Concrete Crosstie Finite Element Modeling Update and Results

FRA and FTA Crosstie and Fastening System Research Program
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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

Finite Element Modeling of Concrete Crossties

Initial Model Focusing on Elastic Behavior

Predict Crack Location and Crack Propagation

Failure Analysis with Four-point Bend Test

Previous Model

FRA

FTA

Collected Field Data

Model Calibration using Strain Gauge Calibration Curves

Developed model used to predict initial behavior

Improve Model to Predict Crosstie Behavior in Field

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

Failure Analysis with Four-point Bend Test

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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

- **Initial Model**
  - Start with previously developed material properties

- **Model Development**
  - Recreate lab/field setup with similar load and support conditions

- **Model Calibration/Validation**
  - Displacement/strain calibration

- **Model Application**

**Model Refinement**

Example steps include:
- Test Matrix Optimization (FRA)
- Failure Mechanism Study (FRA)
- Parametric Studies (FRA and FTA)
- Optimize Crosstie Design (FTA)
Design Characteristics

- Total length of crosstie = 102 in. (2591 mm)
- Prestress wire arrangement – 20 wires, 5 rows
- Wire diameter = 0.21 in. (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:
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
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
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.

![Graph of Load vs Displacement](image)
Proposed Parameter for Comparison: Load vs Displacement

• Benefits:
  – Compare post cracking behavior of the different crosstie designs

![Graph showing the relationship between load and displacement, with annotations indicating the first kink refers to the first crack.]

Proposed Parameter for Comparison: Load vs Displacement

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

![Graph showing the relationship between load and displacement, with annotations indicating the peak refers to the ultimate strength.]
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](lab_image)

![Compression cracking zone as predicted by FE model](abaqus_image)

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](lab_image)

![ABAQUS Image](abaqus_image)
Stress Simulation

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

![Diagram showing stress simulation results]

Deformation scale factor = 5

Review of Existing FE Analysis (cont.)

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

![Graph showing load vs. displacement for different support conditions]
Review of Existing FE Analysis (cont.)

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

![Graph showing load vs. displacement for different support conditions.]

Center Section Length = 24 in.

![Graph showing center negative moment vs. displacement for different support conditions.]

Support conditions:
- Support - 48 in.
- Support - 24 in.
- Support - 12 in.
- Support - 6 in.
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

![Graph showing the effect of prestress reduction on total load versus center displacement. The graph includes lines for 0%, 10%, 20%, and 30% reduction.]
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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