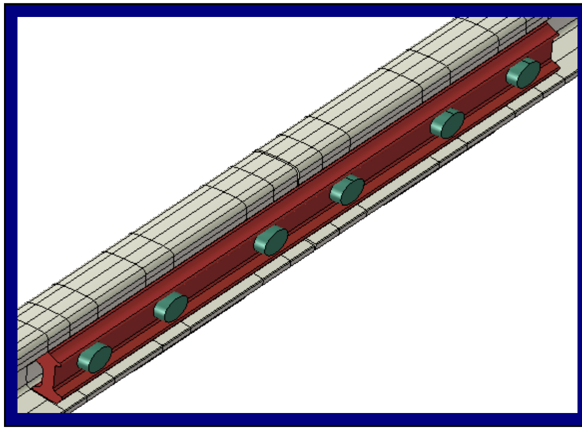
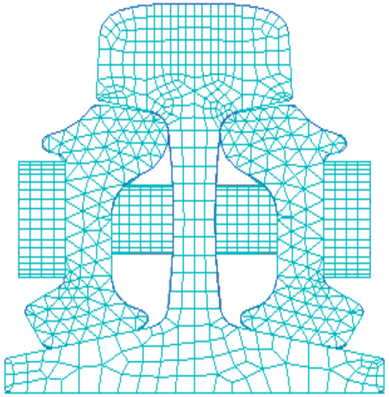
Investigation of Feasible Methods to Mitigate Rail End Bolt-Hole Cracks Using Finite Element Analysis





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Presentation Outline

- Background and Problem Statement
- Purpose and Scope of Work
- Literature Review Summary
- Static Finite Element (FE) Modeling
- Preliminary Static FE Results
- Future Work and Path Forward

Background and Problem Statement

- Rail joints classification:

Insulated Joints
- Bonded
- Nonbonded

Bolted Joints
- Compromise
- Standard

- Common defects:

End Batter

Head-Web Separation

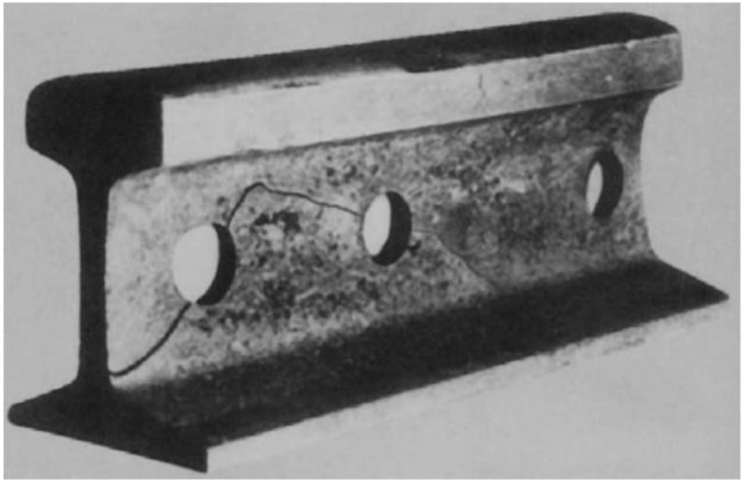
Joint Bar Center Crack

Bolt-Hole Crack

(The pictures are from CEE 409 Railroad Track Engineering, Learning Module 4. University of Illinois.)

Background and Problem Statement

- The primary cause of rail joint defects is the **discontinuity of both geometry and mechanical properties**, and the resulting impact loads.
- Bolt-hole cracks at rail joint propagating in the rail longitudinal direction is a major hazard, causing rail break or even loss of rail running surface
- Most cracks are found to propagate from the first bolt-hole at the end of the rail toward the end of the rail section.



(The picture is from Wen et al. (2005), *Contact-impact stress analysis of rail joint region using the dynamic finite element method*)

Purpose and Scope of Work

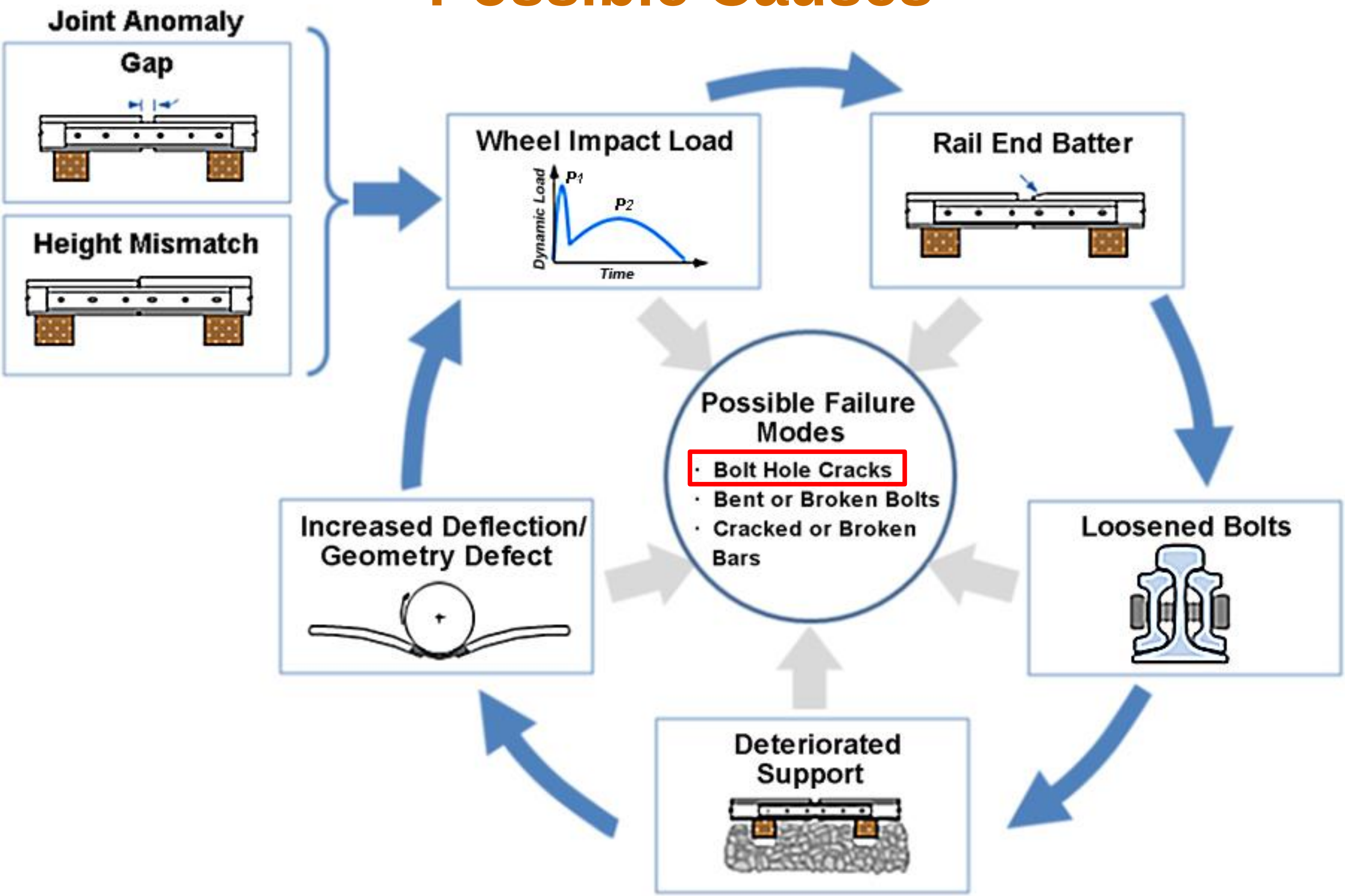
- A large number of bolted rail joints still exist in North America rail infrastructure for a variety of reasons, especially in some early-built rail transit systems.
- Scope → to find feasible method(s) to solve or mitigate the bolt-hole crack problem.

- **Phase I – Literature Review and Finite Element Modeling**
- **Phase II – Laboratory Experimentation**

Literature Review Summary – Key Findings

- Bolt-hole cracks typically initiate at receiving rail end of the joint, at approximately **45° to the neutral axis of rail**;
- For the standard joints between continuously welded rail (**CWR**) strings, **thermal-induced longitudinal stresses** play a significant role causing the crack;
- For the standard joints among bolted-joint rail (**BJR**) track, the crack driving force could be represented by the **positive shear stress at the bolt-hole**.

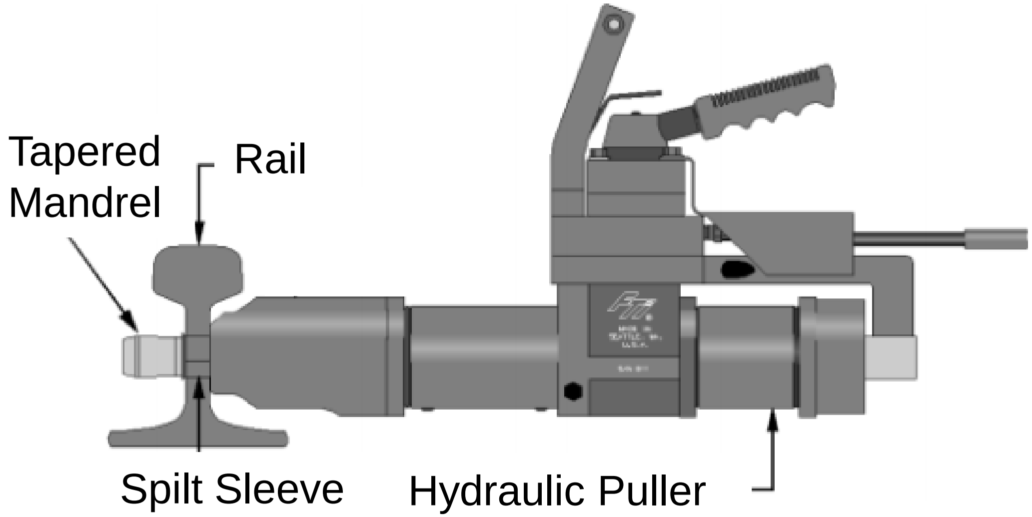
Possible Causes



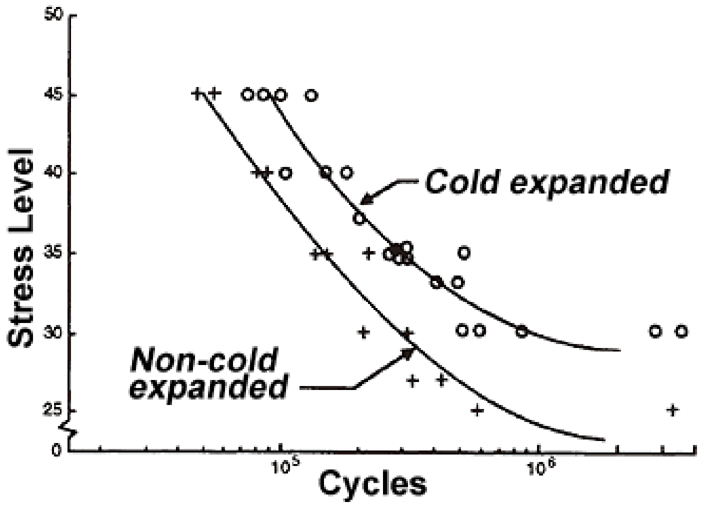
(The picture is from Carolan et al. (2014), *Engineering studies on joint bar integrity, part II: finite element analyses*)

Existing Remedial Methods – Cold Expansion

- Apply cold expansion to the bolt-hole, by pulling an oversize tapered mandrel through it.
- The residual compressive stress could help lower the cyclic tensile stress around the hole.
- The reduced net stress help increase the fatigue life.



Schematic of the Cold Expansion Process using Hydraulic Puller

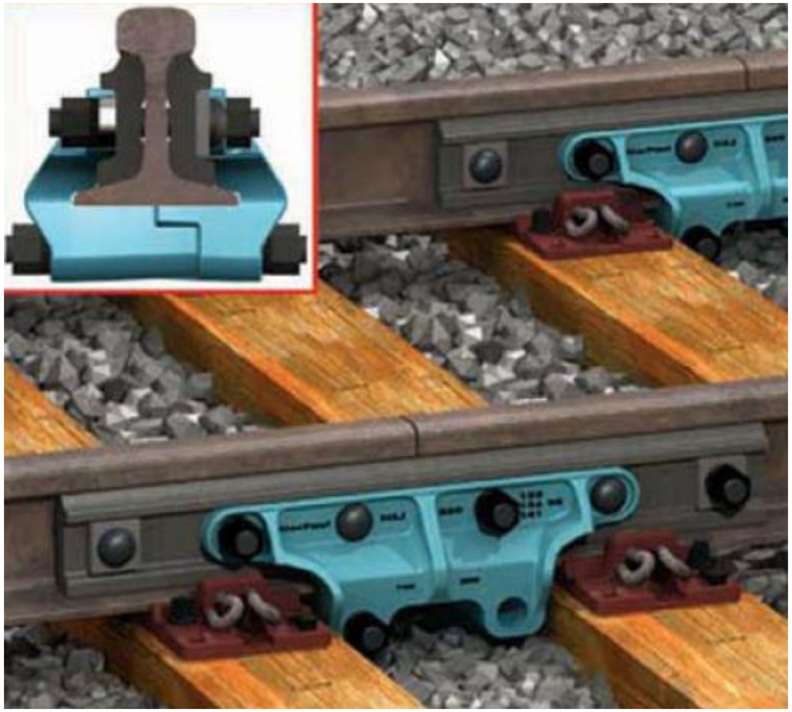


Increase in Fatigue Life for Cold vs. Non-Cold Expanded Holes

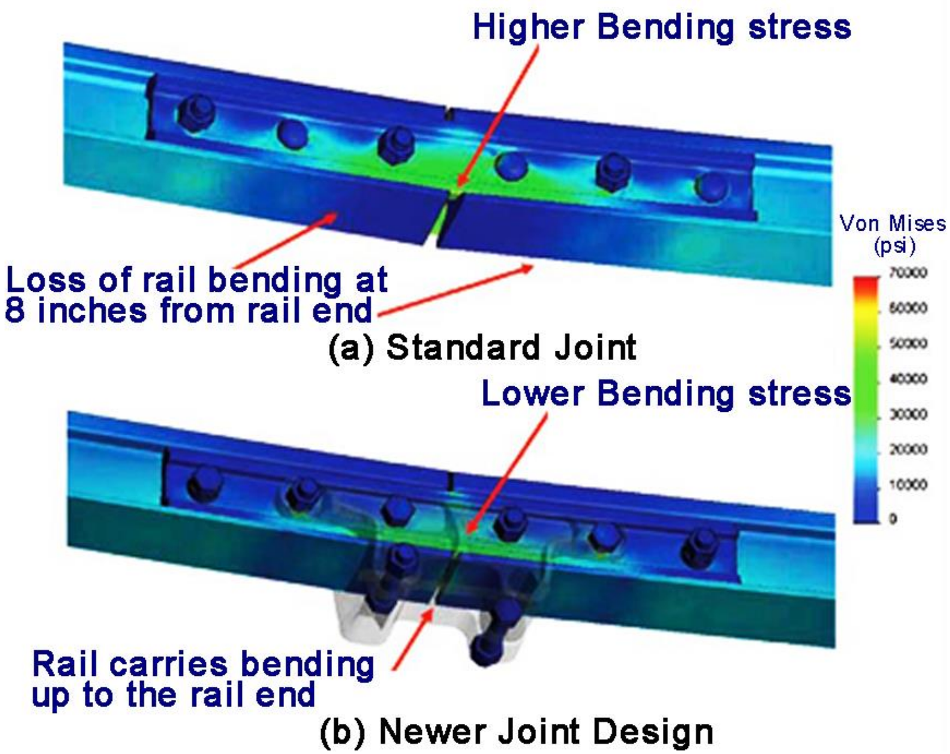
(The picture is from Reid (1993), *Beneficial residual stresses at bolt holes by cold expansion*)

Existing Remedial Methods – Saddled Joints

- Install “saddle” to protect and support joint bar.
- Saddled joint has better mechanical properties.



A Newer Joint Design with Web-Hugging Bars and Saddle



Stresses in Standard and Newer Joints

(The picture is from Igwemezie, J. and Nguyen, A.T. (2010), *Anatomy of joint bar failures III*)

Static FE Model Steps

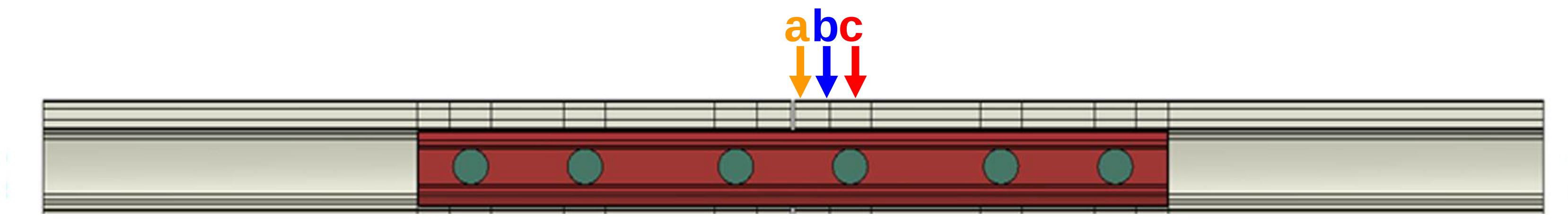
Step 1 – Develop models for nominal and worst scenario cases;

Step 2 – Develop models of standard joints to study the influences of possible bolt-hole crack causes;

Step 3 – Develop models of remedial joint designs, compare the results with models of standard joints to see the effectiveness.

Static FE Model Variables

Variable	Inputs
Rail Section	100-lb / 115-lb
Plate Type (Track Stiffness)	Resilient Plates (4,000 psi) / Pandrol Plates (Old) (11,000 psi) / Pandrol Plates (New) (22,000 psi)
Joint Support Type	Suspened / Supported
Support Condition	Well (100%) / Poorly (≈0%)
Bolt Condition	Tight (22,000 psi) / Loose (6,000 psi)
Static Wheel Load	16,500 lb / wheel
Impact Wheel Load Factor	$I_m \geq 1.33$
Loading Position	a (on top of rail end) / b (between a and c) / c (on top of first bolt-hole)



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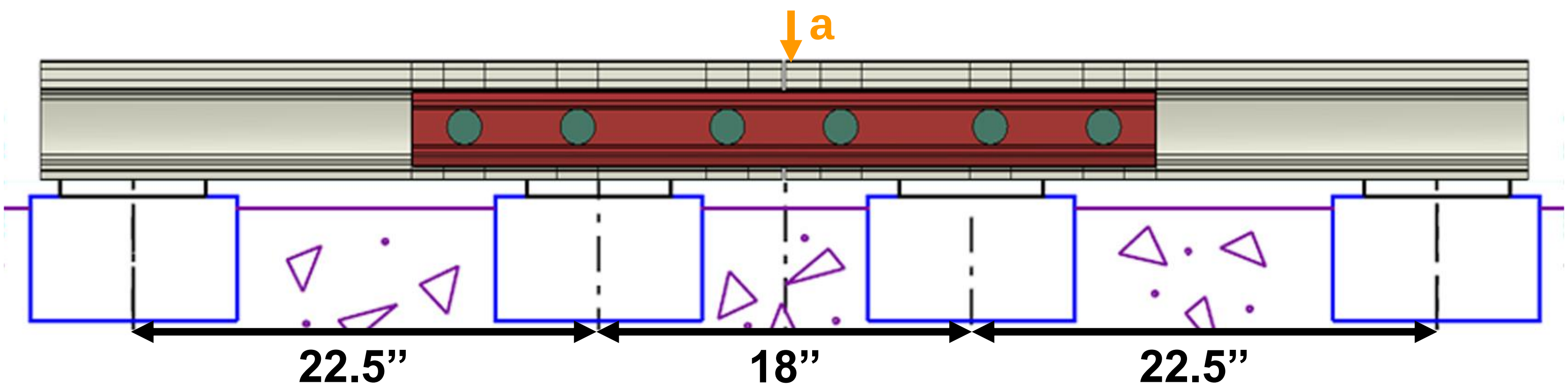
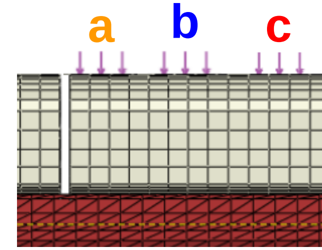
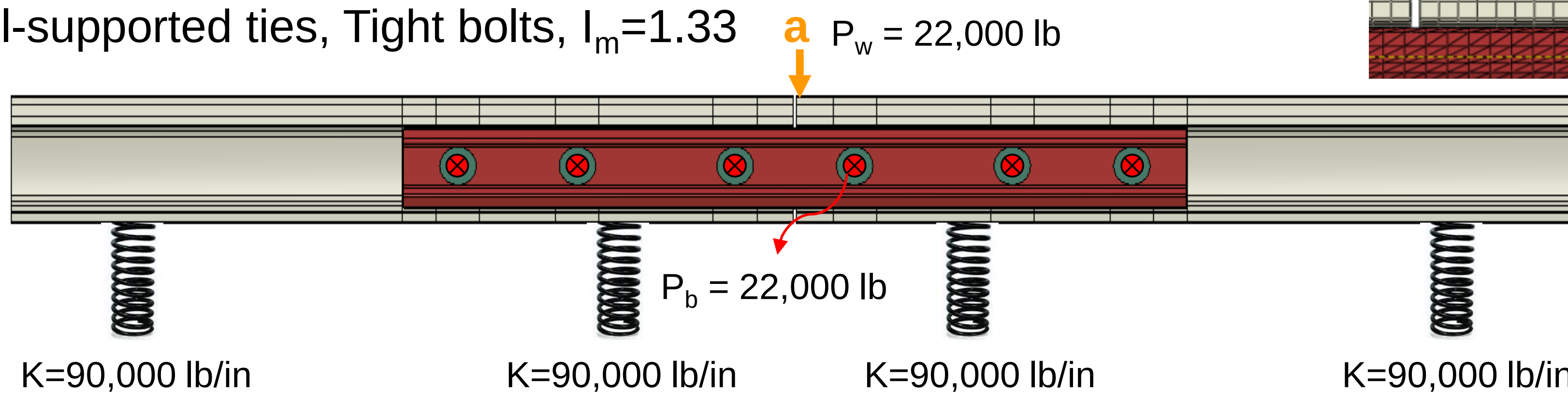
Bolt Condition	**Tight (22,000 psi)** / Loose (6,000 psi)
Static Wheel Load	**16,500 lb / wheel**
Impact Wheel Load Factor	**1.33**
Loading Position	**a (on top of rail end)**



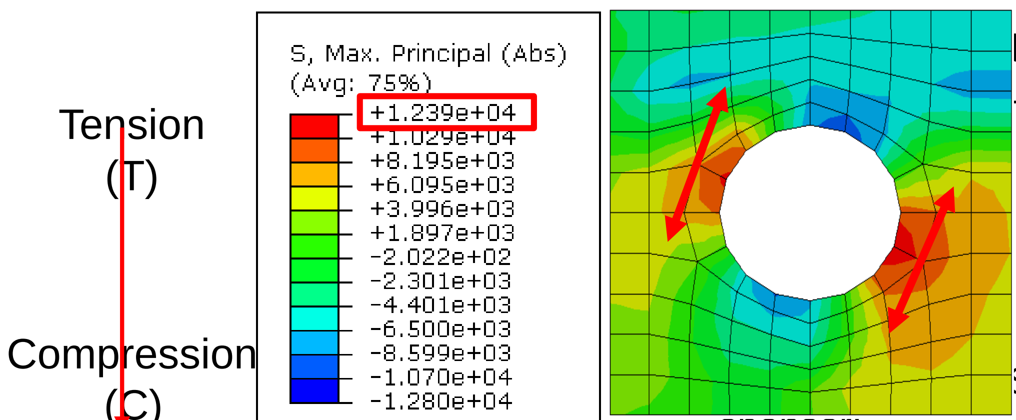
Static FE Models and Results



I – Well-supported ties, Tight bolts, I_m=1.33



P_w = Impact Wheel Load = 1.33 × 16500 = 22,000 lb
P_b = Bolt Preload = 22,000 lb / bolt
K = Track Modulus × Tie Spacing = 4,000 psi × 22.5 in = 90,000 lb/in

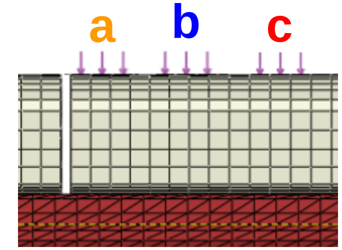


≈ 12,000 psi
(23% Fatigue Strength)

Max. Principal Stress around Rail End Bolt-Hole

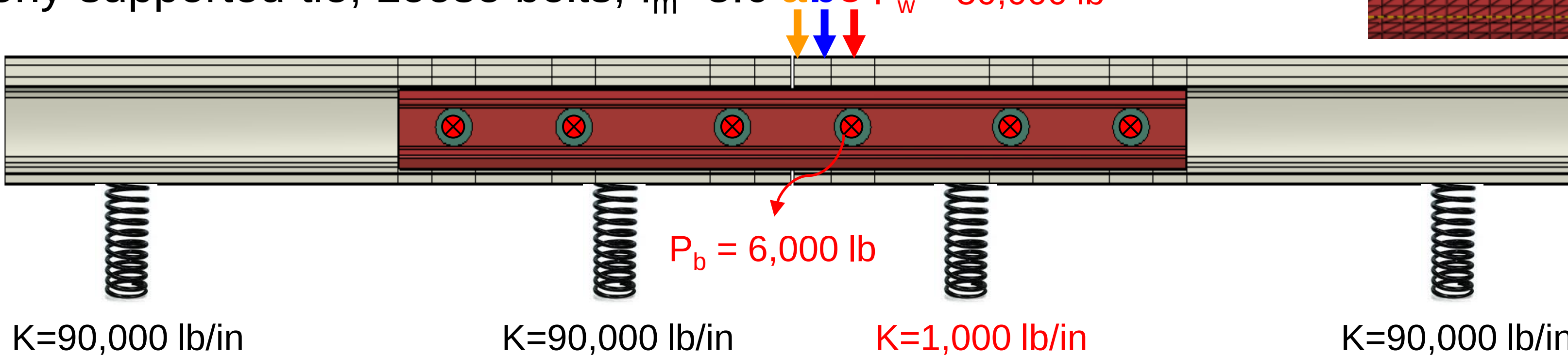
...th	Magnitude (psi)
	177,000
	115,000
	52,000~69,000

...Strengths are provided by sponsor;
2. Fatigue Strength is estimated by 45~60% of Yield Strength



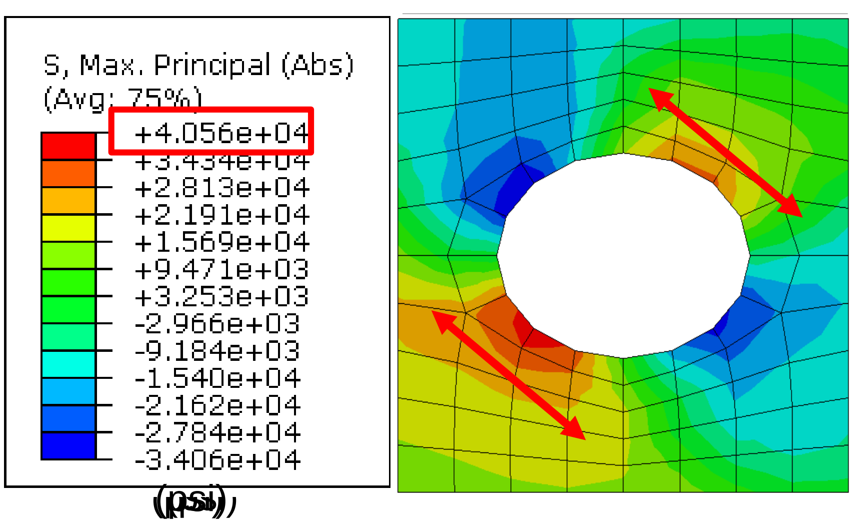
Static FE Models and Results

II – Poorly-supported tie, Loose bolts, I_m=3.0 abc

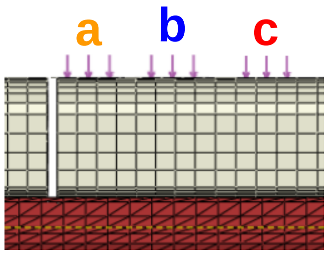


P_w = Impact Wheel Load = 3.0 × 16500 = 50,000 lb

P_b = Bolt Preload = 6,000 lb / bolt

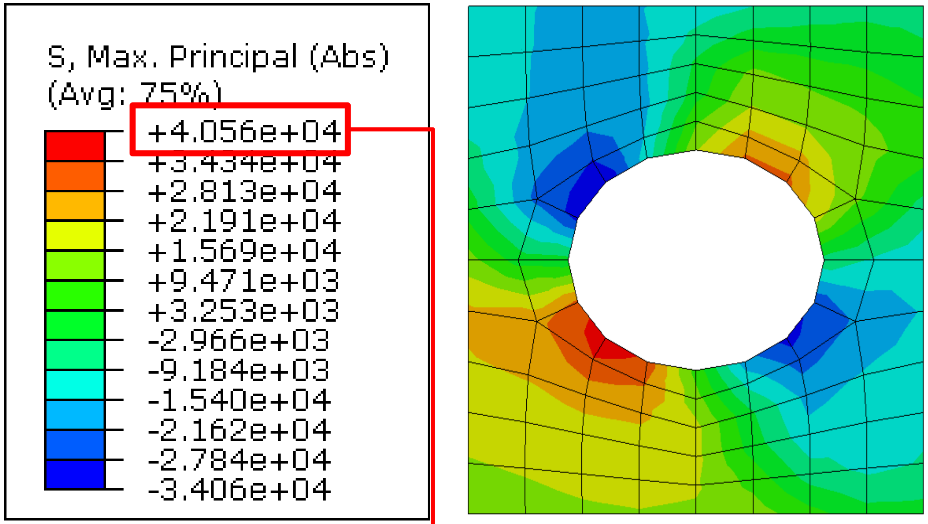


Load Position	Max. Tensile Stress around 1st Rail End Bolt-Hole (psi)
a	19,330
b	27,460
c	**40,560**

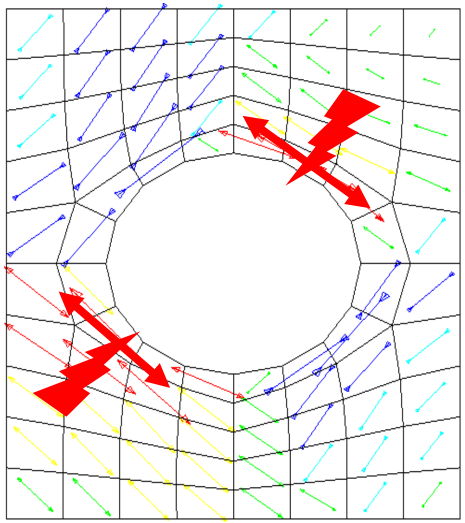


Static FE Models and Results

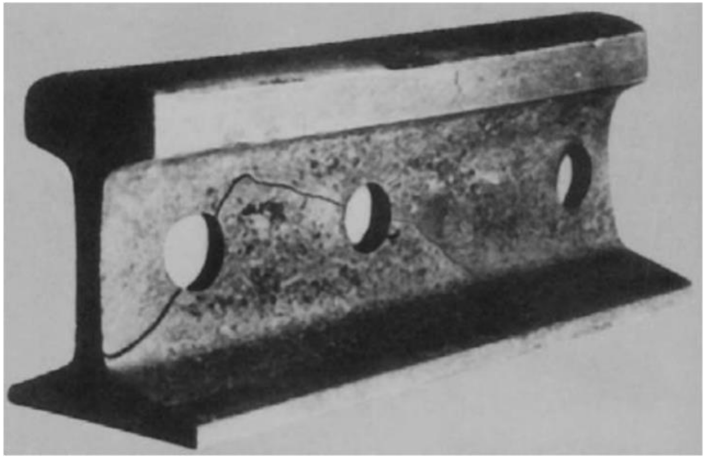
II – Poorly-supported tie, Loose bolts, I_m=3.0, (case **c**)



≈ 41,000 psi
(79% Fatigue Strength)



Vector Plot



(The picture is from Wen et al. (2005), *Contact-impact stress analysis of rail joint region using the dynamic finite element method*)

Preliminary Static FE Model Results

- When the rail joint system is in good condition (i.e. well-supported ties, tight bolts, and low impact wheel loads), **the stresses around the rail end bolt-hole are well below the fatigue strength (23%)**;
- When the rail joint system is deteriorated (e.g. poorly-supported tie, loosened bolts, and high impact wheel loads), **the stresses around the rail end bolt-hole can approach the fatigue strength (79%)**;
- The critical case is when the wheel load is right above the rail end bolt-hole;
- As supported by other literature, the maximum tensile stress regions are at approximately **45°** around rail end bolt-hole.

Future Work and Path Forward

- **Refine the mesh** around the bolt-hole of interest, and **perform the mesh sensitivity analysis** to approach the convergence value of the stresses;
- **Extend the model in longitudinal direction** and import additional crossties along the rail base to reduce boundary effect in simulation, and better represent field conditions;
- **Compare the influences of poorly-supported crosstie**, loose bolts and high impact load, respectively, and find out the dominant one(s);
- **Develop dynamic model** for fatigue analysis via introducing moving wheel(s) into the model.

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