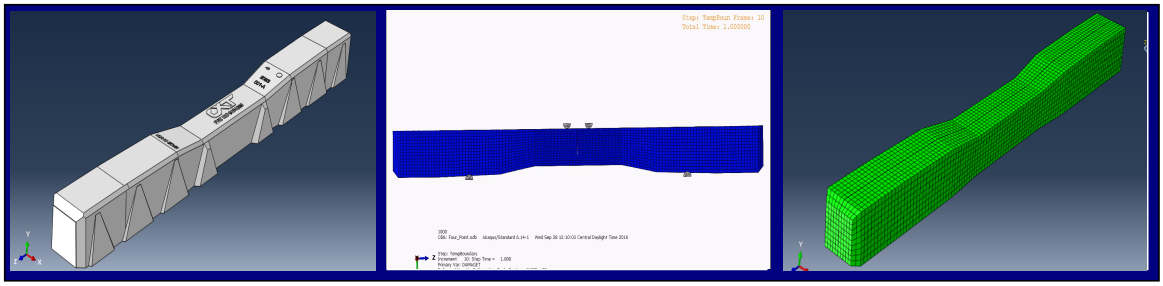
# Concrete Crosstie Finite Element Modeling Update and Results



FRA and FTA Crosstie and Fastening System Research Program
Industry Partners (IP) Meeting
Bonita Springs, FL
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U.S. Department of Transportation
Federal Railroad Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

U.S. Department of Transportation
Federal Transit Administration

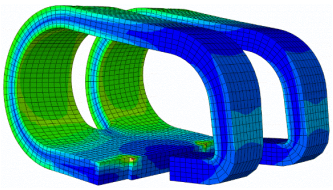


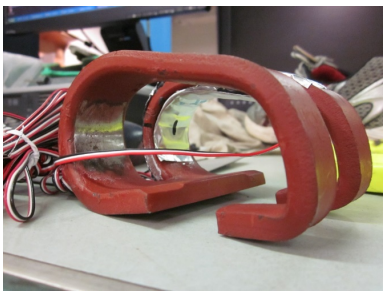
## Outline

- Previous FE Work
- Overview/Role of FE analysis
- Methodology for FE Analysis
- Calibration and Validation of Developed Model
- Review of Existing Model
- Path Forward

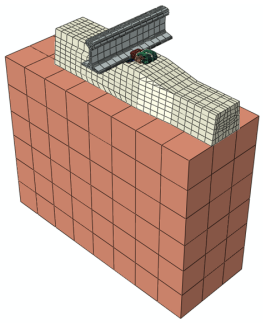
# Previous FE Analysis

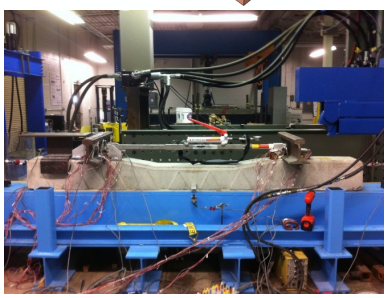
## Component Validation



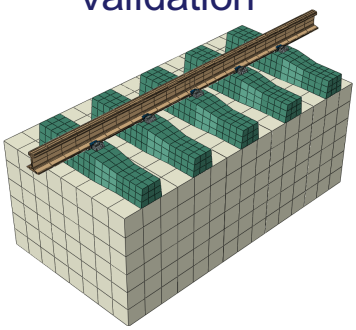


## Laboratory Validation





## Field Validation





**FRA**

Previous Model

Initial Model Focusing on Elastic Behavior

Predict Crack Location and Crack Propagation

Failure Analysis with Four-point Bend Test

Developed model used to predict initial behavior

**FTA**

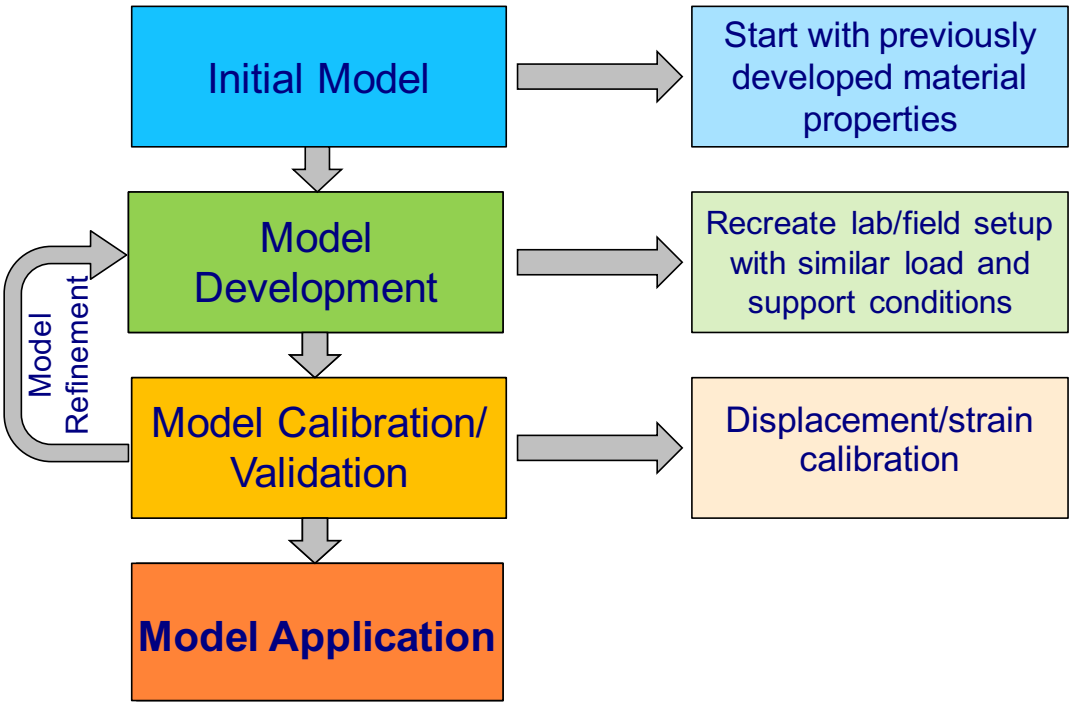
Collected Field Data

Model Calibration using Strain Gauge Calibration Curves

Improve Model to Predict Crosstie Behavior in Field

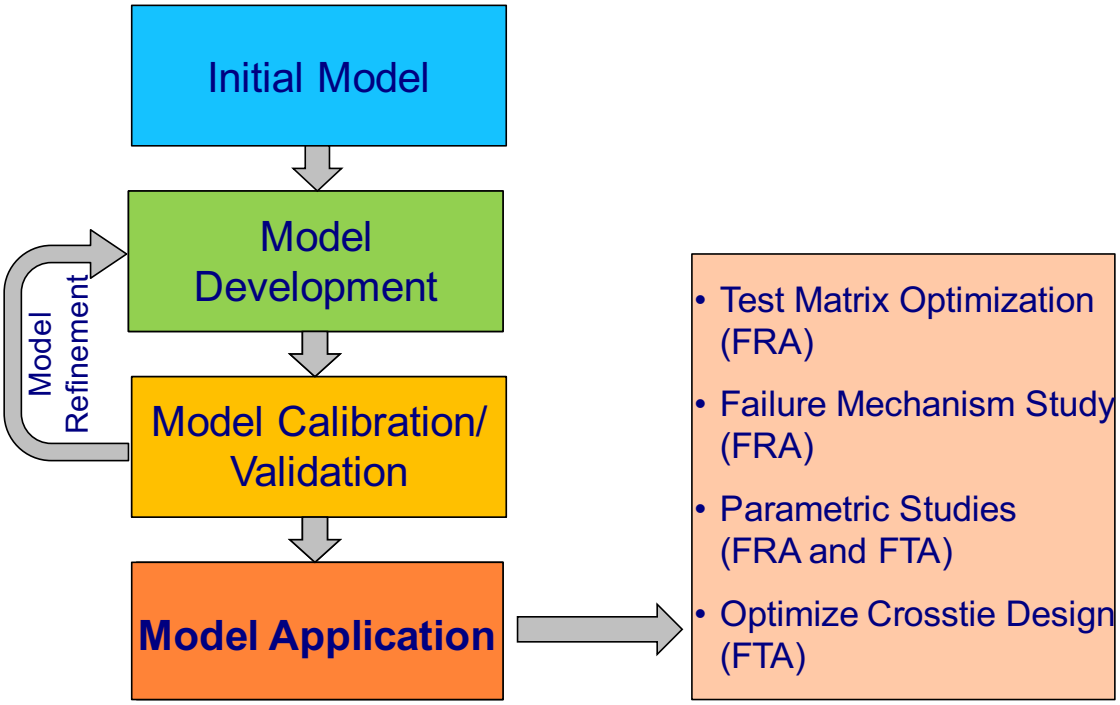
Understand critical parameters for "failure" and optimize the crosstie design based on observed requirements

# Methodology for FE Analysis



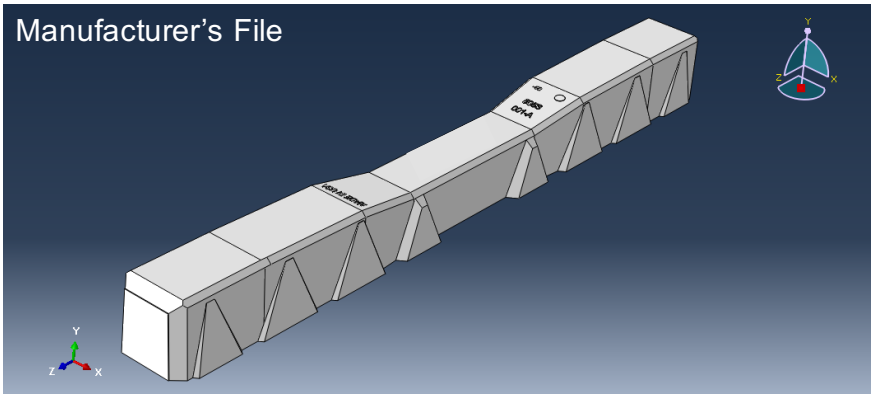



# Methodology for FE Analysis



# Design Characteristics

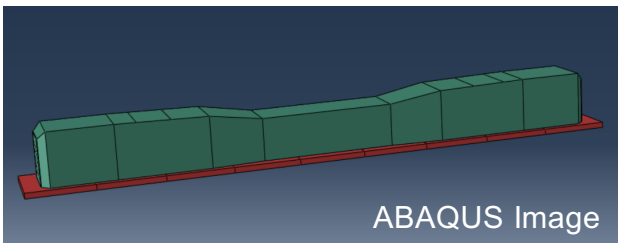
- Total length of crosstie = 102 in. (2591 mm)
- Prestress wire arrangement – 20 wires, 5 rows
- Wire diameter = 0.21in. (5.32 mm)
- Prestress load on each wire = 7,000 lbf (31.14 kN)
- Initial prestress = 203 ksi (1,400 MPa)





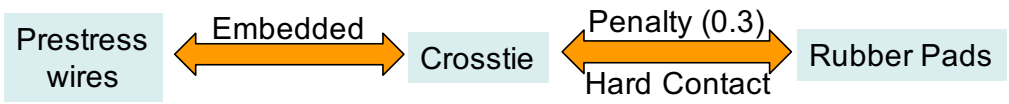

# Arrangement of the Assembly

- The following characteristics about the lab setup were noted and modeled to recreate the setup in FE model:
  - Crosstie is supported by the elastomer (rubber) pads
  - Elastomer pads supported by stiff steel beam (idealized as fixed boundary condition in FE model)
  - Load applied at the rail seat location

# Simulated Interaction Properties

- Interaction properties define how different entities of a multi-part assembly interact in the model
- The prestress wires are 'embedded' in the crosstie
  - Embedded constraint allows no relative slip between the host (crosstie) and embedded (prestress wires) parts
- 'Surface-to-surface contact' is defined between crosstie and elastomer pads
  - Tangential behavior is selected to be 'penalty' with the friction coefficient equal to 0.3 and normal behavior is selected to be 'hard contact'.

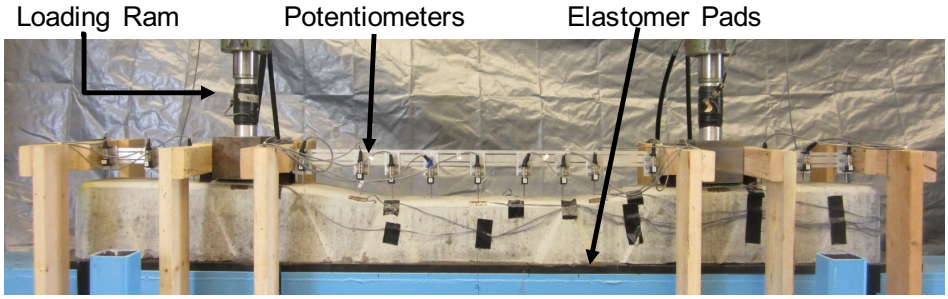




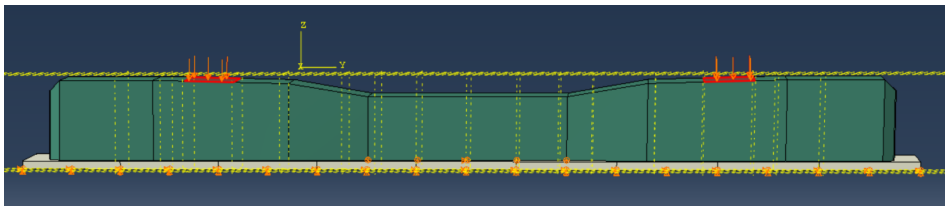

# Loading Conditions

- Rail seat load was applied using Static Load Testing Machine (SLTM) in the lab.
- The following figures compare the load definition in FE model with lab setup:

SLTM Loading

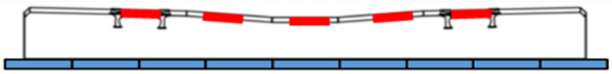



ABAQUS Image

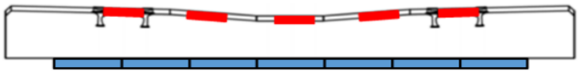


# Test Matrix – FRA Phase 1

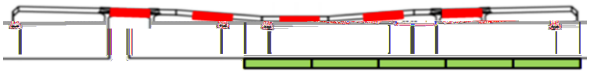
1. Full Support Condition:



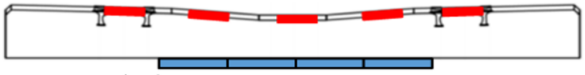
2. Light Center Binding Condition:



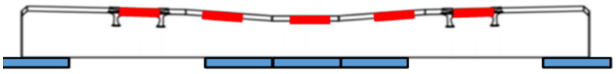
3. High Center Binding Condition:



4. Severe Center Binding Condition:



5. Lack of Rail Seat Support Condition:

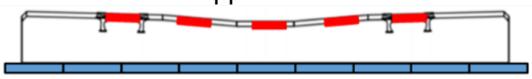


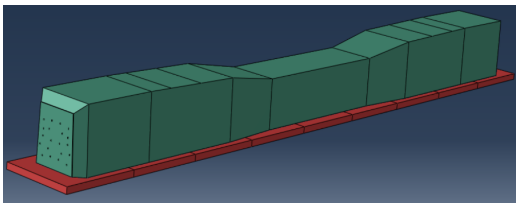
6. Lack of Center Support Condition:



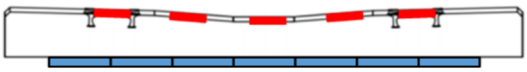
# Modeling Support Conditions as Lab Test Matrix

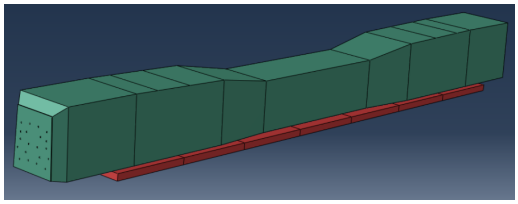
Full Support Condition



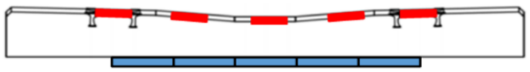


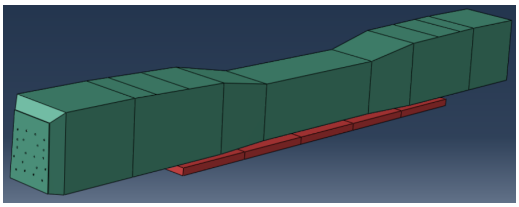
Light Center Binding Condition





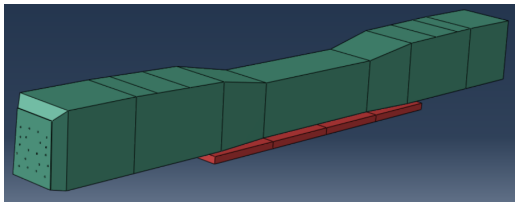
High Center Binding Condition



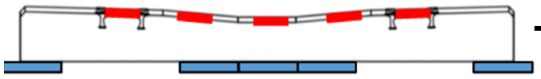


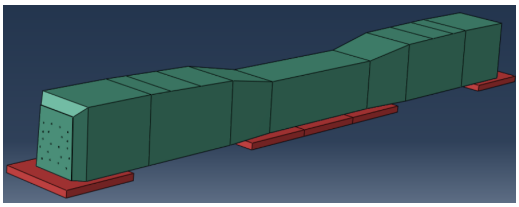
# Modeling Support Conditions as Lab Test Matrix (cont.)

Severe Binding Support Condition

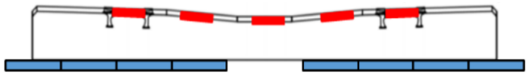


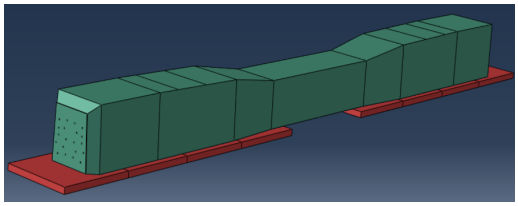
Lack of Rail Seat Support Condition





Lack of Center Support Condition

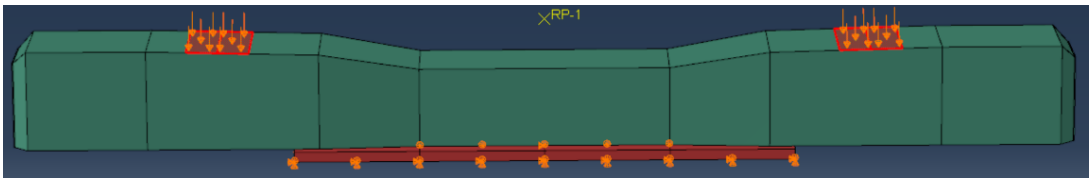


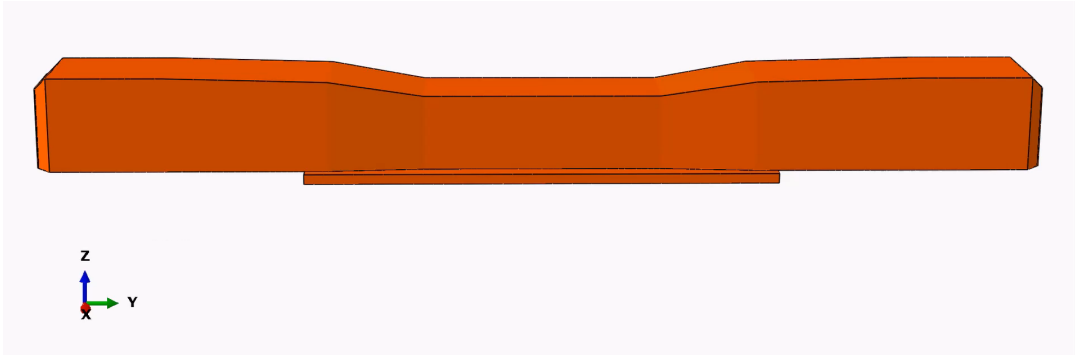




# Example of Simulation – Axial Stress

- Axial-stress developed due to 20 kips load at each rail seat with severe center binding support condition

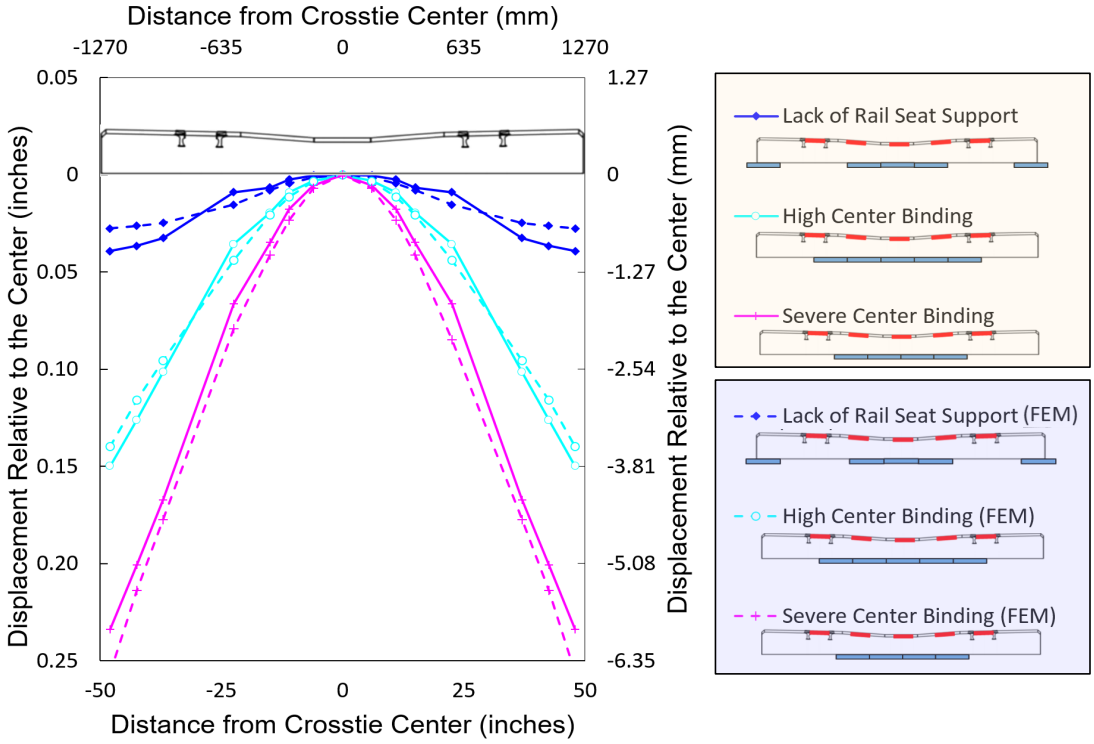



Tension Zero Compression

Deformation scale factor = 5

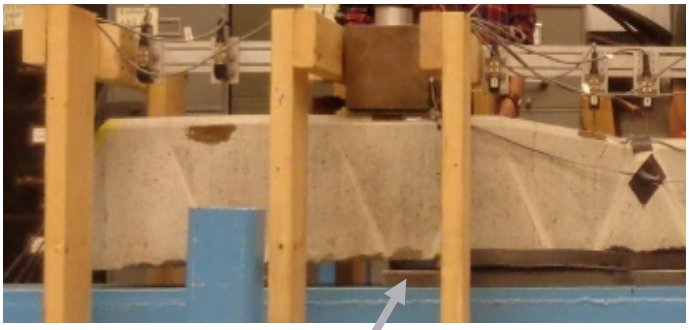
# Model Calibration/Validation (20 kips rail-seat load)






# Challenges Faced in Lab and FE Analysis under High Vertical Loads

- High vertical loads resulted in excessive deformation of the elastomers – requires complex material model
- Lab setup was revised to test certain support conditions

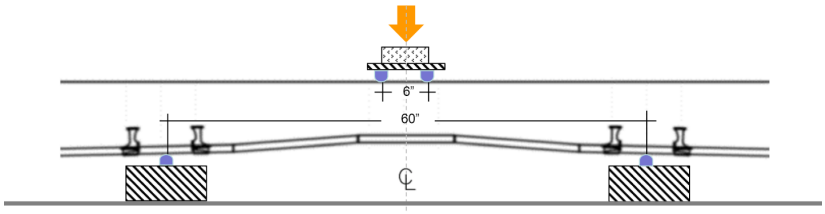


Need for extra steel plate to prevent the crosstie from touching the frame

Excessive deformation of elastomers

# Advantages of Four-point Bending Test

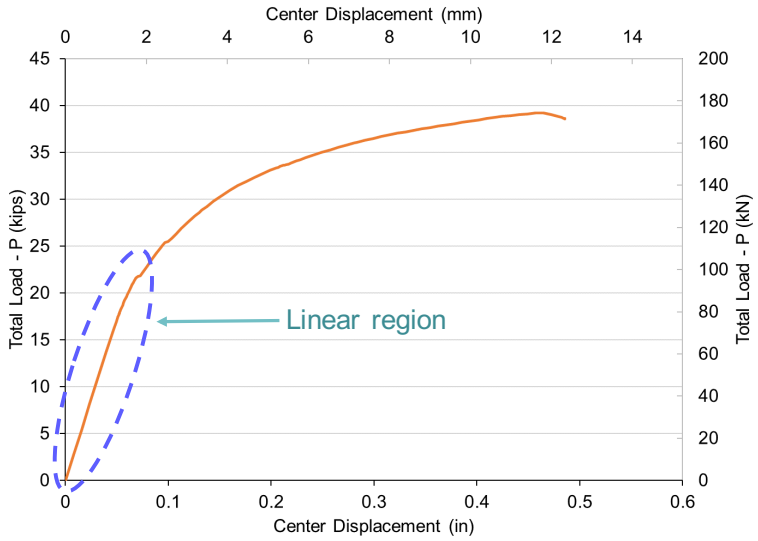
- It is a common practice in structural domain to test concrete beams under four-point bending
- The test setup provides a common platform to compare different crosstie designs under similar boundary conditions
- The setup reduces the complexity of the support conditions and interactions needed to be modeled for FE analysis
- AREMA Ch. 30 Center Negative Bending Test





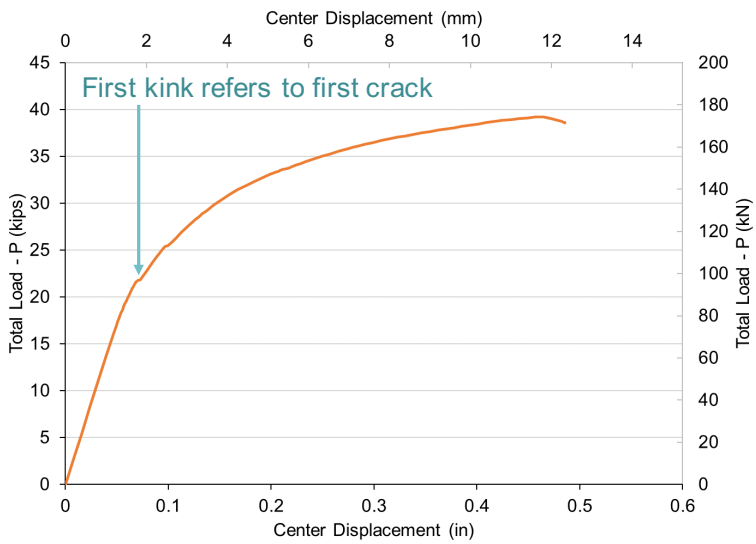

# Proposed Parameter for Comparison: Load vs Displacement

- Benefits:
  - Compare stiffness of different crosstie design



# Proposed Parameter for Comparison: Load vs Displacement

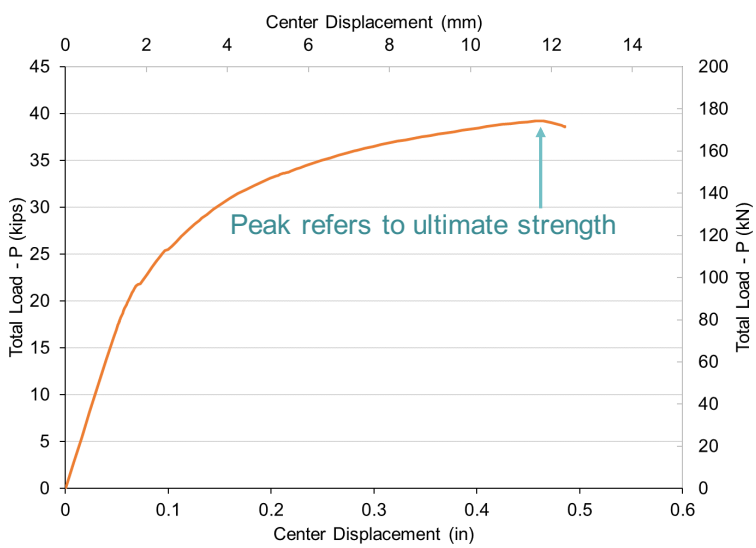
- Benefits:
  - Compare post cracking behavior of the different crosstie designs





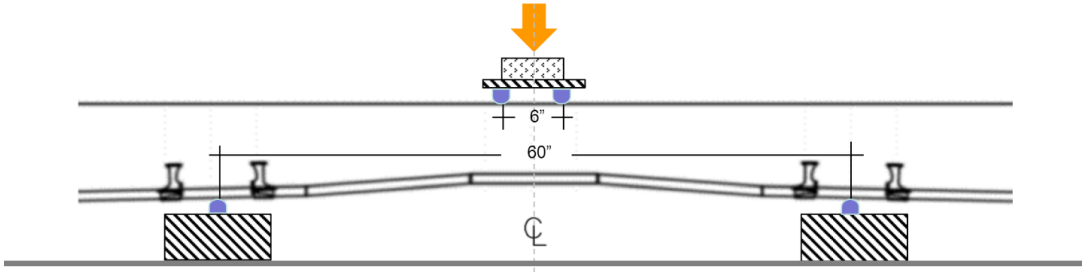

# Proposed Parameter for Comparison: Load vs Displacement

- Benefits:
  - Compare ultimate strength of the crosstie design for the considered support condition



# FE Model with Steel Half-moon Bars

Modified Support Condition

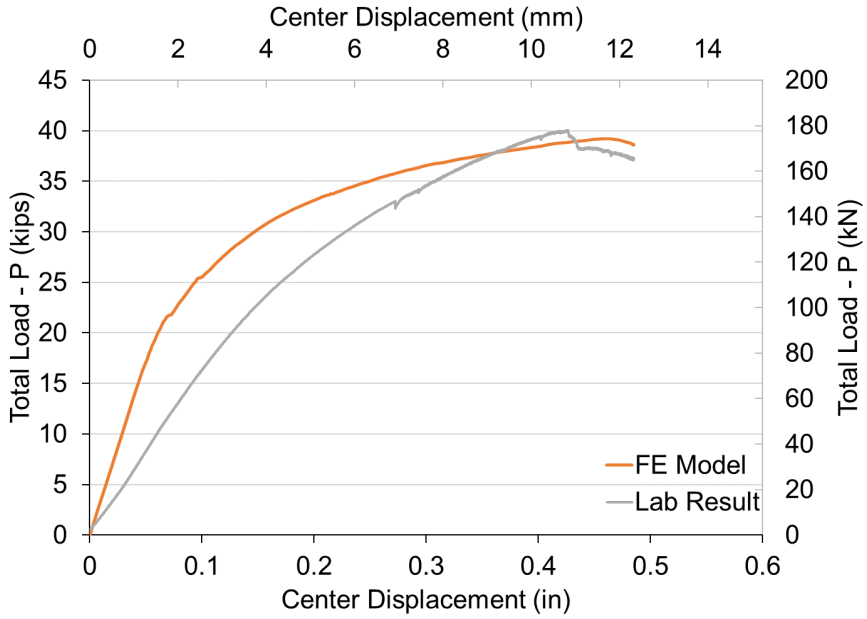



ABAQUS Image



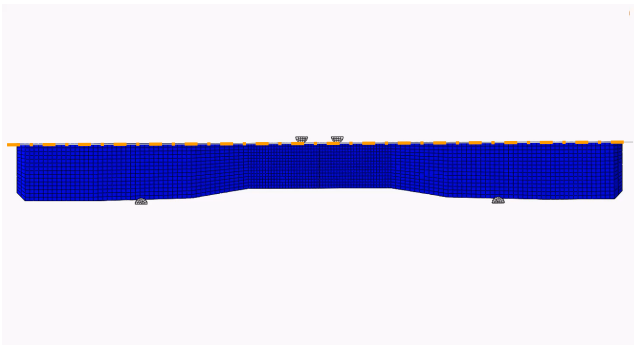

# Challenge with Existing Model

- Currently working to achieve better agreement between laboratory and FE quantitative results

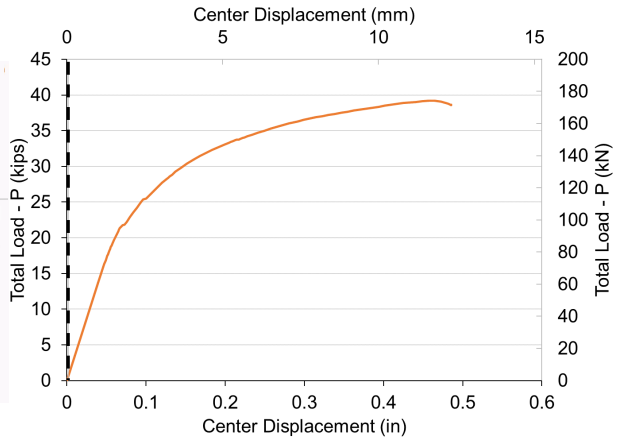


# Crack Simulation

- Center-negative crack development and propagation as predicted by FE analysis



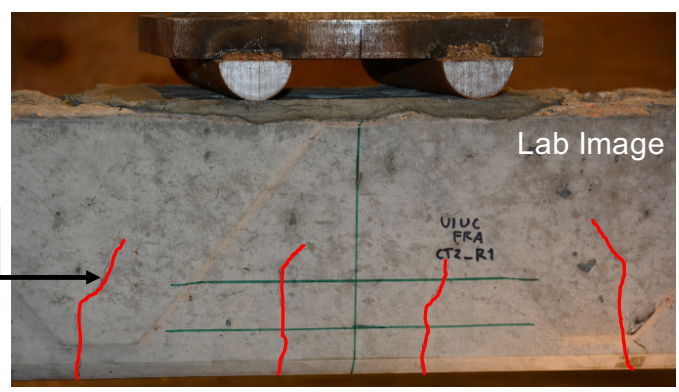
Deformation scale factor = 5



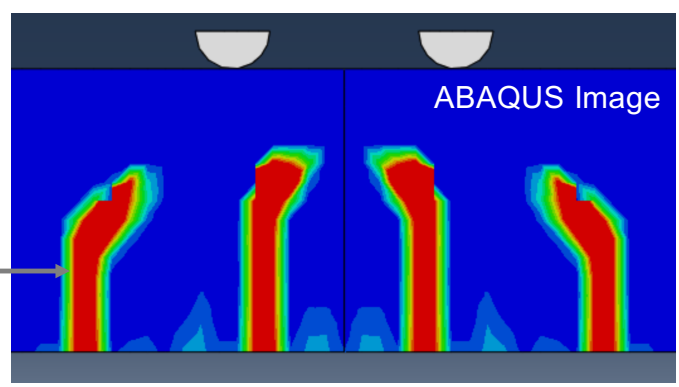



# Crack Simulation (cont.)

Center-negative cracks as observed in lab




Center-negative cracks predicted by FE model

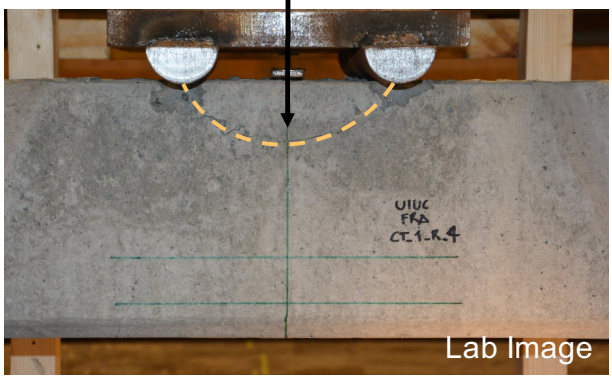


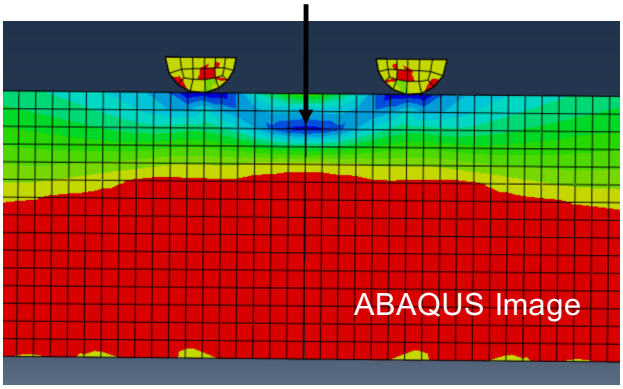
# Crack Simulation (cont.)

- Compression cracking zone simulated by the FE model compared to cracks observed during lab tests

Compression cracks as observed cracks in lab

Compression cracking zone as predicted by FE model

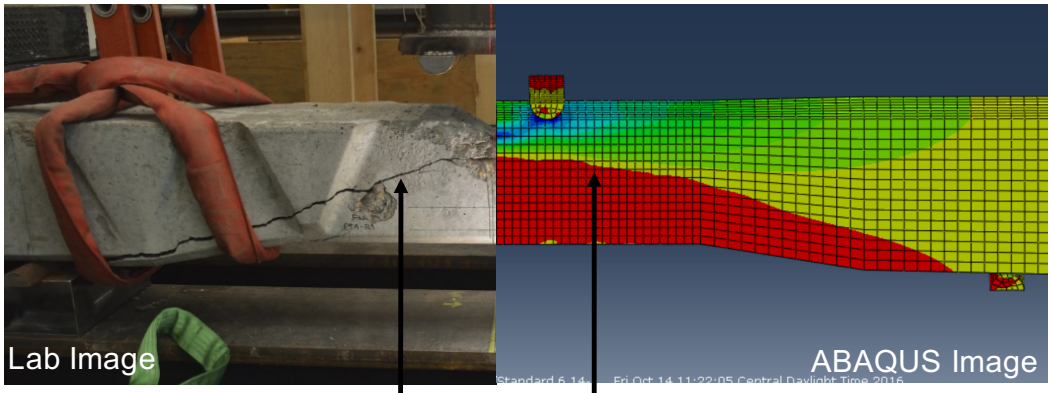





# Crack Simulation (cont.)

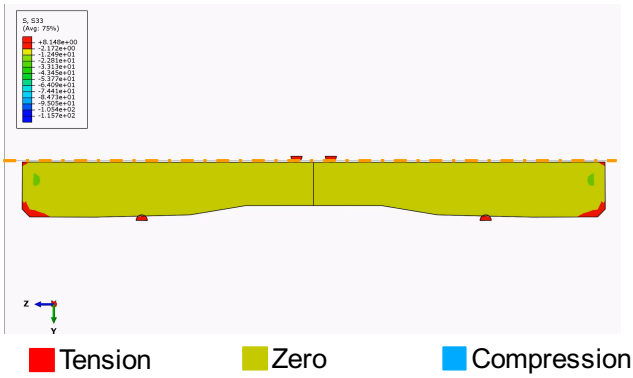
- Shear crack location predicted by FE Model between the support and load bars compared to severe cracking observed in lab at ultimate loads



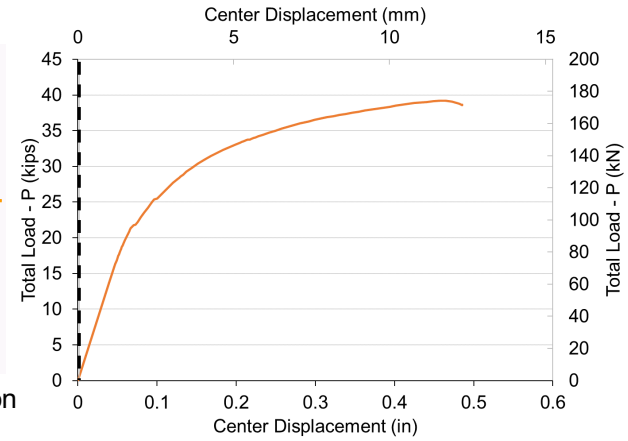

Shear Crack location between the support and loading bars

# Stress Simulation

- Axial-stress developed in the crosstie during loading as simulated by FE model



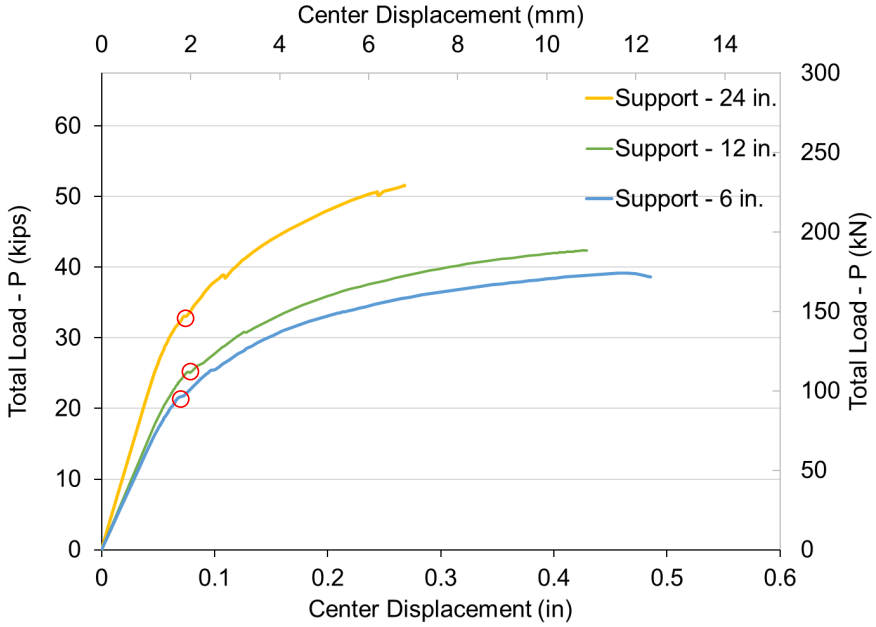

Deformation scale factor = 5





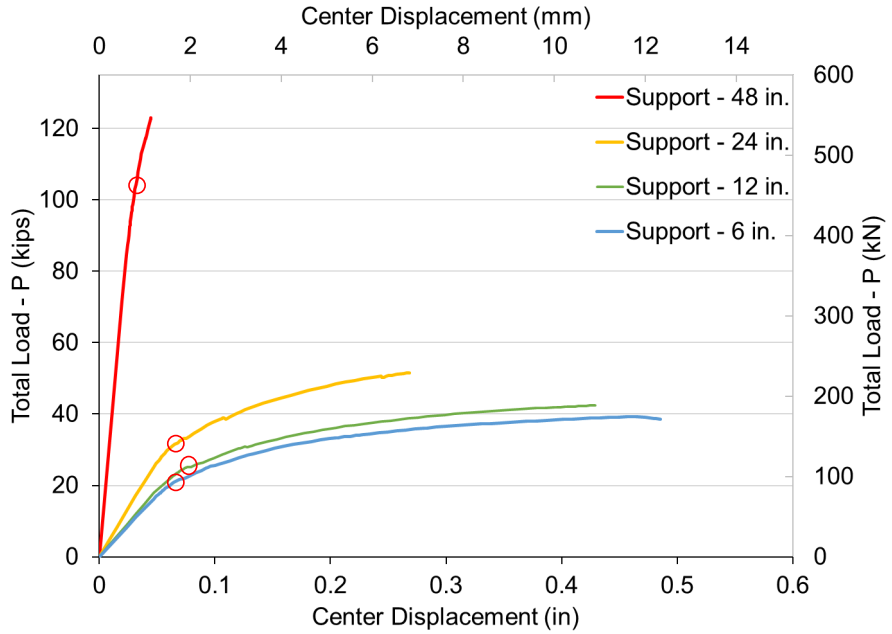

# Review of Existing FE Analysis (cont.)

- Effect of using wider support conditions than 6” at center (Load vs. Displacement)



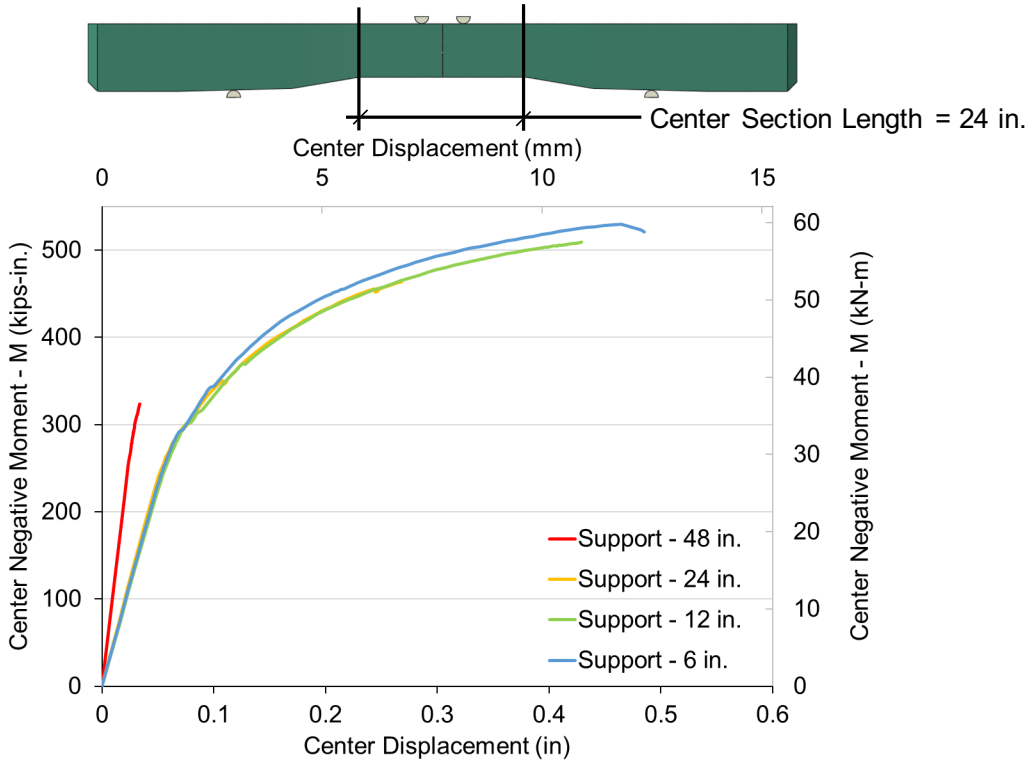
# Review of Existing FE Analysis (cont.)

- Effect of using support conditions wider than 6” at center (Load vs. Displacement)



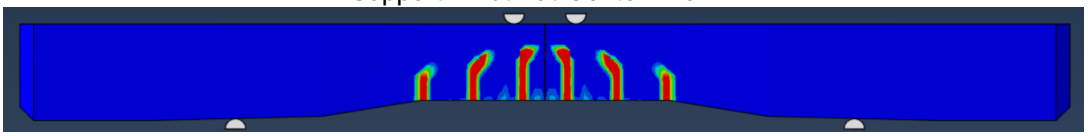



# Review of Existing FE Analysis (cont.)

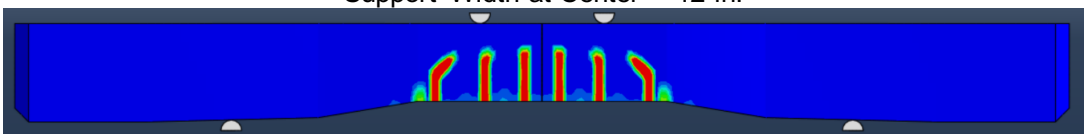


# Center-negative Crack Variation by Increasing Support Width – Ultimate Load

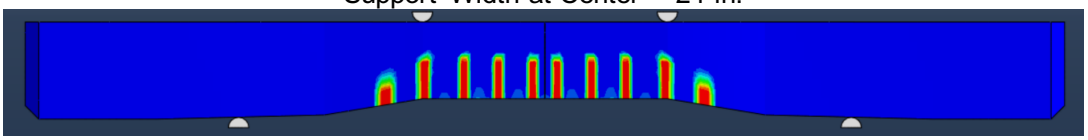
Support Width at Center = 6 in.



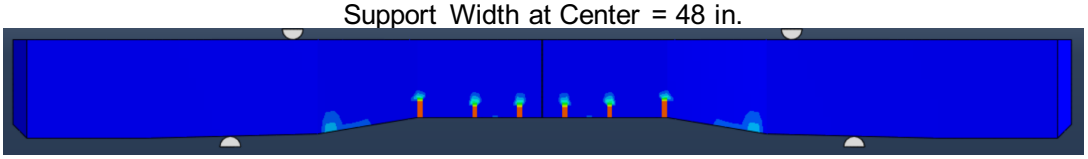
Support Width at Center = 12 in.



Support Width at Center = 24 in.



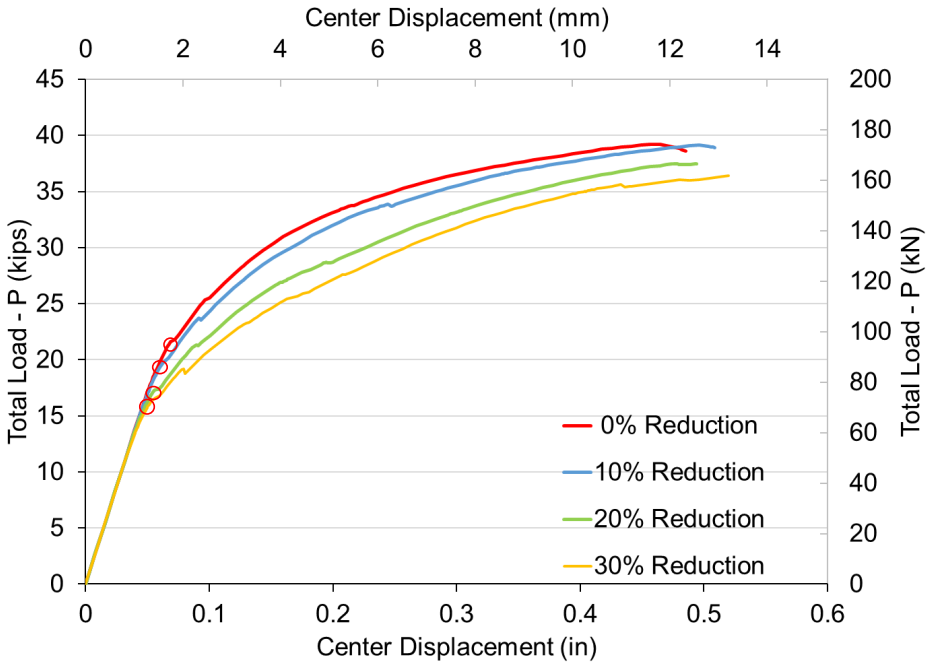
Support Width at Center = 48 in.





# Review of Existing FE Analysis (cont.)

- Effect of prestress reduction (uniformly) in the crosstie



# Path Forward

- FRA:
  - Calibrate FE model using laboratory data and refine material models
  - Conduct parametric analysis and study the effects on crosstie behavior/failure
- FTA:
  - Develop ballast model by calibrating with field data
  - Optimize the crosstie design for the desirable strength requirement on track taking inputs from parametric analysis conducted for FRA



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NURail Center

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  - Hanson Professional Services, Inc.
  - CXT Concrete Ties, Inc., LB Foster Company
  - TTX Company
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- RailTEC Team

**FRA Tie & Fastener BAA Industry Partners:**

Union Pacific BUILDING AMERICA
BNSF Railway
Amtrak
Progress Rail A Caterpillar Company
GiC
Hanson
LB Foster CXT Concrete Ties
TTX

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**FTA Industry Partners:**




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