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SPIKE LOADING ENVIRONMENT IN VARIOUS WOOD-TIE FASTENING SYSTEMS

SUMMARY

The Federal Railroad Administration (FRA) contracted with Transportation Technology Center, Inc. (TTCI) to investigate the spike loading environment in various wood-tie fastening systems. The goal was to understand how dynamic loads are transferred to the spikes in wood-tie fastening systems and identify feasible solutions to the spike breakage issue. Field testing was conducted on a six-degree curve at FRA's Transportation Technology Center (TTC) in Pueblo, CO, in 2021. Researchers instrumented four common wood-tie fastening systems with strain-gaged cut spikes to determine their real-time dynamic bending strains.

Results showed that the load carried by some spikes could be higher than the fatigue limit of the spike material. Loads may result in stresses that exceed the spike's yield strength and lead to permanent spike bending. Specifically, spikes used with elastic fastening systems (without the aid of rail anchors) had the highest peak-to-peak strain levels. In contrast, elastic fastening systems (with rail anchors) and curve-block plates had spike strain levels that were statistically significantly lower even though some spikes still had bending strains exceeding the fatigue limit. The strains of the spikes with the American Railway Engineering and Maintenance-of-Way Association (AREMA) standard plates minimally exceeded the fatigue limit.

BACKGROUND

As both speed and tonnage increased in the railroad industry, elastic fastening systems gained popularity due to their ability to reduce gage widening compared to conventional spike-only systems. For this reason, elastic fastening systems have been installed in both steep-grade locations and high-degree curvatures on many North American heavy-haul railroads. However, multiple Class I railroads have observed broken spikes when using these systems, especially in the aforementioned environments. Researchers found that the majority of the broken spikes were found to be on the high rail. Spike breakage is also considered to be the cause of some recent derailments [1–4].

The team used instrumented spikes to conduct comprehensive in-track testing to understand the failure mechanism for broken spikes in this application. Research specifically focused on understanding the spike loading environment with different fastening systems, some of which exhibited broken spikes previously.

OBJECTIVES

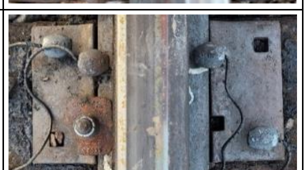
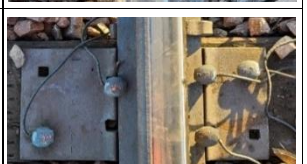
The objective of this effort was to measure the spike loading environment in different wood-tie fastening systems. Research was conducted to understand why broken spikes were failing when used with elastic fastening systems.

METHODS

Field testing was conducted at the Facility for Accelerated Service Testing (FAST) at TTC. Instrumented spikes previously developed by TTCI were used in the test [5]. Four test cases, each with one type of wood-tie fastening system, were included in the study (see Table 1). The wood ties were installed in 2017 and accumulated about 600 million gross tons (MGT). Plate cutting equal to less than 1/8 of an inch was measured on the test ties, and spikes were seated tightly inside the spike holes.

Instrumented spikes were installed only on the high-rail plates in each test case using a sledgehammer. No wood plugs were used for instrumented spikes. All the test cases were located within the same six-degree curve and were subjected to the same traffic conditions, including train speed, train make-up, and operating direction. For each test case, at least 12 instrumented spikes (3 plates worth) were installed for data collection. Data from five to six full-speed passes at 40 MPH were gathered for each test case.

Table 1. Four test cases of fastening systems

Type of Fasteners	Photo of Fasteners
18-inch elastic fastener plates with cut spikes, with rail anchors (i.e., “anchored elastic”)	
18-inch elastic fastener plates with cut spikes, with no rail anchors (i.e., “elastic only”)	
Curve block plates with cut spikes, with rail anchors (i.e., “curve blocks”)	
AREMA 16-inch plates with cut spikes, with rail anchors (i.e., “AREMA”)	

The elastic-only system has a history of broken spikes in both revenue service and in FAST testing. The spikes began to fail around 200 MGT. By 300 MGT, about 13 percent of the spikes (i.e., 39 out of the 300) failed. The three other systems experienced no broken spikes in testing (i.e., within the first 200 MGT for anchored elastic and curve block systems and within the first 640 MGT for the AREMA system).

RESULTS

Previous studies have shown that spike failure is a result of fatigue [1,5]. Therefore, the analysis focused on the peak-to-peak difference between the bending strains in the spikes. The team calculated this difference by subtracting the minimum strain from the maximum strain in one load cycle. A pair of adjacent trucks form one fatigue cycle (Figure 1), meaning the number of load cycles is the same as the number of railcars passing over the tie.

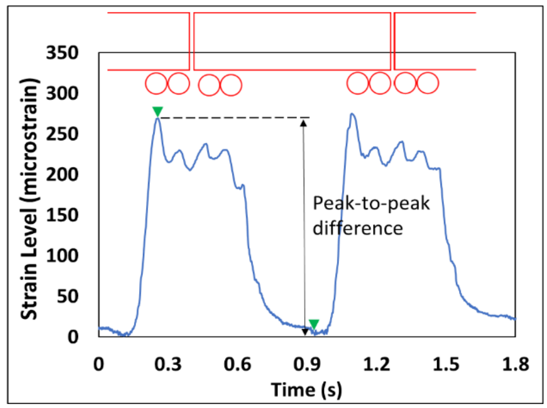


Figure 1. Peak-to-peak difference of the spike strain data

Figure 2 presents a comparison of the mean value of the peak-to-peak difference in the lateral direction. The plot shows a 95 percent confidence interval for the mean of each case. Tukey’s range test was performed to determine whether the means were significantly different from each other, which is shown in Figure 3. The horizontal axis in Figure 3 represents the mean differences between the two cases and the extended lines show the 95 percent confidence intervals. If the confidence interval crosses zero, the difference between the two cases is not considered statistically significant.

In Figure 3, the elastic-only system had the highest lateral strain level, which was significantly higher than the other three systems. The curve block system had the second highest strain level, significantly higher than the anchored elastic and AREMA systems. The lowest strain level was found in the anchored elastic and AREMA systems, which were not significantly different from each other statistically. The same analysis was performed for the longitudinal strain data. The elastic-only system also had a significantly higher strain level than any other test case.

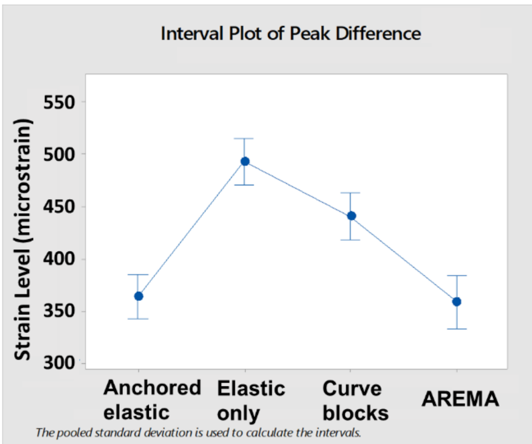


Figure 2. Average peak-to-peak difference of spike bending strains in the lateral direction

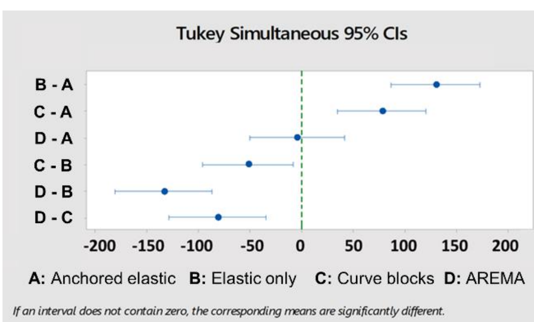


Figure 3. Statistical comparison of the average peak-to-peak difference of spike bending strains in the lateral direction

The distribution of the peak-to-peak difference data was evaluated to understand the spike loading environment in different fastening systems. Typically, 1,500 microstrain is considered the fatigue limit for a steel spike, and the yield strain is over 2,000 microstrain [6]. Figure 4 shows the distribution of lateral bending strains for the anchored elastic and elastic-only systems. The majority of spikes experienced strains under 500 microstrain for both cases. However, the number of occurrences of spikes that experienced higher strain levels (>2,000 microstrain) was substantially higher for the elastic-only system.

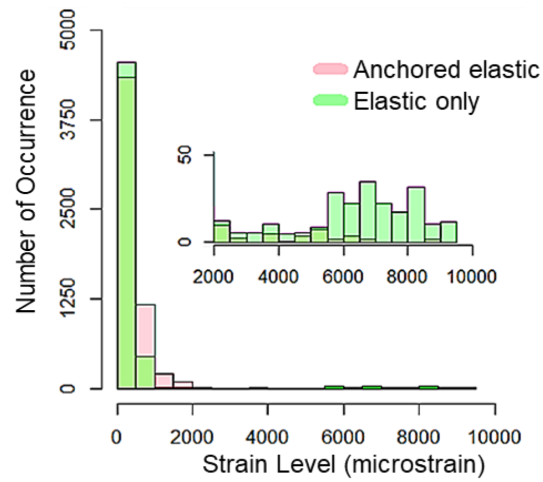


Figure 4. Comparison of lateral bending strains in spikes for anchored elastic and elastic-only systems

Table 2 lists the percentage of spike strains in three strain ranges. The spikes experienced a higher lateral loading than longitudinal. Laterally, the AREMA system had a very small amount of strain values exceeding 1,500 microstrain. The other three cases, however, had values at least 2.3 percent higher than 1,500 microstrain.

Table 2. The distribution of strain values in spikes over 1,500 microstrain

Strain Range	< 1,500 microstrain	1,500–2,000 microstrain	>2,000 microstrain
Lateral Direction			
Anchored Elastic	97.7%	1.6%	0.7%
Elastic Only	95.1%	0.4%	4.5%
Curve Blocks	91.9%	6.2%	1.9%
AREMA	99.9%	0%	0.1%
Longitudinal Direction			
Anchored Elastic	100%	0%	0%
Elastic Only	100%	0%	0%
Curve Blocks	100%	0%	0%
AREMA	100%	0%	0%

CONCLUSIONS

Field testing was conducted on four wood-tie fastening systems at FAST to measure the spike loading environment. Based on the test results, the following observations were made:

- Statistical analysis showed the elastic-only system had the highest average peak-to-peak strains for the spikes. This explains why the elastic-only system experienced broken spikes sooner than any other fastening system.

- The strain distribution showed that anchored elastic, elastic-only, and curve block systems had spike bending strains of 2.3, 4.9, and 8.1 percent above the fatigue limit, respectively. For the strains above the fatigue limit, anchored elastic and curve block systems were mostly in the range of 1,500 to 2,000 microstrain. However, the elastic-only system was mostly above 2,000 microstrain, which exceeds the yield strength for a steel spike.

Throughout the course of this study, spike breakage was found to be due to the excessive bending loads in spikes. With the aid of rail anchors, the anchored elastic and curve block systems showed reduced bending strain level in the spikes, indicating their effectiveness in mitigating the spike breakage issue.

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KEYWORDS

Broken spikes, instrumented spikes, elastic fastening systems, strain measurement