On The Relationship Between Missing Shoulder Ballast and Development of Track Geometry Defects

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Abstract

The presence of a full ballast section, has long been an important part of railroad maintenance. Past research has shown a relationship between inadequate ballast and lateral track resistance, to include resistance to track buckling and lateral track movement. However, no formal relationship has been developed between missing volume of ballast and development of track geometry defects.

Using LIDAR based ballast profile measurement technology, digitized LIDAR data was overlaid onto an idealized track structure to calculate the missing volume area in the ballast shoulders and cribs. This missing ballast was compared to the occurrence of track geometry defects as identified by a track geometry inspection car for the same track locations. The ballast data taken from a US Class 1 railroad consisted of 187,025 segments, each approximately 15 meters in length, for a total length of approximately 2800 km of track. A total of 5440 geometry defects were reported within that stretch of track, distributed over 2278 segments, with many segments having multiple reported geometry defects.

Results show a well-defined trend of increasing number of segments where geometry defects are present as a function of increasing volume of missing ballast. Results also show that the rate of development of ballast-related defects is positively correlated to the volume of missing ballast and that this relationship increases non-linearly. When the data was separated by curve vs. tangent, curve defect rate followed a similar steady trend upward with increasing volumes of missing ballast. However, on a tangent track, there appeared to be a threshold effect, such that a small amount of missing ballast has only a modest effect on defect occurrence, but larger volumes of missing ballast can have a significant effect. A similar result was observed for missing crib ballast.

Increasing volumes of missing ballast results in increases in the occurrence of track geometry defects, and in particular the ballast related track geometry defects, in those segments that have the missing ballast. The results provide a quantifiable relationship, in form of a quadratic equation, between missing ballast and the rate of development of segments with geometry defects (defective segments). This relationship furthermore extends to analysis of curve vs. tangent track, where curve track exhibits the same quadratic type of relationship, while tangent track appears to have more of a threshold effect, where a small volume of missing ballast has a relatively mild effect but a large volume of missing ballast has a significant effect on the rate of development of geometry defects. Analysis of missing shoulder ballast vs. crib ballast provided further insight into the relationship between missing ballast and the occurrence of track geometry defects, suggesting that the lateral resistance of the shoulders is dominant on curves, but on tangents, crib lateral resistance takes on increased importance.

Thus, this data strongly supports the idea that missing ballast section (specifically shoulder and crib ballast) will directly contribute to the development of ballast related track geometry defects.

1. Introduction

The presence of a full ballast section, has long been an important part of railroad maintenance. Past research has shown a relationship between inadequate ballast shoulders and lateral track resistance, to include resistance to track buckling and lateral track movement. However, no formal relationship has been developed between missing volume of ballast and development of track geometry defects.

This study examined conditions of missing ballast as compared to the occurrence of track geometry defects for the same track locations. The missing ballast was obtained from a railbound ballast inspection systems using LIDAR (Laser Imaging Detection And Ranging) technology. The track geometry defect data was obtained from the railroad's bound track geometry inspection vehicle, a Track Recording Car. The ballast data taken from a US Class 1 railroad consisted of 187,025 segments, each approximately 15 meters in length, for a total length of approximately 2800 km of track. A total of 5440 geometry defects were reported within that stretch of track, distributed over 2278 segments, with many segments having multiple reported geometry defects.

The LIDAR system obtained a profile of the track cross-section (see Figure 1) and this data was overlaid onto an idealized track structure to calculate the missing volume area in the ballast shoulders and cribs, as shown in Figure 1.

The calculation of the missing profile ballast can be visualized in Figure 1, where the missing ballast is clearly seen as the gap between the idealized (desired) profile and the actual profile. Thus it can be seen that the left shoulder is missing ballast at the top of the shoulder, and on the right side, the gap is more pronounced and extends down the shoulder slope. In the crib, there is a non-uniform ballast section, with significantly more missing ballast on the right side of the crib.

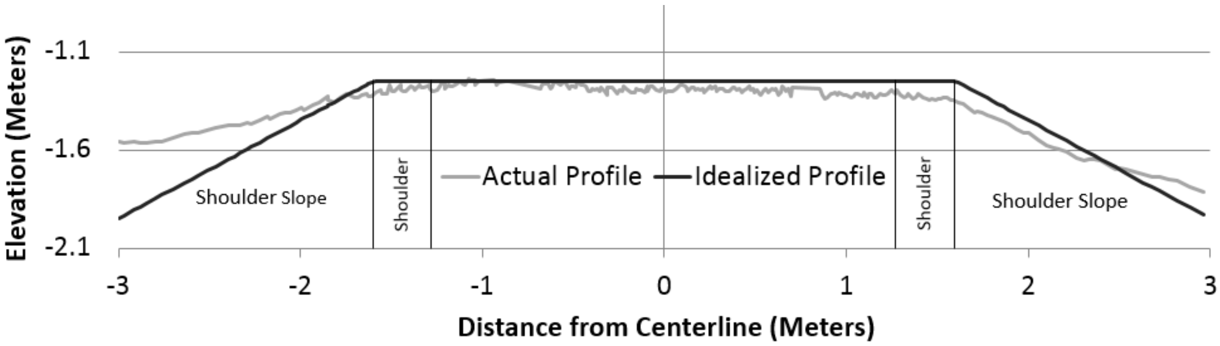

FIGURE 1: Overlay of LIDAR (Actual) profile and idealized ballast profile.

This missing ballast can then be compared to the location of track geometry defects as identified by a track geometry inspection car for the same track locations. In this study, the ballast deficiency data was obtained from Georgetown Rail Equipment Company (GREX) and the track geometry defects were received from the Class 1 railroad owner of the inspected tracks.

2. Discussion and Analysis

The data for the volume of missing ballast consisted of information regarding the location, volume of missing ballast, if it was on a curve or tangent, length of the segment and date of collection. The ballast data consisted of 187,025 segments of approximately 15.24m (50ft) length for a total length of approximately 2893 kilometers (1,798 miles) of track (*2*). The 15.24m (50ft) segment length was selected after analysis of alternate segment lengths, based on the accuracy of location measurement for both the LIDAR measurement vehicle and the track geometry vehicle (so as to allow for matching of geometry defect locations with ballast sections).

The track geometry defect information consisted of the defect type, location, defect amplitude, defect length, date defect was identified, etc. Originally, there were 96 types of defects; however, many of these were similar defect types some of which were consolidated into combined defect classes. Figure 2 presents a graph of the top 15 most numerous defects (by frequency of occurrence) after combining defects categories, and Table 1 lists the definitions of the defects themselves.

Initially, the calculations were focused on the total number of defects, however, due to the defect data containing multiple defects in the same location, either due to the same defect being recorded multiple times or from multiple individual defects, this resulted in a defect rate that was significantly higher than the number of segments with defects. Since the analysis focused on the percentage of segments containing geometry defects ("defective segments") in a larger overall population of segments, the final analysis looked at the number of segments with geometry defects, irrespective of how many defects were in a segment identified as having a defect. Thus the analysis looked at the percentage of segments with geometry defects as a function of total inspected segments (also referred to as "Percentage of Segments with Defects").

Once the initial matching was completed, a determination of the appropriate grouping size (based on cubic yards of missing ballast) was performed. Three higher-level groupings were examined; a 0.28m^3 (10 cubic foot) grouping, a 0.71m^3 (25 cubic foot) grouping and a 1.41m^3 (50 cubic foot) grouping. As shown in Figure 2, the 1.41m^3 (50 cubic foot) grouping appeared to provide the smoothest behavior and as such was selected for use in the analysis.

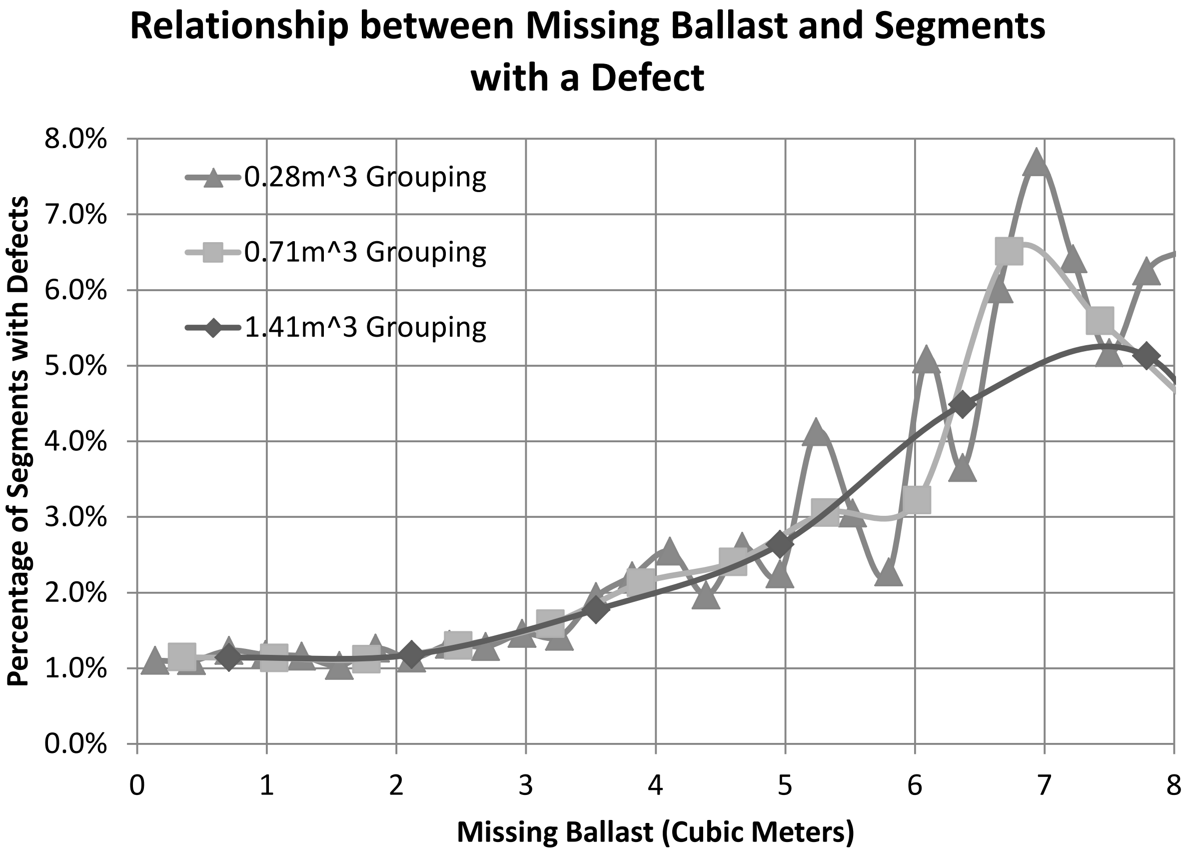

FIGURE 2: Percentage of Segments with Defects vs. Volume of Missing Ballast for three volume groupings.

Figure 3 presents the 1.41m^3 (50 cubic foot) grouping information as a bar chart. (Note, all the segments with volumes greater than 5.66m^3 (200 cubic feet) were consolidated into a single >5.66 (>200) category because of the relatively small number of segments in these categories).

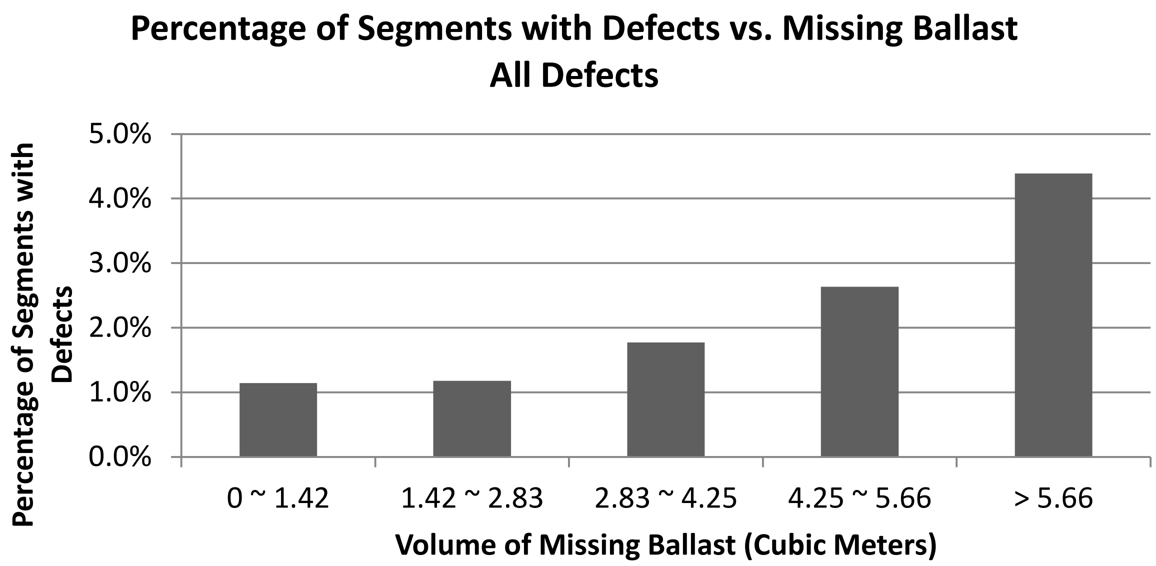

FIGURE 3: Percentage of Segments with Defects vs. Missing Ballast for all defects [1.41m^3 (50 cubic foot) groups].

It should be noted that the majority of the missing ballast occurs in the shoulders with the balance in cribs. Analysis of rate of segments with defects vs. volume of missing shoulder ballast and missing crib ballast are shown for all defects in Figures 4. The behavior of the shoulder ballast analysis (Figure 4) is very similar to the previous analyses looking at total volume of ballast (Figure 3) primarily due to dominance of the shoulder ballast in the determination of missing ballast volume.

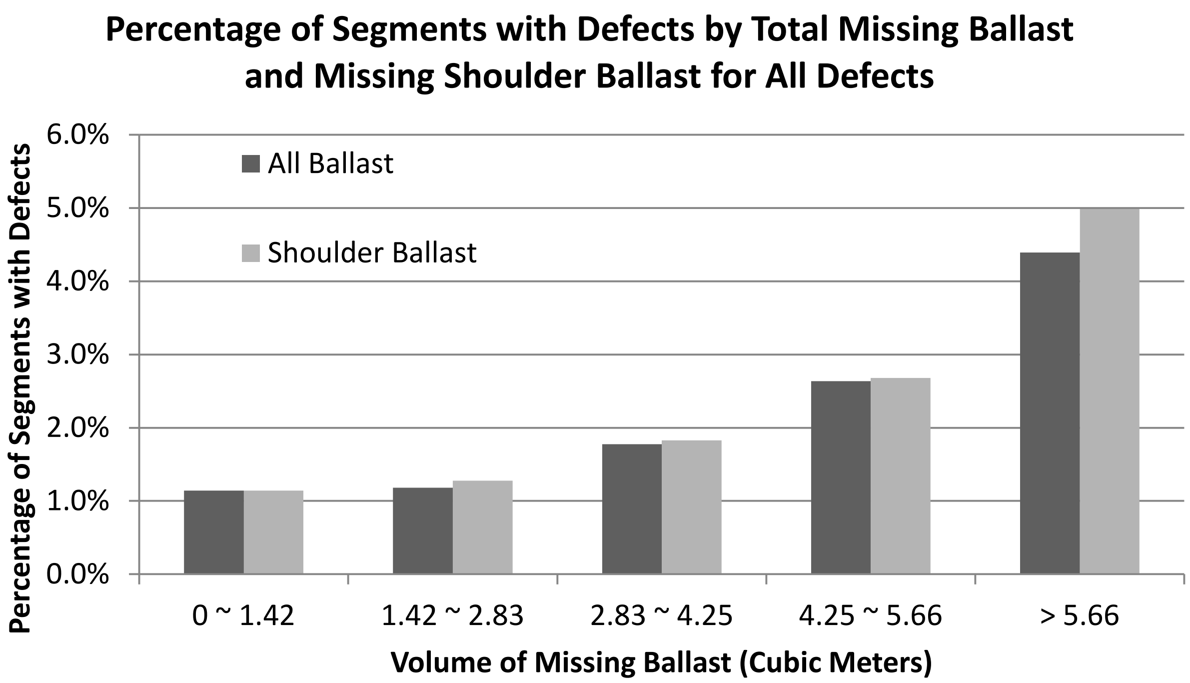

FIGURE 4: Segments with Defects vs. Missing Ballast/Shoulder Ballast for All Defects. [1.41m^3 (50 cubic foot) groups]

The results presented in Figure 3 and 4 show that the rate development of ballast-related defects is positively correlated to the volume of missing ballast and that this relationship increases non-linearly as shown in Figure 5. Note, the extremely good curve fit, as represented by the very high R^2 value. Thus, this data strongly supports the idea that missing ballast section (specifically shoulder ballast) will contribute to the development of ballast related track geometry defects).

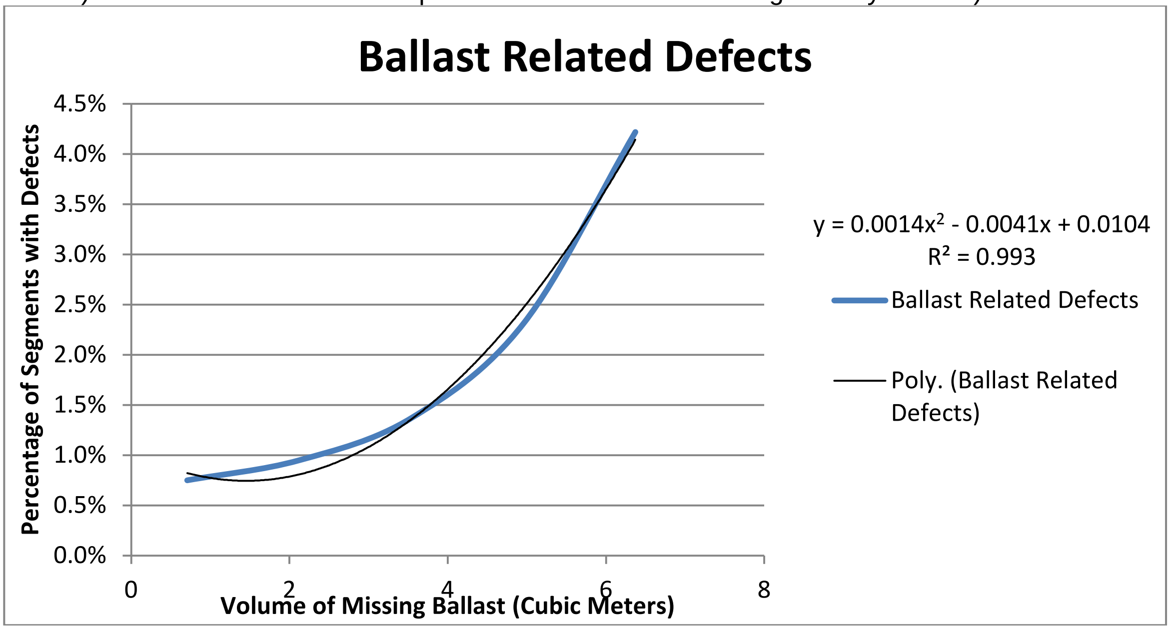

FIGURE 5: Polynomial relationship between segments with ballast defects and missing ballast using the midpoint value of each grouping

Analysis of the effect of missing shoulder ballast on curve vs. tangent track, as shown in Figure 6, likewise shows a relationship similar to that presented in Figure 4, with the development of track geometry defects directly related to an increase in missing ballast.

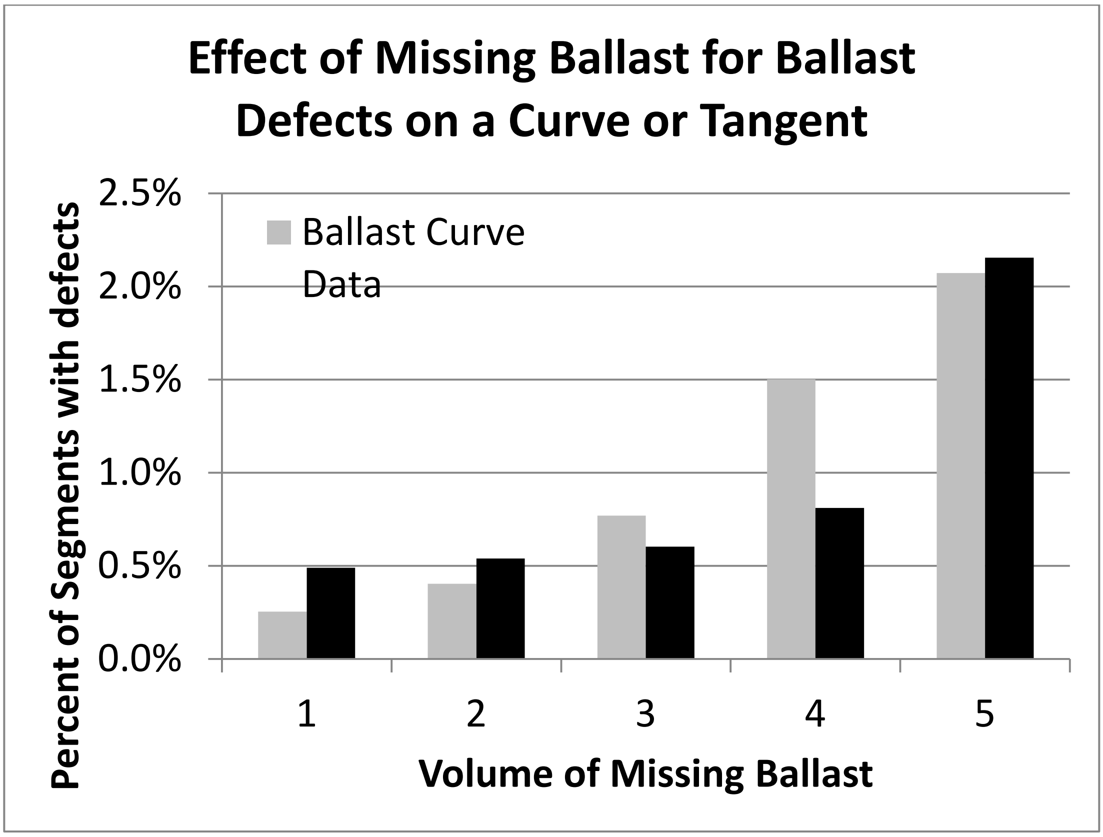

FIGURE 6: Effect of Missing Ballast for Ballast Related Defects on curves or tangents

3. Conclusion

The results of the study show that increasing volumes of missing ballast results in increases in the occurrence of track geometry defects, and in particular the ballast related track geometry defects, in those segments that have the missing ballast. This is consistent with basic industry practices and guidelines which show a relationship between missing shoulder and/or crib ballast and reduced track strength. The results provide a quantifiable relationship, in form of a quadratic equation, between missing ballast and the rate of development of segments with geometry defects (defective segments). Examination of specific classes of geometry defects show a clear and well defined relationship between segments having ballast related track geometry defects.

This relationship furthermore extends to analysis of curve vs. tangent track, where curve track exhibits the same quadratic type of relationship, while tangent track appears to have more of a threshold effect, where a small volume of missing ballast has a relatively mild effect but a large volume of missing ballast has a significant effect on the rate of development of geometry defects.

Analysis of missing shoulder ballastshows that missing shoulder ballast exhibits behavior similar to the more general total missing ballast categories. This suggests that the lateral resistance of the shoulders is an important component in track geometry degradation.