TECHNOLOGY DIGEST

TD-17-006
©MARCH 2017

TIMELY TECHNOLOGY TRANSFER

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Effects of Crossties and Fasteners on Rail Wear and Gage Strength in Heavy Axle Load Service

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Summary

The effects of crosstie and fastener configurations on rail performance in heavy axle load service was evaluated in a controlled experiment. Transportation Technology Center, Inc. (TTCI) has conducted rail wear analysis on a variety of tie and fastener test zones on Section 25 at the Facility for Accelerated Service Testing (FAST). The performance of this premium rail in the 6-degree curve of Section 25 was monitored over 563 million gross tons (MGT). The analysis determined the interactive effects of ties and fasteners on rail wear and track gage.

Although FAST Section 25 has zones containing 22 combinations of ties and fastener systems,[1] the rail wear study focused on the zones having eight different combinations that might possibly exhibit the range of rail wear found in the entire curve. Gage Restraint Measuring System (GRMS) was used to apply a gage widening load to the track in order to measure the ability of the tie and fastener systems to resist gage widening. An instrumented geometry car was also used to determine track geometry changes across different zones of ties and fasteners. Failure analysis of these various tie-fastener combinations and detailed analysis of the GRMS testing are documented in TD-15-013.[2]

Rail profile measurements were taken on the outer rail at different MGTs and data was analyzed using general regression and general linear model (GLM) to correlate rail wear with delta gage (gage strength) of different test zones to understand the effects of ties and fasteners. Results of the rail wear analysis of the eight tie-fastener zones are the following:

- Total area loss due to rail wear was found to be almost uniform across various tie-fastener combinations; gage face wear was one aspect of wear affected by ties and fasteners
- Rail MGT was the most important factor on rail wear
- Mixed hardwood ties and plastic ties with cut spikes showed highest gage widening and lowest rail gage face wear
- Fasteners when categorized by elastic fasteners and cut spikes had the most influence on delta gage
- Ties when categorized by concrete, wood, and plastic showed very small influences on rail wear and delta gage

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INTRODUCTION

The interactions of various track components, such as the effects of crossties and fasteners on rail wear, are known qualitatively by track designers and maintainers from experience. In order to quantify the potential effects, TTCI conducted an experiment on the High Tonnage Loop at FAST. Rail wear was measured in a 6-degree curve with 5 inches of superelevation throughout various crosstie and fastener zones.

During the 563 MGT of testing, the rail had no internal fatigue defects and minimal rolling contact fatigue on the running surfaces. Thus, the primary measure of rail performance was wear. Initial results showed that there were differences in cross-sectional area loss for the high rail of the curve. Rail wear is a likely failure mode (i.e., reason for replacement) of the high rail in this curve due to operations above the balance speed of 33 mph in the curve. The FAST train operates at 40 mph.

TEST SETUP

An ongoing tie and fastener test in Section 25 is in a 6-degree curve with 5 inches of superelevation at FAST, and it offers a unique opportunity to study the effects of various tie and fastener systems on rail wear. Table 1 shows the layout of this test. Eight tie and fastener zones were chosen as they are representative of the range of gage strength and stiffness seen in Class I revenue service. Recent tie and fastener performance results from Section 25 were presented in TD-15-013.[2] In 2012, a new high rail using premium rail was laid throughout Section 25, and a controlled experiment was established to compare any differences in rail wear between the tie and fastener zones. To study the effects of tie and fastener on rail wear, rail profiles were measured and compared with various tie and fastener performance parameters.

Rail wear measurement data was collected at 122, 177, 210, 247, 350, 454, and 563 MGT using a MiniProf™ digital profilometer. Although rail wear data was compared to the effects of track geometry due to tie-fastener properties, it is important to note here that all rail wear data was collected during unloaded normal conditions. Profiles measured by MiniProf at different MGT were used to calculate head, gage corner, gage face wear, and total area loss. The differences in total area loss across different tie-fastener zones were found to be statistically insignificant. But ties and fasteners seemed to affect where on the railhead that wear occurred.

Table 1. Tie and Fastener combinations for Rail Wear

Test Zone	No. of Ties	Tie Type	Tie Plate	Rail Fastener	Hold-Down Fastener
0a	50	Mixed Hardwood	18" Rolled	Longitudinally applied spring clip	Cut Spike
0b	50	Mixed Hardwood	18" Rolled	Longitudinally applied spring clip	Drive Spike
3a	25	Concrete	-	Bolted spring clip	-
3b	28	Concrete	-	Bolted spring clip - large	-
4	50	Concrete	-	Transversely applied spring clip	-
6	100	Plastic	14" Rolled	Cut Spike	Cut Spike
11b	50	Mixed Hardwood	18" Cast	Transversely applied spring clip	Screw Spike
13	100	Mixed Hardwood	18" Rolled	Cut Spike	Cut Spike

TIE AND FASTENER PERFORMANCE: Preliminary Analysis

Track performance data was gathered using the FRA's DOTX218 (T-18) GRMS vehicle, a track geometry car, and the lateral track loading fixture (LTLF) device. The LTLF device applies a 9-kip average static load at the head and web of the rail and measures only changes in track gage. The T-18 car was used to collect track geometry data and gage widening data using the car's deployable GRMS axle. For GRMS testing, an average lateral load of 13.6 kips and an average vertical load of 18.9 kips were applied to each rail to induce gage widening. The T-18 car and the instrumented geometry car measure various track parameters, but unlike the T-18 car, the instrumented geometry car measures only gage, because it does not apply additional loads on the rail apart from the load applied from the wheels of the car. The T-18 car provides delta gage as a calculated parameter of track gage strength: the difference between loaded and unloaded gage caused by the test vehicle applied vertical and lateral loads. Data from 2013, 2014, and 2015 of all three track geometry measuring systems were analyzed. Data collected from the instrumented geometry and T-18 GRMS cars were found to be more consistent than the LTLF data from one year to another. Preliminary general regression models showed delta gage to be the most significant among all parameters.

General regression methods were used to understand the effects of ties and fasteners on rail wear and track gage strength. To eliminate zone transition effects, ten ties at the beginning and ten ties at the end of each zone were eliminated from the analysis apart from the small zones 3a and 3b, which had less ties. Ten ties at beginning of zone 3a and ten ties at the end of zone 3b were eliminated. Multivariate tests of significance showed the relative effect sizes of measured gage data from the T-18 car and the instrumented geometry car on the three dependent variables: rail MGT, tie types, and fastener types as shown in Figure 1. The relative effect sizes are represented here by a parameter called *Partial eta-squared,* which signifies proportions of the variability in the dependent variables. Figure 1 shows delta gage measurement from the T-18 car to be influenced by tie and fastener types more than the gage measurements from the instrumented geometry car.

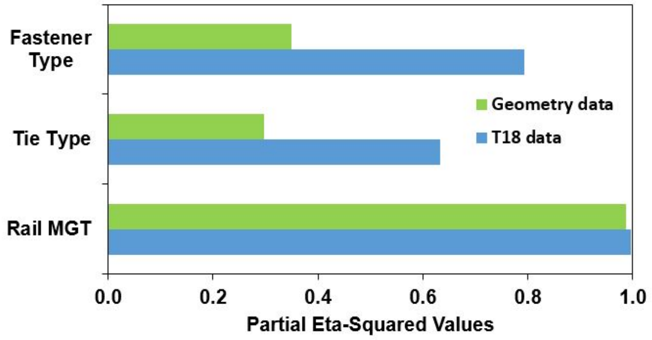


Figure 1. Partial Eta-Squared Values showing effect sizes

Based on the partial eta-squared values, more focus was given to the T-18 data. Figure 2 shows the effects of delta gage on all eight zones measured by the T-18 car in 2013, 2014, and 2015. Data of zone 6 collected in 2015 was excluded, because ties and fasteners in zone 6 were changed in 2015 as a part of a new experiment. Figure 2 clearly shows zones 6 and 13 have more delta gage (i.e., lower gage widening strength) than other zones. Zones 6 and 13 have cut spikes, whereas other zones have different elastic fasteners. But the box and whisker plot in Figure 2 does not explain how the various elastic fasteners affect delta gage.

Since the experiment conducted had several purposes, a full factorial tie, fastener, and rail wear experiment was not conducted. Thus, the influence of each individual tie-fastener combination was not determined. However, the experiment yielded useful information about the effects of tie and fastener types on rail performance. General linear modeling (GLM) methods were used as they are capable, given that the data required Multivariate Analysis of Covariance (MANCOVA) and contrast analysis. The GLM design grouped similar tie types into three categories: concrete, wood, and plastic. Similarly, different elastic fasteners were grouped together, and cut spikes were treated as another group of fastener type.

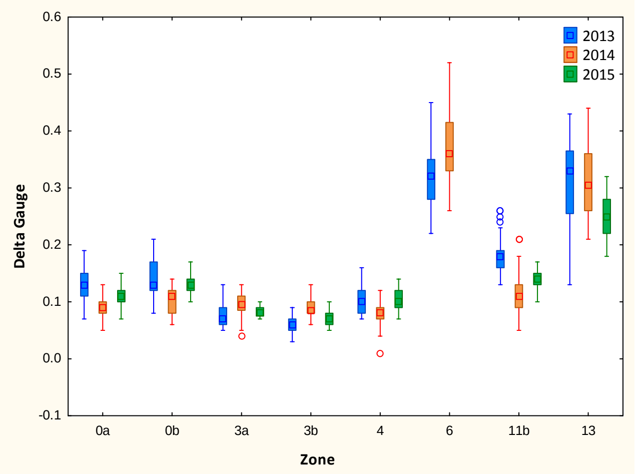
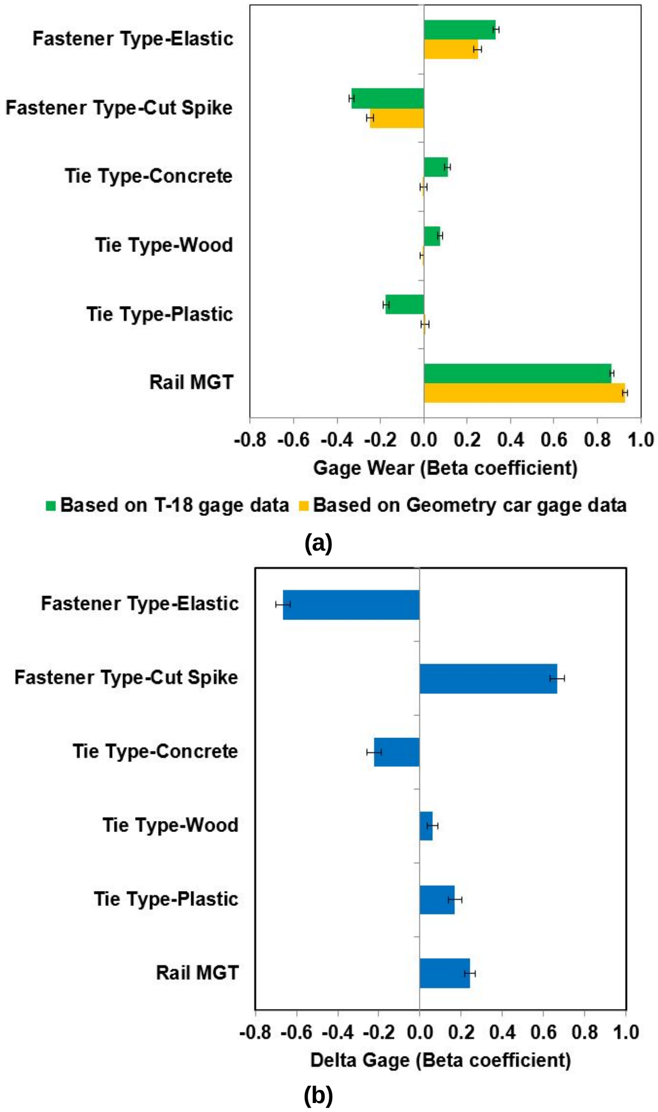


Figure 2. Box plot of delta gage variation across zones of eight tie-fastener combinations

Analysis using General Linear Modeling (GLM)

The GLM model with MANCOVA and contrast analyses showed statistically significant influence of three different tie categories and two fastener categories along with rail MGT on rail wear. The most important finding from this analysis shows rail MGT was the most important parameter for all aspects of rail wear including rail gage face wear (gage wear). Rail MGT was almost three times more influential than cut spikes or elastic fasteners when gage wear was analyzed. Figure 3 shows the influence of different factors on (a) gage wear and (b) delta gage using *Beta (β) coefficients* with 95 percent confidence intervals (CI). Beta coefficients are standardized regression coefficients which compare the relative contribution of each independent variable in the prediction of the dependent variables. Positive beta coefficients mean that the parameter contributes to increases in gage wear and delta gage, whereas negative beta coefficients imply the parameter contributes to reduced gage wear and delta gage. Gage data from both the T-18 and instrumented geometry cars were used in the GLM model to compare the beta coefficients, which in Figures 3a and 3b signify the relative contributions in the relationship between independent and dependent variables. Among the different wear parameters, gage wear was selected as it is directly related to delta gage, because dynamic gage widening affects wear on the gage side more than on the head or gage corner.



(b)

Figure 3. Influence of various tie and fastener groups on (a) gage wear beta coefficients and (b) delta gage beta coefficients (95% CI included)

Figure 3a shows for gage data obtained from the T-18 and instrumented geometry cars, rail MGT has the most influence followed by fastener types. Elastic fasteners seem to have a positive influence on gage face wear (more wear), whereas cut spikes seem to have a negative influence (less wear). This is related to Figure 3b where cut spikes have a positive influence on delta gage and elastic fasteners have a negative influence. A positive delta gage means gage widening. This means gage widening happens on application of load in the zones (6 and 13) with cut spikes, and this gage widening causes less gage wear. Higher gage widening causes the rails to open up, which causes lesser contact between the flange side of the wheel and the rail. Though gage widening can lead to serious issues, results in this study showed that gage wear was reduced by gage widening. Tie categories seem to have the least influence on both gage wear and delta gage. Plastic ties showed positive influence on delta gage and negative influence on gage wear, whereas concrete ties showed the opposite trend.

In this study, rail MGT had less influence on delta gage, because changes in gage were mostly affected by fastener types, and gage wear had less effects from fasteners than rail MGT. The relationship between rail MGT and delta gage is connected through the interplay among the various factors. This suggests it may be possible to further optimize rail life by adjusting maintenance practices to the particular track structure. Since different fasteners seem to influence track gage in opposite ways, which causes opposite influences in the gage wear behavior, the grinding profiles should be adjusted accordingly to avoid further effects on rail gage wear and track gage when the grinder transitions between zones with different fasteners.

CONCLUSIONS

The effects of crosstie and fastener types on premium rail wear performance and gage strength was analyzed using statistical methods with data collected during 3 years. Gage widening was observed in zones with different tie types (plastic and hardwood), but with the same type of fasteners (cut spikes). Zones with cut spike fasteners showed less rail gage face wear as a result of lower gage strength. Area loss due to rail wear was found to be almost uniform across various tie-fastener zones. Individual influence of tie-fastener combinations could not be determined due to uneven sample sizes, but ties and fasteners were grouped by categories for use in statistical modeling. Models showed rail MGT as the most important factor for gage wear with almost three times more influence than fasteners. Tie types had minimal effects on both rail gage wear and delta gage.

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