Field Demonstration of the Use of Track Strength Data to Optimize Tie Replacement Requirements

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ABSTRACT

This paper presents the results of a recent five year cooperative research study looking at the use of lateral track strength measurement (GRMS) technology to optimize tie replacement practices on main line railroad track. The study was a collaborative effort between the Federal Railroad Administration, the Railway Tie Association, CSX Transportation, and ZETA-TECH Associates, Inc. The specific focus of this study was to compare tie replacement strategies based on conventional, visual inspection with one based on track strength measurements taken from Gage Restraint Measurement System (GRMS) inspection data. The study consisted of four test miles, with several miles having tie replacement based exclusively on track strength (GRMS) based condition measurement and others on conventional tie replacement decisions using railroad tie inspectors. A total of 4,209 crossties were installed in this study which spanned approximately five years.

The results of the study showed that GRMS maintained miles outperformed the conventional mile in the effectiveness of the tie replacement/upgrade as defined by its track strength (Gage Widening Ratio) degradation behavior. The track strength based tie replacement generated a stronger track structure, with a lower rate of lateral track strength degradation than conventional techniques, while using fewer ties for targeted tie replacement. Projection of the track strength degradation rates over time showed that the track strength approach provided a 9% extension in tie life.
INTRODUCTION

The last two decades has seen the emergence of track strength measurement systems that monitor the strength of the tie/fastener interface on a continuous basis [1,2,3,4,]. These systems have moved from the research stage into practical usable systems that are commercially available to the industry, and whose measurements are incorporated into the current Federal Railroad Administration Track Safety Standards [5]. Based on these standards and comparable railroad standards, lateral track strength measurements have been used to identify ‘weak spots” in the track, locations where the tie and/or fastener condition is such as to not be able to properly carry traffic loadings. This type of exception reporting is useful and valuable.

However in recent years, interest has been increasingly focused on using these track strength measurements for maintenance planning, particularly for defining future tie replacement requirements [6]. As part of this tie planning usage, the issue of minimizing tie replacement costs comes up repeatedly, since railroads are constantly being challenged to reduce their maintenance costs, and tie replacement is one of the major track maintenance cost areas. Thus, there is a need for an incorporation of this generation of track strength data into the tie planning process and the evaluation of the condition and strength of existing wood tie track in order to assess the “minimum” level of upgrade necessary for ongoing train operation.

This paper presents the results of a Federal Railroad Administration funded effort that brought together the Federal Railroad Administration, Railway Tie Association, CSX Transportation, and ZETA-TECH Associates, Inc. to study optimized crosstie upgrade and maintenance practices.
Specifically the focus of this study was to examine tie replacement strategies based on conventional, visual inspection, and to compare these strategies to one based on track strength measurements taken from Gage Restraint Measurement System (GRMS) inspection data. As a secondary objective, a third set of replacement strategies, based on the TieInspect™ data collection and analysis system was also examined.

This paper presents the results of a full-scale field demonstration allowing for a side-by-side comparison of alternate upgrade approaches and maintenance approaches [7].

**TEST DESIGN AND STRUCTURE**

The study was designed to address two crosstie replacement issues of current interest: (1) to provide a direct comparison of alternate maintenance approaches, and (2) to utilize GRMS data to locate and remove weak spots at the individual tie level. To effectively address these issues it was decided that four one-mile test sites were needed, each with separate upgrade and maintenance philosophies. All four test miles were in zones where passenger trains reach 79 mph, as this study addressed combined freight and high speed passenger operations.

The test miles were located within CSX’s Metropolitan Subdivision (Gaithersburg, MD), which provided the optimal test requirements including:

- High Speed (79mph)
- Passenger Carrying (MARC)
- High tonnage (64 MGT)
- Uniform Traffic and Maintenance History
- Consistent GRMS Vehicle Runs

Table 1 shows the upgrade and maintenance technique employed for each test mile.
MP 22 represented the control mile, which employed current CSX tie replacement strategies. The definitions for the other methodologies are as follows.

**Upgrade** refers to a major tie replacement activity using a CSX production tie gang.

**Conventional** upgrades were performed based on conventional CSX tie replacement strategy.

**GRMS** (Gage Restraint Measurement System) upgrade was based solely on lateral track strength data from CSX’s GRMS vehicle (Figure 1). Locations exceeding a defined Gage Widening Ratio (GWR) threshold level had ties inserted. GWR is used because it is sensitive primarily to track strength, as can be seen by the following equation GWR:

\[
GWR = \frac{(LTG - UTG)}{L} \times 16000
\]

where \(LTG\) is the loaded track gage, \(UTG\) is the unloaded track gage, and \(L\) is the laterally applied GRMS load.

**TieInspect™** upgrade is based on tie condition data as collected by ZETA-TECH’s TieInspect™ tie monitoring system (Figure 2). Ties to be replaced were calculated based on the TieInspect™ replacement logic, which is dependent upon track class and curvature [8].

**Maintenance** refers to a lower scale tie replacement activity using a smaller CSX local tie gang.

**Conventional** maintenance consisted of tie spotting and replacement in accordance with current CSX standards and practices.
**GRMS** maintenance was based on a defined maintenance GWR threshold. The test miles had ties “spotted” in to bring within the gauge strength (as defined by GWR) to a specified “strength” level. The maintenance threshold and upgrade thresholds were different as the upgrade threshold brought the test mile to a tighter standard initially.

*TieInspect™* maintenance was based on a tie condition inspection, where the current tie condition data was evaluated and a tie-by-tie replacement plan was generated from the *TieInspect* tie replacement logic.

The results presented here encompass five years of research and compares the performance of the four different test sections, and specifically the performance of the different upgrade approaches used. The approximate dates for this activity were as follows:

- June 2001: Initial pre-upgrade GRMS run
- April 2003: Installation of Upgrade Ties
- May 2004: Post Upgrade GRMS run
- June 2005: Post Upgrade GRMS run
- October 2005: Installation of Maintenance Ties
- April 2006: Post Maintenance GRMS run

**DATA ANALYSIS AND TIE INSTALLATIONS**

GRMS track strength measurement data was analyzed and formed the basis for the determination of the relative rates of degradation. Figure 3 shows a foot-by-foot record of two GWR runs over a potential test mile with good location correlation.
After assembling and analyzing the data from the test miles, a pre-inspection condition assessment was performed using CSX tie inspectors and TieInspect™ in order to generate an electronic tie-by-tie condition report for each test mile.

To identify ties for the upgrade, based on GRMS data, it was necessary to locate specific ties based upon foot-by-foot data output. The TieInspect™ unit gave the test mile inspector the ability to record the start and end of curves within a test mile. By overlaying the GRMS superelevation channel with the TieInspect™ recorded curves, a functional relationship was established between the “foot counter” of the GRMS vehicle and the TieInspect™ tie number. This produced a relationship of GWR versus tie number (from the TieInspect data). Using a GWR upgrade threshold of 0.25 and the locating procedure described above, MPs 21 and 23 were marked using track strength data (from the CSX GRMS vehicle) exclusively. Figure 4 shows the GWR based tie-by-tie replacement locations, as displayed by the TieInspect™ host software for MP23. The red vertical dashes represent ties taken out by the production tie gang, and the yellow dashes are ties removed by the small tie gang. The ties were removed solely for lateral track strength and represent spots with GWR exceeding the threshold of 0.25. A similar procedure was sued to define the maintenance ties analysis for the 2005 maintenance activity.

Table 2 presents a summary of the upgrade and maintenance ties installed by CSX for each of the test miles.

**MONITORING OF TIE CONDITION DEGRADATION AND RESULTS**

GRMS monitoring runs were performed approximately once a year on the four test sections. Figure 5 illustrates a set of GRMS runs for one test mile showing pre-upgrade and post-upgrade
measurement runs, together with the measured improvement in track strength as defined by the GWR.

Analysis of the this data for all the test sections showed that the average or mean GWR is representative of the track strength across each test zone (of one mile each) and forms the basis for evaluation of tie replacement performance. The data showed a GWR degradation range of 0.066 to 0.094 $in/100\ MGT$ for the replacement methodologies investigated, noting that the test track zones were FRA Class 4 (79 mph passenger speed) predominantly tangent track. (with some limited curvature).

Table 3 summarizes the post-upgrade behavior of the two GRMS track upgrade sections as compared to the conventional upgrade section, looking at mean GWR after upgrade.

As shown in Table 3, the GRMS miles outperformed the conventional mile in the effectiveness of the tie replacement/upgrade as defined by the corresponding mean GWR degradation rate, i.e. both had a lower degradation rate than the conventional Mile 22. It should also be noted that the lowest degradation rate corresponds to the GRMS upgrade mile (Mile 23) with the lowest number of ties installed; 356 vs. 838 for the conventional mile. In addition, examination of the GWR standard deviation show that the GRMS miles had higher pre-upgrade standard deviations, which indicates a wider scatter of tie condition, but ended up with lower standard deviations (less scatter, more uniform condition) after the upgrade. This highlights the ability of the GRMS upgrade approach to provide a more uniform, stronger condition, based on the lateral gage strength of the track.

Figure 6 presents the relative behavior of the three test miles graphically. As can be seen in this Figure, the conventionally upgraded mile (Mile 22) started off (pre-upgrade) with the best
gage strength, as defined by mean, but was outperformed by the GWR miles, particularly MP 23. This is in spite of the fact that MP 23 had 58% fewer crossties installed. The other GRMS mile, MP 21 (GRMS), registered the largest improvement in mean GWR again due to successful targeting of weak spots.

The effects of these relative degradation rates on the time it takes for the track to reach the GWR threshold levels was calculated and presented in Figure 7. Note, the 2nd or maintenance level used is 0.75 inches. A GWR value between 0.75 and 1 inch represents a second level exception and track speed must be set at the maximum for class 3 track [5]. A GWR reading of 1 inch or more represents a first level exception and track speed is to be reduced to 10 mph [5]. Noting the above, the conventional mile on average reaches a second level exception 2.8 years earlier than the best performing GRMS mile. This is a direct function of the higher degradation rate shown above. By averaging the two GRMS mile degradation rates and using the second level exception threshold, it can be shown that the GRMS upgrade approach provides an additional 2.1 years to reach the threshold. Extending this improvement to overall tie life, and noting average tie life for this location is 23 years (Average tie life was calculated using the RTA SelecTie Model II, for the track and operating conditions of the Metropolitan Sub.), this would represent a 9.1% extension in tie life.

In addition to the GRMS vs. conventional tie installation comparison, MP 10 employed the TieInspect system and replacement logic for both the upgrade and maintenance cycle. Inspectors looked for all tie failure mechanisms including the ties ability to hold line and surface, splitting, breaks, plate cutting, plate movement, wheel cuts, decay or hollowness, and the ability to hold cut spikes. The inspections provided a full condition map and allowed for strategic tie replacement. Comparing this approach, using the TieInspect tie replacement logic and data, to
the conventional CSX approach, tie requirements were reduced by 9.8% using the TieInspect system and replacement logic.

Results for the upgrade portion of this study showed that GRMS based tie replacement generated a stronger track structure, with a lower rate of track strength degradation than conventional techniques, while using fewer ties. That is because targeted tie replacement resulted in superior lateral track strength, and decreased lateral degradation rates with an overall extension in the time before the track strength reached GRMS thresholds.

Maintenance ties were installed in October 2005 with a post-maintenance GRMS run conducted in April 2006. Similar to the upgrade findings, the GRMS maintenance mile outperformed the conventional maintenance miles in average GWR improvement, with much fewer ties installed. Table 4 shows the direct comparison of average GWR improvement (From June 2005 to April 2006) and the number of ties installed for the maintenance cycle. The GRMS replacement methodology was once again successful in targeting and reducing GWR peaks.

As shown above, the conventional mile with the most ties installed saw the smallest GWR improvement from the maintenance cycle. This is largely because of instances were GWR peaks were missed, as shown in Figure 8.

Another issue investigated with the GRMS maintenance miles was the track profile (surface) effect, since GRMS based tie replacement is based on lateral (not vertical) track performance. Examining the 62 ft chord profile for GRMS MP 21 showed good improvement in profile deviations (post-upgrade and post-maintenance), even though the tie replacement focused on lateral performance.
For MP 23, noting the very limited 356-tie upgrade performed in April 2003, the June 2005 run showed three areas of surface variations at the middle to end of the mile, which were alleviated by the follow up conventional maintenance cycle. This highlights the need to analyze track profile when performing GRMS based upgrades with greatly reduced tie insertions. By overlaying GWR and profile data, a complete tie replacement strategy can be implemented. However, in this case as well, overall tie insertions (upgrade plus maintenance) were significantly less (14%) than that for the conventional mile.

CONCLUSIONS

The focus of this study was to compare tie replacement strategies based on conventional (subjective), visual inspection to one based on objective track strength measurements taken from Gage Restraint Measurement System (GRMS) inspection data. This paper presents the results of a full-scale field demonstration allowing for a side-by-side comparison of alternate upgrade approaches (GRMS, CSX Conventional and TieInspect™) and maintenance approaches (GRMS, CSX Conventional and TieInspect™).

Analysis of the strength of the track, as measured by CSX’s GRMS inspection car and defined by the Gage Widening Ratio (GWR), showed that the average or mean GWR is representative of the track strength across each test zone (of one mile each) and formed the basis for evaluation of tie replacement performance.

The GRMS miles outperformed the conventional mile in the effectiveness of the tie replacement/upgrade as defined by the corresponding mean GWR degradation rate. The GRMS test miles showed a lower degradation rate with a lower number of upgrade ties installed; as compared to the conventional mile. They also had the lowest total ties (upgrade plus maintenance) installed (907 vs. 1190). In addition, examination of the GWR standard deviation
show that the GRMS miles had higher pre-upgrade standard deviations, which indicates a wider scatter of tie condition, but ended up with lower standard deviations (less scatter) after the upgrade. This highlights the ability of the GRMS upgrade methodology to provide a more uniform, superior condition, based on the lateral gage strength of the track.

Analysis of these relative degradation rates examining the time it takes for the track to reach FRA mandated GWR threshold levels, indicated that the GRMS upgrade approach provides an additional 2.1 years to reach the threshold. Extending this improvement to overall tie life, and noting average tie life for this location is 23 years, (Average tie life was calculated using the RTA SelecTie Model II, for the track and operating conditions of the Metropolitan Sub.) corresponds to a 9.1% extension in tie life.

Using the TieInspect system and replacement logic and comparing this approach to the conventional CSX approach, tie requirements were reduced by 9.8% using the TieInspect system and replacement logic.

Results for the upgrade portion of this study showed that GRMS based tie replacement generated a stronger track structure, with a lower rate of track strength degradation than conventional techniques, while using fewer ties. That is because targeted tie replacement resulted in superior lateral track strength, and decreased lateral degradation rates with an overall extension in the time to GRMS thresholds.

Noting that GRMS based tie replacement is based on lateral (not vertical) track performance, there is a need to analyze track profile when performing GRMS based upgrades with greatly reduced tie insertions. By overlaying GWR and profile data, a complete tie replacement strategy can be implemented.
In total, 4,209 crossties were installed in this study. MP 22 had 1,190 ties spotted and installed based on current (conventional) CSX practices. Total tie requirements for the other miles, to include both the GRMS and the *TieInspect™* miles, were in all cases less than for the conventional MP 22.

**ACKNOWLEDGEMENTS**

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REFERENCES


TABLE 1. Test Mile Descriptions

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<th>Upgrade</th>
<th>Maintenance</th>
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<tr>
<td>23</td>
<td>GRMS</td>
<td>Conventional</td>
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TABLE 2: Summary of Upgrade and Maintenance Ties Installed

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### TABLE 3: Post Upgrade Comparison of GRMS vs. Conventional Tie Installation

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<td>22 (Conv)</td>
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<td>23 (GRMS)</td>
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### TABLE 4: GWR Maintenance Results

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<th>MP</th>
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<td>22</td>
<td>Conv</td>
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<tr>
<td>23</td>
<td>Conv</td>
<td>0.019</td>
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</table>
FIGURE 1: CSX’s GRMS Track Inspection Vehicle

FIGURE 2. ZETA-TECH’s TieInspect™ Unit
FIGURE 3: Representative GWR Data from Two Test Runs

MP 23 GWR

FIGURE 4: Superimposed GWR Defined Replacement Ties With TieInspect Map
FIGURE 5: GRMS Data Comparison

MP 21 Moving Averages (100 ft)
GRMS Upgrade

FIGURE 6: Mean GWR as A Function of Traffic and Upgrade

GWR with Upgrade Condition Interpolated
FIGURE 7: Projected GWR over Time

FIGURE 8: Post Maintenance GWR for MP 23
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TABLE 3: Post Upgrade Comparison of GRMS vs. Conventional Tie Installation

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