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

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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

**Finite Element Model**
- Laboratory Experimentation
- Field Experimentation
  - Parametric Analyses

**I – TRACK**
- Statistical Analysis from FEM
- Free Body Diagram Analysis
- Probabilistic Loading
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

Concrete compressive strength
- From crosstie manufacturer
  \( f'(28d) = 11,730 \text{ psi} \)
- From concrete core drill test & positive bending test
  \( f'(1ya) = 11,000 \text{ psi} \)
Using \( f' = 11,000 \text{ psi} \)

Concrete tensile strength
\( f_t = 7.5\sqrt{f'} = 787\text{psi} \)

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

Using BEAM theory
\[ M_{cracking} = f_t \cdot I / y \]
Where, \( I \) and \( y \) are geometry properties
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
Concrete embedment strains measured 2 inches below both rail seats

Concrete surface strains measured from one side surface of the crosstie
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Rail Seat Load Measurement – Using Embedment Strain Gauge

CXT, Tucson AZ (May 2012)
Rail Seat Load Measurement – Laboratory Calibration

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

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
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Crosstie Bending Moment Calculation Methodology

\[ M(\text{railseat} 1) = (e_{S2} - e_{S1})EI_{12} / d_{12} \]
\[ M(\text{center}) = (e_{S4} - e_{S3})EI_{34} / d_{34} \]
\[ M(\text{railseat} 2) = (e_{S6} - e_{S5})EI_{56} / d_{56} \]

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

Wheel Load (kips) vs. Rail Seat Load (kips)

- Rail Seat E
- Rail Seat U
- Linear (Rail Seat E)
- Linear (Rail Seat U)
Rail Seat Load Under Dynamic Load: Rail Seat E by Car Type

RTT, Rail Seat E (2013)

Rail Seat Load (kips)

Speed (mph)

- Car Weight=260k
- Car Weight=286k
- Car Weight=315k

due to flat spot on wheel

Tangent Track Speed = 2~70 mph
Rail Seat Load Under Dynamic Load: Rail Seat U by Car Type

RTT, Rail Seat U (2013)

- Car Weight=260k
- Car Weight=286k
- Car Weight=315k

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 (1st 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
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FRA Tie and Fastener BAA
Industry Partners:

[Logos of the industry partners]
Questions?

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