Finite Element Modeling Crosstie and Fastening System at UIUC

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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

**Modeling**

**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

Modeling of 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”

Strand tensile stress (psi) vs. Position (in)

- strand_embedded_model
- strand_connector_model
Component Modeling: Concrete Tie and Ballast

Position of concrete surface strain

Rail seat area is between 15.2” to 26.5”

Surface compressive strain

$\varepsilon_t = 19.0$ in
Modeling of Concrete Crosstie and Fastening System

Component Modeling: Concrete Tie and Ballast

- 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

Prestressed Concrete

Pin Support
System Modeling: Fastening Systems

Friction Model between component: Coulomb Model

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

No Slip

- Between the components:
  - Force due to contact pressure
  - Force due to friction stress
System Modeling: Fastening Systems

Lateral Loading Path

- Friction (F1)
- Insulator Post (F2)
- Shoulder to Pad (F3)

Force (lb) vs. L/V Ratio

Lateral Load, Friction + Insulator Post + Shoulder to Pad
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

Fixed at bottom
Symmetric BC in the middle
System Modeling: Single-Tie Modeling

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

- Vertical strain vs. Lateral Loading (kips)

- Graph showing comparisons between test and model results for different loading conditions.

- Key: 7-test, 8-test, 9-test, 10-test, 7-model, 8-model, 9-model, 10-model.

- Gauges labeled on the concrete crosstie model:
  - Field side: 14, 15, 16, 17, 18, 19, 20
  - Gauge side: 4, 5, 6, 7, 8, 9, 10

- Note: The diagram illustrates the strain behavior under varying lateral loads.
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.
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FRA Tie and Fastener BAA
Industry Partners:

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Questions?

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