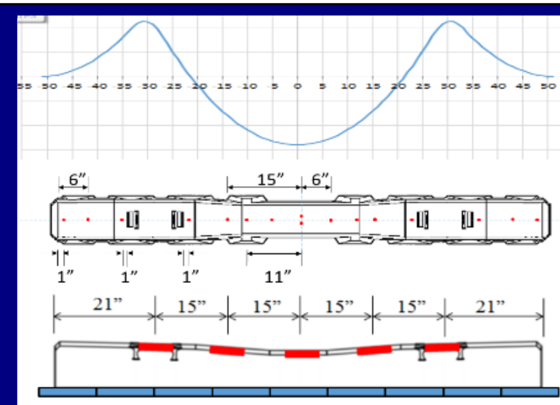
Laboratory Quantification of Flexural Demand on Concrete Crossties under Different Support Conditions



TRB Concrete Crosstie & Fastening System Workshop

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Josué Bastos, Marcus Dersch, Yu Qian, and Riley Edwards

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

U.S. Department of Transportation
Federal Railroad Administration

Outline

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

Motivation for Research

- A 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

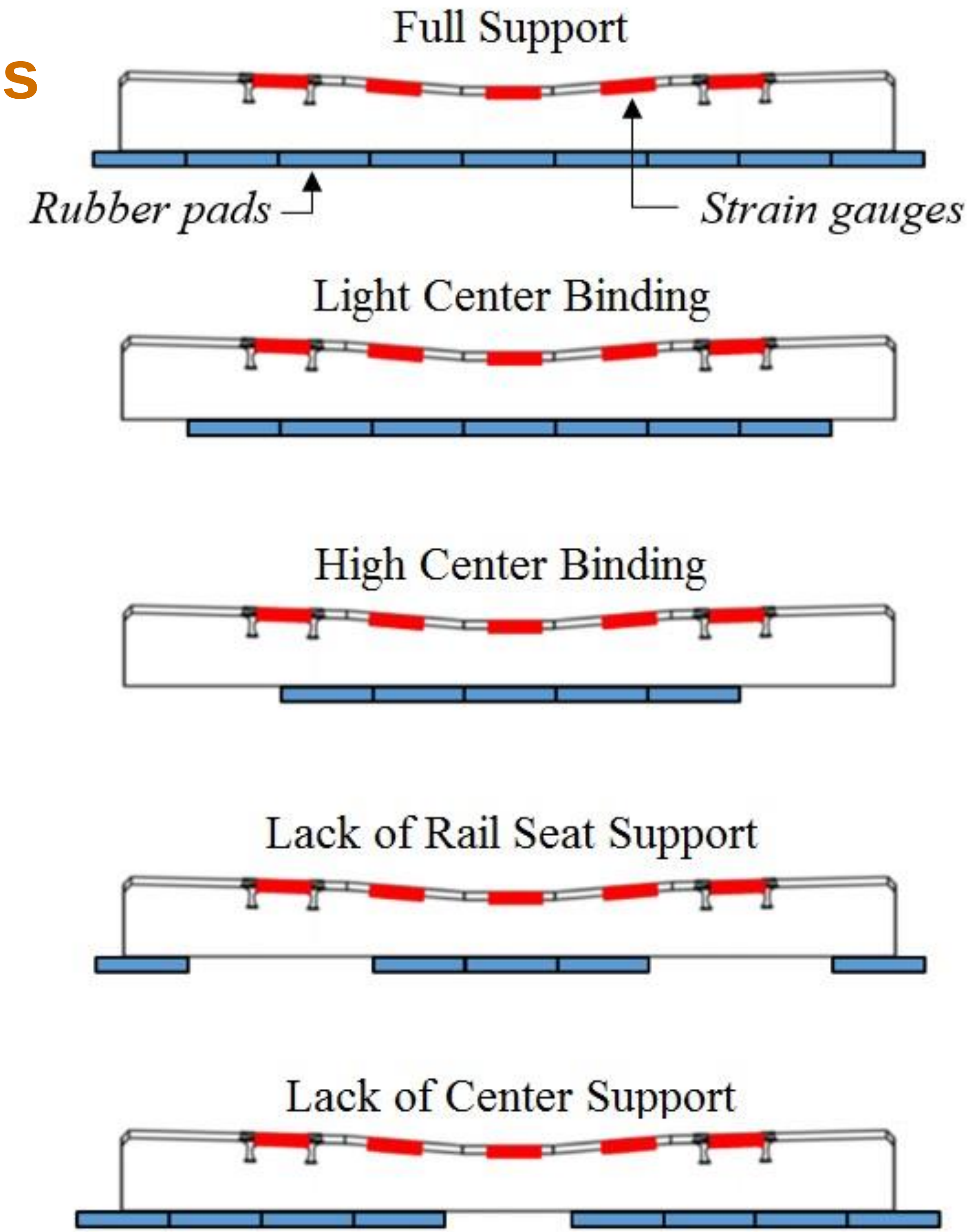
- Previous analysis of FRA accident database indicated that deteriorated concrete crossties and support conditions are among major track related accident causes in the US

Broken crosstie

Fouled ballast

Experimental Variables
Support Conditions

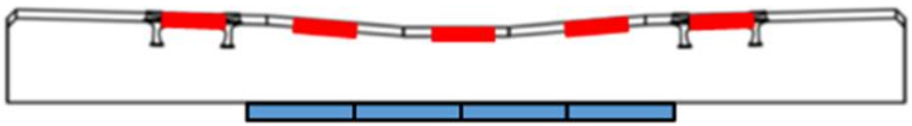
- **Support conditions**
  - Proper support
  - Center binding
  - Rail seat positive
- **Cases were based on:**
  - Field conditions
  - Expert opinion
  - Industry partners feedback on draft experimental matrix



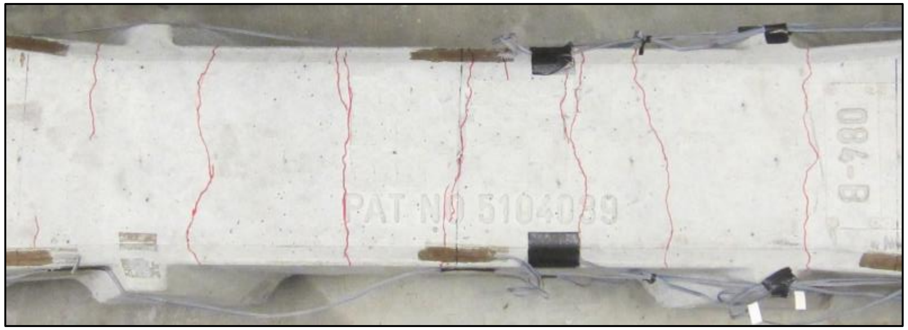
Experimental Variables
Crosstie Cracking

- All cracks were generated with a severe center binding condition, with rail seat load of 20 kips applied at both rail seats

Severe Center Binding



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



Plan view of cracked crosstie

First level of presstress

Profile view

Experimental Matrix

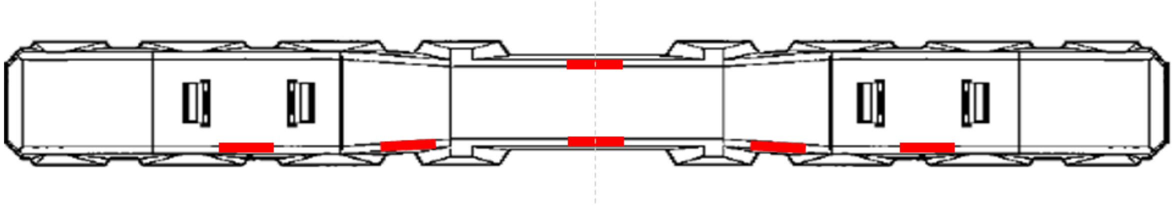
- Matrix was executed five times to account for variability
- 12 combinations of support conditions and crosstie health variation

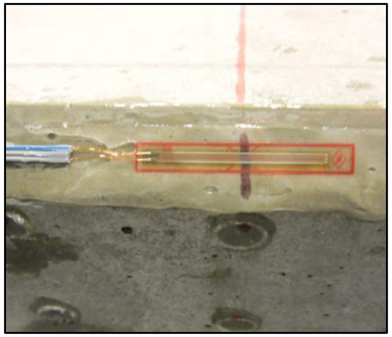
FRA BAA 2014-2 Test Matrix 1 DRAFT

Run Number	Support Condition	Crosstie Condition	Purpose	Vertical Load Applied to Each Rail Seat Simultaneously *kips*	*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		

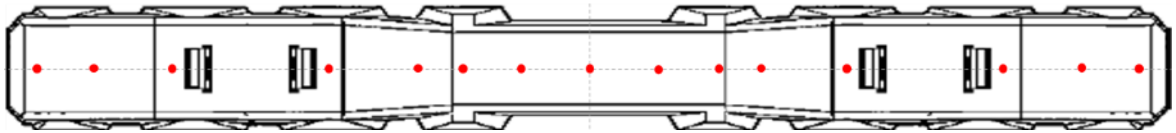
Measurement Devices

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



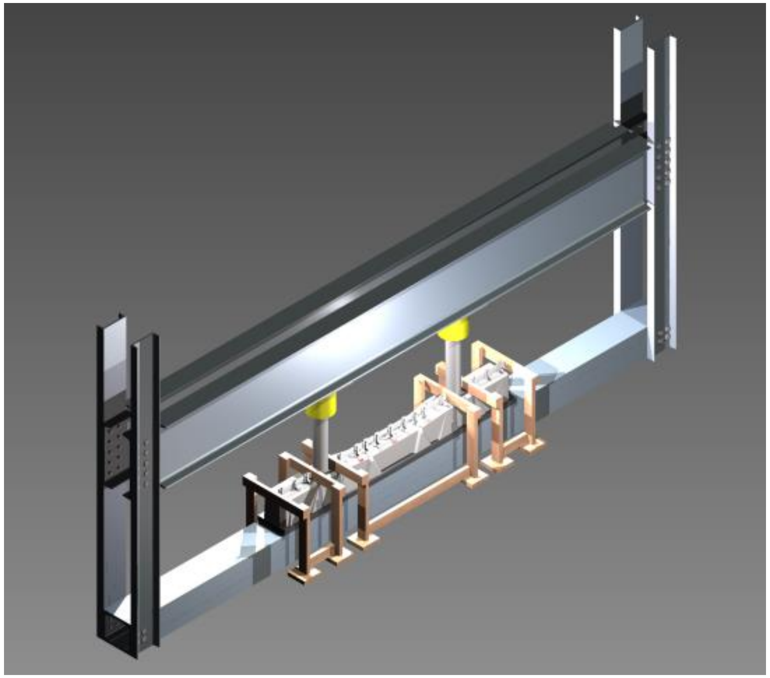


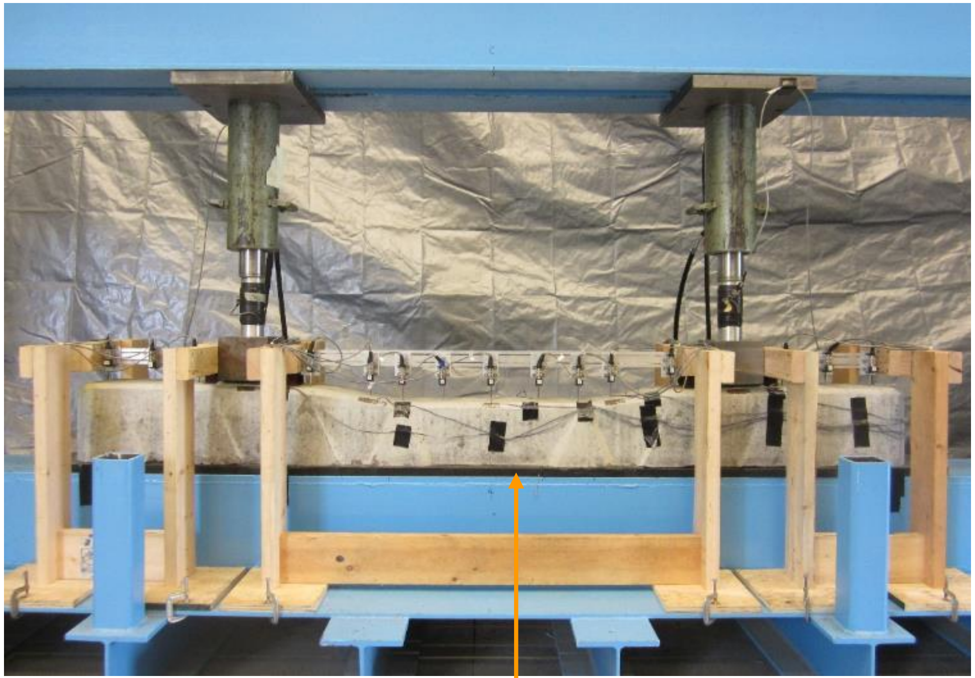
- **Linear Potentiometers**
  - Measurement of vertical displacements
  - Estimation of crosstie shape



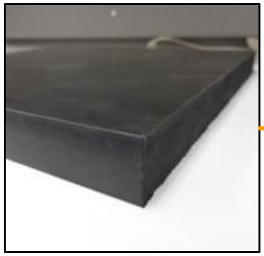
Laboratory Experimentation Equipment

- **Loading frame**





- **Supporting rubber pads**



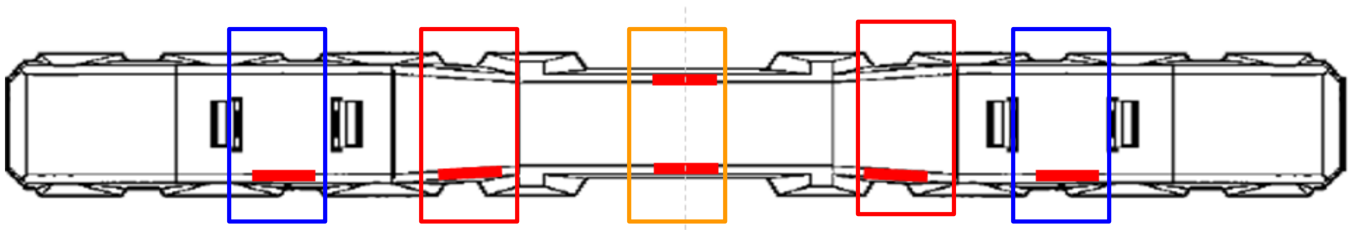
ANOVA - Bending Moments

Rail Seat Load: 20 kips (89 kN)

- Conducted ANOVA (Analysis of Variance) with two factors:
  - Support conditions (5 levels)
  - Crosstie health (2 levels)
- 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

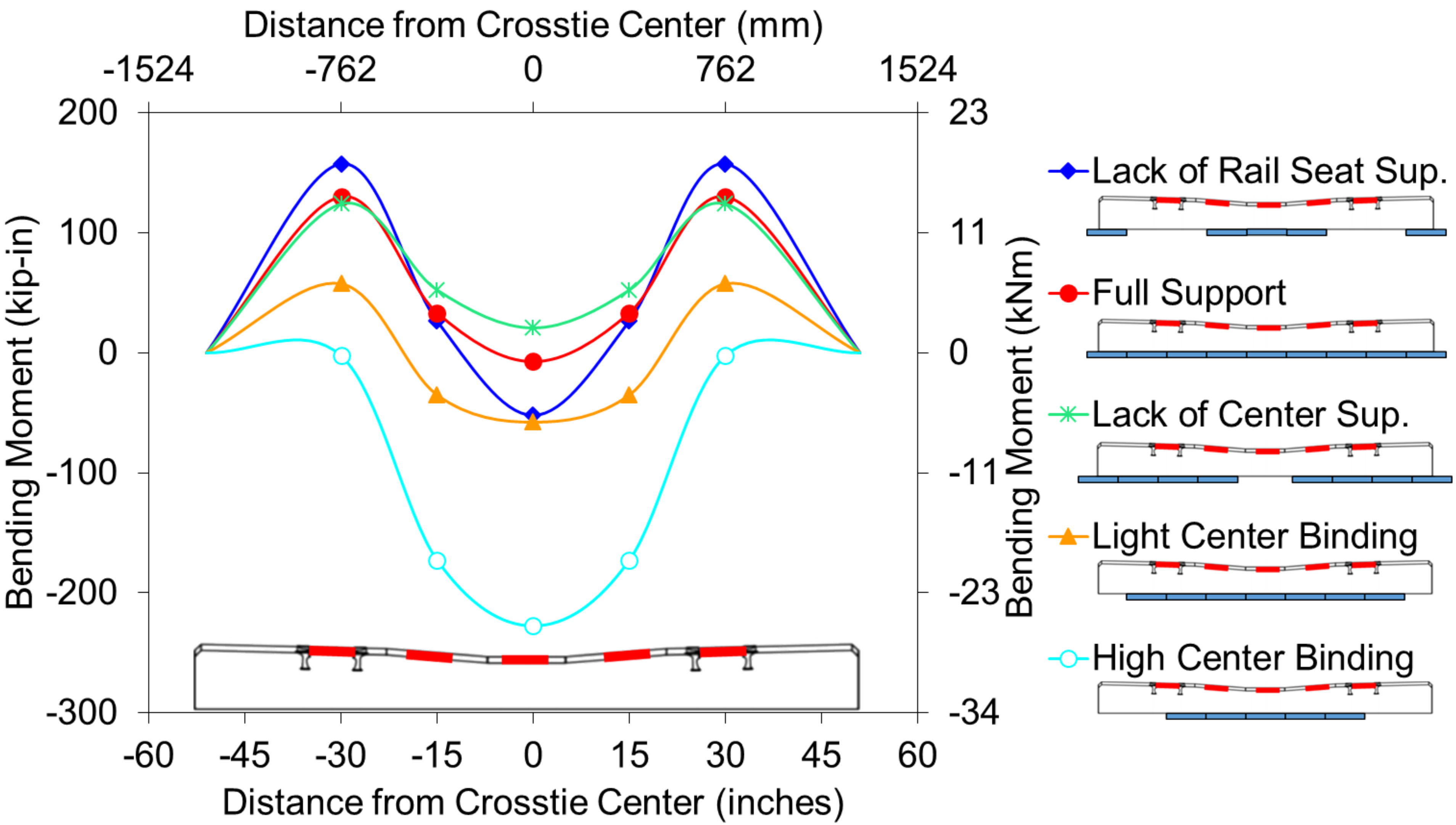
ANOVA Output

	p-value		
	Rail Seat	Intermediate	Center
Support Conditions	<0.0001	<0.0001	<0.0001
Crosstie Health	0.50	0.19	0.60



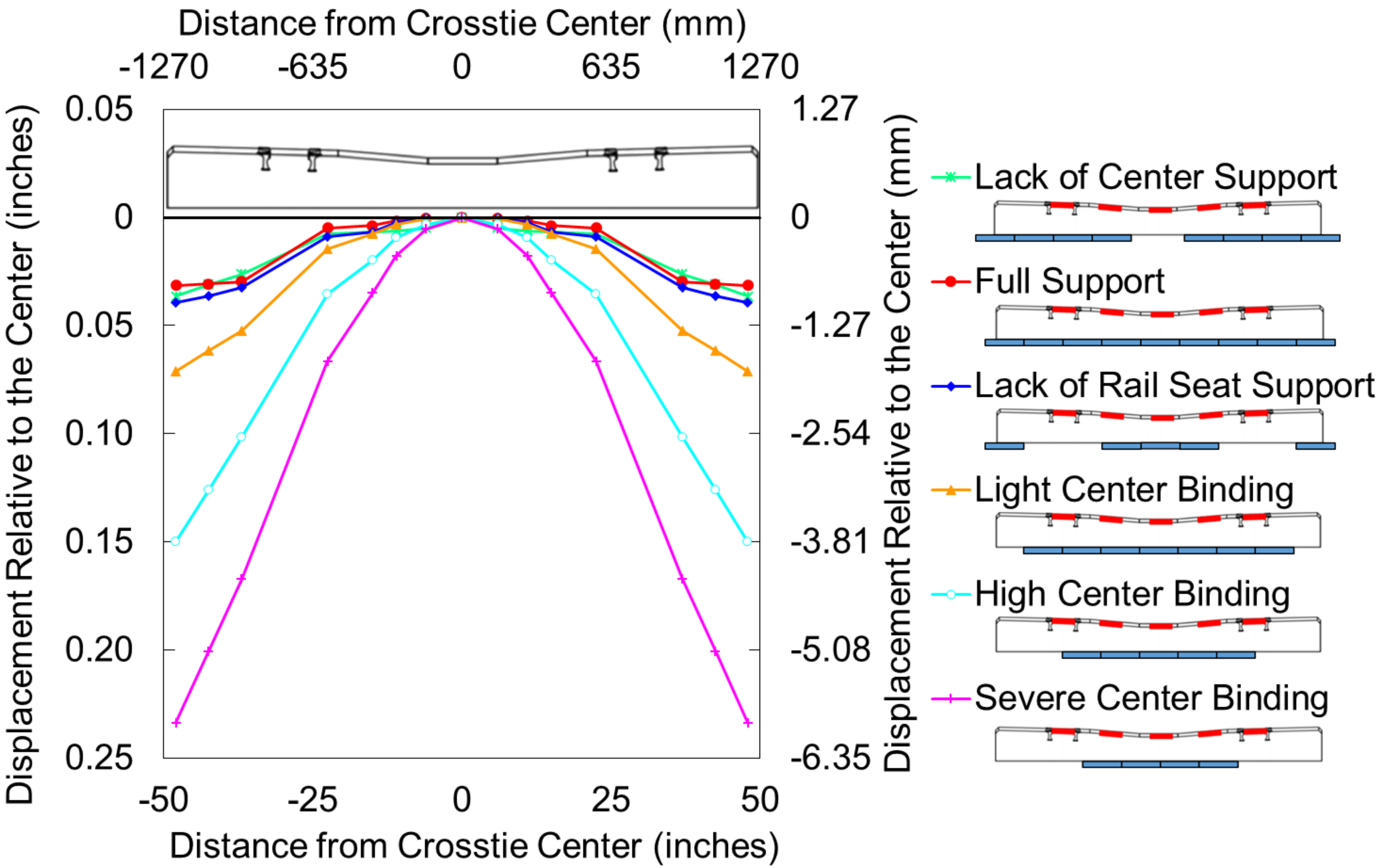
Flexural Performance under Different Support Conditions

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



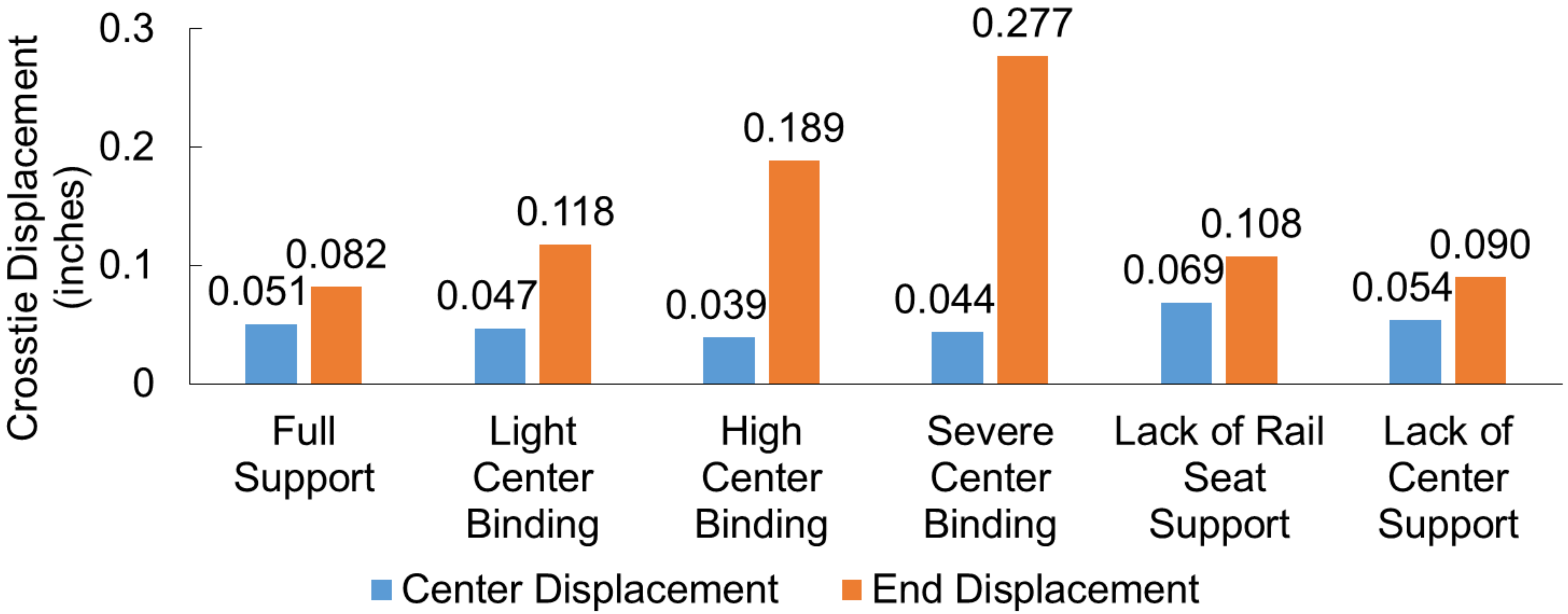
Crosstie Shape under Different Support Conditions

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

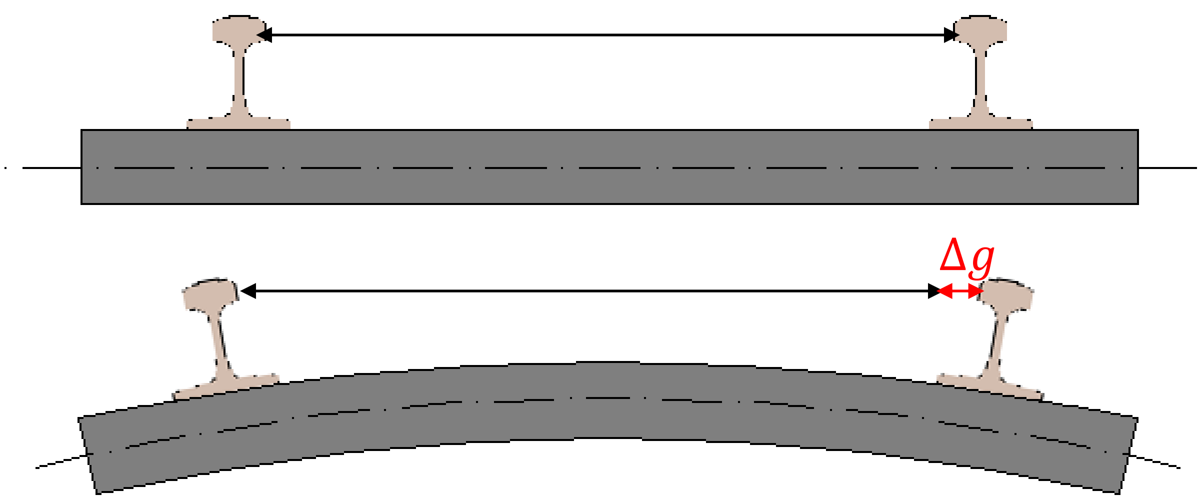
r: Distance between potentiometers close to rail seat

φ: Rail cant angle (1:40)

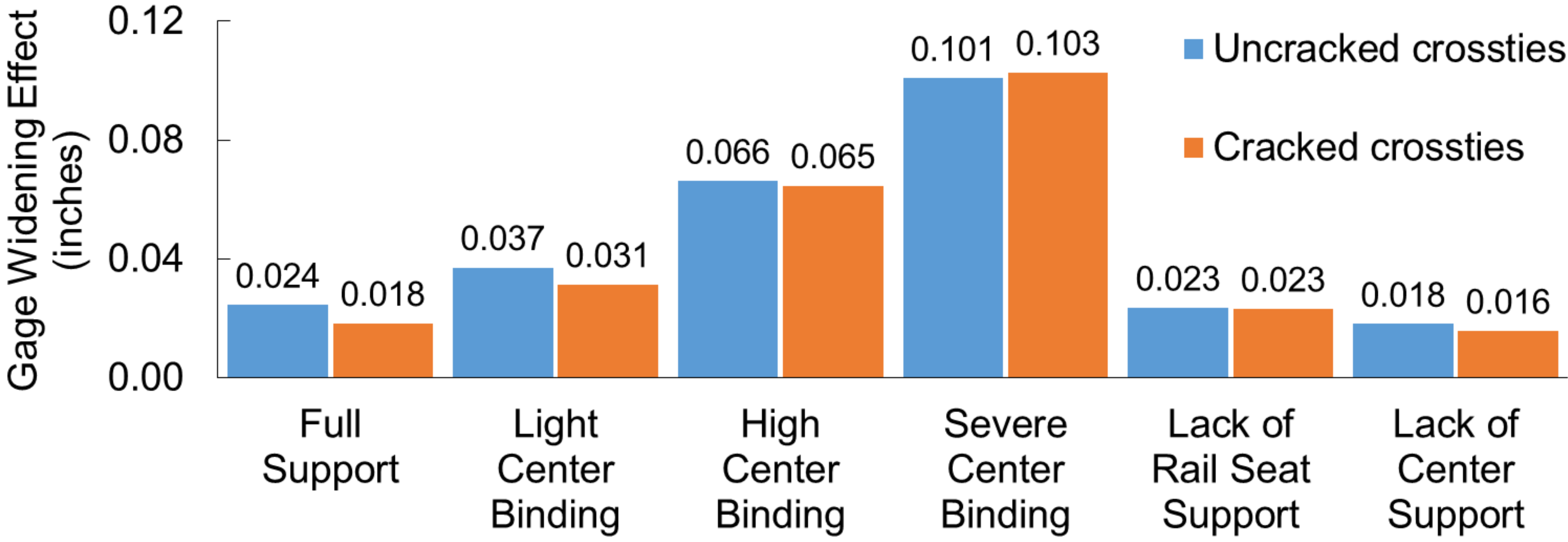
w: Width of rail head

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

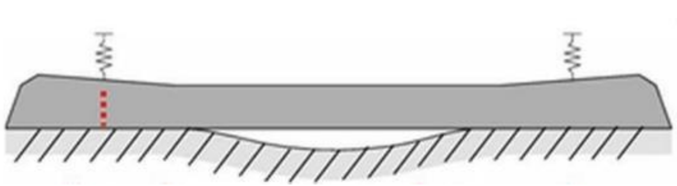
- Support conditions have a significant impact on gage widening
- Cracking does not have a significant impact on gage widening (for particular cracking pattern and crosstie model used in this study)

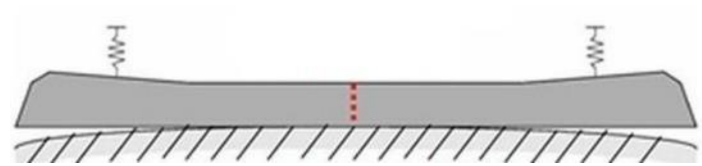
Factor	p-value
Support Conditions	<0.0001
Crosstie Health	0.25

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 significantly reduce center bending moments
- 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

- Plan future finite element modeling (FEM) on system level
- Plan future experiments using the Track Loading System (TLS)
- Study more severe deteriorated conditions

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Questions or Comments?

Josué César Bastos
Graduate Research Assistant
cesarba2@illinois.edu

Riley Edwards
Senior Lecturer and Research Scientist
jedward2@illinois.edu

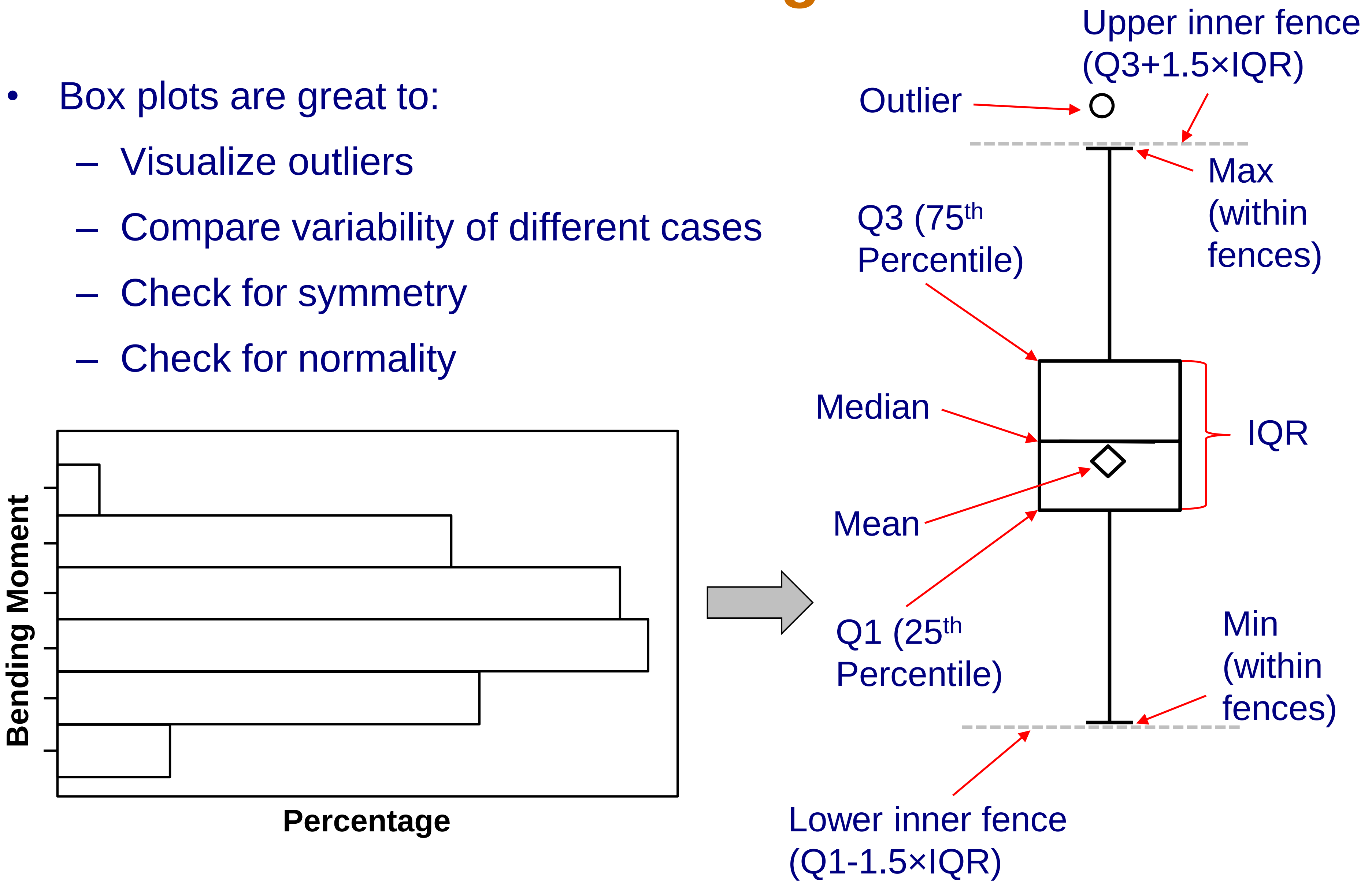
Marcus Dersch
Senior Research Engineer
mdersch2@illinois.edu

Yu Qian
Research Engineer
yuqian1@illinois.edu

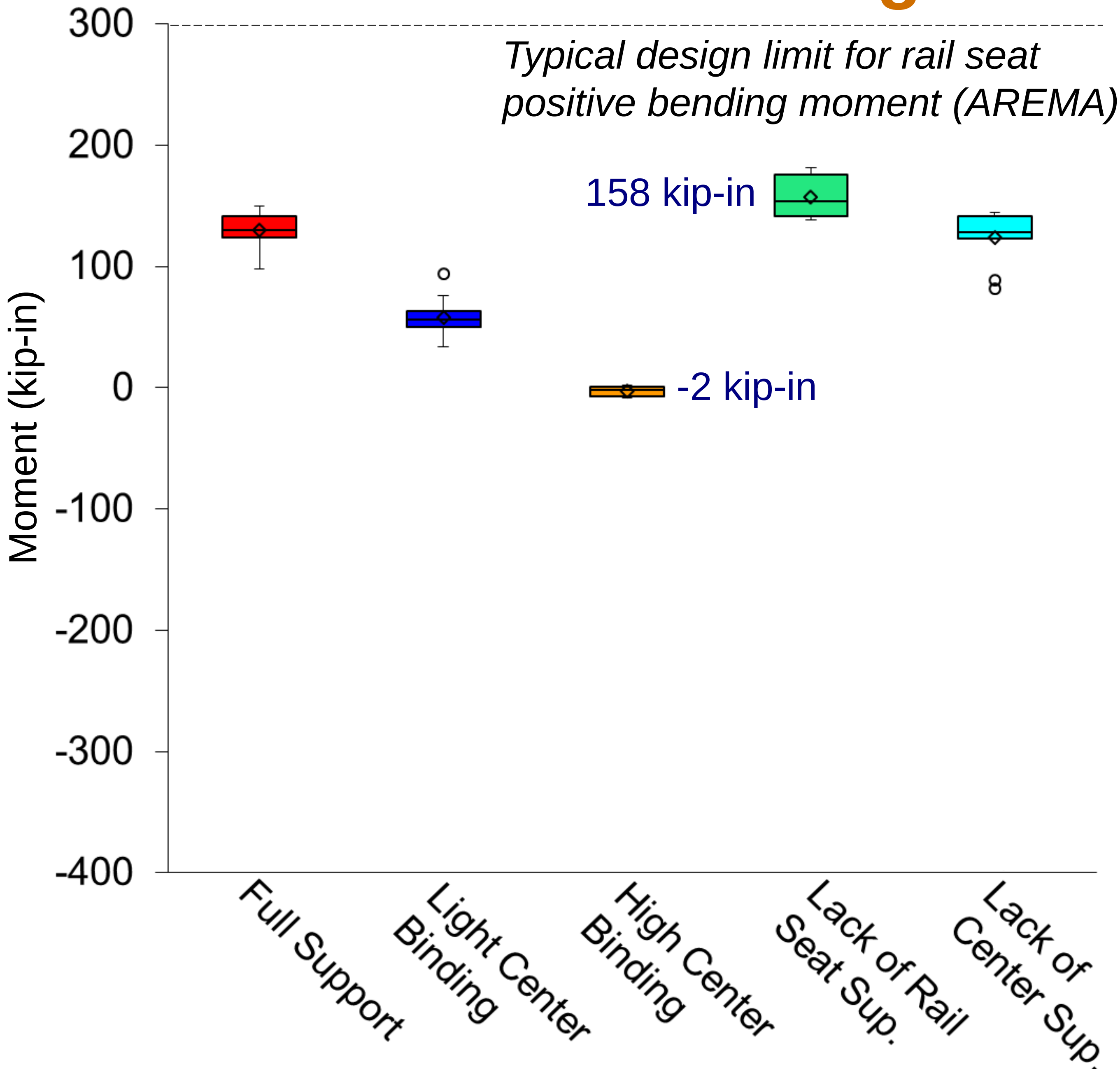
RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Box Plot Background

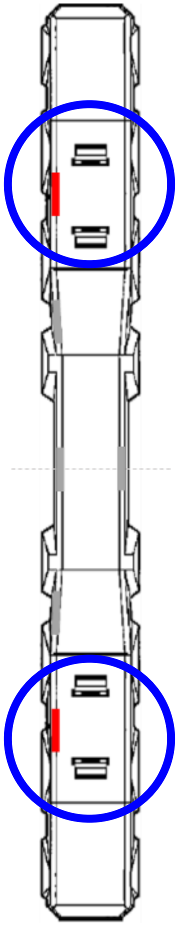
- Box plots are great to:
  - Visualize outliers
  - Compare variability of different cases
  - Check for symmetry
  - Check for normality



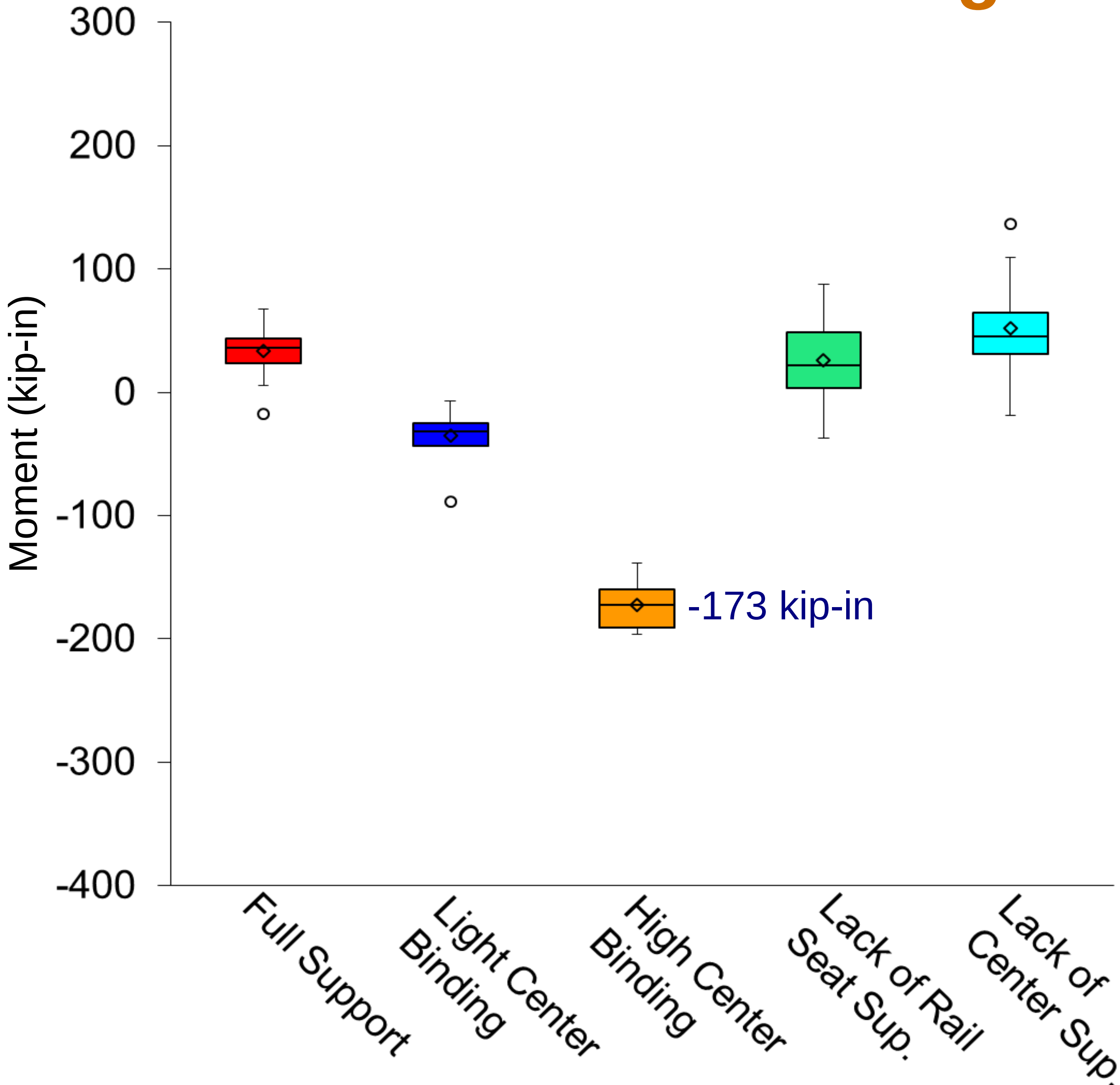
Rail Seat Bending Moments



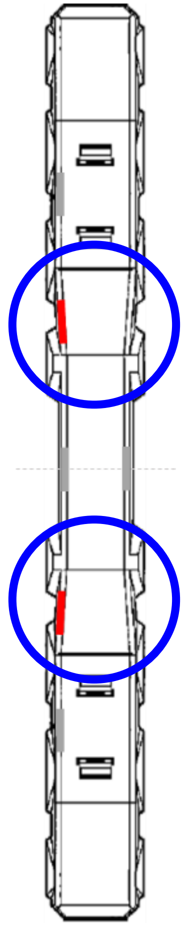
- Rail Seat Load: 20 kips
- Healthy crosstie
- 10 replicates



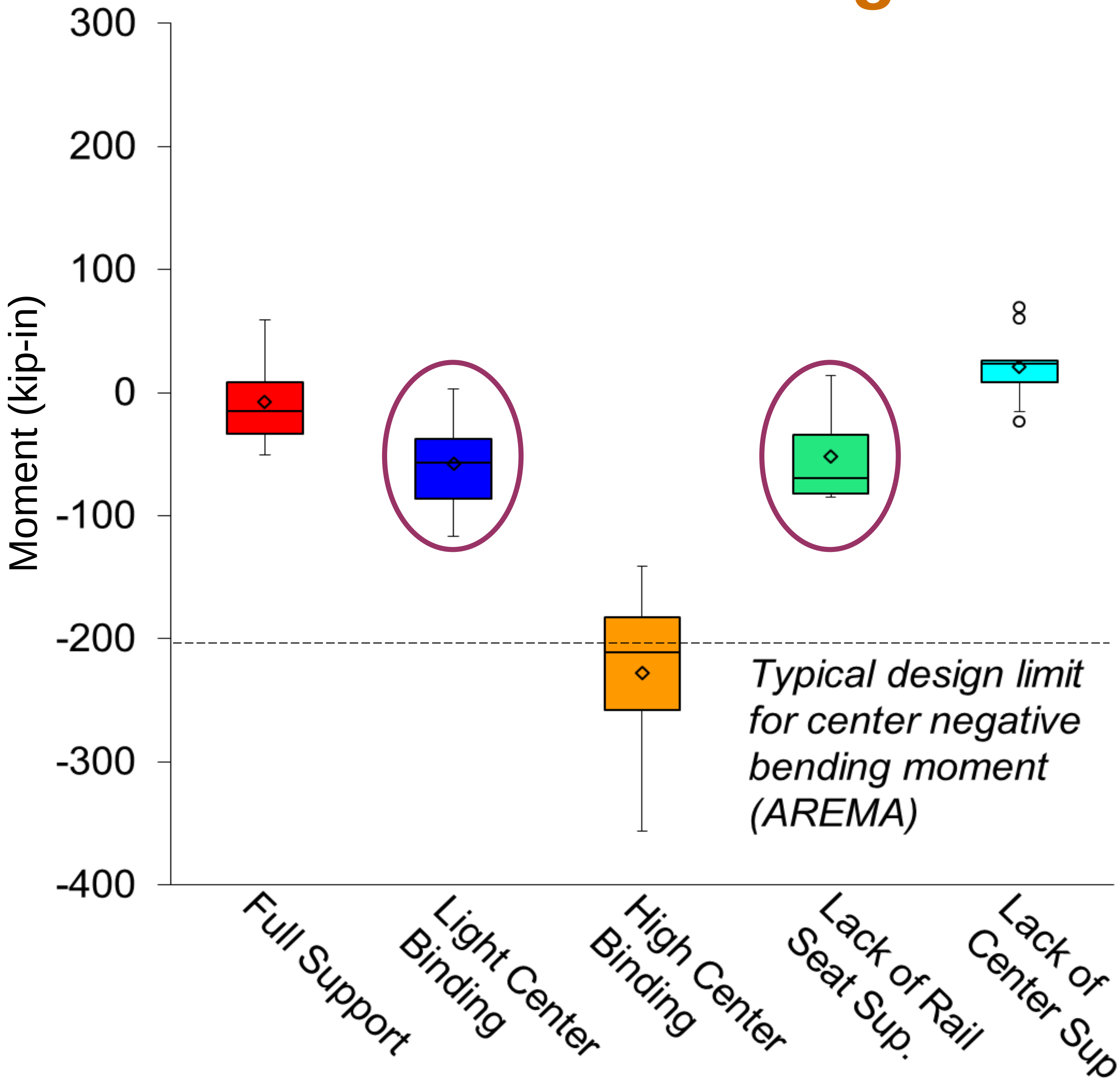
Intermediate Bending Moments



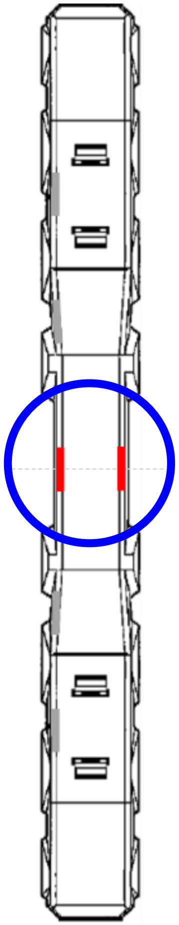
- Rail Seat Load: 20 kips
- Healthy crosstie
- 10 replicates



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)

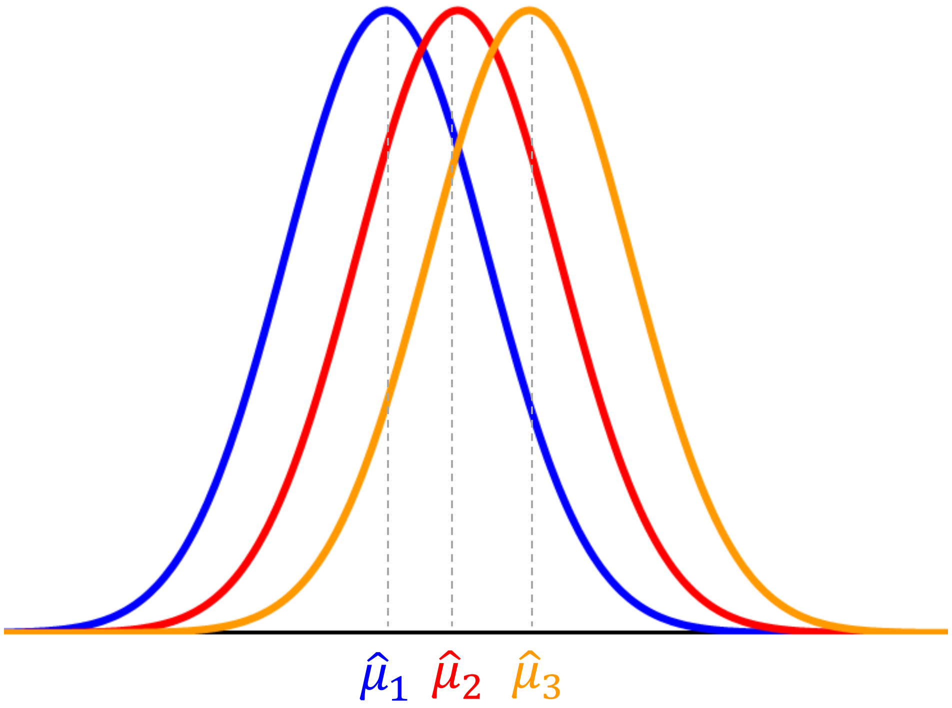
Location	Rail Seat		Intermediate		Center	
Support	t Grouping	Mean	t Grouping	Mean	t Grouping	Mean
Full Support	B	130.1	A B	33.2	A	-7.3
Light Center Binding	C	57.5	C	-35.1	B	-57.8
High Center Binding	D	-2.5	D	-172.8	C	-227.5
Lack of Rail Seat Support	A	157.5	B	26.5	B	-52.1
Lack of Center Support	B	124.0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

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