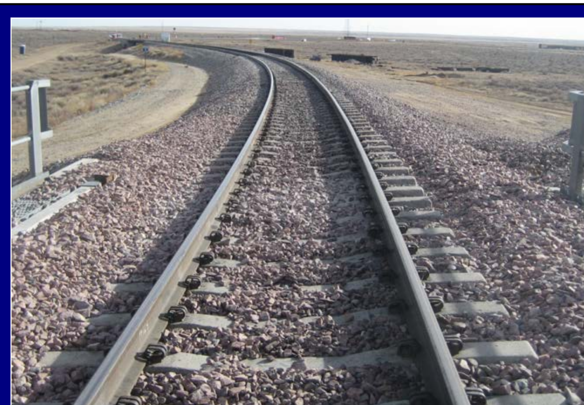
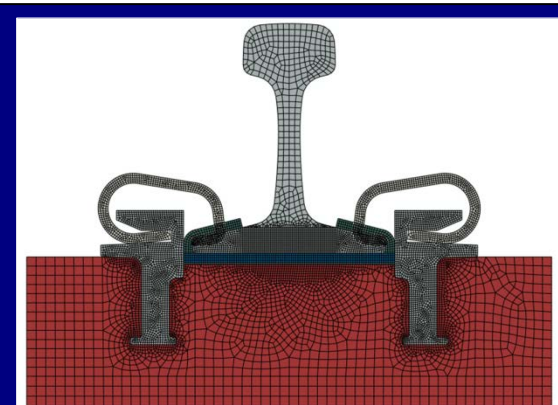
Considerations for Mechanistic Design of Concrete Sleepers and Elastic Fastening Systems in North America





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U.S. Department of Transportation
Federal Railroad Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Background
- Principles of Mechanistic Design
- Shared Use Loading Environment
- Load Quantification Efforts
  - Field Instrumentation
  - Laboratory Instrumentation
  - Analytical Methods
- Conclusions
- Acknowledgements

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:

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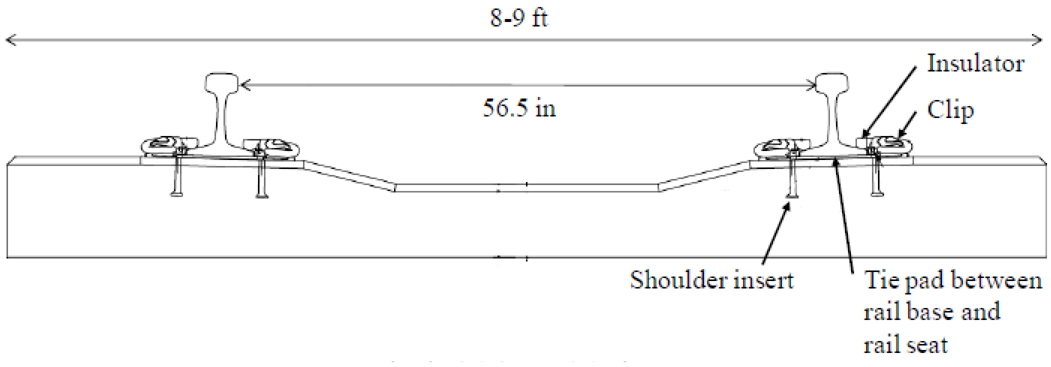
AMTRAK®
Amsted RPS
Amsted Rail
GIC INGENIERÍA Y CONSTRUCCIÓN S.A. DE C.V.
HANSON
LBFoster CXT Concrete Ties

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



Pavement Example of Mechanistic Design

"Mechanistic Interpretation of Nondestructive Pavement Testing Deflections", 1981

- Exploration of factors affecting pavement response to various loading regimes
- Material properties measured from laboratory and backcalculated from system testing agree
  - Can be used for asphalt concrete overlay design
- ILLI-PAVE: stress dependent finite element model used to interpret measured deflections

Applicable to the rail industry?

Source: M.S. Hoffman & M.R. Thompson

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.)

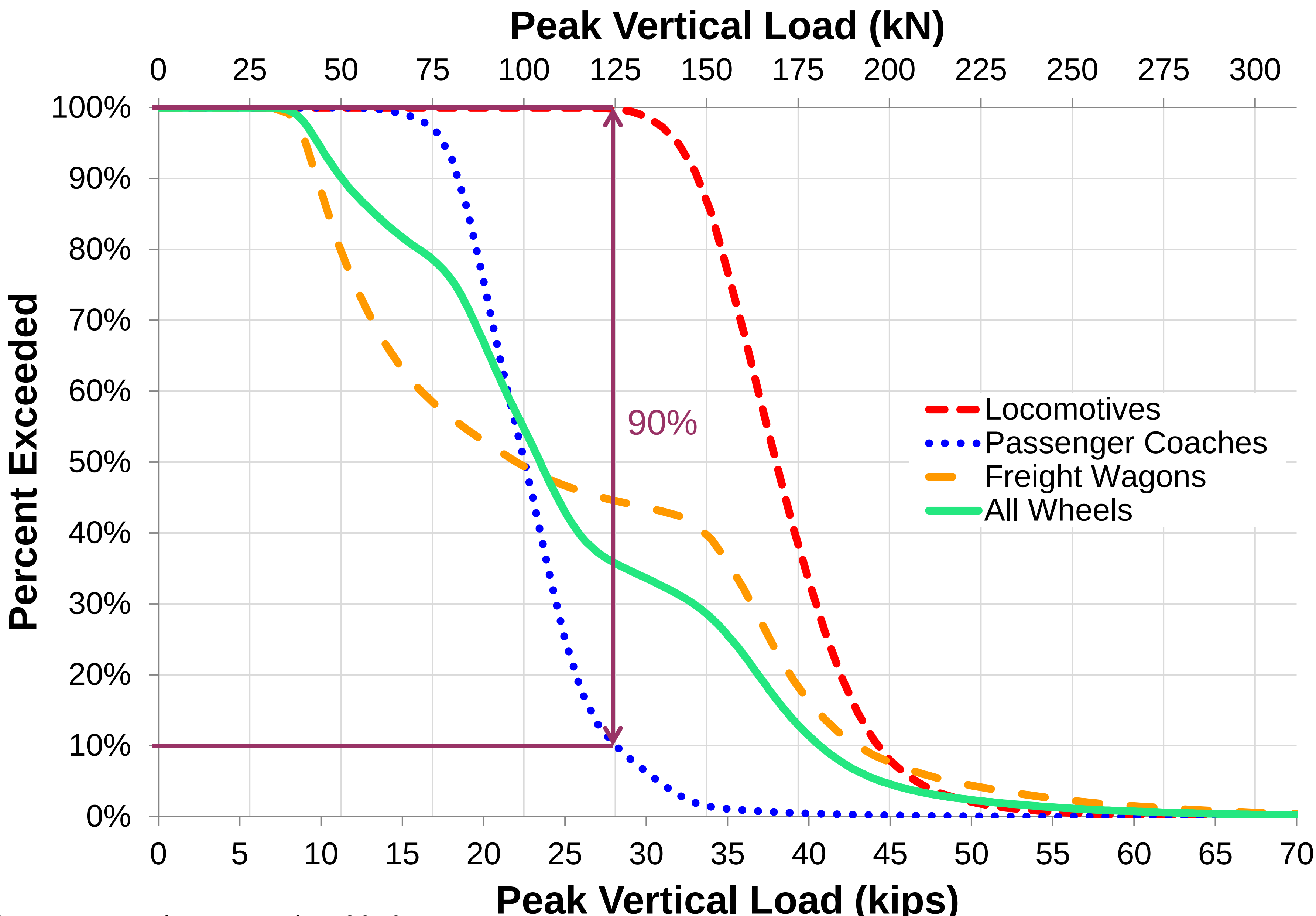
5. Relate loading to failure modes (e.g., how does lateral loading relate to post insulator wear?)
6. Investigate interdependencies through modeling
7. Run parametric analyses
   – Materials, geometry, load location
8. *Development and testing of innovative designs*
   – *Novel rail pad, sleeper, insulator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

1. Quantifying System Input Loads

- Methods of data collection:
  - Wheel Impact Load Detectors (WILD)
  - Instrumented Wheel Sets (IWS)
  - Truck Performance Detectors (TPD)
  - UIUC Instrumentation Plan (FRA Tie BAA)
- Most methods are used to monitor rolling stock performance and assess vehicle health
- Can provide insight into the magnitude and distribution of loads entering track structure

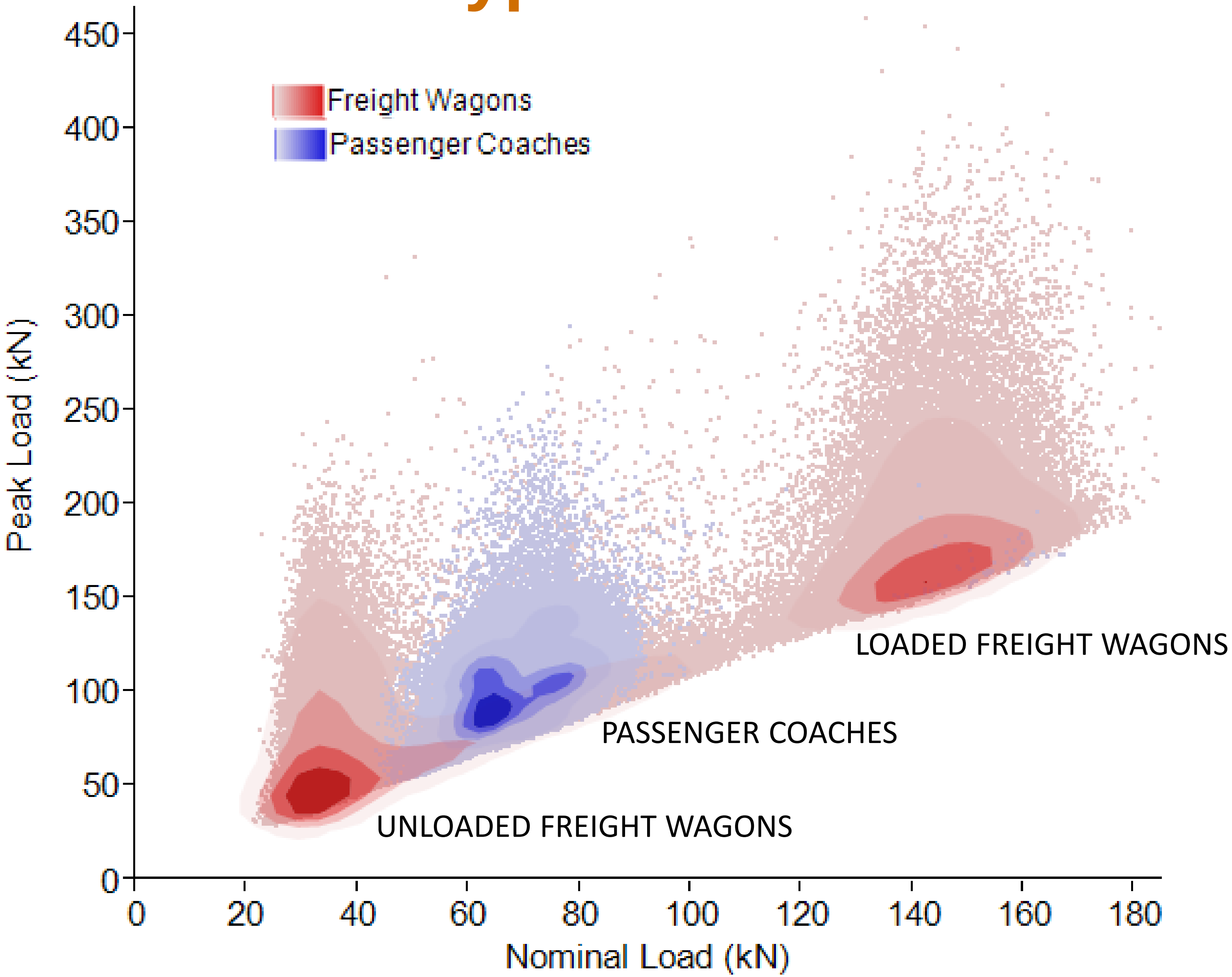
Wheel Impact Load Detectors (WILD)

Vertical Wheel Loads – Edgewood, MD



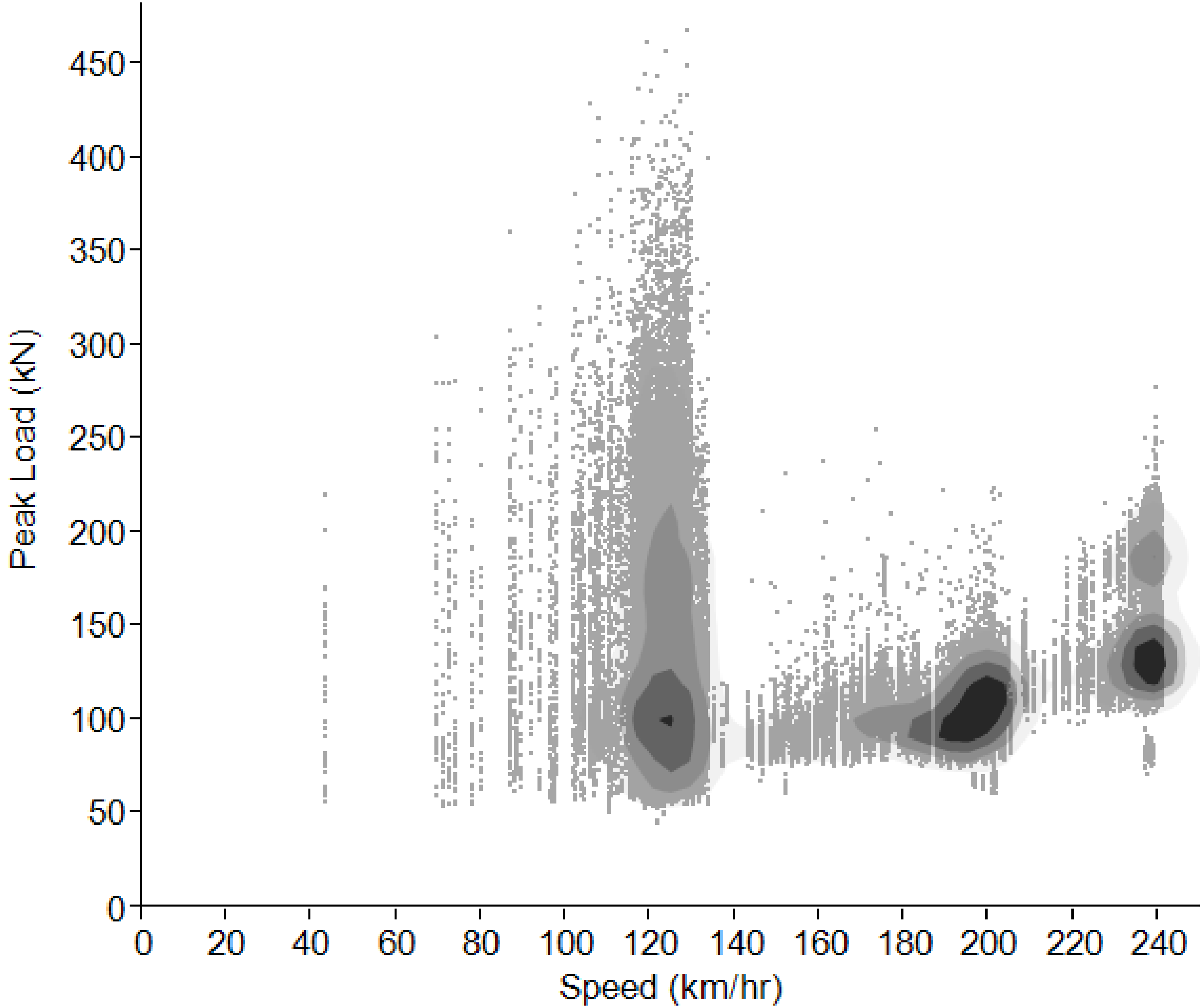
Source: Amtrak – November 2010

Effect of Traffic Type on Peak Wheel Load



Source: Amtrak – Edgewood, MD (November 2010)

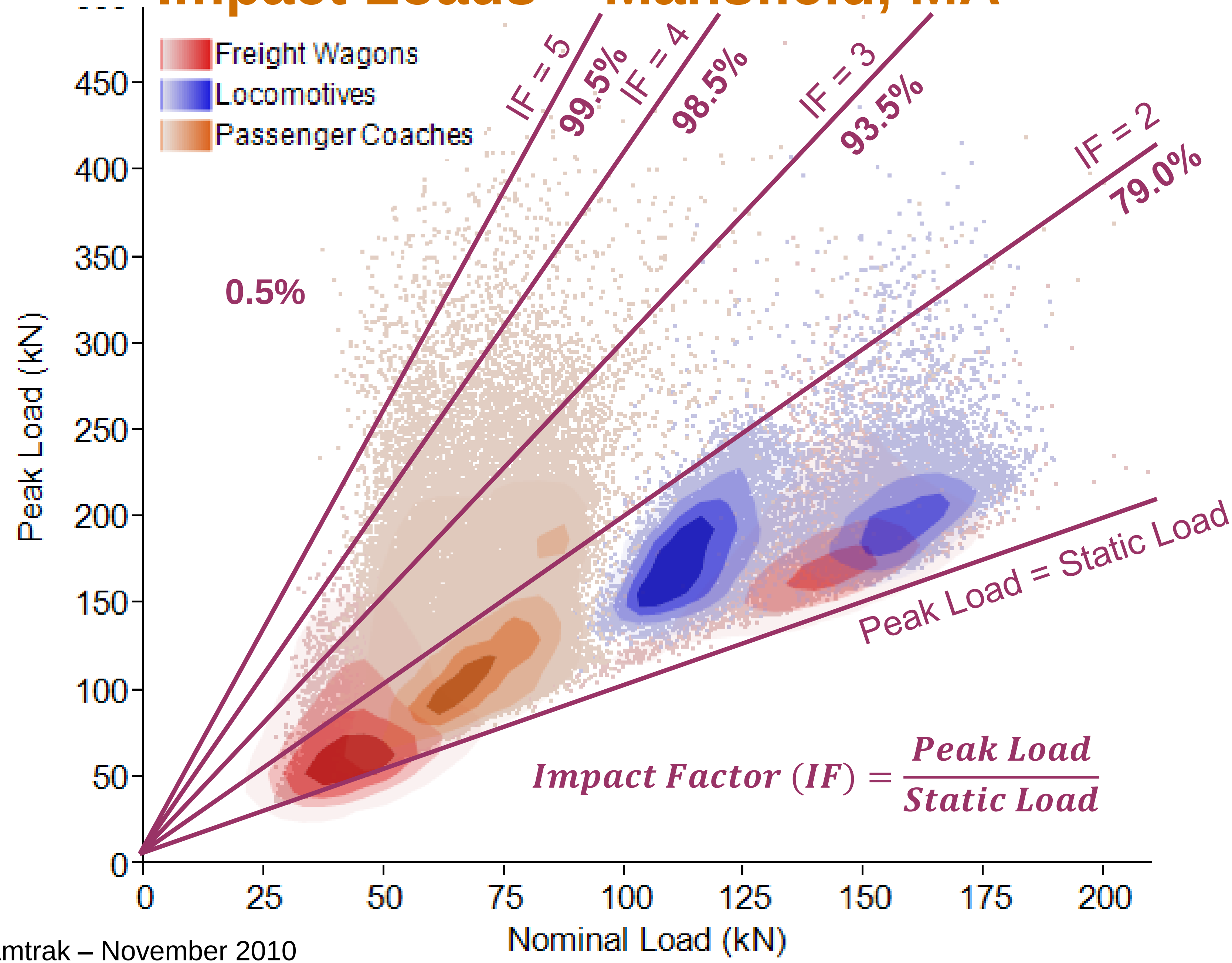
Effect of Wheel Condition on Peak Wheel Load



Source: Amtrak – Mansfied, MA (November 2010)

Passenger Coaches

Impact Loads – Mansfield, MA

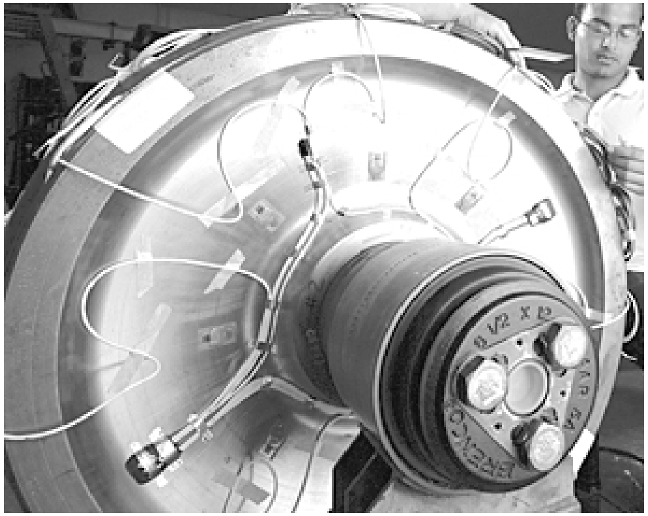


Source: Amtrak – November 2010

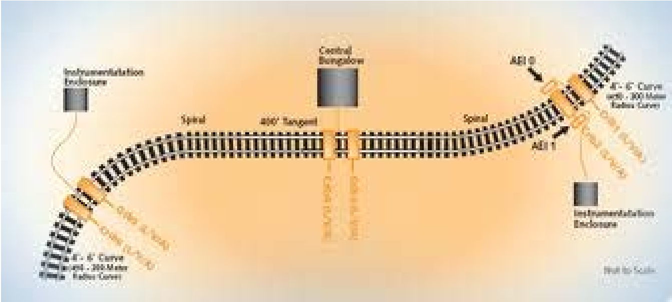
Other Factors Affecting Wheel Loads

- Speed
- Temperature and moisture
- Position within the train
- Curvature
- Grade
- Track quality

Need alternative data collection methods (Curvature, Grade, Track quality)



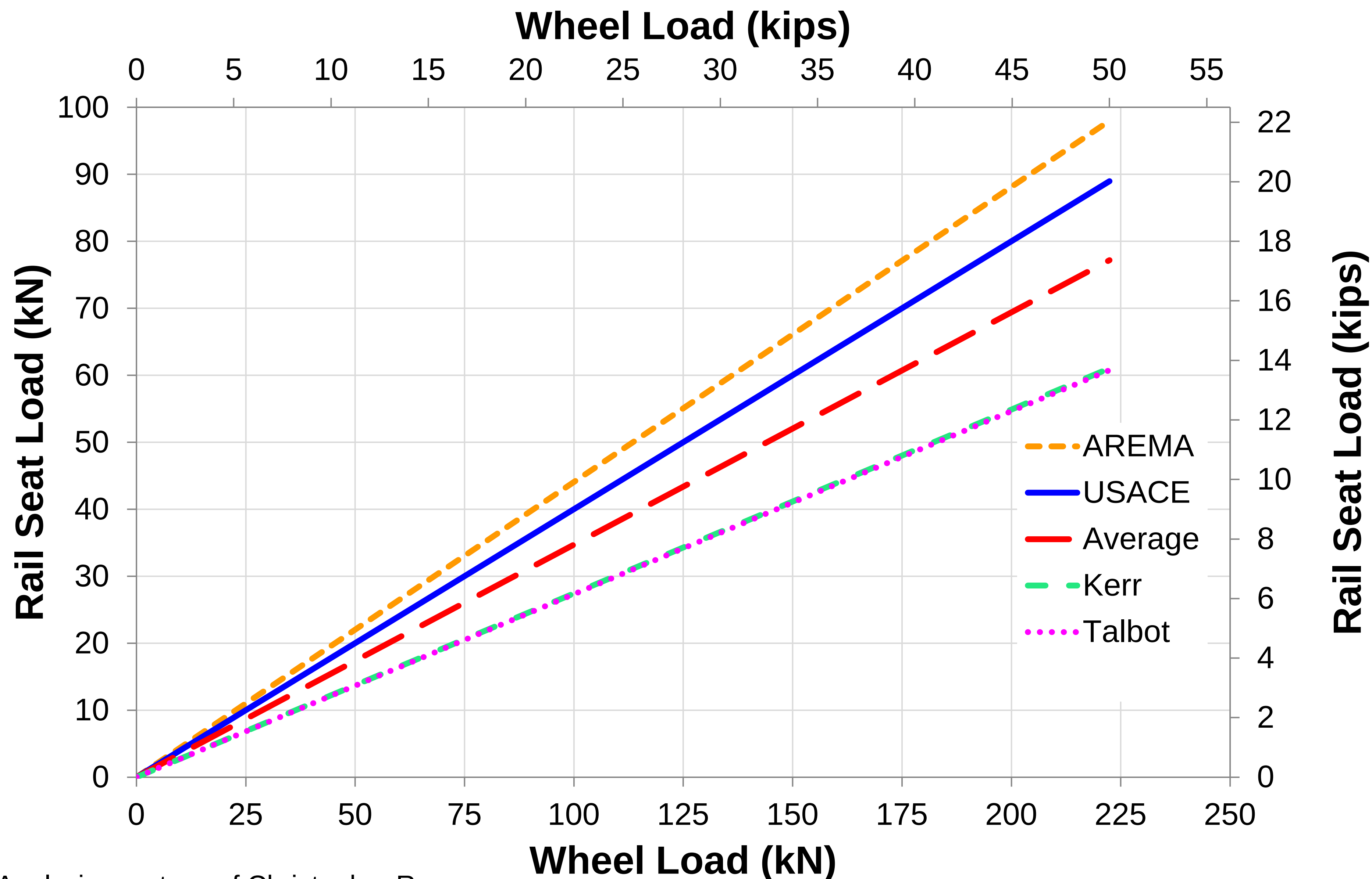
Instrumented Wheel Set



Truck Performance Detector

UIUC Instrumentation Plan

Rail Seat Load Calculation Methodologies

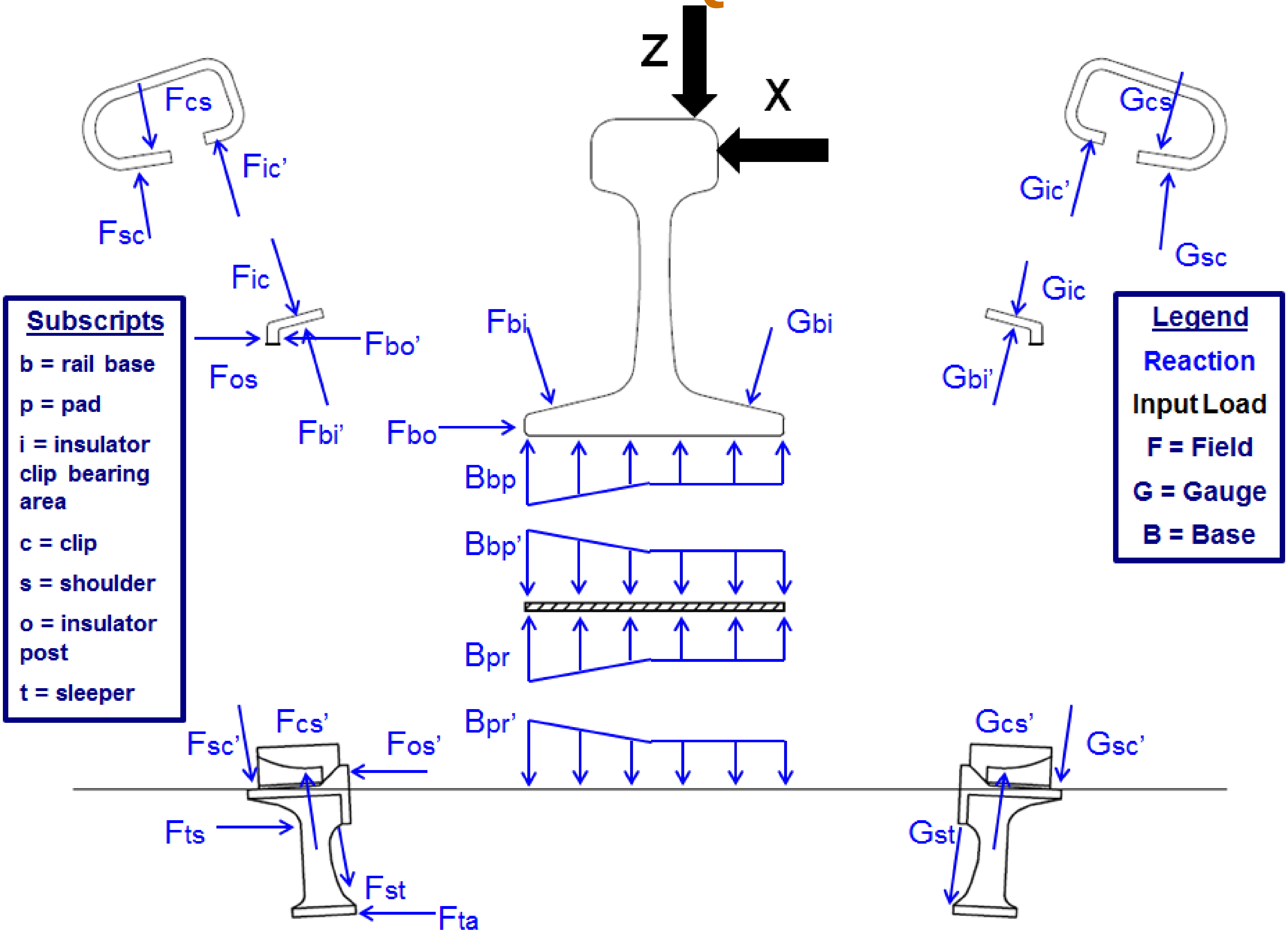


Analysis courtesy of Christopher Rapp

2. Establishment of the Qualitative Load Path

- Development of a static load path map for entire concrete sleeper and fastening system
- Identification and classification of all forces acting on and internal forces within each component
- Helps understand demands on each component
- Identification of component interactions
- Development of component relationships

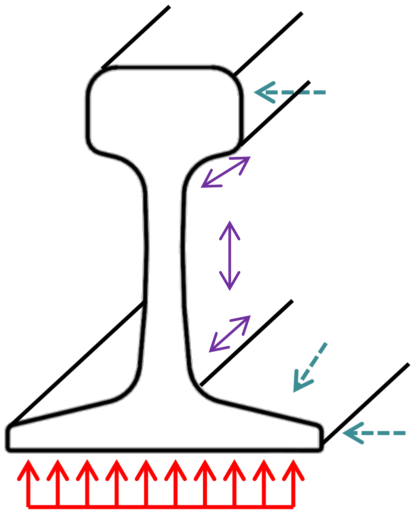
2. Establishment of the Qualitative Load Path



3. Quantifying Loads: Instrumentation

Rail

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

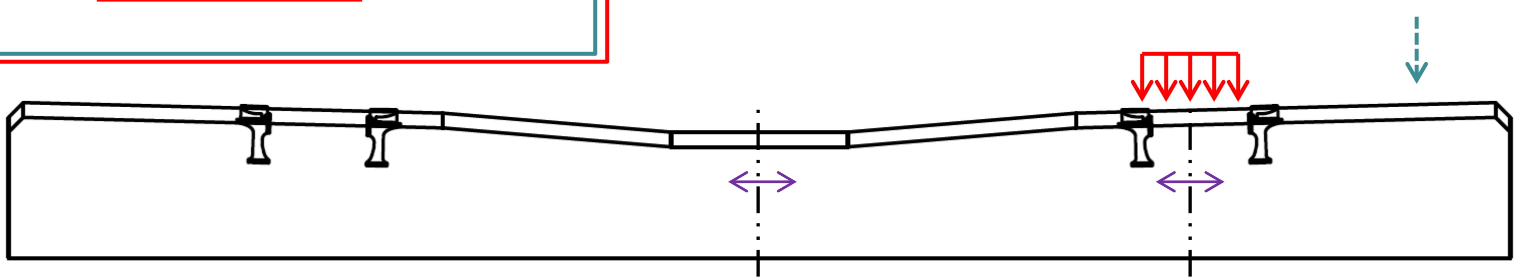


Fasteners/ Insulator

- Strain of fasteners
- Stresses on insulator

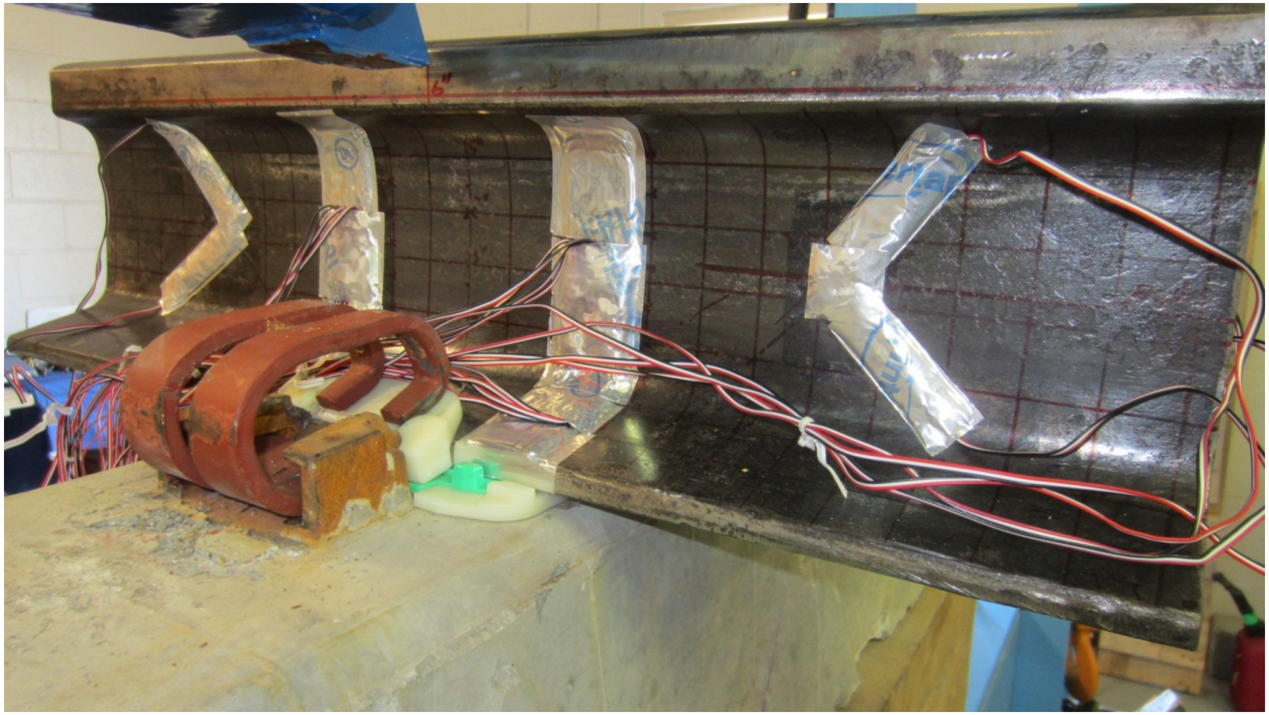
Concrete Sleepers

- Internal strains
  - Midspan
  - Rail Seat
- Stresses at rail seat
- Global displacement of the sleeper



3a. 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



3b. Field Instrumentation

Monticello Railway Museum – Fall 2011

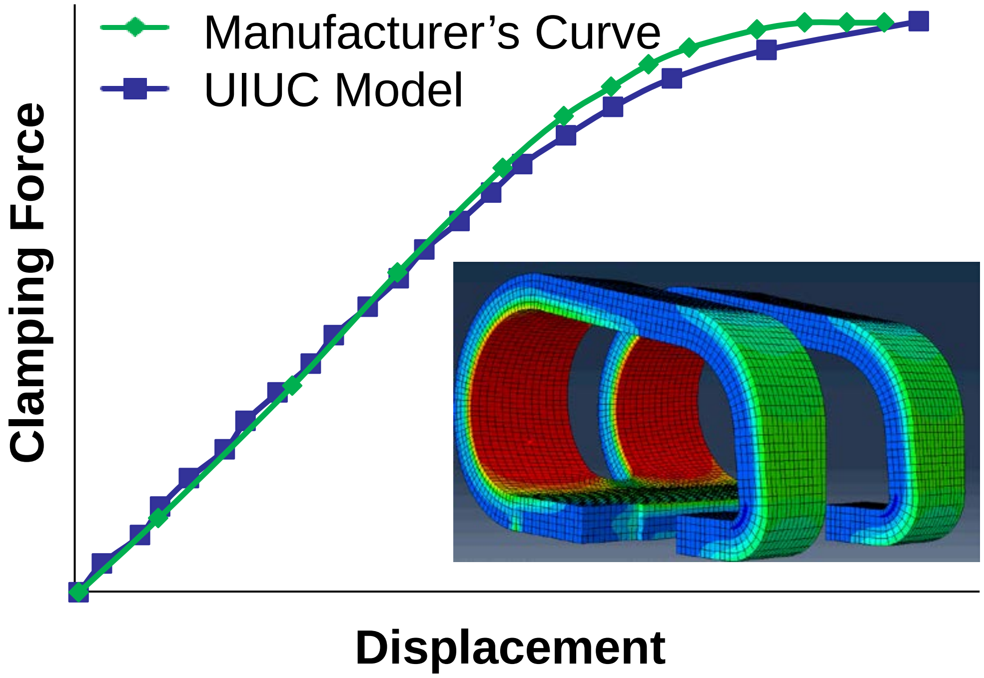
- Proof of concept for future field experimentation

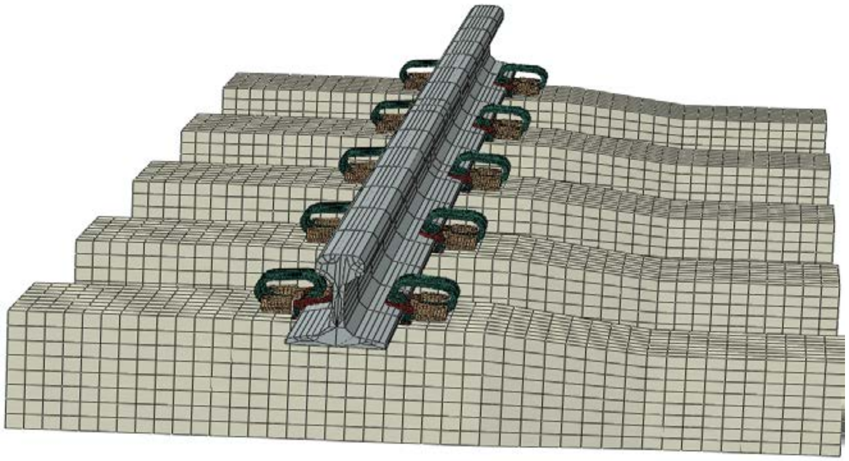
Transportation Technology Center (TTC) – July 2012

- Seven consecutive sleepers instrumented
- Tangent and curve sections
- Additional testing at TTC – May 2013

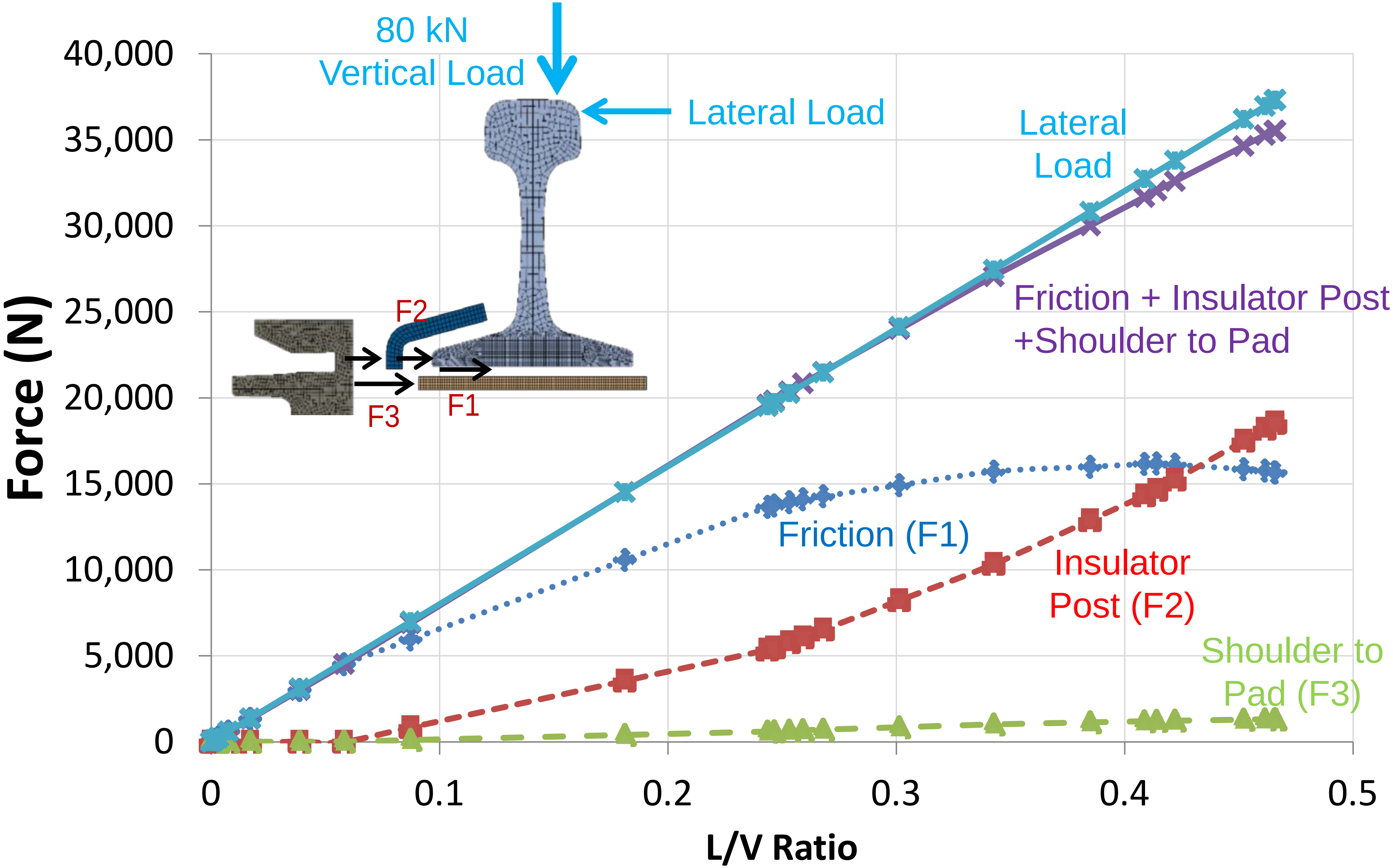
3c. Quantifying Loads: Finite Element Modeling

- Component models to provide reference for lab and field experimental efforts
- Detailed structural model for conducting parametric analyses on materials and geometries of components
- System model to understand component interactions





3c. System Modeling: Lateral Load Path



Conclusions

- Passenger and freight loads on shared infrastructure can cause divergent design recommendations due to varied loading
  - Quantification of loads is critical in improving design and performance of infrastructure
  - Component interaction must be well understood for adequate design methodologies
- Mechanistic design provides a framework for improved recommended design practices
- **Ultimate objective**: increase safety and lower life cycle costs of the concrete sleeper and fastening system

Acknowledgements

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