Monitoring Crosstie Behavior and Crosstie/Ballast Interaction

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2014 International Crosstie and Fastening System Conference
University of Illinois at Urbana-Champaign
• Transient & Permanent Displacements
• Impact Loads

Stark and Wilk (2014)
Tie-Ballast Interaction Model

0 Passes

> 1 Pass

Stark and Wilk (2014)
Tie-Ballast Interaction Field Data (Norfolk Southern)

MP 352.2 (13 ft.) vs. MP 352.2 (31 ft.) – November 2013

- Loaded cars
- Unloaded cars

Stark and Wilk (2014)
LS-DYNA – Train Bogey

• 110 mph

Stark and Wilk (2014)
LS-DYNA – Tie-Ballast Gap Behavior

Stark and Wilk (2014)
• 39%/22%/10%
• Significant effect from adjacent ties
• Need to instrument multiple ties
  – 5 minimum is recommended
Track Structure Assessment

- Non Destructive Testing
- Defects
- No defects
- Facilitate selection of remediation

Stark and Wilk (2014)
Advantages:
- Non-invasive, quick installation
- Low cost, portable, easy measurement, reusable
- Inclement weather, poor visibility, permanent setup, solar power

Increased tie accelerations: $F=ma$
- Track movement $\rightarrow$ Track damage $\rightarrow$ Geometry issues

Accelerometers

Stark and Wilk (2014)
Miniature Accelerometers
Miniature Accelerometers

Stark and Wilk (2014)
Wireless Monitoring

• Permanent installation
  – Environmental changes
  – Seasonal changes

Stark and Wilk (2014)
Tie and Rail Accelerometers

- Tie-mounted accelerometers
  - Tie and substructure defects
  - Evaluate tie-ballast gap
- Rail-mounted triaxial accelerometer
  - Rail defects
  - Evaluate rail-tie gap

Stark and Wilk (2014)
Objective

- Relate accelerations to track serviceability and failure

<table>
<thead>
<tr>
<th>Tie Displacements</th>
<th>POSSIBLE Estimated Acceleration Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe</td>
<td>&gt; 90 g</td>
</tr>
<tr>
<td>High</td>
<td>50 – 90 g</td>
</tr>
<tr>
<td>Elevated</td>
<td>25 – 50 g</td>
</tr>
<tr>
<td>General Risk</td>
<td>5 – 25 g</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 5 g</td>
</tr>
</tbody>
</table>

Stark and Wilk (2014)
Track Examples

• Site 1: Amtrak’s Northeast Corridor (NEC) near Chester, PA
  (1) Analyze tie support conditions

• Site 2: UP’s South Morrill Line near Ogallala, NE
  (2) Analyze tie damage conditions
  (3) Analyze ballast conditions
  (4) Analyze applied load

• Site 3: TTCI near Pueblo, CO
  (5) Ballast moisture conditions
(1) Tie Support Conditions

- Good tie support (Green – Accel #3)
- Poor tie support (Red – Accel #2)
  - Greater peak acceleration
  - Gap?

Stark and Wilk (2014)
(1) Tie Support Conditions

- **Poor Support**
  - Dominated by lower frequencies
  - High amplitude of low frequencies

- **Medium Support**
  - Similar to bad support but lower amplitude of low frequencies

- **Good Support**
  - Dominated by higher frequencies
  - Low amplitude of low frequencies

Stark and Wilk (2014)
(1) Tie Displacements

- Upland (15 ft)
- Displacement Difference
  - Crosslevel
  - Damaged Tie
(2) Tie Damage Conditions

- Damaged Tie & Clean Ballast
  - Accelerometer #1
- Good Ties & Clean Ballast
  - Accelerometers #2 & 3

Stark and Wilk (2014)
(2) Tie Damage Conditions

- **Accel #1 (Damaged Tie & Clean Ballast)**
  - Average: ~40 g
  - Maximum: ~80g
  - Greater peak accelerations than good ties
  - Largest impact force \( F = ma \)

- **Accel #2 (Good Tie & Clean Ballast)**
  - Average: ~0.5 g – Note: same graph scale
  - Maximum: >100 g (bad wheels?)
  - Similar to Accel #3 below

- **Accel #3 (Good Tie & Clean Ballast)**
  - Average: ~0.5 g
  - Maximum: ~20 g
  - Similar to Accel #2

Stark and Wilk (2014)
(3) Ballast Conditions

- Dry Highly Fouled Ballast
  - Accelerometers #1 & 2
- Dry Moderately Fouled Ballast
  - Accelerometers #3
- Visual inspect of fouling

Stark and Wilk (2014)
(3) Ballast Conditions

- NO EFFECT because **Dry Fouling**

- **Accel #1 (Dry Highly Fouled Ballast)**
  - Average: ~5 - 25 g
  - Maximum: ~50 g
  - Response similar to partially fouled ballast

- **Accel #2 (Dry Highly Fouled Ballast)**
  - Average: ~5 – 50 g
  - Maximum: >75 g

- **Accel #3 (Dry Moderately Fouled Ballast)**
  - Average: ~5 - 50 g
  - Maximum: >75g
(4) Applied Loads

- **Empty Coal Cars**
  - Average: \(~2\) g
  - Maximum: \(~20\) g

- **Loaded Coal Cars**
  - Average: \(~5 - 50\) g
  - Maximum: \(>75\)g
  - Larger accelerations than empty trains (\(~2\) g)

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Stark and Wilk (2014)
(5) Ballast Moisture Conditions

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Seismic Testing Young’s Modulus (ksi)</th>
<th>Field Young’s Modulus (ksi)</th>
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</thead>
<tbody>
<tr>
<td>Clean Ballast</td>
<td>30 – 40</td>
<td>~30 – 35</td>
</tr>
<tr>
<td><strong>Dry</strong> Fouled Ballast</td>
<td>50 – 55</td>
<td>~40 - 55</td>
</tr>
<tr>
<td><strong>Wet</strong> Fouled Ballast</td>
<td>20 – 25 (Brief soaking)</td>
<td>~7 – 15</td>
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</table>
Summary

- Non-Destructive Testing to Monitor Track/Tie Behavior
  1. Tie support
  2. Tie damage
  3. Ballast condition
  4. Applied load
  5. Ballast moisture condition
- Corroborate with alternative NDT methods

Stark and Wilk (2014)
Non-Destructive Corroboration

Wheeler et al. (2014)
Acknowledgments

- Federal Rail Administration and Volpe Center
  - Gary Carr
  - Michael Coltman
  - Brian Marquis
  - Cameron Stuart
  - Hugh B. Thompson II
  - Theodore R. Sussmann, Jr.
- Union Pacific
- Amtrak
- Norfolk Southern
- TTCI
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