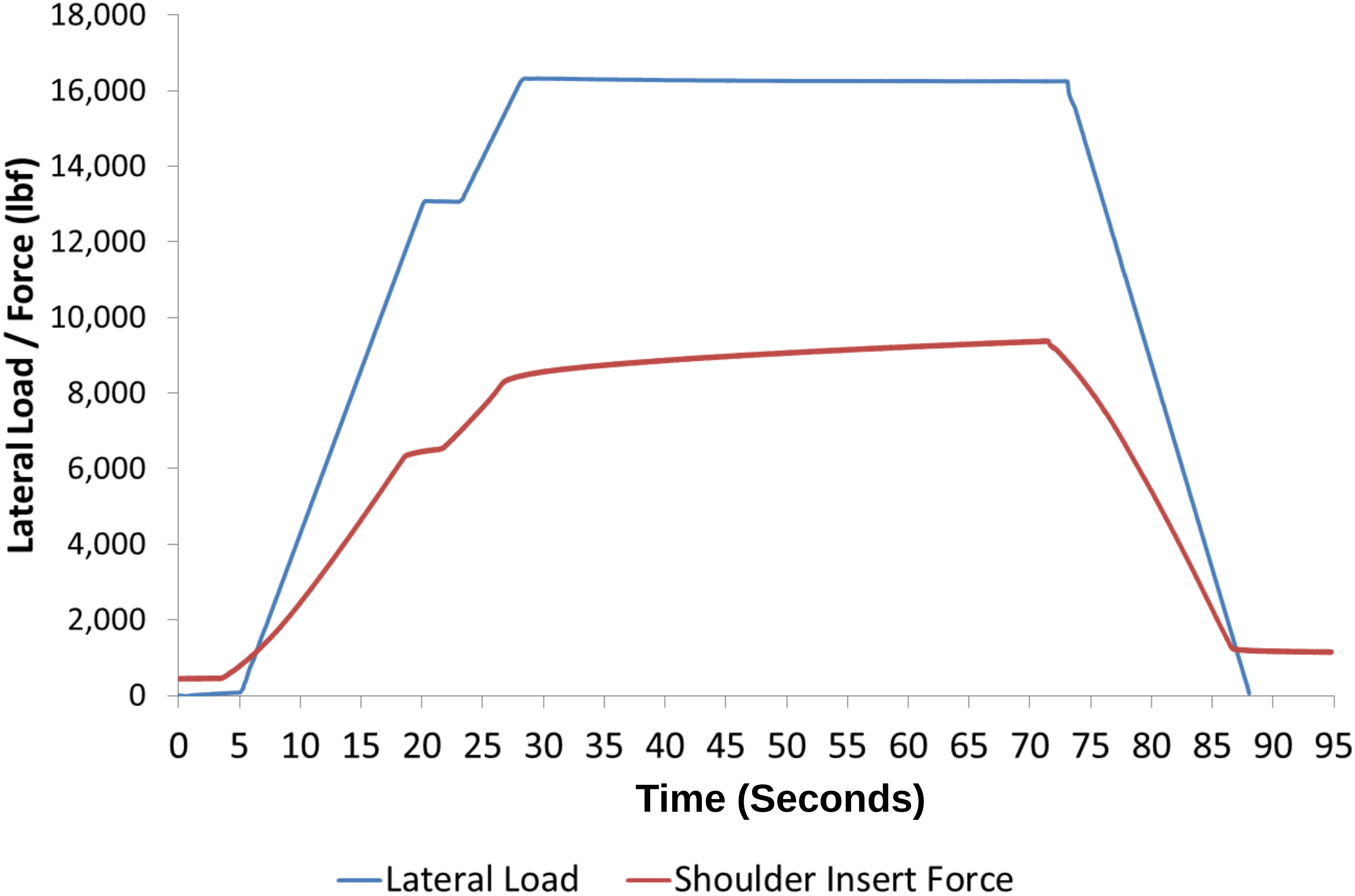
Quantification of Lateral Loads Entering the Shoulder Face (Insert)

- Instrumented shoulder face insert
  - Original shoulder face is removed
  - Small beam insert replaces removed section
  - 4-point bending beam experiment
    - Beam strategy is a well-established, successful technology

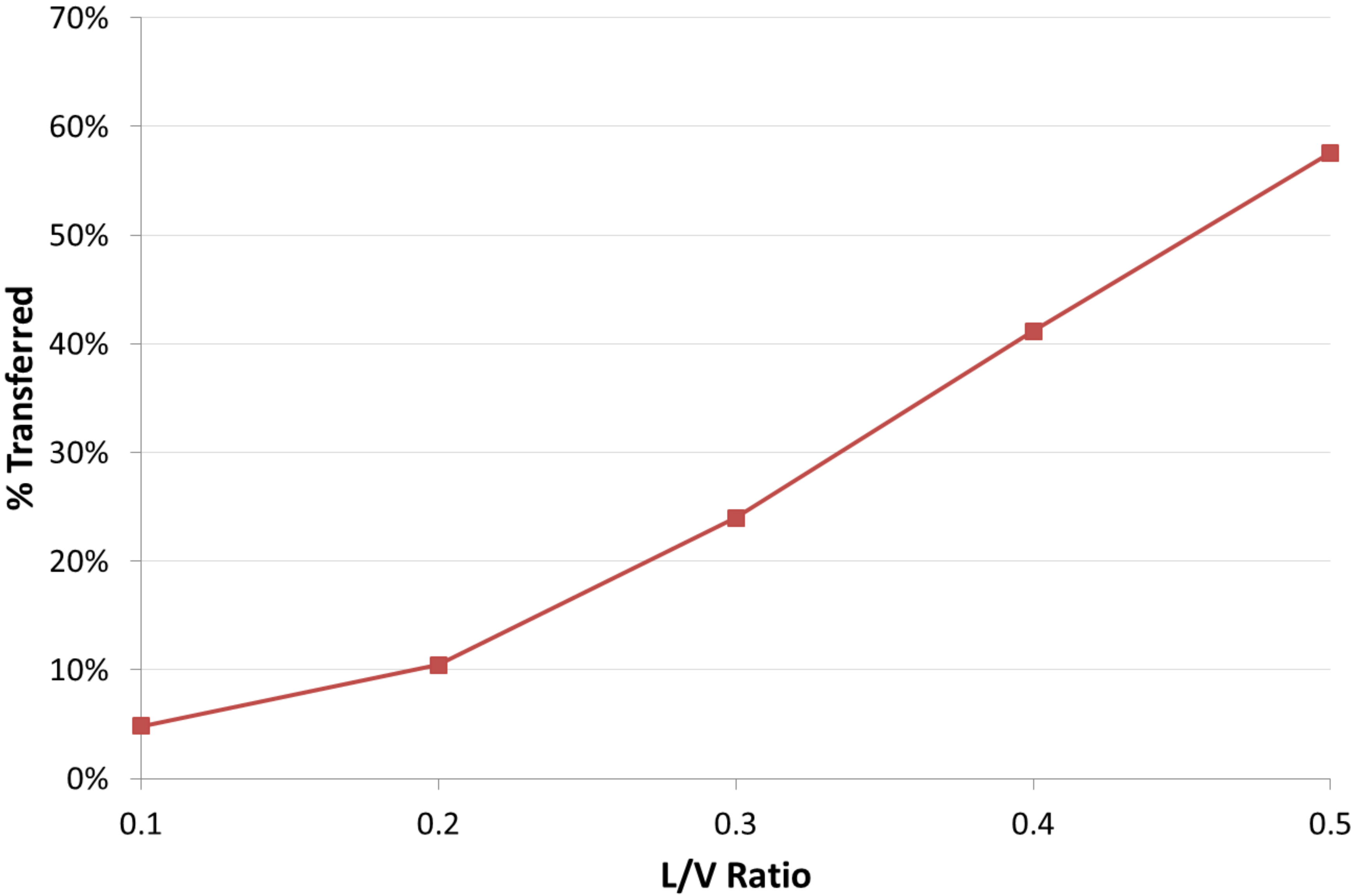


Transfer of Lateral Load to Shoulder Face

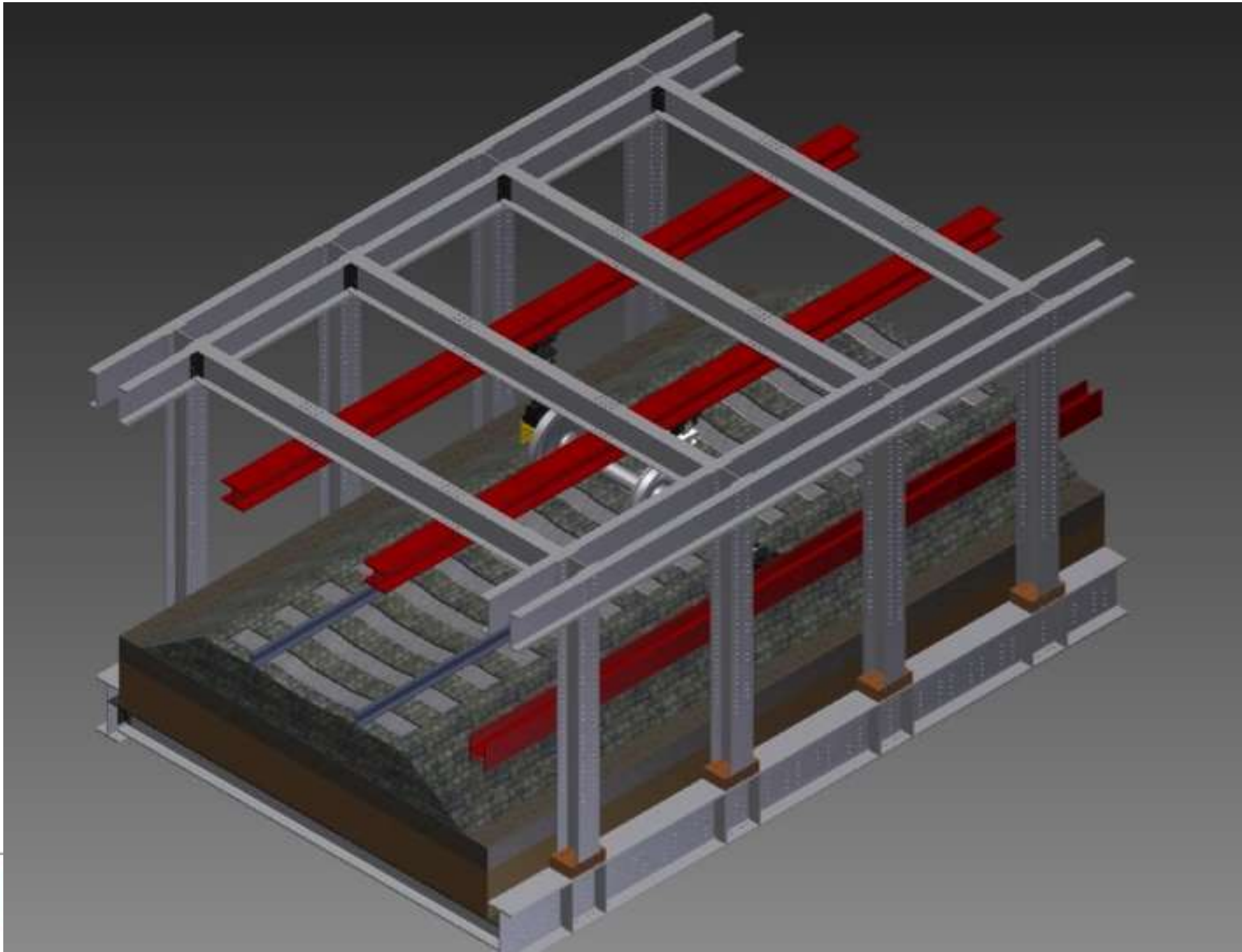
32.5 kip vertical load, 0.5 L/V ratio



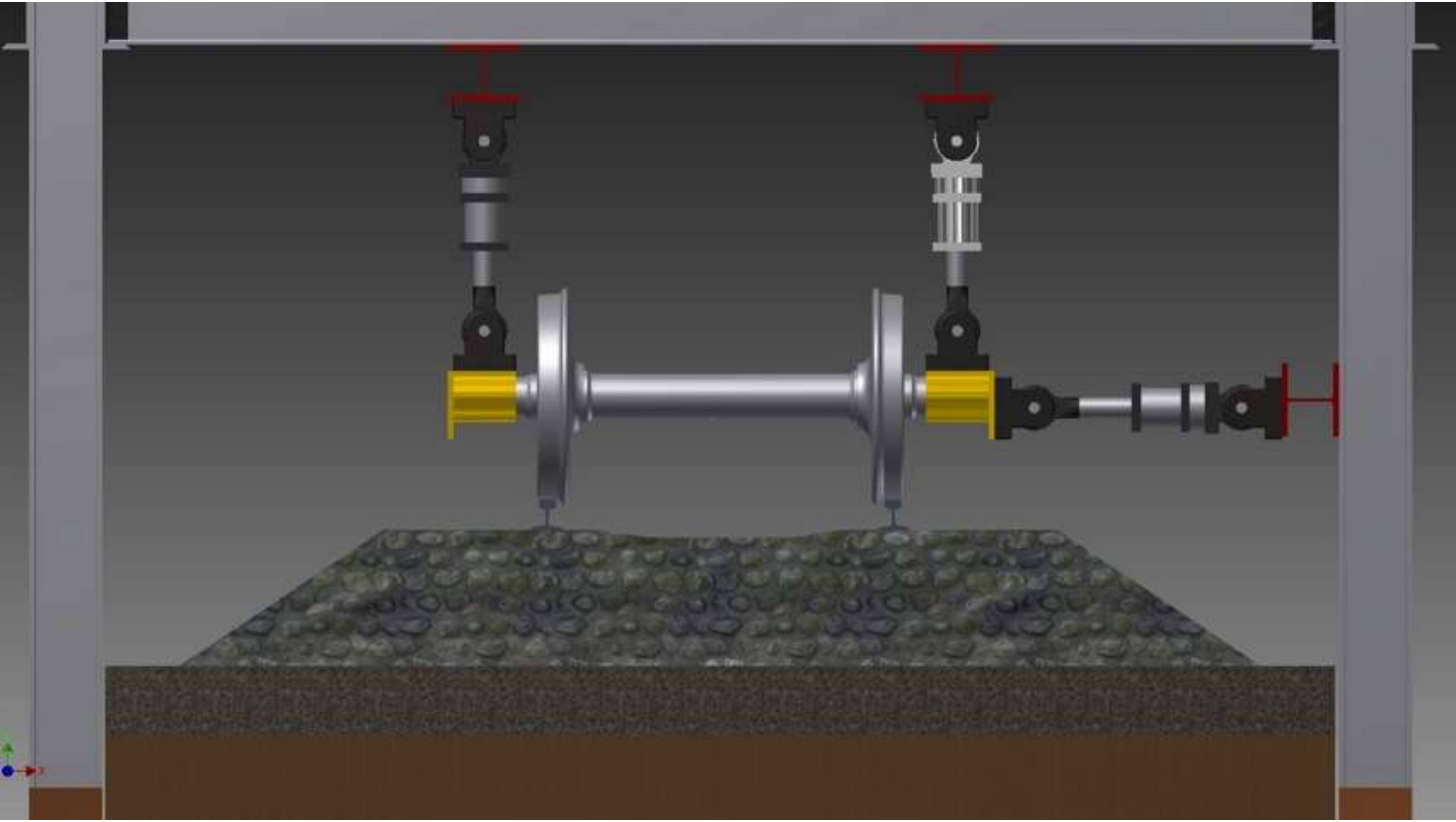
Percent of Lateral Load Transferred to Shoulder
Preliminary Data



Full Scale Track Response Experimental System



Full Scale Track Response Experimental System

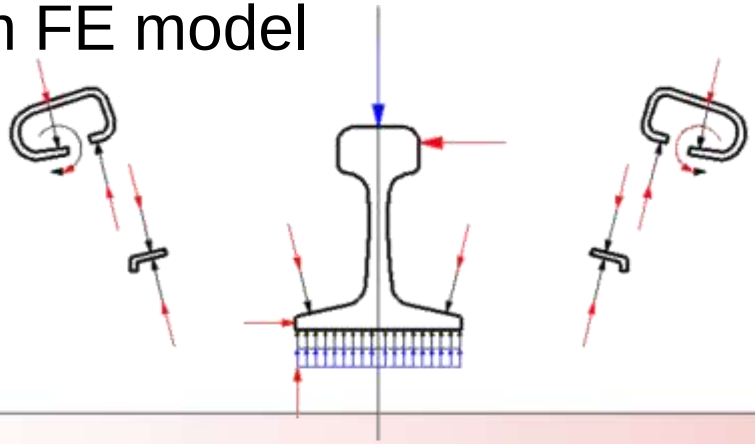


Outline

- Background and Research Justification
- RailTEC Concrete Crosstie Research
- Mechanistic Design Introduction
- Key Research Thrust Areas and Summary of Results
  - Laboratory Instrumentation
  - **Field Instrumentation**
  - Analytical Methods (FEA)
- Future Work
- Acknowledgements

Goals of Field Instrumentation

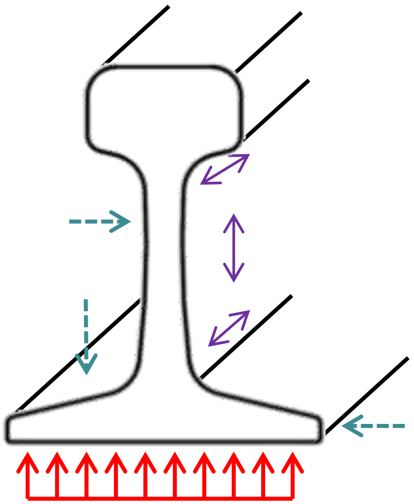
- Lay groundwork for mechanistic design of concrete crossties and elastic fasteners
- Quantify the demands placed on each component within the system
- Develop an understanding into field loading conditions
- Provide insight for future field testing
- Collect data to validate the UIUC concrete crosstie and fastening system FE model



Areas of Investigation

Rail

- Stresses at rail seat
- Strains in the web
- Displacements of web/base

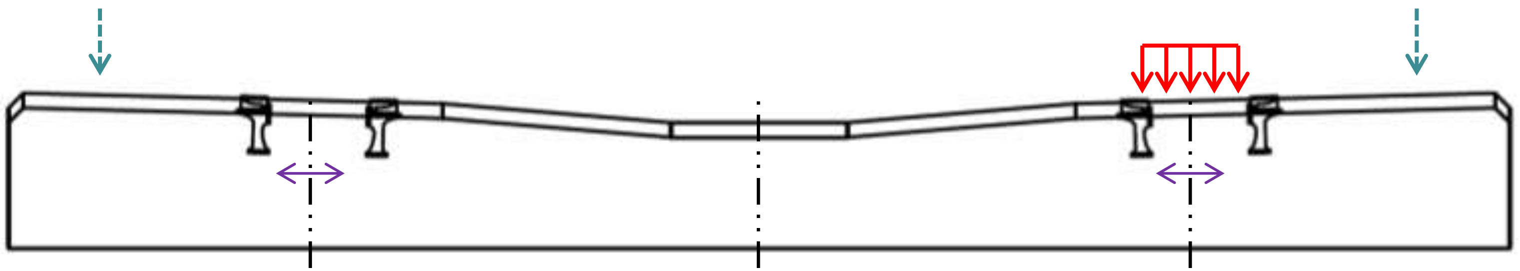


Fasteners/ Insulator

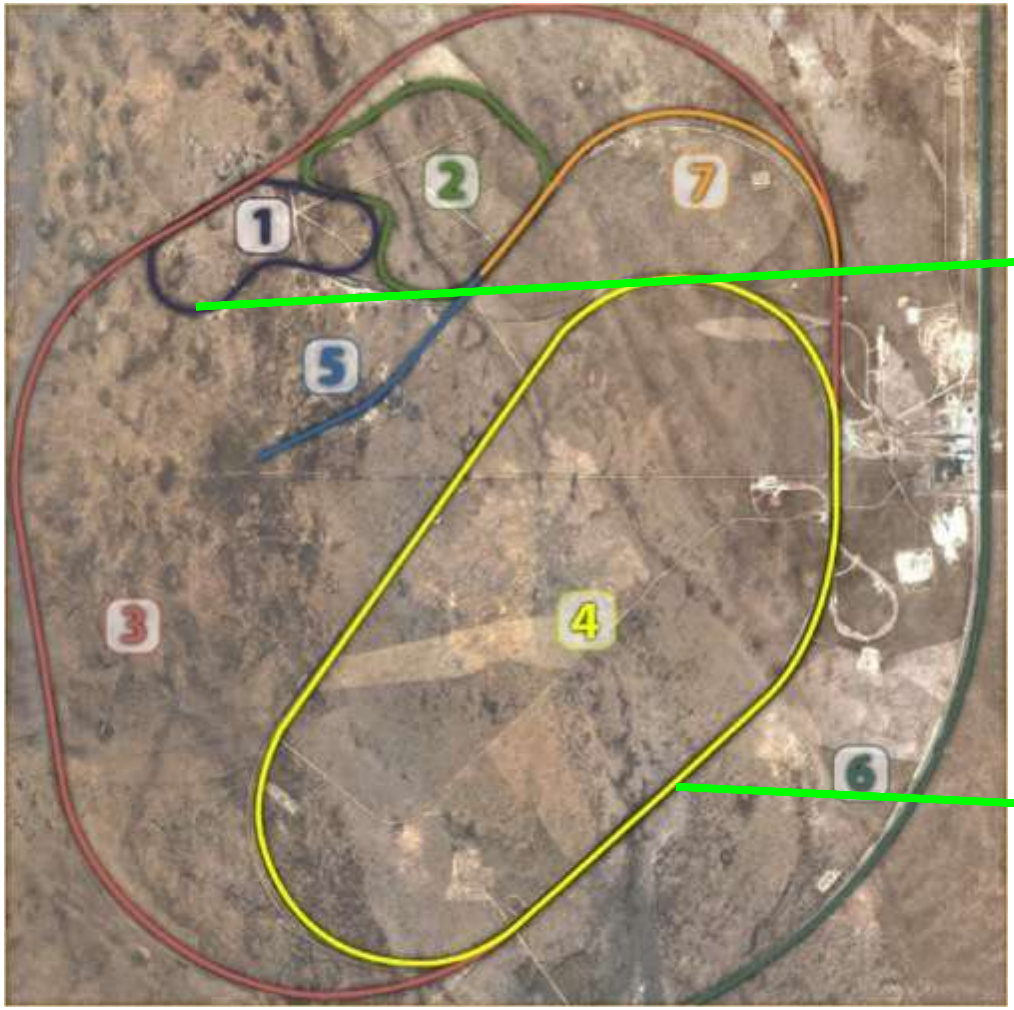
- Strain of fasteners
- Stresses on insulator

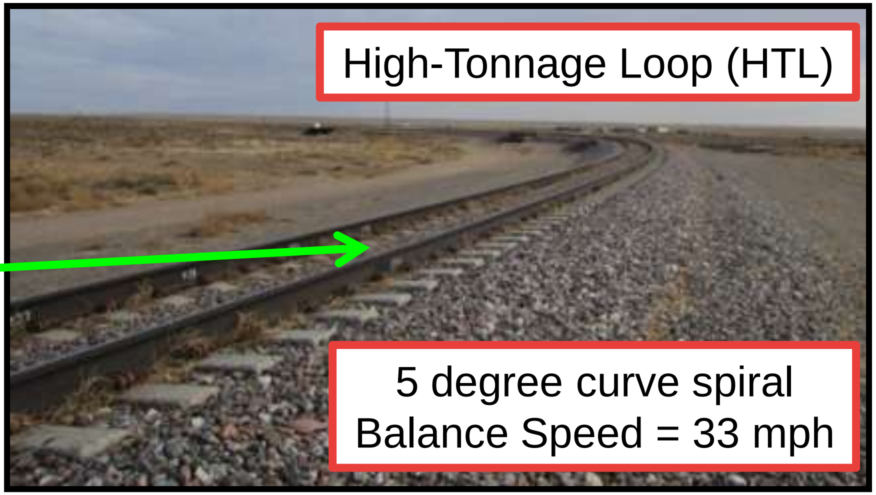
Concrete Crossties

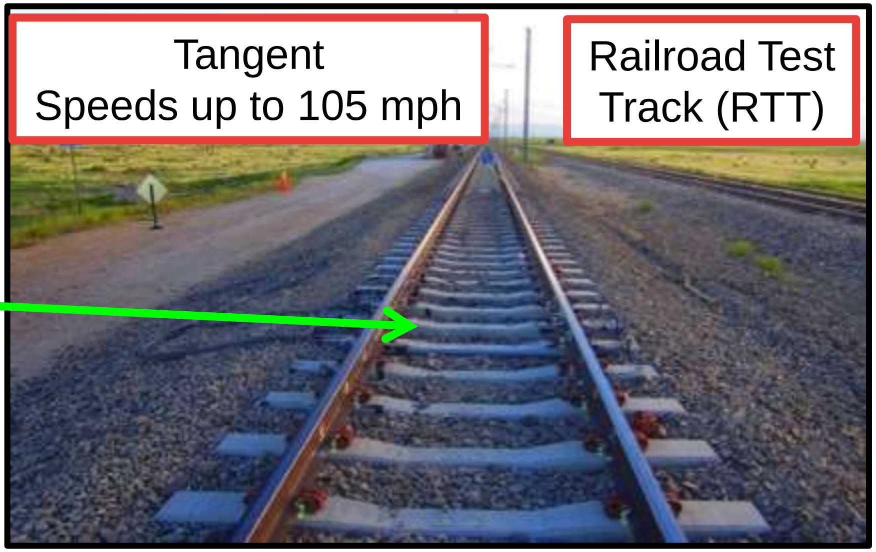
- Moments at the rail seat
- Stresses at rail seat
- Vertical displacements of crossties



TTCI Field Testing Locations





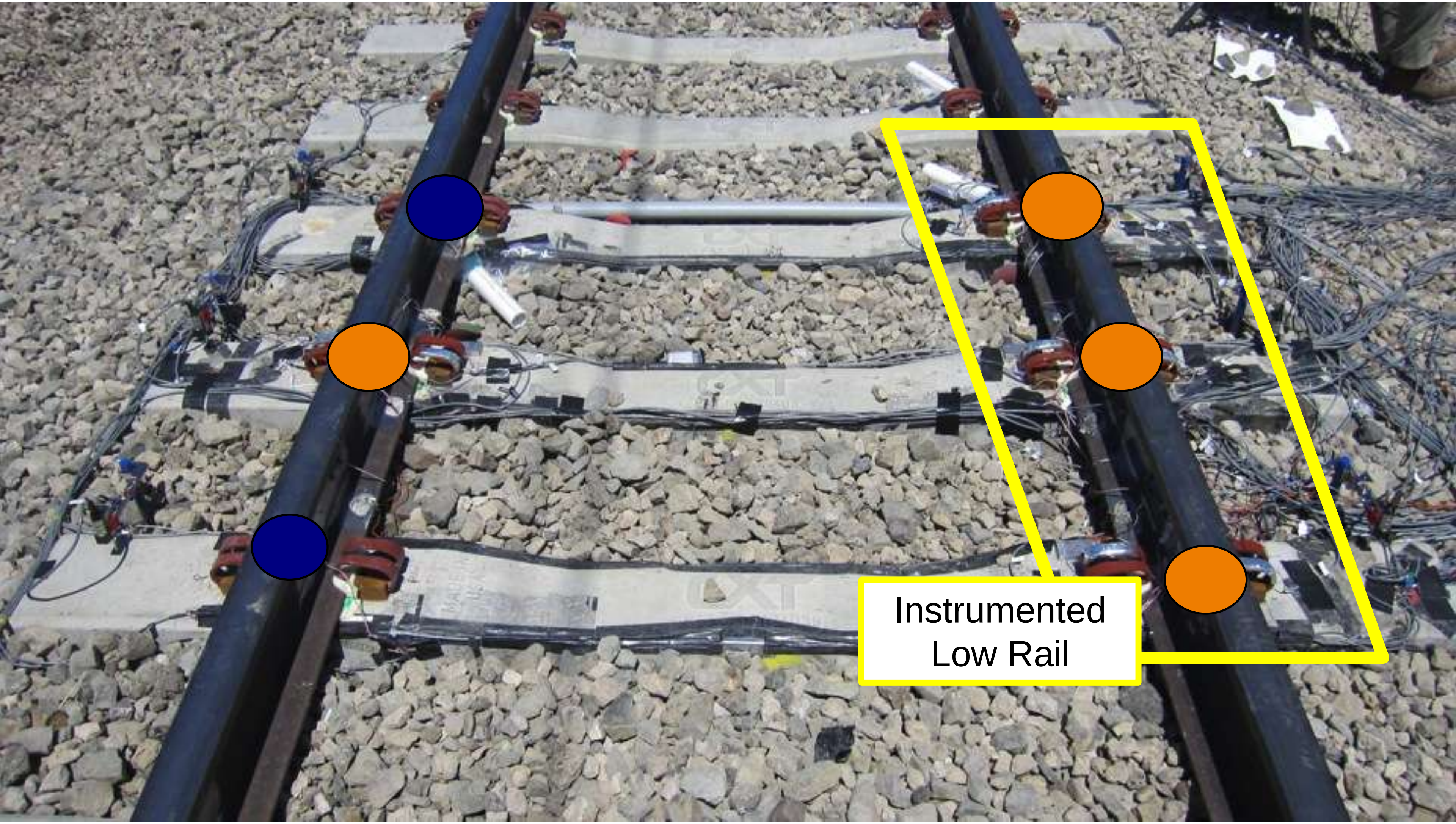


Loading Environment

- Track Loading Vehicle (TLV)
  - Static
  - Dynamic
    - Track modulus

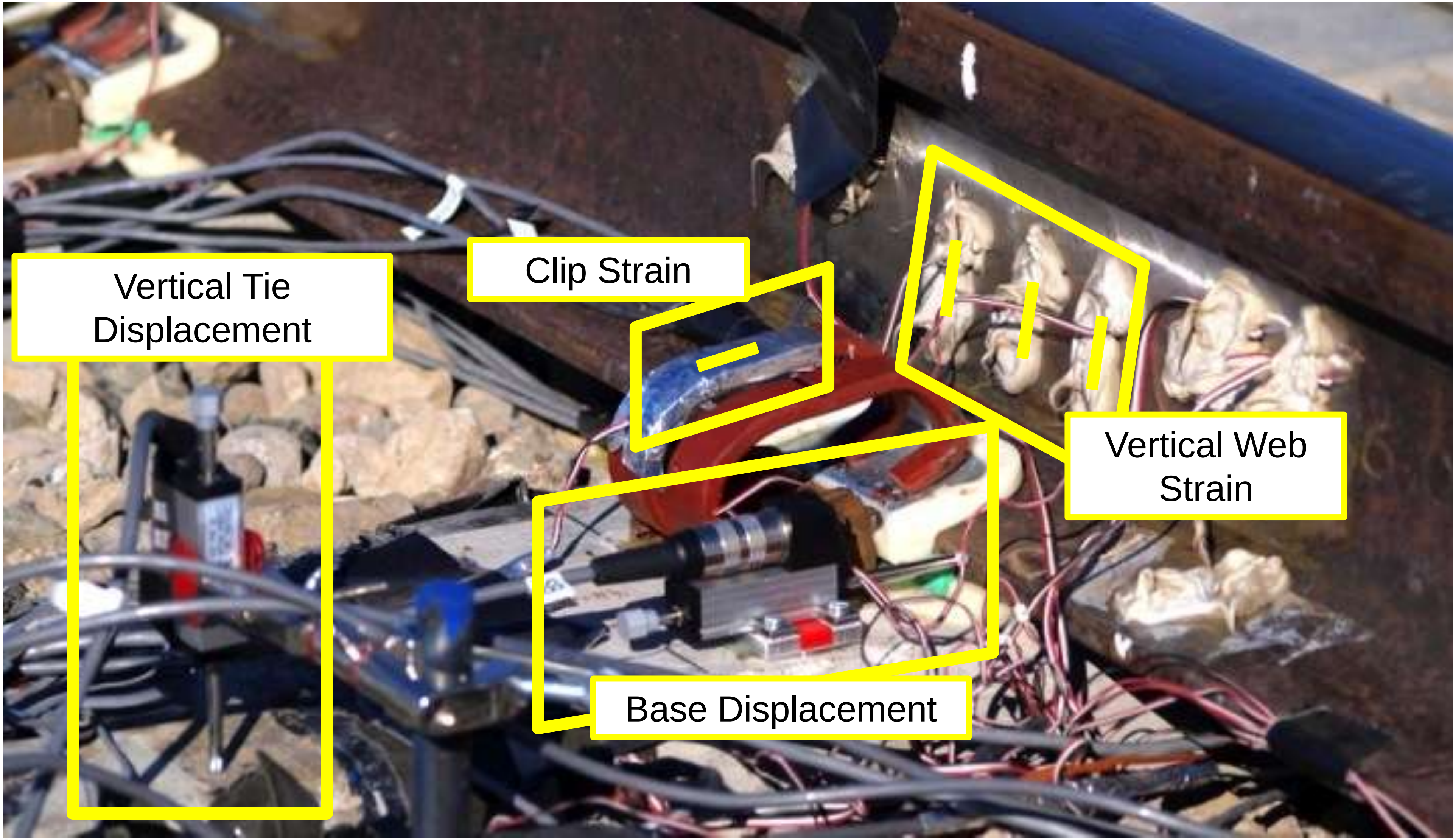
- Freight Consist
  - 6-axle locomotive (393k)
  - Instrumented car
  - Nine cars
    - 263, 286, 315 GRL Cars
- Passenger Consist
  - 4-axle locomotive (255k)
  - Nine coaches
    - 87 GRL

Fully Instrumented Rail Seats

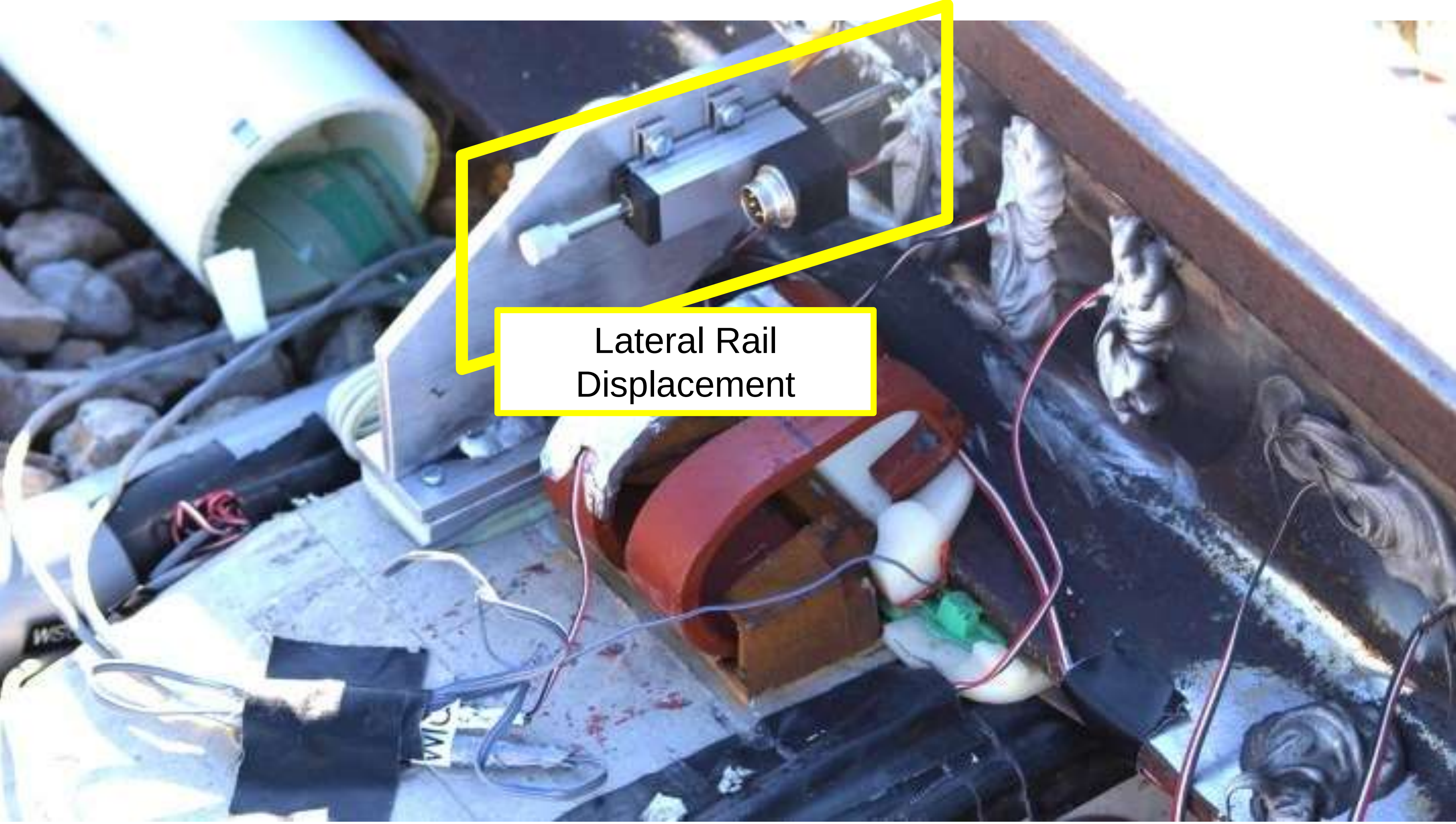


Instrumented Low Rail

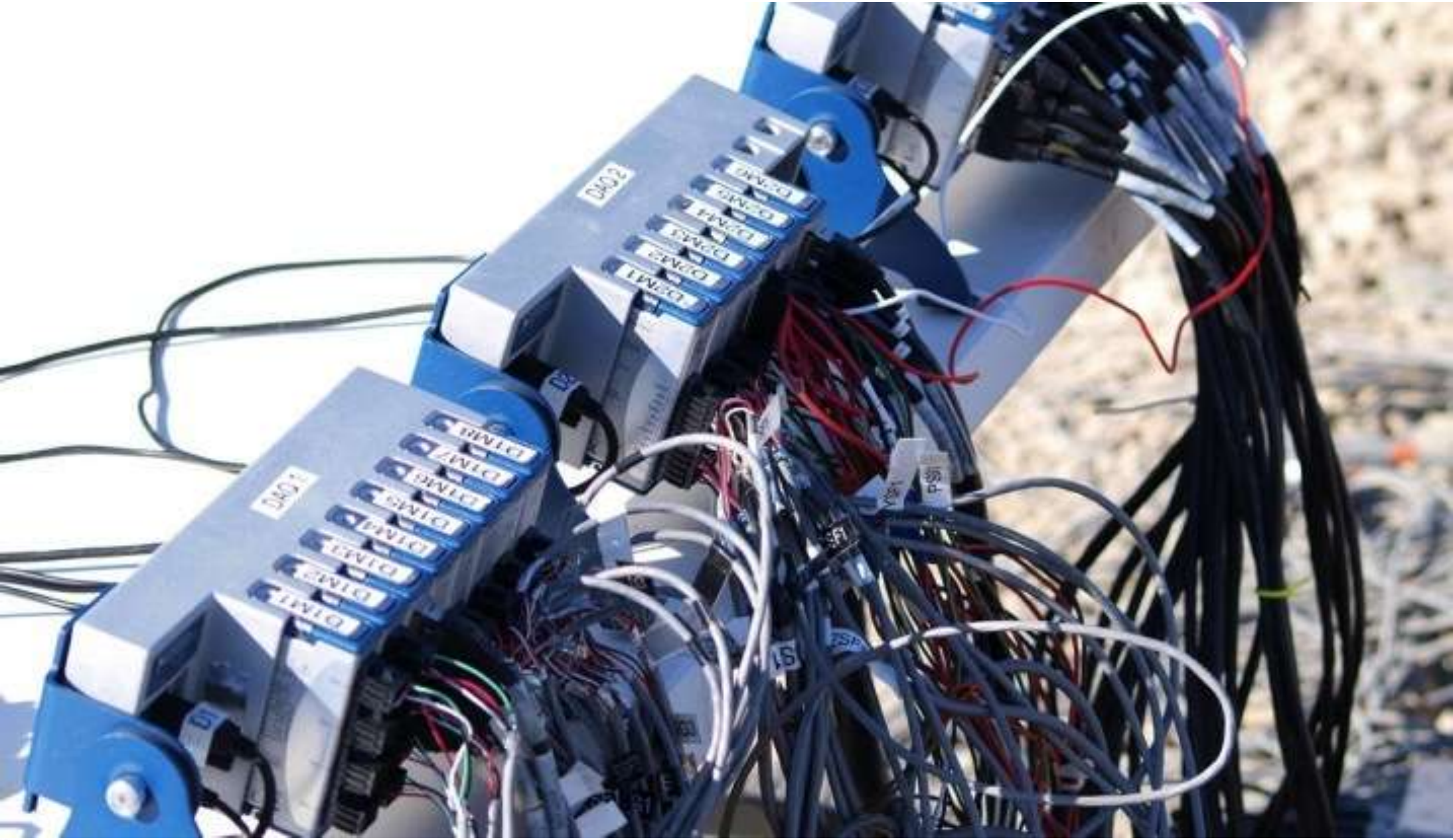
Field-side Instrumentation



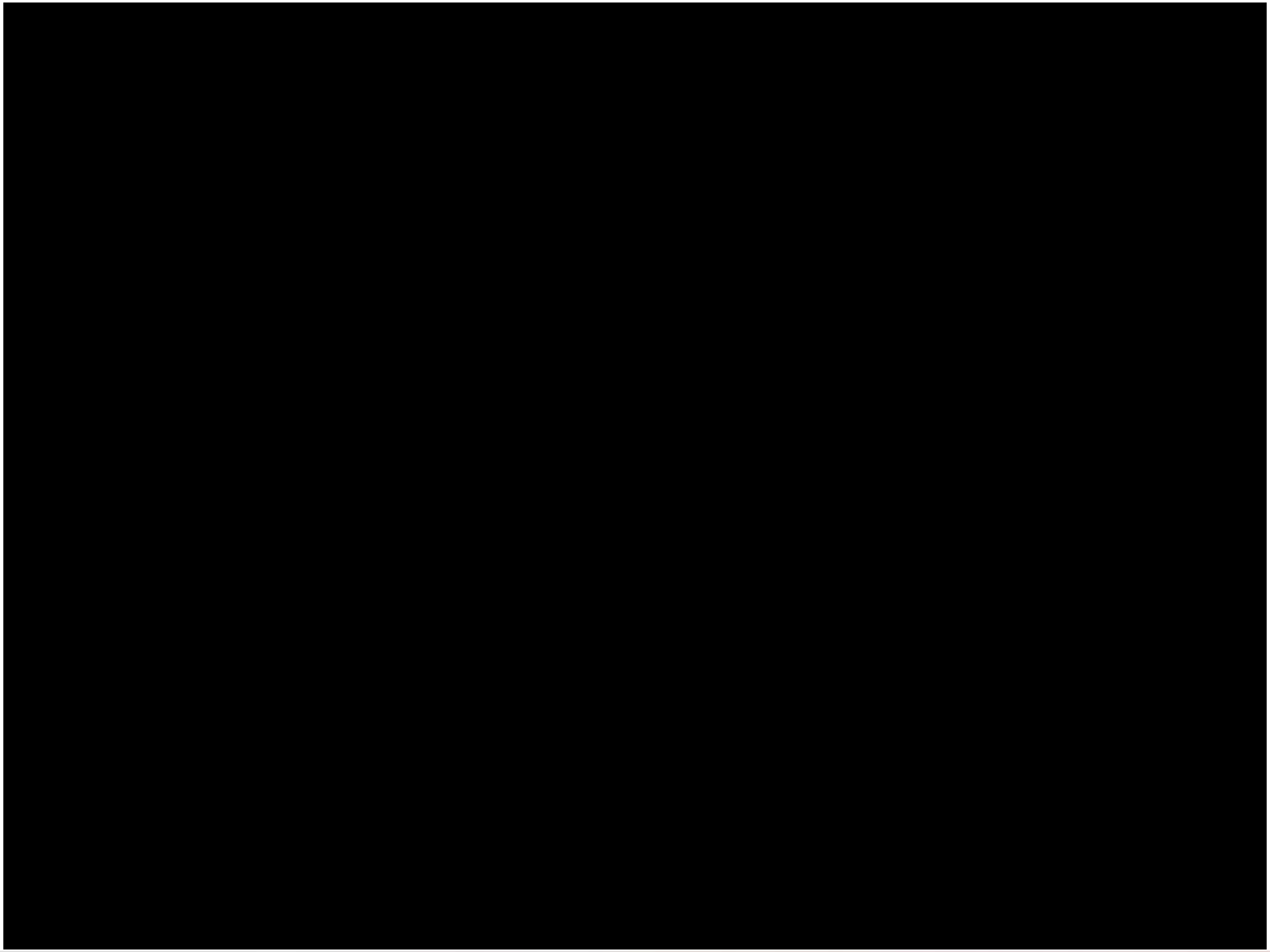
Gauge-side Instrumentation



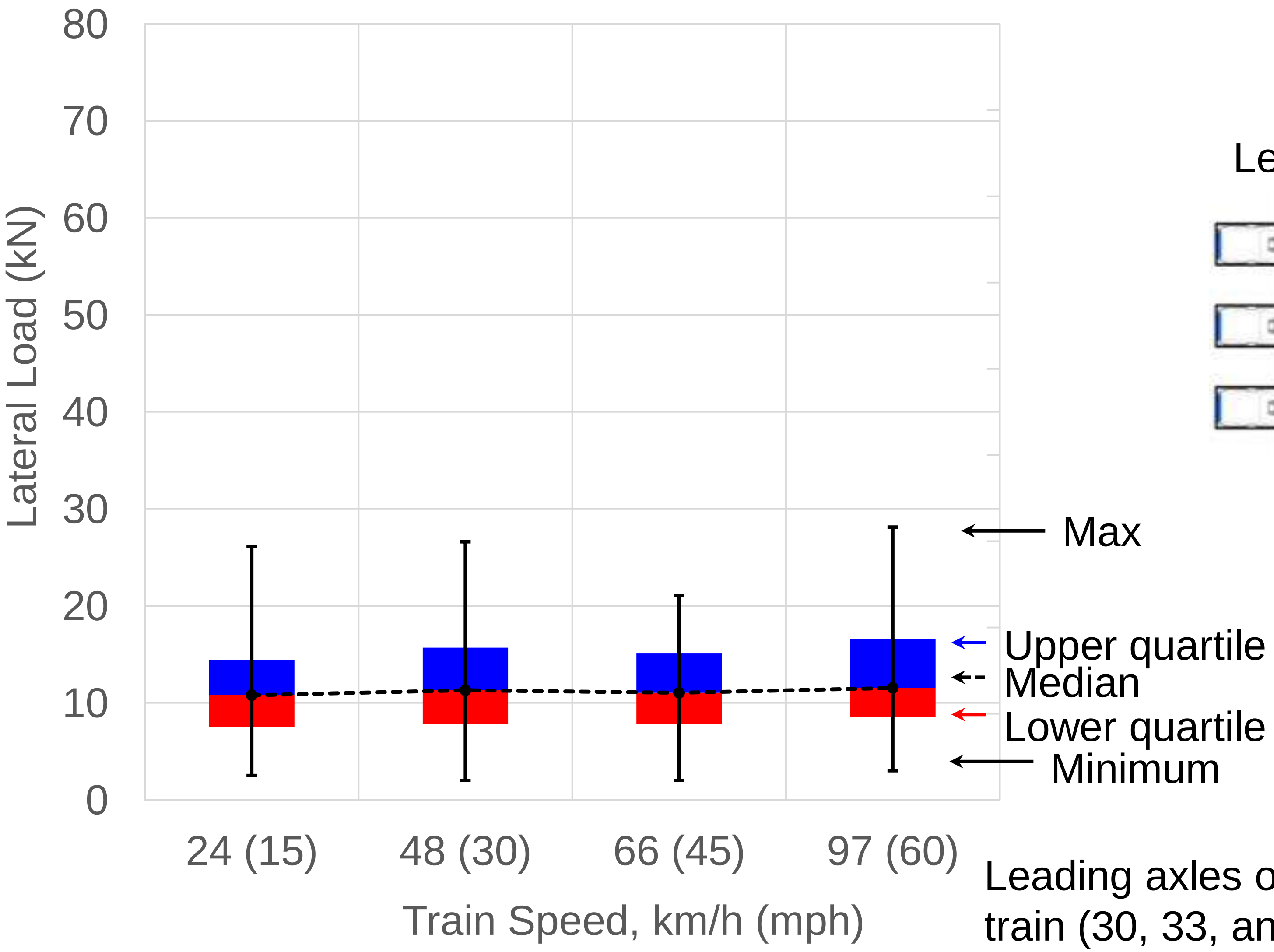
Data Acquisition System

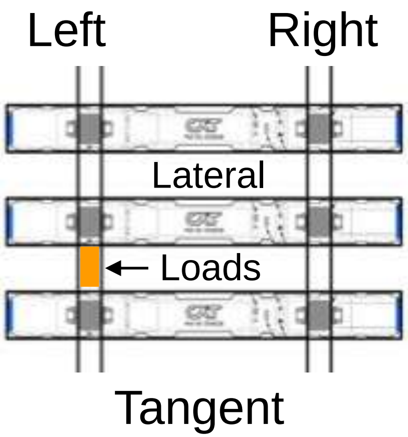


Tangent Track (RTT) – Passenger Train



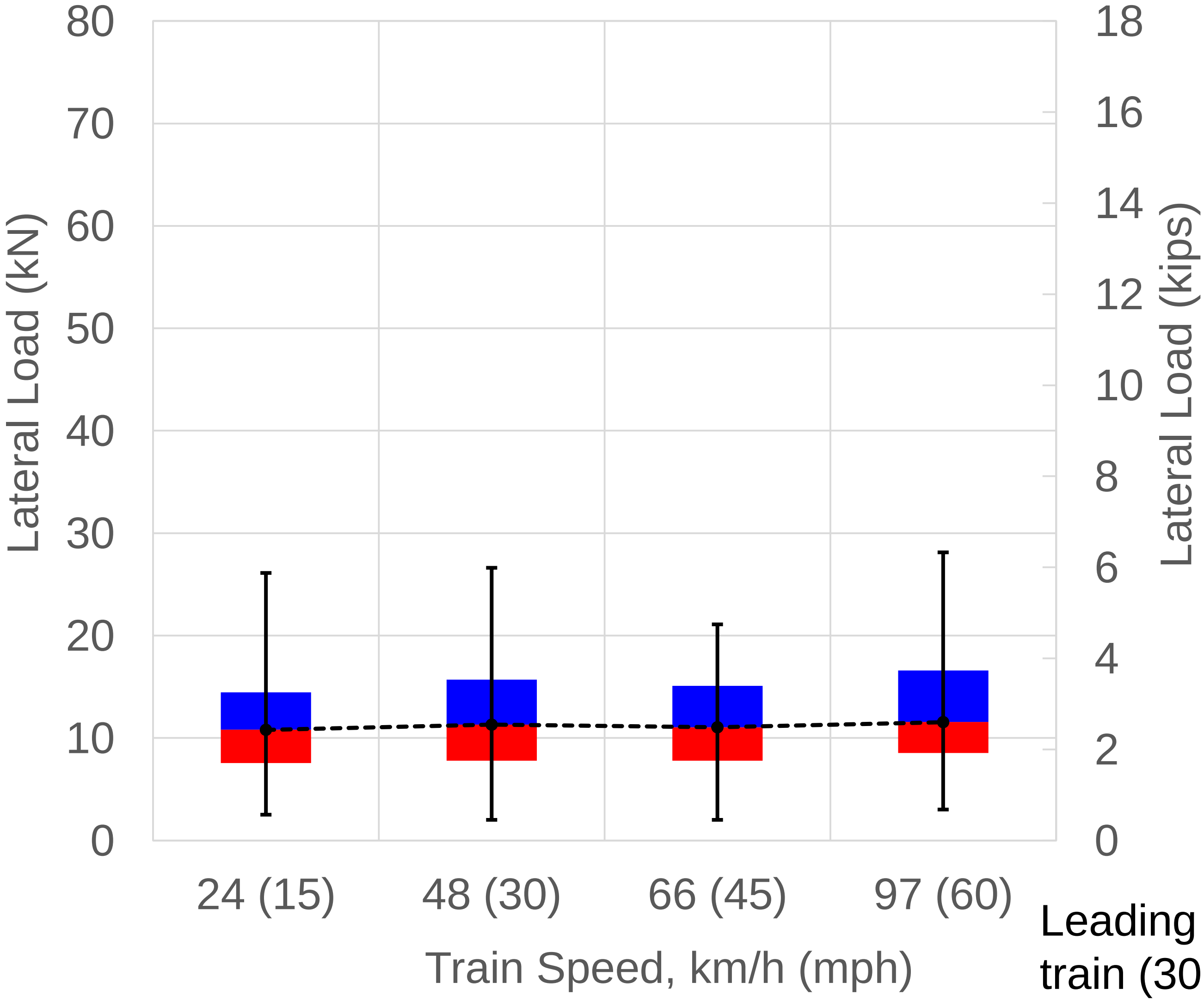
Lateral Loads on Tangent Track (Freight)

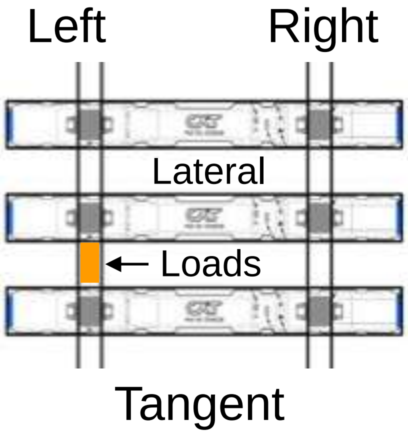




Leading axles of a 10-car freight train (30, 33, and 36t axle loads).

Lateral Loads on Tangent Track (Freight)

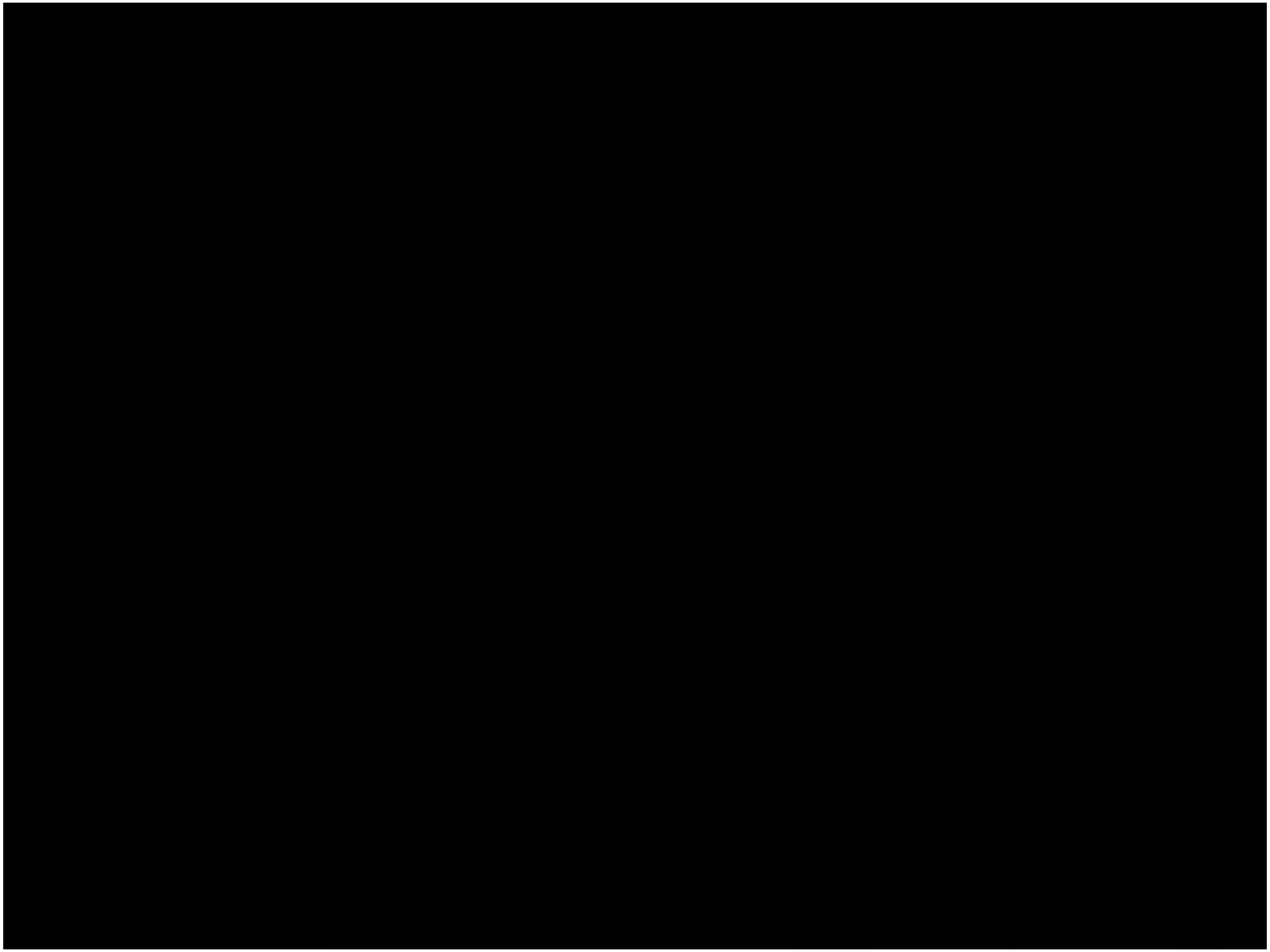




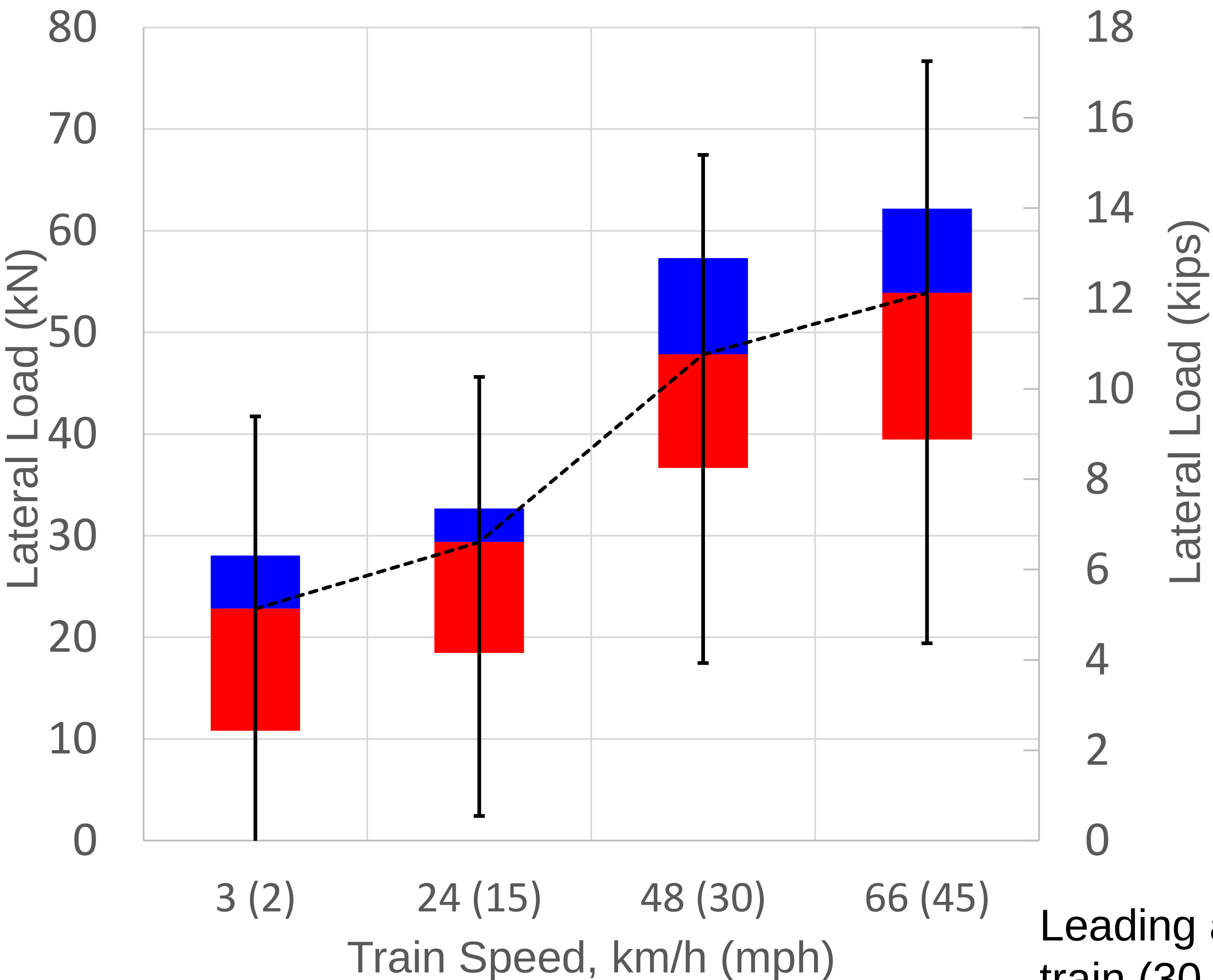
- No correlation between lateral loads and train speed on tangent track.

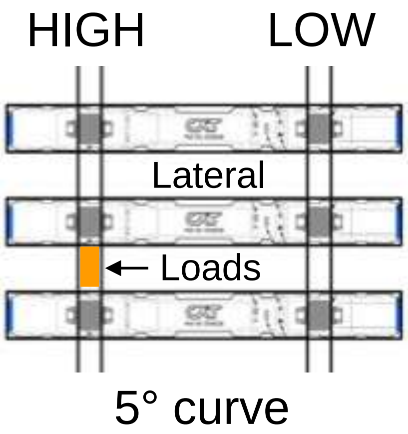
Leading axles of a 10-car freight train (30, 33, and 36t axle loads).

RTT Curved Instrumentation – Train Pass



Lateral Loads Acting on a Curve Track

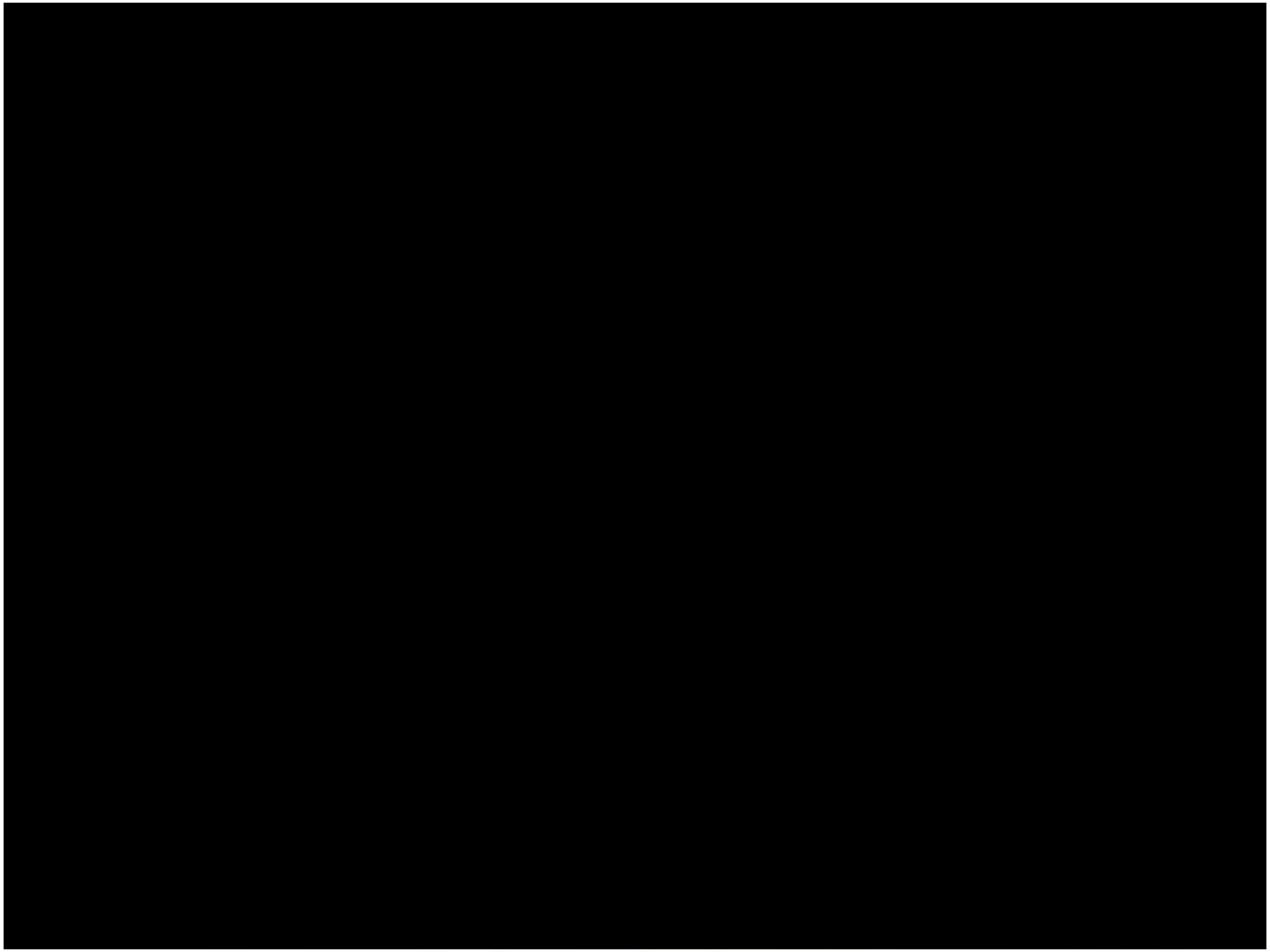




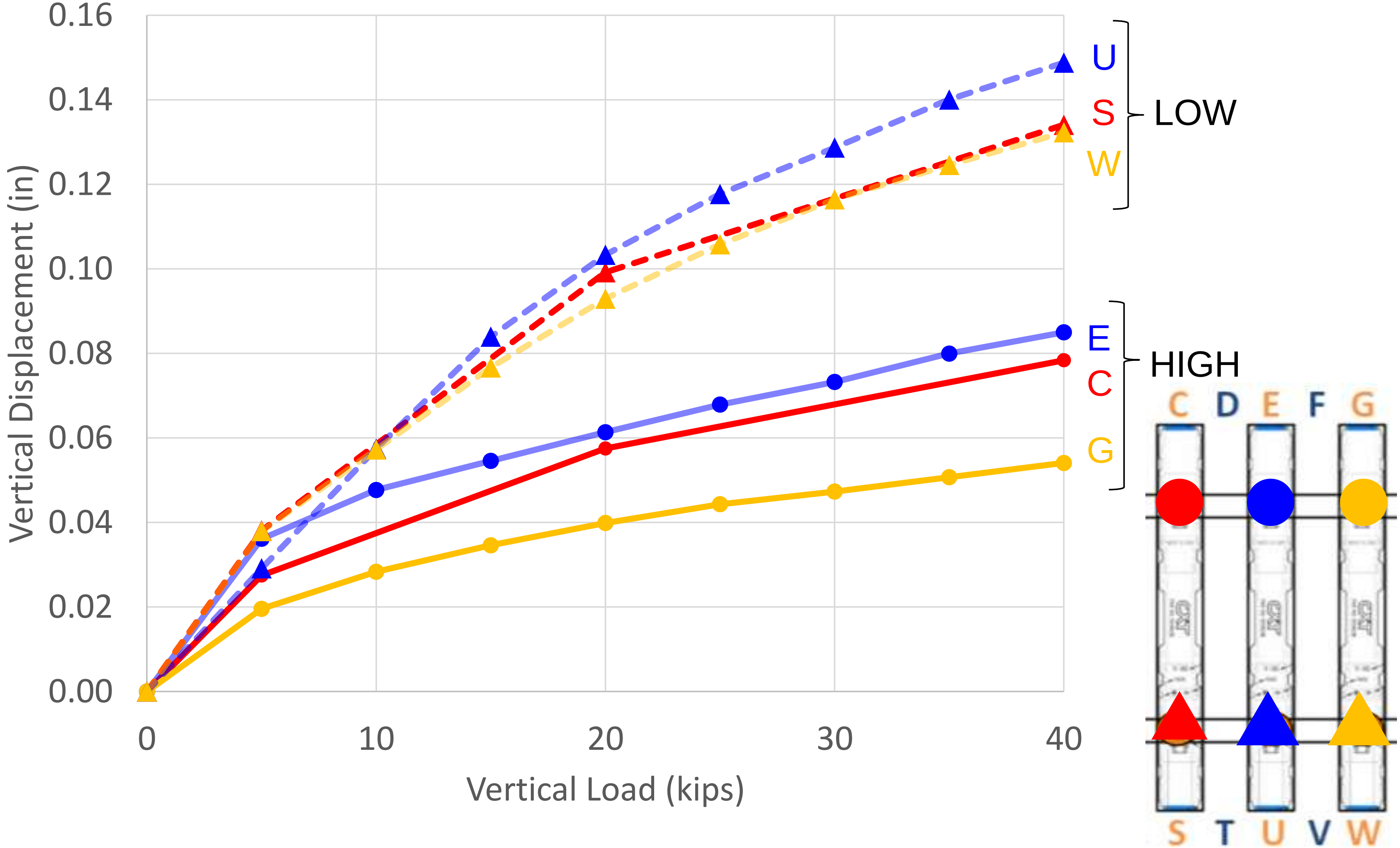
- Median load is ~5.5 times larger than what was recorded in tangent track.

Leading axles of a 10-car freight train (30, 33, and 36t axle loads).

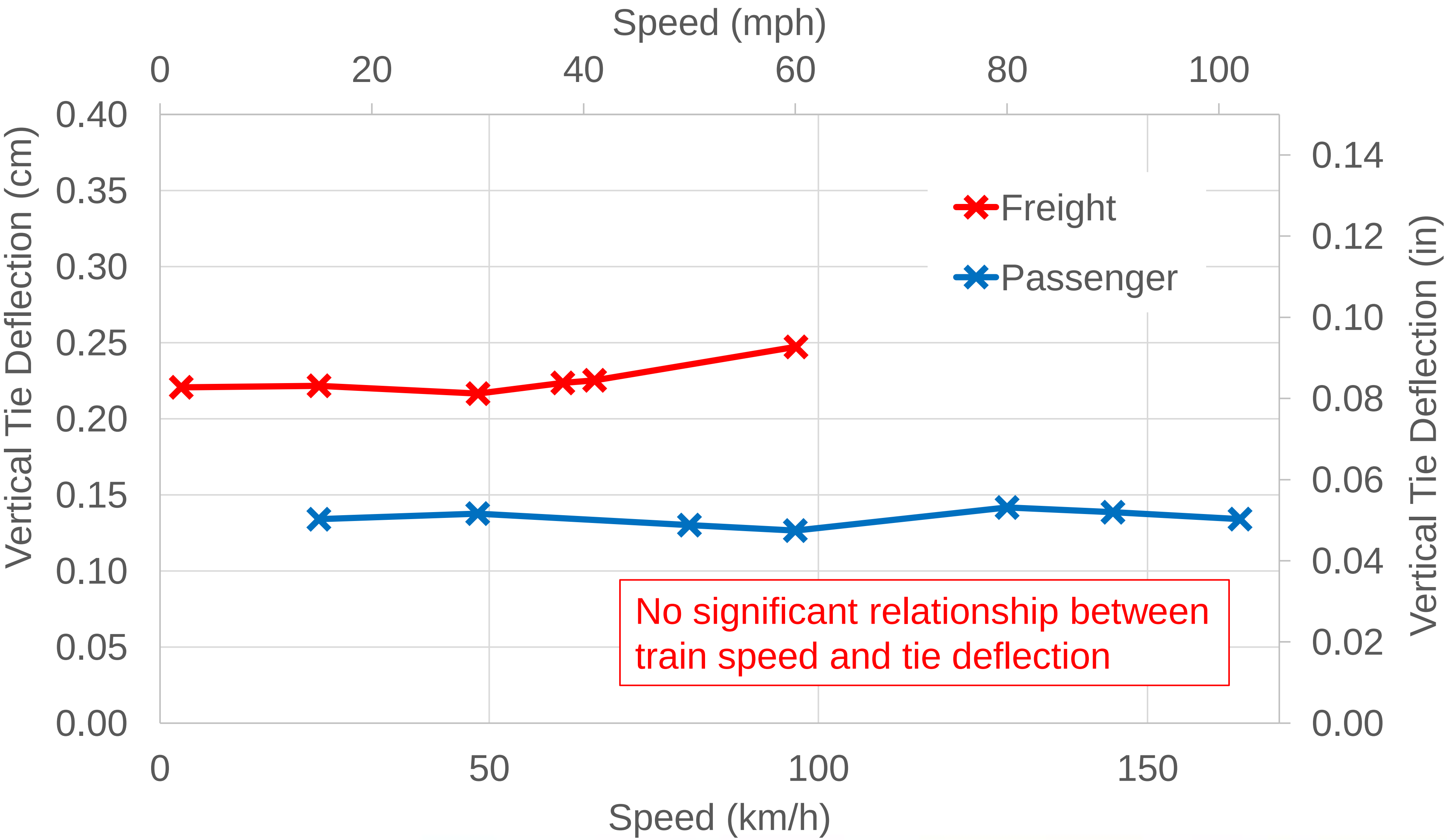
Global Track Deflections Under Passage of Freight Train



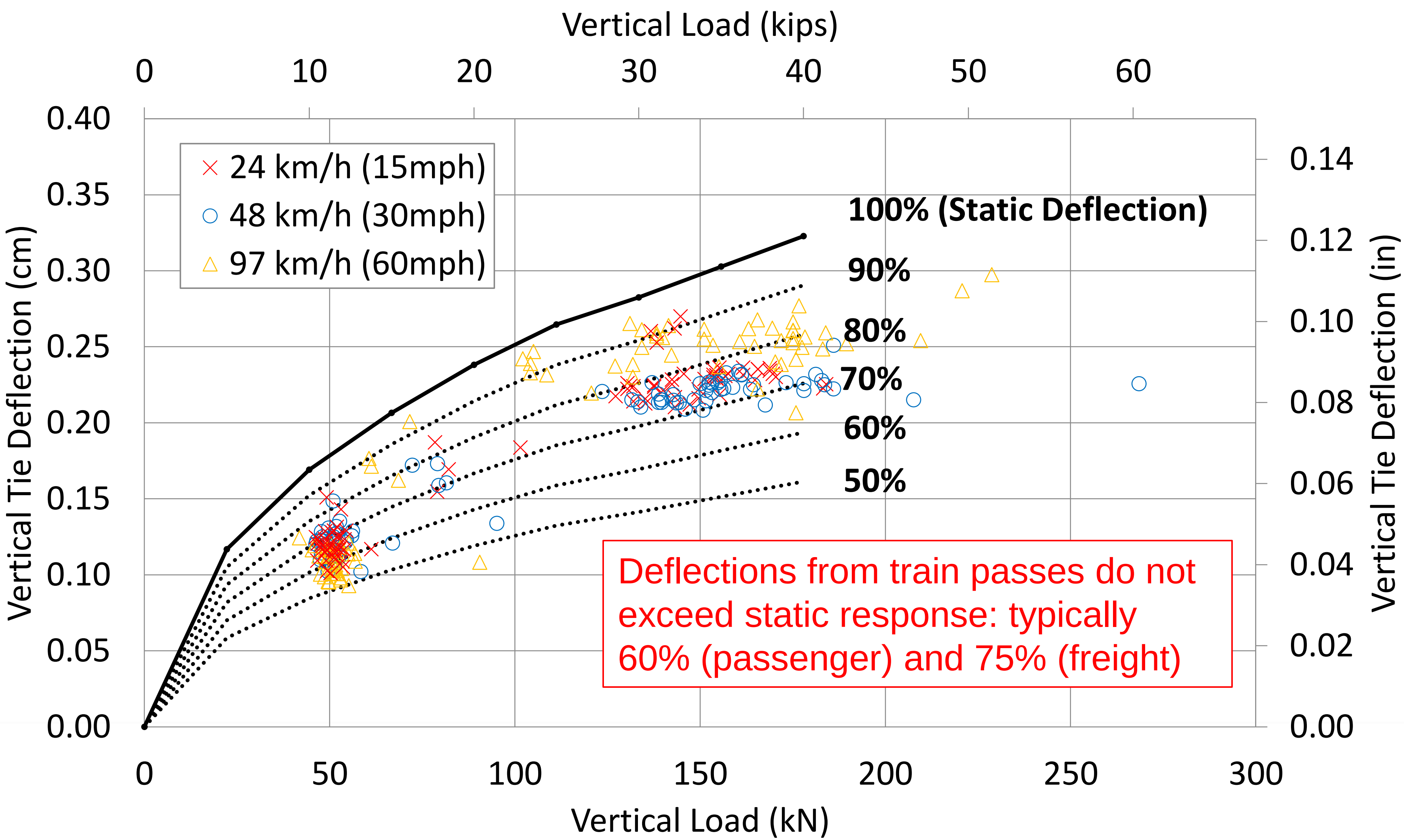
Vertical Displacements of Crossties (HTL)



Effect of Train Speed on Tie Deflection



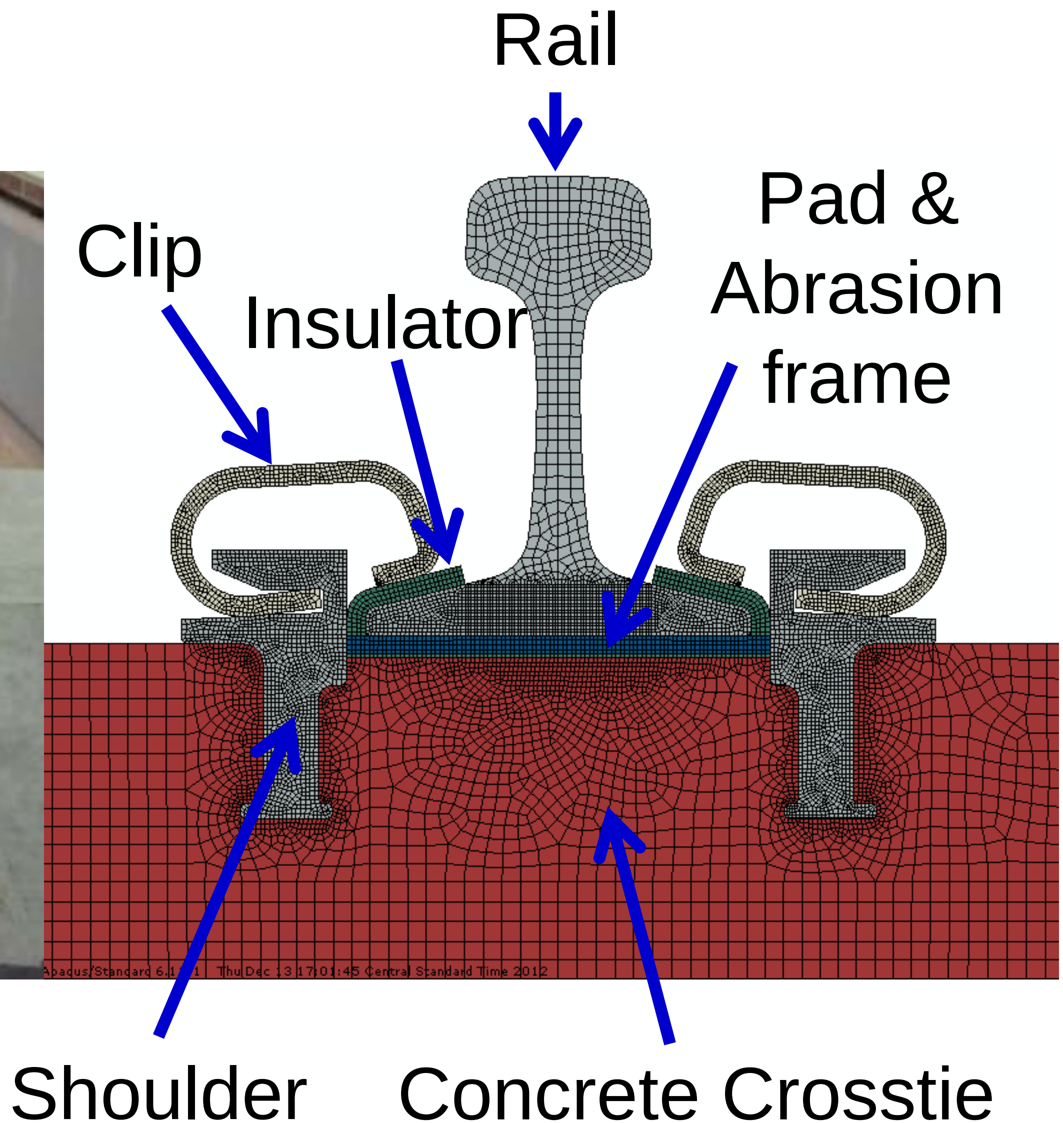
Effect of Load on Tie Deflection



Outline

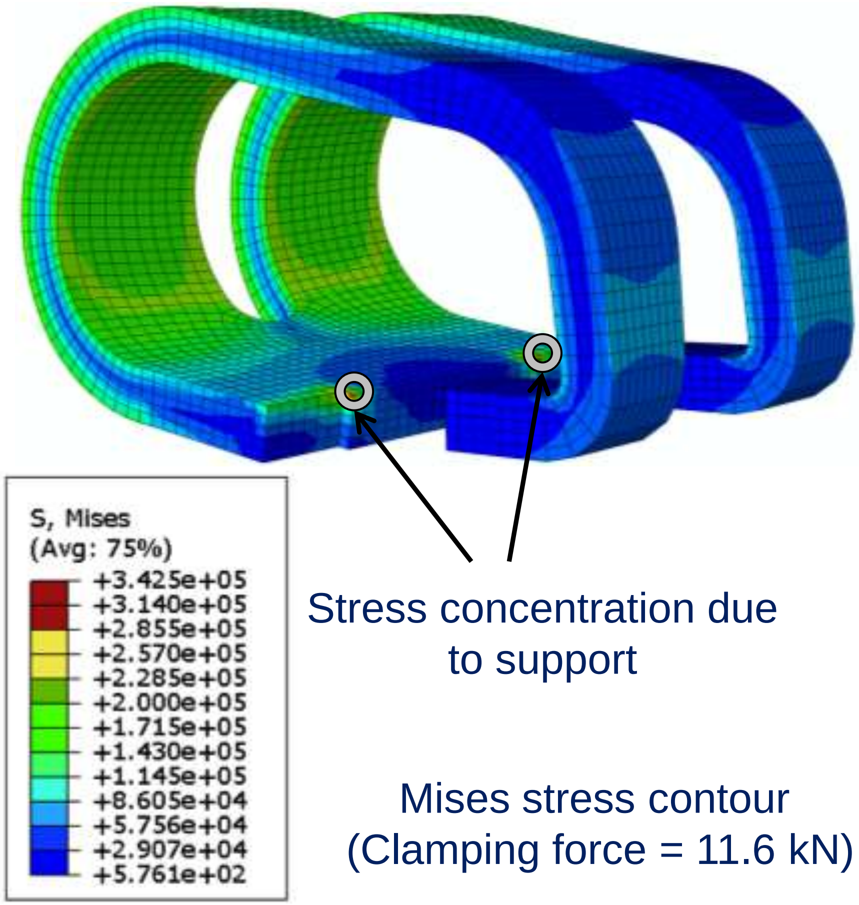
- Background and Research Justification
- RailTEC Concrete Crosstie Research
- Mechanistic Design Introduction
- Key Research Thrust Areas and Summary of Results
  - Laboratory Instrumentation
  - Field Instrumentation
  - **Analytical Methods (FEA)**
- Future Work
- Acknowledgements

Concrete Crosstie and Fastening System



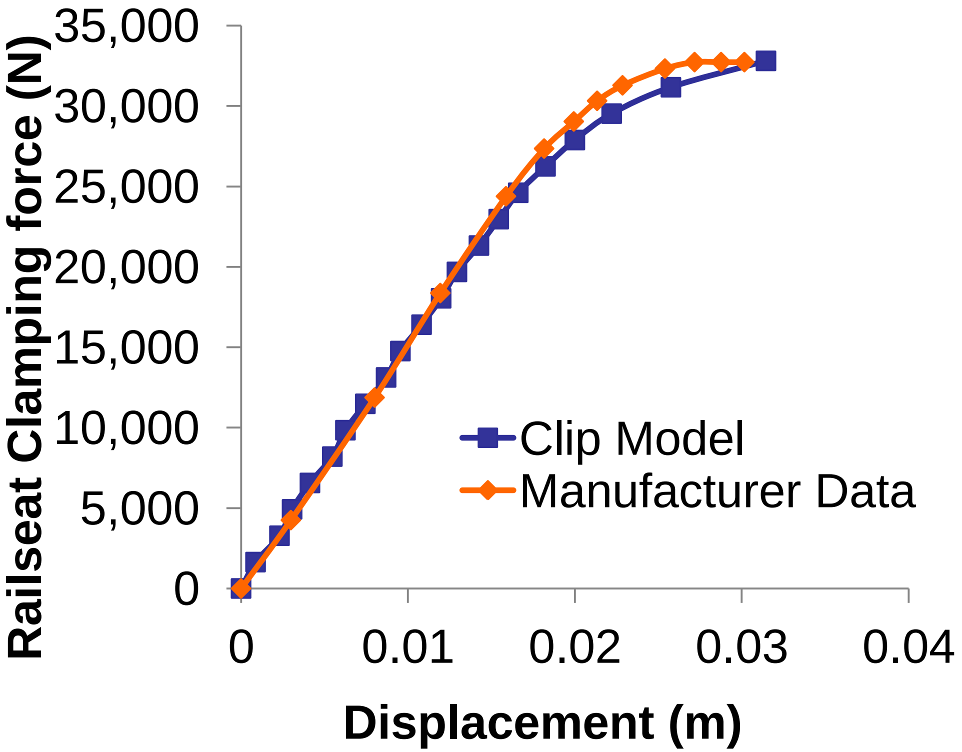
Component Modeling: Validation

- Clip Model



Stress concentration due to support

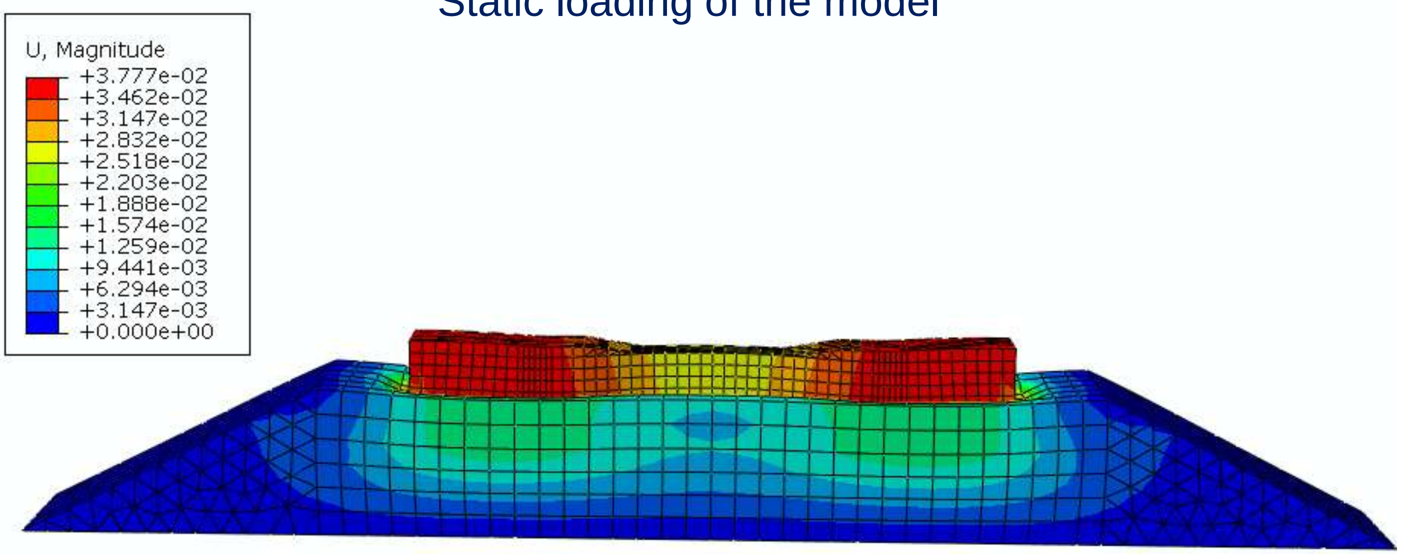
Mises stress contour (Clamping force = 11.6 kN)



Clamping force-displacement curves

Component Modeling: Concrete Crosstie and Ballast

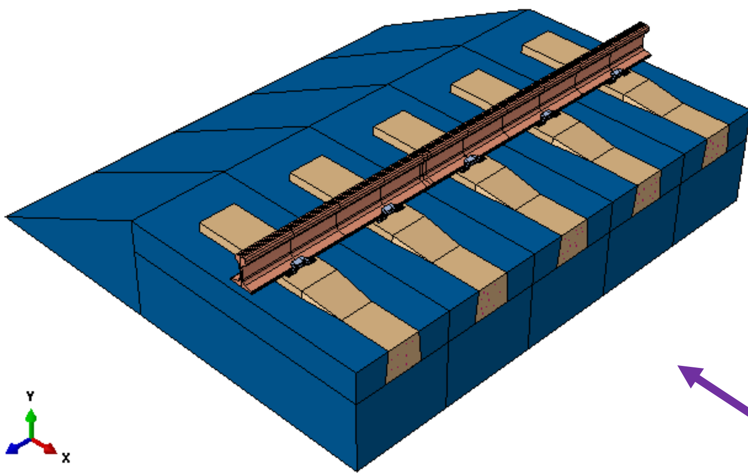
Static loading of the model



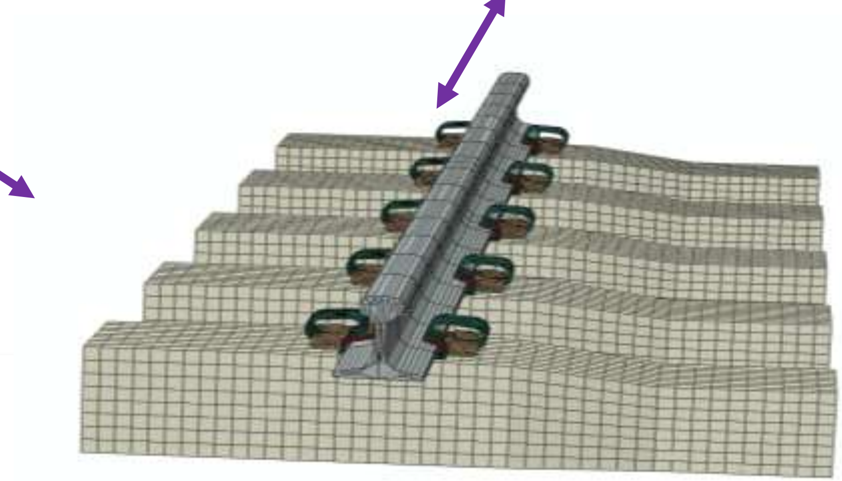
Deformation contour

System Model: Multiple-Tie Modeling

- Track loading vehicle (TLV) applying vertical and lateral loads to the track structure in field
- The symmetric model including 5 crossties

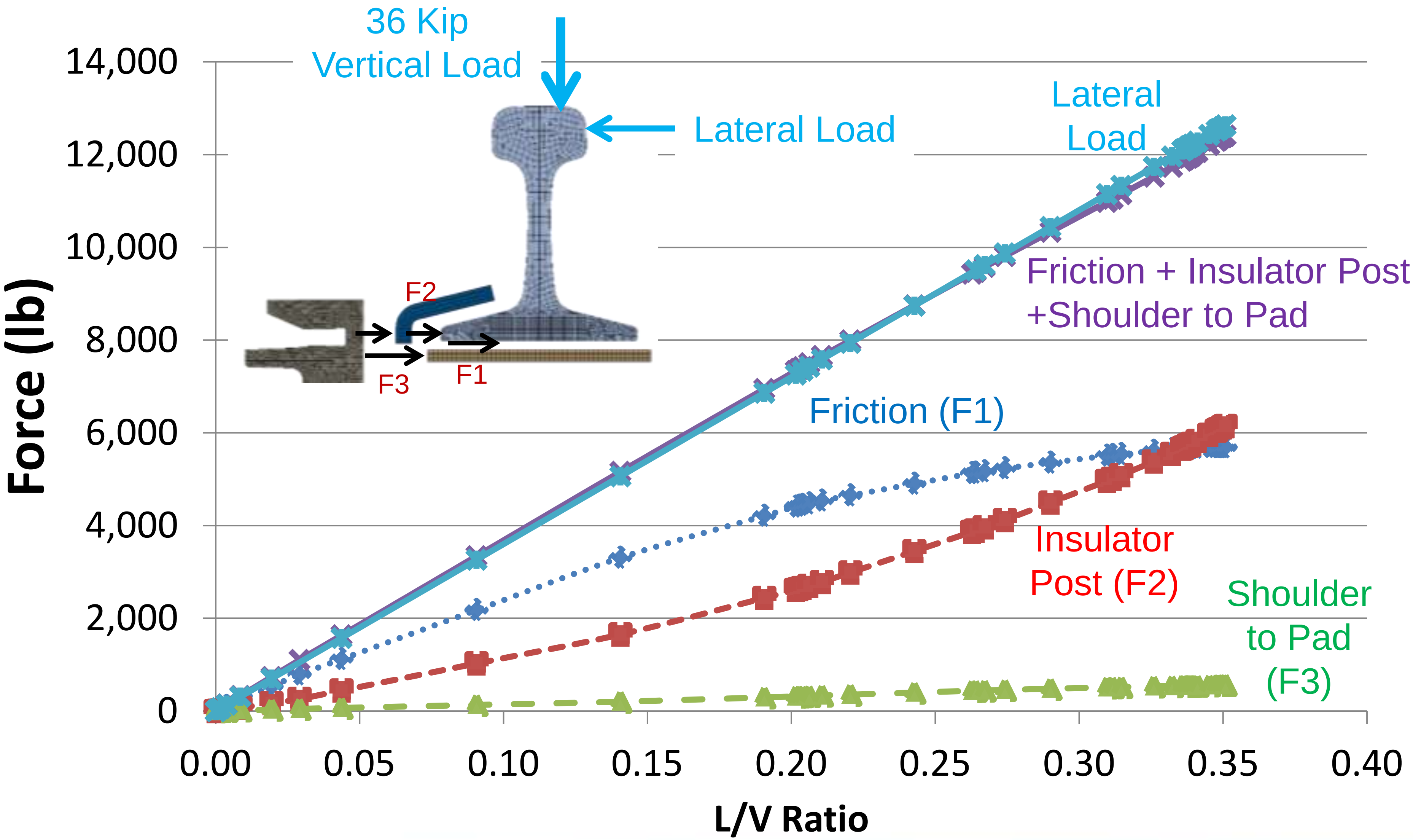


Simplified model:
Fastening system were replaced by BCs and pressure



Detailed model with the fastening system

System Modeling: Lateral Load Path



Outline

- Background and Research Justification
- RailTEC Concrete Crosstie Research
- Mechanistic Design Introduction
- Key Research Thrust Areas and Summary of Results
  - Laboratory Instrumentation
  - Field Instrumentation
  - Analytical Methods (FEA)
- **Future Work**
- Acknowledgements

Current Research Thrust Areas

- Continued **data analysis** to understand the governing mechanics of the system by investigating the:
  - elastic fastener (clamp) strain response
  - number of ties effected simultaneously
  - bending modes of the crossties
  - pressure magnitude and distribution at the rail seat
- Continued **comparison and validation** of the UIUC tie and fastening system finite element model (Chen, Shin)
- Preparation for **instrumentation trip** (May 2013)
  - Focus on lateral load path by gathering
    - relative lateral tie displacements
    - global lateral tie displacements
    - load transferred to the clip, insulator-post, and shoulder
- Small-scale, **evaluative tests** on Class I Railroads

RailTEC Concrete Tie Research Team

Acknowledgements

Research Sponsors:

U.S. Department of Transportation
Federal Railroad Administration

Amsted RPS

Amsted Rail

National University Rail Center

Association of American Railroads

Mextrans

Kansas City Southern Lines

CN

FRA Tie and Fastener BAA Industry Partners:

Union Pacific BUILDING AMERICA®

GIC Ingeniería y Construcción S.A. de C.V.

Amsted RPS

Amsted Rail

BNSF Railway

LBFoster CXT Concrete Ties

Amtrak®

Hanson

TTX

Other Supporting Organizations

BNSF RAILWAY

UNION PACIFIC BUILDING AMERICA®

AMTRAK®

NORFOLK SOUTHERN

CSX

CN

CANADIAN PACIFIC RAILWAY

U.S. Department of Transportation

Federal Railroad Administration

Amsted RPS

Amsted Rail

GIC

GIC INGENIERÍA Y CONSTRUCCIÓN S.A. DE C.V.

LBFoster

CXT Concrete Ties

HANSON

NORTRAK

BASF

The Chemical Company

PANDROL

TRACK SYSTEMS

DELACHAUX GROUP

vossloh

TTCI

Transportation Technology Center, Inc.

RAILTEC
Rail Transportation And Engineering Center

Questions?

Riley Edwards
Senior Lecturer
Department of Civil and Environmental Engineering
University of Illinois, Urbana-Champaign
Email: jedward2@illinois.edu

Brandon Van Dyk
Graduate Research Assistant
Department of Civil and Environmental Engineering
University of Illinois, Urbana-Champaign
Email: vandyk2@illinois.edu