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Influences of Track Geometry, Crossties, and Fasteners on Rail Wear under Heavy Axle Loads

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Summary

In 2008, Transportation Technology Center Inc. (TTCI) began testing different ties and fasteners in a 6-degree curve on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST). In 2012, new premium rail was installed in the 6-degree curve. The tests evaluated the effects of crosstie and fastener configurations on rail performance under heavy axle loads. Lubrication, tonnage, and metallurgy are major factors affecting rail wear, but extensive research has not been done to evaluate the effects of tie and fastener types on rail wear. The data collected on the HTL from 2012 to 2016 shows effects of tie and fastener types on track geometry parameters which influence rail gage face wear. This data may assist railroads in determining optimal track design and maintenance limits for improved track system performance. General linear modeling (GLM) was used for statistical correlation among wear, track geometry, and tie-fastener conditions.

After accumulating 563 million gross tons (MGT), initial analysis showed head wear (vertical height loss) varied less in comparison to gage face wear (side wear) across the zones having various tie-fastener combinations. Gage face wear showed significant differences and was chosen as the dependent variable for the analysis. Forty-six different GLM models were tested. Three of the models were chosen for analysis because of their high coefficient of determination (R^2) values. Analysis of these three models determined that track gage strength parameters that affect track gage, such as rail roll and gage widening ratio (GWR), affected gage wear due to changes in track conditions. Tonnage accumulation and tie-fastener combinations directly affect changes in track conditions. Cross level also affects rail wear, although it is a track geometry parameter unrelated to track gage. In all three models, cross level stood out as one parameter with a positive contribution to gage wear. Changes in cross level cause differences in steering of trucks, which might cause changes in wheel/rail contact and lateral forces leading to changes in gage wear.

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INTRODUCTION

The effects of ties and fasteners on rail wear has been an ongoing evaluation at TTCI. An experiment was started in 2008 on the HTL at FAST in a 6-degree curve with five inches of superelevation and multiple zones of different combinations of crossties and fasteners. New premium rail was installed in 2012 and rail wear data was collected over 563 MGT of testing. Rail wear measurement data was collected using a MiniProf™ digital profilometer at 122, 177, 210, 247, 350, 454 and 563 MGT. Rail grinding was done as needed on the entire curve, maintaining consistent grinder settings and speed throughout the curve. Rail grinding was infrequent, with minimal metal loss, thus grinding effects were not considered in the analysis.

The first phase of this analysis included different statistical approaches that led to important findings documented in *Technology Digest* TD-17-006 by Banerjee, et al.[1] Details of the test layout are shown in Table 1. Tonnage (MGT) was the leading factor for gage face wear. Gage strength was found to be the most important track parameter correlating with gage face wear. Ties and fasteners were categorized in large groups and relative influences of each type were determined. The second phase focused on other geometry parameters which were found to be less significant than delta gage, which is gage strength measured by gage widening, in the first phase of analysis.

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

Analysis Methodology

Figure 1 shows differences in gage wear and head wear at 563 MGT across different zones with some scatter in the data. As shown in Figure 1, head wear had comparatively smaller variation than gage wear across the various tie-fastener zones.

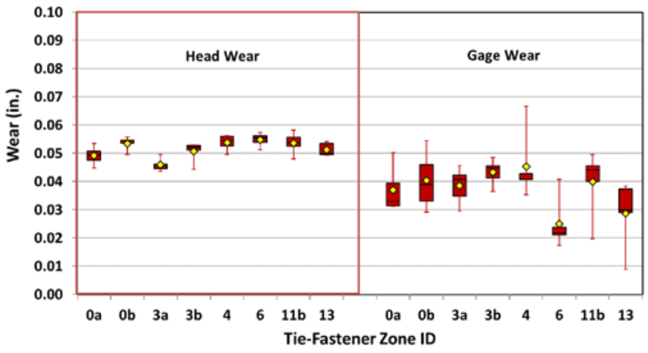


Figure 1. Head and Gage Wear Differences across Different Tie-fastener Combinations at 563 MGT

The differences in wear among various zones as shown in Figure 1 made it difficult to quantify the effects of individual tie-fastener combinations beyond the initial graphical analysis. Track geometry data from different track measurement methods were used to understand the correlations with rail wear.[2] Since the original experimental design had several purposes, a full factorial tie, fastener, and rail wear experiment as needed for this study was not feasible. Every possible combination of tie and fastener did not exist in the layout. The effects of this unbalanced design had to be eliminated; thus each zone's data gathered over the entire curve was regrouped prior to analysis. Three tie type categories remained (wood, concrete, and plastic), while fasteners were regrouped simply as cut spikes and elastic fasteners.

The Federal Railroad Administration's (FRA) DOTX218 (T-18) vehicle provides track geometry data and gage widening data using the car's deployable gage restraint measurement system (GRMS) vehicle.[1] For GRMS testing, an average lateral load of 13.6 kips and average vertical load of 18.9 kips were applied to each rail to induce gage widening. Delta gage was found to be the most significant parameter affected by the different crossties and fasteners. Additional parameters, assumed to be constants in the test, were analyzed. The effects of minor variations in track geometry are thought to affect performance variations seen in controlled experiments at FAST. Superelevation and track curvature measured by the T-18 vehicle were studied. Almost no influence was observed on rail wear. For the same reasons, the effects of additional track performance measures, such as changes in rail roll, rail cant, cross level and measured wheel-rail forces caused by gage widening test loads were examined.

To encompass all parameters, rail wear, tie, and fastener groups into consideration, different models were tested using GLM methods. GLM involves a multi-way, univariate between-subject design where all parameters are classified in three categories — predictor variables, factors, and dependent variables. As applied in this study, GLM extends multiple linear regression methods for relating multiple predictors to a single response variable. GLM analysis can provide a solution to quantify relative importance of predictors and factors (including subgroups; i.e., tie type), in spite of correlations between those variables. In this analysis, tonnage (MGT) and track geometry parameters were considered as multiple predictor variables, while ties and fasteners were considered as multiple factors, and gage wear as the only dependent variable. Delta gage and GWR were also used as predictor variables, but not as dependent variables as in the first phase of analysis. GWR is the ratio of delta gage over lateral load and is a direct manifestation of delta gage.

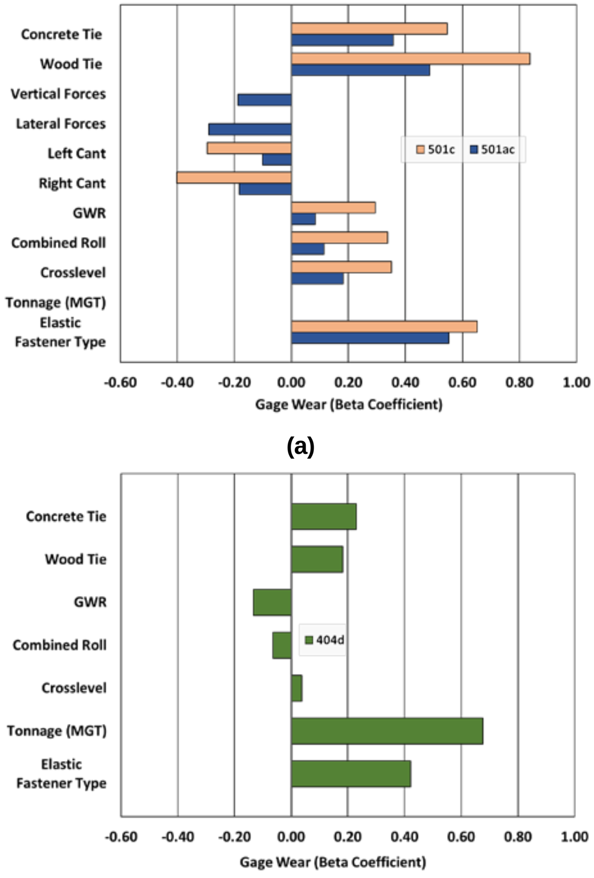
RESULTS OF GENERAL LINEAR MODELING

To understand the relative influences of various tie and fastener groups and other track geometry parameters on gage wear, cut spikes and plastic ties were considered as baseline. These ties and fasteners were chosen as baseline because they had negative beta coefficient values when tested for effects on gage wear in a previous GLM model mentioned in Figure 3a of *Technology Digest* TD-17-006.[1] Beta coefficients are standardized regression coefficients, which compare the relative contribution of each independent variable in the prediction of the dependent variable. Positive beta coefficients mean that the parameter contributes to increases in gage wear, whereas negative beta coefficients imply that the parameter contributes to reduced gage wear.[1] Forty-six variations of GLM models were tested, three of which were preferred because of their high coefficient of determination (R^2) values. A model with the highest R^2 value is considered to represent the best estimate of the relative strength of the relationships among the parameters. Table 2 shows the chosen three models along with the parameters chosen in each model.

Table 2. GLM Models with High R^2 Chosen for Analysis

Model ID	R^2	Parameters
501ac	0.858	Cross level, Combined Roll, GWR, Left and Right Cants, Lateral and Vertical Forces
501c	0.733	Cross level, Combined Roll, GWR, Left and Right Cants
404d	0.965	Tonnage (MGT), Cross level, Combined Roll, GWR

Accumulated tonnage and track gage strength (delta gage) are the predominant factors in rail wear, as was shown in TD-17-006.[1] To better understand the effects of additional parameters, which the track engineer may be able to control, models 501ac and 501c were built. Tonnage and delta gage are excluded from these models so that the potential effects of other track parameters can be determined. As shown in Figures 2a and 2b, wheel-rail forces and rail cant had negative beta coefficients indicating lesser effects on rail wear than other parameters.



(a)

(b)

Figure 2. Beta Coefficients of Different Parameters Analyzed in (a) 501c, 501ac and (b) 404d Models

Among all the three models mentioned in Table 2, 404d has the highest R^2 which indicates its strong predictive capability. Tonnage still stands out as the leading factor, followed by elastic fasteners, concrete ties, and wood ties. Among the different track geometry parameters, GWR and combined roll have negative beta coefficients, while cross level has a small but positive beta coefficient

DISCUSSION

The results of the GLM methods discussed here need to be analyzed with the assumption that no single model has the best predictive capability. Testing of 46 GLM models and their R^2 values indicate which parameters are important to consider. GLM assumes all parameters have the same role in influencing gage wear, but tonnage, tie type, and fastener type have direct influence, while any track geometry parameter is indirect, being a result of the variations in track conditions due to tie–fastener combinations and tonnage. Thus, it is expected that tie types and fasteners, along with tonnage, would show significant effects.

GWR, combined roll, and cross level changes showed positive beta coefficients as shown in Figure 2a. GWR by definition is directly related to delta gage. Combined roll is a data channel provided by the T-18 vehicle’s GRMS and is a combined measure of the amount of rolling of both left and right rails. The rolling of rails is a direct effect of the ability of the tie-fastener combination to hold the rail and maintain the desired track gage. Thus, GWR and combined roll are related to one another as both are dependent on delta gage, while delta gage is a direct measure of the gage strength. In Figure 2a, wheel-rail forces and rail cant showed negative beta coefficients and comparatively lesser effects on rail wear than the other parameters.

In the 404d model shown in Figure 2b, the relative contributions of GWR and combined roll became negative due to the presence of strong factors like tonnage, elastic fasteners, wood ties, and concrete ties. However, cross level showed positive beta coefficient values in all three models. This shows cross level to be one important track geometry parameter apart from gage strength parameters (delta gage, GWR, combined roll). Cross level is the measurement of the difference in height between the top surfaces of the two rails not including superelevation. Since the FAST train runs 40 mph with about a 2-inch overbalanced speed for the curve, the steering of the trucks will be affected by the variation in cross level, which can affect the gage wear on the high rail. If the change in cross level is negative, the high rail will be lower than its original position, which will cause the truck to steer outwards and the wheels to flange and cause gage wear.

CONCLUSIONS

The effects of crosstie and fastener types on rail wear performance was determined using statistical methods. Among the wear measures examined, gage wear had the highest variation while variation in vertical head wear was minimal among the tie-fastener zones. Forty-six GLM models were tested using various parameters and three models were shortlisted for analysis for their high coefficient of determination (R^2) values.

GWR and combined roll exhibited positive effects on gage wear in the first two models, but their relative contributions weakened in the presence of the direct variables — tonnage, tie types, and fastener types. Both these parameters are direct manifestations of gage strength. Cross level was one track geometry parameter independent of gage strength, but seemed to affect gage wear in a positive sense. This is attributed to changes in truck steering forces that can cause gage wear on the high rail if there is a change in cross level.

References

1. Banerjee, Ananyo, David D. Davis, Ivan Aragona, Mike McHenry, R.B. Wiley. June 2017. “Effects of Crossties and Fasteners on Rail Wear and Gage Strength in Heavy Axle Load Service” *Technology Digest*, TD-17-006. AAR/TTCI, Pueblo, Colorado.
2. McHenry, Mike, Joe LoPresti. May 2015. “Tie and Fastener System Gage Restraint Performance at FAST” *Technology Digest,* TD-15-013. AAR/TTCI, Pueblo, Colorado.