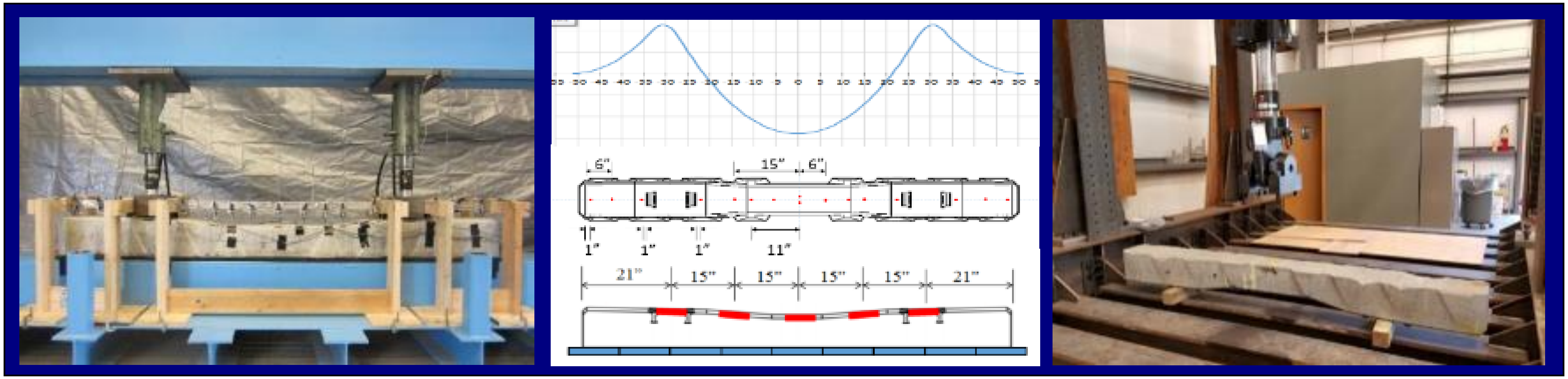
Investigation of Deteriorated Crossties and Support Conditions



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U.S. Department of Transportation
Federal Railroad Administration

Outline

- Motivation and Industry Impact
- Phase 1: Healthy vs Cracked Crossties
  - Matrix, Instrumentation, and Setup
  - Results
  - Phase 1 Conclusions
- Phase 2: More Severe Crosstie Cracking & Prestress Loss
  - Methodology
  - Results
- Path Forward – Phase 3
  - Load vs Displacement as Design Metric
  - Center Negative Repeated Load Test

Motivation for Research

- Analysis of FRA accident database indicated that deteriorated concrete crossties and support conditions are among major track related accident causes in the US

- The Industry Survey conducted by UIUC reported that North American Class I Railroads and other railway infrastructure experts would like to see laboratory experiments on concrete crosstie support conditions

Broken crosstie

Fouled ballast

Expected Industry Impact

Expected Impacts

- Improved safety
- Improved failed crosstie definition
- Improved AREMA chapter 30 test and design protocol
- Crosstie bending moment range with varying support and load
- Crosstie load vs. deflection and gauge widening characterization
- Estimation of crosstie support condition based on bending moment measurements and cracking observation

Impacted Groups

- Railroads
- Crosstie manufacturers
- AREMA Committee 30
- Federal Railroad Administration

Phase 1:
Healthy vs Cracked Crossties

Healthy vs. Cracked Crossties

Further Deteriorated Crossties

New Setup

Load vs. Displacement

Dynamic Test

Phase 1 Experimental Matrix

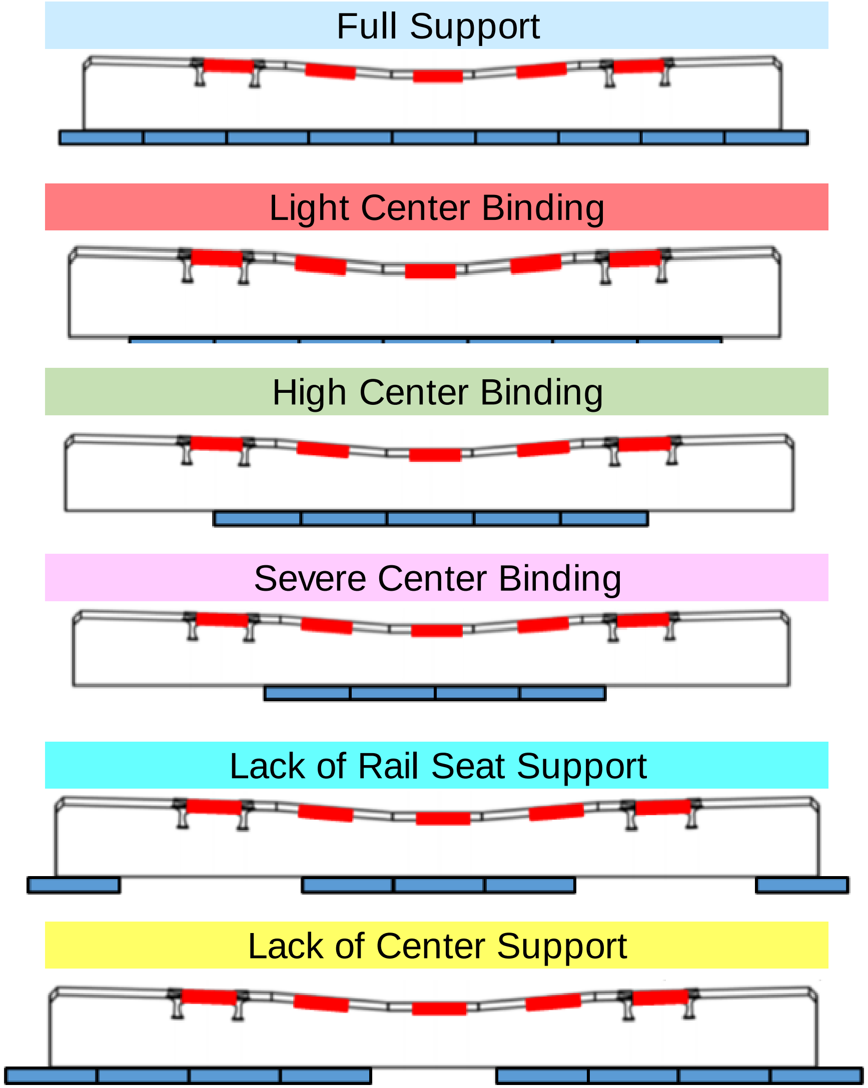
- **Phase 1a**
- 12 combinations of support conditions and crosstie health variation
- Matrix was executed five times to account for variability
- **Phase 1b**
- Additional tests executed on a different crosstie design at two levels of support
- Matrix was executed three times to account for variability

FRA BAA 2014-2 Test Matrix 1

Run Number	Support Condition	Crosstie Condition	Purpose	Rail Seat Load	
Phase 1a				*kips*	*kN*
1	1	Healthy Crosstie - Design A	Baseline - Healthy Crosstie, Full Support	0-20	0-89
2	2		Healthy Crosstie, Light Center Binding		
3	3		Healthy Crosstie, Moderate Center Binding		
4	4		Healthy Crosstie, Severe Center Binding		
5	5		Healthy Crosstie, High Impact Loads		
6	6		Healthy Crosstie, Newly Tamped		
7	1	Center Cracked Crosstie (Beyond First Level of Presstress)	Deep Cracks, Full Support		
8	2		Deep Cracks, Light Center Binding		
9	3		Deep Cracks, Moderate Center Binding		
10	4		Deep Cracks, Severe Center Binding		
11	5		Deep Cracks, High Impact Loads (Rail Seat Positive)		
12	6		Deep Cracks, Newly Tamped		
Phase 1b					
13	1	Healthy Crosstie - Design B	Healthy Crosstie, Full Support		
14	4		Healthy Crosstie, Severe Center Binding		

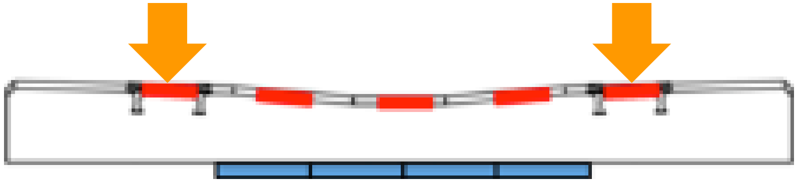
Support Conditions

- **Support conditions**
  - Proper support
  - Center binding
  - Rail seat positive
- **Cases were based on:**
  - Field conditions
  - Expert opinion
  - Industry partners feedback on draft experimental matrix

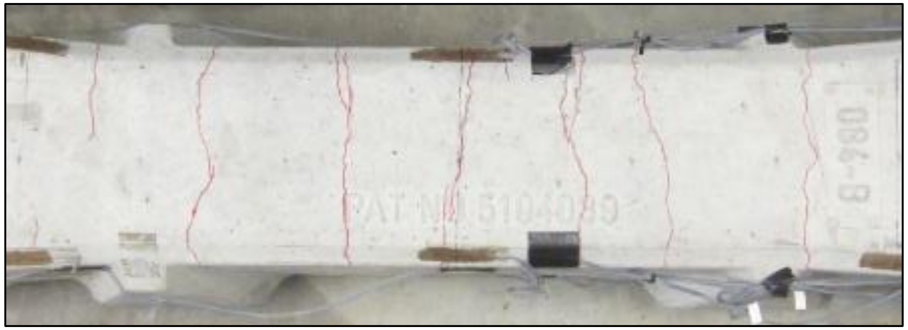


Crosstie Cracking

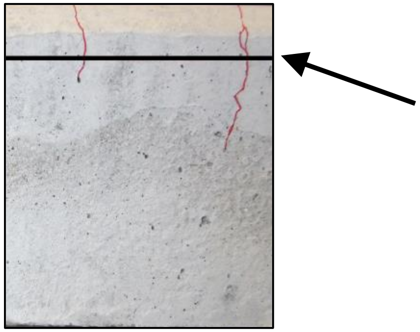
- All cracks were generated with a severe center binding support condition and load of 20 kips applied at each rail seat



- Cracks along the crosstie span were approximately symmetric about the center
- Cracks closed up after unloading (indication of prestressing members)
- Cracks were deeper than the first level of prestress
  (*e.g. failure for AREMA center negative test*)
- Cracked crossties are not classified as failed crossties according to CFR 213



Plan view of cracked crosstie

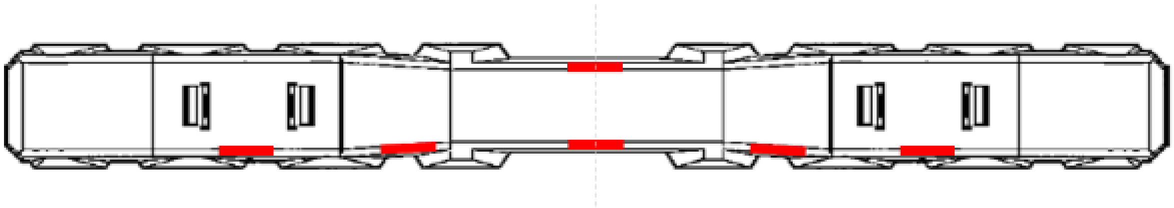


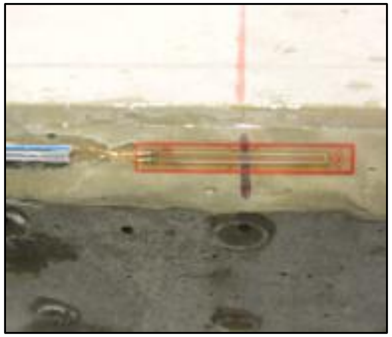
First level of prestress

Profile view

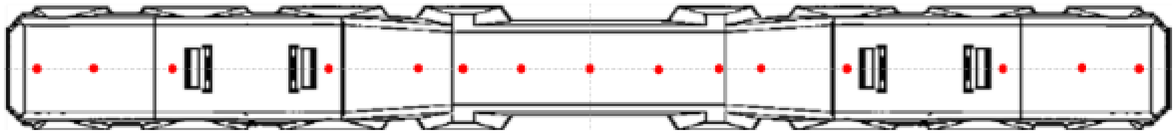
Measurement Devices

- **Surface Strain Gauges**
  - Calculation of bending moments



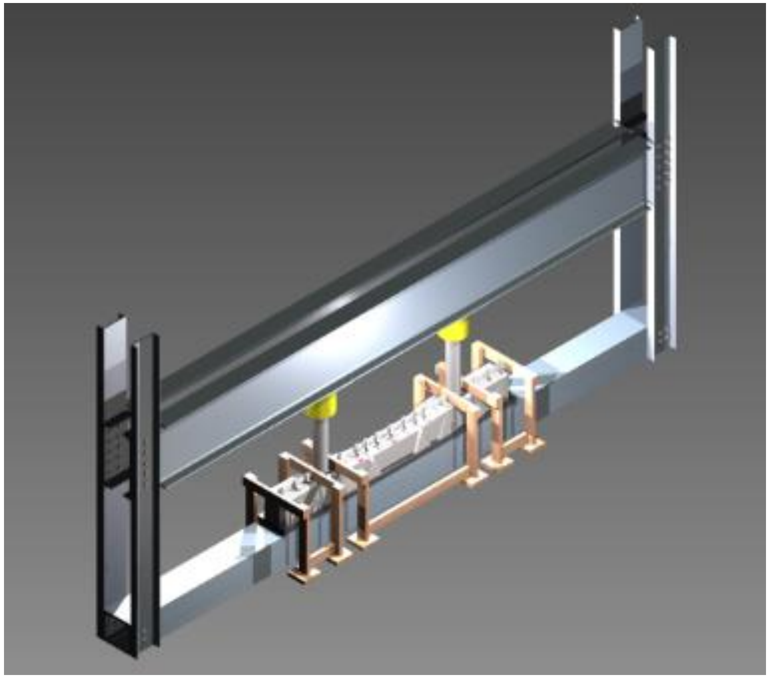


- **Linear Potentiometers**
  - Measurement of vertical displacements
  - Estimation of crosstie shape and gauge widening

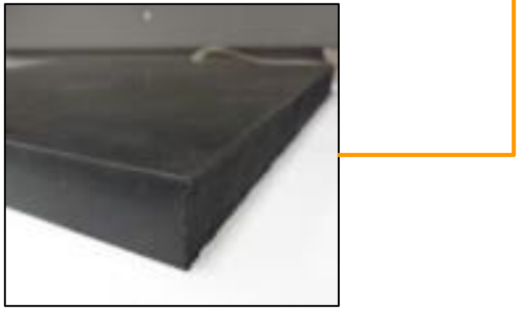


Static Loading Testing Machine (SLTM)

- **Loading frame**

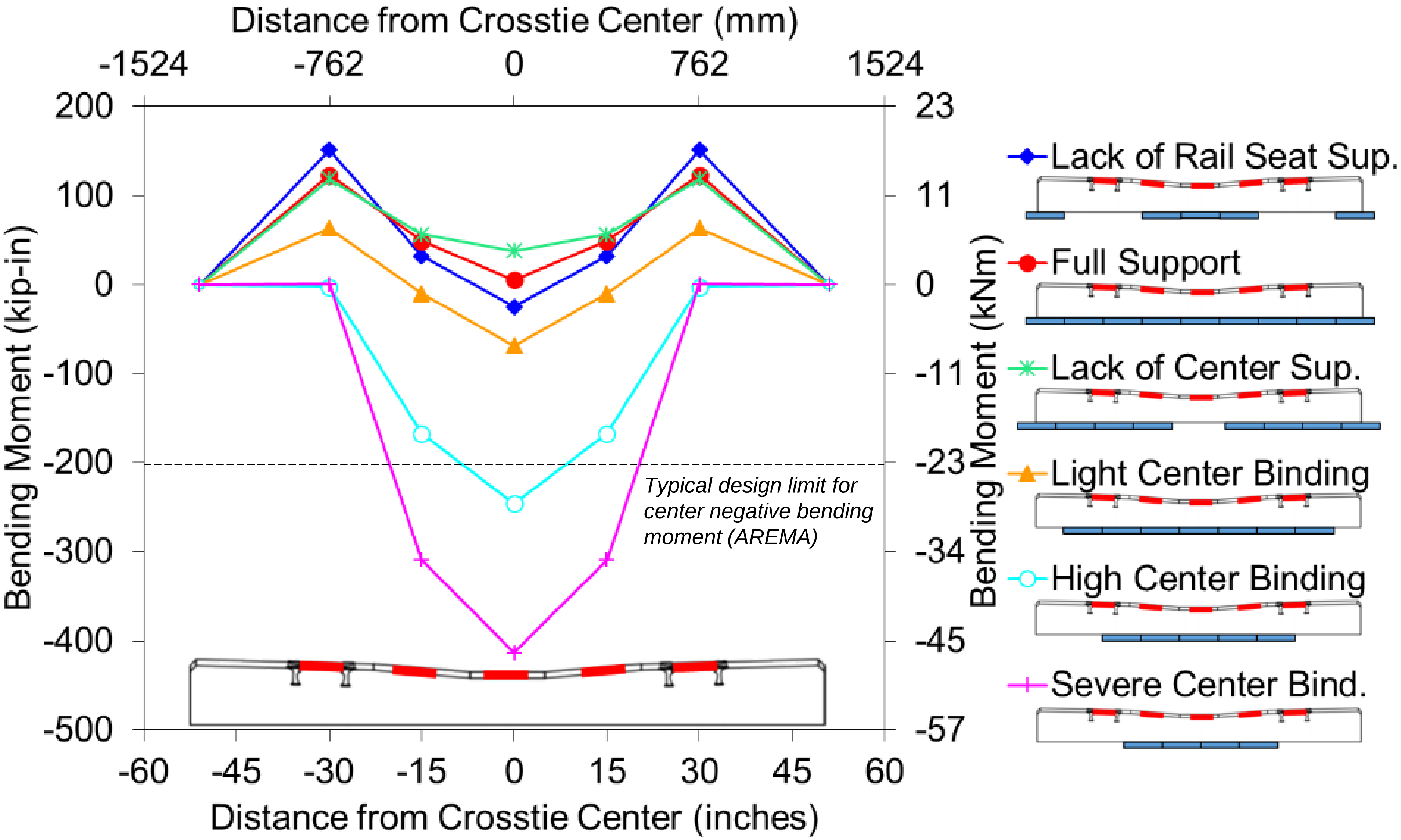


- **Supporting rubber pads**



Flexural Performance under Different Support Conditions

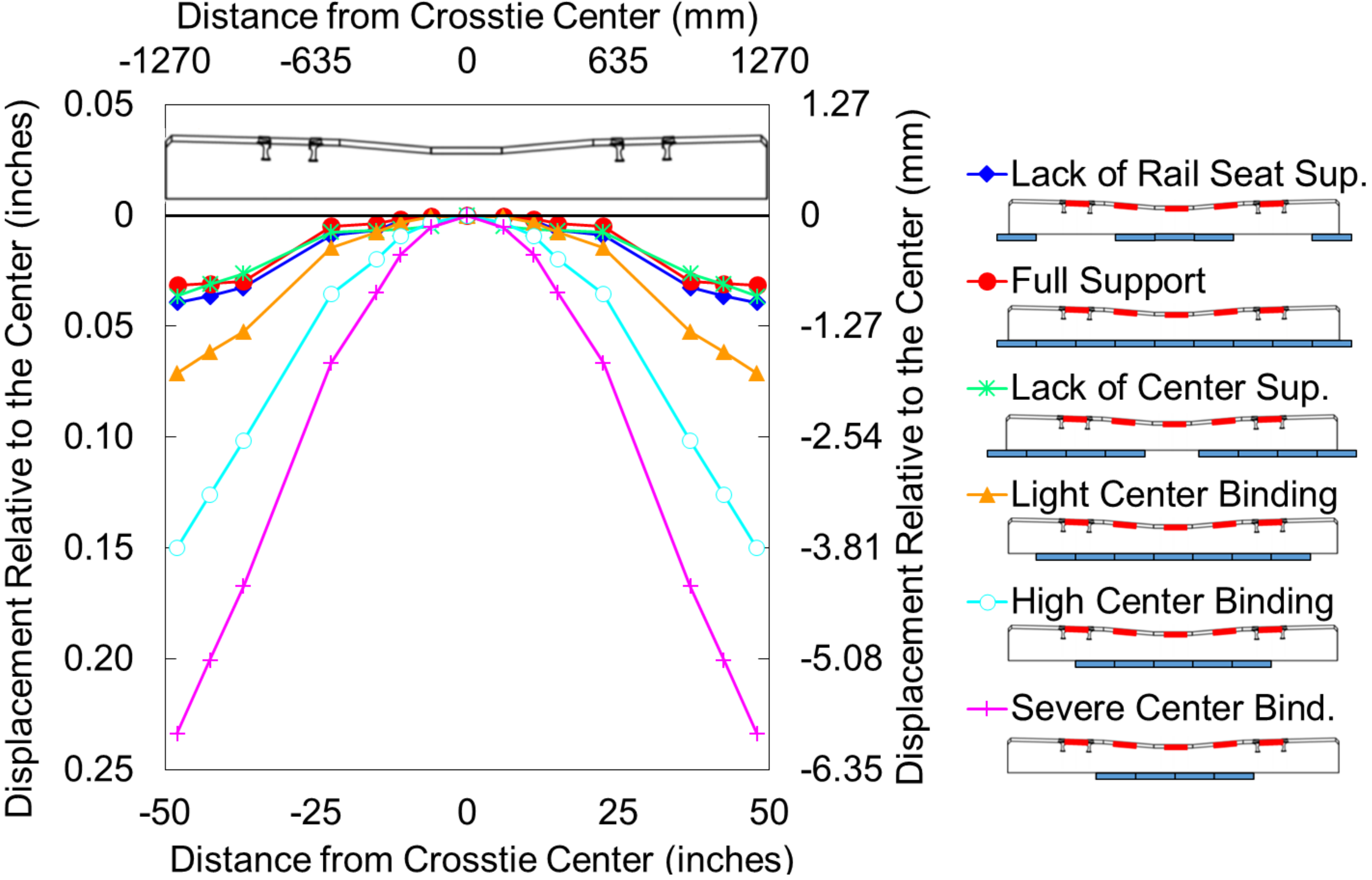
Rail Seat Load: 20 kips (89 kN), Healthy Crosstie



Typical design limit for center negative bending moment (AREMA)

Crosstie Shape under Different Support Conditions

Rail Seat Load: 20 kips (89 kN), Healthy Crosstie



Derivation of Gauge Widening Equation due to Crosstie Bending

$$\frac{1}{2}\Delta g = \sqrt{2\left[l^2 + \frac{r^2}{4}(1+\sin^2\varphi)\right](1-\cos\theta)} \times \sin\left\{\arctan\left[\frac{l}{\frac{r^2}{4}(1+\sin^2\varphi)}\right] tan^{-1}\left(\frac{l}{r/_2}\right) + \varphi - \frac{\theta}{2}\right\} + \frac{w}{2}[\cos(\varphi-\theta) - \cos\varphi]$$

$$\theta = \arctan\left(\frac{\Delta d}{r - \Delta d\tan\varphi + r\tan^2\varphi}\right)$$

Δg: Change of gauge

r: Distance between potentiometers close to rail seat

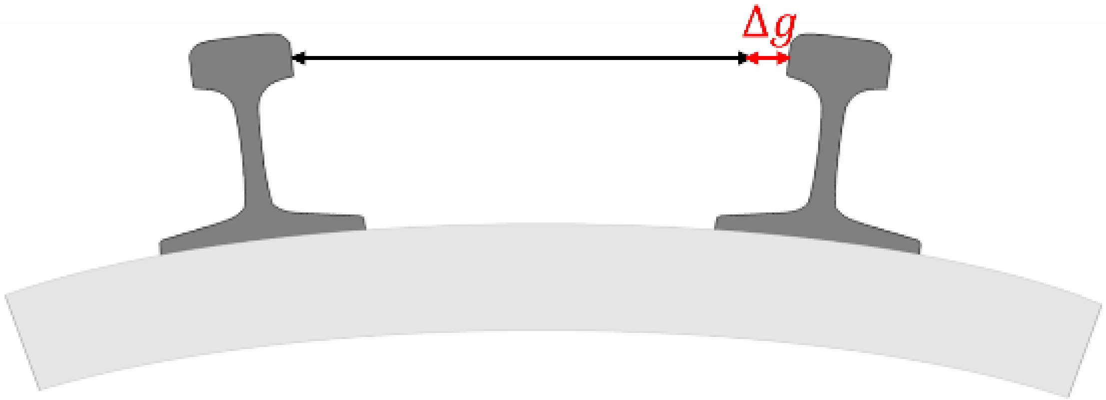
φ: Rail cant angle (1:40)

w: Width of rail head

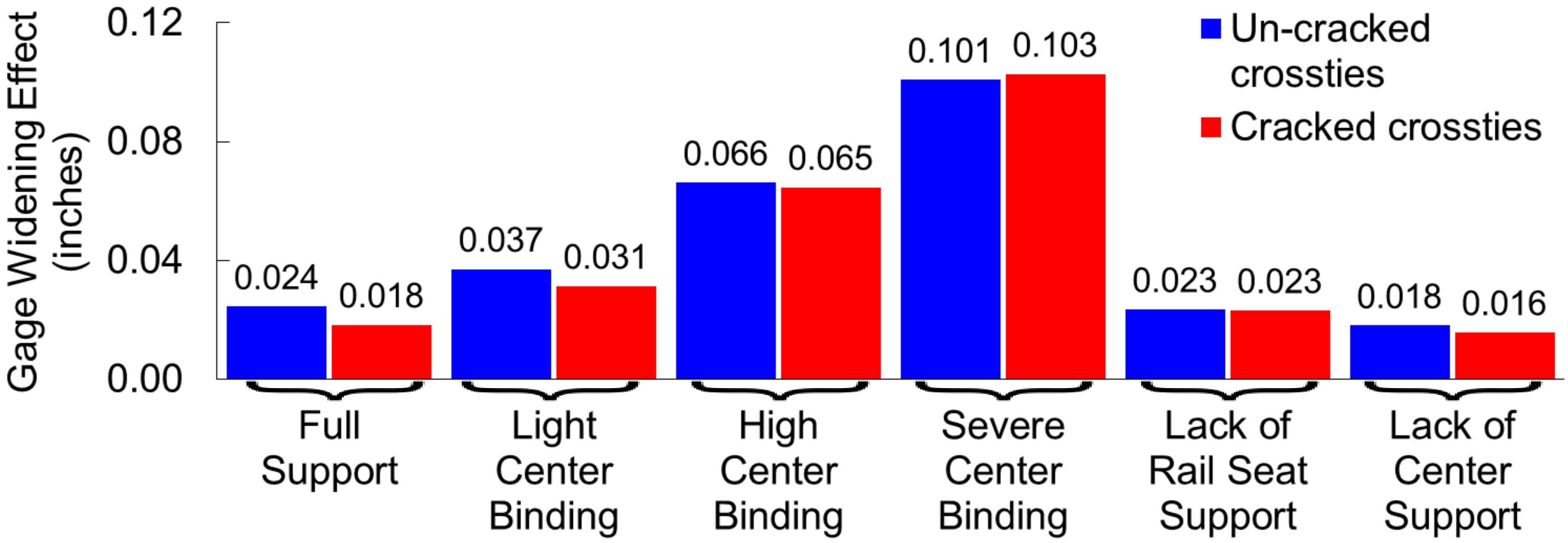
l: Rail height

θ: Rail rotation angle

Δd: The difference of vertical displacements between potentiometers close to rail seat



Gauge Widening Effect due to Crosstie Bending



ANOVA* for gauge widening has the same conclusions as for bending moments

- Support conditions have a significant impact on gauge widening (p-value <0.0001)
- Cracking does not have a significant impact on gauge widening for particular cracking pattern and crosstie model used in this study (p-value of 0.25)

**Gauge widening data was transformed to meet ANOVA assumptions*

Estimate of track gauge increase due to various track infrastructure conditions

Track Infrastructure Condition	Estimated Maximum Track Gage Increase *inches (mm)*	Citation
Concrete Crosstie Manufacturing Tolerance	0.0625 (1.588)	(AREMA, 2014)
Crosstie RSD Tolerance*	1.130 (28.702)	(Choros et al., 2007)
Rail Manufacturing Tolerance	0.125 (3.175)	(AREMA, 2014)
Rail Wear Tolerance	0.6 (15.24)	(Jeong et al., 1998)
Maximum Tolerable Rail Lateral Movement Allowed by Fastenying Systems	0.5 (12.7)	(FRA, 2015)

**The FRA track safety standards allows for 0.5 inch of RSD (Federal Railroad Administration, 2015), which, based on Choros (2007), could lead up to 1.13 inches of gauge widening for the worst case scenario with rail profile 136 RE.*

- Track gauge increase up to 0.103 inches due to concrete crosstie bending
- The change in gauge due to crosstie bending is small but not negligible

Comparison of Two Crosstie Designs

Rail Seat Load: 20 kips, Severe Center Binding

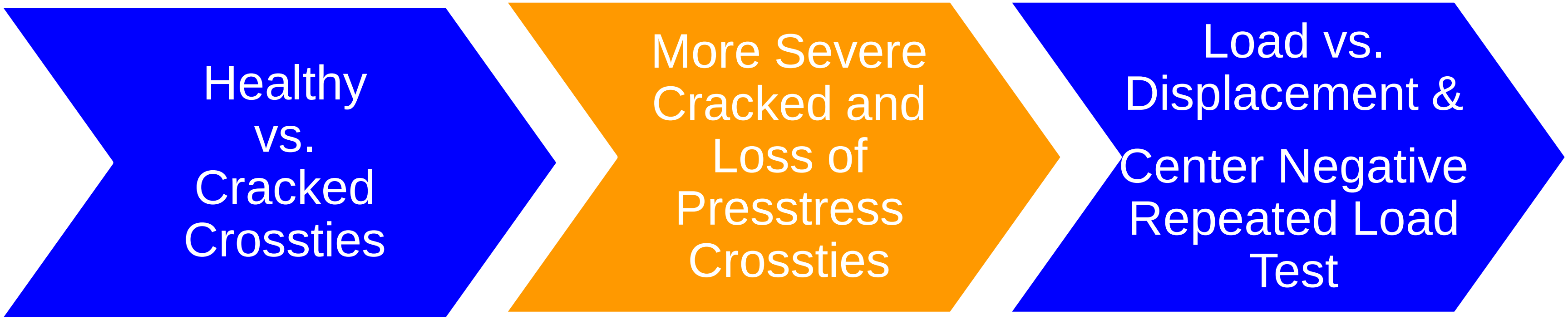
- Additional experiments with different crosstie models shows the influence of design on the crosstie performance

	Design A		Design B		% Change
End Displacement in (mm)	-0.234	(-5.94)	-0.314	(-7.97)	34%
Expected Gauge Widening in (mm)	0.101	(2.56)	0.119	(3.02)	18%
Center Moment kip-in (kNm)	-413	(-46.6)	-309	(-34.8)	-25%

Phase 1 Conclusions

- The center cracks generated at the laboratory seem to have no effect on crosstie bending moments or displacements (p-values of 0.19 and 0.68)
- Gauge widening effect due to pure concrete crosstie bending is small (max of 0.1 inch), but not negligible when compared to other gauge widening causes
- Different crosstie designs show different deflections and bending moments
- Center cracks constitute a strong indication of poor support conditions, but do not play a significant role in gauge widening

Phase 2:
More Severe Crosstie Cracking & Prestress Loss



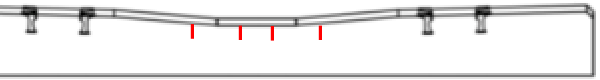
Healthy vs. Cracked Crossties

More Severe Cracked and Loss of Presstress Crossties

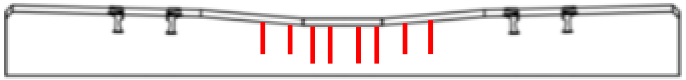
Load vs. Displacement & Center Negative Repeated Load Test

More Severe Crosstie Cracking and Prestress Loss

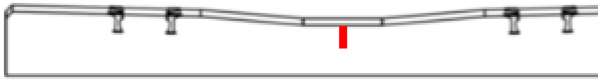
- Additional tests were performed to investigate crosstie performance (deflection, gauge widening, etc.) with more severe cracks and prestress loss
- **Phase 2a – More Severe Cracks**
- Severe cracks were generated in crossties with:
  - Severe center binding support condition and
  - 55 and 65 kip rail seat loads
    - *(increased from 20 kips in Phase 1)*
- **Phase 2b – Prestress Loss**
- Prestress loss was generated by varying saw-cut depth
  - 2 wires (10% prestress loss) were cut at 1.5”
  - 4 wires (20% prestress loss) were cut at 2.0”
- Crossties were then subjected to simplified Phase 1 matrix:
  - Severe center binding support
  - 20 kip rail seat loads



Phase 1



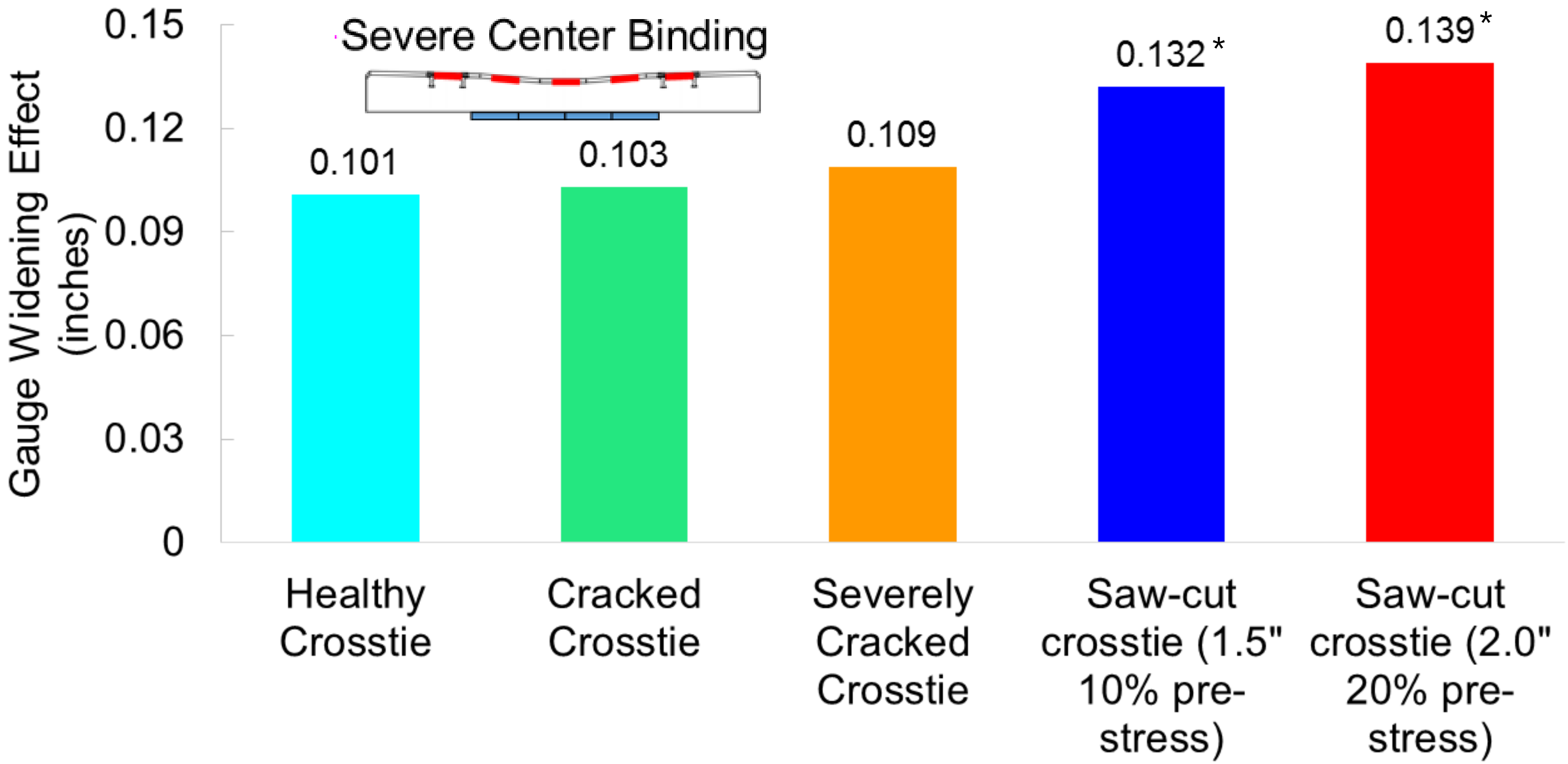
Phase 2a



Phase 2b

Gauge Widening in Different Crosstie Conditions

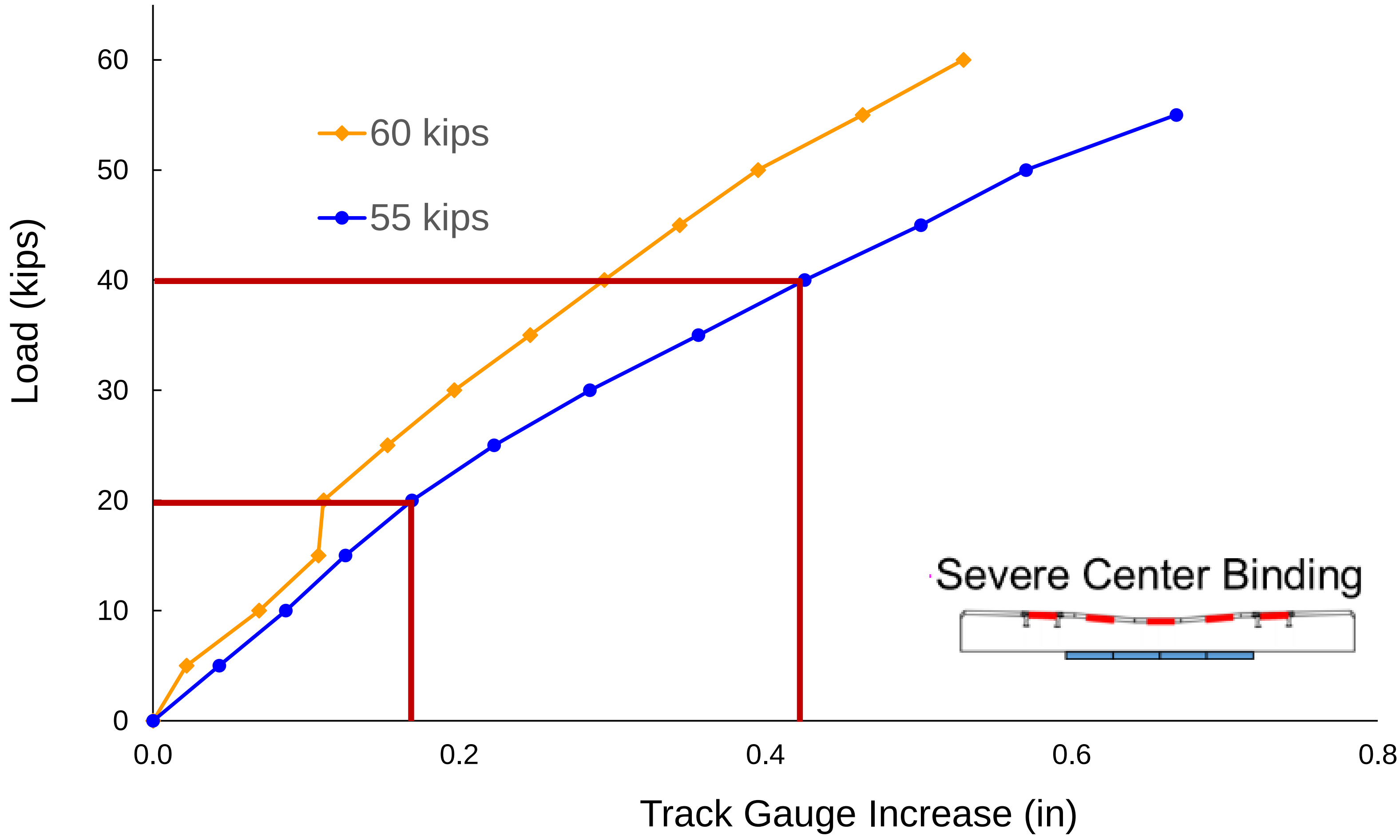
Rail Seat Load: 20 kips (89 kN) Severe Center Binding Support



- Gauge widening effect differences with full support are smaller
- These results suggest that center cracks and even some loss of pre-stress do not play a significant role in gauge widening

**Test performed in only one crosstie, single load application*

Load vs. Gauge Widening at Higher Loads



- Gage widening was between 0.1 – 0.2” when subjected to 20 kip rail seat load
- Gage widening becomes potentially significant at higher rail seat loads

Path Forward – Phase 3

Healthy vs. Cracked Crossties

More Severe Cracked and Loss of Presstress Crossties

Load vs. Displacement &

Center Negative Repeated Load Test

Load vs Displacement as Design Metric

Learning More from AREMA Center Negative Test

- AREMA Chapter 30 recommends a center negative bending moment threshold to prevent center cracking
  - E.g. crosstie must withstand X-load without crack extending beyond first level of prestress
- Manufacturers and railroads have been increasing this threshold
  - leading to higher concrete strengths and/or prestress forces
- Many concrete crossties installed previously are still perform as-designed
- More recent designs, though performing well, still exhibit cracking
  - It is hypothesized that excessive stiffness and/or brittleness could lead to more severe/sudden failures when cracks occur
- Phase 3 will assess the performance of different designs of crossties using a different metric:
  - Load vs displacement relationship until “crosstie failure” in conjunction with a crack reaching the first level of prestress

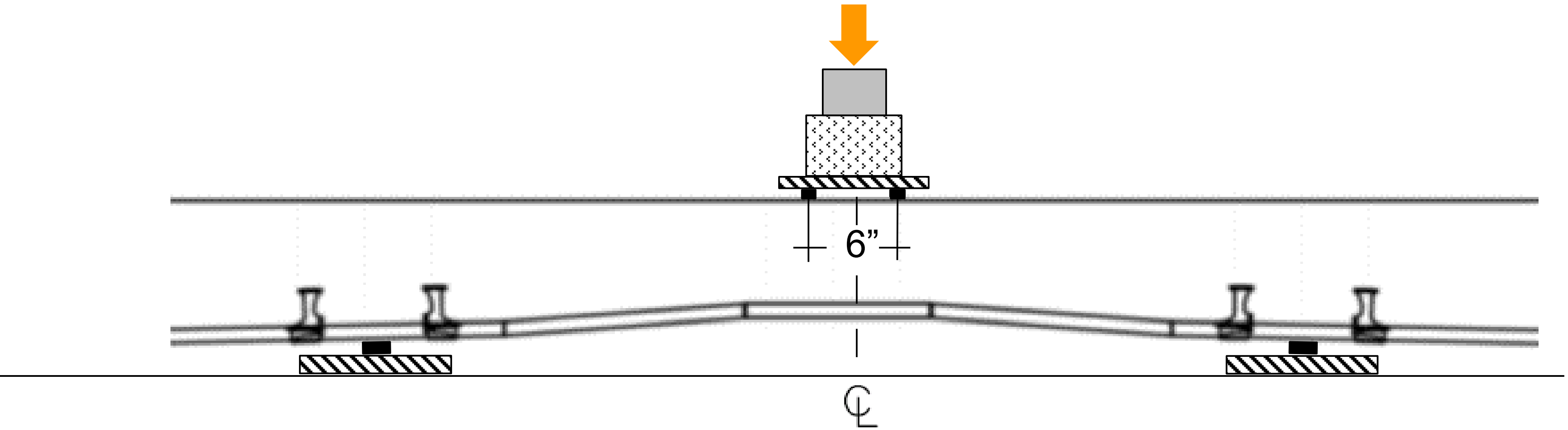
Center Negative Repeated Load Test

Crack Propagation Direction and Rate Study

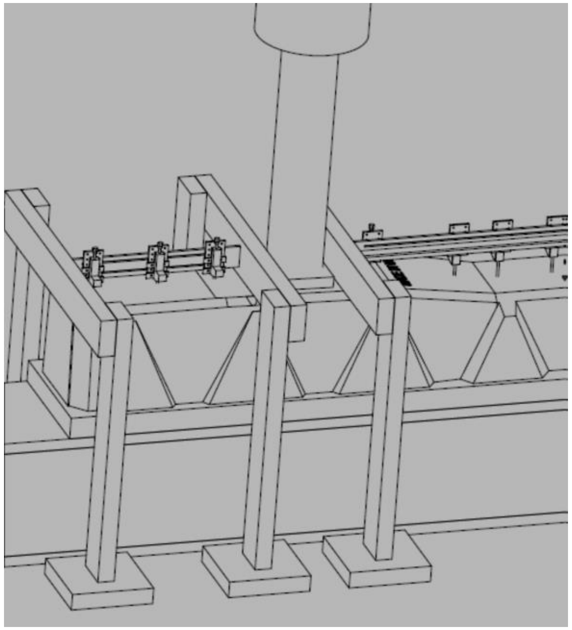
- Center cracks still constitute a risk that are not fully understood
  - Testing to-date has consisted of applying a single static load
- Dynamic, center negative repeated load tests will be performed to investigate center crack propagation direction and rate
  - Could impact AREMA Chapter 30 design tests
  - Could also improve inspection/maintenance guidelines

Phase 3 Experimental Setup and Loading

- The test setup will follow AREMA Chapter 30 Test 4.9.1.6 Center Negative Bending Moment Test (C-)
- Load vs displacement tests will be run according to a modified version of the C-, in that loads will progress beyond the first crack to tie failure
- Repeated load tests will be run according to a modified version of AREMA Chapter 30 Test 4.9.1.5 – Rail Seat Repeated Load Test
  - Determine load (P) to crack crosstie to first level of prestress
  - Cycle load up to 1.1P (or other levels) for 3 million cycles



Large Scale Test Frame (LSTF)



- New frame currently installed at RAIL
- Linear potentiometers to capture deflections

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  - TTX Company
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