Analysis of Effects of Friction on Lateral Fastening System Forces

FRA Tie & Fastener BAA Industry Partners Meeting

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Outline

- Motivation for research
- Defining Lateral Load Path and Fastening System
- Field Experimental Setup – TTC
  - Model used to guide frictional analysis
  - Effect of varying vertical wheel load
  - Global distribution of lateral forces
- Laboratory Experimental Setup - TLS
  - Effect of varying frictional characteristics of fastening system
  - Analysis of results with proper and poor support conditions
  - Global distribution of lateral forces
- Conclusions

Motivation

- Lateral forces in track contribute to many track component failures/deteriorations.

Broken/Worn Insulator

Rail Seat Deterioration

Worn Pad

Broken/Worn Insulator

Motivation

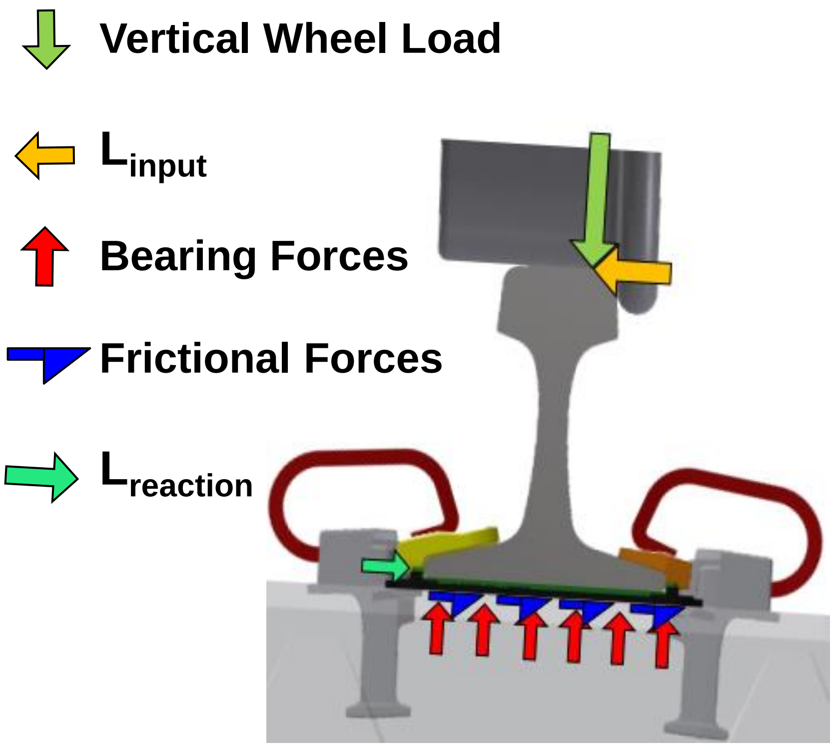
- Current track remediation protocols for concrete crossties as well as fastening system designs alter the lateral friction resistance between fastening system and concrete crosstie.
- Research endeavor is to better understand the role friction resistance plays in the lateral load path and lateral load distribution through the track.

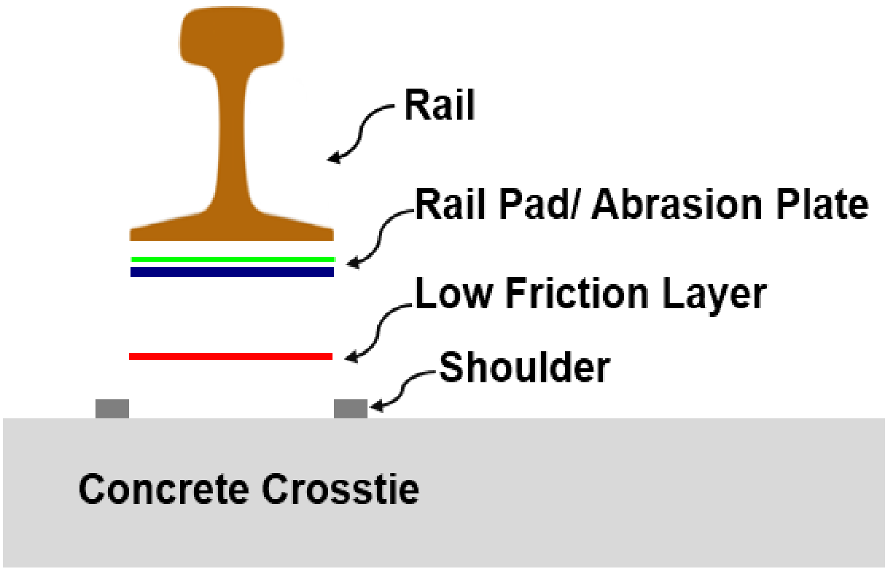
Steel Abrasion Plate

Rail Seat Epoxy Remediation

Direct Fixation Fastening System

Lateral Load Path and Fastening System Setup



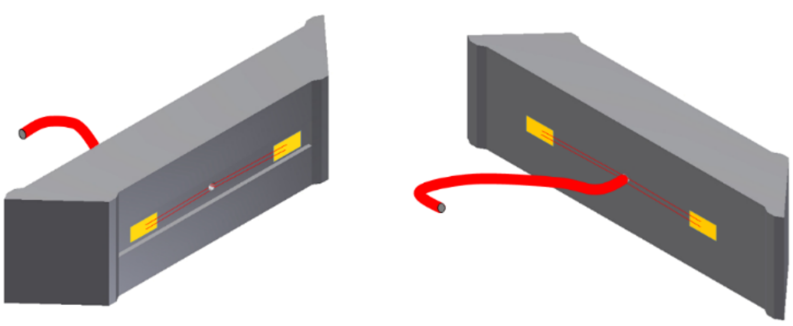


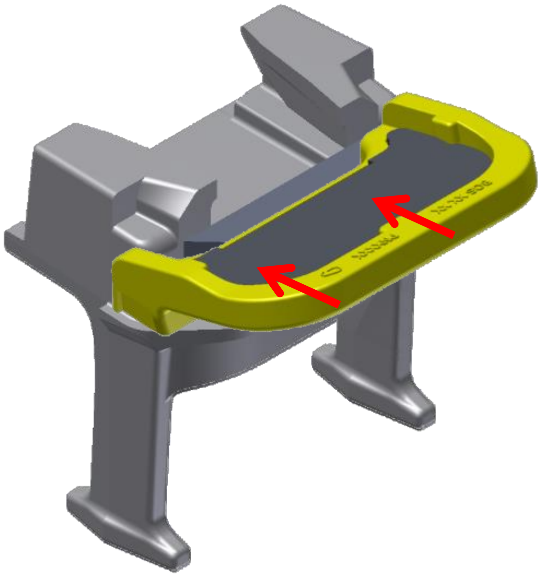
- Primary research objective is to study the Frictional Force between the rail pad and the rail seat.
- Low friction layer made of BoPET used to investigate the importance of friction in lateral force distribution through track infrastructure

Measurement Technology

Lateral Load Evaluation Device (LLED)

- Replaces original face of cast shoulder
- Maintains original fastening system geometry
- Designed as a beam in four-point bending
- Bending strain is resolved into force through calibration curves generated in the lab





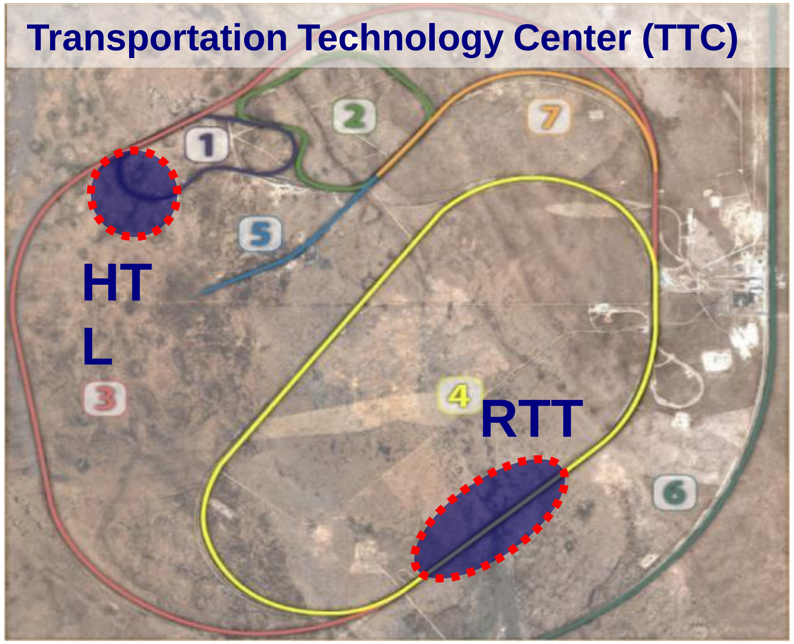
Field Experimental Setup

- **Objective:** Analyze the distribution of forces through the fastening system and impact on components relative displacements

- **Location:** Transportation Technology Center (TTC) in Pueblo, CO
  – **Railroad Test Track (RTT):** tangent section
  – **Heavy Tonnage Loop (HTL):** curved section

- **Instrumentation:**
  - Lateral load evaluation devices
  - Potentiometers to capture rail base lateral displacement

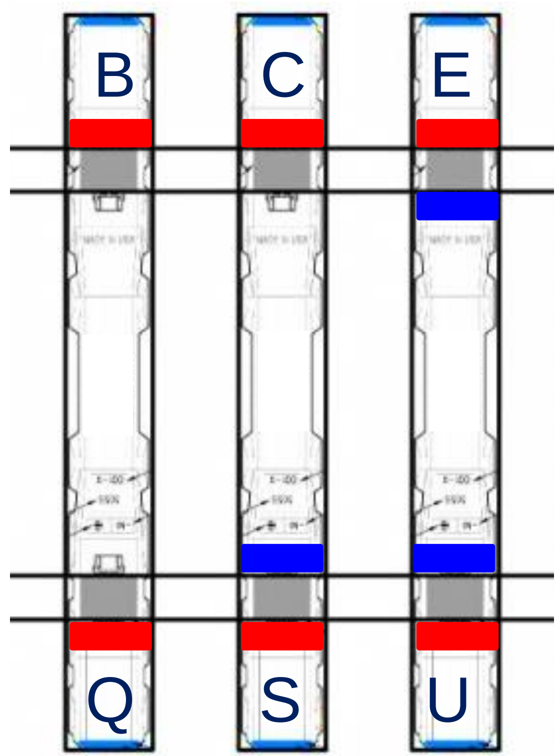
- **Loading:** Track Loading Vehicle (TLV) used to apply static loads to the track structure
  – Modified railcar with instrumented wheelset on hydraulic actuators



Field Instrumentation Map

High Rail (HTL)

Low Rail (HTL)



LLED

Lateral Rail Base Potentiometer

Lateral Load Model Equations for Analysis

$\Sigma L_L = \Sigma L_B + \Sigma L_F$

where,

ΣL_L = Total lateral load

ΣL_B = Lateral bearing force

ΣL_F = Lateral frictional force

$F_F = \mu N$

where,

F_F = Frictional Force

μ = Coefficient of Friction

N = Normal Force

Effect of Varying Vertical Load

Assume load distribution of: 50% bearing, 50% friction

If $L_L = \Sigma L_B + \Sigma L_F$, then $\Sigma L_L = \Sigma L_B + \Sigma(\mu N)_{\text{rail seat}}$

where,

μ = Coefficient of Friction between rail pad and rail seat

N = Force normal to frictional plane (vertical wheel load)

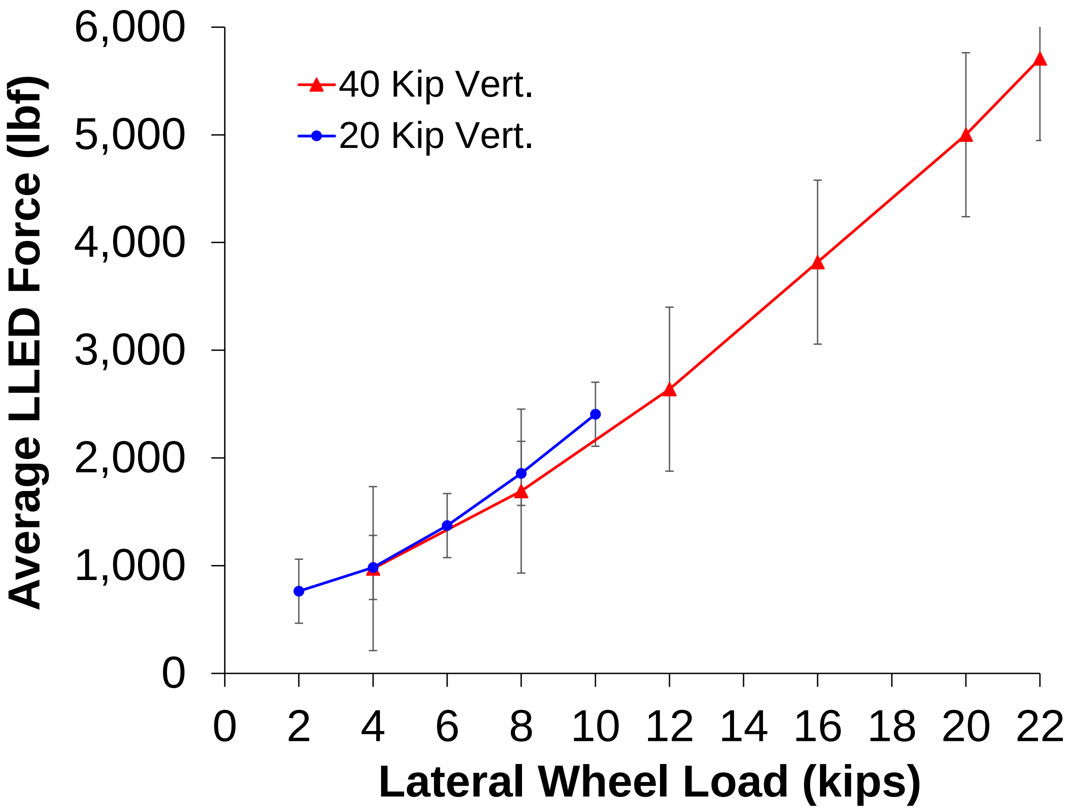
If N decreases by 50%, load distribution changes to:

75% bearing, 25% friction

Effect of Varying Vertical Load

Average for Single Rail Seat*

- Difference between lines:
  - increases as lateral wheel load increases
  - likely due to the lower normal force (vertical wheel load) applied to the rail seat
- Trend does not agree with theoretical equations

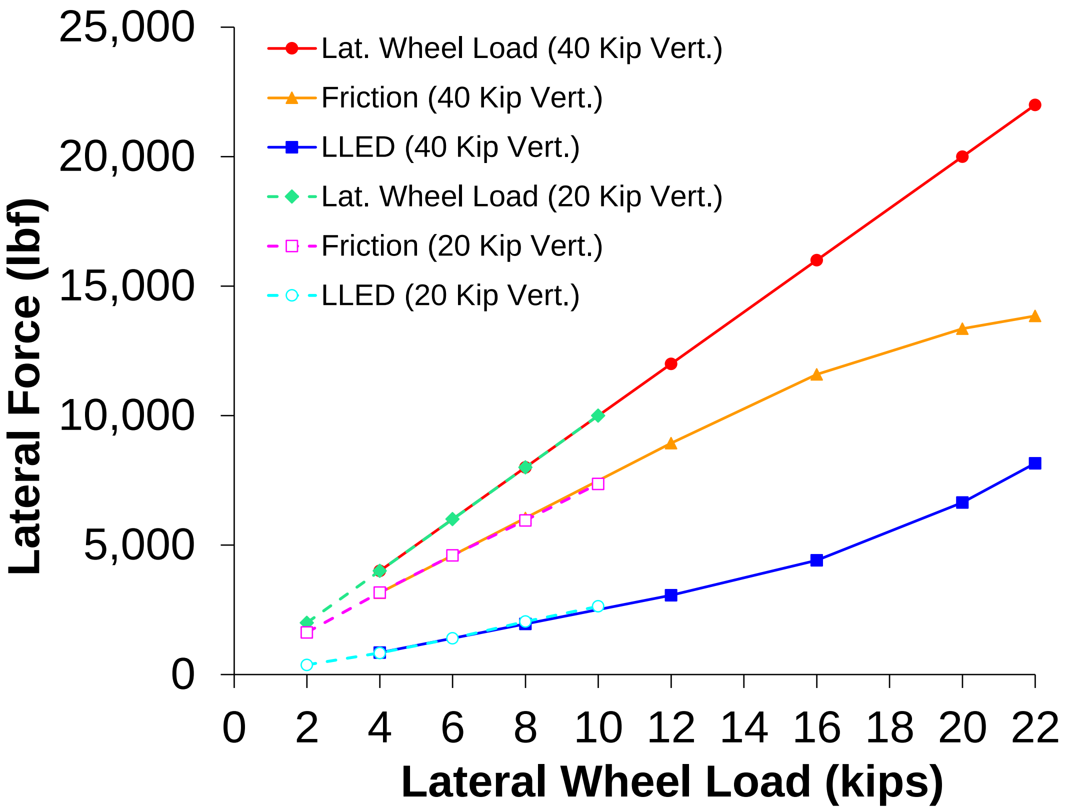


Average from static tests on five rail seats (B, C, E, S, U)

Effect of Varying Vertical Load

Total Lateral Forces in Track*

- 20 kip and 40 kip vertical wheel load tests produce extremely similar results
- Frictional and bearing forces start to converge as lateral wheel load increases
- Trend does not agree with $F_F = \mu N$ equation

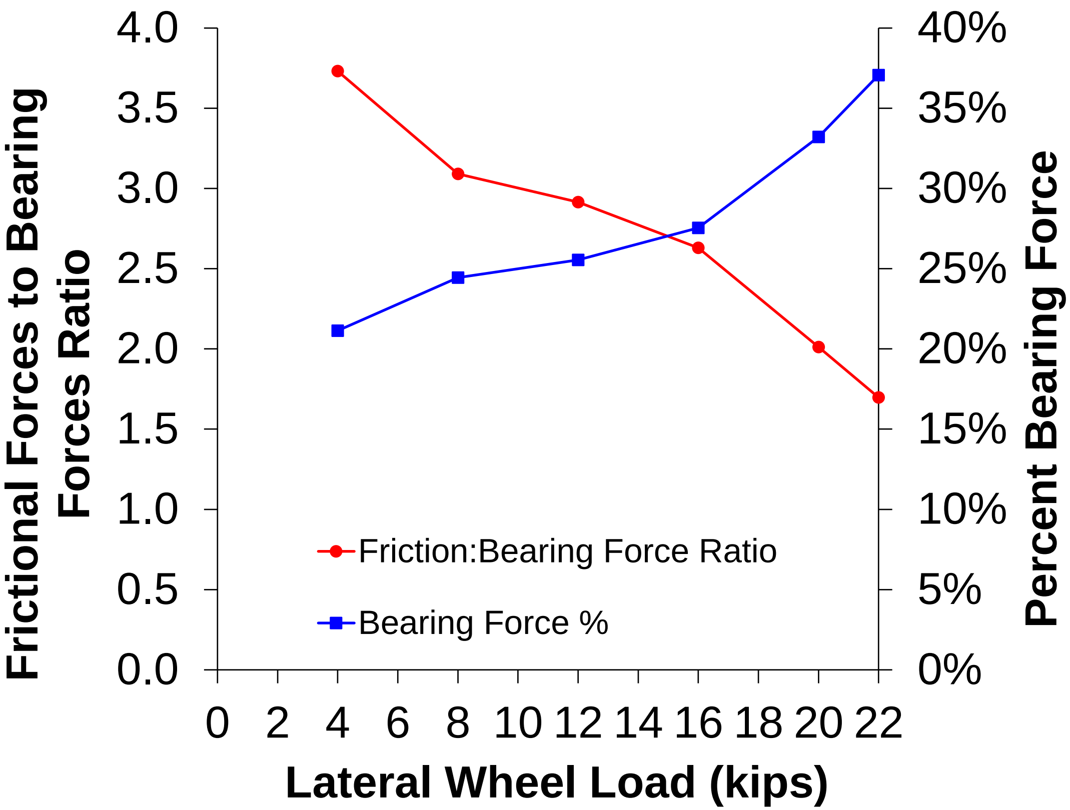


Sum of three adjacent rail seats (B, C, E)

Effect of Varying Vertical Load

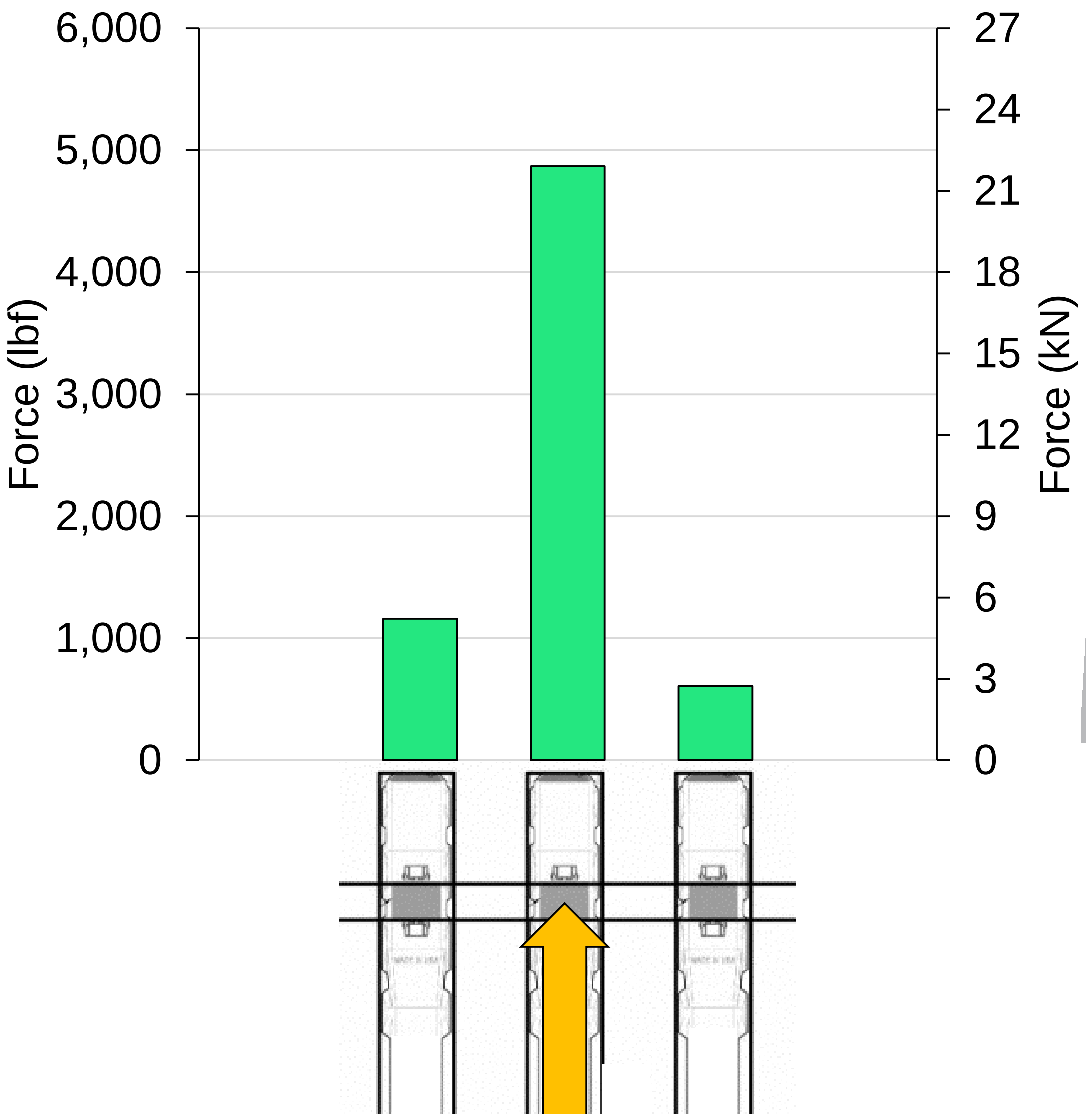
Total Lateral Forces in Track*

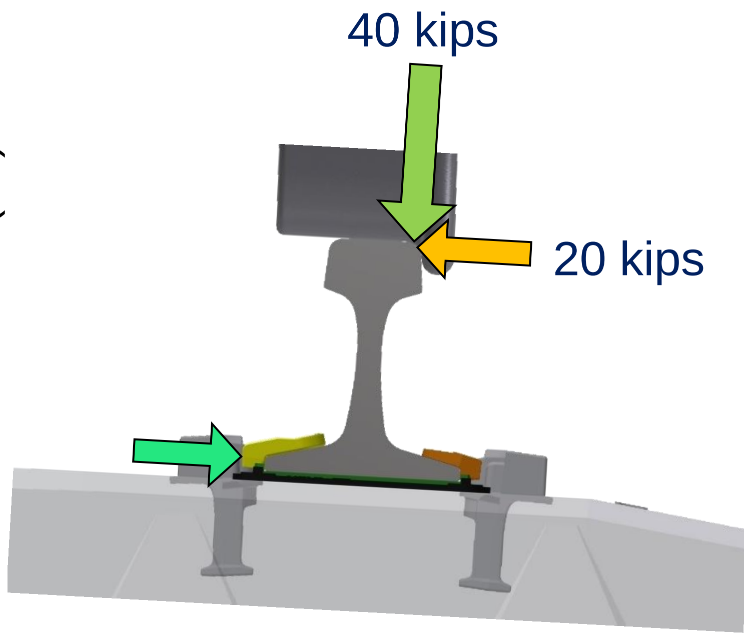
- As lateral wheel load increases
  - ratio of frictional force to bearing force decreases from 3.7 to 1.7, or 54%
  - percent bearing force increases from 21% to 37%



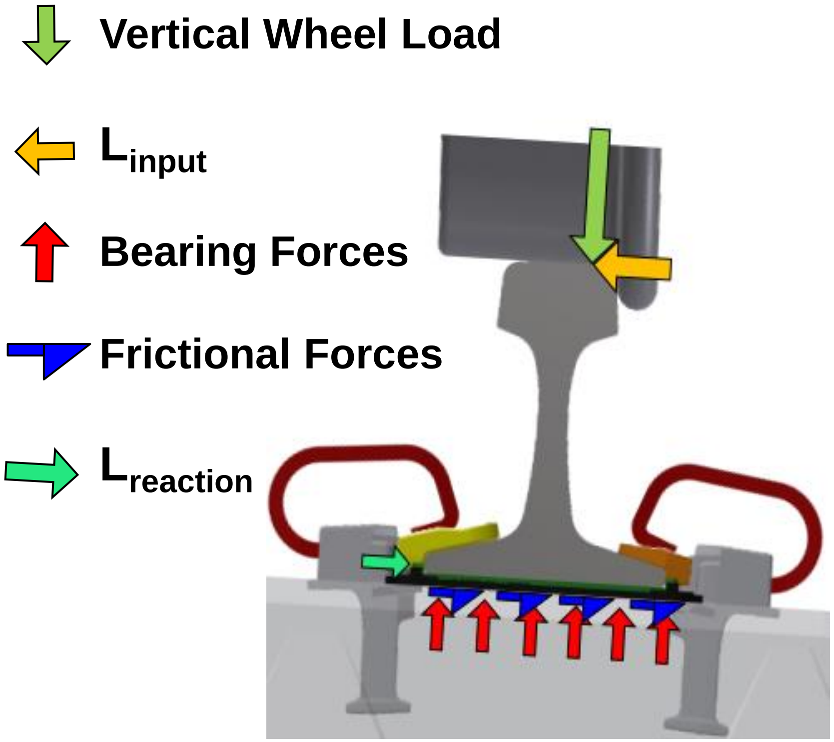
Sum of three adjacent rail seats (B, C, E)

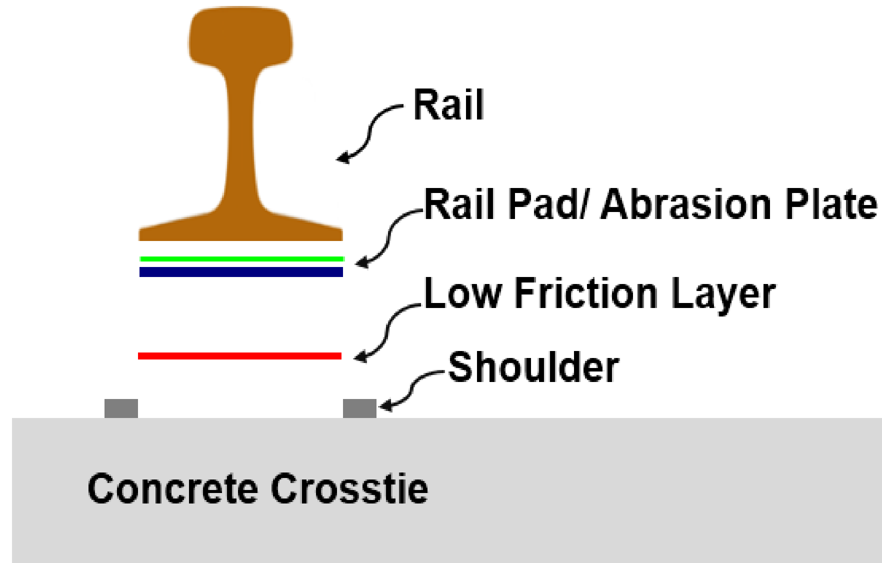
Global Distribution of Lateral Forces





Lateral Load Path and Fastening System Setup





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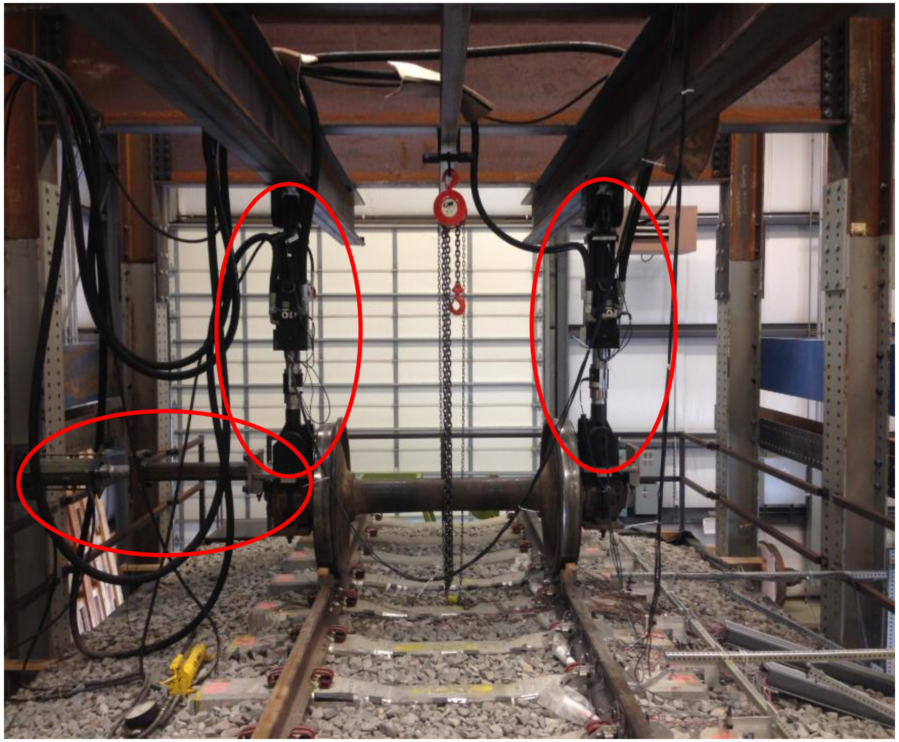
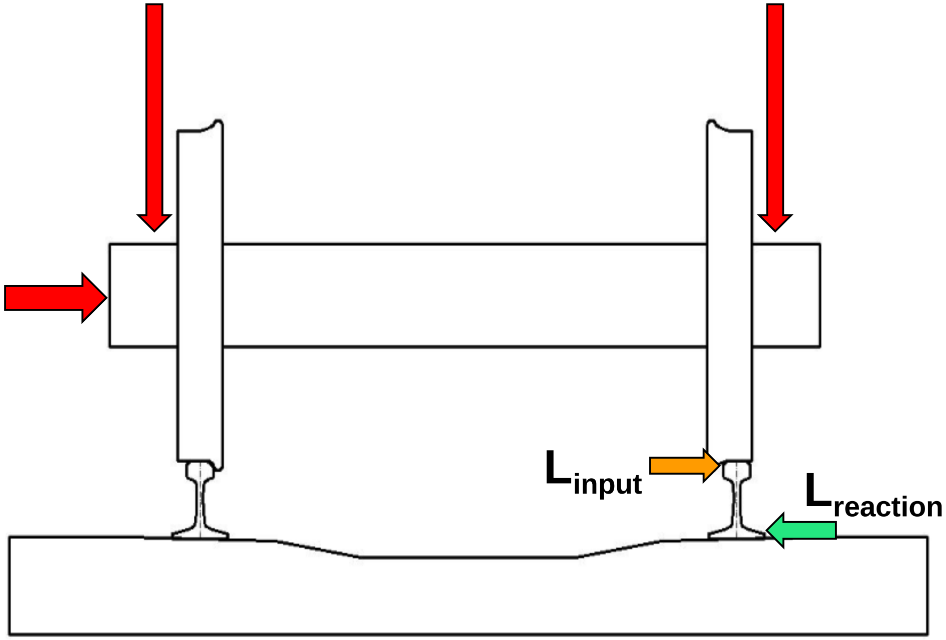
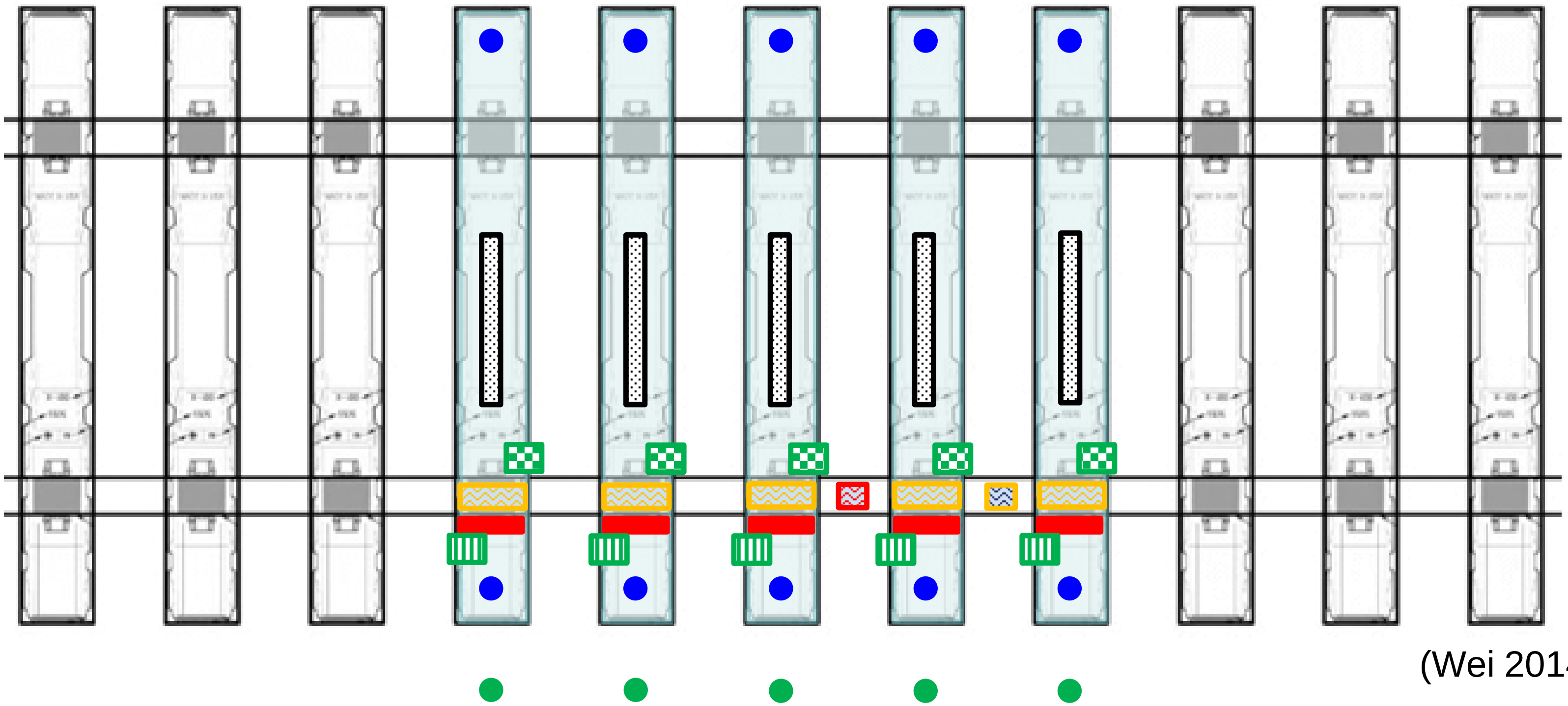
Track Loading System (TLS) Setup





- TLS allows for testing of track infrastructure similar to field conditions.
- L_{input} is obtained from strain gauges attached to the rail
- $L_{reaction}$ is obtained from LLED devices installed in the shoulder of crossties being tested.

TLS Instrumentation Map

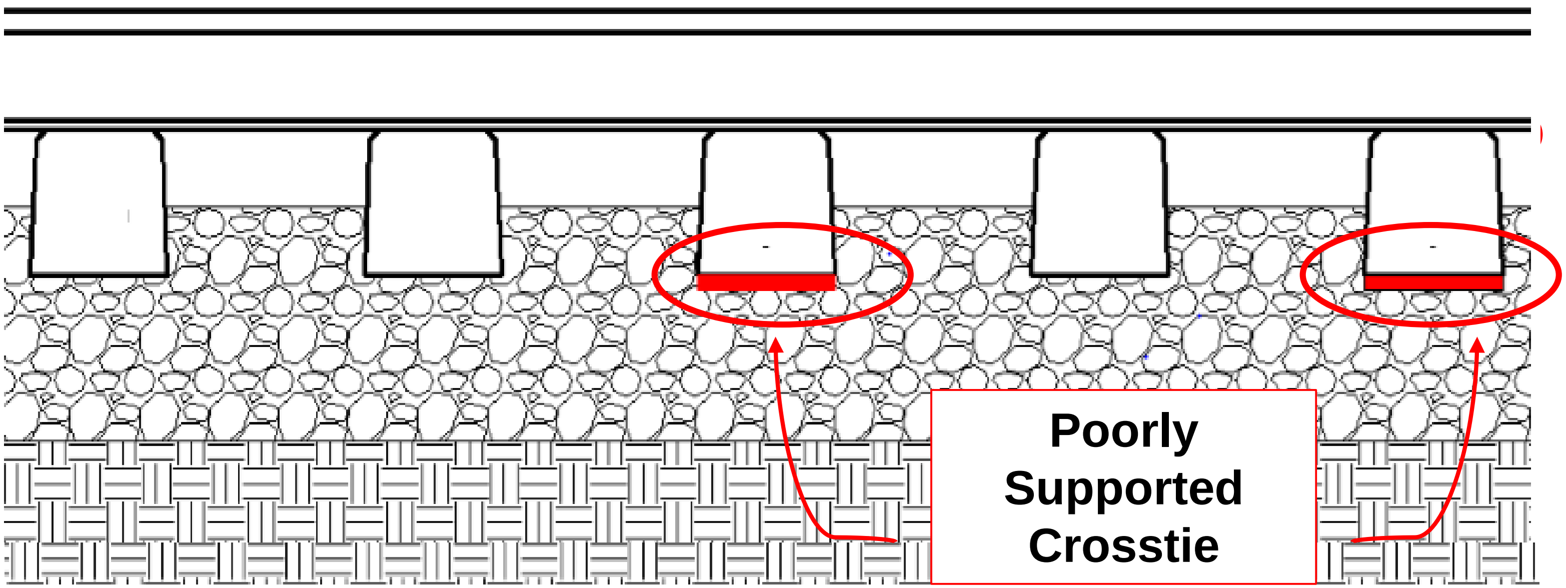


(Wei 2014)

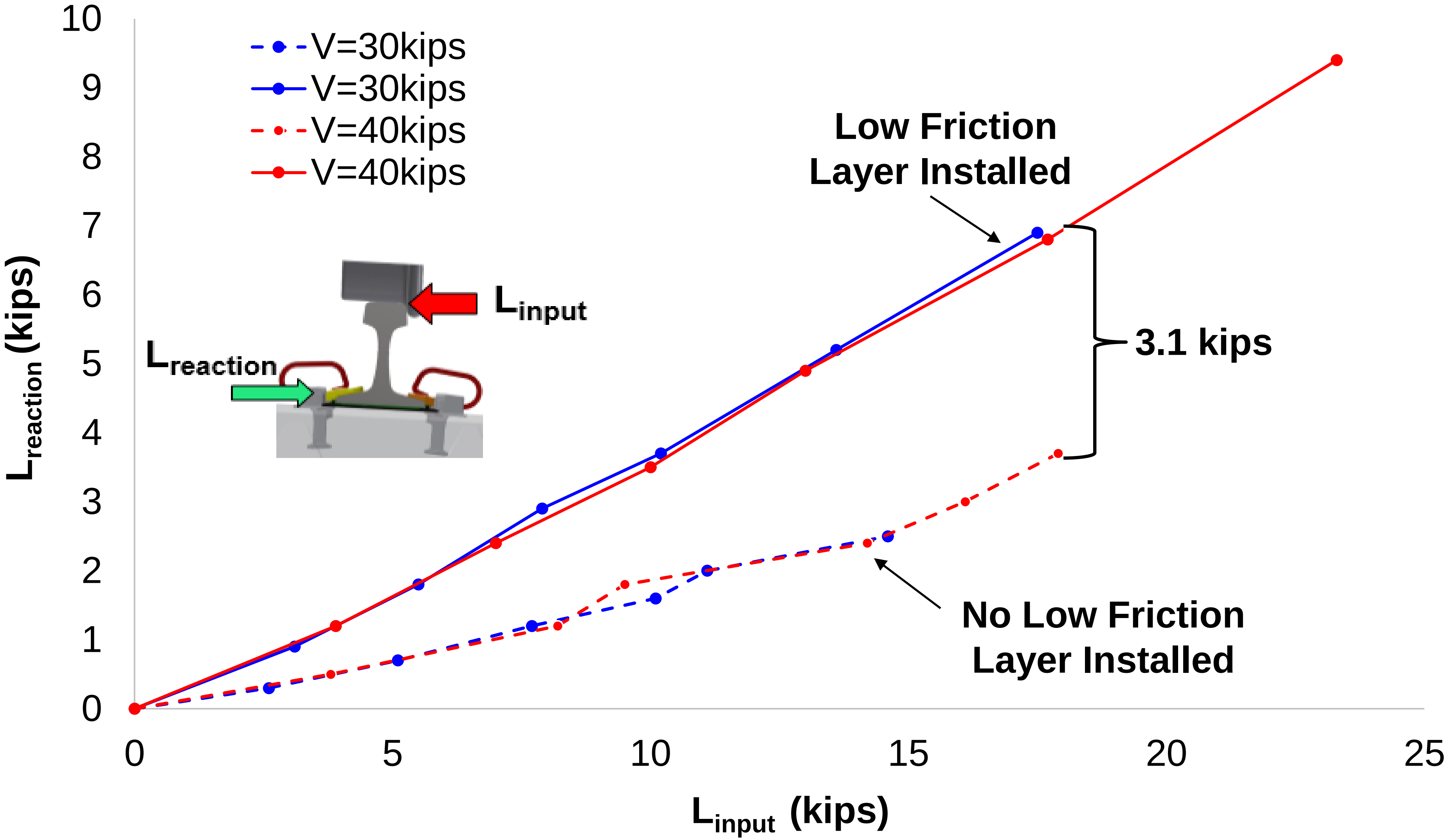
- Lateral Load Evaluation Device (LLED)
- Lateral and Rail Seat Load Circuits
- Vertical Load Circuit
- Lateral Load Circuit
- Rail Displacement (Base Vert. Gauge, Base Lat., Web Lat.)
- Rail Displacement (Base Vert. Field)
- Embedment Gauges
- Crosstie Surface Strains
- Lateral Crosstie Displacement
- Vertical Crosstie Displacement

TLS Track Installation

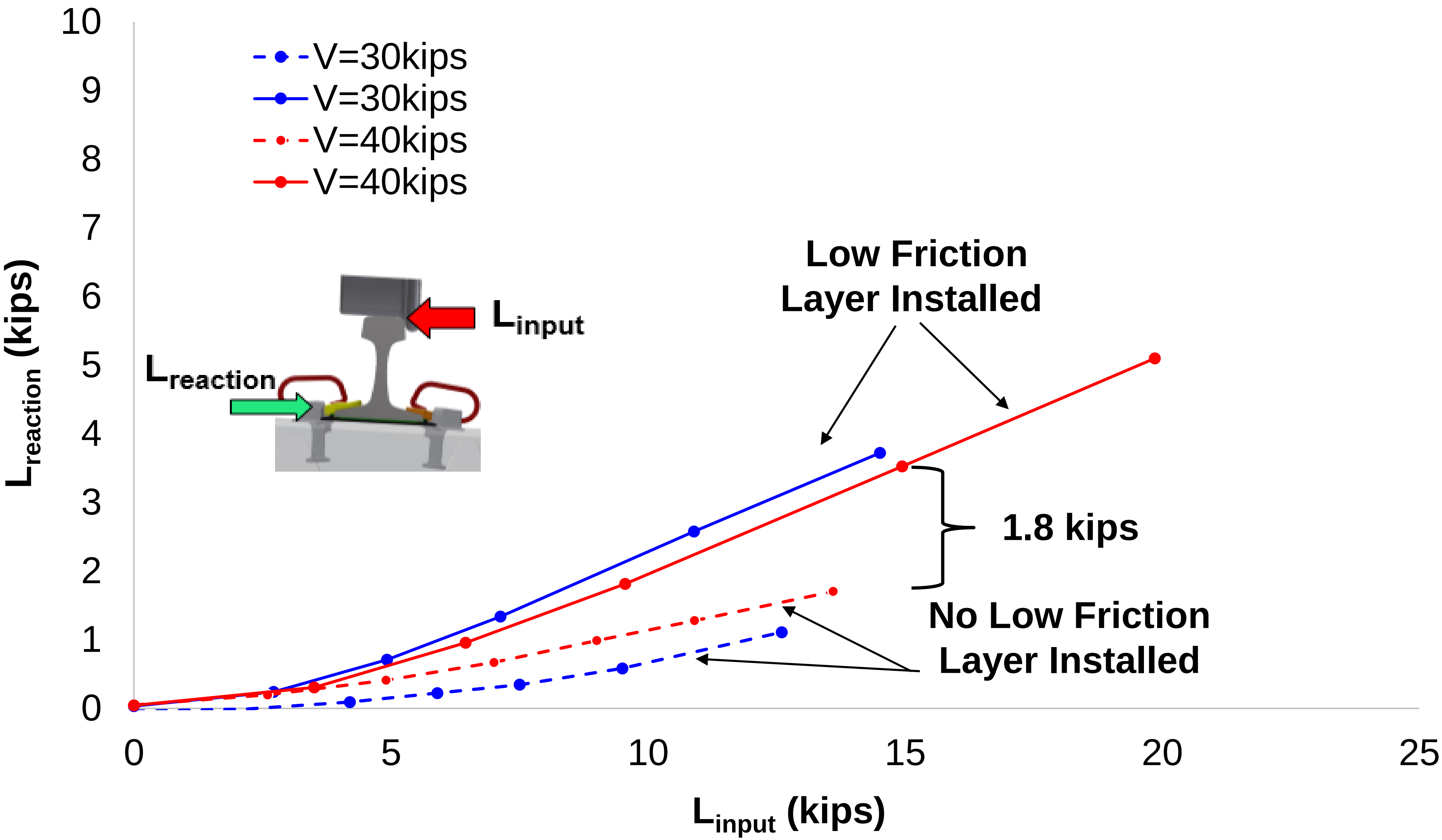
After Clip Installation



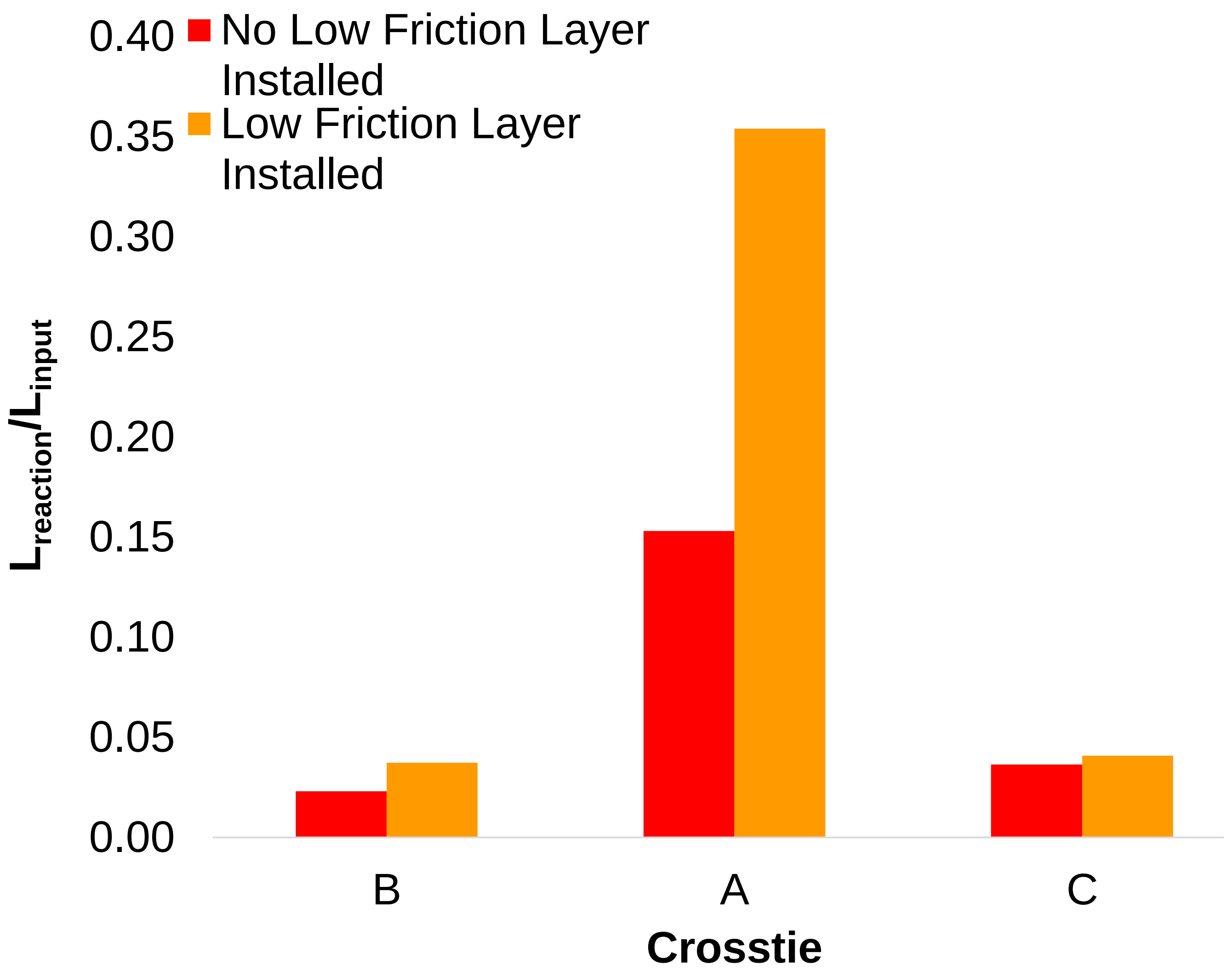
Contribution of Friction in Properly Supported Crosstie

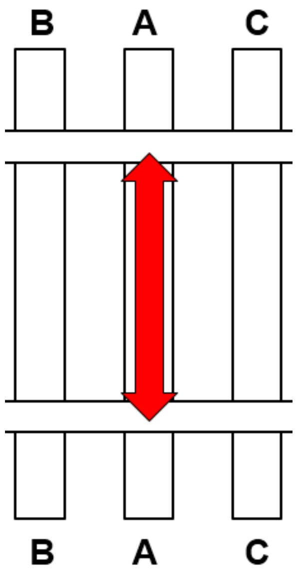


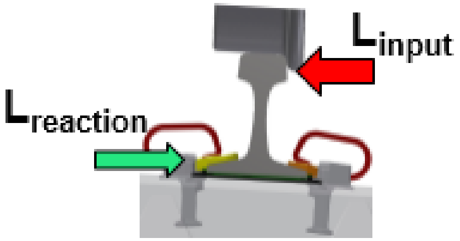
Contribution of Friction in Poorly Supported Crosstie



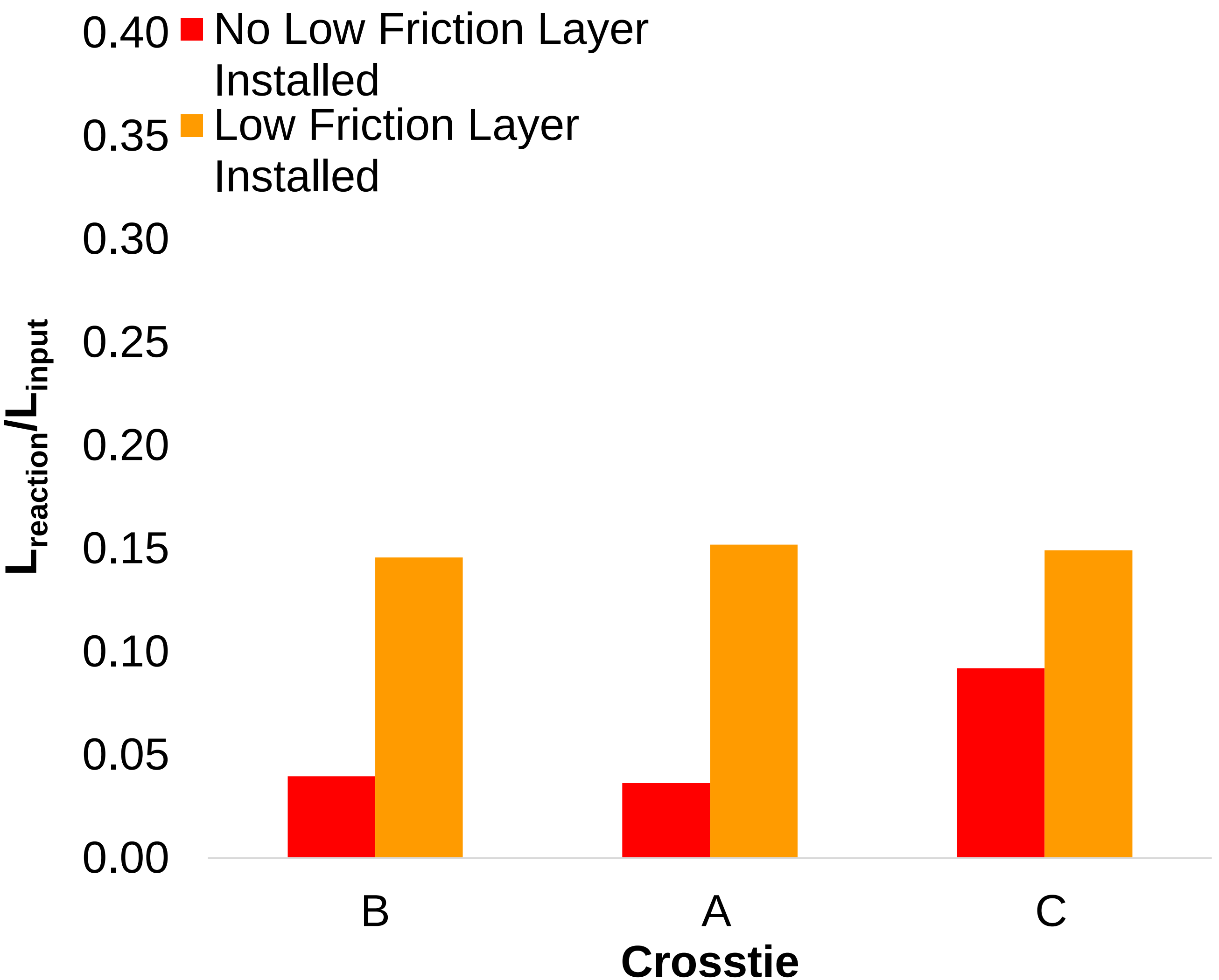
Global Distribution of Lateral Forces in Properly Supported Crosstie

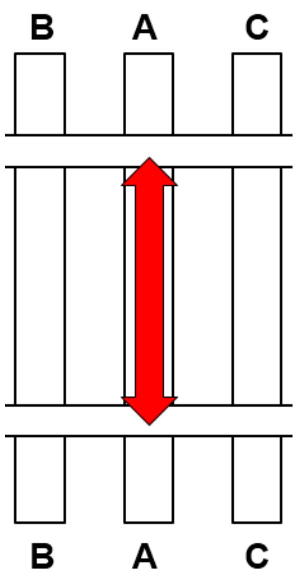


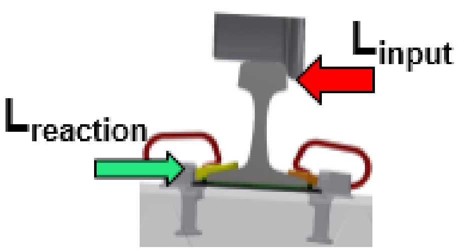




Global Distribution of Lateral Forces in Poorly Supported Crosstie







Conclusions

- Data shows that current friction model is too simple:
  - Frictional force does not decrease as much as model predicts as vertical load decreases
  - Under half the vertical load, bearing forces only increase by approximately 10%
  - Further investigation will look into this in more detail
- Altering the lateral friction between rail pad and rail seat affects the magnitude of lateral bearing force at the shoulder
- Support conditions alter the global lateral force distribution
  - Lateral wheel loads are primarily distributed to the crosstie directly beneath the axle applying the force in properly supported crosstie
  - Lateral wheel loads are globally distributed to more crossties in poorly supported crosstie

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