Presentation Outline

• Problem Statement and Scope of Work
• Finite Element Analysis Results Summary
• Laboratory Experimentation Plan
Background and Problem Statement

- Rail joints classification:
  - Insulated Joints
  - Bolted Joints
    - Bonded
    - Nonbonded
    - Compromise
    - Standard
    - Permanent (BJR)
    - Temporary (CWR)

- Common defects:
  
  ![End Batter](image1)
  ![Joint Bar Center Crack](image2)
  ![Head-Web Separation](image3)
  ![Bolt-Hole Crack](image4)

- Bolt-hole cracks and upper fillet cracks are two of the major hazards, which might cause rail break or even loss of rail running surface.

- Most cracks are found to propagate from the first bolt-hole or upper fillet at the end of the rail.

  ![Bolt-Hole Crack](image5)
  ![Upper Fillet Crack](image6)
Scope of Work

- Study the feasibility of sponsor-proposed remedial methods to solve or mitigate the rail bolt-hole crack and rail head-web separation problems:

  - Literature Review
  - Static Elastic Finite Element Simulation
  - Fatigue Analysis
  - Laboratory Experimentation

Phase I:
- Wheel Load Position
- Impact Load Factor
- Tie Arrangement
- Rail Plate Type

Phase II:

Presentation Outline

- Problem Statement and Scope of Work
- Finite Element Analysis
- Results Summary
- Laboratory Experimentation Plan
### Static FE Parametric Study Matrix

<table>
<thead>
<tr>
<th>Rail Type</th>
<th>2</th>
<th>100-8 Rail, 115RE Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track Modulus</td>
<td>3</td>
<td>4,000 psi, 11,000 psi, 22,000 psi</td>
</tr>
<tr>
<td>Joint Bar Arrangement</td>
<td>8</td>
<td>Standard Method, Remedial Method 1, Remedial Method 1A, Remedial Method 2, Remedial Method 3, Thickened Bar 1 &amp; 1A*</td>
</tr>
<tr>
<td>Tie Arrangement</td>
<td>5</td>
<td>Nominal, Suspended, Supported (tie), Supported (plate edge), Broken Plate</td>
</tr>
<tr>
<td>Loading Positions</td>
<td>3</td>
<td>a, b, c</td>
</tr>
<tr>
<td>Loading Magnitude</td>
<td>3</td>
<td>1.33, 2.0, 3.0 × 16,500 lb (Static Wheel Load)</td>
</tr>
</tbody>
</table>

Total runs for FE Models = 2 × 3 × 8 × 5 × 3 × 3 = 2,160

* The Thickened Joint Bars was added on later

### NYCT-Proposed Remedial Methods

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Technical Drawing and FE Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td><img src="image" alt="SM Sketch" /></td>
</tr>
<tr>
<td>RM1</td>
<td><img src="image" alt="RM1 Sketch" /></td>
</tr>
<tr>
<td>RM1A</td>
<td><img src="image" alt="RM1A Sketch" /></td>
</tr>
<tr>
<td>RM2</td>
<td><img src="image" alt="RM2 Sketch" /></td>
</tr>
<tr>
<td>RM3</td>
<td><img src="image" alt="RM3 Sketch" /></td>
</tr>
</tbody>
</table>
NYCT-Proposed Support Cases

**Case A:**
Nominal

**Case B:**
Suspended

**Case C:**
Supported (tie)

**Case D:**
Supported (plate edge)

**Case E:**
Broken Plate

Wheel Loading Cases

The wheel load is assigned as a pressure load over a small area of about 0.5 in².
### Static FE Model Example

**Resilient plate**

Wooden ties embedded in concrete slab

**Wheel Load**

---

**K_s** = 90 kips/in

9 × 10 kips/in

9 × 10 kips/in

9 × 10 kips/in

90 kips/in

---

**P_w** = Wheel Load

\[ P_w = \text{Impact Factor} \times \text{Static Wheel Load} = 1.33 \text{ or } 2.0 \text{ or } 3.0 \times 16.5 \text{ kips} \]

**K_s** = Spring Stiffness

\[ K_s = \text{Track Modulus} \times \text{Average Tie Spacing} = 4,000 \text{ psi} \times 22.5 \text{ in} = 90,000 \text{ lb/in} = 90 \text{ kips/in} \]

---

### Static FE Model Example Results

**Note:** Deformation Scale Factor = 50;

Only portion of the model is plotted, with the length of 108 in.;

---

**U, U_2** (in.)

---

**S, Mises** (Avg.: 75%) (psi)

---

**S, Max. Principal (Aaxo)** (Avg.: 75%) (psi)

---

(a) Wheel Load

(b) 108 in.

(c) Only portion of the model is plotted, with the length of 108 in.;
Static FE Models Results — Effect of Wheel Load Position

Static FE Models Results — Displacement (in.)

Maximum Displacement at 100-8 Rail End

Maximum Displacement at 115 RE Rail End
Static FE Models Results
— Bolt-Hole Tensile Stress (ksi)

Maximum Tensile Stress around 100-8 Rail End Bolt-Hole

Support Condition

Maximum Tensile Stress around 115 RE Rail End Bolt-Hole

Support Condition

Static FE Models Results
— Bolt-Hole Mises Stress (ksi)

Maximum Mises Stress around 100-8 Rail End Bolt-Hole

Support Condition

Maximum Mises Stress around 115 RE Rail End Bolt-Hole

Support Condition

\[ c = 3WL \quad u = 4,000 \text{ psi} \]
Static FE Models Results — Fillet Mises Stress (ksi)

- Fatigue Limit = 61.5 ksi

**Joint Bar Study**

- Maximum Mises Stress around **100-8 Rail End Fillet**
  - SM
  - RM1
  - RM1A
  - RM2
  - RM3

- Maximum Mises Stress around **115 RE Rail End Fillet**

Fatigue Analysis – Procedure

- Stress calculated from elastostatic FE simulations by **Abaqus**

- **Loading history**
  - Material properties:
    - Ultimate tensile strength (UTS);
    - Surface finish factor ($K_t$) …

- **Fatigue algorithms**:
  - Brown-Miller;
  - Principal stress;
  - Von Mises stress …

- **Mean stress corrections**:
  - Morrow;
  - Goodman;
  - Gerber …

- Predicted fatigue life
Fatigue Analysis – Material Properties

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbols</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile Strength</td>
<td>UTS</td>
<td>177.0 ksi</td>
</tr>
<tr>
<td>Strength at 10^6 cycles</td>
<td>-</td>
<td>112.2 ksi</td>
</tr>
<tr>
<td>Strength at 10^7 cycles</td>
<td>-</td>
<td>61.5 ksi</td>
</tr>
<tr>
<td>(Fatigue Limit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>E</td>
<td>29,000 ksi</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>ν</td>
<td>0.33</td>
</tr>
<tr>
<td>Strain Hardening Coefficient</td>
<td>K’</td>
<td>292.0 ksi</td>
</tr>
<tr>
<td>Strain Hardening Exponent</td>
<td>n’</td>
<td>0.15</td>
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<tr>
<td>Fatigue Strength Coefficient</td>
<td>σ’</td>
<td>265.5 ksi</td>
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<tr>
<td>Fatigue Strength Exponent</td>
<td>b</td>
<td>-0.087</td>
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<tr>
<td>Fatigue Ductility Coefficient</td>
<td>ε’</td>
<td>0.361</td>
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<tr>
<td>Fatigue Ductility Exponent</td>
<td>c</td>
<td>-0.58</td>
</tr>
<tr>
<td>Surface Finish Factor</td>
<td>K_t</td>
<td>1.38</td>
</tr>
</tbody>
</table>

Note: For steel, reaching the loading cycles of 10^7 indicates that no damage will occur under same condition.
New Thickened Joint Bar Designs

- **Standard**
  - Two Joint Bars Area: 6.80 in²
  - Moment of Inertia: 8.10 in⁴

- **New 1**
  - Two Joint Bars Area: 10.16 in²
  - Moment of Inertia: 9.75 in⁴

- **New 1A**
  - Two Joint Bars Area: 9.25 in²
  - Moment of Inertia: 7.90 in⁴

Finite Element Models Results — Fillet Mises Stress (ksi)

- **Standard**
  - Mises Stress (Avg: 75%)
  - S, Mises

- **New 1**
  - Mises Stress (Avg: 75%)
  - S, Mises

- **New 1A**
  - Mises Stress (Avg: 75%)
  - S, Mises
Fatigue Analysis – Upper Fillet

Note: For steel, reaching the loading cycles of $10^7$ indicates that no damage will occur under same condition.

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Laboratory Experimentation Setup (under Construction)

Note: block will be embedded in concrete

Dynamic Model Simulation
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