Field Evaluation of Sleeper and Fastener Designs for Freight Operations

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Abstract

As train speeds, axle loads, and tonnage increase on North American freight railroads, improved sleeper and fastener designs that are both economical and serviceable may be necessary to maintain acceptable track safety and quality in these high demand environments. TTCI continues to evaluate the performance of various sleeper and fastener systems at its Facility for Accelerated Service Testing (FAST) High Tonnage Loop (HTL) under heavy axle load (35.4-tonne) traffic. The objective of this testing is to assess the relative performance of these sleeper and fastener systems throughout their lifecycle and how certain failure modes affect track performance.

Working with North American railroads, specific sleeper and fastener designs were chosen for this testing. The test section includes zones of hardwood and softwood sleepers with and without elastic fasteners, polymer composite sleepers with both elastic and cut spike fastening systems, and a variety of concrete sleepers and fastening systems. These test sections are located in a 290 meter radius curve on the HTL.

TTCI is documenting the observed failure modes and assessing performance of these systems with the following performance tests: gage restraint measurement system (GRMS) testing; lateral track loading fixture (LTLF) testing; and track geometry measurement. The GRMS and LTLF testing are two ways to apply a gage widening load to the track to assess the fastening system's ability to resist gage widening. GRMS testing is performed using an in-motion vehicle with a deployable loading axle, while LTLF testing involves a statically applied load.

The systems being tested have exhibited various failure modes including severe plate cutting on the softwood sleepers, raised cut spikes and broken sleeper plates on polymer composite sleepers, and broken concrete tie insulators, particularly on narrower field side insulators. The track geometry, GRMS and LTLF results demonstrate the manifestation of these failure mechanisms in track performance.

Currently, the results of this study are being used to develop a novel dynamic vehicle/track simulation model that incorporates connections at the sleeper and fastening system level. The application of this modelling approach to predicting service failures and guiding sleeper and fastener purchasing and maintenance decisions is presented.

1. Introduction

The sleepers and fasteners of conventional ballasted track act together as a system to transfer vertical and lateral load applied at the wheel-rail interface into the ballast, and to maintain proper track geometry, particularly track gage. The sleeper and fastener system, depending on its design, can fail in a multitude of ways, inhibiting one or more of its primary functions. These failures typically occur over time at the interface of two of the system's components. As part of the Association of American Railroads' (AAR)

Strategic Research Initiative program to assess sleeper and fastener system performance, lateral track loading fixture (LTLF) and gage restraint measurement system (GRMS) testing was conducted on a variety of sleeper and fastener systems installed at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado USA since 2008. The objective of this research was to assess the relative performance of these various designs and related observed failures to track strength.

2. Background and Test Setup

In 2008, TTCI installed 5 concrete and 13 wood sleeper and fastener test zones at FAST.[1] Two additional hardwood sleepers and elastic fastener test zones were subsequently installed in 2009. Two existing composite sleeper test zones (installed in 2000 and 2004, respectively) were also incorporated into this test. At the initiation of the test, these zones represented the state-of-the-art in sleeper and fastening system design from multiple manufacturers. The test zones are located in Section 25 of the High Tonnage Loop at FAST — a 6-degree curve with 5 inches of superelevation — maintained to Federal Railroad Administration (FRA) Class 4 track safety standards.[2] Heavy axle load tonnage is accumulated on the test zones with a consist of approximately 110 gondola cars, each weighing 315,000-pounds (39-ton axle load). The train is operated at 40 mph, which is about a 2-inch overbalanced speed for the curve helping to accelerate component wear, particularly on the high rail.

Table 1 shows the layout of the test zones as well as the accumulated tonnage in million gross tons (MGT) at the time of the various gage strength measurements taken.

Table 1. Sleeper and Fastener Test Zones

Test Zone	Install Date	MGT at Spring 2014 Testing	MGT at Spring 2015 Testing	No. of Sleepers	Sleeper Type	Sleeper Plate	Rail Fastener	Hold-Down Fastener
0a	9/3/2009	646	891	50	Mixed Hardwood	18" Pandrol Victor Rolled	eClip	Cut Spike
0b	9/3/2009	646	891	50	Mixed Hardwood	18" Pandrol Victor Rolled	eClip	Drive Spike
1	10/20/2009	561	806	100	Mixed Hardwood	14" AREMA Rolled	Cut Spike	Cut Spike
2	5/8/2004	1336	1581	100	RTI Composite*	14" AREMA Rolled	Cut Spike	Cut Spike
3a	5/15/2008	761	1006	25	Rocla Concrete	-	Vossloh W30**	-
3b	5/15/2008	761	1006	28	Rocla Concrete	-	Vossloh W40**	-
4	5/15/2008	761	1006	50	Rocla Concrete	-	Pandrol Safelok	-
5a	5/15/2008	761	1006	25	Rocla Concrete	-	Airboss	-
5b	5/15/2008	761	1006	25	Rocla Concrete	-	Airboss	-
6	8/28/2000	1801	2046	100	TieTek Composite	14" AREMA Rolled	Cut Spike	Cut Spike
7	5/15/2008	761	1006	100	Mixed Hardwood	16" Cast Cleated	eClip	HS Screw Spike
8a	5/15/2008	761	1006	50	Mixed Hardwood	18" Vossloh Rolled	Vossloh BT30	HS Screw Spike, SS8
8b	5/15/2008	761	1006	50	Mixed Hardwood	18" Vossloh Rolled	Vossloh BT30	Drive Spike
9a	5/15/2008	761	1006	50	Mixed Hardwood	16" NorFast, Cast*	NorFast	Drive Spike
9b	5/15/2008	761	1006	50	Mixed Hardwood	16" NorFast, Cast*	NorFast	HS Screw Spike
10a	5/15/2008	761	1006	50	Mixed Hardwood	16" Pandrol, Rolled HS Steel	eClip	HS Screw Spike
10b	5/15/2008	761	1006	50	Mixed Hardwood	16" Pandrol Victor Rolled	FastClip	Drive Spike
10c	5/15/2008	761	1006	50	Softwood (Red Pine)	16" Pandrol Victor Rolled	FastClip	HS Screw Spike
11a	5/15/2008	761	1006	49	Softwood (Red Pine)	18" Leading Edge, Cast	Safelok	HS Screw Spike
11b	5/15/2008	761	1006	50	Mixed Hardwood	18" Leading Edge, Cast	Safelok	HS Screw Spike
12	5/15/2008	761	1006	100	Mixed Hardwood	16" Airboss, Cast	AirBoss	HS Screw Spike
13	5/15/2008	761	1006	100	Mixed Hardwood	18" AREMA Rolled	Cut Spike	Cut Spike
14	5/15/2008	761	1006	100	Softwood (Red Pine)	18" AREMA Rolled	Cut Spike	Cut Spike

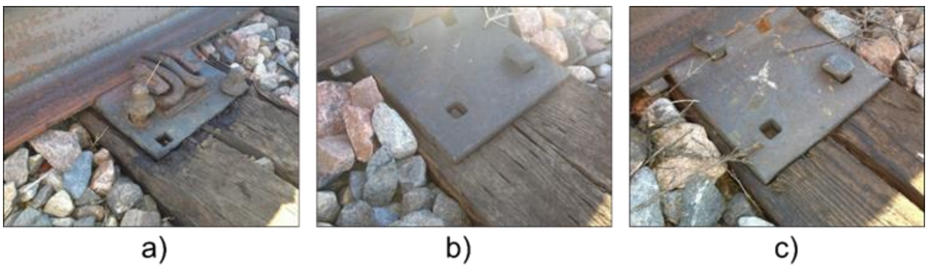
Notes: *RTI and NorFast are no longer in business. **Replaced original W14 clamps w ith W30 and W40 on 1/22/13

3. Observed Failure Modes

The primary failure mode of the two composite sleeper zones (2 and 6) has been raised cut spikes. As tonnage has accumulated, maintenance has been performed to re-drive the cut spikes. In September 2014, the gage side low rail spike holes in Zone 6 needed to be plugged in order to retain spike hold-down capacity as loose spikes were being observed. These loose spikes appear to be manifested in the LTLF testing results. Structural failure modes (e.g., sleeper center cracking or cracking of the sleeper at spike holes) in either of the composite sleeper test zones have not been observed. Plate bending failures (cracking) have been observed in the composite sleeper test zones, likely because of higher stresses placed on the plate in compound bending with a lower modulus composite sleeper compared to stiffer wood sleepers.[3]

In the mixed hardwood sleeper zones, screw spikes tend to fail more predominantly through breaking, and drive spikes appear to fail more predominantly through rising. Screw spike breakage tends to occur at the interface of the threaded and non-threaded area of the spike. Zones 11a and 12 had the greatest percentage of broken or missing gage side screw spikes. The screw spikes for both of these fastening systems are located closer to the base of the rail than other sleeper plate designs. Hold down spikes are often located closer to the rail base in the system design in order to accommodate driving of the clip. This observation suggests that the location of the spike on the plate plays a role in the forces acting on the spike and fastening system lifecycle.

The three softwood sleeper zones (10c, 11a, and 14) have exhibited severe plate cutting relative to similar mixed hardwood sleeper zones. Zone 10c, with 16-inch plates, has shown the highest severity of plate cutting with approximately 0.5 inch on the high rail and 0.25 inch (uniformly) on the low rail. The softwood sleepers in Zone 14 have approximately 0.25 inch to 0.5 inch of plate cutting on the high rail, while the same fastening system on mixed hardwood sleepers in Zone 13 has less than 0.1 inch of plate cutting. For comparison, Figure 1 shows the typical plate cutting observed in Zones 10c, 13 and 14.



a) 16-inch rolled plates on softwood sleepers in Zone 10c
b) 18-inch AREMA plates on mixed hardwood sleepers in Zone 13
c) 18-inch AREMA plates on softwood (red pine) sleepers in Zone 14 all after 832 MGT of accumulated tonnage.

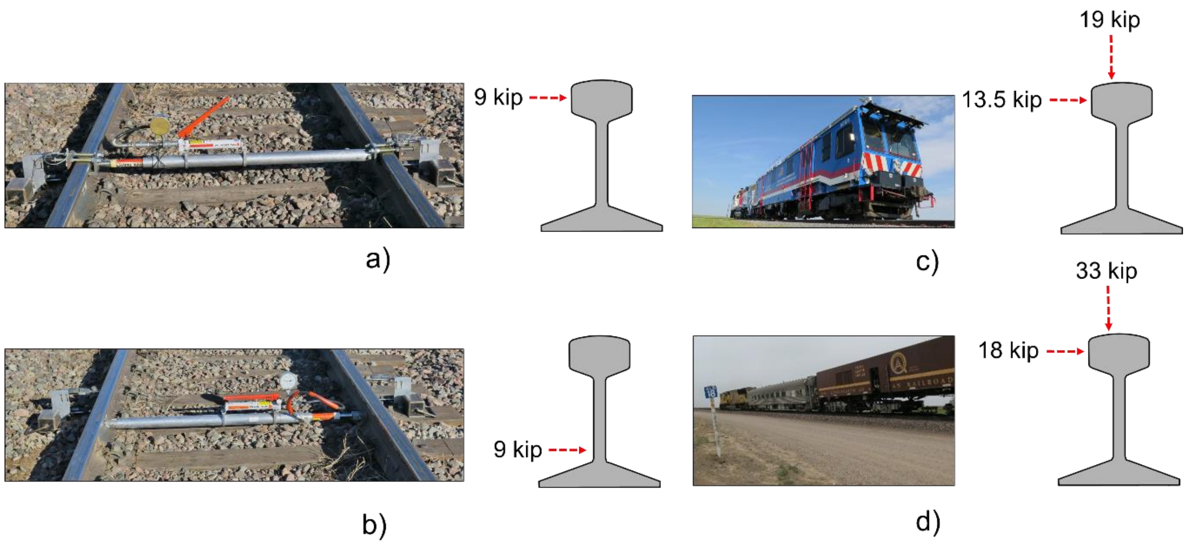
Figure 1. Typical plate Cutting Observed on the Field side of the High Rail

In general, sleepers with poorer gage side hold-down condition (missing, loose, or broken spikes) tended to have greater plate cutting. Mechanically, this result is consistent with the rail relying on the gage side fasteners to resist rail roll, or loaded gage widening. Also, as would be expected in the overbalanced speed condition, plate cutting on the field side of the high rail tended to be the most severe.

For the concrete sleeper test zones, roughly 20 percent of the high rail field side insulators in Zones 4 and 5 (Airboss® and Pandrol® SAFELOK I fasteners) were broken or missing. No broken insulators or clips were noted in Zone 3 (Rocla® sleepers with Vossloh™ fastening systems), which has a wider insulator bearing surface. No structural cracking or failure was noted for any of the concrete sleepers. Consistent with historical performance at FAST, concrete sleeper rail seat deterioration has not been observed. No significant breakage of elastic clips have been noted.

4. Gage Strength Testing

In 2014 and 2015, static gage, LTLF, and GRMS testing was performed to quantify each sleeper and fastener combination's ability to resist gage widening. LTLF testing is a static, localized method in which a gage spreading load is applied at a single location to the rails and the gage widening is recorded. Two varieties of LTLF loading were performed: web-applied and head-applied. Head-applied loading better exercises rail rotation, while web-applied loading better exercises translational failure modes. Two GRMS vehicles were used for testing: the FRA's DOTX 218 (T-18) and the AAR's Track Loading Vehicle (TLV). Both GRMS vehicles applied an in-motion gage widening load to the track and measured unloaded gage and loaded gage. Figure 2 details the four gage strength testing methods and their respective load magnitudes.



Device/ Vehicle	Date	Lateral Load Magnitude (kips)	Vertical Load Magnitude (kips)	Average L/V Ratio	Speed (mph)
a) LTLF head-applied	March 2014	9	0	∞	Static
b) LTLF web-applied	March 2014	9	0	∞	Static
c) T-18 GRMS	March 2014	13.6 average; σ=0.23	18.9 average; σ=0.35	0.72	20-29
d) TLV GRMS	May 2015	18.04 average; σ=0.68	32.96 average; σ=1.84	0.55	19-22

Figure 2. a) Head-applied LTLF, b) Web-applied LTLF, c) T-18 GRMS, and d) TLV GRMS

The T-18's applied loads were lower in magnitude, but produced a higher applied L/V ratio of 0.72. The TLV applied higher load magnitudes, but a lower L/V ratio of 0.55. The vertical load component of the applied force vector generally acts to resist the rail from rolling. However, failure modes such as plate cutting or rail seat deterioration may be more sensitive to higher vertical loads that seat the rail or plate into these failures and generate wider loaded gage. Figure 3a shows the loaded gage overlaid on the unloaded gage for both GRMS vehicles. Standard gage (targeted at installation for all zones) of 56.5 inches is shown as a black dotted line. Figure 3b shows the GRMS delta loaded track gage (DLTG equal to loaded gage minus unloaded gage) plotted alongside the measured LTLF gage widening for the 9-kip head-applied and 9-kip web-applied loads.

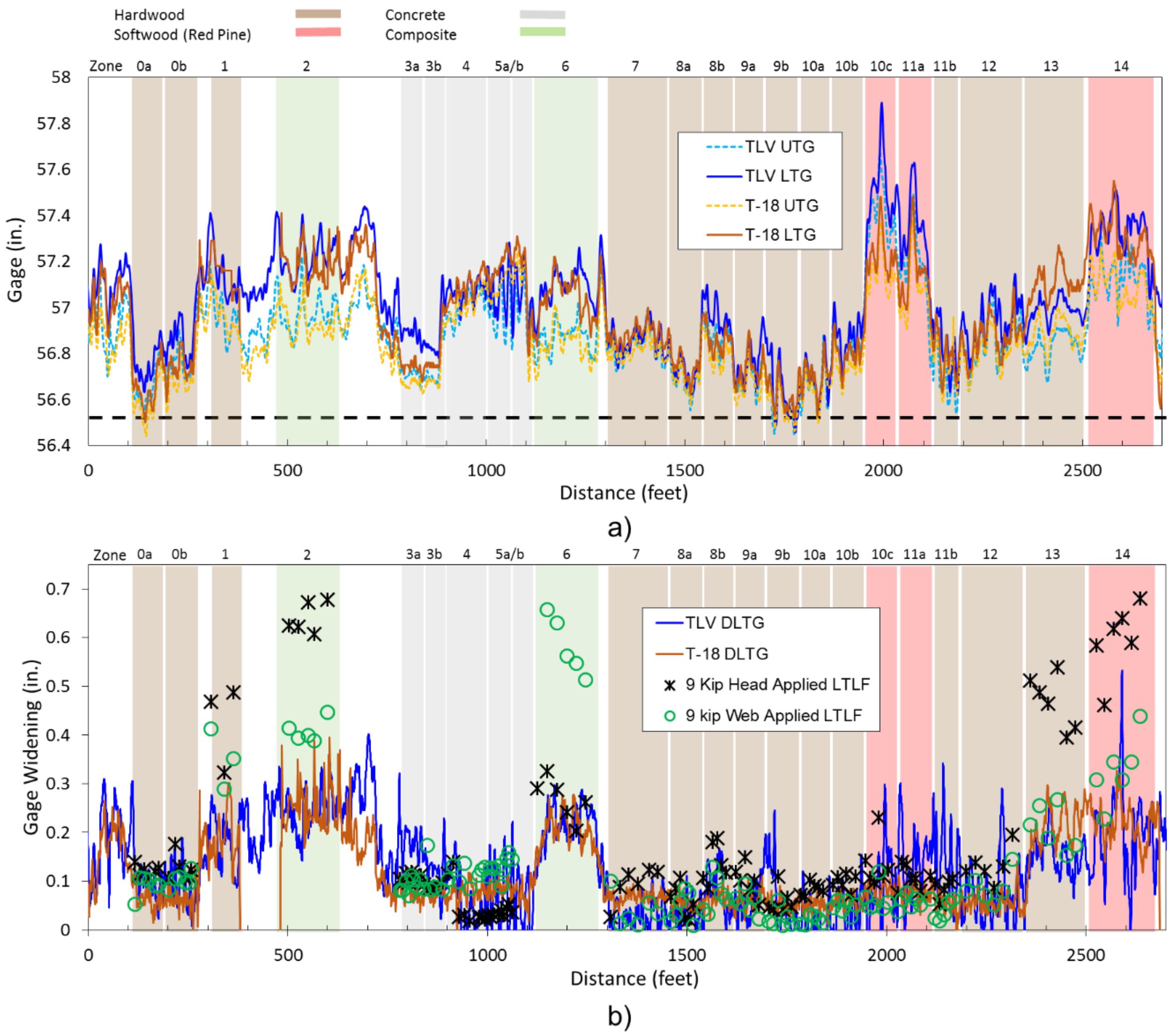


Figure 3. a) Unloaded Track Gage (UTG) and Loaded Track Gage (LTG) for the T-18 and TLV GRMS Tests; b) Delta Loaded Track Gage (DLTG) for each of the GRMS Vehicles Compared to the Head- and Web-applied LTLF Gage Widening

Unloaded gage tended to be higher in Zones 4 and 5 (plastic composite), as well as, the softwood sleeper zones of 10c, 11a, and 14. This is likely related to the broken field side insulators on the Airboss and SAFELOK I fasteners and the severe plate cutting observed in the softwood sleeper zones. In general, the T-18 and TLV GRMS results were similar despite their load magnitudes and L/V ratios being different. This confirms that L/V ratio, on its own, is not a comprehensive indicator of the severity of the loading environment. In addition, the wheel-rail contact location and the load magnitudes must be considered. The TLV appears to have generated slightly higher gage widening than the T-18 in the softwood sleeper zones with more severe plate cutting.

GRMS delta gage was significantly higher for the zones with cut spike rail fasteners (Zones 1, 2, 6, 13, and 14). In general, the GRMS delta gage was below 0.1 inch for all wood sleeper and elastic fastener zones regardless of plate size, clip type, or hold-down fastener. Zones with higher degrees of plate cutting had higher unloaded gage; however, the loaded gage appears to be more dependent on the type of rail fastener. Similar performance, in this regard, is seen in the concrete sleeper zones as no rail seat deterioration has been observed in Zones 3, 4 and 5.

In general, the web-applied LTLF load appears to better simulate the T-18 and TLV GRMS loading than does the head-applied load. For most zones, the LTLF gage widening due to the web-applied load tends to be lower than that due to the head-applied load. However, for Zone 6 (TieTek® composite sleepers) and Zones 4 and 5 (concrete sleepers with Airboss and SAFELOK I fasteners), the gage widening due to the web-applied load exceeded that due to the head-applied load. These results suggest that the web-applied LTLF better exercises rail translation related failure modes such as the loose spikes observed in Zone 6 and the broken field side insulators observed in Zones 4 and 5. Similarly, the head-applied LTLF appears to better exercise rail rotation related failure modes such as raised gage side cut spikes or reduced elastic fastener toe load.

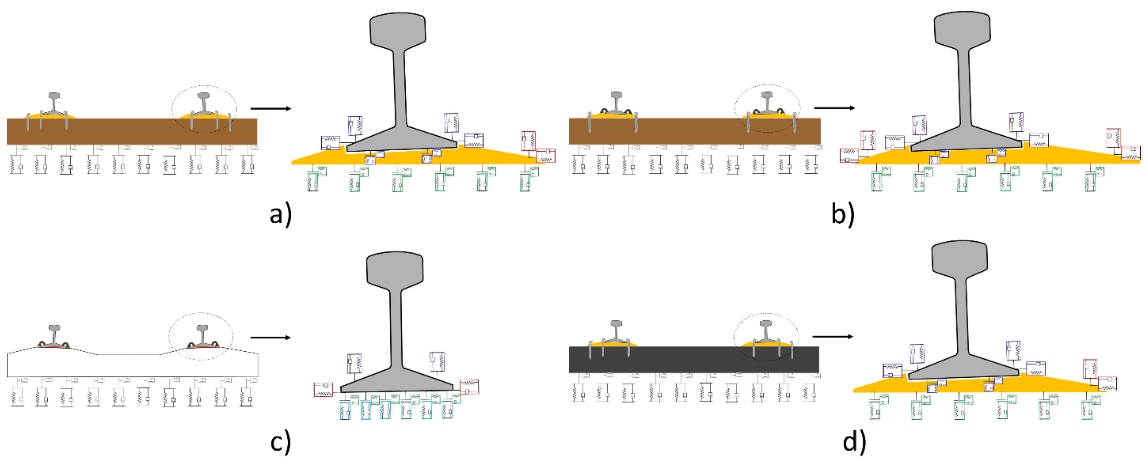
Zones 0a (18-inch Pandrol® VICTOR plate and cut spike) and 0b (18-inch VICTOR plate and drive spike) appear to be performing similarly at this time suggesting that the more economical cut spike plate hold down in Zone 0a is performing equally as well as the drive spike. Conditions may exist where drive spikes may perform better. No significant maintenance has been performed in either zone since installation.

5. Sleeper and Fastener Degradation Modeling

TTCI has developed a mechanistic sleeper and fastener model using the NUCARS® multibody dynamics model, a model capable of simulating the dynamic response of railroad vehicles and track components as they interact. NUCARS®, a registered trademark of TTCI, has been benchmarked against other multibody vehicle dynamics programs and validated in numerous studies.

In the modeling environment, rails, sleepers, and sleeper plates are modeled as individual bodies with appropriate translational, rotational, and bending degrees of freedom and characteristics. Track bodies are connected to each other using spring-damper and friction connections as appropriate and characteristic of the system being modeled. The model is capable of simulating the dynamic responses of these track components and connections. The model allows for parameters such as track geometry (including actual, measured geometry), wheel-rail friction, wheel and rail profiles, and component properties (such as pad stiffness or sleeper plate size) to be considered in the analysis.

Lab tests performed according to American Railway Engineering and Maintenance-of-Way Association (AREMA) recommendations are being used to generate the characteristic data for these bodies and connections[4]. GEOTRACK®, a multi-layer railway substructure simulation program, is being used to characterize various support conditions. Typically output at 10 locations along the length of the sleeper, load and deflection results can be fed into the sleeper-to-ground connections of the mechanistic model.[5] Figure 4 shows four example sleeper and fastener models that have been constructed and analyzed in preliminary studies.



a) Wood sleeper, 14-inch AREMA plate and cut spikes
b) Wood sleeper, 18-inch rolled plate, elastic fasteners and screw spikes
c) Concrete sleeper and conventional pad and elastic fasteners
d) Composite sleeper, 14-inch AREMA plate and cut spikes.

Figure 4. Four Example Sleeper and Fastener Models

Using the failure modes observed at FAST and in revenue service to guide further investigation, additional studies are being conducted to better understand the effect of load environment on sleeper and fastener failures. Ultimately, as the relationship between load environment and revenue service failures is better established, a predictive degradation model will be developed to better guide maintenance, planning, and design.

6. Conclusions

The failure modes observed in the various sleeper and fastener zones are visible in the GRMS and LTLF data. Plate cutting appears to have manifested itself more in unloaded gage, while cut spike rail fasteners produced the highest amount of loaded gage widening. The results have identified stronger performing systems and allowed relative performance comparisons under the heavy axle load, overbalanced speed conditions at FAST.

As some of the fastening systems being tested have fallen out of use (with some no longer being manufactured), TTCI will continue to work with the North American railroad industry to assess the performance of new and improved components. To that end, a new composite sleeper test was installed in 2015. Two types of composite sleepers were installed, with a third scheduled to be installed in 2016.

Moving forward, the failure modes and performance test data from FAST is being used to guide future work on a sleeper and fastener degradation model that will relate load environment to lifecycle costs for a variety of sleeper and fastener designs.

7. Acknowledgements

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8. References

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