Finite Element Modeling of the Fastening Systems and the Concrete Sleepers in North America

10th International Heavy Haul Association Conference

4-6 February 2013

New Delhi, India

George Zhe Chen, Moochul Shin, and Professor. Bassem O. Andrawes

U.S. Department of Transportation
Federal Railroad Administration

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

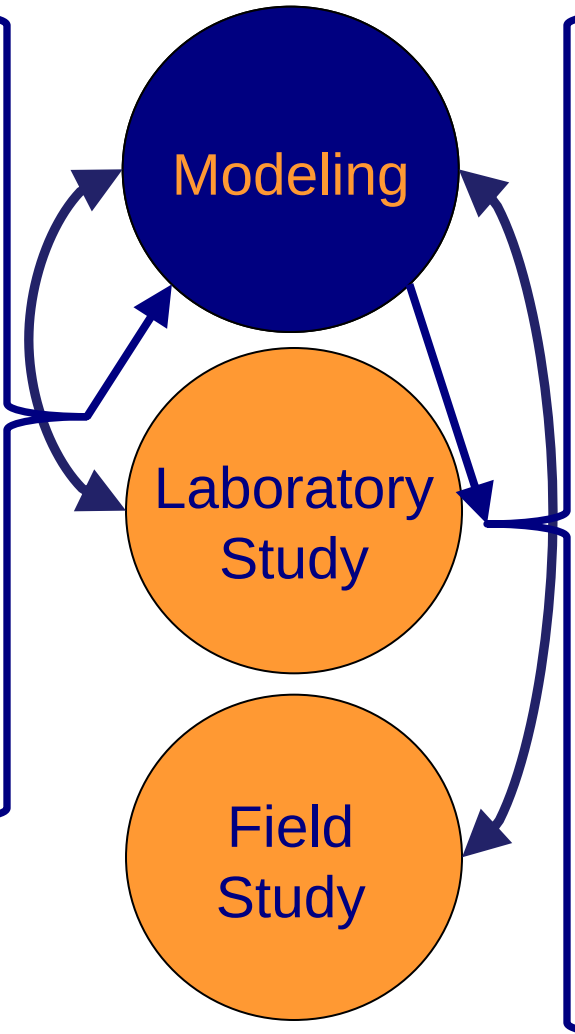
Outline

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

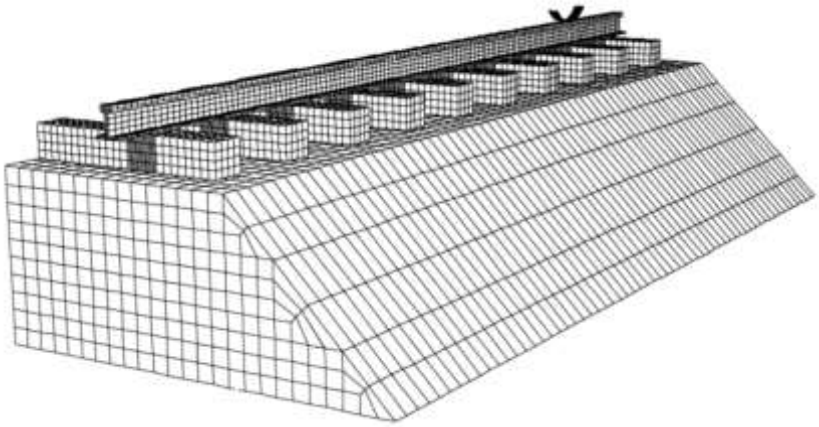
- Data Collection
- Document Depository
- Groundwork for Mechanistic Design
- International Survey Report
- Validated Tie and Fastening System Model
- Load Path Map
- Parametric Analysis
- State of Practice Report

Improved Recommended Practices

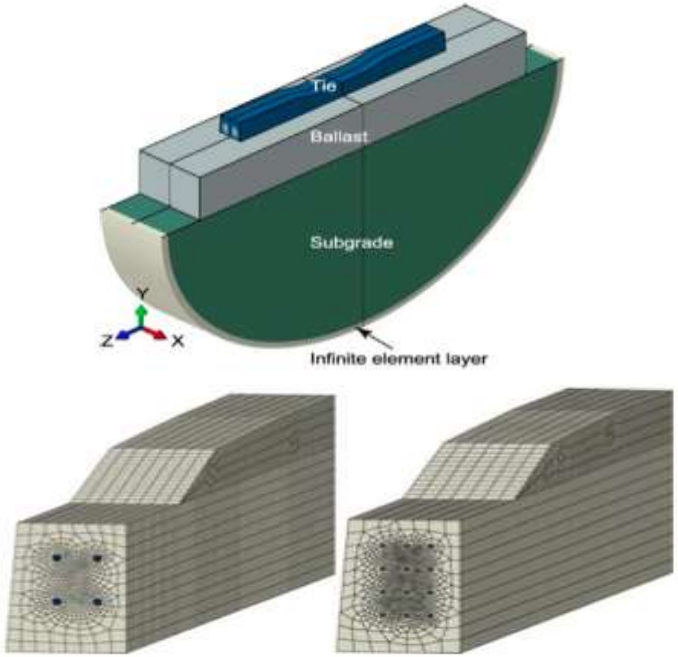
State of the Art

Track System Modeling

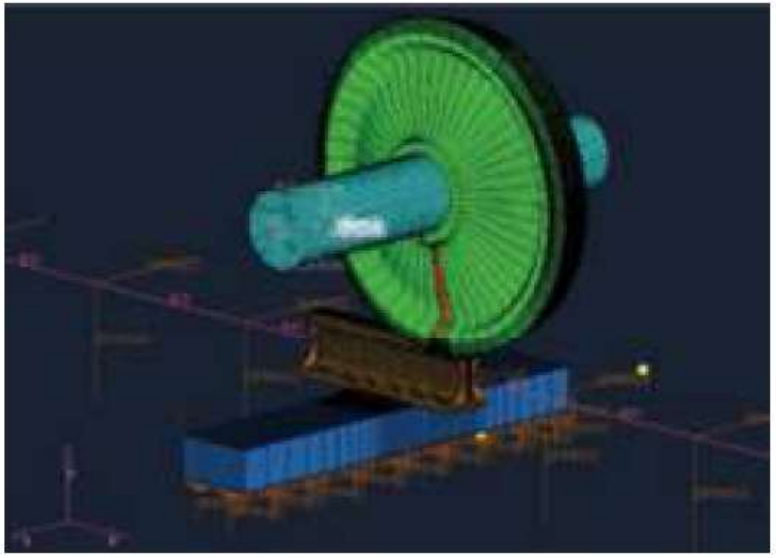
- Simplified fastening systems
- Focused on vertical loading
- Simplified support conditions



(Lundqvist and Dahlberg, 2005 - Sweden)

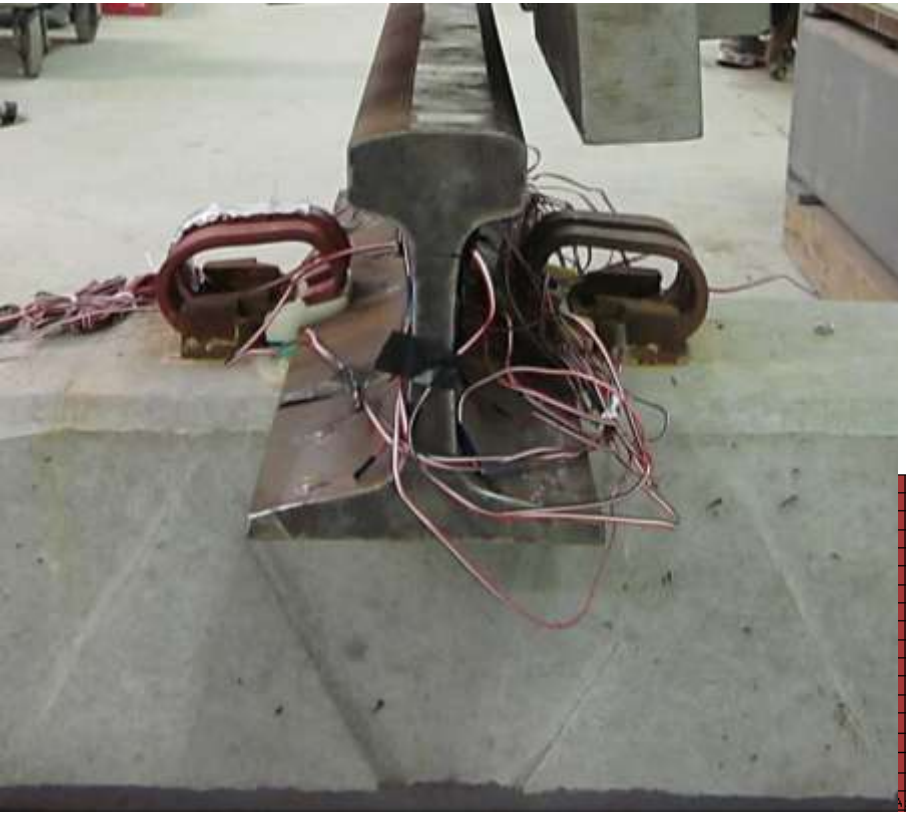


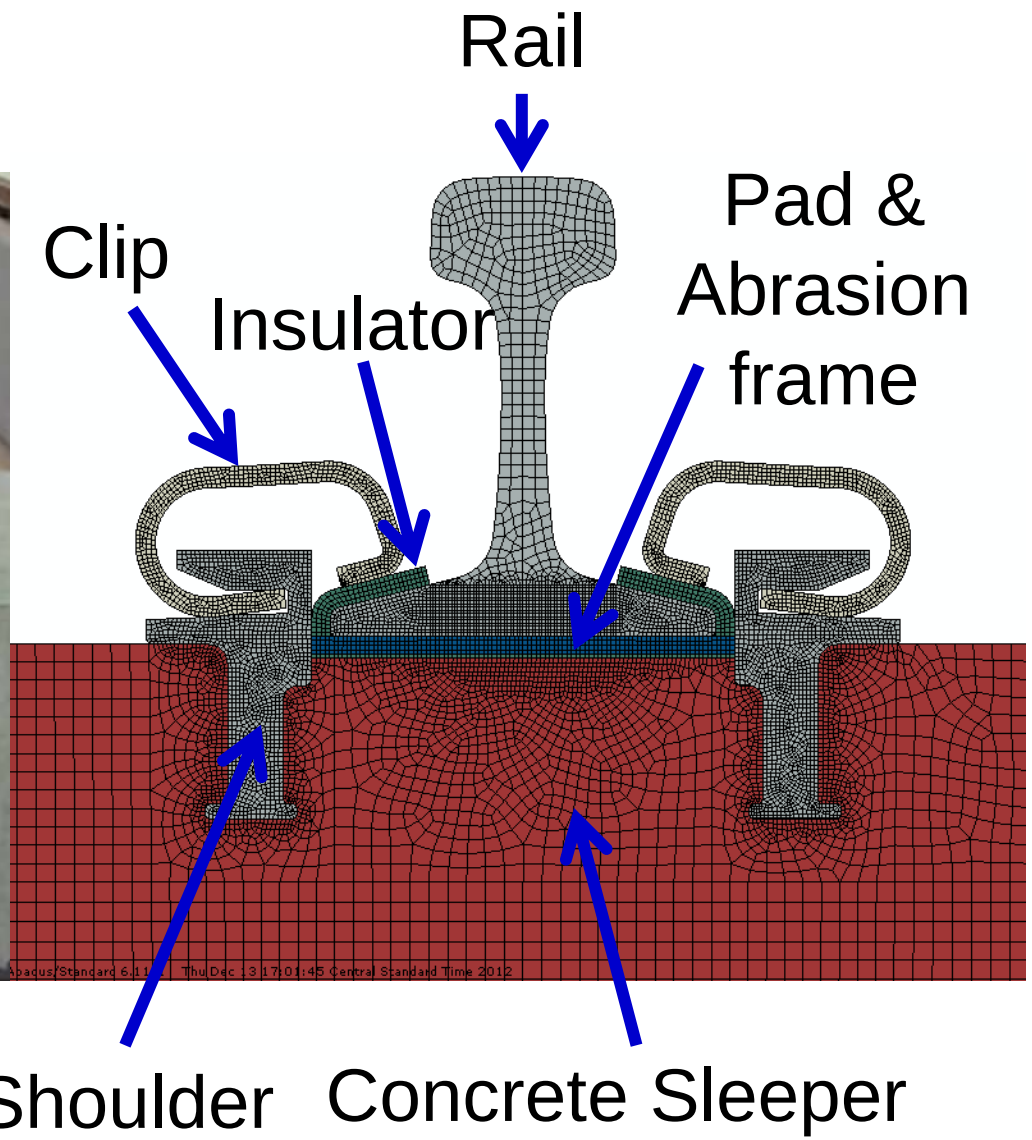
(Yu and Jeong, 2011)



(Tangtragulwong 2009)

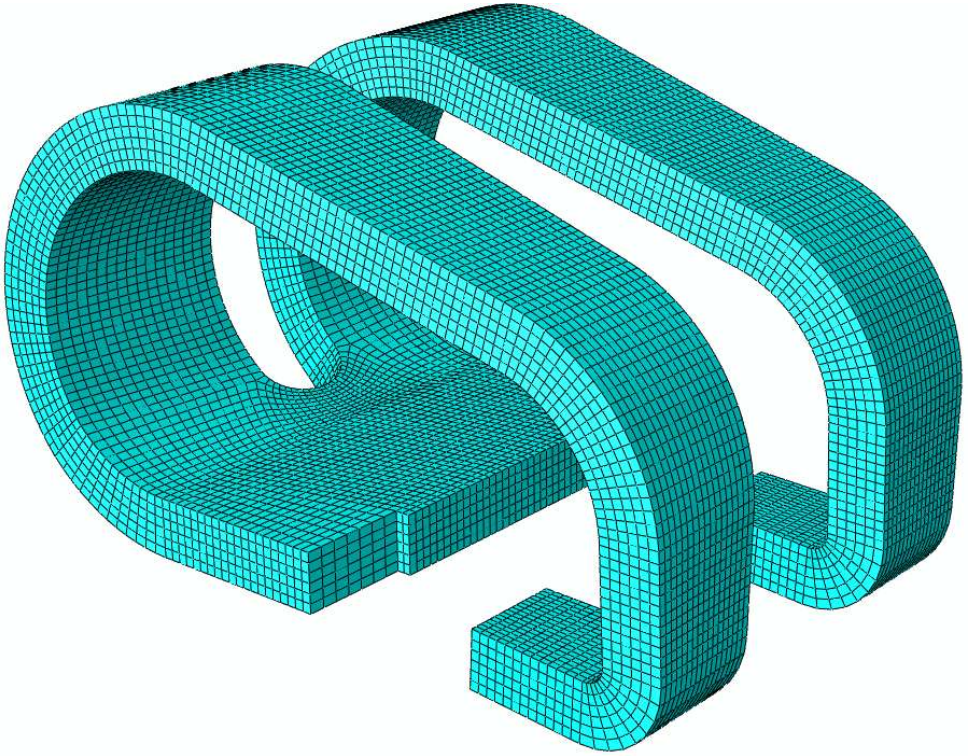
Concrete Sleeper and Fastening System





Component Modeling

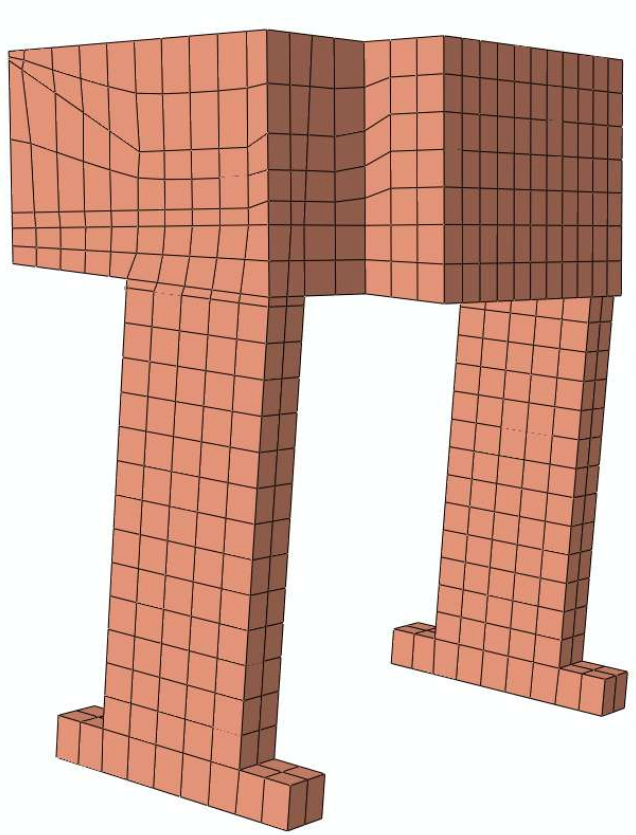
Rail Clip



Rail Clip model

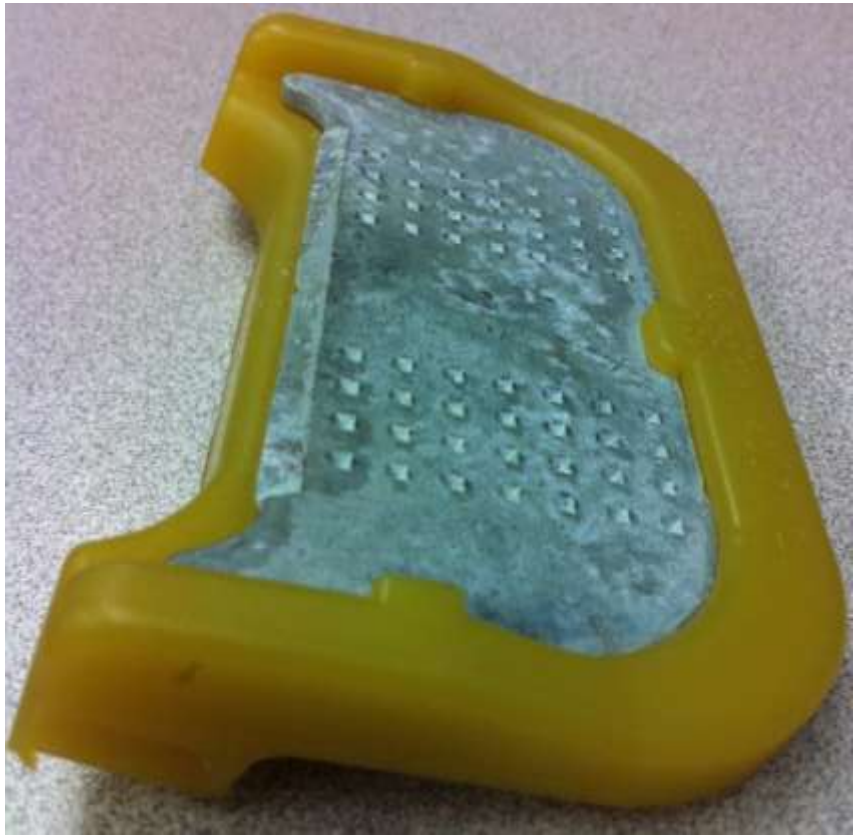
Component Modeling

Rail Shoulder

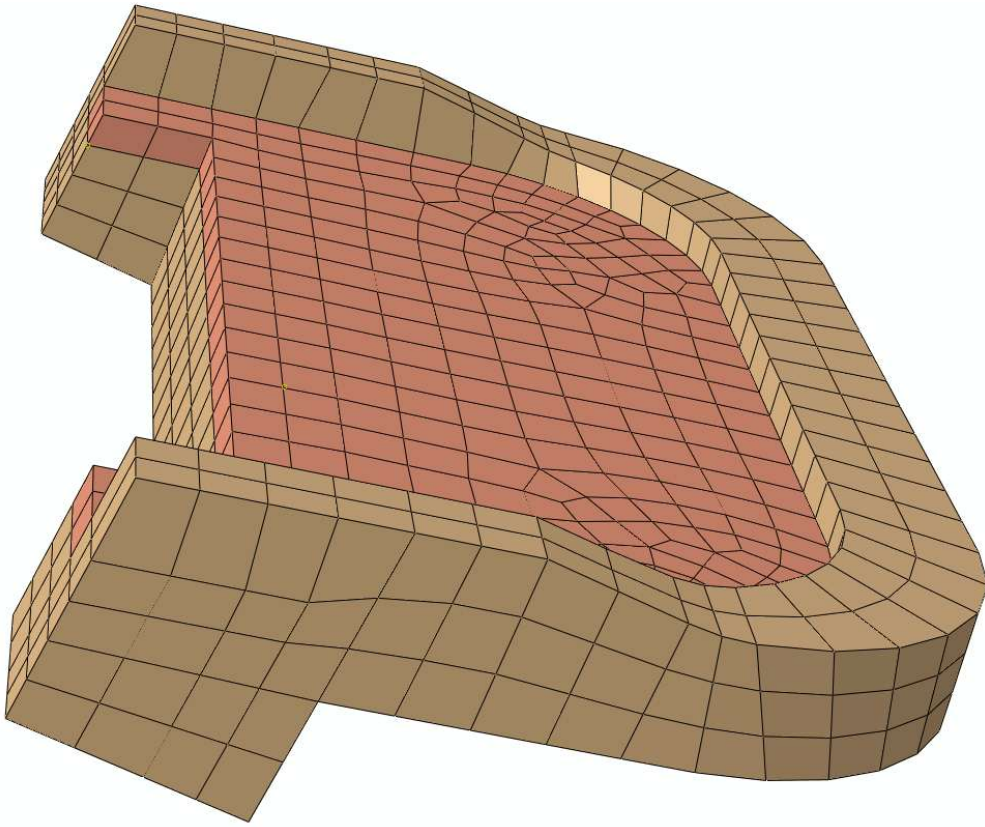


Rail Shoulder model

Component Modeling



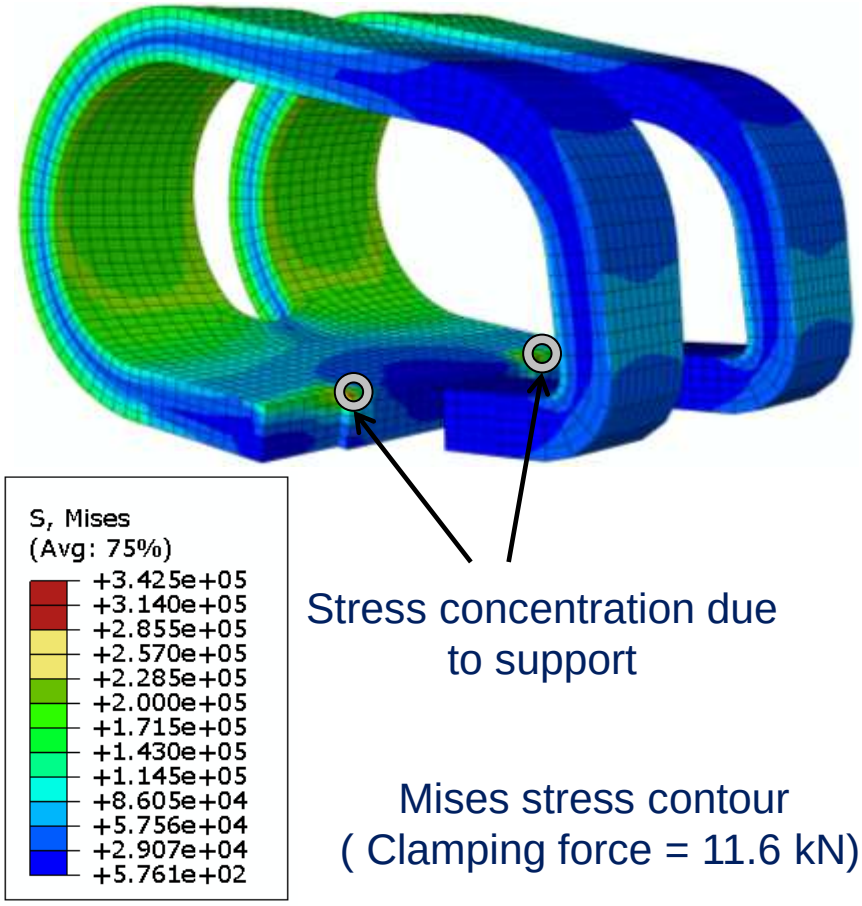
Rail Insulator



Rail Insulator model

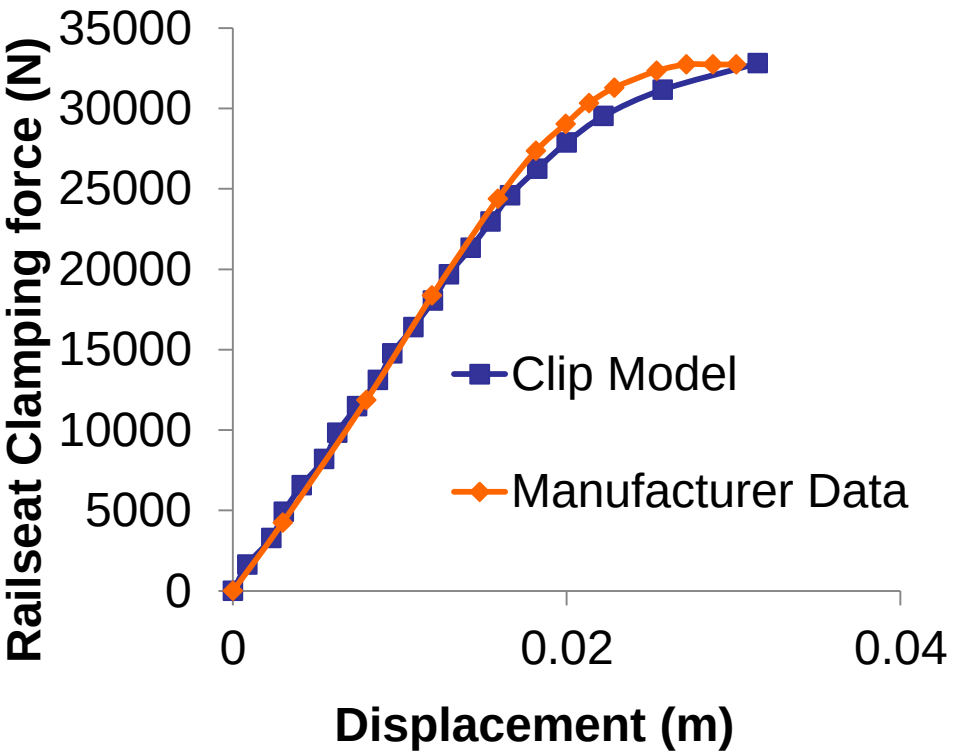
Component Modeling: Validation

- Clip Model



Stress concentration due to support

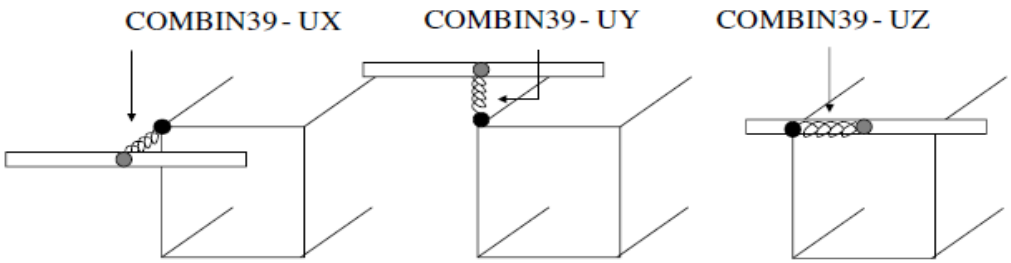
Mises stress contour
(Clamping force = 11.6 kN)



Clamping force-displacement curves

Component Modeling: Concrete Sleeper and Ballast

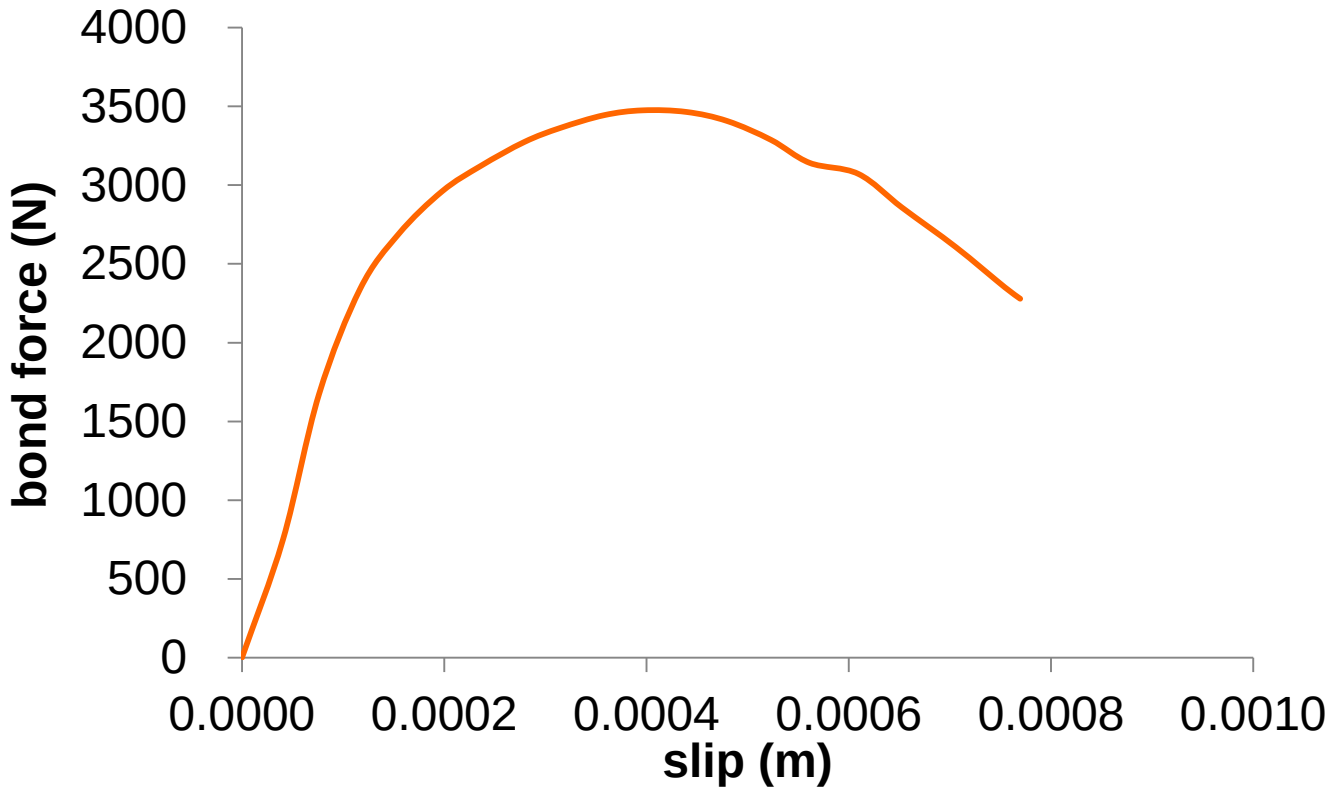
- Model Features:
  - Concrete material property: damage plasticity model
  - Connector element is used to simulate the bond relationship between concrete and strand
  - The effect of confining pressure on material property is considered in ballast modeling



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

Component Modeling: Concrete Sleeper and Ballast

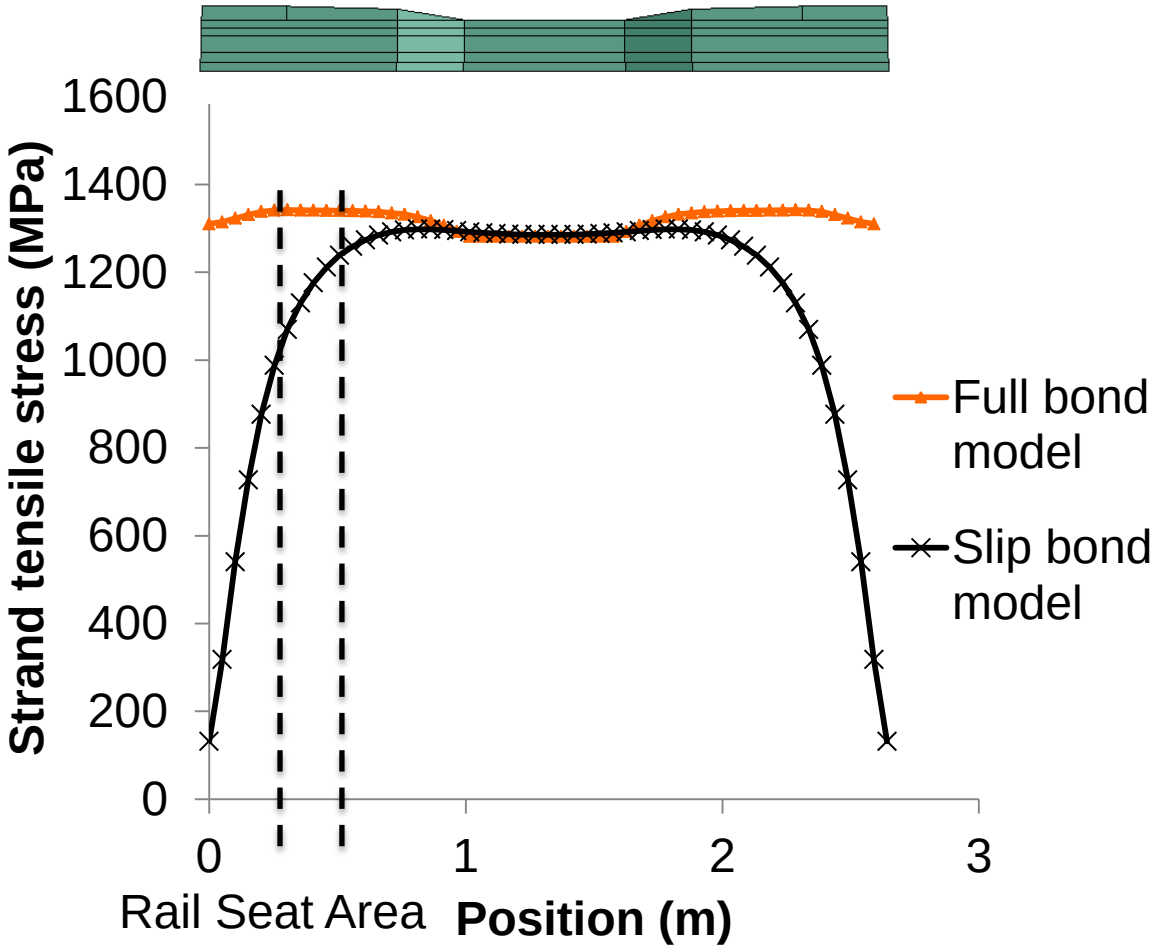
- A bonding force-slip relationship is defined in the model



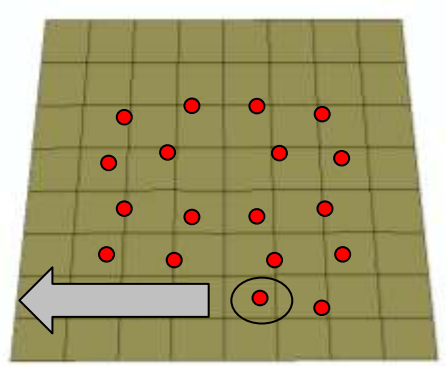
Bonding force-slip Relationships

(Testing Data from the Kansas State University)

Component Modeling: Concrete Sleeper and Ballast

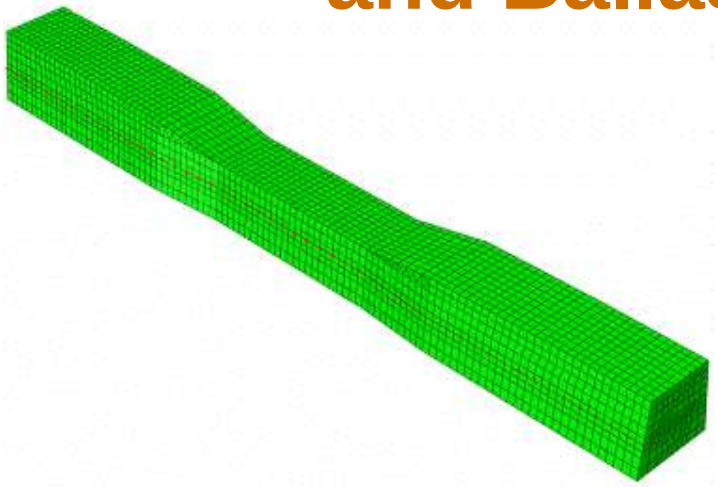


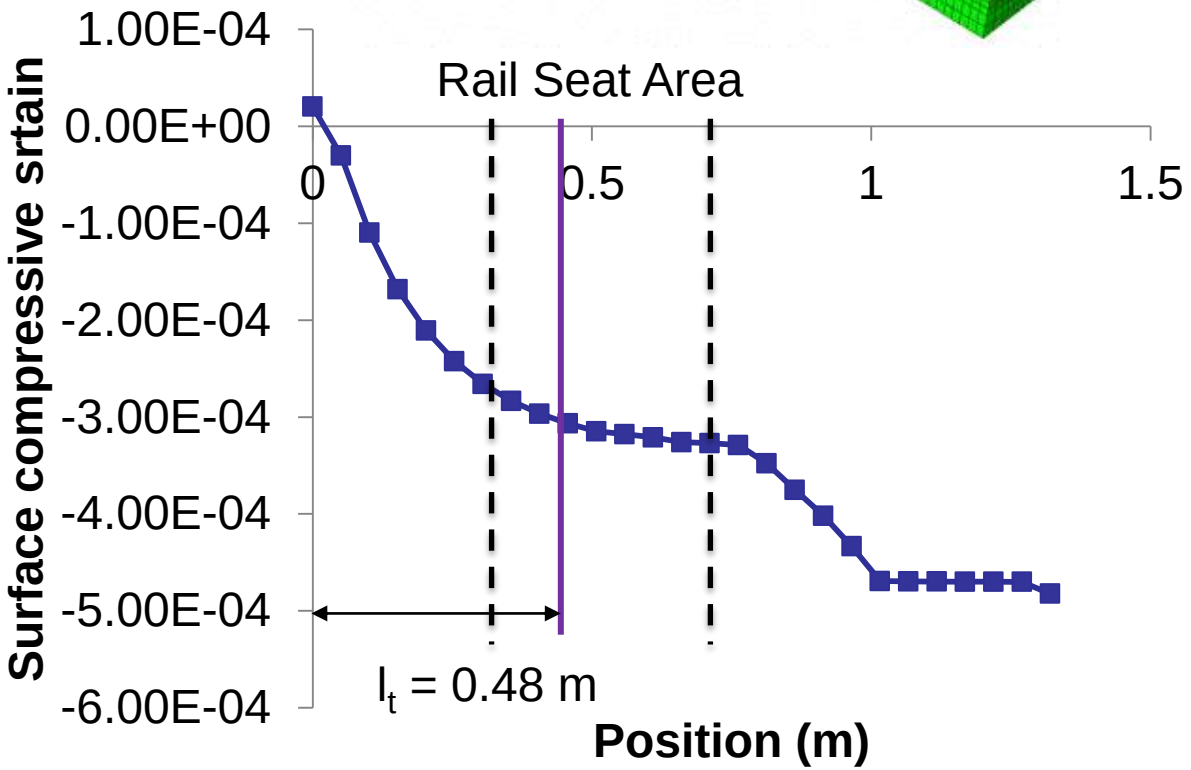
Positions of strands



Rail seat area is between 0.39 m to 0.67 m

Component Modeling: Concrete Sleeper and Ballast



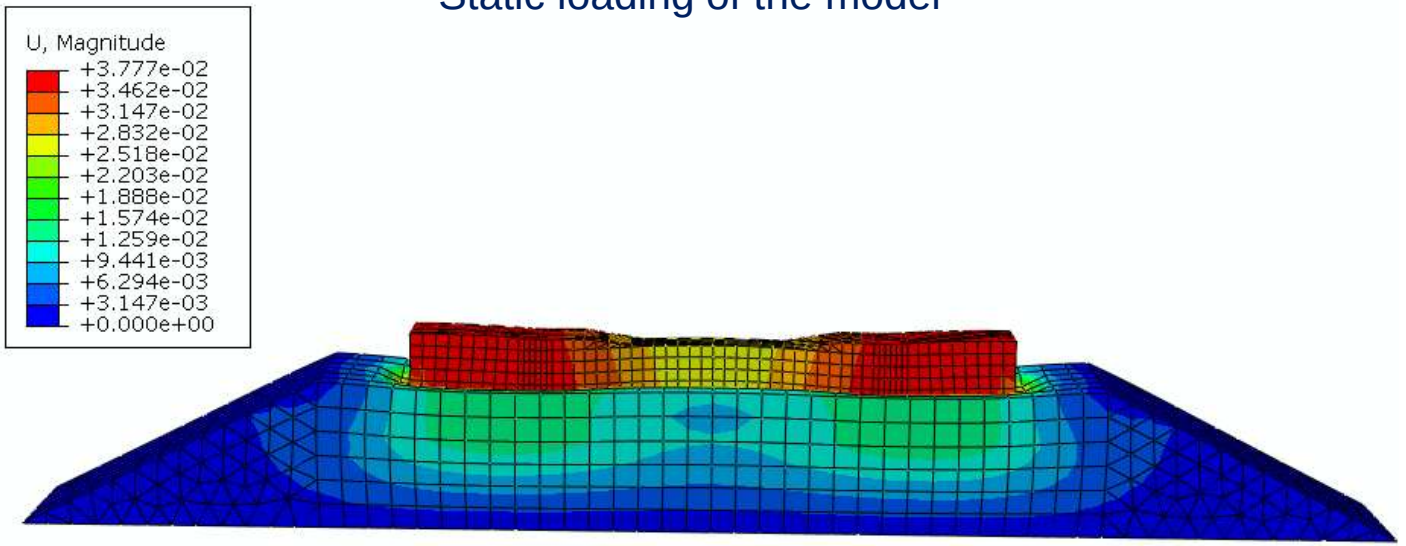


Position of concrete surface strain

Rail seat area is between 0.39 m to 0.67 m

Component Modeling: Concrete Sleeper and Ballast

Static loading of the model

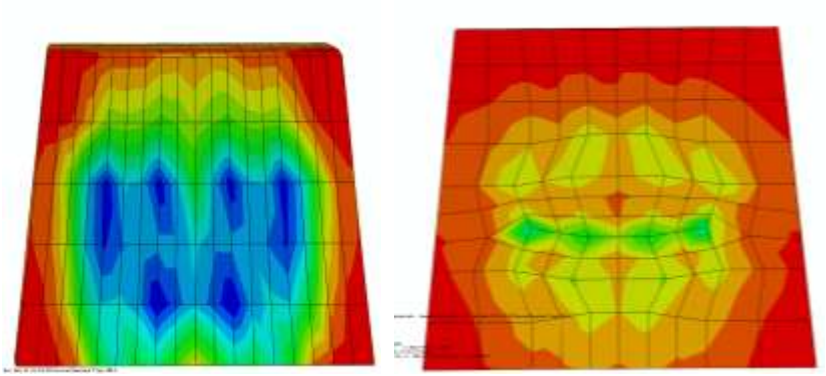


Deformation contour

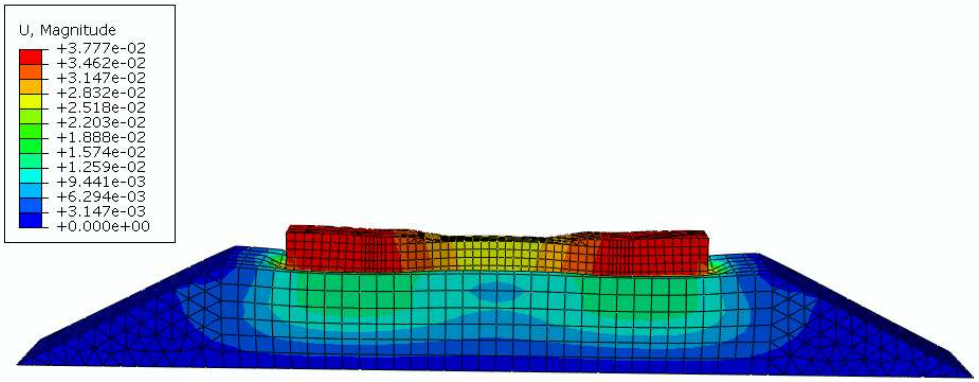
- Prestress and static loading (133.4 kN) is applied to the model to look into component stress distribution and system deflection.

Component Modeling: Concrete Sleeper 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 133.4 kN 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)

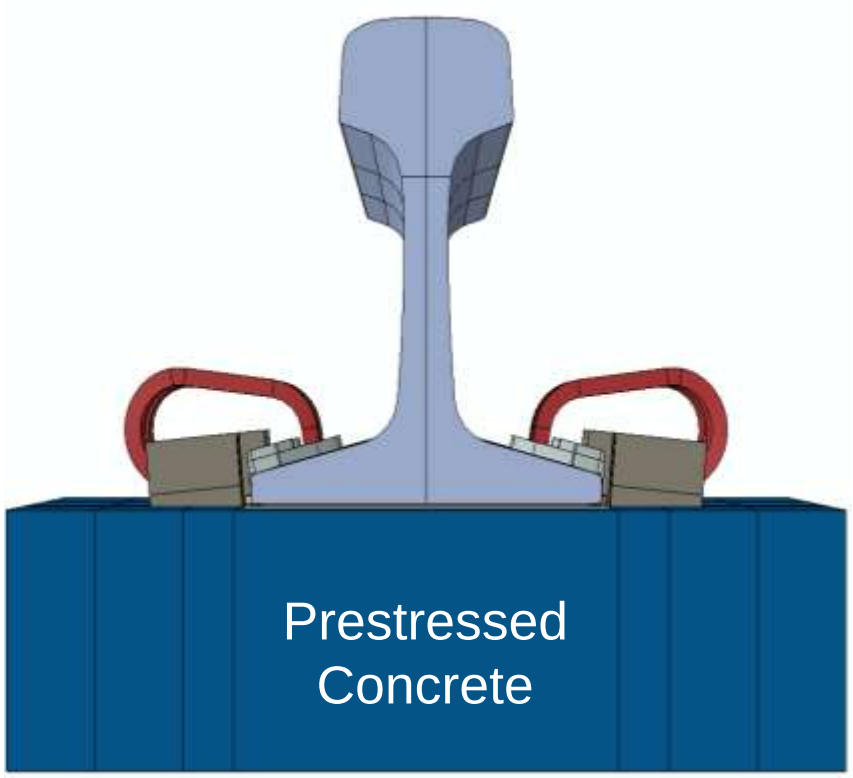


Deformation contour of under the vertical loading

System Modeling: 2D and 3D Modeling

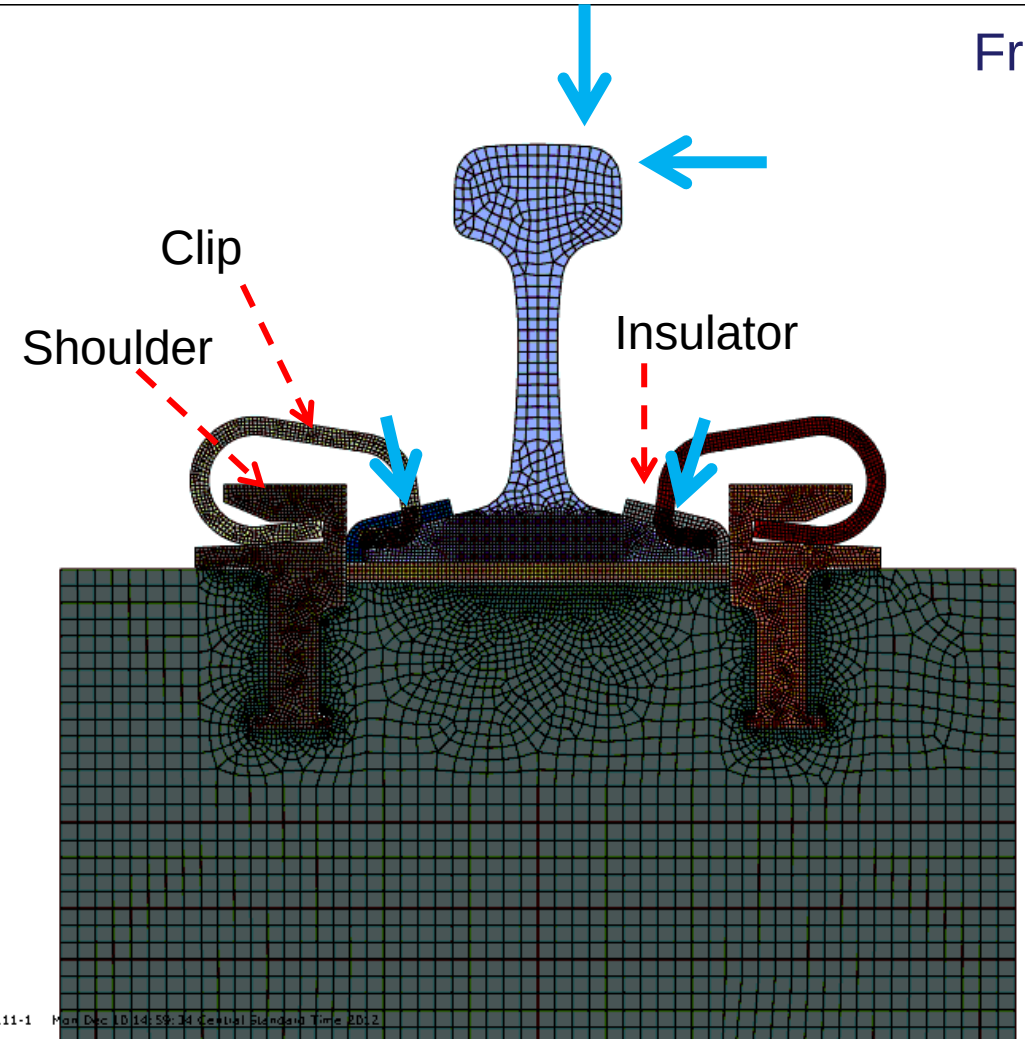
2D Modeling

3D Modeling

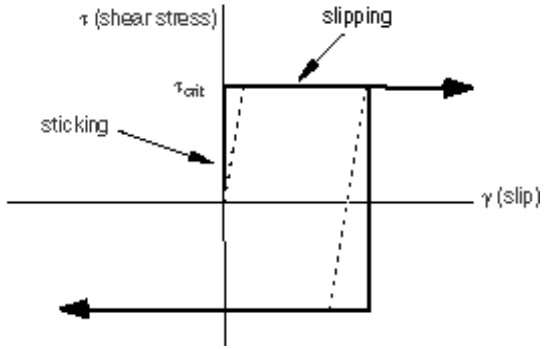


Pin Support

System Modeling: Fastening Systems



Friction Model between component:
Coulomb Model

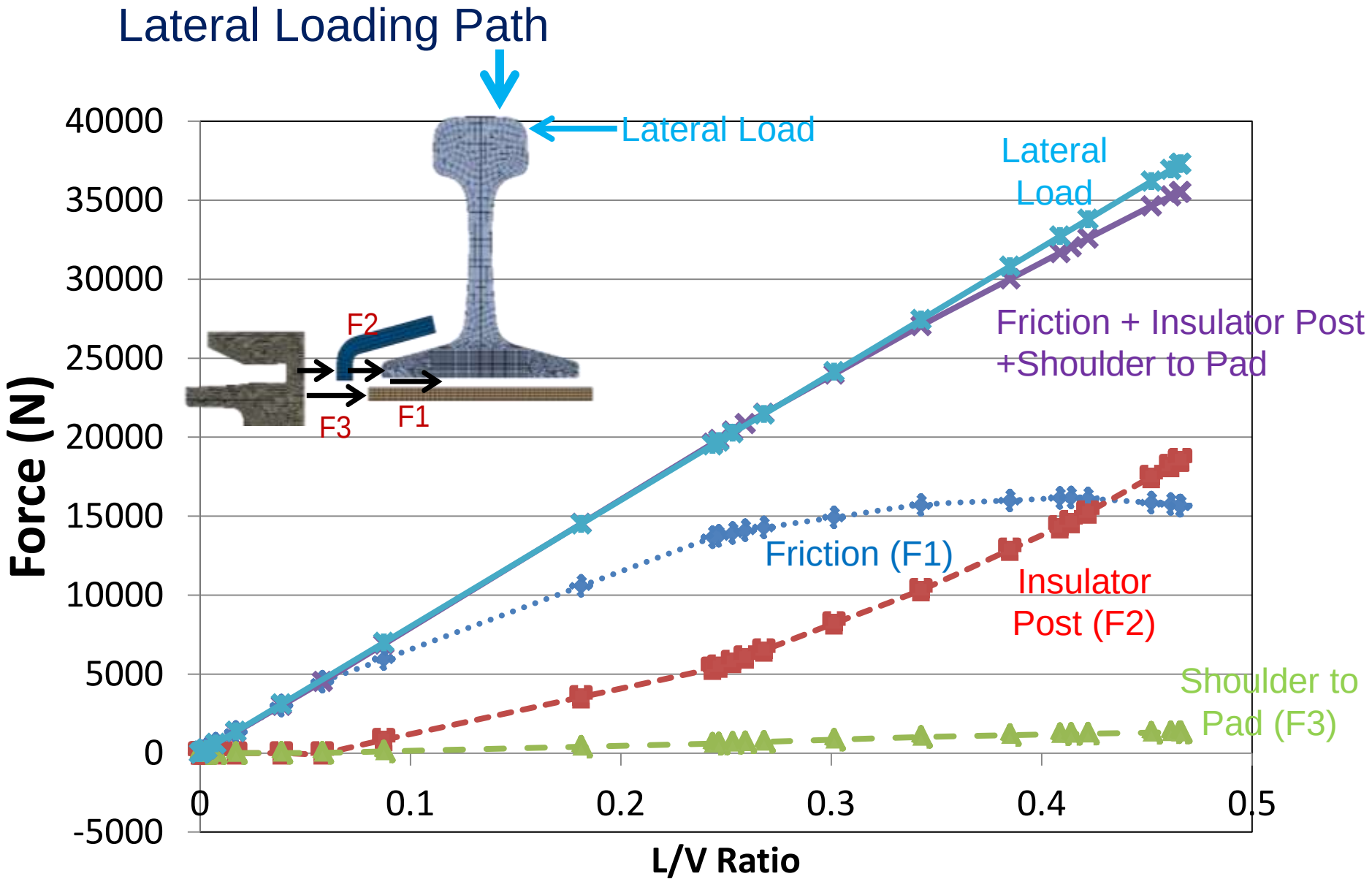


$$\tau_{crit} = \mu P_n > \tau_{eq} = \sqrt{\tau_1{}^2 + \tau_2{}^2}$$

No Slip

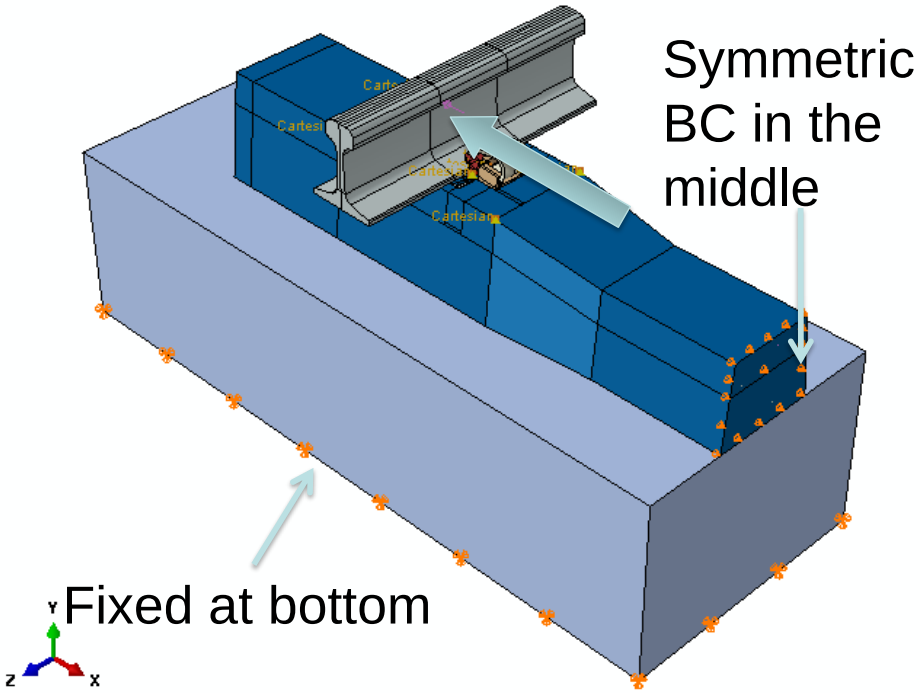
- Between the components:
  - Force due to contact pressure
  - Force due to friction stress

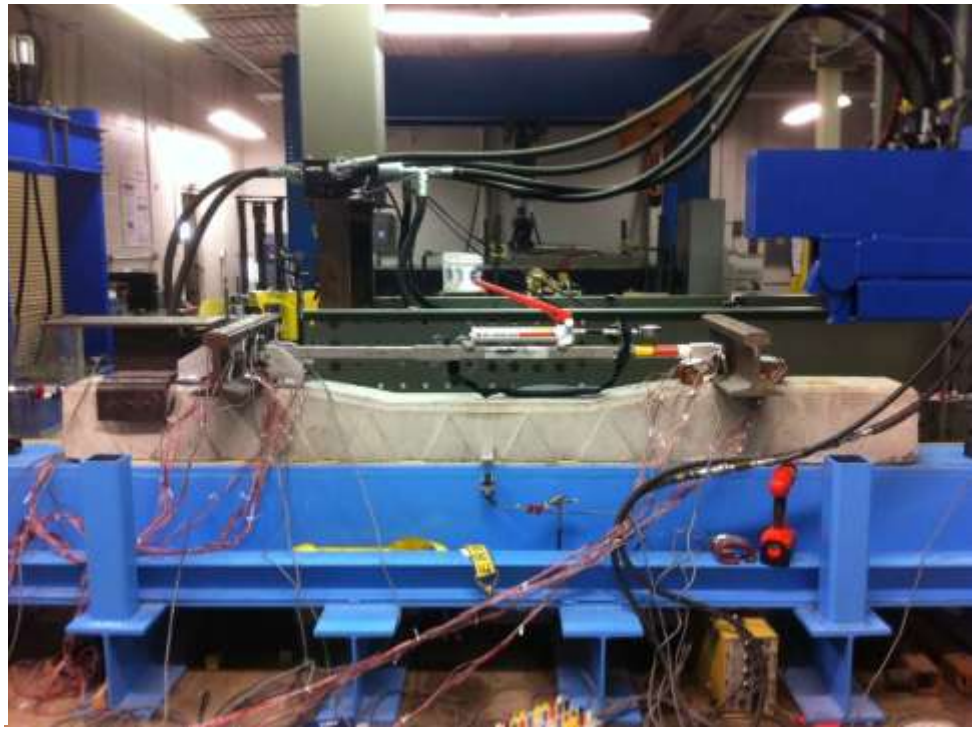
System Modeling: Fastening Systems



System Modeling: Single-Sleeper Modeling

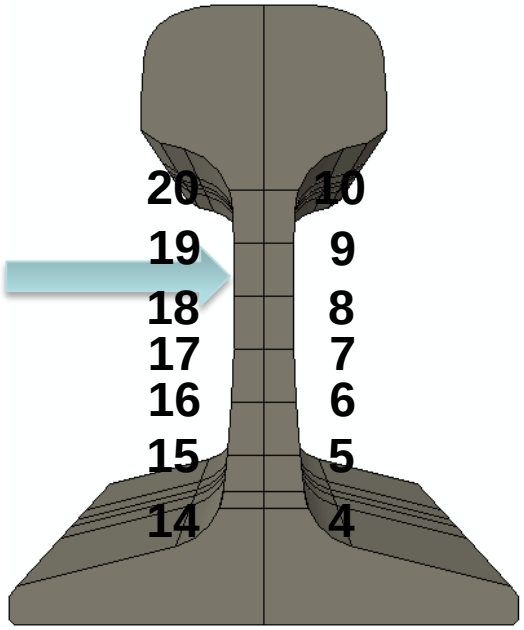
Laboratory Test Validation

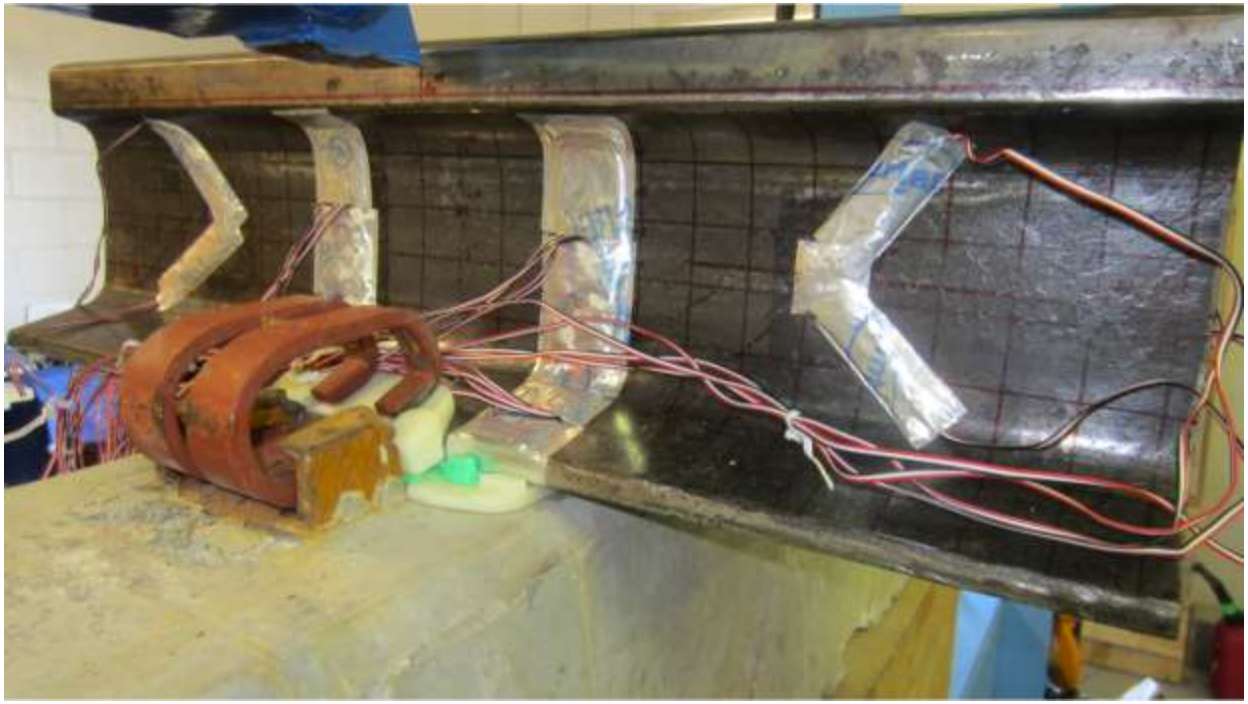




System Modeling: Single-Sleeper Modeling

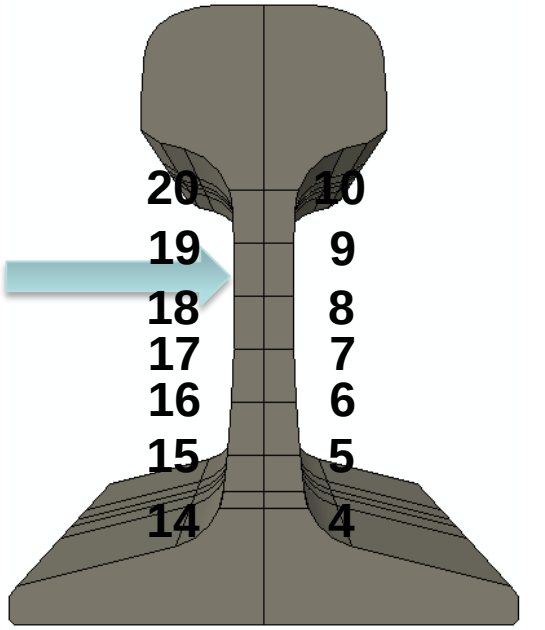
- Strain gauges are attached to the rail to measure vertical web strain
- Lateral loading is applied on rail web.

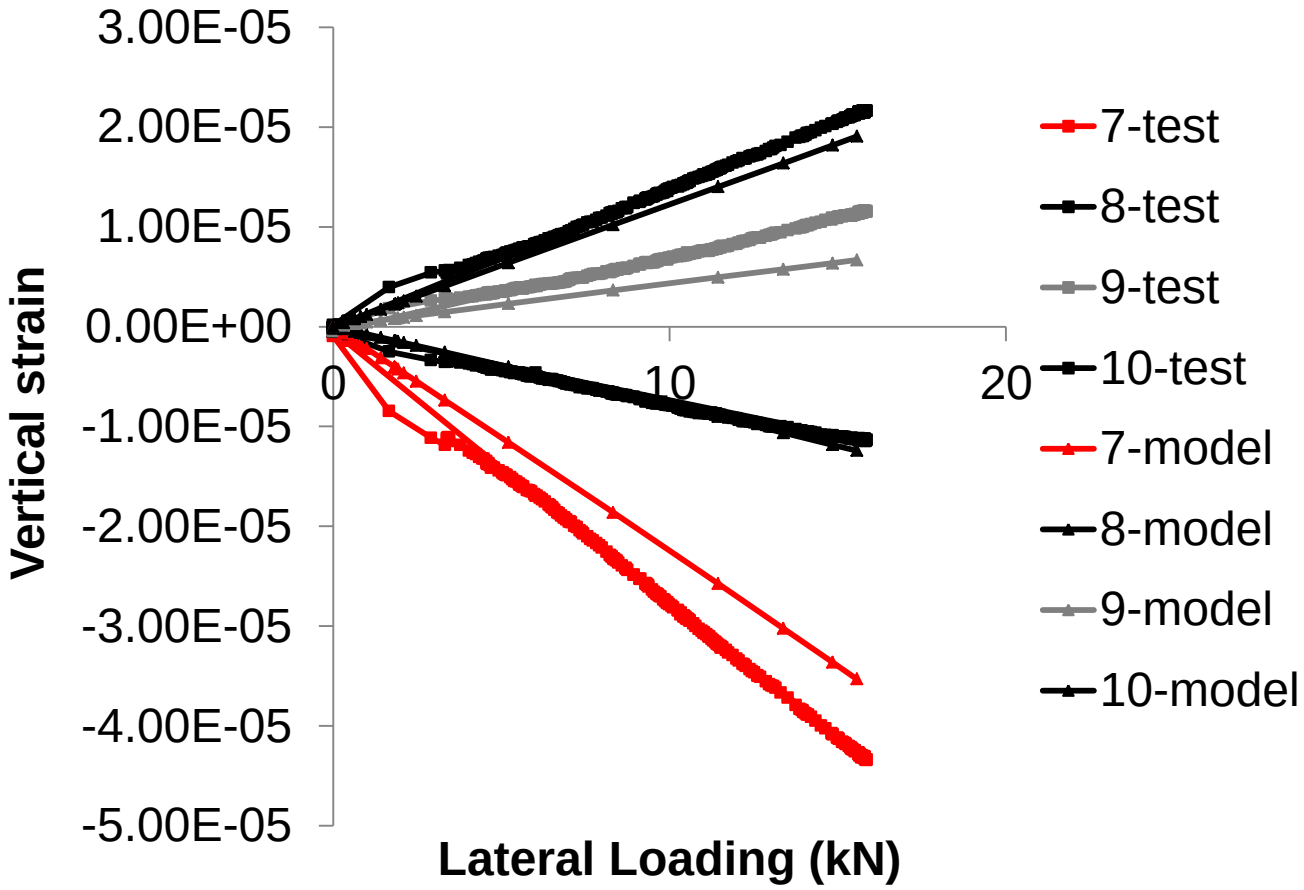




System Modeling: Single-Sleeper Modeling

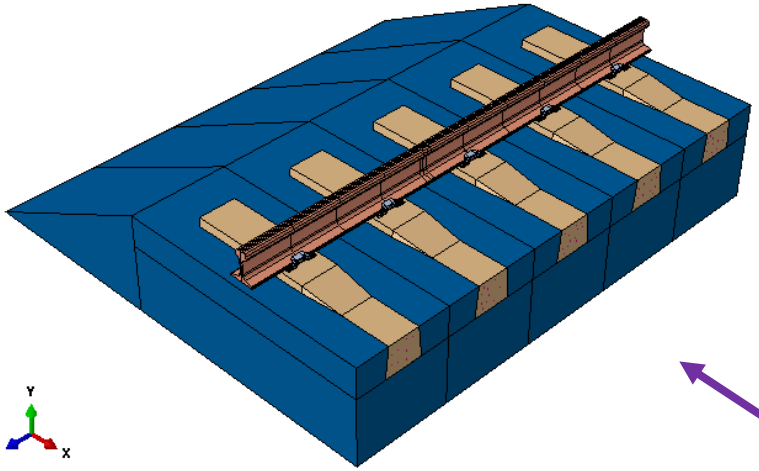
Comparisons of strains



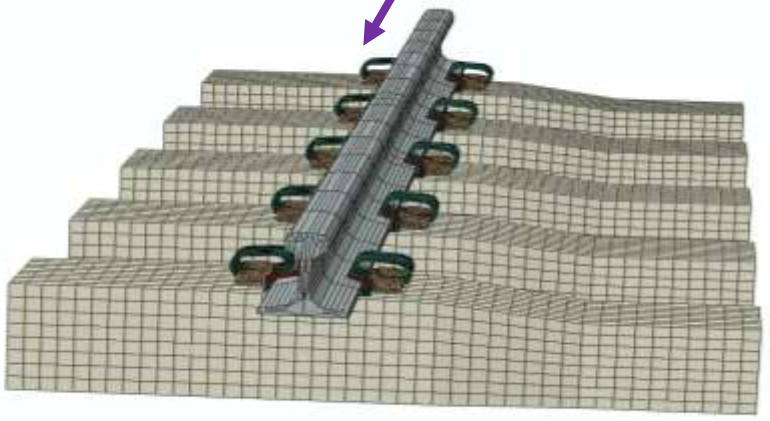


System Model: Multiple-Sleepers Modeling

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



Simplified model:
Fastening system were replaced by BCs and pressure



Detailed model with the fastening system

Conclusions

- Clip model was validated with manufacturer data
- 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-sleeper models have been developed and is 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:** More Models will be built to look into 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

- Funding for this research has been provided by the Federal Railroad Administration (FRA)
- Industry Partnership and support has been provided by
  - Union Pacific (UP) Railroad
  - BNSF Railway
  - National Railway Passenger Corporation (Amtrak)
  - Amsted RPS / Amsted Rail, Inc.
  - GIC Ingeniería y Construcción
  - Hanson Professional Services, Inc.
  - CXT Concrete Ties, Inc., LB Foster Company
- Professor Tutumluer for assisting with ballast modeling. (UIUC)
- Professor Peterman for strand bond-slip test data. (KSU)
- Amsted RPS (Jose Mediavilla) and CXT Concrete Tie Inc. (Pelle Duong) for providing resources including engineering drawings, models, and other advice.

FRA Tie and Fastener BAA Industry Partners:

UNION PACIFIC

BUILDING AMERICA®

BNSF RAILWAY

AMTRAK®

Amsted RPS

Amsted Rail

GIC

GIC INGENIERÍA Y CONSTRUCCIÓN S.A. DE C.V.

HANSON

LB Foster

CXT Concrete Ties

Questions?

Research Engineer, Ryan Kernes

Department of Civil and Environmental Engineering
University of Illinois, Urbana-Champaign
Email: rkernes2@illinois.edu