Gauging of Concrete Crossties to Investigate Load Path in Laboratory and Field Testing

Joint Rail Conference 2014

Colorado Springs, CO

3 April, 2014

Sihang Wei, Daniel Kuchma

U.S. Department of Transportation
Federal Railroad Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- **Project Objectives**
- **Introduction and Background**
- **Instrumentation and Laboratory Calibration**
- **Rail Seat Loading and Crosstie Bending Moment Calculation Methodology**
- **Results Analysis**
- **Conclusions and Future Work**

FRA Concrete Crosstie and Fastening System Research Program
Overall 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

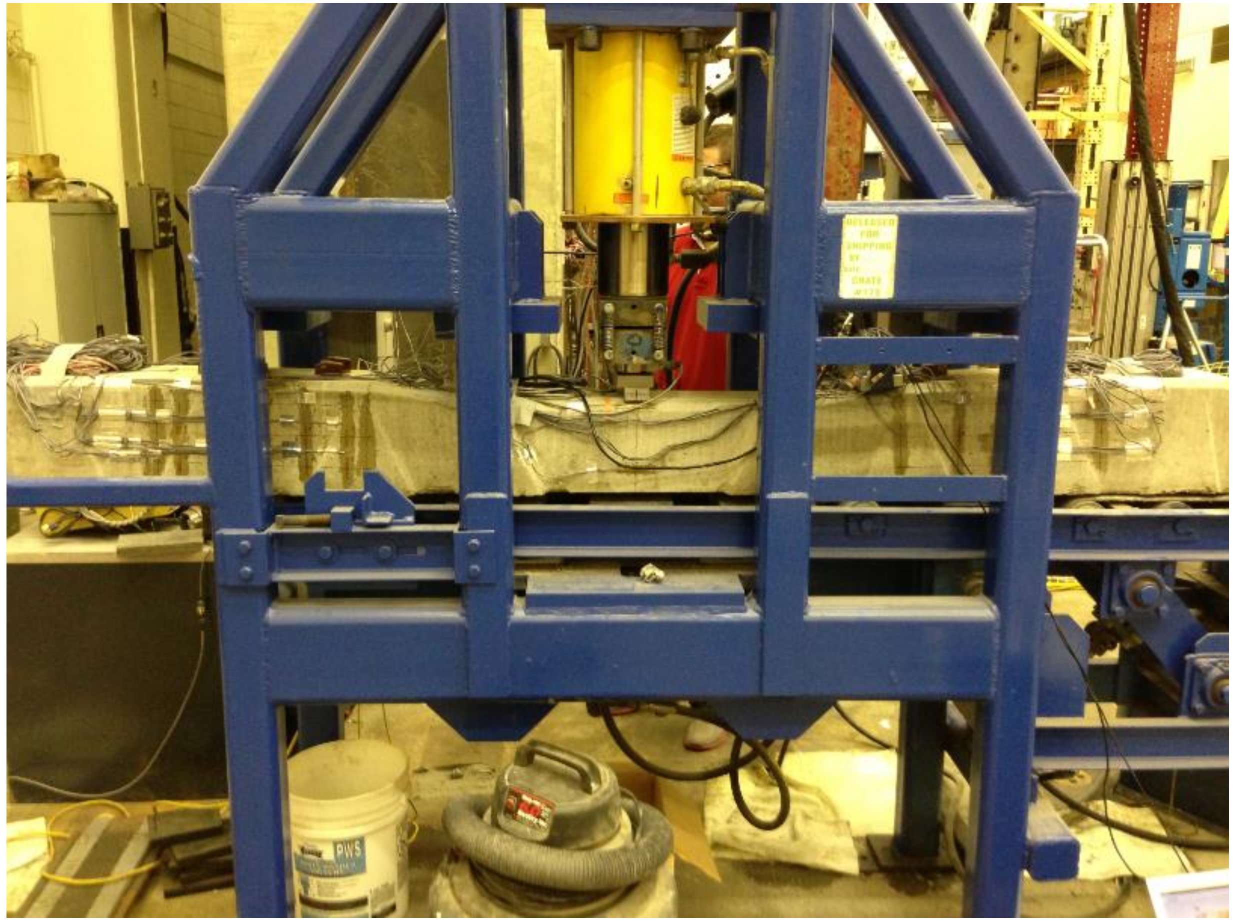
Field Experimentation

Parametric Analyses

Objectives of Crosstie Bending and Compression Experimentation

- Determine the vertical rail seat loads
- Determine the bending moments at the crosstie rail seats and the crosstie center when subject to:
  - Static and dynamic loads
  - Varying load magnitude of rail cars (empty – 315 kips)
- Determine support conditions below crossties
- Determine the load path going through the crosstie
- Determine the effect of rail seat loading and support conditions to the behavior of the crosstie
- Determine how the support conditions effects the load path in the system

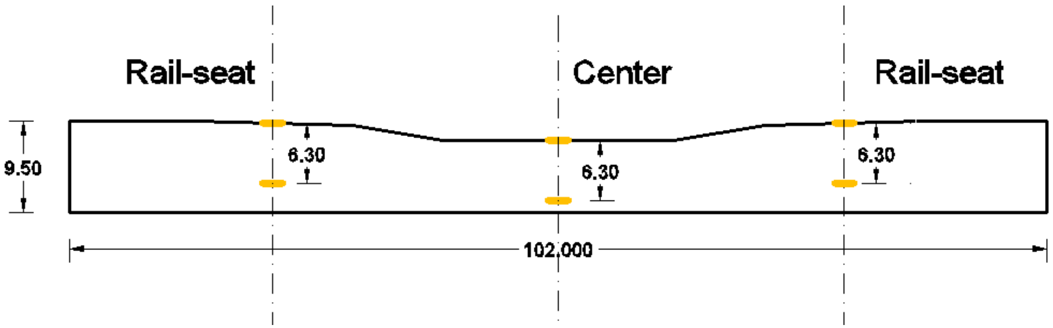
Background: Concrete Material Properties



Concrete core testing
Newmark, UIUC

Crosstie center positive bending test
Newmark, UIUC

Background: Concrete Crosstie Design Cracking Moment



Using BEAM theory

$$M_{cracking} = f_t \cdot I/y$$

Where, I and y are geometry properties

Concrete compressive strength

From crosstie manufactorer

$f'c(28d) = 11{,}730\ psi$

From concrete core drill test & positive bending test

$f'c(1\ ya) = 11{,}000\ psi$

Using $f'c = 11{,}000\ psi$

Concrete tensile strength

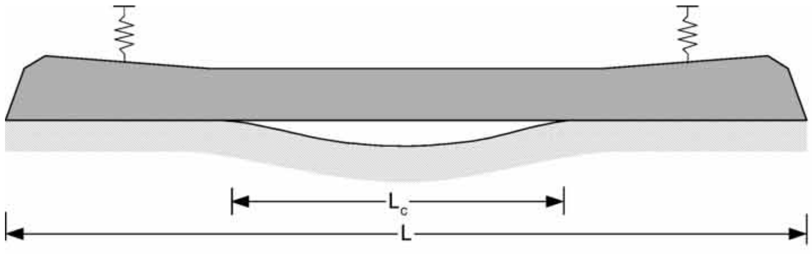
$$ft = 7.5\sqrt{f'c} = 787psi$$

Positive: top in compression

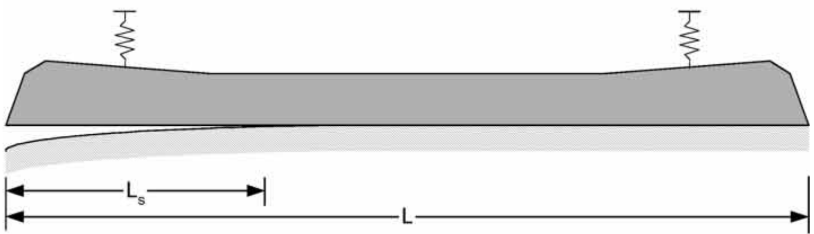
Negative: top in tension

- Crosstie Center Cracking Moment
  - positive: 196.8 k-in
  - negative: -256.8 k-in
- Crosstie Rail-seat Cracking Moment
  - positive: 405.6 k-in
  - negative: -219.6 k-in

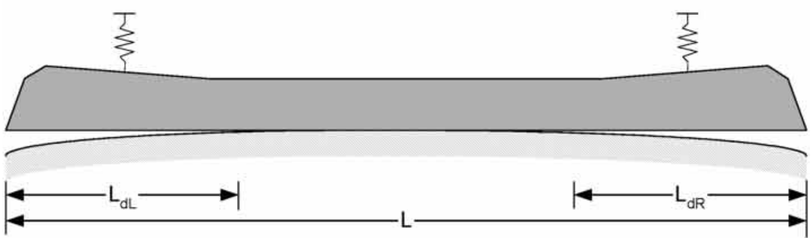
Background: Previous Research on Support Conditions



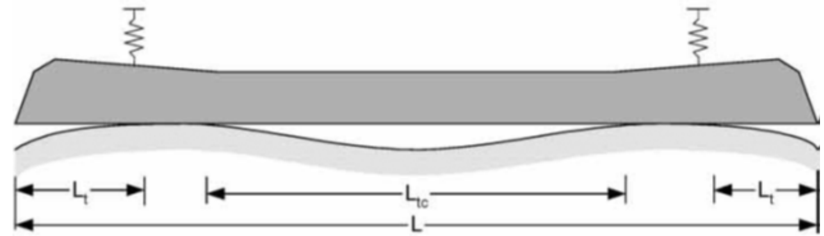
(a) central void



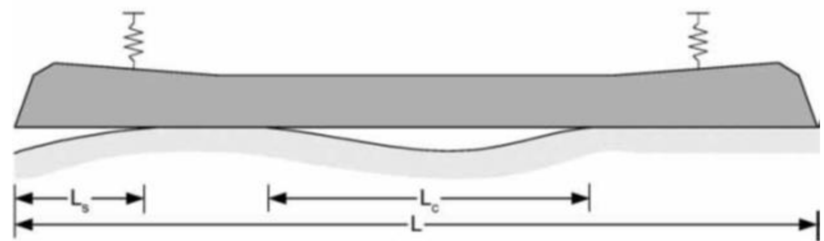
(b) single hanging



(c) double hanging



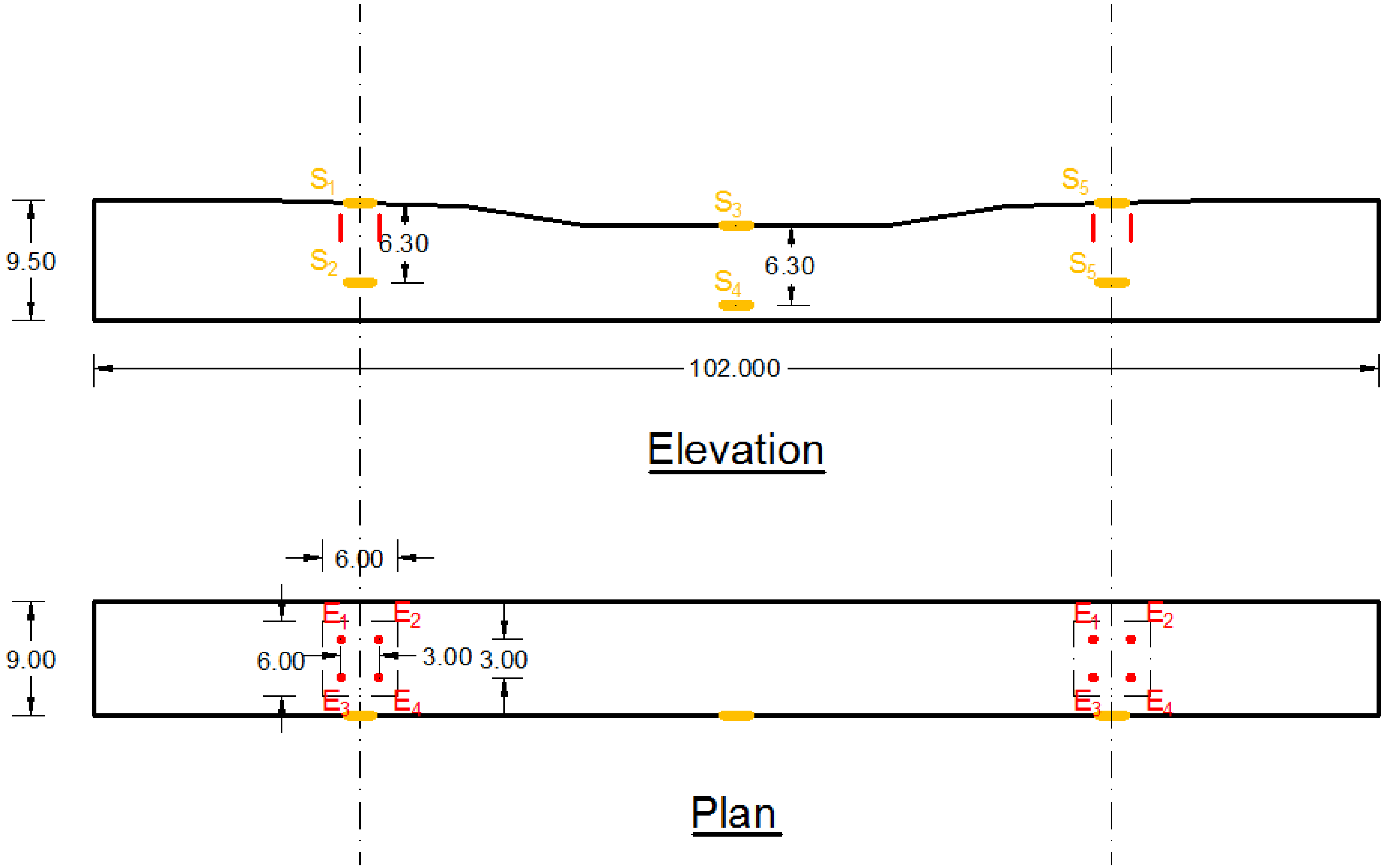
(d) triple hanging



(e) side-central voids

Kaewunruen & Ramennikov, 2007

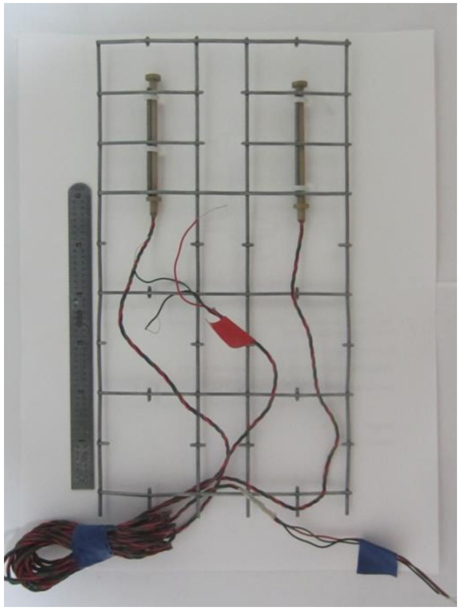
Crosstie Instrumentation Methodology

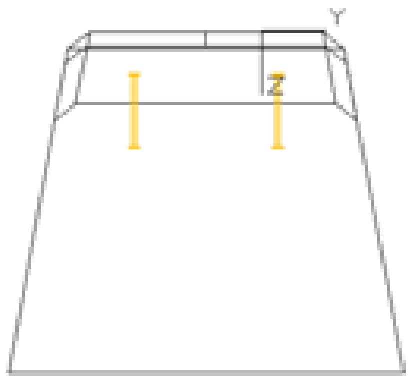


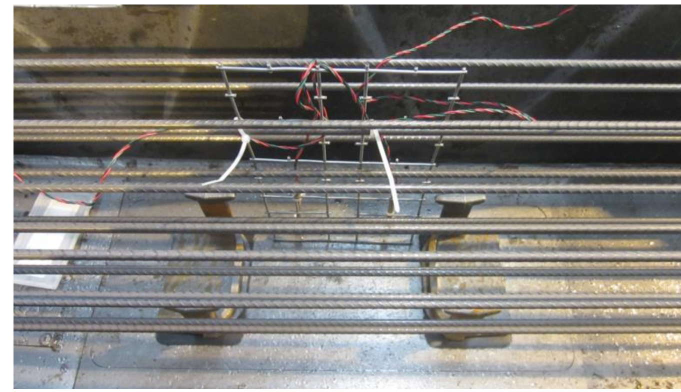
Concrete embedment strains measured 2 inches below both rail seats

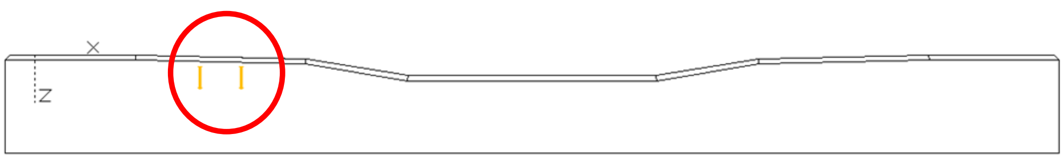
Concrete surface strains measured from one side surface of the crosstie

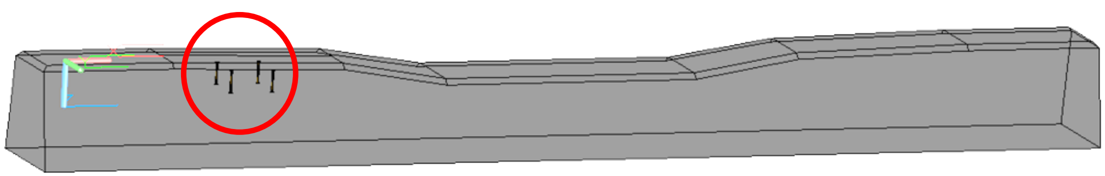
Rail Seat Load Measurement – Using Embedment Strain Gauge







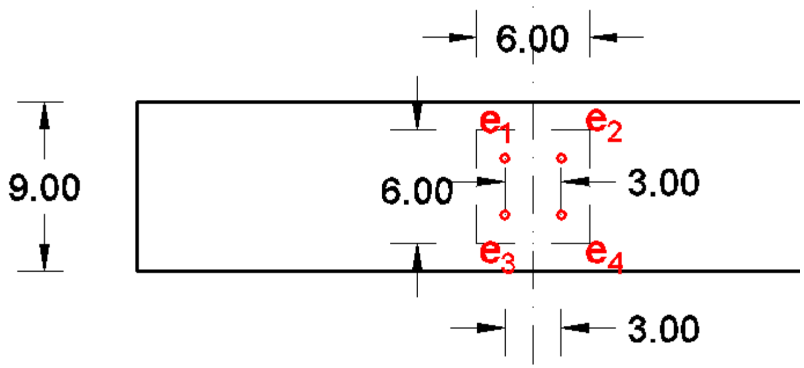




CXT, Tucson AZ (May 2012)

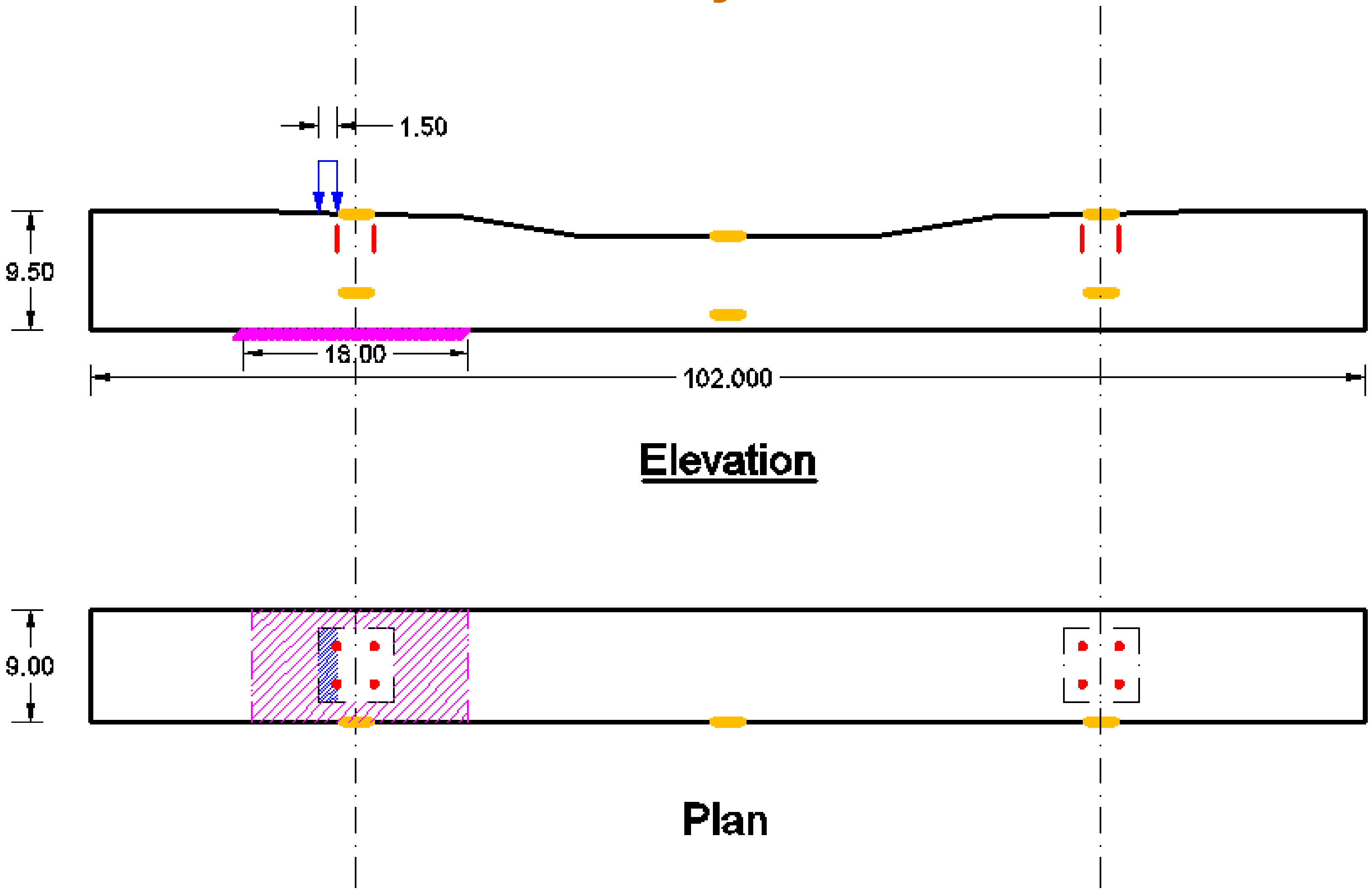
Rail Seat Load Measurement – Laboratory Calibration

$$V(kips) = e_{AVG} \cdot E_c \cdot A \cdot Q_1 \cdot Q_2 \cdot Q_3$$

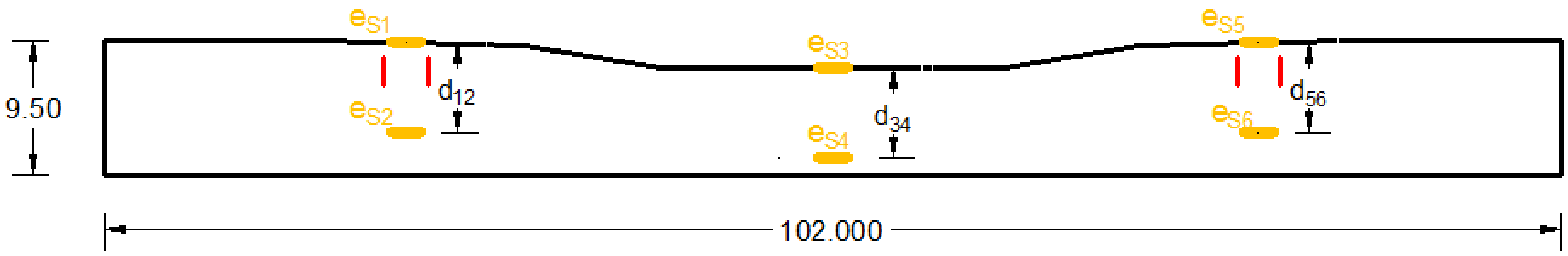


Where,
V – vertical load applied on the rail seat
e_{AVG} – average strain recorded
E_C – elastic modulus of concrete
A – simplified bearing area at the center of embedment strain gauges (equal to the area of rail seat, 6”x6”)
Q_1 – correct factor for equivalent bearing area
Q_2 – correct factor for loading eccentricity
Q_3 – correct factor for support length

Rail Seat Load Measurement – Laboratory Calibration



Crosstie Bending Moment Calculation Methodology



Rail Seat 1 Tie Center Rail Seat 2

$$M(railseat1) = (e_{S2} - e_{S1})EI_{12} / d_{12}$$

$$M(center) = (e_{S4} - e_{S3})EI_{34} / d_{34}$$

$$M(railseat2) = (e_{S6} - e_{S5})EI_{56} / d_{56}$$

Where,

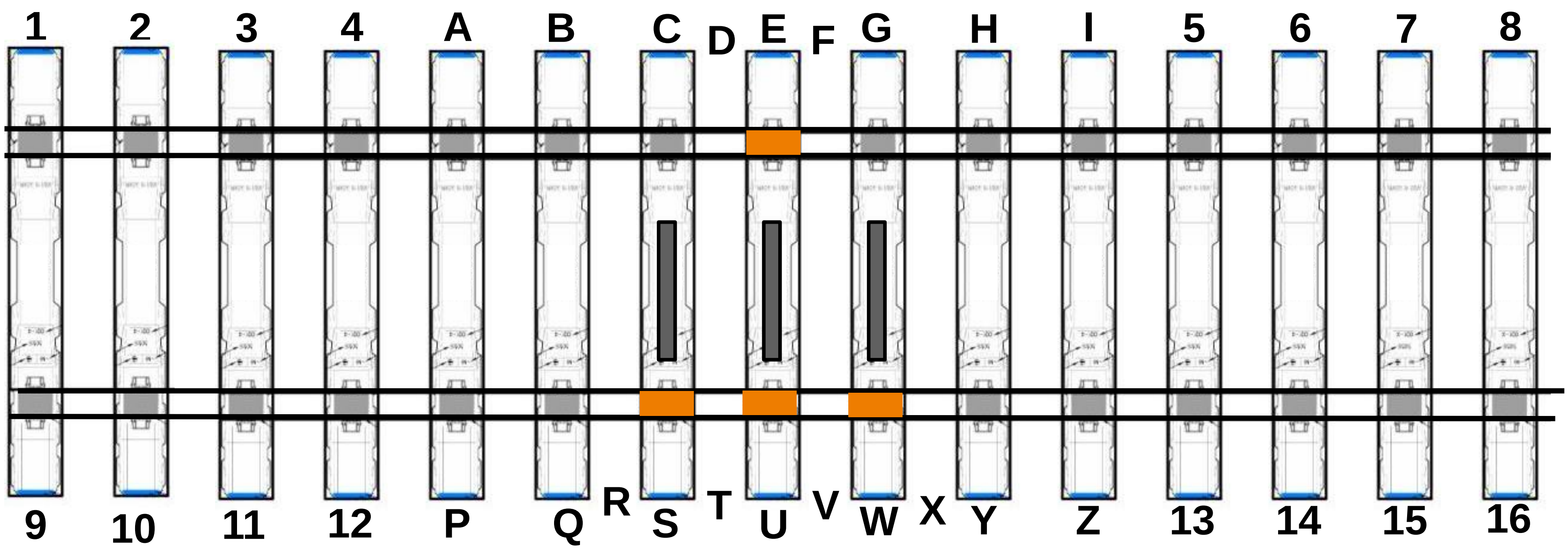
e: strain recorded from concrete surface gauge #1~#6

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

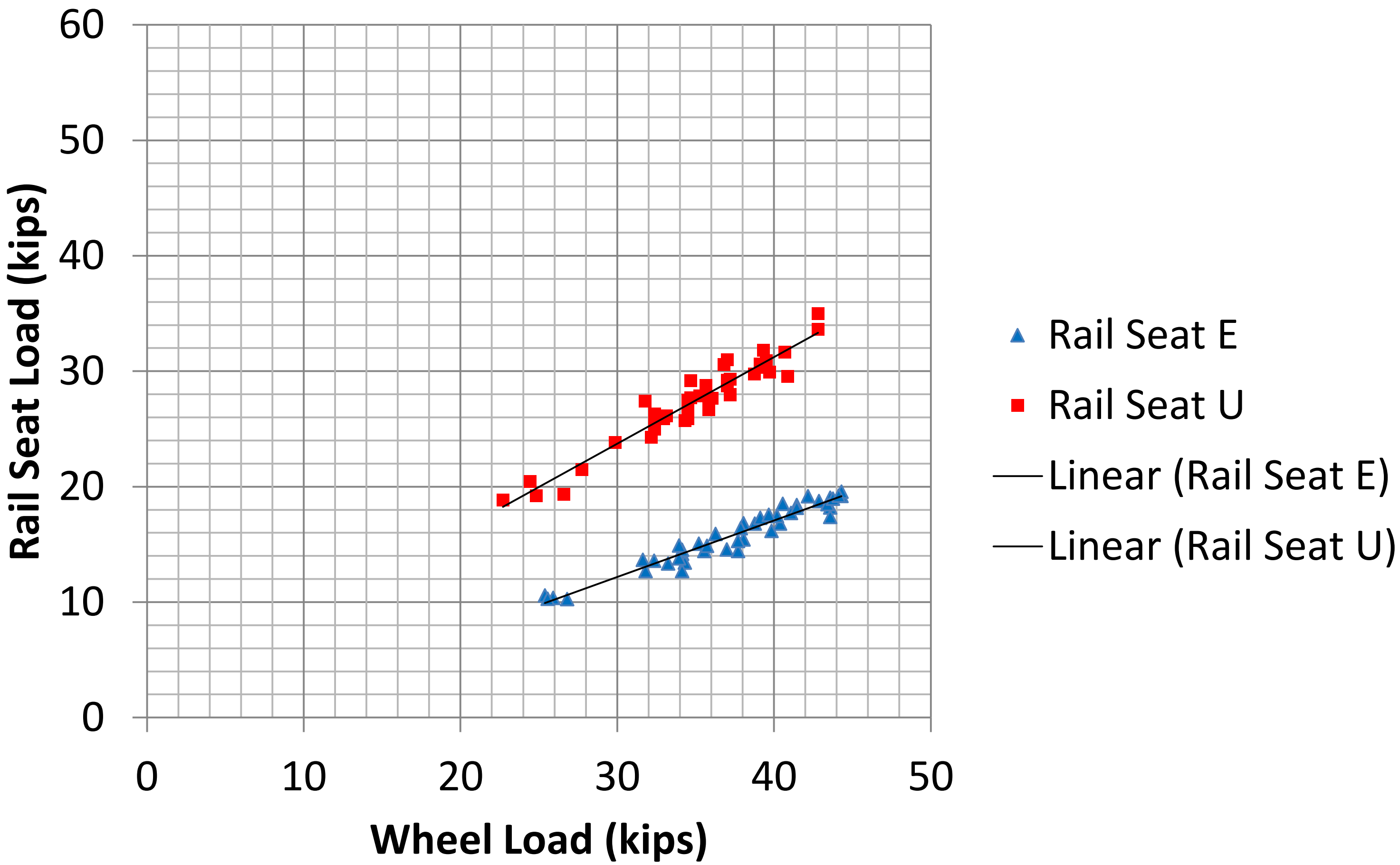
Instrumented Crossties

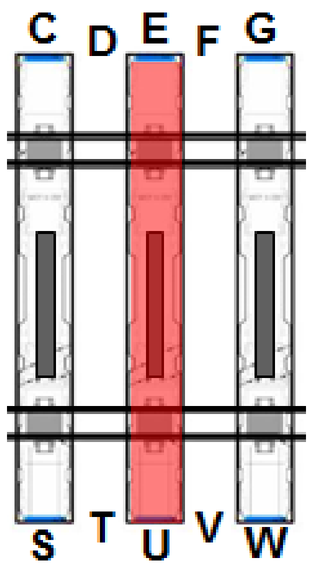


Embedment Gages, Vertical Circuit, Clip Strains

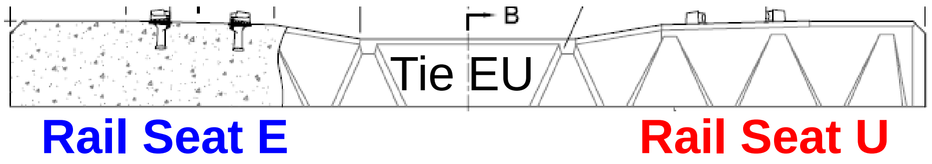
Crosstie Surface Strains

Rail Seat Load Under Dynamic Load: Rail Seat E & U by Wheel Load

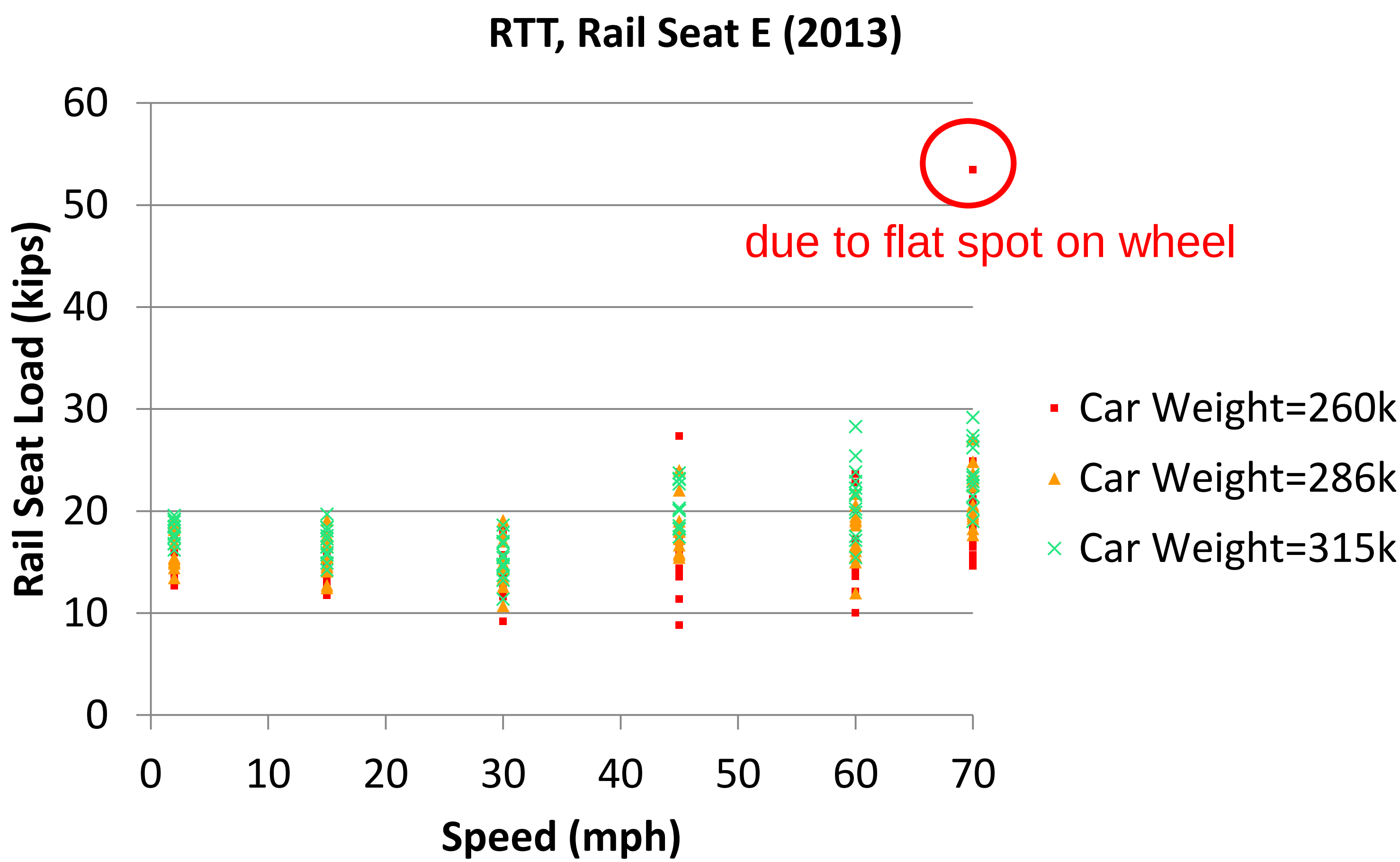


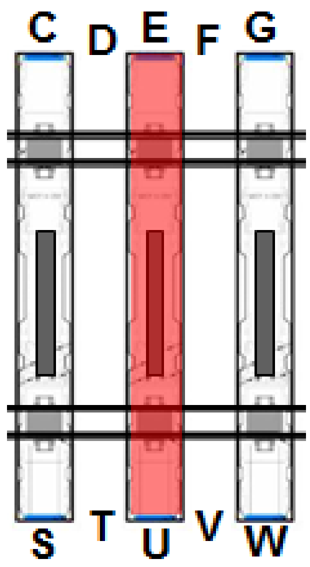


Tangent Track Speed = 2 mph

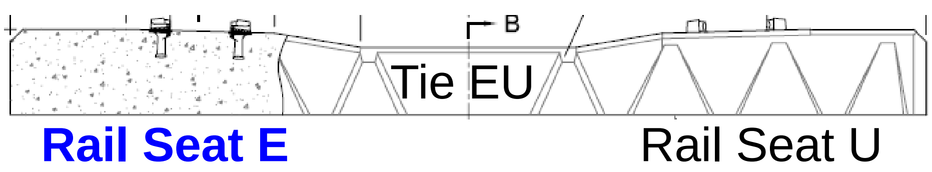


Rail Seat Load Under Dynamic Load: Rail Seat E by Car Type

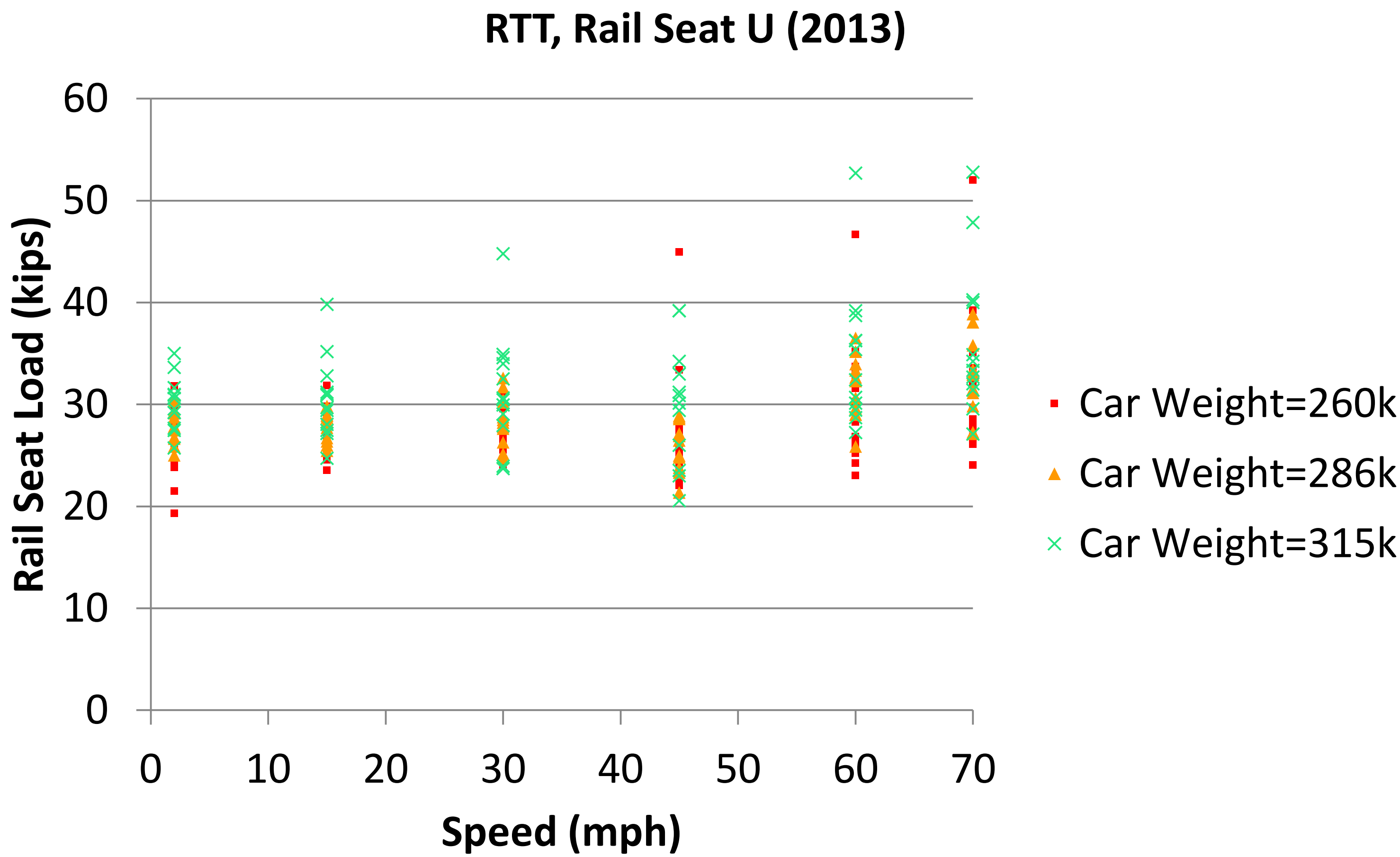


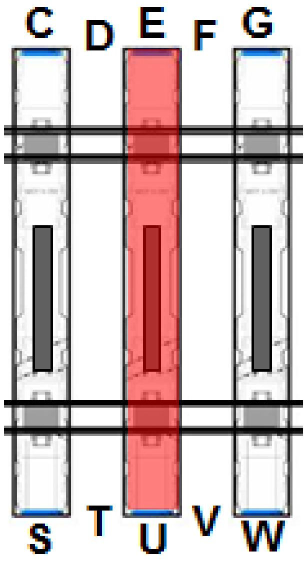


Tangent Track Speed = 2~70 mph

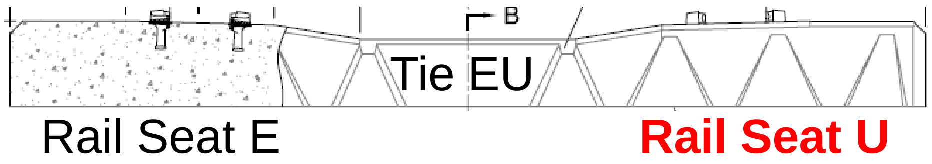


Rail Seat Load Under Dynamic Load: Rail Seat U by Car Type

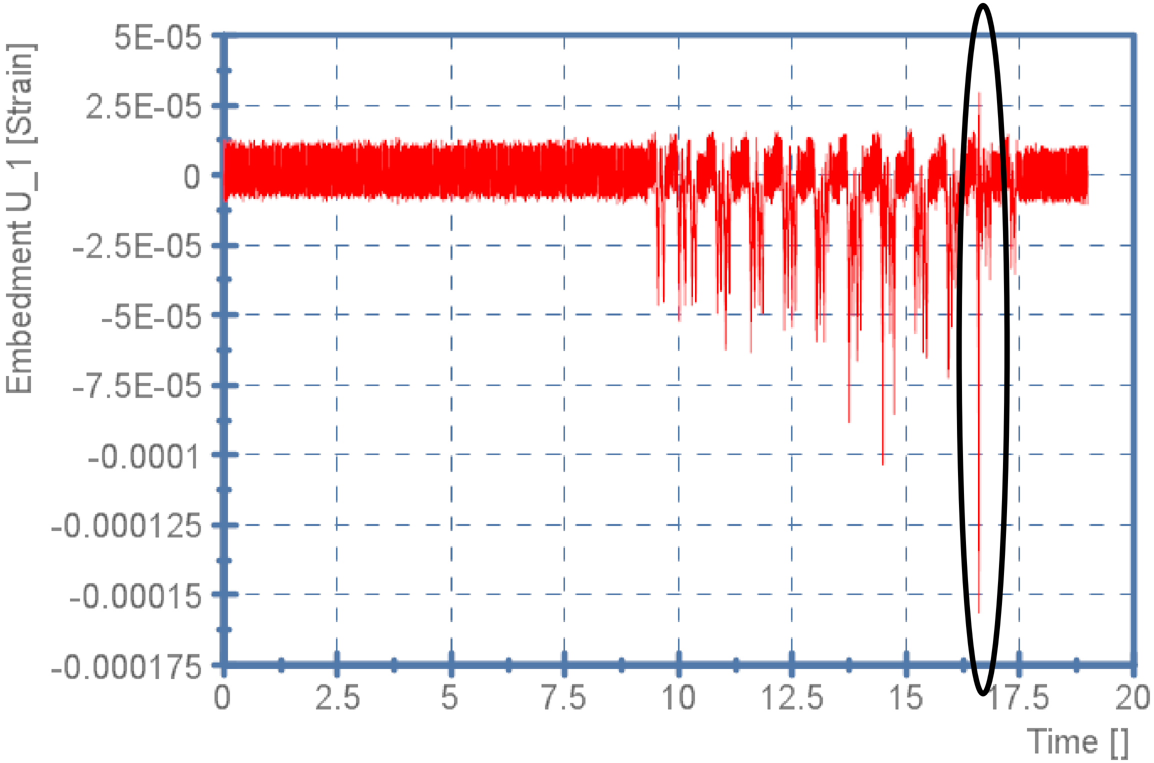


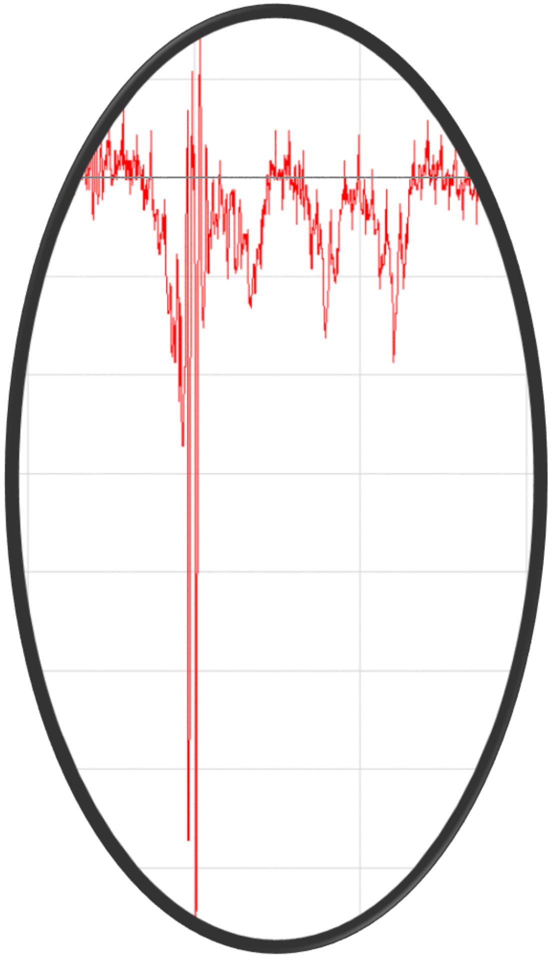


Tangent Track Speed = 2~70 mph



Flat Spot on Wheel

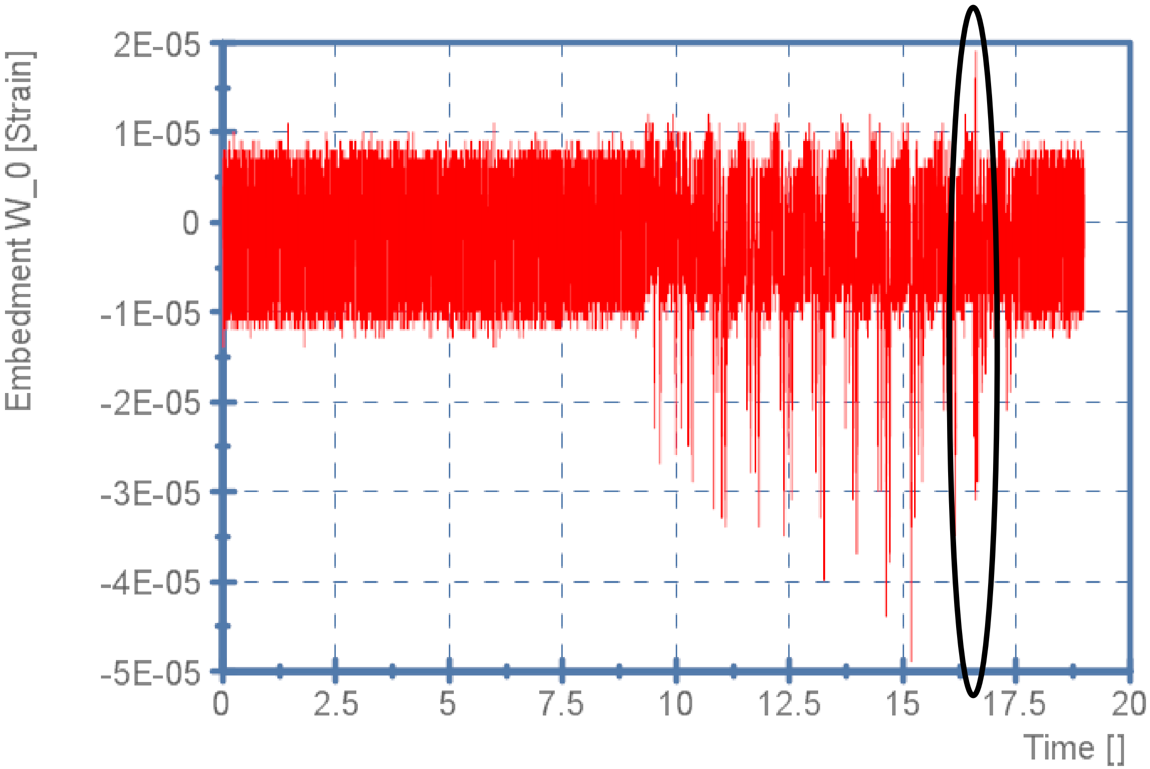


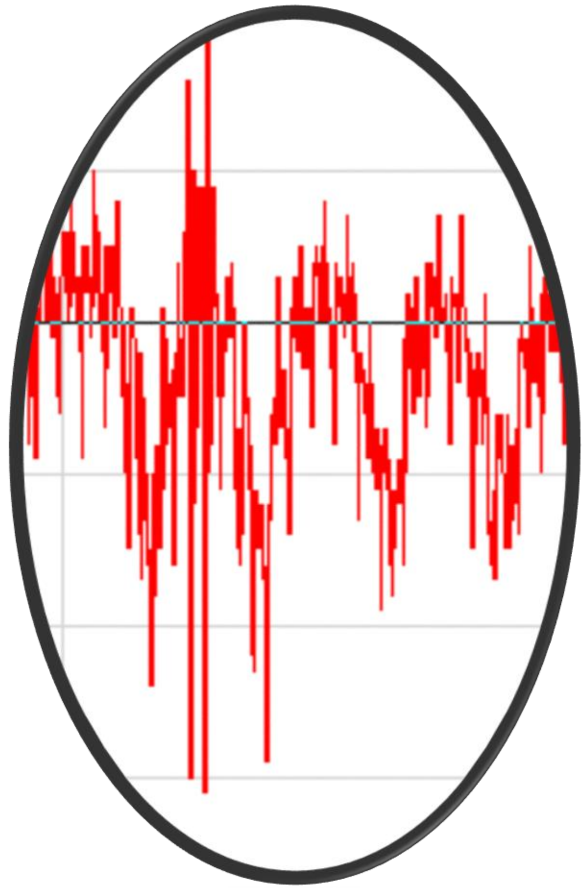


Flat spot hit rail right above the sensor

Tangent Track Speed = 45 mph
Flat spot on car #9 (1^{st} wheel)
Sensor: Embedment strain gauge @ rail-seat U

Flat Spot on Wheel

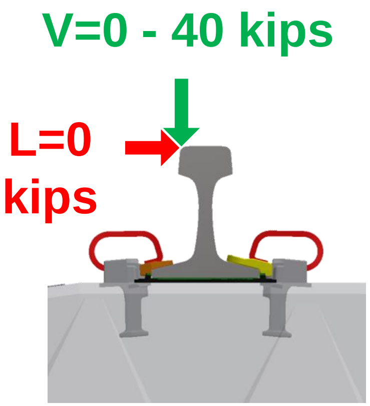


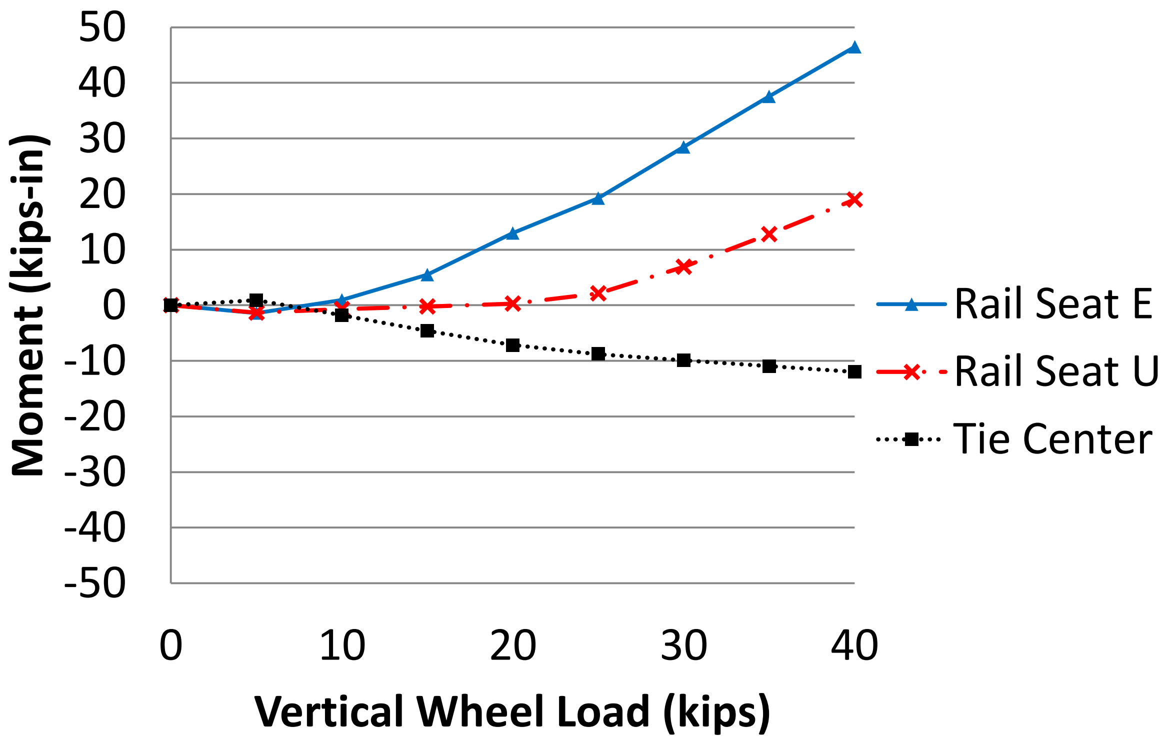


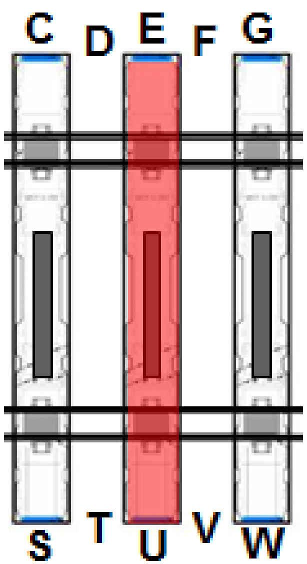
Flat spot hit rail away from the sensor

Tangent Track Speed = 45 mph
Flat spot on car #9 (1st wheel)
Sensor: Embedment strain gauge @ rail-seat W

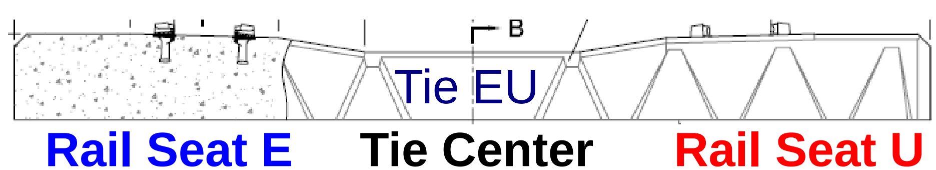
Bending Moments Under Static Load: Rail Seats E and U and Crosstie Center E-U



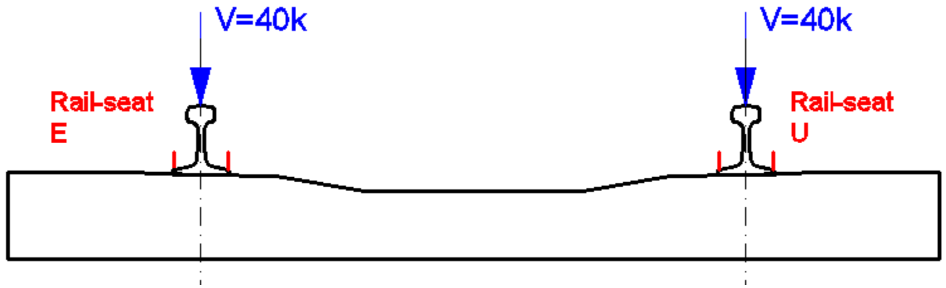


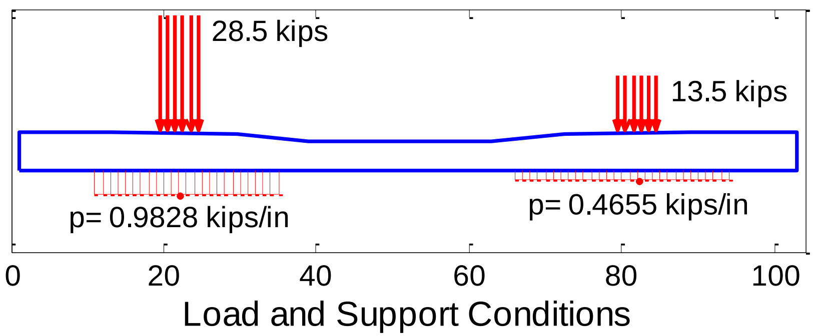


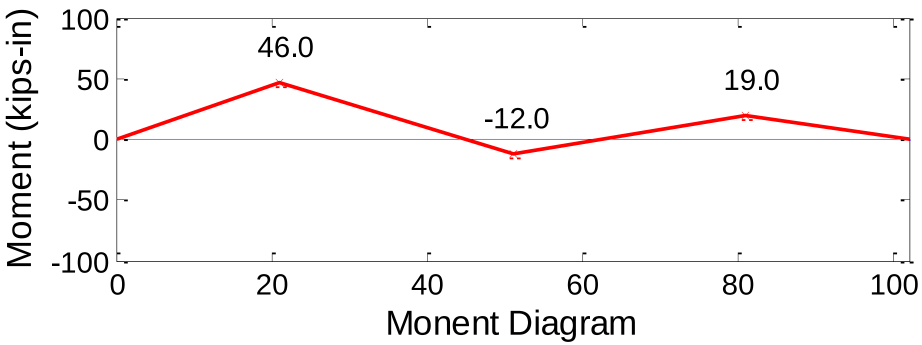
- Design rail seat cracking moments
  - positive: 405.6 k-in
  - negative: -219.6 k-in
- Design tie center cracking moment
  - positive: 196.8 k-in
  - negative: -256.8 k-in

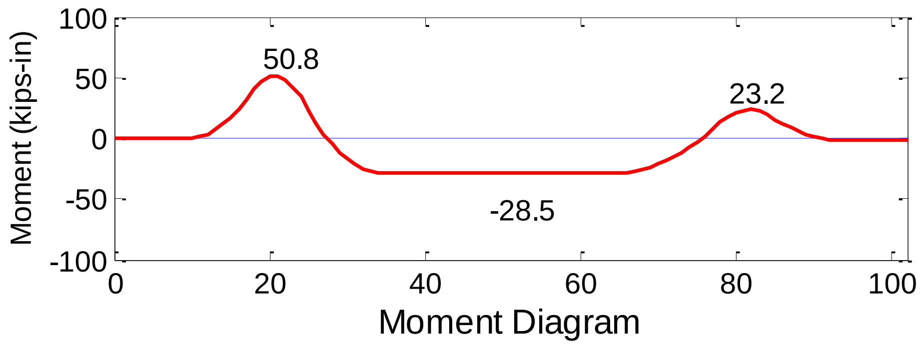


Discussion on Support Length









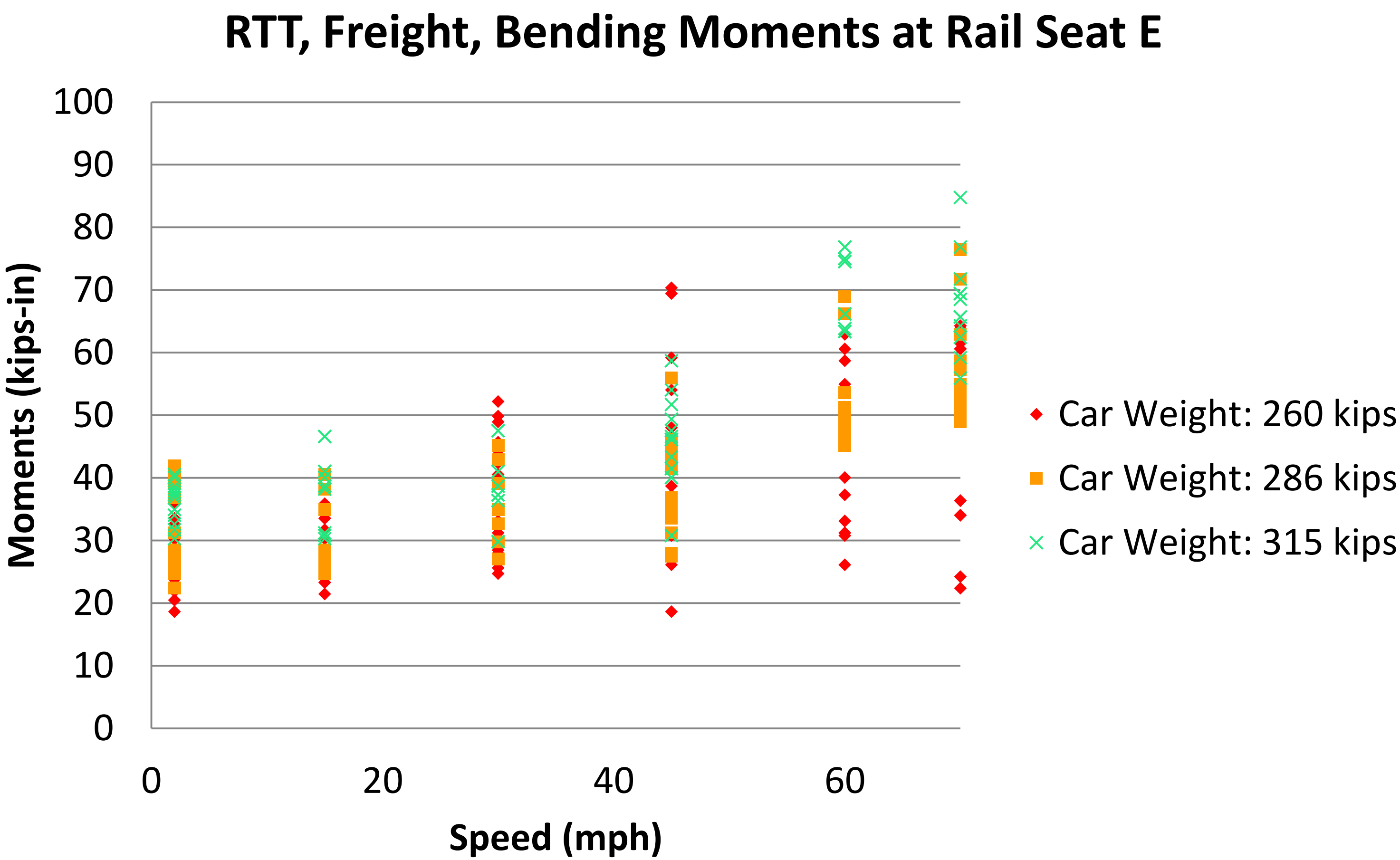
From field test

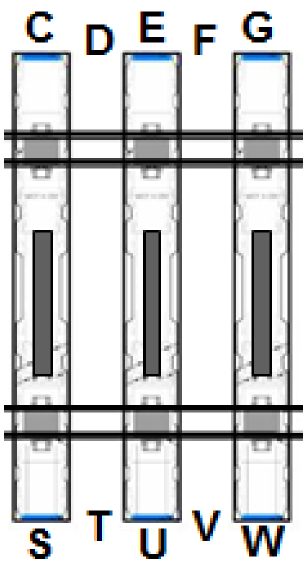
- Tangent track crosstie E-U
- Static loading
- 40 kips vertical wheel load
- 3 moment (strain) measurements from crosstie

From analysis

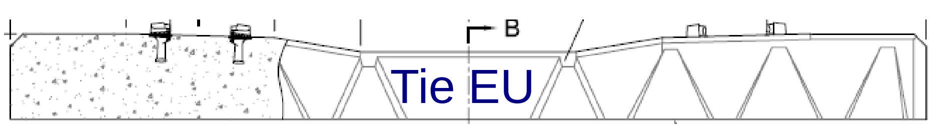
- Rail-seat loads were measured using embedment strain gauges
- Beam theory was applied
- Support conditions were calculated to match the moments measured

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

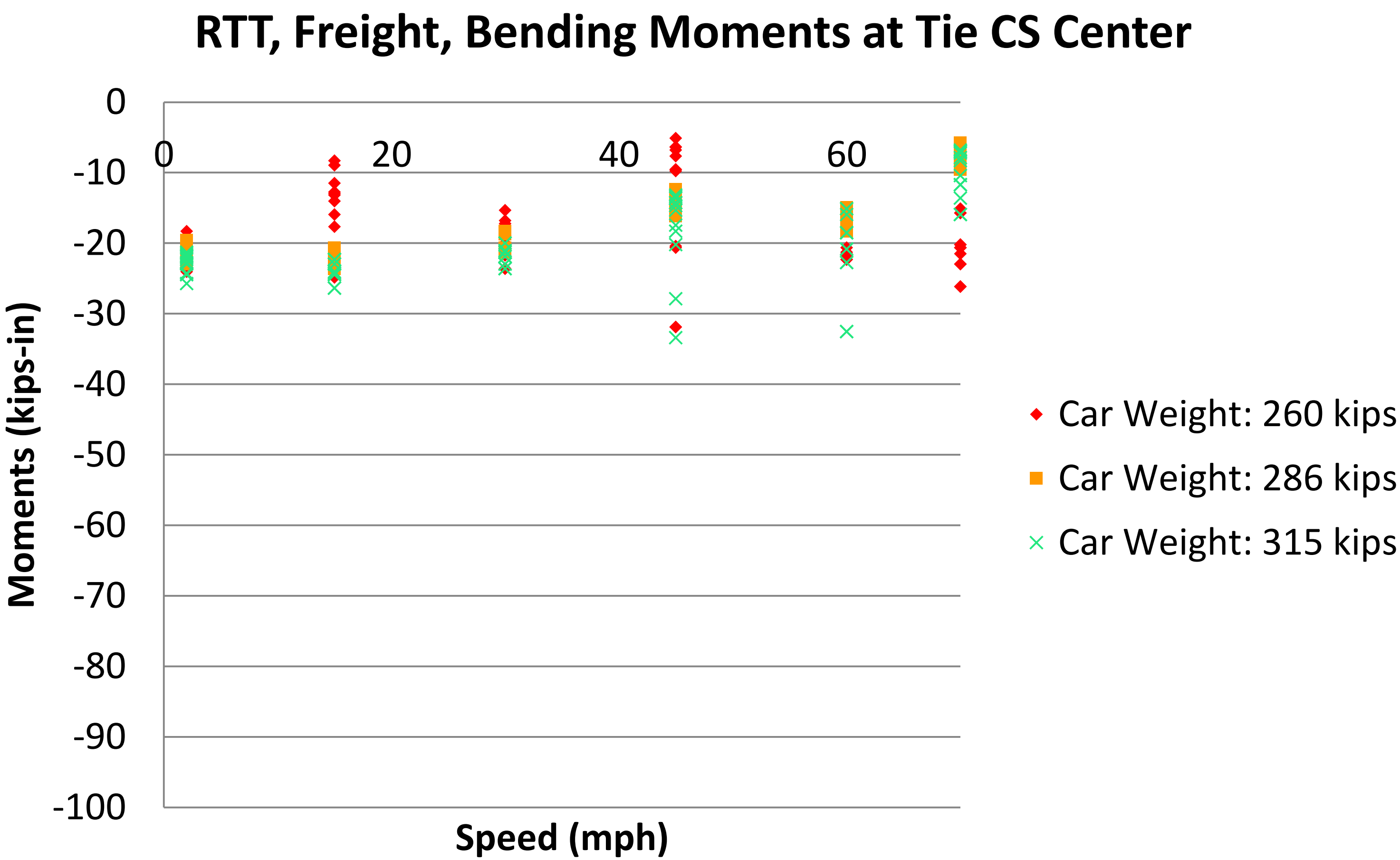


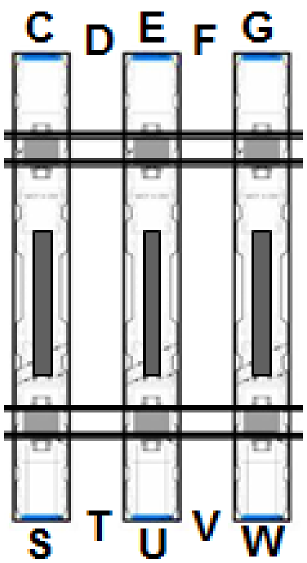


- Design rail seat cracking moments
  - positive: 405.6 k-in
  - negative: -219.6 k-in

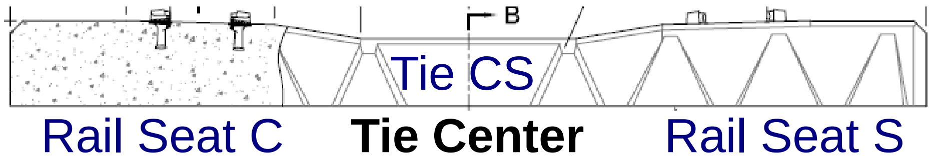


Bending Moments Under Dynamic Load: Crosstie Center C-S by Car Type





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

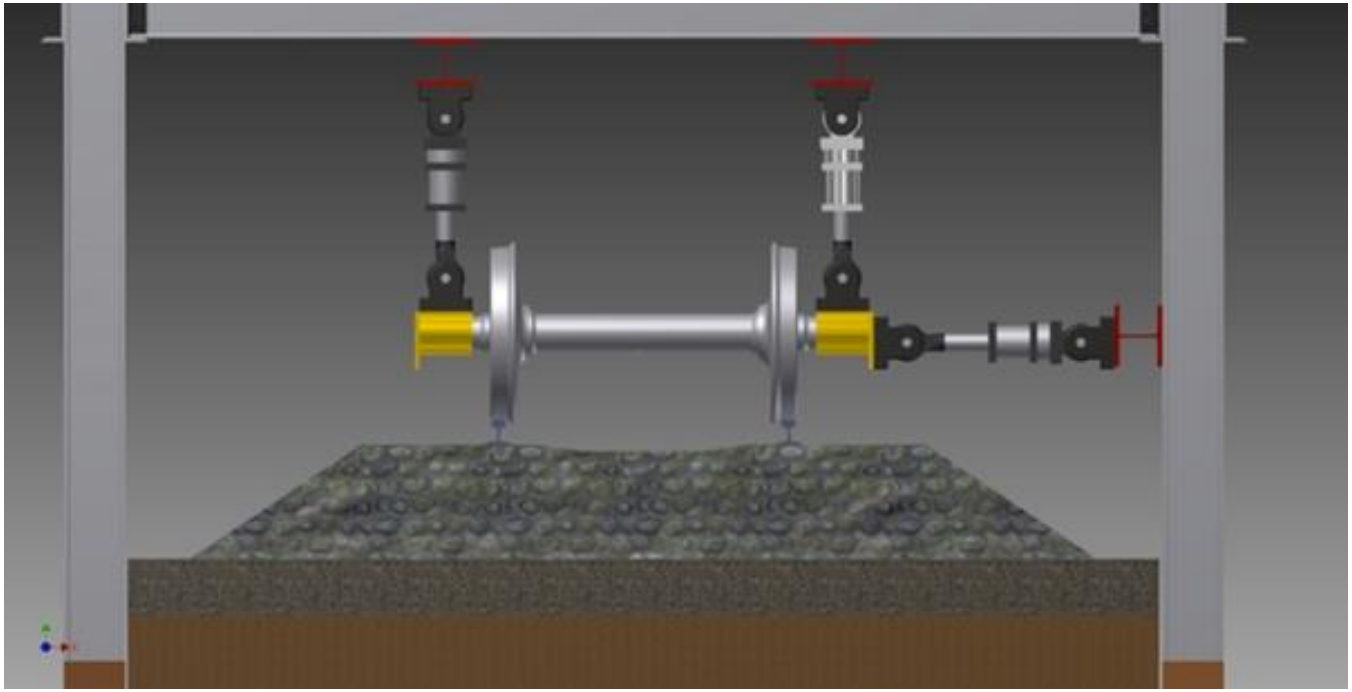


Conclusions

- 50%~75% of vertical wheel load was supported by the crosstie below the wheel
- In general, the recorded rail seat load and bending moment increased slightly as the nominal car weight increased
- The recorded rail seat load and bending moment at high speed shows more variability than at low speed
- Due to impact load (flat spot), the rail seat load recorded could be as great as 200% of normal rail seat load
- Bending moments recorded in field didn’t not approach the cracking limit
- Crosstie bending moment highly depended on the support condition (contact between crosstie and ballast)

Future Work

- Full-scale laboratory experiment with multiple crossties will be accomplished in Schnabel Lab in UIUC
- Various case of support conditions will be tested



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

FRA Tie and Fastener BAA Industry Partners:

Questions?

Sihang Wei
Graduate Research Assistant
Department of Civil and Environmental Engineering
University of Illinois, Urbana-Champaign
Email: wei22@illinois.edu