Validating Finite Element Model with Field Data

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Outline

- Role of Finite Element (FE) analysis in mechanistic design

- Methodology and background for FE Analysis – global and detailed model

- FE models for field experiments

  - Displacement calibration

  - Load distribution validation

- Applications for the calibrated models

- Conclusions

- Future work

Overall Project Deliverables

Mechanistic Design Framework

Literature Review

Load Path Analysis

International Standards

Current Industry Practices

AREMA Chapter 30

I – TRACK

Statistical Analysis from FEM

Free Body Diagram Analysis

Probabilistic Loading

Finite Element Model

Laboratory Experimentation

Field Experimentation

Parametric Analyses

Methodology for FE Analysis

- Model development
    - Component model
    - Single-tie model
    - Multiple-tie model
- Model calibration
    - Displacement measurement
    - Strain measurement
- Model validation
    - Vertical load distribution
    - Lateral load distribution
- Model application
    - Parametric studies
    - Simplified tool

Model improvement

Model development

Model calibration

Model validation

Model application
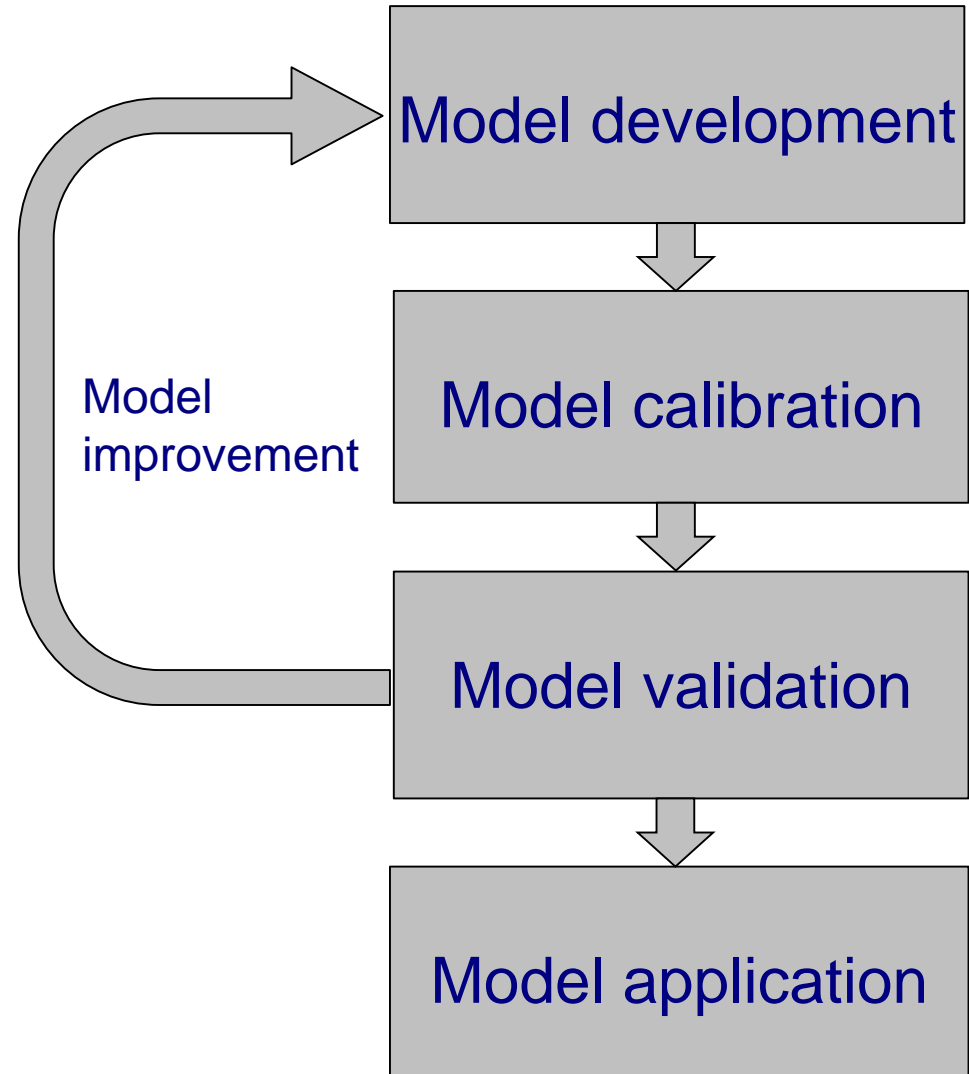
FE models for Field Experiment

- Two symmetric models with identical loads are used to simulate the behavior of track in the field:

  - Global model includes five crossties and fastening systems along with substructure support
  - Detailed model includes a single crosstie and fastening system with substructure support
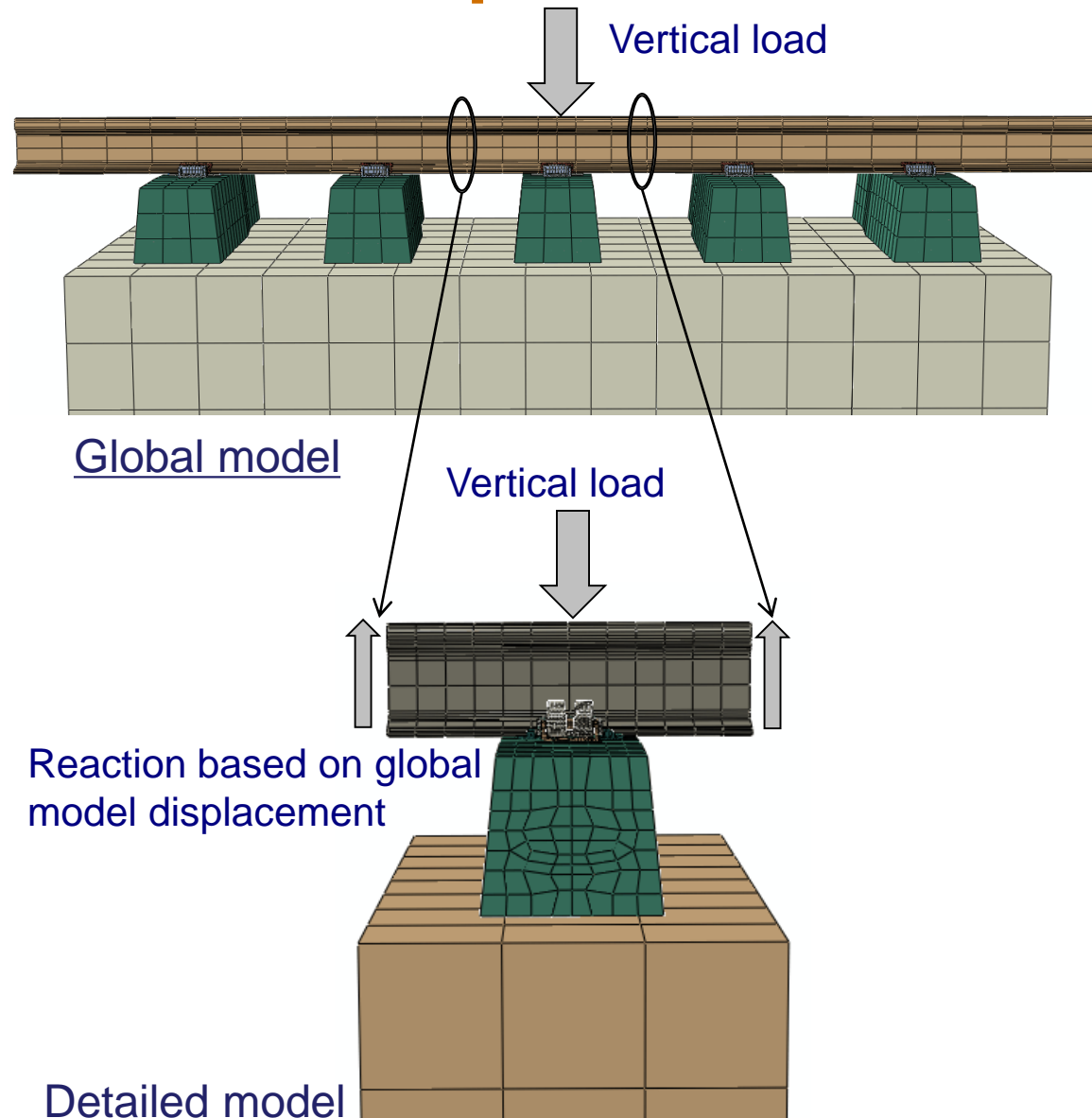
<u>Global model</u>
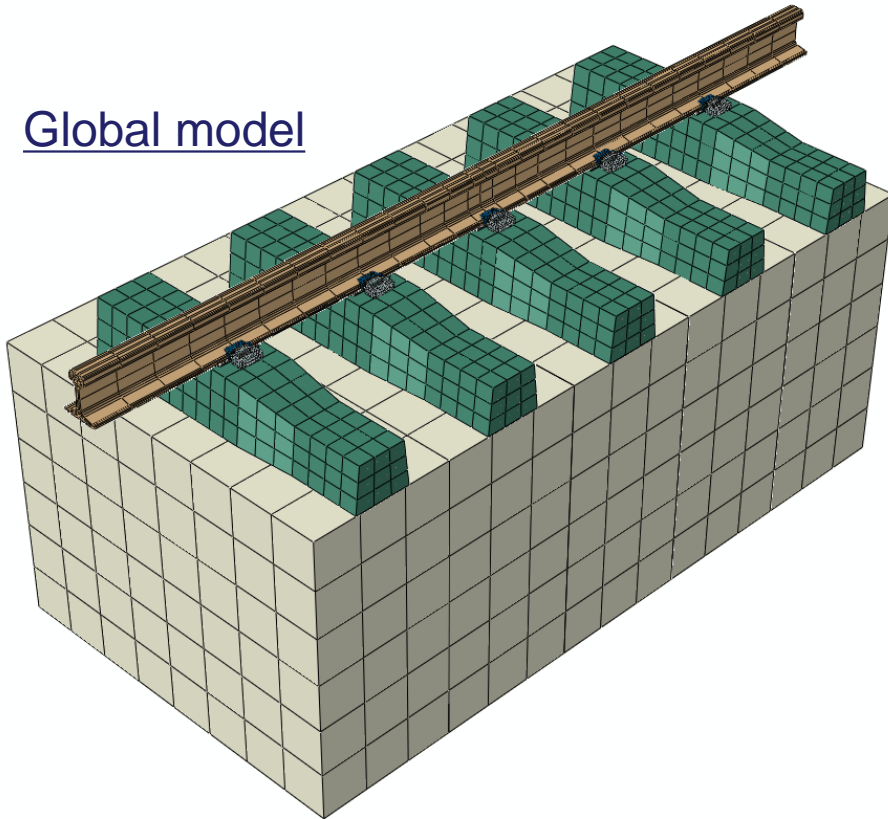
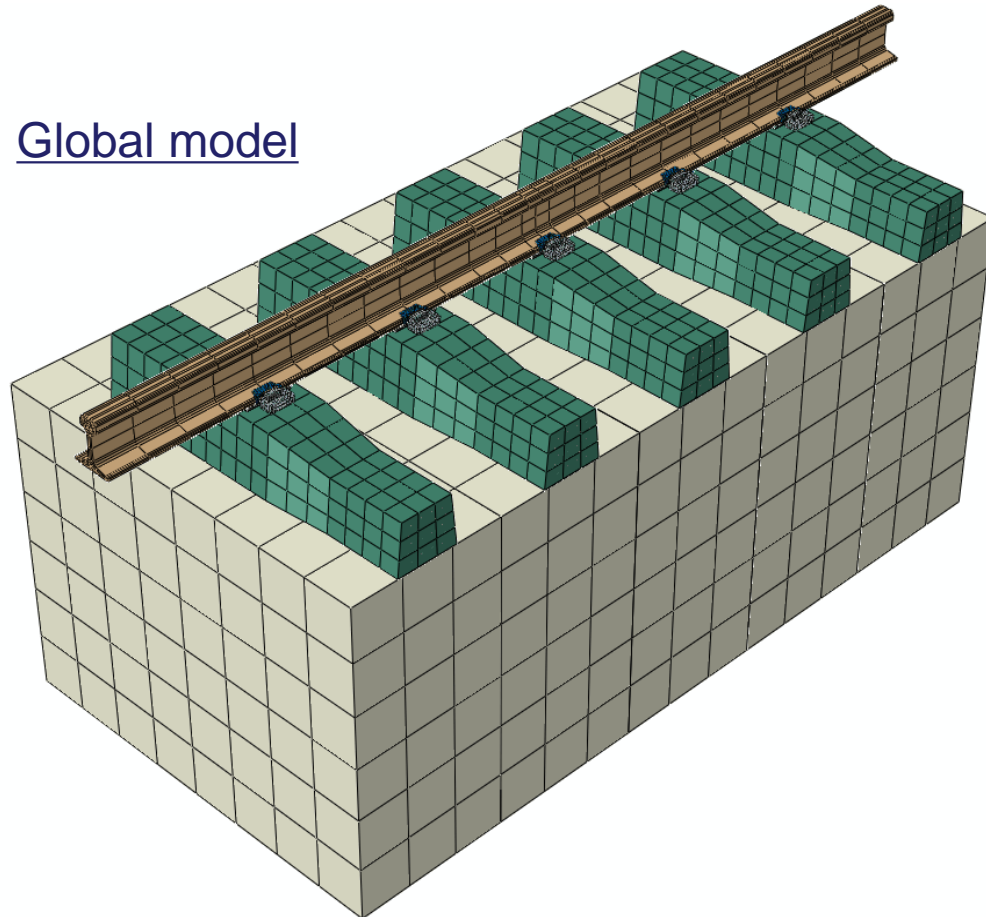<u>Detailed model</u>
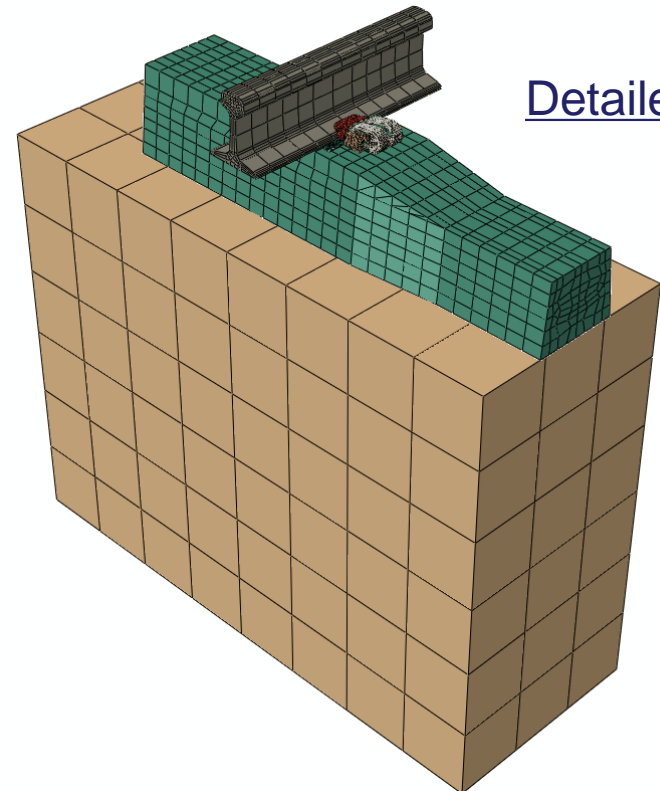
FE models for Field Experiment

- Global model simulates the system-level track behavior

- The displacement at the end of rail segment in the detailed model is the same as that in the global model

  (submodel technique)

- The combination of the two models capture the global behavior of the track system, and provide accurate prediction close to the loading point within a reasonable calculation time

Vertical load

Global model

Vertical load

Reaction based on global model displacement

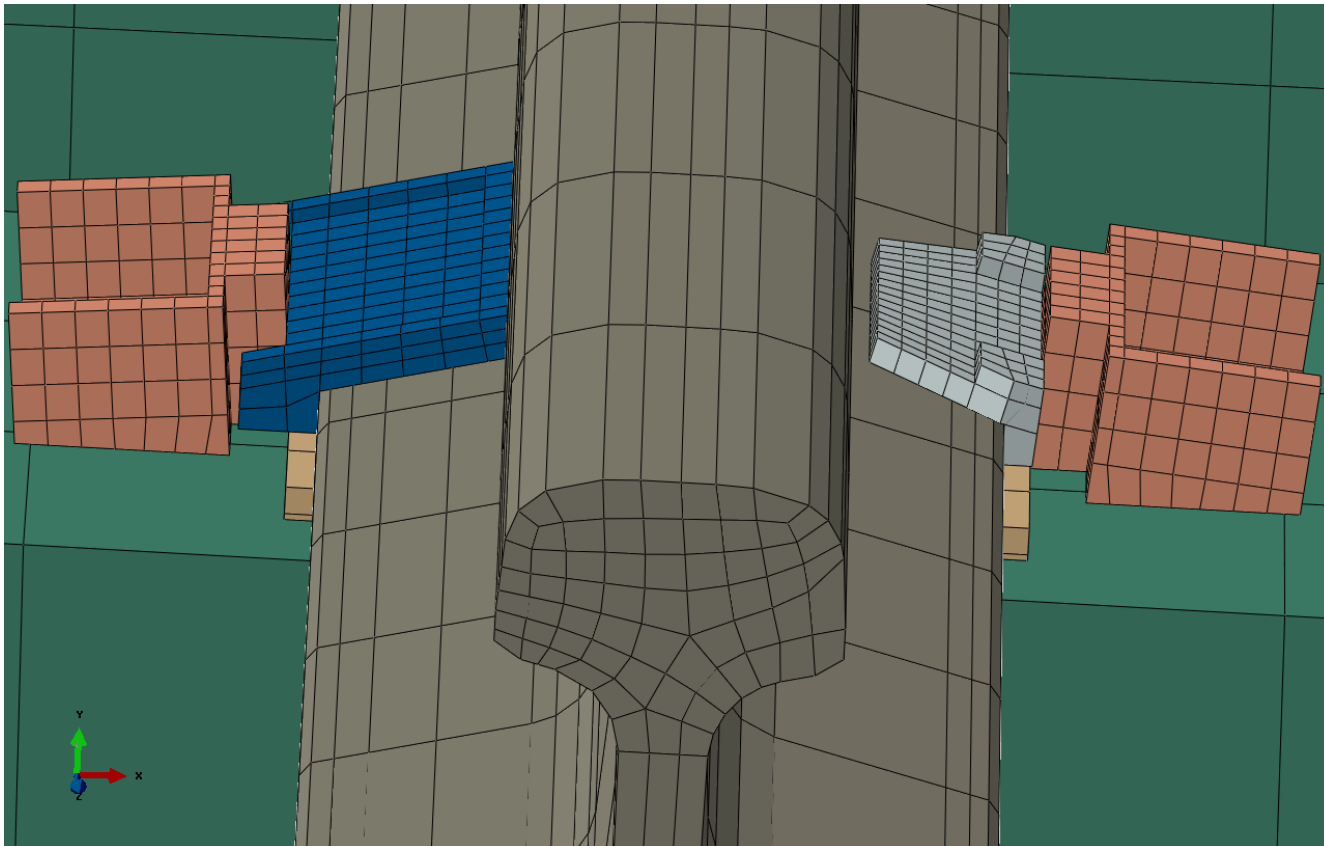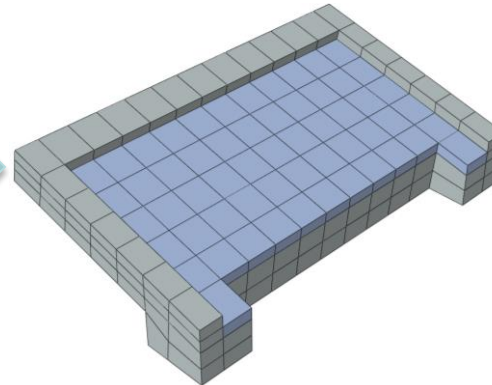Detailed model

FE Models for Field Experiment: Global Model

- Global model includes five crossties and fastening systems
- Clamping forces are represented with pressure
- Coarse mesh is defined and component geometry is simplified

Global model
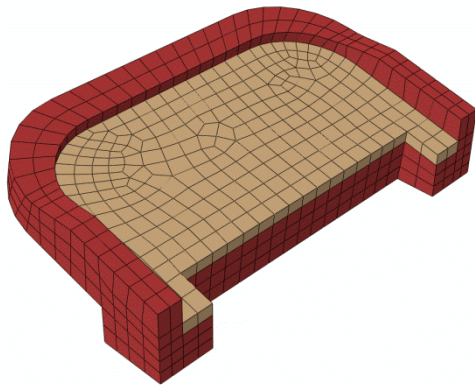
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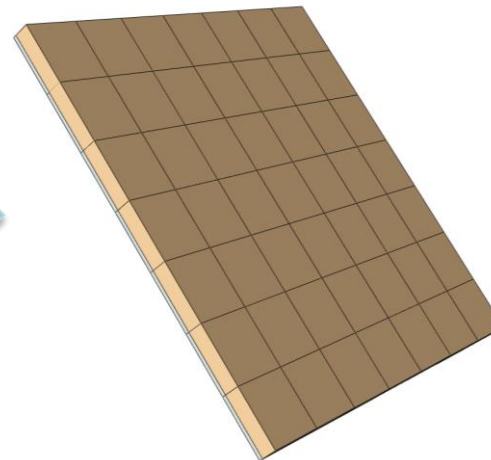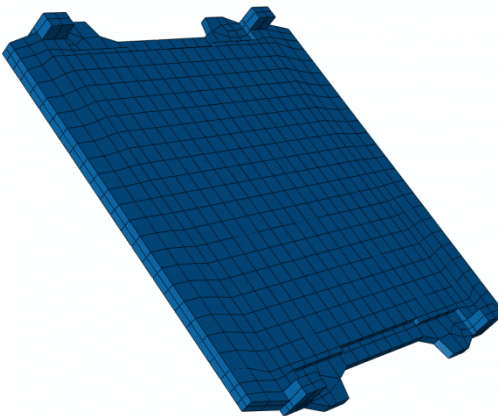- Coarse mesh is defined and component geometry is simplified

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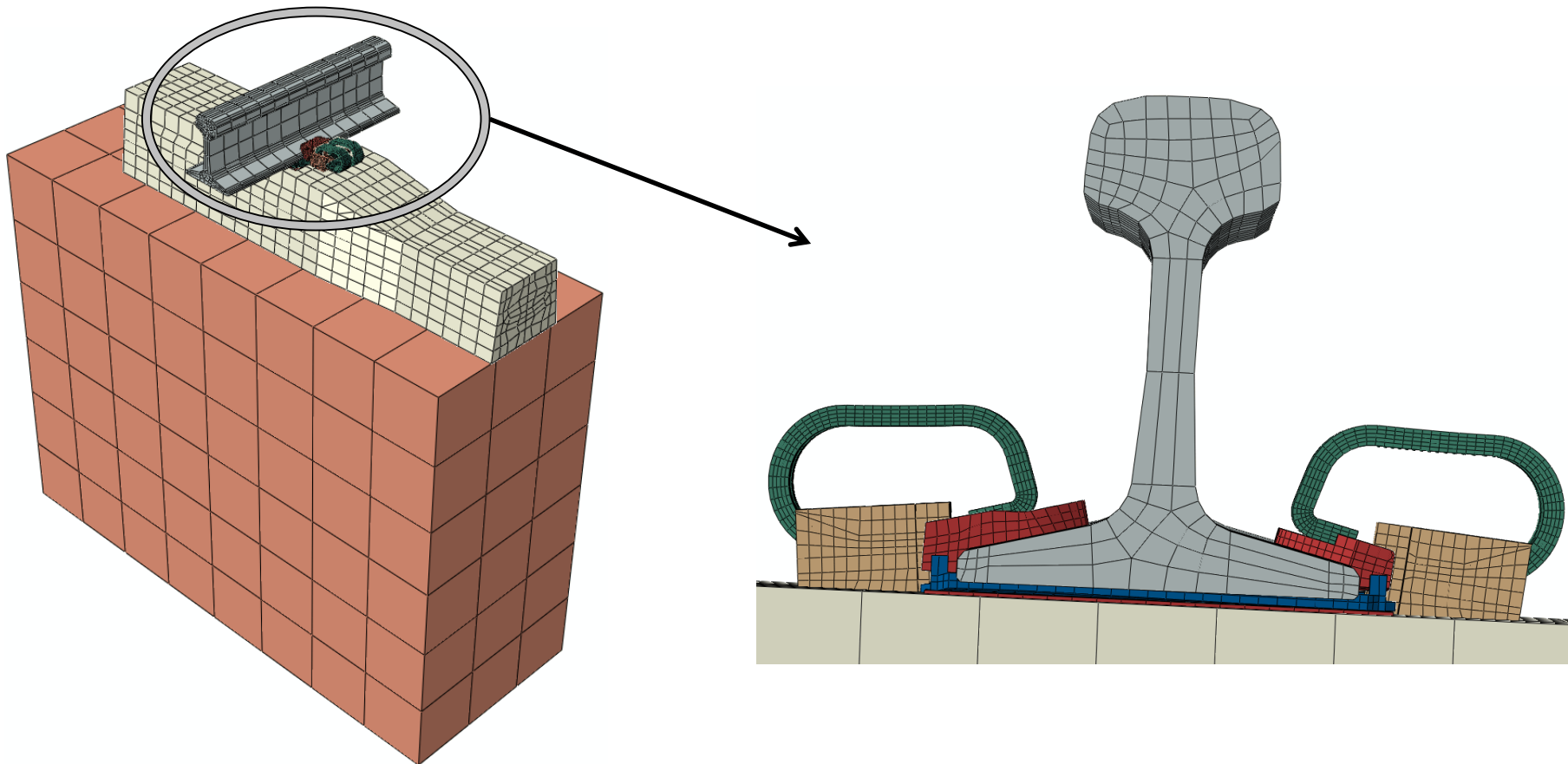- Coarse mesh is defined and component geometry are simplified

Detailed model

Global model

FE Models for Field Experiment: Detailed Model

- Detailed model simulates the center crosstie and fastening system in the global model

- Displacement at the end of rail segment is the same as global model

- Fine mesh is defined, and clamping force is simulated by inserting the clips

Model Calibration Based on Field Experiment Results

- Vertical behavior of the model is calibrated based on vertical crosstie displacement measurements from field experiment at TTC

- The measurements are from static test using the Track Loading Vehicle (TLV) on the Railroad Test Track (RTT)
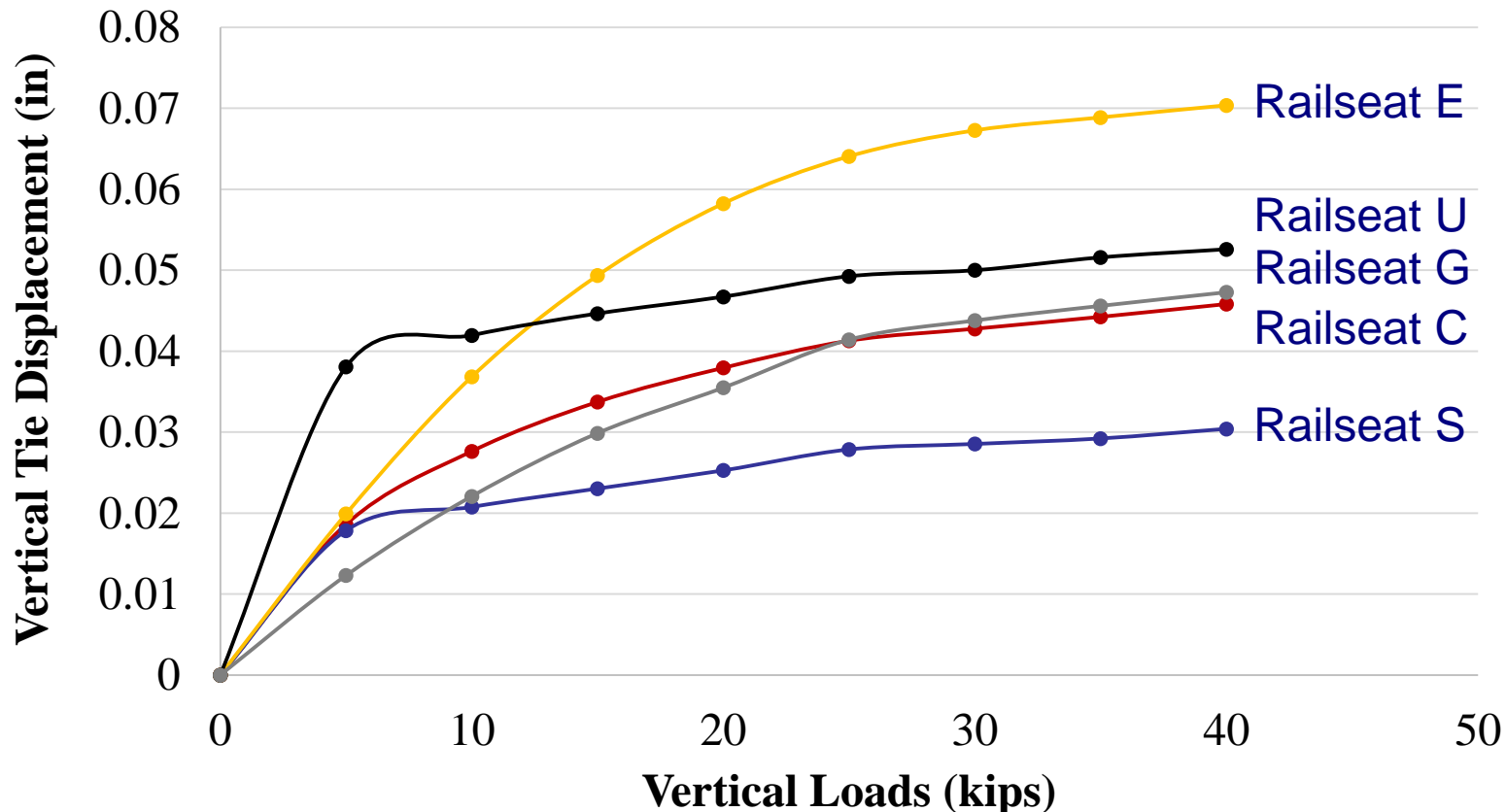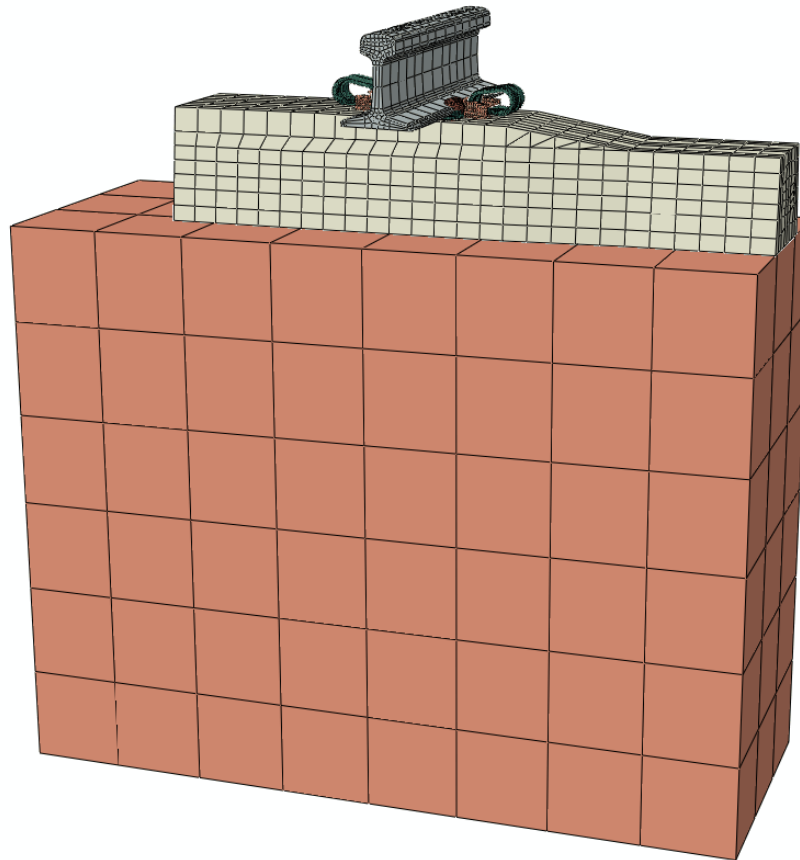
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Model Calibration Based on Vertical Displacement Measurement

- A block is modeled as a general support for the track system to represent the ballast, subballast, and subgrade

- Hyperelastic material model is defined for the block, and it is calibrated to match the displacement measurement
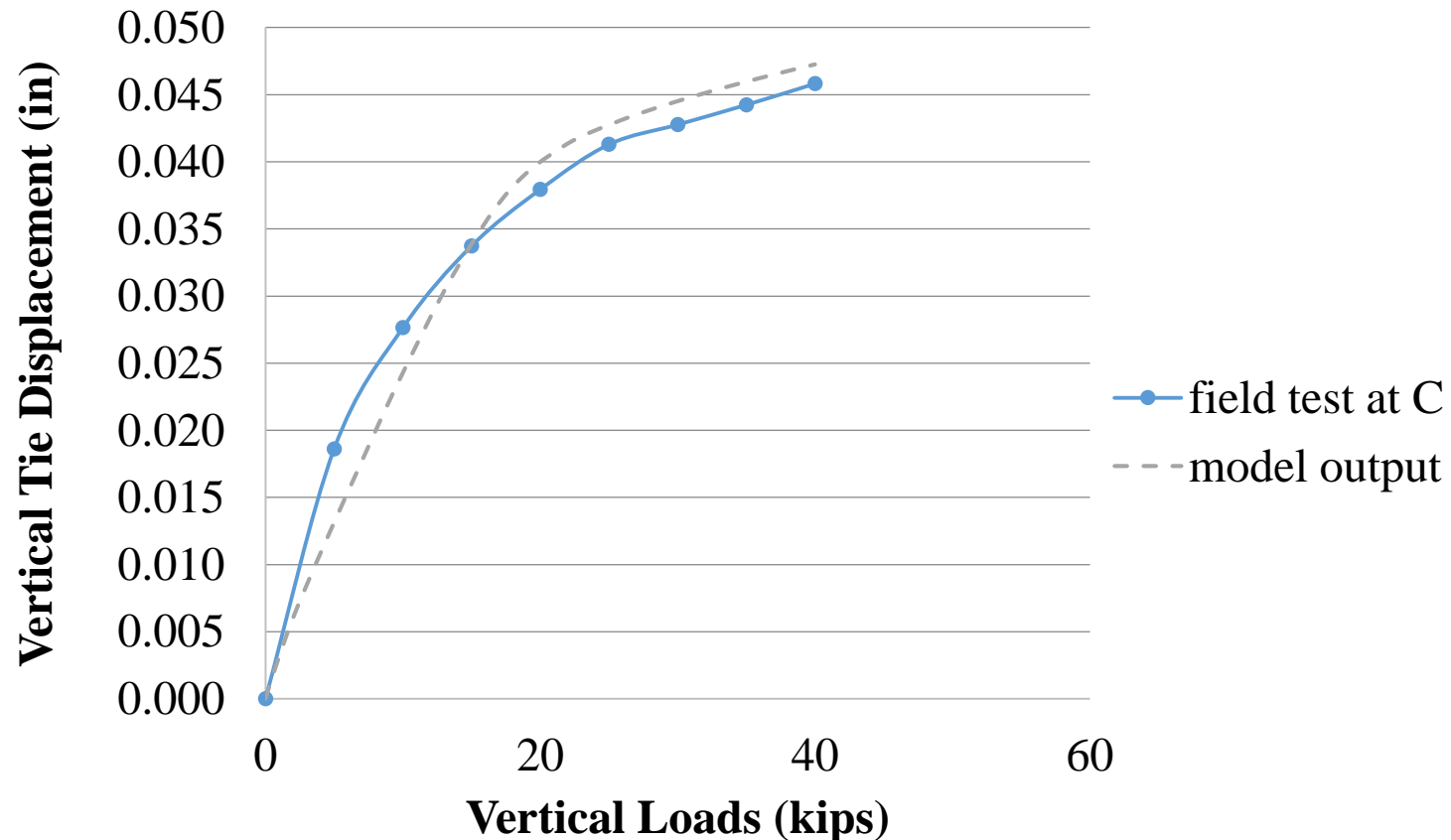
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Model Calibration Based on Lateral Displacement Measurement

- Lateral behavior of the model is calibrated based on lateral rail displacement measurements from field experiment at TTC

- The measurements are from static tests using the Track Loading Vehicle (TLV) on the Railroad Test Track (RTT)

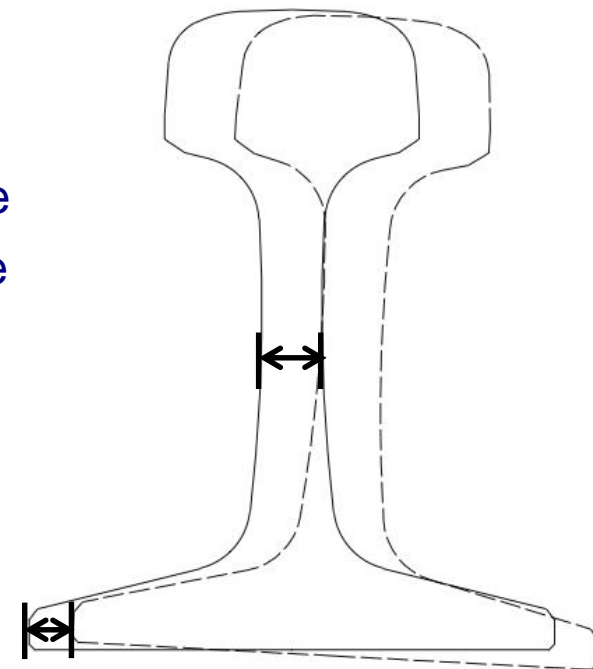# Model Calibration Based on Lateral Displacement Measurement

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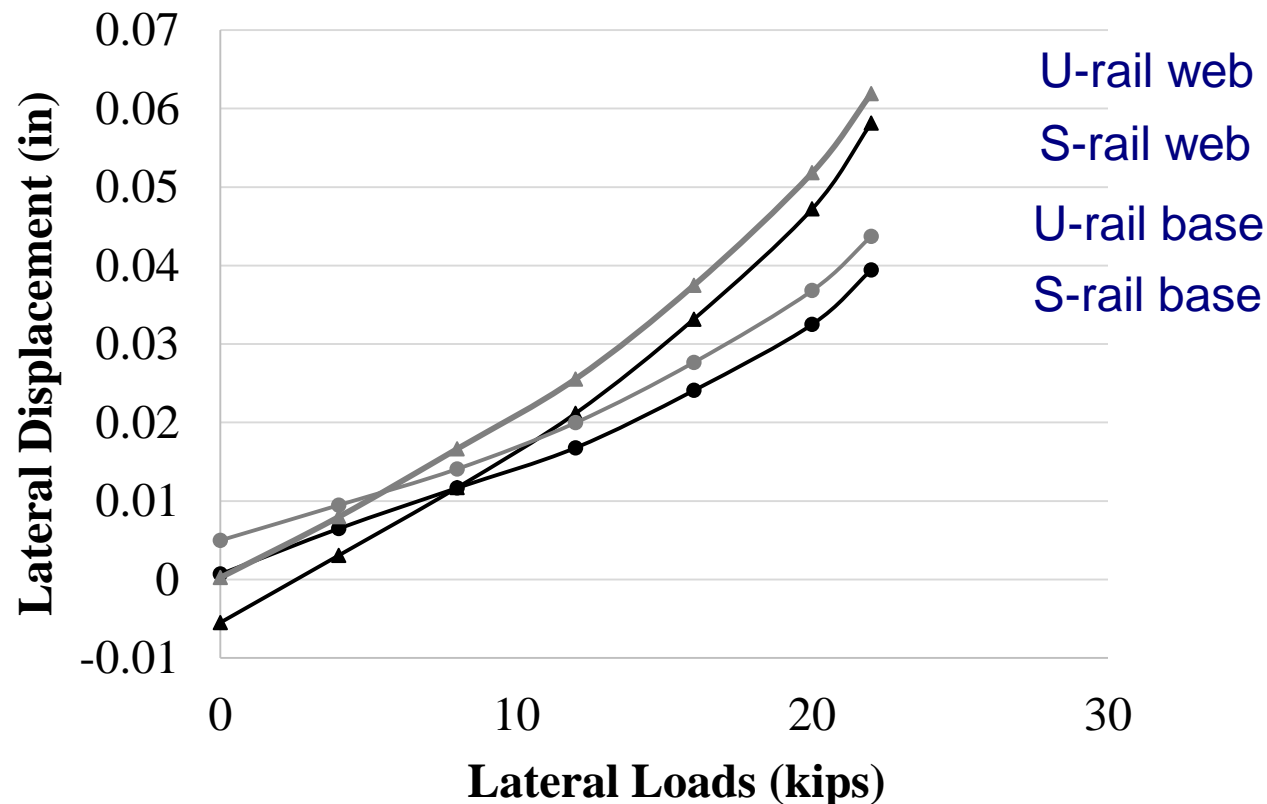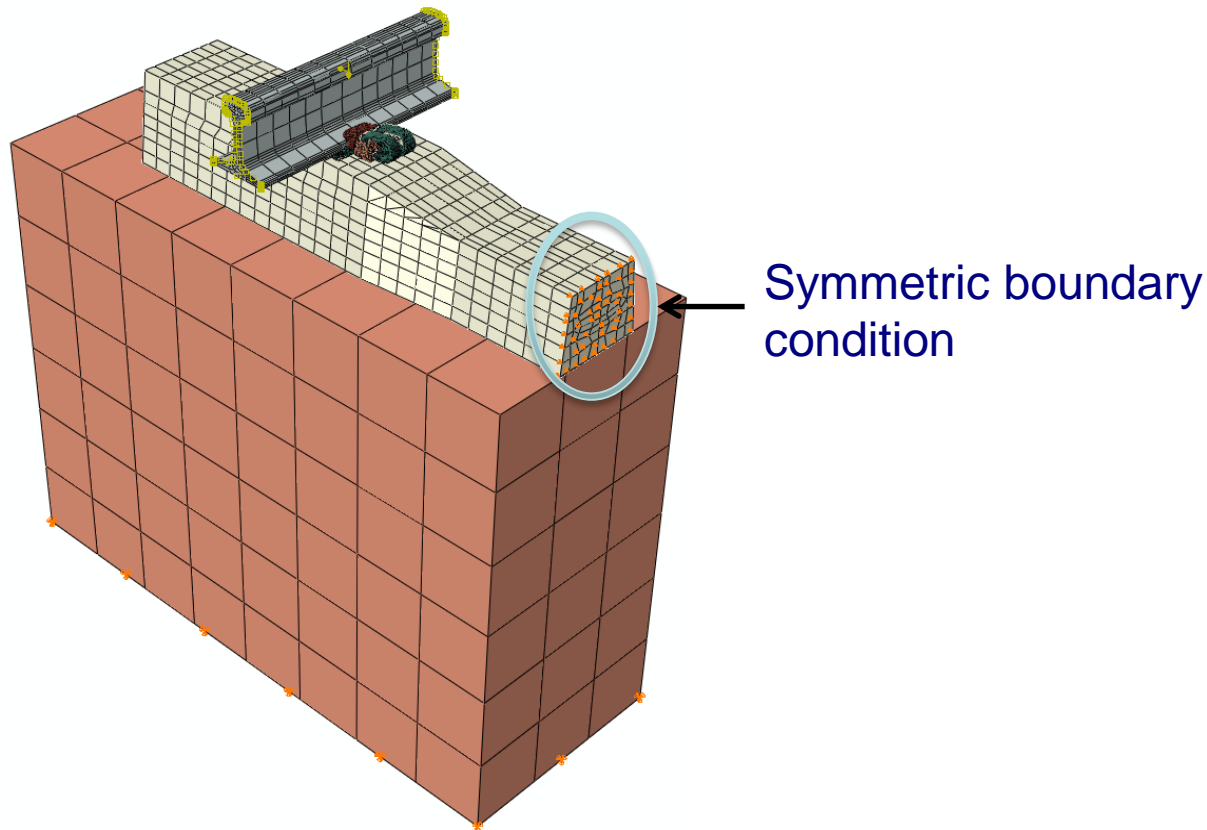# Model Calibration Based on Lateral Displacement Measurement

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TLV at V=40 and varying lateral loads

# Model Calibration Based on Lateral Displacement Measurement

- As during the static test of TLV on tangent track, identical vertical and lateral loads were applied on each rail, the crossties were in tension

- Symmetric boundary condition is defined at the section of crosstie

- The lateral behavior of the model is calibrated by the property of interaction between concrete and shoulder

Symmetric boundary condition

# Model Calibration Based on Lateral Displacement Measurement

- As during the static test of TLV on tangent track, identical vertical/lateral load was applied on each rail, the crossties were in tension

- Symmetric boundary condition is defined at the section of crosstie

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**TLV at V=40 and varying lateral loads**
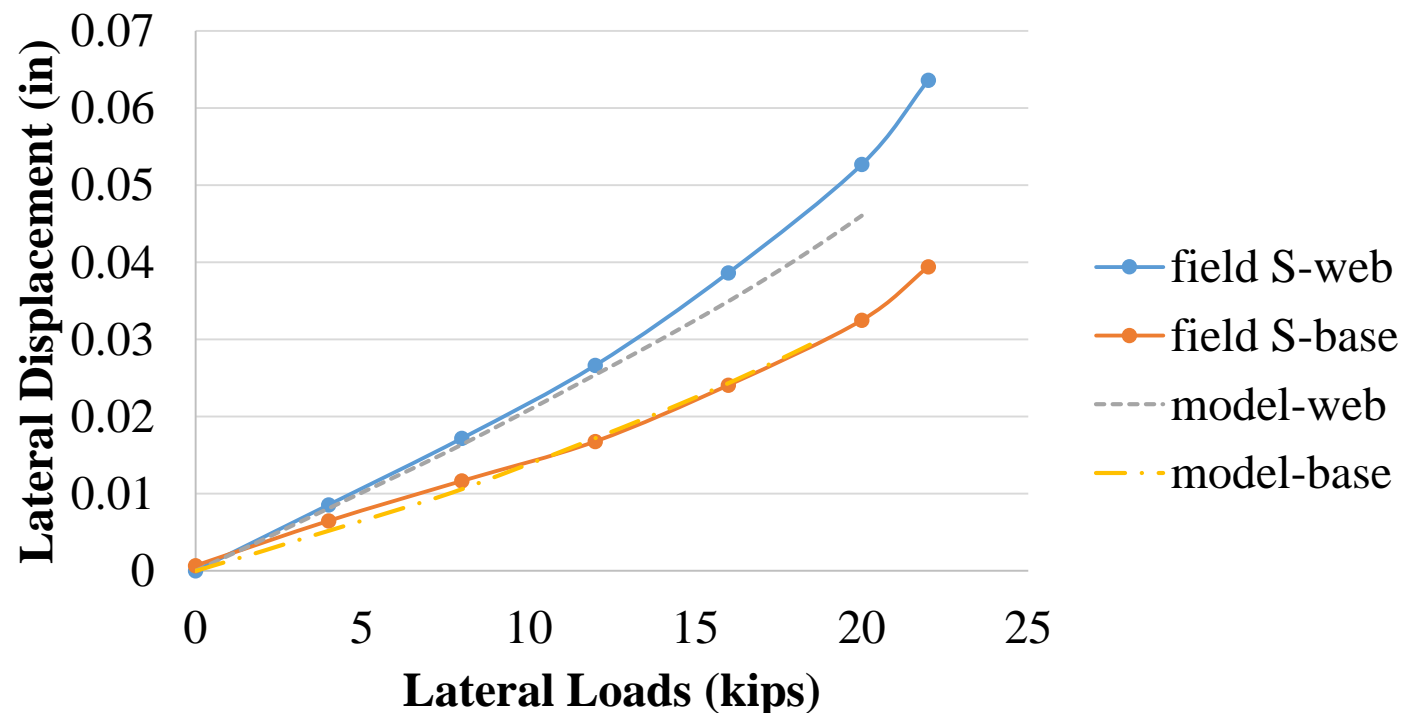
Vertical Load Distribution-Field Data

- The vertical/lateral load distribution based on model output is also compared with test measurements, and similar distribution is observed

- The model vertical load distribution is compared with the shear force measurement based on chevron gauge pairs

- Due to tie-to-tie variability in support condition, some difference is observed
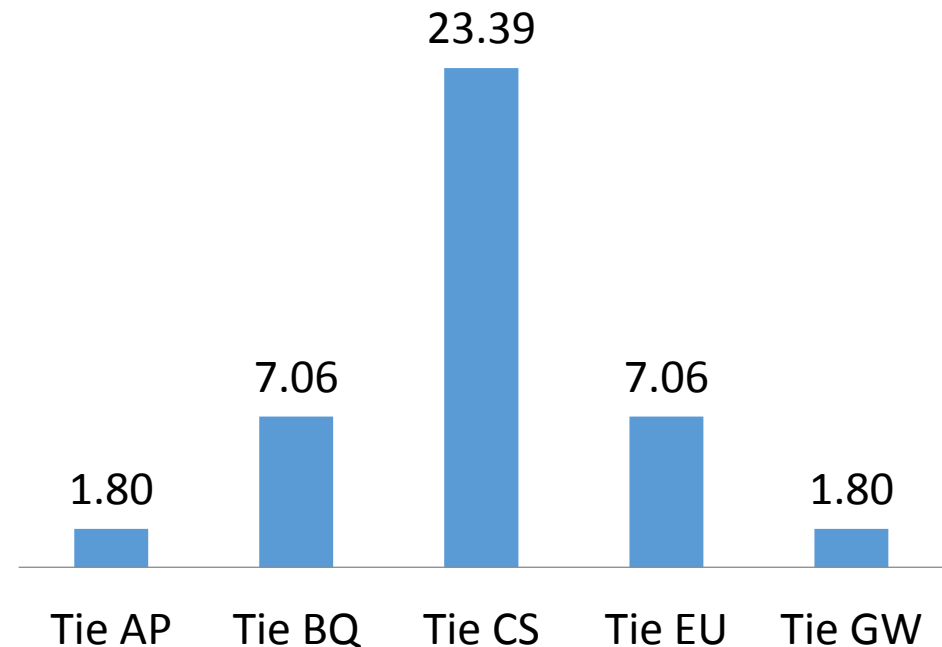

40 kips vertical load
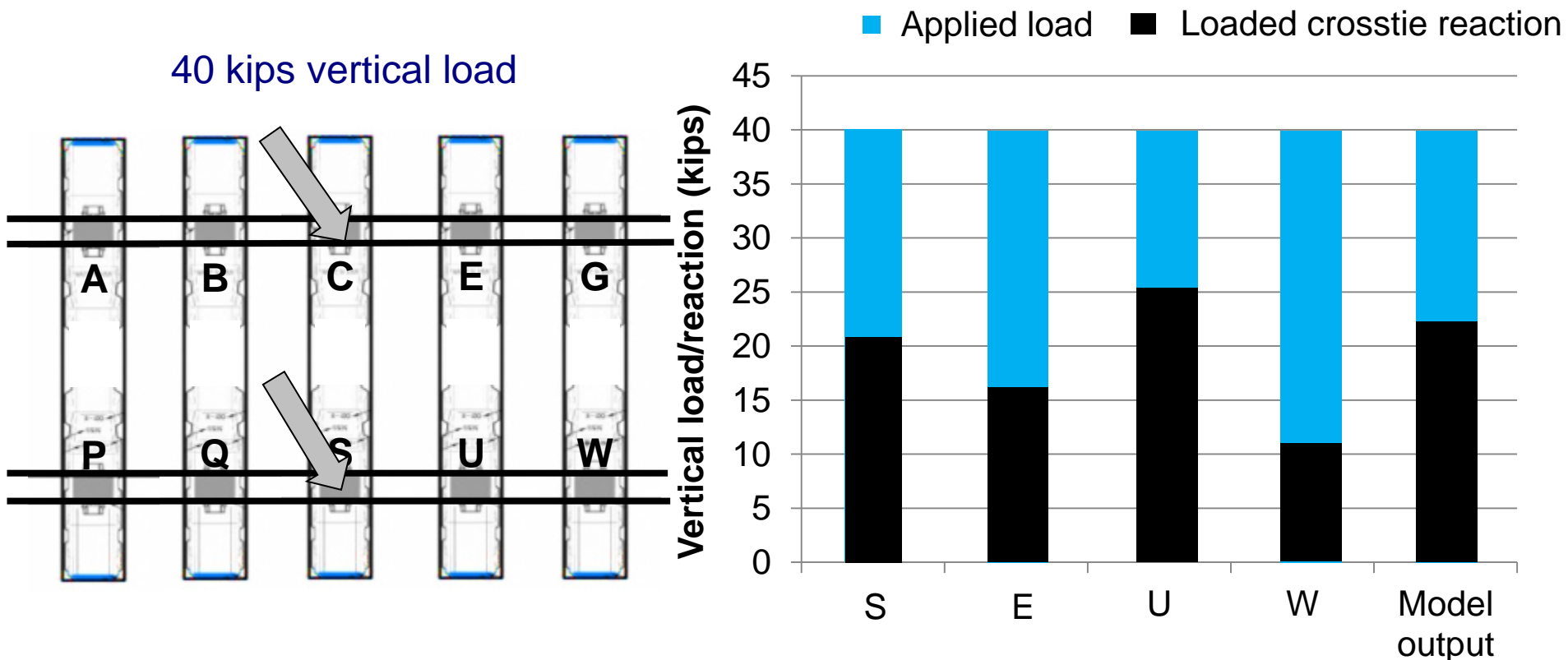
Vertical Load Distribution-Calibrated Model

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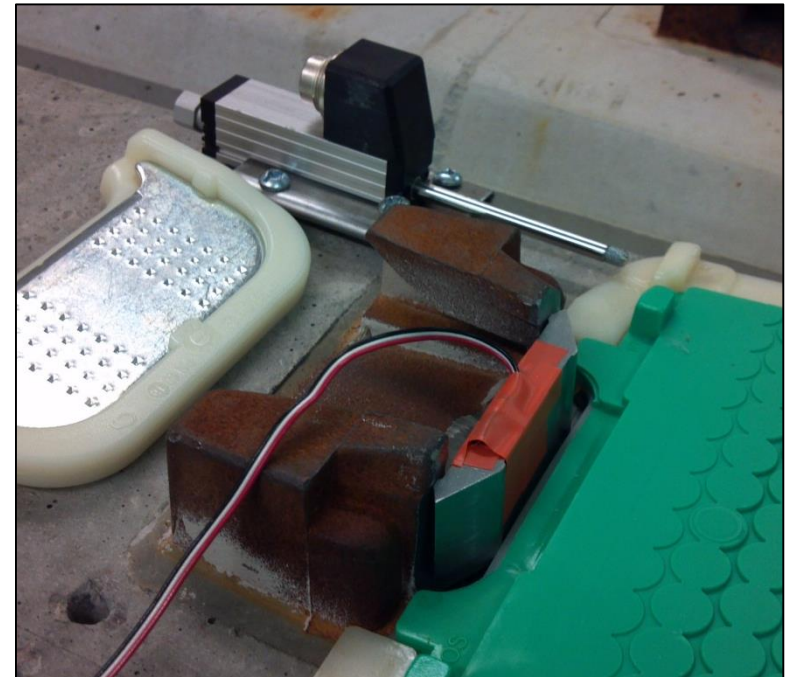- Due to tie-to-tie variability in support condition, some difference is observed
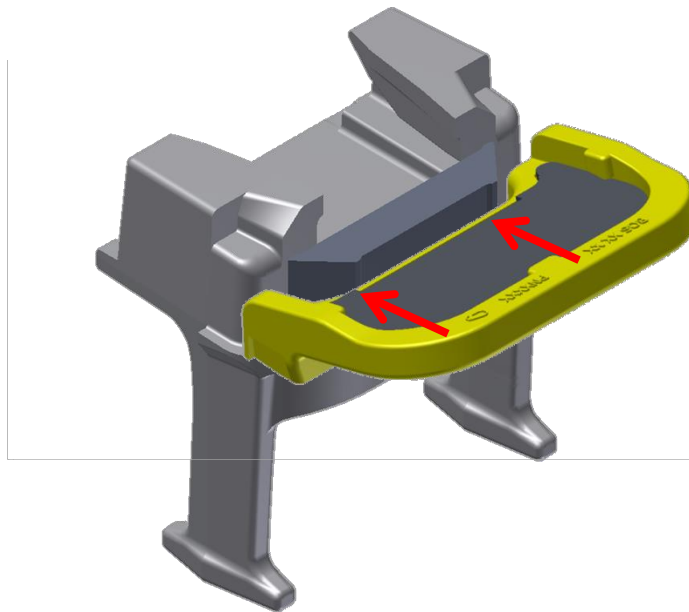
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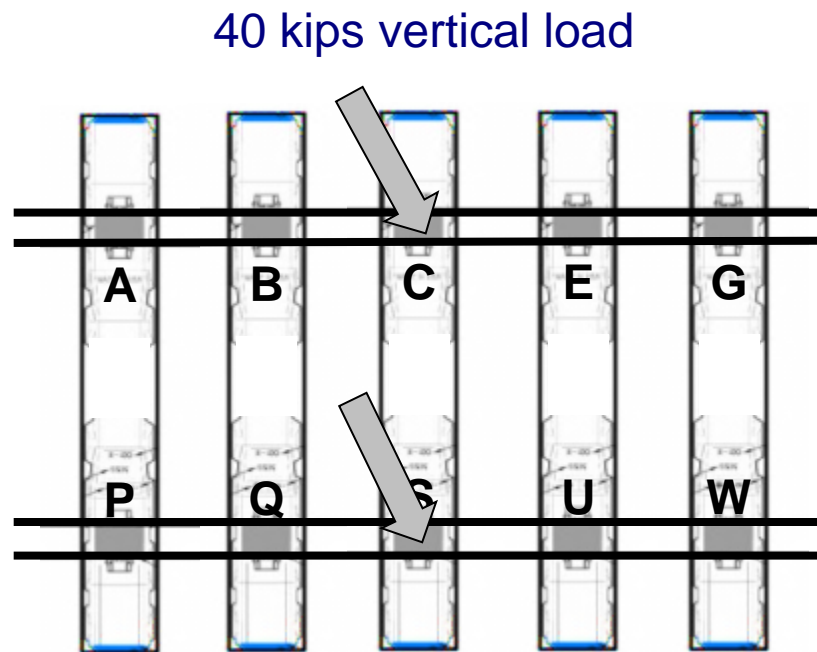
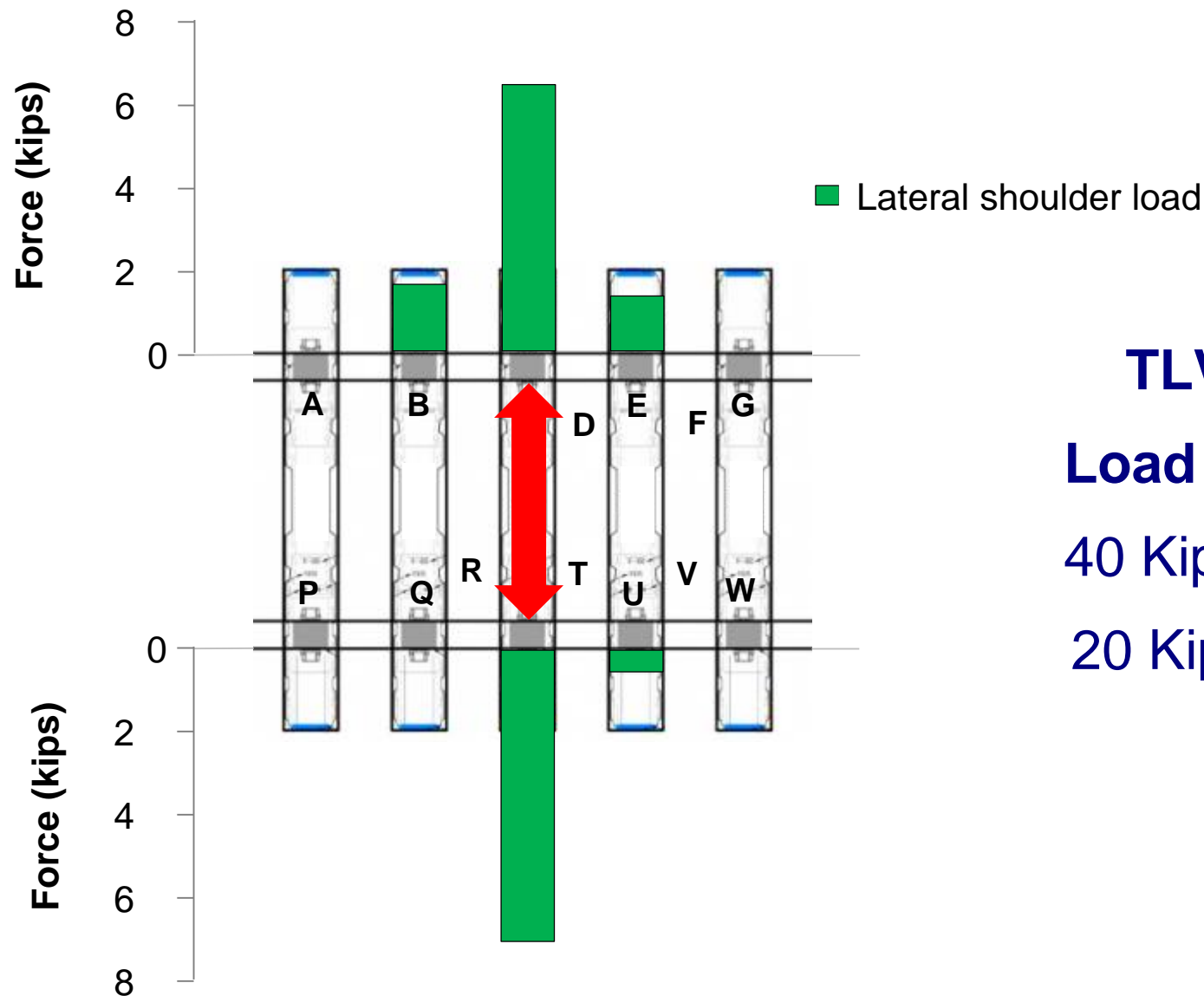**Rail seat vertical load model output (kips)**

Lateral Load Distribution-Field Data

- the FE model lateral load distribution is compared with measurement of shoulder beam insert

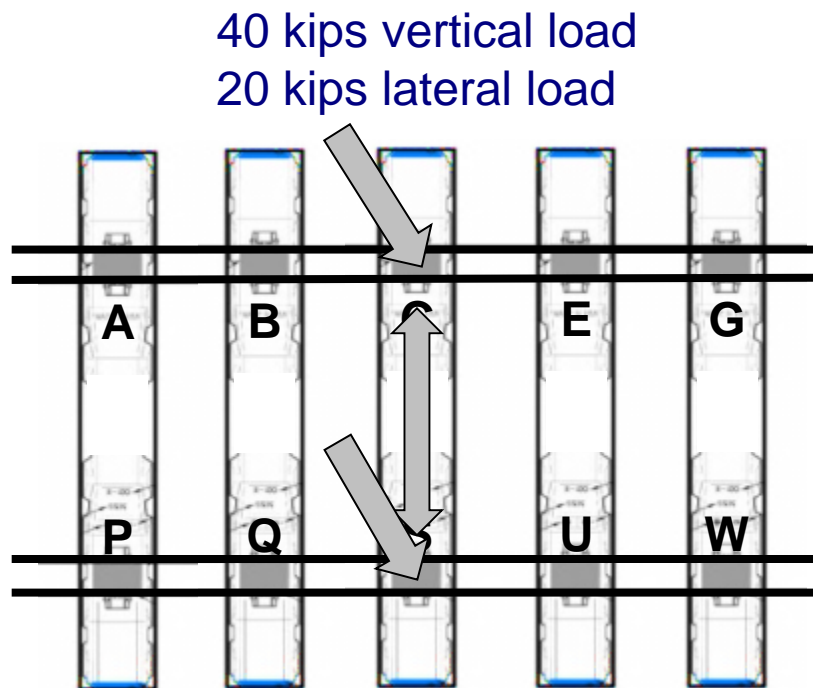# Lateral Load Distribution-Field Data

TLV - RTT

Load at Tie CS

40 Kips Vertical
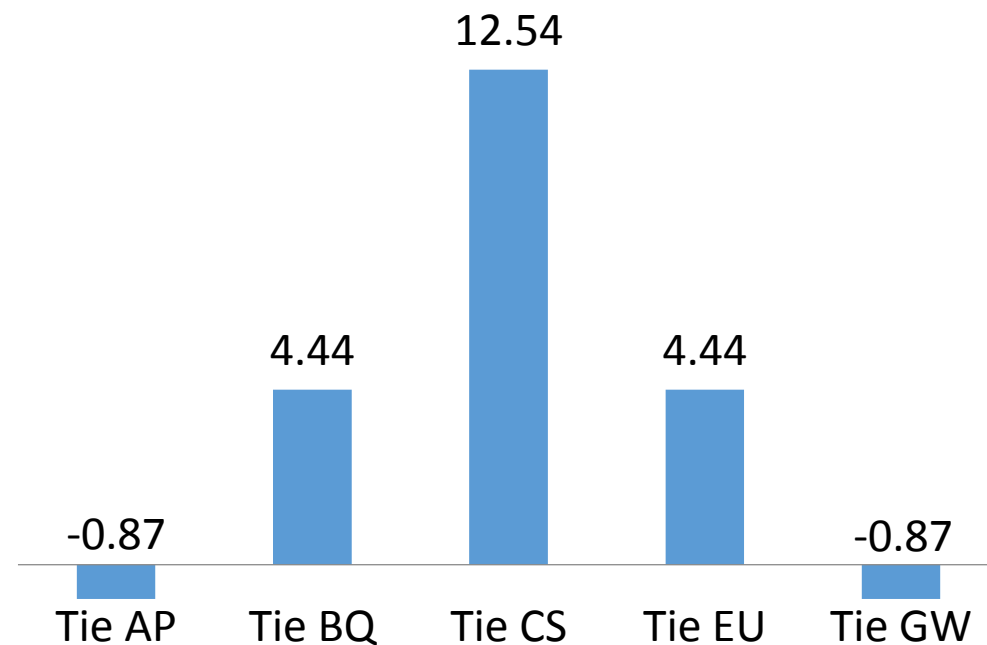
20 Kips Lateral

Lateral Load Distribution-Calibrated Model

- Based on previous analysis, approximately 50% of the lateral load at a railseat is resisted by the shoulder

40 kips vertical load
20 kips lateral load

A   B   C   E   G

P   Q   S   U   W

Railseat lateral load – model output (kips)

12.54

4.44

4.44

-0.87

-0.87

Tie AP   Tie BQ   Tie CS   Tie EU   Tie GW

Application of the Validated Model

- Parametric studies have been conducted:
  - Tensile cracking of concrete
  - Lateral load path of the fastening system
  - Bond-slip behavior between prestressing strand and concrete
- Based on design of experiments, results from preliminary parametric studies are used to build a simplified calculation tool (I-TRACK) on track response


Gap
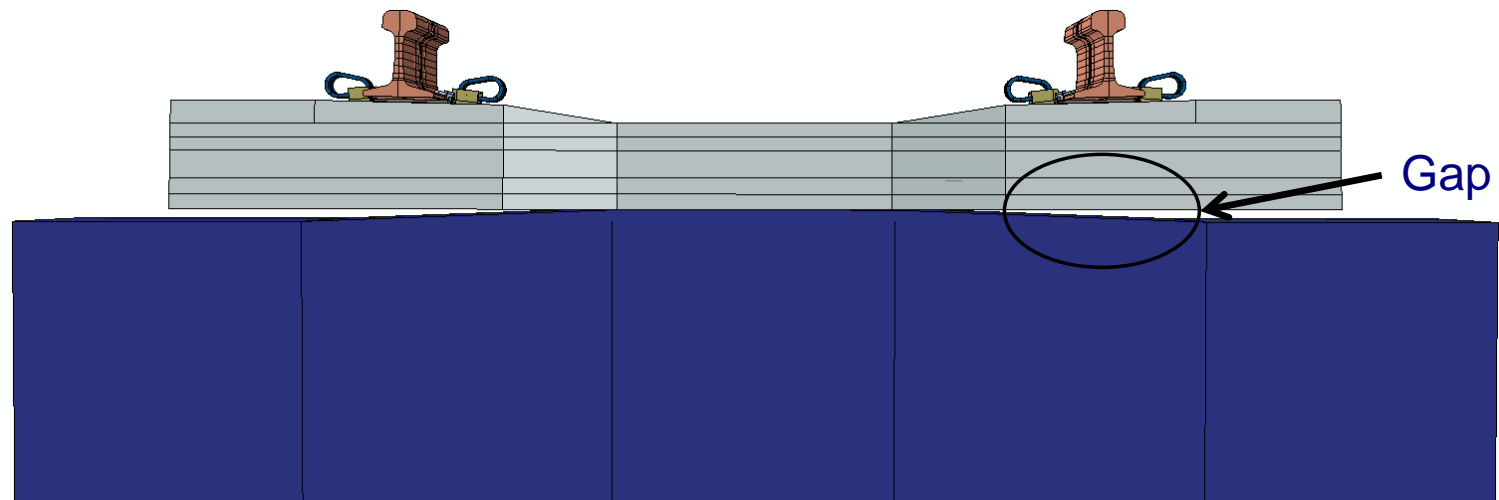
Conclusions

- Using submodel technique, a global model and a detailed model are used to provide comparison to field experiment

- The models are calibrated with rail and crosstie displacements from the field experiment, and good agreement is observed

- Similar vertical and lateral reaction distribution are observed between the model output and the field test result

- The validated models are used to generate outputs for parametric analyses and a simplified calculation tool (I-TRACK) on track response

Future Work

- The submodel technique will be incorporated into the full-scale model to simulate the loading scenario in curved track

- Further parametric studies will be conducted to evaluate:
  - Effect of surface interaction properties (i.e. friction)
  - Vertical track modulus
  - Effect of component geometry on system behavior
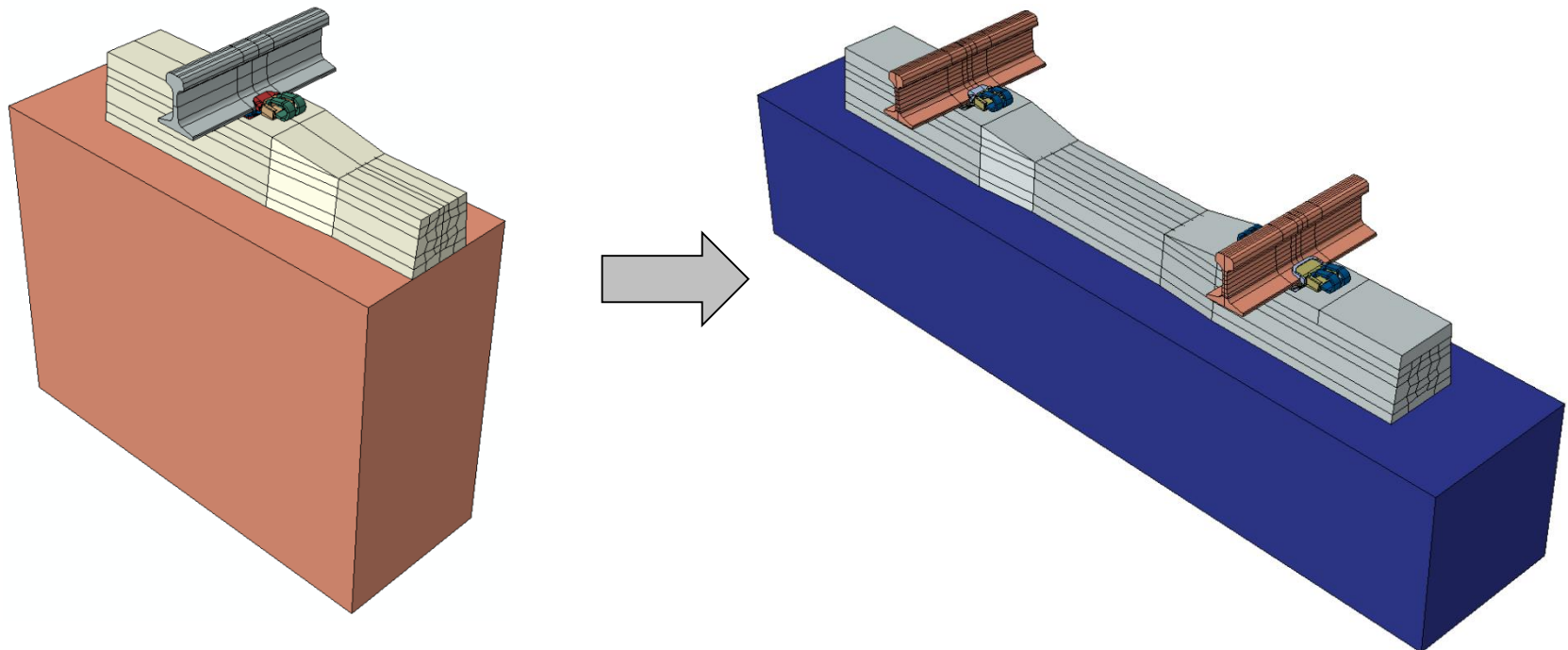
Acknowledgements

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Federal Railroad Administration

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    - National Railway Passenger Corporation (Amtrak)
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    - Hanson Professional Services, Inc.
    - CXT Concrete Ties, Inc., LB Foster Company
    - TTX Company

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Questions?

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