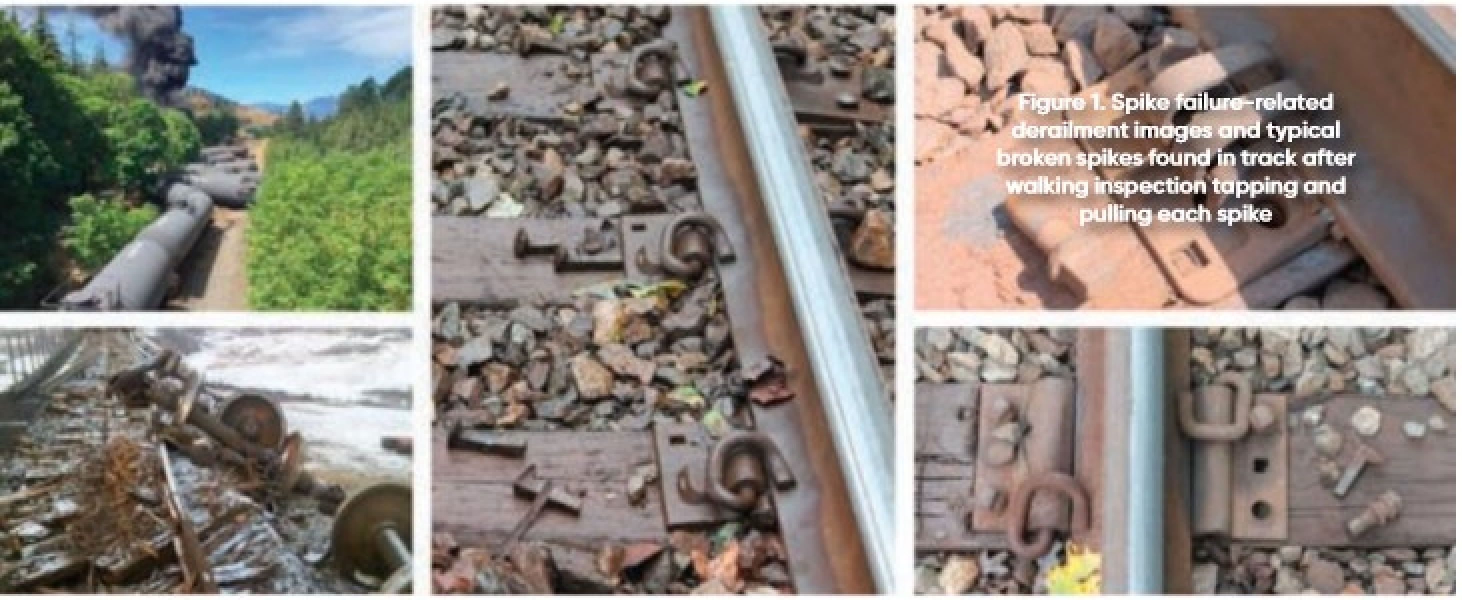

Figure 1. Spike failure-related derailment images and typical broken spikes found in track after walking inspection tapping and pulling each spike

Photo Credit: RailTEC

MADE *ELASTIC*

Broken spikes created by elastic fastening systems

By Marcus Dersch, Cameron Stuart, Arthur de O. Lima, and Riley Edwards, Contributing Authors

The Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana-Champaign (Illinois) has continued a comprehensive investigation into timber crosstie spike fastener fatigue failures. As documented in the July 2019 *RT&S* article "Spiked!", these spike failures are primarily found in track constructed with elastic fasteners and located in high-degree curves with grades (Figure 1 above). These failures have caused at least 10 recent mainline derailments, including oil train derailments in 2014 and 2016 and an Amtrak derailment in 2009.

RailTEC continued its investigation to isolate the root cause of these spike failures and to develop and test mitigation measures, with sponsorship from the Federal Railroad Administration (FRA) and support from the Volpe Center and AAR/TTCI. Activities included:

1. Field experiments with Norfolk Southern to quantify the load environment and train operational characteristics at a track location with a history of spike failures;
2. Laboratory experiments and finite element modeling (FEM) to identify fastening system and crosstie characteristics that reduce spike stresses and failures; and
3. Testing at the Transportation Technology Center (TTC) to demonstrate the performance of spring washers to improve plate-to-crosstie contact that reduce spike failure.

The research data and analysis reveal that these spikes are failing due to fatigue from longitudinal loads transferred to the spikes through the elastic fastening system. This longitudinal load is in addition to the lateral load carried by the spikes and is made worse due to the loss of friction between the plate and crosstie from uplift forces ahead of loaded wheels (Figure 2).

This plate-to-tie friction is critical to the load-carrying capacity of the elastic fastening system. Elastic fasteners clamp the rail to the tie plate and spikes clamp the tie plate to the crosstie. Vertical rail uplift forces ahead of and behind loaded wheels can degrade spike clamping performance, resulting in plate uplift (loss of friction), excessive spike loads, and eventual spike fatigue failure. Timber crosstie strength also influences spike stress. Timber crossties are approximately 10 times weaker across the grain (i.e., longitudinal load direction) than with the grain (i.e., lateral load direction). When the timber crushes, the spike stress increases.

RailTEC identified and tested methods to reduce spike stresses and eliminate or reduce spike fatigue failures. This work yielded effective strategies that railroads can implement to improve operational safety and increase track resilience:

- Train operations: Operate at or near balanced speed or re-balance the curve to match train speeds and employ distributed power to maintain vertical loads on tie plates;
- Fastening system designs: Ensure plate-to-crosstie friction using screw spikes and spring washers or other methods; and
- Crosstie properties: Consider engineered composite crossties with increased mechanical properties to strengthen the spike support structure.

A problem with the curve

Trains operating above or below track balanced speed can increase spike loads and spike failure rates. Underbalance operations tend to unload the high rail in a curve, reducing plate-to-tie friction.

Working with Norfolk Southern, RailTEC instrumented track to quantify the vertical, lateral, and longitudinal loads on Tracks 1 and 3 in the full body of a 9.2° (623-ft [190-m] radius) curve located near Altoona, Pa. At the time of the test (July 2019), the curve supported three timber tie tracks employing elastic fasteners with cut spikes. Figure 3 describes the test location and instrumentation.

This curve is located on a 1.76% grade. Loaded freight trains primarily operate downhill on Tracks 1 and 2, while empty trains run uphill on Track 3. Tracks 1 and 3 each accrue approximately 50 MGT annually. Spike fatigue failures are frequently observed along the high rail of Track 3, but infrequently on Track 1. Measurements of rail forces during train passes between the two tracks revealed significantly different loading conditions.

Figure 2. Examples of plate-to-tie uplift and of damaged spike.

Data revealed underbalance speed train operation on Track 3, reducing the vertical rail load on the high rail and thus reducing plate-to-tie friction. Track 1 operations are near balance speed, resulting in more even loads between low and high rails (Figure 4, left). Combining these field data with modeling failure thresholds (Figure 4, right) illustrates the impact of unbalanced operation on spike failures.

The two lines represent the modeled spike failure thresholds for Track 1 (blue) and Track 3 (red) based on a combined lateral and longitudinal loading condition. The data points are field data from Track 1 (blue) and Track 3 (red). The points represent the 50th, 90th, 95th, and 99th percentile lateral and longitudinal field loading data. All Track 1 data are contained within the boundaries of the blue line—indicating that forces are below the failure threshold. Meanwhile, some Track 3 high rail datapoints extend beyond the boundaries of the red line—forces exceed the failure threshold. The unbalanced operating condition on Track 3 unloads the high rail, reducing the plate-to-tie friction and transferring excessive loads to the spikes.

Trains operating uphill on Track 3 are normally configured with multiple locomotives at the head end. RailTEC analyzed the effect of multiple locomotives, with all axles operative and providing tractive effort. The superposition of wheel forces from the locomotives has a cumulative effect on the longitudinal rail seat loads, and the modeling results show that the peak load is between adjacent powered locomotives (Figure 5, left). This superposition is reduced or eliminated when locomotives are separated within the train consist. The longitudinal rail seat load is reduced by 40% when locomotives are separated by just one unpowered railcar (Figure 5, right). RailTEC plans to validate these results with future field data.

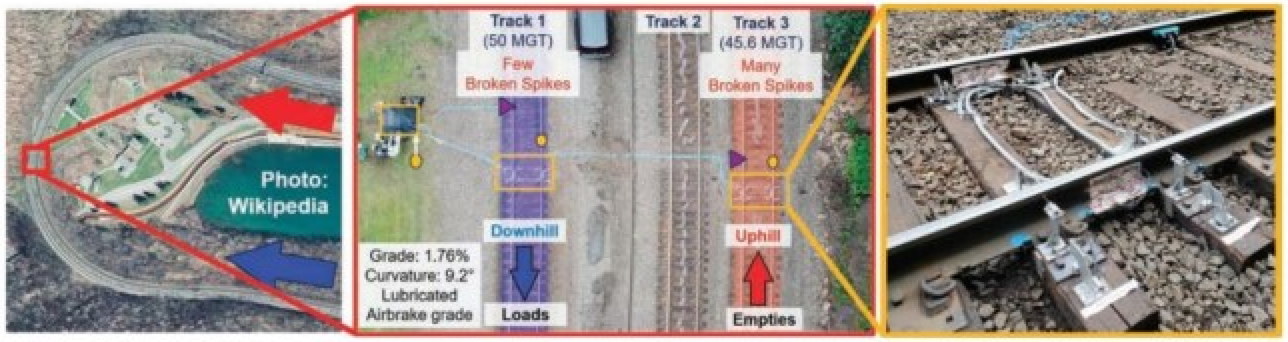

Photo Credit: RailTEC

Figure 3. Aerial views of the test site with relevant track geometry and operations information (left and middle) and instrumentation on Track 3 (right), July 2019.

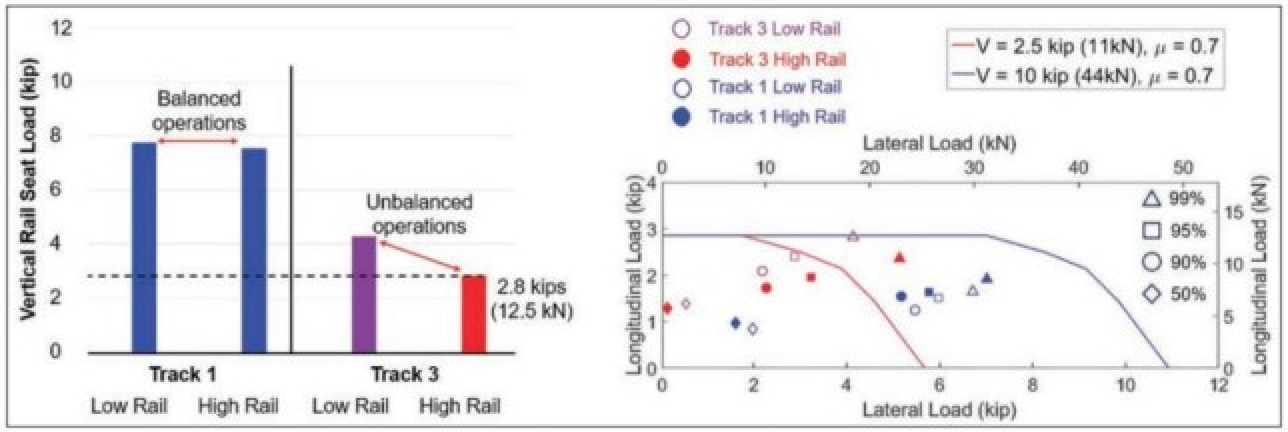

Figure 4. Median vertical rail seat load data (left). The effect of train balance speed on spike loads and failure thresholds (right).

The hold-down force

Fastening system design also plays a role in spike failures. Research results from field tests, laboratory experiments, and modeling show that spike stresses are significantly reduced when there is friction between the tie plate and the crosstie.

Figure 6 illustrates the importance of the plate-to-tie hold-down force in reducing spike stresses. The left graphic shows the model data comparing the relative impact of hold-down force on spike stress in a four-spike plate arrangement loaded to 2,500 lb. Spike stresses are much higher with zero hold-down force and much lower with 4,000 lb of hold-down force. Stress levels did not change appreciably with higher hold-down force. Laboratory test data confirm the modeling results and the influence of vertical load (Figure 6, right). The hold-down force ensures that plate-to-tie friction is helping the fastening system carry the train loads. This friction can reduce spike stresses by up to 80%.

With assistance from TTCI, RailTEC completed a field test at the Facility for Accelerated Service Testing (FAST) at TTC to compare the performance of a cut spike elastic fastening system and an elastic system employing screw spikes and spring washers.

The test was conducted in a track section with a history of spike failures and consisted of a 20-tie control zone with cut spike fastening systems adjacent to a 30-tie test zone with a screw spike/spring washer system (Figure 7). The test accumulated 170 MGT under FAST train loading.

TTCI conducted periodic visual inspections to document the performance of the fastening systems, the results of which are displayed in Table 2. The control zone accumulated six broken spikes during the test, while the test zone had none. The control zone showed evidence of plate movement, spike uplift, and crosstie skew. The test zone had no indication of plate movement and had minimal crosstie skewing. There was very minor spring washer loosening in three locations after 60 MGT and additional loosening after 170 MGT, indicating the likely need for periodic fastening system maintenance. These results confirm the positive effect of plate-to-tie friction in reducing spike stresses.

Reducing the strain

Timber crossties are mechanically stronger in the lateral direction (i.e., along the wood grain) than in the longitudinal direction (i.e., across the grain). Spike loads can crush wood fibers around the spike holes, enlarging the holes and reducing spike support. RailTEC research shows engineered composite crossties are up to six times stronger than timber crossties in supporting longitudinal loads. An engineered composite crosstie with targeted, isotropic compressive strength properties can improve the load-carrying capacity of the crosstie and maintain good support for the spikes.

RailTEC performed laboratory experiments with instrumented spikes and modeling to study an engineered, glass fiber reinforced composite (GFRC) crosstie with isotropic compressive strength properties. The experimental data show a 30% reduction in spike strain at critical depths compared to the same test with a timber crosstie (Figure 8). In addition, fatigue testing, with 2,200-lb longitudinal loads and up to 5.5 million cycles, resulted in multiple spike failures in timber crossties and no failures in the GFRC crossties.

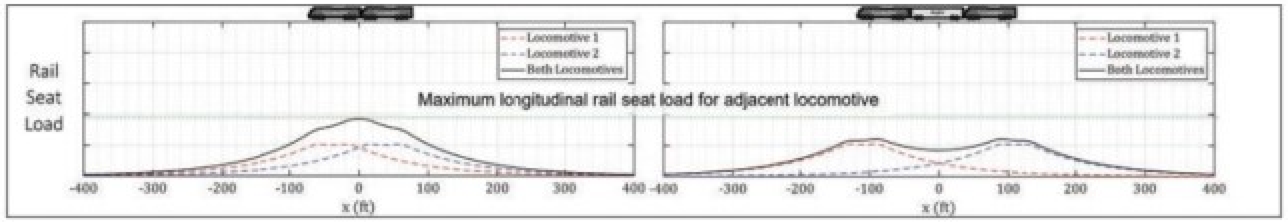

Figure 5. Modeling of longitudinal rail seat loads with adjacent locomotives (left) and separated locomotives (right).

Photo Credit: RailTEC

These data indicate that a carefully engineered composite crosstie provides better support for the spikes and may reduce the chances of spike failures in track.

Conclusions

Spike fastener fatigue failures in elastic fastening systems pose a risk to rail safety. RailTEC research identified the root cause of spike failures and explored ways to mitigate spike failures by reducing the loads carried by spikes. The rail industry can employ several practical mitigation methods to improve the safety and reliability of elastic fastening systems in timber crosstie track. Our suggestions include:

- Operate trains at, or near, the balanced speed of track to eliminate plate unloading, loss of plate-to-tie friction, and the resulting high stress on spikes. Or ensure curves are properly balanced for predominant train operations;
- Avoid superposition of longitudinal rail seat forces by distributing locomotive tractive effort throughout the train. A single, unpowered buffer car placed between two locomotives at the head end of a train can reduce longitudinal fastener loads by 40%;
- Maintain plate-clamping forces with improved components. RailTEC data shows even a relatively small plate-to-crosstie hold-down force can reduce spike forces up to 80%; and
- Consider engineered composite crossties for track segments prone to broken spikes. Crossties with a compressive strength of at least 2,225 psi can reduce spike strains by up to 30%.

RailTEC continues to work with FRA and industry partners to test these mitigation strategies in the field. These efforts are expected to serve the industry by improving track safety and reliability. Select references for this work are provided below. For additional questions or more information about this work, visit railtec.illinois.edu or contact RailTEC Principal Research Engineer Marcus Dersch at mdersch2@illinois.edu.

Acknowledgements

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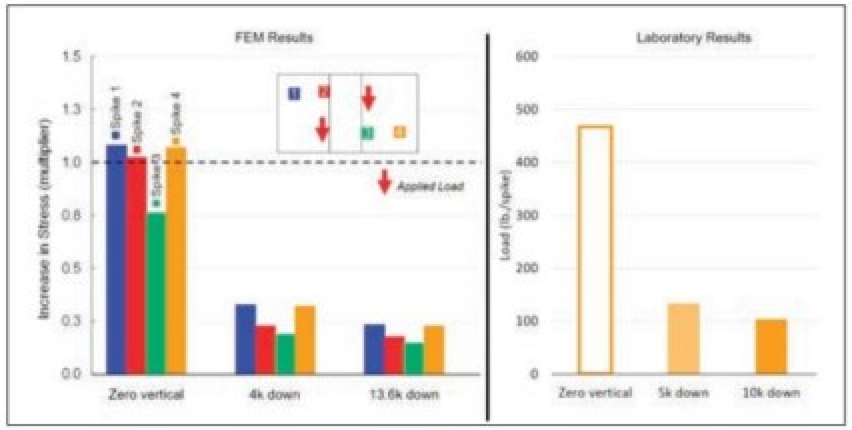

Figure 6. Effect of plate hold-down force on spike stresses—modeling (left) and laboratory (right).

Photo Credit: RailTEC

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Figure 7. Transition between control zone (left) and test zone (right) at TTC FAST, 2019–2020.

Photo Credit: RailTEC

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Table 1. Overview of Inspection Results

	Control Zone	Test Zone
Plate Cutting	Minimal	None
Broken Components	6 broken spikes	None
Loosened Components	Spike uplift	3 spikes at 60 MGT; Additional spikes at 170 MGT
Plate Movement	Some evidence	None
Skewed Crossties	Many ties, significant	2 ties, minimal

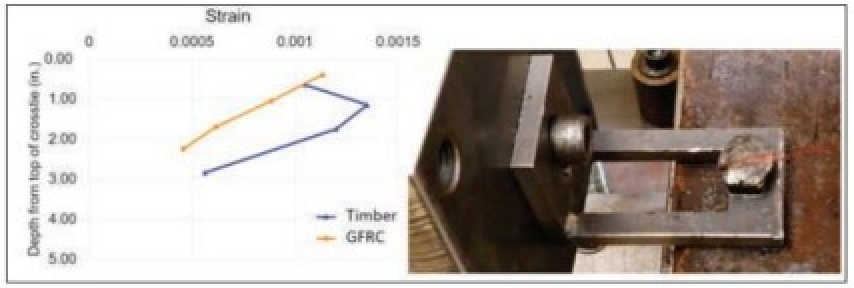

Figure 8. Spike strain data for timber and GFRC composite crossties (left) and instrumented spike installed in timber crosstie (right).

Photo Credit: RailTEC