Mechanistic Investigation of Timber Crosstie Spike Failures

Matheus Trizotto, Tom Roadcap, Marcus Dersch, J. Riley Edwards

University of Illinois at Urbana-Champaign
Acknowledgements

► Project Sponsor:

U.S. Department of Transportation
Federal Railroad Administration

► Industry Partnership:

NORFOLK SOUTHERN

CSX

BNSF

VOSSLoh

Progress Rail

PANDROL

BUILDING AMERICA

UNION PACIFIC

LEWIS

BOLT & NUT COMPANY

North America

A Caterpillar Company
Project Overview

► **PHASE I:** How large is the problem?
  - Industry Survey
  - Interviews and Site Visits
  - Document scope of the problem
  - Hypotheses about spike breakage

► **PHASE II:** What is causing spike failures?
  - Execute laboratory experimentation plan developed in PHASE I
  - Attempt to replicate failures in the laboratory
  - Develop and perform parametric analyses with FE models of fastening systems
  - Validate models with laboratory work

► **PHASE III:** How do we prevent the failures?
  - Perform additional lab tests/FEA as needed
  - Investigate design improvements
  - Recommend improvements
Types of Fastening Systems

Traditional or Conventional

Premium or Elastic
Challenges: Broken Spikes

► Spike failures are not limited to a particular type of elastic fastener or spike
Broken Spike Derailments

- Fabyan, AB - 2012 (TSB Canada)
- Mosier, OR - 2016 (Sean Aiken)
- Vandergrift, PA - 2014 (Brad Kerchof)
- Glacier Park, MT - 2006 (BNSF)

- 11 derailments since 2000
- All track sections had complied with regulatory requirements
Industry Survey Overview

► **Survey Objective:** Collect information about the scope of the broken spike problem and data to focus the future phases of the project

► 8 out of 9 agencies reported broken spike problems

► All railroads:
  • Identified tight curves and new ties as major problem areas
  • Saw rapid gage deterioration and inspection challenges as key concerns

► Most railroads:
  • Saw broken spikes partially or primarily in premium systems
  • Saw breakage as a moderate to serious problem
  • Did not identify a strong seasonal correlation with spike breakage

► One railroad:
  • Does not have many premium fasteners installed on the system
  • Saw the problem as a relatively small one
  • Has long-standing experience with the issue
  • Has wintertime GRMS testing to locate broken spikes
Field Visits and Derailment Locations

- Collect data about the characteristics of locations with and without broken spikes and maintenance practices
- Visited various railroad companies, using different fasteners
Summary of Field Visits

- Broken spikes were found:
  - Primarily on *premium fastening system*
  - Often *new ties*
  - Mainly on *curves*, but also in *special trackwork*
- Often in the same curves and even the same spike holes
- Broken spikes found both individually and in clusters
- Gage irregularity, curve grease build-up, and false-flange wear often found around clusters of broken spikes
- Identifying broken spikes is time and labor intensive
  - Temperature affects how easily they are identified
  - Screw spikes generally harder to remove than cut spikes
Potential Driving Factor: Longitudinal Load

► The effect of no rail anchor and elastic fastener: higher spike stress

Traditional System with Rail Anchor

\[ F_{\text{Rail-Tie}} = F_{\text{Anchor}} + F_{\text{Spikes}} + F_{\text{Plate-Tie Friction}} \]

Premium System

\[ F_{\text{Rail-Tie}} = F_{\text{Spikes}} + F_{\text{Plate-Tie Friction}} \]
Evidence of High Longitudinal Forces
Compounding Factor: Rail Uplift

- Rail uplift reduces or eliminates plate-crosstie friction

\[ F_{\text{Rail-Tie}} = F_{\text{Spikes}} \]
Video 1: Uplift in a Premium System
Video 2: No Uplift in a Traditional System
Potential Driving Factor: Lateral and Longitudinal Stiffness

**Key idea:** stiff fastening system spreads load over fewer ties

**Lateral direction**
- Premium systems allow less rail head deflection than traditional systems
- This results in rail movement being confined to fewer ties
- Spikes in loaded ties have to take more stress

**Longitudinal Direction**
- Track with traditional plates and anchors:
  - Some longitudinal rail movement allowed
  - More ties absorb longitudinal load (low longitudinal stiffness)
  - Lower fastener-to-tie forces on an individual tie
- Track with premium fasteneners:
  - Little longitudinal rail movement due to clamping force
  - Fewer ties can absorb longitudinal load (high longitudinal stiffness)
  - Higher fastener-to-tie forces on an individual tie ( = spike breakage)
Stress in Spikes – Hypothetical Graph

Total Stress into Spikes

Threshold Stress for Spike Failure

Traditional Systems

Longitudinal

Lateral

Anchor Tangent Flat

Anchor Curve Grade

Anchor Curve Grade (extreme case)

Premium Systems

Longitudinal

Lateral

No Anchor Curve Grade

Anchor Curve Grade

Total Stress into Spikes

Threshold Stress for Spike Failure

Traditional Systems

Longitudinal

Lateral

Anchor Tangent Flat

Anchor Curve Grade

Anchor Curve Grade (extreme case)

Premium Systems

Longitudinal

Lateral

No Anchor Curve Grade

Anchor Curve Grade

RailTEC at Illinois | 16
Longitudinal load is more detrimental than an equivalent lateral load
- This is due to the timber being less resistant on that direction
- This finding supports the theory that spike failures in premium fastening systems are primarily related to longitudinal loads

Stress can exceed the fatigue limit of spike steel at regular service loads

Max. stress depth varies with the magnitude and direction of applied load
Phase II Finite Element Model

- Improve upon basic model developed in Phase I
  - Calibrate and validate model with laboratory data
  - Incorporate anisotropic behavior beyond timber yield with subroutines

- Potential variables to investigate
  - Timber and steel properties
  - Fastening system clamping force
  - Spike hole shape/condition
  - Spike skew
  - Spike placement within fastening system
  - Spike size
Phase II Laboratory Investigation

Understanding Fastener Mechanics

► Single spike testing
► Single system longitudinal load test
► Full-scale track tests
Phase II Field Instrumentation Plan

► Data to be collected
  • Loading environment (Vertical, Lateral, Longitudinal)
  • Rail and fastener displacements
Acknowledgements

► Project Sponsor:

U.S. Department of Transportation
Federal Railroad Administration

► Industry Partnership:
Thank you for your attention!

Matheus Trizotto  
Graduate Research Assistant  
trizott2@Illinois.edu

Tom Roadcap  
Graduate Research Assistant  
roadcap2@Illinois.edu

Marcus Dersch  
Senior Research Engineer  
mdersch2@Illinois.edu

University of Illinois at Urbana-Champaign (UIUC)  
Rail Transportation and Engineering Center (RailTEC)

This project is supported by the National University Rail Center (NURail),  
a US DOT-OST Tier 1 University Transportation Center