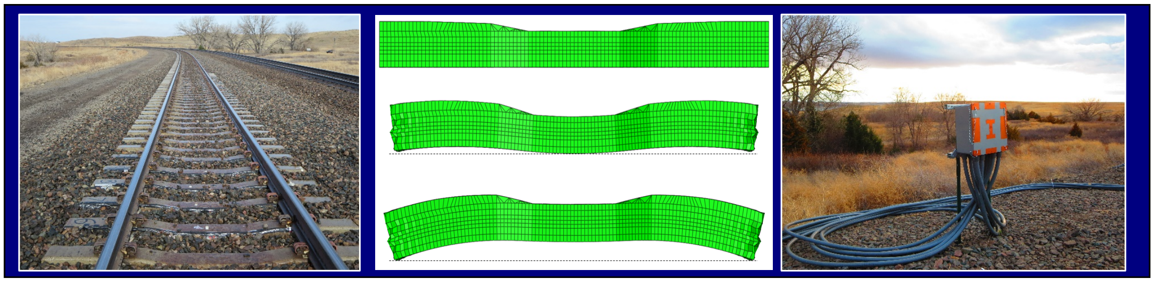
Temperature-Induced Curling of Concrete Crossties



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

Tucson, AZ

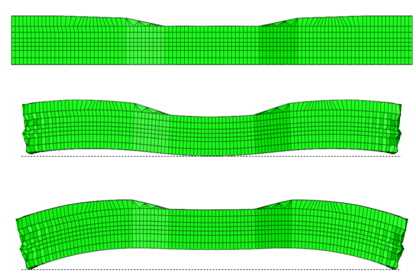
4 November 2015

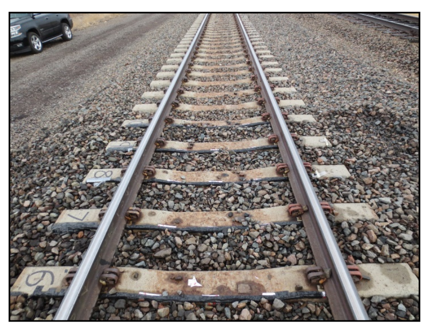
Henry Wolf, Riley Edwards, Marcus Dersch, David Lange, Yu Qian, Matt Csenge, and Zhengboyang Gao

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

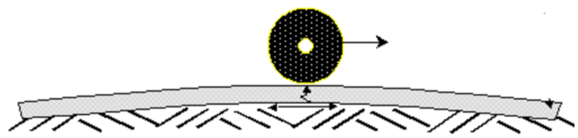
- Background
- Purpose
- Approach
  - Finite element analysis
  - Laboratory experimentation
  - Field experimentation
- Results Comparison
- Conclusions



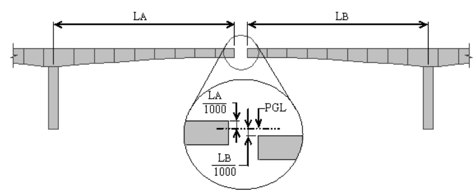


Background

- Curling due to temperature gradients is well-documented in other concrete infrastructure applications
  - Curling in concrete slabs
    - Slab curling and joint movements affect response of pavement to traffic loads

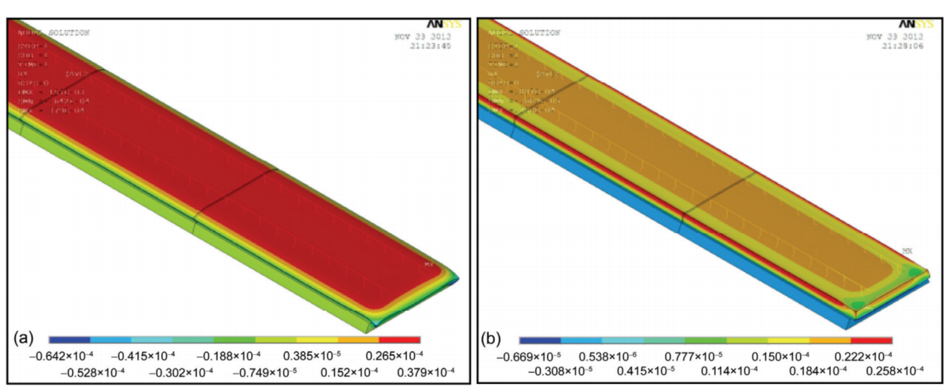


  - Camber in concrete bridge girders
    - Can cause re-distribution of internal stresses in bridge superstructure and difficulty in construction

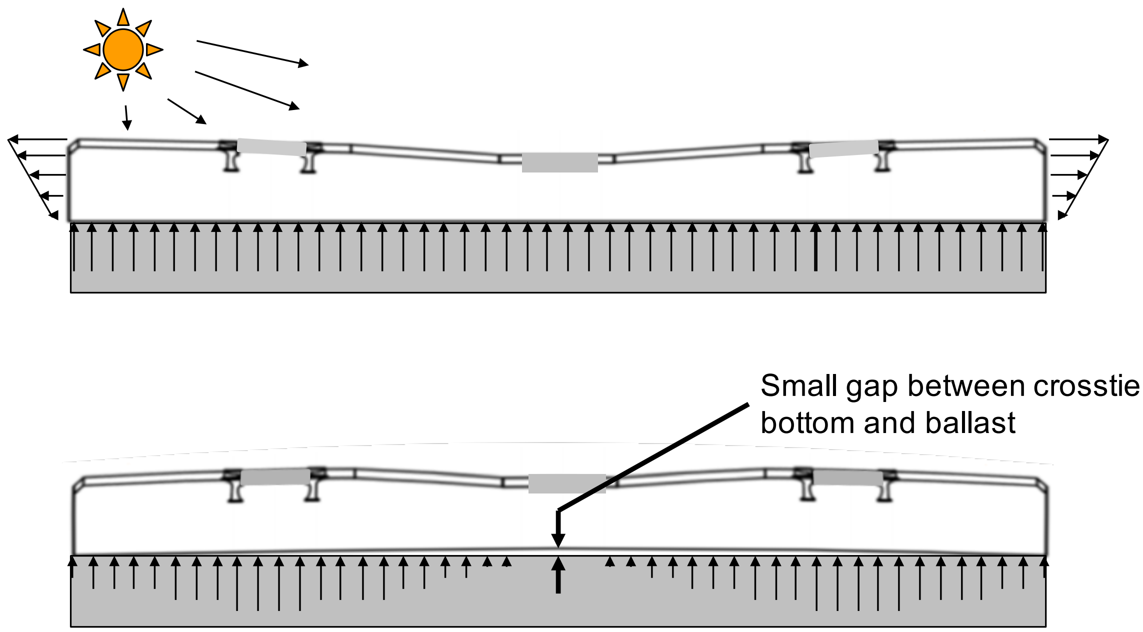


Background (cont.)

- Curling due to temperature gradients is well-documented in other concrete infrastructure applications
  - Curling in concrete slab track
    - Slab curling causes loss of bond between concrete slab and supporting layer

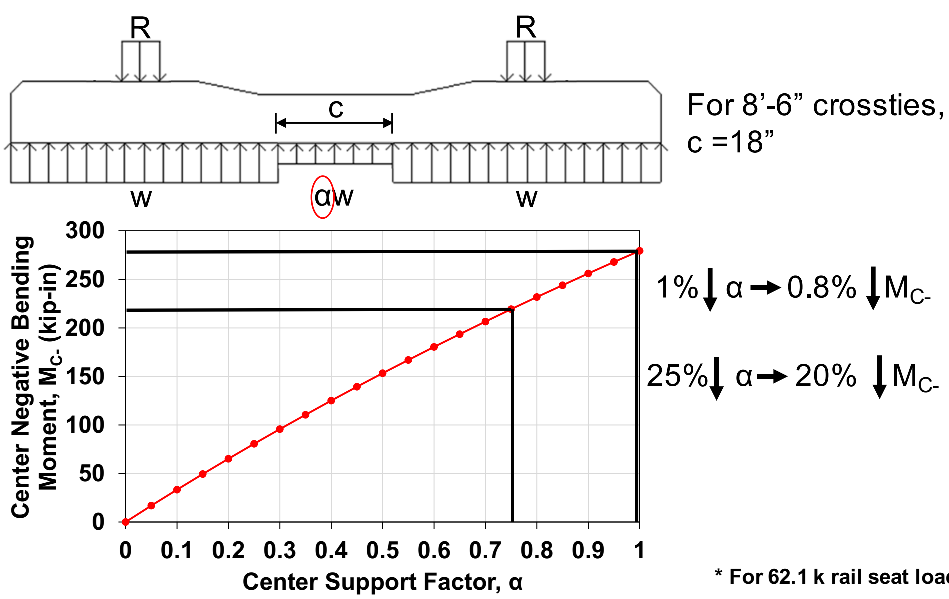


Crosstie Curling Under Temperature Gradient



Why it matters…

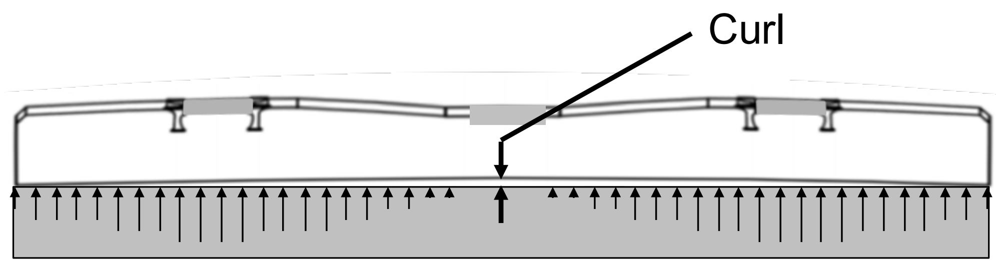
- Center negative crosstie bending moments are highly sensitive to small changes in ballast reaction at the center support region of the crosstie



* For 62.1 k rail seat load

Why it matters… (cont.)

- If temperature-induced curl can cause reductions in the ballast reaction at the crosstie center it can lead to decreases in center negative bending moment and increases in rail seat positive bending moment



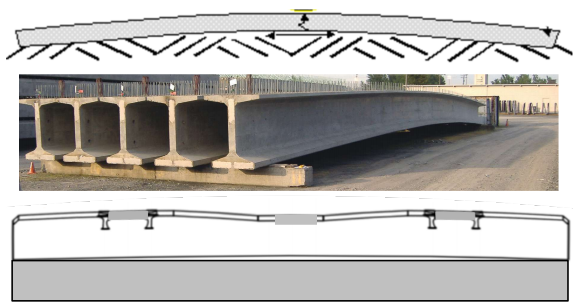
Approach

- Perform literature review to estimate magnitude of crosstie curl
- Perform finite element (FE) analysis to confirm behavior and estimate magnitude of crosstie curl
- Execute laboratory experimentation to measure magnitude of crosstie curl
  - Comparison with other published values
  - Comparison with FE results
- Execute field experimentation to quantify revenue service bending moments vs. temperature gradients

Published Magnitudes of Curl

- Compared published values of curl for concrete pavements and bridge girders

	Temp. Grad. (°F)	Member Length (in)	Curl (in)	Curl/Length (10^{-4})	Curvature (1/in) (10^{-6})
Pavement	23-34	120-146	0.039-0.07	2.67-5.83	14.6-38.9
Girder	20	960-1644	0.33-0.76	3.44-4.62	2.3-2.9
Crosstie	?	102	?	?	?

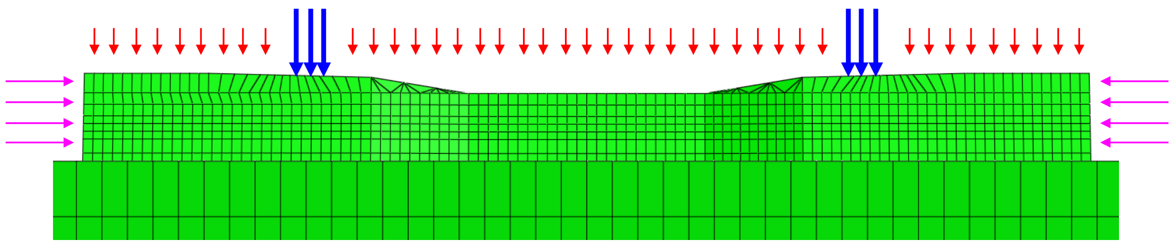


Finite Element Analysis

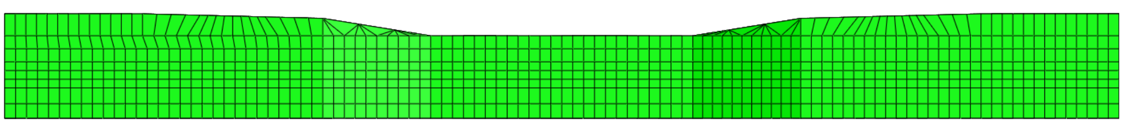
- Validated FE model has been used to attempt to predict and confirm these findings numerically
- Curl is dependent on coefficient of thermal expansion of concrete
  - Use published values – 5.5×10^{-6} in/°F

Finite Element Analysis

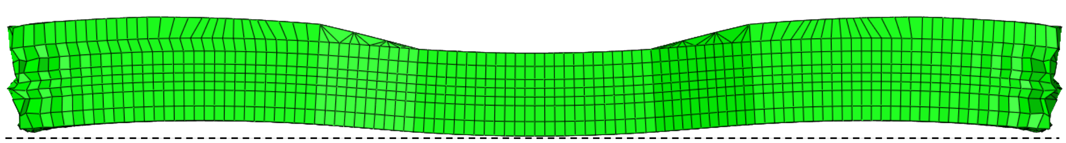
- Validated FE model based on CXT 505S
  - Includes ballast support
- Loading sequence:
  1. Prestress force
  2. Temperature gradient (30 °F)
  3. Vertical load (18 k)



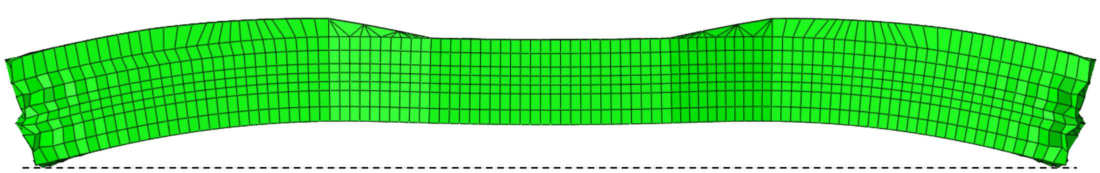
Finite Element Analysis: Deformed Shape



Undeformed



After prestress transfer

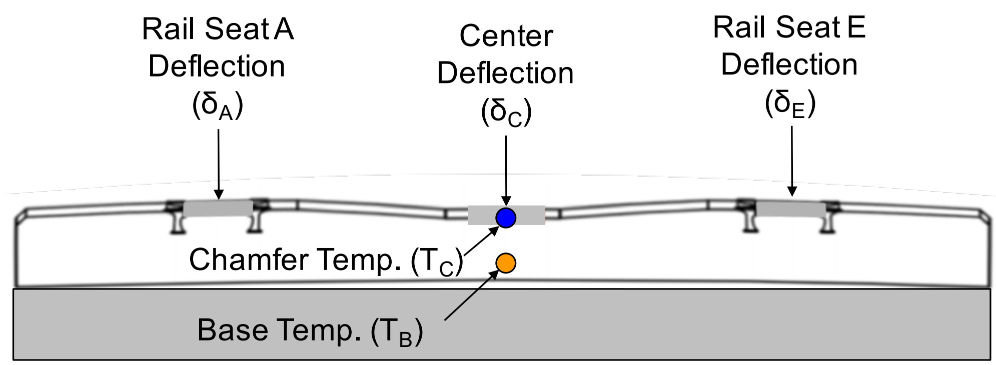


30 °F temperature gradient
(max curl = 1.69×10^{-2} in)

Scale factor = 200

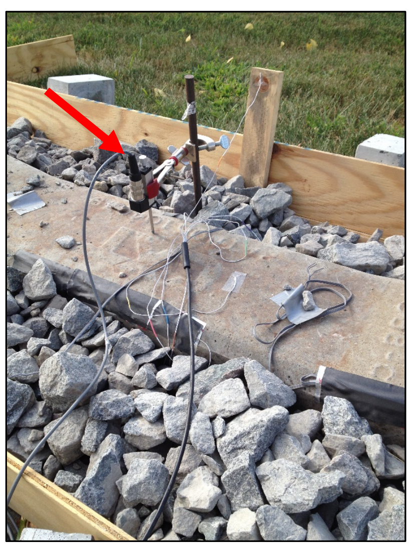
Laboratory Experimentation to Measure Curl

- Installed potentiometers on rail seats and center of the crosstie to measure deflection
- Installed thermocouples at chamfer and base of the crosstie to measure temperature



Laboratory Experimentation to Measure Curl: *Set-up*


Full set-up

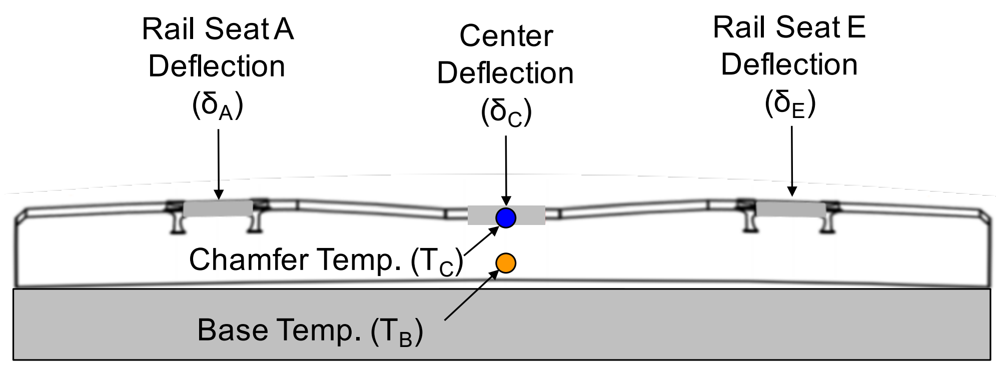

Potentiometer


Thermocouple

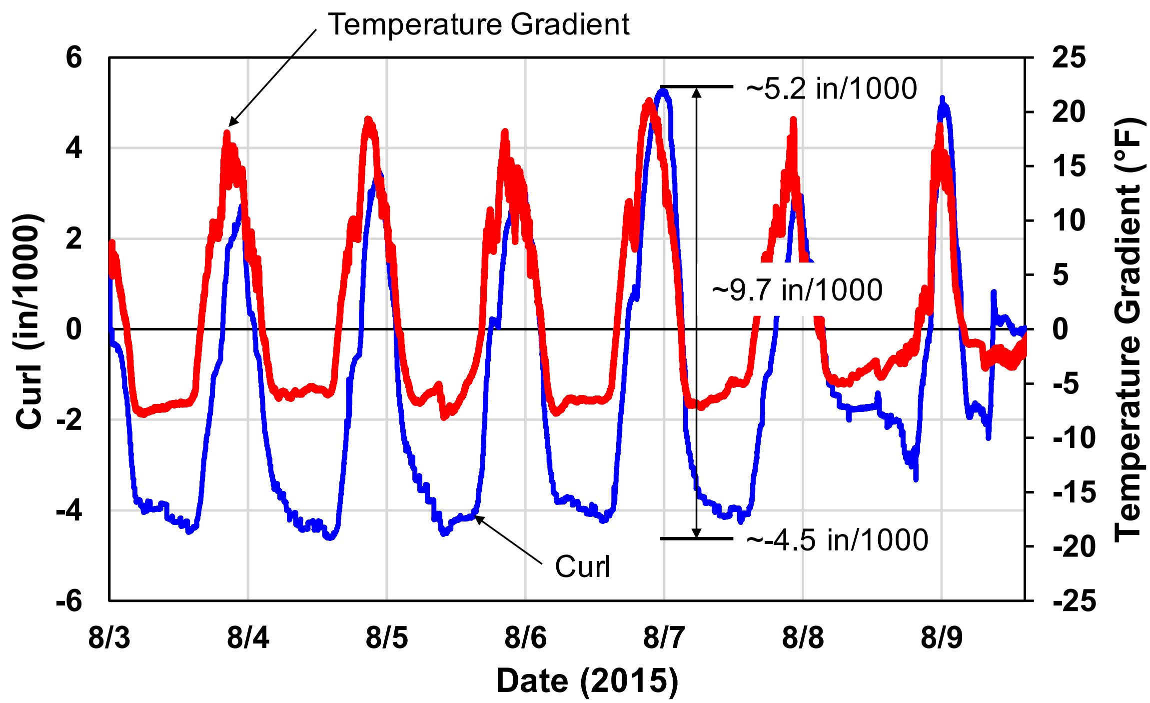
Laboratory Experimentation to Measure Curl: *Definitions and Calculations*

$$\text{Curl} = \delta_C - 0.5(\delta_A + \delta_E)$$

$$\text{Temperature Gradient} = T_C - T_B$$

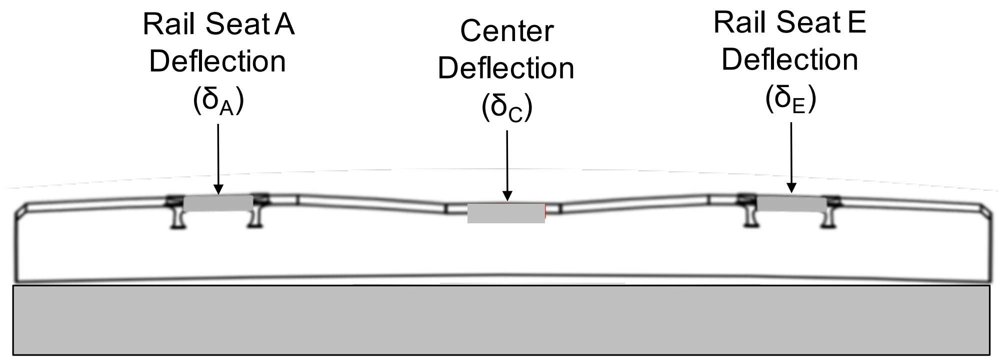


Laboratory-Measured Curl of Concrete Crosstie Caused By Temperature Gradient (8/3/15-8/10/15)



Laboratory Experimentation to Measure Curl: *Results*

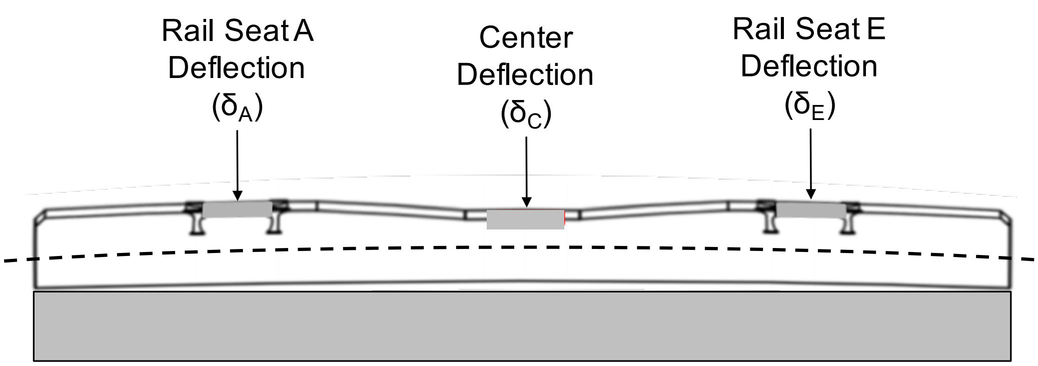
$$\text{Curl} = \delta_C - 0.5(\delta_A + \delta_E)$$



Max Curl = 9.69 in/1000

Laboratory Experimentation to Measure Curl: *Results*

$$\text{Curl} = \delta_C - 0.5(\delta_A + \delta_E)$$



Max Curl = 28.0 in/1000

Max Curl, FE = 16.9 in/1000

Similar magnitudes, same behavior!

Comparison of Measured and Published Curl Values

	Temp. Grad. (°F)	Member Length (in)	Curl (in)	Curl/Length (10^{-4})	Curvature (1/in) (10^{-6})
Pavement	23-34	120-146	0.039-0.07	2.67-5.83	14.6-38.9
Girder	20	960-1644	0.33-0.76	3.44-4.62	2.3-2.9
Crosstie	29.6	102	0.028	2.75	21.5

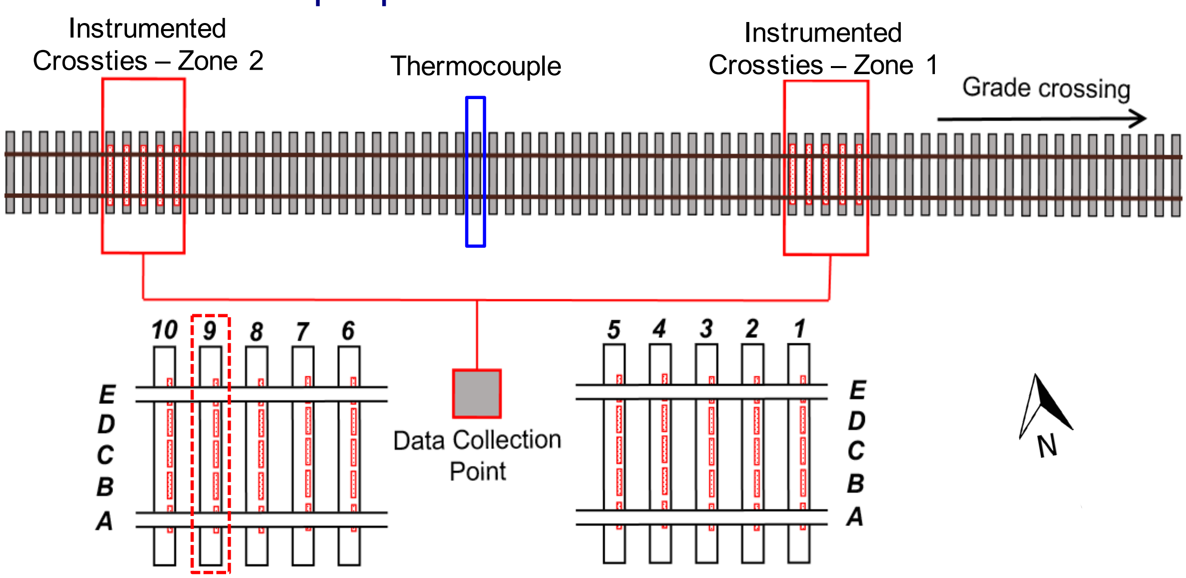
- Crosstie curl and curvature are similar to pavements
- Crosstie curl/length ratio is within range of both pavements and girders

Field Experimentation Location

- Test site is located in western Nebraska
- Concrete crossties and elastic fasteners installed in 1999
- Track experienced approximately 220 MGT of traffic in 2014

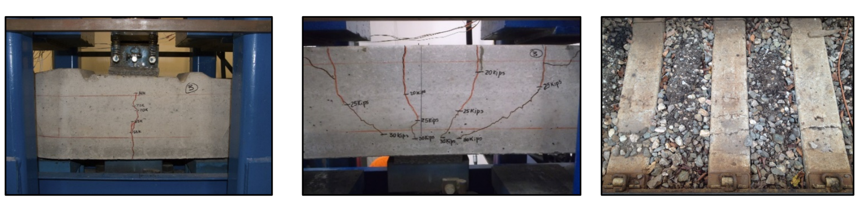
Field Site Layout

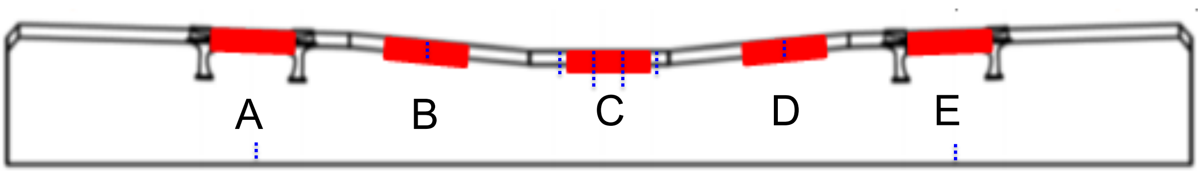
- Site split into two zones of five crossties each
- 50 surface strain gauges installed on 10 crossties
- Thermocouple placed between zones



Crosstie Instrumentation

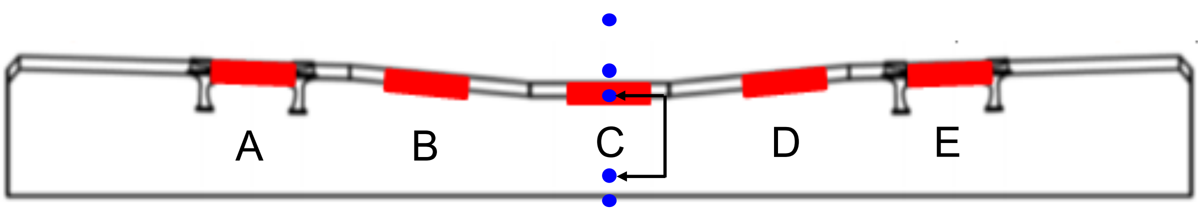
- 5 surface strain gauges installed on each crosstie:
  - Rail seat gauges (to measure rail seat positive bending)
  - Center gauge (to measure center negative bending)
  - Intermediate gauges (to measure asymmetric loading or support)



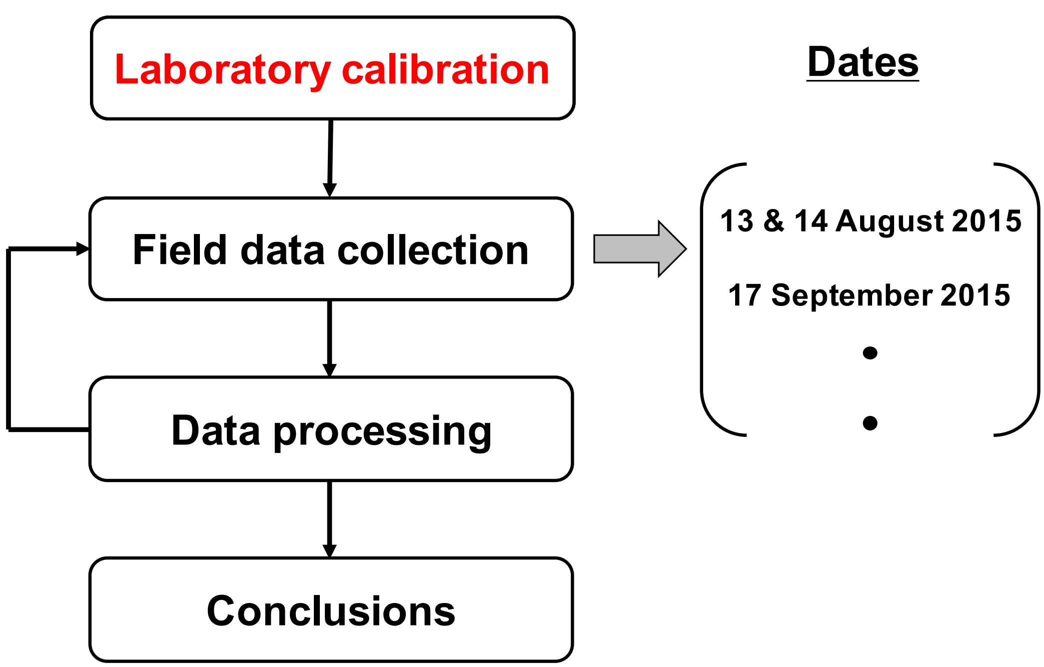


Crosstie Instrumentation

- 5 thermocouples installed on central crosstie:
  - Ambient temperature
  - Top of crosstie temperature
  - Chamfer temperature
  - Ballast/Base temperature
  - Under crosstie temperature



Project Approach



Strain to Moment Laboratory Calibration: *Purpose*

- Measured bending strains can be converted to bending moments through sectional properties,

$$M = \left(\frac{EI}{y}\right)\varepsilon$$

where,

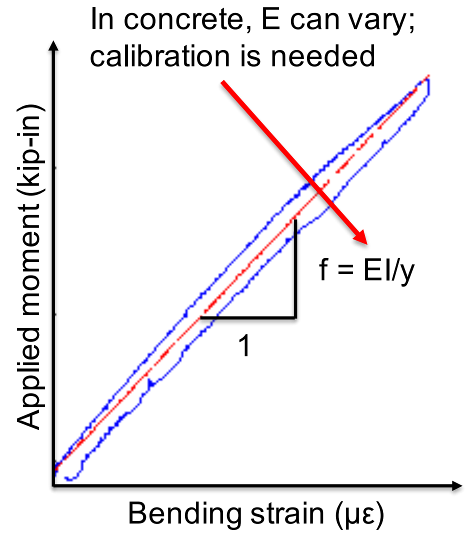
M = bending moment

E = elastic modulus

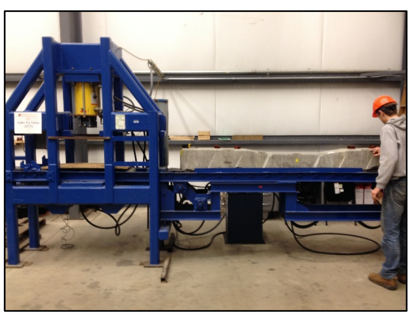
I = moment of inertia

y = distance from neutral axis

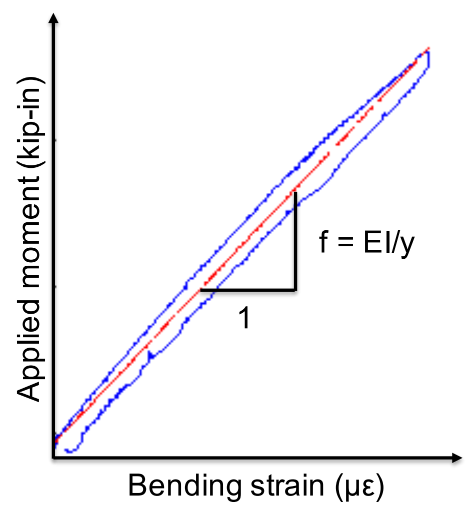
ε = bending strain

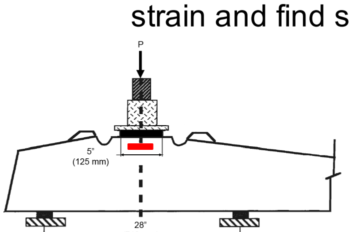


Strain to Moment Laboratory Calibration: *Procedure*

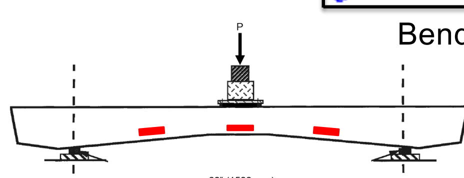


Known moment applied with Static Tie Tester (STT) to crosstie in controlled loading configurations, record bending strain and find slope of curve





Rail Seat Positive



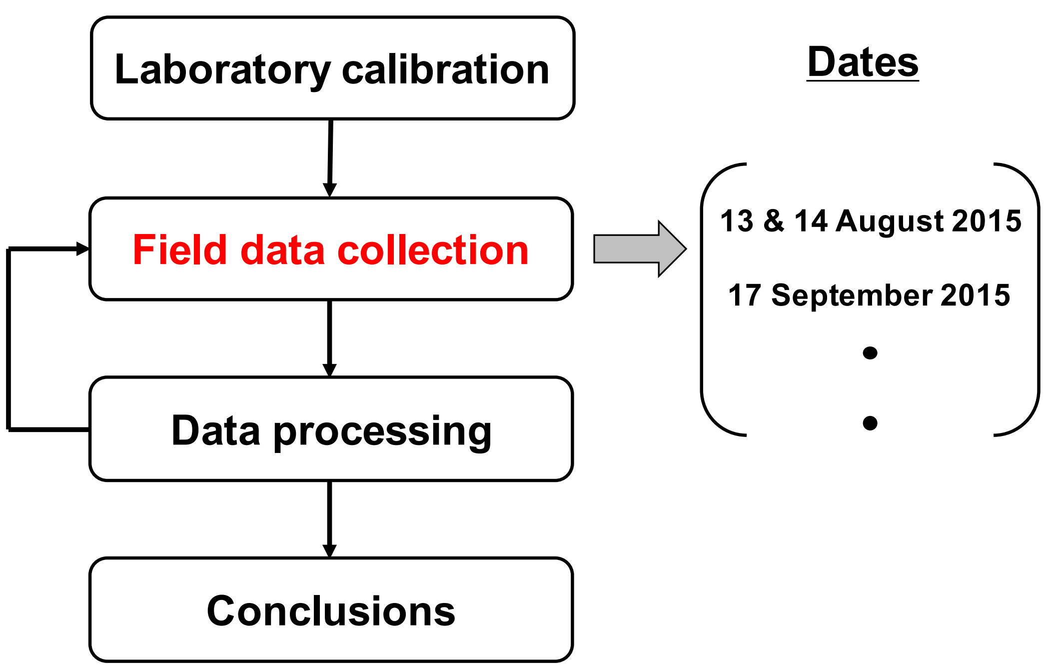
Center Negative

Strain to Moment Laboratory Calibration: *Results*

- Used crossties of same model and vintage (1999)
  - Same model, same moment of inertia (I)
  - Same vintage, similar elastic modulus (E)
- Tested three replicates and average calibration factors

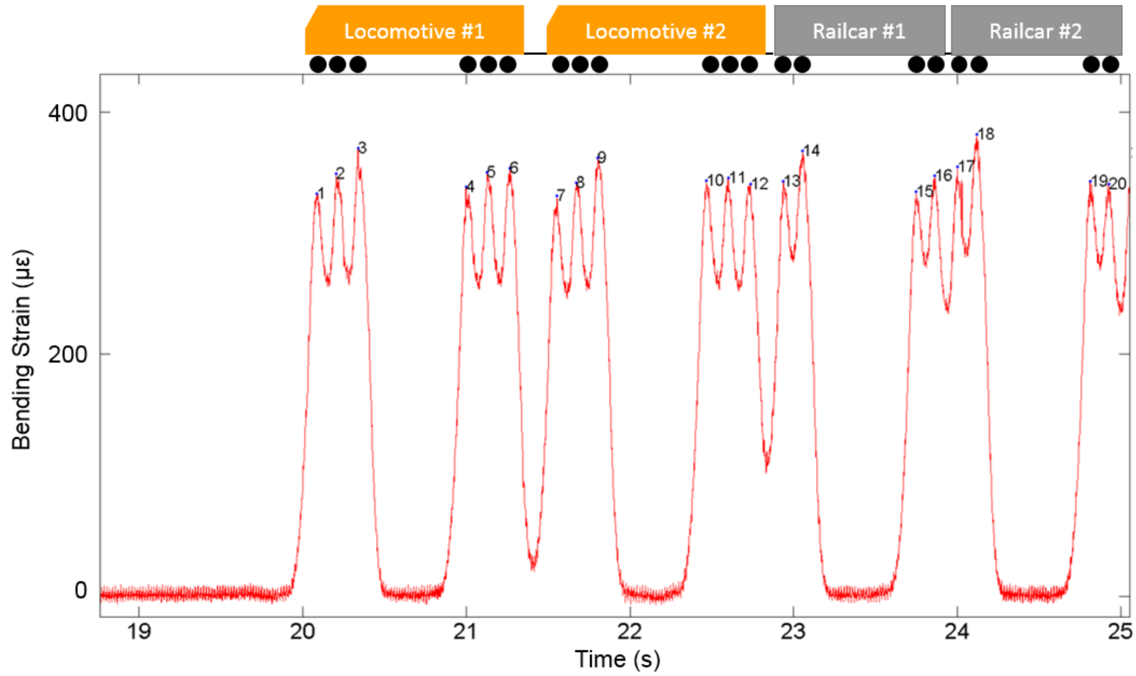
Location	Rail Seat (Gauge A & E)	Intermediate (Gauge B & D)	Center (Gauge C)
Calibration factor	-768,572.9	615,979.3	504,946.7

Project Approach



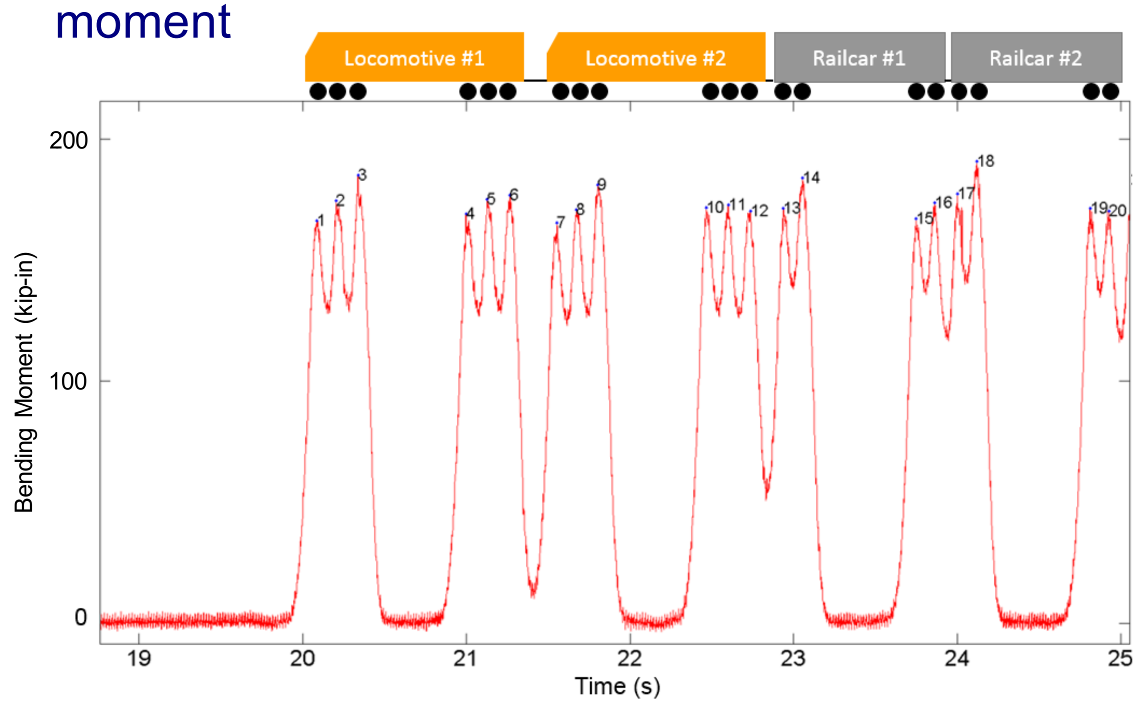
Example Strain Signal (Gauge C)

- Strain peaks correspond to loaded axles



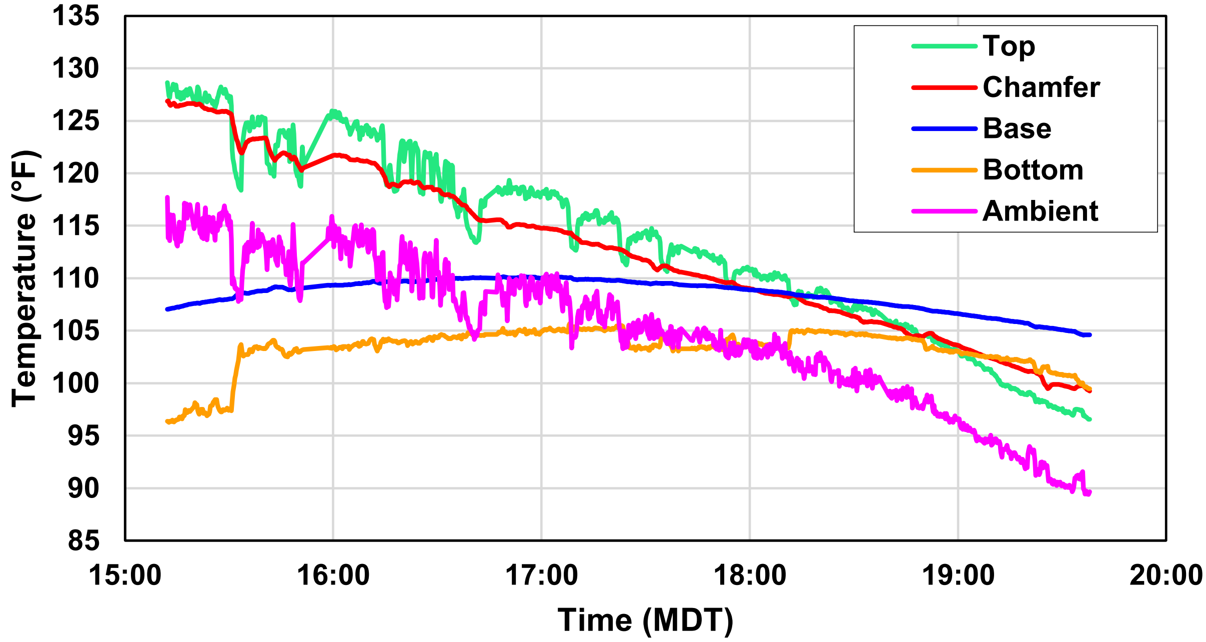
Example Bending Moment Signal (Gauge C)

- Multiply strain by calibration factor to convert to moment



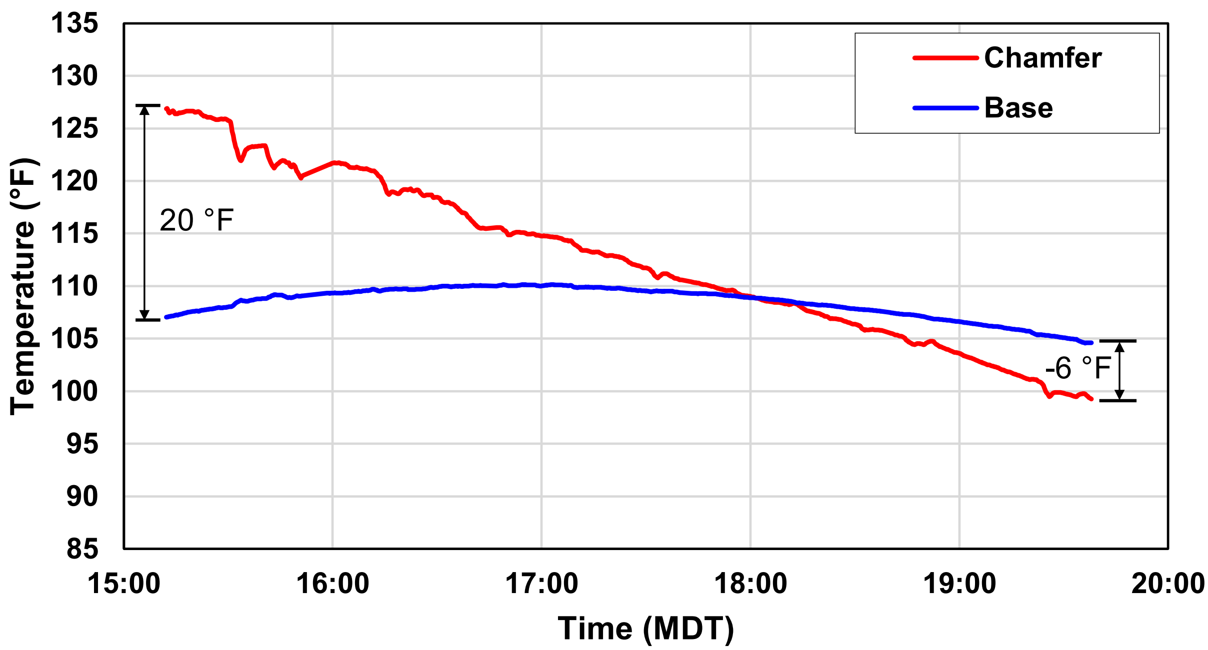
Example Thermocouple Signal

- Subtract chamfer by base to determine gradient

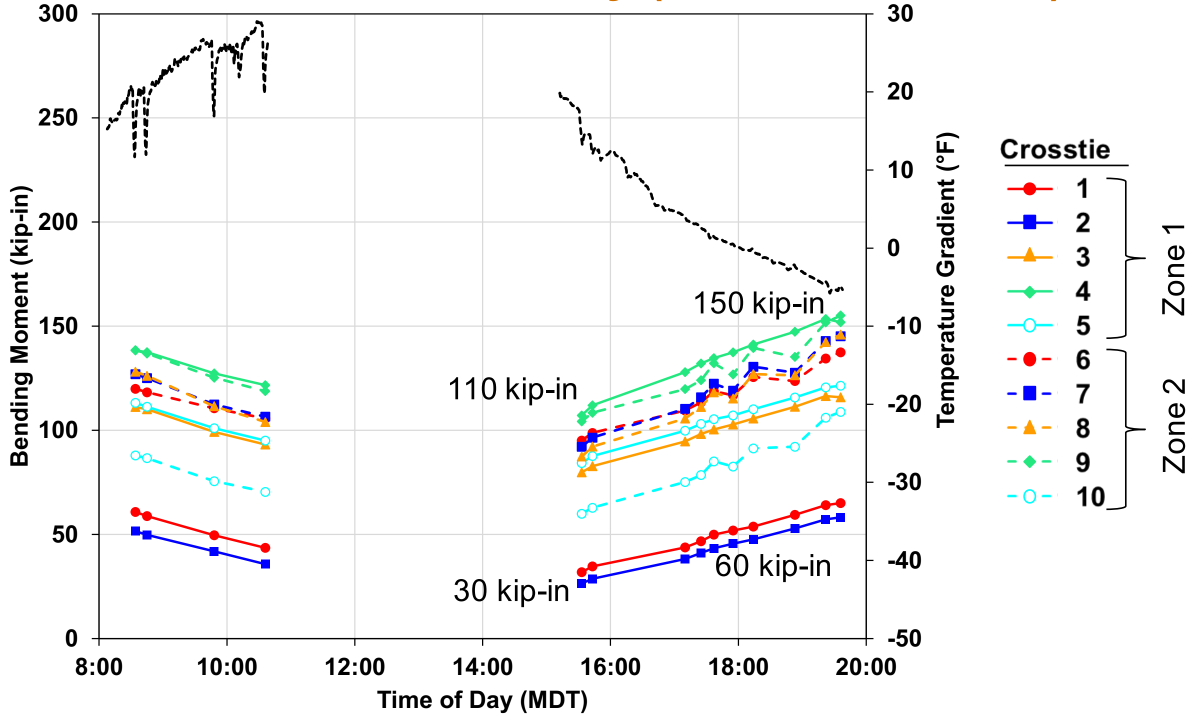


Example Thermocouple Signal

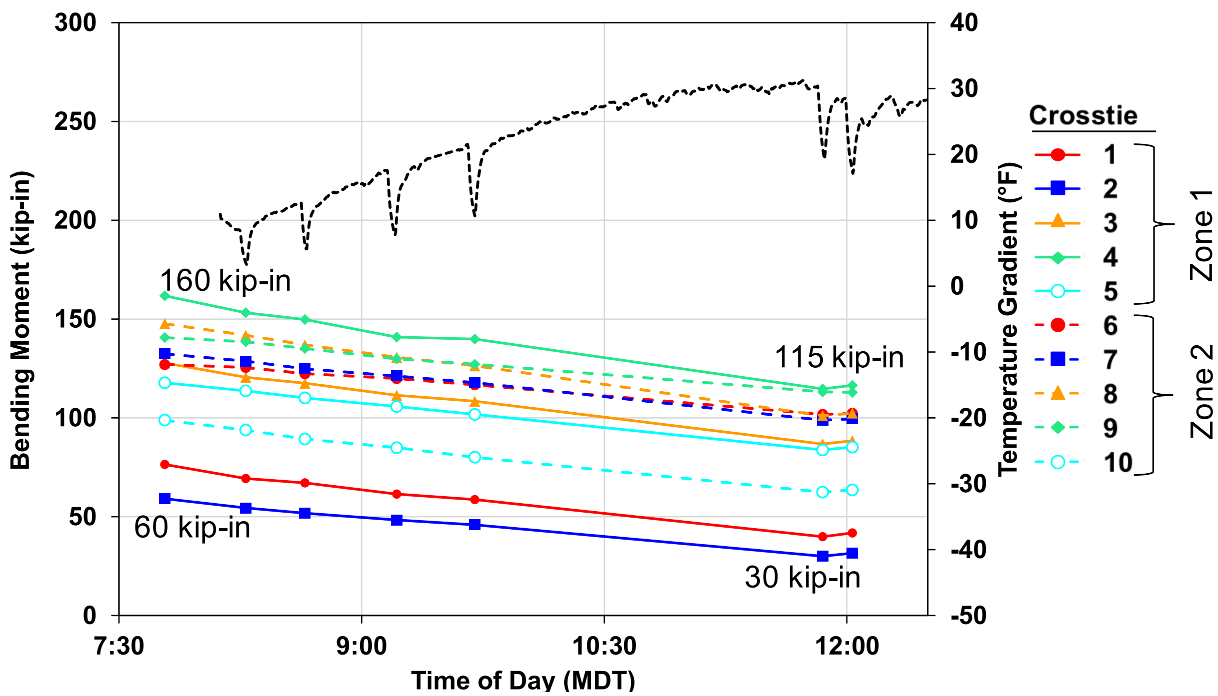
- Subtract chamfer by base to determine gradient



Field-Measured Average Center Negative Bending Moments and Temperature Gradients Over Course of Day (8/13/15 & 8/14/15)



Field-Measured Average Center Negative Bending Moments and Temperature Gradients Over Course of Day (9/17/15)



Conclusions

- Curling behavior can be predicted with FE modelling
  - Preliminary analyses show similar curl (0.017 in FE vs. 0.028 in measured)
- Curl in concrete crossties is within range of published curl for concrete pavements
  - Laboratory measured curl is 0.028 in
- Field measurements show increase in temperature gradient causes decrease in center negative bending moment
  - 25-30 °F temperature gradient can cause 30-50% reduction in center negative bending moment

Acknowledgements

NURail Center

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  - BNSF Railway
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Contact Information

Henry E. Wolf
Graduate Research Assistant
email: wolf24@illinois.edu

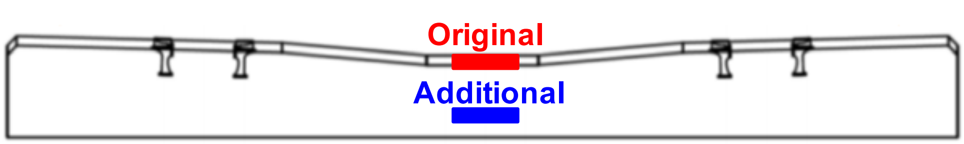
Marcus S. Dersch
Senior Research Engineer
email: mdersch2@illinois.edu

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

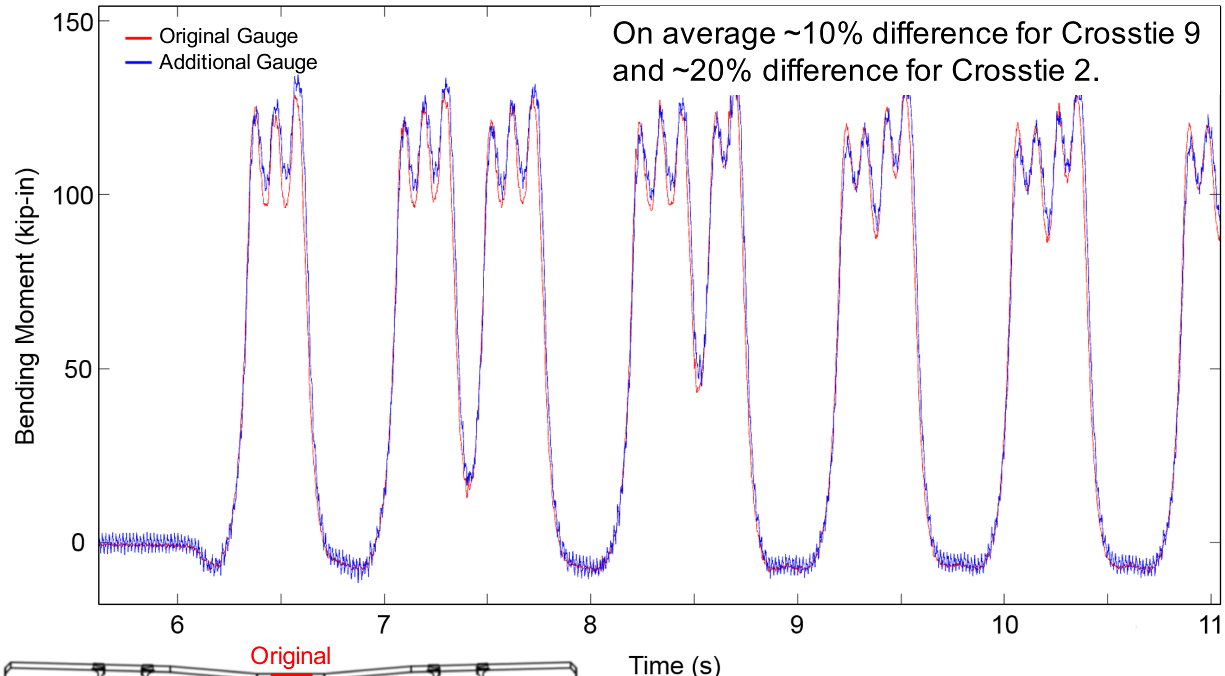
David A. Lange
Professor
email: dlange@illinois.edu

Hypothesis: Artifact of Instrumentation

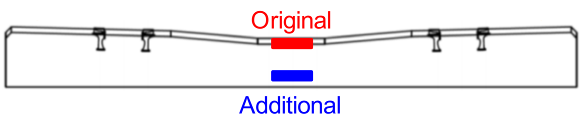
- Installed an additional strain gauge near the bottom of Crosstie 2 & Crosstie 9
  - Original gauge was exposed to sunlight and higher temperatures
  - Additional gauge exposed to no sunlight and lower temperatures
- Compared calibrated bending moments



Original Gauge vs. Additional Gauge Measurements Crosstie 9 (7/7/15)



On average ~10% difference for Crosstie 9 and ~20% difference for Crosstie 2.



Difference is consistent, most likely due to strain gauge placement or calibration