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BROKEN SPIKES
Research shows a certain type of fastener is behind damaged spikes

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SPIKED!

Broken spikes continue to cause problems on the rails, and the focus is on the fastening systems

By Marcus Dersch, Tom Roadcap, and Riley Edwards

At least 10 mainline derailments have been caused by wide gauge due to broken cut spikes or screw spikes since 2000 (Figure 1). Several recent derailments have brought attention to the problem of broken spikes. Notable derailments include major oil train derailments in 2014 and 2016 and an Amtrak derailment in 2009.

Spikes typically break 1.5 in. beneath the top of the tie but continue to sit within it once broken, often making visual inspection impossible. Derailment reports show that broken spikes can be present in track that has previously met relevant standards.

Many spike failures occur in premium elastic fastening systems. Premium fastening systems use a clip to clamp the rail to the tie plate, and spikes or screws are used to hold the tie plate to the timber crosstie. These premium systems are popular because they offer increased resistance to rail rollover, improved gauge-widening resistance, and typically do not require rail anchors to control longitudinal rail forces.

The University of Illinois (UIUC) researchers completed the first phase of an investigation into timber crosstie spike fastener failures on North American railroads in 2018. This investigation, funded by the Federal Railroad Administration (FRA), and supported by multiple Class 1 railroads, included a review of derailment reports and literature, an industry survey, and an extensive program of field visits to determine the extent of spike failures in track and to characterize the track conditions where these failures occur. In addition, UIUC has developed a validated finite element model (FEM) to better understand the spike failure modes and the underlying causes. The investigation discovered that spike failures are prevalent in the industry and pose a significant risk to railroad operations.

Gathering Data

UIUC designed an industry survey to learn more about the magnitude of spike failure problems. The survey contained questions about the magnitude of the failures, where and when spike breakage occurs, and how railroads are currently locating and mitigating spike failures. Twenty-four responses were received from employees at nine railroads/agencies: Amtrak, BNSF Railway (BNSF), Canadian National Railway (CN),

Figure 1. Premium elastic fastener with five broken spikes and broken lag screws in McKay fastening system.

CSX, Kansas City Southern Railway, Norfolk Southern Corporation (NS), Southern California Regional Rail Authority (SCRRA), Transportation Technology Center, Inc. (TTCI), and Union Pacific Railway (UP). Respondents were primarily track standards engineers or maintenance-of-way field managers.

Field visits were used to complement and further investigate the survey results. Researchers visited many, geographically different locations on four Class 1 railroads (BNSF, CSX, NS, and UP). These field visits involved inspecting track with a history of spike failures and interviewing field maintenance personnel and track standards engineers about their experience with spike failures. UIUC collected information about the grade, curvature, traffic characteristics, track conditions, fastening system characteristics, climate, maintenance practices, etc., to help identify trends and conditions that lead to failures.

Premium Problems

A literature review found evidence of broken spikes as early as 1915, though the problem has become more pronounced with the recent adoption of premium fastening systems. Testing conducted at the Transportation Technology Center (TTC) between 1978-1979 found broken spikes to be a problem in premium fastening systems. Subsequent tests at the TTC have found similar problems with broken lag screws and spikes. Dick et al. (2007) studied spike stresses in screw spikes and found that stresses may be unevenly distributed among spikes in a plate. Gao et al. (2018) used a NUCARS® model and finite element analysis to investigate the effects of rail uplift and spike contact position on spike stress.

The literature review, derailment reports, and field visits reveal that spike failures occur in a variety of fastening systems, regardless of spike type (cut, screw, hair-pin, etc.), geometry, steel properties, or manufacturer. Spikes have broken in multiple, different fastening systems on multiple railroads. This suggests that spike failure is a mechanism problem due to a certain stress condition, and not a material problem or a matter of manufacturing defects.

Eight of the nine railroads responding to the survey had experienced broken spike problems in some form.

When asked if the problem was a relatively small, moderate, or large problem compared to other track-related challenges, opinions were divided equally among the severity levels.

Respondents expressed concern over the challenges of inspecting for broken spikes (walking curves, tapping every spike) and the rapid gage deterioration that can occur in broken spike clusters. One respondent said, "On several heavy tonnage, steep grade territories, broken spikes are the problem that represents the greatest risk to the safety of train operations."

Field interviews shed light on the amount of time maintenance-of-way crews spend on locating and fixing broken spikes (Figure 4).

Railroads rely on manual methods performed by experienced personnel to locate broken spikes before they lead to defective conditions. At present, there is no reliable, automated inspection method for identifying broken spikes. This could change in the future given the FRA's current call for proposals for improved broken spike inspection methods.

Researchers found locations with single broken spikes and other locations with clusters of broken spikes, including consecutive ties with multiple broken spikes. The most severe site had 121 broken spikes in length of 150 ties along the high rail.

Researchers developed a set of mechanistic hypotheses about the causes of spike breakage based on the results of the literature review, survey, and field visit data. As shown in Figure 5, in a traditional fastening system with cut spikes and anchors, spike stresses tend to increase with greater curvature (lateral forces), and in extreme cases this may cause spike breakage. It is theorized that premium fastening systems further increase spike stress because they do not use rail anchors to transfer longitudinal load into the ties. The longitudinal force is carried by the fasteners. Finally, premium fasteners are thought to be stiffer in both the lateral and longitudinal directions, further increasing spike stress by reducing the number of ties over which loads are distributed.

A validated FEM was developed and used to investigate the effect of load direction and magnitude as well as timber type on spike stress. It was found that longitudinal load has a more detrimental effect on spike stress than lateral load given the timber grain is weaker when resisting longitudinal loads (perpendicular to grain) than lateral loads (parallel to grain). To exceed the fatigue strength of the cut spike, a longitudinal load approximately 30 percent lower than a lateral load would be applied. Additionally, loading direction significantly effects the depth to maximum stress; longitudinal loads create deeper failures. Further, timber species significantly affected the magnitude and depth of maximum stress. It is believed that the timber mechanical properties driving this are compressive, tensile, shear, and rolling shear strengths. Therefore, when using premium fastening systems, specifications should recommend as high of strengths as locally sourced timber can provide.

A Broken Risk

The results of this investigation provide evidence that broken spike conditions are present in North American railroad track and pose a risk to rail safety. Additional research is needed to determine the root cause(s) of spike failures and to develop solutions that will prevent future failures.

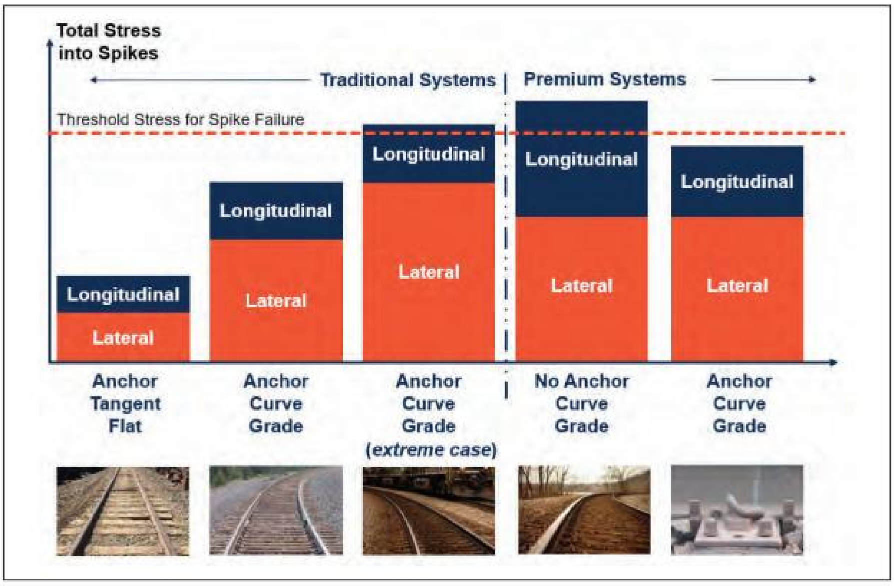

Figure 5. Hypothetical graph showing relation of spike stress to curvature, grade, and fastener type.

Still Working

As part of Phase 2 of this project, RailTEC is currently conducting laboratory experimentation to examine fatigue performance of spikes and load transfer in various fastening systems with success in recreating failures in the lab. Additionally, field experimentation is planned to quantify the load

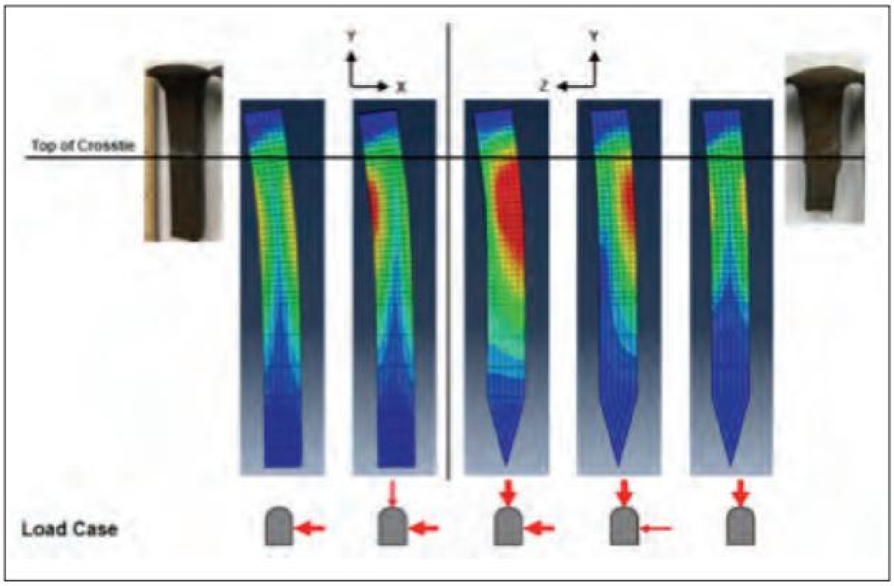

Figure 6. Preliminary qualitative FEM stress results with varying load cases.

environment and fastener response when subjected to revenue service traffic. And finally, the finite element modelling is being continued to further quantify the effects of crosstie, spike, and fastening system properties and geometry on failure. With the goal of improving fastener designs and/or installation and maintenance practices to prevent spike failures these efforts will serve the industry by reducing derailment risk and reducing track maintenance and repair costs.

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