Experimental Field Investigation of the Transfer of Lateral Wheel Loads on Concrete Crosstie Track

AREMA Annual Conference

Chicago, IL

30 September 2014

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Presentation Outline

- FRA project overview
- Motivation for research
- Experimentation overview
- Measurement technology
- Effects of varying vertical loads
- Dynamic effect on lateral loads
- Conclusions and future work

FRA Tie and Fastening System BAA Objectives and Deliverables

- **Program Objectives**
  - Conduct comprehensive state-of-the-art design and performance assessment via international literature review
  - Execute laboratory and field experimentation to better define demands at critical interfaces as well as validate a finite element (FE) model
  - Update current design recommended practices where applicable

U.S. Department of Transportation
Federal Railroad Administration

FRA Tie and Fastener BAA Industry Partners:

UNION PACIFIC BUILDING AMERICA®
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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

Overall FRA Project Update

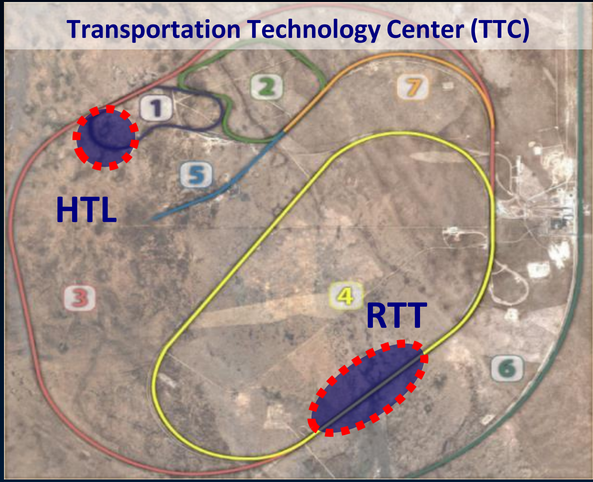
- Currently wrapping up all reports
- Greatest accomplishments
  - Improved understanding into the lateral load path through the development of a novel lateral load measurement device
  - Improved understanding into the critical design parameters through the development of a validated multi-crosstie and fastening system 3D FE model
  - Improved understanding of the pressure distribution at the rail seat, as well as other information through successful field and laboratory experimentation
  - Development of a full-scale laboratory track loading system
- For more information, please visit:
  - *ict.uiuc.edu/railroad/CEE/crossties/downloads.php*

Motivation for Research

- The lateral load path was not well defined
- Lateral loads can contribute to premature fastening system component failure
- Data acquired will provide railroads and suppliers information for future fastening system designs
  - i.e. mechanistic design approach of fastening system components
- ~60% of North American concrete crossties in service today use Safelok I type fastening system

Field Experimental Program

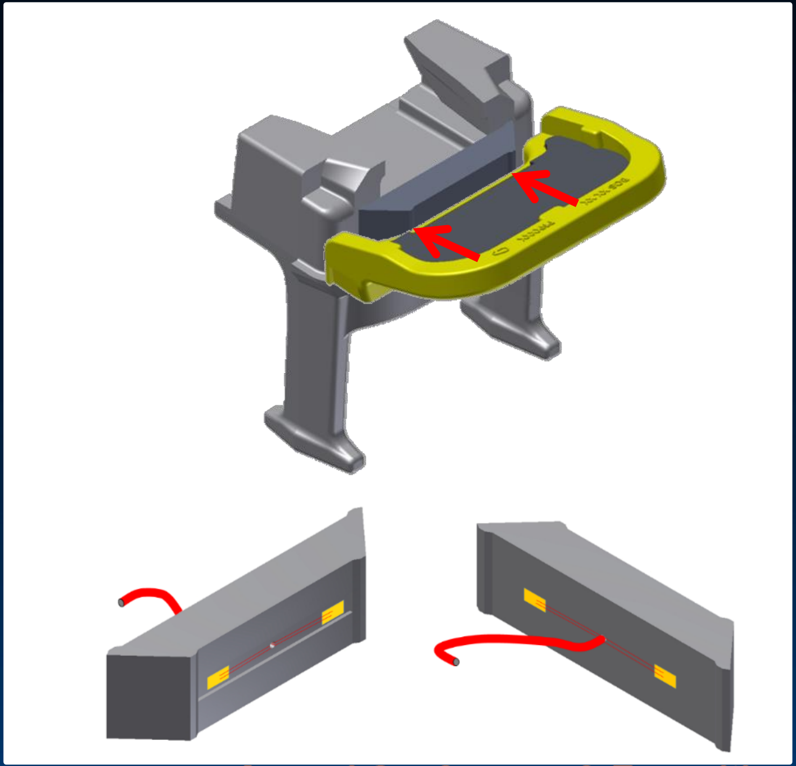
- **Objective:** Analyze the distribution of forces through the fastening system and impact on components relative displacements
- **Location:** Transportation Technology Center (TTC) in Pueblo, CO
  - **Railroad Test Track (RTT):** tangent section
  - **Heavy Tonnage Loop (HTL):** curved section
- **Instrumentation:**
  - 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



Measurement Technology

Lateral Load Evaluation Device (LLED)

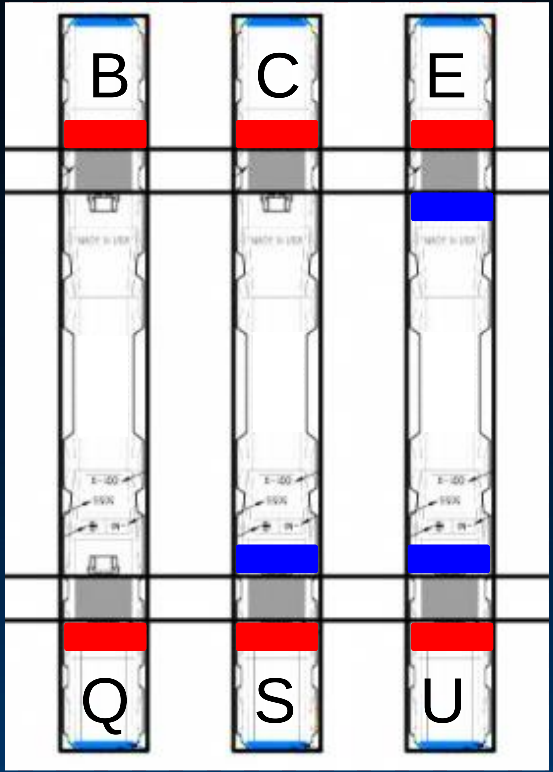
- Replaces original face of cast shoulder
- Maintains original fastening system geometry
- Designed as a beam in four-point bending
- Bending strain is resolved into force through calibration curves generated in the lab



Instrumentation Layout

High Rail (HTL)

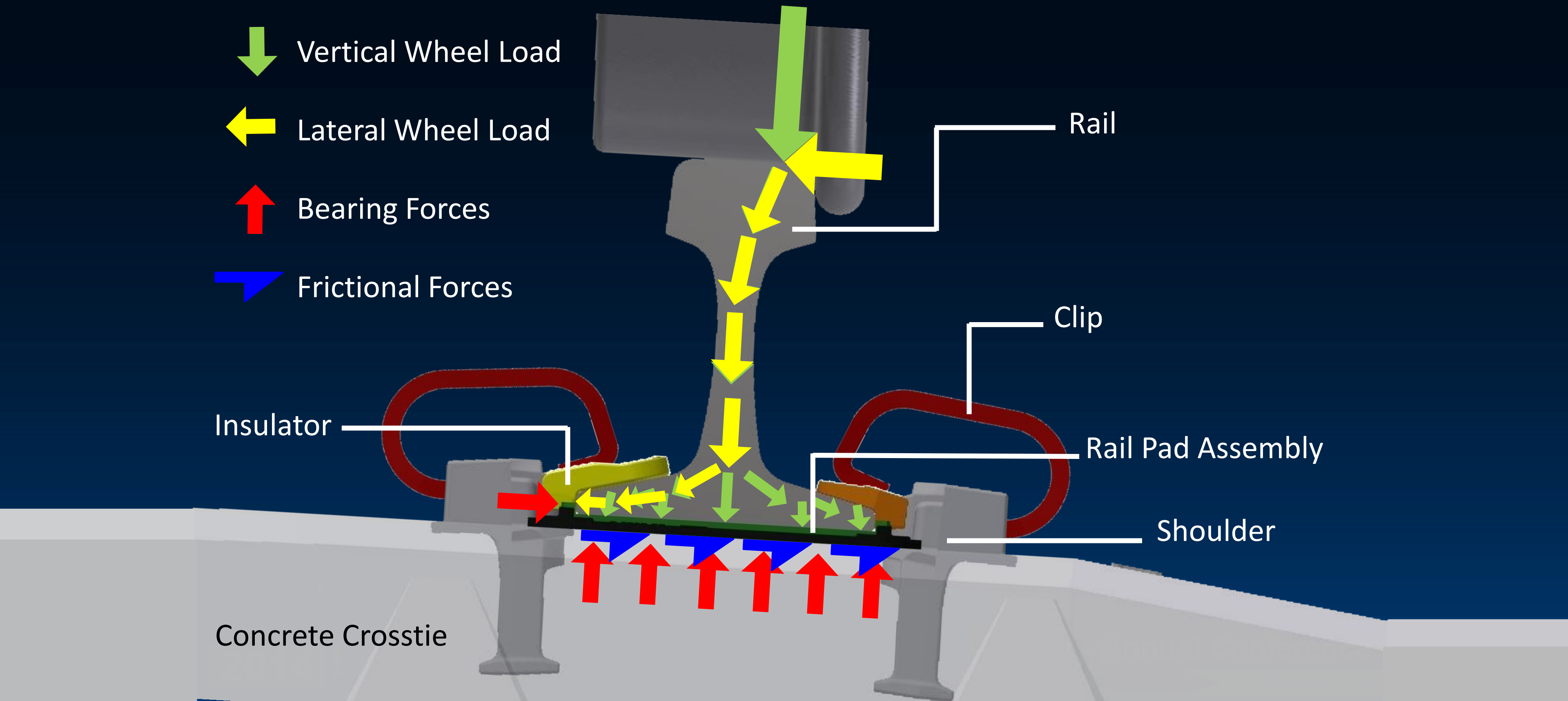
Low Rail (HTL)



LLED

Lateral Rail Base Potentiometer

Defining the Lateral Load Path



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 $\Sigma L_L = \Sigma L_B + \Sigma(\mu N)_{rail\ seat}$

where,

μ = Coefficient of Friction between rail pad and rail seat

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

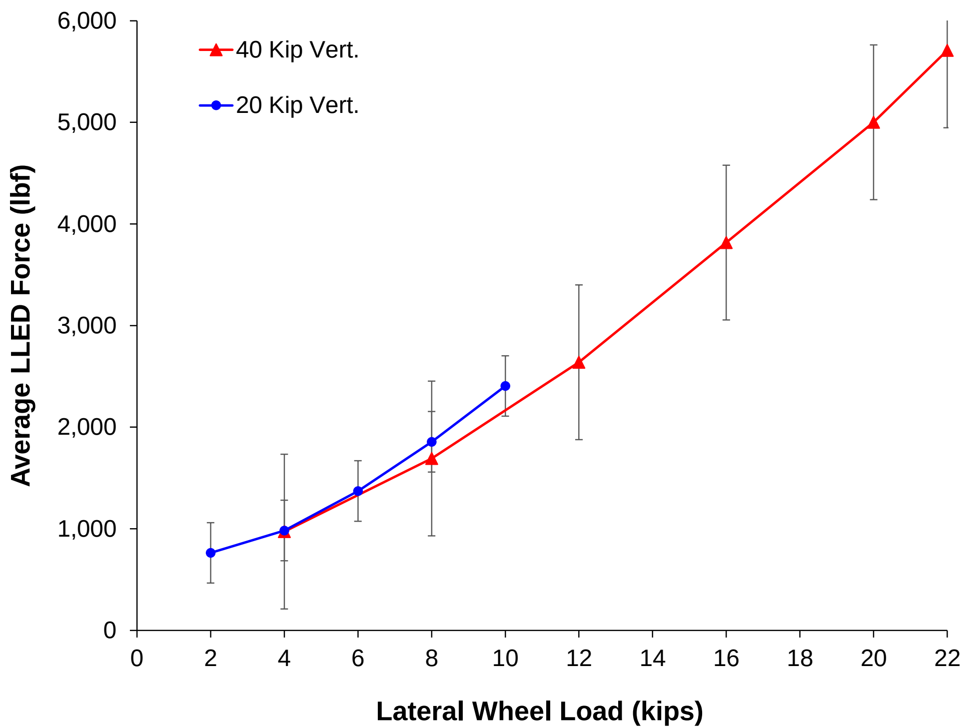
If N decreases by 50%, then load distribution changes to:

75% bearing, 25% friction

Effect of Varying Vertical Load

Average for Single Rail Seat*

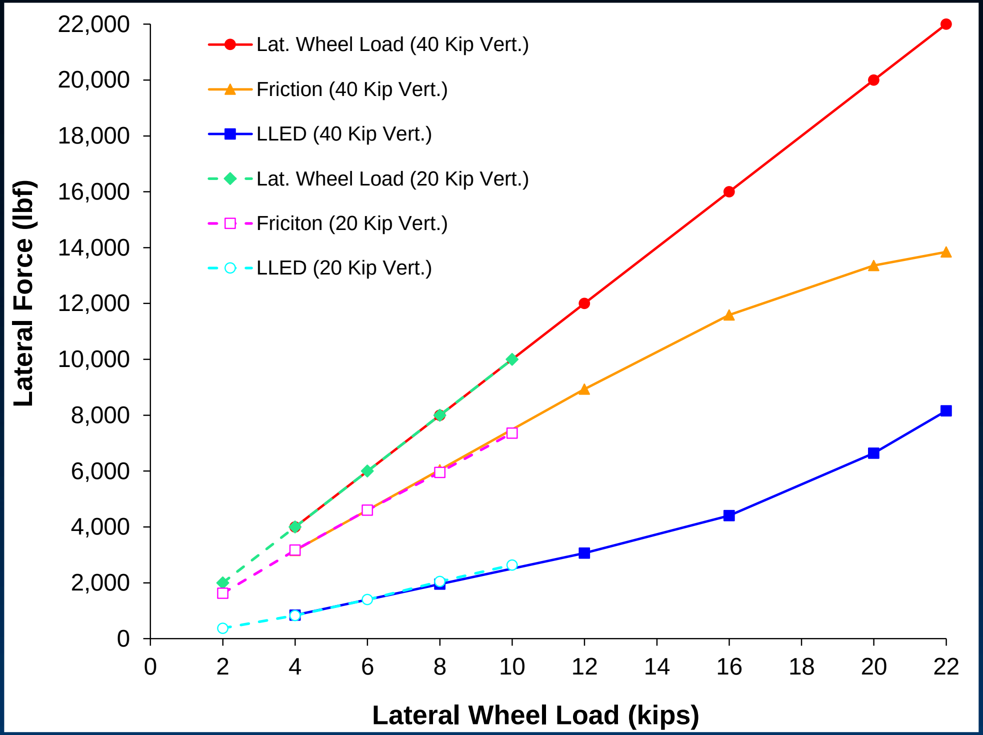
- Difference between lines:
  - increases as lateral wheel load increases
  - likely due to the lower normal force (vertical wheel load) applied to the rail seat
- Trend does not agree with theoretical equations



*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

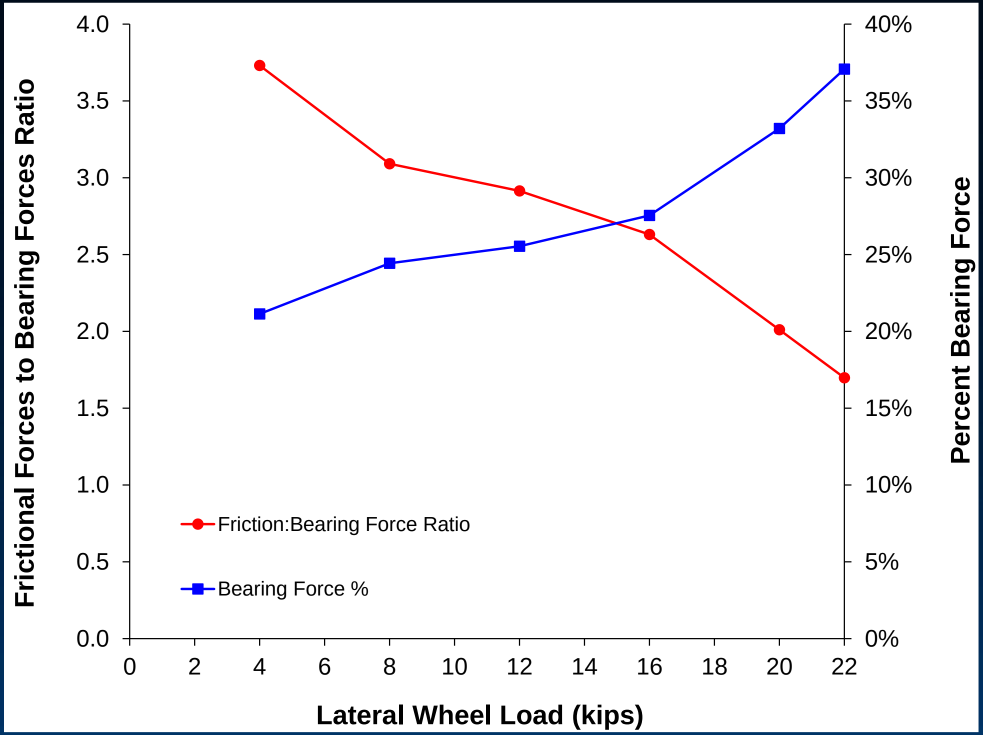


Sum of three adjacent rail seats (B, C, E)

Effect of Varying Lateral Load

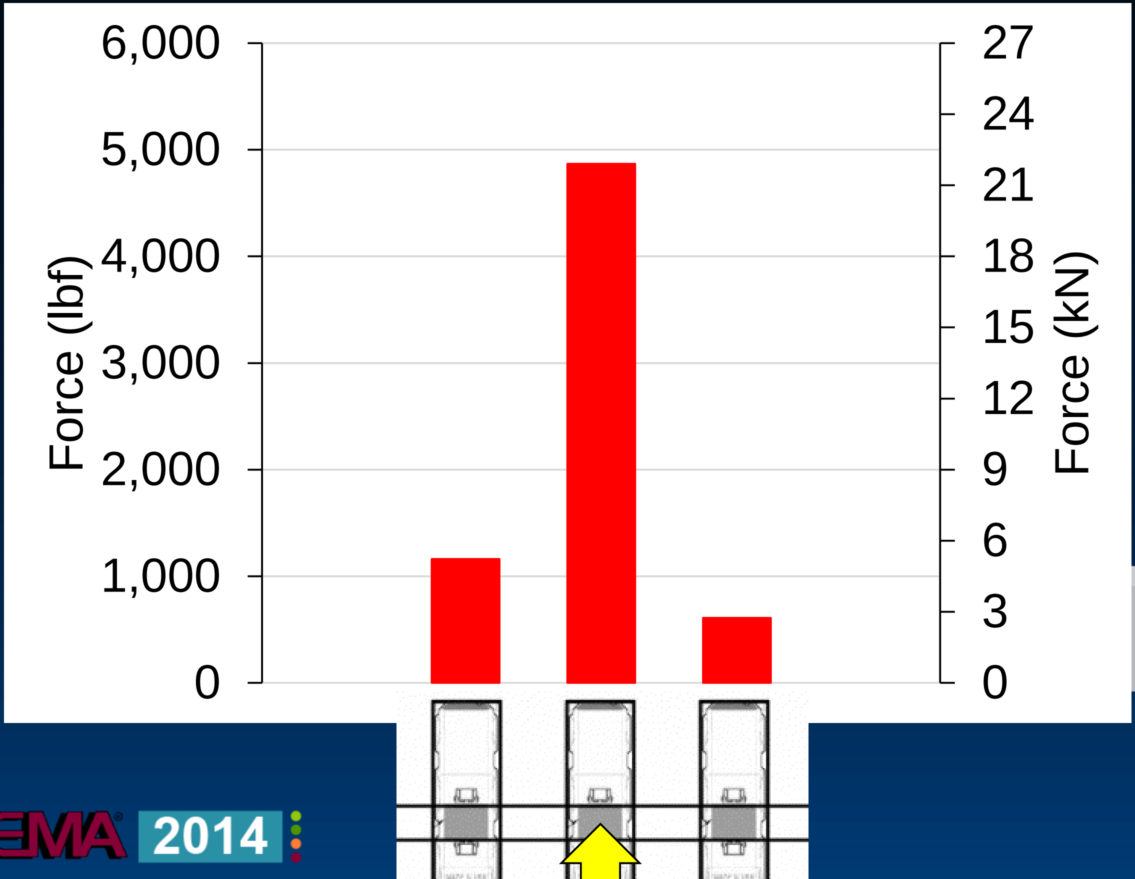
Total Lateral Forces in Track*

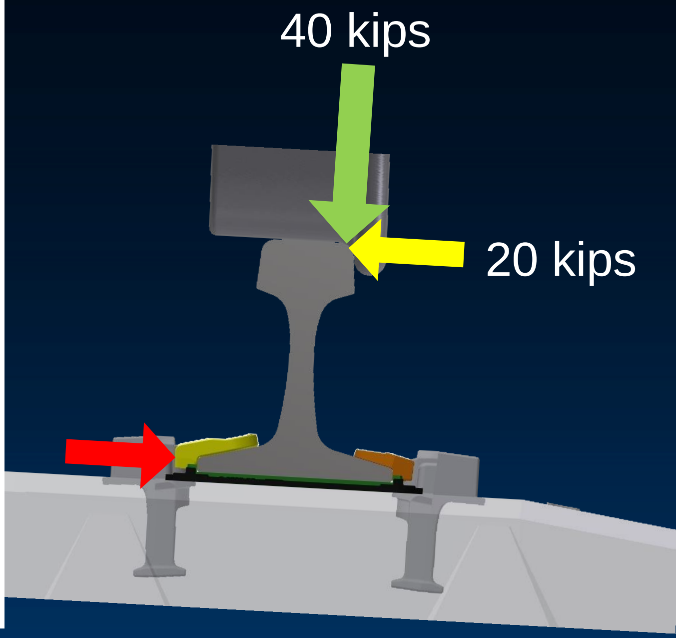
- As lateral wheel load increases
  - ratio of frictional force to bearing force decreases from 3.7 to 1.7, or 54%
  - percent bearing force increases from 21% to 37%



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

Longitudinal Distribution of Lateral Loads

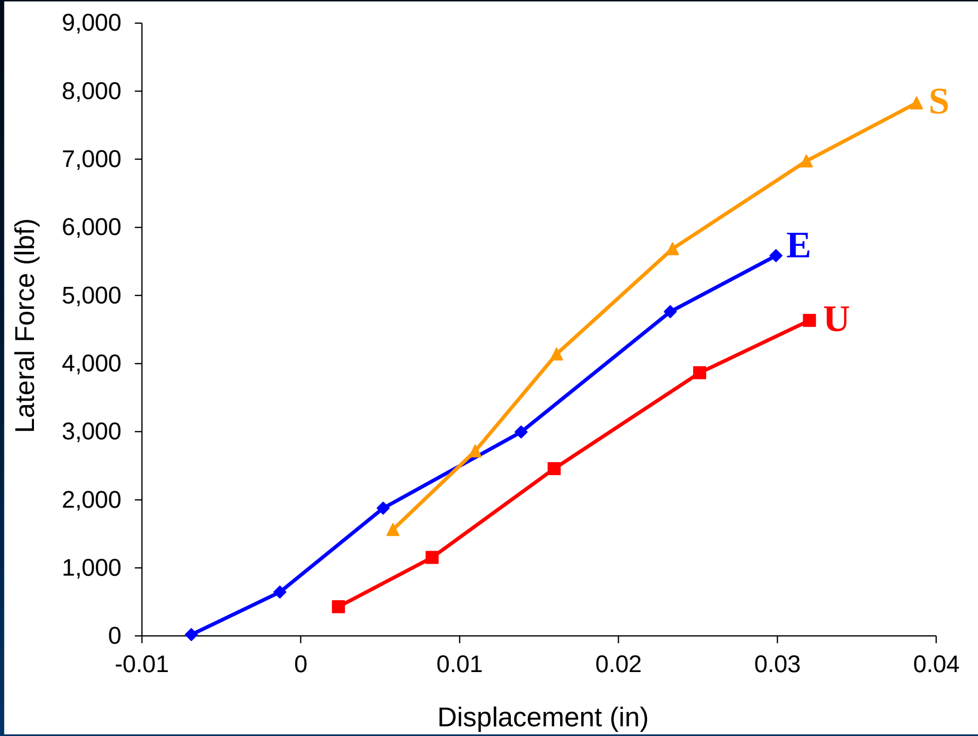




Effect of Lateral Stiffness

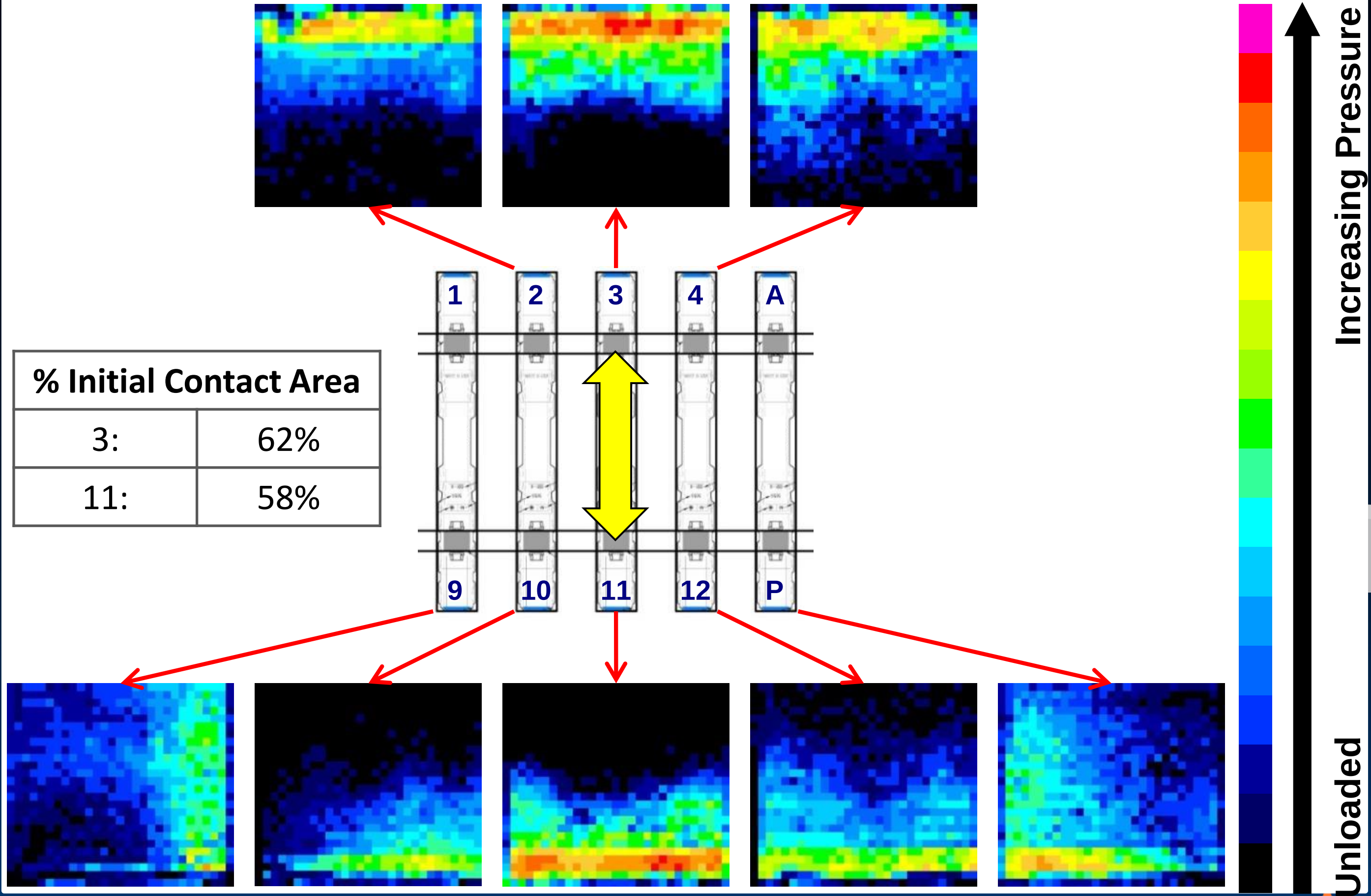
- A higher lateral stiffness leads to more lateral bearing load carried by that particular rail seat

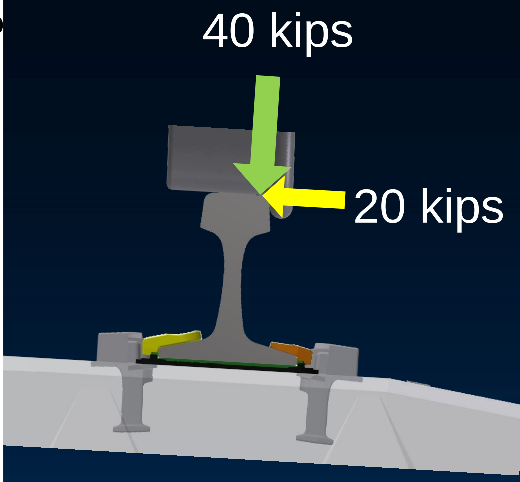
Rail Seat	Lateral Stiffness (lbf/in)	Max. Force (lbf)
S	192,498	7,828
E	155,369	5,582
U	146,322	4,632



Effect of Lateral Load: Rail Seat Pressure Distribution

% Initial Contact Area	
3:	62%
11:	58%



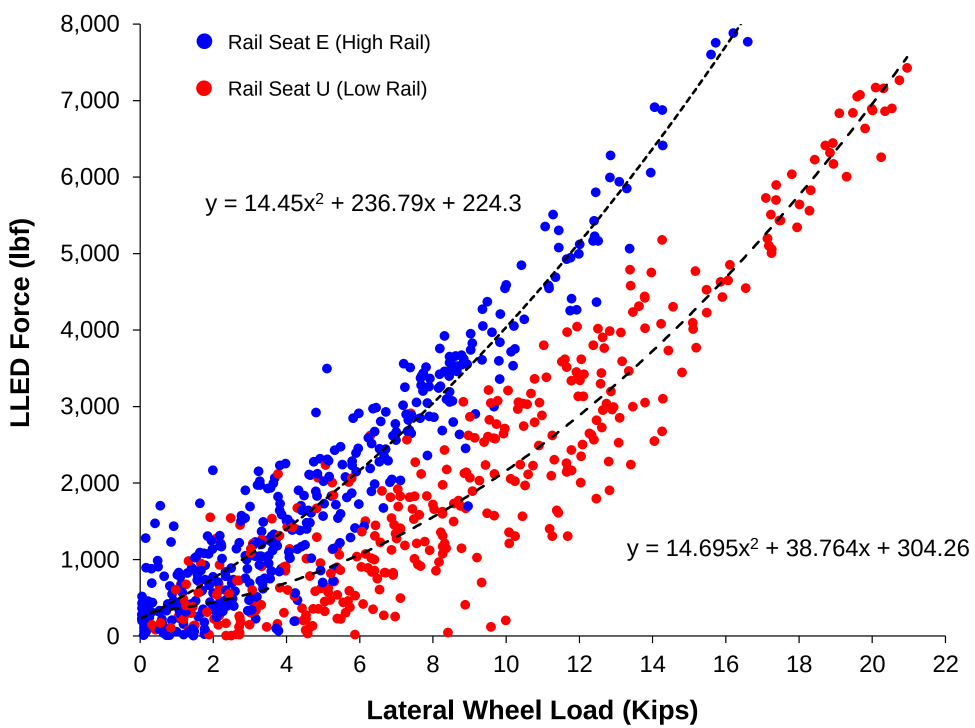


Dynamic Load Input: Moving Trains

- Freight train
  - Three six-axle locomotives
  - Ten freight cars with 263k, 286k, and 315k cars
  - Speeds run at 2 mph,15 mph, 30 mph, 40 mph, and 45 mph
- Passenger train
  - One six-axle locomotive
  - Nine passenger cars
  - Speeds run at 2 mph,15 mph, 30 mph, and 40 mph
- Tested on HTL (curved section)

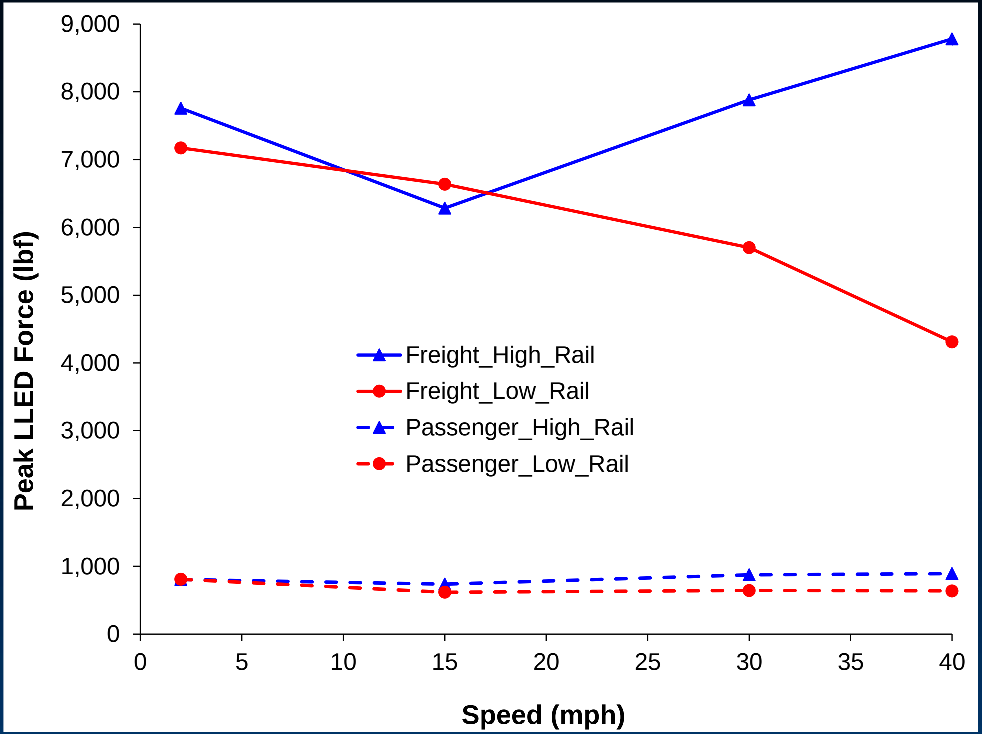
Dynamic Transfer of Lateral Loads:
Wheel to Fastening System

- Peak LLED and lateral wheel loads from each passing freight wheel
- Dynamic loads are applied at much higher rates than static
  - Higher bearing forces may be caused by lowered COFs due to dynamic friction



Dynamic Transfer of Lateral Loads:
Wheel to Fastening System

- Peak LLED forces as a function of speed
- As hypothesized, high rail forces increase and low rail forces decrease as speed increases
- Passenger trains yielded forces an order of magnitude lower than freight trains



Conclusions: Static Observations

- Theoretically, decreasing vertical load should decrease frictional forces and increase bearing forces
- However, the data do not support this theoretical assumption
- Under half the vertical load, the bearing forces only increase by approximately 10%
- Future work will focus on improving upon the current lateral load model
- Rail seat pressure distribution becomes highly non-uniform as lateral load increases

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Conclusions: Dynamic Observations

- A higher percentage of lateral wheel loads is transferred to the fastening system under dynamic loading than static loading
- Lateral fastening system stiffness can affect the lateral load transfer characteristics
- The percentage of lateral wheel load transferred to the shoulder increases as lateral wheel load increases
- Freight cars imparted 10x greater forces on the shoulder than passenger cars

Future Work

- Lateral load measurement on high-traffic, high-tonnage Class I track
  - What are magnitudes under true demanding field conditions?
  - What are the effects of varying track geometry?
- Full-scale laboratory testing at UIUC
  - What are the effects of varying fastening system frictional characteristics?
  - How does lateral track stability affect lateral fastening system forces?
- Component-level laboratory testing
  - What are the thresholds of plastic damage for components in the lateral load path?
  - How do alternative material properties affect load transfer and distribution of forces within the fastening system?

Acknowledgements

- **Funding for this research has been provided by:**
  - **Association of American Railroads (AAR)**
  - **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
- For assistance with research and lab work
  - Andrew Scheppe, UIUC Machine Shop, Harold Harrsion

FRA Tie and Fastener Industry Partners:

Thank You

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