ABSTRACT

The portable track loading fixture (PTLF) has been used as a nondestructive means of testing track gage widening strength by the railroad industry and the Federal Railroad Administration (FRA). A new method was developed to alleviate the concerns of repeatability found in the field measurements. It has been observed that some locations which exceed the displacement criteria on initial loadings are within the limits on subsequent loadings. Through track strength testing conducted at seventy locations over three railroads, five methods for analyzing PTLF measurements were assessed for reliability and repeatability.

The paper focuses on the analysis of the cycle-to-cycle variability using the different methods considered. Preliminary results of the analysis indicate that a method referred to as the Exercise Gage Method results in a reduction in cycle-to-cycle variability by a factor of four. Details of this method with data analysis to support the conclusions drawn are presented in the paper.

Keywords: Gage Strength, FRA Track Safety Standards, Ties, Track Strength, Portable Track Loading Fixture, Repeatability, Exercise Gage Method

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1. INTRODUCTION

The portable track loading fixture (PTLF) has been used as a nondestructive means of testing track strength as per the Federal Railroad Administration's (FRA) Track Safety Standards (TSS) §213.110 (m). The PTLF is operated by applying a 4,000-pound-force (lbf) lateral load as close to the shear center of the rails as possible, while the change in gage (delta gage) is measured using a gage bar. This delta gage is compared against the threshold of 0.625" specified in the TSS. Although it is widely accepted that delta gage caused by the PTLF loading is a strong indicator of track strength, repeatability of measurements has been a concern. It has been observed that some locations, which exceed the displacement criteria on initial loadings, are within the displacement limit on subsequent loadings. As a result of this variation, the reliability of the PTLF test has been questioned in the past.

Through testing it has been determined that this variability in delta gage is largely because of the rail set. Rail set is defined as the difference between the initial unloaded gage and the gage following a load application and release. As the load is removed, the rail does not return to its initial position due to friction between the ties and tie plates. This resting position after a load-release cycle has been named the “exercised gage” for this study. During testing, rail set was observed to lead to significant cycle-to-cycle variability in the deflection of the head of the rail.

It has been found that recent track excitation can have a significant impact on the rail set during a PTLF test. These excitations can be caused by external loadings, such as trains or hi-rail vehicles capable of applying lateral load passing the location, or internal forces caused by factors such as temperature. It is believed that continued vibrations resulting from a passing train allow the rails to overcome the friction, leaving them in a position of equilibrium set, whereas other forms of excitation result in different values of rail set for that same track location. This means that recent excitation of the track can change the initial conditions for the PTLF test. With the exact initial conditions for the PTLF test unknown, variability is introduced into the measurements. This study encompasses multiple field measurements using the PTLF loads and various gage measurement devices to arrive at a consistent, repeatable and simple method for PTLF testing.

2. FIELD SURVEY OVERVIEW AND APPROACH

Six PTLF field surveys were conducted to date under this study. Surveys were conducted on three railroads between 2007 and 2013. Initial surveys were used to understand the relation between the applied force and delta gage and general characteristics of the force-delta gage curve. The later surveys were conducted to further validate the method developed using the initial surveys as well as to test a prototype PTLF described in this paper. Details each survey conducted.
Table 1 details each survey conducted.

### Table 1. PTLF Survey Tests

<table>
<thead>
<tr>
<th>Survey</th>
<th>Date</th>
<th>Surveyed Locations</th>
<th>Usable Surveys</th>
<th>PTLF</th>
<th>Gage Measurement</th>
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<td>25</td>
<td>23</td>
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<td>Gage Bar</td>
</tr>
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<td>2</td>
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<td>12</td>
<td>12</td>
<td>Instrumented PTLF</td>
<td>LVDT</td>
</tr>
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<td>14</td>
<td>Instrumented PTLF</td>
<td>LVDT</td>
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<tr>
<td>4</td>
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<td>4</td>
<td>4</td>
<td>Instrumented PTLF</td>
<td>Gage Bar</td>
</tr>
<tr>
<td>5</td>
<td>December 2012</td>
<td>9</td>
<td>9</td>
<td>Instrumented PTLF</td>
<td>Gage Bar</td>
</tr>
<tr>
<td>6</td>
<td>December 2013</td>
<td>8</td>
<td>8</td>
<td>Instrumented PTLF</td>
<td>Instrumented PTLF</td>
</tr>
</tbody>
</table>

Survey 1 was performed in November 2007 on Railroad 1; a standard PTLF was used to load the track with a standard gage bar used to measure the gage at the head of the rail (referred to as head gage) and a tape measure used to measure the distance between the webs of the two rails perpendicular to the track (referred to as web gage). The survey team traveled in a hi-rail vehicle, which induced minimal loading on the track structure, so this survey was considered to be performed on unexercised track. Test locations were chosen by the test engineers using visual conditions of the ties on the track. Measurements were recorded before and after application of a 4,000 lbf lateral load. This procedure was repeated 3 times, with the rails pulled inward before the third test to match the initial unloaded condition. The data analysis of this survey revealed that greater understanding of the force-delta gage curve was needed which led to Survey 2 in which the applied force and rail movement were continuously recorded during track loadings.

Survey 2 was performed in July 2009 on Railroad 1 with sensors to continuously record the applied load, head gage, and web gage. The applied load was measured using a pressure transducer connected to the hydraulic line attached to the PTLF’s piston. A string potentiometer was connected to the main body of the PTLF and the moving shoe to measure the web gage. The head gage was measured utilizing a fabricated gage bar which utilized a magnet on one side and spring loaded linear variable displacement transducer (LVDT) on the other side to ensure constant contact with the rails. This custom gage bar is illustrated in Figure 1; the bar is inverted in the picture to display the instrumentation. As with the first survey, the team was traveling in a hi-rail vehicle,
testing unexercised rail. Figure 2 illustrates the setup used to gather continuous PTLF loading data; the data acquisition computer is not shown for the sake of clarity.

Figure 2. Test Setup of the Modified PTLF and Gage Bar during 2009 Testing

Survey 3 was performed in November 2009 on Railroad 2 and utilized the same data collection configuration as the July 2009 survey. During this survey, the team collected data behind DOTX-218, the FRA’s Gage Restraint Measurement System (GRMS) vehicle which applies a specific vertical and lateral load to the rails to measure track strength. GRMS data from DOTX-218 was used to identify weak track locations on the track for PTLF testing. Due to the recent passage of the GRMS and subsequent lateral and vertical load application, this data is considered to be collected on recently exercised track.

Following the surveys described above, the PTLF was modified to include the instrumentation needed to measure the applied load, gage, and web gage. A data acquisition card was housed in an enclosure on the PTLF chassis, sending the data to a tablet computer through Bluetooth. The instrumented PTLF is shown in Figure 3.

Figure 3. Instrumented PTLF used for 2012 Survey 4

Survey 4 was performed in August of 2012 on Railroad 2 using the newly instrumented PTLF to collect data. As was done in the November 2009 survey, this survey was performed following a vehicle equipped with a GRMS. Redundant measurements of the
gage and web gage were taken using a gage bar and tape measure, respectively, as a means of confirming the recorded data. Because the instrumented PTLF was still in development, data from the gage bar was used for analysis on this data set.

Following the August 2012 survey, a prototype electronic PTLF was built to incorporate the sensors used in previous test efforts while housing all of the electronics within the chassis for a more compact device. This prototype, shown in Figure 4, was used on subsequent surveys. A brief description of the instrumentation and capabilities of the prototype is detailed in Section 3.

![Figure 4. Prototype PTLF used during Surveys 5 and 6](Image)

Survey 5 was performed in December of 2012 on Railroad 3, again utilizing the instrumented PTLF with a gage bar and tape measure. This survey was performed following a large hi-rail vehicle. As with the prior survey, the analysis of this data set used the measurements collected with the gage bar.

Survey 6 was performed in December of 2013 on Railroad 2, only utilizing the instrumented PTLF. Prior to testing, the sensors used to measure the gage were modified to provide for a more accurate measurement, allowing for the collected sensor data to be used for analysis. This test was performed following a vehicle equipped with a GRMS on recently exercised track.

### 3. INSTRUMENTED PTLF PROTOTYPE

As part of this study, an instrumented PTLF prototype was developed to collect more complete and accurate data during PTLF testing. The prototype system consists of an instrumented PTLF and tablet computer running an application designed to collect and process the data. Repeatability testing of the instrumented PTLF prototype consistently produced results within 0.01 inches; this variability is less than 0.03 inch, the maximum resolution of a standard gage bar.

The instrumented PTLF prototype includes sensors to collect data for three parameters of interest - the applied load, the web gage, and the traditional track gage measured at the gage point. A pressure transducer is used to measure the hydraulic pressure supplied to the piston, which is used to calculate the applied force. An LVDT is mounted in-line with the piston to measure the web gage. Rotary sensors are mounted on each end of the PTLF to measure the rotation of the rail head with respect to the PTLF; these measurements are combined with the LVDT measurement to determine
the track gage. A battery and Bluetooth-enabled data acquisition card are mounted within the chassis of the PTLF.

An Android application was developed to collect and process the sensor data received through a Bluetooth connection. The application allows the user to input information about the test including division/subdivision, location referenced to mileposts and test notes; the date, time, and GPS location are automatically acquired from the tablet computer. During testing, the application displays the applied load in real time, with the gage at the web and gage point displayed as specific trigger loads are achieved. After releasing the applied load, the application will calculate and display the exercised gage parameters to determine a pass/fail rating. The information is saved into a summary file for reporting purposes and a raw data file to allow the user to examine the data in further detail. A screenshot of the application’s user interface is shown in Figure 5.

![Figure 5. Display from Application Developed for use with the Instrumented PTLF Prototype](image)

4. ANALYSIS
In order to determine a suitable method to reduce the variability of PTLF test results, a baseline was determined by comparing the results based on the current standards. Survey 3 was used initially to determine the feasibility of alternative measurement methods, with the data from Survey 2 being used for confirmation. Following this analysis, the chosen method was applied to all six datasets. The plots for each of the methods compared in this analysis section show data for Survey 3 only and comparison for all six surveys is shown in the final two plots of this paper. Survey 3 was chosen for analysis because it had a wide range of track quality with respect to lateral restraint and was collected with precision instrumentation. Following the establishment of a consistent method of measuring the track strength, the three surveys in 2012 and 2013 were performed for further confirmation as well as testing of the electronic PTLF prototype.

a. Current Method (FRA TSS §213.53)

The current method of taking standard gage measurements at the head of the rail as defined in the FRA TSS §213.53 with no vertical load on the track, and with the 4,000 lbf load at the shear center was initially analyzed as a comparison for the other methods. Because the delta gage (difference between the loaded and unloaded gage measurements) during the first loading at a particular location is widely accepted as having a strong relationship with track strength, it was used for all comparisons. Figure 6 shows a cross-plot of delta gage from two loading cycles from Survey 3 over fourteen (14) test locations. The current method of measuring the head gage displacement under PTLF loads resulted in a cycle-to-cycle standard deviation of 8.28 percent with an $R^2$ value of 0.9553.

![Figure 6. Cycle 1 Delta Gage vs. Cycle 2 Delta Gage from Survey 3](image)
b. Web Gage Method

The web gage displacement during the loading cycle was also analyzed. Web gage, if found to be a good measure of track strength, would be a very simple measurement, that would isolate the traditional gage measurement from track strength. The web gage displacement represents the majority of the lateral displacement without considering the roll of the rails. Figure 7 shows that the web deflection has a moderately higher variability from cycle-to-cycle, with a moderately lower correlation for Survey 3 data. The cycle-to-cycle standard deviation of the web gage displacement was determined to be 11.70 percent with an $R^2$ value of 0.9482.

![Figure 7. Cycle 1 Delta Web Gage vs. Cycle 2 Delta Web Gage for Survey 3 Data](image)

Further analysis of the web and head deflection revealed that the roll of the rail during PTLF loading was unpredictable and did not correlate to the delta gage measurement. This unpredictability contributed to the lower correlation seen in the web gage measurements. Figure 8 and Figure 9 illustrate the rail roll under loading compared to its preload condition. These locations both show very similar web gage displacements, but the gage displacements differ significantly. Historically, it is regarded that the PTLF lateral load application causes only translation of the rails. However, in practice, it has been observed that most rail locations show rail roll upon PTLF load application. Outward rail roll under a combination of lateral and vertical loads would increase the gage over which the trains operate. The rail size for Survey 3 was uniform at 136 lb per yard and does not seem to be the cause of the difference in rail roll observed at the test locations.
c. Area Ratio Method

The Area Ratio Method attempts to compare the work required to displace the track using the PTLF with the work calculated from a limit work curve. Because this method uses the work as calculated by the area under the force deflection curve, it is able to incorporate the effects of both the displacement and the path taken to reach the displacement. This is potentially useful when the force-deflection curve for the track location is not linear, which is evident in a lot of weak track locations. Generally the force-deflection curve is divided into three regions with different stiffness values.
designated as k1, k2 and k3. k1 is a high stiffness region exhibiting very small displacements representing the friction between the rail and tie plate. k2 is a low stiffness region representing slack in the track. Finally, k3 is another high stiffness region which is attributed to the fasteners becoming engaged. An example location used for illustration is shown in Figure 10 with the red lines drawn on top of the actual force deflection curve to show the three different stiffness regions. For this study a simplified curve with only k2 and k3 region stiffness values was used.

Figure 10. Example Location to Illustrate the Three Stiffness Region in a Typical Force-Deflection Curve During PTLF Load Application and Release

The first step of the area ratio method was to find a limit load curve, which would be an approximation of the path of the force-deflection curve for a hypothetical location where the head displacement would reach 0.625” (the FRA TSS threshold) at a load of 4,000 lbf. This curve would represent the most common path taken by a track location during a loading cycle for a PTLF force application with the displacement being 0.625”. In order to determine the k3 stiffness value for such a limit curve, the data gathered in this study was statistically analyzed. For the determined k3 stiffness value, a displacement value was arrived at using the same data. A correlation plot of k3 stiffness value and the delta gage for the test locations is shown in Figure 11. The next few paragraphs describe the process of arriving at the limit curve points in detail.

From this relationship, Equation 1 was derived to determine the k3 stiffness for the limit curve.

\[
k_3 = 35942e^{-2.145(20)}
\]  

(1)

Using this equation and the maximum acceptable deflection of 0.625”, the ideal k3 stiffness was determined to be 9,405 lbf/in.
The next step was to determine how much of the deflection of the ideal curve would be in the $k_3$ region. A plot was made of the deflection in the $k_3$ region versus the $k_3$ stiffness, which can be seen in Figure 12, and the relationship in Equation 2 was determined.

$$\delta G_{k_3} = 13757(k_3)^{-1.470}$$  \hspace{1cm} (2)

By plugging 9,405 lbf/in into the equation for the $k_3$ stiffness, the $k_3$ deflection was determined to be 0.24".

With the $k_3$ stiffness and $k_3$ deflection determined, a limit curve was made. From the above analysis, it was determined that the last 0.24" would be considered the $k_3$ region,
so from 0.385" to 0.625" the slope of 9405 lbf/in was used. The region from 0" to 0.385" is assumed to the linear $k_2$ region which starts at 0" and 0 lbf. The $k_2$ region stiffness is equal to 4,415 lbf/in for the limit curve. The plot in Figure 13 shows the limit curve used in the area ratio calculations for this study.

![Image of Figure 13: Derived Limit Load Curve for a Location that Would Reach 0.625" of Displacement with a 4,000 lbf Load](image)

**Figure 13. Derived Limit Load Curve for a Location that Would Reach 0.625" of Displacement with a 4,000 lbf Load**

By calculating the area under the limit load curve, a work curve was created. The curve includes the area from 0-4000 lbf of load.

![Image of Figure 14: Limit Work Curve](image)

**Figure 14. Limit Work Curve**

which shows the estimated total work required to achieve the limit deflection of 0.625".
To determine the strength of the track at a particular location, the work required to displace the track in that location is compared to the limit work curve. If the measured displacement exceeded 0.625”, the data was compared to the limit work curve at 0.625”, shown as the blue vertical line in Figure 15. For locations where the displacement was less than 0.625”, the maximum measured displacement was used and compared to the limit work curve for the corresponding displacement, shown as the green and red vertical lines in
Figure 16. If the ratio of the measured location to the limit work curve is greater than one, the track is stronger than the condemning limit. If the ratio is less than one, the track is weaker than the condemning limit.
The work used to displace the track with the PTLF was compared to the limit work curve to calculate the area ratio for each location and cycle. Figure 17 shows the calculated area ratios for all Survey 3 data. This method had a strong correlation to the cycle 1 head deflection, with an $R^2$ value of 0.9342. The weakness of this method is a high cycle-to-cycle variability, which was calculated to have a standard deviation of 12.79 percent, compared to 8.28 percent using the current method in the FRA TSS.

Figure 17. Area Ratio Calculated for Each Location and Cycle

d. Load Cycle Empirical Method

A number of sub-methods were investigated which considered different parts of the force-deflection curve to determine if the variability could be reduced. All of the data regions investigated were compared against the first cycle total head deflection data, as that is the parameter with an established correlation to the track strength.

The first set of sub-methods continued using the head displacement data but disregarded the low load data because it was realized that the initial part of the force-deflection curve exhibited the greatest variability. The displacements were determined for the loads from 1,000 to 4,000 lbf and from 2,000 to 4,000 lbf. Figure 18 and Figure 19 show the regions used for both of these methods.
With the 1,000-4,000 lbf displacements determined, the two cycles were plotted against each other to determine their relationship; the results of this are exhibited in Figure 20. The cycle-to-cycle standard deviation of this method was 7.82 percent, which is a slight improvement over the current method, while the correlation was reduced slightly, with an $R^2$ value of 0.9216.
Figure 20. Cycle 1 Delta Gage vs. Cycle 2 Delta Gage from 1,000-4,000 lbf Load

The displacements from 2,000-4,000 lbf were then plotted against each other; the results of this are exhibited Figure 21. The cycle-to-cycle standard deviation of this method was 7.66 percent, which improved slightly upon the 1,000-4,000 lbf displacement measurement results. The relationship between the two cycles from 2,000-4,000 lbf had an $R^2$ value of 0.9522.

Figure 21. Cycle 2 Delta Gage vs. Cycle 2 Delta Gage from 2000-4000 lbf Load
The second set of sub-methods was to repeat this analysis using the web gage rather than the head gage. The plot for the web displacements from 1,000-4,000 lbf are shown in Figure 22, with a cycle-to-cycle standard deviation of 10.13 percent. The web deflections resulting from 2,000-4,000 lbf are shown in Figure 23, which had a cycle-to-cycle standard deviation 12.33 percent. The 1,000-4,000 lbf web deflection has an $R^2$ value of 0.9402 while the $R^2$ value of the 2,000-4,000 lbf web deflection is 0.9374.

![Figure 22](image1.png)

**Figure 22.** Cycle 1 Delta Web Gage vs. Cycle 2 Delta Web Gage from 1000-4000 lbf Load

![Figure 23](image2.png)

**Figure 23.** Cycle 1 Delta Web Gage vs. Cycle 2 Delta Web Gage from 2000-4000 lbf Load
e. Exercise Gage Method

When analyzing the data for the above empirical methods, it was found that while the initial unloaded gage may differ from cycle-to-cycle, the loaded gage and exercised gage remained very close, as seen in Figure 24. The loaded gage value is the value where the load is 4,000 lbf and the exercised gage is the value where the gage comes back to rest after the load is released completely. The exercised gage displacement was determined for both the head and web, and variability/correlation analyses were performed.

![Figure 24. Comparison of Load Cycles at Location 1 from Survey 3](image)

Using the exercised head gage displacement, both a strong correlation and a low cycle-to-cycle variability were found. Figure 25 shows the exercised head deflection for each cycle. The cycle-to-cycle variability using this method was 2.39 percent, with an $R^2$ value of 0.9937, both of which represented vast improvement over the other methods considered.
The Exercise Gage Method for the web gage was the most repeatable of the web measurements however, not as good as the exercised head gage measurement. Figure 26 shows the two exercised web gage measurements, where a cycle-to-cycle standard deviation of 6.52 percent and an $R^2$ value of 0.9715 were determined.
Figure 26. Cycle 1 Delta Web Gage Exercised vs. Cycle 2 Delta Web Gage Exercised

It was found that the source of the low correlation of the web gage measurements to the Cycle 1 head gage displacement was that the rail rotation was not predictable. During some tests the rail rolled inward with the PTLF load applied, while others experienced outward roll. The roll was analyzed to determine if a correlation existed with the loaded or unloaded gage as well as with the web or head deflection. This analysis revealed no strong correlations that could help predict the roll amount.

f. Method Comparison

Figure 27 shows the variability and correlation of each of the methods detailed in this section, where \( G_h \) indicates that gage measured at the gage point on the head of the rail and \( G_w \) indicates gage measured at the web. \( \delta \) denotes the change in gage between the various measurement points. The method highlighted by the red square is the current method, with the method highlighted by the green square being the method with the best combination of low variability and high correlation to track strength as currently defined.
Based on the analysis, it was determined that the method of measuring the difference in gage from the loaded state back down to the exercised gage, would be selected for further analysis.

**g. Exercise Gage Method Validation**

Using the data from Survey 3, which was performed on track exercised by the GRMS vehicle, a reduction in variability from 8.28 to 2.39 percent was observed. Figure 28 shows the comparison between consecutive loadings for the current and Exercise Gage Method on Survey 3. With the data from Survey 2, which was on unexercised track, the variability was reduced from 23.31 percent to 1.89 percent. A comparison of the two methods can be seen in Figure 29. These two data sets show that regardless of the track condition, the Exercise Gage Method is capable of delivering highly repeatable numbers. As a result of this, the Exercise Gage Method was applied to the combined dataset from all six surveys. A comparison for all surveys can be seen in Figure 30, where the variability was reduced from 15.01 percent to 3.71 percent.
Figure 28. Comparison of Cycle-to-Cycle Variation for the Current Method and Exercise Gage Method for Survey 3

Figure 29. Comparison of Cycle-to-Cycle Variation for the Current Method and Exercise Gage Method for Survey 2
Figure 30. Comparison of Cycle-to-Cycle Variability for the Current Method and Exercise Gage Method for all Surveys

When comparing the Exercise Gage Method to the current method, it was observed that the measured displacement values are reduced slightly due to the removal of the set in the rails. The exercised gage data was compared with the current method, shown in Figure 31. From this comparison, it was determined that the Exercise Gage Method reduced the magnitude of the displacement measurement by approximately 16 percent. Using Figure 31, it can be observed that for the current threshold of 0.625” for the delta gage parameter, the exercised gage measurement is approximately 0.5”. Due to this reduction in magnitude of the measured parameter, further consideration as well as additional data collection is recommended to arrive at a comparable threshold for the Exercise Gage Method.
5. CONCLUSIONS

A number of alternative methods were examined in an attempt to reduce the variability that has been observed when testing with the PTLF while still retaining a strong correlation to track strength. Through the analysis, it was determined that much of the variability in the measurements is due to the set in the rails, or the change in the initial gage due to a previous loading. For this reason, a method which could eliminate or reduce the measurements dependence on the initial conditions was desired.

Analysis on the November 2009 survey revealed that a method called the Exercise Gage Method, which measured the difference between the loaded gage and the gage after releasing the load, or the exercised gage, resulted in the largest reduction in variability. This method also resulted in almost no loss in correlation to the current method when compared to a subsequent loading of the current method. For this reason, the Exercise Gage Method was applied to all survey data, revealing a reduction of variability from 15.01 percent to 3.71 percent.

The Exercise Gage Method was shown to be a viable option to significantly reduce variability, while retaining a strong correlation to track strength. Data collected during this study shows that a comparable threshold for the Exercise Gage Method would be 0.5” for identifying weak locations as exceptions to the FRA TSS. Careful consideration needs to be given to setting up of the threshold for the new method using the current study as well as recommended additional data collection using the PTLF.
6. ACKNOWLEDGEMENTS

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Development of Exercise Gage Method for Portable Track Loading Fixture Measurements

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Hugh Thompson (FRA Office of Research, Development and Technology)
Overview of the PTLF

• The Portable Track Loading Fixture (PTLF) is used as a track maintenance tool by railroads and as a tool to evaluate track strength
• PTLF uses a pump and cylinder combination to apply load laterally to the rails to test the track
• Gage is measured at the unloaded condition and loaded condition

Current Process in Track Safety Standards

• Per §213.110: “Delta Gage” is the difference between the loaded and unloaded measurements.
  – A higher delta gage value indicates weaker track.
• In general, there is a strong correlation between delta gage and track strength on unexercised track, but the subsequent load cycles do not produce the same results.
  – Track which has not been recently exercised will experience a set (difference between initial unloaded position of rails and their position after release of the load).
  – Due to this set, lower displacements are measured during subsequent loadings.

Problem/Objectives

• Problem
  – Current method used with the Portable Track Loading Fixture (PTLF) results in high variability between measurements at a given location for consecutive loadings
  – Complicated by temperature changes and recent track conditions
• Objectives
  – Develop a simple measurement method that will reduce the cycle-to-cycle variability of the PTLF data
  – Approach should require minimal training for track maintainers or inspectors
  – Process must retain a strong correlation between chosen measurement method and track strength
• Approach
  – Analysis methods were developed using the test data collected on several railroads during multiple field surveys conducted between Nov 2007 and Dec 2013

Program Overview

• The Federal Railroad Administration (FRA) sponsored research to investigate causes of track strength measurement variability and to arrive at a method that would produce more repeatable measurements.
• During this research effort, 6 field tests were conducted on 3 different railroads.

<table>
<thead>
<tr>
<th>Survey Number</th>
<th>Survey Date</th>
<th>Survey Location</th>
<th>PTLF Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>November 2007</td>
<td></td>
<td>Standard PTLF</td>
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<td>December 2012</td>
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<tr>
<td>6</td>
<td>December 2013</td>
<td></td>
<td>Enhanced Instrumented PTLF</td>
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</table>

• Data from the first survey showed that it was necessary to instrument the PTLF to collect continuous pressure (force) and displacement data in order to understand the entire force deflection cycle.

Instrumented PTLF Used for Surveys 2, 3 and 4

• Instrumented PTLF consisted of a typical PTLF with the following sensors/instrumentation
  – Gage measurement using an LVDT mounted to an aluminum frame
  – Pressure sensor to measure the force applied to the rails
  – Data acquisition through interface laptop computer

Observations from Survey 2 and 3

• Unloaded gage for consecutive loading cycles are not the same
• “Slack” in the track may be significant and leads to repeatability issues for the current delta gage method
• The force deflection curve is non-linear and has different stiffness regions
Discrepancies of Current Process

- Data collected on two different railroads using an instrumented PTLF to continuously measure force and deflection parameters at the gage point and the web.
- Cycle-to-cycle standard deviation of Delta Gage measurements at a given location was calculated to be 8.38% (Survey 3) where GRMS car had exercised the track and 23.31% (Survey 2) where it had not.

Different Analytical Methods

- Method 1 - Area Ratio Method, which uses the work required to displace the track as a measure of strength
- Method 2 – Load Cycle Empirical Method, uses data collected from 1000-4000 lbf and 2000-4000 lbf load ranges to determine if data is more repeatable in the higher load region
- Method 3 – Exercise Gage Method, uses gage data while the load is being removed to determine the gage displacement during the return cycle after the track has been exercised
  - Determined to be the most repeatable method and recommended for further field validation and testing

Area Ratio Method – Method 1

- Uses the work required to displace the track as a measure of strength
- Area under the curve for each location is calculated using the force-deflection cycle
- Method considers how the track responds across the entire load range
- Method was not as repeatable as desired because the work done to get to the final loaded gage is dependent on the initial unloaded gage

Load Cycle Empirical Method – Method 2

- Uses portions of the force deflection cycle
- High load data more repeatable than the low load deflection data
- Improved repeatability for delta gage measurements taken between 2000 & 4000 lbf but not enough for weak locations
- Displacement values are smaller than the current delta gage parameter which increases the need for high resolution devices

Exercise Gage Method (EGM) – Method 3

- Uses the return or unloading portion of the load deflection cycle
- Loaded gage and exercised gage are very repeatable for a given location
- Requires no additional equipment or calculations in the field, retaining the simplicity of the existing process
- It can be implemented with the existing PTLF and gage bar combination
- Requires re-evaluating existing delta gage threshold

Method Comparison

- Comparison shows that EGM measurements have the best combination of a strong correlation to detect weak track and high repeatability
- Based on Survey 3 data, repeatability determined by calculating the standard deviation gage measurements is greatly improved from approximately 8.38% using the existing delta gage method, to 2.39%, using the EGM

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Exercise Gage Method Validation

- EGM measurements compared with conventional delta gage measurements from all survey data
- The current threshold of 0.625" intersects with 0.5" of the EGM parameter
- EGM threshold needs to be considered carefully to ensure it appropriately identifies weak track locations

New Prototype Electronic PTLF

- Completely digital PTLF with electronic sensors for measuring displacement and applied force
- Android based platform for measuring, storing, and displaying various parameters including unloaded, loaded and return gage
- A pass/fail criteria is used against the FRA threshold for each test location

Conclusions

- Methods relying on the initial unloaded gage value are less repeatable due to the "set" the track takes after the first load cycle
- Survey data from 70 unique locations collected during different times of the day and year on 3 railroads was used to develop and validate the method
- EGM improves repeatability from 15.01% standard deviation to 3.71% for the entire data set of 6 surveys
- EGM approach is straightforward and easy to implement with existing device
- EGM threshold needs to be considered carefully to ensure it appropriately identifies weak track locations

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Questions?