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Investigation of Broken Spikes on Elastic Fastener Tie Plates Using Modeling Techniques

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Transportation Technology Center, Inc (TTCI) investigated an elastic fastening system that uses elastic clips and cut spikes in order to identify the root causes of broken spikes, to understand the stress level and distribution in the broken spikes, and ultimately prolong the service life of this elastic fastening system. NUCARS®* modeling and finite element analysis (FEA) were performed. The NUCARS® model comprised a detailed multi-body train, wheel-rail contact parameters, and a track model to estimate the dynamic loading environment of the fastening system. This loading environment was then replicated in an FEA model of the track structure (ties, tie plates, and cut spikes). The stresses of the cut spikes generated in these simulations were compared to broken cut spikes in revenue service.

The most common tie and fastener system used on North American freight railroads is a conventional AREMA rolled steel tie plate and cut spikes to fasten the rail to a solid sawn timber tie. In more severe loading environments (high-degree curves, high grades, and high tonnages), elastic clips are often used to fasten the rail to a specially designed tie plate. The tie plates can be restrained by either cut spikes or threaded screw or drive spikes. Mechanically, these systems behave differently than cut spike-only systems in that the rail is elastically fastened to the tie plate. In high degree curves, elastic fasteners have been shown to reduce gage widening and decrease the potential for rail roll compared to cut spike-only systems.[1]

However, recent field inspections in mountainous, high degree curve territory on one Class I railroad have found a higher frequency of broken cut spikes when used with these types of elastic fastener tie plates compared to conventional AREMA plates with cut spikes.[1]

INTEGRATED MODELING TECHNIQUE FOR BROKEN SPIKES

TTCI used the following two integrated steps in the modeling methodology:

1. A NUCARS® vehicle-track dynamics model to obtain the rigid body motion of a rail-fastener-tie system under dynamic loading.
2. An FEA model incorporating modeling results from the first step to simulate the detailed loading environment of individual cut spikes in the system.

Key Findings:

- The stress level in the cut spikes in a curve can be high enough to generate fatigue cracks. In addition, the spike position in spike holes (centered, contacting faces, skewed) appears to affect the estimated stress levels in the spikes.
- Broken cut spikes may be caused by a combination of lateral and longitudinal forces that are transferred into the fastening system.
- When tie plates are firmly attached to the rails, for example by the elastic fasteners, the tie plates can move with the rails vertically, laterally, and longitudinally; unlike the conventional cut spike-only system with rail anchors. This mechanism might allow more wheel-rail forces to be transferred into the spikes in the elastic fastener system.

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*NUCARS® is a registered trademark of TTCI

Vehicle Dynamics Model

NUCARS® is a general multi-body rail vehicle dynamics computer simulation model developed by TTCI. A multi-layer model (vehicle-rail-plate-tie) was built to investigate the relative vertical movement of each component under dynamic train loading. Rails, ties, and tie plates were connected by springs and dashpots. Since elastic fastener tie plates were being simulated, the tie plates in the model were directly fixed to the rails during upward displacement. Tie bending and compressive stiffnesses were determined using historical data from standard AREMA tests for wood ties.[2]

Figure 1 shows a simplified case in which a 286-kip hopper car was run at 40 mph on tangent track, and the modeling results confirm that the tie plates have a dynamic uplift before and after consecutive truck (wheel pairs) pass, and the tie uplift is negligible. The plate uplift is the result of the elastic clips holding the plates firmly to the rail.

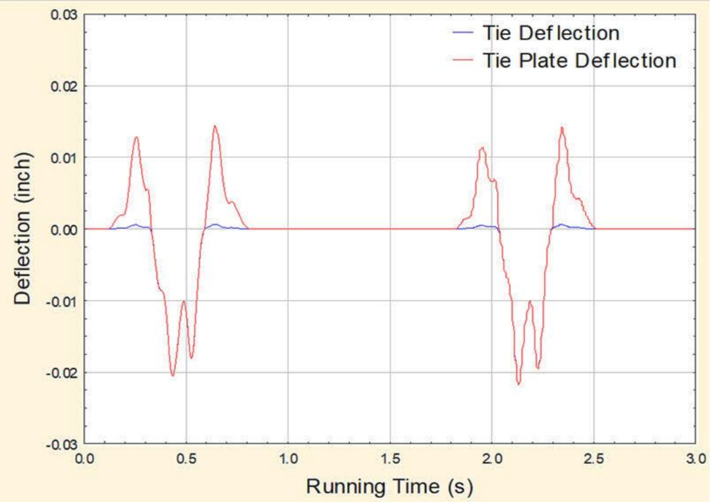


Figure 1. Relative deflection of tie and tie plate

Similarly, the tie plates will move with the rail laterally and longitudinally once the rail moves. This mechanism is not thought to occur on conventional cut spike-only systems, as there is no positive clamping force between the rail and the tie plate.

With the dynamic mechanism further understood, subsequent FEA modeling allows the effect of this mechanism on individual cut spikes to be examined. The vertical and lateral wheel loads generated by NUCARS® were used as inputs in the FEA model.

FEA Model

To understand the transfer of dynamic loading into cut spikes installed on elastic fastener tie plates, FEA was conducted. The FEA model (Figure 2) was built including a nine-tie track panel with two rails, tie plates, ties, and cut spikes. Rails and tie plates were bonded to each other to simulate the elastic fastening, and a frictional contact was established between tie plates and ties. The simulation used a conservative 36-kip vertical load and an 18-kip lateral wheel load (0.5 L/V ratio) generated by NUCARS®, coupled with a 7.5-kip longitudinal load applied to the head of the rail, directly over the tie. The longitudinal load of 7.5 kips was chosen as a conservative estimate of tractive or braking forces applied by a locomotive and thermal forces in the rail.[3]

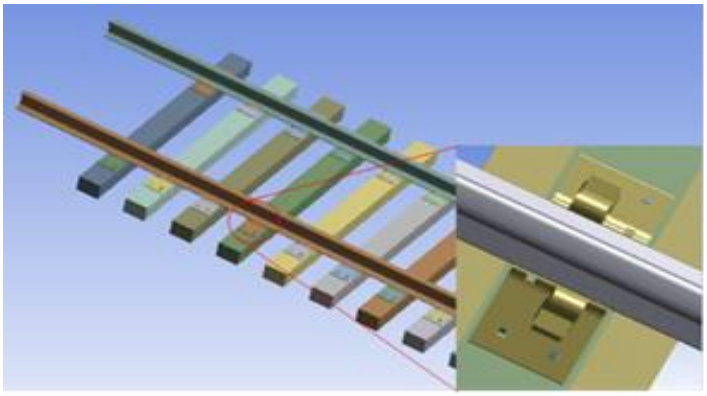


Figure 2. The schematic of the FEA model

Due to typical inconsistencies in spike installation and the movement of tie plates under dynamic loading (confirmed above), spikes could be oriented in a variety of positions relative to the tie plate spike holes. Different positions appear to result in significantly different spike loading environments. Table 1 shows the four spike-plate loading environment cases that were considered in the FEA model.

Table 1. Possible spike positions with different loading conditions

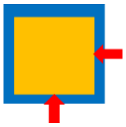
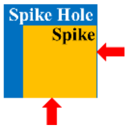
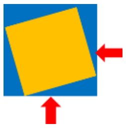
Case 1	Case 2	Case 3	Case 4
			
Centered Spike with vertical wheel-rail load	Centered spike with vertical, lateral, longitudinal load	Contacting spike with vertical, lateral, longitudinal load	Skewed spike with vertical, lateral, longitudinal load

Figure 3 shows the stress contours of the anchor spike on the field side of the high rail for the four cases. The highest stress modeled in each case was predicted to be 1 to 1.5 inches below the top of the tie. In Case 1, the peak stress in the spike was about 23.1 MPa (3.4 ksi), which was not high enough to cause fatigue. In Case 2, the peak stress increased by four times when lateral and longitudinal loads were applied to the rail (approximately 95 MPa or 14 ksi), but still below the fatigue limit. Case 3 led to a peak stress of 273.4 MPa (39.7 ksi) in the contacting spike case, which was high enough to assume that fatigue may be generated under repeated applications of this stress. In Case 4, the skewed spike, had the highest stress of the four cases at a stress level of 376.5 MPa (54.6 ksi). In Cases 3 and 4, the contacting spike and the skewed spike experienced much higher stresses than the other spikes on the tie plate.

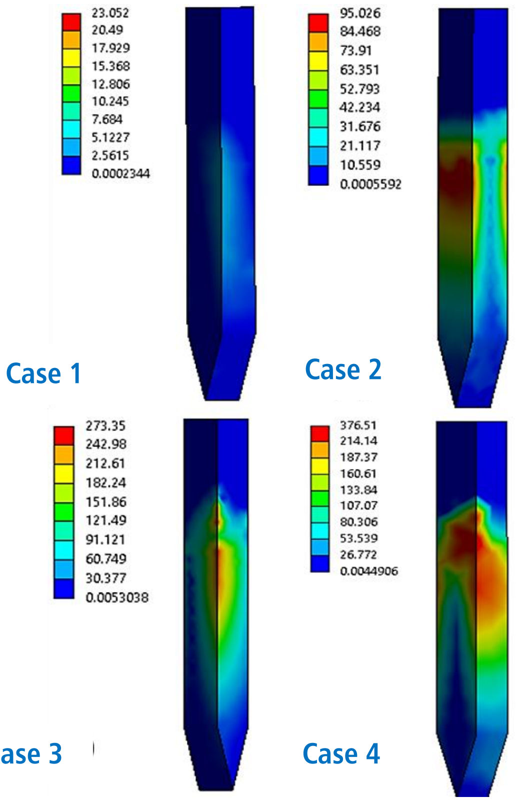


Figure 3. Stress contours for four different loading scenarios (MPa)

MODELING RESULTS ANALYSIS

The modeling results showed that the combination of loading conditions (lateral and longitudinal loading) and spike position/orientation could significantly affect the stress distribution in a spike. The FEA result in Figure 4 shows the same stress contour as Figure 3, Case 3. Figure 4 shows that the stress concentrates along the edge of the spike. The spike is withstanding the combined shear forces, which cause concentrated tensile stress on one edge and compressive stress on its face diagonal to that edge.

Figure 4 shows two key areas of stress concentration appear to coincide with the areas of fretting/wear (yellow arrows) as well as the ultimate location of the fatigue, generally about 1.5 inches below the tie surface (red arrows). Metallurgical analysis of broken cut spikes has shown that cracks initiate at the corner of the spike shaft. Modeling results appear to suggest a similar point of concentrated stresses when longitudinal and lateral loads are considered.

Figure 4. Comparing stress contour from FEA model and actual broken cut spike from revenue service

One Class I railroad has employed two remedial measures to address broken cut spikes: 1) adding rail anchors to the high rail, and 2) using screw/drive spikes instead of cut spikes on a tie plate punched with round holes instead of square holes (Figure 5). These two remedial measures were installed in 2016 and 2017. Current inspections show positive results, but it is too soon to confirm that they represent effective remedies to be widely implemented.

When elastic fastener systems are implemented, traditional longitudinal rail anchors are typically not installed, as the elastic clip is designed to provide enough longitudinal rail restraint. Rail anchors can help share some of the longitudinal load that appears to otherwise be transferred directly to the cut spikes, reinforcing the less ideal spike-to-plate contacting conditions that were modeled. Additionally, the hold-down force provided by screw spikes fasten rails, tie plates, and ties as an integrated structure that reduces the initial relative movement between components. However, as screw spikes work loose or rise out of their initial position, the same load transfer mechanism described for cut spikes is likely to occur.

Broken screw spikes and drive spikes have historically been observed on elastic fastening systems at FAST.[4]

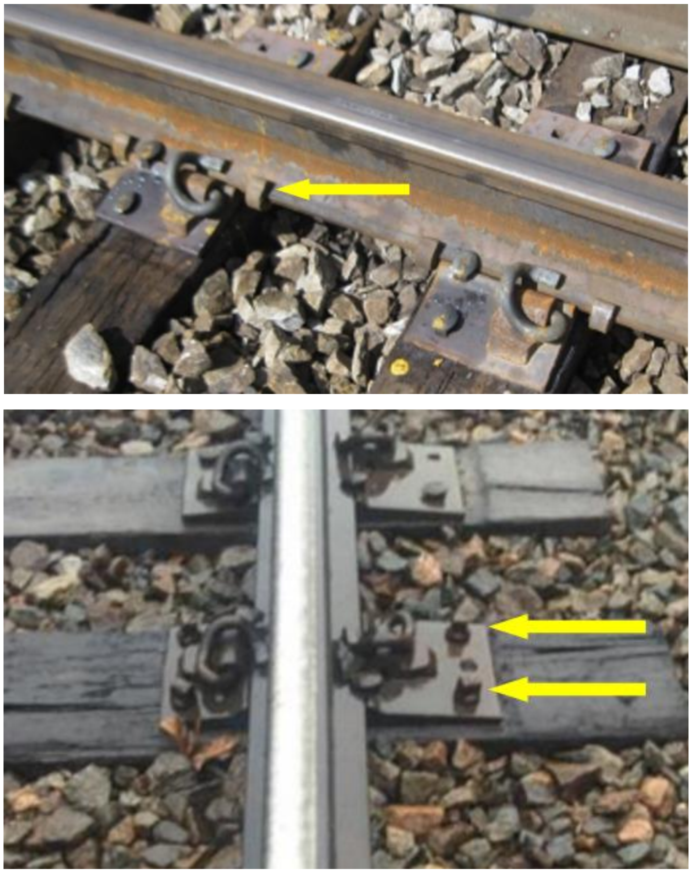


Figure 5. Rail anchors and screw spikes

CONCLUSIONS AND FUTURE WORK

Results to date have led to the following conclusions:

- The breakage of cut spikes appears to result from fatigue failure involving a combination of lateral and longitudinal forces transferred into the spikes. Peak stress locations identified in analyses correspond to where cracks have been observed in the field.
- The position of the spike in the spike hole substantially affects the stresses in the spikes. Typical plate/spike size tolerances and variability in installation (angle/skew) are large enough to create an observed effect on stresses.
- Elastic fasteners hold the tie plates firmly to the rails, allowing the tie plate to move with the rails vertically, laterally, and longitudinally. This load transfer mechanism differs from the conventional cut spike-only system with rail anchors. This interaction contributes to the spike-to-plate contacting conditions and higher spike stresses that were modeled.

Recommendations for future research include further refinement of the NUCARS® and FEA models. TTCI will perform tests using instrumented spikes to measure spike stresses in track at Transportation Technology Center, Pueblo, CO, and in revenue service to further investigate the stress distributions of cut spikes.

References

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