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Interim Report: Broken Spike Remediation

Yin Gao and Joseph LoPresti

Key Findings:

- An advanced version of an instrumented spike was developed at TTCI and has proved the feasibility to measure the loading environment of cut spikes under an in-track operating environment.
- The loads that were taken by spikes could be high enough to cause fatigue cracking and even permanent bending to the spike material.
- One spike on the plate carried most of the applied loads in this test.
- The loads during the insertion and removal processes could cause the spikes to permanently bend.
- Minimal train braking effort and the lack of rail anchors did not show much effect on the loading in the spikes. However, the conditions on some high-degree and high-grade curves in revenue service might be high enough to show the difference.
- Rail bending circuits (truck performance detector system) synced with instrumented spike data showed that the worst loading environment in spikes occurred when the wheel was directly over that tie plate.

[Transportation Technology Center, Inc. \(TTCI\)](#) has been evaluating the performance of various tie and fastener systems for many years. Elastic fasteners have been shown to reduce gage widening and decrease the potential for rail roll compared to conventional cut-spike-only systems. For this reason, elastic fastening systems have been installed in high-degree curves on many North American heavy haul railroads. Field observations in the United States, however, have noted broken cut spikes and screw/drive spikes on this type of fastening system — especially in steep-grade, high-degree curve territories. Class 1 railroads attributed the broken spikes to the recent derailments.

Recent numerical modeling has found that the bending stress in spikes can exceed the fatigue limit of spike material. To further investigate the in-track loading environment of spikes, spikes instrumented with strain gages were developed and calibrated by TTCI at the Transportation Technology Center (TTC), Pueblo, CO. In-track testing was then carried out at the Facility for Accelerated Service Testing (FAST) High Tonnage Loop (HTL) at TTC. The test investigated the loading environment of spikes by considering several in-track conditions. The results showed that the load transferred to spikes during insertion and train passing could cause spike stresses higher than the fatigue limit and lead to permanent bending of spikes. The bending moment was primarily carried by one of the four spikes from the same plate in this test. This effect would be highly dependent on the position of the spikes relative to the plate. This test at FAST also served as a proof-of-concept test of the instrumented spikes for revenue service testing which will be more comprehensive and under more severe conditions.

BACKGROUND

The most common tie and fastener system used on North American freight railroads is an American Railway Engineering and Maintenance-of-Way Association (AREMA) rolled steel tie plate and cut spikes. In mountainous, high-degree curve territories, elastic clips are often used to fasten the rail to a specially designed tie plate. However, recent field inspections on one Class I railroad have found a higher frequency of broken cut spikes when used with these types of elastic fastener tie plates than the conventional AREMA plates with cut spikes in those territories. Previous research has focused on understanding the loading mechanism in the elastic fastening.^{1,2}

Norfolk Southern Railway (NS) used instrumented spikes to investigate spike breakage in the early 2000s.³ The NS-developed instrumented spikes were designed to be used in laboratory conditions and applied one strain gage on one side, which only allows measurement of either the lateral or the longitudinal stress in spikes at one time. Based on this approach, TTCI developed an advanced version of instrumented spikes to further investigate the in-track loading environment of spikes. This new version of instrumented spikes allows measurement of both longitudinal and lateral stresses; in particular, to capture the area of peak stress where spikes appear to be fatiguing. This *Technology Digest* presents the development of the instrumented spikes and the in-track test results at FAST.

DEVELOPMENT OF INSTRUMENTED SPIKES

To use instrumented spikes to measure the loading environment of spikes in actual field conditions, TTCI researchers improved the design in several aspects:

1. All four surfaces along spike shaft were instrumented with strain gages so that both longitudinal and lateral forces applied to spikes can be measured.
2. The bending circuit of strain gages was used on the instrumented spikes. This strain gage design is expected to increase the sensitivity of the sensors and reduce the temperature effect on the measurements.

According to the field observations from NS,¹ spikes typically break 1 to 1.5 inches below the top surface of a tie. Due to the varying thickness of a tie plate at different spike locations, two instrumented locations on spikes were used to differentiate a rail spike and an anchor spike. As Figure 1 shows, rail spikes were instrumented 3.25 inches below the bottom of the spike head, while anchor spikes were instrumented 2.5 inches below the bottom of the spike head.

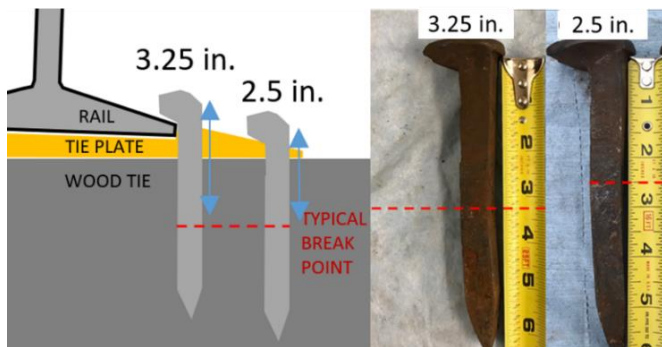


Figure 1. Instrumented locations of strain gages

A laboratory calibration test was performed prior to field instrumentation of the strain gaged spikes. Four-point bending

tests were conducted to calibrate the instrumented spikes. The strain gages were placed in the constant moment area and the relationship between bending moments and voltage was documented for each instrumented spike. The calibration showed very little crosstalk between two bending circuits. The bending in the lateral direction would not interfere with the bending signal in the longitudinal direction. The lateral and longitudinal load inputs can be recorded independently.

FAST TEST SETUP

A two-day test was conducted to evaluate the loading environment in spikes at FAST. Four instrumented spikes were installed on the high rail tie plate of a single tie as shown in Figure 2. The test tie was located in HTL Section 25, a 6-degree curve with 5-inch superelevation. This curve has a history of broken cut spikes and drive/screw spikes. The existing spikes on the plate were pulled out and were replaced by four instrumented spikes without wood plugs. The wood tie that was instrumented had accumulated more than 1,000 million gross tons (MGT) and the tie condition is considered to be old. The test section was box-anchored on Day 1. On Day 2, anchors on 10 adjacent ties were removed to represent a non-anchored track. To capture some longitudinal force, air braking was applied to the FAST train on the last lap of each test day. The train configuration was 115 cars with 3 locomotives pulling in the front. The car axle load was 39 tons and the operation speed were 40 mph. The FAST train was running counterclockwise for both test days.

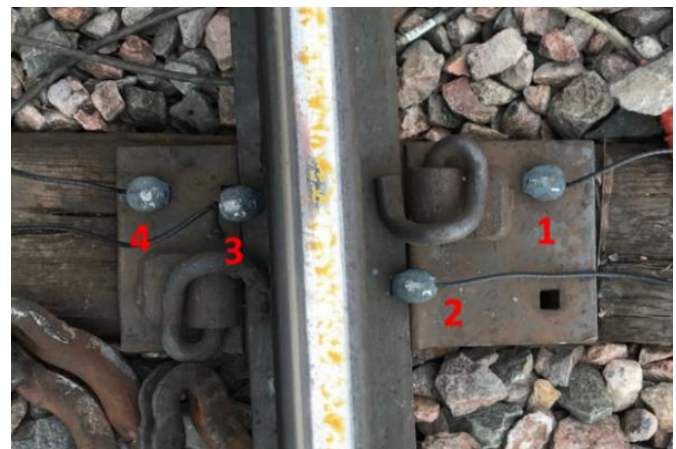


Figure 2. The test setup

TEST RESULTS

Bending Moment Distribution in Spikes

Bending moment was measured under constant-speed FAST operations to evaluate the loading environment in the spikes. Figure 3a shows the bending moment in all four spikes of the instrumented plate on Day 1 (with rail anchors). The name

convention of each channel is based on the spike number and loading direction. “Lat” is the lateral direction and “Long” is the longitudinal direction. For example, Mom_Lat_1 stands for the bending moment of Spike No. 1 in the lateral direction of the track.

Table 1 lists the average peak bending moment for each spike. The largest bending moment (around 3,000 lbs./in.) occurred in the lateral direction of Spike No. 1. The second largest bending of moment (around 1,000 lbs./in.) occurred in the longitudinal direction Spike No. 1 and the lateral direction of Spike No. 3. All the other channels were below 500 lbs./in.

Table 1. The bending moment distribution among the instrumented spikes (constant-speed 40 mph FAST operations – anchored rail)

Spike No.	Lateral (lb/in)	Percent of Total Lateral Load	Longitudinal (lb/in)	Percent of Total Longitudinal Load
1	2,900	70.6%	930	62.0%
2	240	5.8%	130	8.6%
3	870	21.2%	250	16.7%
4	100	2.4%	190	12.7%

A bending moment value of 1,500 lbs./in. is equivalent to a bending stress value of 41.6 ksi (the dashed red line in Figures 3a and b). Therefore, 3,000 lbs./in., equivalent to 83.2 ksi, is well above the fatigue limit of the spike material and could cause the spike to yield. Permanent bending was observed in the spike after it was removed. Additionally, the percent of bending moment of each spike in each direction, indicating how the bending moment was distributed among the spikes, is presented in the table. As can be seen, Spike No. 1 carried more than 60 percent of the bending moment in both directions, while none of the other spikes had a share more than 21.2 percent. This suggests Spike No. 1 was in the most severe contacting position and most susceptible to higher

stresses. However, since only one plate was instrumented, this observation might not be common in other tie plates. More tests are needed to verify the finding.

Spike Insertion and Removal

The loading environment during the spike insertion and removal process was also evaluated. Spike insertion was performed using a sledgehammer to drive spikes. The removal process was completed using a spike puller to pull spikes vertically, gradually raising the pivot point of the spike puller using wood shims. The bending moment measurement during removal was not as severe as that during insertion. Figure 3b shows the bending moment measurement during the spike insertion process. The highest bending moment (around 1,850 lbs./in.) observed in Spike No. 3 exceeded the fatigue limit and could potentially cause permanent bending in the spike. The residual stresses observed after insertion were close to the highest values measured during insertion, which means the stresses induced by the driving process were mostly retained in the spikes after they seated in the tie.

Braking Effect

The effect of braking also was investigated in this test. The train was set to apply minimum braking in the last lap of each test day. Figure 4 shows the bending moment measured in Spike No. 3 under braking (red) and no-braking (blue) conditions as an example.

The data did not show much difference in bending moment measurement. Consider that the braking effort was set to minimum and air braking which distributes the braking effort to the entire train consist was used, it may explain why there is no significant change in bending moment. More severe braking conditions (possibly with high grade) will be investigated in later revenue service testing.

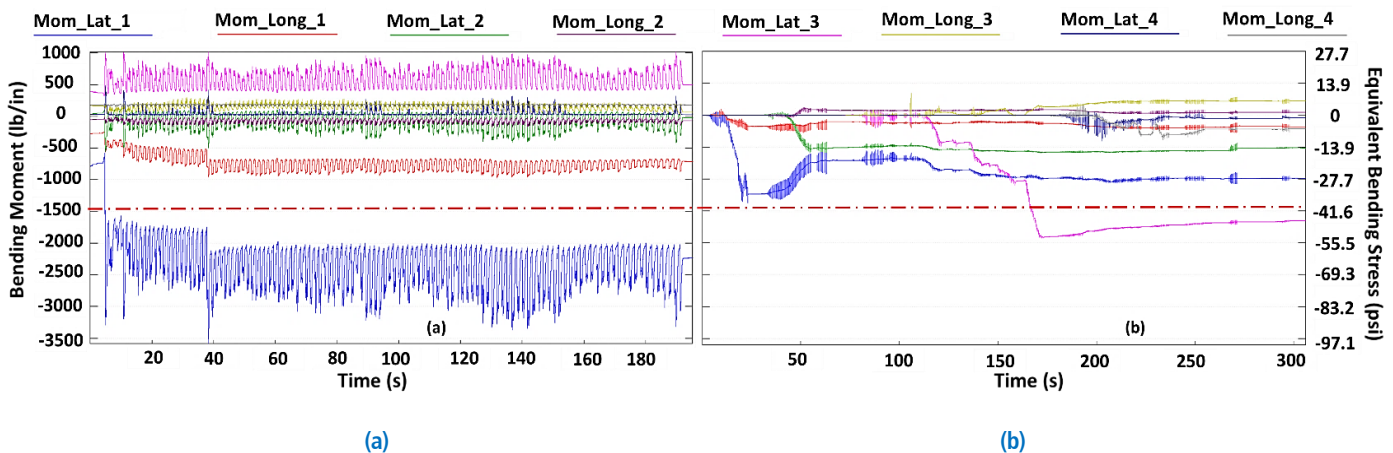


Figure 3. Bending moment measurements: (a) Bending moment of spikes, one train pass, Day 1 (anchored); (b) Bending moment during spike insertion

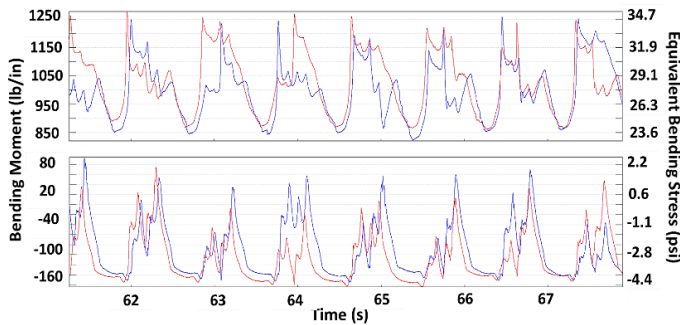


Figure 4. Bending moment measurements of Spike No. 3 under braking condition (red) and constant speed condition (blue)

Rail Anchors

Rail anchors on 11 ties (the tie with instrumented spikes and five ties on each side) were removed for Day 2. Little difference in spike bending moment was observed between the anchored and non-anchored conditions. Track with only 11 non-anchored ties may not be sufficient to differentiate itself from an anchored track. The train may not have generated enough longitudinal force in the rail to show an obvious difference. The effect of rail anchors will be investigated on track with higher tractive and braking efforts in future testing.

Truck Performance Detector (TPD) and Spikes

TPD data collection was also conducted along with the spike test. The TPD consists of a series of strain gage sensors that are placed along a track to measure wheel/rail lateral and vertical forces during the negotiation of a curve. The TPD data suggested that the spikes experienced the largest bending moments when the wheel load was directly over that plate. This indicates that the forces in spikes were mainly provided by vehicle body forces rather than train-induced track vibration.

CONCLUSION

The development of an advanced version of an instrumented spike was documented. An in-track test at FAST using instrumented spikes was carried out to evaluate the loading environment of cut spikes on elastic fasteners. The test results have shown:

- The loads that were carried by spikes could be high enough to cause fatigue cracking to the spike material.
- In this test, one spike on the plate carried most of the applied loads. More than 70 percent of the lateral load and more than 60 percent of the longitudinal load was distributed to Spike No. 1 in this test.
- The loads during insertion and removal could cause the spikes to bend permanently.
- Minimal train braking effort and the lack of rail anchors did not produce significant difference in the loading environment of the spikes. However, the actual conditions in revenue service can be more severe than those in this test, which may be high enough to show a difference.
- Rail bending circuits (truck performance detector system) synced with instrumented spike data showed that the worst loading environment in spikes occurred when the wheel was directly over that tie plate.

References

1. Gao, Y., McHenry, M. and Kerchof, B. (2018). "Investigation of Broken Cut Spikes on Elastic Fastener Tie Plates Using an Integrated Simulation Method." Proceedings, 2018 ASME/IEEE Joint Railroad Conference.
2. Gao, Y., McHenry, M. (2019). "Modeling and field investigation of spike breakage on elastic fastener tie plates." Proceedings, International Heavy Haul Association Conference.
3. Bowman, R., "Reduce Spike Breakage," (2002). *Norfolk Southern Railway Report*.

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