UIUC FRA Crosstie and Fastening System BAA 2014-2: Investigation of Deteriorated Crossties and Support Conditions

Experimental Results

FRA and FTA Crosstie and Fastening System Research Program
Industry Partners (IP) Meeting

Tucson, AZ

4 November 2015

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U.S. Department of Transportation
Federal Railroad Administration

Outline

- Motivation for Research
- Expected Industry Impact
- Laboratory Experimentation
- Preliminary Results
  - ANOVA
  - Effect of Support Conditions
  - Effect of Crosstie Cracking
- Conclusions
- Future Work

Motivation for Research

- The recent 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

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

Broken crosstie

Fouled ballast

Expected Industry Impact

Impacted Groups

Expected Impacts	FRA - CFR 213	AREMA Chapter 30	Railroads	Crosstie Manufacturers
Consensus on definition of failed concrete crossties	x	x	x	x
Input on expected crosstie bending moments		x	x	x
Input on expected concrete crosstie deflections and gage widening effect based on crosstie shape	x		x	
Estimation of crosstie support conditions based on bending moment measurements and cracking observation	x		x	

Experimental Matrix

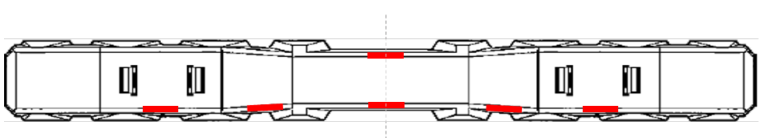
- Matrix was executed five times to account for variability
- 12 combinations of support conditions and crosstie health variation

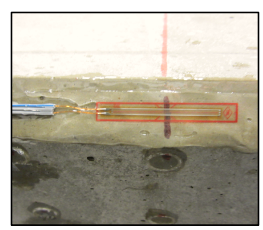
FRA BAA 2014-2 Test Matrix 1 DRAFT

Run Number	Support Condition	Crosstie Condition	Purpose	Vertical Load Applied to Each Rail Seat Simultaneously (*kips*)	Vertical Load Applied to Each Rail Seat Simultaneously (*kN*)
1	1	Healthy Crosstie	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 (Rail Seat Positive)		
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		

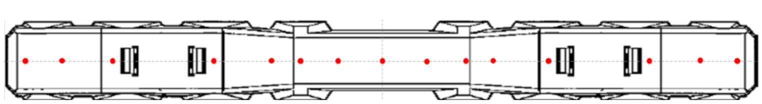
Measurement Devices

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



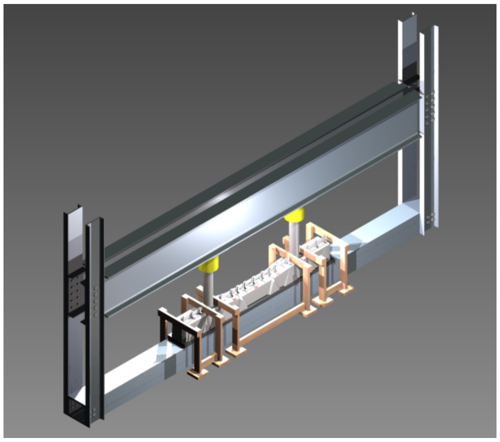


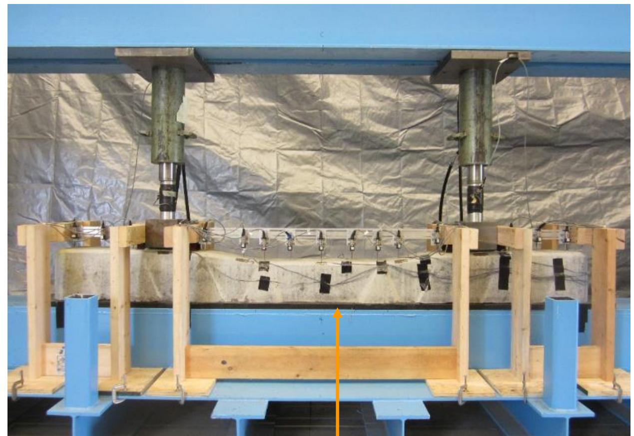
- **Linear Potentiometers**
  - Measurement of vertical displacements
  - Estimation of crosstie shape



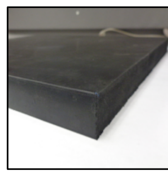
Laboratory Experimentation Equipment

- **Loading frame**



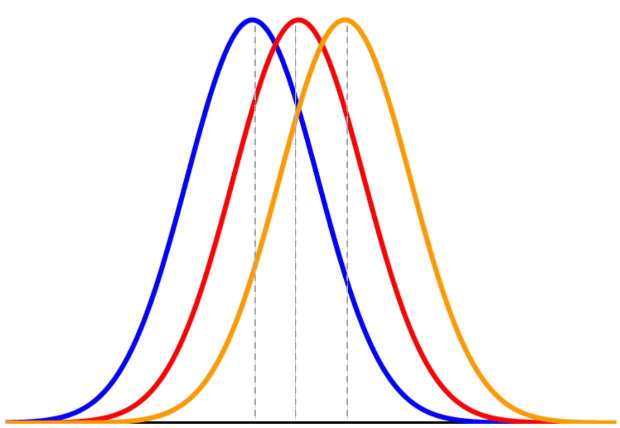


- **Supporting rubber pads**



Analysis of Variance (ANOVA) Background

- Null hypothesis: $\mu_1 = \mu_2 = \mu_3$ (same population mean)
- If the null hypothesis is true, then the sample means should be similar, but not necessarily identical
- What level of variability of the sample means makes the null hypothesis wrong?



ANOVA Application - Bending Moments

- Conducted ANOVA with two factors
  - Support conditions (5 levels)
  - Crosstie health (2 levels)
- 300 total data points representing bending moments
  - 3 Locations: rail seat, center, and intermediate
  - 10 Factor combinations (5 support conditions x 2 crosstie health variations)
  - 10 Replicates for each factor combination
- One of the key values produced by ANOVA is the probability under the null hypothesis (p-value)
  - **The higher the p-value, the less significant the factor**

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Pr > F

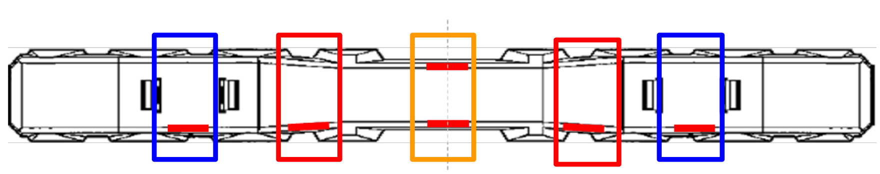
p-value

ANOVA Results - Bending Moments
Rail Seat Load: 20 kips (89 kN)

- Support conditions have a significant impact on bending moments
- The particular experimental cracking pattern (AREMA recommended practice for flexural performance) does not have a significant impact on bending moments

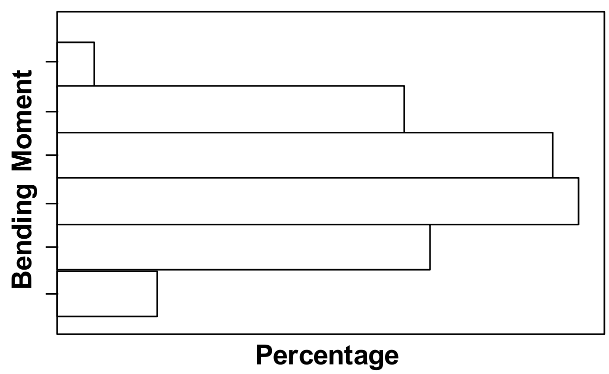
ANOVA Output

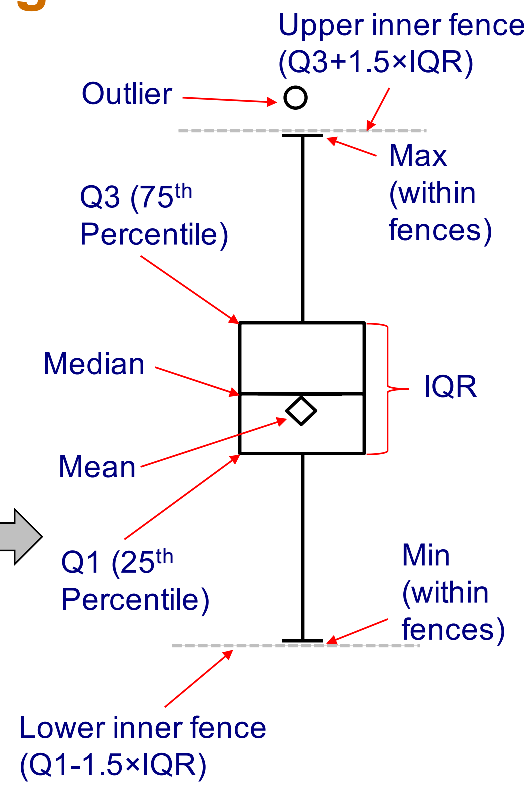
	P-value		
	Rail Seat	Intermediate	Center
Support Conditions	<.0001	<.0001	<.0001
Crosstie Health	0.50	0.19	0.60



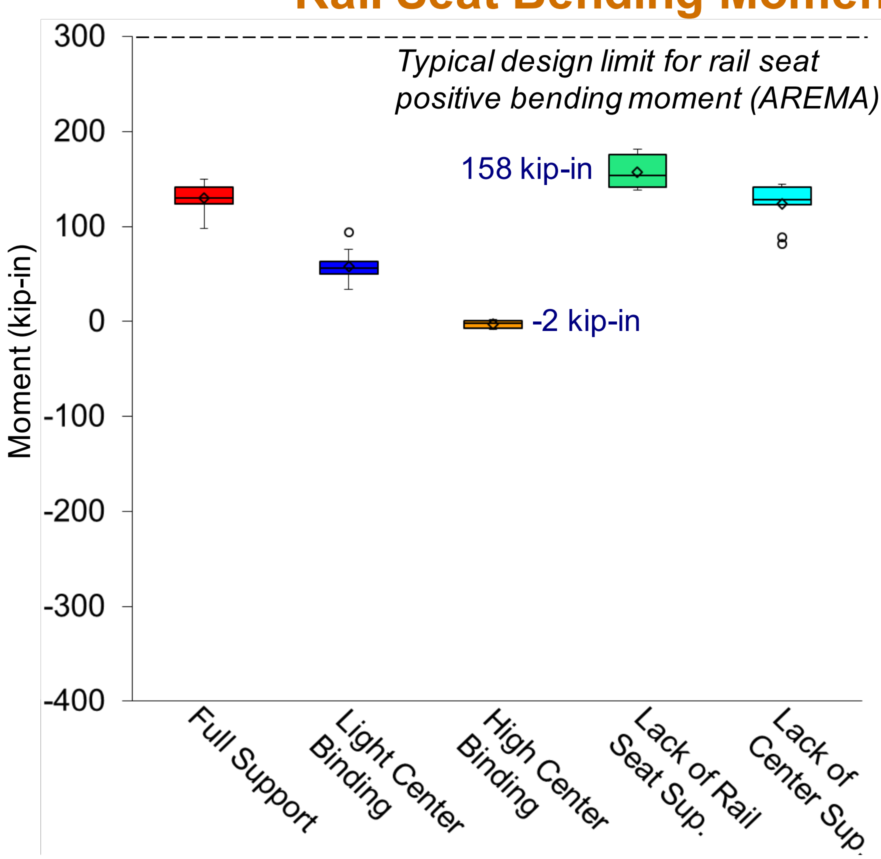
Box Plot Background

- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality

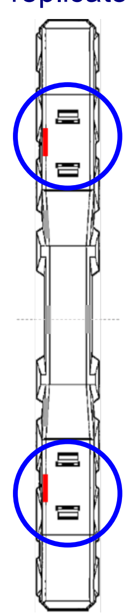




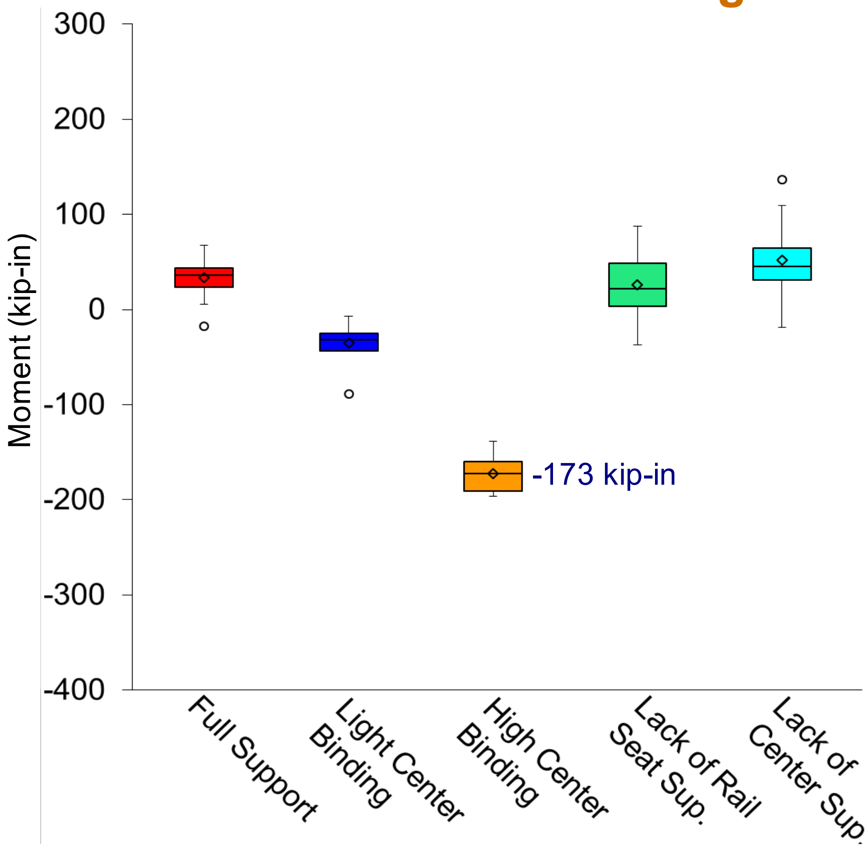
Rail Seat Bending Moments



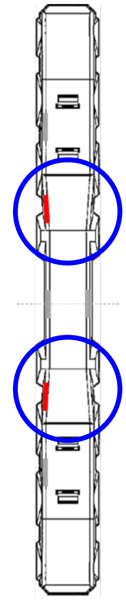
- Rail Seat Load: 20 kips
- Healthy crosstie
- 10 replicates



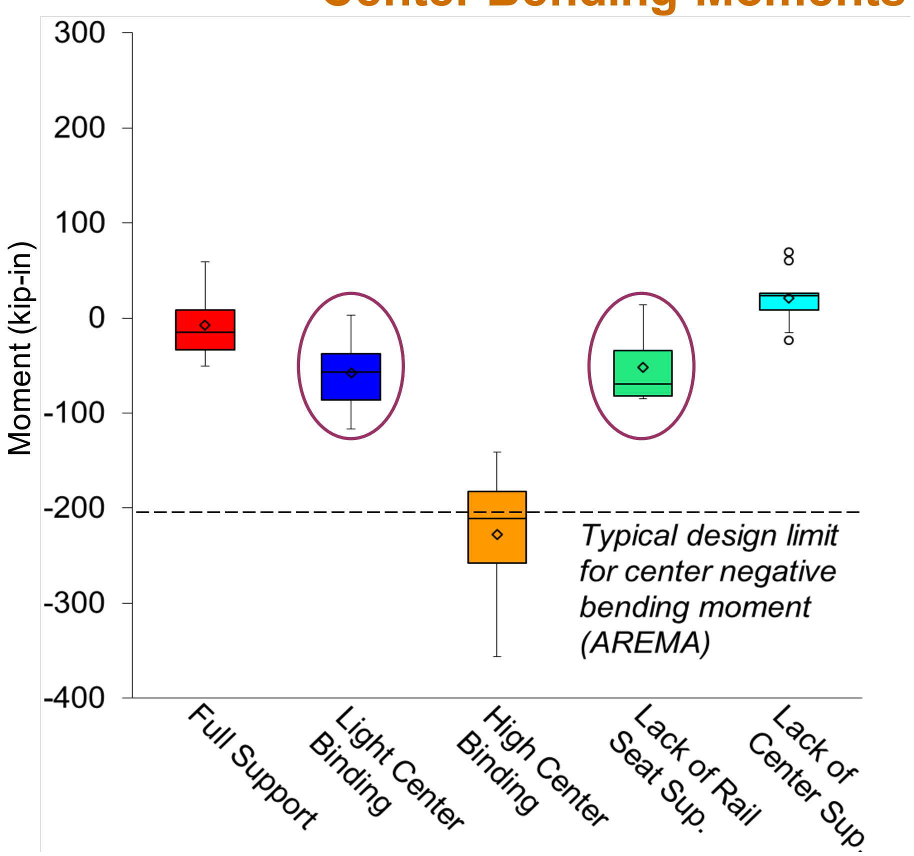
Intermediate Bending Moments



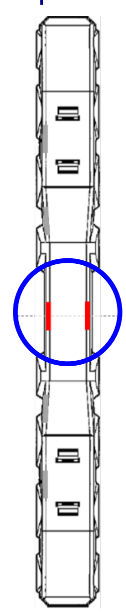
- Rail Seat Load: 20 kips
- Healthy crosstie
- 10 replicates



Center Bending Moments



- Rail Seat Load: 20 kips
- Healthy crosstie
- 10 replicates



Mean Separation Procedure

- **Objective:** Confirm that the results from different support conditions are significantly different due to many overlapping data
- **Method:** Use mean separation procedure
  - Used Fisher's **Least Significant Difference** (LSD) Method
  - Confidence level of 90% (i.e. alpha = 0.1)

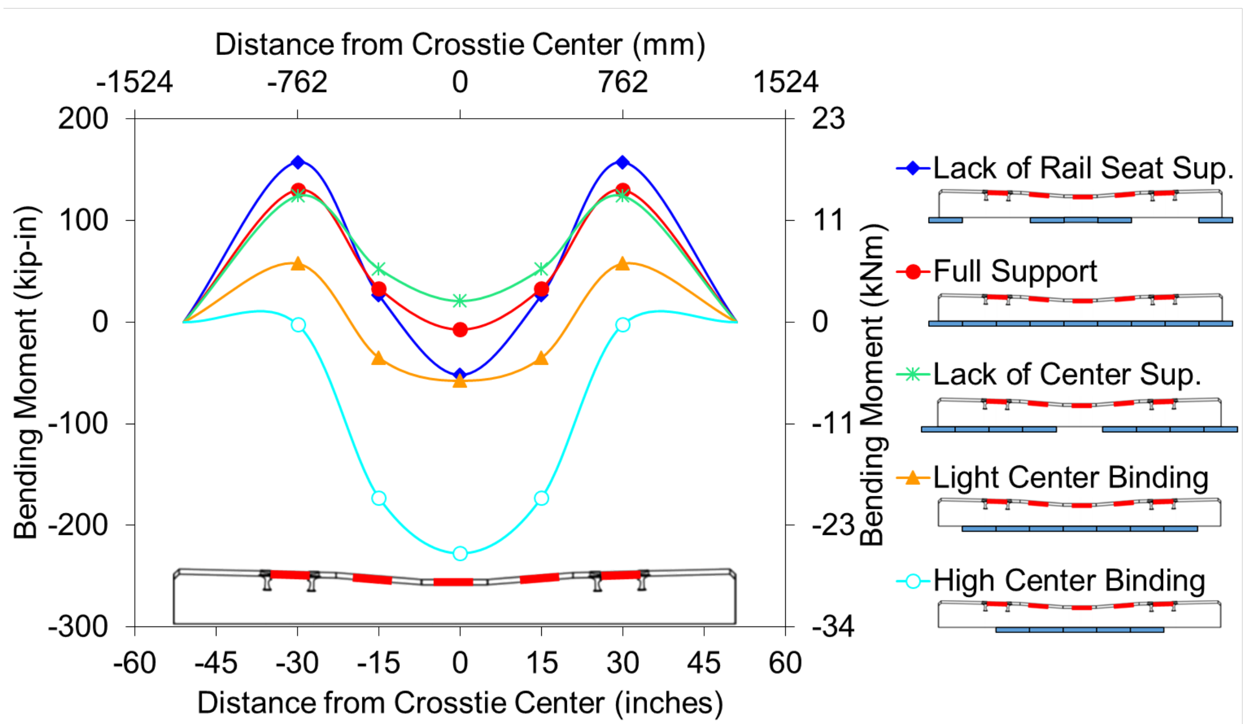
Location	Rail Seat		Intermediate		Center	
Support	t Grouping	Mean	t Grouping	Mean	t Grouping	Mean
Full Support	B	130.1	A B	33.2	A	-7.3
Light Center Binding	C	57.5	C	-35.1	B	-57.8
High Center Binding	D	-2.5	D	-172.8	C	-227.5
Lack of Rail Seat Support	A	157.5	B	26.5	B	-52.1
Lack of Center Support	B	124.0	A	52.3	A	20.8

**All values are in kip-in and correspond to a rail seat load of 20 kips (89 kN). Note: 1 kip-in = 8.851 kN-m.*

- "Full Support" and "Lack of Center Support" were never found to be significantly different

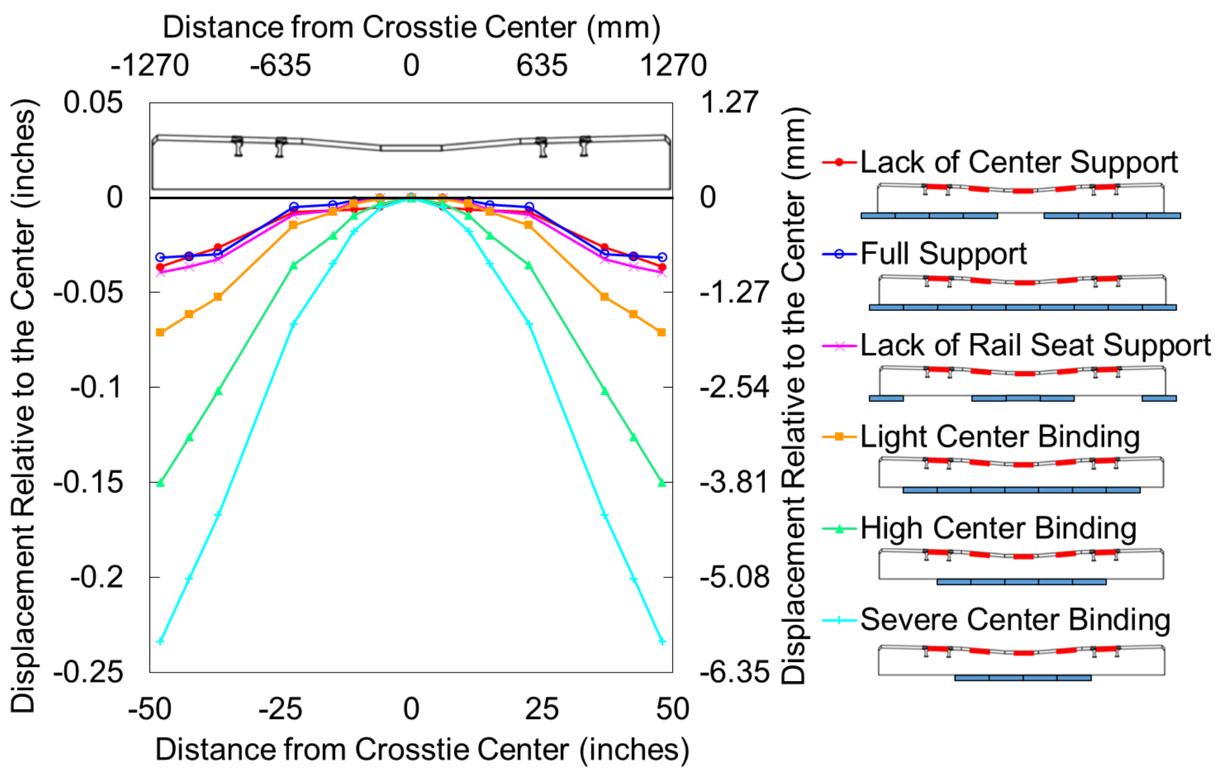
Flexural Performance under Different Support Conditions

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



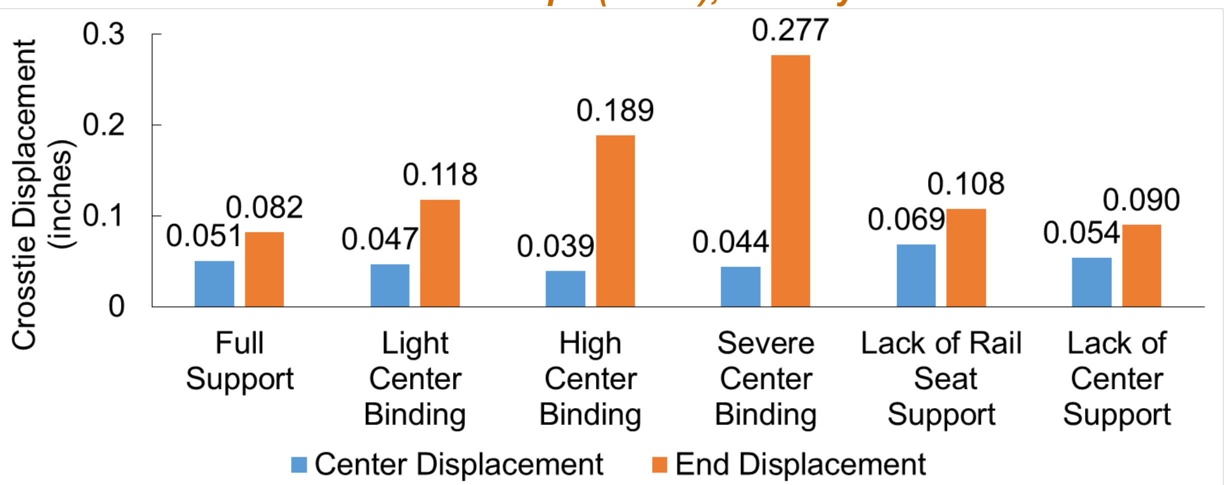
Crosstie Shape under Different Support Conditions

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



Crosstie Displacement under Different Support Conditions

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



- Results are comparable to field data obtained at TTC in 2012-2013 as part of prior FRA-funded crosstie research at UIUC

Derivation of Gage Widening Equation due to Crosstie Bending

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

$$\theta = sin^{-1}\left[\frac{\Delta dcot\varphi\times sin\varphi}{\sqrt{(\Delta dcot\varphi)^2+(r-\Delta dcsc\varphi)^2+2(\Delta dcot\varphi)(r-\Delta dcsc\varphi)(cos\varphi)}}\right]$$

Δg: Change of gage

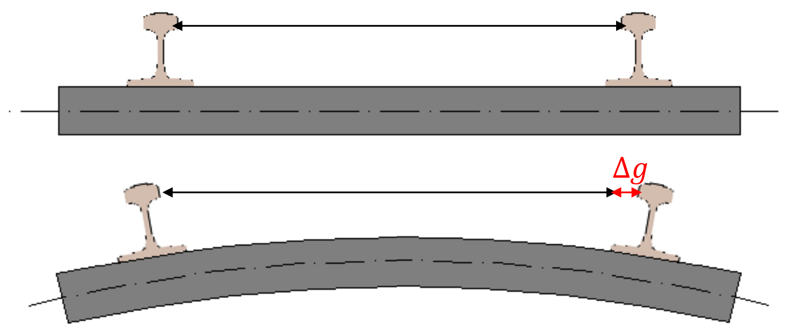
r: Distance between potentiometers close to rail seat

φ: Rail cant angle (1:40)

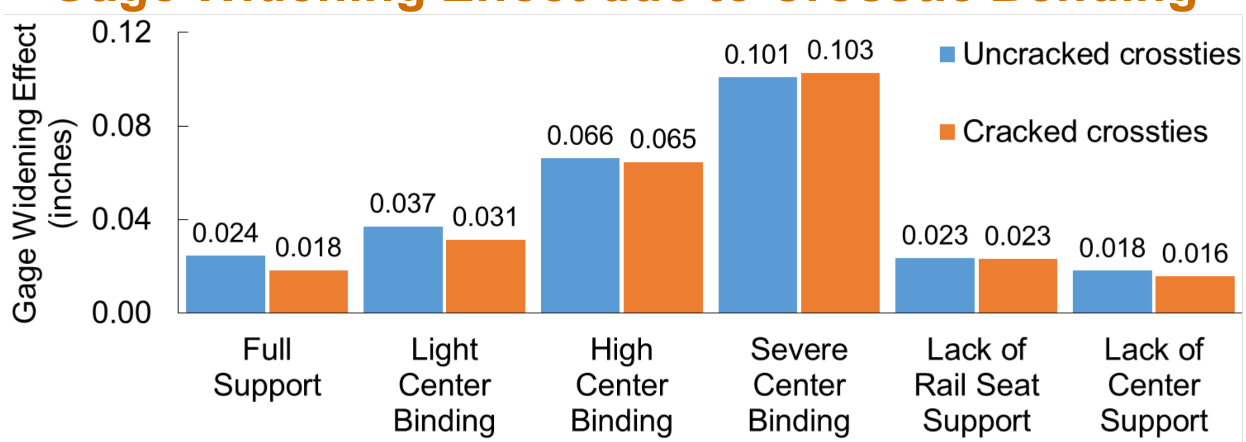
w: Width of rail head

l: Rail height

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



Gage Widening Effect due to Crosstie Bending



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

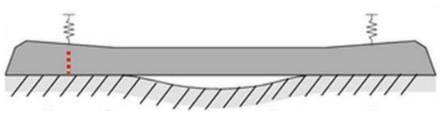
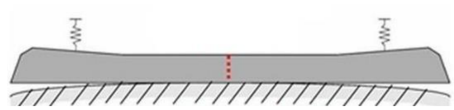
- Support conditions have a significant impact on gage widening
- Cracking does not have a significant impact on gage widening (for particular cracking pattern and crosstie model used in this study)

Factor	p-value
Support Conditions	<.0001
Crosstie Health	0.25

Gage widening data was transformed to meet ANOVA assumptions

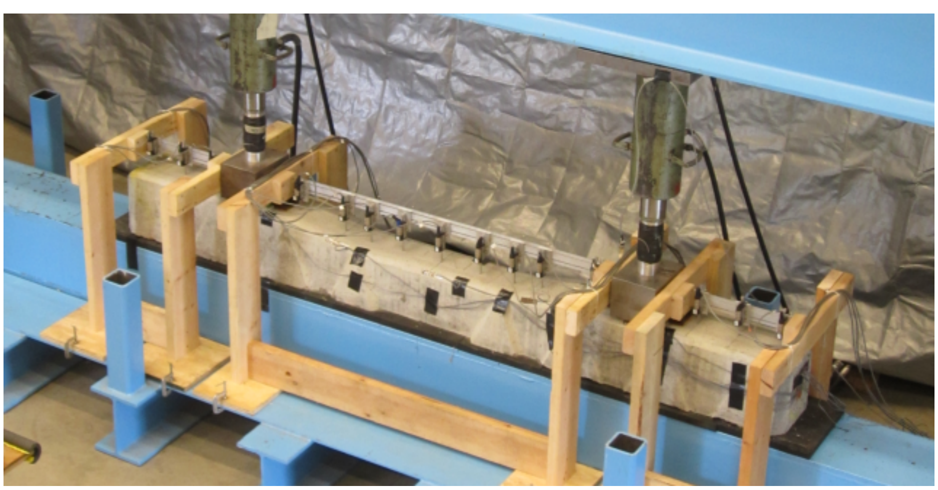
Conclusions

- Small amounts of center binding can result in large differences in center bending moment. In comparison with the lack of center support case:
  - 241.2 kip-in change for high center binding (at center)
  - 78.6 kip-in change for light center binding (at center)
- Rail seat bending moments are less sensitive to changes in support. In comparison with the lack of center support case:
  - 33.4 kip-in change for lack of rail seat support (at rail seat)
- The results above indicate that tamping (removing center support) can drastically reduce center bending moments
- Typical design recommended practices might underestimate center negative bending moments (-227 kip-in experimental vs. -201 kip-in design)
- 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)
- Gage widening effect due to pure concrete crosstie bending is very small, even with worst experimental support condition case (0.1 inch)

Path Forward

- Refine analysis of experimental data
- Plan future finite element modeling (FEM) on system level
- Plan future experiments using the Track Loading System (TLS)
- Study ways to positively impact AREMA Chapter 30 and CFR 213



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Acknowledgements

- **Funding for this research has been provided by**
  - **Federal Railroad Administration (FRA)**
- Student's scholarship is provided by
  - CAPES Foundation
    Ministry of Education of Brazil
- Industry Partnership and support has been provided by
  - Union Pacific Railroad
  - BNSF Railway
  - National Railway Passenger Corporation (Amtrak)
  - Rail Product Solutions (RPS), Inc.
  - GIC Ingeniería y Construcción
  - Hanson Professional Services, Inc.
  - CXT Concrete Ties, Inc., LB Foster Company
  - TTX Company
- John A. Volpe National Transportation Center
  - Hailing Yu and Ted Sussmann
- RailTEC Team

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