Finite Element Modeling Crosstie and Fastening System at UIUC

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U.S. Department of Transportation

Federal Railroad Administration

RAILTEC

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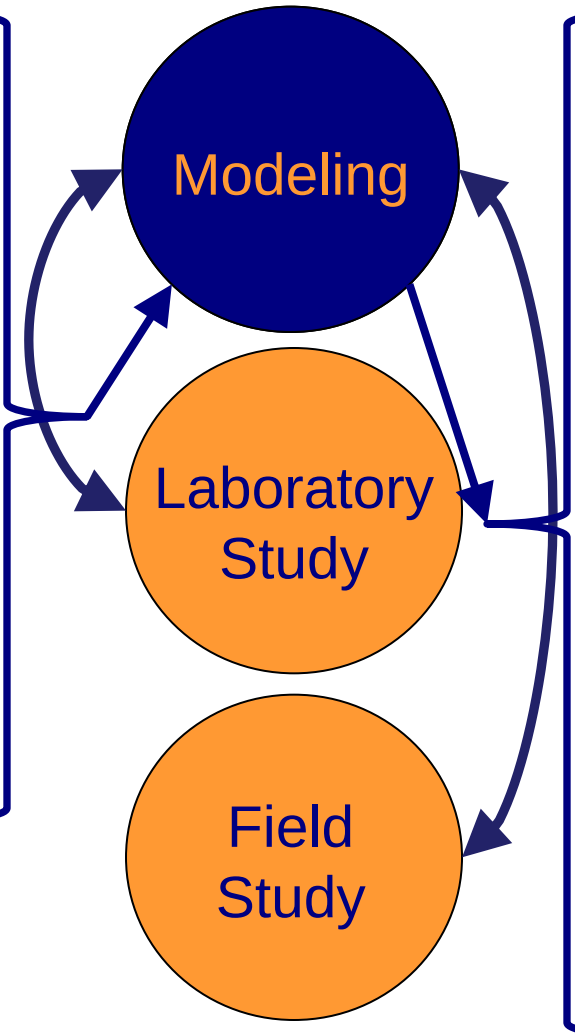
Outline

- Research Objective and the Role of Modeling
- State of the Art
- Component Modeling
- System Modeling
  - Fastening System (2D and 3D)
  - Single-Tie System Modeling
  - Multiple-Tie System Modeling
- Conclusions
- Future Work

FRA Tie and Fastener Project Structure

Inputs

- Comprehensive Literature Review
- Loading Regime (Input) Study
- Rail Seat Load Calculation Methodologies
- Involvement of Industry Experts



Outputs/Deliverables

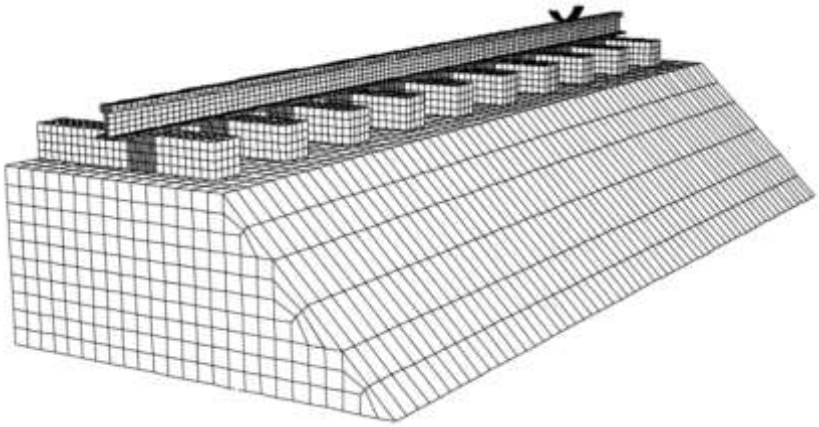
- Data Collection
- Document Depository
- Groundwork for Mechanistic Design
- International Survey Report
- Validated Tie and Fastening System Model
- Load Path Map
- Parametric Analysis
- State of Practice Report

Improved Recommended Practices

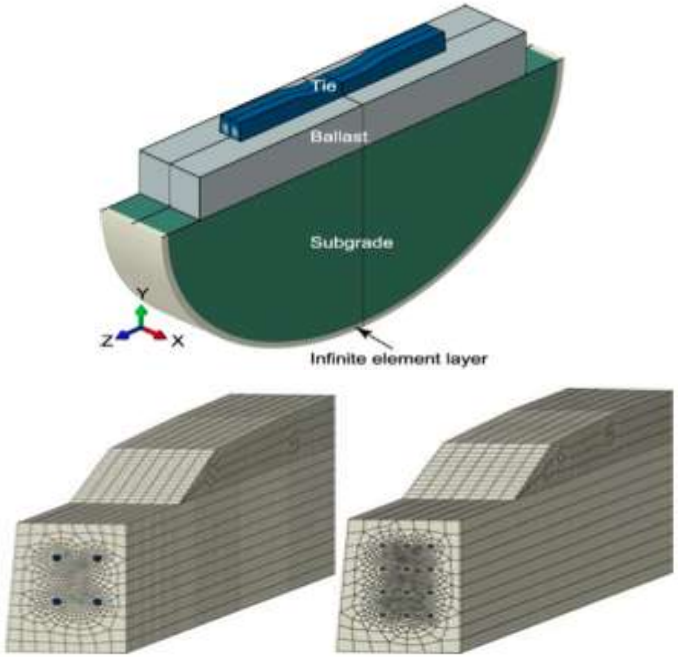
State of the Art

Track System Modeling

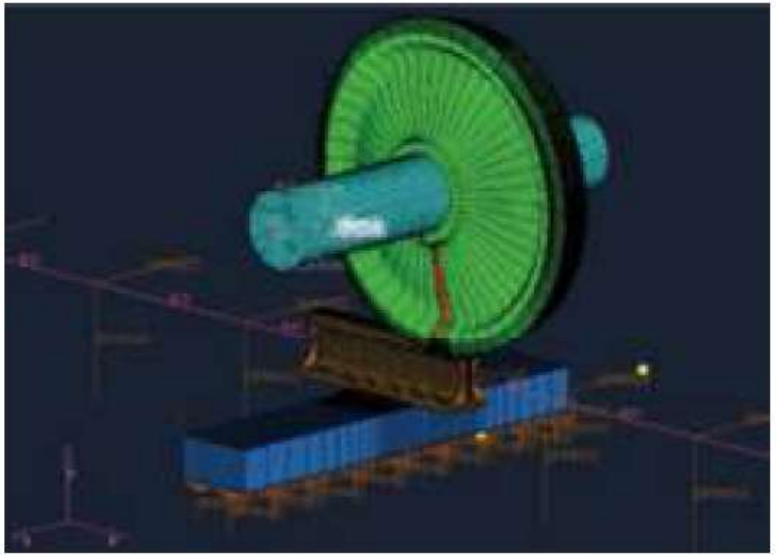
- Simplified fastening systems
- Focused on vertical loading
- Simplified support conditions



(Lundqvist and Dahlberg, 2005 - Sweden)

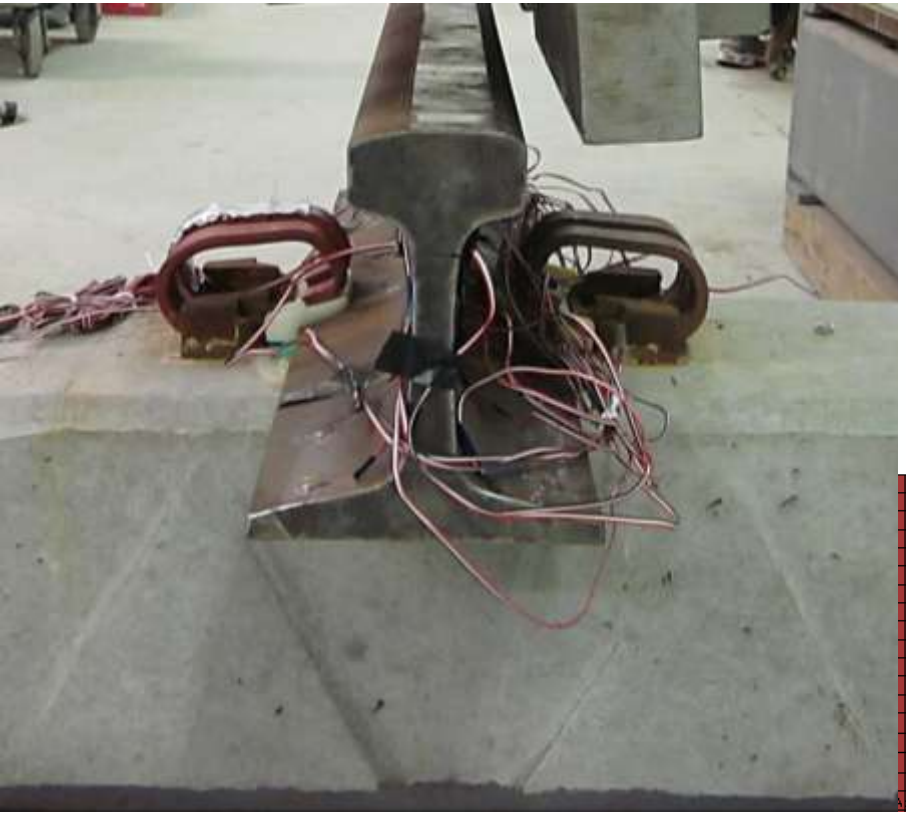


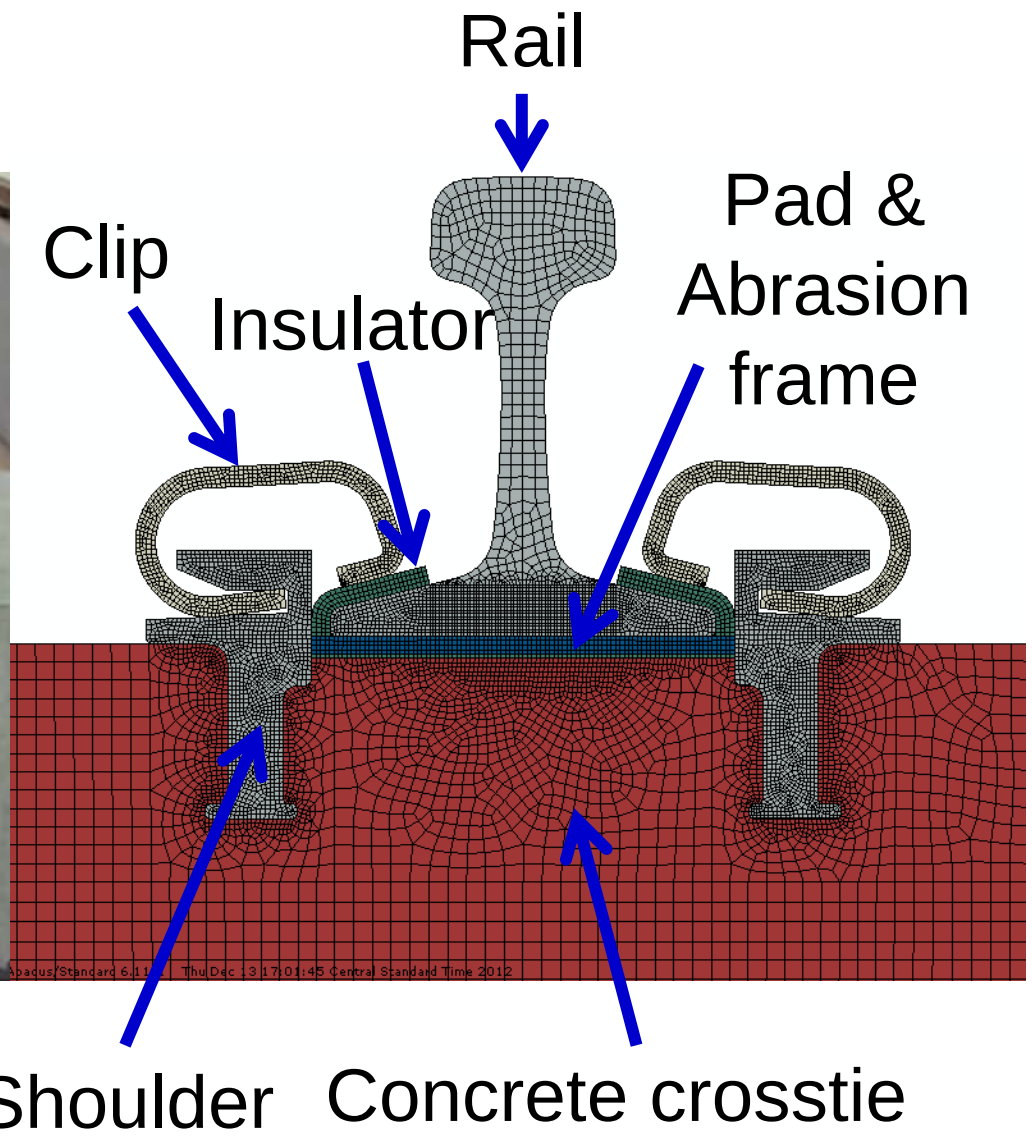
(Yu and Jeong, 2011)



(Tangtragulwong 2009)

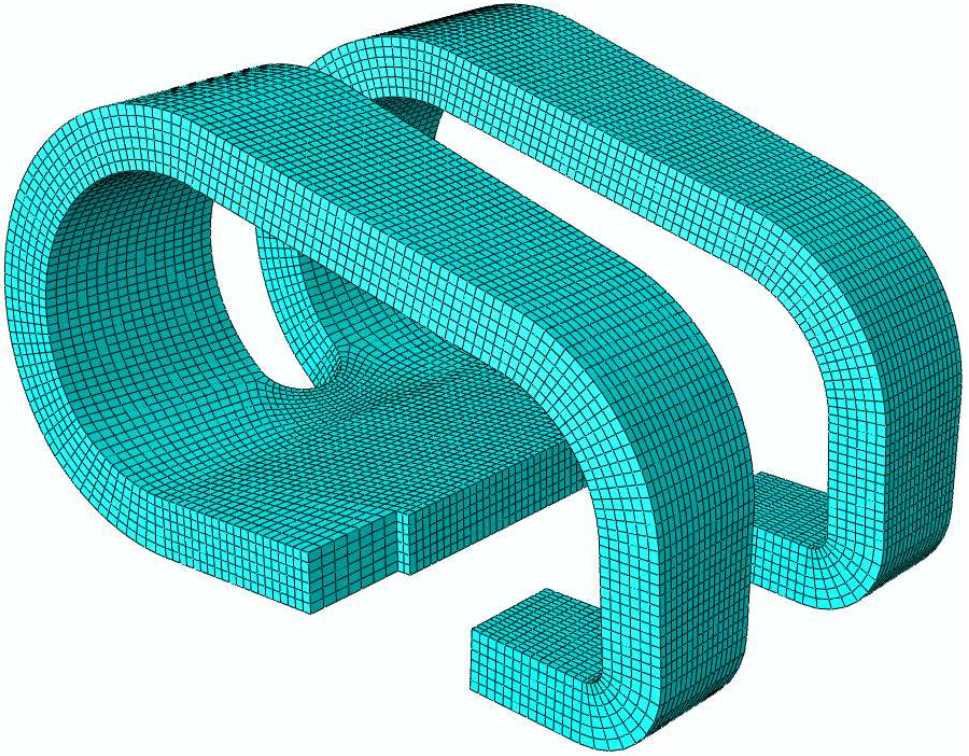
Concrete Crosstie and Fastening System





Component Modeling

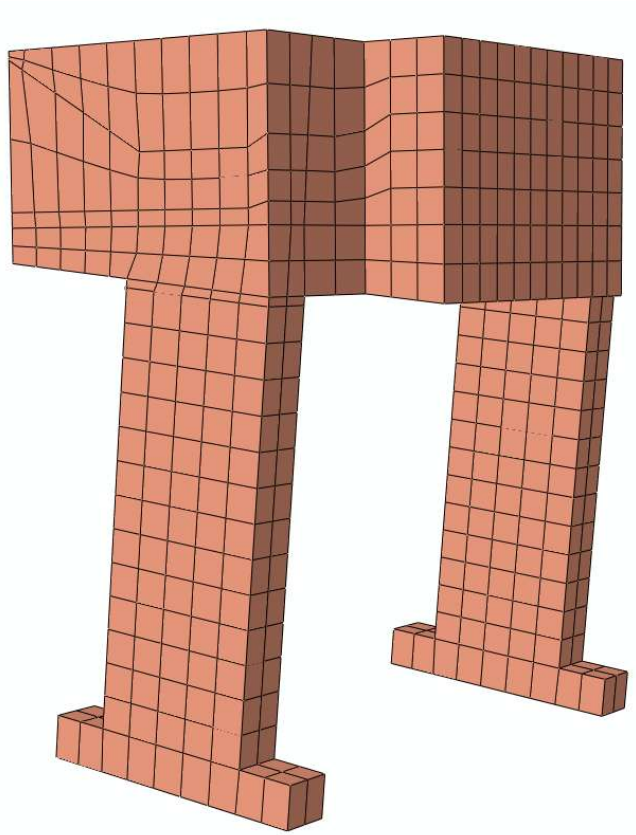
Rail Clip



Rail Clip model

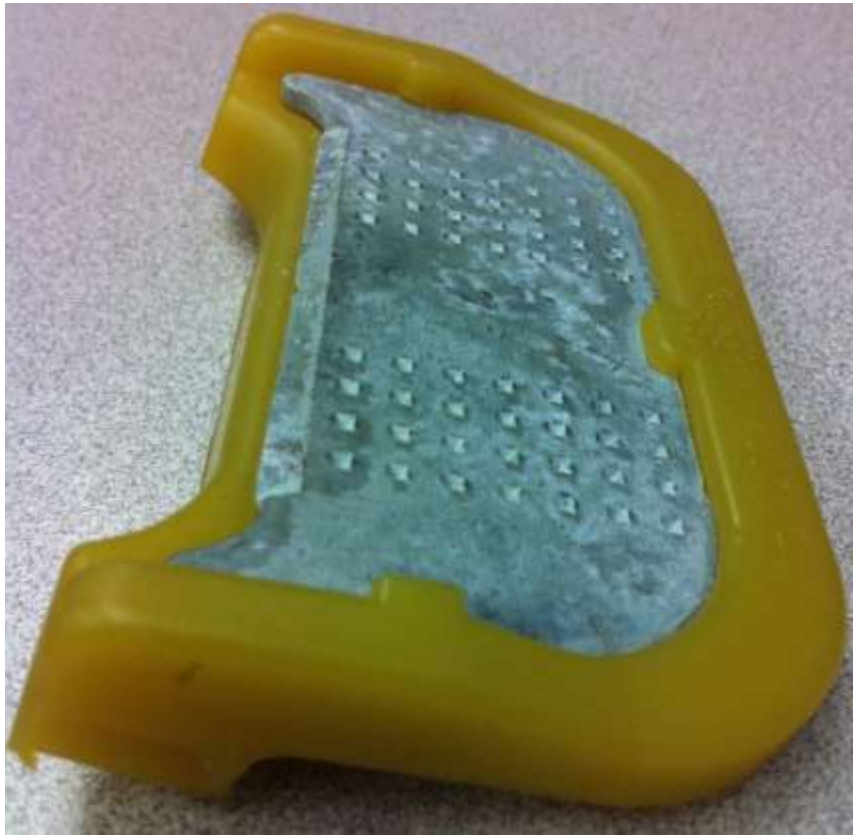
Component Modeling

Rail Shoulder

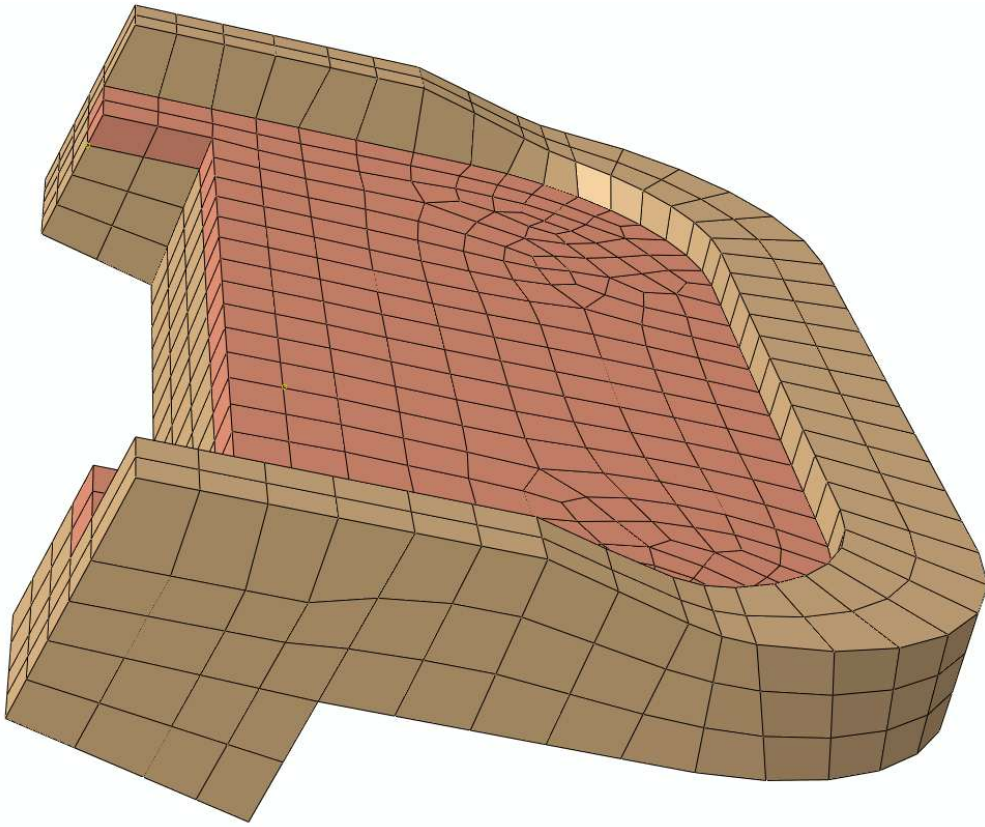


Rail Shoulder model

Component Modeling



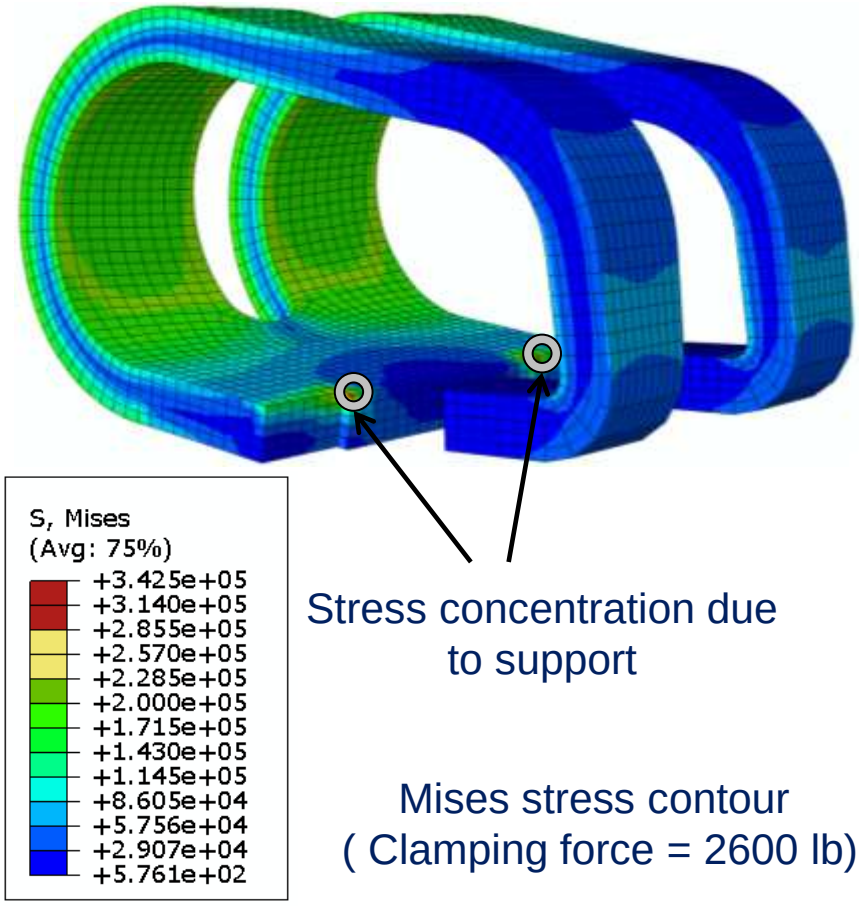
Rail Insulator



Rail Insulator model

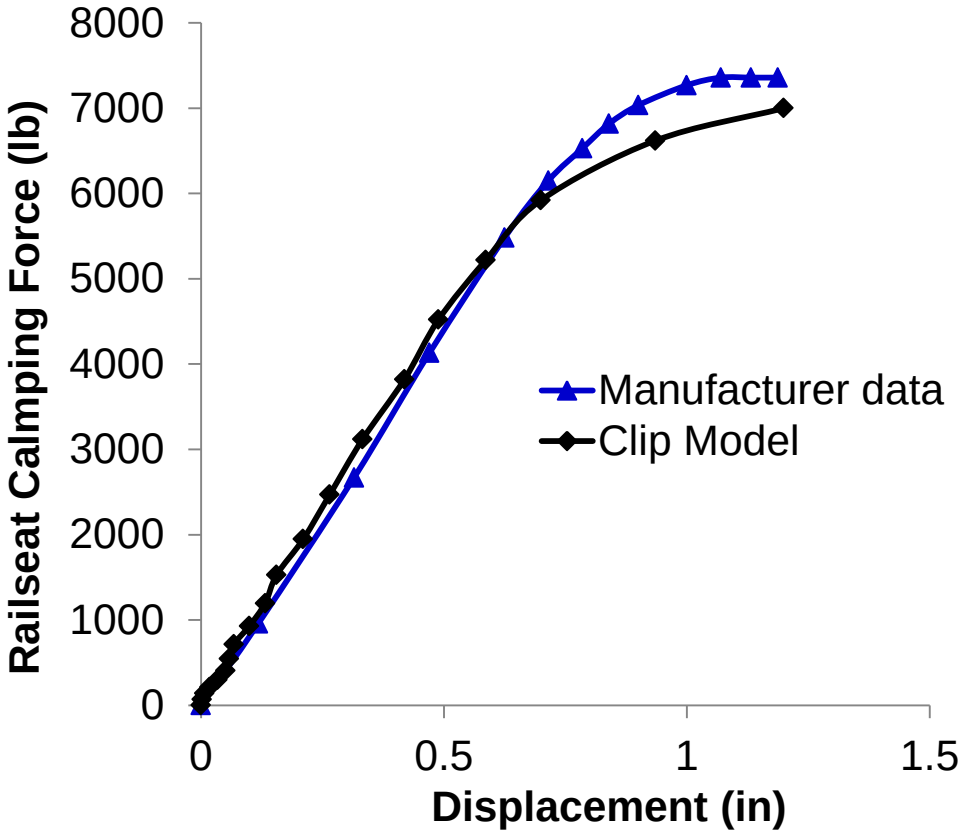
Component Modeling: Validation

- Clip Model



Stress concentration due to support

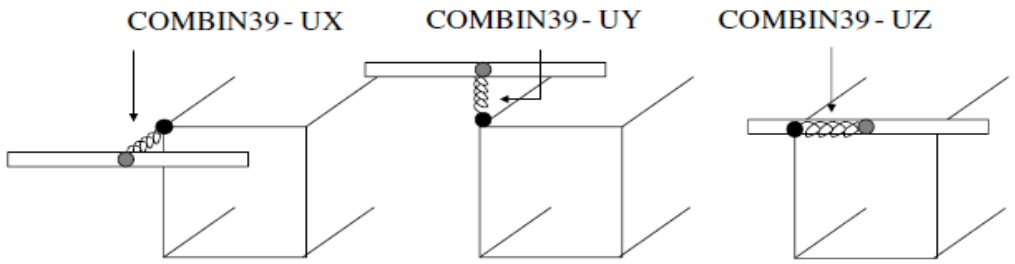
Mises stress contour
(Clamping force = 2600 lb)



Clamping force-displacement curves

Component Modeling: Concrete Tie and Ballast

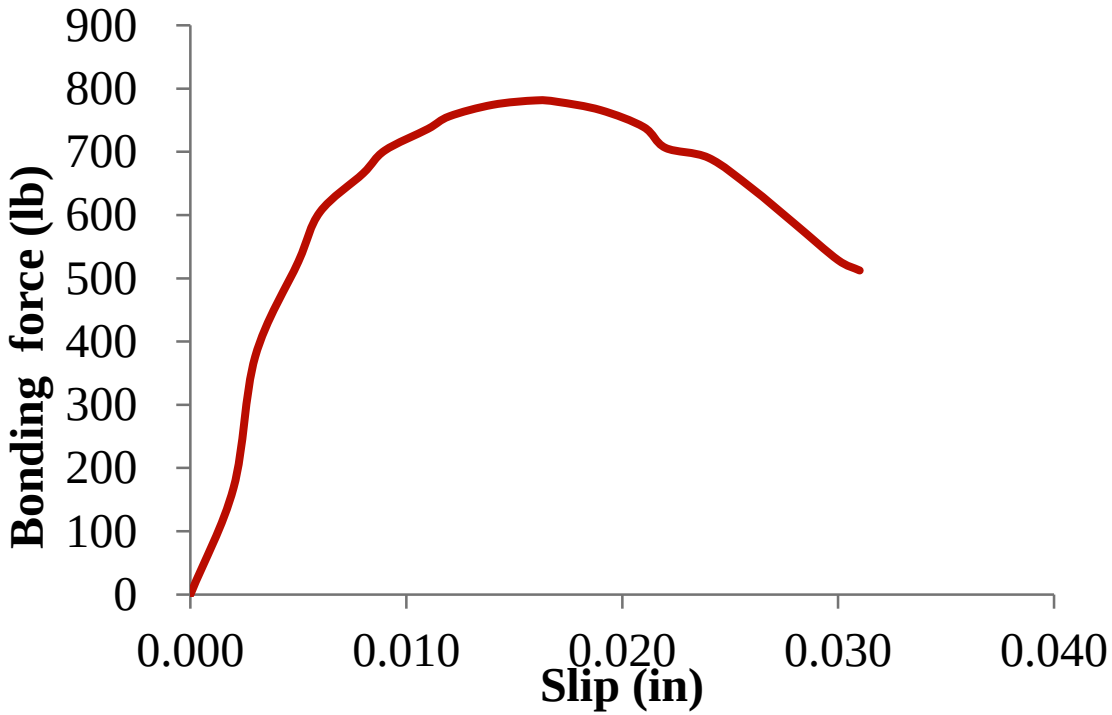
- Model Features:
  - Concrete material property: damage plasticity model
  - Connector element is used to simulate the bond relationship between concrete and strand
  - Prestress and vertical static loading is applied in the model
  - The effect of confining pressure on material property is considered in ballast modeling



3-D elastic spring connection between concrete and strand
(Pozolo and Andrawes 2011)

Component Modeling: Concrete Tie and Ballast

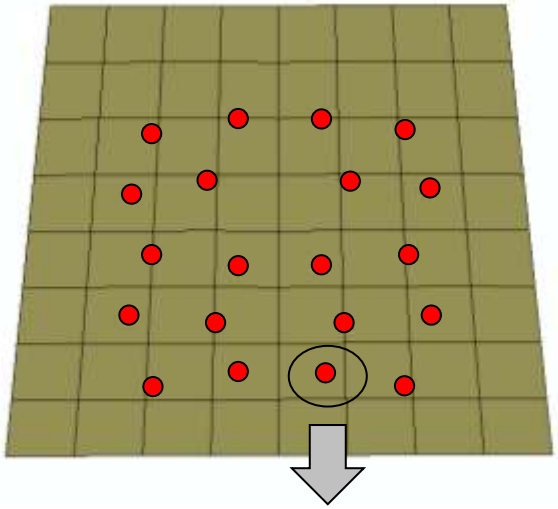
- A bonding force-slip relationship is defined in the model



Bonding force-slip Relationships

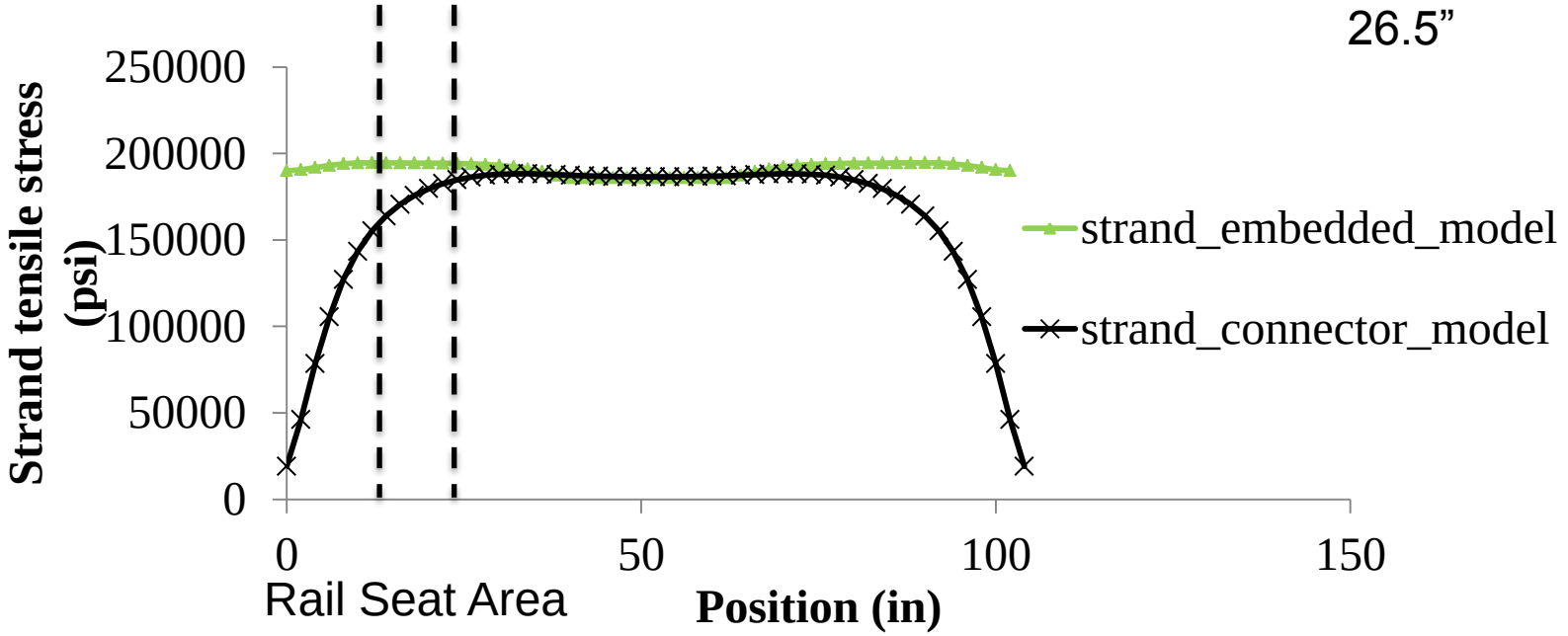
(Testing Data from the Kansas State University)

Component Modeling: Concrete Tie and Ballast

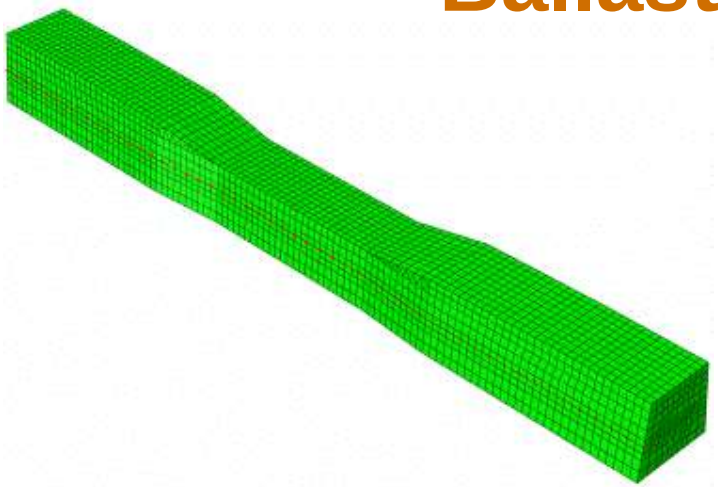


Positions of strands

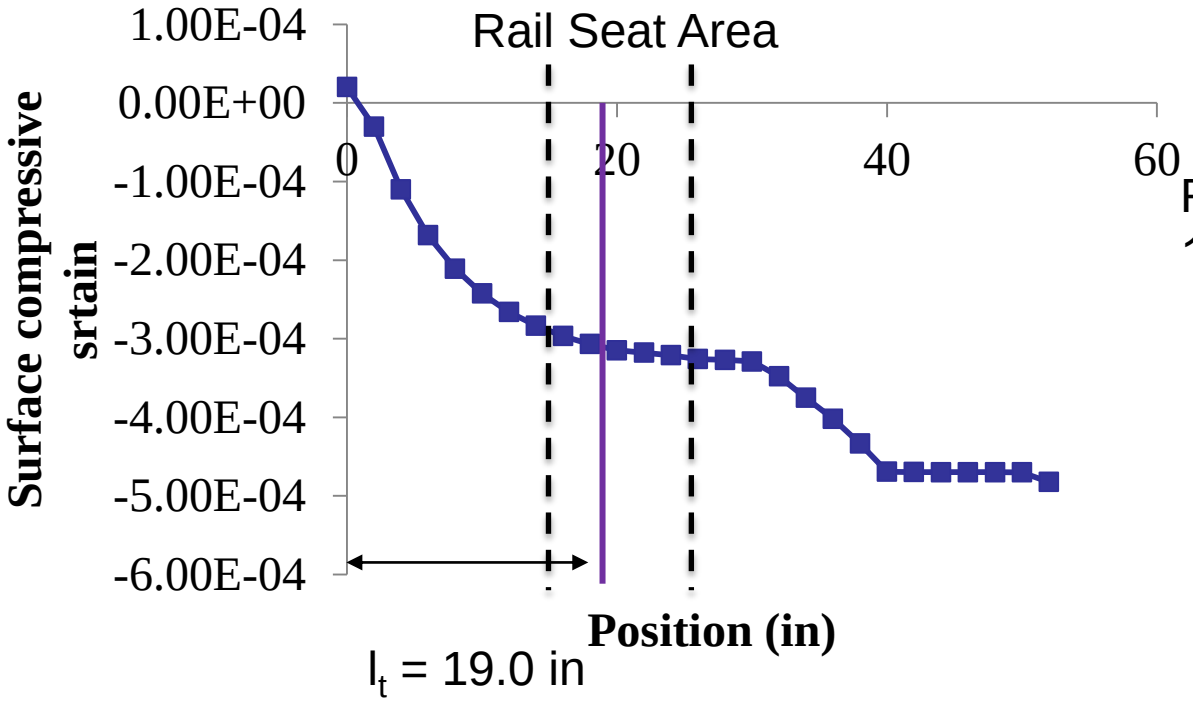
Rail seat area is between 15.2” to 26.5”



Component Modeling: Concrete Tie and Ballast



Position of concrete surface strain

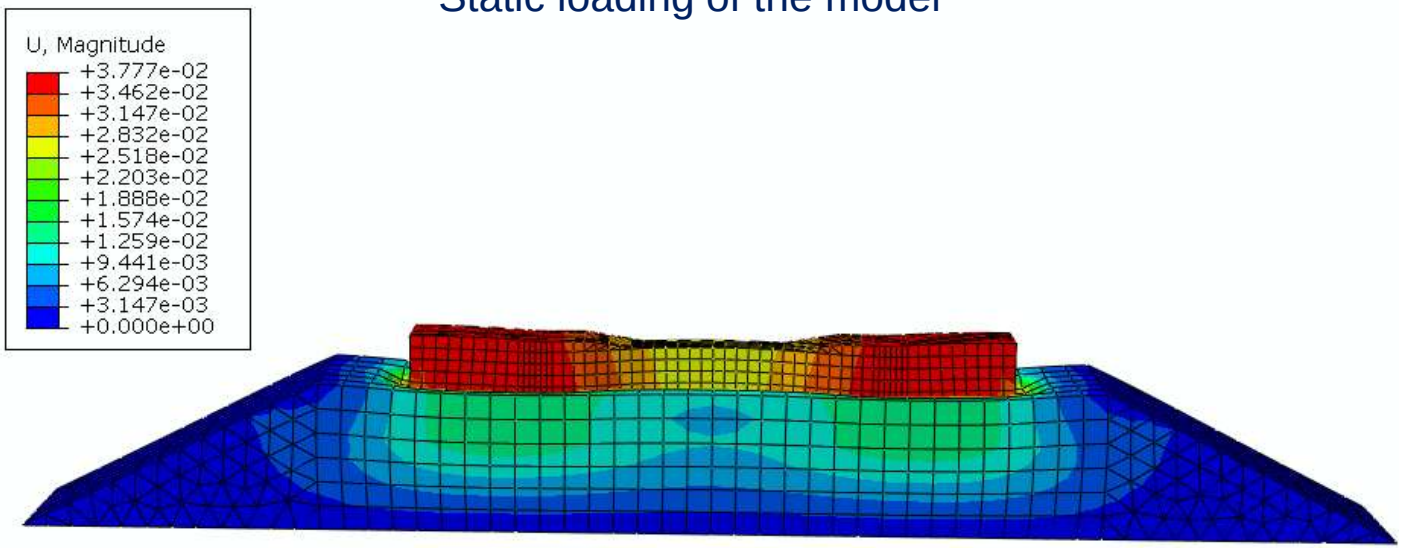


l_t = 19.0 in

Rail seat area is between 15.2” to 26.5”

Component Modeling: Concrete Tie and Ballast

Static loading of the model

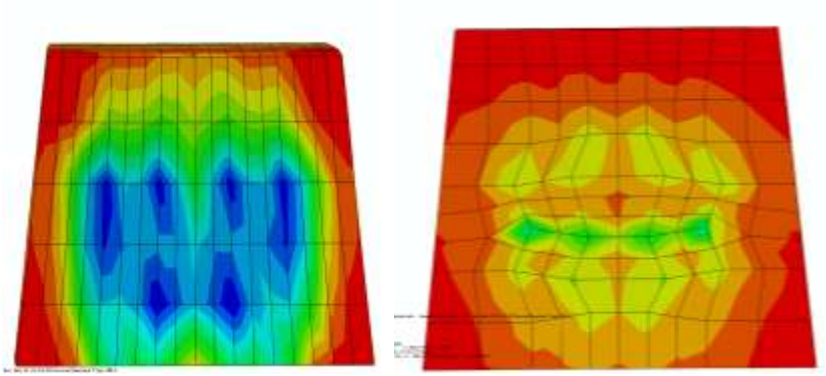


Deformation contour

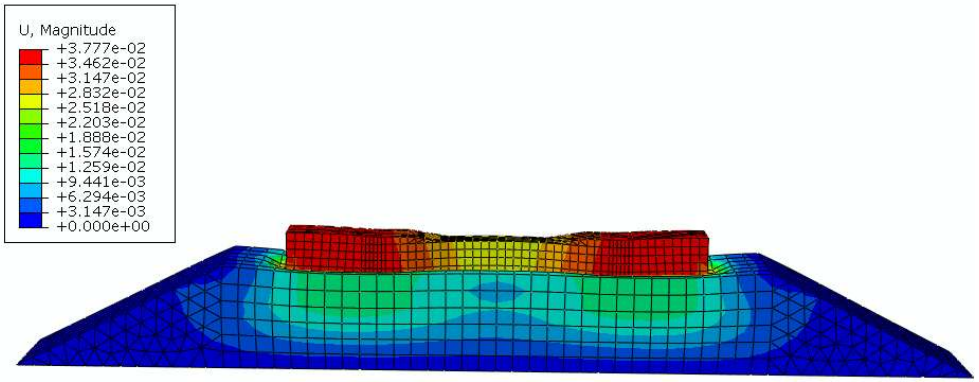
- Prestress and static loading (30 kips) is applied to the model to look into the stress distribution and transfer length after release.

Component Modeling: Concrete Tie and Ballast

- In comparison with full bond model, relative-slip bond model can prevent unreasonable stress concentration and provide more realistic simulation for concrete-strand interaction
- At a wheel loading of 30kips elasto-plastic model could provide sufficiently accurate estimation for the performance of ballast, but non-uniform material model is needed at higher loading



Lateral compressive stress contour (full bond model & slip bond model)

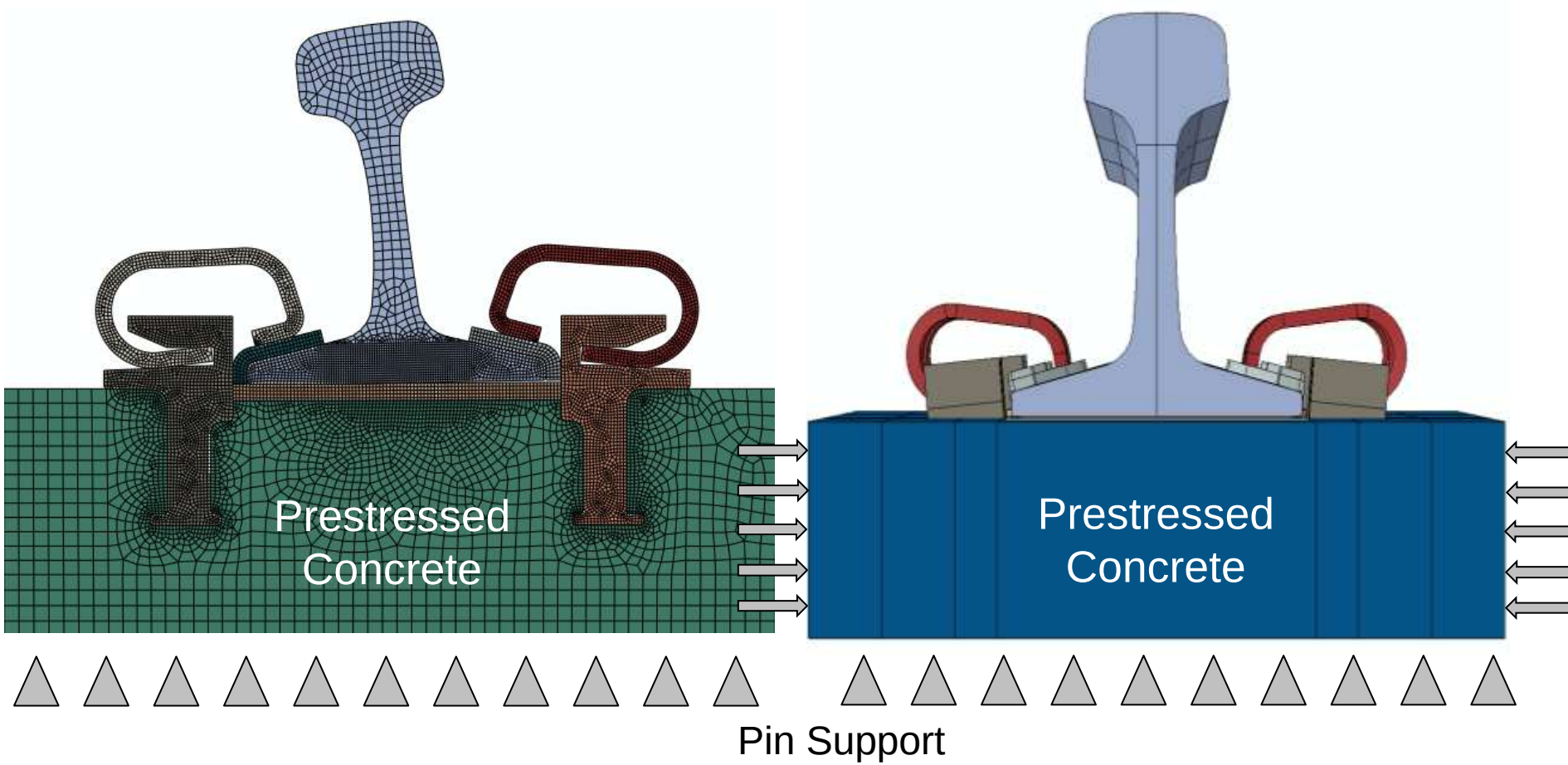


Deformation contour of under the vertical loading

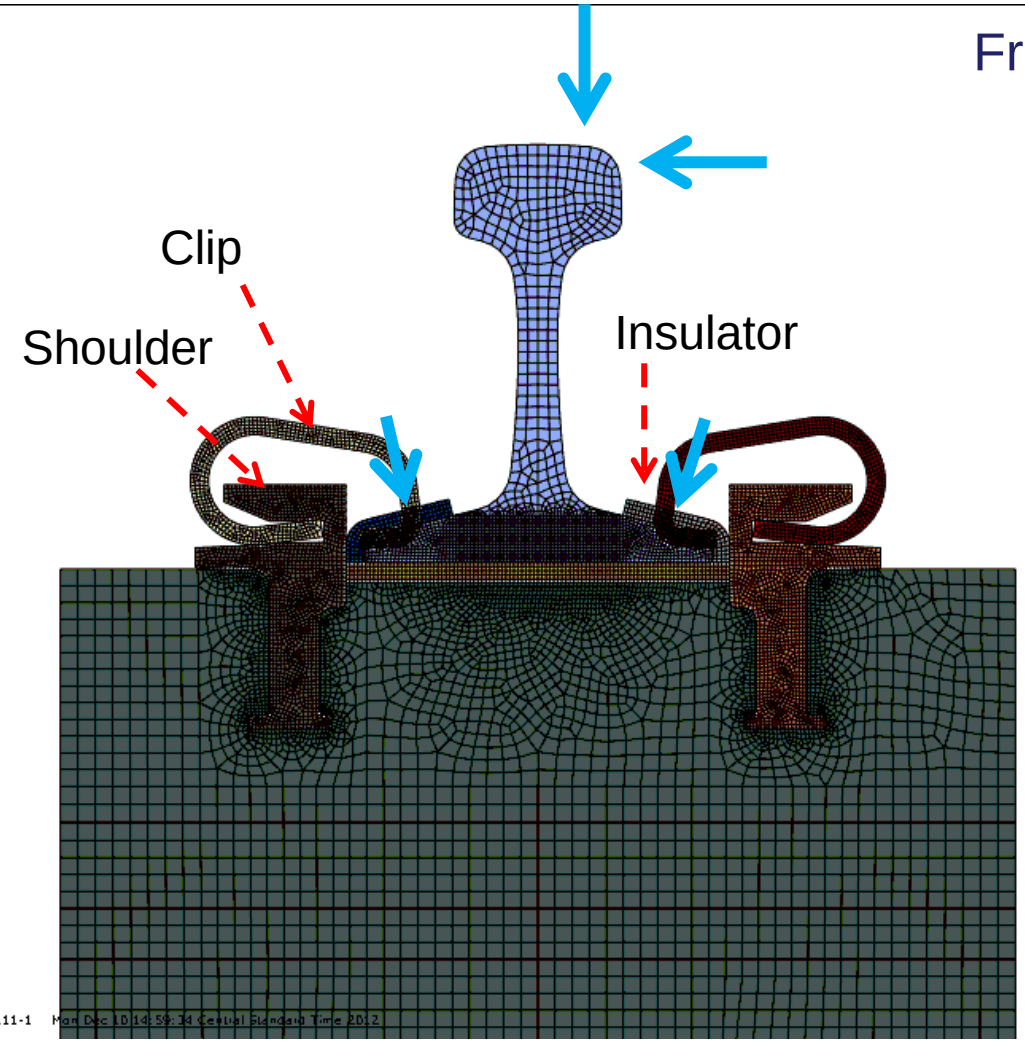
System Modeling: 2D and 3D Modeling

2D Modeling

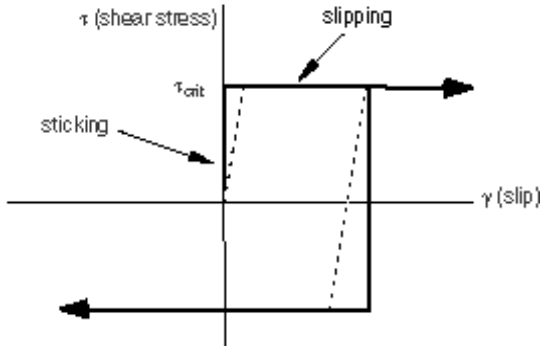
3D Modeling



System Modeling: Fastening Systems



Friction Model between component:
Coulomb Model



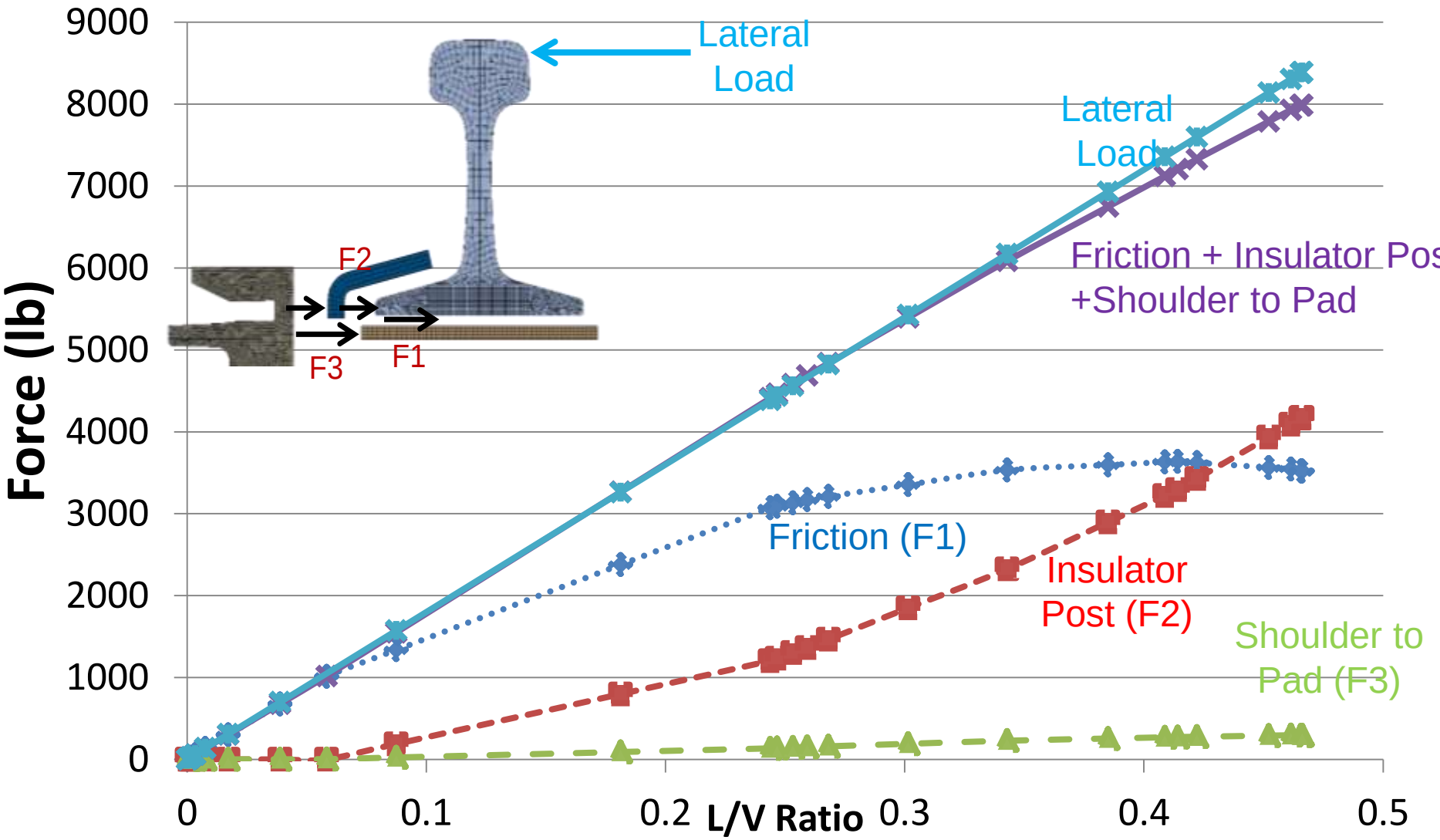
$$\tau_{crit} = \mu P_n > \tau_{eq} = \sqrt{\tau_1{}^2 + \tau_2{}^2}$$

No Slip

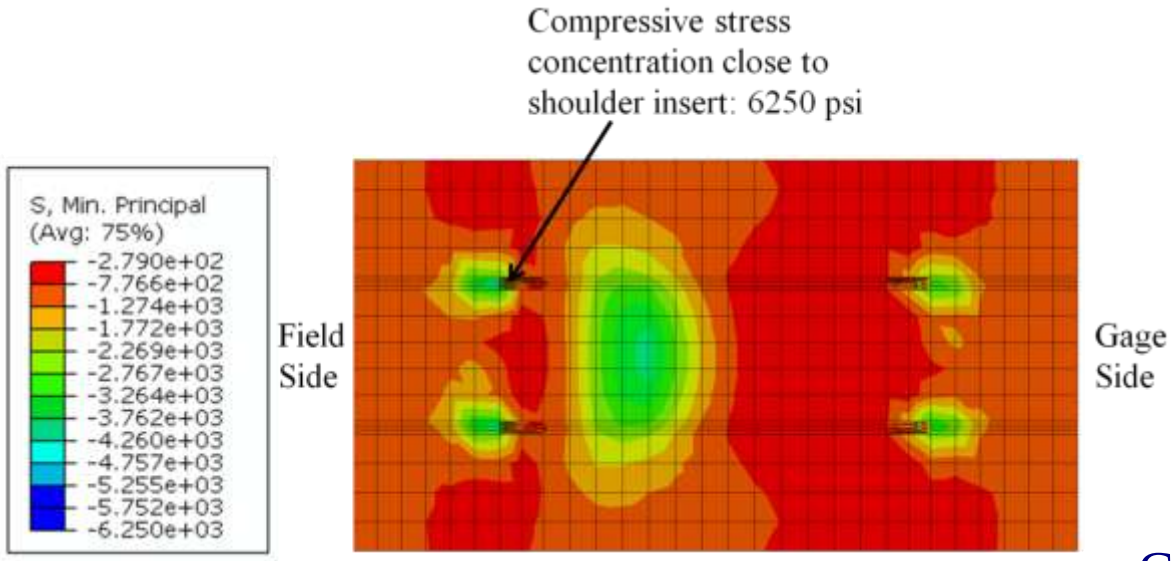
- Between the components:
  - Force due to contact pressure
  - Force due to friction stress

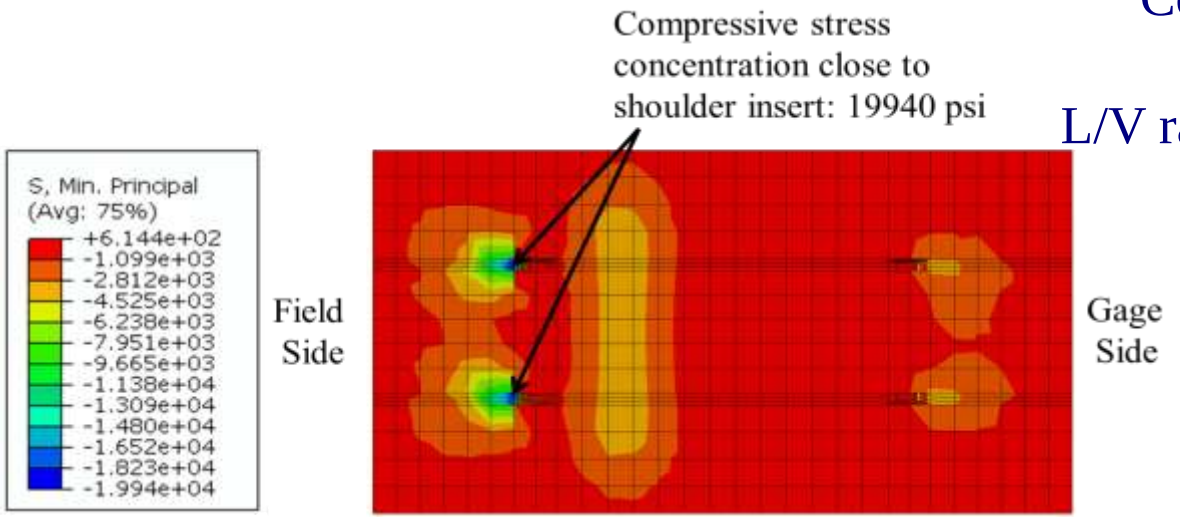
System Modeling: Fastening Systems

Lateral Loading Path



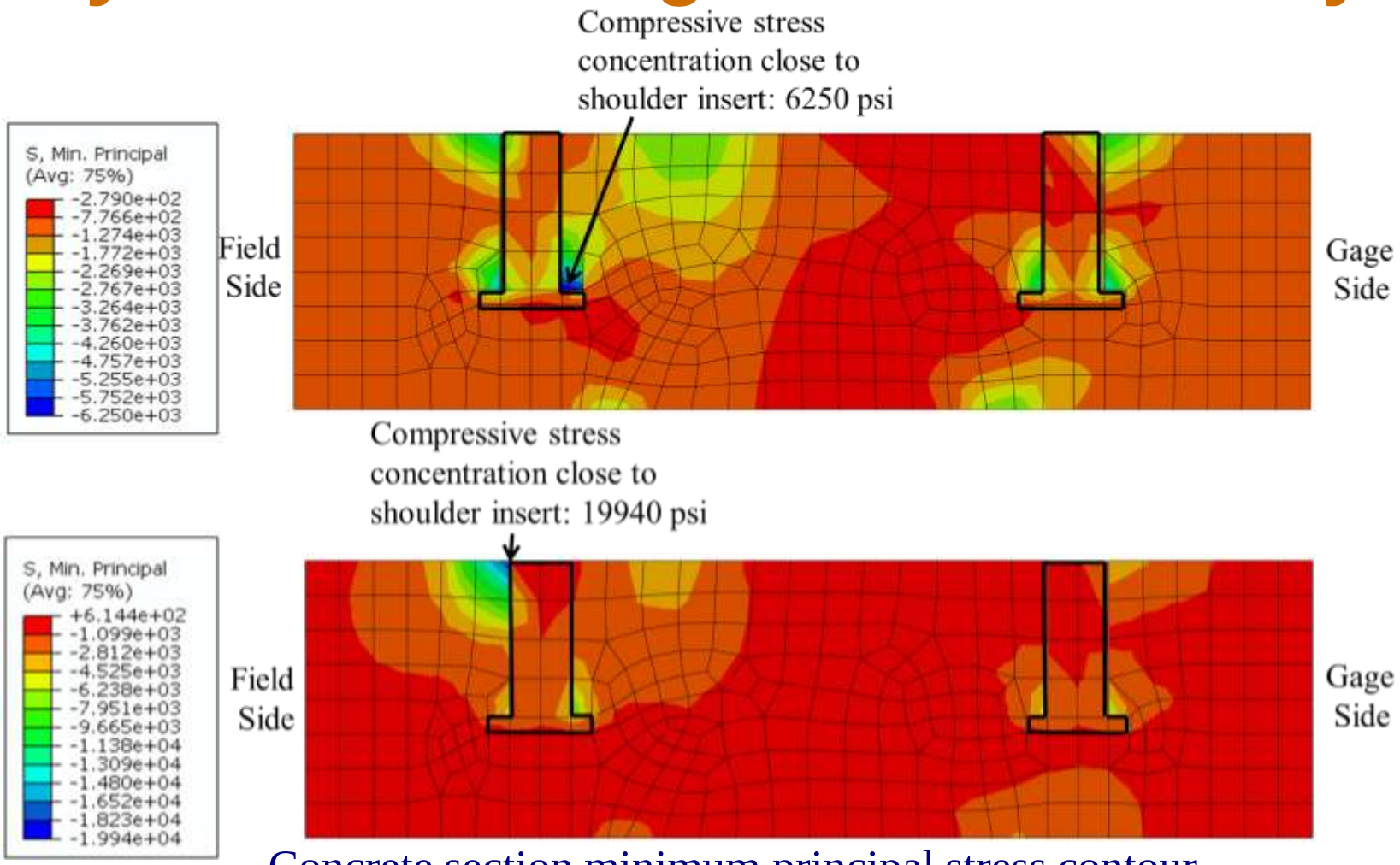
System Modeling: 3D Model Analysis





Concrete surface minimum principal stress contour
L/V ratio =0.25 (up) & 0.5 (down)
Plan view
(Unit: psi)

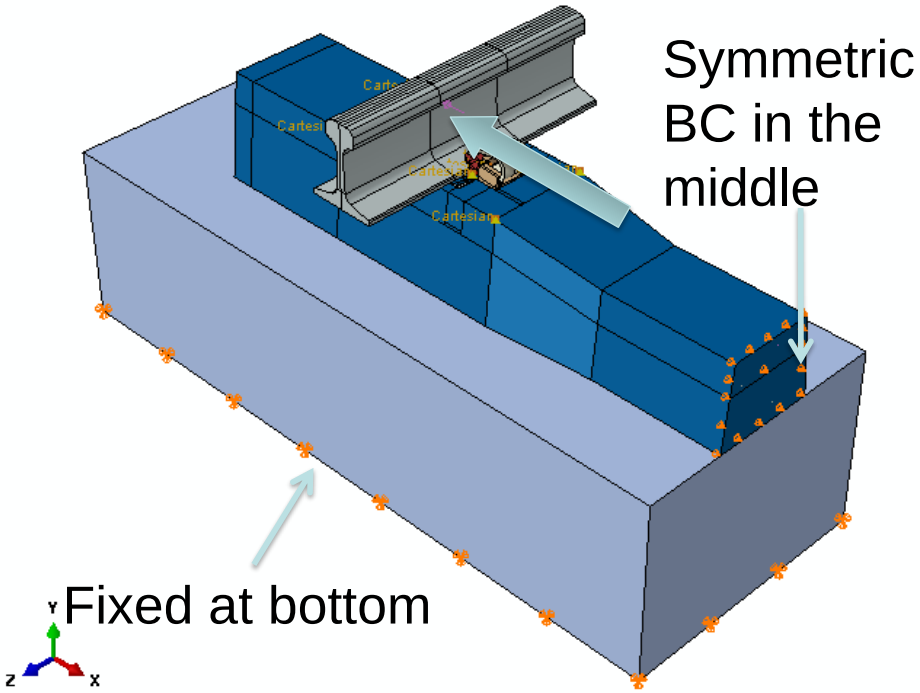
System Modeling: 3D Model Analysis

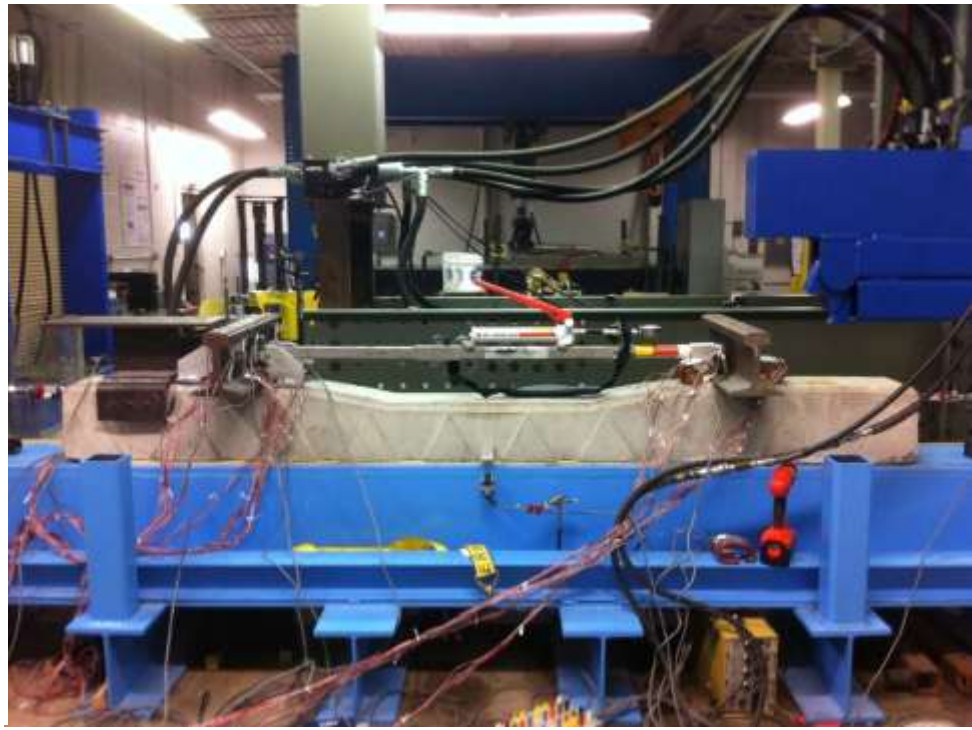


Concrete section minimum principal stress contour
L/V ratio =0.25 (up) & 0.5 (down) Section View (Unit: psi)

System Modeling: Single-Tie Modeling

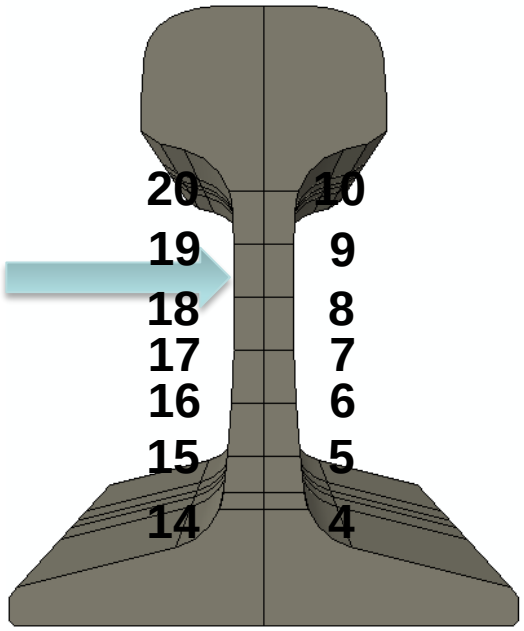
Laboratory Test Validation

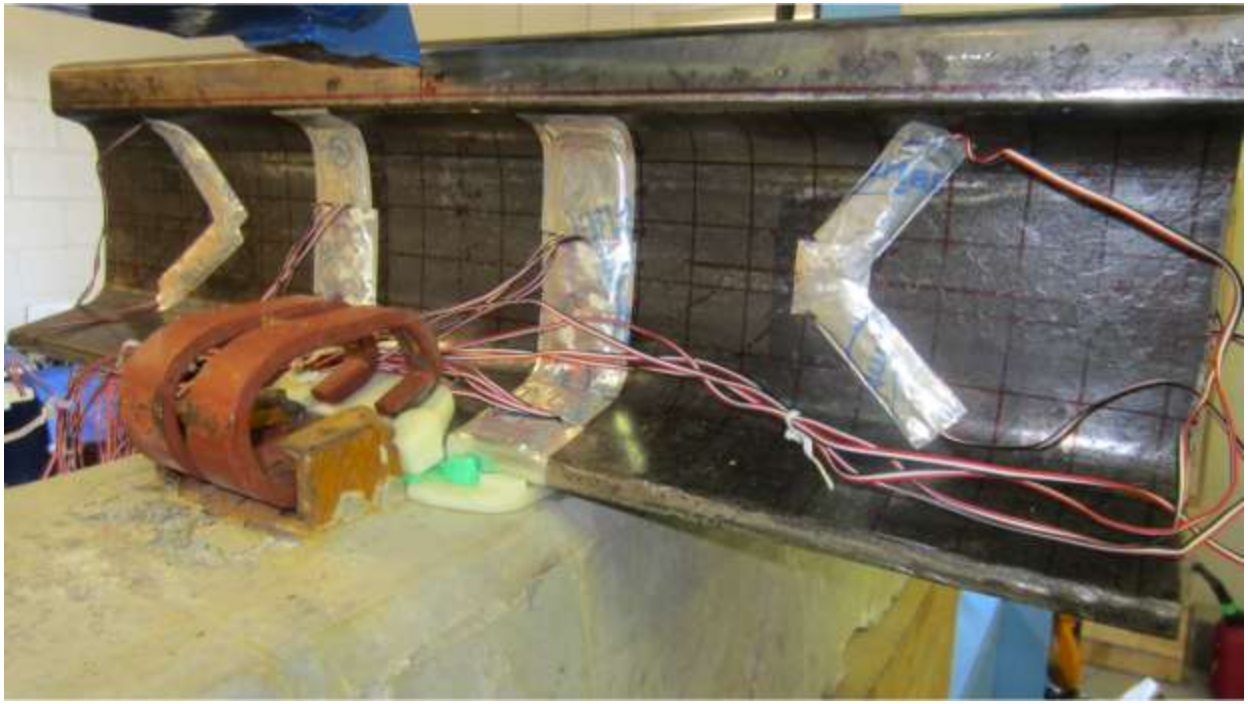




System Modeling: Single-Tie Modeling

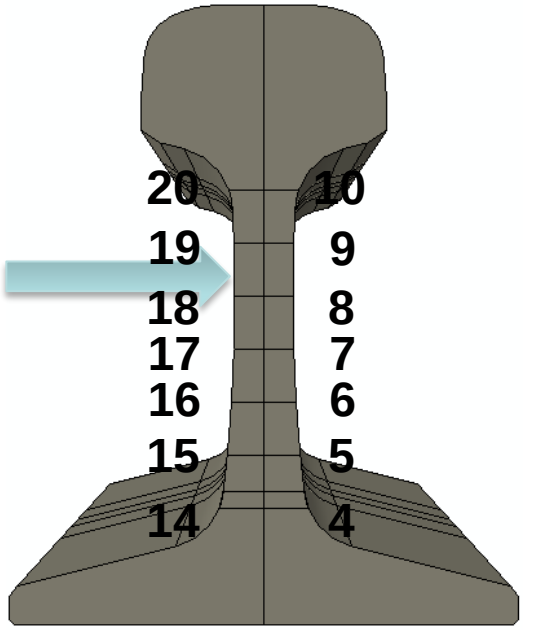
- Strain gauges are attached to the rail to measure vertical web strain
- Lateral loading is applied on rail web.

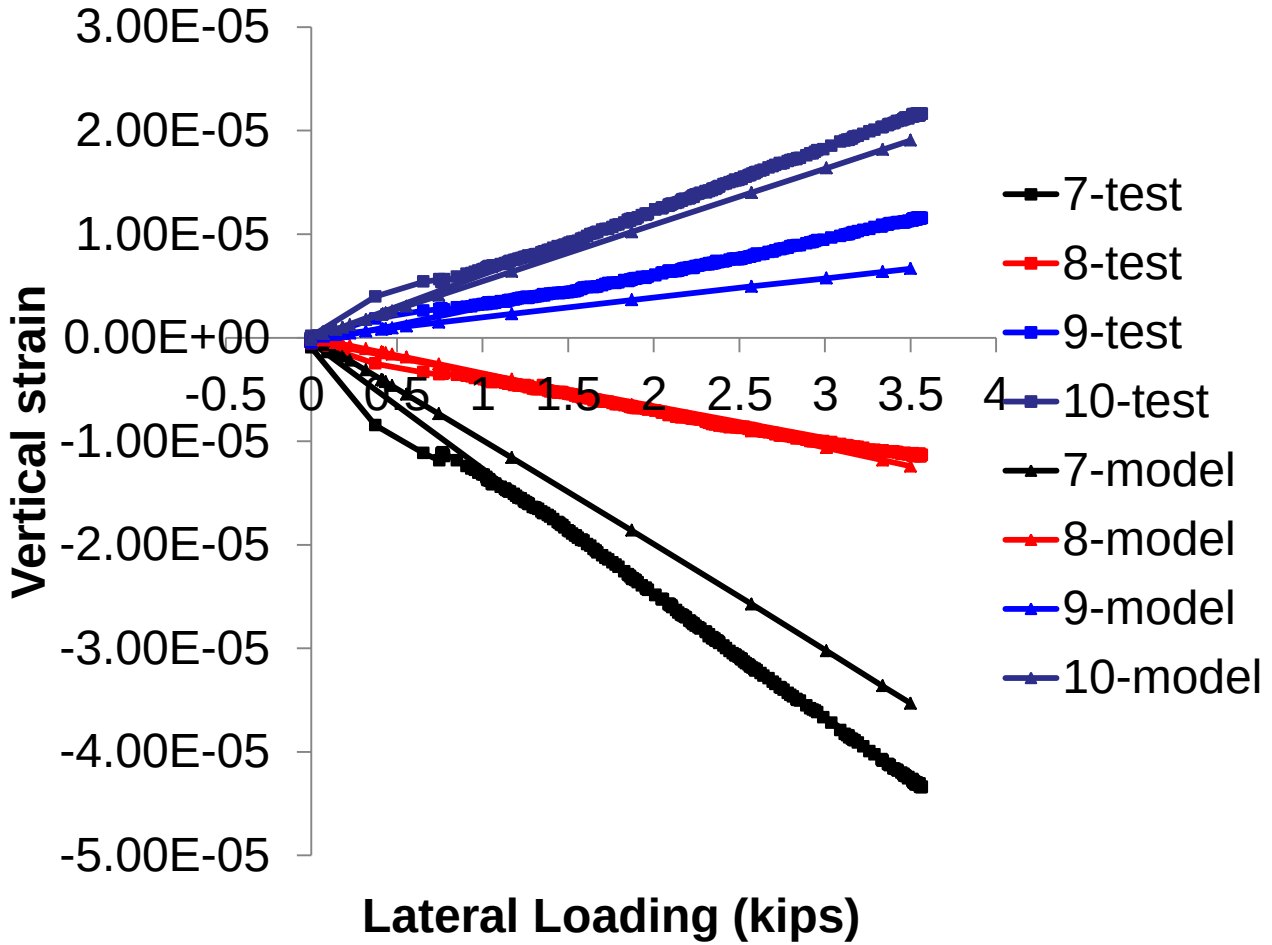




System Modeling: Single-Tie Modeling

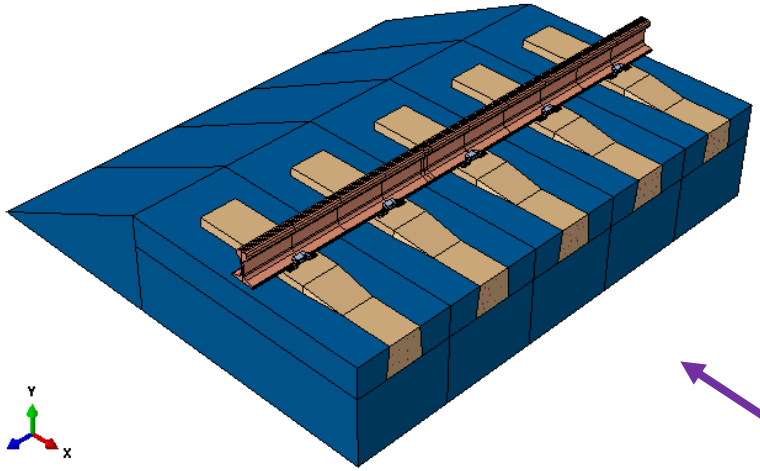
Comparisons of strains



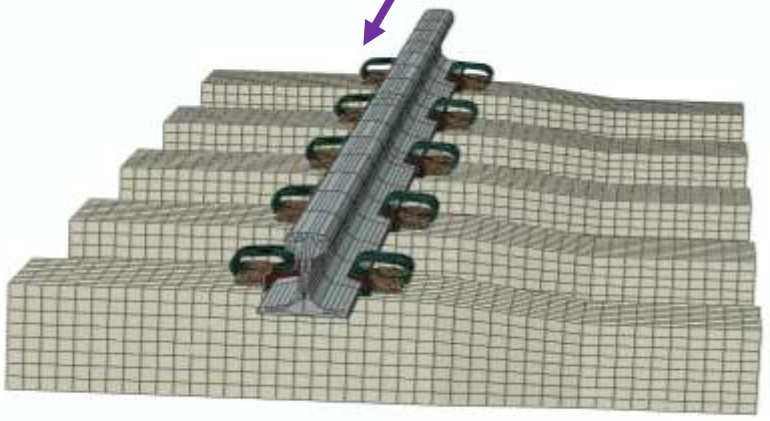


System Model: Multiple-Tie Modeling

- Track loading vehicle (TLV) applying vertical and lateral loads to the track structure in field
- The symmetric model including 5 ties



Simplified model:
Fastening system were replaced by bcs and pressure



Detailed model with the fastening system

Conclusions

- Some component models were validated with manufacturer data
- Single tie model was used to study bond-slip behavior of strands
- With the fastening system model, the loading path (vertical and lateral) can be identified
- Current laboratory tests were validated, and good agreement was observed
- Multiple tie models have been developed and ready to validate the track system models in field

Future Work

- **Further comparisons:** More measurements on the lab testing set-ups will be deployed and compared with the models
- **Large-scale modeling:** Future model will include multiple ties and simplified the fastening system to consider the distribution of loading among multiple ties and the discrete support condition of rail
- **Realistic loading**: More load types (vertical, lateral, and longitudinal loads) and load forms (static and dynamic load) will be applied to the track system to better simulate the actual loading environment
- **Parametric studies**: Parametric studies about material properties and geometric dimensions will be conducted using the model

Acknowledgements

U.S. Department of Transportation

Federal Railroad Administration

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  - Hanson Professional Services, Inc.
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CXT Concrete Ties

Questions?

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