MADE ELASTIC

Broken spikes created by elastic fastening systems

By Marcus Diesch, 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 crook set fastener fatigue failures. As documented in the July 2019 RT65 article "Spikes!" these spikes 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 2006.

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/RT65. Activities included:

1. Field experiments with Norfolk Southern to quantify the headed 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 crookset characteristics that reduce spike stresses and failures;
3. Testing at the Transportation Technology Center (TTC) to demonstrate the performance of spring washers to improve plate-to-crookset 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 crookset 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 crookset. 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 crookset strength also influences spike stress. Timber crooksets are typically 10 mm weaker across the grain (i.e., longitudinal load direction) than with the grain (i.e., lateral load direction). When the timber crookset, 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 the plate-to-tie friction and transferring excessive loads to the spikes.
- Trains operating above or below track balanced speed can increase spike loads and spike failure rates. Underbalanced operations tend to unload the high rail in a curve, reducing plate-to-tie friction.

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 represent the 50th, 90th, and 99th percentile lateral and longitudinal load data points. Track 3 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.

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

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 importance 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 forces, but more 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 TTI, RaITEC 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.

Reducing the strain
Timber crossings 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. RaITEC research shows engineered composite crossings are up to six times stronger than timber crossings in supporting longitudinal loads. An engineered composite crossing with targeted, isotropic compressive strength properties can improve the load-carrying capacity of the crossing and maintain good support for the spiked.

RaITEC performed laboratory experiments with instrumented spikes and modeling to study an engineered, glass fiber reinforced composite (GFRC) crossing with isotropic compressive strength properties. The experimental data showed a 30% reduction in spike strain at critical depths compared to the same test with a timber crossing (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 crossings and no failures in the GFRC crossings.

The results confirm the positive effect of plate-to-tie friction in reducing spike stresses.

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

**Conclusions**
Spike failure fatigue failures in elastic fastening systems pose a risk to rail safety. RaITEC 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 crossings. Our suggestions include:

- **Operate trains at or near the balanced speed of track to eliminate unloading, loss of plate-to-tie friction, and the resulting high stress on spikes.**
- **Ensure curves are properly balanced for pre-emption train operations.**
- **Avoid superposition of longitudinal rail seat forces by distributing locomotive inertial forces evenly throughout the train.**
- **Use an equalizer bar placed between two locomotives at the head end of a train to reduce longitudinal forces by 40%.**
- **Consider plate-clamping forces with improved components.**
- **Consider engineered composite crossings for track designs prone to broken spikes.**
- **Consider engineered composite crossings for track segments prone to broken spikes.**

RaITEC continues to work with FRA and industry partners to test these mitigation strategies in the field. These efforts are expected to improve rail safety and reliability.

**References**

Table 1. Overview of Inspection Results

<table>
<thead>
<tr>
<th></th>
<th>Control Zone</th>
<th>Test Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate Cutting</td>
<td>Minimal</td>
<td>None</td>
</tr>
<tr>
<td>Broken Components</td>
<td>6 broken spikes</td>
<td>None</td>
</tr>
<tr>
<td>Loosened Components</td>
<td>Spike uplift</td>
<td>3 spikes at 60 MGT; Additional spikes at 170 MGT</td>
</tr>
<tr>
<td>Plate Movement</td>
<td>Some evidence</td>
<td>None</td>
</tr>
<tr>
<td>Skewed Crossties</td>
<td>Many ties, significant</td>
<td>2 ties, minimal</td>
</tr>
</tbody>
</table>

Figure 8. Spike strain data for timber and GFRP composite cross ties (left) and instrumented spike installed in timber cross tie (right).

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

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