# Exploration of Alternatives for Prestressed Concrete Monoblock Crosstie Design Based on Flexural Capacity


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Matthew V. Csenge, Henry E. Wolf, Marcus S. Dersch, J. Riley Edwards, Ryan G. Kernes, and Mauricio Gutierrez

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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  - Center Negative Bending
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- Laboratory Testing
  - Prescribed Moments and Loads
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  - Testing Protocol
  - Experimental Results
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# Background

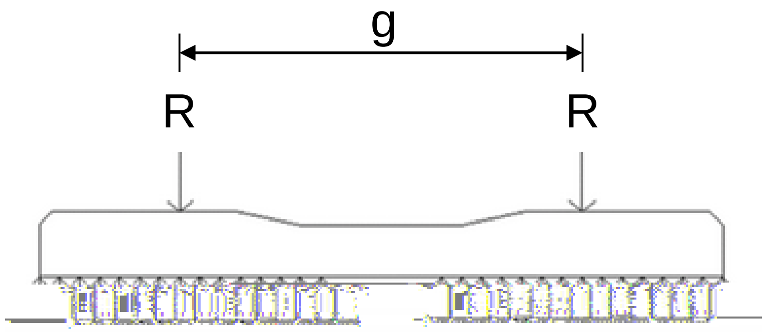
- Currently the majority of North American concrete crossties are 8'-6" in length
- Recently an 8'-0" crosstie has been developed and introduced to the industry
  - A shorter crosstie will experience different moment demands
  - 8'-0" crosstie design must account for different moment demands and be proven through lab and field testing
- When combined with a new manufacturing methodology the 8-0" crosstie has potential to improve efficiency of track structure, but only feasibly with advanced prestress reinforcement design
  - Eliminates need for transfer length
  - More uniform distribution of prestress force
  - Reduces internal stresses and risk of end splitting
  - Concrete and steel materials savings

# Methodology

- Because of the potential performance of these crossties, it was desired to investigate the effects of new crosstie design on the flexural capacity and behavior of the crosstie
- A flexural analysis was performed investigating:
  - Rail seat positive bending moments ($M_{RS+}$)
  - Center negative bending moments ($M_{C-}$)
- Laboratory testing was performed to determine actual moment capacities

# Flexural Analysis – Rail Seat Positive Bending Moment ($M_{RS+}$)

- Comparison of bending moments
  - AREMA 2014
  - Structural analysis




$$M_{RS+} = \frac{R(L-g)}{8}$$

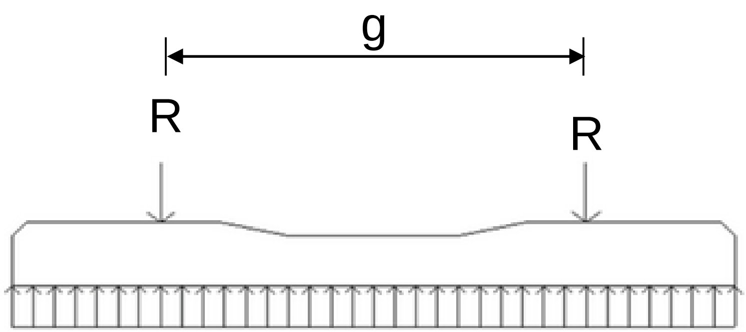
Where: g = rail seat center-to-center distance
R = rail seat load
L = crosstie length

| Crosstie Length (L) | AREMA 2014 | Structural Analysis |
|---|---|---|
| 8'-0" | 250 in-kip | 270 in-kip |
| 8'-6" | 300 in-kip | 315 in-kip |

- Structural analysis suggests less demanding rail seat positive bending moments for 8'-0" crossties

# Flexural Analysis – Center Negative Bending Moment ($M_{C-}$)

- Comparison of bending moments
  - AREMA 2014
  - Structural analysis




$$M_{C-} = R\left(\frac{g}{2} - \frac{L}{4}\right)$$

Where: g = rail seat center-to-center spacing
R = rail seat load
L = crosstie length

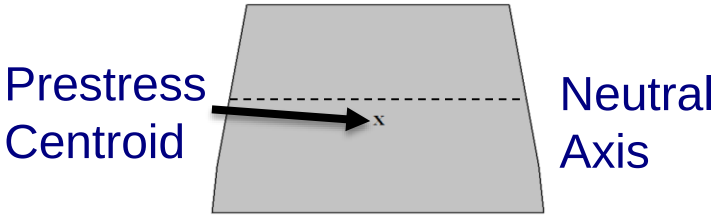
| Crosstie Length (L) | AREMA 2014 | Structural Analysis |
|---|---|---|
| 8'-0" | 230 in-kip | 360 in-kip |
| 8'-6" | 201 in-kip | 270 in-kip |

- Structural analysis suggests more demanding center negative bending moments for 8'-0" crossties

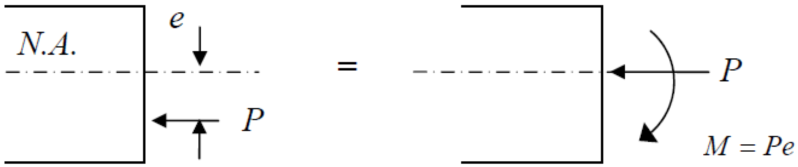
# Theoretical Flexural Capacity (Section Geometry)

- In response to the higher $M_{C-}$ demand, cross sectional properties must be changed to ensure that the crosstie performs adequately under field loading conditions
- To compare the cross-sectional properties of the 8'-0" and 8'-6" crossties a comparison of the following was made:
  - Area

  - Moment of inertia
    - $I \approx {bh^3}/{12}$ - exact I calculated by Response 2000 software
  - Height of prestress centroid




  - Prestress eccentricity



# Theoretical Flexural Capacity (Section Geometry - cont.)

| Location | Area ($in^2$) | Moment of Inertia ($in^4$) | Height of Prestress Centroid (in) | Prestress Eccentricity*+ (%) |
|---|---|---|---|---|
| 8'-0" $M_{RS+}$ | 97 | 670 | 4.1 | 4.9 |
| 8'-6" $M_{RS+}$ | 90 | 650 | 4.1 | -2.3 |
| 8'-0" $M_{C-}$ | 77 | 458 | 3.9 | 15.0 |
| 8'-6" $M_{C-}$ | 60 | 296 | 3.9 | -5.7 |

* *Positive prestress eccentricity below bending neutral axis, resists positive bending*

\+ *Prestress eccentricity expressed as a percentage of section height*

- 8'-0" crosstie has a larger area at the rail seat and center
- The height of prestress centroid is the same for both crossties
  - Prestress pattern may differ

# Introduction to Laboratory Testing

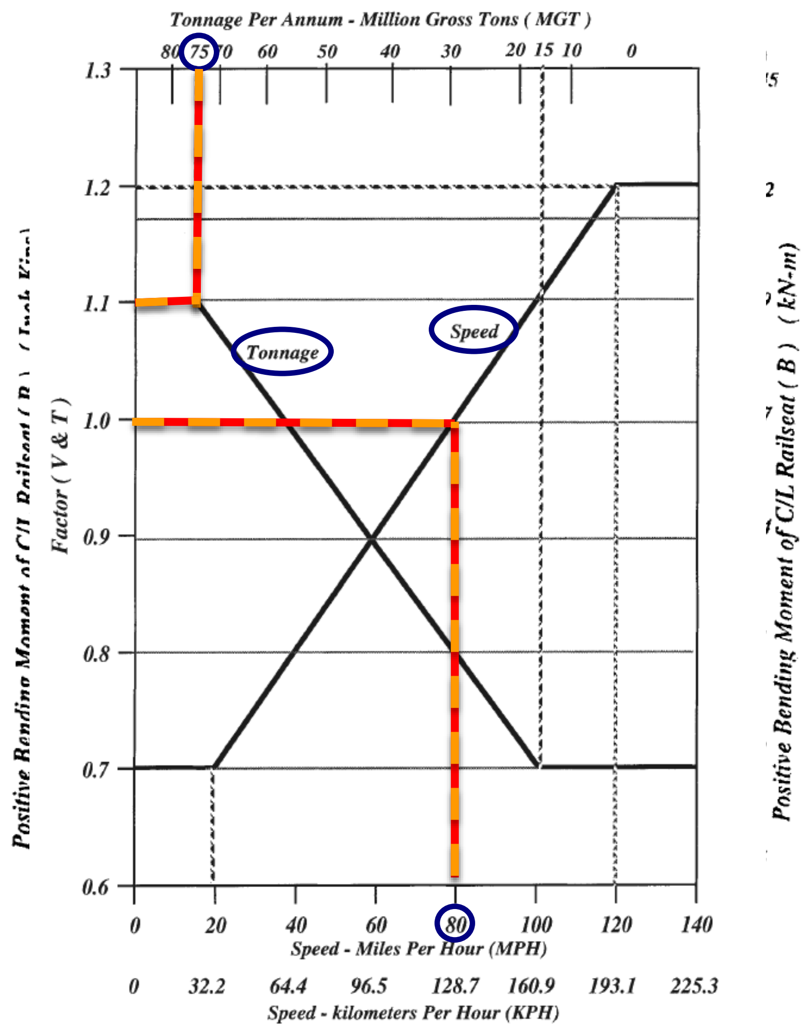
- Laboratory testing was performed to validate structural analysis results as well as determine actual capacity of the crossties
- Loads to be applied during lab testing were calculated using the equations and figures provided in Article 30.4.4.1 of the 2014 AREMA Manual

# Determination of Moments and Loads

$$M_{RS+} = BVT$$

Where: $M_{RS+}$ = rail seat positive bending moment
B = the bending moment in inch-kips for a particular crosstie length and spacing
V = the speed factor
T = the tonnage factor

| Factor | Assumed or Determined Value |
|---|---|
| Crosstie Spacing (in) | |
| B (8'-0" Crosstie) (in-kips) | |
| B (8'-6" Crosstie) (in-kips) | |
| Speed (mph) | |
| V | |
| Annual Tonnage (MGT) | |
| T | |




*Equations and figures from Article 30.4.4.1 of the 2014 AREMA Manual*

# Prescribed Moments and Loads

| Test | Moment Factor* (8'-0") | Moment Factor* (8'-6") | Prescribed Moment (8'-0") (in-kips) | Prescribed Moment (8'-6") (in-kips) |
|---|---|---|---|---|
| $M_{RS+}$ | 1 | 1 | 275 | 330 |
| $M_{RS-}$ | 0.64 | 0.53 | 176 | 175 |
| $M_{C+}$ | 0.56 | 0.47 | 154 | 155 |
| $M_{C-}$ | 0.92 | 0.67 | 253 | 221 |

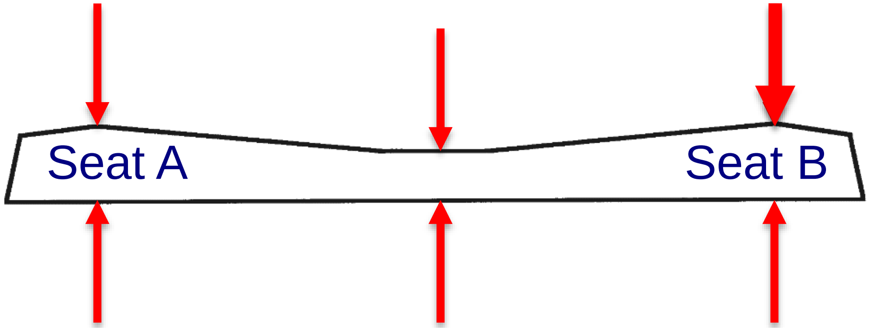
- Loads selected as a baseline for comparison are representative of common values used by North American freight railroads

| Test | Load (kips) |
|---|---|
| $M_{RS+}$ | 64 |
| $M_{RS-}$ | 32 |
| $M_{C+}$ | 12 |
| $M_{C-}$ | 17 |

**Factors from Article 30.4.4.1 of the 2014 AREMA Manual*

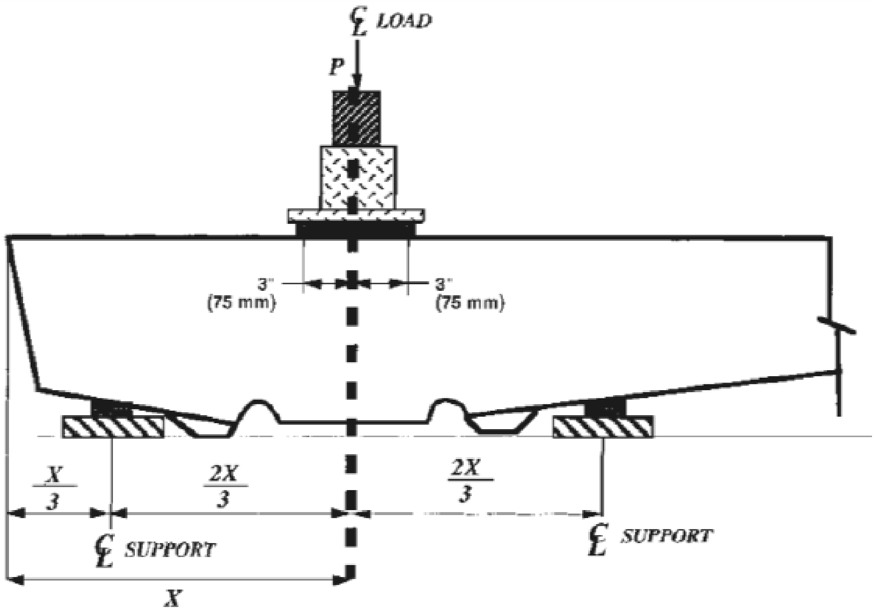
# Sequence of Laboratory Tests

- Per AREMA Chapter 30, Section 4.9.1.1
  - Rail Seat Negative Moment Test ($M_{RS-\ A}$)
  - Rail Seat Positive Moment Test ($M_{RS+\ A}$)
  - Center Negative Bending Moment Test – Modified ($M_{C-}$)
  - Center Positive Bending Moment Test ($M_{C+}$)
  - Rail Seat Negative Moment Test ($M_{RS-\ B}$)
  - Rail Seat Positive Moment Test ($M_{RS+\ B}$)
  - Rail Seat Repeated Load Test – Modified – Seat B



# Testing Protocol: Rail Seat Negative

- Load was applied continuously in the location and direction specified until the desired load was reached
- This load was held for 3 minutes while the crosstie was inspected for cracks



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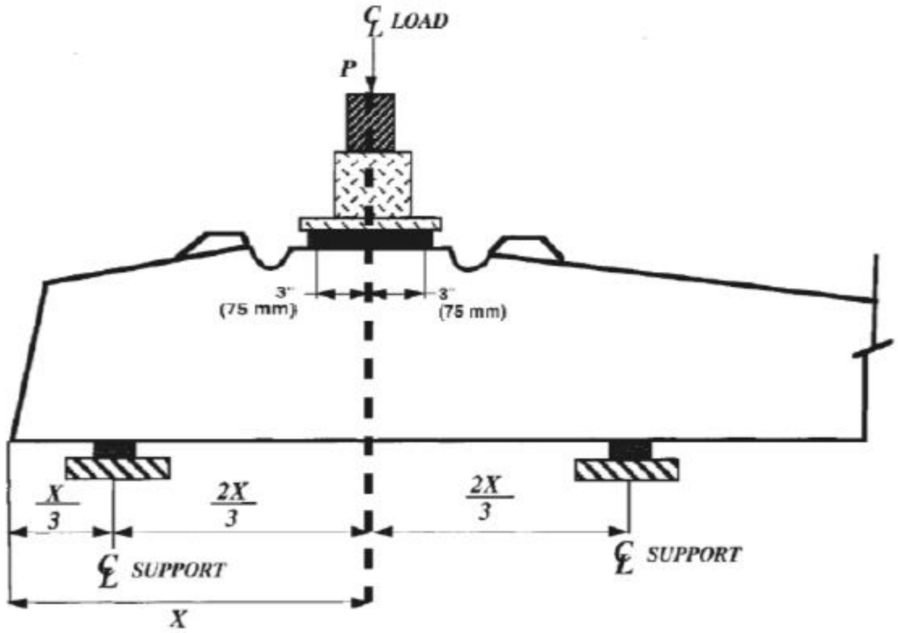
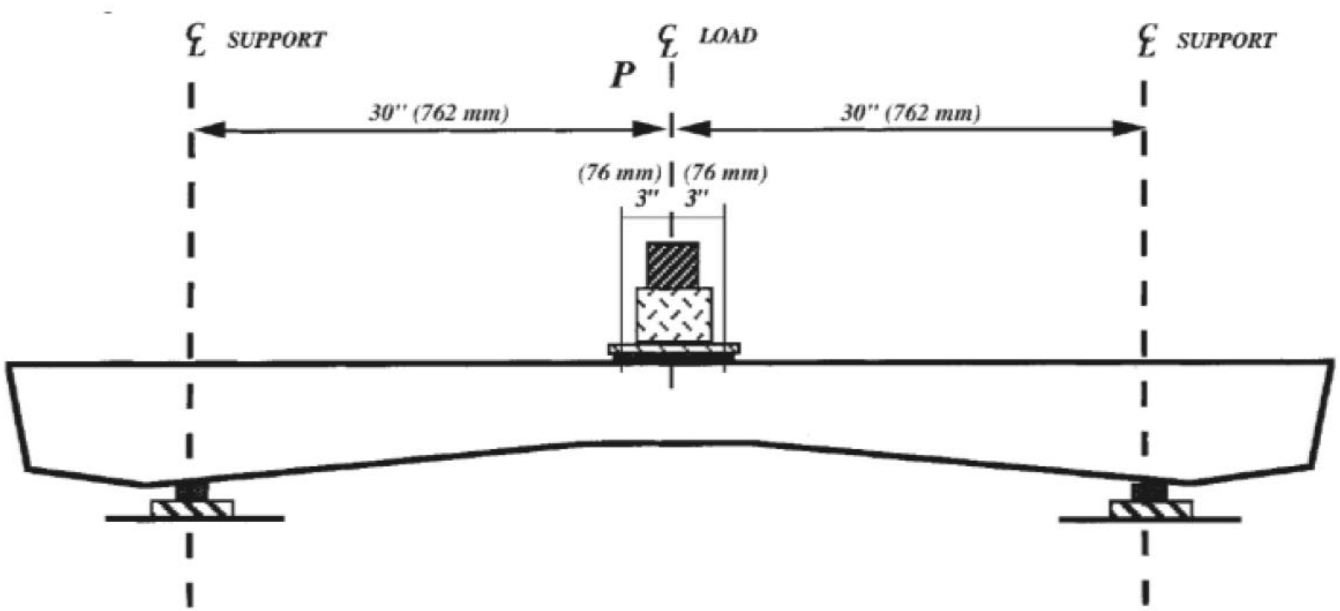


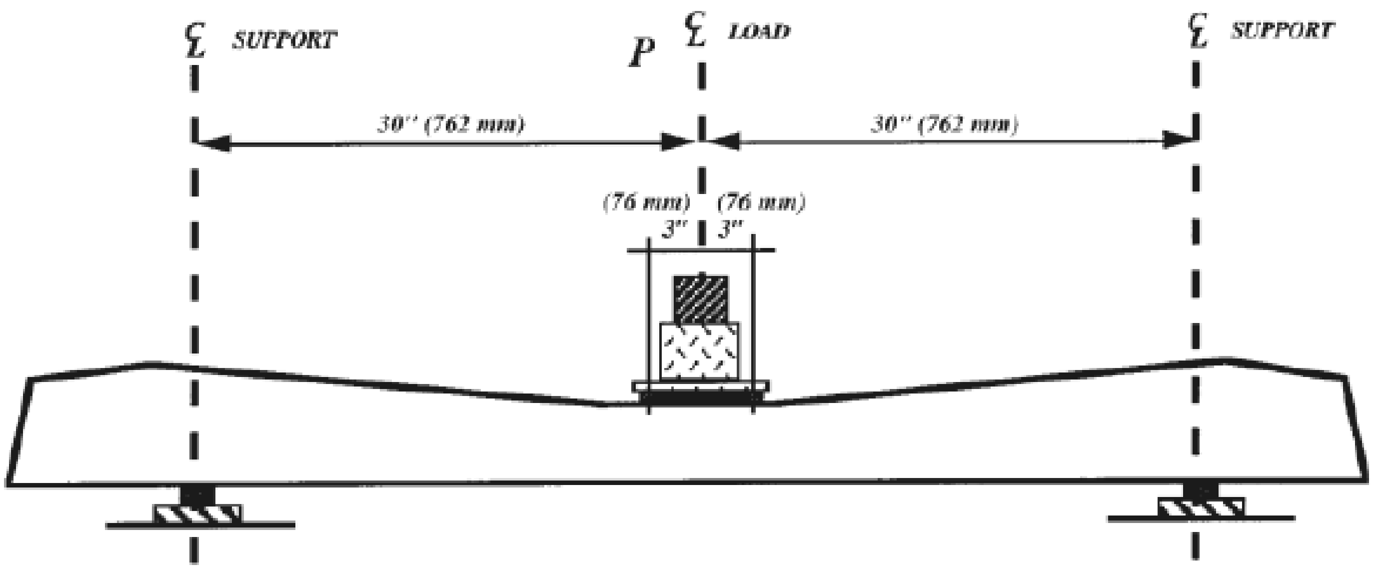
# Testing Protocol: Center Negative

- Load was applied continuously until the desired load was reached
- This load was held for 3 minutes while the crosstie was inspected for cracks



# Testing Protocol: Center Positive

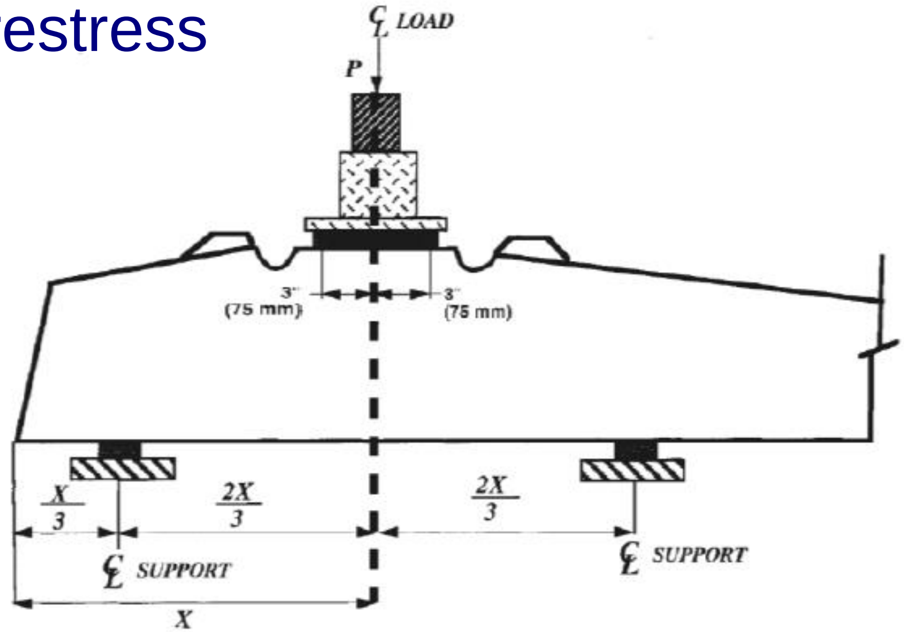
- Load was applied continuously until the desired load was reached
- This load was held for 3 minutes while the crosstie was inspected for cracks



# Testing Protocol

## Rail Seat Repeated Load - Modified

- Immediately following the rail seat positive test on Seat B, load was increased until structural cracking was observed
- As per AREMA, structural cracking is defined as a crack that propagates from the tensile face to the first layer of prestress



# Experimental Results

| Test | Prescribed Load (kips) | Crosstie | | | | | |
|---|---|---|---|---|---|---|---|
| | | S1[1] | S2 | S3 | L1[2] | L2 | L3 |
| $M_{RS-\ A}$ | 32.0 | Pass | Pass | Pass | Pass | Pass | Pass |
| $M_{RS+\ A}$ | 64.0 | Pass | Pass | Pass | Pass | Pass | Pass |
| $M_{C-}$ | 17.0 | Pass | Pass | Pass | 17.0*+ | 17.0*+ | Pass |
| $M_{C+}$ | 12.0 | 12.0*+ | Pass | Pass | Pass | Pass | Pass |
| $M_{RS-\ B}$ | 32.0 | Pass | Pass | Pass | Pass | Pass | Pass |
| $M_{RS+\ B}$ | 64.0 | Pass | Pass | Pass | Pass | Pass | Pass |
| Structural Failure (RS+) | | | | | | | |
| Test Load (kips) | N/A | 73.0 | 77.4 | 78.5 | 85.1 | 74.9 | 85.9 |
| Moment (in-kips) | N/A | 355.9 | 377.3 | 382.7 | 500.0 | 440.0 | 504.7 |

*[1]Short crosstie (8'-0")*
*[2]Long crosstie (8'-6")*
**Structural cracking was noted during 3 minute observation period*
*+Units are kips*

# Conclusions

- Flexural analysis confirmed that under similar loading conditions a shorter crosstie will:
  - Experience lower rail seat positive bending moments
    - Shorter lever arm for rail seat positive bending
  - Greater center negative bending moments
    - Shorter length resisting rail seat loads
- Based upon flexural capacity analysis and testing of actual crossties the shorter crosstie has greater flexural capacity in:
  - Center positive bending
  - Center negative bending
  - Rail seat negative bending
- Both crosstie types exhibited flexural capacity beyond the prescribed test loads and the theoretical bending moments

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# Contact Information

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

**Matthew V. Csenge**
*Graduate Research Assistant*
email: holder2@Illinois.edu

**Henry E. Wolf**
*Graduate Research Assistant*
email: csenge2@Illinois.edu

**Marcus S. Dersch**
*Senior Research Engineer*
email: mdersch2@Illinois.edu

**J. Riley Edwards**
*Research Scientist and Senior Lecturer*
email: jedward2@Illinois.edu

**Ryan G. Kernes**
Engineer & Technology Development Manager
email: rkernes@gic-usa.com

**Mauricio Gutierrez**
Vice President – Commercial Director
email: mgutierrez@grupogic.com