OFFICE OF RESEARCH & DEVELOPMENT

2012 R&D REVIEW

Research on Concrete Ties

U.S. Department of Transportation

Federal Railroad Administration

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Program Area & Risk Matrix

Research on Concrete Ties

Program Areas / Risk Factors	Trespass	Grade Crossing	Derailment	Train Collision	All Other Safety Hazards
Railroad Systems Issues					
Human Factors					
Track & Structures			X		
Track & Train Interaction					
Facilities & Equipment					
Rolling Stock & Components					
Hazardous Materials					
Train Occupant Protection					
Train Control & Communications					
Grade Crossings & Trespass					

Motivation for Research

- Rail seat deterioration was determined as the probable cause of two Amtrak derailments on curved track:
  - Home Valley, WA on April 3, 2005
  - Sprague, WA on January 28, 2006

- Widespread damage observed on concrete ties on Northeast Corridor (NED) and elsewhere

- Service life of concrete ties appears to be less than original design life (50 years)

- FRA has awarded several contracts via the High-speed Rail BAA to conduct research on concrete tie performance

Research Constituents

FRA Track Systems Research Program
• Volpe National Transportation Systems Center • Transportation Technology Center, Inc.

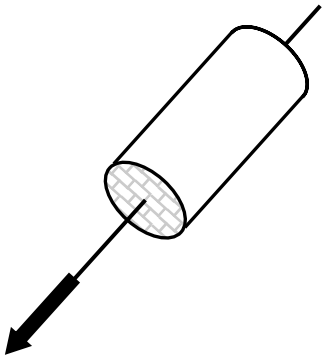
FRA High-Speed Rail Broad Agency Announcement (BAA) Program
• University of Illinois – Urbana-Champaign • Kansas State University • Silica Fume Association • NDT Corporation

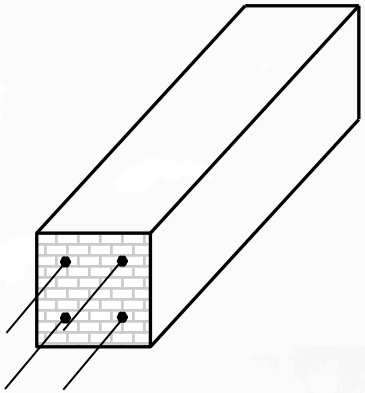
Other Stakeholders
• Amtrak and North American Railroads • Concrete Tie Manufacturers

FRA High-Speed Rail Broad Agency Announcement (BAA) Projects on Concrete Ties

- **Improved Concrete Crossties and Fastening Systems for US High Speed Rail and Joint Passenger/Freight Corridors -** University of Illinois at Urbana-Champaign (UIUC)
- **Quantifying Effect of Prestressing Steel and Concrete Variables in the Transfer Length in Pretensioned Concrete Crossties -** Kansas State University (KSU)
- **Development of Optimal High Performance Concrete Mixture to Address Concrete Tie Rail Seat Deterioration -** Silica Fume Association (SFA)
- **Characterizing Damaged Concrete Ties with Nondestructive Pulse Velocity Measurements-** NDT Corporation
- **Freeze-Thaw Performance of Concrete Railroad Ties -** Kansas State University (KSU)

Example of Coordination with BAA Projects





Untensioned and Tensioned Pullout Tests

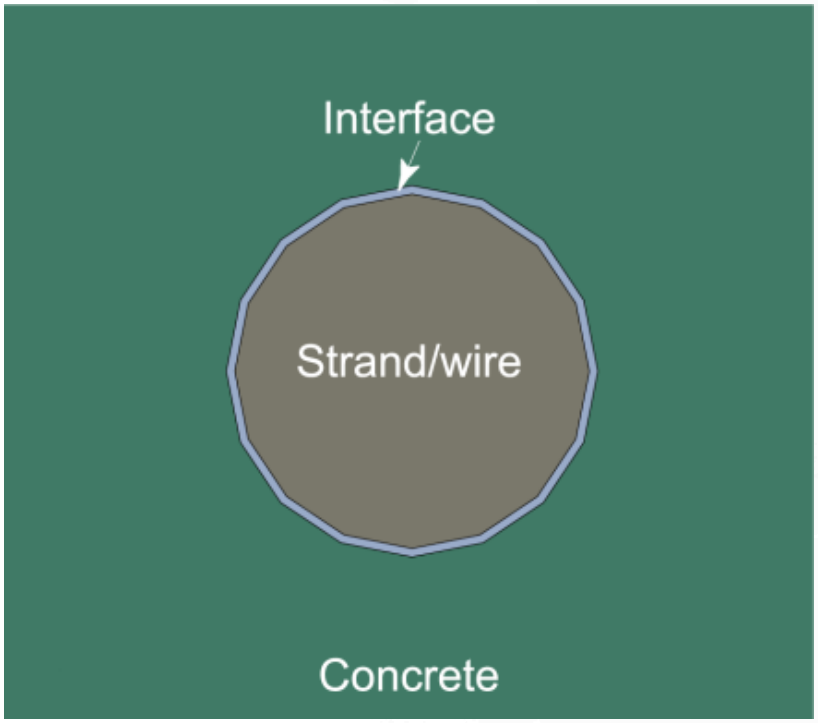
Pretensioned Concrete Prism Tests

Concrete Railroad Tie Under Load

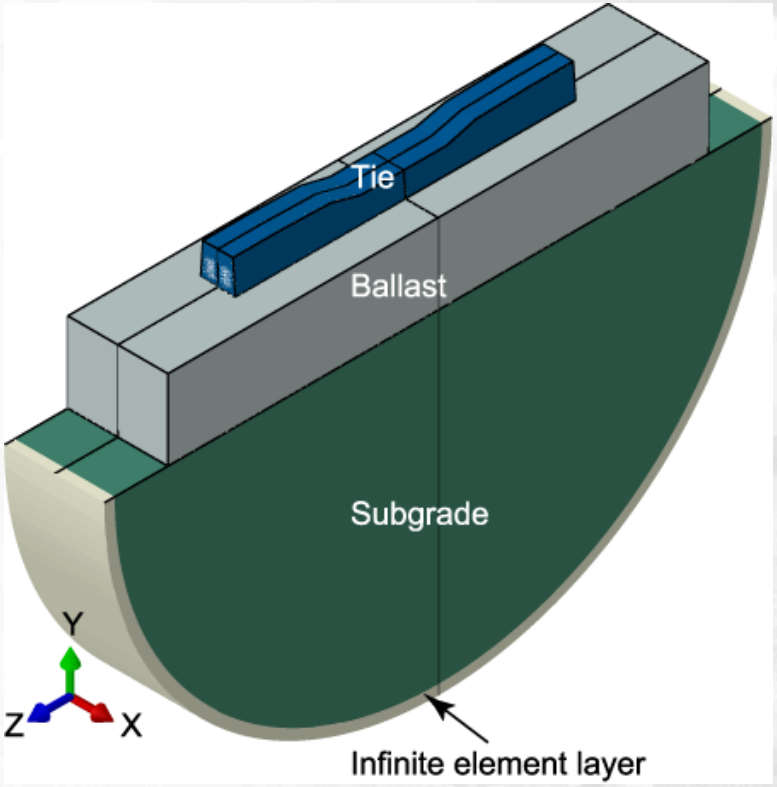
Kansas State University

Volpe Center

Finite Element Modeling



Heterogeneity



Concrete Tie Supported by Ballast and Subgrade

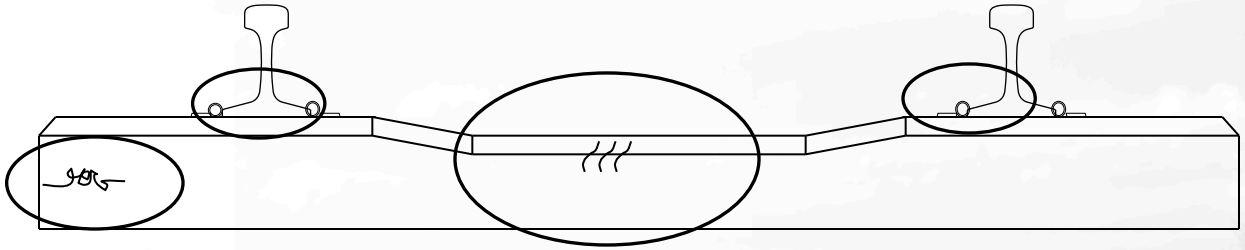
Motivation for Analysis and Modeling

- Identify potential conditions for failure
- Provide guidance for testing
- Interpret test data
- Extrapolate test results for difficult-to-test conditions
- Evaluate “what-if” scenarios

Common Concrete Tie Failure Modes

Rail Seat Deterioration

Fastener Failure



Cracking Due To Excessive Tensile Force in Anchorage Zone

Flexural Cracking (Center-Binding)

Others:

- Environmental degradation (freeze-thaw)
- Alkali-Silica Reactivity
- Electrical Isolation Failure

Photographs of Failures in Wood and Concrete Ties

Plate Cutting in Wood Ties

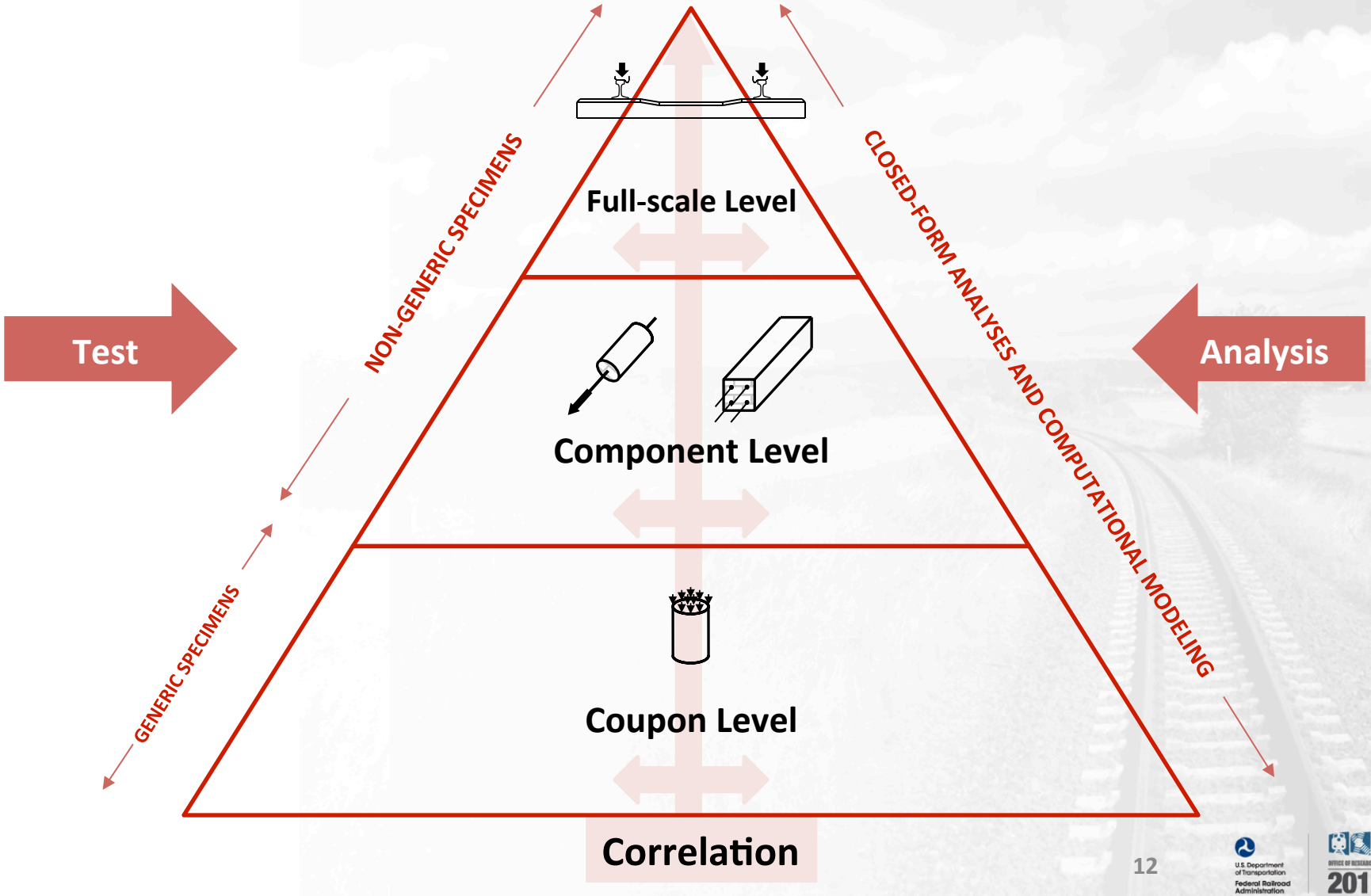
Rail Seat Deterioration in Concrete Ties

Examples of Rail Seat Damage

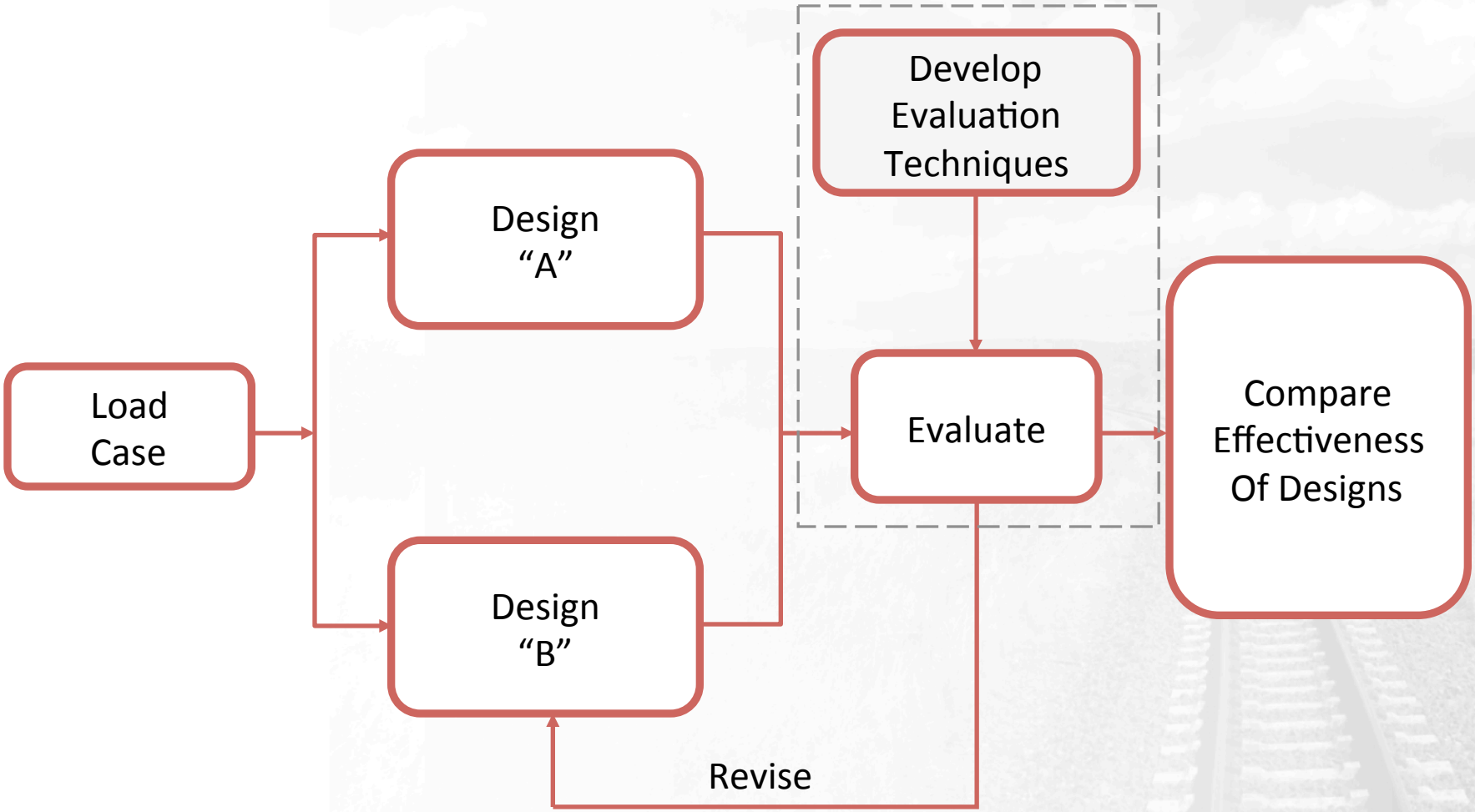
Triangular-shaped Damage

Abrasion due to Water Intrusion

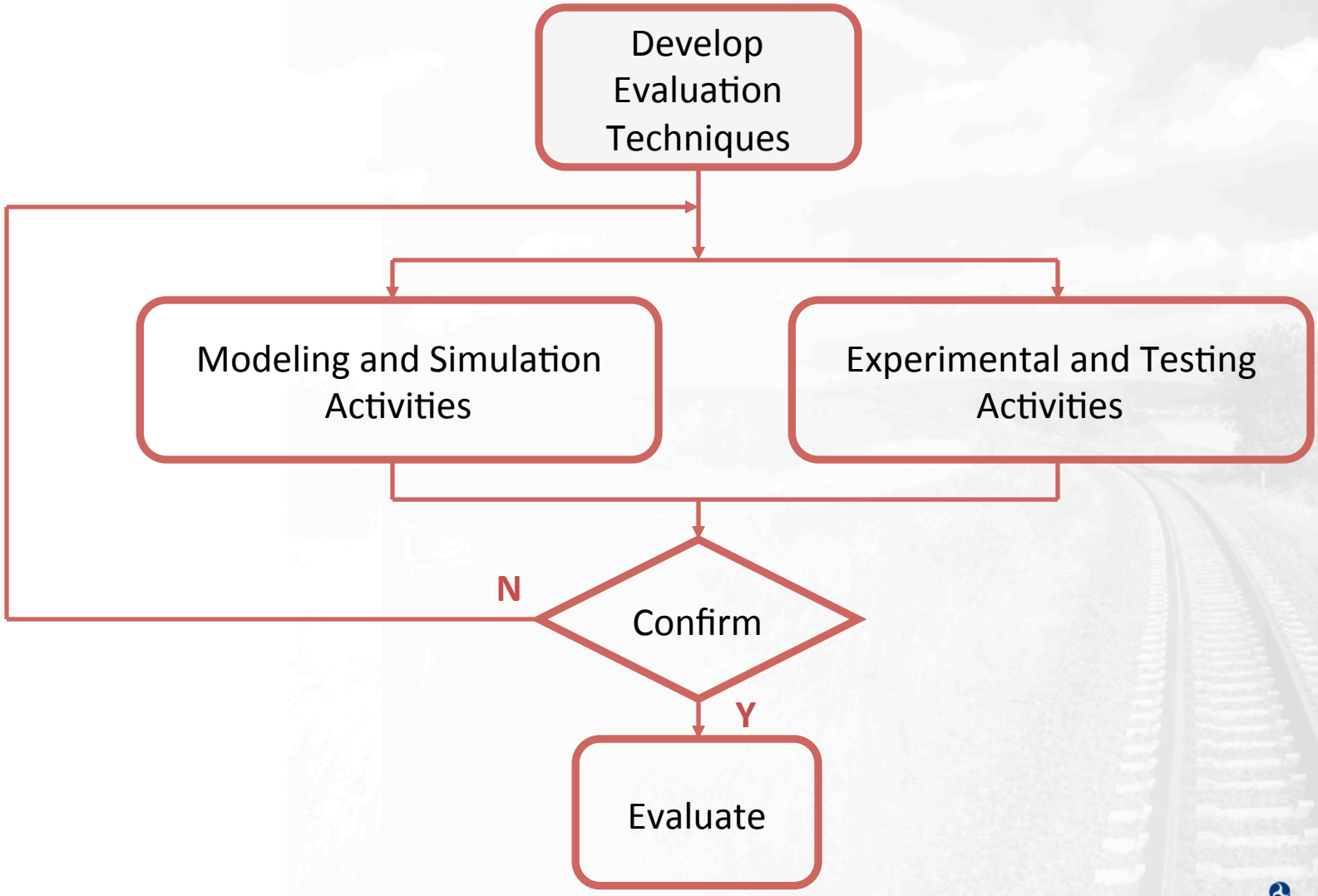
Building Block Approach



Framework for Failure Analysis



Development of Evaluation Techniques



Establishing Credibility and Confidence

Verification

- Credibility from understanding the mathematics
- Compare computed results to known solutions

Validation

- Credibility from understanding the physics
- Compare computed results to experimental data

Uncertainty Analysis

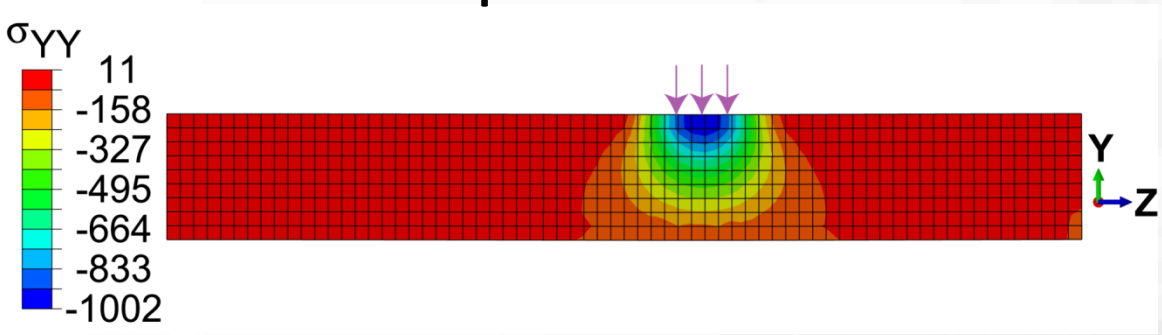
- Credibility from understanding the statistical evidence
- Quantify uncertainty and variability from all sources

Example Applications

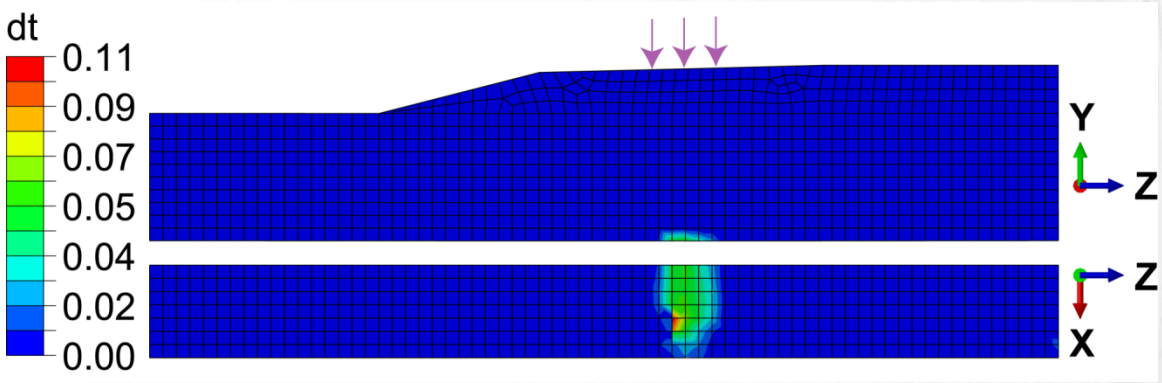
- Wood vs. Concrete Ties
- 8-strand vs. 24-wire Concrete Ties
- Untensioned Pullout Tests in Mortar
- Pretensioned Concrete Prism Tests

Predicted Failure Mode Under Rail Seat Pressure

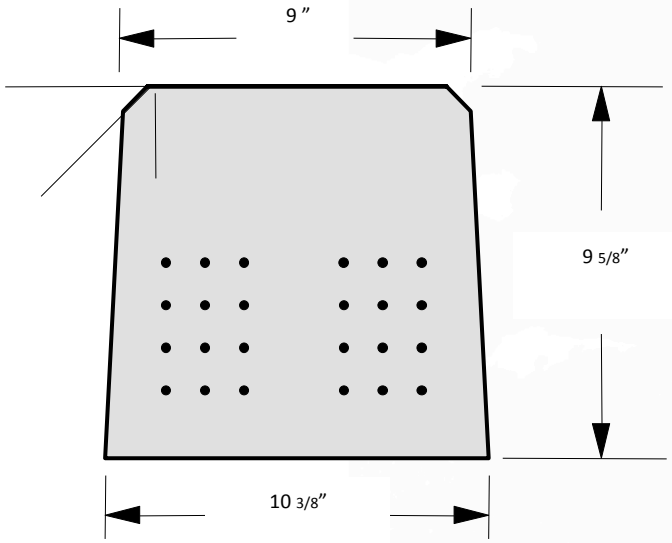
Wood tie – compressive rail seat failure



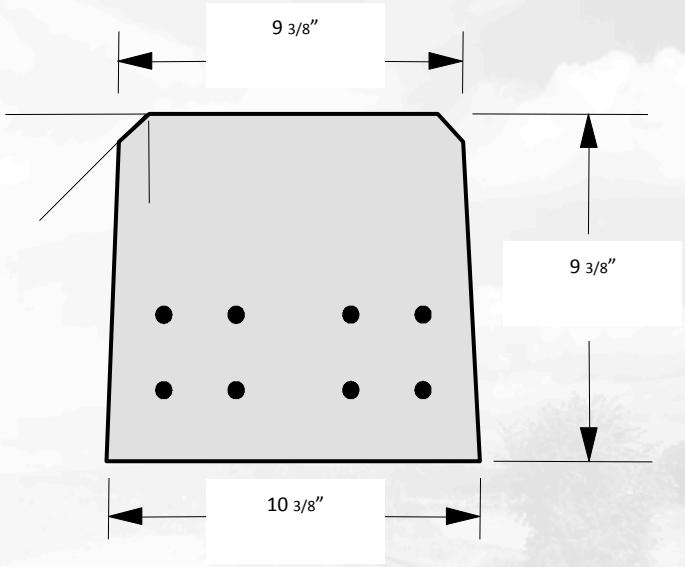
Concrete tie – tensile cracking at tie base



Example Application: 8-strand vs. 24-wire Reinforcement



Tie Cross Sections at Rail Seat



Total Cross Sectional Area = 92.7 in^2

Area of Pre-stressed Tendons = (24) p $(0.207)^2/4$=0.81 in^2

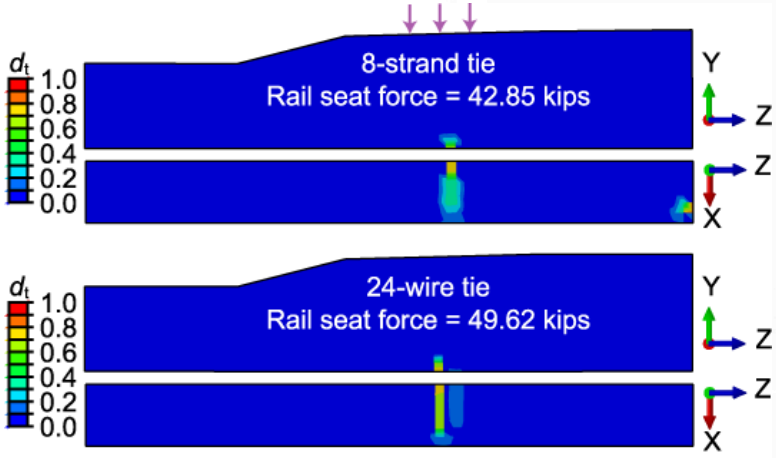
Interface Area = (24)p (0.207)(102) = 1592 in^2

Total Cross Sectional Area = 94.0 in^2

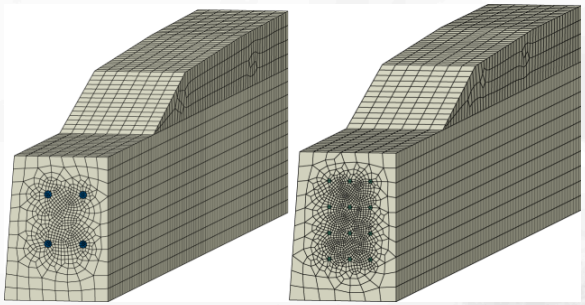
Area of Pre-stressed Tendons = (8) p $(0.375)^2/4$ = 0.88 in^2

Interface Area = (8) p (0.375)(102) = 961.3 in^2

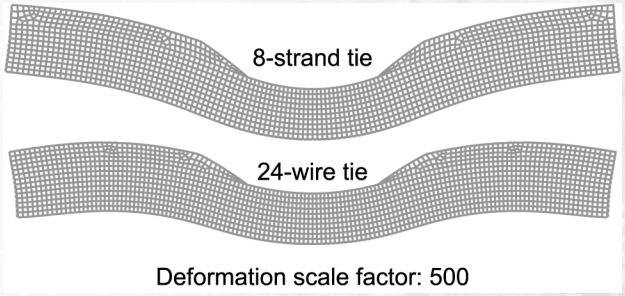
Example Application: 8-strand vs. 24-wire Reinforcement



Prediction of Damage from Excessive Rail Seat Loads

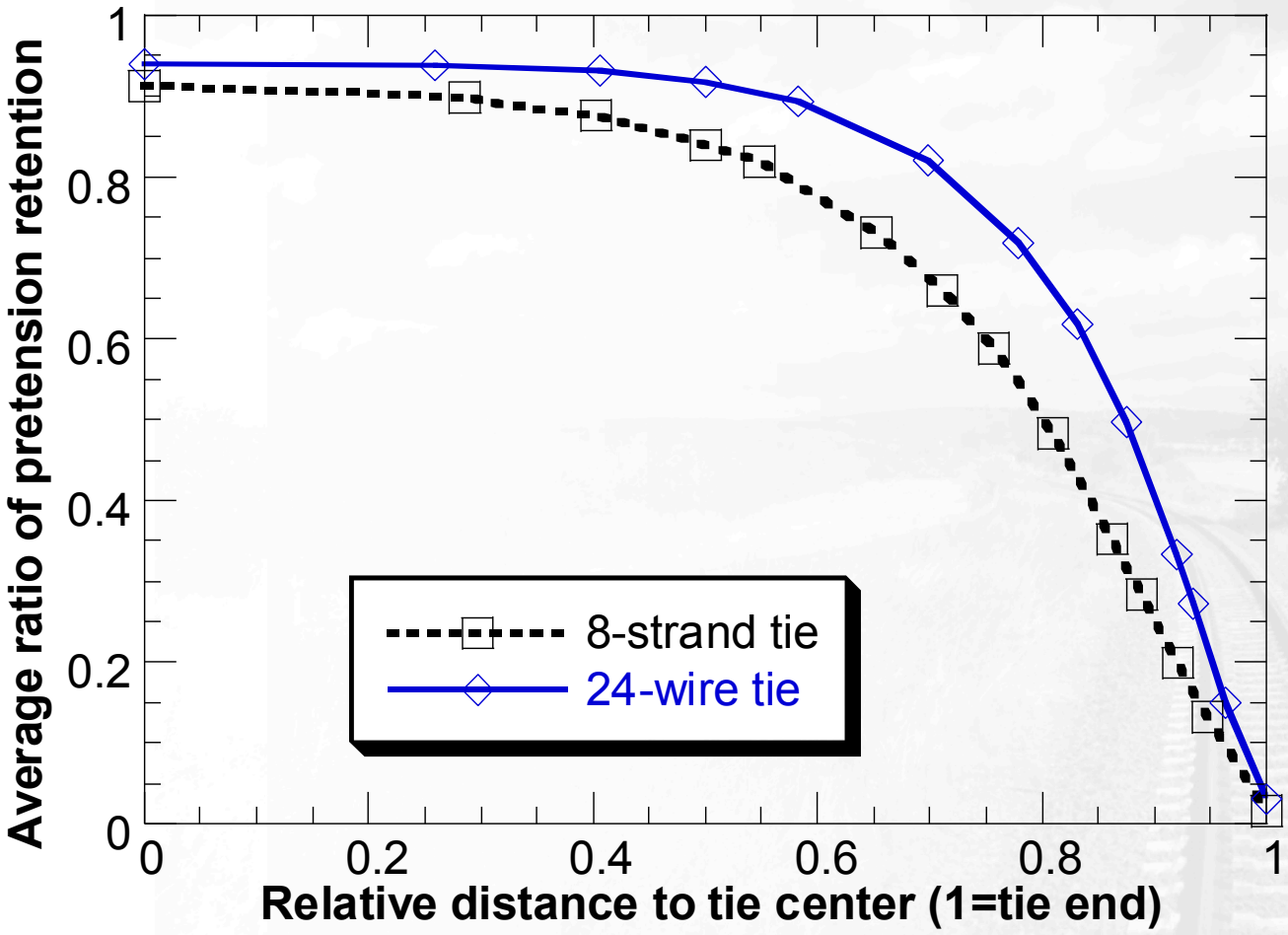


8-strand vs. 24-wire Concrete Ties

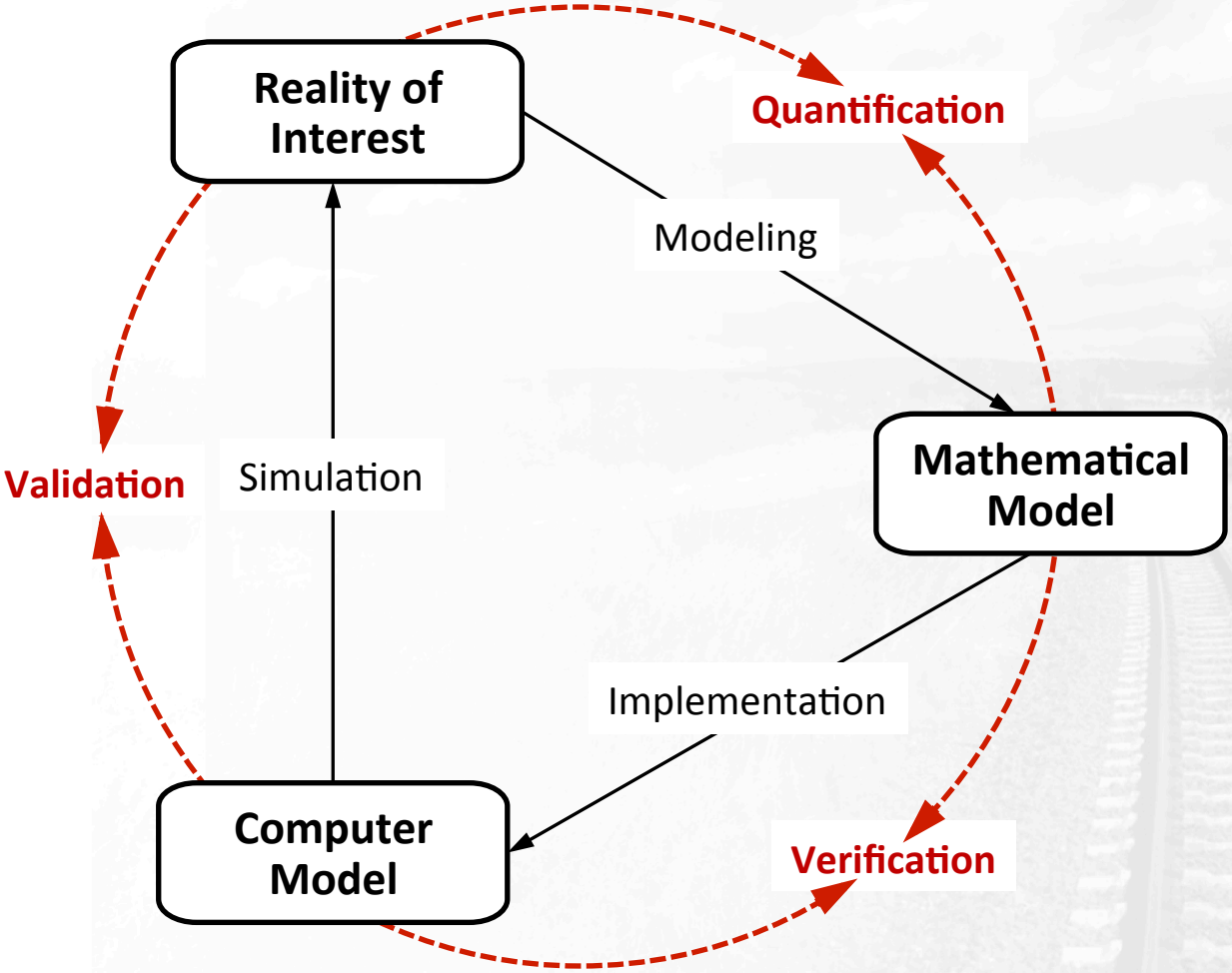


Deformed Tie Shape After Pretension Release

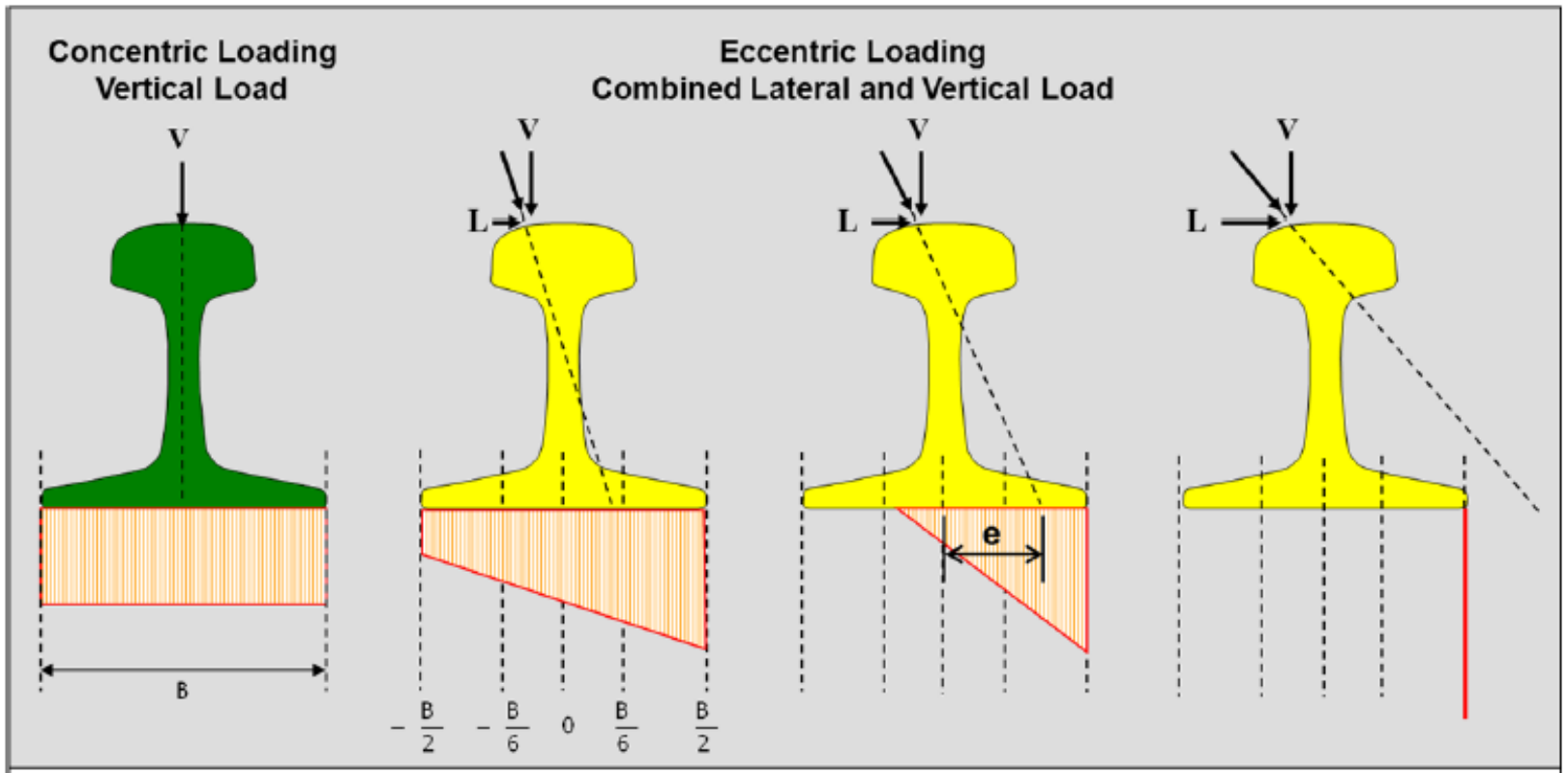
Ratio of Pretension Retention



Model Verification and Validation Process



Effect of Eccentric Loading on Rail Seat Pressure



Case 1: e = 0

$$p = \frac{V}{B}$$

Case 2: 0 ≤ e < B/6

$$p = \frac{V}{B}\left(1 + \frac{6e}{B}\right)$$

Case 3: B/6 ≤ e ≤ B/2

$$p = \frac{V}{B}\frac{4B}{3(B - 2e)}$$

Case 4: B/2 ≤ e

$$p = \infty$$

Recent Volpe Publications

- H. Yu and D.Y. Jeong, "Railroad Tie Responses to Directly Applied Rail Seat Loading in Ballasted Tracks: A Computational Study," JRC2012-74149, August 2012.

- B. Marquis et al., "Effect of Wheel/Rail Loads on Concrete Tie Stresses and Rail Rollover," RTDF2011-67025, September 2011.

- H. Yu et al. "Finite Element Modeling of Prestressed Concrete Crossties with Ballast and Subgrade Support," DETC2011-47452, August 2011.