Clamping Force & Concrete Crosstie Bending Behavior Analysis

FRA Tie and Fastener BAA - Industry Partners Meeting

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Federal Railroad Administration

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Outline

- **Project Objectives**
- **Clamping Force Analysis**
  - Introduction
  - UIUC clip instrumentation
  - Clamping force calculation methodology
  - Change of clamping force due to wheel load
  - Clip strain diagram
  - Conclusions
- **Concrete Crosstie Bending Behavior Analysis**
  - Introduction
  - UIUC concrete crosstie instrumentation
  - Bending moment at rail seats and center
  - Conclusions

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

Objectives of Clamping Force Analysis Experimentation

- Define the components of the clamping force vector
- Determine the range that the components of clamping force may vary under the following operating conditions:
  - Clip installation
  - Tangent and curvature
  - Low speed and higher speed
  - Round wheels and wheels with irregularities
- Determine how the change in clamping force effects the load path in the system

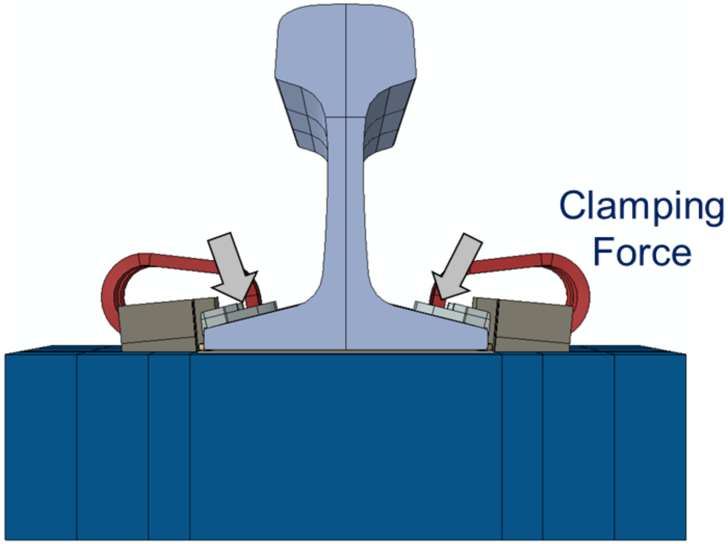
Background

- Clamping force as defined by manufacturer is the force applied by the clips vertically relative the rail seat
- Clamping force and clip behavior is examined in detail using finite element analysis
- Laboratory experimentation was used to validate the boundary conditions within the system model
- Clamping force as defined by the manufacturer is calculated via:

$$R = D \times K$$

where,
R: Clamping force
D: Vertical displacement at clip tip
K: Stiffness of clip toe

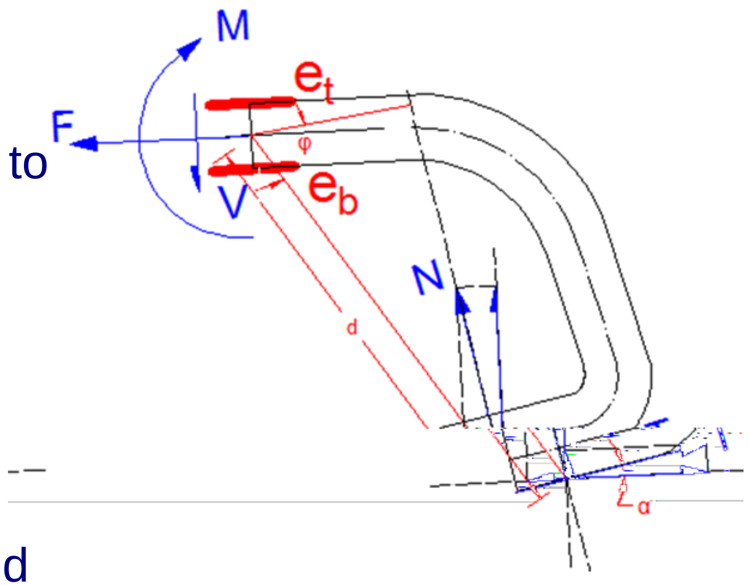
For “Amsted RPS UAB2000”
R = 2,375 lbs (expected)
K = 8,223 lbs/in



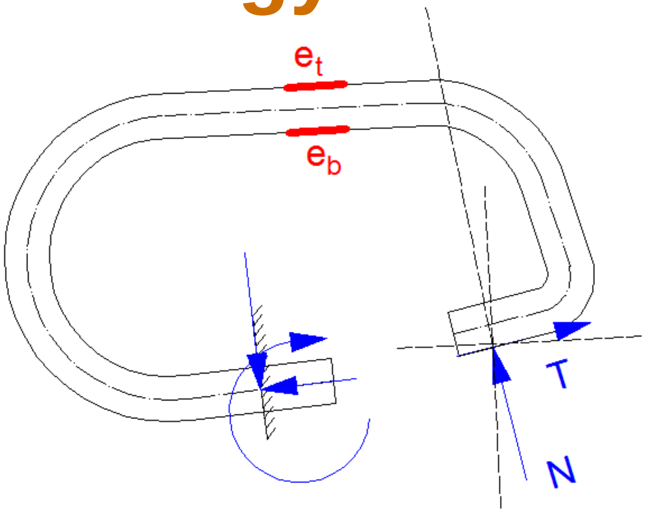
Finite-element model

Clamping Force Components

- Clamping force can be broken into two components
  - Normal force (N)
  - Tangential force (T)
- Normal force is
  - The component of the clamping force normal to the clip toe
  - Affected by the rail base rotation and rail pad assembly compression
- Tangential Force is
  - The component of the clamping force tangential to the clip toe
  - Affected by the rail base lateral translation and frictional interface between the clip and insulator



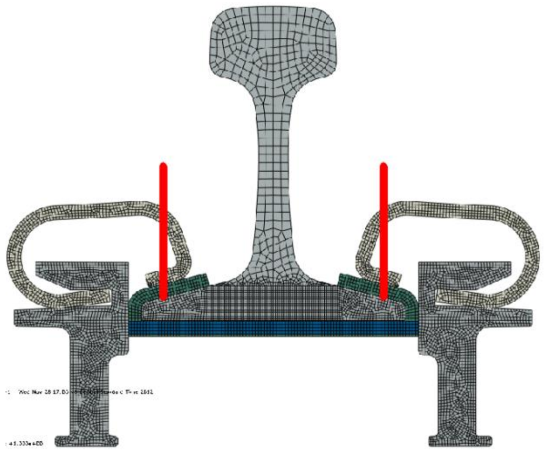
UIUC Clip Instrumentation and Force Calculation Methodology



- Clip strains were measured using strain gauges:
  - Four (4) on each clip
  - One (1) on both flat portions of clip, top and bottom
- Rail base vertical displacement, near the clip toe was measured using a potentiometer
- Change of force for each toe was calculated using the following methodology

$$\Delta N = D_G \cdot (1250 lbs / 0.289 in)$$

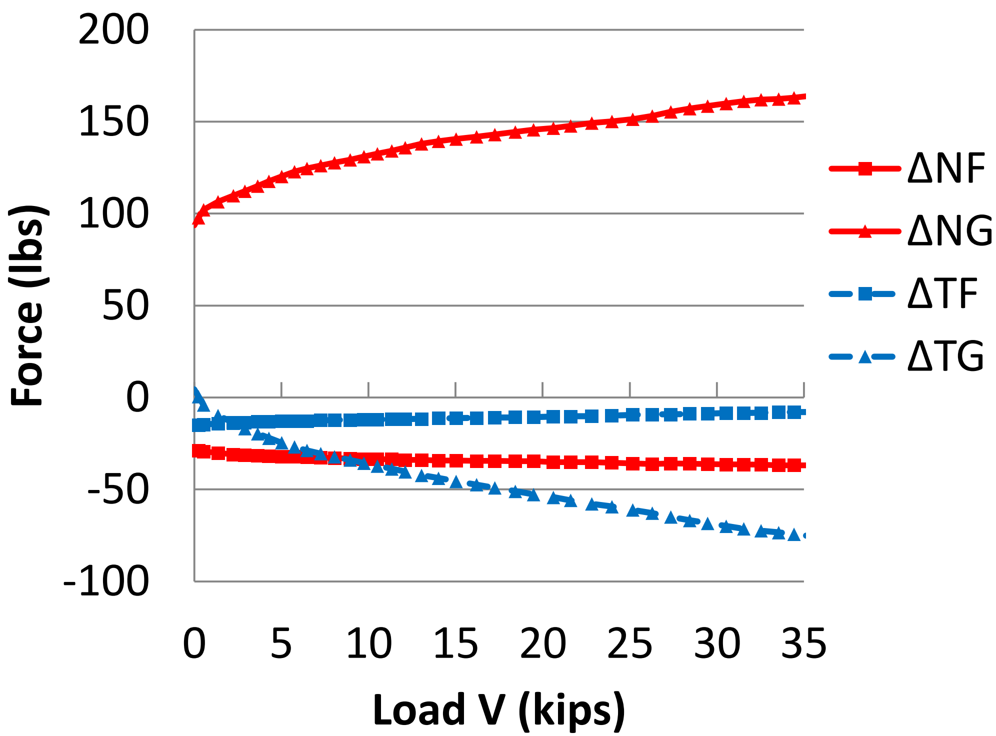
$$\Delta T = \left(\frac{-e_t + e_b}{2} - \frac{\Delta N d (t/2) \cos\varphi}{EI}\right) \cdot \frac{EI}{d(t/2)\sin\varphi}$$

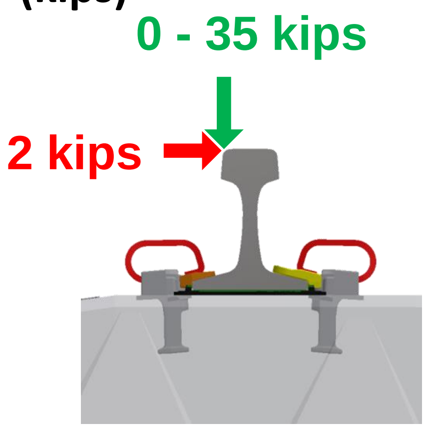


- Where:
  - D_G is the gage side rail base vertical displacement
  - e_t is the strain measured at the top of the clip
  - e_b is the strain measured at the bottom of the clip
  - d is the distance from clip contact to strain gauge

Laboratory Experimentation Results: Change in Normal and Tangential Clamping Force Under Load

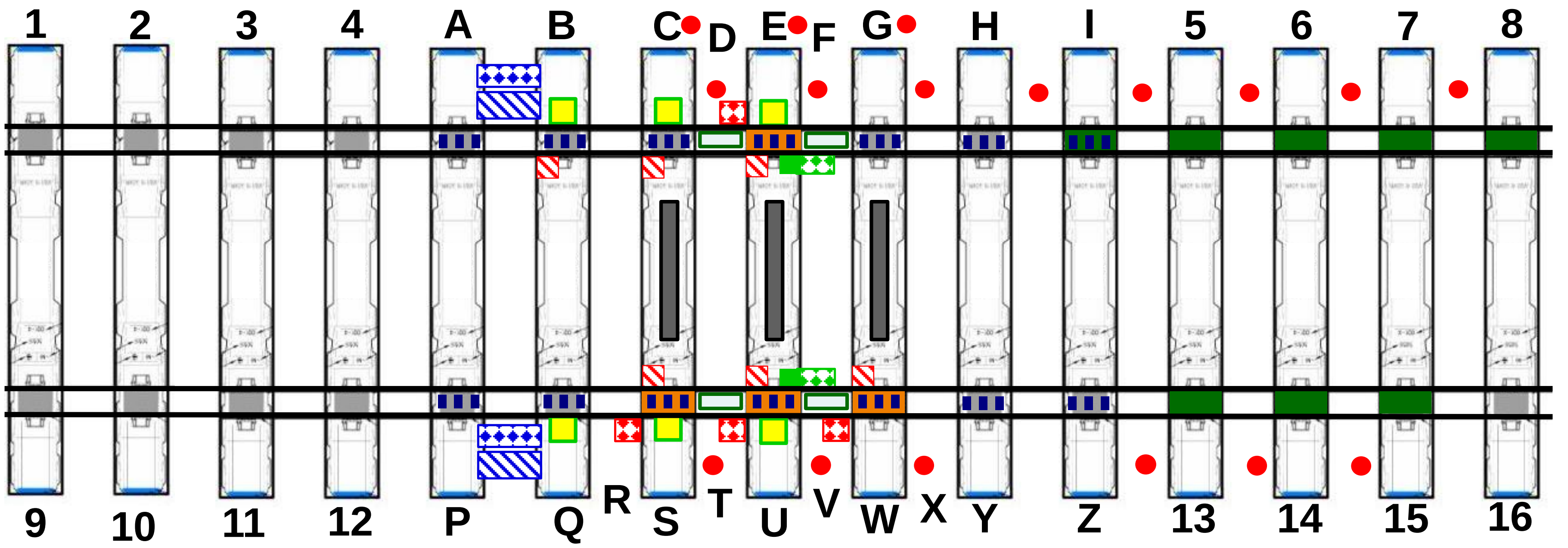
- An experiment was performed to investigate the change in clamping force components under varying load
- The gage-side normal and tangential clamping force components showed greater changes than the field-side components
- Gage-side clamping force components to be investigated in the field experimentation





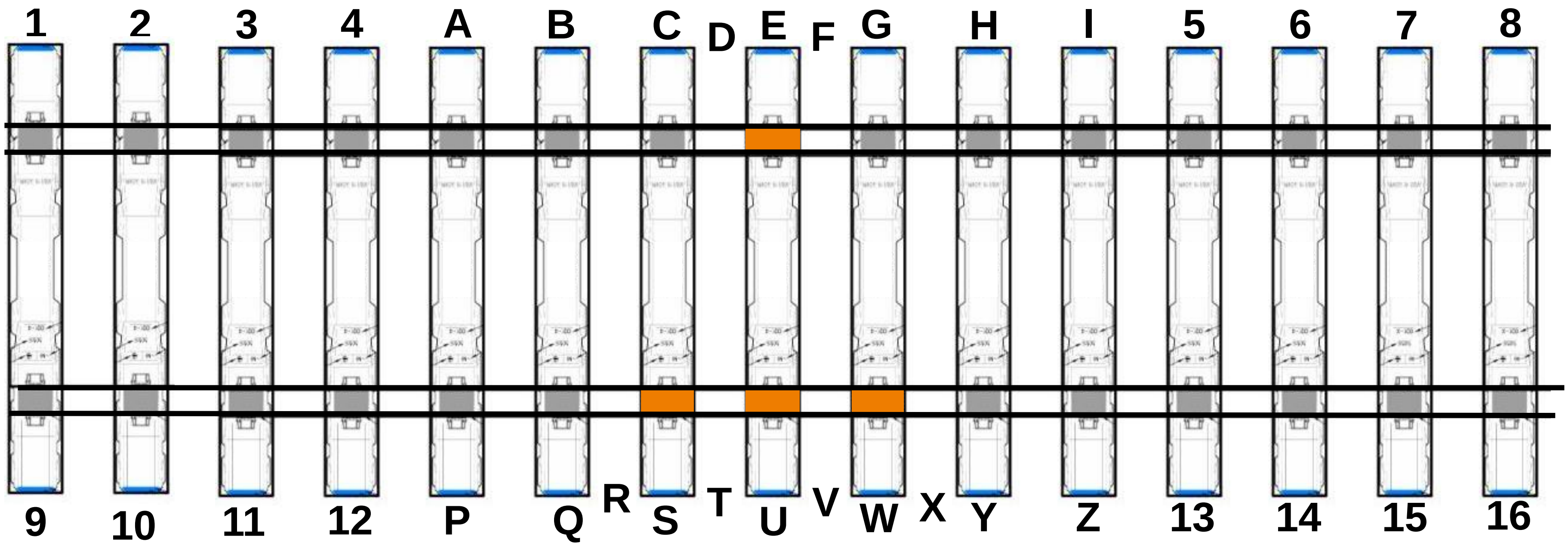
ΔNF/G: Change of normal force at field/gauge side
ΔTF/G: Change of tangential force at field/gauge side

Instrumentation Location (Full Map)

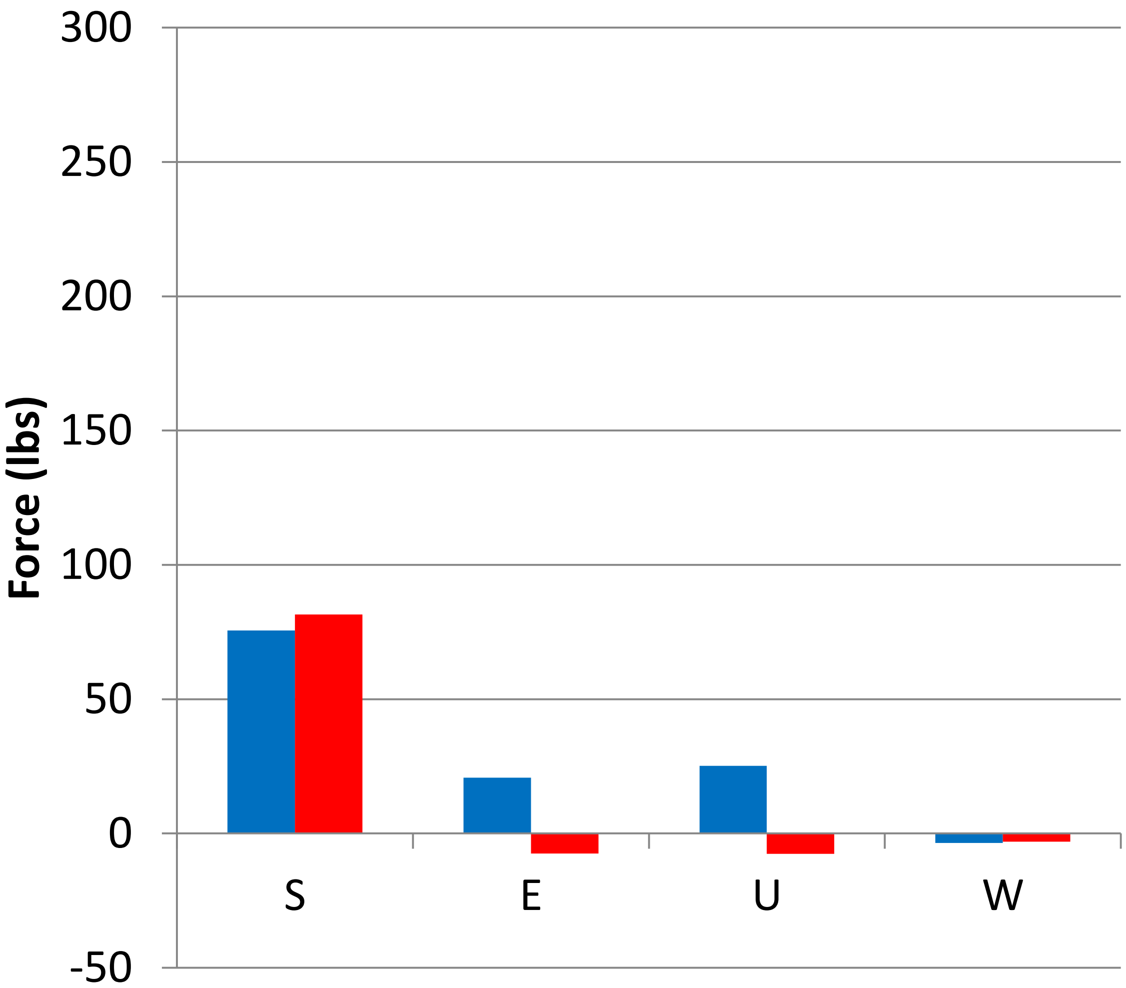


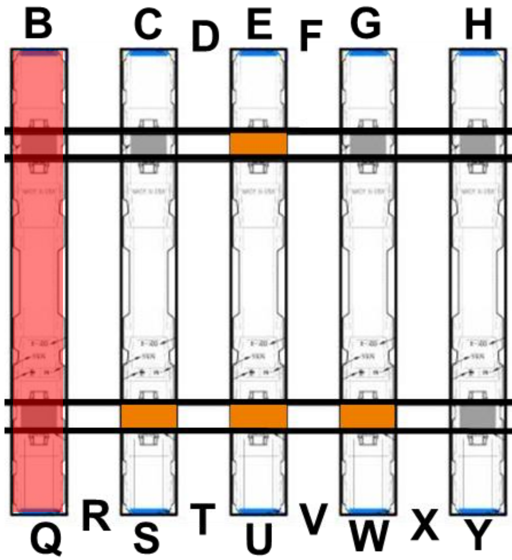
- Rail Displacement Fixture
- Rail Longitudinal Displacement/Strains
- Pad Assembly Longitudinal Displacement
- Pad Assembly Lateral Displacement
- Insulator Longitudinal Displacement
- Insulator Vertical Displacement
- Steel Rods
- Vertical Web Strains
- Vertical and Lateral Circuits
- Shoulder Beam Insert (Lateral Force)
- Embedment Gages, Vertical Circuit, Clip Strains
- Crosstie Surface Strains
- MBTSS

Instrumented Clips

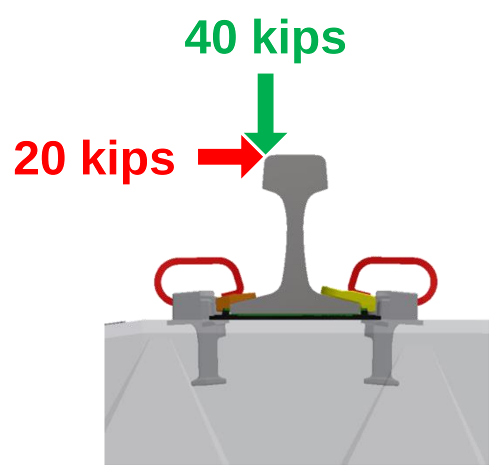


Change in Clamping Force





ΔN: change in normal force
ΔT: change in tang. force



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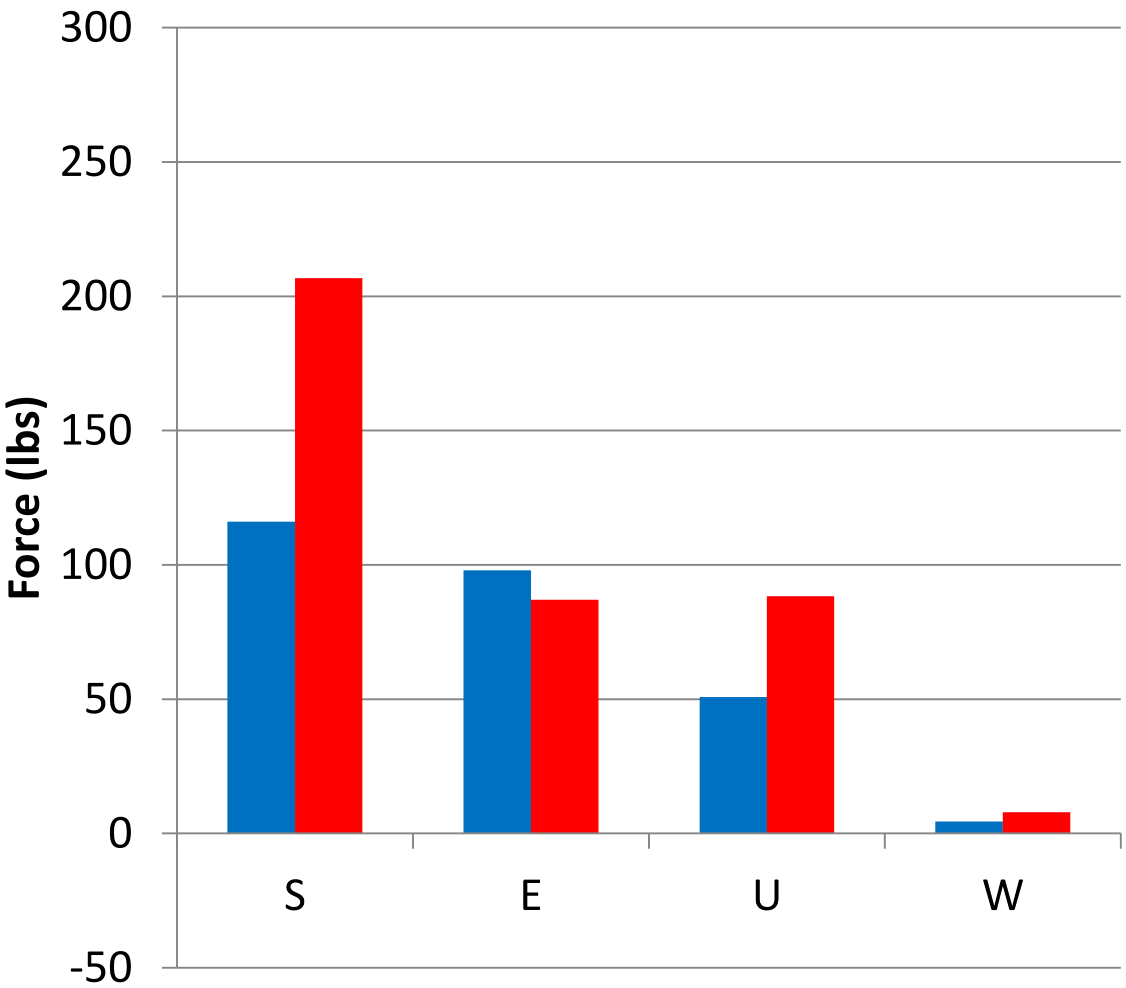

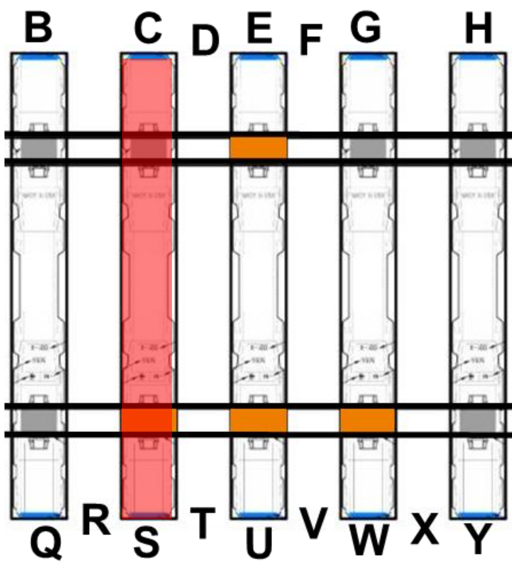

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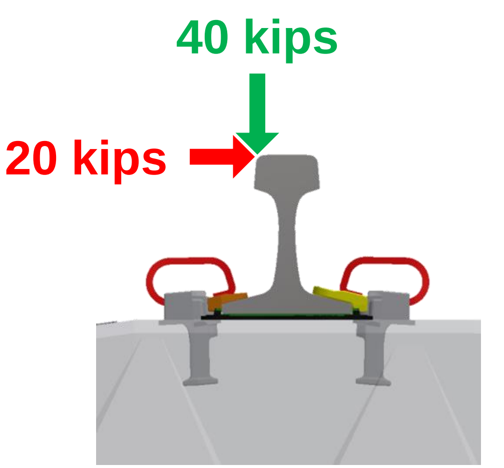
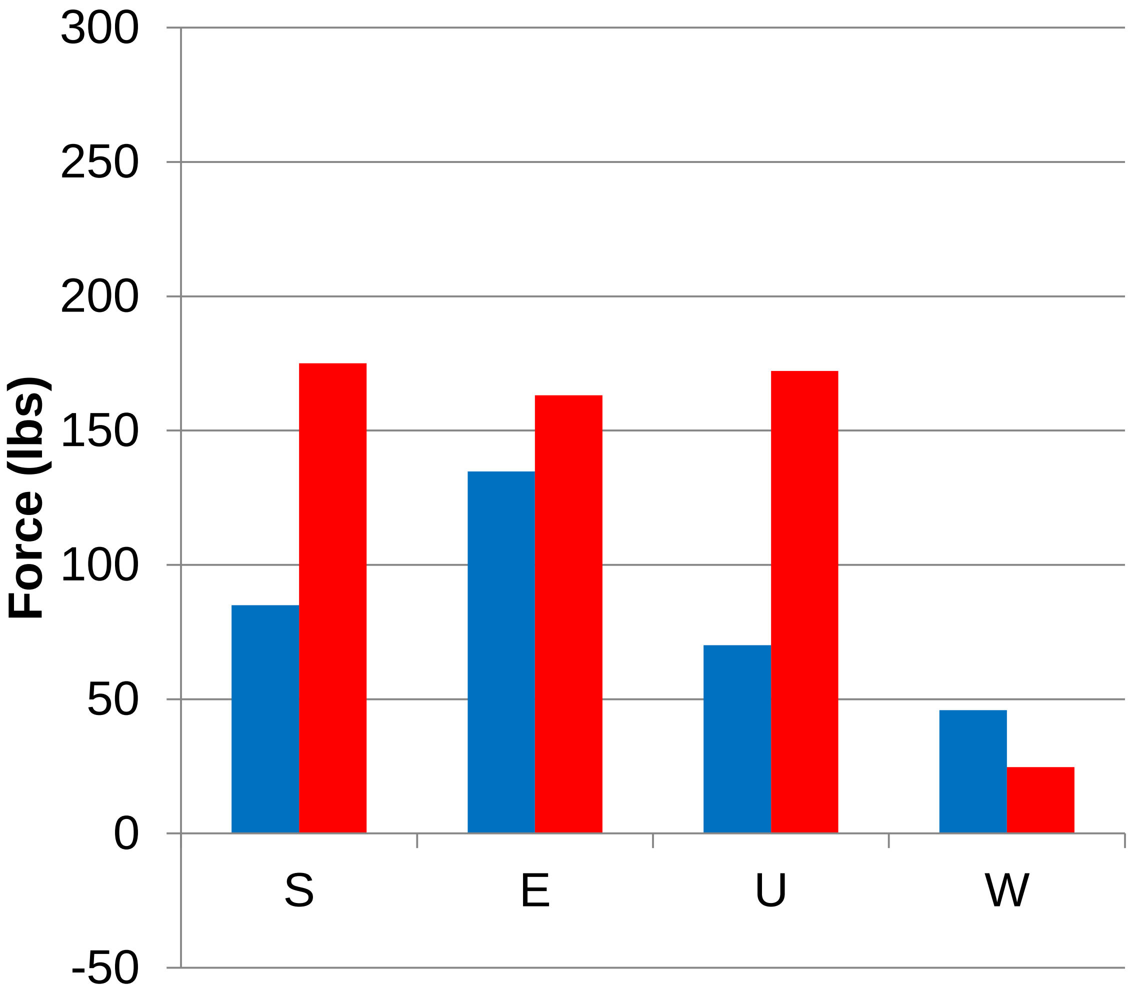
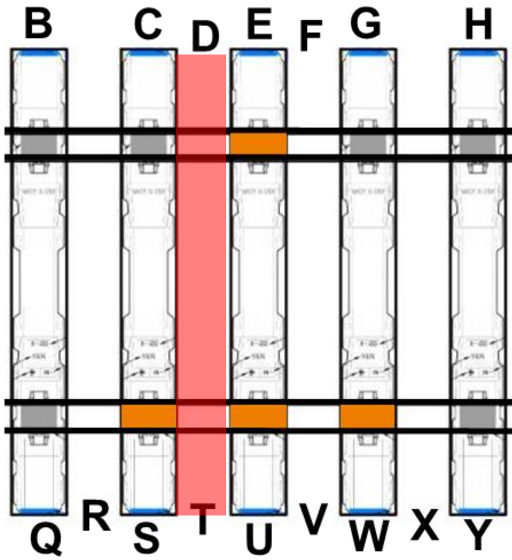


Change in Clamping Force





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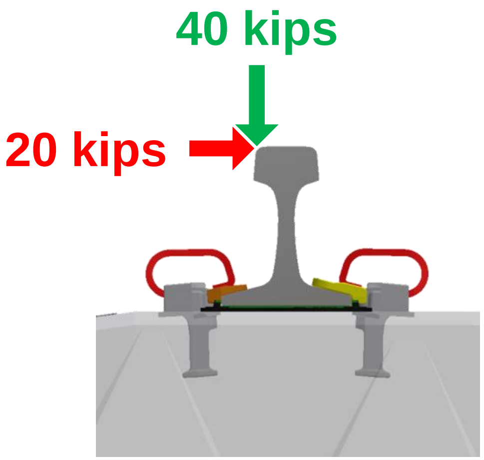

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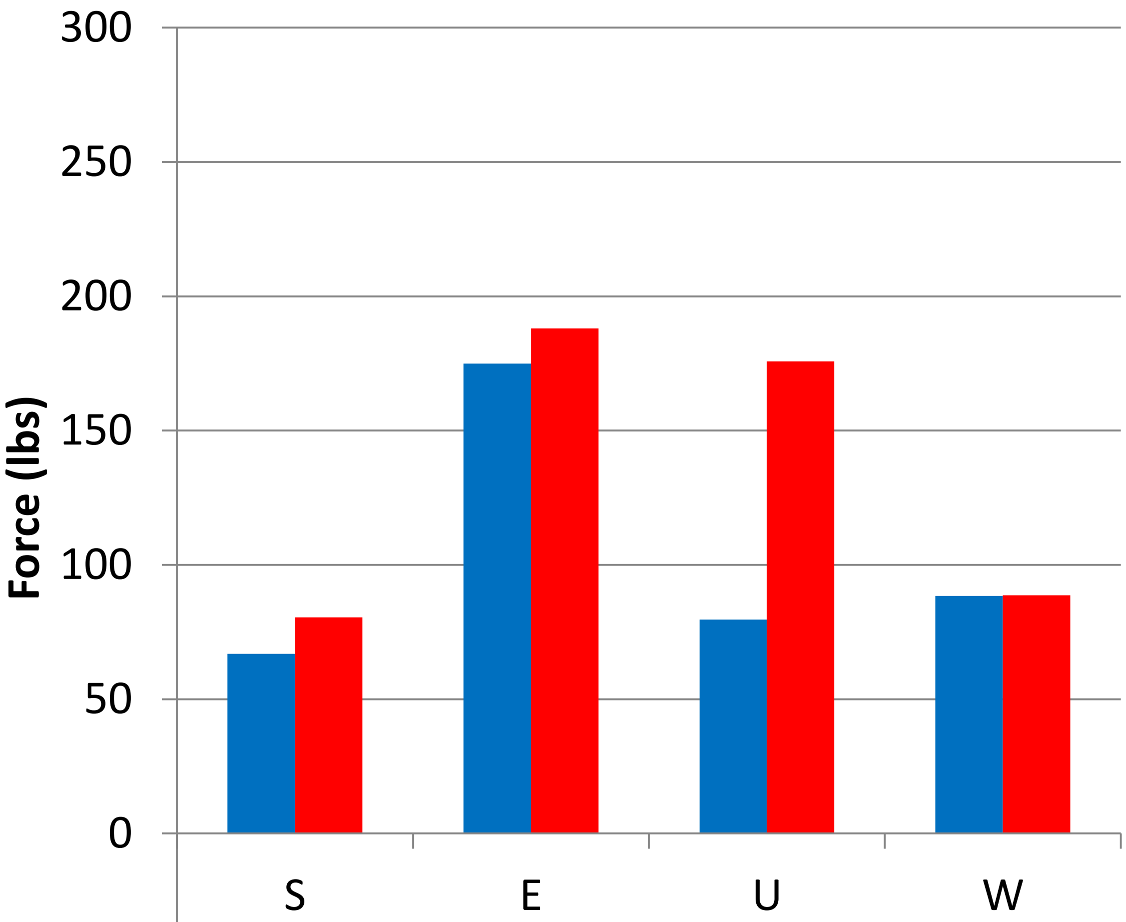

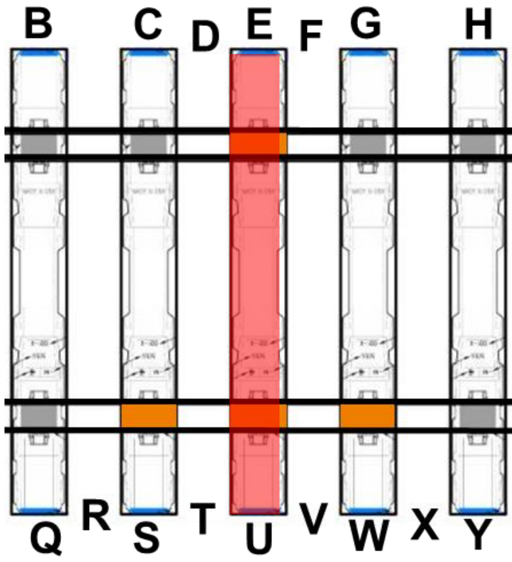

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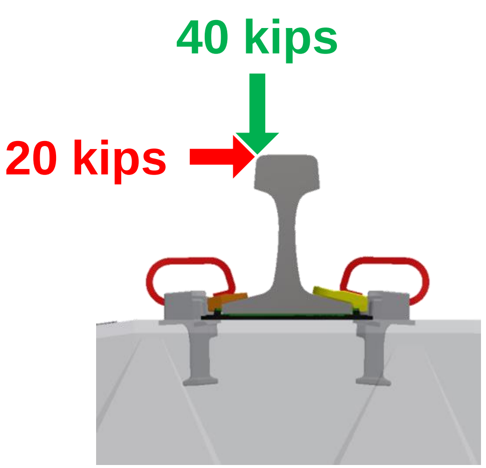
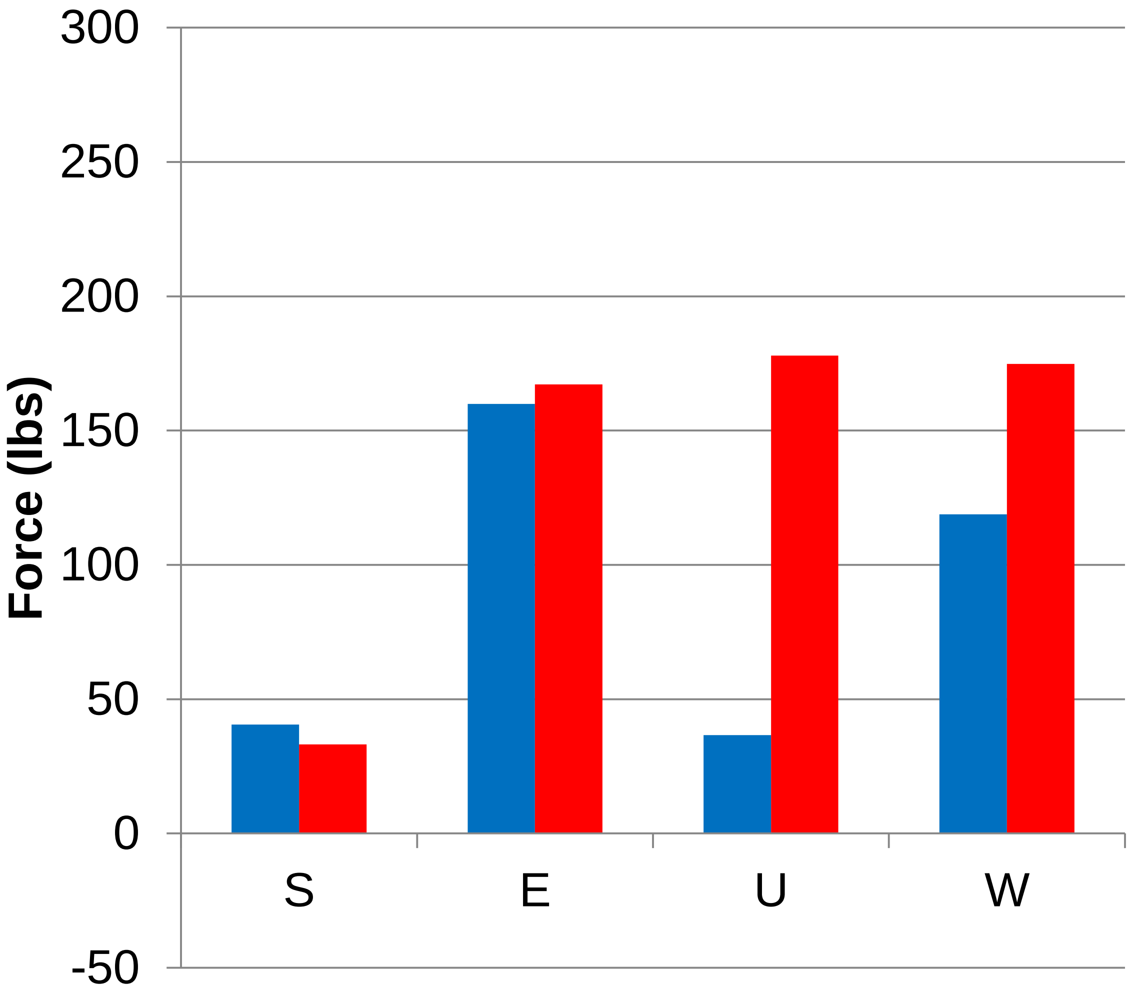
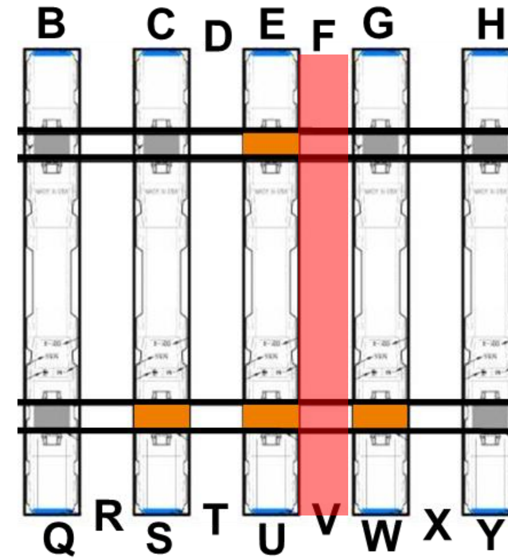


Change in Clamping Force





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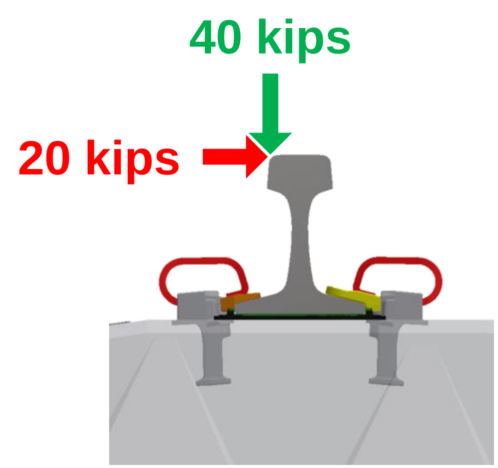

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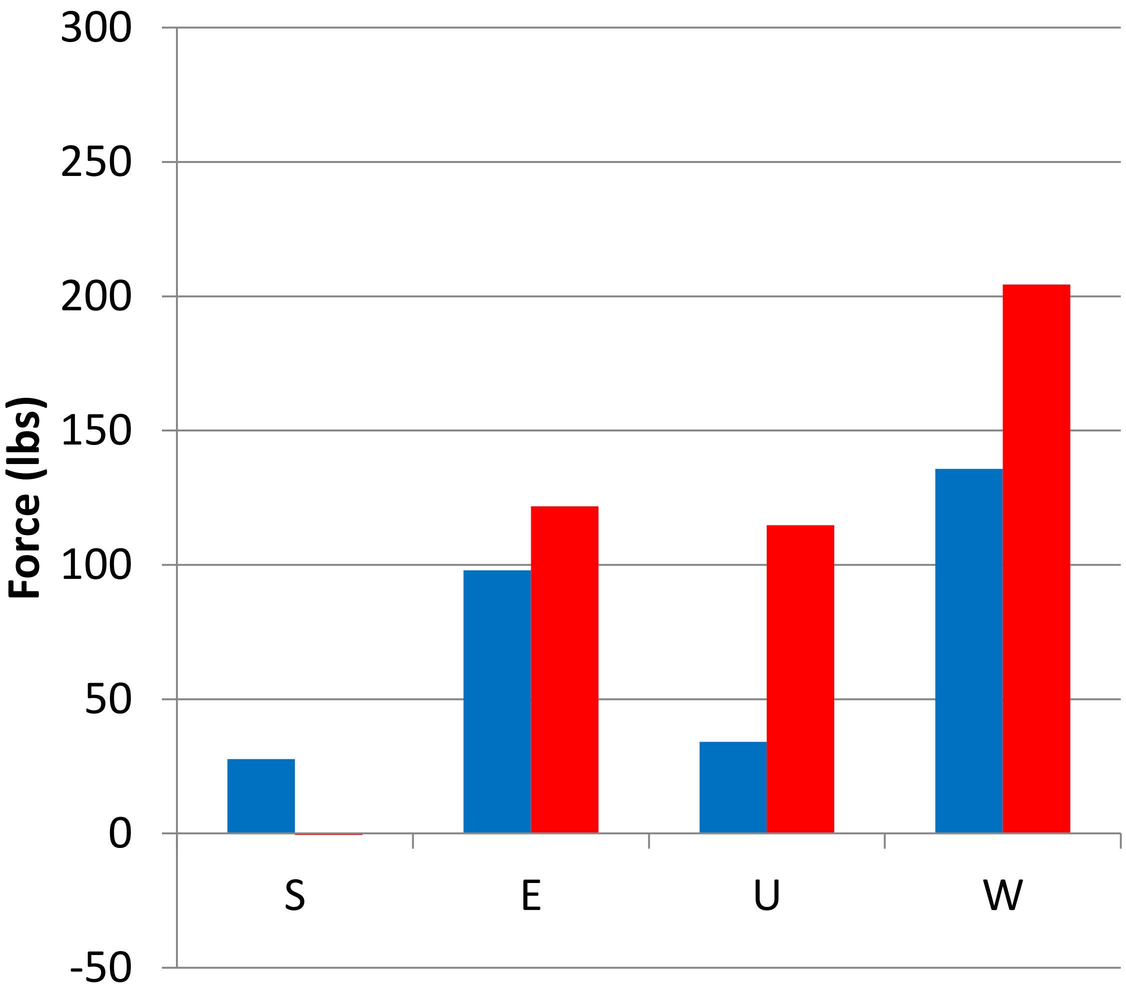

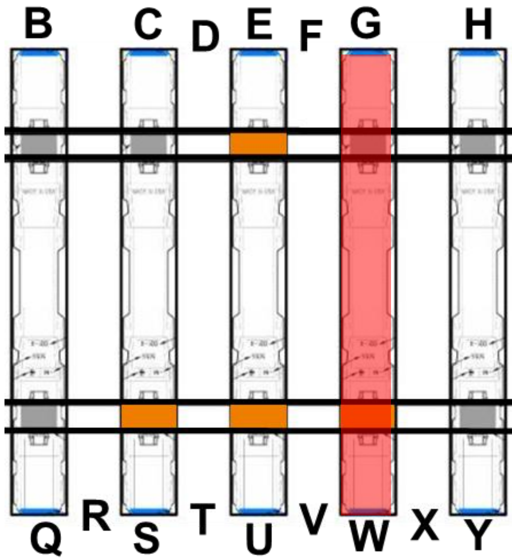

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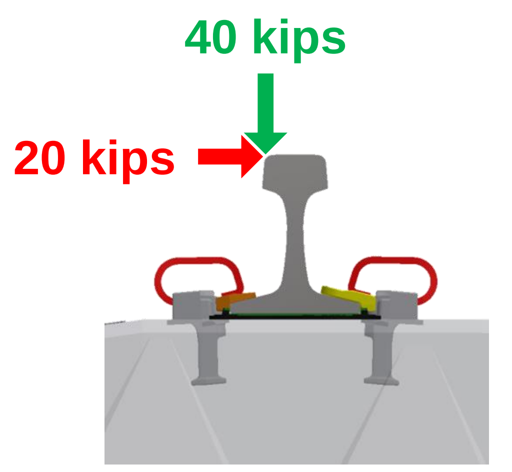
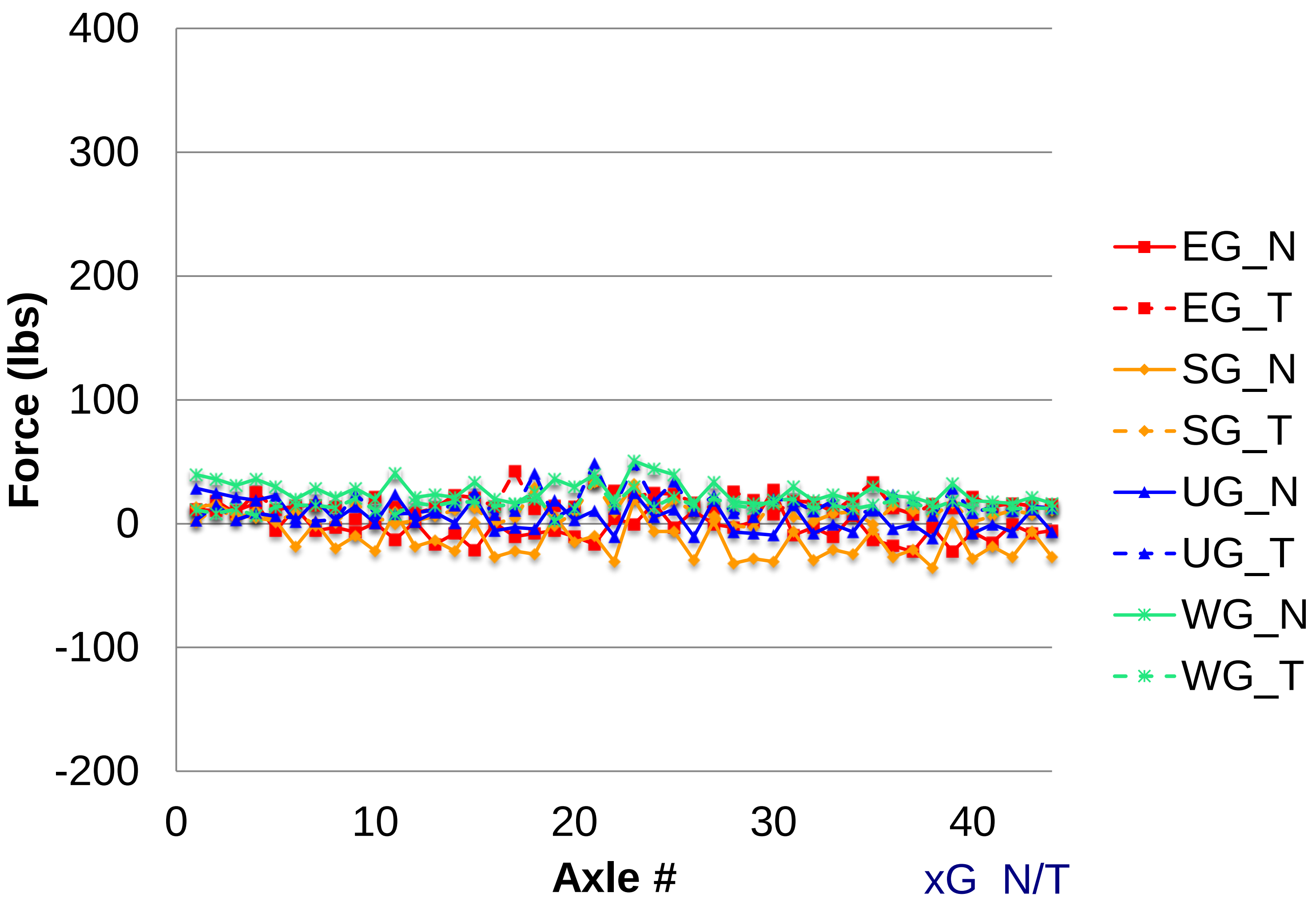


Change of Clamping Force Under Dynamic Load

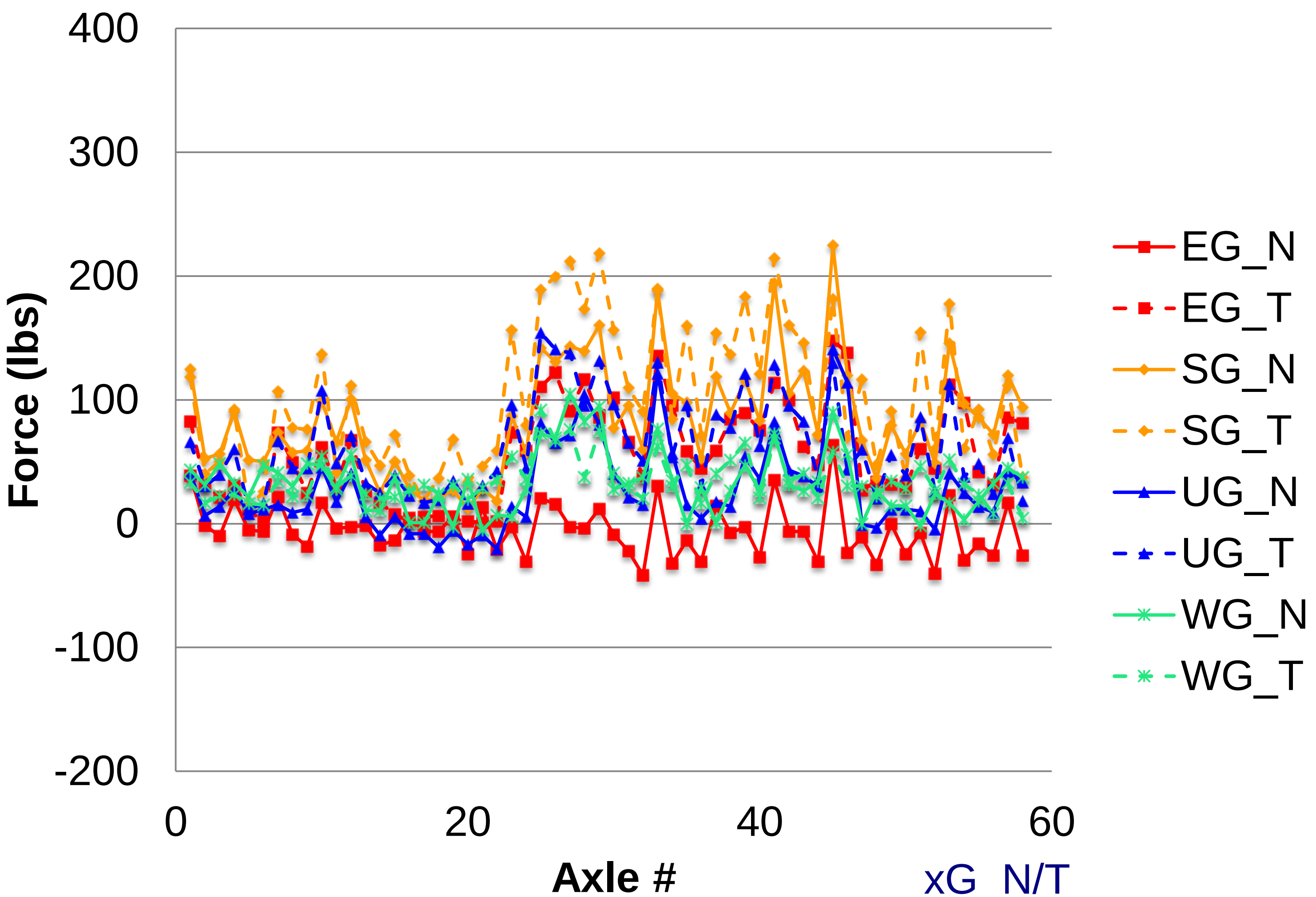
Location: **Tangent** Equipment: **Freight** Speed: **2 mph**



xG_N/T
x: location (E, S, U, W)
N/T: normal/tangential force

Change of Clamping Force Under Dynamic Load

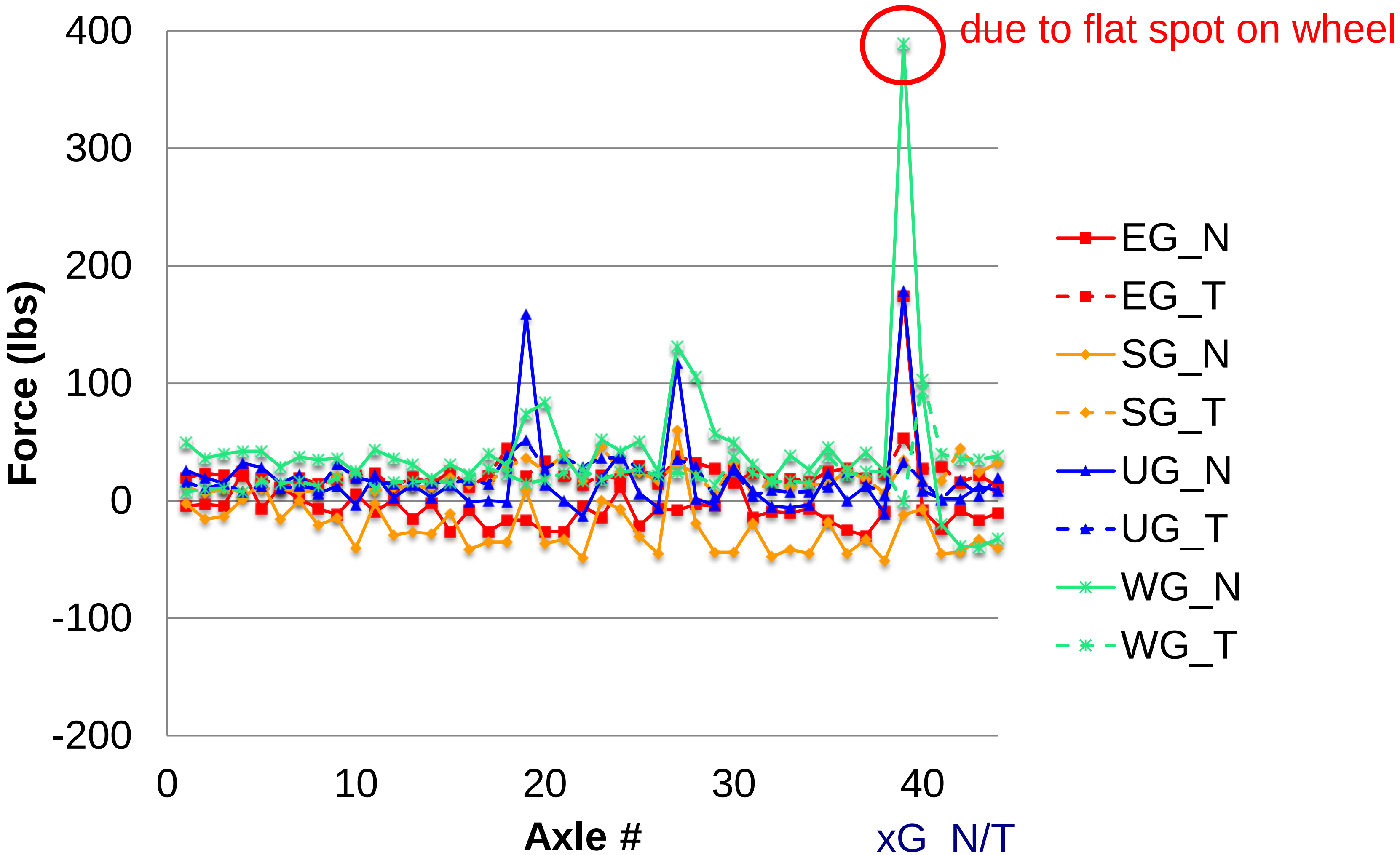
Location: **Curve** Equipment: **Freight** Speed: **2 mph**



xG_N/T
x: location (E, S, U, W)
N/T: normal/tangential force

Change of Clamping Force Under Dynamic Load

Location: **Tangent** Equipment: **Freight** Speed: **70 mph**



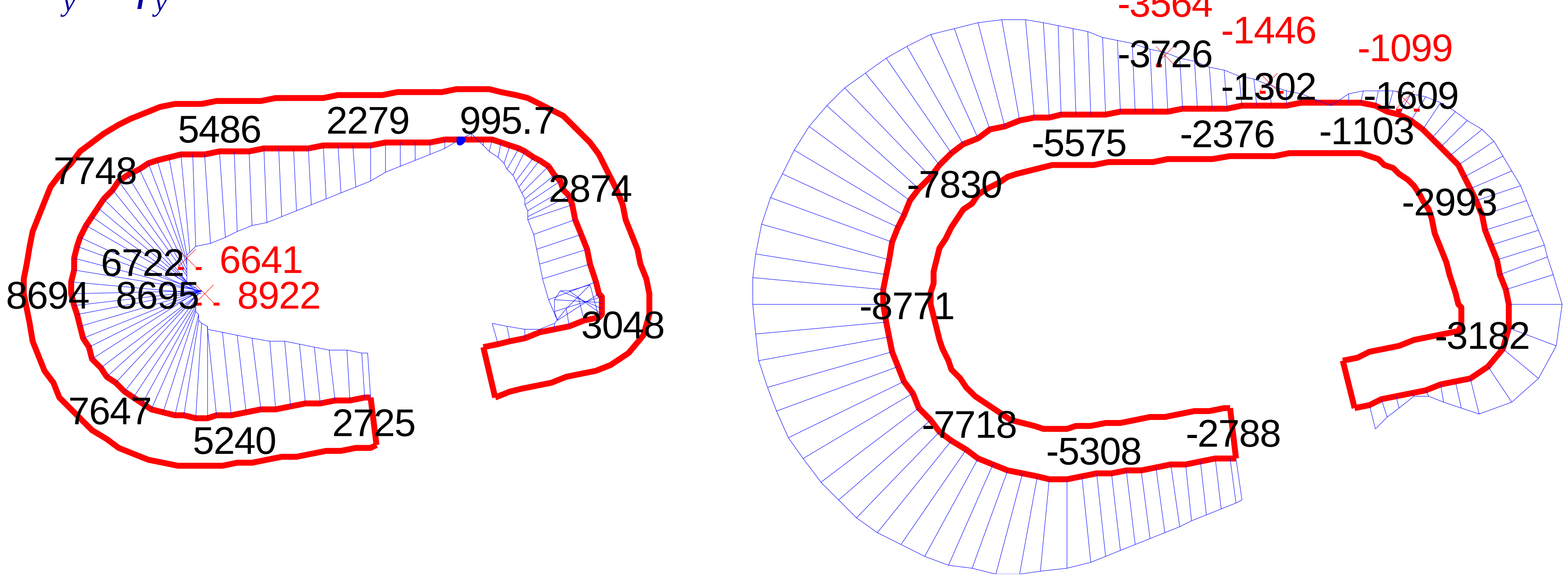
xG_N/T
x: location (E, S, U, W)
N/T: normal/tangential force

Strain Diagram After Installation (Actual)

- The inner and outer calculated surface strain distributions shown in blue
- The inner and outer calculated surface strain values are listed in black
- The inner and outer recorded surface strain values are listed in red
- Recorded strain is very close to calculated strain
- Resulting clamping force components: N = 2740 lbs, T = -140 lbs

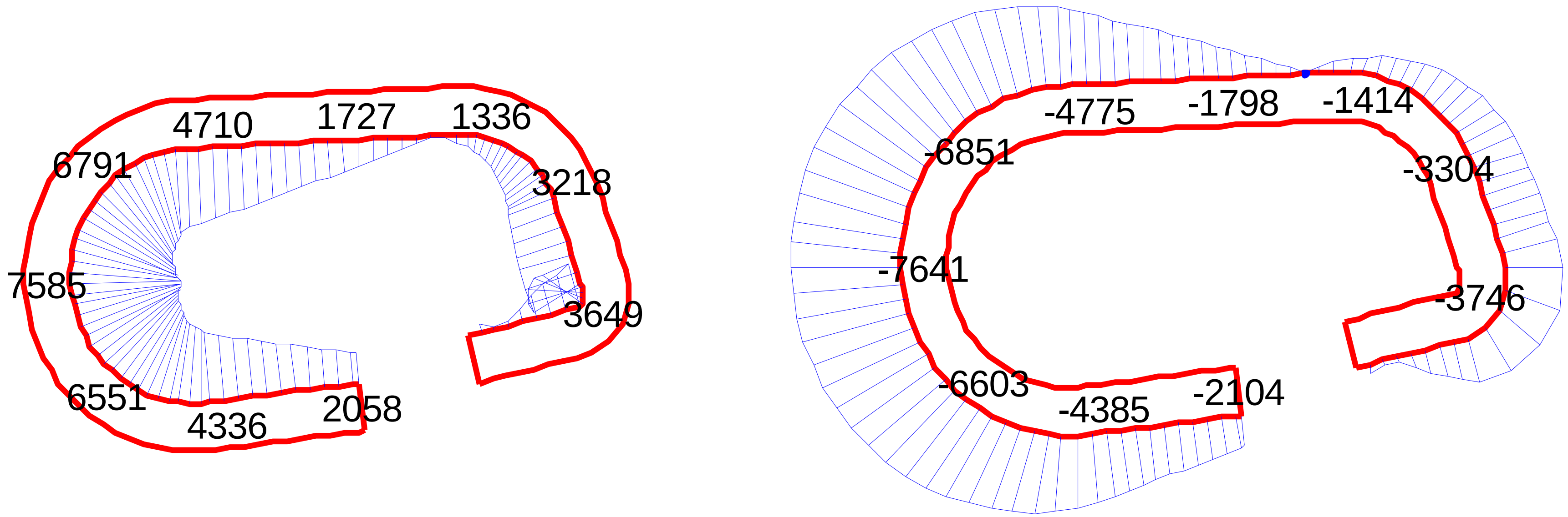
- Comparing with yielding strain of steel:

$$e_y = f_y / E = 183ksi / 23000ksi = 7957ms$$



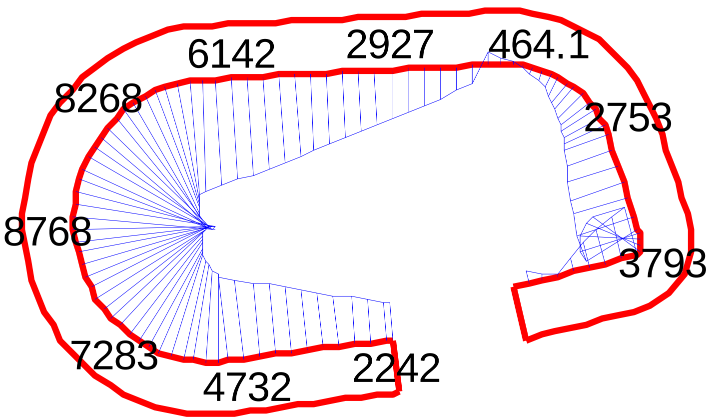
Strain Diagram After Installation

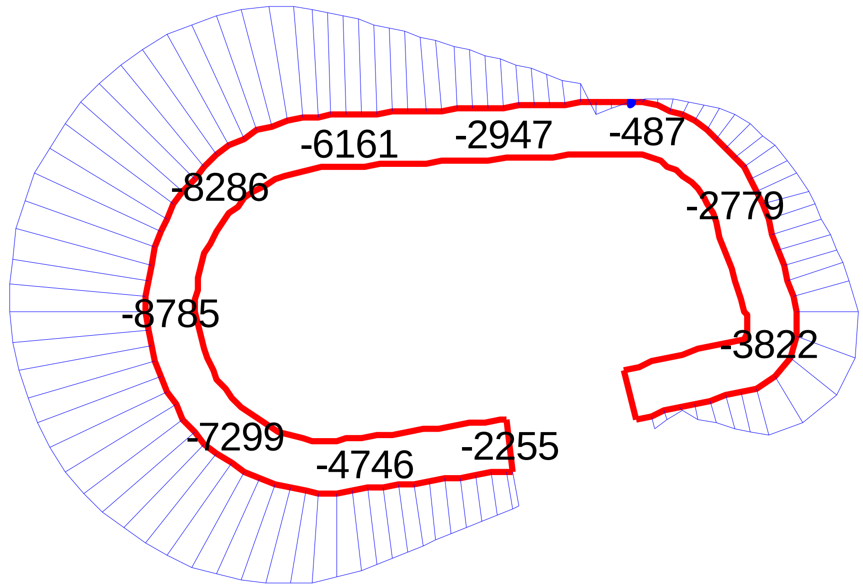
- Yielding strain: $e_y = f_y / E = 183ksi / 23000ksi = 7957ms$
- The strain distribution for inner and outer surface are shown below for case
  N = 2500 lbs,
  T = 0 lbs (assuming no tangential force)



Strain Diagram due to Typical Wheel Load

- Yielding strain: $e_y = f_y / E = 183 ksi / 23000 ksi = 7957 ms$
- The strain distribution for inner and outer surface are shown below for case
  N + ΔN = 2500 lbs + 200 lbs,
  T + ΔT = 0 lbs + 200 lbs

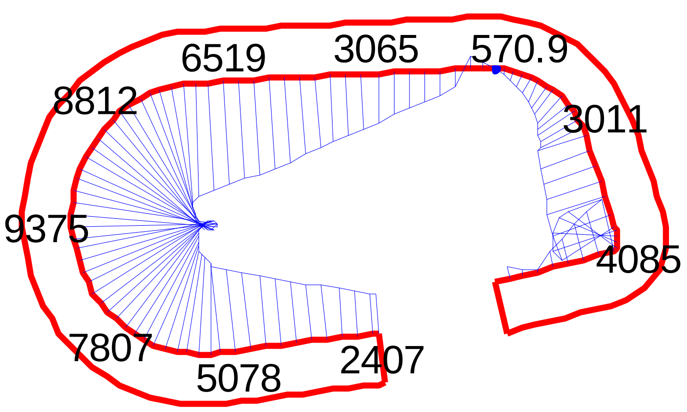


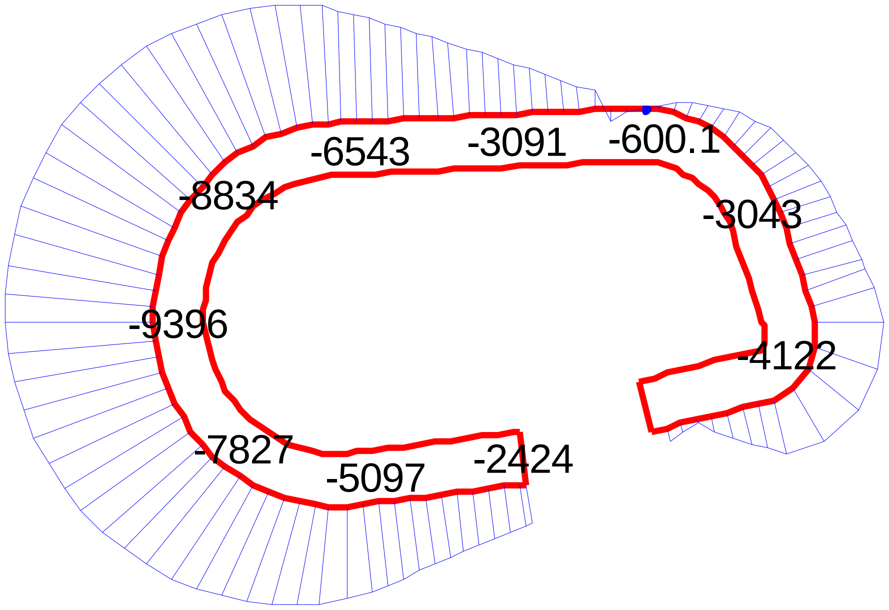


Strain Diagram Due to Impact Load

- Yielding strain: $e_y = f_y / E = 183ksi / 23000ksi = 7957ms$

- The strain distribution for inner and outer surface are shown below for case
  N + ΔN = 2500 lbs + 400 lbs,
  T + ΔT = 0 lbs + 200 lbs





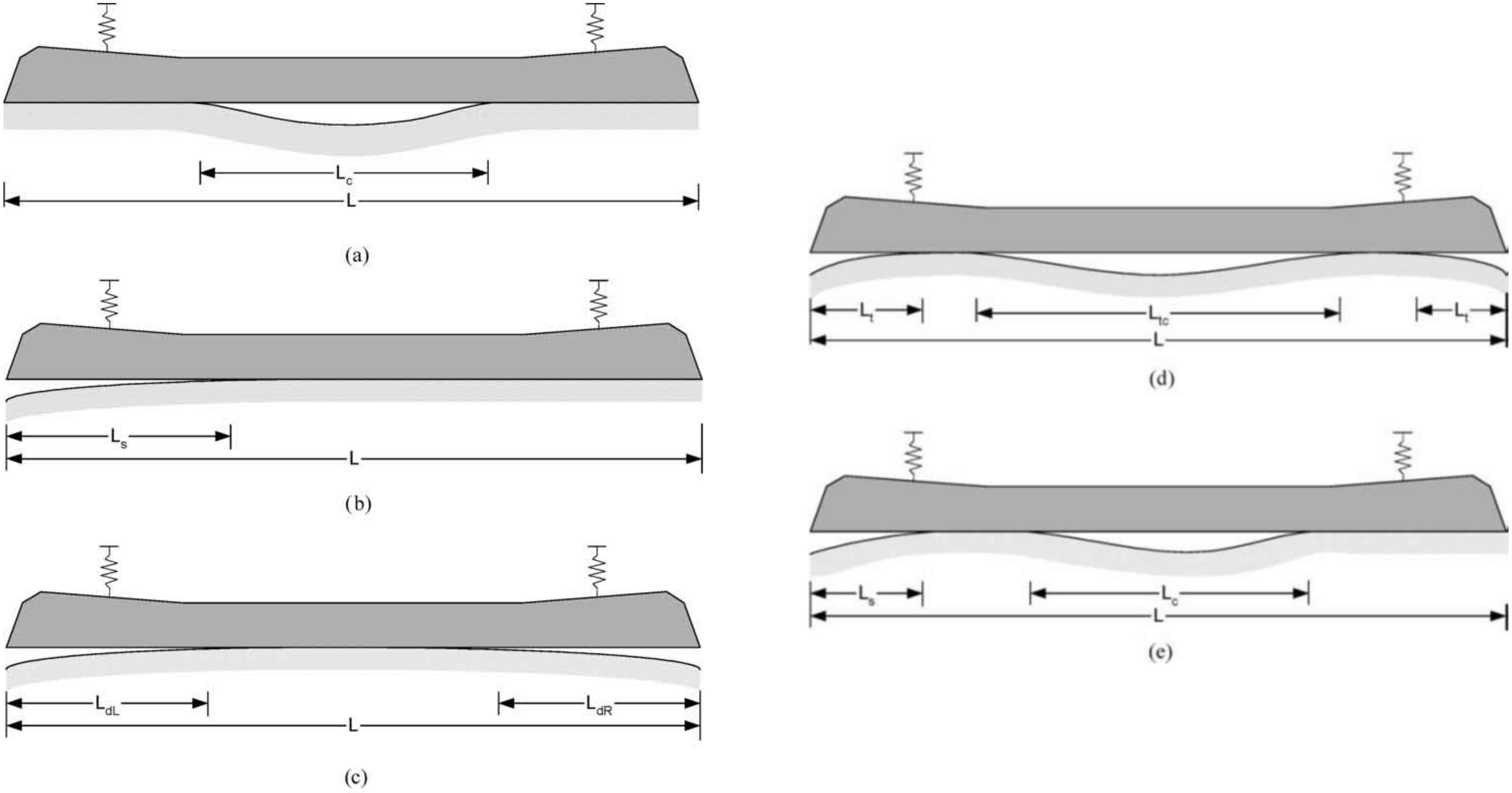
Conclusions from Clamping Force Analysis Experimentation

- Clamping force can be represented by two orthogonal forces
  - Normal and tangential
- The clamping force of a clip will not vary significantly when it is positioned two ties from the applied load
- The normal and tangential components of the clamping force do not change significantly under typical train operation
- Impact loads can impart significant strain into the clip
- The initial strain during installation may approach yield limit
- A more conservative design could be accomplished by closing up the gap between the two clip toes

Objectives of Crosstie Bending Behavior Analysis Experimentation

- Determine support conditions below crossties
- Determine the bending moments at the crosstie rail seats and the crosstie center when subject to:
  - Static and dynamic loads
  - Varying load magnitude (empty – 315 kips)

Background: Previous Research on Support Conditions

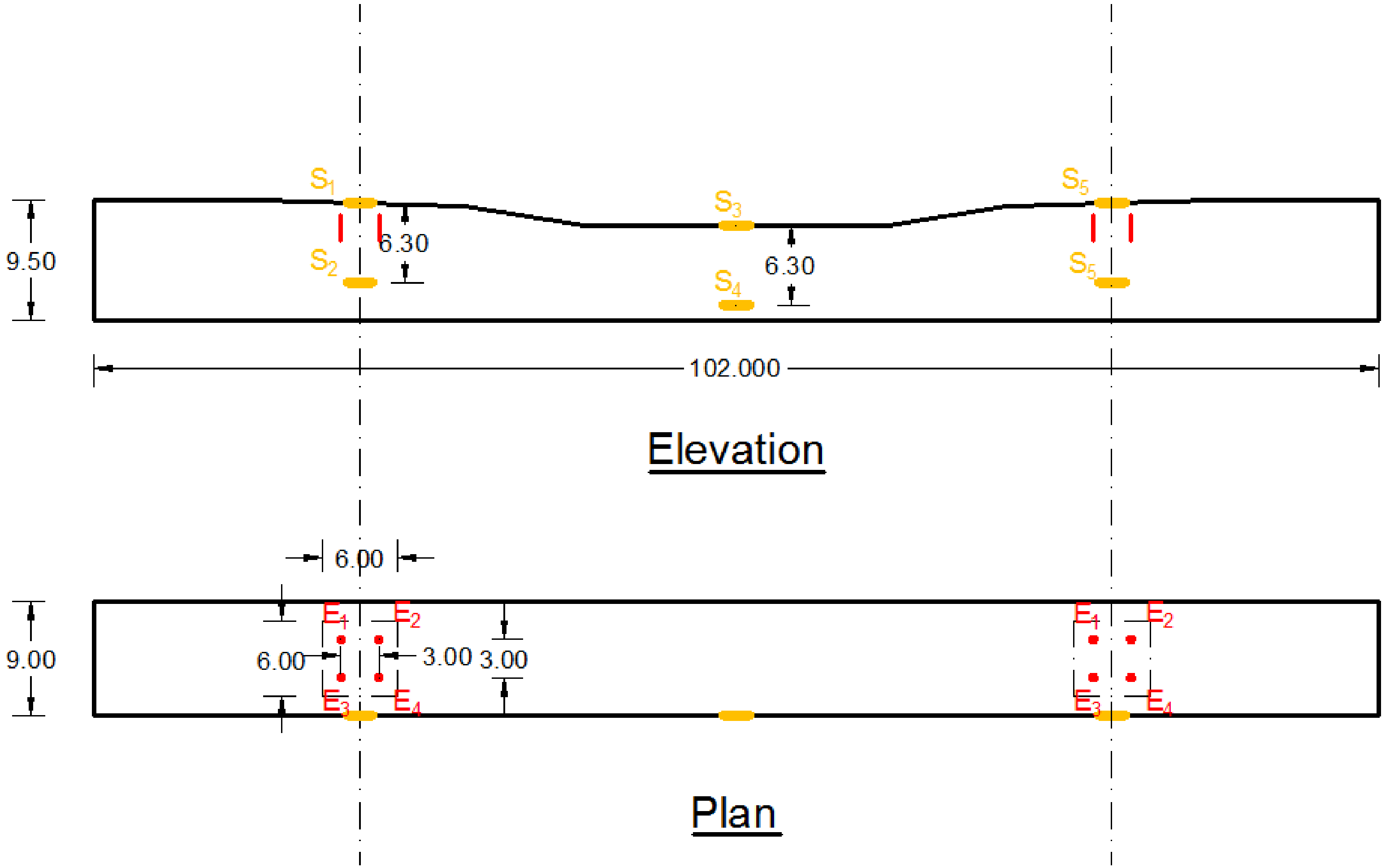


Sleeper/ballast contact patterns:

(a) central void, (b) single hanging, (c) double hanging,
(d) triple hanging, and (e) side-central voids

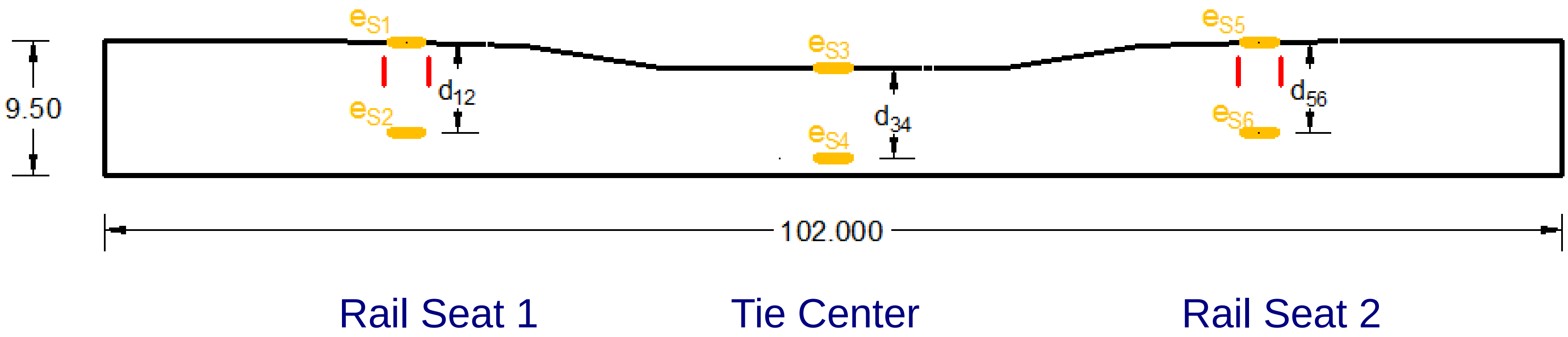
Kaewunruen & Ramennikov, 2007

Crosstie Instrumentation Methodology



- Strains measured at the top and bottom of both rail seats and the crosstie center
- Bending moments can then be calculated at both rail seats and crosstie center

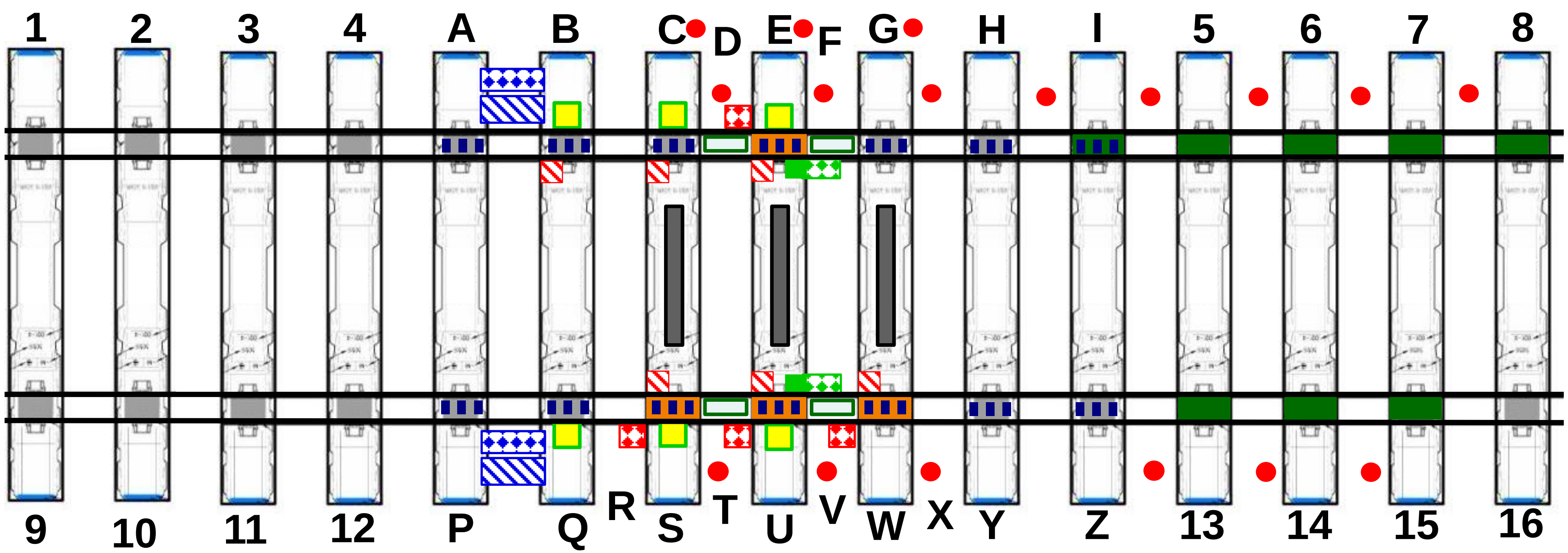
Crosstie Bending Moment Calculation Methodology



$$M(railseat1) = (e_{S2} - e_{S1})EI_{12} / d_{12}$$
$$M(center) = (e_{S4} - e_{S3})EI_{34} / d_{34}$$
$$M(railseat2) = (e_{S6} - e_{S5})EI_{56} / d_{56}$$

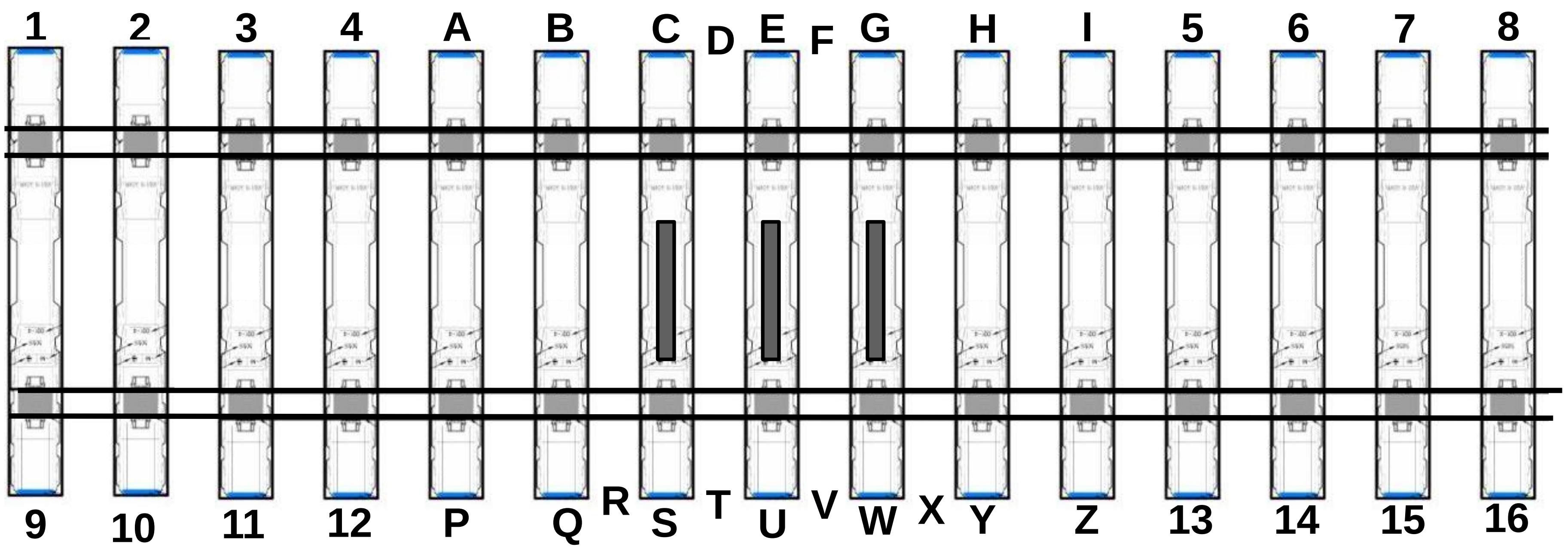
Where,
e: strain recorded from concrete surface gauge #1~#6
E: elastic modulus of concrete, 4500 ksi
I: moment of inertia at each location
d: the distance between the upper and lower gauges at each location

Instrumentation Location (Full Map)

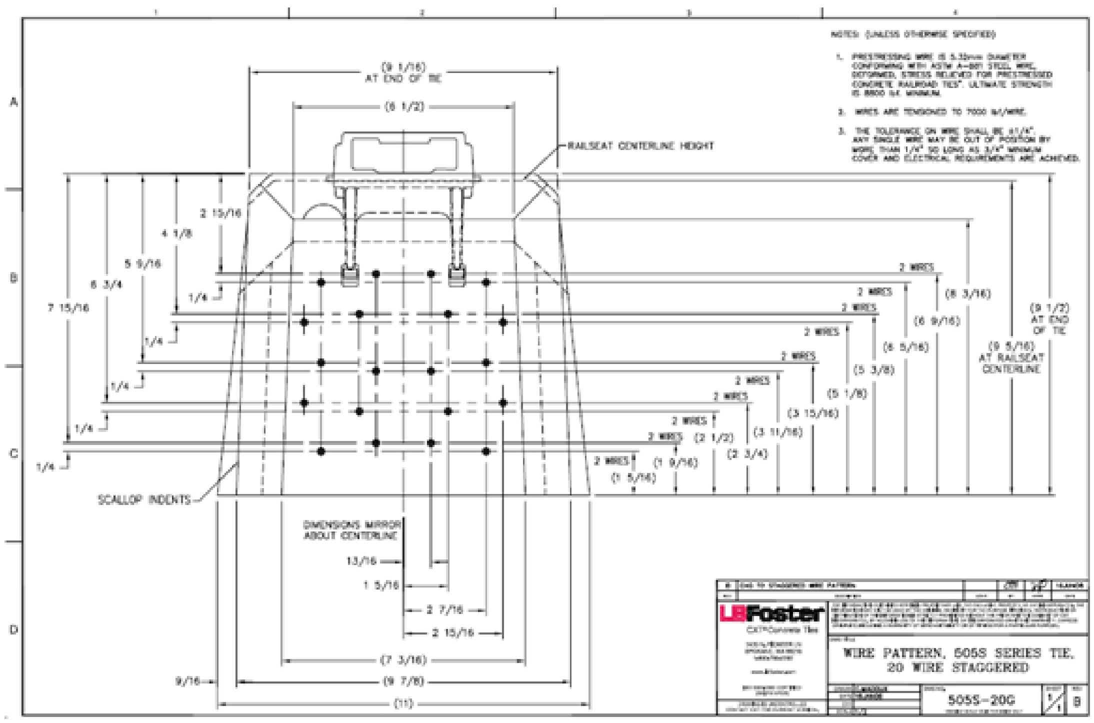


- Rail Displacement Fixture
- Rail Longitudinal Displacement/Strains
- Pad Assembly Longitudinal Displacement
- Pad Assembly Lateral Displacement
- Insulator Longitudinal Displacement
- Insulator Vertical Displacement
- Steel Rods
- Vertical Web Strains
- Vertical and Lateral Circuits
- Shoulder Beam Insert (Lateral Force)
- Embedment Gages, Vertical Circuit, Clip Strains
- Crosstie Surface Strains
- MBTSS

Instrumented Crossties



Concrete Crosstie Design Cracking Moment

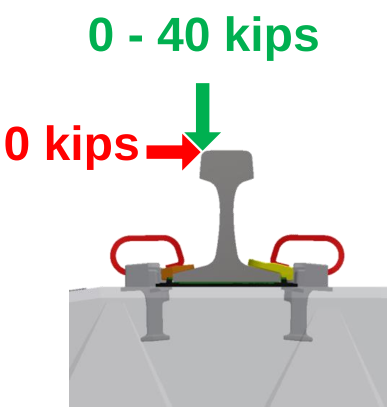


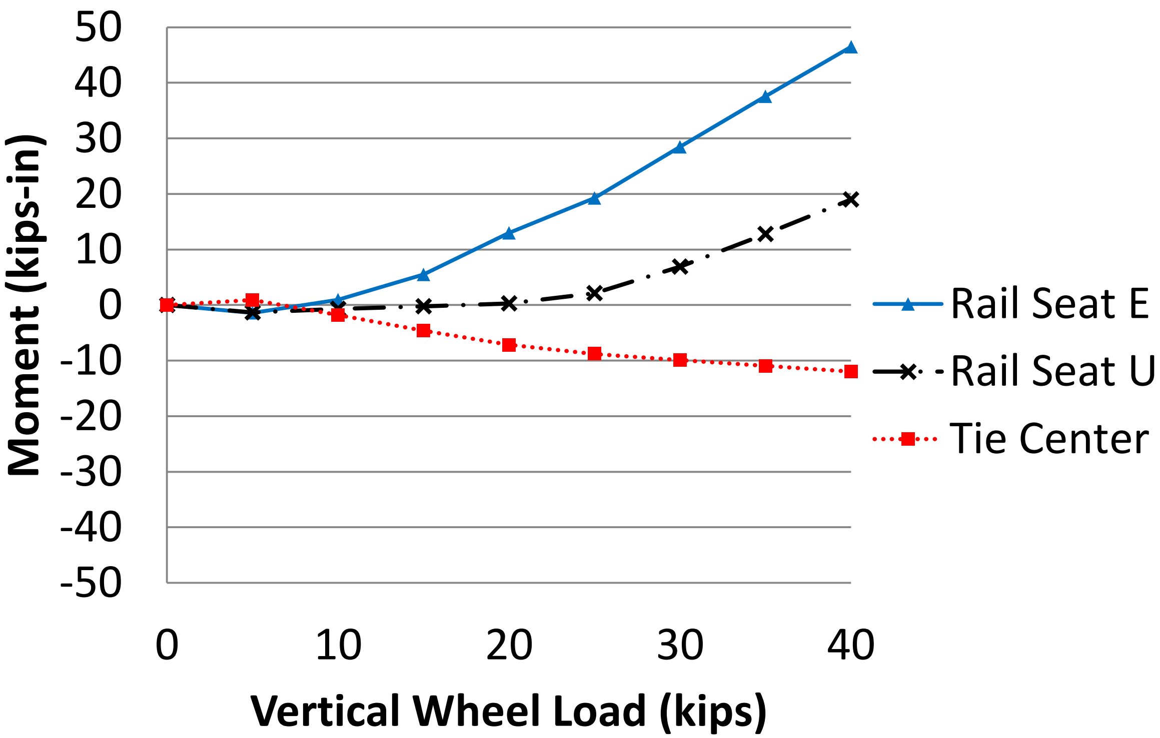
From CXT f’c(28d)=11,730 psi
Using f’c=11,000 psi

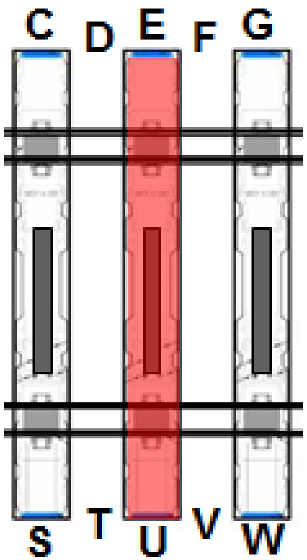
Positive: top in compression
Negative: top in tension

- Mid-point
  - positive: 196.8 k-in
  - negative: -256.8 k-in
- Rail-seat
  - positive: 405.6 k-in
  - negative: -219.6 k-in

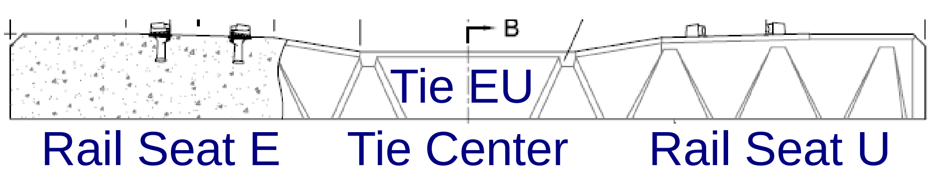
Bending Moments Under Static Load: Rail Seats E and U and Crosstie Center E-U



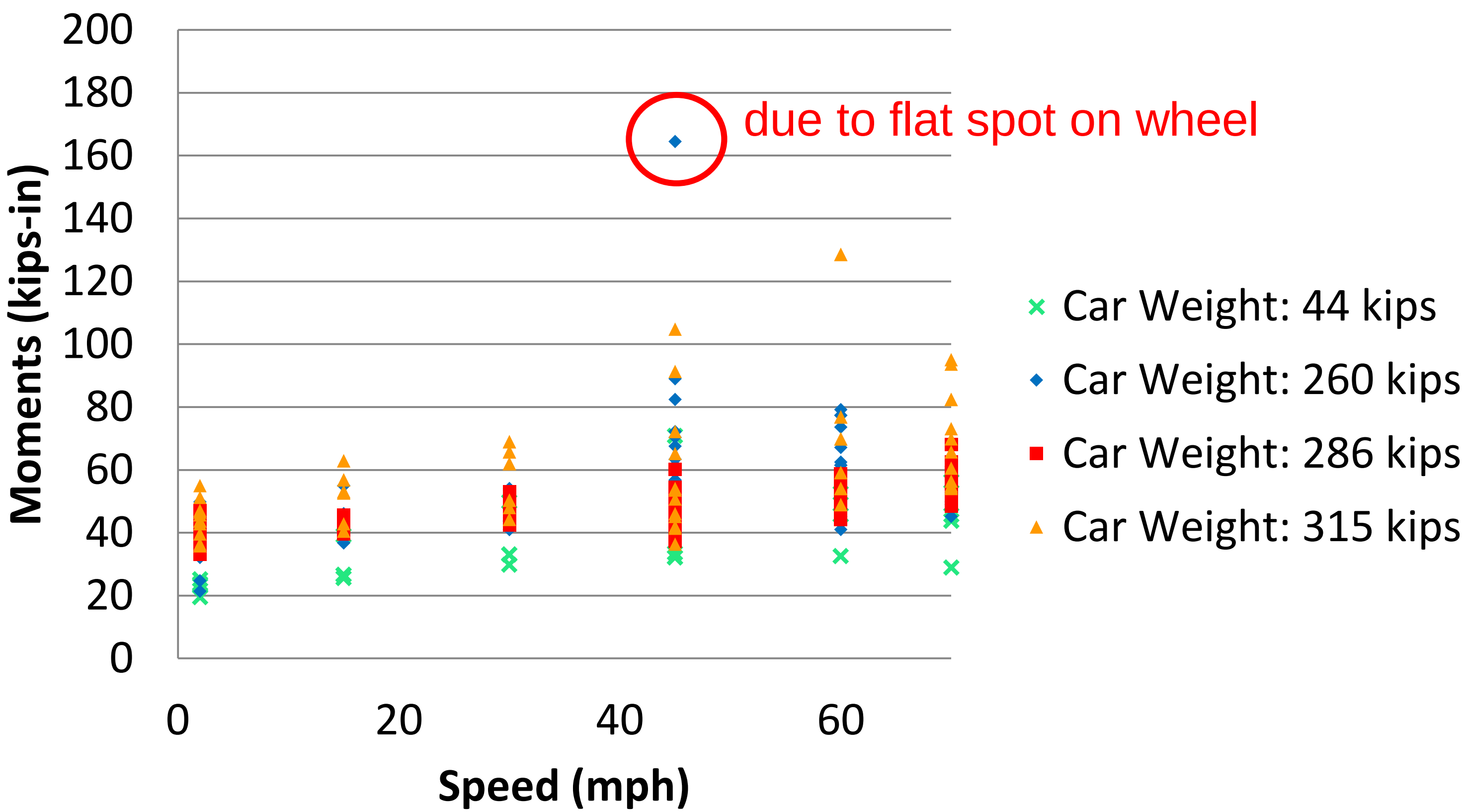


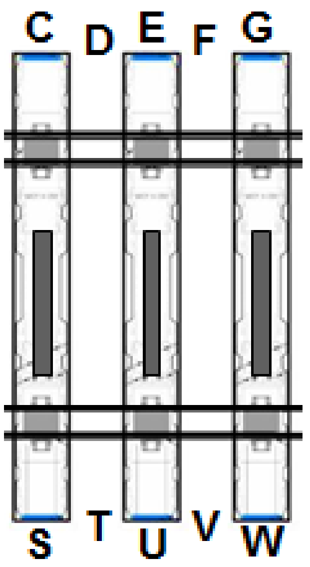


- Design rail seat cracking moments
  - positive: 405.6 k-in
  - negative: -219.6 k-in
- Design tie center cracking moment
  - positive: 196.8 k-in
  - negative: -256.8 k-in

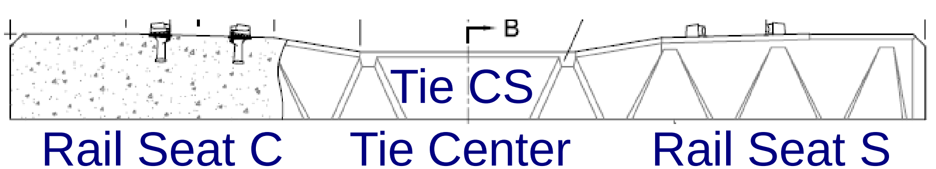


Bending Moments Under Dynamic Load: Rail Seat C by Car Type

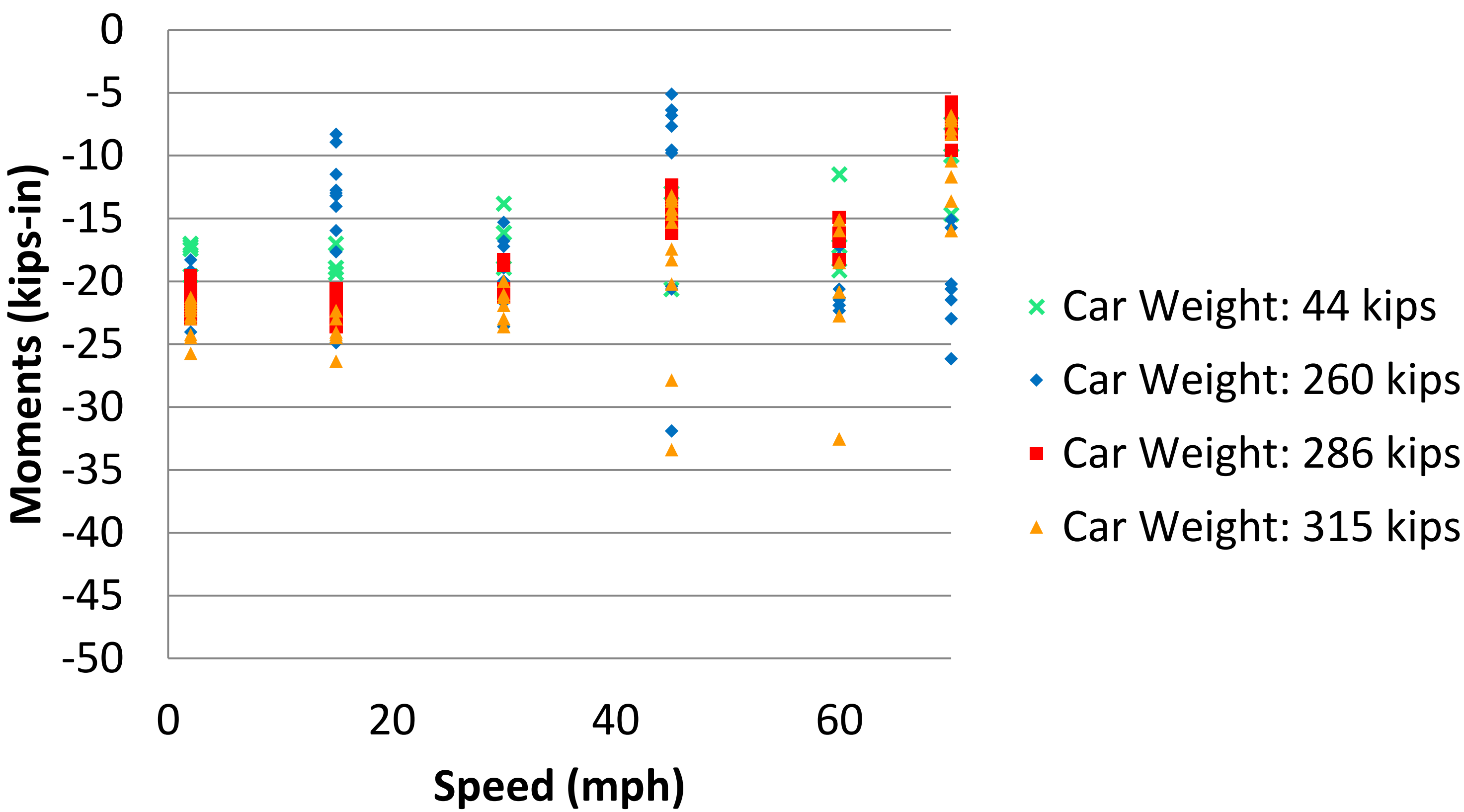


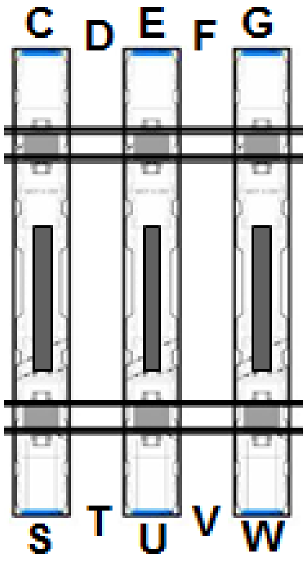


- Design rail seat cracking moments
  - positive: 405.6 k-in
  - negative: -219.6 k-in

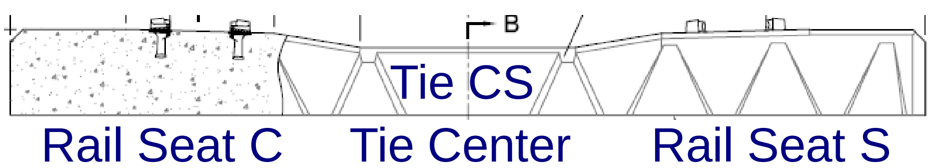


Bending Moments Under Dynamic Load: Crosstie Center C-S by Car Type

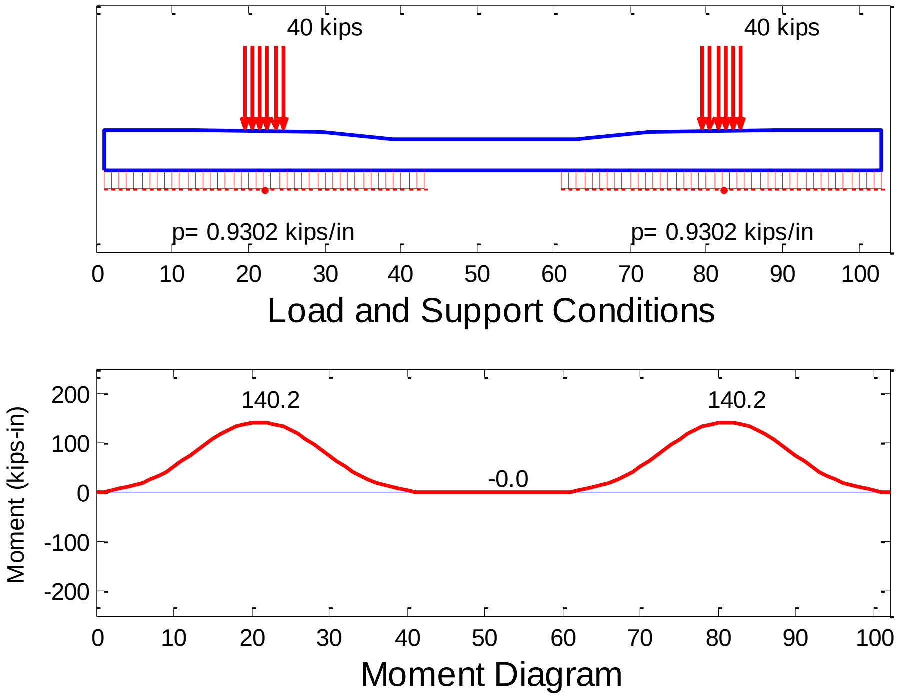




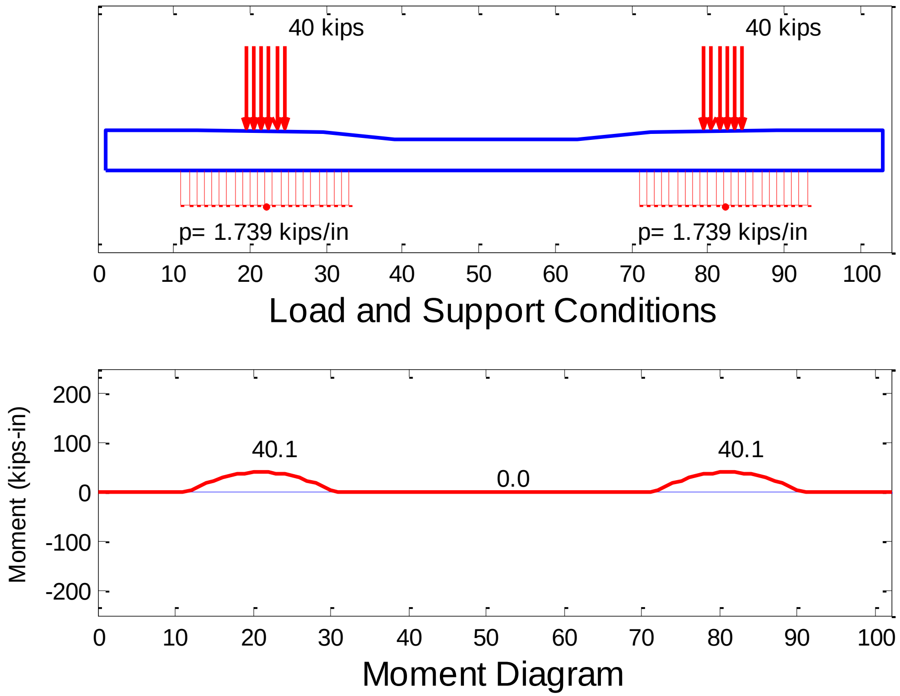
- Design tie center cracking moment
  - positive: 196.8 k-in
  - negative: -256.8 k-in



Discussion on Support Length



“Newly tamped track” in UIC



Reduced support length

- As crosstie support length is reduced, the resulting rail seat moment is reduced

Conclusions from Bending Behavior Analysis Experimentation

- Bending moments recorded during dynamic train runs are larger than those recorded during static tests
- In general, the recorded bending moment increased as the nominal car weight increased
- Impact loads can significantly effect the crosstie bending moments
- Bending moments recorded in field do not approach the cracking limit
- Low bending moments at rail seat may be due to a short support length in the field

Future Work

- Clip Performance
  - Effect of cyclic loading on tangential and normal components of clamping force
  - Effect of repeated impact load on tangential and normal component of clamping force
- Crosstie Performance
  - Rail seat vertical load will be analyzed via concrete embedment strain gauges cast below the rail seat
  - Rail seat vertical load and concrete crosstie bending behavior will be compared
  - More detailed analysis of the effect of support conditions on concrete crossties bending

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FRA Tie and Fastener BAA Industry Partners:

Questions?

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