Crosstie and Elastic Fastener Field Experimentation for Mechanistic Design

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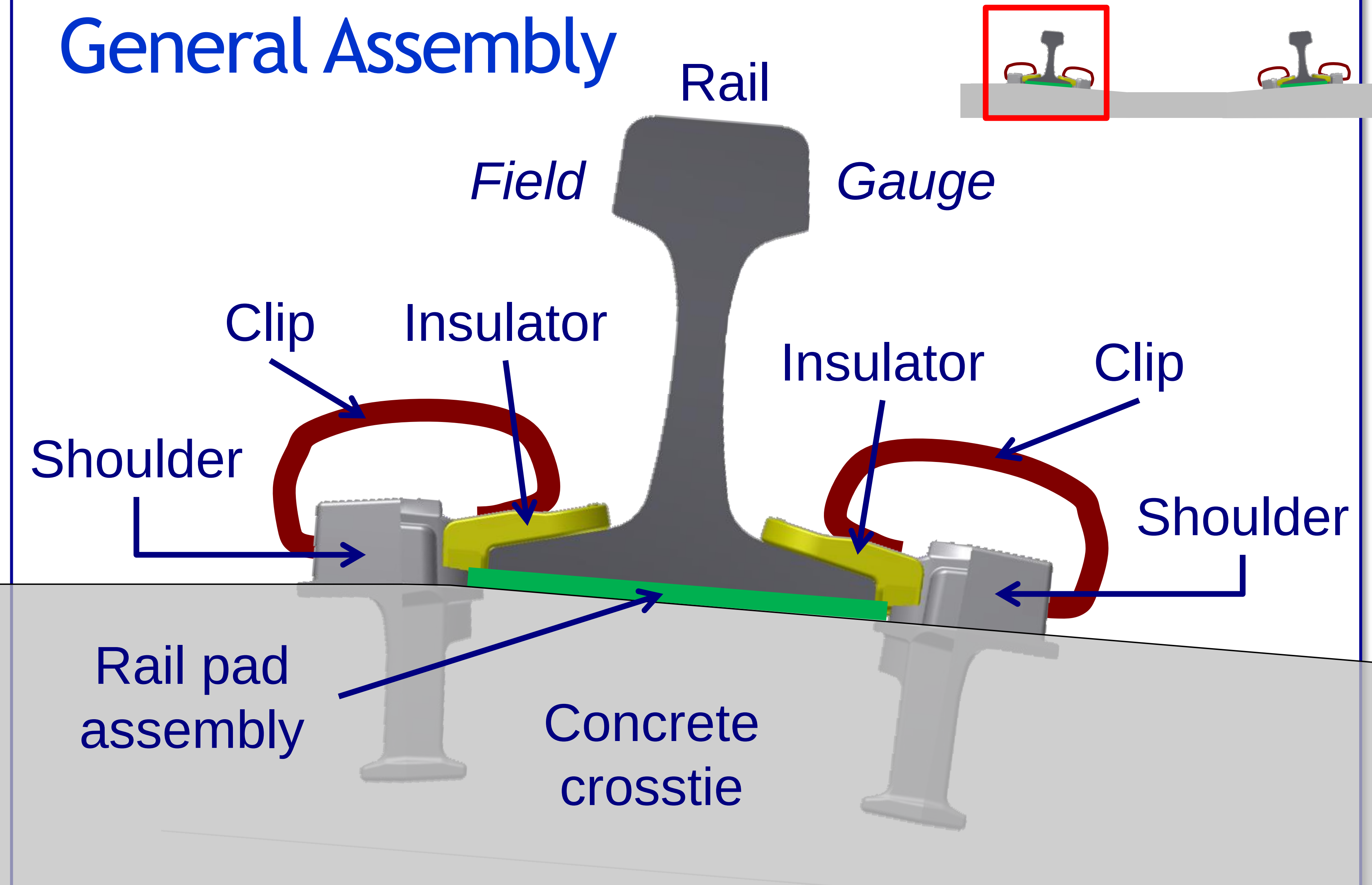
U.S. Department of Transportation
Federal Railroad Administration

Outline

- Introduction
  - Components
  - Purpose for Research
  - Project Structure
- Field Experimentation
  - Objectives
  - Instrumentation Strategy
  - Testing at Transportation Technology Center (TTC)
- Experimental Results and Preliminary Findings
  - Vertical Load Path
  - Lateral Load Path
- 3D Finite Element Model
- Future Work

General Assembly



Common Concrete Crosstie and Fastener Failures


Rail seat positive flexural cracking


Center negative flexural cracking


Prestress wire bond loss


Broken shoulder


Rail seat deterioration


Insulator post wear


Fastener fatigue


Pad wear

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

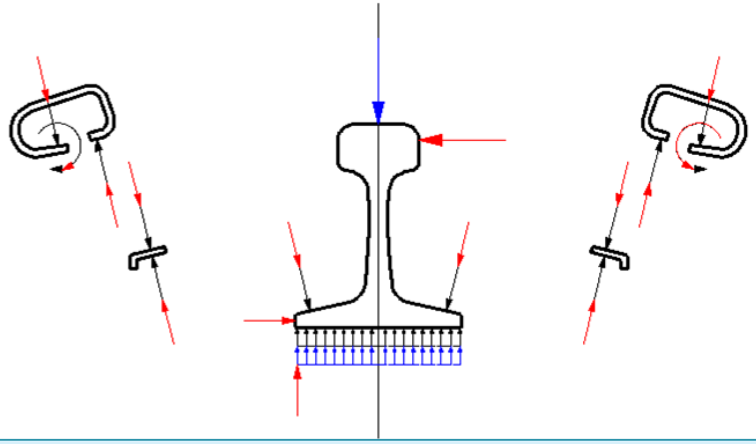
Outputs/Deliverables

- 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

Goals of Field Instrumentation

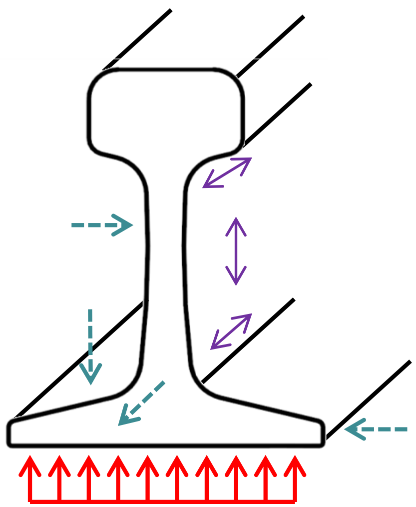
- Lay groundwork for mechanistic design of concrete crossties and elastic fasteners
- Quantify the demands placed on each component within the system
- Develop an understanding into field loading conditions
- Provide insight for future field testing
- Collect data to validate the UIUC concrete crosstie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



Areas of Investigation

Rail

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

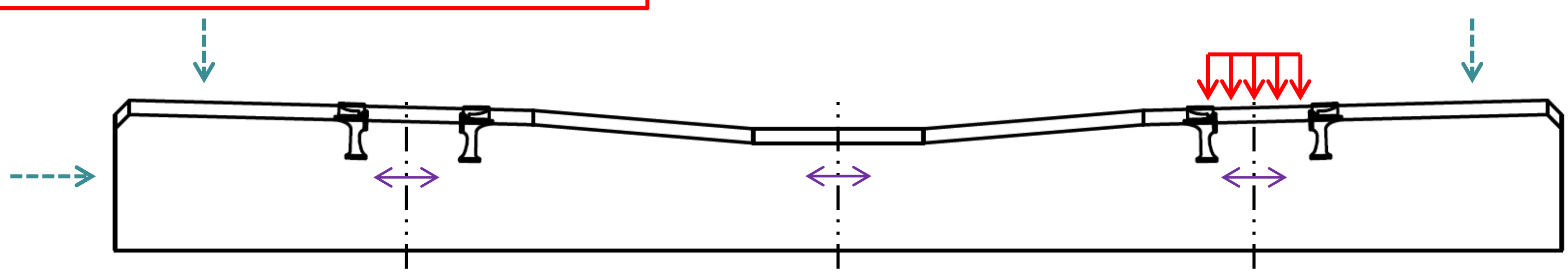


Fasteners/ Insulator

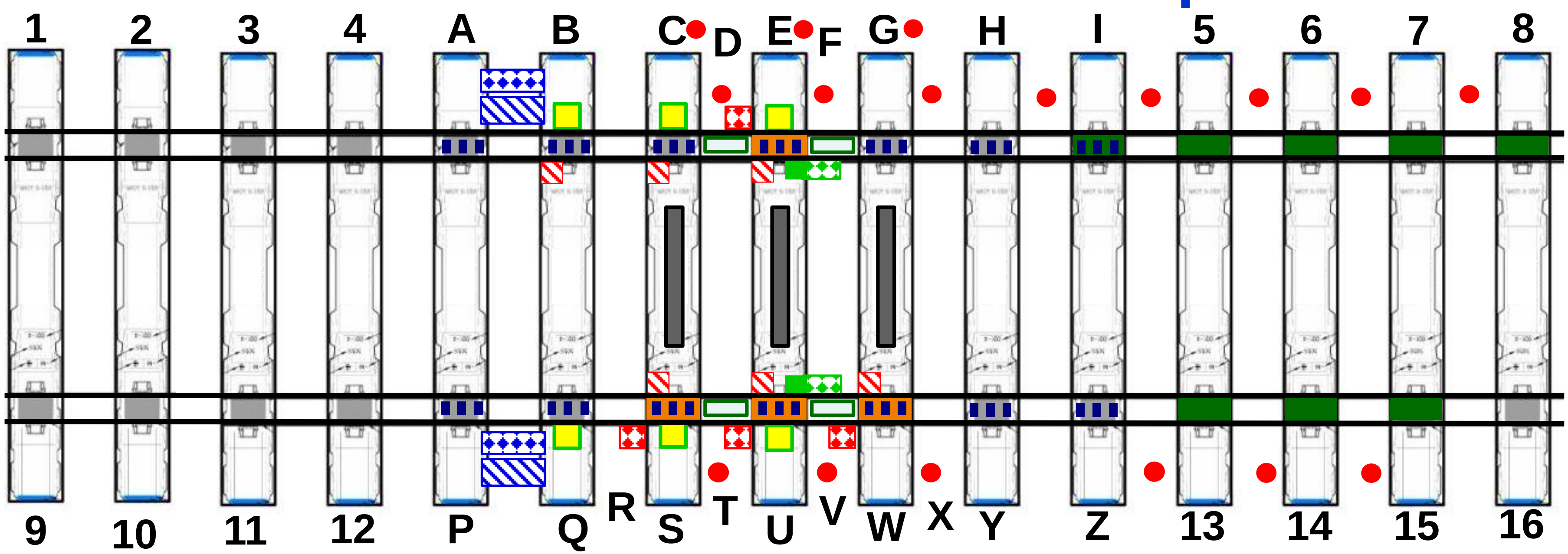
- Strain of fasteners
- Stresses on insulator

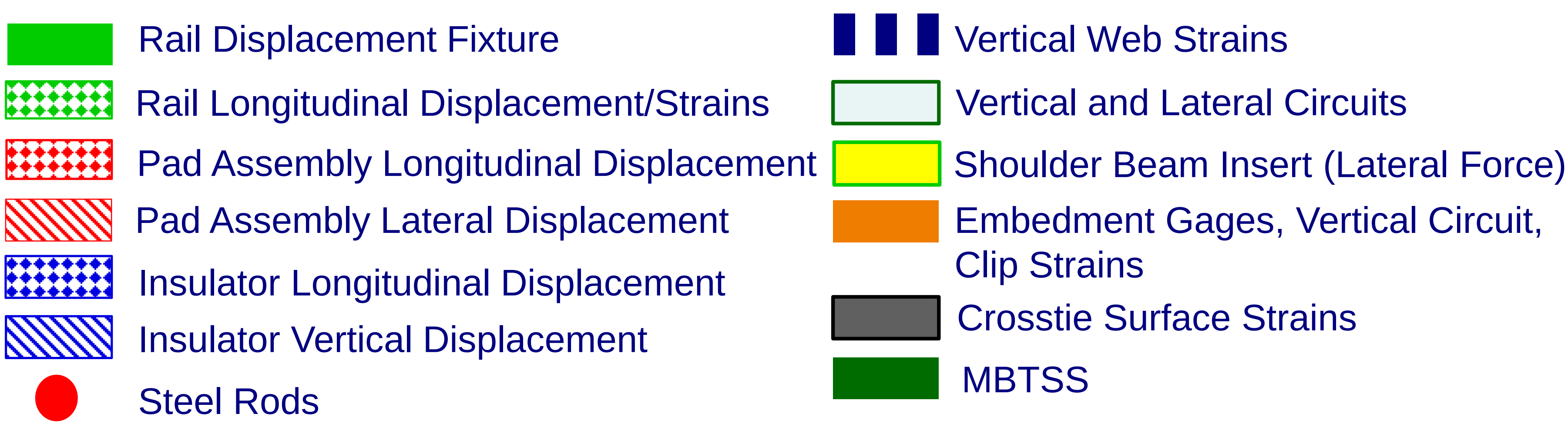
Concrete Crossties

- Moments at the rail seat/tie center
- Stresses at rail seat
- Vertical/Lateral displacements of crossties

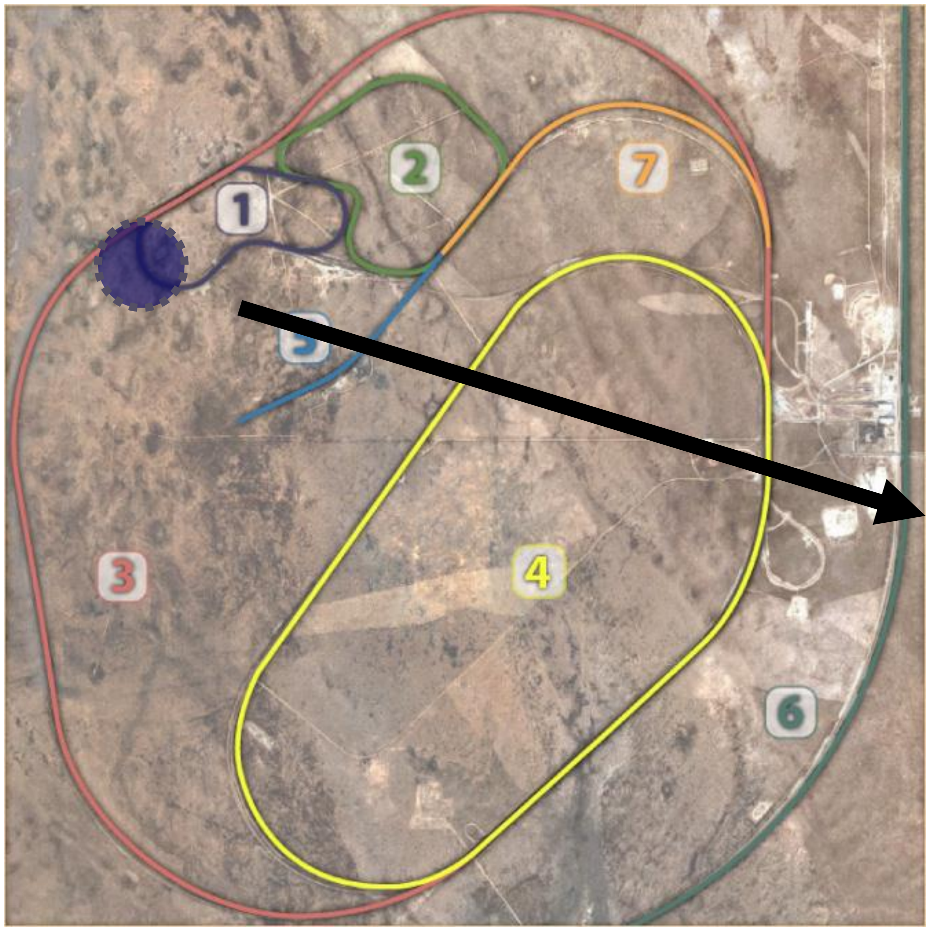


2013 Field Instrumentation Map



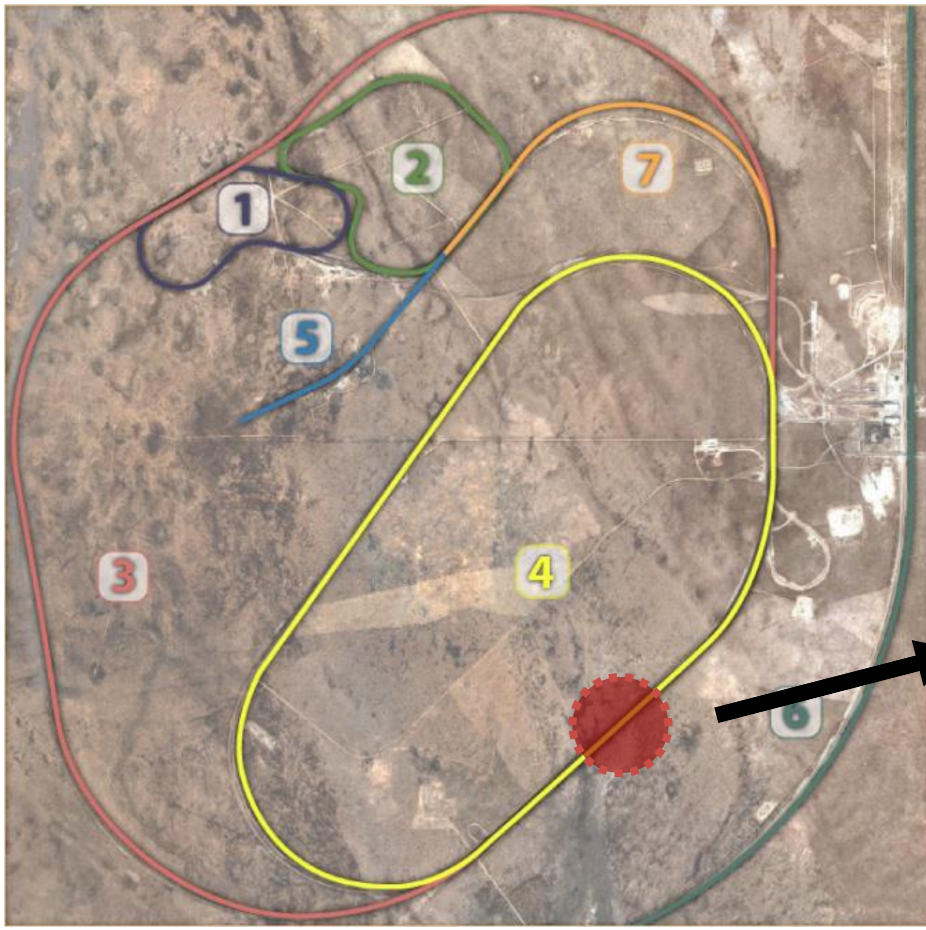


Field Instrumentation Locations (TTC)



- High Tonnage Loop (HTL)
  - Curve (~5°)
  - Design balance speed of 30 mph
  - Safelok I Fasteners

Field Instrumentation Locations (TTC)

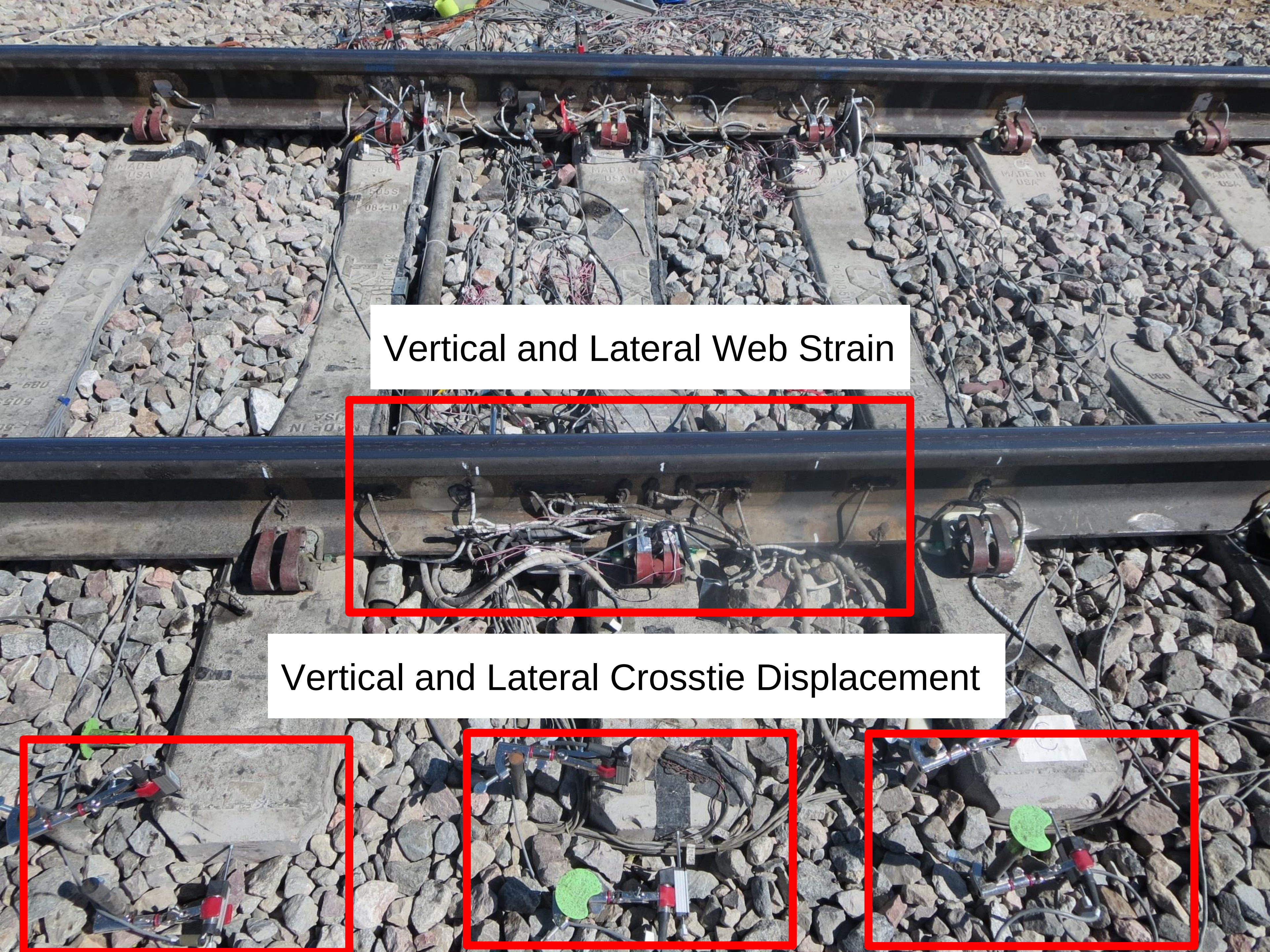


- Railroad Test Track (RTT)
  - Tangent
  - Safelok I Fasteners

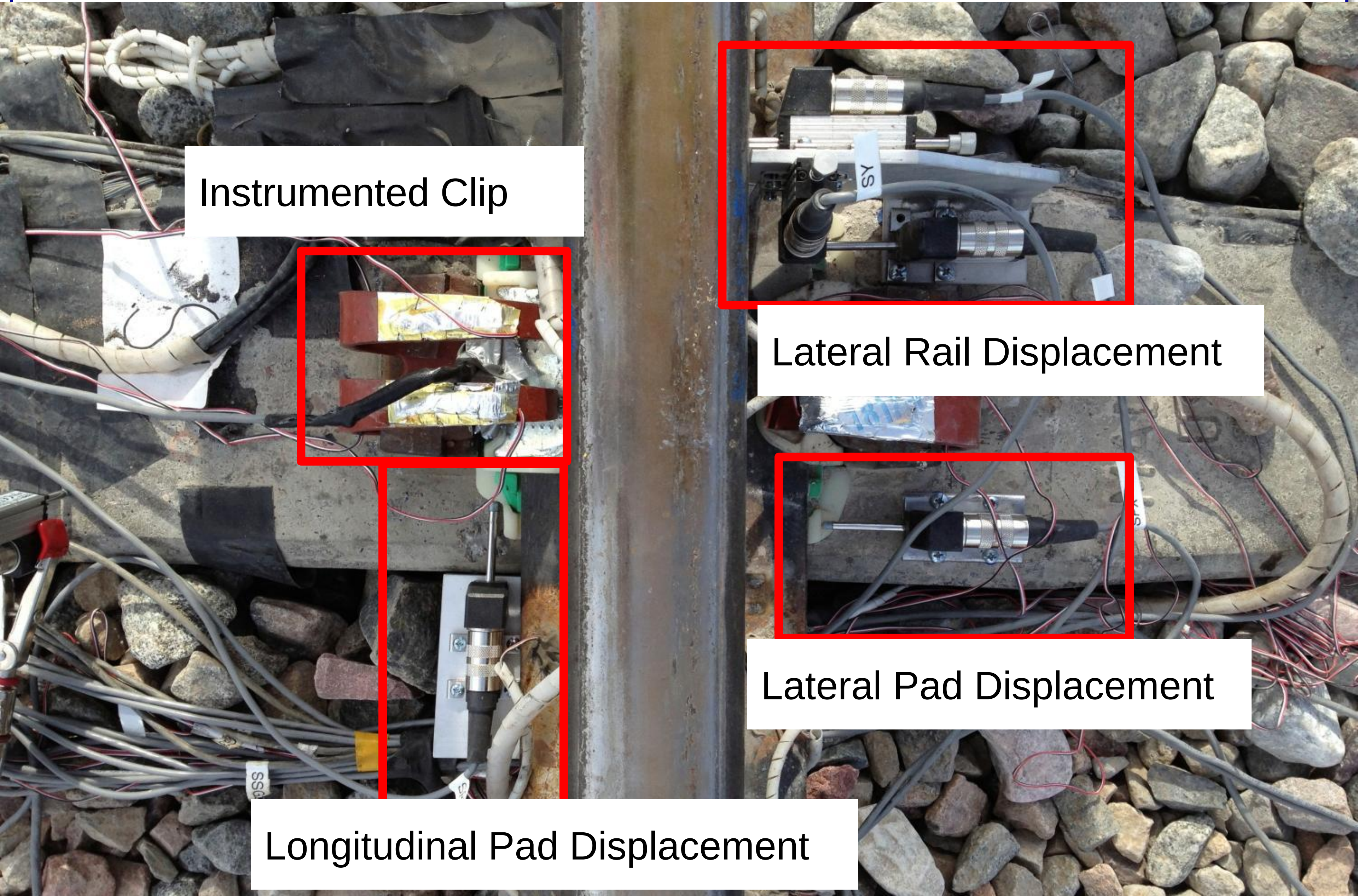
Loading Environment

- Track Loading Vehicle (TLV)
  - Static
  - Dynamic
- Track Loading A-Frame
  - Vertical: 0 – 50 kip
  - Lateral: 0 – 10 kips
- Freight Consist
  - 6-axle locomotive (393k)
  - Ten cars
    - Empty, 263, 286, 315 GRL Cars
  - FAST Train
- Passenger Consist
  - 4-axle locomotive (255k)
  - Nine coaches
    - 87 GRL

Full Instrumentation

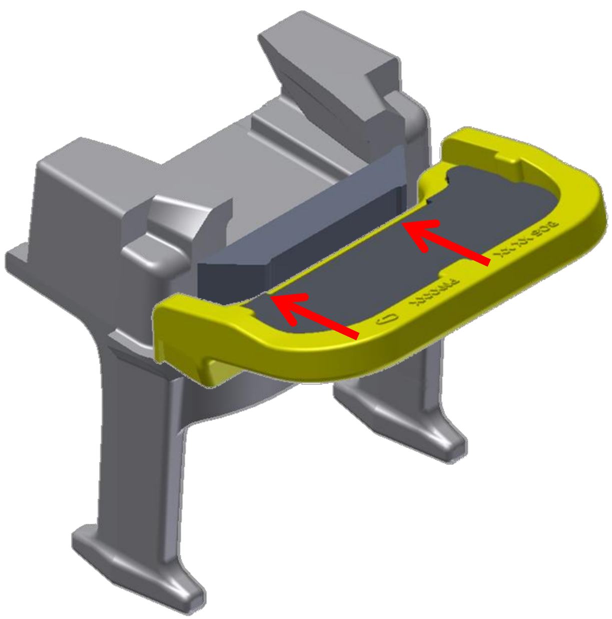

Vertical and Lateral Web Strain
Vertical and Lateral Crosstie Displacement

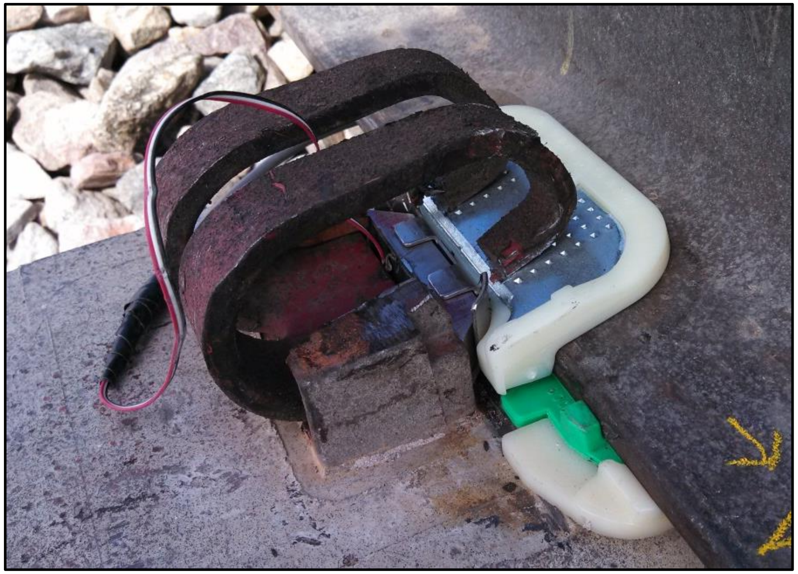
Fully Instrumented Rail Seat



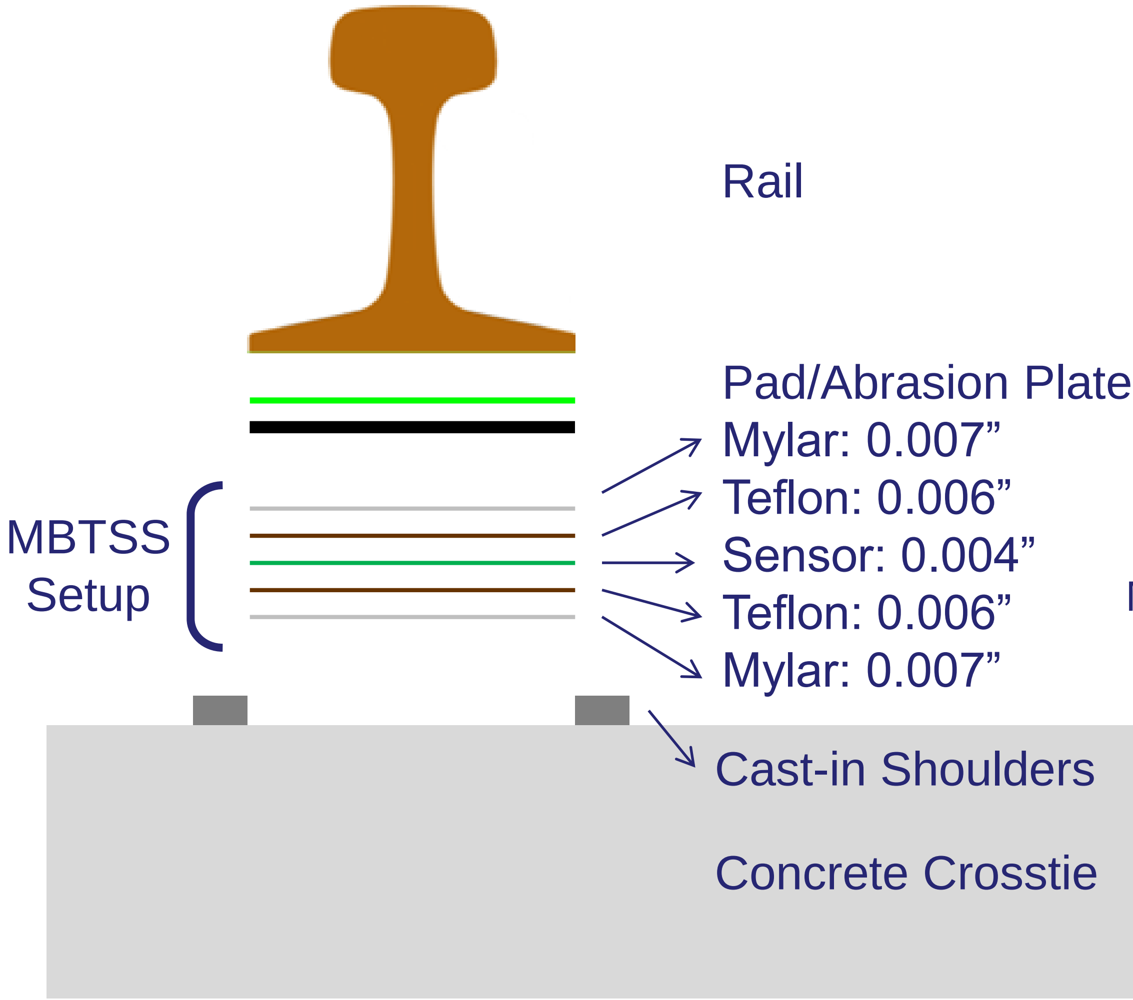
Lateral Shoulder Load Instrumentation

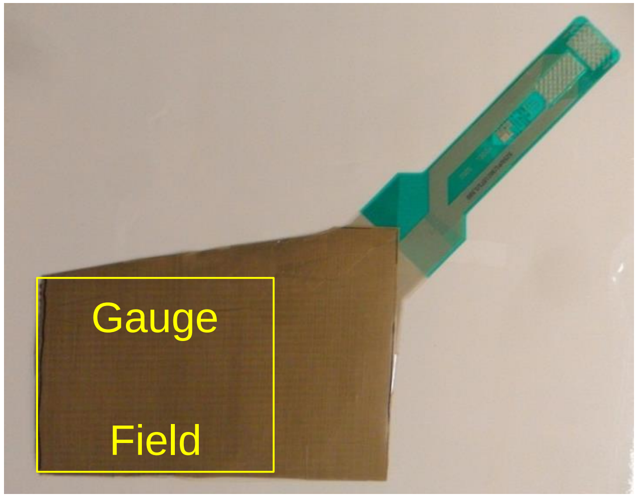
- Instrumented shoulder face insert
  - Original shoulder face is removed, grinded away
  - Insert designed as a beam and optimized to replace removed section
  - Measures bending strain of beam under 4-point bending
    - Measuring bending strain is a proven technique





Rail Seat Pressure Distribution Instrumentation



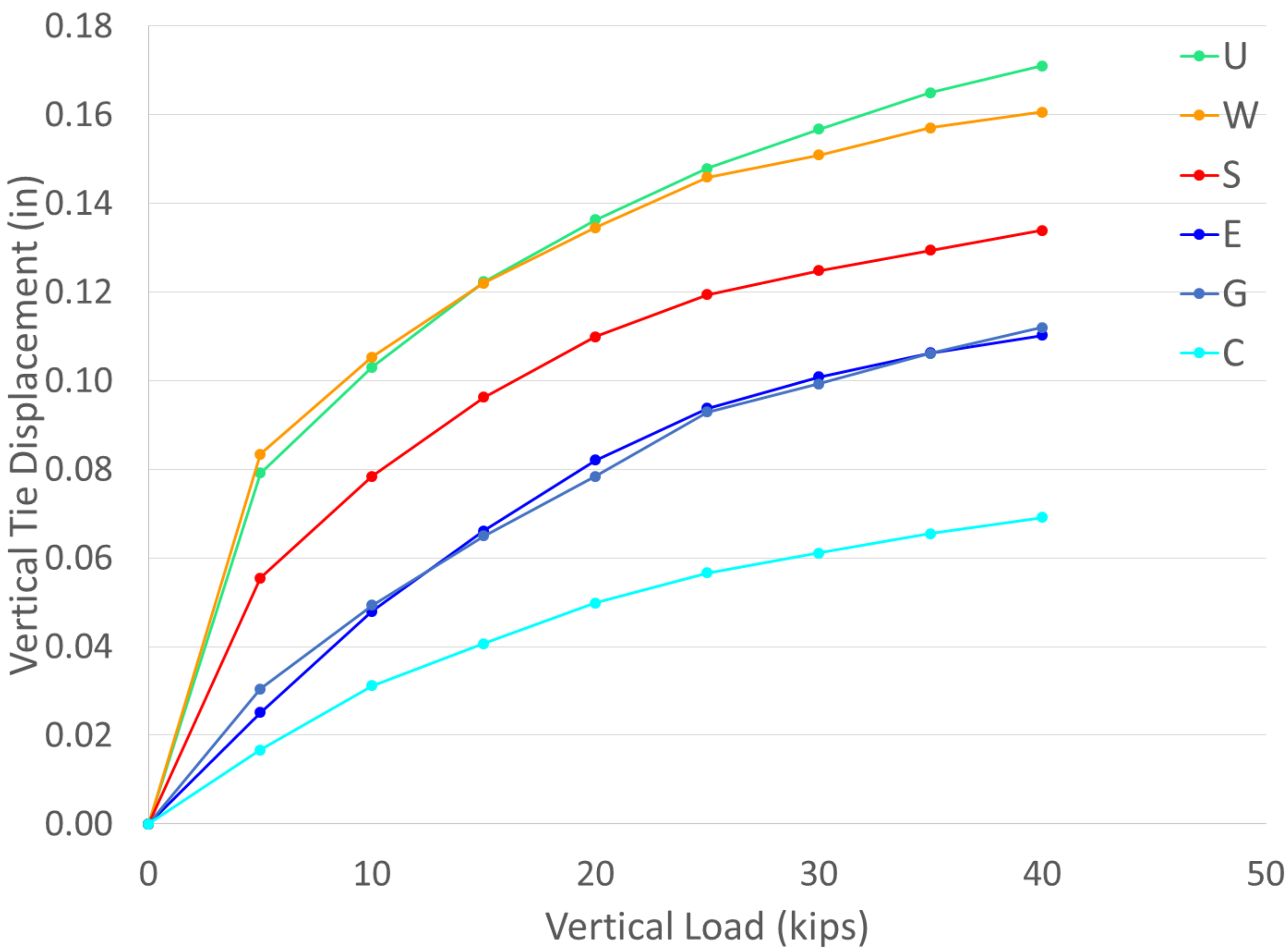


Matrix Based Tactile Surface Sensor

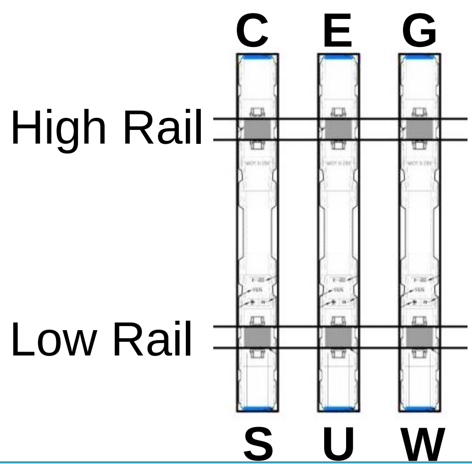
Select Experimental Results

- Vertical Loading Path
  - Crosstie Support Conditions
  - Rail Seat Loads
  - Vertical Load Distribution
  - Rail Seat Pressure Distribution
- Lateral Loading Path
  - Lateral Rail Loads (Tangent and Curve)
  - Lateral Shoulder Loads

Crosstie Support Variability:
Vertical Crosstie Displacement – HTL

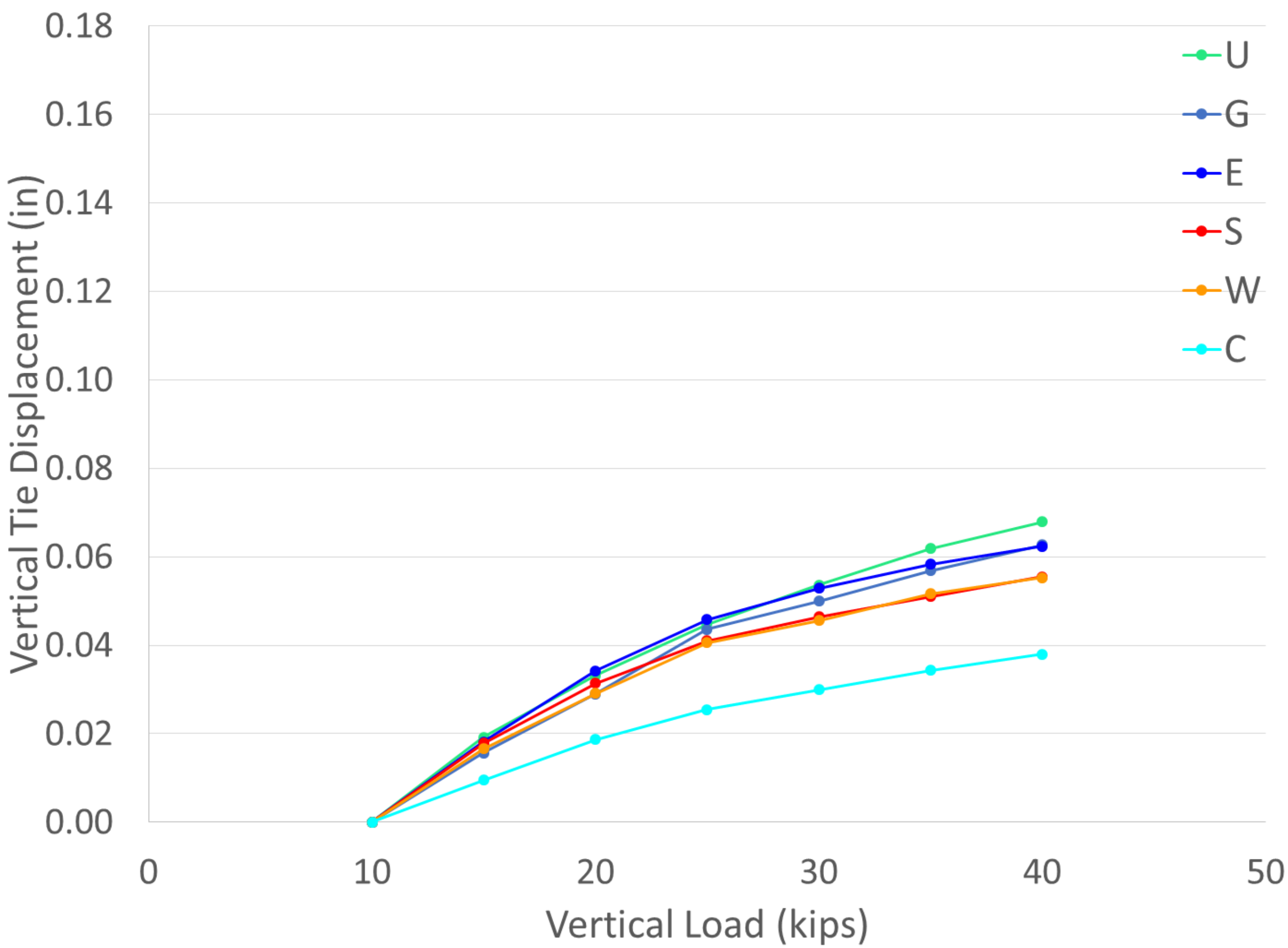


- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Low rail: weak support (slack or gap in support system)
- Modulus according to Kerr ranges from 3,600 – 10,000+ lb/in^2

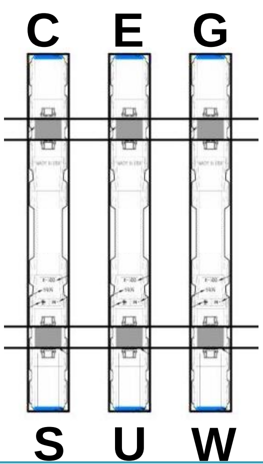


Crosstie Support Variability:

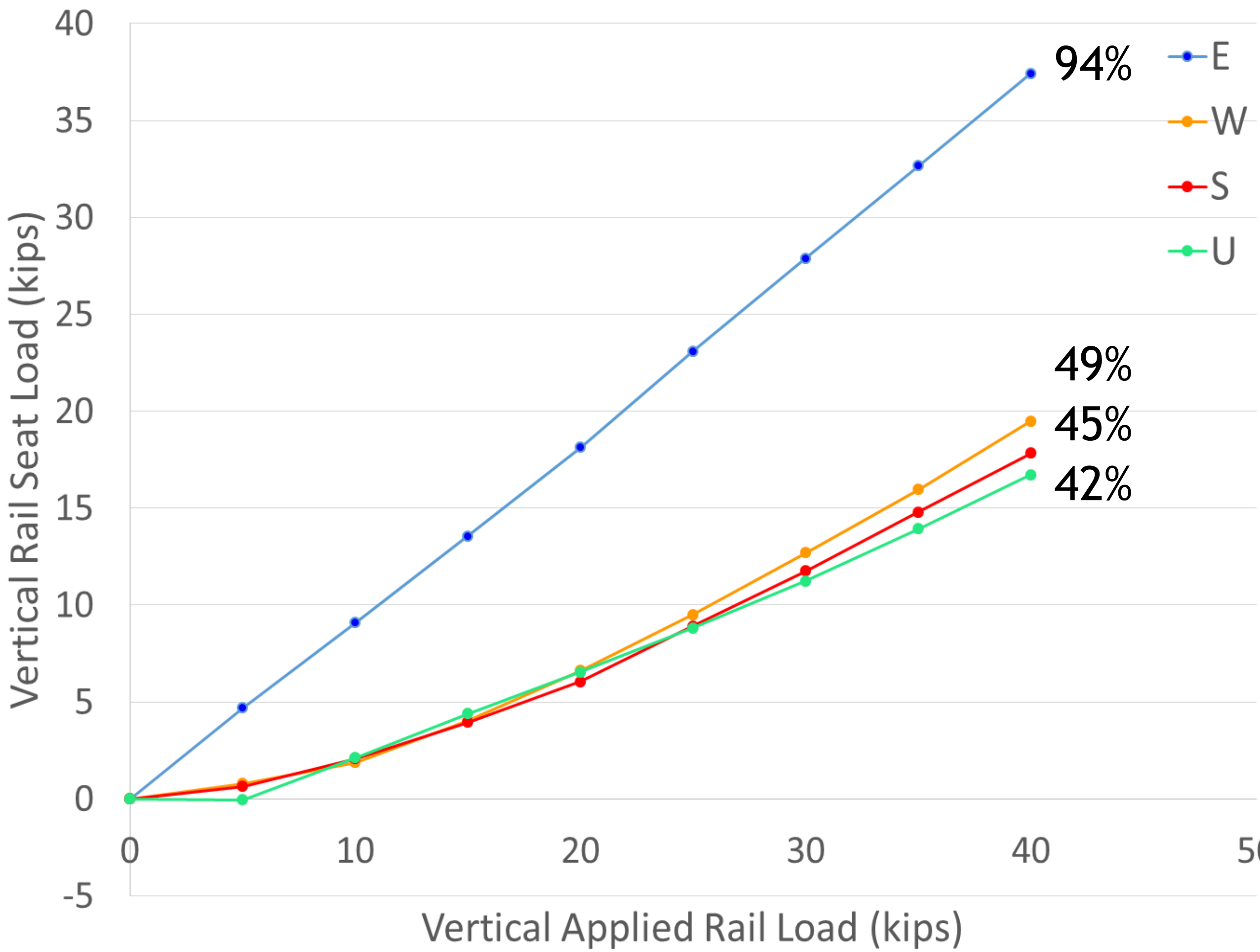
Vertical Crosstie Displacement – HTL with 10 kip zero



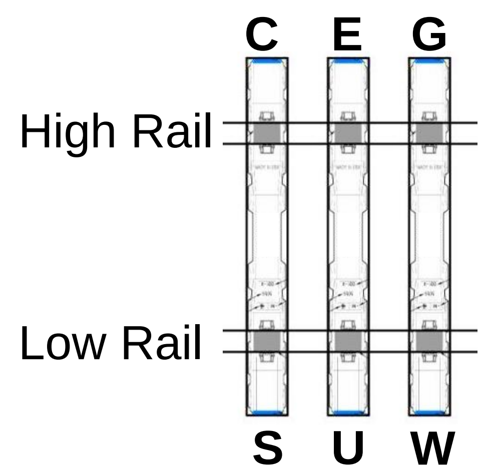
- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Subgrade modulus ranges from 6000 – 12,900 lb/in^2
- Range is only 6000 – 7,800 lb/in^2 if rail seat C is discarded



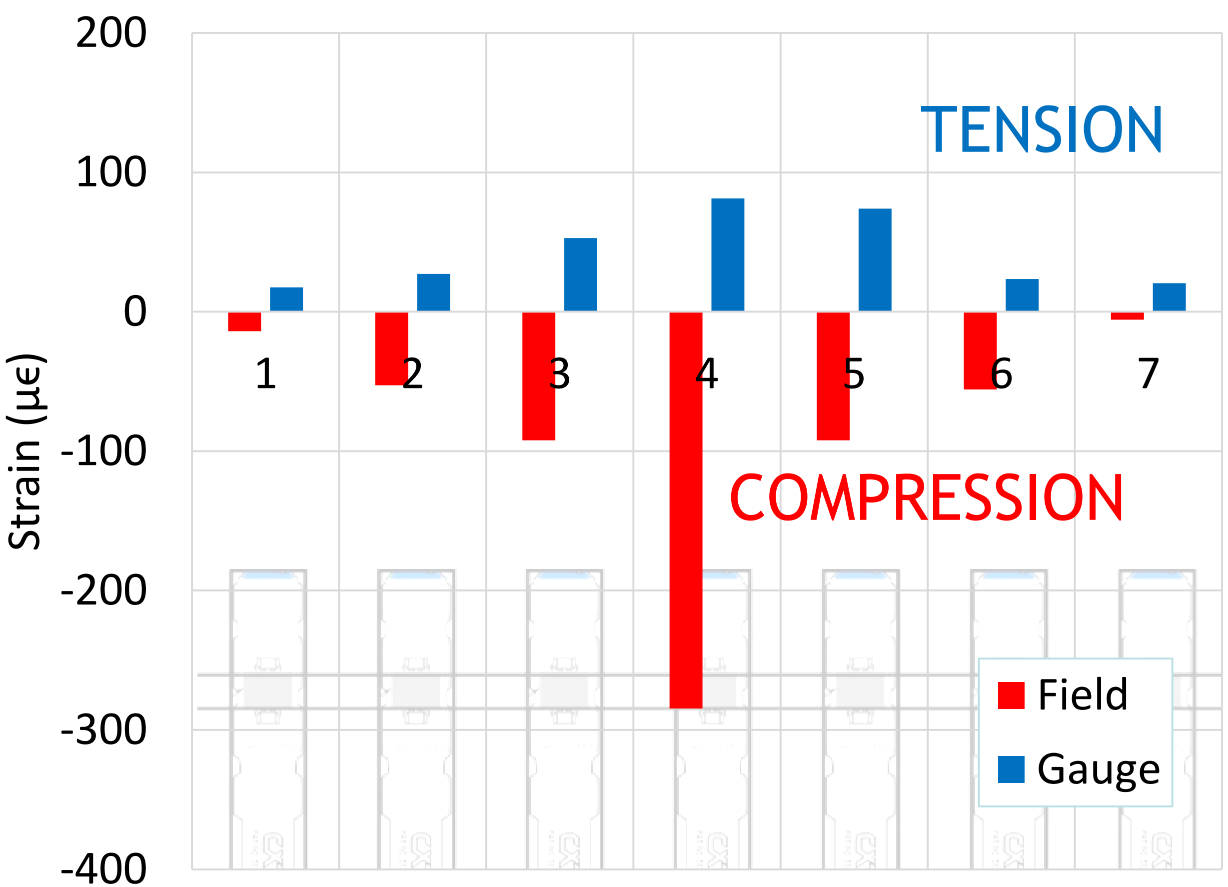
Rail Seat Load Variability:
Vertical Rail Seat Load - HTL



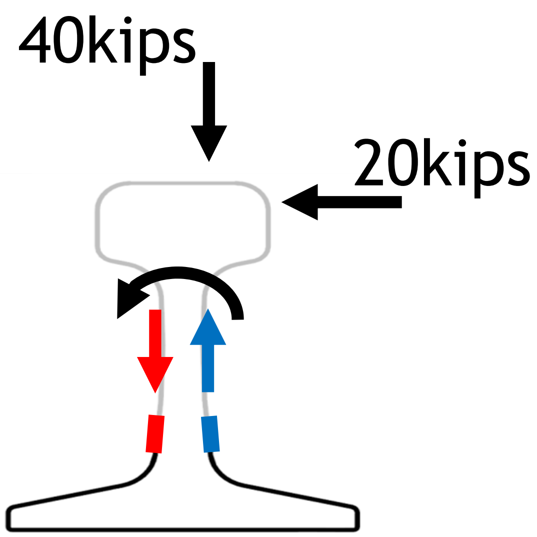
- Curve track
- Static vertical loads
- Max applied load = 40 kips
- Rail seat load transfer percentages range from 42 – 94%



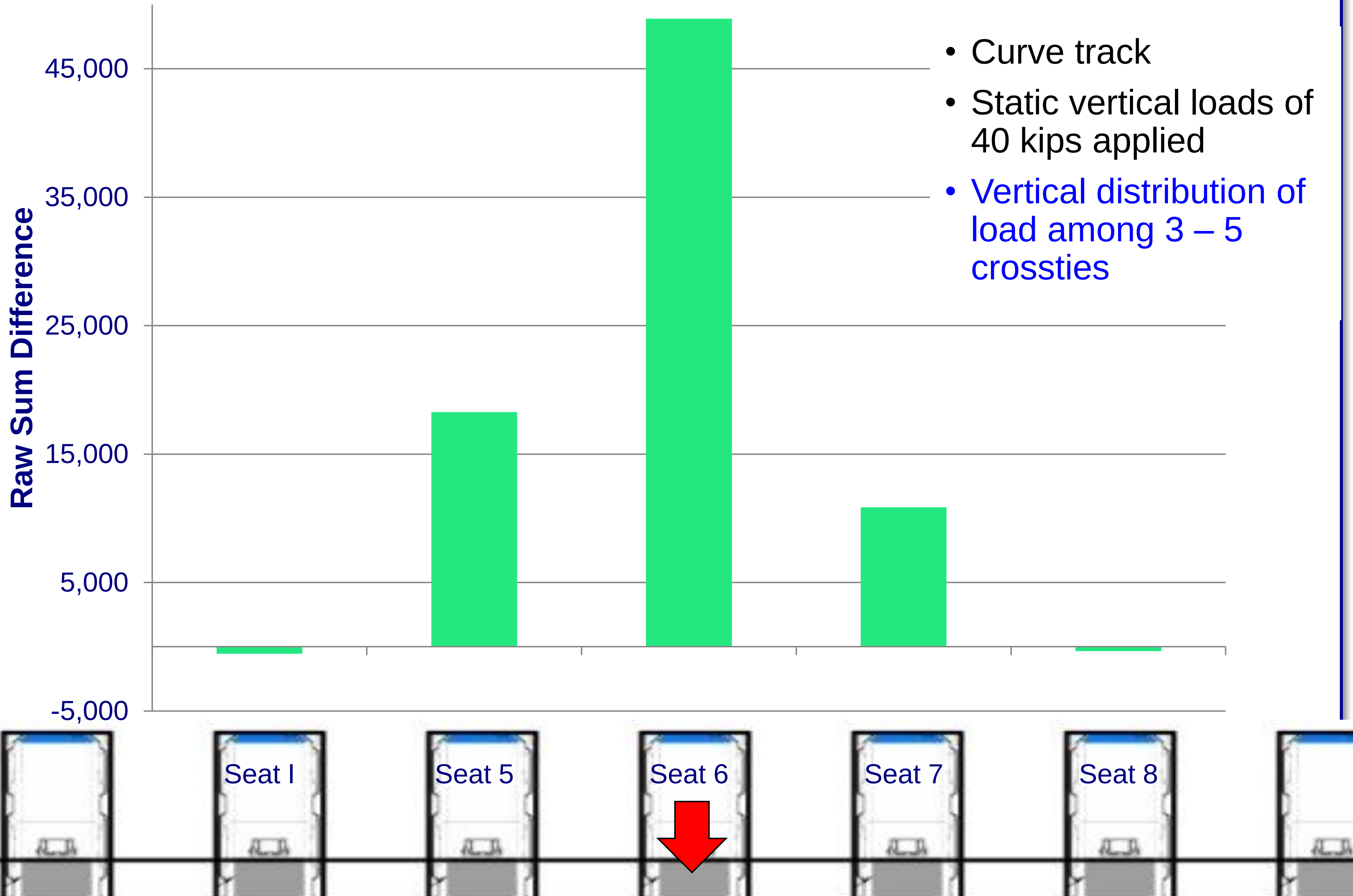
Vertical Strain Distribution in the Rail



- Curve track
- Static vertical loads of 40 kips applied
- Static lateral load of 20 kips applied
- Vertical distribution of load among 5 – 7 crossties



Vertical Load Distribution at Rail Seat

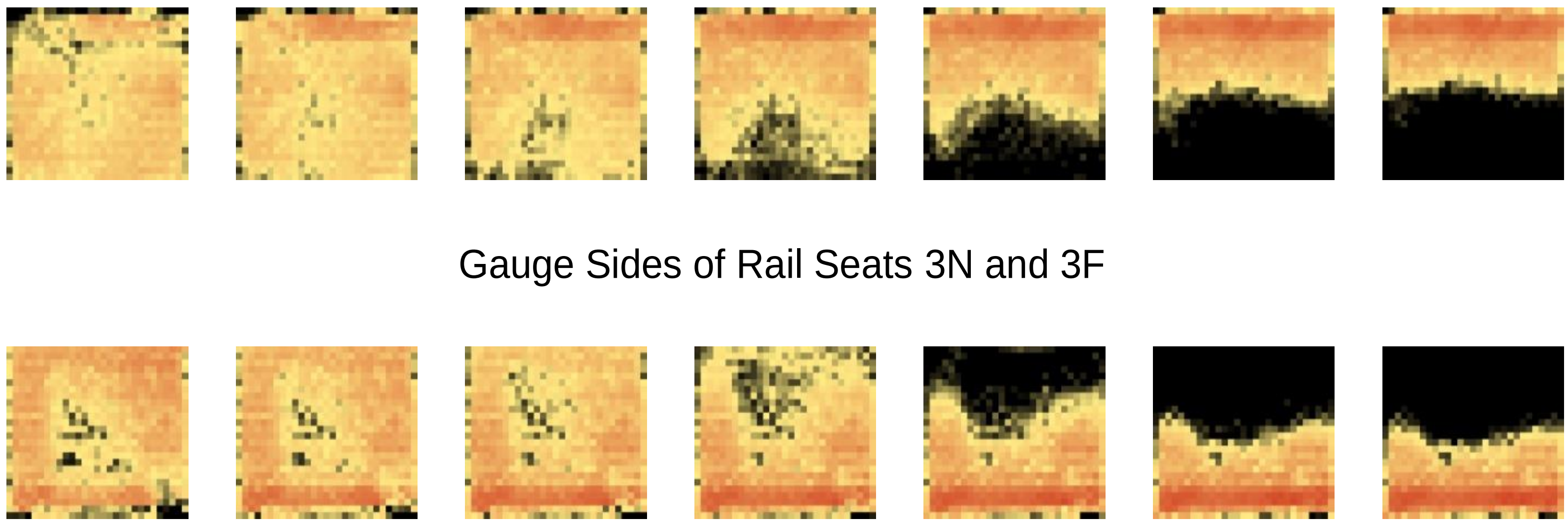


- Curve track
- Static vertical loads of 40 kips applied
- Vertical distribution of load among 3 – 5 crossties

Rail Seat Pressure Distributions Under Varying L/V Force Ratios

L/V Force Ratio	0.0	0.1	0.2	0.3	0.4	0.5	0.55

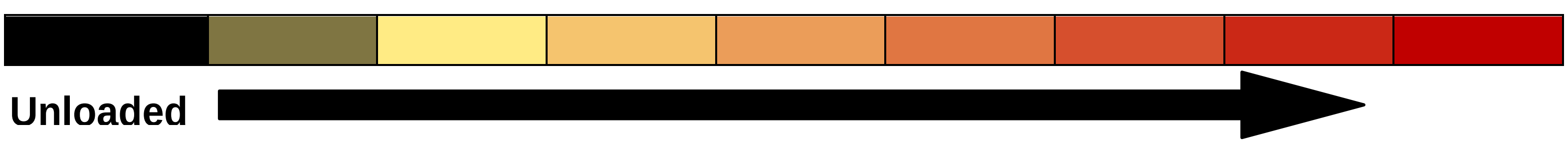
Rail Seat 3F (Far Rail)



Gauge Sides of Rail Seats 3N and 3F

Rail Seat 3N (Near Rail)

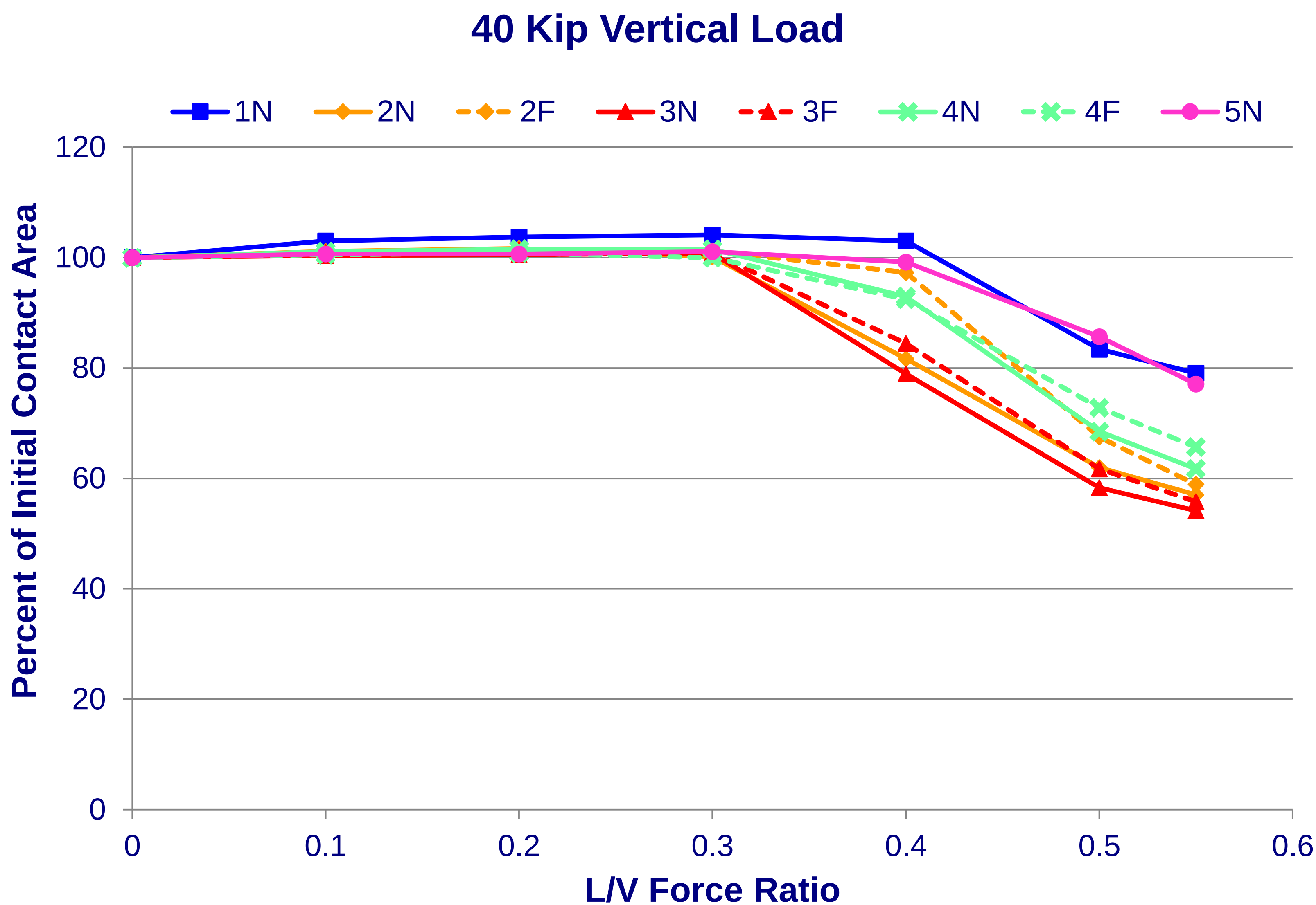
Pressure



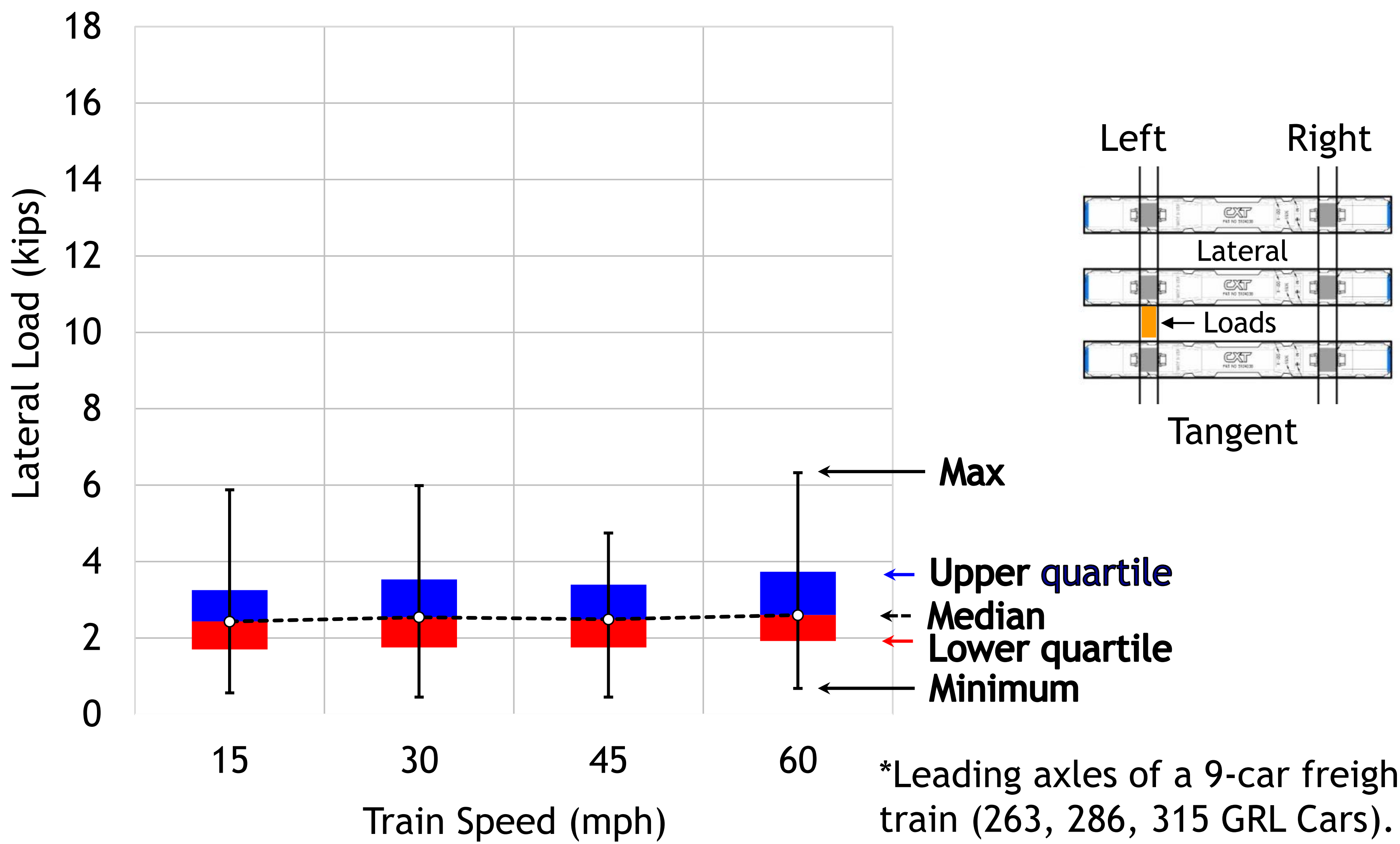
Unloaded

Increasing Pressure

Rail Rotation under Varying Lateral Load

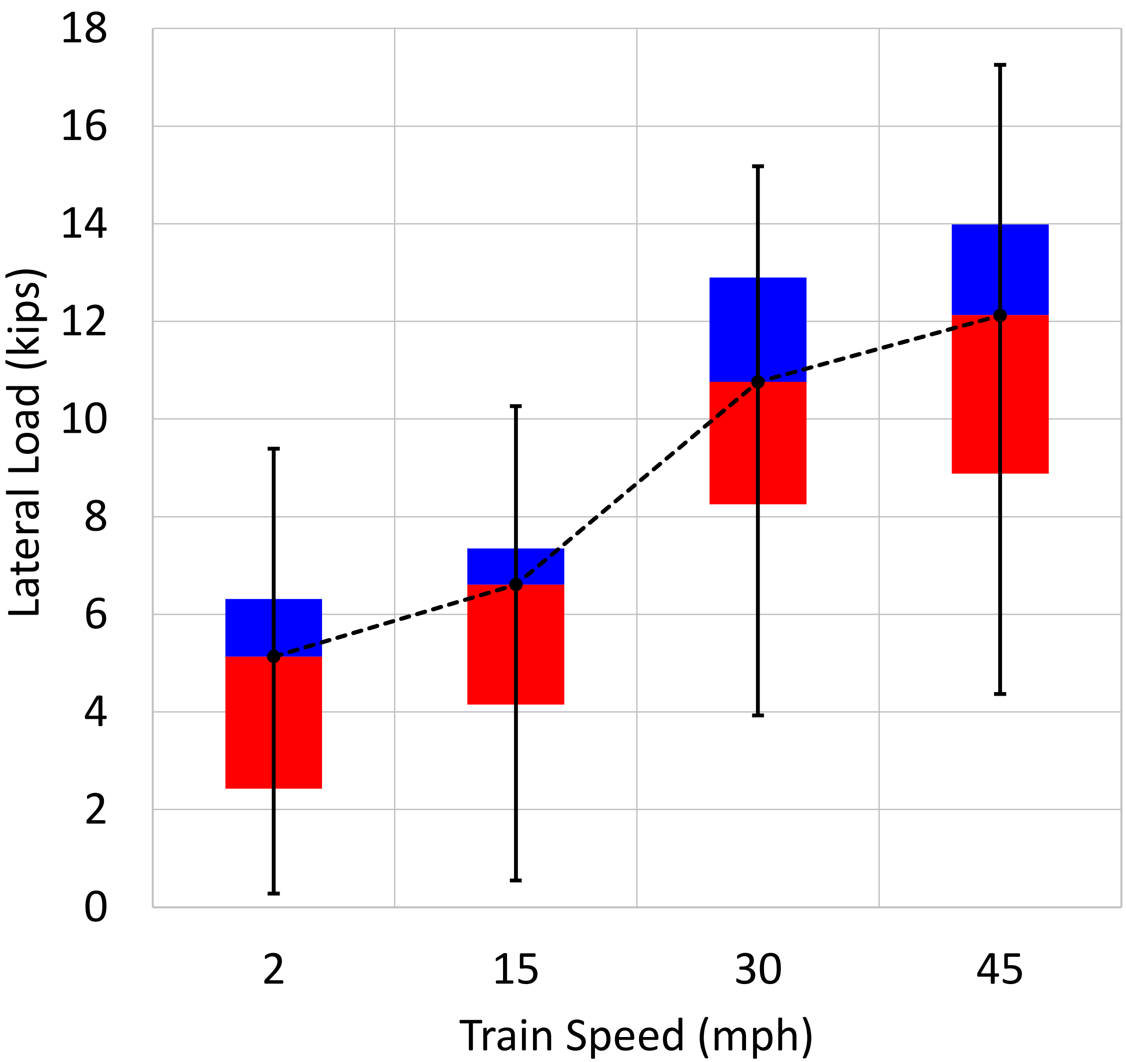


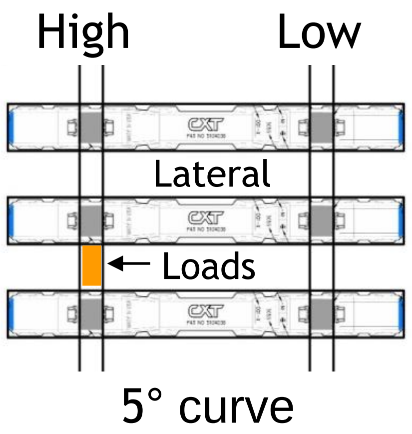
Lateral Loads Acting on Tangent Track



*Leading axles of a 9-car freight train (263, 286, 315 GRL Cars).

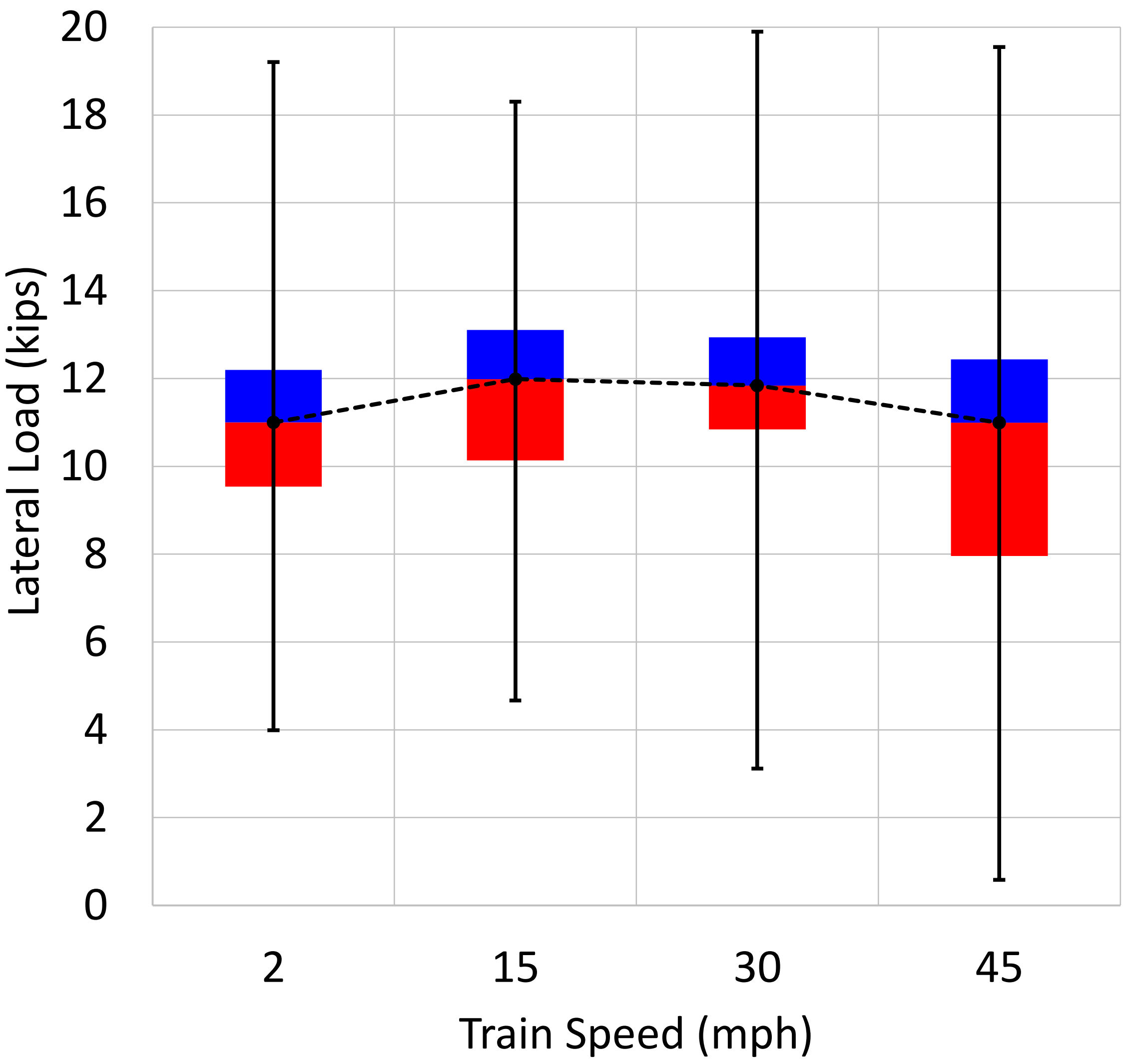
Lateral Loads Acting on Curved Track

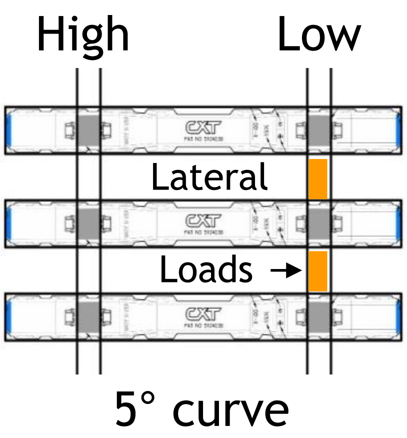




- Median loads can be 4 times larger than loads on tangent track.

Lateral Loads Acting on Curved Track

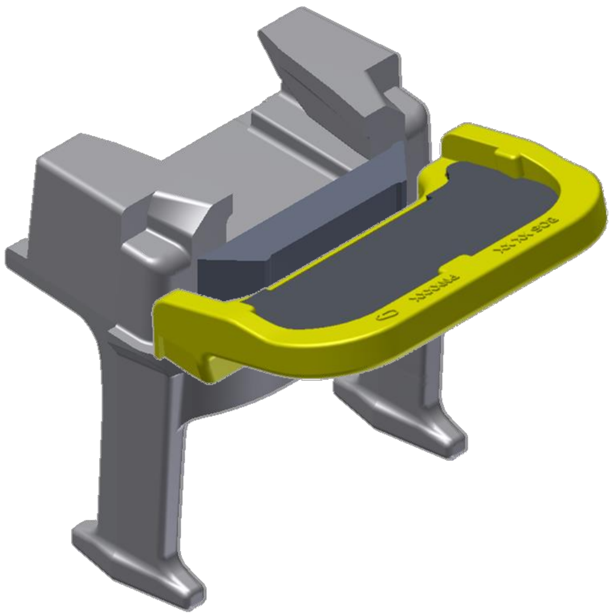


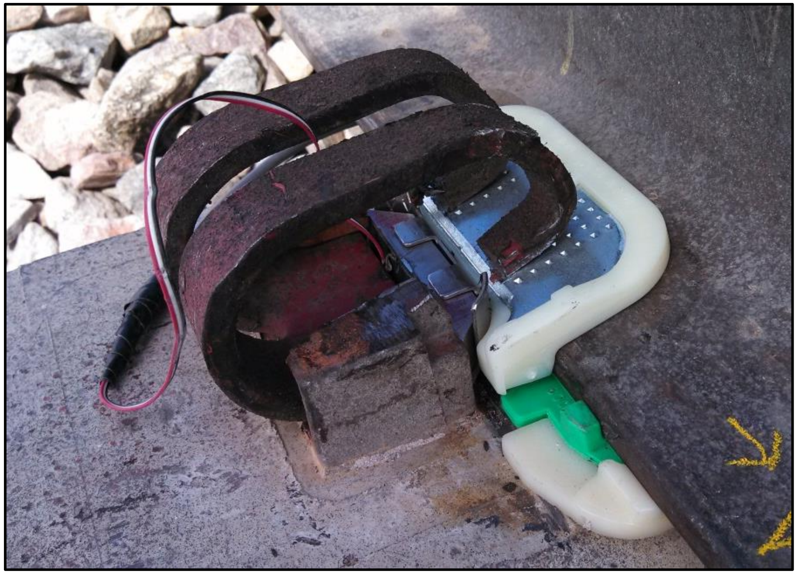


- Highest loading demands
- Twice as high as high rail at low speeds

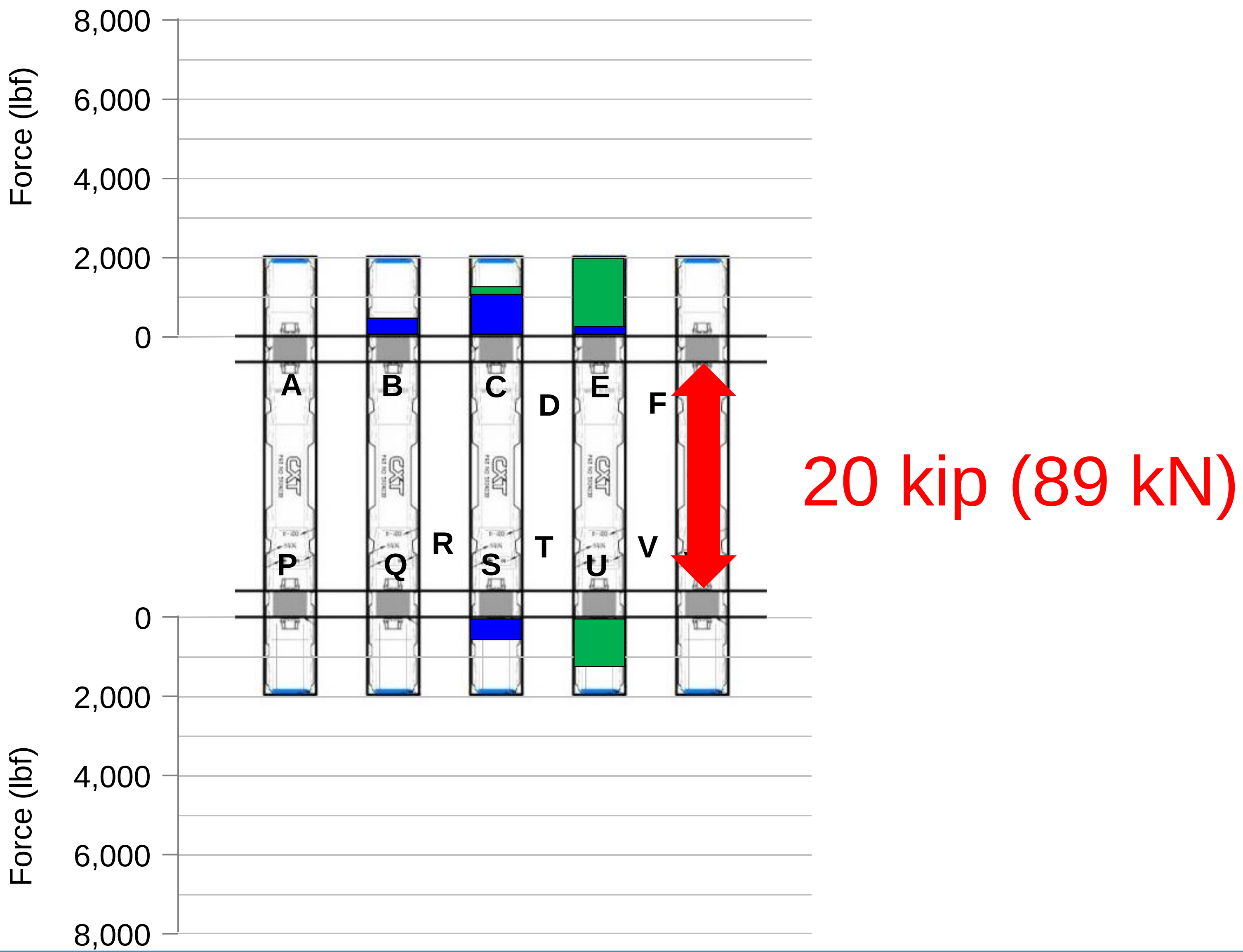
Analysis of Lateral Load Distribution

Location: RTT
Equipment: TLV
V = 40 kip (177.9 kN)
L = 20 kip (89 kN)
L/V = 0.5





Distribution of Lateral Loads



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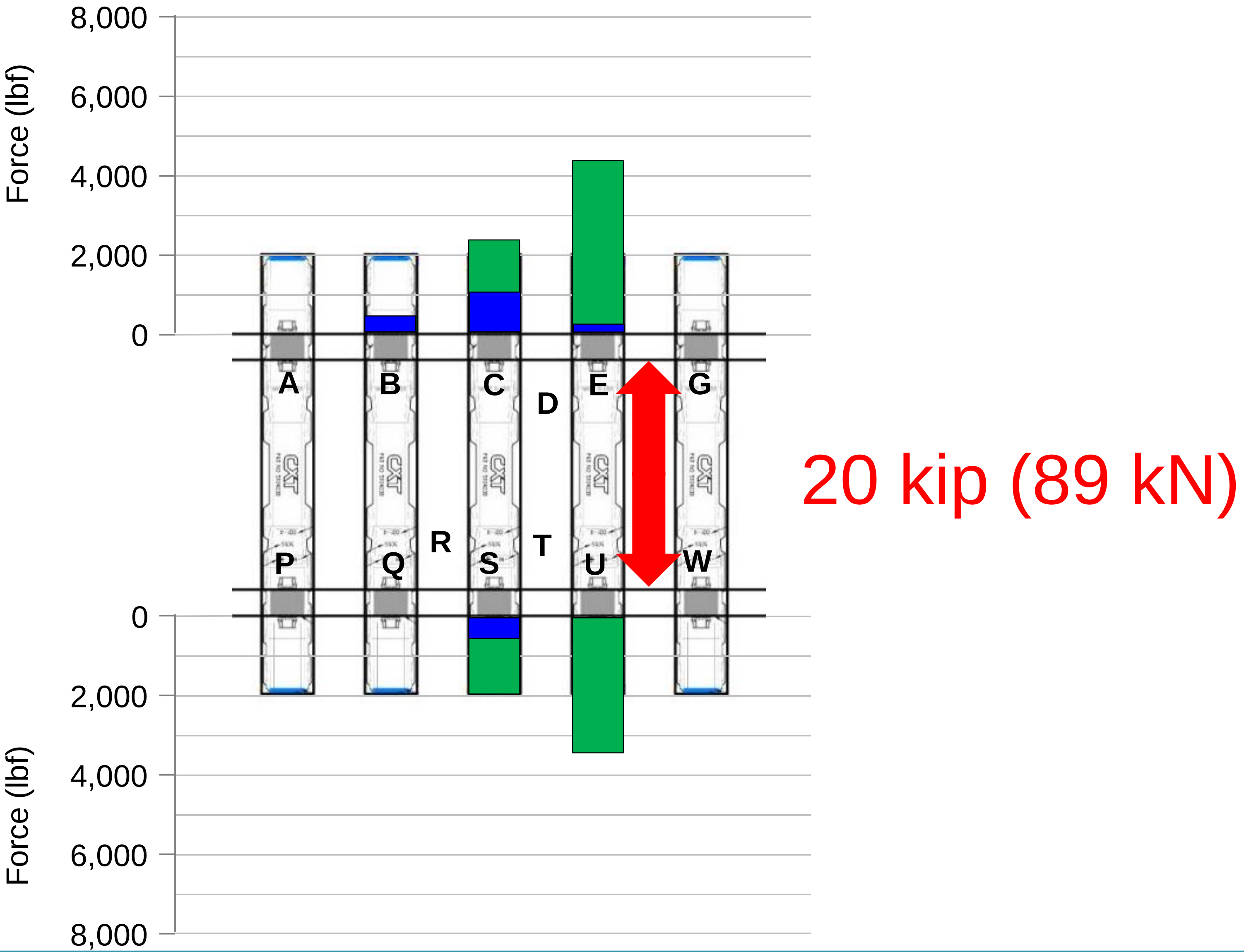

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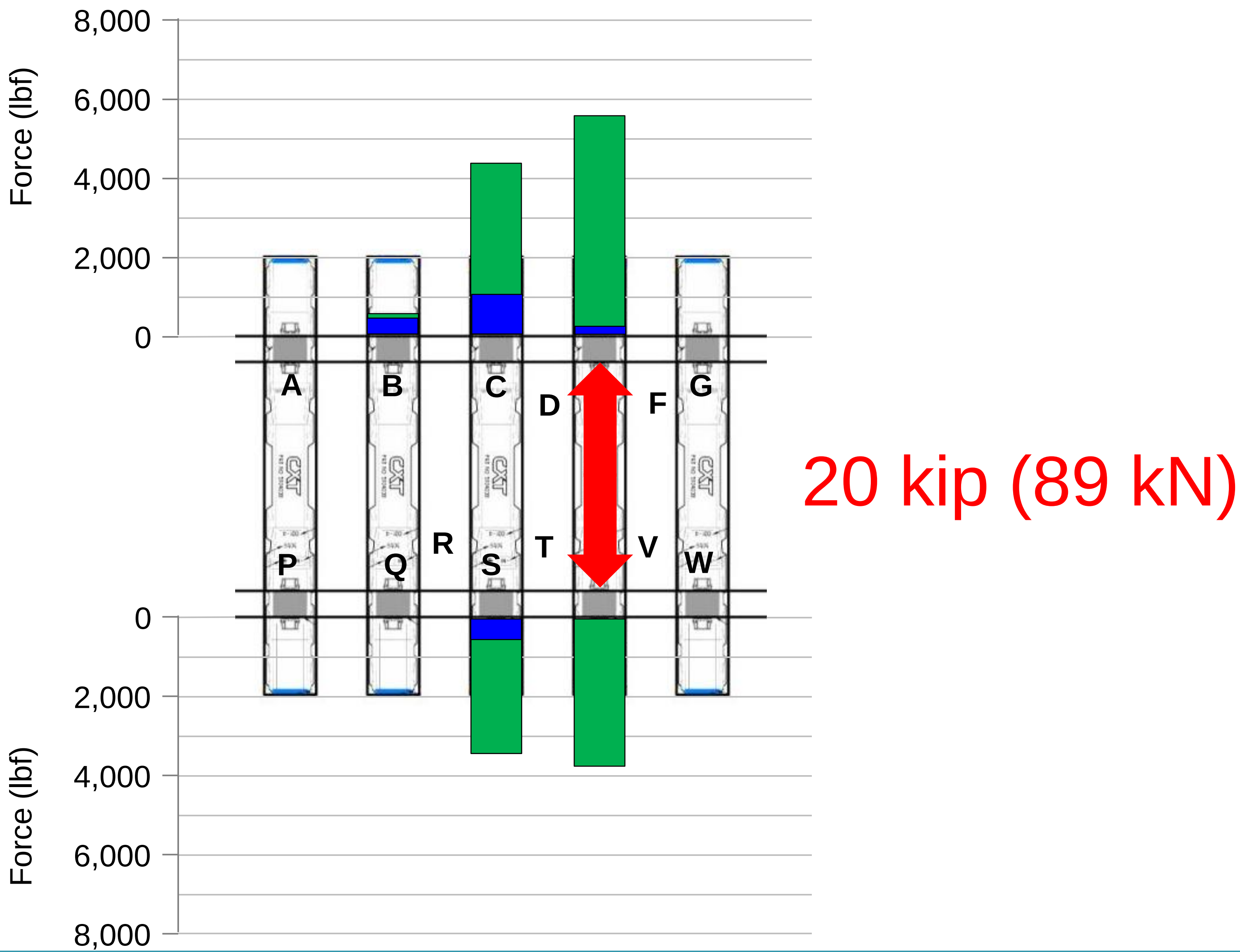
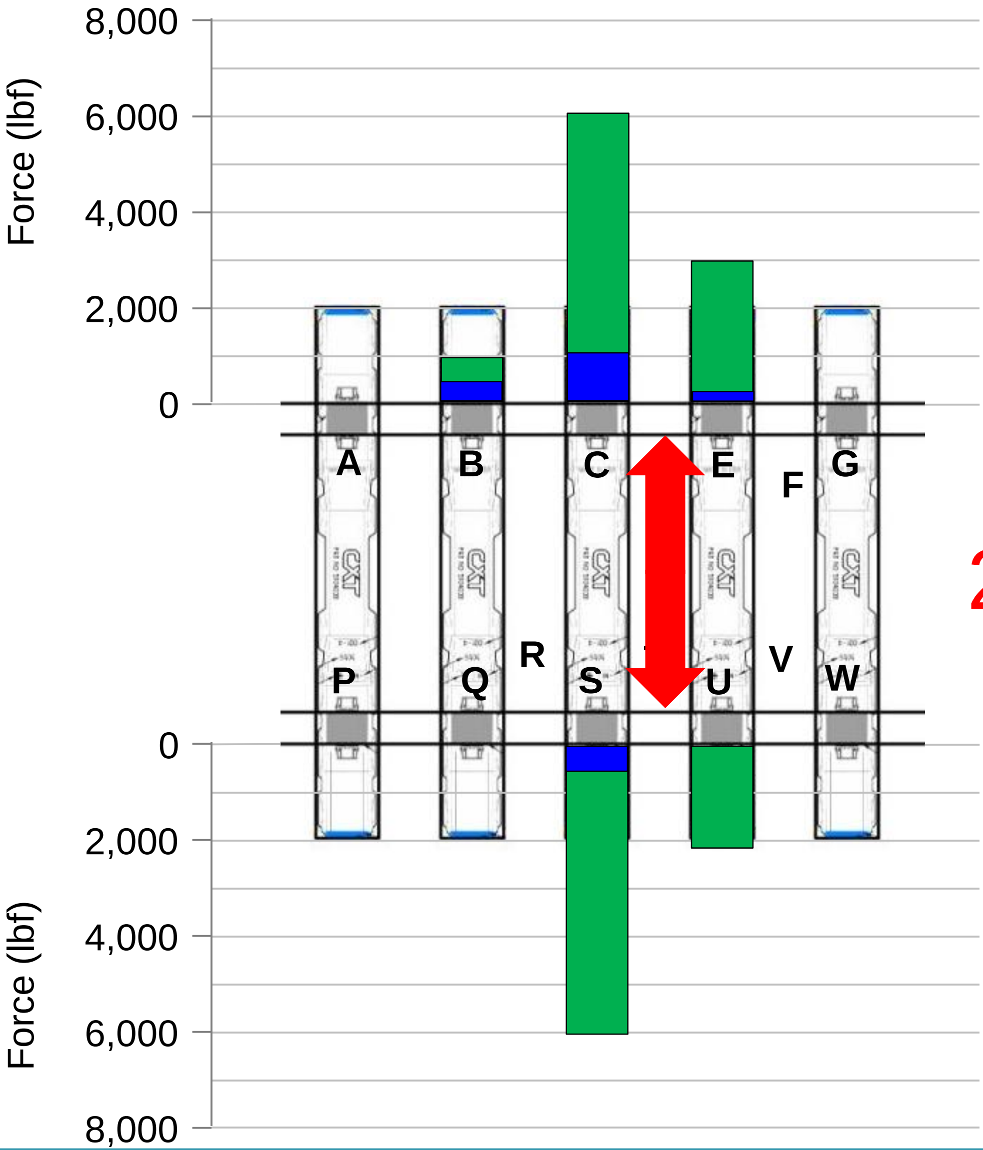
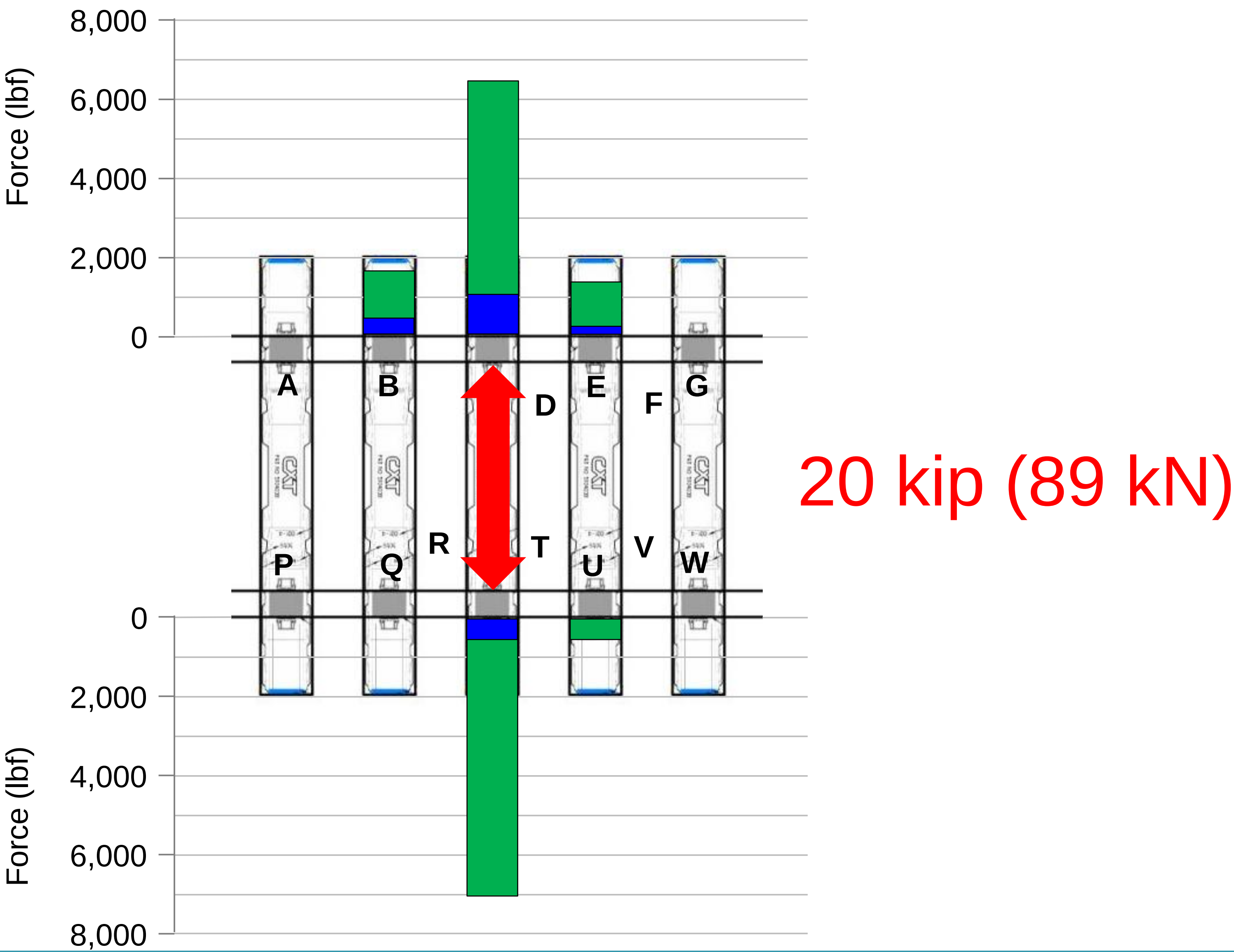


Distribution of Lateral Loads

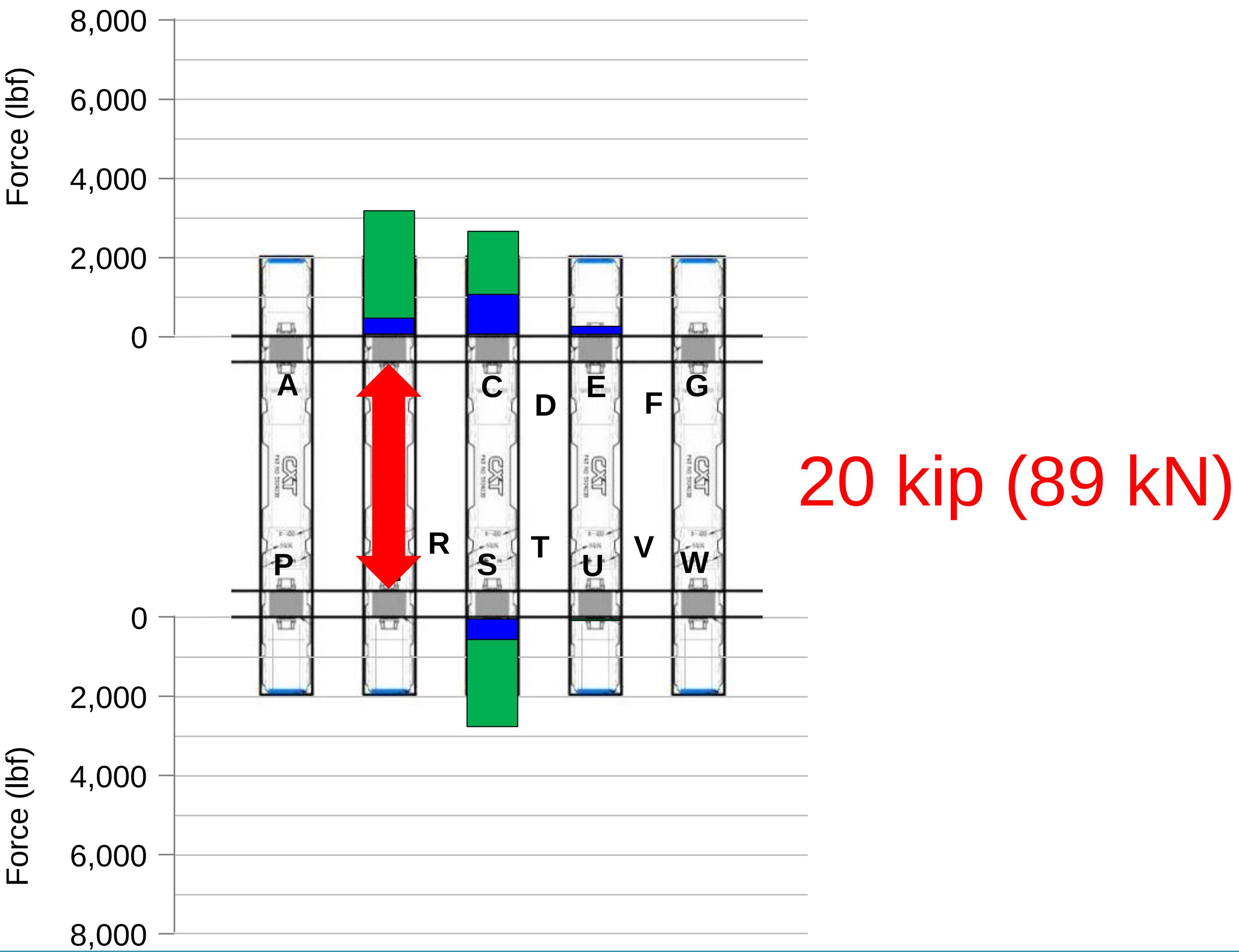


20 kip (89 kN)

Distribution of Lateral Loads



Distribution of Lateral Loads



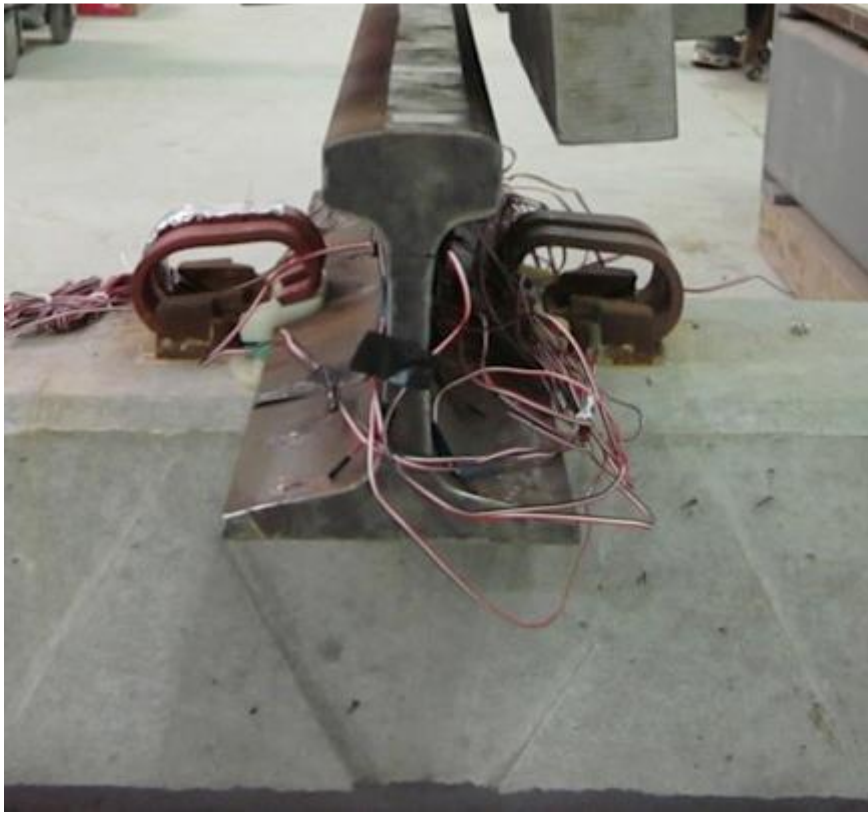
Findings and Potential Design Considerations

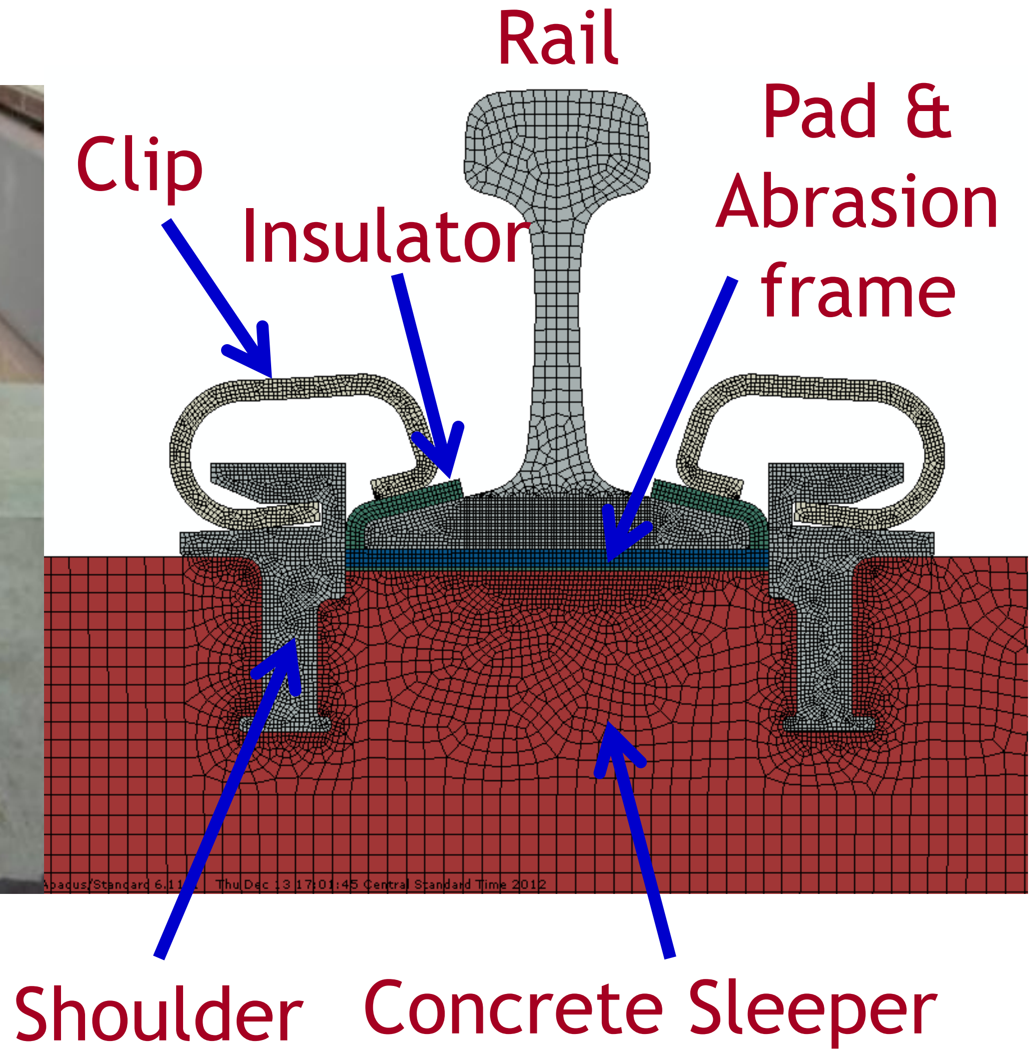
- **Vertical loading**
  - Measured static loads had a distributed response over 5-7 crossties at the wheel rail interface, and as low as 3 crossties at the rail seat
  - Vertical loading demands were highest at higher speeds on high rail
  - Rail seat forces are highly dependent on the stiffness of the substructure and support conditions and range from 20% to 90% of the wheel-rail load
  - Design of crossties and fastening systems should incorporate probabilistic loading conditions (wide variations of loading inputs)
- **Lateral loading**
  - Static lateral loads were distributed over 3 rail seats (approximately half of the load distribution area compared to vertical loads)
  - On average, loads were found to be 3-6 times higher on curved track than on tangent track
  - Design should consider transfer of lateral loads and the potential for use of specialized components on curves

Future Work

- Continue analysis of data to understand the governing mechanics of the system by investigating the:
  - Factors that determine vertical and lateral load distribution
  - Bending moments of the crossties
  - Pressure magnitude and distribution at the rail seat
  - Stresses and displacements in the fastening system
- Complete construction and begin experimentation with full scale track loading system at UIUC
- Complete validation of the UIUC finite element model using field and laboratory results
- Develop a simplified design tool to facilitate mechanistic design of concrete crossties and fastening systems
- Small-scale, evaluative experimentation on Class I Railroads

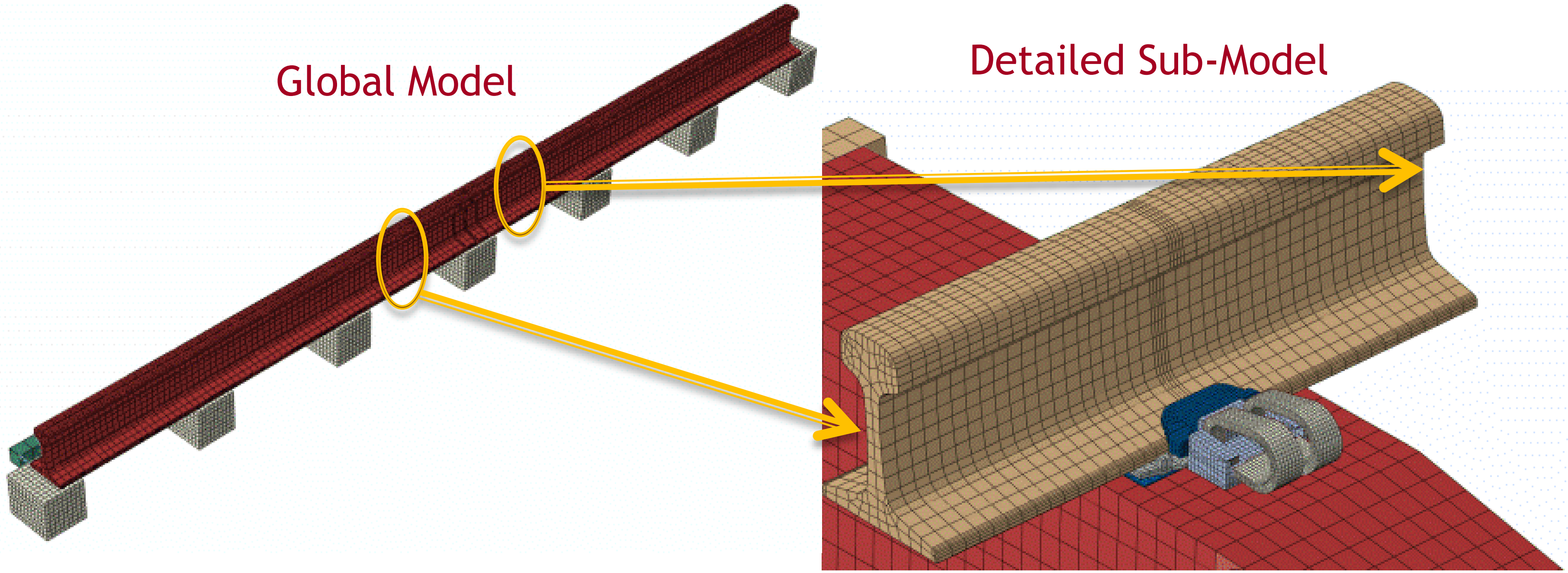
Modeling of Concrete Sleeper and Fastening System



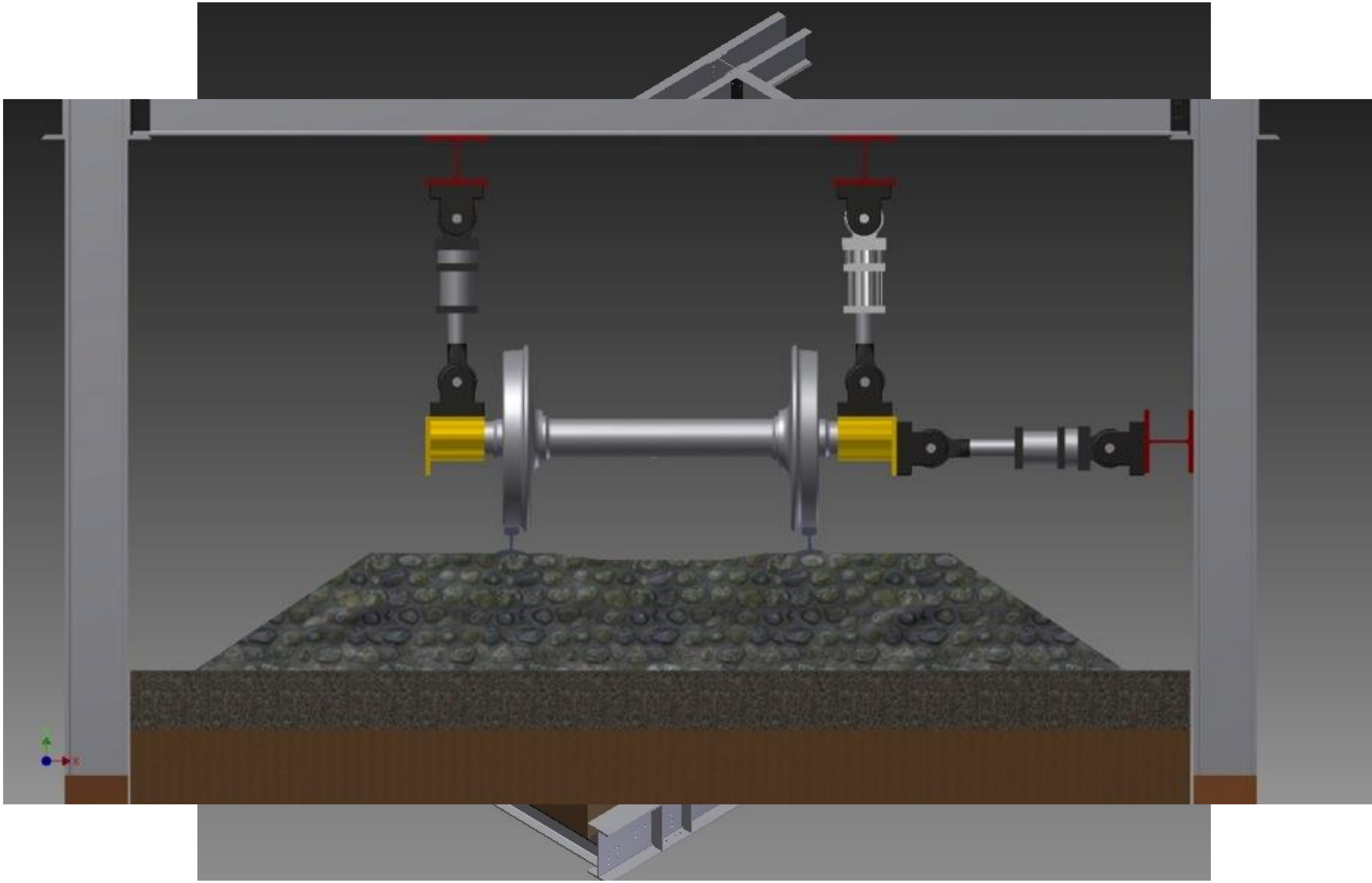


Multiple-Crosstie Modeling

- Model is validated using field data from TTC experiments
- Both global model and sub-model are used to provide accurate representation of interaction of multiple crosstie systems
- Objective for sub-model technique: Have identical or similar global behaviors (load distribution, displacement) in both models



Full-Scale Track Loading System (Under Construction)



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