Causes of Load Amplification: Using WILD Data to Quantify Wheel Loads

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Outline

• Objectives of quantifying load amplification
• Rail seat load calculation methodologies
• Wheel load distribution on shared infrastructure
  – Causes of load amplification
• Evaluation of load amplification factors
  – Dynamic wheel load factors
  – Impact factors
• Conclusions and Acknowledgements
FRA Tie and Fastening System BAA Objectives and Deliverables

• Program Objectives
  – Conduct comprehensive international literature review and state-of-the-art assessment for design and performance
  – Conduct experimental laboratory and field testing, leading to improved recommended practices for design
  – Provide mechanistic design recommendations for concrete sleepers and fastening system design in the US

• Program Deliverables
  – Improved mechanistic design recommendations for concrete sleepers and fastening systems in the US
  – Improved safety due to increased strength of critical infrastructure components
  – Centralized knowledge and document depository for concrete sleepers and fastening systems
Principles of Mechanistic Design

1. Quantify track system input loads (wheel loads)
2. Qualitatively establish load path (free body diagrams, basic modeling, etc.)
3. Quantify demands on each component
   a. Laboratory experimentation
   b. Field experimentation
   c. Analytical modeling
4. Link quantitative data to component geometry and materials properties (materials decision)
5. Relate loading to failure modes
6. Investigate interdependencies through modeling
7. Establish mechanistic design practices and incorporate into AREMA Recommended Practices
Objectives

• Characterize and quantify increase above static wheel load due to several factors
  – Temperature
  – Speed
  – Irregularities
• Evaluate effectiveness of dynamic and impact wheel load factors
• Determine rail seat load entering tie and fastening system
Rail Seat Load Calculation Methodologies

Wheel Load (kips)

Wheel Load (kN)

Rail Seat Load (kN)

- AREMA
- USACE
- Average
- Kerr
- Talbot

Analysis courtesy of Christopher Rapp
Wheel Impact Load Detectors (WILD)

- Sixteen sets of strain gauges to detect full rotation of most wheels
- For each wheel,
  - Labels by vehicle type
  - Measures speed, nominal (static) wheel load, and peak wheel load
Traffic Distribution – Nominal Wheel Loads

Source: Amtrak – Edgewood, MD (November 2010)
Traffic Distribution – Peak Wheel Loads

Source: Amtrak – Edgewood, MD (November 2010)
Nominal vs. Peak Vertical Load

- Freight Locomotives
- Passenger Locomotives
- Non-Intermodal Freight Cars

Source: Amtrak – Edgewood, MD (November 2010)
Distribution of Nominal Wheel Loads

Source: Amtrak – Edgewood, MD (November 2010)
Distribution of Peak Wheel Loads

Source: Amtrak – Edgewood, MD (November 2010)
Effect of Traffic Type on Peak Wheel Load

- Freight Cars
- Passenger Coaches

Source: Amtrak – Edgewood, MD (November 2010)
Dynamic vs. Impact Load

- Static load – load of vehicle at rest
- Quasi-static load – static load at speed, independent of time
- Dynamic load – high frequency effects of wheel/rail interaction, dependent on time
  
  - E.g., \( \text{Dynamic Factor} = 1 + \frac{33 \text{(speed)}}{100 \text{(diameter)}} \)

- Impact load – high-frequency and short duration load caused by track and vehicle irregularities
  
  - E.g., increase of 200% (found in AREMA Chapter 30)
Effect of Speed on Wheel Load

Source: Amtrak – Edgewood, MD (November 2010)
Comparison of Dynamic Wheel Load Factors

- Talbot/Hay
- Indian Railways
- Eisenmann
- Birmann

Dynamic Wheel Load Factor vs. Speed (mph)

AREMA Chapter 30 Speed Factor
Dynamic Wheel Load Factors

Source: Amtrak – Edgewood, MD (November 2010)
Effect of Wheel Condition on Peak Wheel Load

Source: Amtrak – Mansfied, MA (November 2010)
Passenger Coaches
More than a Dynamic Factor: Impact Factor

Impact Factor (IF) = \( \frac{\text{Peak Load}}{\text{Static Load}} \)

Source: UPRR – Gothenburg, NE (January 2010)
Intermodal Cars

Impact Factor (IF) = \frac{\text{Peak Load}}{\text{Static Load}}

Source: UPRR – Gothenburg, NE (January 2010)
Impact Factor (IF) = Peak Load / Static Load

Source: UPRR – Gothenburg, NE (January 2010)
Thoughts on Impact Factor

• Chapter 30 Impact Factor (300%) exceeds majority of locomotive and loaded freight car loads
  – Greater impact factor may be necessary for lighter rolling stock (passenger coaches and unloaded freight cars)
  – Wheel condition significantly affects load
  – Speed causes highest impacts to be higher

• Evaluating effectiveness of impact factor dependent on static weight of car
Other Factors Affecting Wheel Loads

- Moisture and temperature
- Position within the train
- Curvature
- Grade
- Track quality

UIUC Instrumentation Plan

Need alternative data collection methods

Instrumented Wheel Set

Truck Performance Detector
Alternative Data Collection Methods

• Instrumented Wheel Set
  – Vehicle-mounted; collects data at 300 Hz
  – Measures vertical and lateral loads in tangent, curved, and graded sections

• Truck Performance Detector
  – Wayside detector in tangent and curved sections
  – Measures vertical and lateral loads of each wheel

• UIUC Instrumentation Plan
  – Instrumented track in tangent and curved sections
  – Continuously measures each wheel in multiple locations for vertical load, lateral load, and various deflections
Conclusions

• A clear distinction between dynamic and impact loads should exist

• Colder temperatures do not increase the majority of the wheel loads; stiffer subgrade does increase highest impact loads

• Various dynamic wheel load factors can be compared and evaluated
  – AREMA Chapter 30 Speed Factor may no longer reflect current loading trends

• Impact factor to account for wheel and track irregularities appropriate in many instances; requires further investigation
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- TTX Company

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Questions

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Appendix
Concrete Crossties and Fastening Systems – Characterizing the Loading Environment

Variation of Loads on Amtrak’s Northeast Corridor

Percent Exceeding Peak Vertical Load (kips)

- **Edgewood Locomotives**
- **Edgewood Passenger Coaches**
- **Edgewood Freight Cars**

Source: Amtrak (April 2011)
Future Work

- Further utilize IWS and UIUC data for lateral load information on curved and graded track
- Evaluate Chapter 30 tonnage factor using “dynamic” or “actual” tonnage
- Develop numerical model to predict loading environment
Concrete Crossties and Fastening Systems – Characterizing the Loading Environment

Source: Amtrak – Edgewood, MD (November 2010)
Variation of Loads on Amtrak’s Northeast Corridor

Source: Amtrak (April 2011)
Variation of Loads on Amtrak’s Northeast Corridor

Source: Amtrak (April 2011)
Effect of Traffic Type on Wheel Load

Source: Amtrak – Mansfield, MA (November 2010)
Effect of Speed on Impact Factor

Impact Factor = 1 + \( \frac{33 \times \text{speed}}{100 \times \text{diameter}} \)

Source: Amtrak – Edgewood, MD (November 2010)
Concrete Crossties and Fastening Systems – Characterizing the Loading Environment

Source: Amtrak – Edgewood, MD (November 2010)
Effect of Speed on Impact Factor

\[ \text{Impact Factor} = 1 + \frac{33(\text{speed})}{100(\text{diameter})} \]

Source: Amtrak – Mansfield, MA (November 2010)
Comparison of Dynamic Wheel Load Factors

Speed (mph)

0  20  40  60  80  100  120  140  160

Dynamic Wheel Load Factor

0.0  0.5  1.0  1.5  2.0  2.5

Talbot/Hay
Indian Railways
Eisenmann
Birmann
Effect of Static Load on Impact Factor – Mansfield, MA

Impact Factor ($IF$) = $\frac{\text{Peak Load}}{\text{Static Load}}$

Source: Amtrak – (November 2010)
Impact Loads – Edgewood, MD

Impact Factor (IF) = \frac{\text{Peak Load}}{\text{Static Load}}

Source: Amtrak – (November 2010)
Impact Loads – Mansfield, MA

Impact Factor (IF) = \( \frac{\text{Peak Load}}{\text{Static Load}} \)

Source: Amtrak – (November 2010)
Seasonal Variation of Freight Wheel Loads

Source: Union Pacific – Gothenburg, NE (2010)
Seasonal Variation of Highest Freight Wheel Loads

Source: Union Pacific – Gothenburg, NE (2010)
Concrete Crossties and Fastening Systems – Characterizing the Loading Environment

Variation of Freight Wheel Loads

![Graph showing the variation of freight wheel loads. The graph illustrates the percent exceeding peak vertical load (kips) for different types of freight cars: All Wheels, Locomotives, Intermodal Cars, and Other Freight Cars. The data is sourced from Union Pacific – Gothenburg, NE (January 2010).]
Variation of Freight Wheel Loads

Source: Union Pacific – Gothenburg, NE (January 2010)
Variation of Highest Freight Wheel Loads

Source: Union Pacific – Gothenburg, NE (January 2010)
Load Environment
AREMA Chapter 30 Section 1.2

- **Existing Content:**
  - Expected vertical, lateral, longitudinal loads at wheel/rail interface
  - Table 30-1-1 shows effects of traffic type, speed, and curvature

- **Proposed Improvements:**
  - Generally update based on current loading conditions
  - Complete areas where data are “estimated or interpolated”
  - Provide clearer definition and description of expected loads

- **Methodology:**
  - Use of existing wheel impact load detector (WILD) and instrumented wheel set (IWS) data
  - Define dynamic and impact loads based on data evidence

- **Timeline:**
  - Submit to full committee for ballot (Spring 2013)
Section 1.2 Load Environment

Table 30-1-1 defines the load environment expected to be encountered in North American Freight, High Speed Passenger and Transit Railroad segments of the industry. Specifically, Table 30-1-1 presents the available data in terms of vertical, horizontal and longitudinal loads that can be expected at the wheel/rail interface. The service categories are distinguished as follows. Mainline Freight represents lines other than Light Density Freight. Light Density Freight represents lines with less than five million gross tons and excludes A/C Traction. High Speed Passenger represents passenger loadings whether in mixed service or on dedicated routes. Speeds are given in miles per hour.

Table 30-1-1. Wheel to Rail Loads (kips)

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<td>Lat</td>
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<td></td>
<td>40 to 60</td>
<td>120</td>
<td>30*</td>
</tr>
<tr>
<td></td>
<td>&gt;60</td>
<td>120</td>
<td>30</td>
</tr>
<tr>
<td>Light Density Freight (no A/C Traction)</td>
<td>&lt;40</td>
<td>80</td>
<td>20</td>
</tr>
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<td>40 to 60</td>
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</tbody>
</table>

* This data estimated or interpolated

** Generally accepted superelevation practice excludes these values
Speed Characterization – Edgewood, MD

Source: Amtrak – (November 2010)
Characterization of Speeds on Amtrak’s Northeast Corridor (April 2011)

Source: Amtrak
Concrete Crossties and Fastening Systems – Characterizing the Loading Environment

Speed Characterization – Gothenburg, NE

Source: Union Pacific – January 2010
Seasonal Effects on Peak Vertical Load – Edgewood, MD

Peak Vertical Load (kips) vs Number of Wheels

- November 2010 Locomotives
- November 2010 Passenger Coaches
- November 2010 Freight Cars
- February 2011 Locomotives
- February 2011 Passenger Coaches
- February 2011 Freight Cars
- April 2011 Locomotives
- April 2011 Passenger Coaches
- April 2011 Freight Cars
- August 2011 Locomotives
- August 2011 Passenger Coaches
- August 2011 Freight Cars

Source: Amtrak
Seasonal Effects on Peak Vertical Load – Edgewood, MD

Cumulative Frequency vs. Peak Vertical Load (kips)

- November 2010 Locomotives
- November 2010 Passenger Coaches
- November 2010 Freight Cars
- February 2011 Locomotives
- February 2011 Passenger Coaches
- February 2011 Freight Cars
- April 2011 Locomotives
- April 2011 Passenger Coaches
- April 2011 Freight Cars
- August 2011 Locomotives
- August 2011 Passenger Coaches
- August 2011 Freight Cars

Source: Amtrak
Seasonal Effects on Peak Vertical Load – Mansfield, MA

Source: Amtrak
Variations of Peak Vertical Load by Traffic – Edgewood, MD

Source: Amtrak (November 2010)
Vertical Wheel Loads – Mansfield, MA

Percent Exceeded

Peak Vertical Load (kips)

Source: Amtrak – Mansfield, MA (November 2010)
Distribution of Passenger Wheel Loads

Source: Amtrak – November 2010
Effect of Traffic Type on Static Wheel Load

Source: Amtrak – Edgewood, MD (November 2010)
Effect of Traffic Type on Peak Wheel Load

Source: Amtrak – Edgewood, MD (November 2010)
Load Effects on Impact Factor – Edgewood, MD (November 2010)
Effect of Speed on Lateral Load – Edgewood, MD (November 2010)
Effect of Speed on L/V Ratio – Edgewood, MD (November 2010)
Frequency of Peak Vertical Loads

Source: Union Pacific – Gothenburg, NE (January 2010)
Where the WILD Things Are

- Mansfield, MA (1)
- Enfield, CT (2)
- Hook, PA (3)
- Edgewood, MD (4)

Source: University of Virginia
Union Pacific Railroad Current and Proposed WILD Site Locations

All Sites (With the Exception of Fields, OR) Provide Vertical and Lateral Measurements

- In Service WILD Locations
- Parsons Sub WILD .. Under Construction
- Proposed WILD Installations - 2008 and Beyond
- Truck Performance Detector (TPD) Location(s)
Concrete Crossties and Fastening Systems – Characterizing the Loading Environment

- L/V Force Ratio vs Distance (feet)
- #60 A L/V (L)
- #60 B L/V (R)