Shoulder Ballast Cleaning Effectiveness

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ABSTRACT

Shoulder ballast cleaning is a cost effective alternative to improve track performance and restore drainage. There are many advantages associated to the practice of shoulder ballast cleaning, such as significant enhancements in productivity, less disruptive to the track substructure, and less resource intensive. Shoulder ballast cleaning optimizes the productivity of ballast rehabilitation programs with less required track time, no speed restrictions, and less evasive work to the track structure allowing crews to capitalize on short track windows.

The practice of shoulder ballast cleaning compared to other traditional ballast renewal methods proves to be superior due to improved cost, productivity, and finished product. The following study provides a comparison of the various traditional methods of ballast maintenance coupled to empirical data that demonstrates the effectiveness of shoulder ballast cleaning through a sieve analysis test on a heavy axle load main line immediately before and after ballast shoulder cleaning operations and periodically over time after shoulder cleaning. The sieve analysis is a collection of nine sets of samples over a period of three years.

The sieve analysis immediately before and after ballast shoulder cleaning illustrates that the ballast shoulder cleaning process was highly effective in removing fines and restoring desirable shoulder ballast support and drainage properties. Further periodic analysis also supports that the fines in the center of the track and along the shoulders tend to move outward and downward during the test with the percentage of fines in the cleaned shoulder ballast either remaining close to the condition after ballast shoulder cleaning or was slightly increasing. This study demonstrates shoulder ballast cleaning improves track performance through increased drainage and support throughout the track structure.

INTRODUCTION

Ballast shoulder cleaning effectiveness is predicated on restored drainage capacity of the shoulders and the outward transport of fines from the center of the track to the cleaned ballast shoulders. The test was performed to determine the effectiveness of shoulder cleaning based on periodic sieve analysis of ballast samples collected immediately before and after ballast shoulder cleaning operations and periodically after shoulder cleaning.

BALLAST DETERIORATION

The ballast section is a coarse aggregate layer that supports the rail and tie superstructure, resists and distributes wheel loads and rail forces, and provides a drainage path to remove water from the track. Over time, however, the ballast layer deteriorates as the void spaces and frictional forces between ballast particles is reduced with the increase of fines generated by ballast wear and breakdown and the intrusion of material from outside the track, such as windblown fines or soil. The generation of fines is the basic mode of ballast deterioration and renewal and/or cleaning is the remediation used to restore its functionality.

Ballast has a finite life; the life of ballast is determined by the condition of the track subgrade, ballast quality, the amount of train traffic, axle loadings, the commodities hauled over the track, and environmental conditions. Track surfacing, ballast replacement, renewal, and/or cleaning are the typical remediation used to restore ballast functionality after deterioration has occurred. Acceptable ballast performance requires interlocking of the ballast particles for strength and adequate void space between the particles for drainage. Over time the void spaces between the ballast particles become filled with fines, which decreases frictional forces between ballast particles and interferes with water drainage. This reduces the strength of the track and increases the need for track maintenance that would not be required if the ballast were clean.

RAILROAD TRACK

The railroad track structure is designed to distribute the large loads from vehicle wheels to the subgrade under the track. Modern railroad ballast is ideally hard, dense, angular rock particle structure with sharp corners and cubical fragments and free of deleterious materials. Ballast materials provide high resistance to temperature changes and chemical attack, have high electrical resistance, have low absorption properties, and are free of cementing characteristics. Ballast materials should have sufficient unit weight and have a limited amount of flat and elongated particles.[i]

For ballast to perform properly, moisture needs to drain freely away from the track. Without well-draining ballast, the deterioration rates of ties, ballast, and track profile are accelerated. Additionally, moisture trapped in fines plugging voids in the ballast reduces the strength of the track and reduces its ability to transmit loads to the subgrade. It can also allow trapped moisture to infiltrate into the track subgrade, which further weakens the overall track structure.

Ballast has four primary functions:

1. Transmits and distributes the load of the track and railroad rolling equipment to the subballast and subgrade
2. Restrains the track laterally, longitudinally, and vertically under dynamic loads imposed by railroad rolling equipment and thermal stress exerted by the rails
3. Provides adequate drainage for the track
4. Maintains proper track cross-level, surface, and alignment.[ii]

Poorly draining ballast with a high content of fines may not perform primary functions properly, particularly when wet. When ballast is clean, the ballast particles interlock with each other. The particles are large enough to allow voids between the individual particles that allow water to drain away from the track. As the ballast deteriorates, the amount of fines filling the voids increases. These fines are typically generated by degradation of the ballast particles or from the intrusion of wind-blown materials from outside the track. When the voids are filled with fines, free drainage of water is impaired and the individual ballast particles do not interlock with each other. Ballast faces may also become lubricated with the hydrated fines slurry, causing lowered internal friction of the ballast mass.

Shoulder Cleaning

Ballast shoulder cleaning machines have large cutting wheels that run along both ends of the ties and completely remove the ballast shoulder without disturbing the track geometry. Most shoulder cleaning machines process the removed ballast, screen out the fines, and return the clean ballast to the track. Because the shoulder ballast is not subjected to particle size reducing wear, such as tamping and train action, the cleaning process recovers nearly all of the volume, only removing the fines to re-create the voids needed for effective drainage. During the shoulder cleaning process, the ballast shoulder is regulated and the tops of the ties are broomed, completely restoring the ballast shoulders.

Unlike many other ballast cleaning or replacement processes, shoulder ballast cleaning is self-sufficient, and there is minimal disturbance to the track and little support such as ballast trains and surfacing and alignment equipment is needed. When working under traffic conditions, the shoulder cleaning process can be quickly stopped to clear for trains, and typically no speed restrictions are required. Some railroads will surface and align the track following ballast shoulder cleaning to introduce clean ballast under the ties to improve further track drainage.

SIEVE ANALYSIS TEST

Test Site Selection Criteria

The test site was selected using the following criteria:

- High annual precipitation
- Heavy axle loadings
- High annual tonnage
- Stable subgrade
- Both curved and tangent track
- Unit mineral ore train traffic
- Adjacent right of way road for site access
- No scheduled out-of-face tie, surfacing, or rail changes for at least 2 years following the start of test
- Quality ballast (ballast with a low degradation rate)
- Both concrete ties and wood ties
- Good visibility of approaching trains
- Close to the host railroad's crew reporting point to save on host railroad’s employee-in-charge travel time.

Test Site Description

The selected site is subjected to approximately 170 MGT of mixed heavy axle load freight traffic annually including unit mineral ore trains. The track has 136RE continuously welded rail with wood ties using AREMA tie plates with cut spikes. The general area in the vicinity of the test site consists of low rolling hills and is part of the Mississippi river drainage. Land usage adjacent to the test site primarily farming with corn being the predominate crop. The local native soil appears to be a fine to very fine sandy silt loam.

Samples were collected at four locations at this site: Two on tangent track and two on curved track. The curved track has curvature of 0.67° (8,530-foot radius) with 2.25 inches of superelevation. The maximum freight train speed through the test site is 60 mph.

One of the selection criteria for the test site was high annual precipitation, and the annual rainfall at the test site is approximately 35 inches. The test site met all of the predetermined site selection criteria with the exception of having both wood and concrete ties.

Test Site Layout

There were four ballast sample collection zones at the test site (Figure 1). Two zones were located on curved track (Zones 1 and 2) in the full body of the curve, and the other two were located on tangent track (Zones 3 and 4). The ballast shoulders were covered on one curved zone (Zone 2) and one tangent zone (Zone 3). Covers were installed over the ballast shoulders to prevent external sources of fines (mineral fines dust or wind-blown dust) from infiltrating the ballast and to provide a comparison to the uncovered sample locations. No discernable difference was seen in the results between the covered and uncovered areas indicating that the primary source of fouling material is not external. Each zone was approximately 100 feet long.

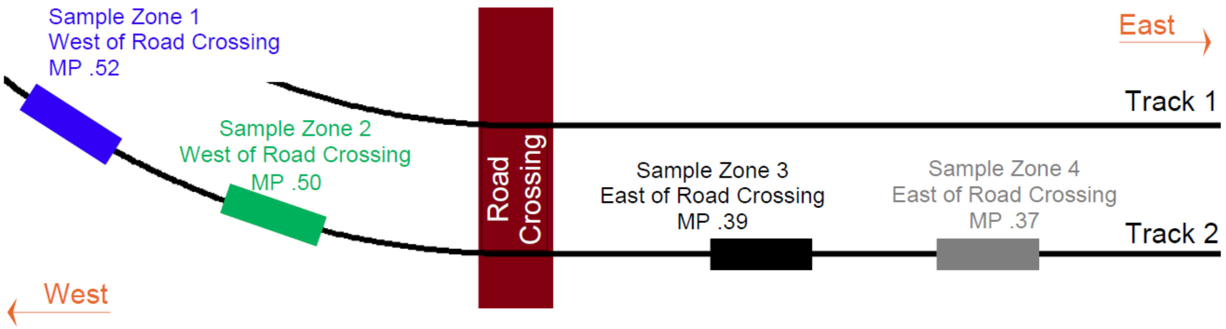


Figure 1 Test Site Layout

Test Narrative

Shoulder Cleaning Operations

Ballast samples were collected immediately before and after Loram's ballast shoulder cleaner. Four additional sets of samples were collected over a period of approximately two years to monitor ballast conditions after shoulder cleaning operations. Loram performed ballast shoulder cleaning throughout the test site as part of a normal shoulder cleaning operation on this subdivision.

August 27, 2012

This first set of samples was collected prior to the ballast shoulder cleaning operations. The test site received 1.7 inches of rain on the day before; the samples collected were heavily deteriorated and very wet. A small amount of makeup ballast had been previously distributed along the ballast shoulder through the test site, in advance of the shoulder cleaning operations. This new makeup ballast was not included in the pre-test sample analysis, because samples were collected at levels below the ties.

August 28, 2012

Shoulder cleaning was attempted through the test site. Operations were halted because the ballast was too wet from the recent rains for efficient cleaning. Ballast samples, including samples of the waste material, were collected.

September 1, 2012

Shoulder cleaning was performed. There was no rain in the test site area in the time between the pre-cleaning samples and this date. Out-of-face track surfacing operations were planned to occur very soon after the shoulder cleaning, so the ballast mat shoulder covers were not installed. The surfacing operations did not immediately occur as planned. Samples were collected only at the north and south shoulders, in each respective test zone, because the center, north tie crib, and south tie cribs would have been in the same condition as the pre-shoulder cleaning samples. Samples of the waste materials were also collected.

December 4, 2012

The second set of post-shoulder cleaning samples was collected.

May 13, 2013

The third set of post-shoulder cleaning samples was collected.

December 10, 2013

The fourth set of post-shoulder cleaning samples was collected. The track through the test site was disturbed, apparently by an out- of-face track surfacing operation. The ballast cribs along the north tie cribs were frozen, and no samples were collected at these specific test locations. All of the other samples were collected.

To prevent contamination or impacts to the test results, each iteration of ballast samples were collected at different locations within each of the respective test zones. Each sample set was collected perpendicularly to the track and through the same tie crib for each sampling iteration.

Pre / Post Analysis

Pre-Shoulder Cleaning Ballast Condition

The Selig Ballast Fouling Index[iii] is commonly used in North America to describe the level of ballast deterioration. Table 1 details these indices. These indices are easier to use for comparison and to better define the level of deteriorated ballast conditions than the semi-logarithmic scatter charts typically used for sieve analysis results.

Table 1. Selig Fouling Index

Category	Fouling Index
Clean	Less Than 1
Moderately Clean	1 to Less Than 10
Moderately Fouled	10 to Less Than 20
Fouled	20 to Less Than 40
Highly Fouled	Greater Than or Equal to 40

Figure 2 shows the average of the results of the ballast sieve testing for the 20 pre-shoulder cleaning samples using a semi-logarithmic scatter chart. The black lines indicate the upper and lower limits of new AREMA No. 4a ballast for comparison. The large percentage of ballast particle sizes less than 1.5 inches in the pre-cleaning samples indicates deteriorated ballast.

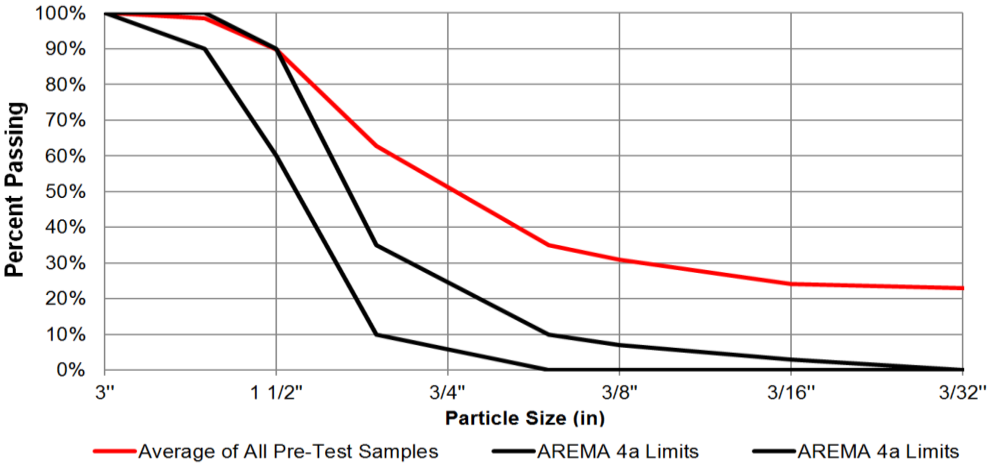


Figure 2 - Pre-Shoulder Cleaning Sample

The average fouling index of the 20 pre-shoulder cleaning samples collected was 33 (fouled) and ranged between a 21 (fouled) and 40 (highly fouled). In comparison, new AREMA No. 4a ballast would be less than 1 (clean).

Another method of comparing the deterioration of ballast uses the percent passing the ½-inch sieve size. This measured the relative percentage, by weight, of small ballast particles not present in new ballast in large quantities. Ballast particles of this size are removed by ballast cleaning operations. The average percent passing the ½-inch sieve size for the pre-shoulder cleaning samples was 37% (ranging from 25%–43%). In comparison, new AREMA No. 4a ballast would average 5 percent. The average of fine material less than 3/16 inch in the pre-cleaning sample was 25%.

All of these indices highlight the large amount of fines mixed in with the ballast prior to shoulder cleaning operations that were reducing the overall performance of the track structure.

Ballast Shoulder Cleaning Waste Analysis

Samples of the waste fines removed by the ballast shoulder cleaning were collected and tested once, immediately after ballast cleaning operations. Figure 3 show the average results of the sieve analysis of all of the waste samples collected. Test results indicate that 99% of the waste material removed during the ballast shoulder cleaning process was ½ inch or less.

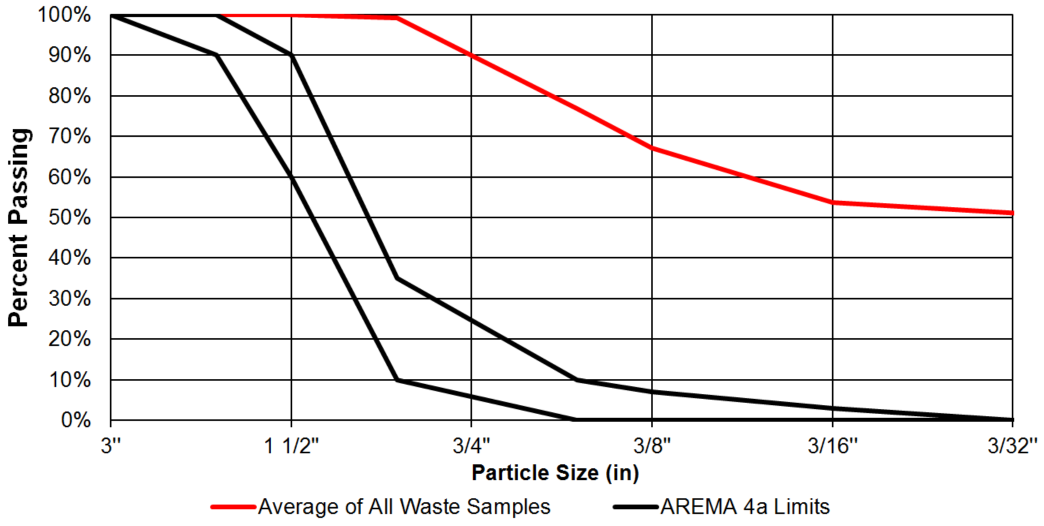


Figure 3 - Ballast Shoulder Cleaning Waste Sieve Analysis

EFFECTIVENESS OF BALLAST SHOULDER CLEANING

Figure 4 show the results of the sieve analysis for samples taken immediately before and after ballast cleaning. The data from sieve analysis of the waste materials is also included for comparison. These graphs show how the ballast shoulders were nearly restored to the condition of AREMA No. 4a ballast, eliminating nearly all of the fine materials. The only variance was near the 1-inch sieve size. All of the fine materials were well below the maximum allowable amount.

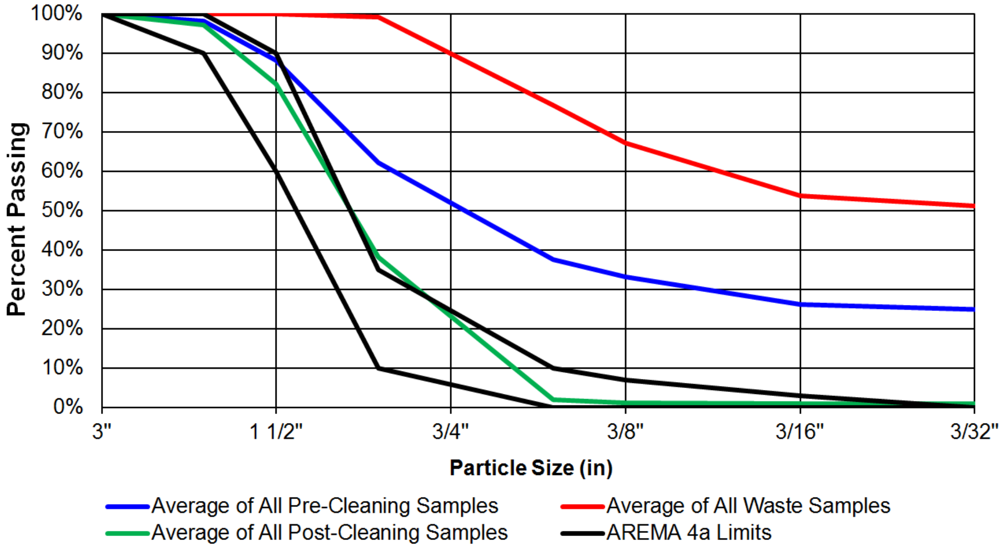


Figure 4 - Sieve Analysis Before and After Cleaning

BALLAST SAMPLE COMPARATIVE ANALYSIS

Analysis of Pre-Shoulder Cleaning Ballast Samples

The pre-shoulder cleaning samples were collected on August 27, 2012, prior to ballast shoulder cleaning operations. shows the results of the analysis.

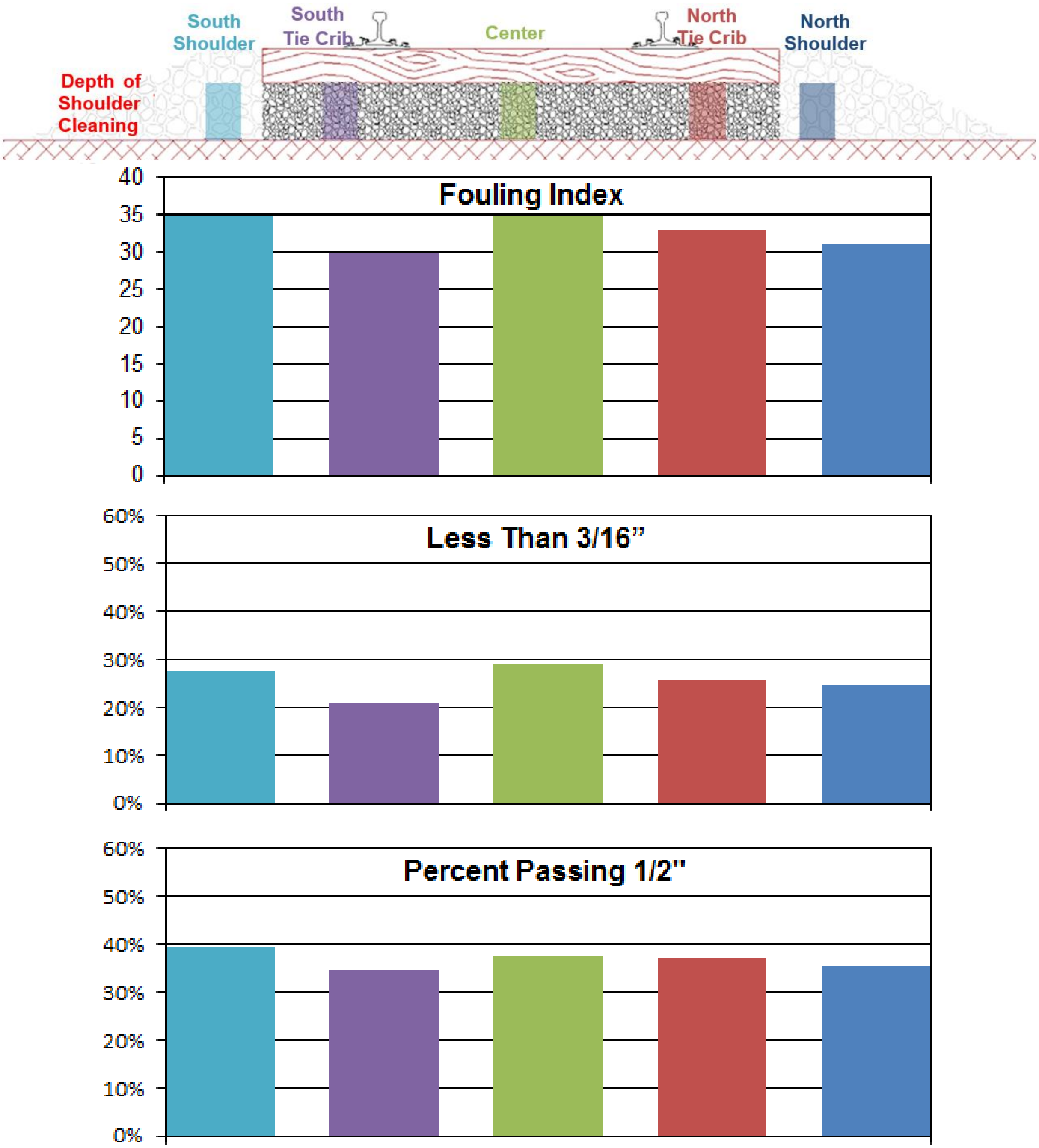


Figure 5 - Sieve Analysis for Pre-Shoulder Cleaning Samples

Analysis of First Post-Shoulder Cleaning Ballast Samples

The first set of samples after the shoulder cleaning samples were collected on September 1, 2012. Only north and south shoulder samples were collected, because the center, north tie crib, and south tie cribs would have been in the same condition as taken a few days before in the post-shoulder cleaning sample sets. For comparative purposes, the pre-test results for the center and north/south tie cribs are repeated here. Figure 6 show the results of the analysis.

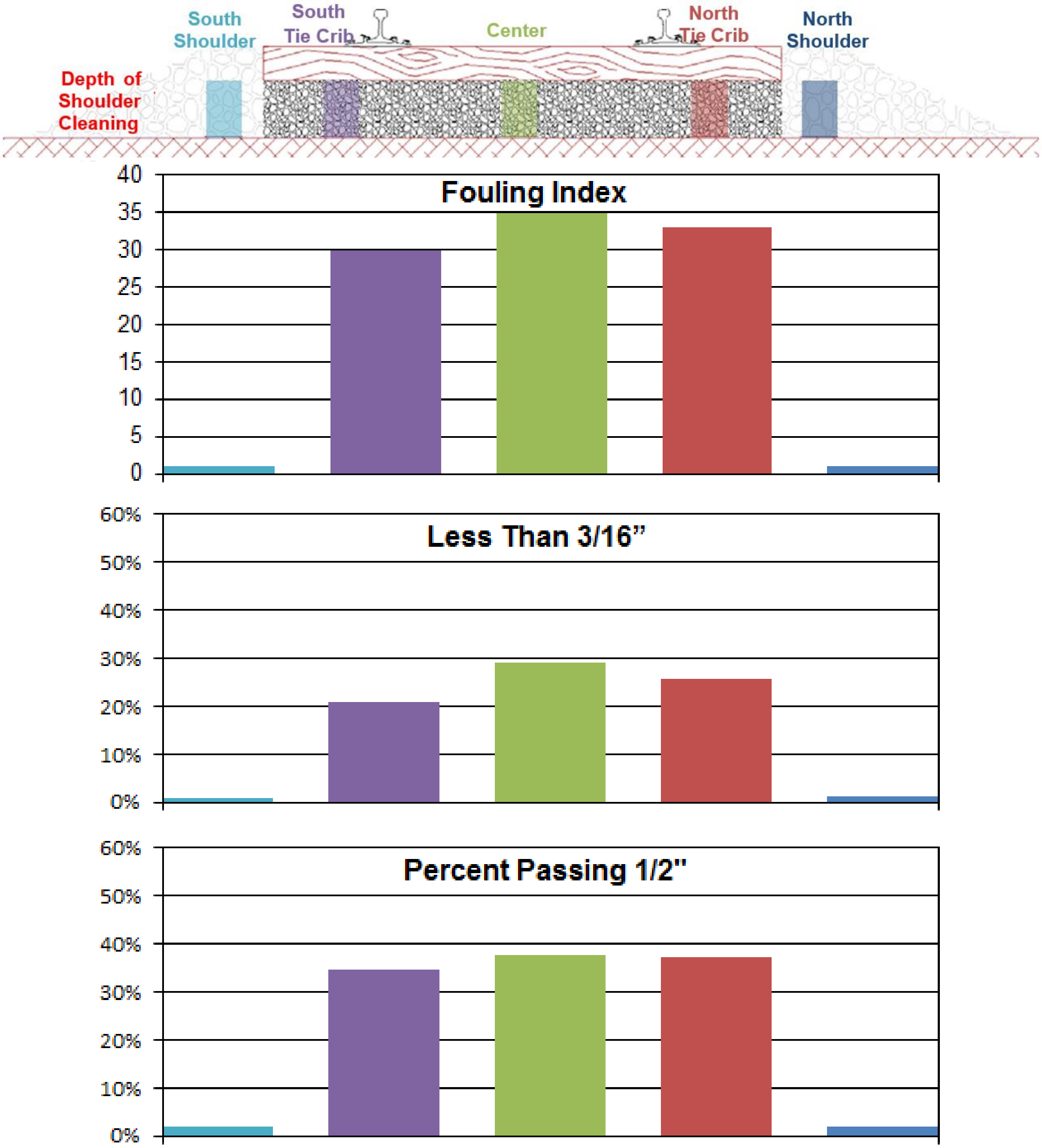


Figure 6. Sieve Analysis Indices for First Post-Shoulder Cleaning Ballast Samples

Analysis of Second Post-Shoulder Cleaning Ballast Samples

The second set of samples after the shoulder cleaning was collected on December 4, 2012. The average results of the analysis are shown in Figure 7.

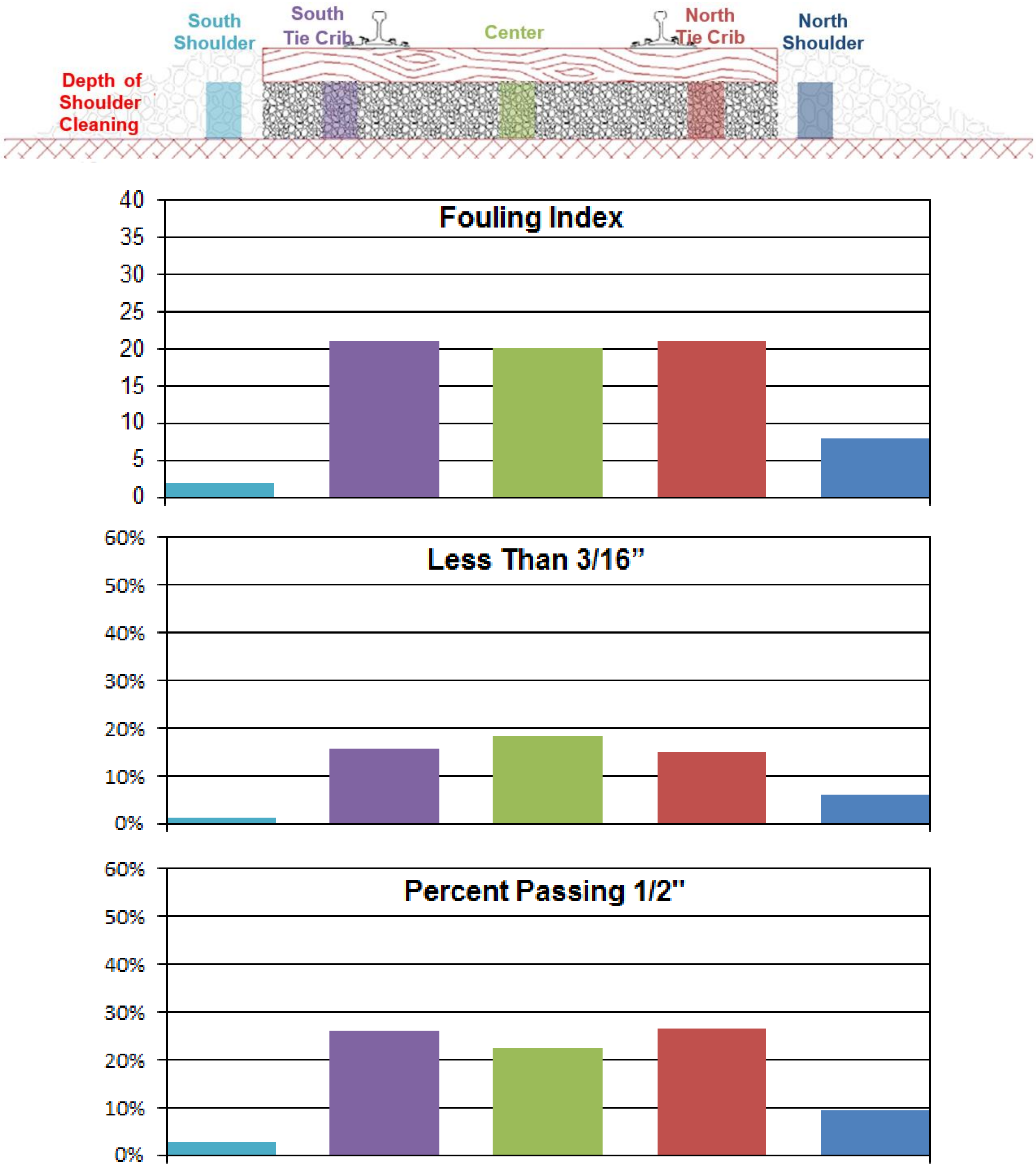


Figure 7 - Sieve Analysis Indices for Second Post Shoulder Cleaning Samples

Analysis of Third Post-Shoulder Cleaning Ballast Samples

The third set of samples after the shoulder cleaning was collected on May 13, 2013. Figure 8 show the average results of the analysis.

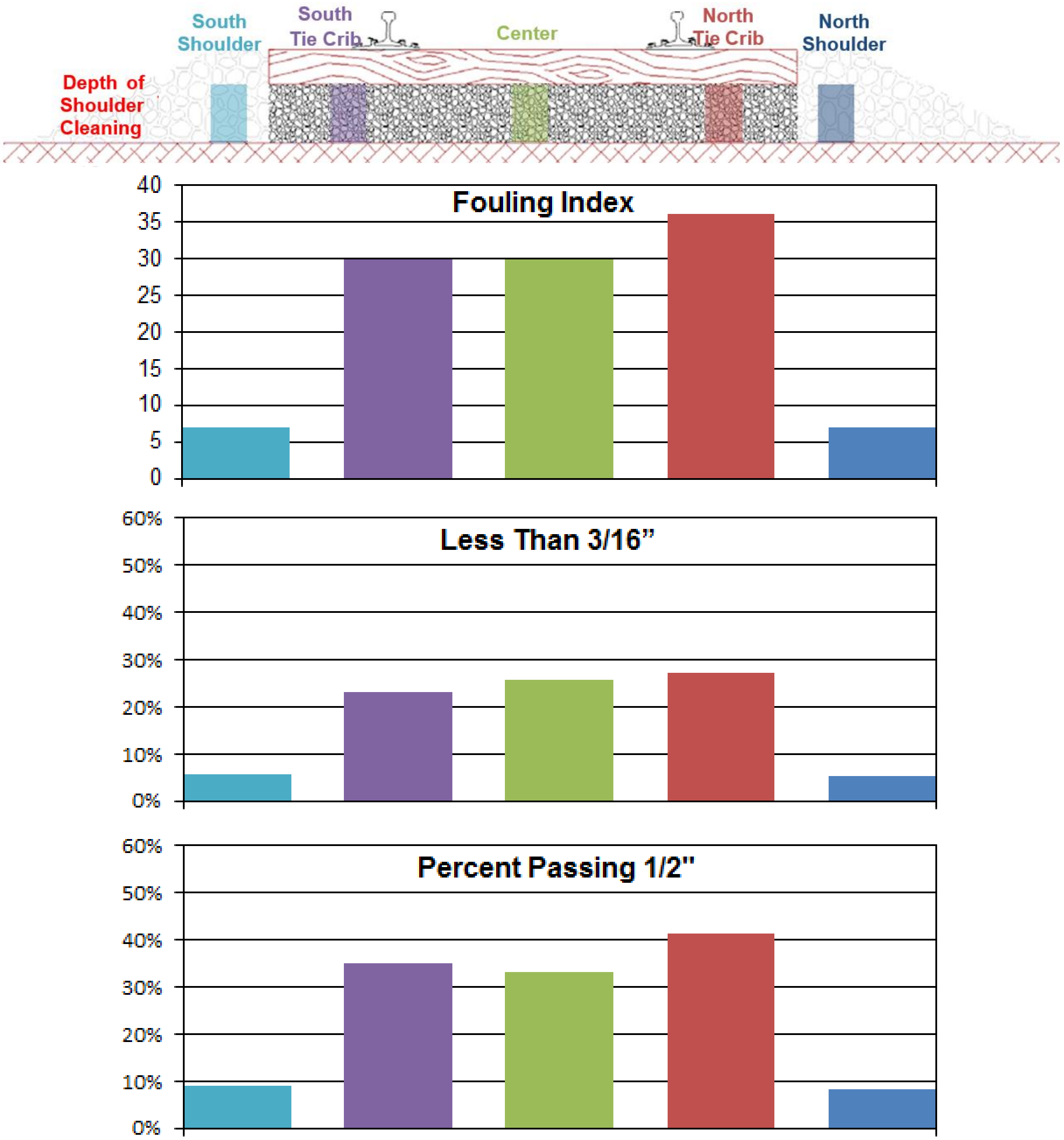


Figure 8. Sieve Analysis Indices for Third Post-Shoulder Cleaning Ballast Samples

Analysis of First Post-Shoulder Cleaning Ballast Samples

The fourth set of samples after the shoulder cleaning was collected on Tuesday, December 10, 2013. Figure 9 shows the average results of the analysis. As previously noted, the ballast cribs along the north tie cribs were frozen when the samples were collected, so no samples were collected from the north tie cribs. Samples were collected from all of the other locations in each test zone.

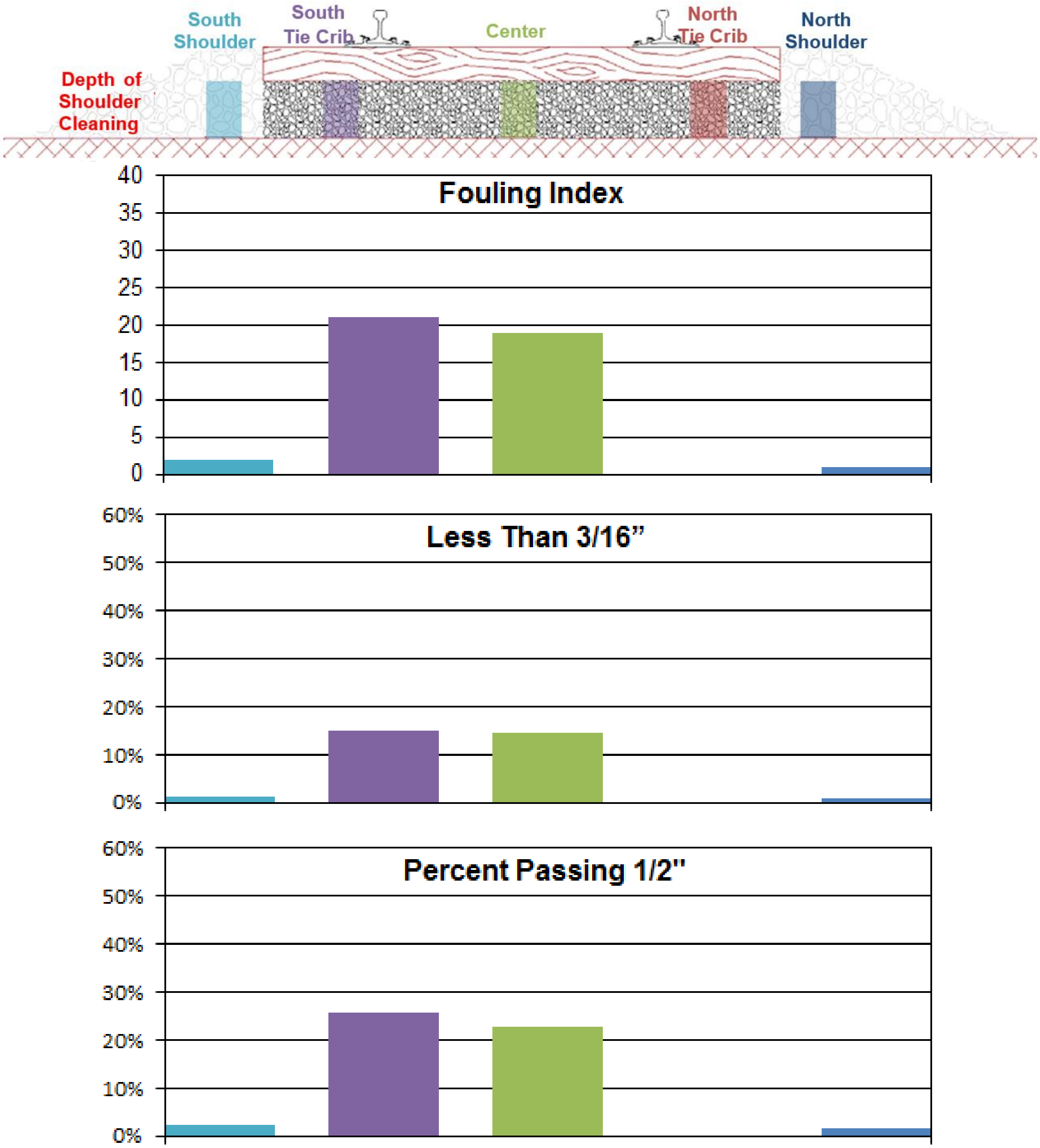


Figure 9 - Sieve Analysis Indices for Fourth Post-Shoulder Cleaning Ballast Samples

Analysis of Fifth Post-Shoulder Cleaning Ballast Samples

The fifth set of samples after the shoulder cleaning was collected on October 21, 2014. Figure 10 shows the average results of the analysis.

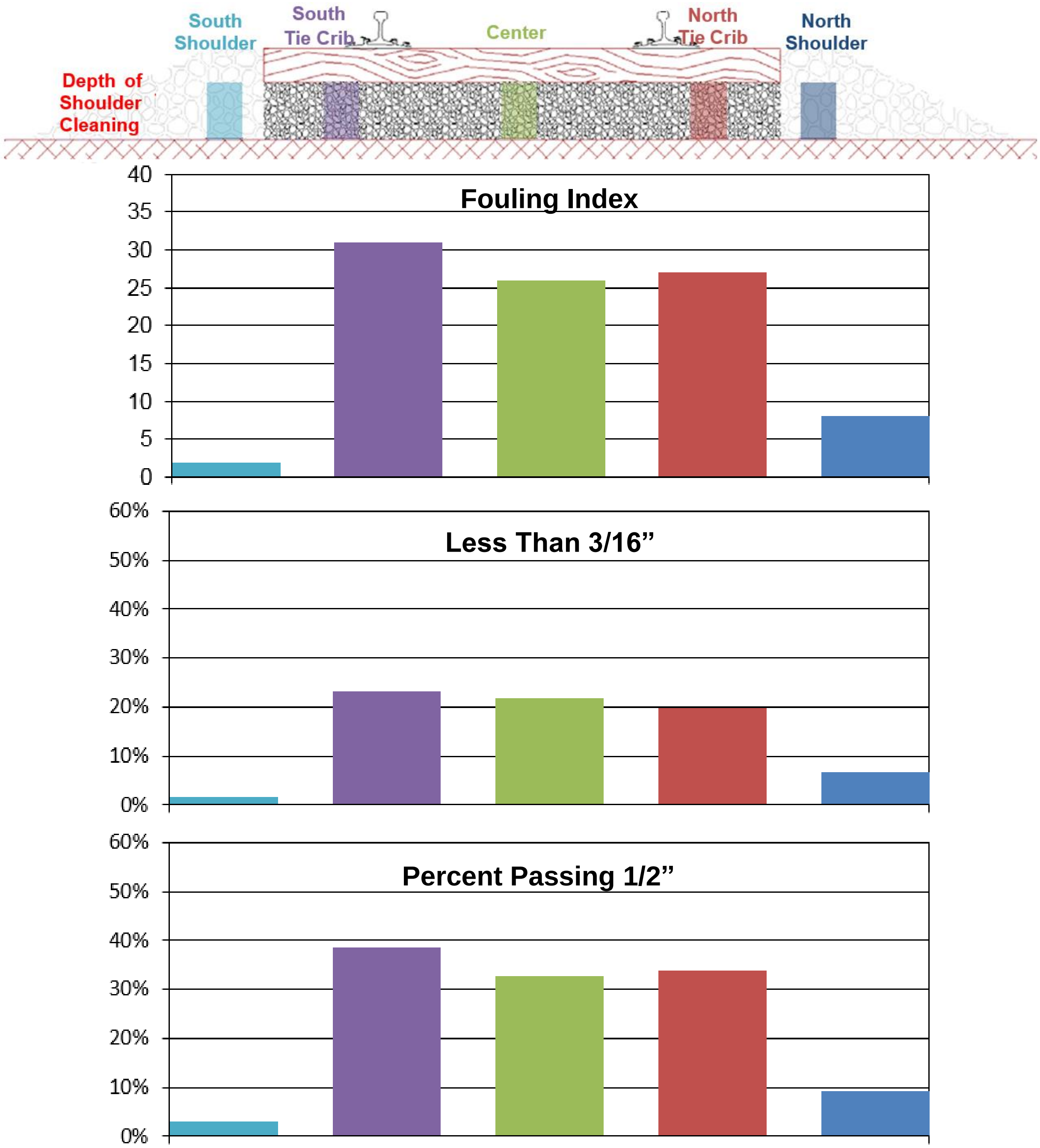


Figure 10 - Sieve Analysis Indices for Fifth Post-Shoulder Cleaning Ballast Samples

Comparison of Center and Field Shoulders

The test site is located on double track, with the shoulder cleaning performed on one of the tracks. The analysis in this section compares the data from the inside and outside shoulders. Additionally, two of the sampling locations are located on superelevated track with the track leaning towards the adjacent track.

Figure 11 shows the details of the sieve analysis results for all of the ballast shoulder samples through the life of the test. The Fouling Index, Percent Retained in Pan (Less Than 3/16 inch), and Percent Passing 1/2 inch are all trending up.

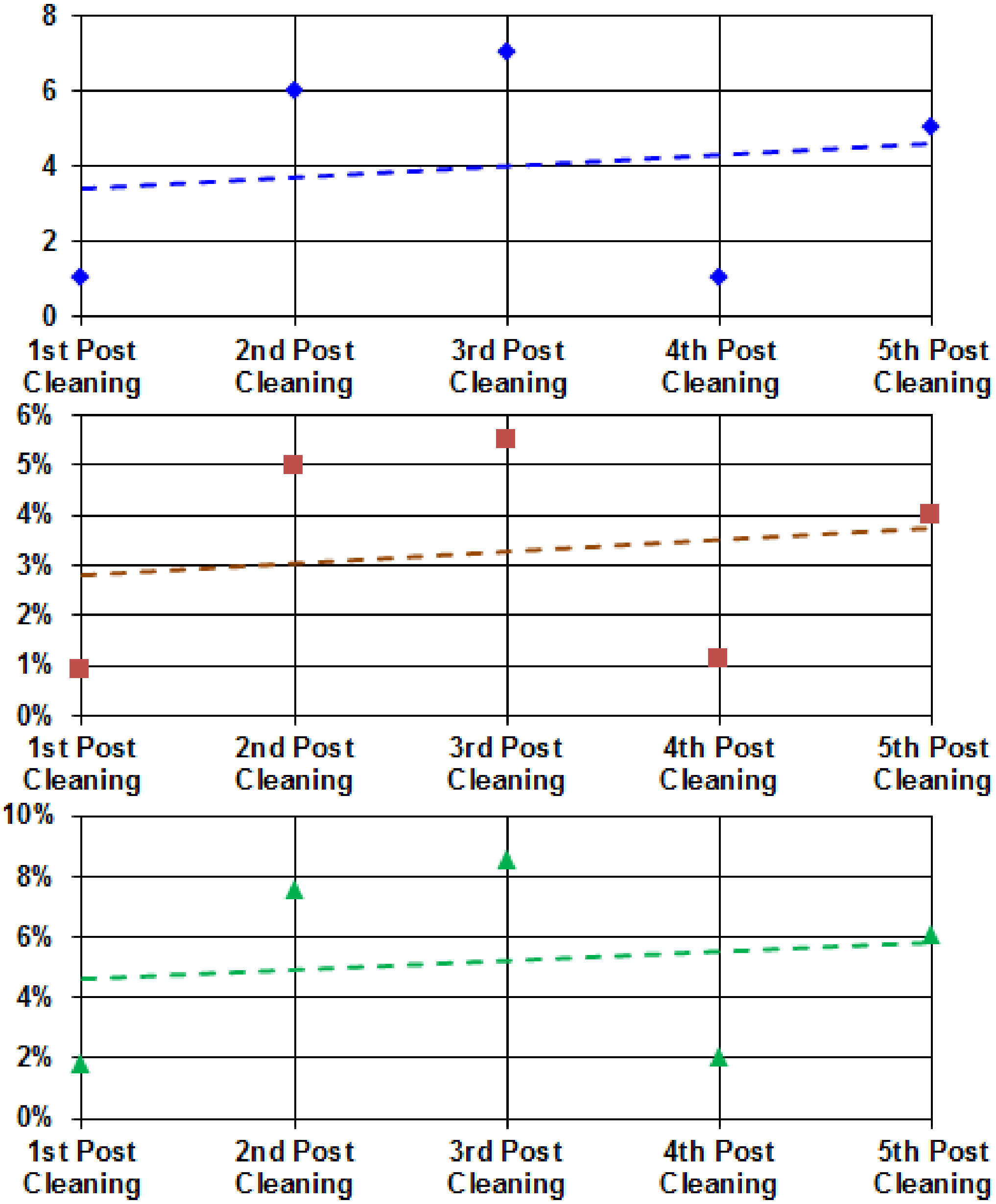


Figure 11 - Combined Sieve Analysis Results for All Samples

Figure 12 shows the results of the combined analysis for the curved track sample locations, along the low side of the superelevated curve (located between tracks). Figure 15 shows the results of the combined analysis for the curved track sample locations, along the high side of the superelevated curve (located along the outside of the trackway). Figure 16 shows the results of the combined analysis for the tangent track sample locations, located between the two tracks. Figure 17 shows the results of the combined analysis for the tangent track sample locations, along the outside of the trackway.

Both curved and tangent tracks show similar trends as all of the results combined, with the shoulders between the two tracks showing approximately double the amount of fines as the outside shoulders. The results of the north shoulders on the curved track are slightly higher than the north shoulders on tangent track. This suggests that fines may have a higher propensity to migrate towards the low side of superelevated curves.

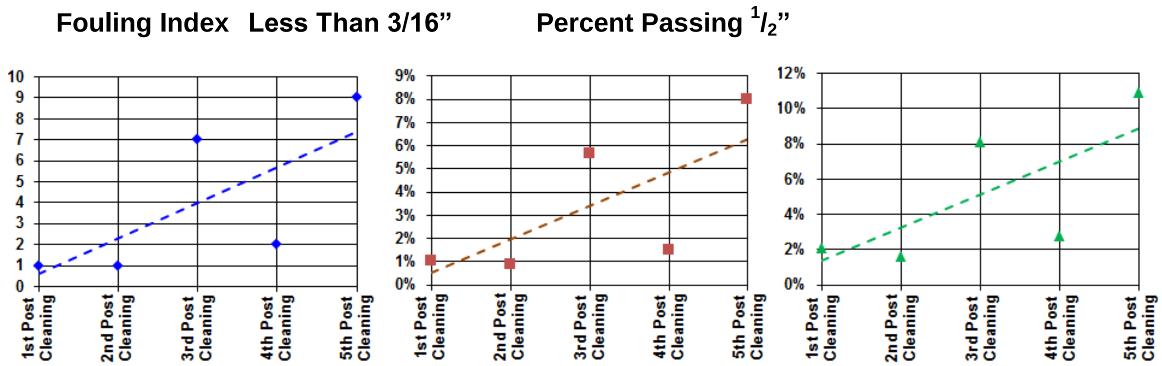
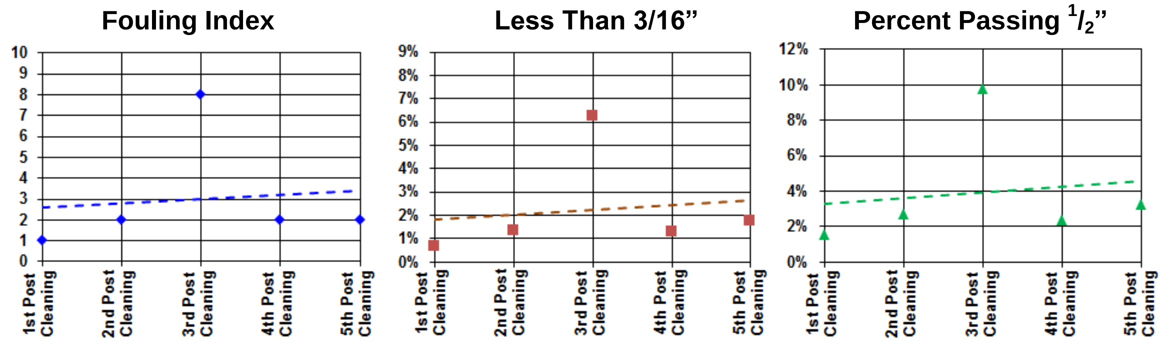

Fouling Index Less Than 3/16" Percent Passing $^1/_2$"

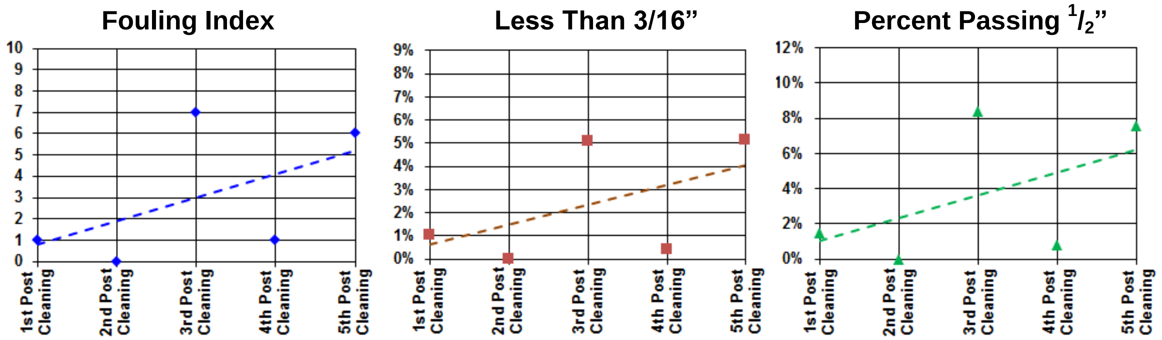
Figure 12 - Combined Sieve Analysis Curved Track, North Shoulder (Low-Side Between Tracks)


Fouling Index

Less Than 3/16"

Percent Passing $^1/_2$"

Figure 13 - Combined Sieve Analysis Tangent Track, North Shoulder (Outside-High Shoulder)


Fouling Index

Less Than 3/16"

Percent Passing $^1/_2$"

Figure 14 - Combined Sieve Analysis Tangent Track North Shoulder (Between Tracks)

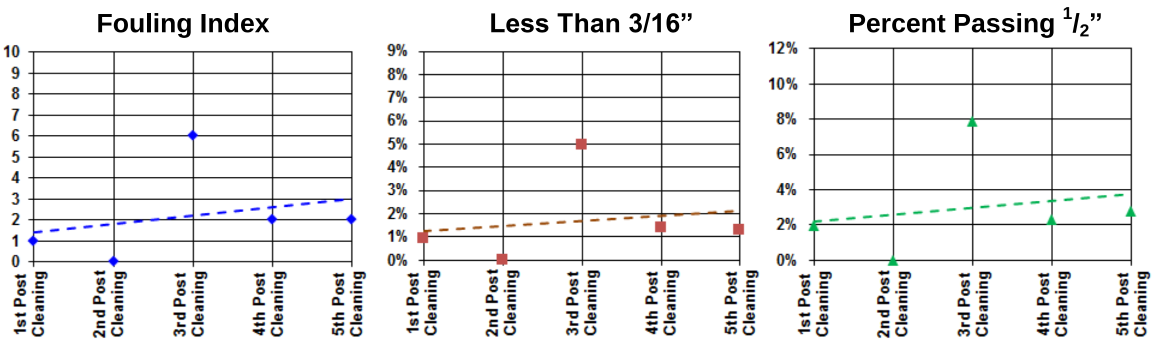


Figure 15 - Combined Sieve Analysis Tangent Track, South Shoulder (Outside Shoulder)

CONCLUSIONS

The results of the sieve analysis immediately before and after ballast shoulder cleaning shows that the ballast shoulder cleaning process was effective in removing fines and restoring the shoulder ballast.

The data shows that the fines in the center of the track and along the north and south cribs are trending down. The fines in the cleaned ballast shoulder are increasing.

Where a single shoulder is cleaned between two tracks, improved drainage is provided for both tracks, not just the track from which the cleaning was performed. The results of the sieve analysis suggest that fines migrate away from both tracks into the cleaned shoulder located between the two tracks.

The results of the sieve analysis suggest that fines have a higher propensity to migrate towards the low side of tracks with superelevated curves, even though the shoulders on both sides of the track were cleaned.

TABLE OF FIGURES

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[i] AREMA *Manual for Railway Engineering* (2011), Volume 1 Track, Chapter 1: Roadway and Ballast, Part 2: Ballast, Section 2.2: Scope (1991)

[ii] Code of Federal Regulations, 49 CFR Part 213 §213.103

[iii] Track Technology and Substructure Management, Selig & Waters, Chapter 7 and Table 7.2

Special acknowledgements to TTCI – Colin Basye, Michael Brown, and Yin Gao