Vertical Load Path Analysis

FRA Tie and Fastener BAA – Industry Partners Meeting

Incline Village, NV

7 Oct 2013

Kartik Manda, David Lange, Riley Edwards, Marcus Dersch, and Ryan Kernes

U.S. Department of Transportation
Federal Railroad Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Objectives
- Background
- Instrumentation Overview
- Defining the vertical load path
- Understanding rail seat loads
  - Fraction of vertical load
- Vertical tie deflections
  - Effect on rail seat load
- Dynamic wheel loads

Overall Project Deliverables

Mechanistic Design Framework

Literature Review

Load Path Analysis

International Standards

Current Industry Practices

AREMA Chapter 30

I – TRACK

Statistical Analysis from FEM

Free Body Diagram Analysis

Probabilistic Loading

Finite Element Model

Laboratory Experimentation

Field Experimentation

Parametric Analyses

Purpose of Vertical Load Path Analysis

- Identify the load path of vertical forces through the concrete crosstie and fastening system
- Quantify the demands on each component in the system
- Determine how crosstie support variability effects the demands on the components within the vertical load path
- Provide vital inputs to the development of a finite element (FE) model and method of performing mechanistic design of the concrete crossties and fastening systems
- Provide insight for future field testing in revenue service applications

Background Knowledge and Findings

- Field experimentation and modeling show that vertical load is distributed over multiple ties
- Rail seat load is of more relevance than the wheel load with respect to the design of the concrete crosstie and fastening system
- Stiffness of each component is critical to the system and contributes to overall behavior

July 2012 Field Instrumentation

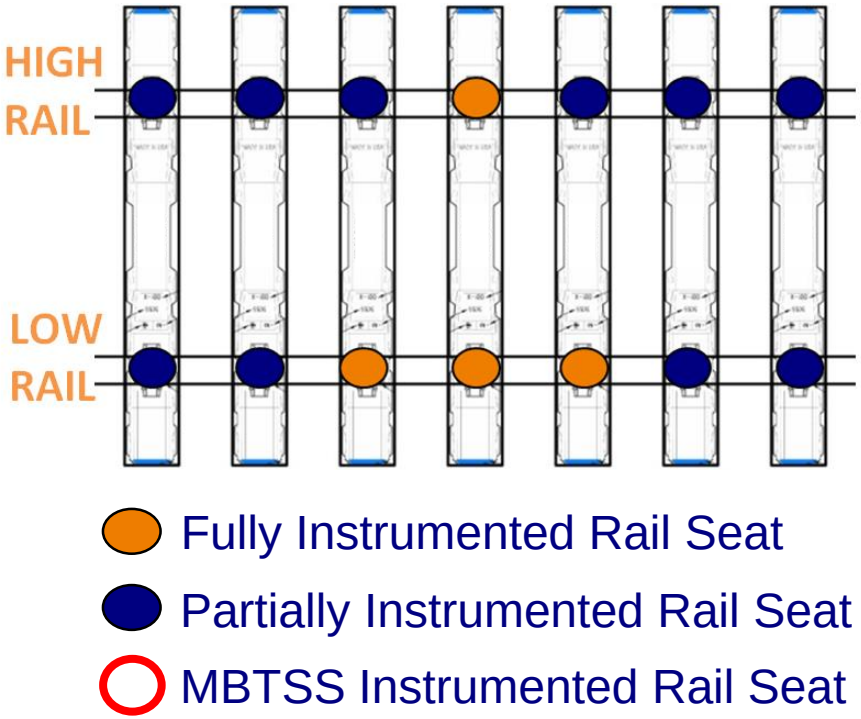
First stage of field instrumentation conducted to capture loads and understand the behavior of the system

Findings:

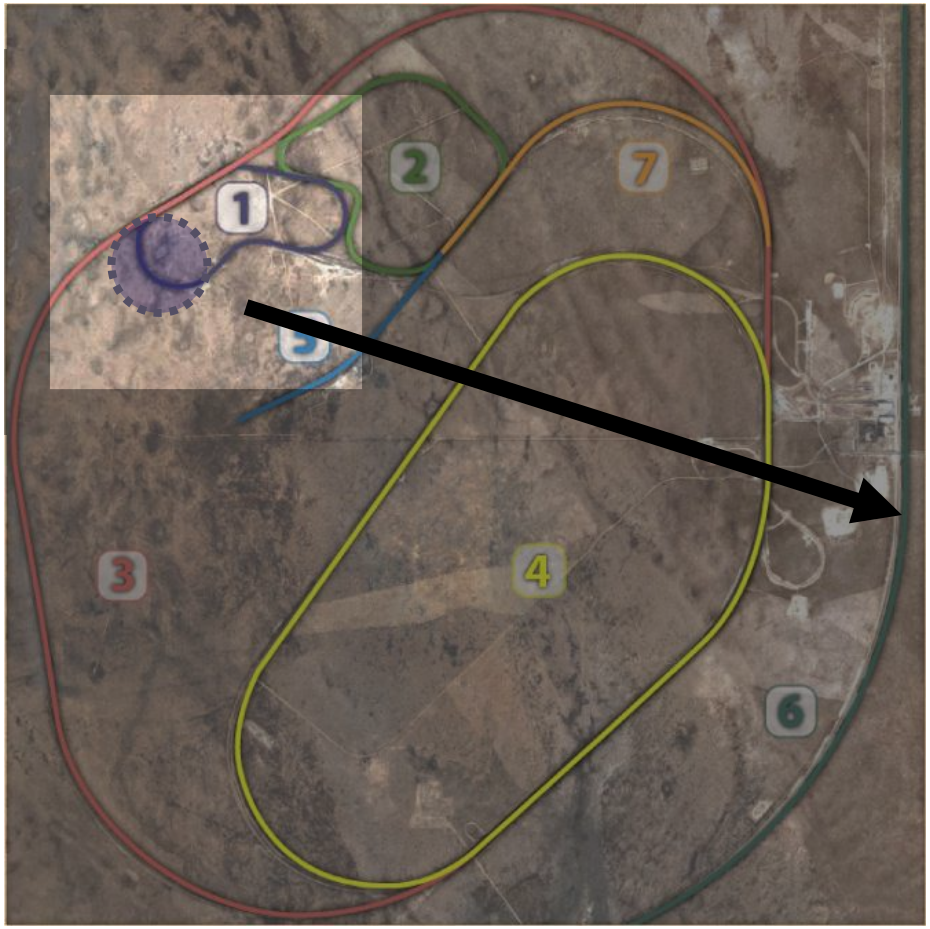
- Global tie displacements are important to understand load distribution
- Highest loads were imparted by the locomotives and leading axles of railcar trucks

Limitations:

- Comparison and validation through FEM analysis
- Lateral load path not effectively understood

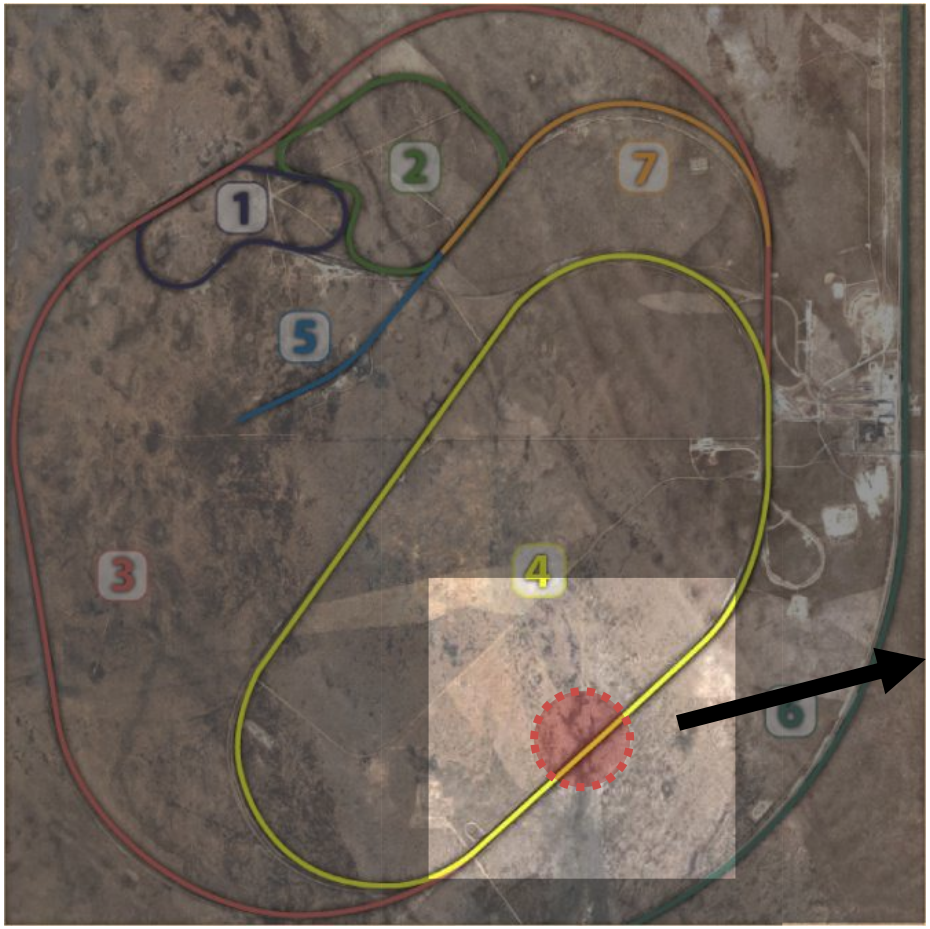


Field Instrumentation Locations



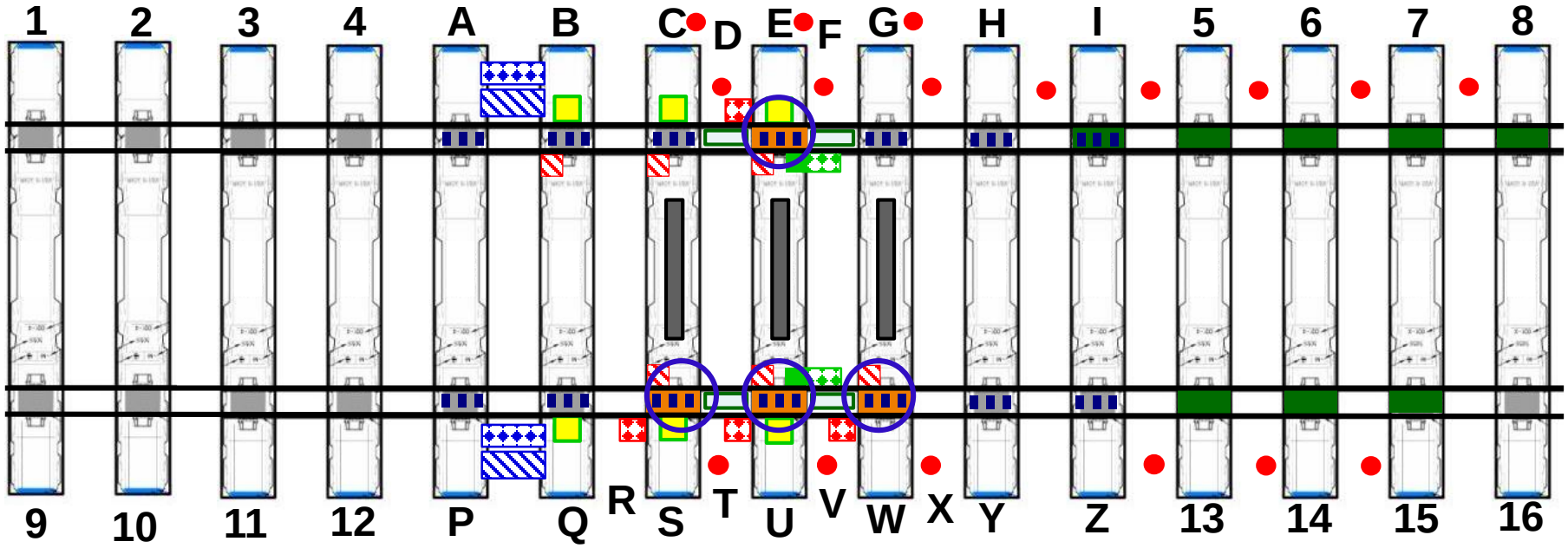
- TTCI (Pueblo, CO)
- High Tonnage Loop (HTL)
  - Curve (2-3°)
  - Safelok I Fasteners

Field Instrumentation Locations



- TTCI (Pueblo, CO)
- Railroad Test Track (RTT)
  - Tangent
  - Safelok I Fasteners

Field Instrumentation Strategy (May 2013)



Rail Displacement Fixture

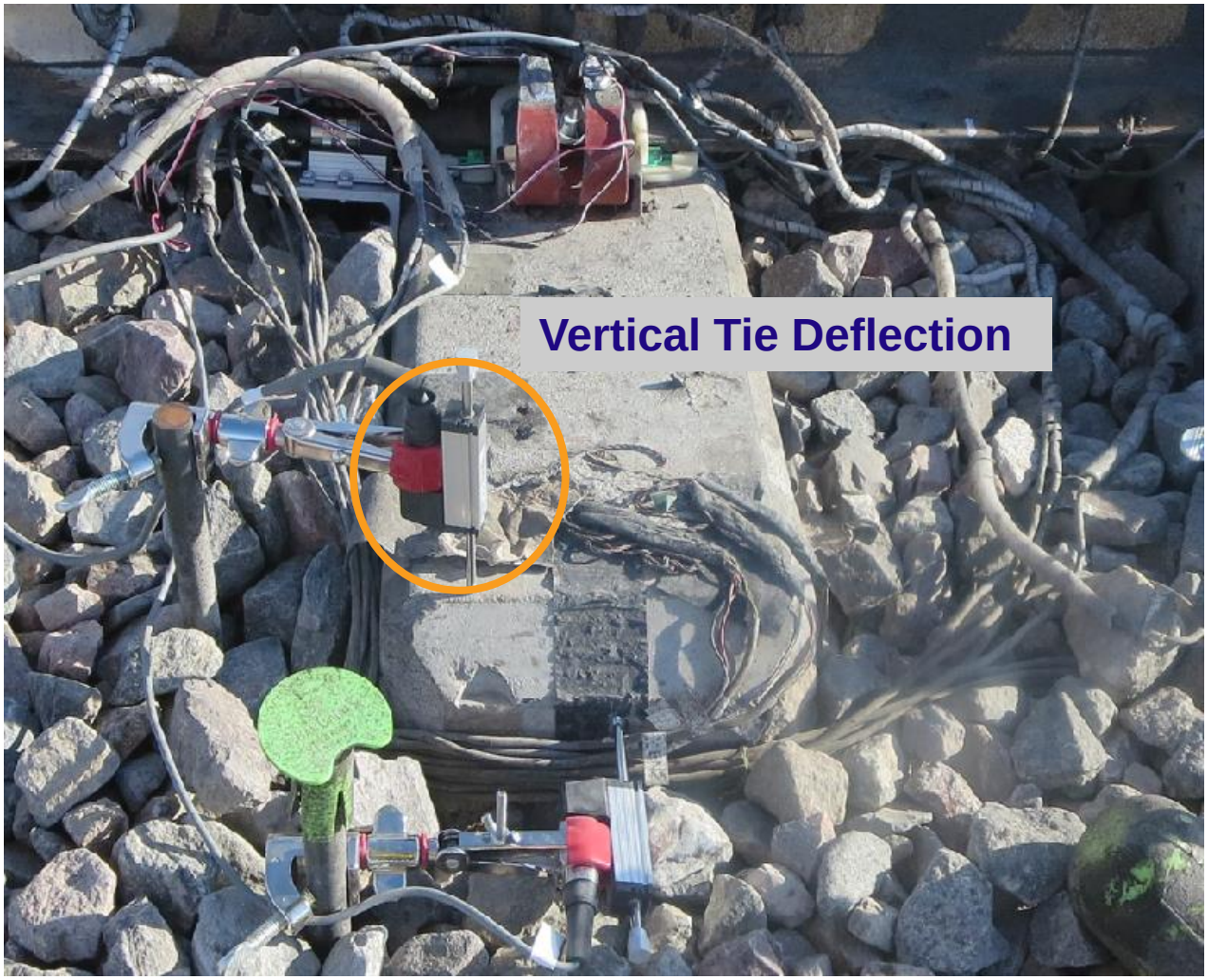
Rail Longitudinal Displacement/Strains

Vertical Web Strains

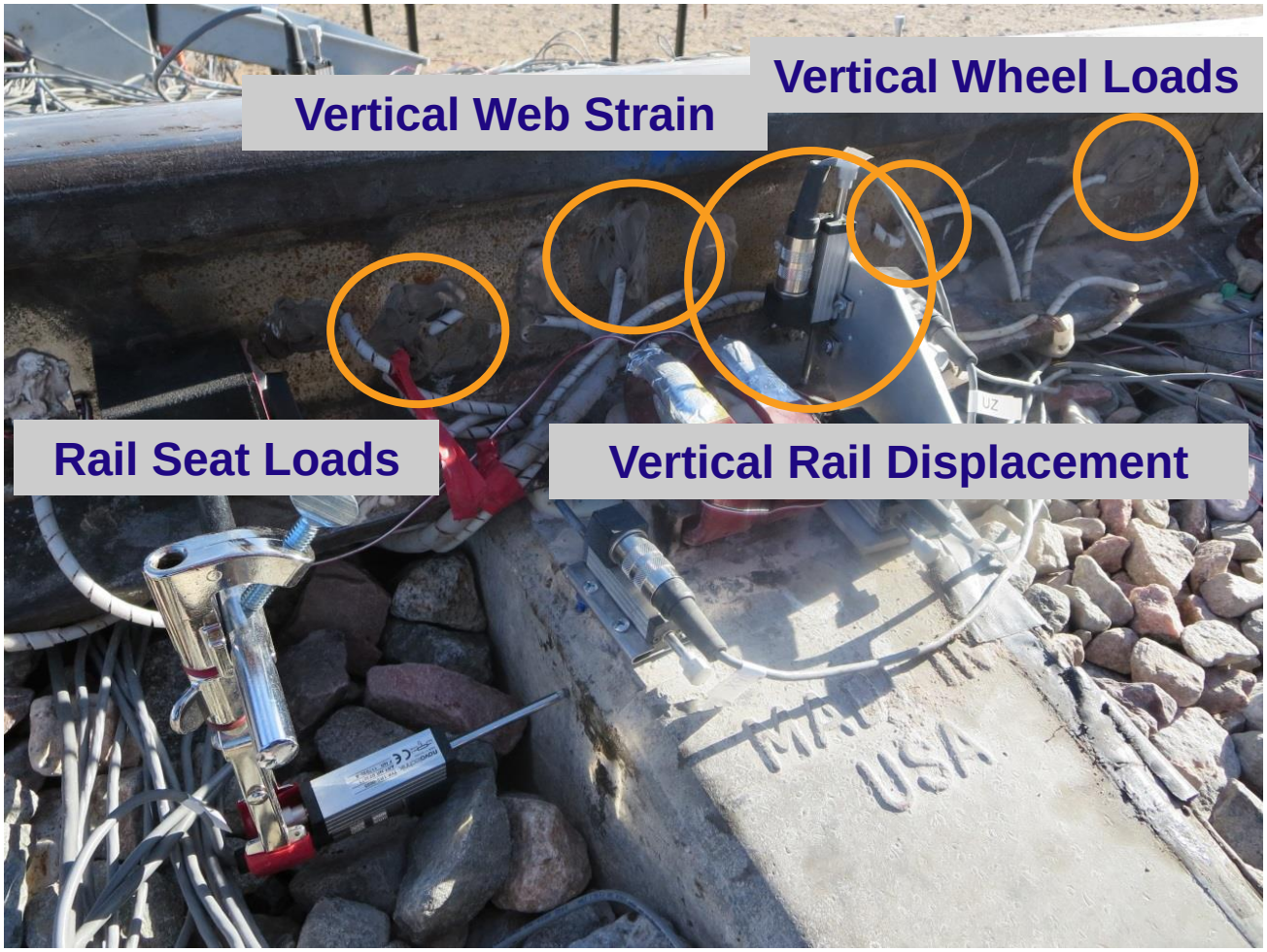
Vertical and Lateral Circuits

Steel Rods

Vertical Load Path Instrumentation
Field Side



Vertical Load Path Instrumentation
Gauge Side



Track Modulus Estimation

- Classical method (most commonly used) – based on load deflection characteristics

$$EI\frac{d^4w}{dx^4} + kw(x) = q(x) \quad \Longrightarrow \quad k = \frac{1}{4}\sqrt[3]{\frac{P^4}{EIw_m^{\ 4}}}$$

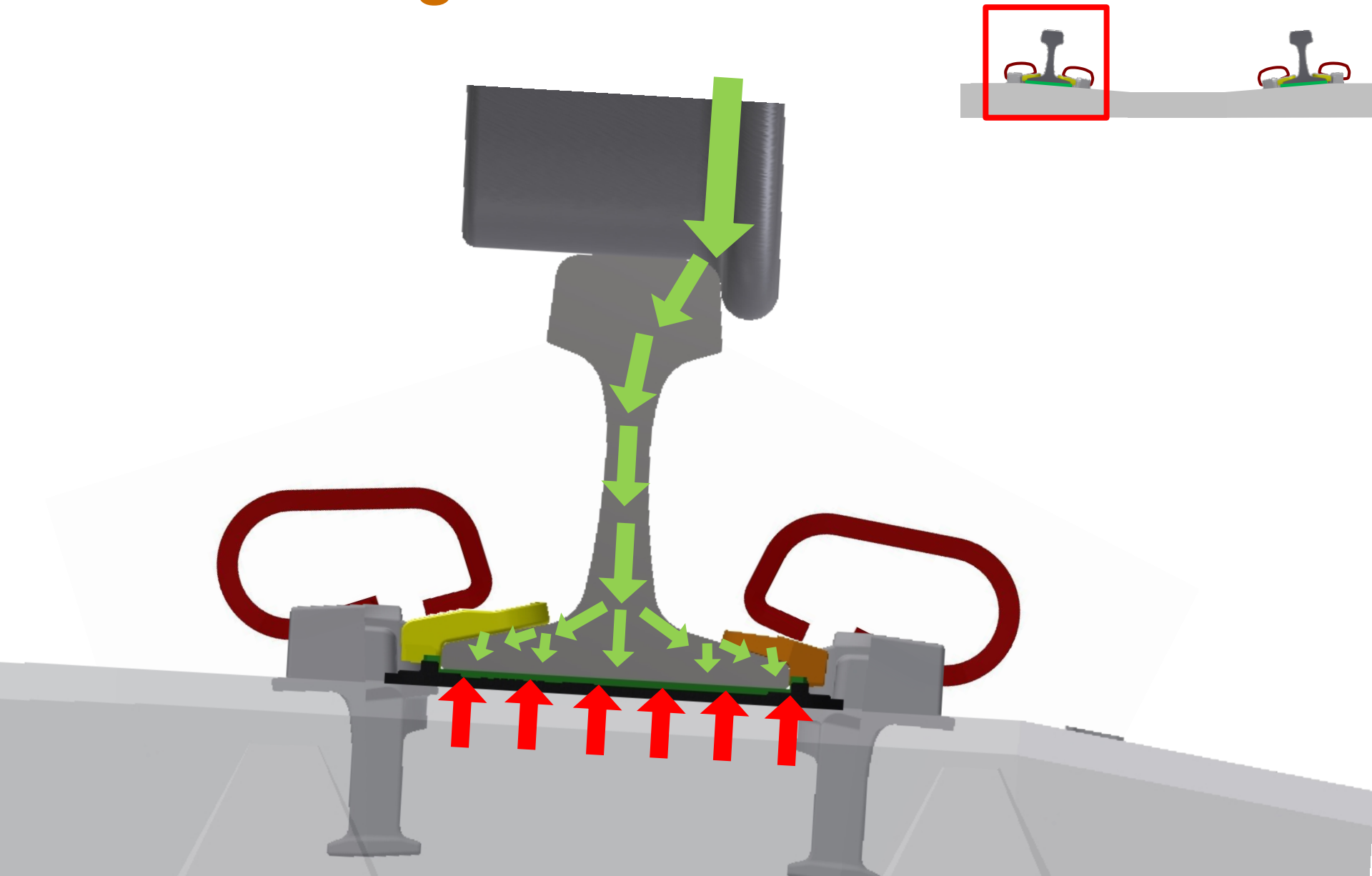
- TTCI proposed – Similar strategy with 10kip pre-load
- Other empirical and classical mechanics approaches do exist
  - Timoshenko and Langer (1932)
  - Hay (1982)
  - Eisenmann and Fastenrath (1981)

Loading Environment

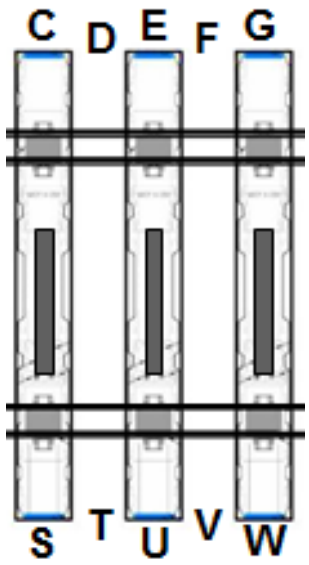
- Track Loading Vehicle (TLV)
  - Static
  - Dynamic

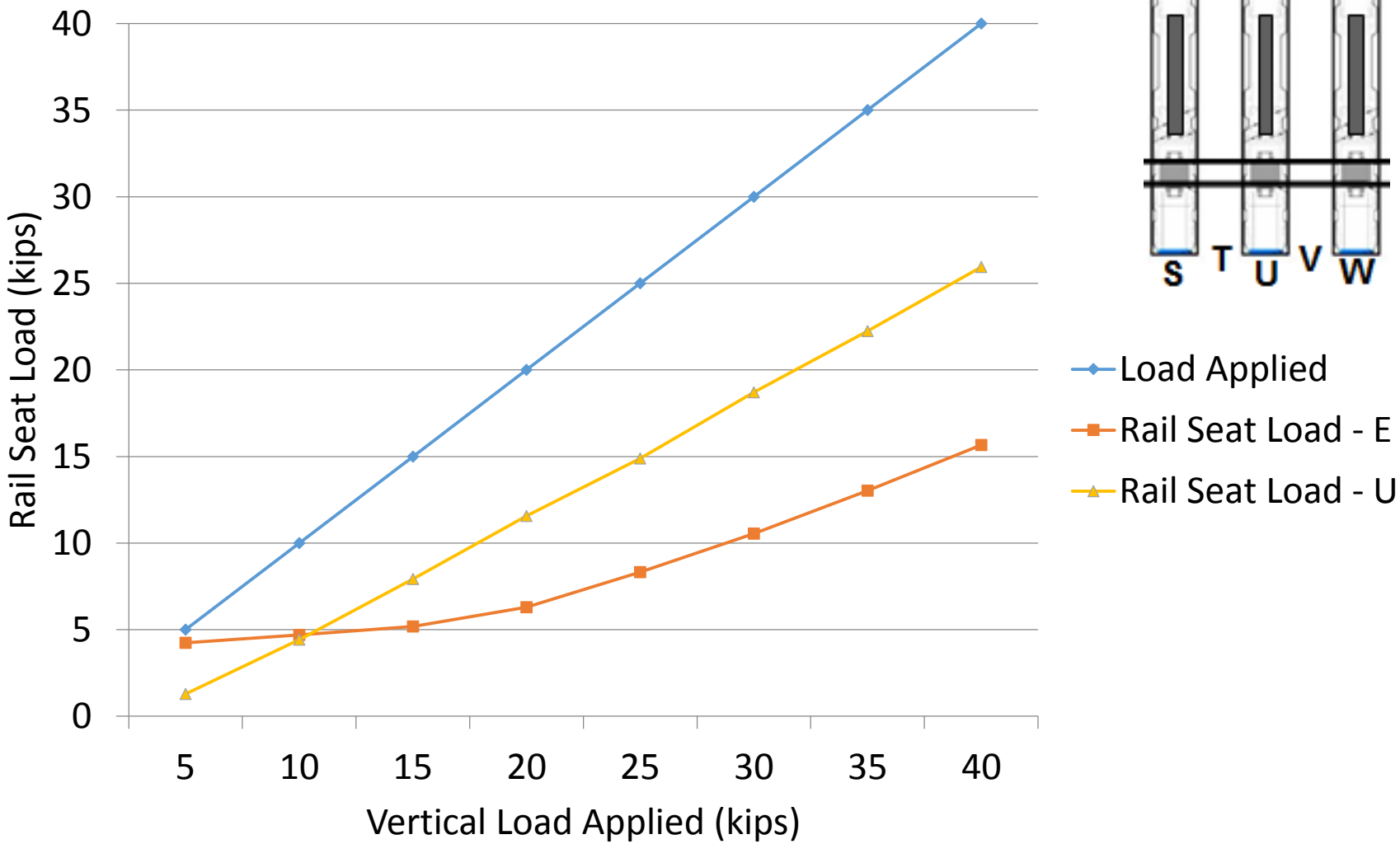
- Freight Consist
  - 3, 6-axle locomotives on HTL
  - 4-axle locomotives on RTT
  - 9 loaded and one empty freight cars
- Passenger Consist
  - 6-axle locomotive on HTL
  - 4-axle locomotive on RTT
  - 10 coaches
- FAST Train

Defining the Vertical Load Path

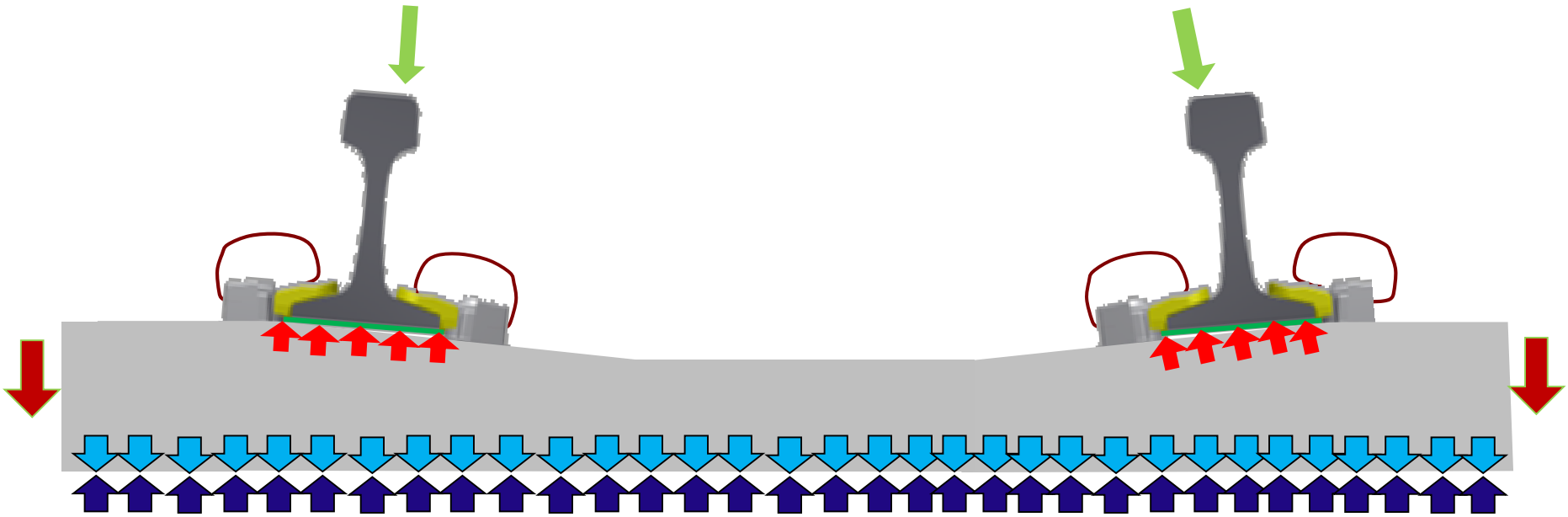


Rail Seat Loads
Tangent Track, RTT



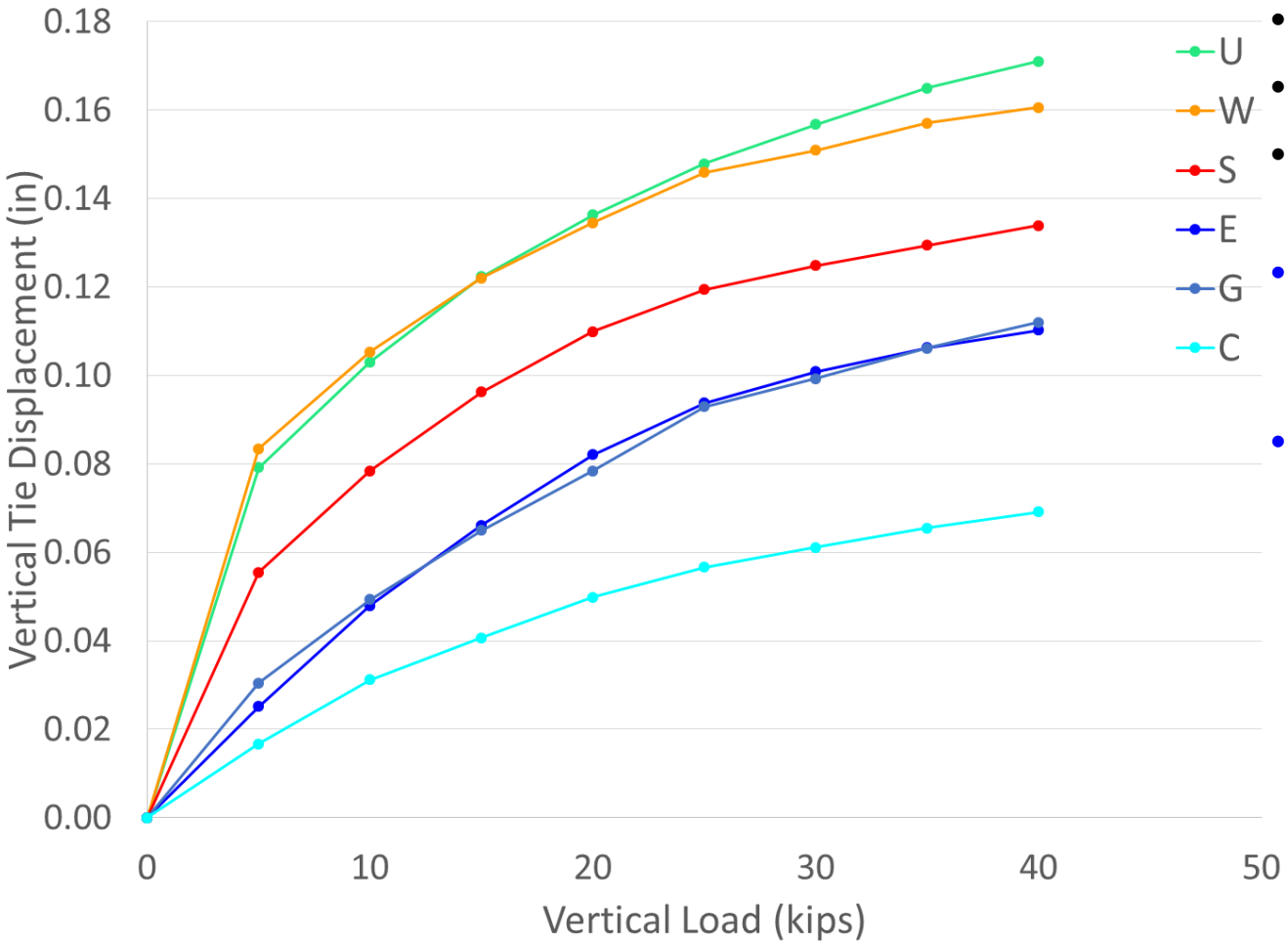


Defining the Vertical Load Path

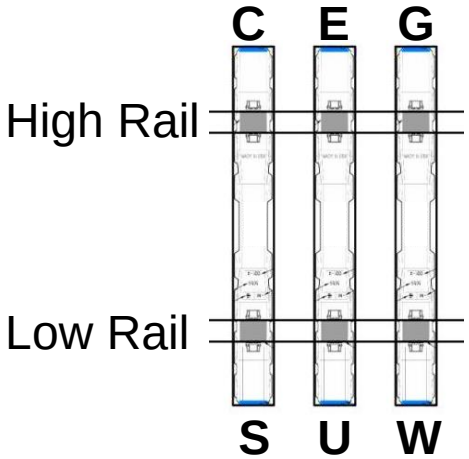


Crosstie Support Variability:

Vertical Crosstie Displacement

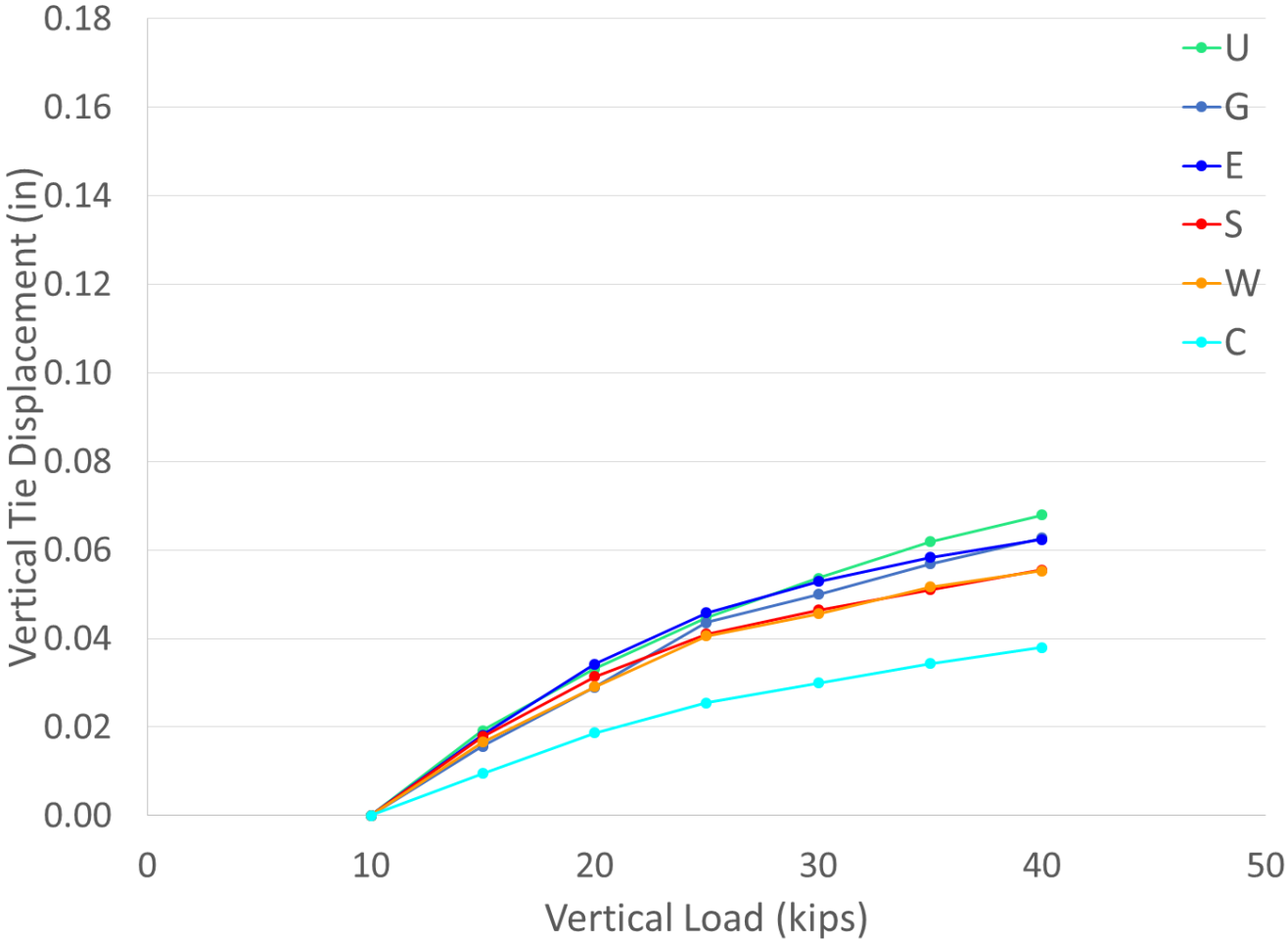


- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Low rail: soft support (slack or gap in support system)
- Modulus calculated as per classical method 2,500 – 4,500 lb/in^2 (except C =8500)

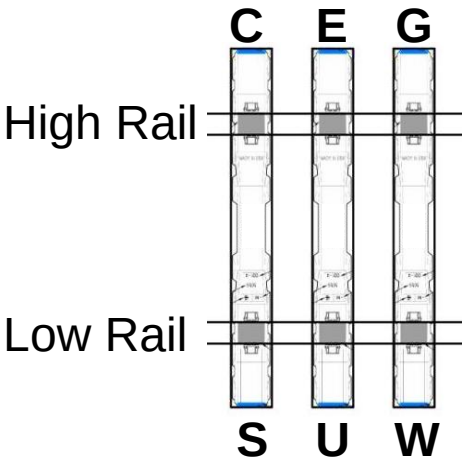


Crosstie Support Variability:

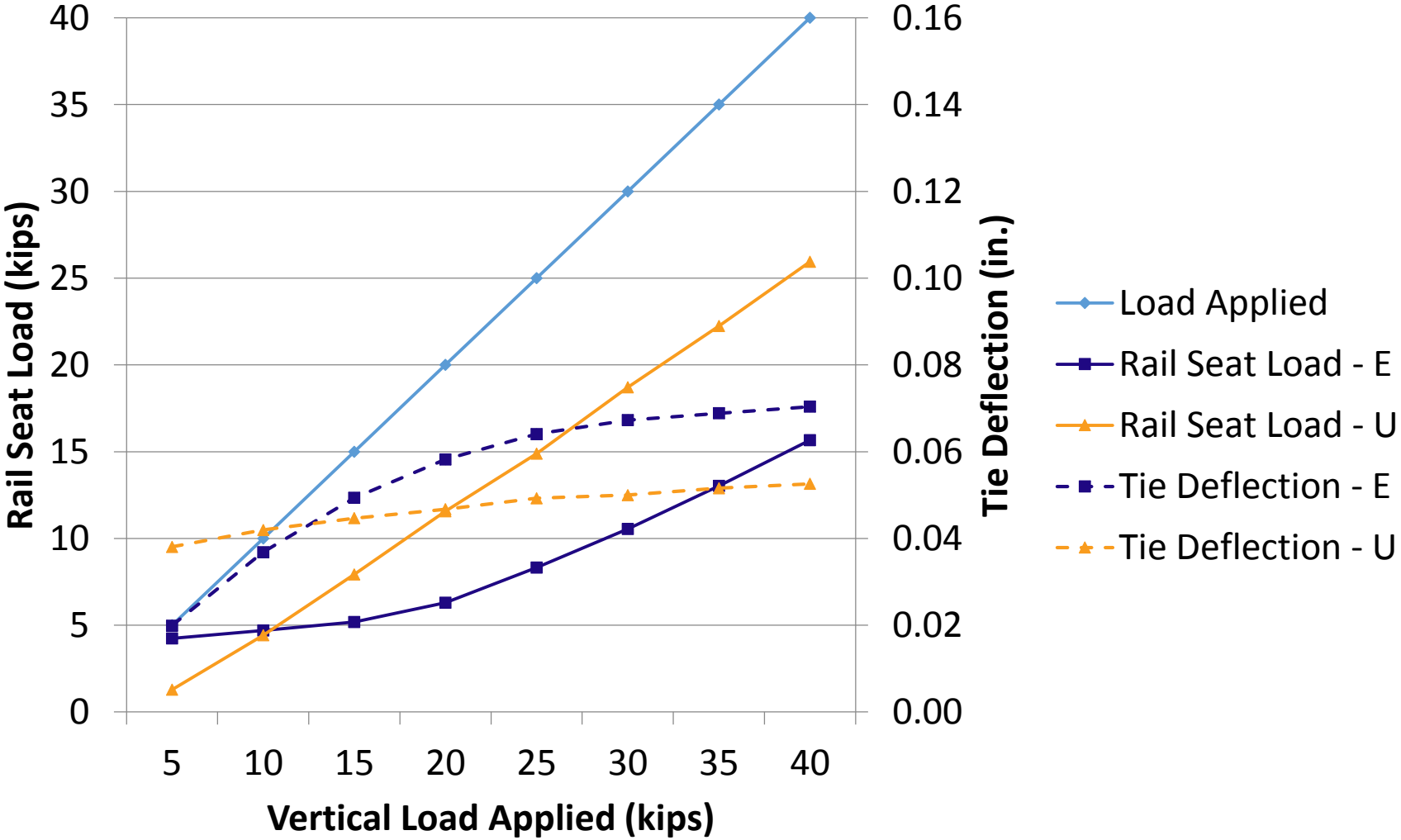
Vertical Crosstie Displacement – with 10 kip zero



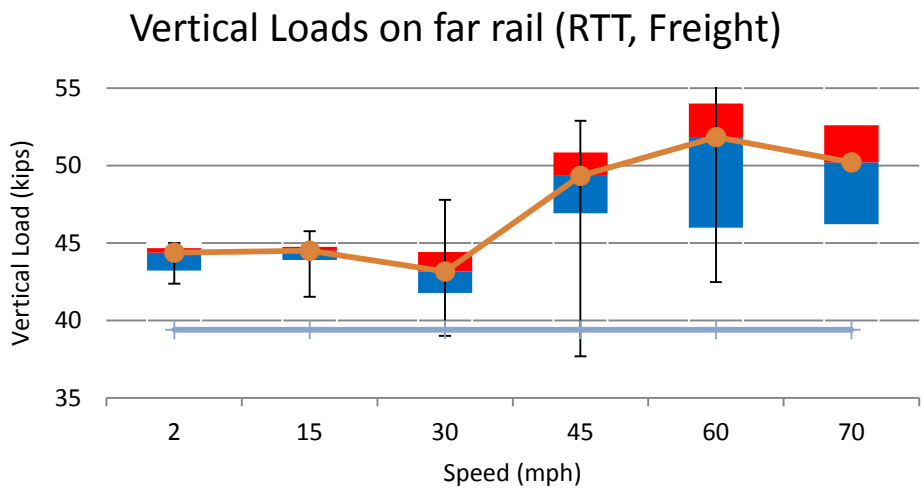
- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Support modulus ranges from 6000 – 7,800 lb/in^2 (except C)

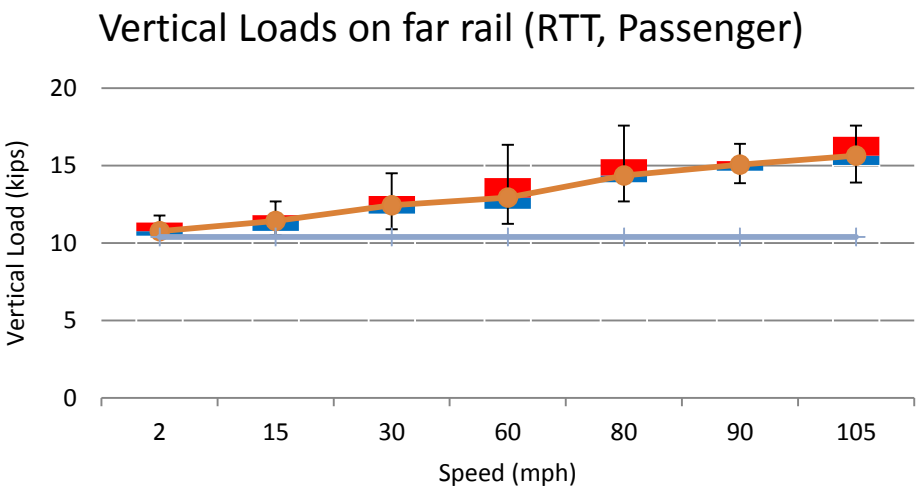


Rail Seat Loads and Deflection



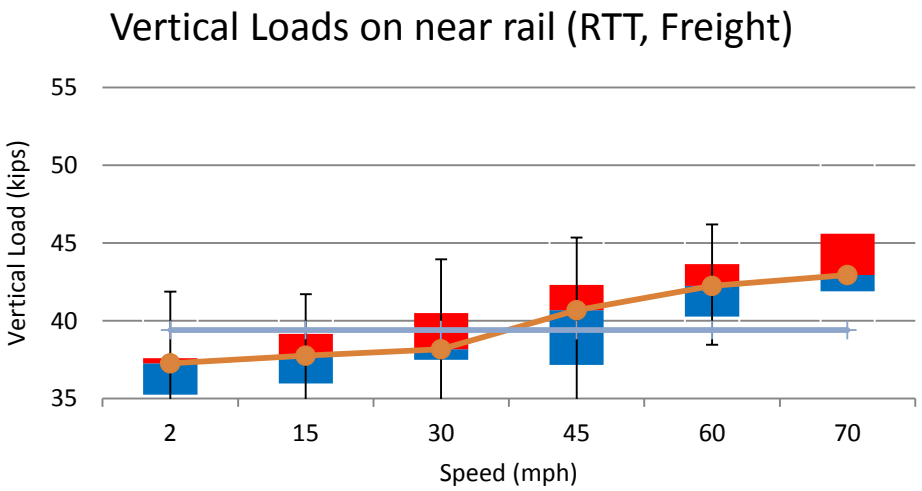
Vertical Wheel Loads - RTT

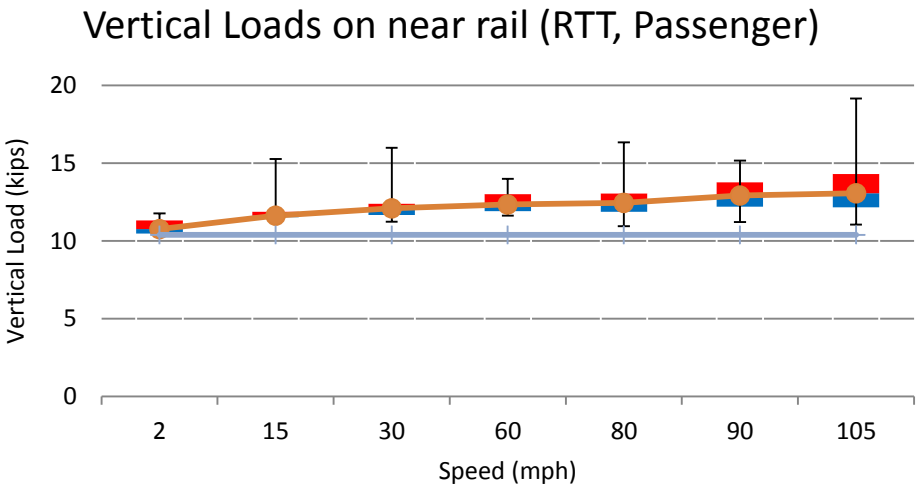




Dynamic Wheel Load

Static Load





Conclusions

- **Observed Loads**
  - Dynamic wheel loads are not significantly higher than static wheel loads
  - Observed loads are similar to revenue service loads, minus the impact loads
- **Rail Seat Loads**
  - 30-80% of the vertical wheel load is resisted by each
    rail seat (high variability)
  - Ballast stiffness plays key role
  - Vertical rail seat load is independent of lateral loads
- **Tie Deflection**
  - Tie deflections are highly affected by track stiffness
  - Static deflection is considered an important system parameter for design

Future Work

- Continue analysis of data to understand the governing mechanisms of the tie and fastener system
- Continue to compare and validate the FE model
- Relate ballast stiffness to the tie deflections
- Create empirical models relating stiffness to loading demands on each component (rail pad, rail seat, etc.)
- Investigate the influence of lateral loads on the vertical load path
- Conduct small-scale, evaluative revenue service testing on Class I railroads

Acknowledgements

U.S. Department of Transportation

Federal Railroad Administration

- Funding for this research has been provided by the Federal Railroad Administration (FRA)
- Industry Partnership and support has been provided by
  - Union Pacific Railroad
  - BNSF Railway
  - National Railway Passenger Corporation (Amtrak)
  - Amsted RPS / Amsted Rail, Inc.
  - GIC Ingeniería y Construcción
  - Hanson Professional Services, Inc.
  - CXT Concrete Ties, Inc., LB Foster Company
  - TTX Company
- Transportation Technology Center, Inc.
  - Dave Davis, Justin Penrod
- For assistance in instrumentation preparation:
  - Harold Harrison, Mike Tomas

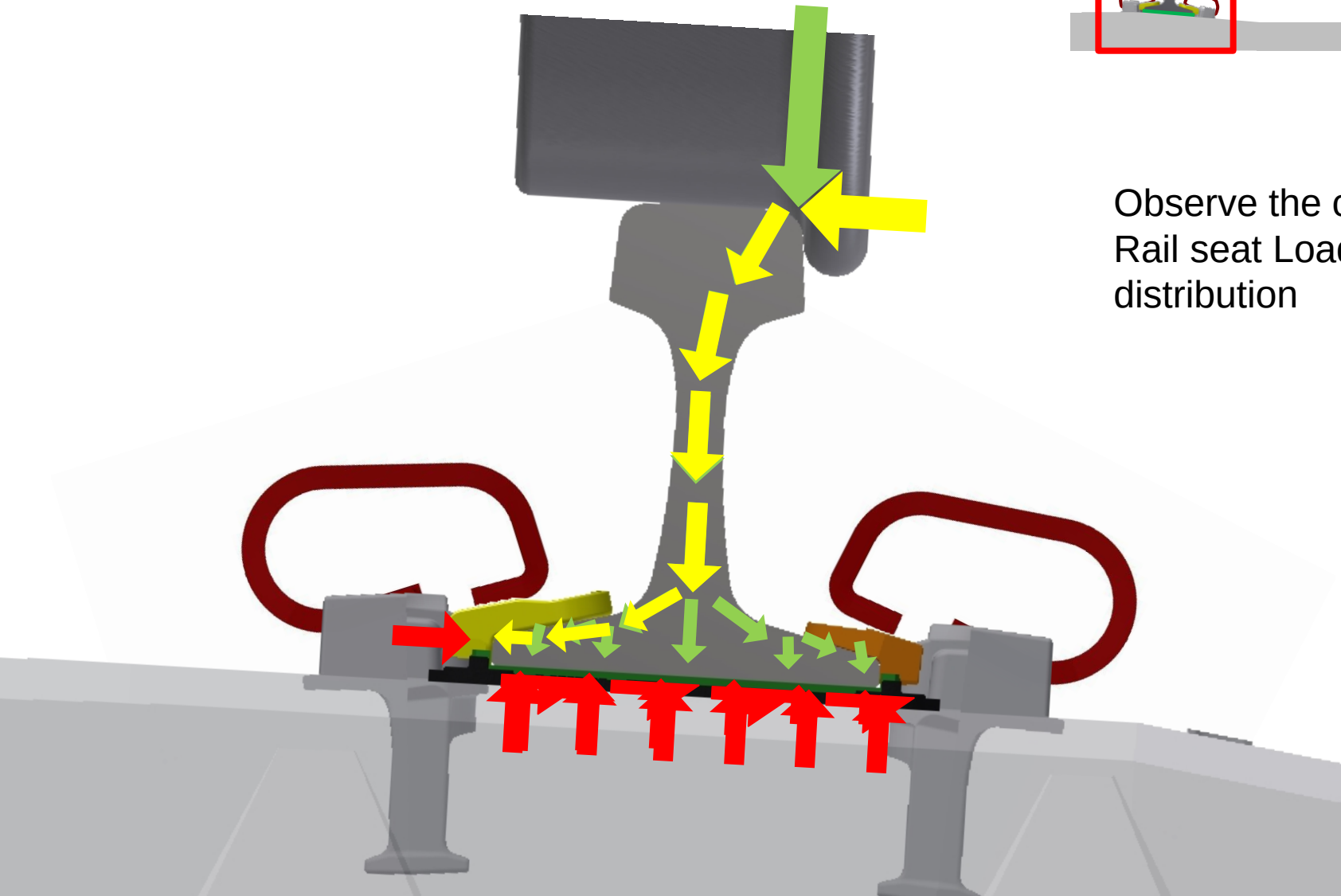
FRA Tie and Fastener BAA Industry Partners:

Questions or Comments?

Kartik Manda
Graduate Research Assistant
Railroad Transportation and Engineering Center – RailTEC
email: kmreddy2@illinois.edu
Office: (217) 419-0220

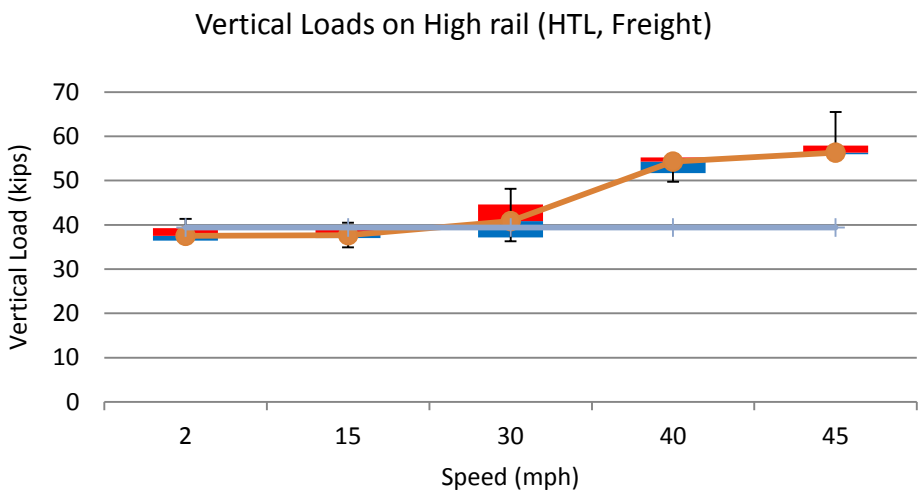
Appendix

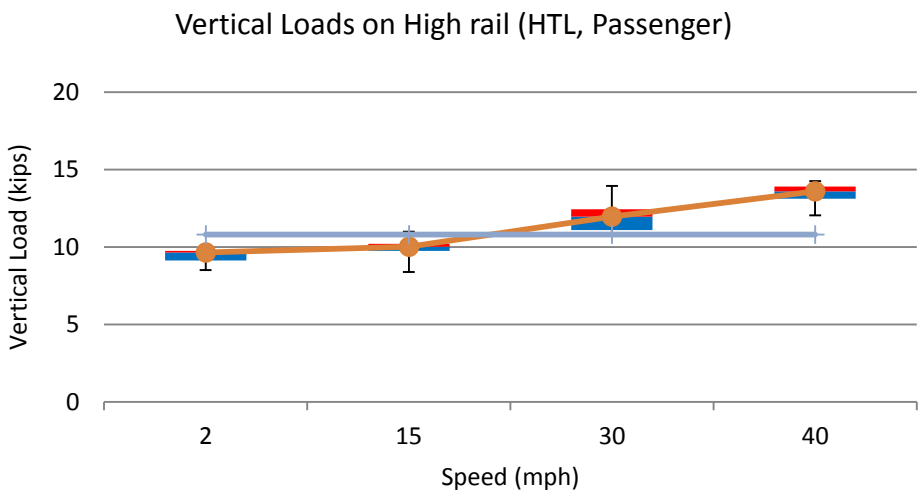
Defining the Vertical Load Path



Observe the change in Rail seat Load distribution

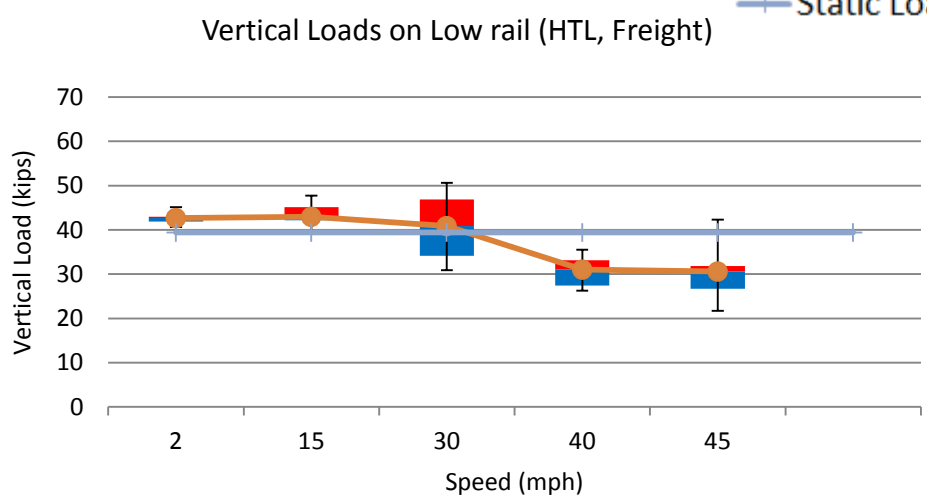
Vertical Wheel Loads - HTL

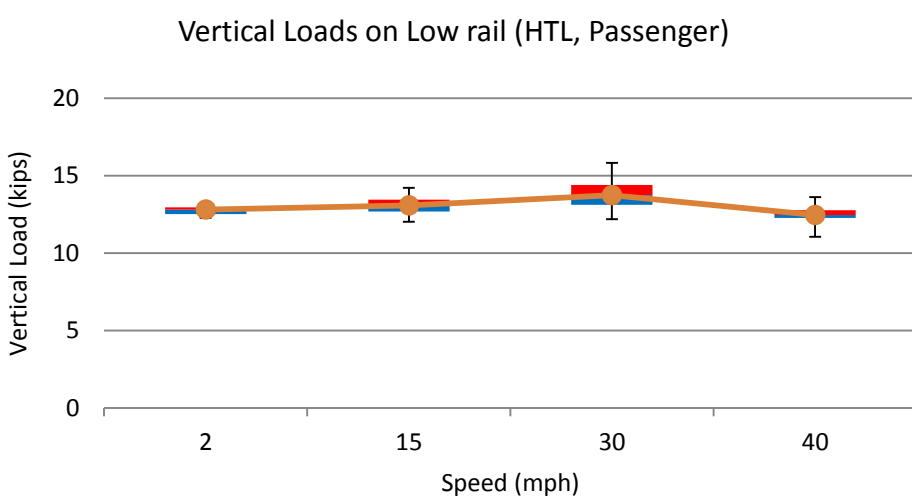




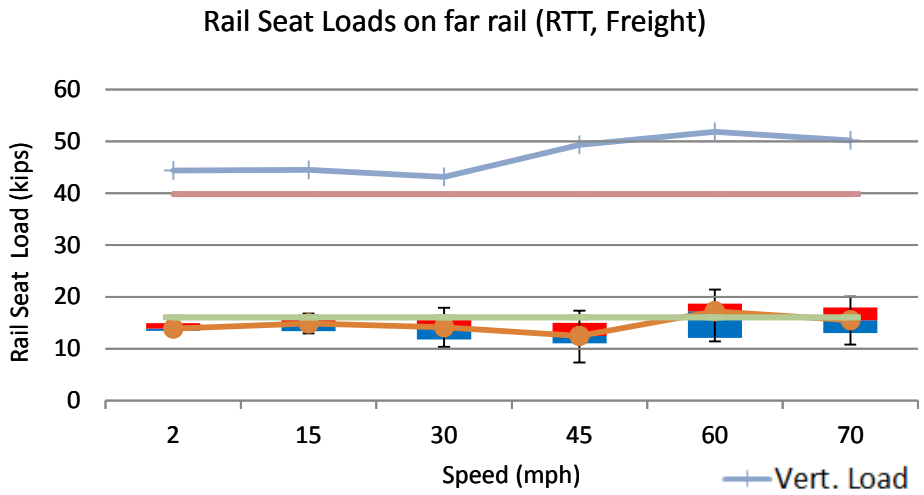
Dynamic Wheel Load

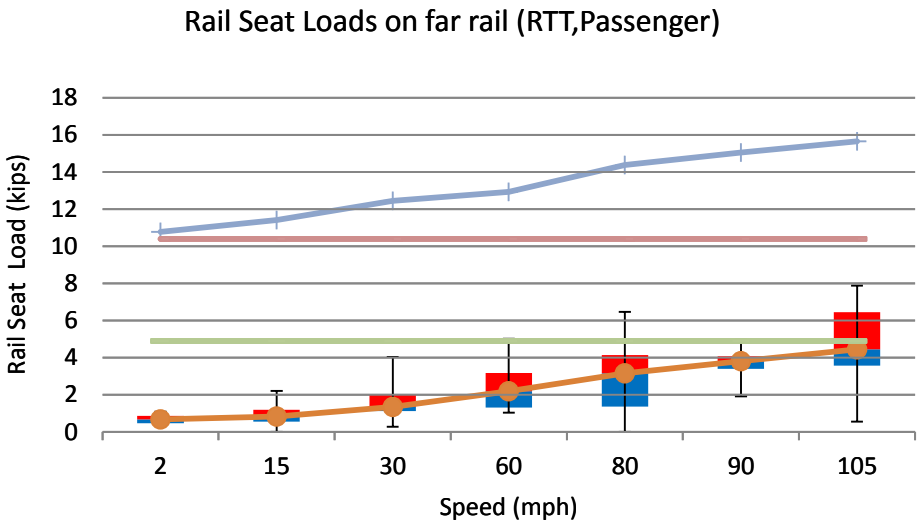
Static Load





Rail Seat Load - RTT





Vert. Load
Static Load
Static Rail Seat Load
Dynamic Rail Seat Load