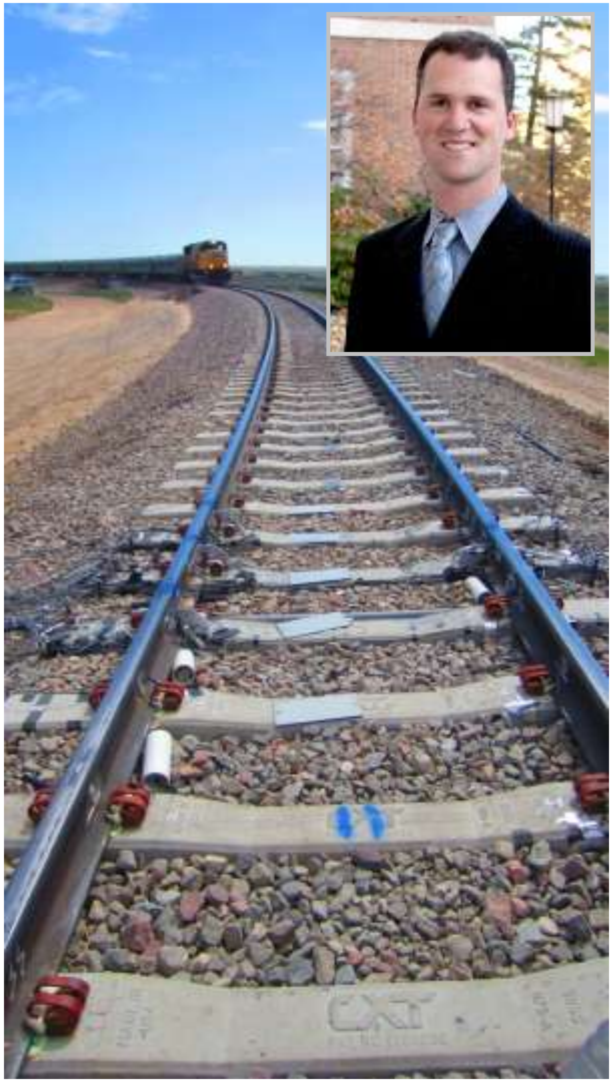
William W. Hay Railroad Engineering Seminar



Concrete Crossties and Fastening Systems: Previous Experiences, Current Research, and Future Advances

J. Riley Edwards

Senior Lecturer – RailTEC

University of Illinois at Urbana-Champaign

12:00 - 1:30 PM • 1 March 2013

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UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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Concrete Crossties and Fastening Systems: Previous Experiences, Current Research, and Future Advances



William W. Hay Railroad Engineering Seminar

Urbana, IL, USA

1 March 2013

J. Riley Edwards and the entire UIUC Concrete Crosstie Research Team

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
  - Materials Research
  - Laboratory Instrumentation
  - Field Instrumentation
  - Analytical Methods (FEA)
- Future Work
- Acknowledgements

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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)

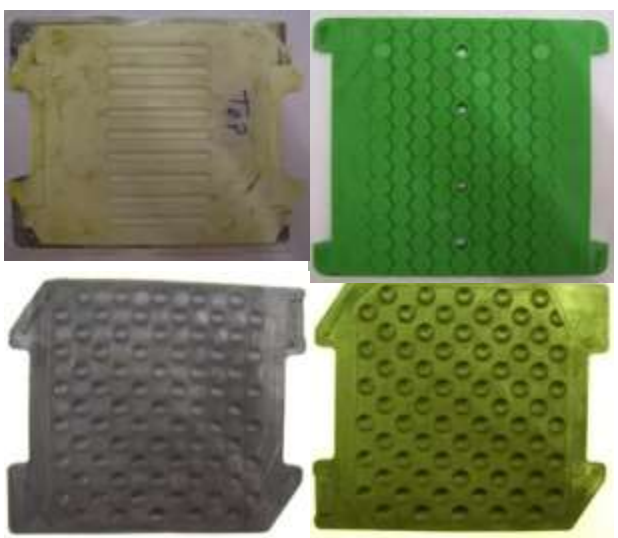
Approximate

Concrete Crosstie and Fastening System Components

Concrete Crossties

Clips

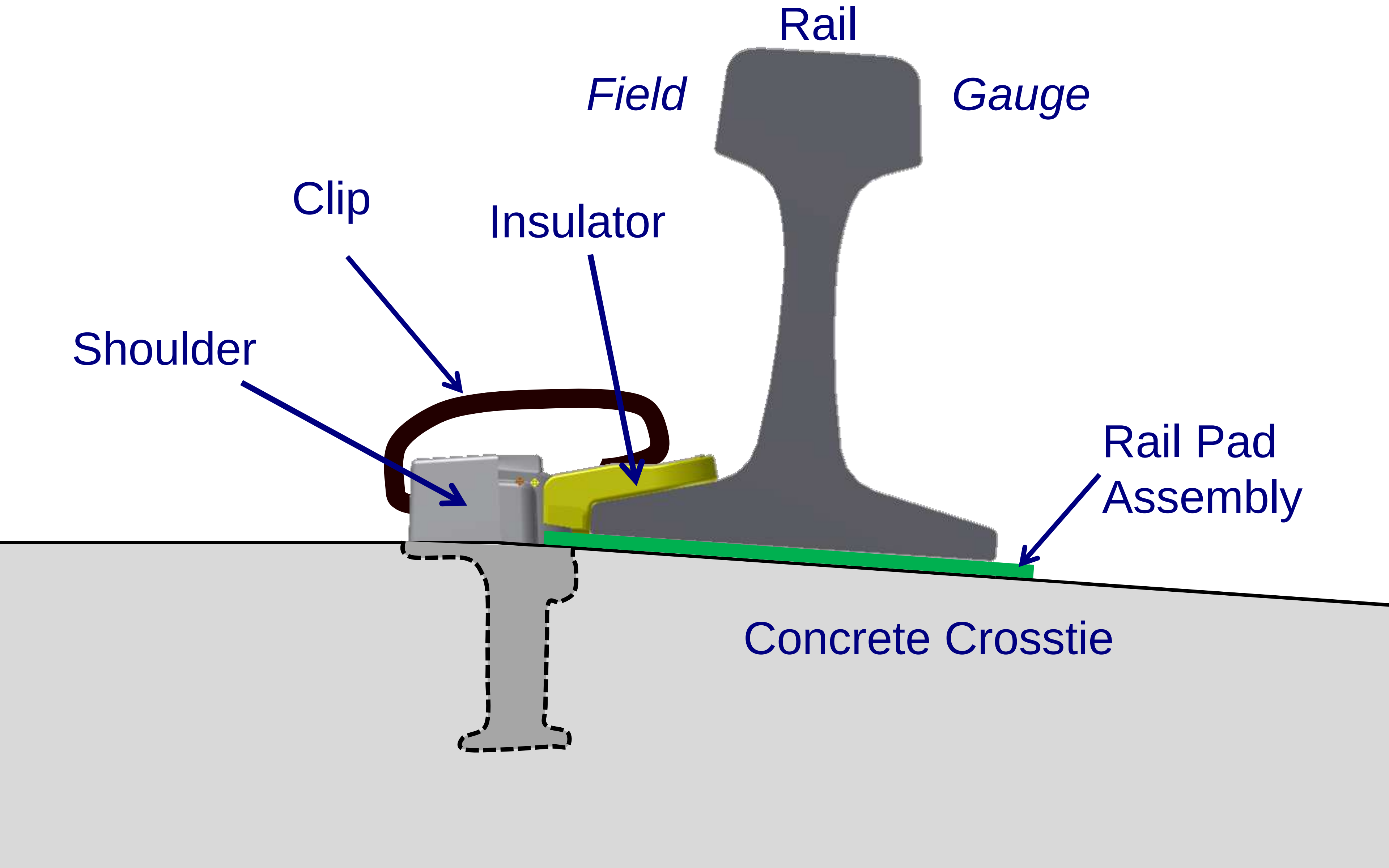
Rail Pads



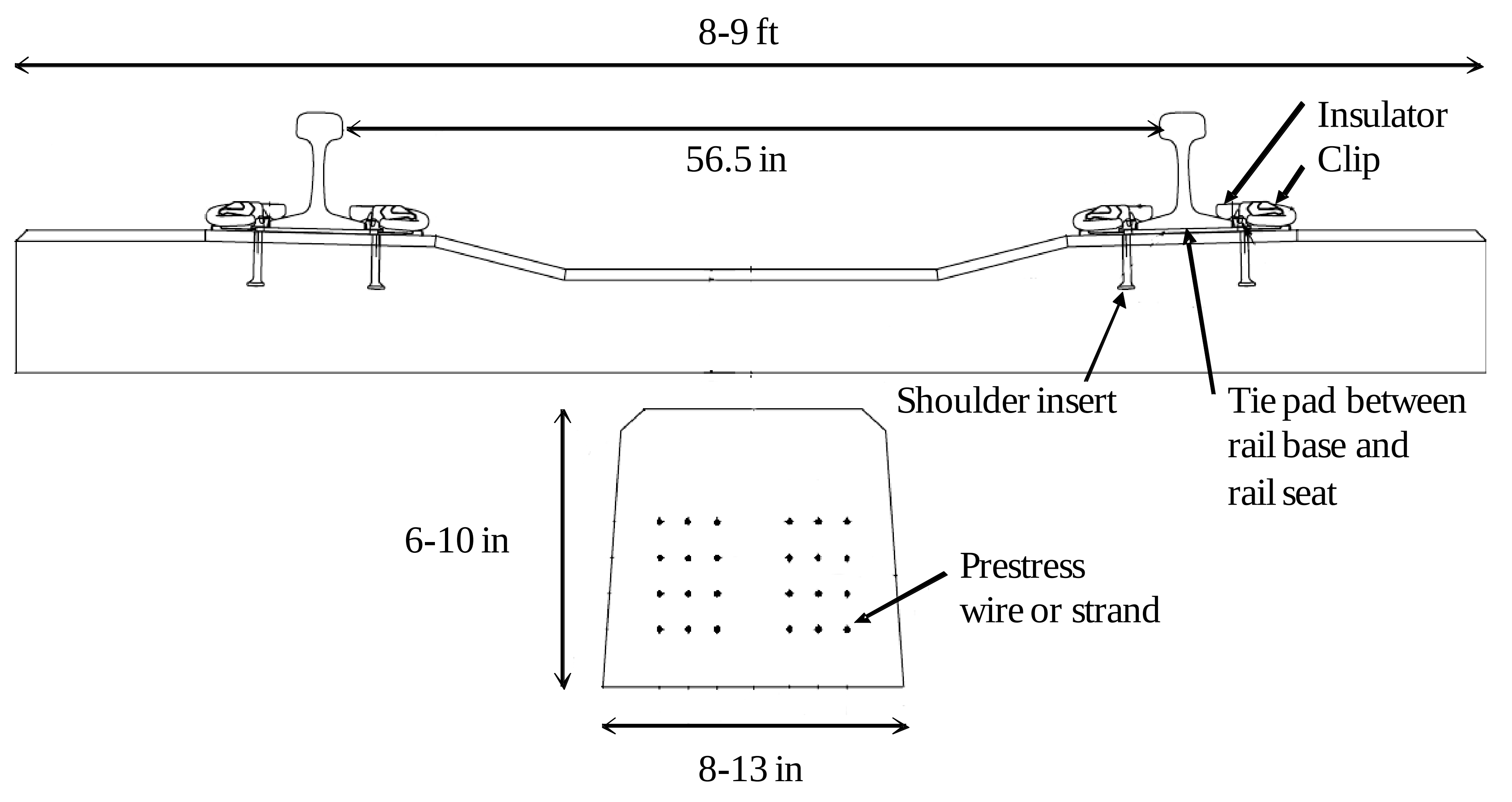
Fastening Insulators

Shoulder

Fastening System Components



Complete System



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

2012 International Survey Results – Research Needs

Research topic (higher ranking is more important)	Average Rank
International Responses	
Track system design	4.08
Optimize crosstie design	3.93
Fastening system design	3.50
Materials design	2.23
Prevention or repair of rail seat deterioration (RSD)	1.58
North American Responses	
Prevention or repair of rail seat deterioration (RSD)	3.60
Fastening system design	3.60
Materials design	3.00
Optimize crosstie design	2.80
Track system design	2.00

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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

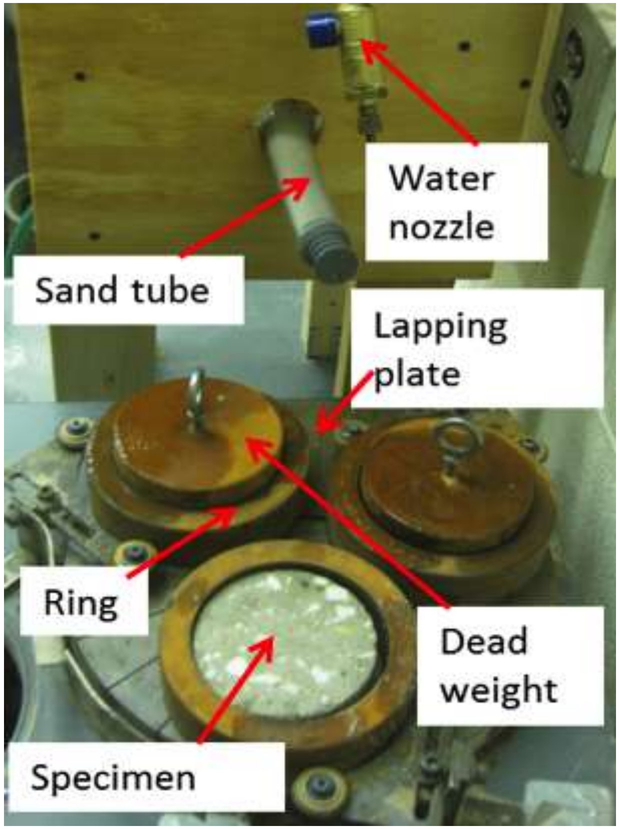
- Finite Element Modeling
- Full-Scale Laboratory Experimentation
- Field Experimentation

Current Research Sponsors

- Federal Railroad Administration (FRA) (Fastening System Design, Performance, Wear, Fatigue, Cracking, Environmental, etc.)
- Amsted RPS / Amsted Rail, Inc. (Fastening System Wear and Fatigue)
- Association of American Railroads (AAR) Technology Scanning Program (RSD and Fastening System Wear and Fatigue)
- Kansas City Southern (KCS) (Crosstie Design)
- NEXTRANS Region 5 Transportation Center (RSD)
- National University Rail (NURail) (Fastening System Wear and Fatigue)
- CN Fellowship in Rail Engineering (RSD)

Materials Experimentation

Large Scale Abrasion Test:
Used to investigate abrasion as a mechanism leading to rail seat deterioration (RSD) while varying load magnitude, displacement, pad material, etc.



Small Scale Abrasion Resistance Test (SSART):
Evaluate various approaches to increasing the abrasion resistance of concrete and determine wear rates

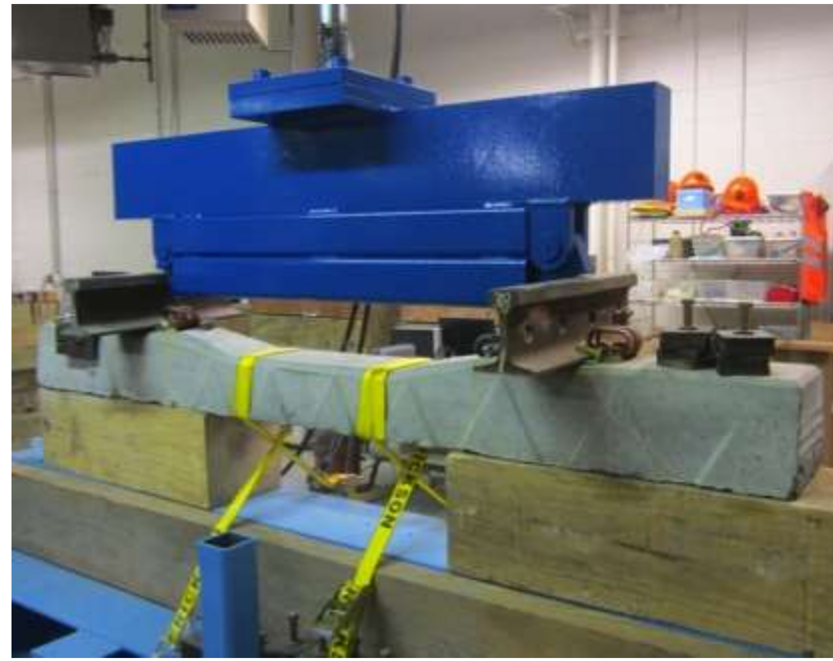
Component Experimentation

Static Tie Tester:
Used to study the rail seat compression and bending moment behavior of the concrete crosstie under static loading conditions

Rail Bending Test:
Used to prove the concept of using the rail as a built-up load cell using strain gauges

System Experimentation - Laboratory

Pulsating Load Testing Machine (PLTM): Conduct full-scale concrete tie and fastening system Testing by simulating various L/V ratios under repeated loads



Static Load Testing Machine (SLTM): Provides a means to study the behavior of the crosstie and fastening system under static load

System Experimentation - Field

Field installation at Monticello Railway Museum (MRM):
Full-scale concrete tie and fastening system field preparation testing site

Field Installation at the Transportation Technology Center (TTC):
Conduct full-scale concrete tie and fastening system testing in field while varying track geometry, train type, and speed

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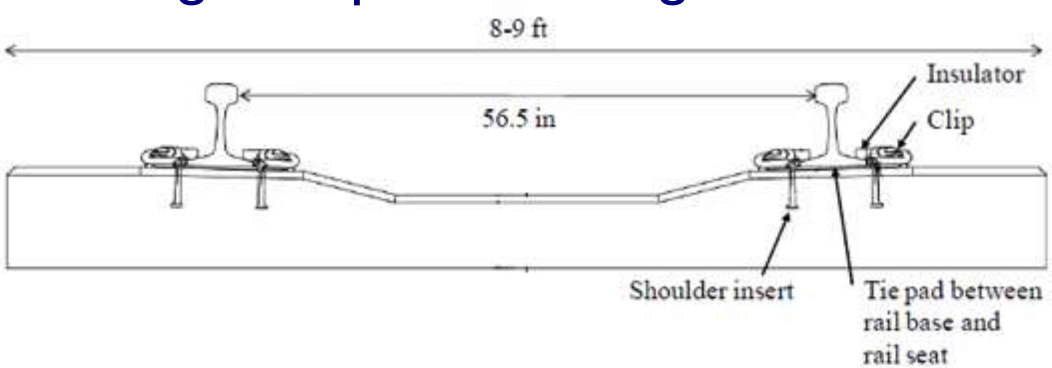
Current Design Process

- 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.)
   – Establish the locations for load transfer
3. Quantify loading conditions at each interface / component (including displacements)
   a. Laboratory experimentation
   b. Field experimentation
   c. Analytical modeling (basic → complex/system)
4. Link quantitative data to component geometry and materials properties (materials decision)

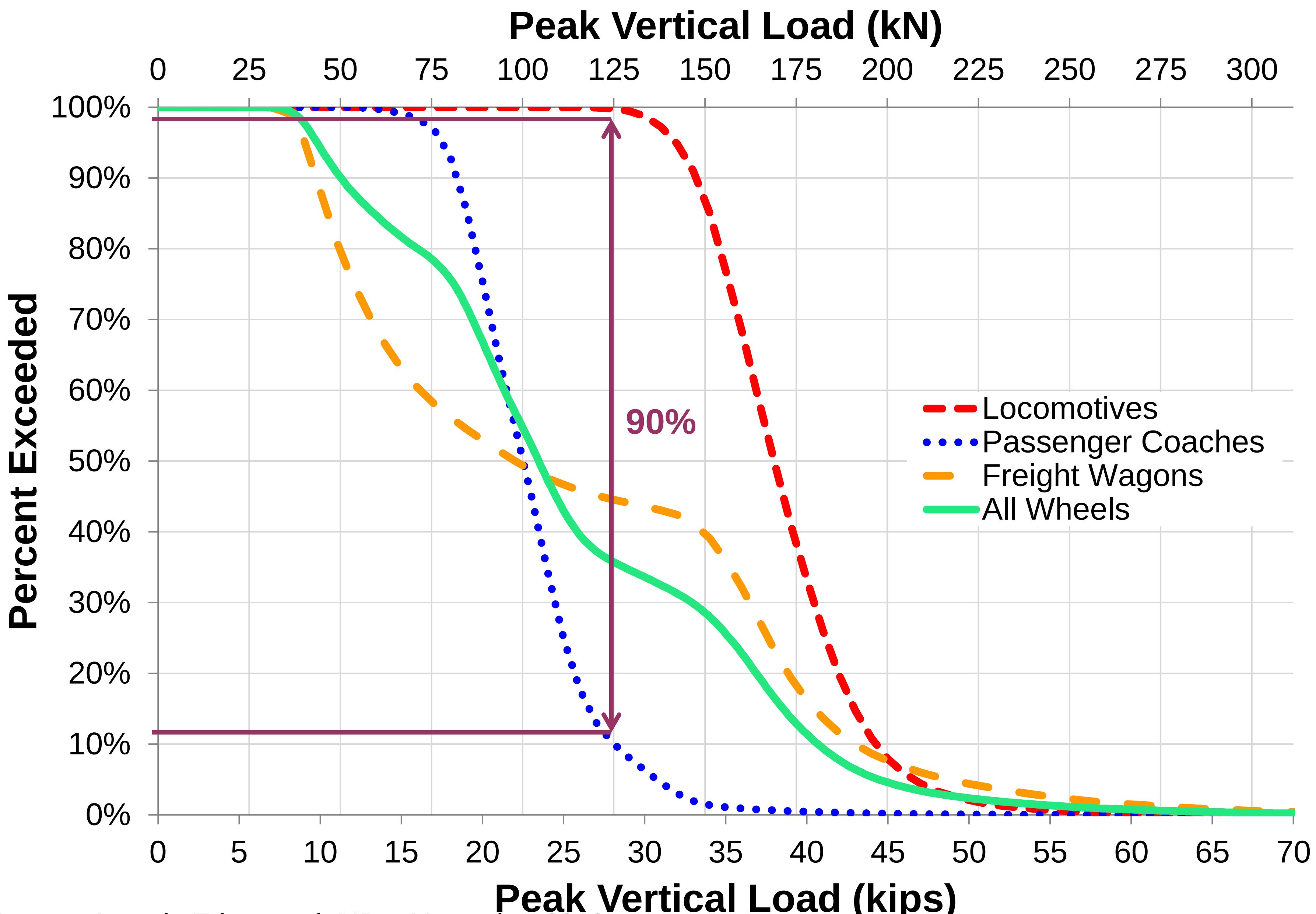
Principles of Mechanistic Design (cont.)

5. Relate loading to failure modes (e.g., how does lateral loading relate to post insulator wear?)
6. Investigate interdependencies through modeling
7. Run parametric analyses
   - Materials, geometry, load location
8. *Development and testing of innovative designs*
   - *Novel rail pad, sleeper, insulator designs*
   - *Geometry and materials improvements*
9. Establish mechanistic design practices
10. Adoption into AREMA Recommended Practices

Determining System Input Loads

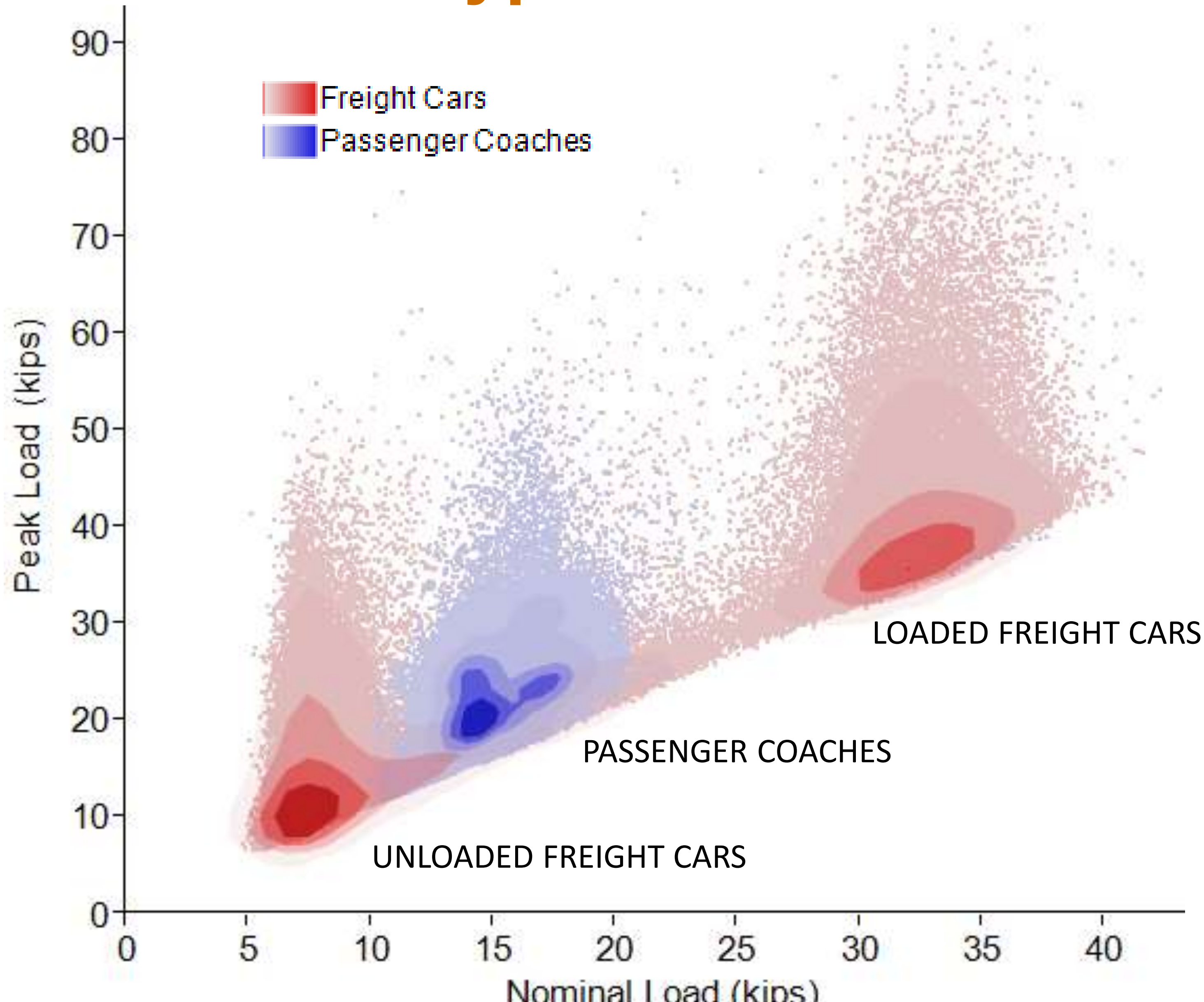
- Quantitative methods of data collection (Step 1):
  - Wheel Impact Load Detectors (WILD)
  - Instrumented Wheel Sets (IWS)
  - Truck Performance Detectors (TPD)
  - UIUC Instrumentation Plan (FRA Tie BAA)
- Most methods above are used to monitor rolling stock performance and assess vehicle health
- 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



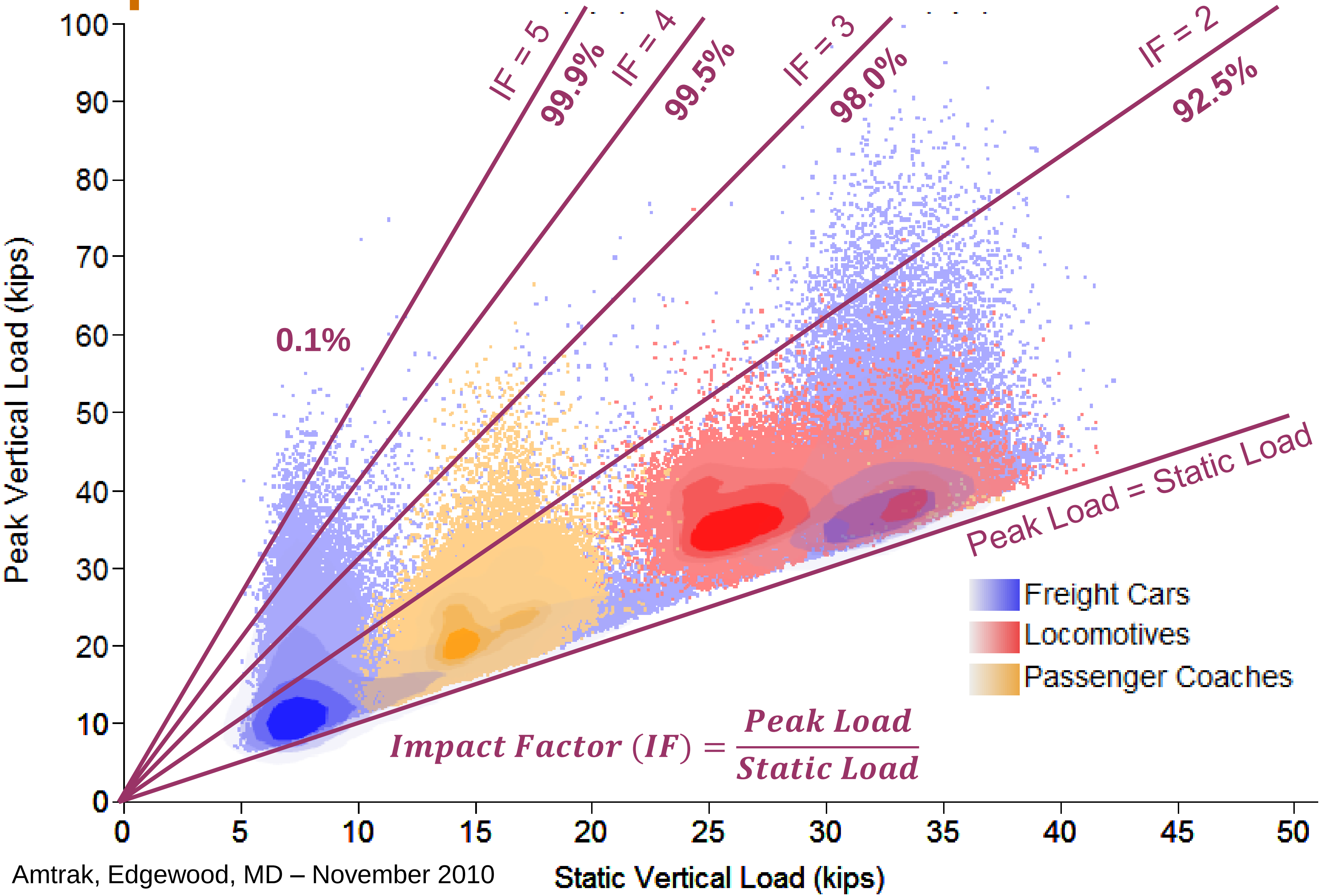
Source: Amtrak, Edgewood, MD – November 2010

Effect of Traffic Type on Peak Wheel Load



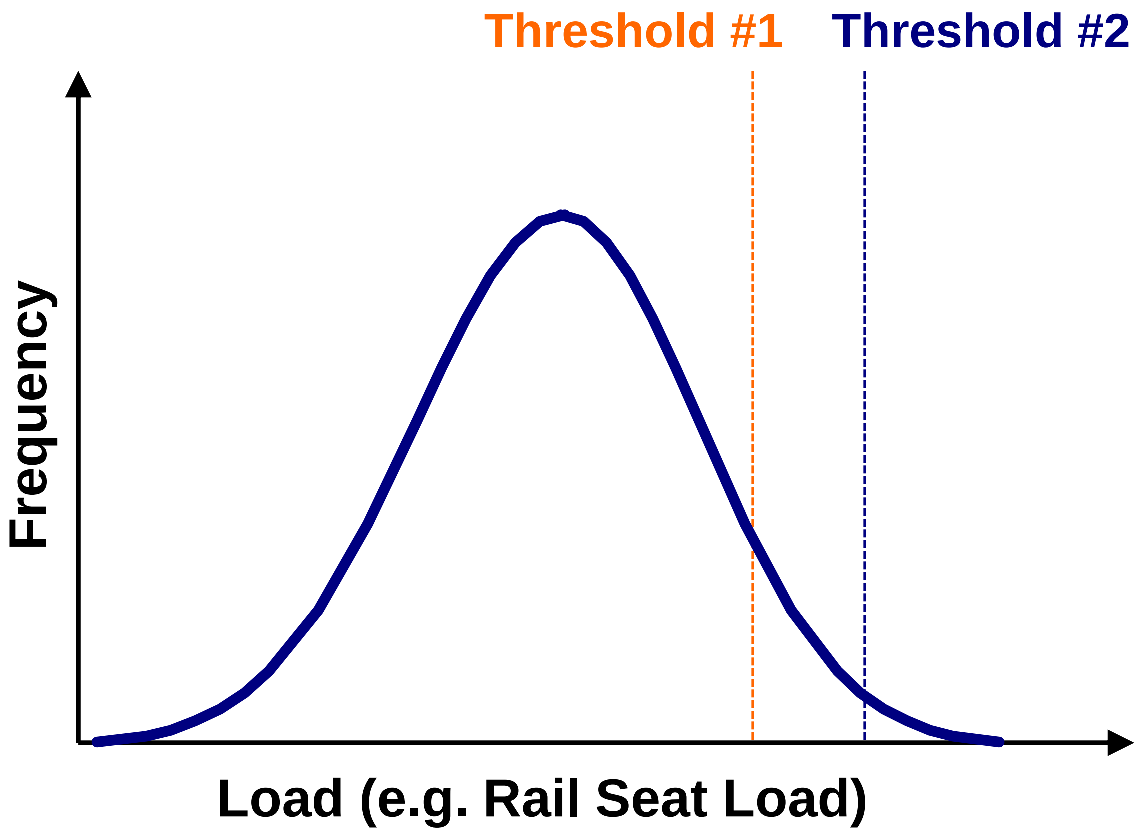
Source: Amtrak – Edgewood, MD (November 2010)

Impact Loads and Percent Exceedance



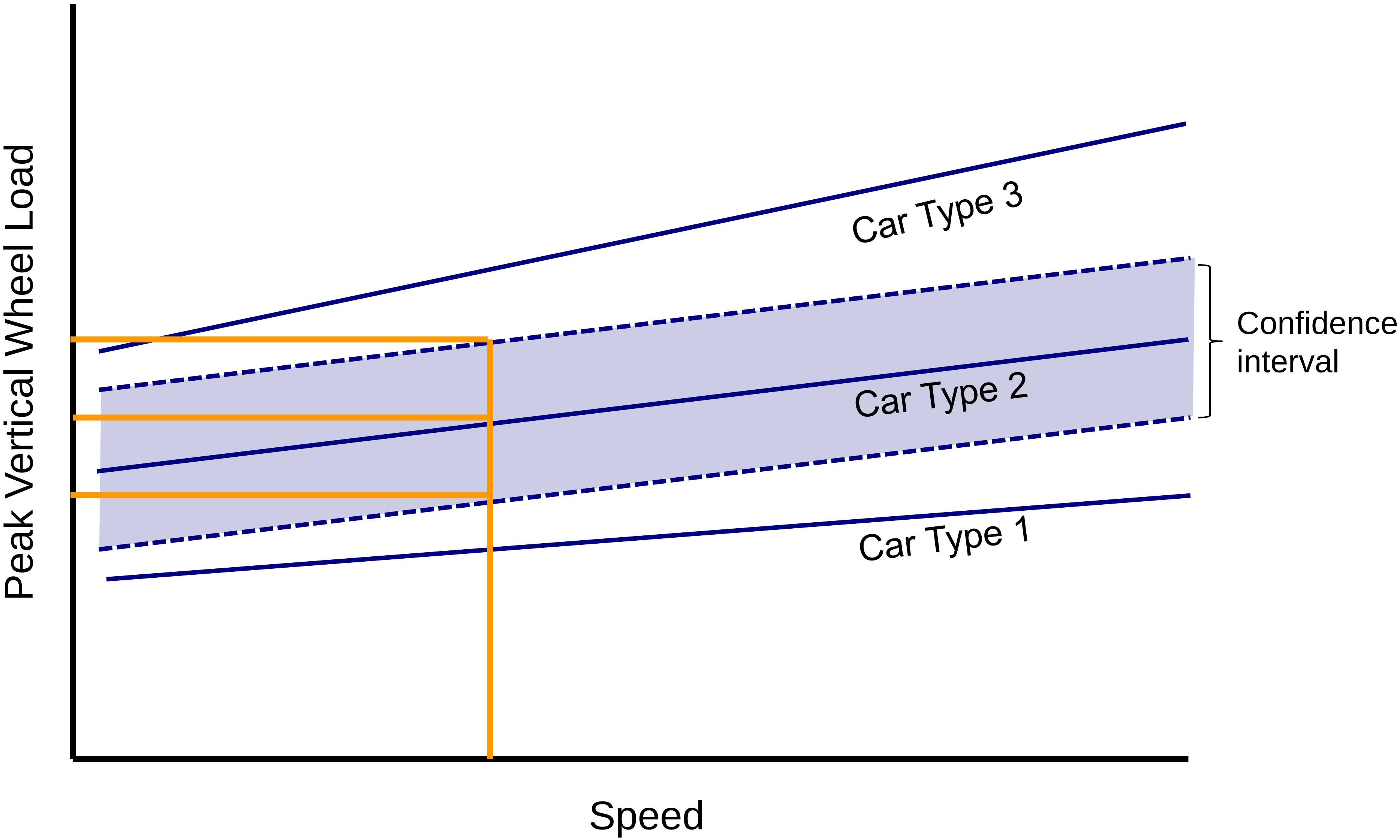
Amtrak, Edgewood, MD – November 2010

So What is Our Design Threshold?



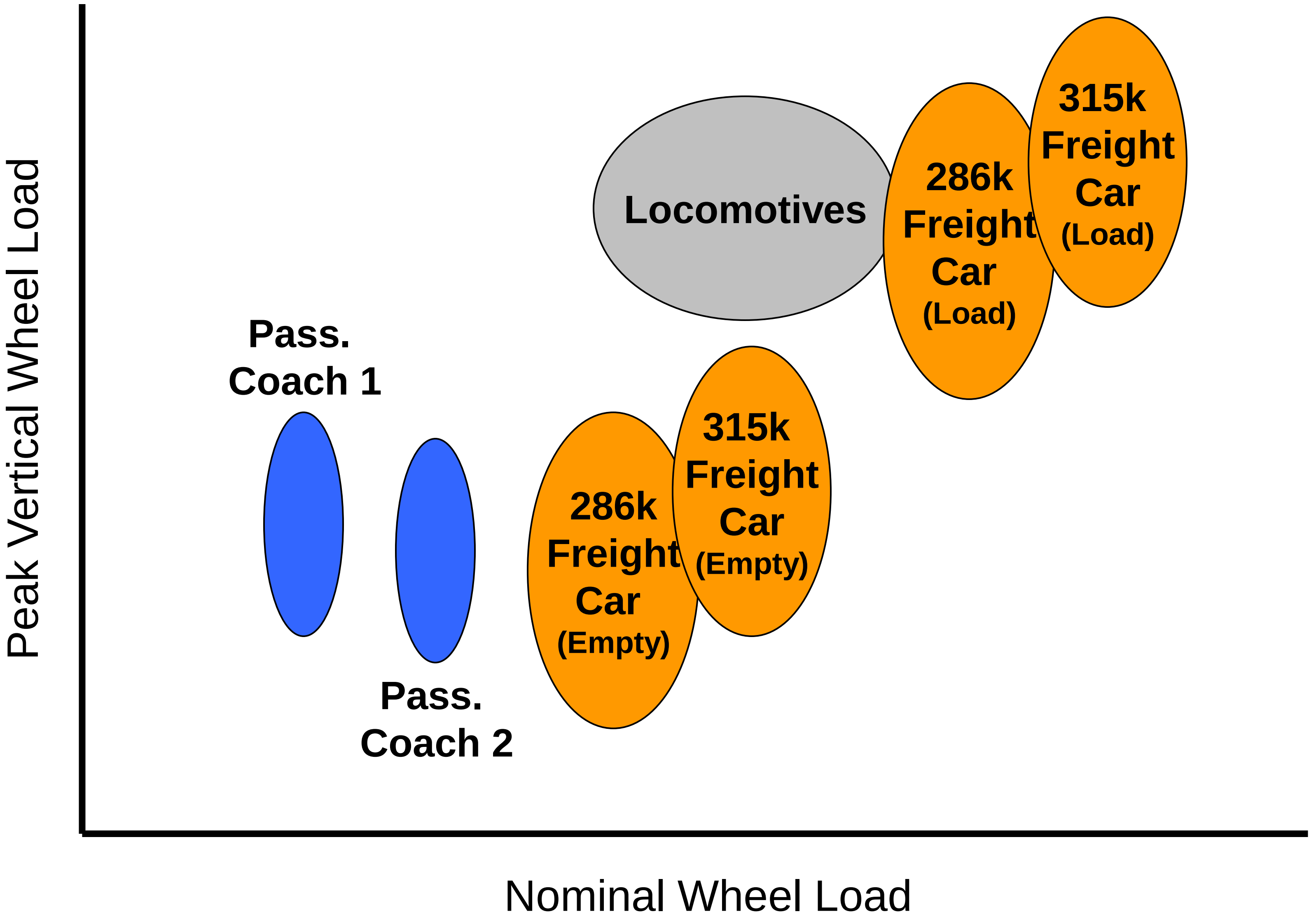
***Need curves for each component / interface and failure mode**

Development of Quantitative Loading Model



Development of Quantitative Loading Model

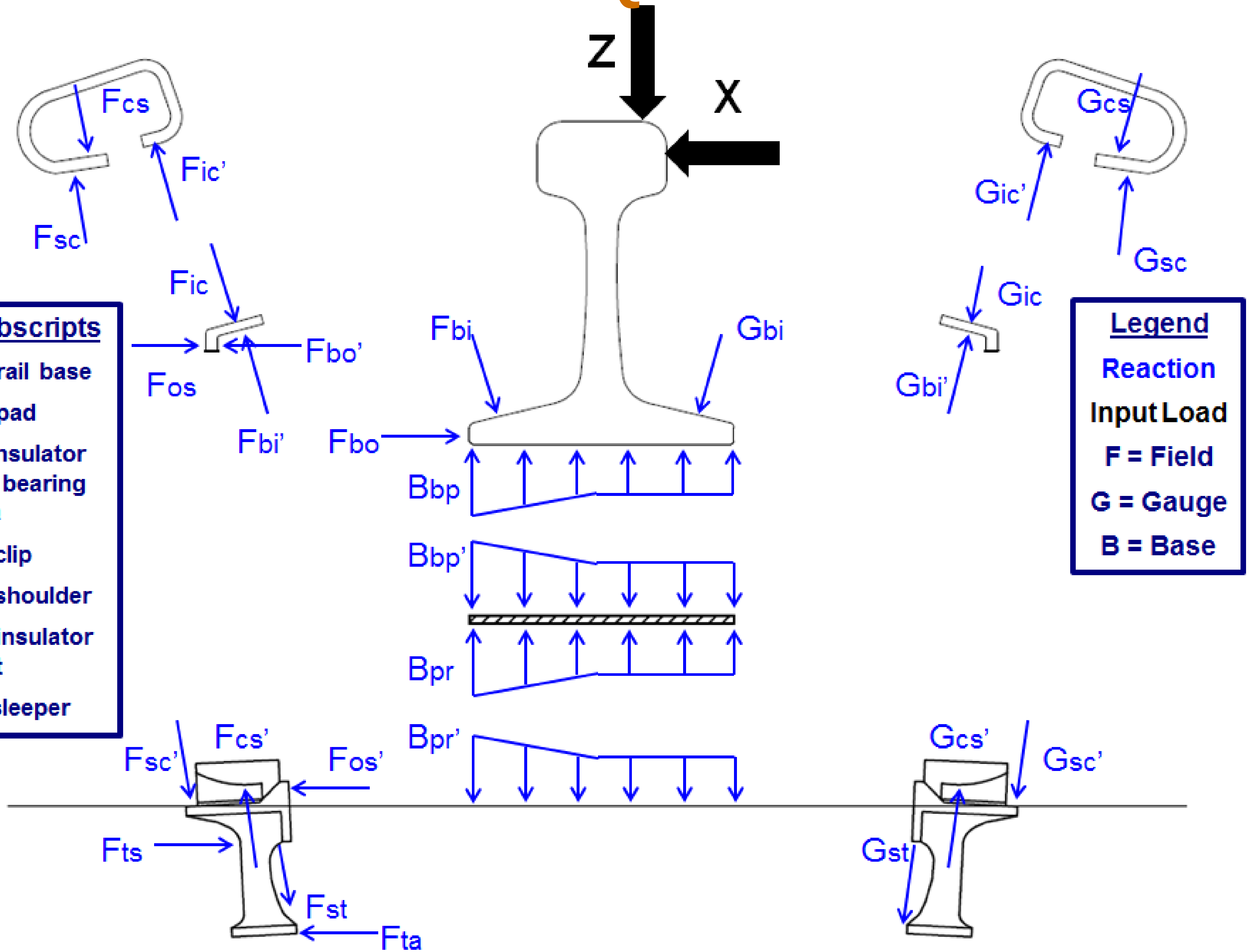
Conceptual Sketch



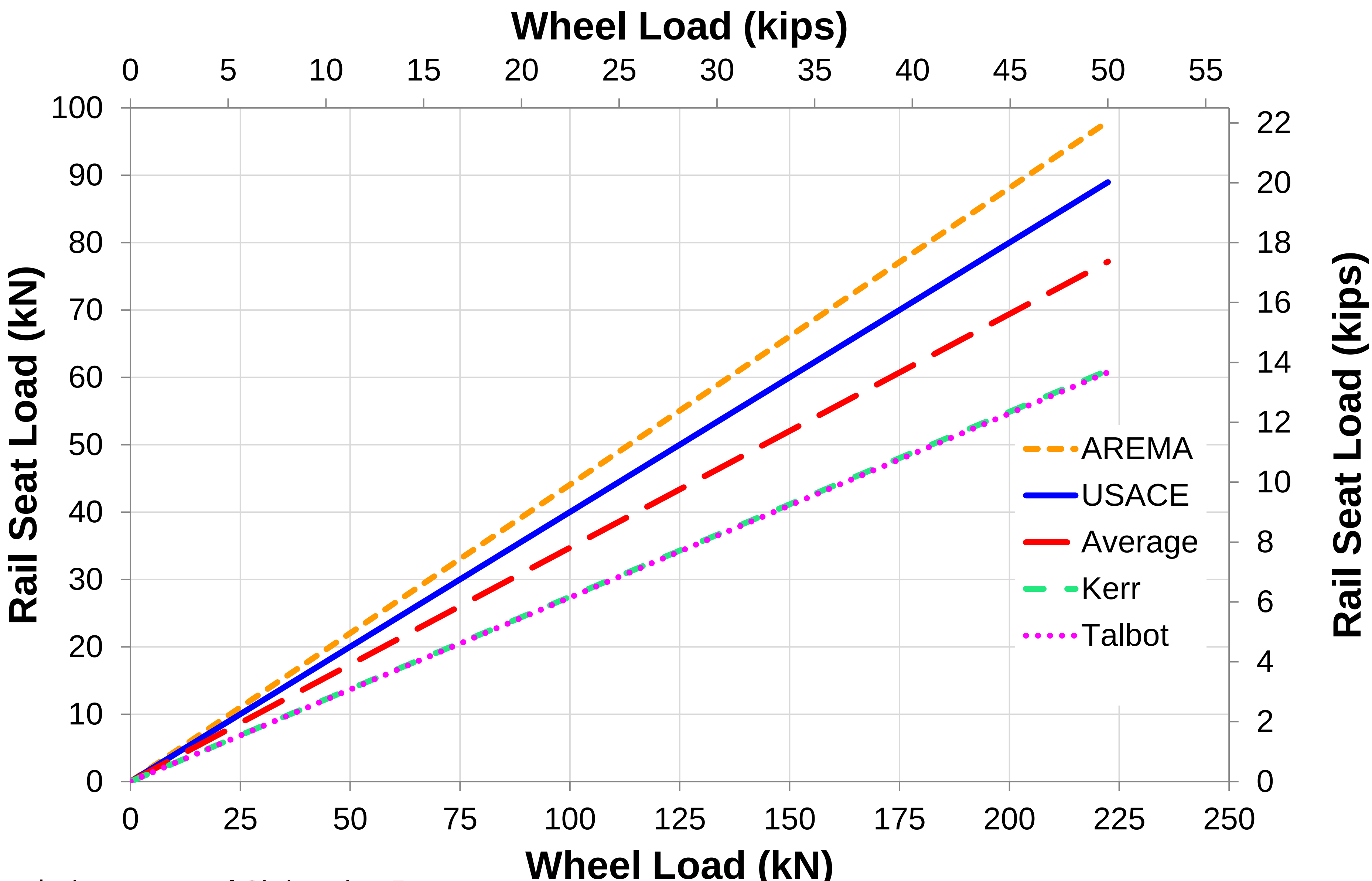
Establishment of the Qualitative Load Path

Subscripts

- b = rail base
- p = pad
- i = insulator clip bearing area
- c = clip
- s = shoulder
- o = insulator post
- t = sleeper



Rail Seat Load Calculation Methodologies



Analysis courtesy of Christopher Rapp

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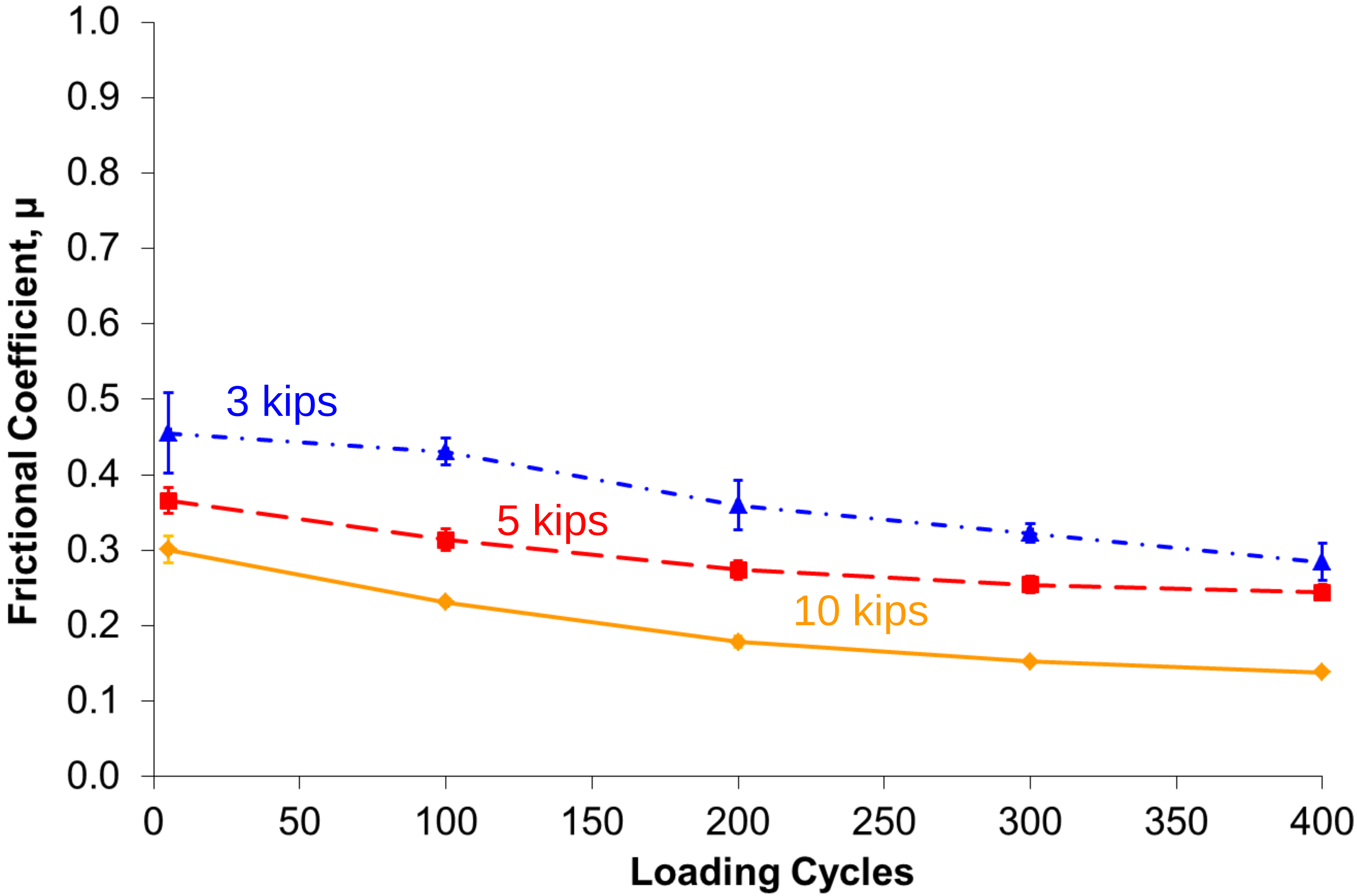
Large Scale Abrasion Test – Deterioration Test Results

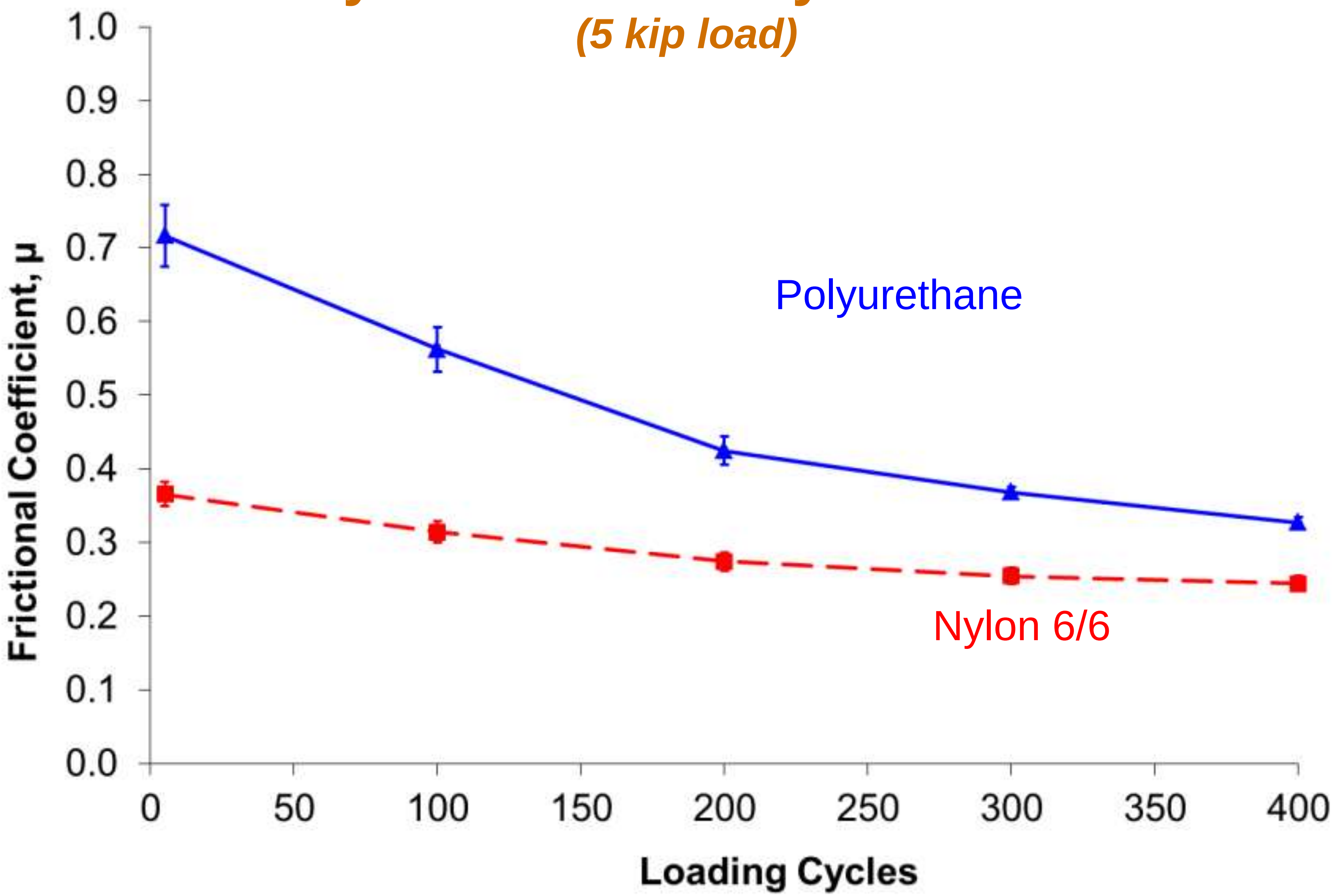
- Consistently able to cause deterioration of concrete due to abrasion
- Concrete deterioration initiated near pad edges and propagates inward
- Heat build up in pad materials at local contact points lead to softening
- Difficult to correlate severity of abrasion to input variables
  - Heterogeneity of concrete surface
  - Contact angle and pressure distribution

Mean Coefficient of Friction (COF) – Nylon 6/6



Mean Coefficient of Friction (COF) – Nylon 6/6 and Polyurethane

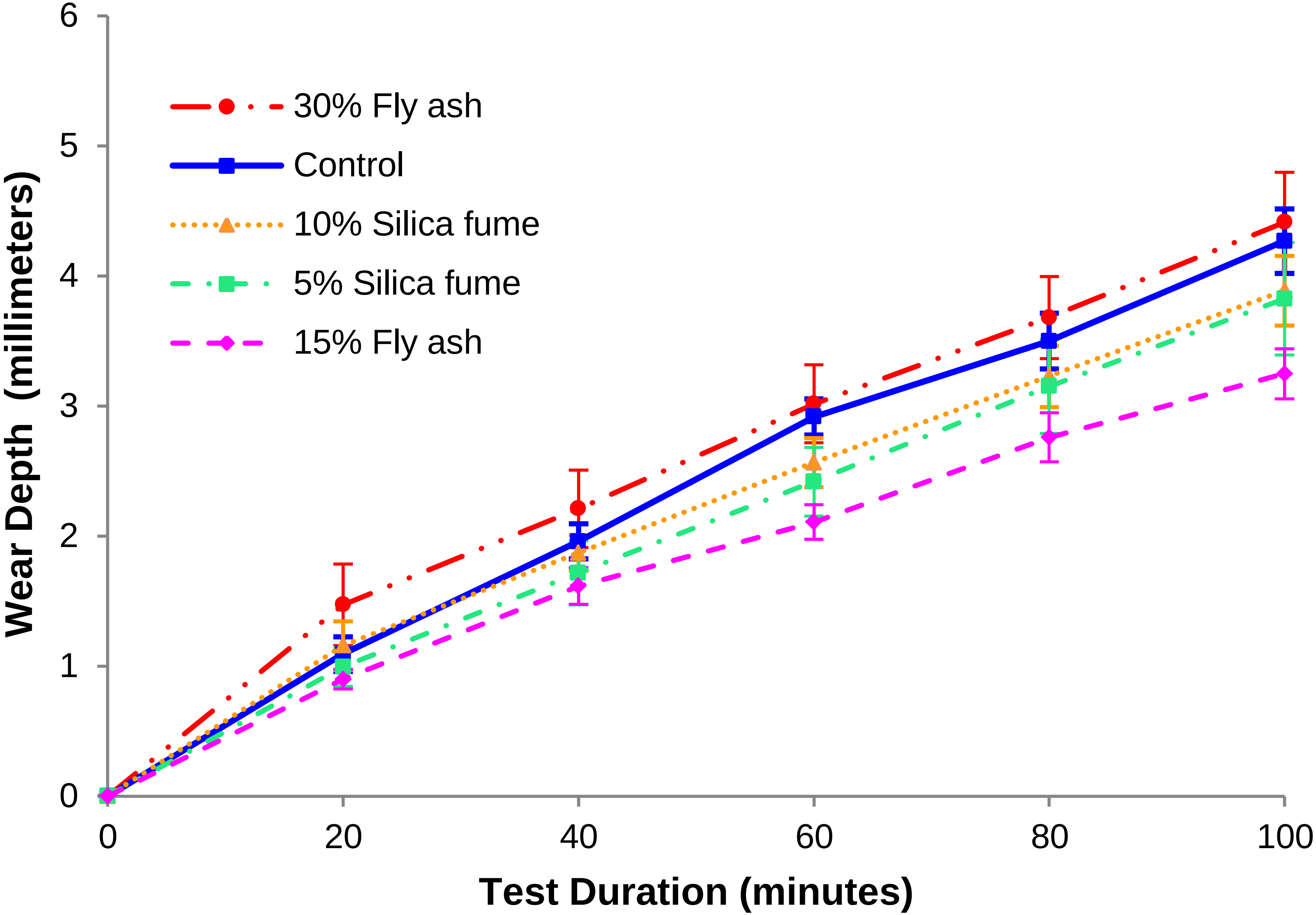
(5 kip load)



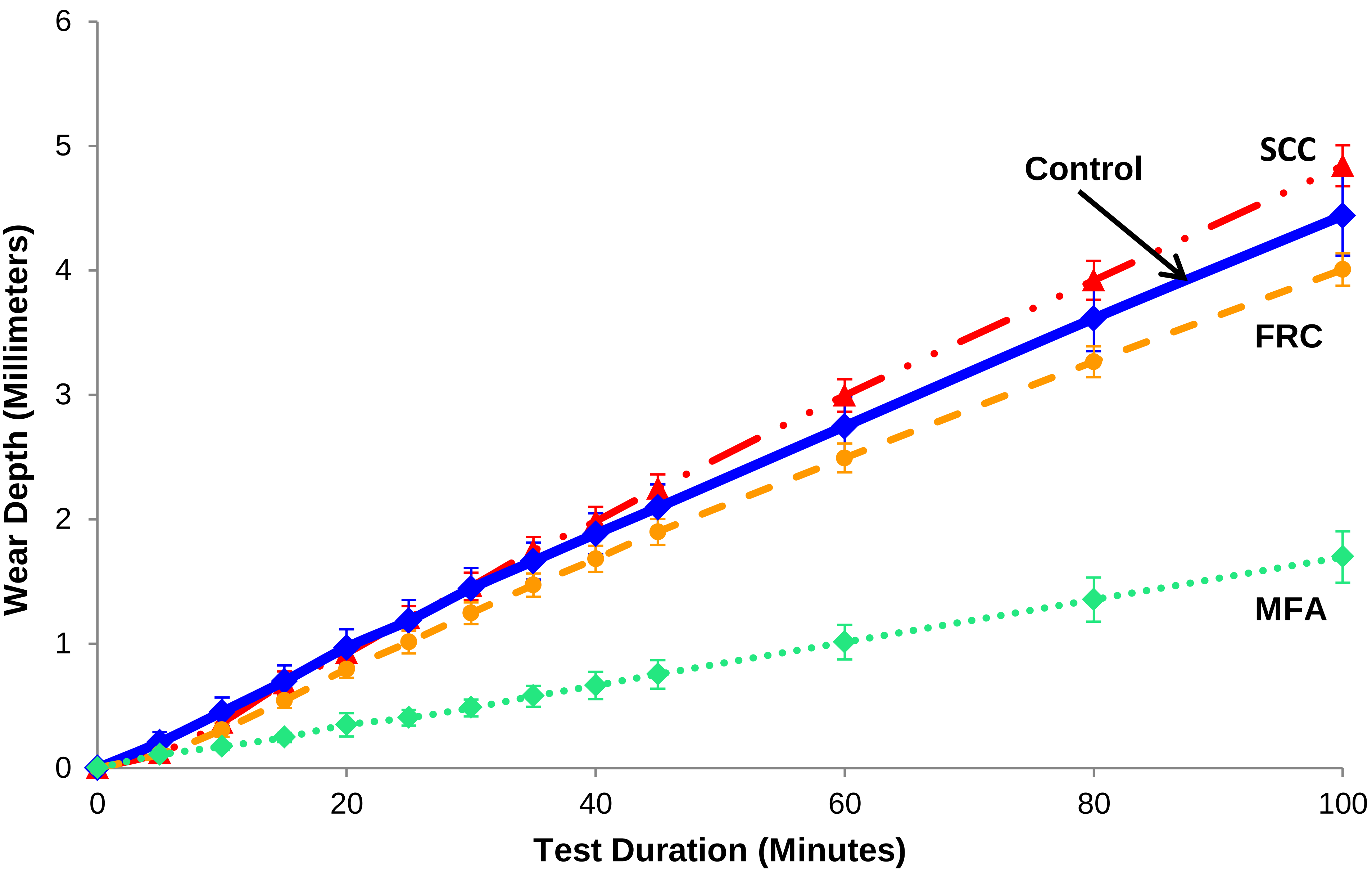
Small-Scale Test for Abrasion Resistance (SSTAR): Test Setup Overview

- Consists of a powered rotating steel wheel with 3 lapping rings
  - Lapping rings permitted to rotate about their own axis
  - Vertical load applied using the dead weights (4.5 pounds)
  - Abrasive sand and water dispensed during testing

Effect of Mineral Admixtures



Effect of Other Variations in Mix Design



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FRA Tie and Fastening System BAA Objectives and Deliverables

U.S. Department of Transportation
Federal Railroad Administration

- **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 sleepers and fastening system design in the US
- **Program Deliverables**
  - Improved mechanistic design recommendations for concrete sleepers and fastening systems in the US
  - Improved safety due to increased strength of critical infrastructure components
  - Centralized knowledge and document depository for concrete sleepers and fastening systems

FRA Tie and Fastener BAA Industry Partners:

Union Pacific – Building America®
BNSF Railway
Amtrak®
Amsted RPS
Amsted Rail
GIC Ingeniería y Construcción S.A. de C.V.
Hanson
LBFoster CXT Concrete Ties

FRA Tie and Fastener Project Structure

Inputs

Comprehensive Literature Review

International Tie and Fastening System Survey

Loading Regime (Input) Study

Rail Seat Load Calculation Methodologies

Involvement of Industry Experts

Modeling

Laboratory Study

Field Study

Outputs/Deliverables

Data Collection

Document Depository

Groundwork for Mechanistic Design

International Survey Report

Load Path Map

Parametric Analysis

State of Practice Report

Validated Tie and Fastening System Model

Improved Recommended Practices

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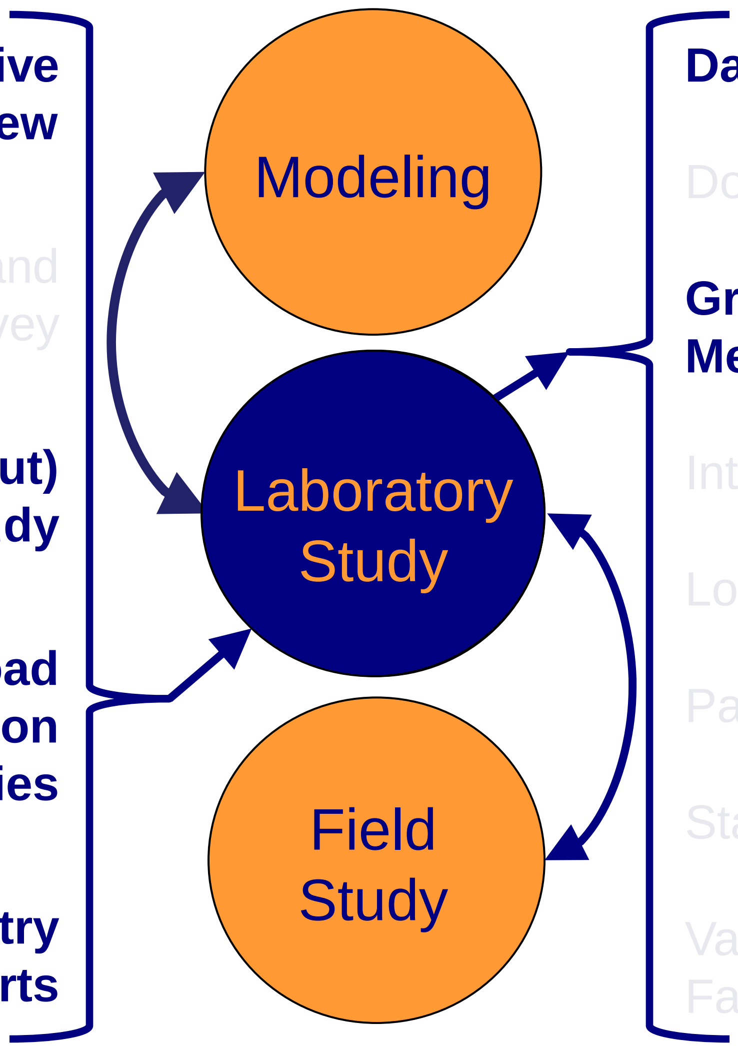
- Involvement of Industry Experts



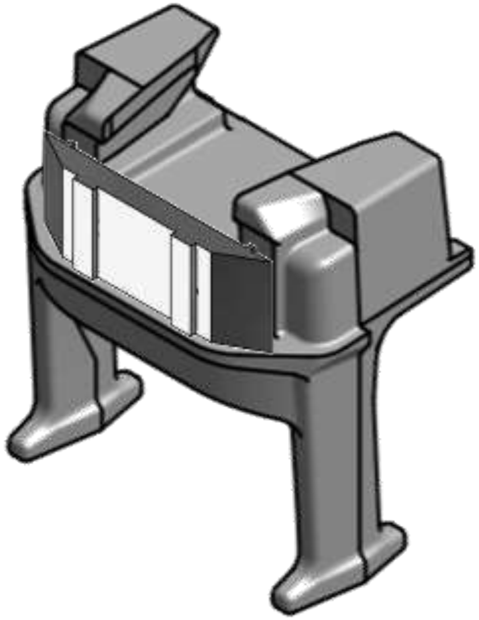
Outputs/Deliverables

- Data Collection
- Document Depository
- Groundwork for Mechanistic Design
- International Survey Report
- Load Path Map
- Parametric Analysis
- State of Practice Report
- Validated Tie and Fastening System Model

Improved Recommended Practices

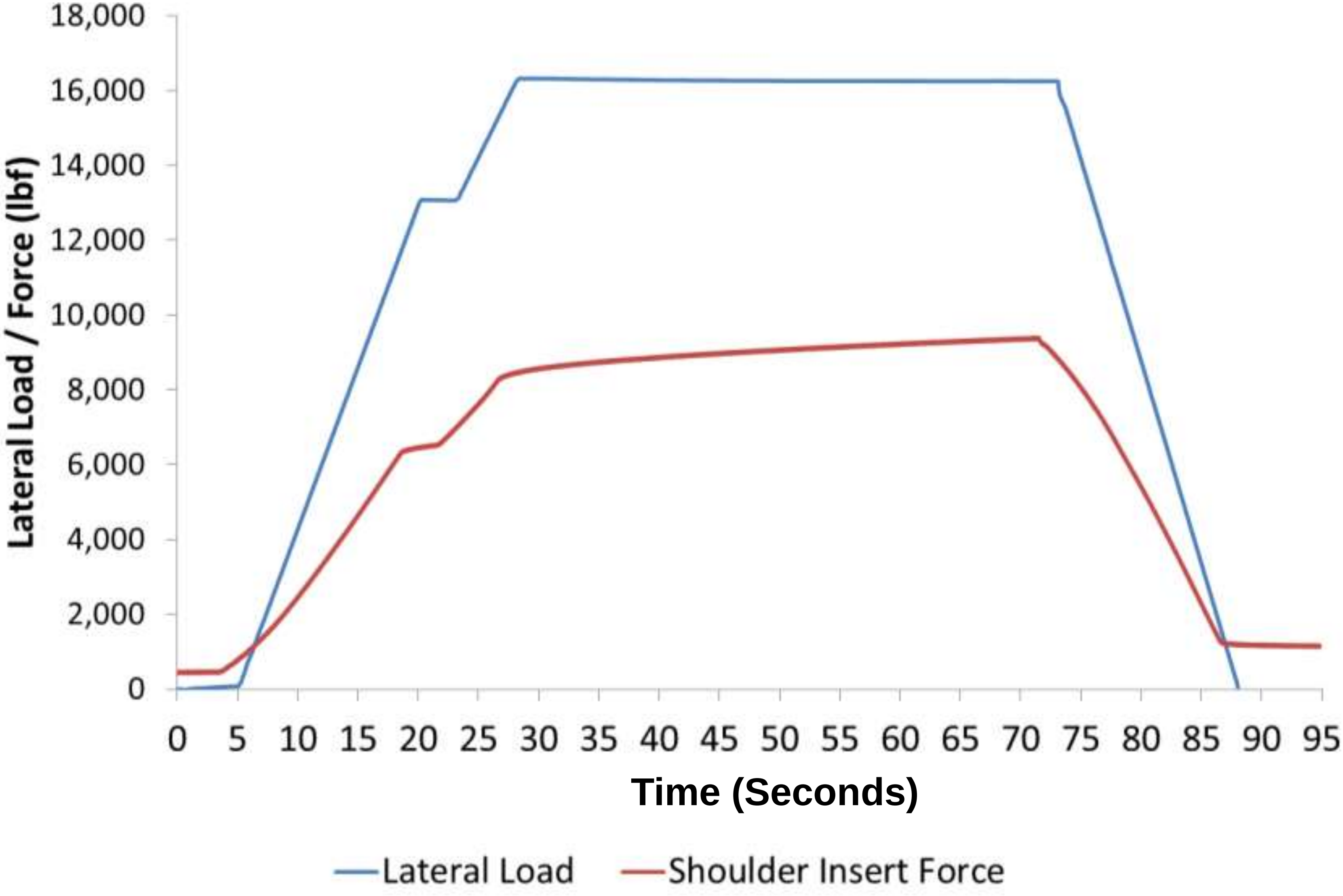
Quantification of Lateral Loads Entering the Shoulder Face (Insert)

- 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



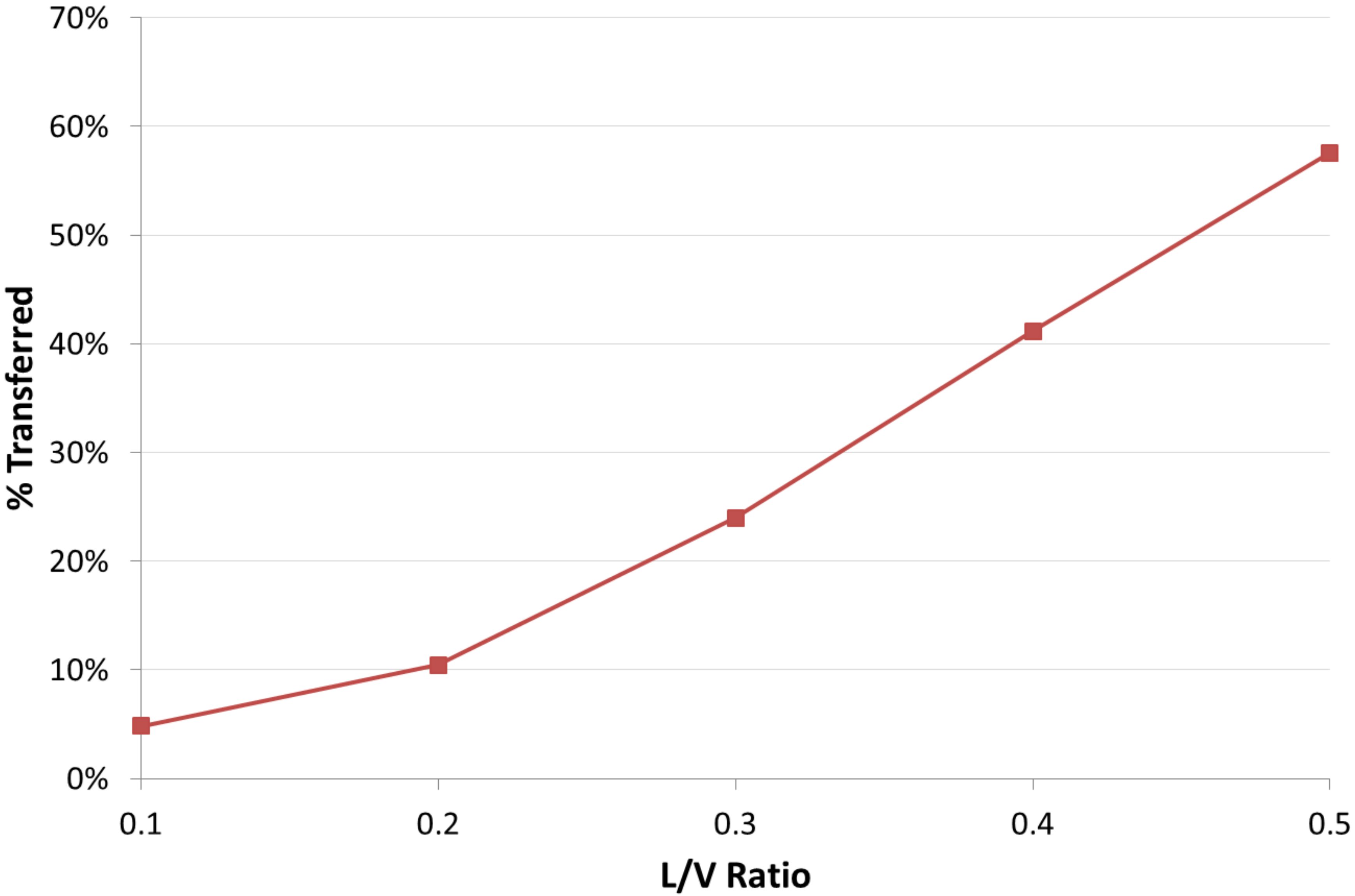
Transfer of Lateral Load to Shoulder Face

32.5 kip vertical load, 0.5 L/V ratio



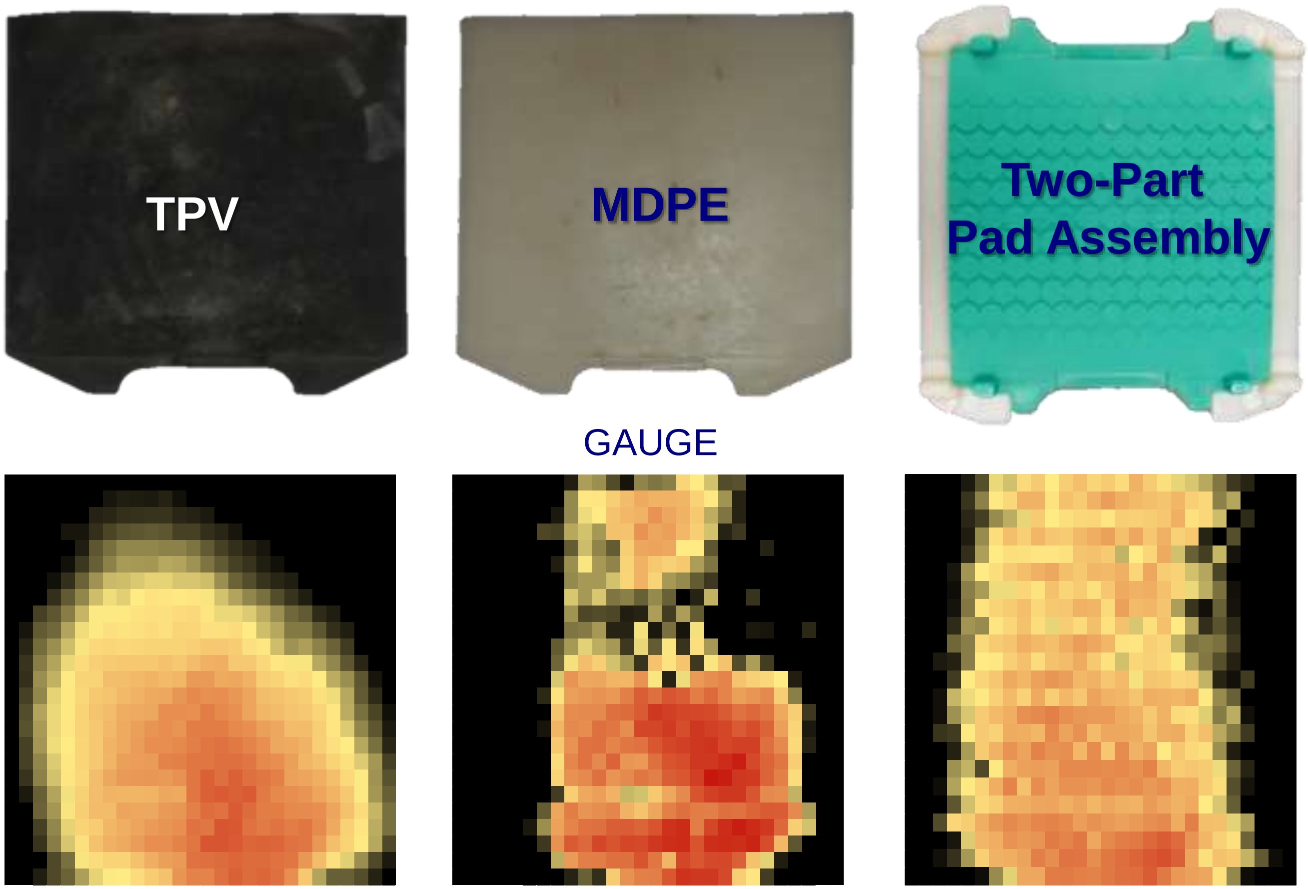
Percent of Lateral Load Transferred to Shoulder

Preliminary Data



Railseat Pressures Under Different Rail Pads

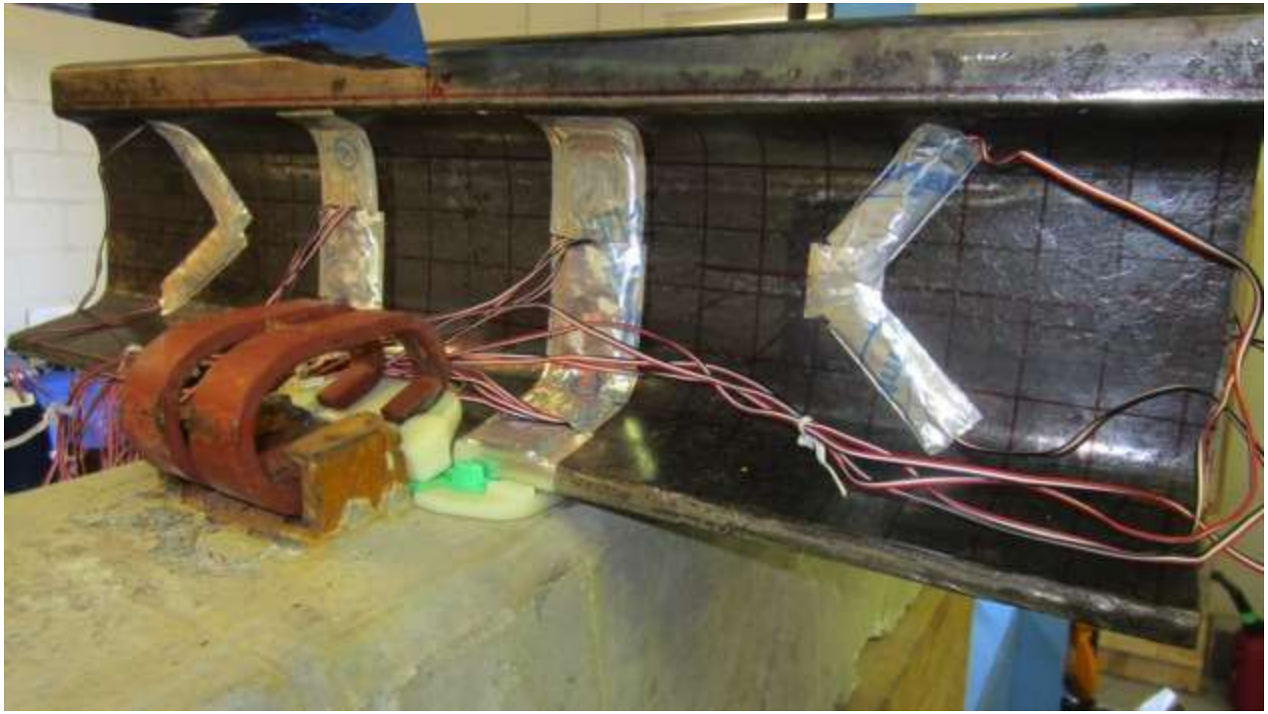
- Load Applied: 32.5 kip vertical, 16.9 kip lateral (0.52 L/V)



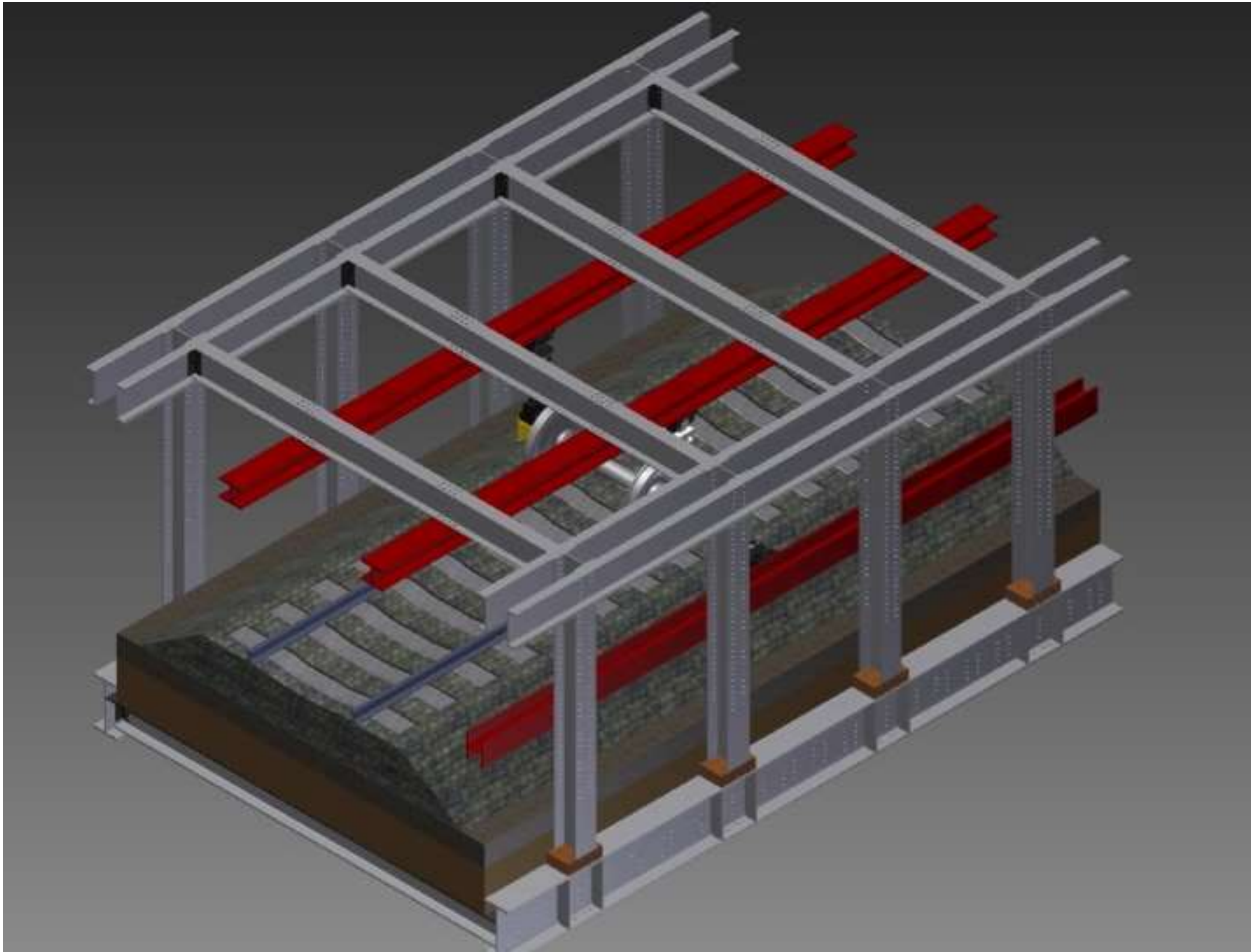
Contact Area (in^2)	25.8	19.0	23.9
Max Pressure (psi)	2,925	3,721	2,990

Laboratory Instrumentation

- Development and refinement of field instrumentation
- Research with controlled variables to investigate
  - Displacement of rail and fastening system components
  - Pressure distribution under different L/V ratios, support conditions, and fastening system components



Full Scale Track Response Experimental System



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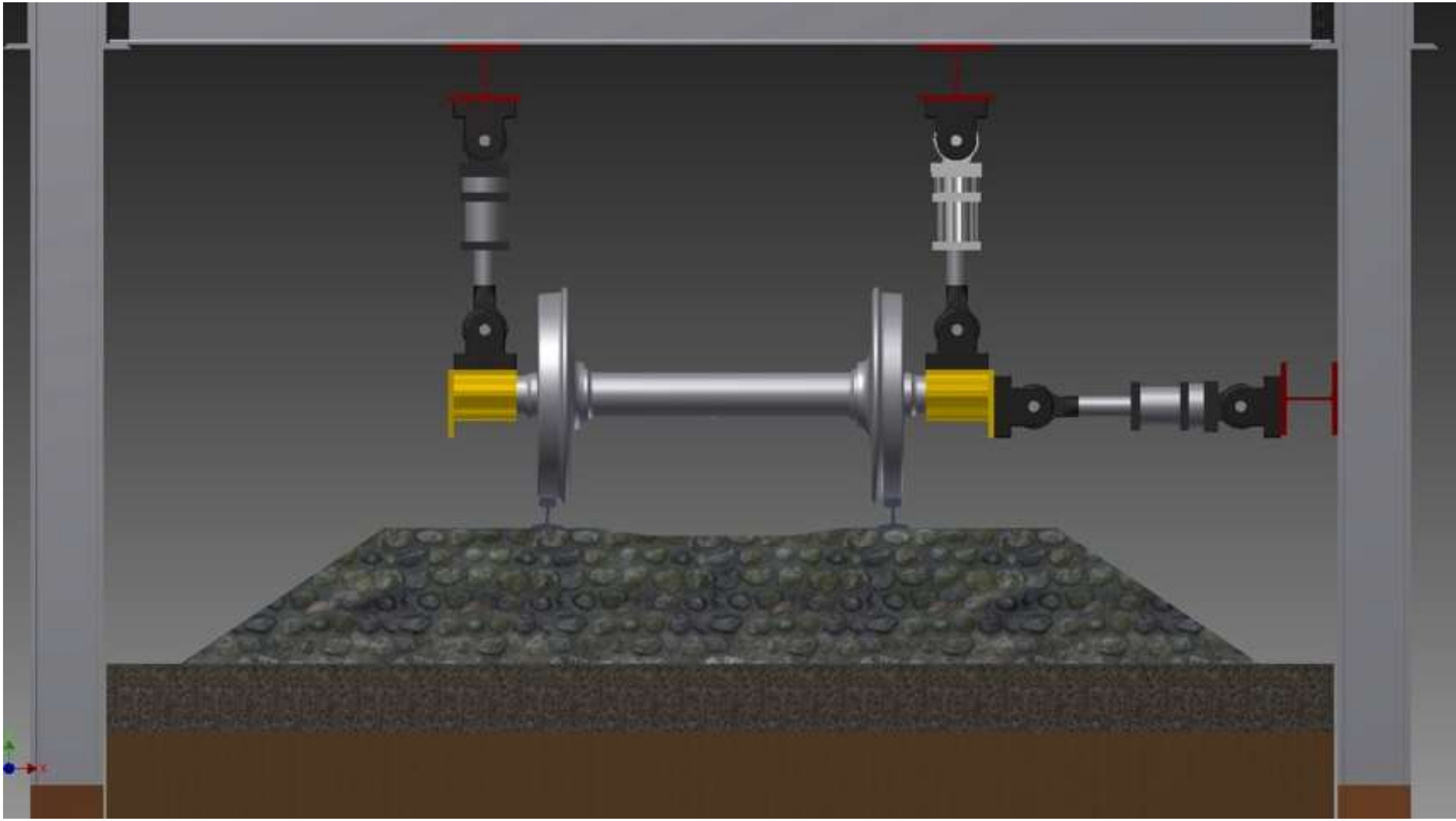

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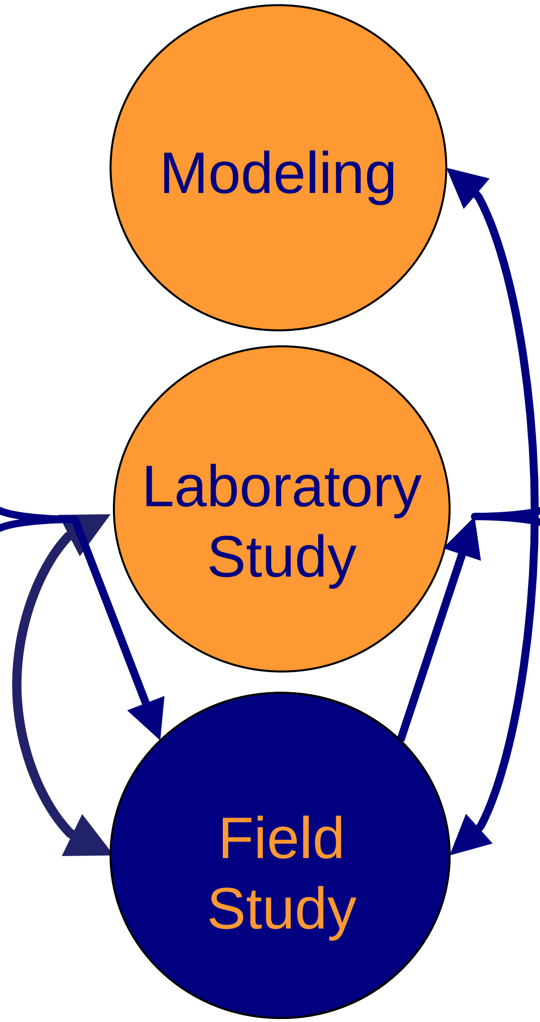

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Document Depository

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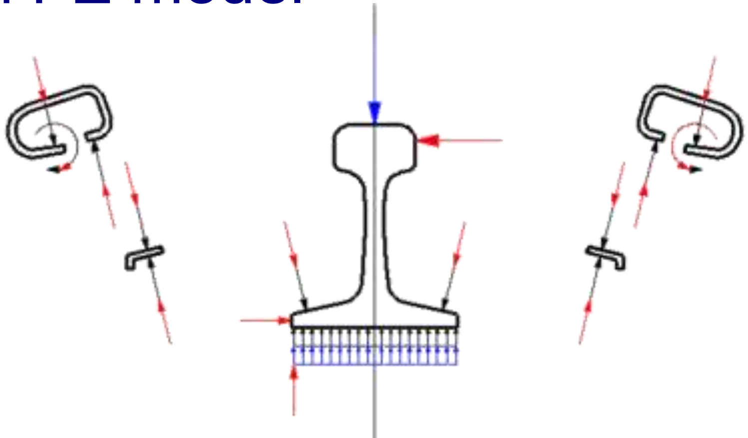
Improved Recommended Practices

Goals of Field Instrumentation

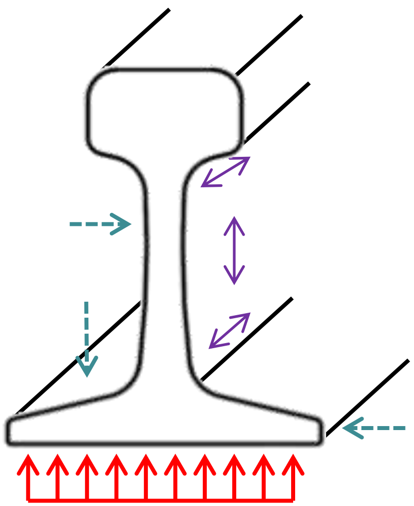
- Lay groundwork for mechanistic design of concrete sleepers and elastic fasteners
- Quantify the demands placed on each component within the system
- Develop an understanding into field loading conditions
- Provide insight for future field testing
- Collect data to validate the UIUC concrete sleeper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



Areas of Investigation

Rail

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

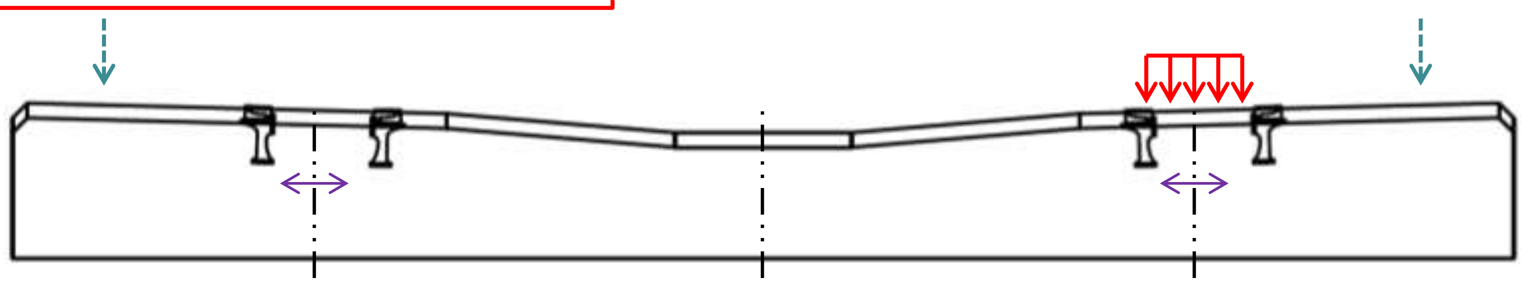


Fasteners/ Insulator

- Strain of fasteners
- Stresses on insulator

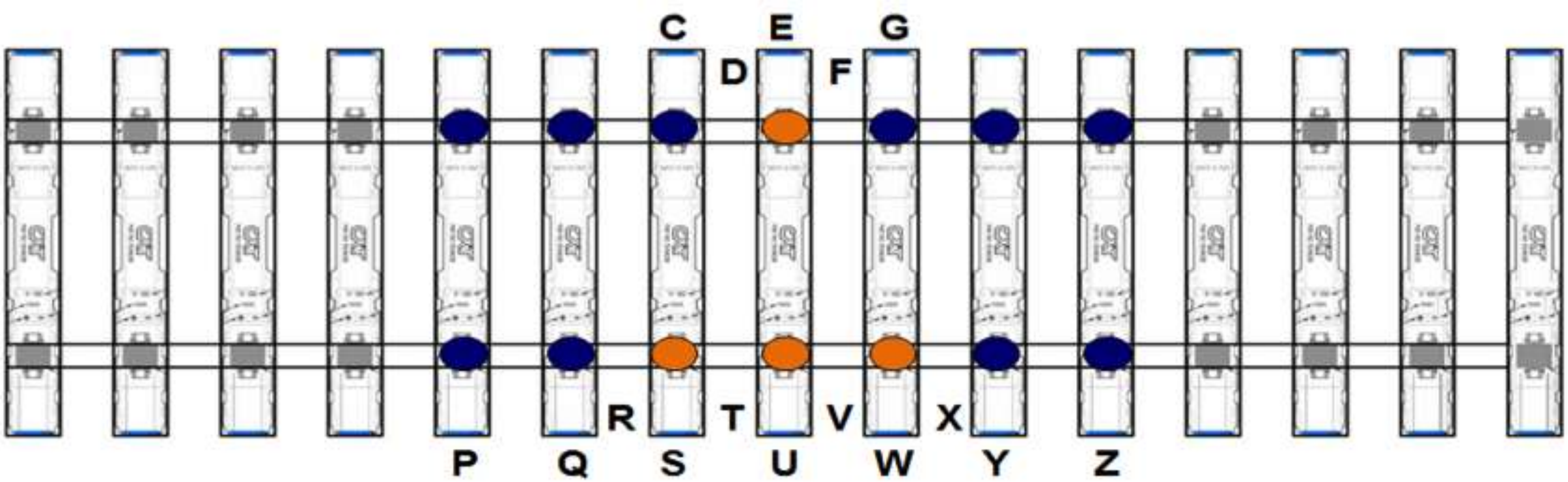
Concrete Sleepers

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

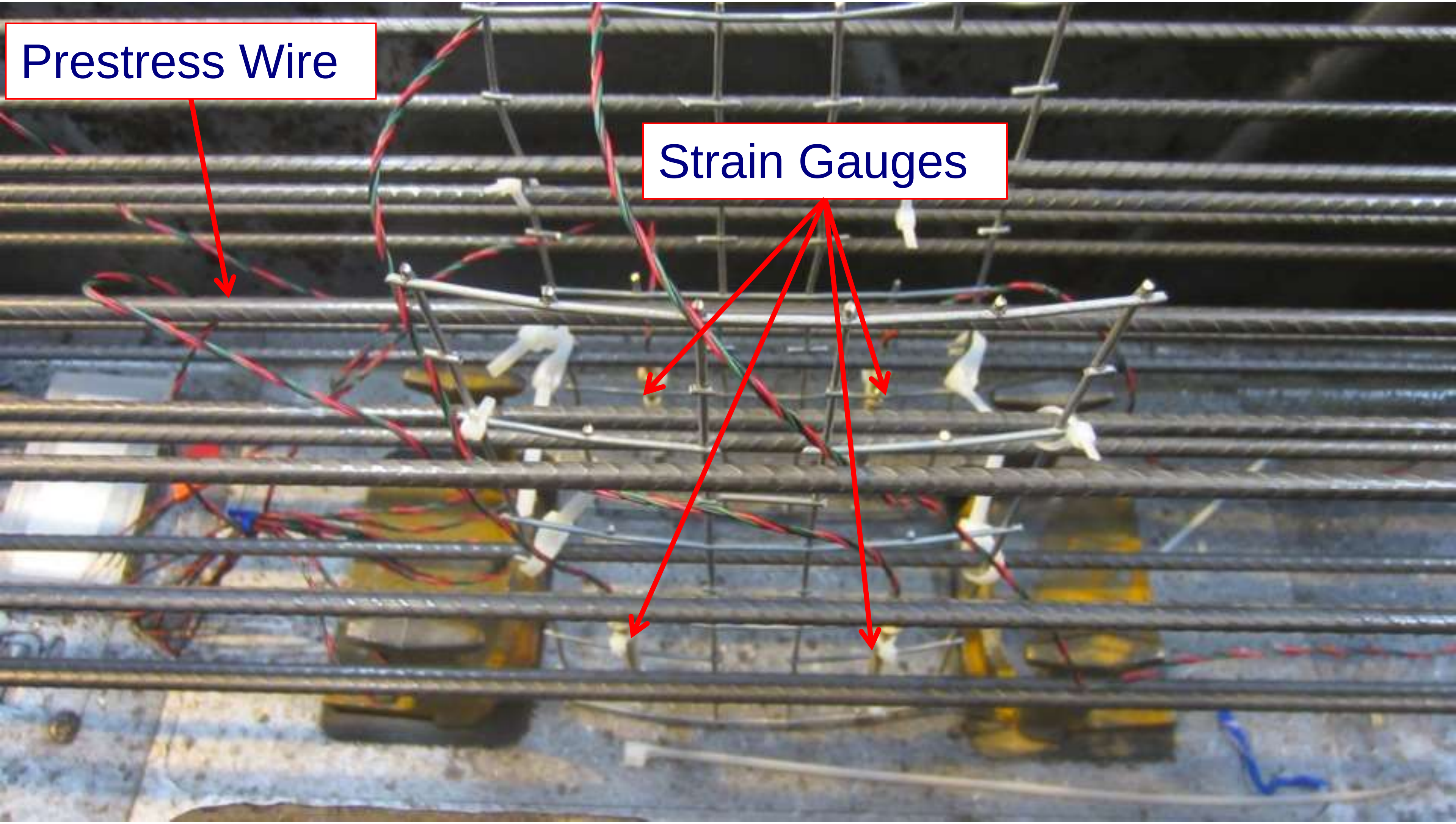


Field Instrumentation Map (July 2012)

- **Full Instrumentation**
  - Lateral, vertical, and chevron strain gauges on rail
  - Embedment and external concrete strain gauges on crosstie
  - Matrix based tactile surface sensors at rail seat (at rail seat W)
  - Linear potentiometers on rail and crosstie
- Partial Instrumentation
  - Vertical strain gauges on rail
  - Matrix based tactile surface sensors (at rail seats G and Y)
  - Linear potentiometers on crosstie (at rail seats C and G)



Instrumented Crosstie Construction

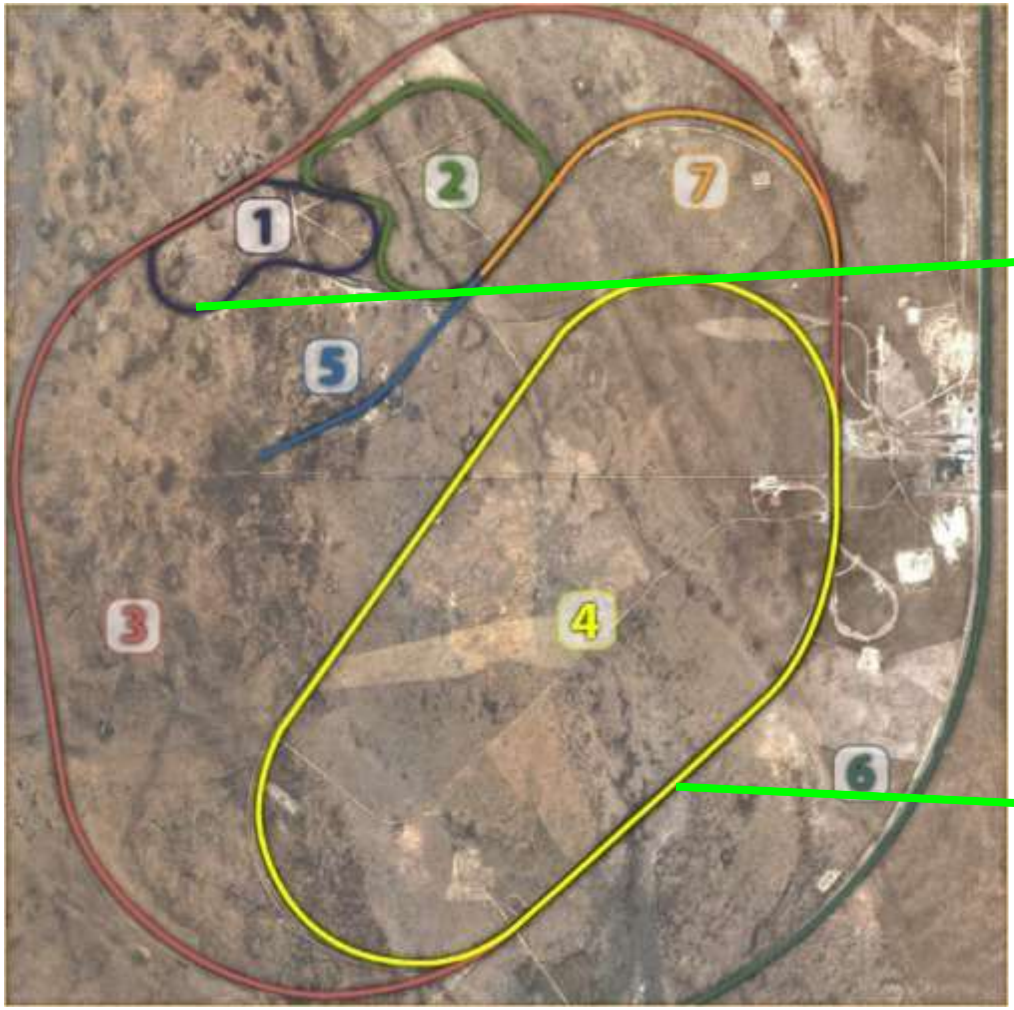


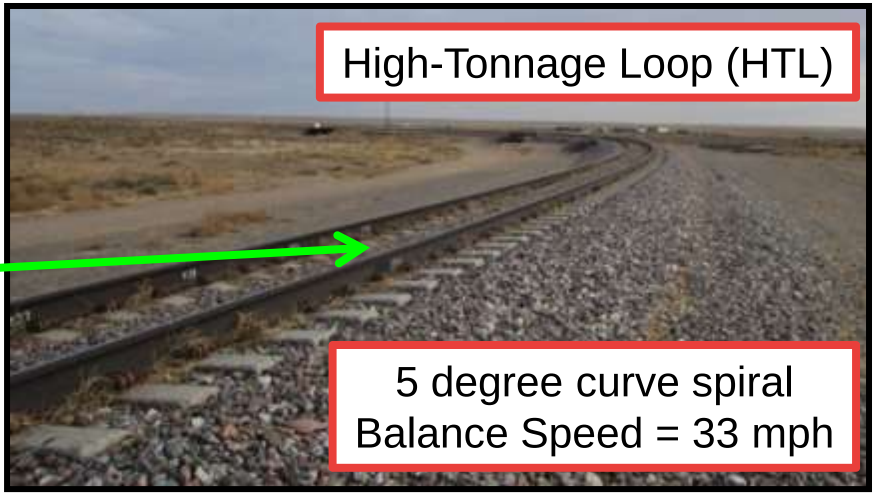
Embedment gauge installed between shoulders on prestress wire

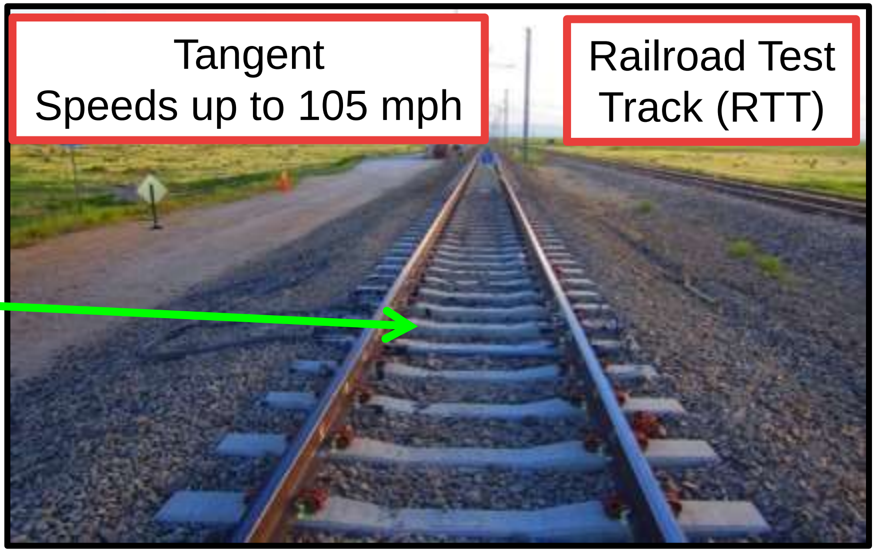
Instrumented Crosstie Construction

Placement and protection of surface strain gauges

TTCI Field Testing Locations







Objectives of Field Experimental Program

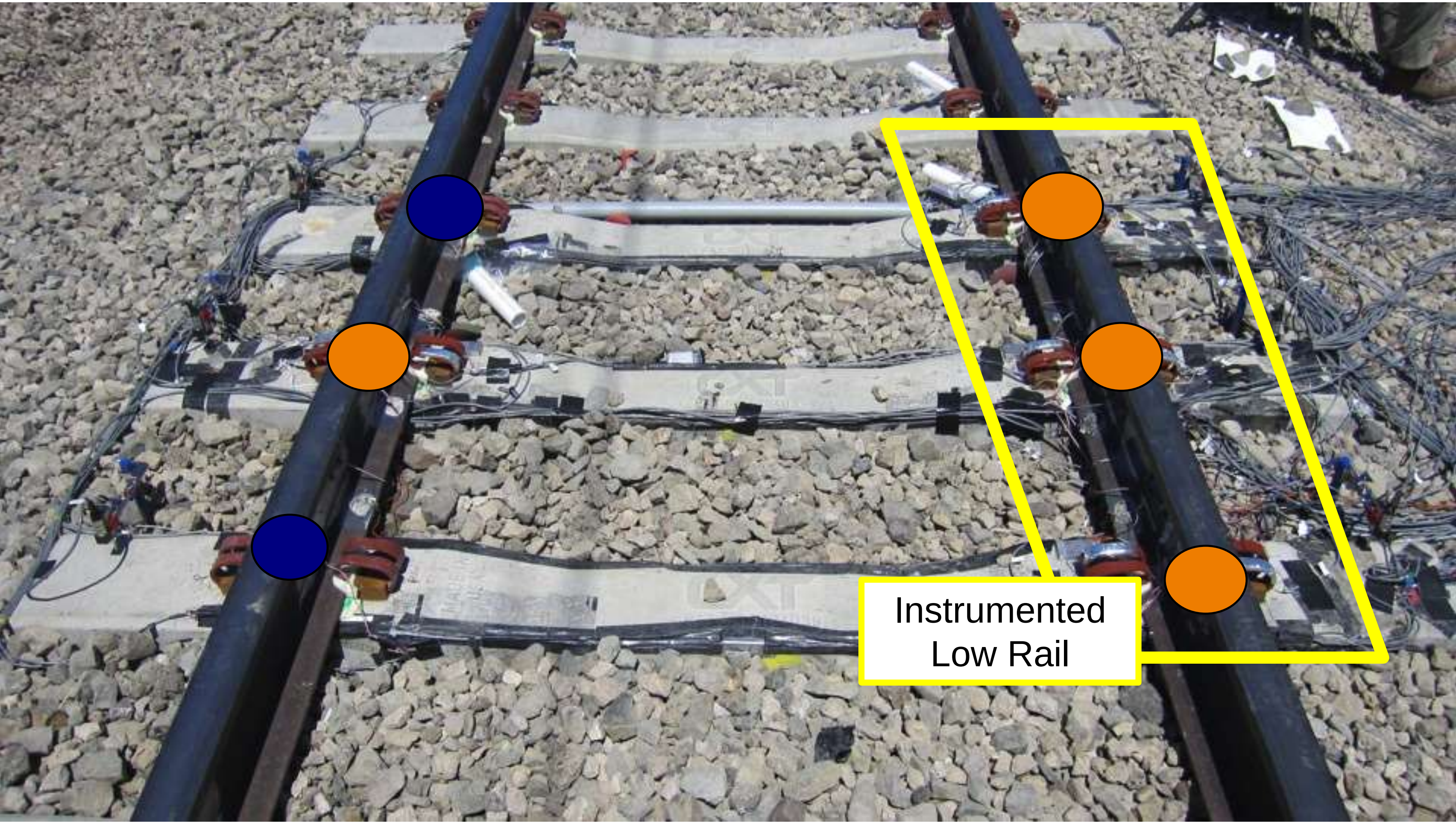
Loading Environment

- 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

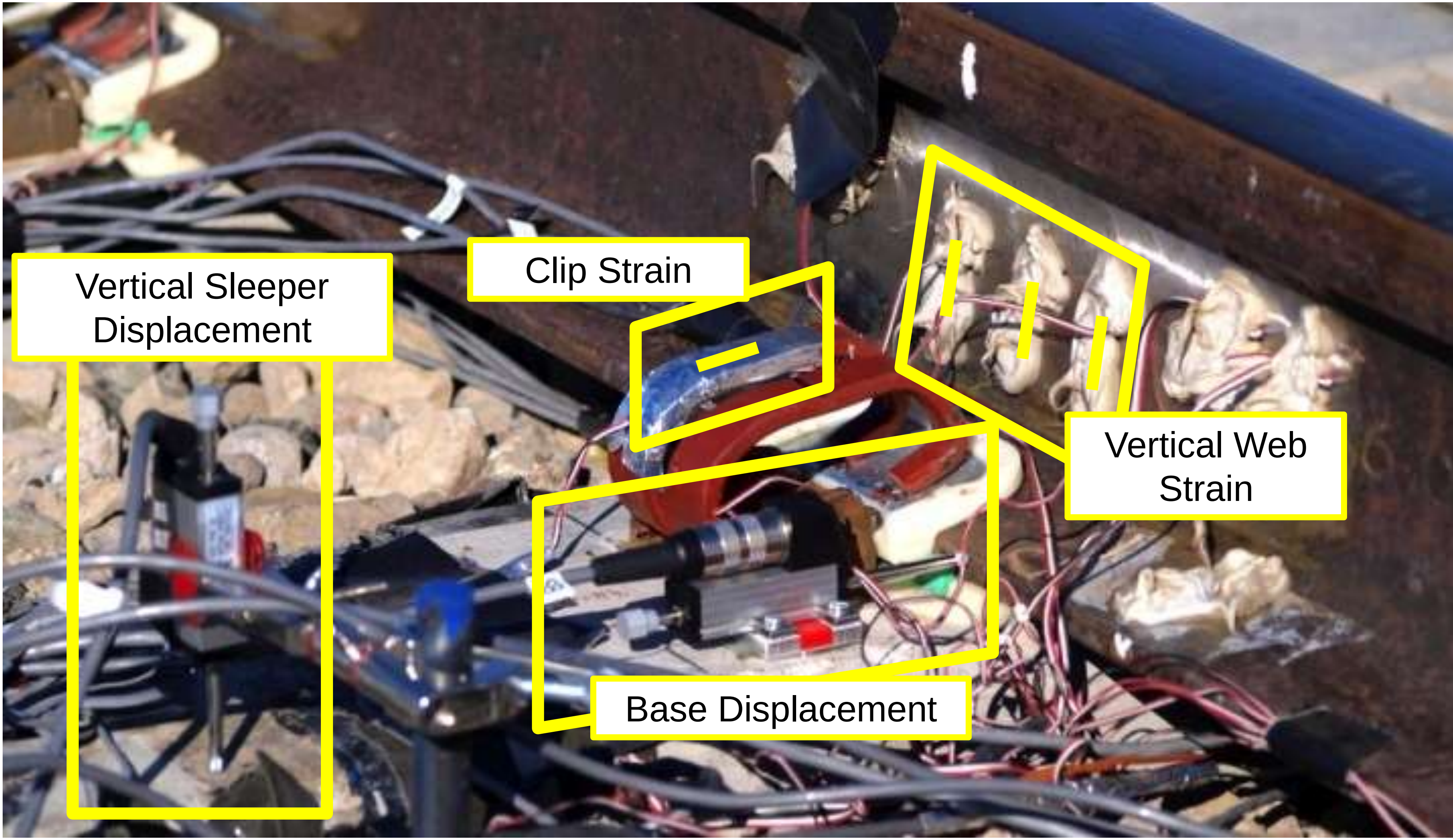
Installation of Clip by Professors ("experts")

Fully Instrumented Rail Seats

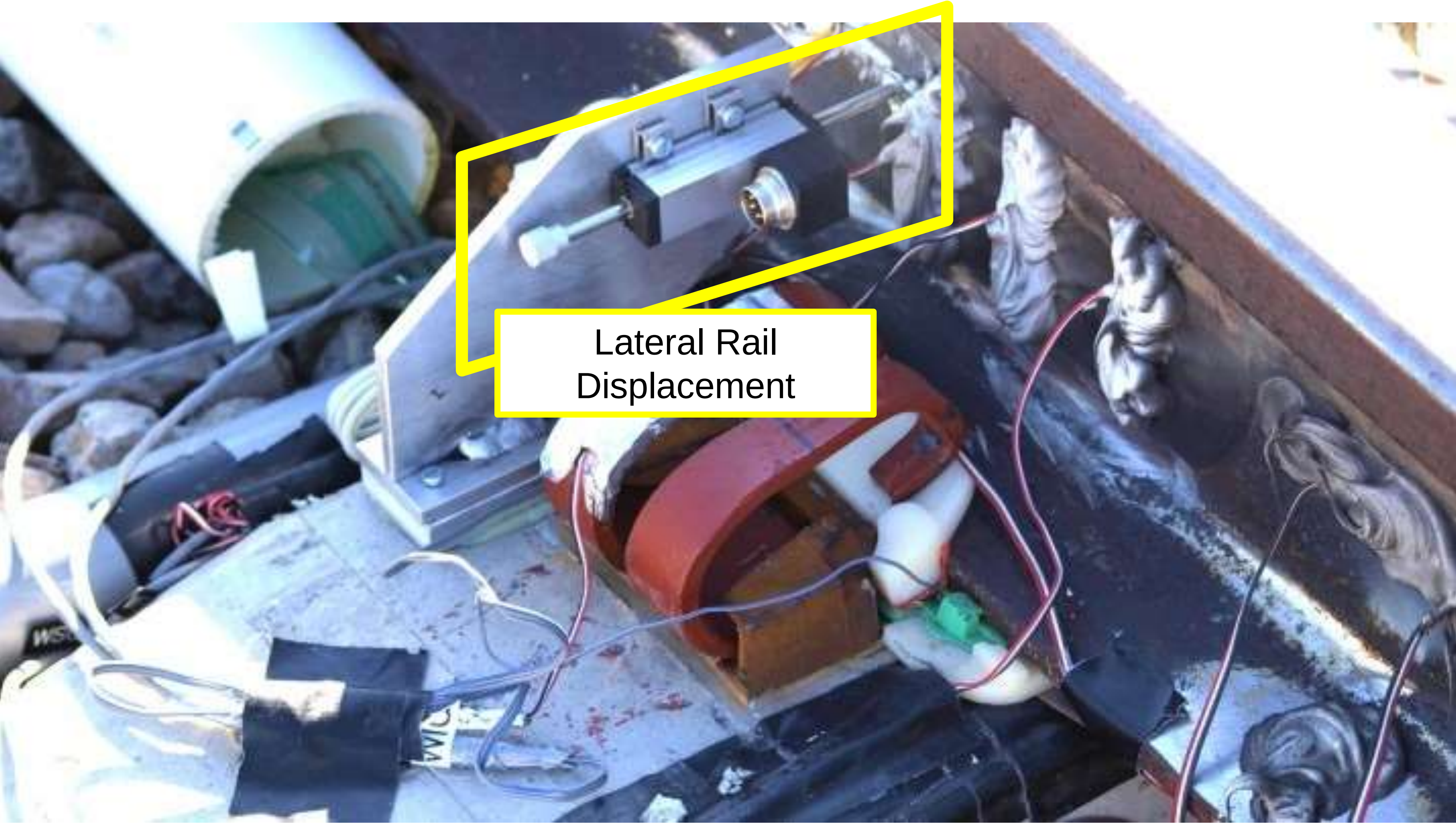


Instrumented Low Rail

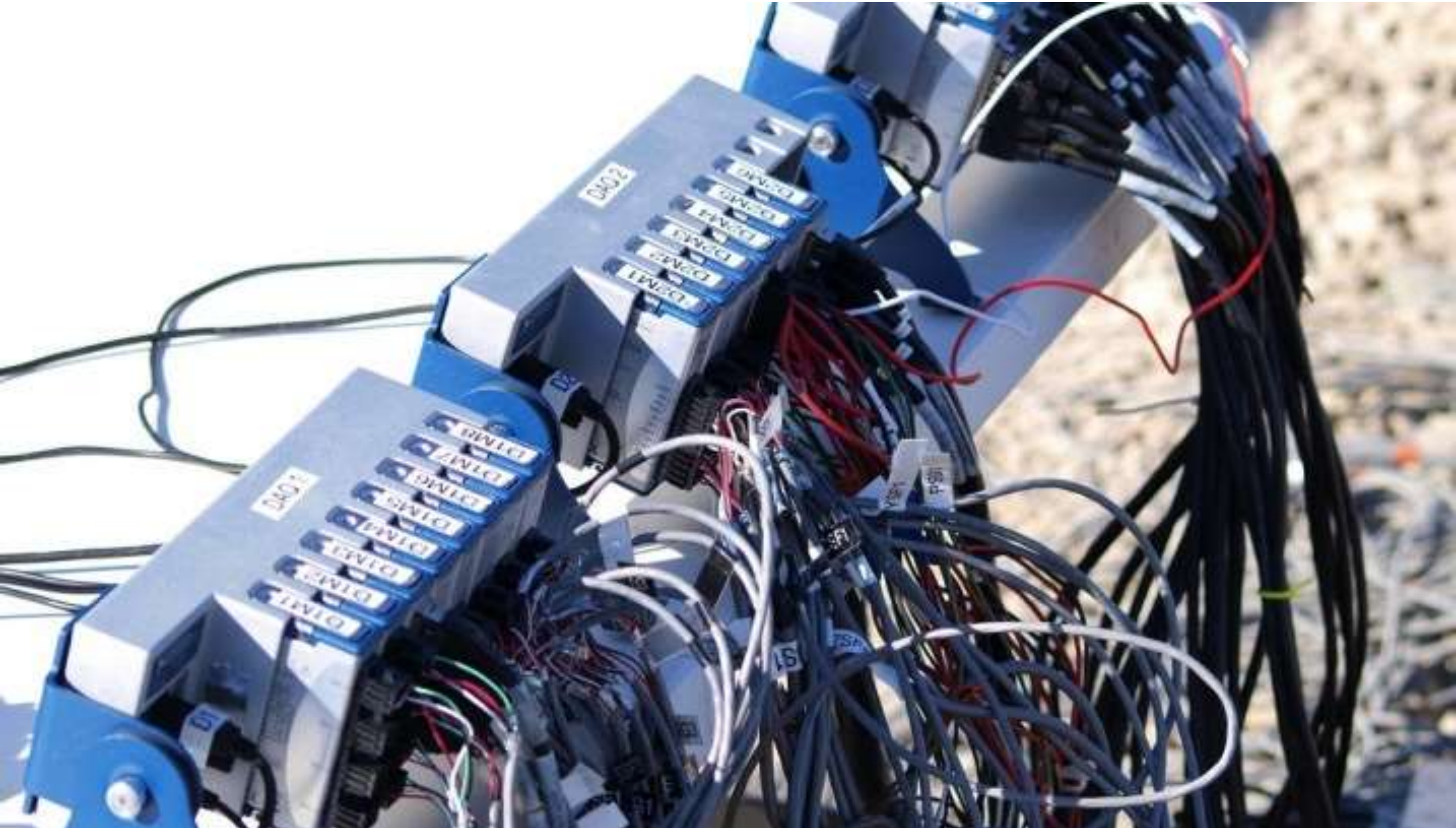
Field-side Instrumentation



Gauge-side Instrumentation



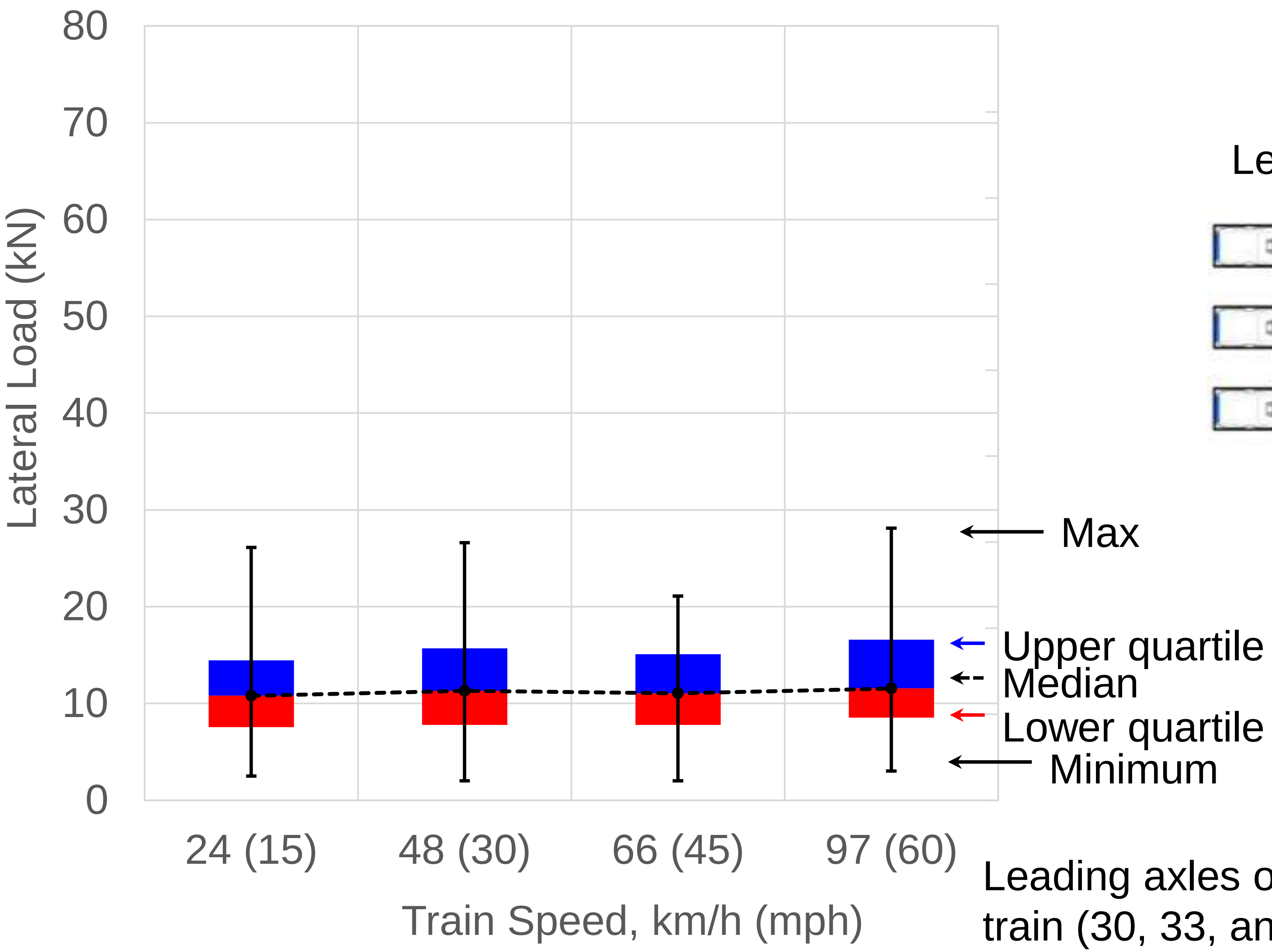
Data Acquisition System

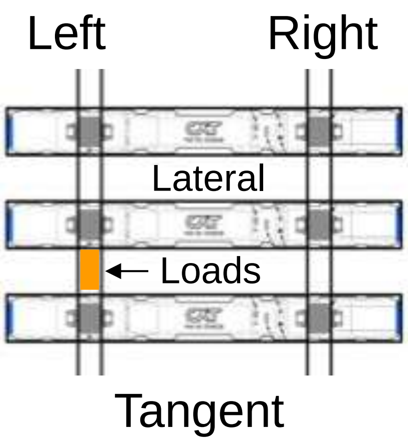


Tangent Track (RTT) – Passenger Train

Tangent Track (RTT) – Freight Train

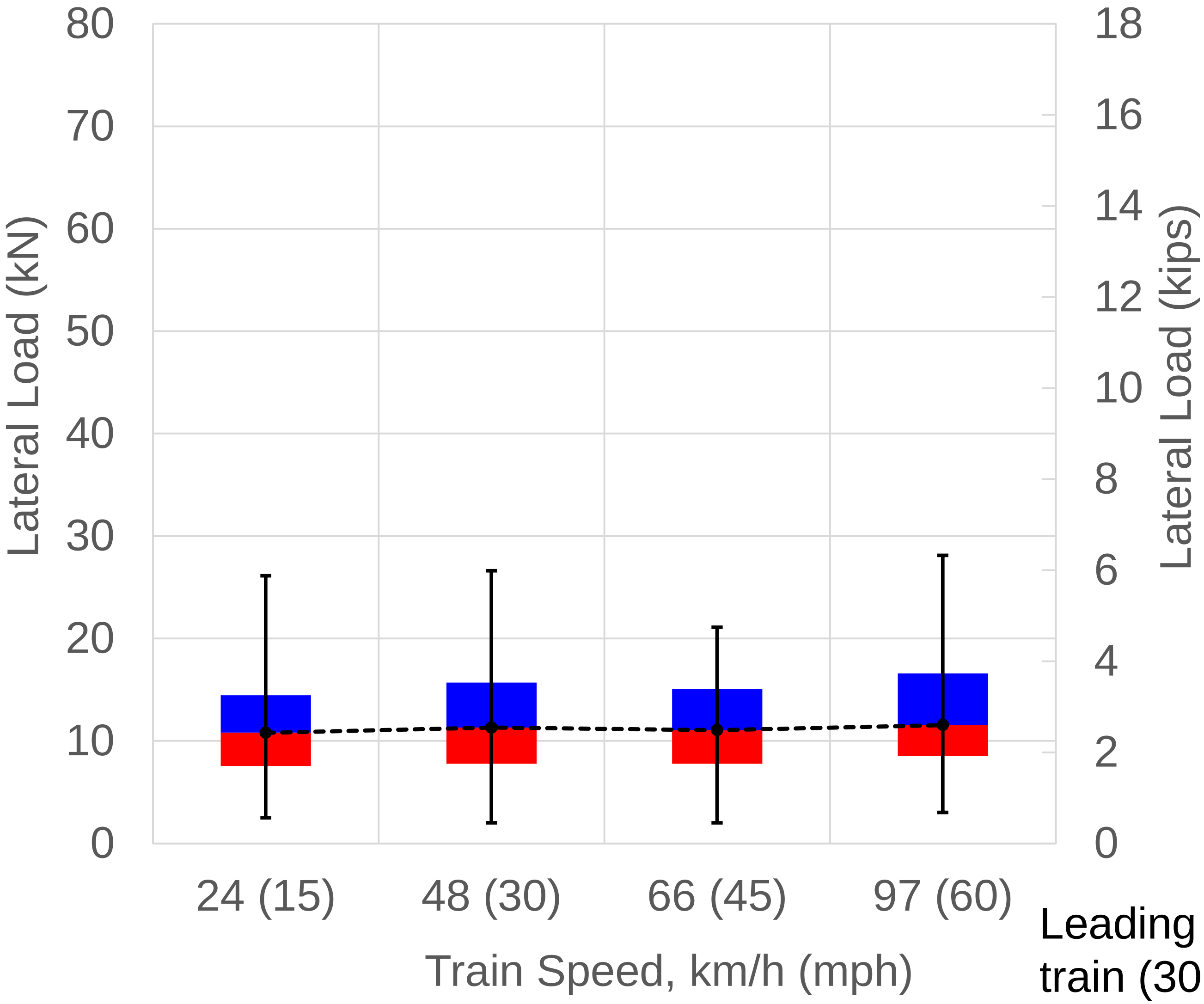
Lateral Loads on Tangent Track (Freight)

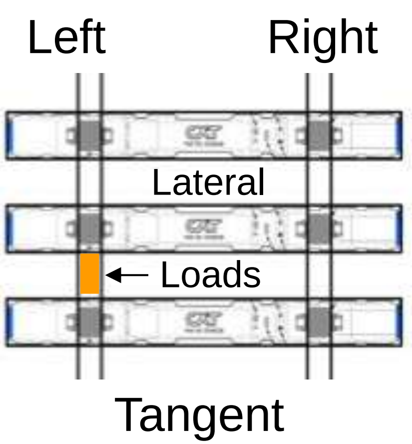




Leading axles of a 10-car freight train (30, 33, and 36t axle loads).

Lateral Loads on Tangent Track (Freight)



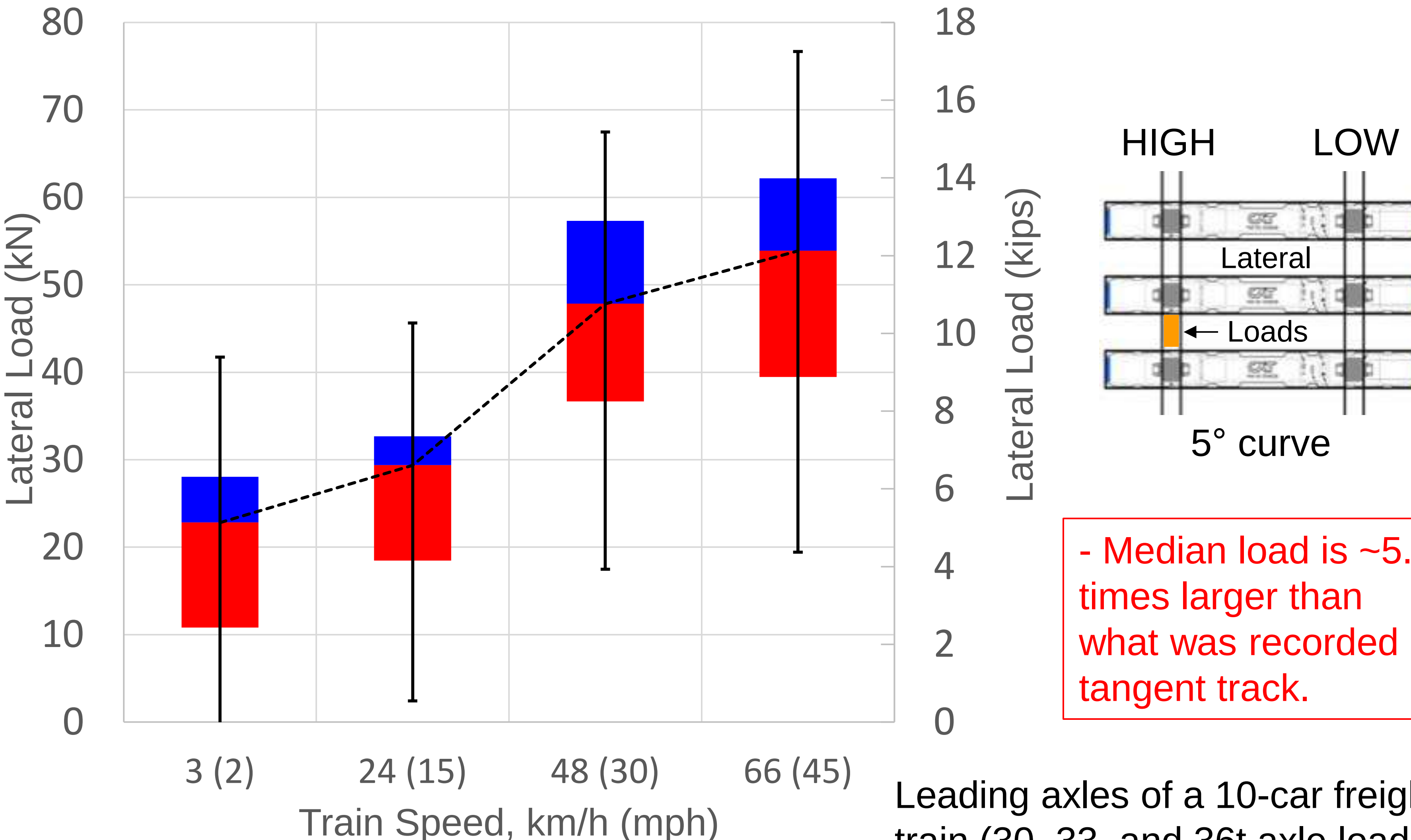


- No correlation between lateral loads and train speed on tangent track.

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

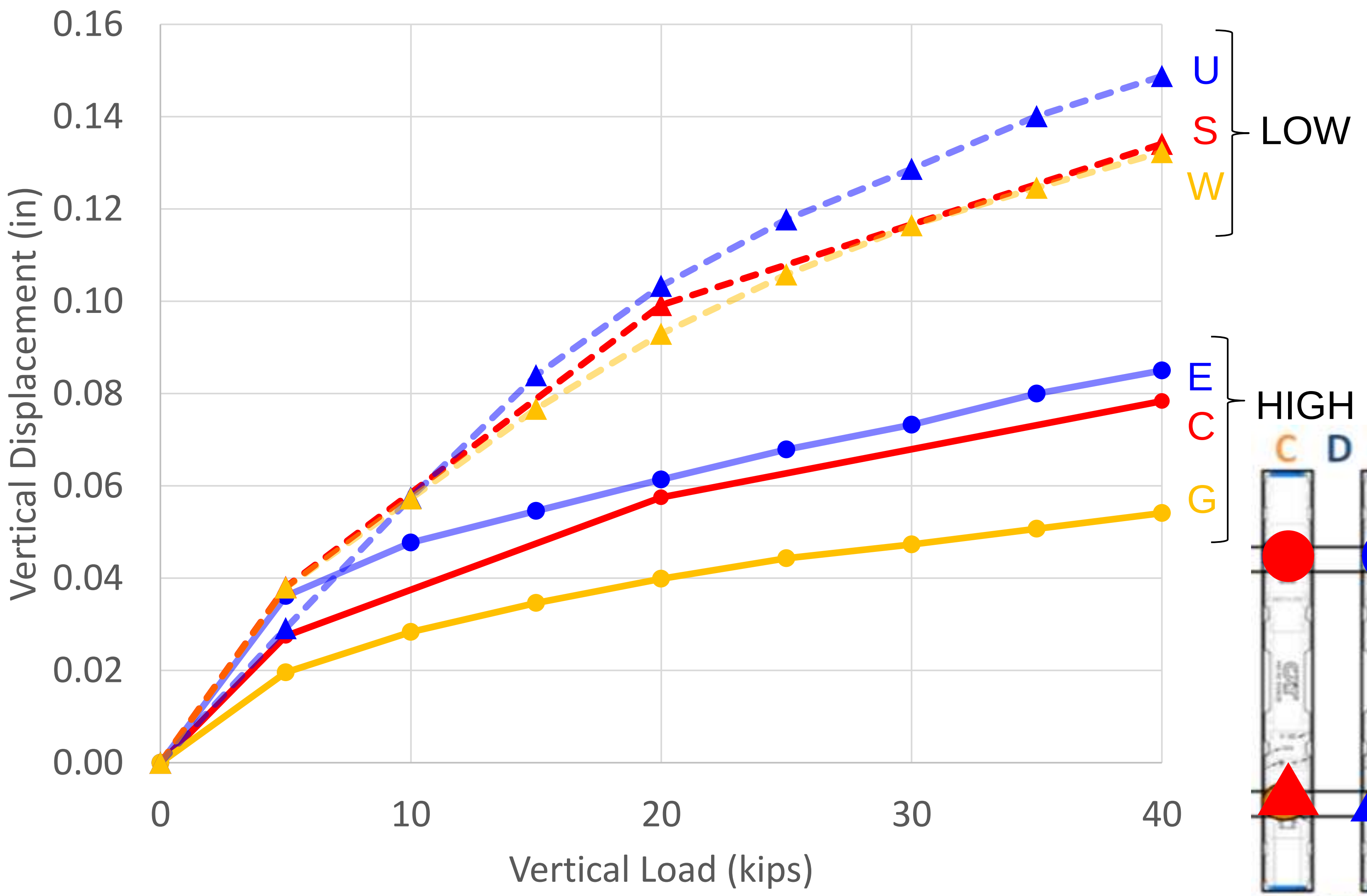


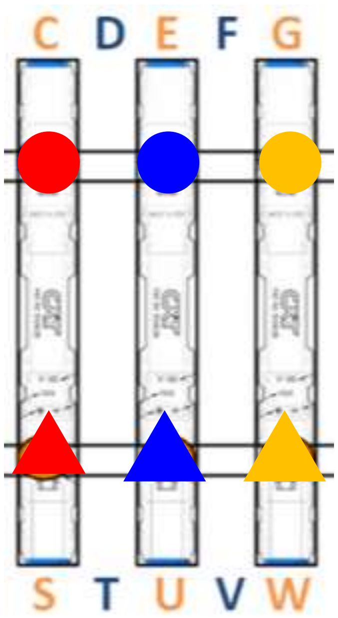
- Median load is ~5.5 times larger than what was recorded in tangent track.

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

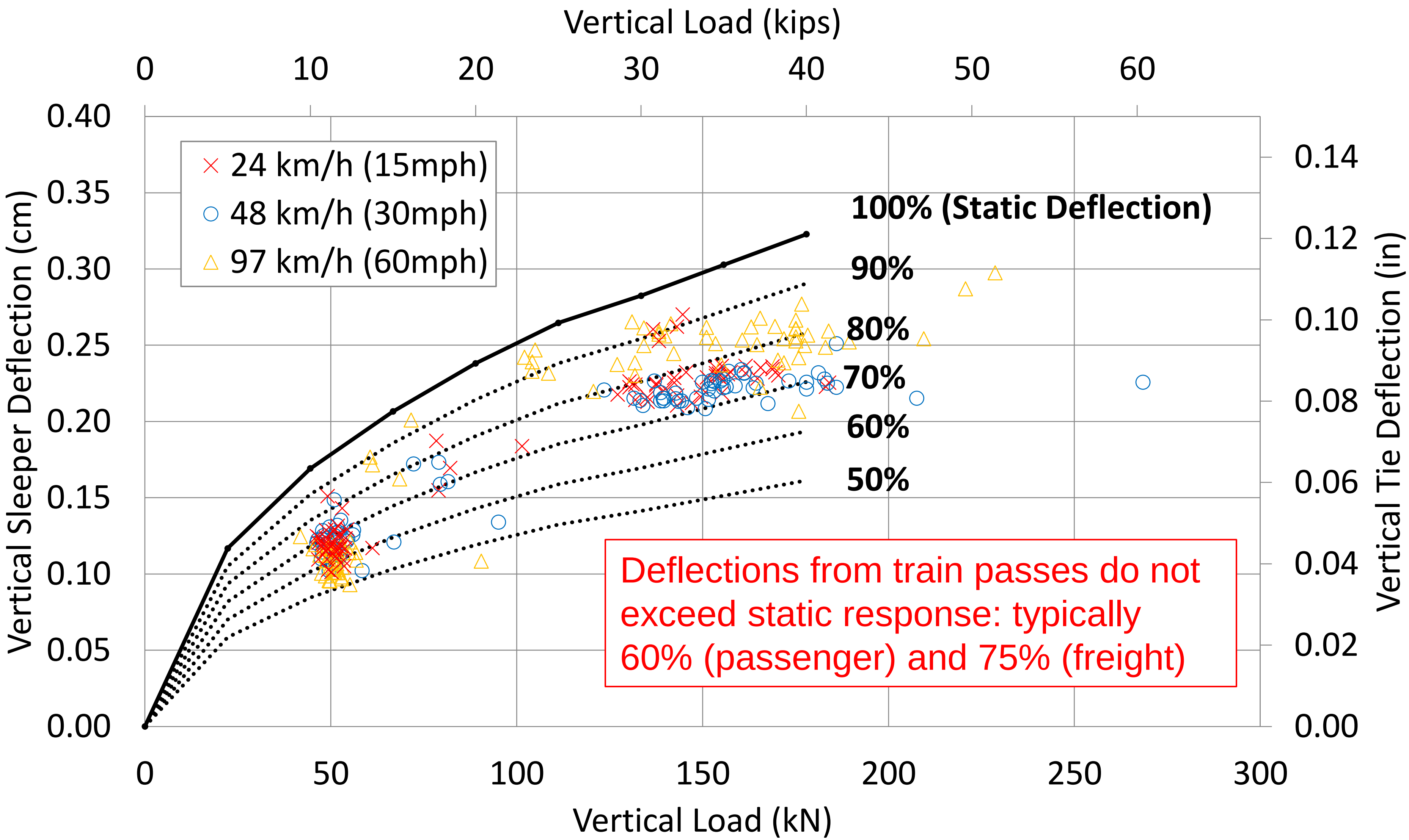
Global Track Deflections Under Passage of Freight Train

Vertical Displacements of Crossties (HTL)

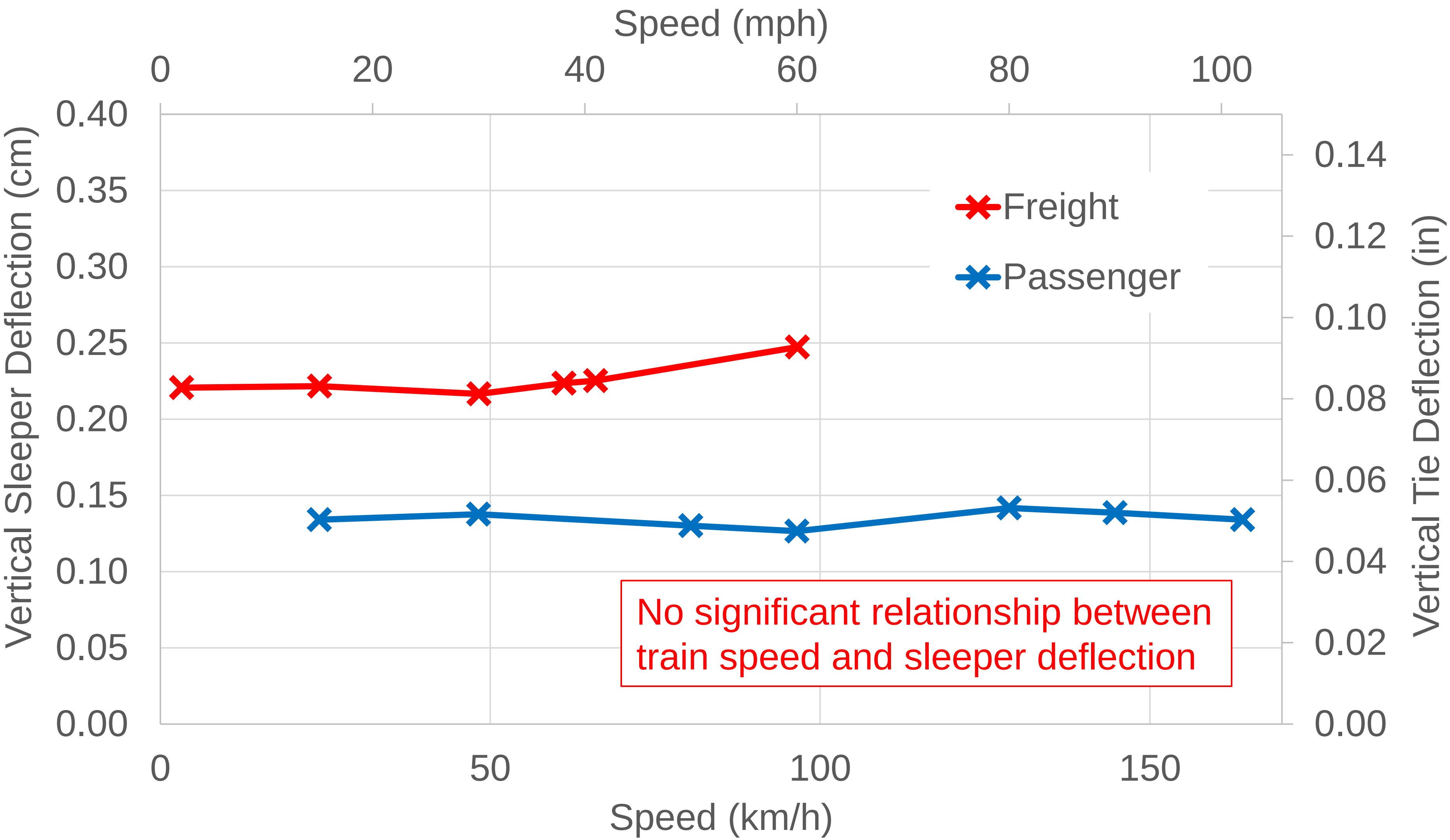




Effect of Train Speed on Sleeper Deflection (cont.)



Effect of Train Speed on Sleeper Displacement



Outline

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

FRA Tie and Fastener Project Structure

Inputs

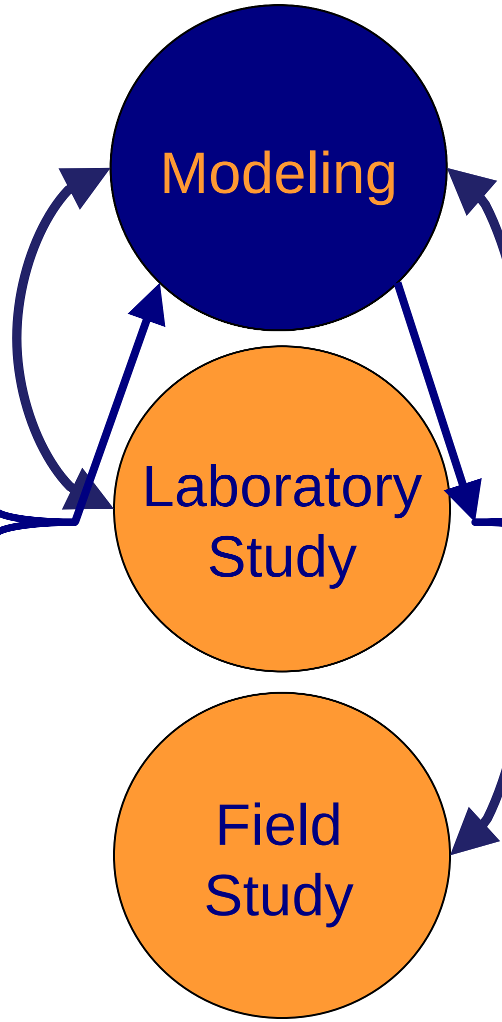
Comprehensive Literature Review

International Tie and Fastening System Survey

Loading Regime (Input) Study

Rail Seat Load Calculation Methodologies

Involvement of Industry Experts



Outputs/Deliverables

Data Collection

Document Depository

Groundwork for Mechanistic Design

International Survey Report

Load Path Map

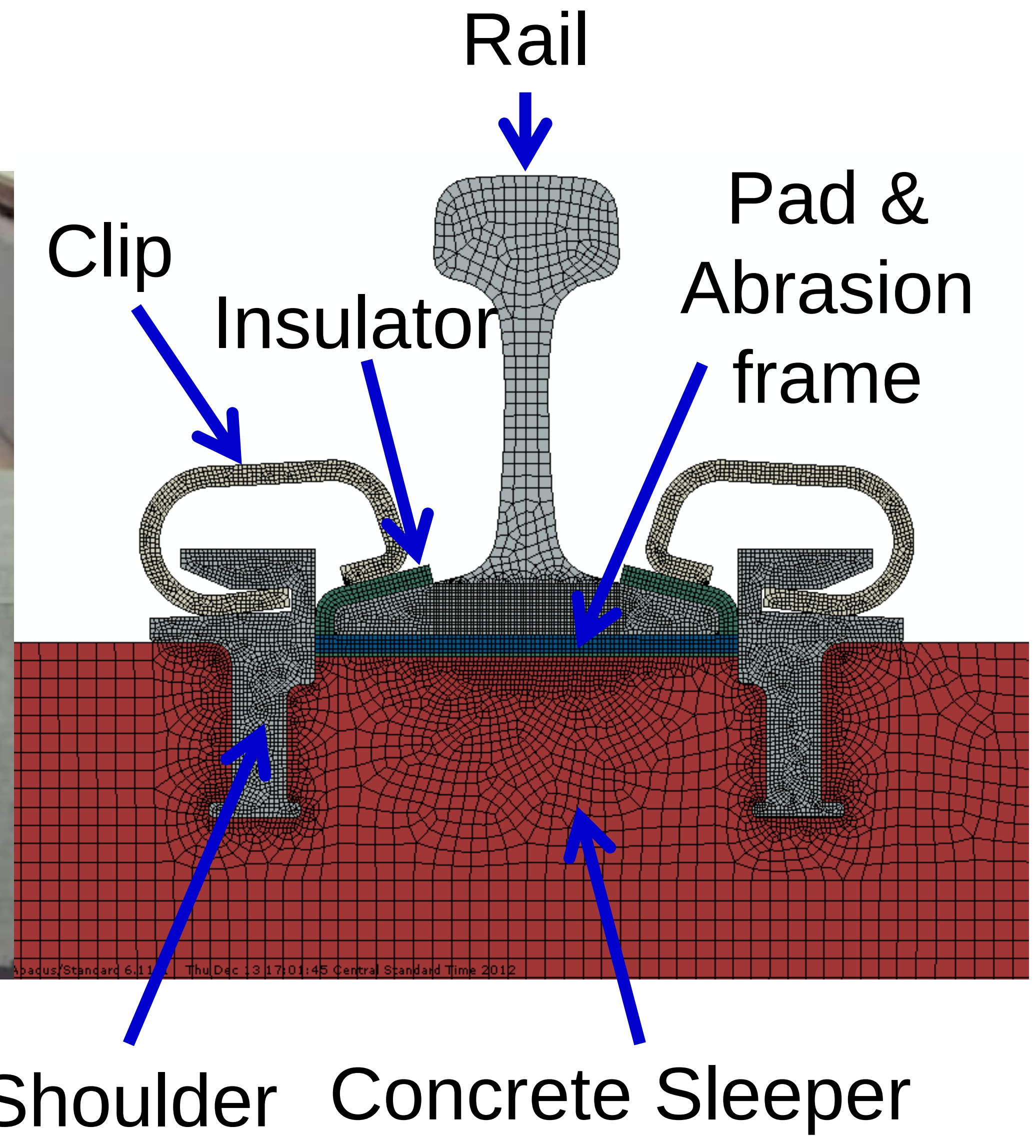
Parametric Analysis

State of Practice Report

Validated Tie and Fastening System Model

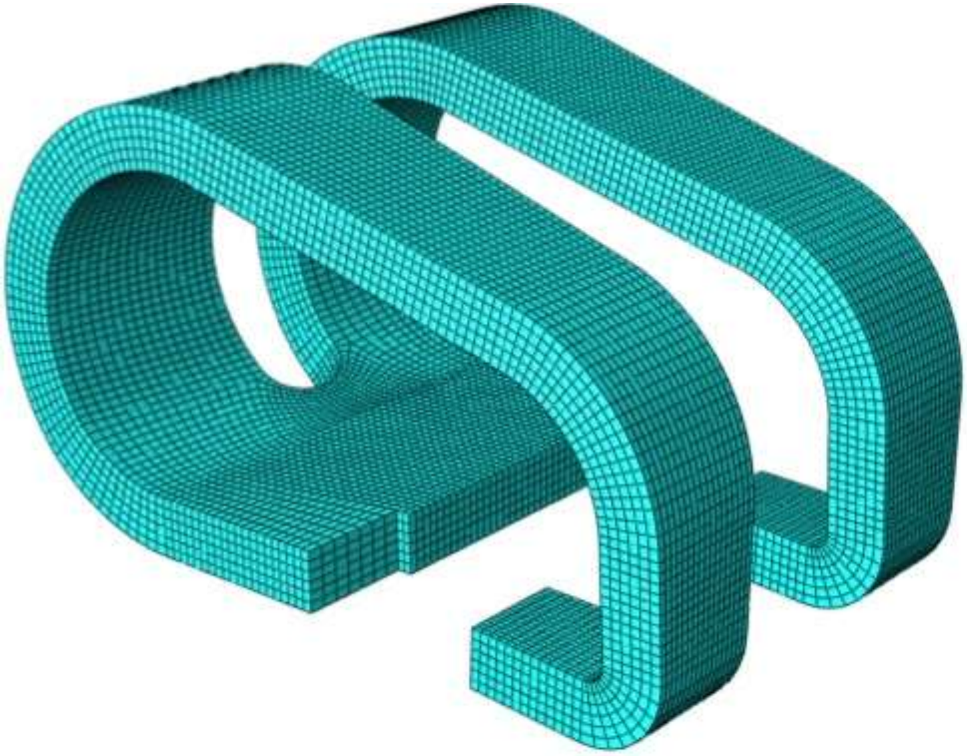
Improved Recommended Practices

Concrete Sleeper and Fastening System



Component Modeling

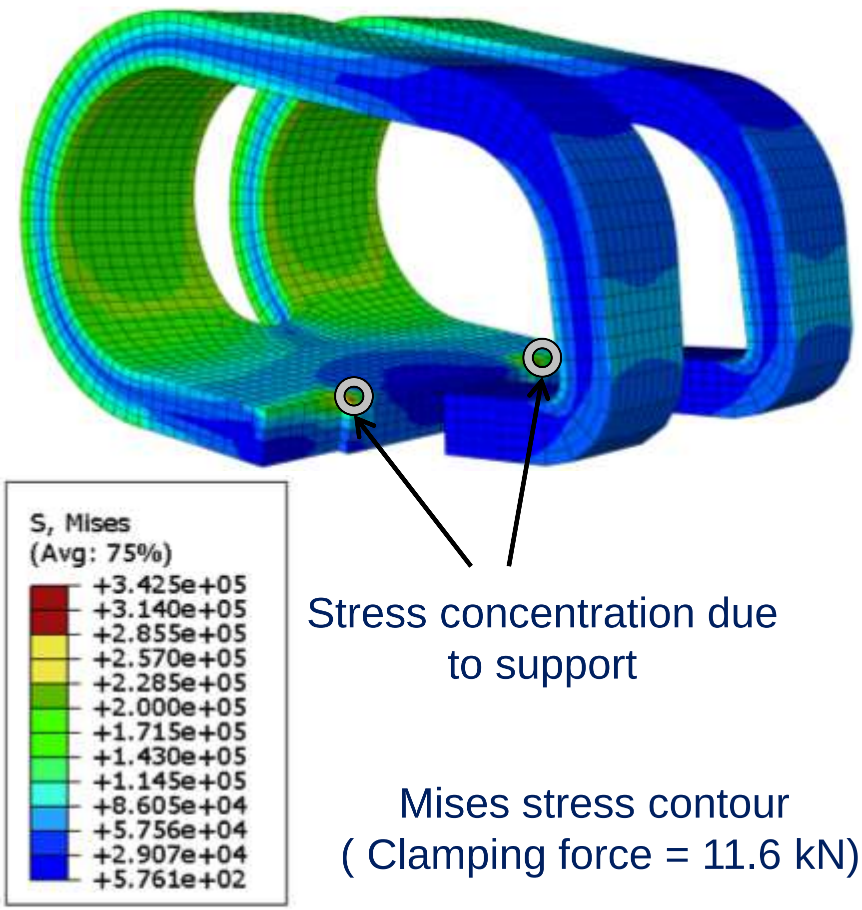
Rail Clip



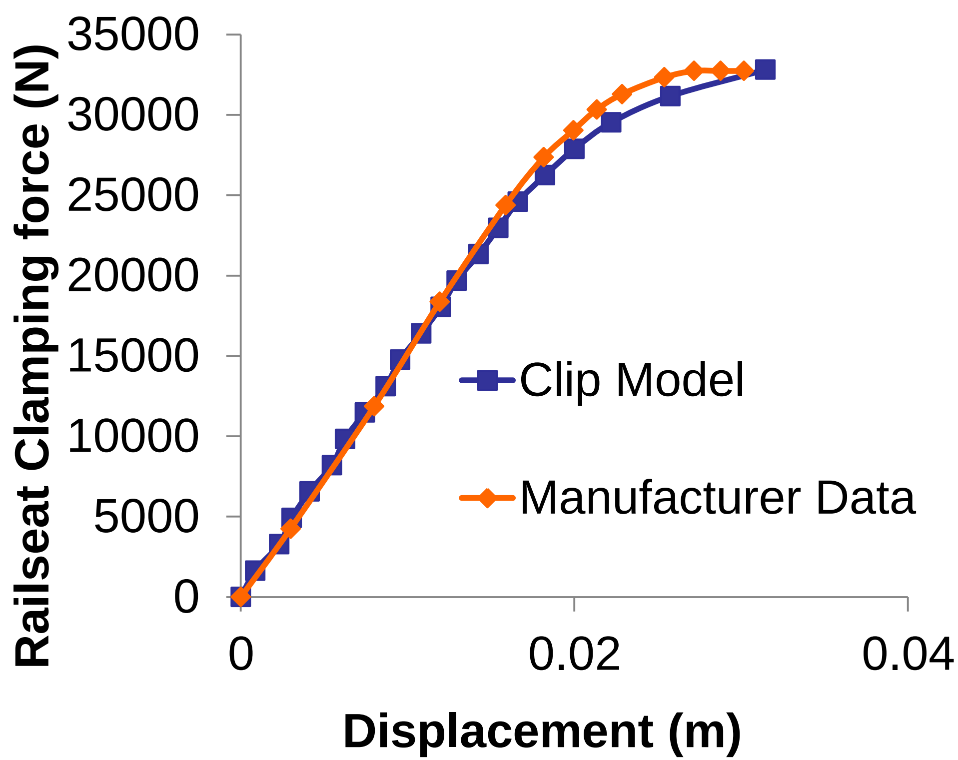
Rail Clip model

Component Modeling: Validation

- Clip Model



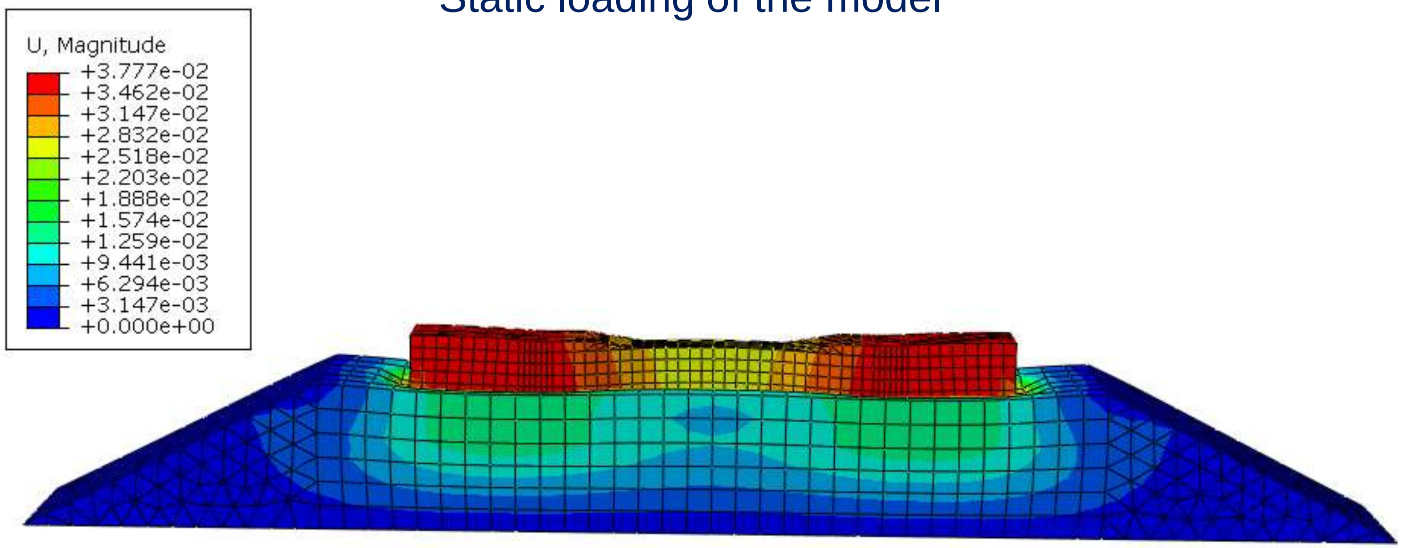
Mises stress contour
(Clamping force = 11.6 kN)



Clamping force-displacement curves

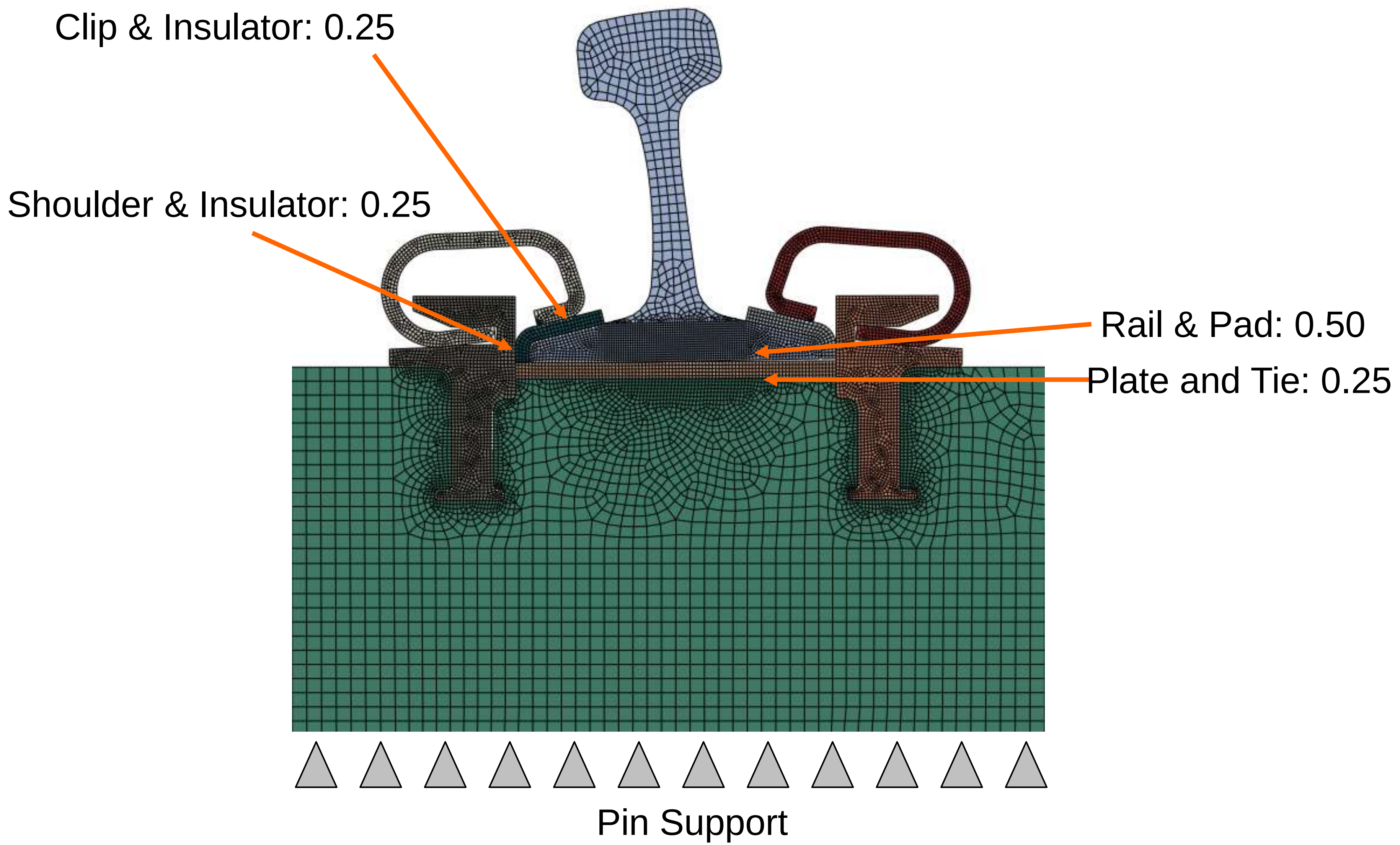
Component Modeling: Concrete Sleeper and Ballast


Static loading of the model



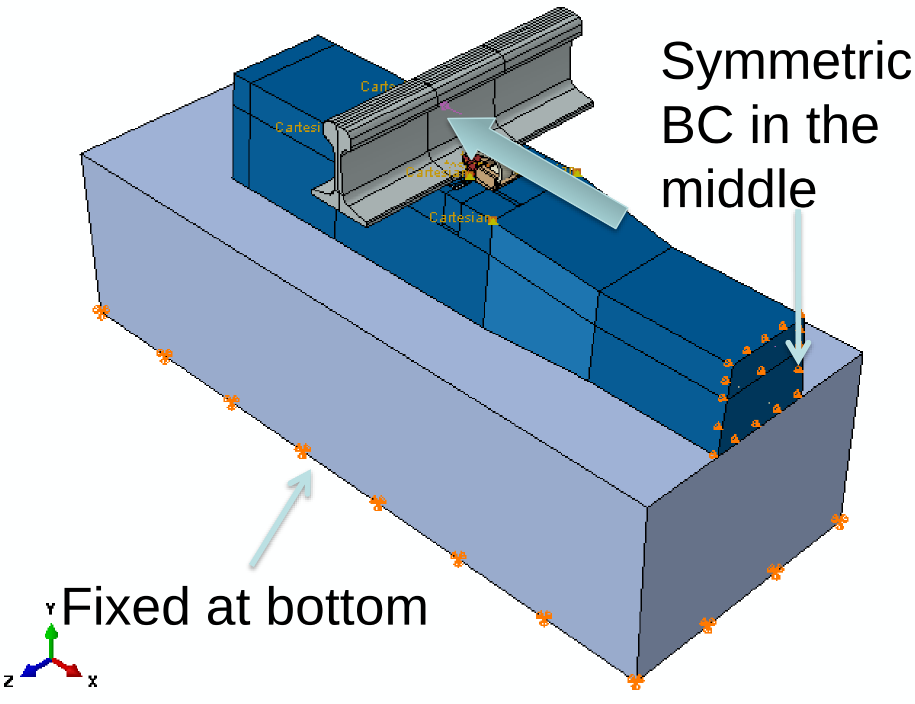
Deformation contour

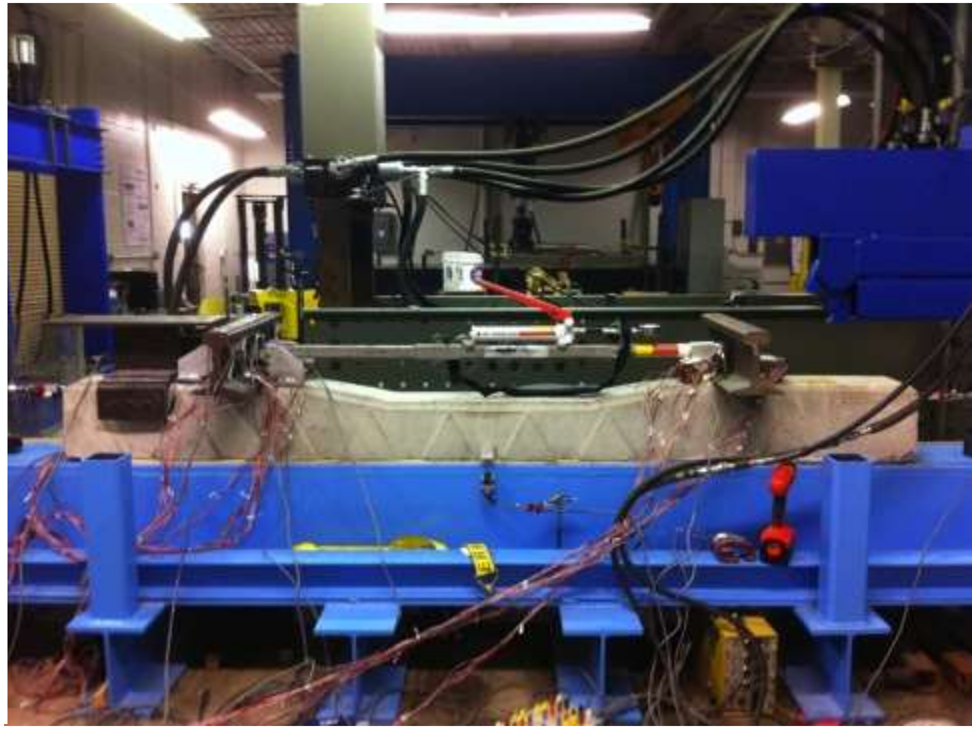
System Modeling - COF Estimation



System Modeling: Single-Sleeper Modeling

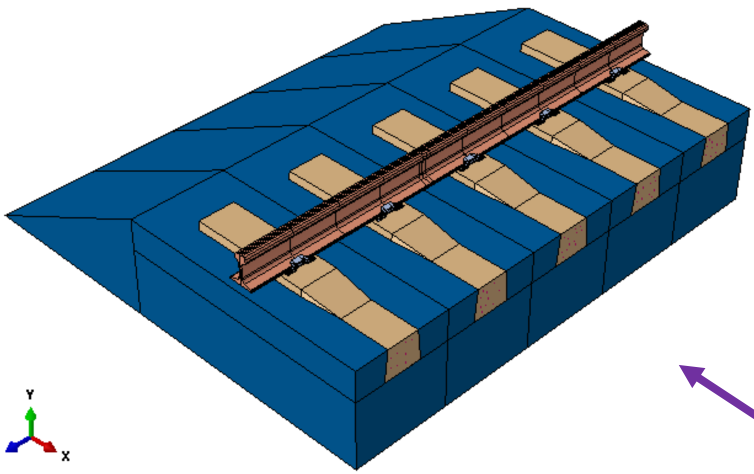
Laboratory Test Validation



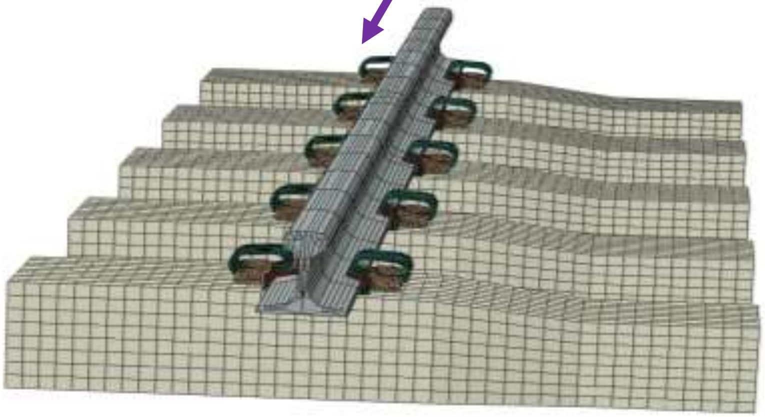


System Model: Multiple-Sleeper Modeling

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

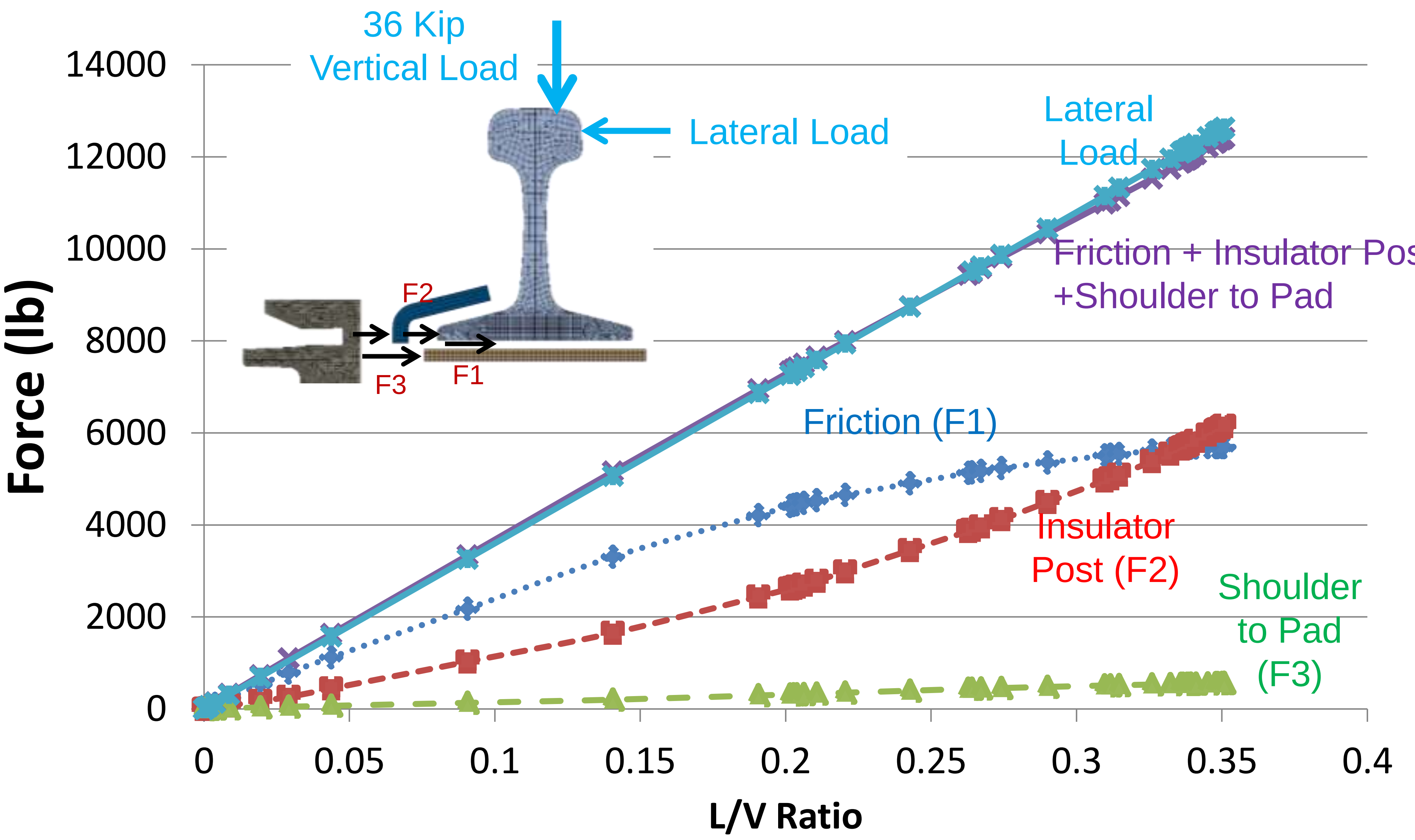


Simplified model:
Fastening system were replaced by BCs and pressure



Detailed model with the fastening system

System Modeling: Lateral Load Path



Future System-Level Modeling Work

- **Additional comparisons:** More measurements on the lab testing set-ups will be deployed and compared with the models
- **Large-scale modeling:** More Models will be built to look into the distribution of loading among multiple ties and the discrete support condition of rail
- **Realistic loading**: More load types (vertical, lateral, and longitudinal loads) and load forms (static and dynamic load) will be applied to the track system to better simulate the actual loading environment
- **Parametric studies**: Parametric studies about material properties and geometric dimensions will be conducted using the model

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- **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 sleepers
  - 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 sleeper displacements
    - global lateral sleeper displacements
    - load transferred to the clamp, insulator-post, and shoulder
- Small-scale, **evaluative tests** on Class I Railroads

The Future of Concrete Crossties and Fastening Systems…

- Mechanistic design and materials choices
  - Concrete materials (e.g. mineral and chemical admixtures, coatings, etc.)
  - Improved plastics (e.g. Nylon abrasion frame, polyurethane rail pad, etc.)
  - Other advanced materials (e.g. tie armor)
- Considerations of friction at **all** system interfaces, and how it relates to overall system design
  - Improved understanding of component interaction
- ***Lowering the stress state*** of the tie and fastening system:
  - Larger rail seats
  - Under Sleeper Pads (USP)
- Improved design validation tests (AREMA C-30 Modifications)
- System level design, once components are better optimized

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

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TRACK SYSTEMS
DELACHAUX GROUP

vossloh

TTCI™
Transportation Technology Center, Inc.

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- BNSF Railway: **John Bosshart, Tom Brueske, Hank Lees, Seth Ogan, Hal Lewandoski,**
- Union Pacific Railroad: **Kevin Hicks, Eric Gehringer, Dwight Clark, Steve Ashmore**
- Vossloh: **Winfred Boesterling, Michael Steidl, Rigi Chackanad, Chris Kenyon**
- Pandrol Track Systems: **Bob Coats, Scott Tripple, Dave Kangas, Frank Brady**
- CXT Concrete Ties: **Pelle Duong, Jim Parsley, Mark Hammons, Vince Petersen**
- VAE Nortrak: **Steve Mattson**
- Rocla Concrete Tie: **Al Smith (retired), Rusty Crowley, Pedro Lemmertz**
- GIC: **Mauricio Gutierrez, Carlos Gutierrez**
- TTCI: **Dave Davis, Richard Reiff, Michael Brown, Ken Laine**
- Engis Corporation: **Peter Kuo, Steven Griffin**
- Others: **Jerry Rose, Tim Johns, Bill Riehl, Brandon Hunter, Al Smith, Fabian Weber, John Clark, Jim Gauntt, Michael Land, Rob Loomis, Jeff DeGross**
- UIUC: **Tim Prunkard, Don Marrow, Darold Marrow, Marc Killion, Ernie Barenberg, Greg Banas, Jim Meister, Dauren Kumarbekov, Josh Brickman, Steven Jastrzebski, Michael Wnek, Andrew Kimmle, Calvin Nutt, Alex Ng, Kris Gustafson, Chris Naranjo, Matthew Greve, Brad Jones, Dan Rivi, Alex Schwarz, Matthew Jarrett, Scott Schmidt, Andrew Stirk**

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Questions?

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