
**BALLAST SHOULDER
CLEANING EVALUATION**

P-15-006

BALLAST SHOULDER CLEANING EVALUATION

P-15-006

for Loram Maintenance of Way, Inc.

**Prepared by
Michael Brown
Colin Basye
Yin Gao**

**Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
Pueblo, Colorado USA
February 25, 2015**

Disclaimer: This report was prepared for Loram Maintenance of Way, Inc. (Loram) by Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads, Pueblo, Colorado. It is based on investigations and tests conducted by TTCI with the direct participation Loram to criteria approved by them. The contents of this report imply no endorsements whatsoever by TTCI of products, services or procedures, nor are they intended to suggest the applicability of the test results under circumstances other than those described in this report. The results and findings contained in this report are the sole property of Loram. They may not be released by anyone to any party other than Loram without the written permission of Loram. TTCI is not a source of information with respect to these tests, nor is it a source of copies of this report. TTCI makes no representations or warranties, either expressed or implied, with respect to this report or its contents. TTCI assumes no liability to anyone for special, collateral, exemplary, indirect, incidental, consequential, or any other kind of damages resulting from the use or application of this report or its contents.

Executive Summary

The Transportation Technology Center, Inc. was contracted by Loram Maintenance of Way, Inc. (Loram) to study the performance of ballast in track that has been shoulder cleaned. 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 over time after shoulder cleaning. Eight sets of samples were collected over a period of 2 years.

Sieve analysis immediately before and after ballast shoulder cleaning shows that the ballast shoulder cleaning process was effective in removing fines and restoring desirable drainage properties.

The test data shows that the fines in the center of the track and along the north and south ballast shoulders tend to migrate downwards. The percentage of fines in the cleaned ballast shoulders has increased over time.

Where a single shoulder is cleaned between two tracks, improved drainage is provided for both tracks, not just the track that was cleaned. 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.

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. Acceptable ballast performance requires interlocking of the ballast particles for strength and adequate void space between the particles to facilitate drainage.

Over time, however, the ballast layer deteriorates as the void space and frictional contact between ballast particles becomes reduced with fine material from ballast wear and breakdown and the intrusion of material from outside the track, such as wind-blown mineral 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.

Loram manufactures production ballast cleaning machines and offers a variety of ballast cleaning services. Ballast shoulder cleaning is offered as a high production, cost effective alternative to other methods of ballast cleaning. Ballast shoulder cleaning effectiveness is predicated on restored track drainage and the outward transport of fines from the center of the track to the cleaned ballast shoulders.

Table of Contents

1.0	INTRODUCTION AND OBJECTIVES.....	1
2.0	RAILROAD BALLAST DETERIORATION.....	1
3.0	RAILROAD TRACK.....	2
3.1	Typical Ballast Maintenance	3
3.1.1	Track Surfacing Operations.....	3
3.1.2	Undercutting.....	5
3.1.3	Track Lifting.....	6
3.1.4	Vacuuming	9
3.1.5	Shoulder Cleaning.....	11
4.0	TEST SITE	12
4.1	Test Site Selection Criteria.....	12
4.2	Test Site Description	13
4.3	Test Site Layout	15
5.0	WEATHER DURING TEST	17
6.0	TEST NARRATIVE	19
6.1	Shoulder Cleaning Operations	19
6.2	Site and Sampling History	21
7.0	PRE- AND POST-SHOULDER CLEANING ANALYSIS.....	23
7.1	Pre-Shoulder Cleaning Ballast Condition	23
7.2	Ballast Shoulder Cleaning Waste Analysis	25
7.3	Effectiveness of Ballast Shoulder Cleaning.....	26
8.0	BALLAST SAMPLE COMPARATIVE ANALYSIS	28
8.1	Analysis of Pre-Shoulder Cleaning Ballast Samples.....	28
8.2	Analysis of First Post-Shoulder Cleaning Ballast Samples	30
8.3	Analysis of the Second Post-Shoulder Cleaning Ballast Samples ...	32
8.4	Analysis of the Third Post-Shoulder Cleaning Ballast Samples	34
8.5	Analysis of the Fourth Post-Shoulder Cleaning Ballast Samples	36
8.5	Analysis of the Fifth Post-Shoulder Cleaning Ballast Samples	38
9.0	COMPARISON OF CENTER AND FIELD SIDE SHOULDERS.....	40
10.0	CONCLUSIONS.....	43

APPENDIX A	Fouling Index Trends	A-1
APPENDIX B	Trends of Fines Less Than 3/16 inch	B-1
APPENDIX C	Trends of Fines Passing ½-inch Sieve	C-1

List of Figures

Figure 1. Typical New Ballasted Track Structure	2
Figure 2. Comparison of Clean and Deteriorated Ballast.....	3
Figure 3. Track Surfacing and Alignment Machine	3
Figure 4. Track Surfacing Without Shoulder Cutting	4
Figure 5. Shoulder Cutting to Improve Drainage.....	4
Figure 6. Shoulder Cutting to Improve Drainage.....	5
Figure 7 Track Undercutting	6
Figure 8. Track Undercutting	6
Figure 9. Track Sledding.....	7
Figure 10 Loram Track Lifting Machine.....	7
Figure 11. Track Lifting	8
Figure 12. Loram RAILVAC™ Ballast Vacuum Machine	10
Figure 13. Ballast Vacuuming	10
Figure 14. Ballast Shoulder Cleaning.....	11
Figure 15. Test Site.....	14
Figure 16. Iowa Annual Rainfall (inches)	15
Figure 17. Test Site Layout.....	15
Figure 18. Test Site Before Shoulder Cleaning Operations	16
Figure 19. Test Site Before Shoulder Cleaning Operations	16
Figure 20. Ballast Mat Shoulder Covers	17
Figure 21 Ballast Sample Locations.....	17
Figure 22. Test Site Weather Station Data	18
Figure 23. Loram Ballast Shoulder Cleaning Consist.....	19
Figure 24. Details of Loram Ballast Shoulder Cleaning Operation.....	19
Figure 25 Test Site before Ballast Shoulder Cleaning	20
Figure 26. Exposed Ballast Section at Test Site	20
Figure 27. Test Site after Ballast Shoulder Cleaning	20
Figure 28. Disposed Waste Fines Removed by Ballast Shoulder Cleaning.....	21
Figure 29. Example of Ballast Conditions before Ballast Shoulder Cleaning	21
Figure 30. Pre-Shoulder Cleaning Samples Sieve Analysis Results	23
Figure 31. Pre-Ballast Shoulder Cleaning Ballast Conditions	24

Figure 32. Ballast Shoulder Cleaning Waste Sieve Analysis Results	25
Figure 33. Ballast Shoulder Cleaning Waste Sieve Analysis Results	25
Figure 34. Results of Sieve Analysis Before and After Ballast Shoulder Cleaning	26
Figure 35. Results of Sieve Analysis Before and After Ballast Shoulder Cleaning	26
Figure 36. Comparison of Before and After Indices	27
Figure 37. Sieve Analysis Indices for Pre-Shoulder Cleaning Ballast Samples ..	28
Figure 38. Sieve Analysis Results of Pre-Shoulder Cleaning Ballast Samples ...	29
Figure 39. Sieve Analysis Indices for First Post-Shoulder Cleaning Ballast Samples.....	30
Figure 40. Sieve Analysis Results for the First Post-Shoulder Cleaning Ballast Samples.....	31
Figure 41. Sieve Analysis Indices for Second Post-Shoulder Cleaning Ballast Samples.....	32
Figure 42. Sieve Analysis Results of Second Post-Shoulder Cleaning Ballast Samples.....	33
Figure 43. Sieve Analysis Indices for Third Post-Shoulder Cleaning Ballast Samples.....	34
Figure 44. Sieve Analysis Results of Third Post-Shoulder Cleaning Ballast Samples.....	35
Figure 45. Sieve Analysis Indices for Fourth Post-Shoulder Cleaning Ballast Samples.....	36
Figure 46. Sieve Analysis Results of Fourth Post-Shoulder Cleaning Ballast Samples.....	37
Figure 47. Sieve Analysis Indices for Fifth Post-Shoulder Cleaning Ballast Samples.....	38
Figure 48. Sieve Analysis Results of Fifth Post-Shoulder Cleaning Ballast Samples.....	39
Figure 49. Combined Sieve Analysis Results for All Shoulder Samples	40
Figure 50. Combined Sieve Analysis Results North Shoulders	41
Figure 51. Combined Sieve Analysis Results South Shoulders.....	41
Figure 52. Combined Sieve Analysis Results Curved Track North Shoulder.....	42
Figure 53 Combined Sieve Analysis Results Tangent Track North Shoulder	42
Figure 54. Combined Sieve Analysis Results Tangent Track North Shoulder	42
Figure 55. Combined Sieve Analysis Results Tangent Track South Shoulder.....	42

List of Tables

Table 1. Comparison of New Ballast Requirements for Ballast Cleaning Operations.....	12
Table 2. Selig Fouling Index	23

1.0 INTRODUCTION AND OBJECTIVES

The Transportation Technology Center, Inc. (TTCI) was contracted by Loram Maintenance of Way, Inc. (Loram) to study the performance of ballast in track that has been shoulder cleaned.

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.

2.0 RAILROAD 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 wind-blown 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 remediations 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, however, the void spaces between the ballast particles become filled with fines, decreasing frictional forces between ballast particles and interfering 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.

Ballast shoulder cleaning is offered as a cost effective alternative to full undercutting. Unlike ballast undercutting, shoulder cleaning does not disturb the ballast directly under the ties, eliminating the expense and addition of new ballast or track resurfacing. Additionally, ballast shoulder cleaning production rates per on-track time hour are generally faster than undercutting, require less track time; it also does not require train speed restrictions. An additional benefit of shoulder cleaning is that useful production can be performed in short track access windows.

3.0 RAILROAD TRACK

The railroad track structure is designed to distribute the large loads from vehicle wheels to the subgrade under the track. Figure 1 details a typical new ballasted track structure.

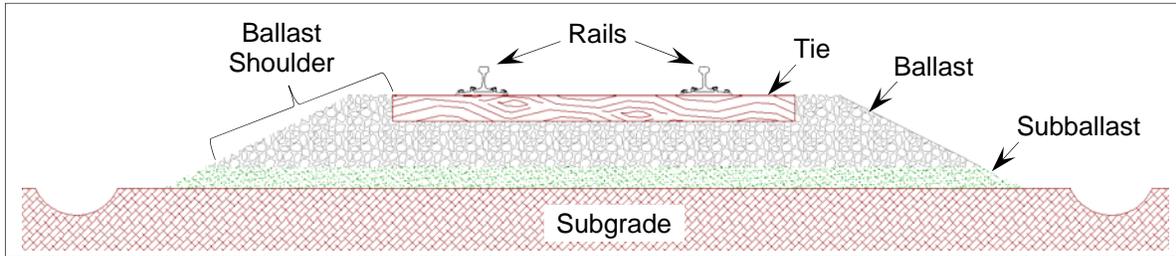


Figure 1. Typical New Ballasted Track Structure

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, chemical attack, have high electrical resistance, 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.¹

For ballast to properly perform, moisture needs to freely drain 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, further weakening 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 alignment²

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

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

² Code of Federal Regulations, 49 CFR Part 213 §213.103

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 (see Figure 2).

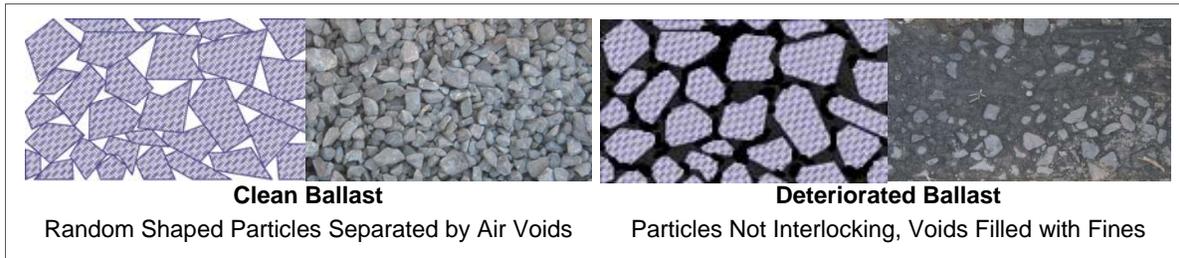


Figure 2. Comparison of Clean and Deteriorated Ballast

3.1 Typical Ballast Maintenance

Railroad ballast is primarily maintained with five typical methods: Track Surfacing, Undercutting, Track Lifting, Vacuuming, and Shoulder Cleaning.

3.1.1 Track Surfacing Operations

Track surfacing is typically performed using large machines that lift the track and packs ballast under the ties, as Figure 3 shows.

If track surfacing is performed on track with poor draining ballast without treating the shoulders, track deterioration can be accelerated by moisture trapped under the ties, as Figure 4 shows.



Figure 3. Track Surfacing and Alignment Machine

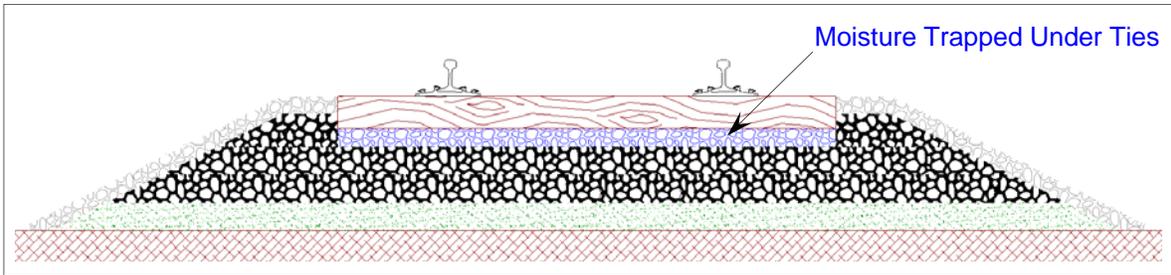


Figure 4. Track Surfacing Without Shoulder Cutting

If the ballast is highly deteriorated, advance ballast shoulder cutting may be performed to improve track drainage, prior to track surfacing, as Figures 5 and 6 show. This methodology requires the replacement of large amounts of ballast and requires sufficient right of way space to waste the deteriorated ballast. The disadvantage to this strategy is that all of the shoulder ballast is wasted, requiring a significant amount of makeup ballast. For a typical ballast section, with 12 inches of ballast below the ties, and 12-inch shoulders with 2:1 slopes, this could be as much as 1,600 cubic yards of ballast per mile, where little or no makeup ballast is required for shoulder cleaning. With ballast weighing 1.35 tons per cubic yard, this equates to approximately 2,160 tons of ballast or twenty-two 100-ton ballast cars per mile.



Figure 5. Shoulder Cutting to Improve Drainage

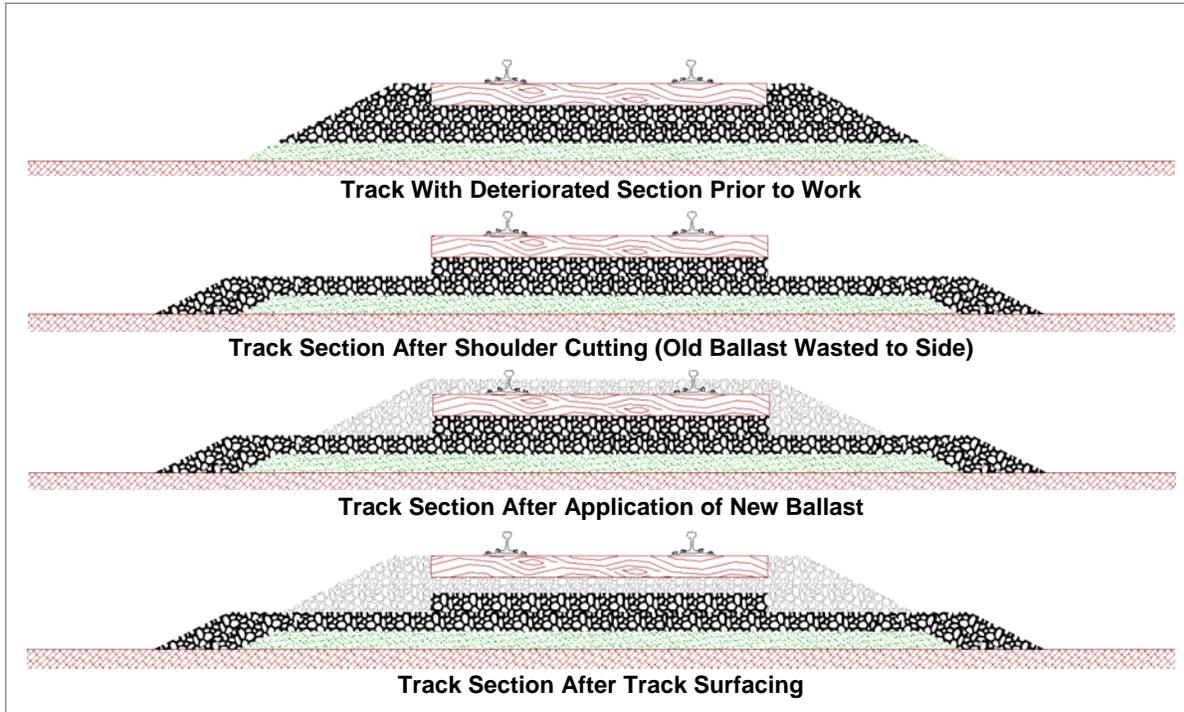


Figure 6. Shoulder Cutting to Improve Drainage

3.1.2 Undercutting

Track undercutting uses a digging arm under the ties. Utilizing a combination of the undercutting arm and conveyor system, the old ballast is lifted into the machine and then screened to remove fines. The clean ballast is then returned to the track (see Figures 7 and 8). For a typical ballast section, with 12 inches of ballast below the ties and 12-inch shoulders with 2:1 slopes, and assuming a 50 percent recovery rate of the old ballast, this process may require as much as 1,892 cubic yards of ballast per mile. With ballast weighing 1.35 tons per cubic yard, this equates to approximately 2,600 tons of ballast or twenty-six 100-ton ballast cars per mile.



Figure 7. Track Undercutting³

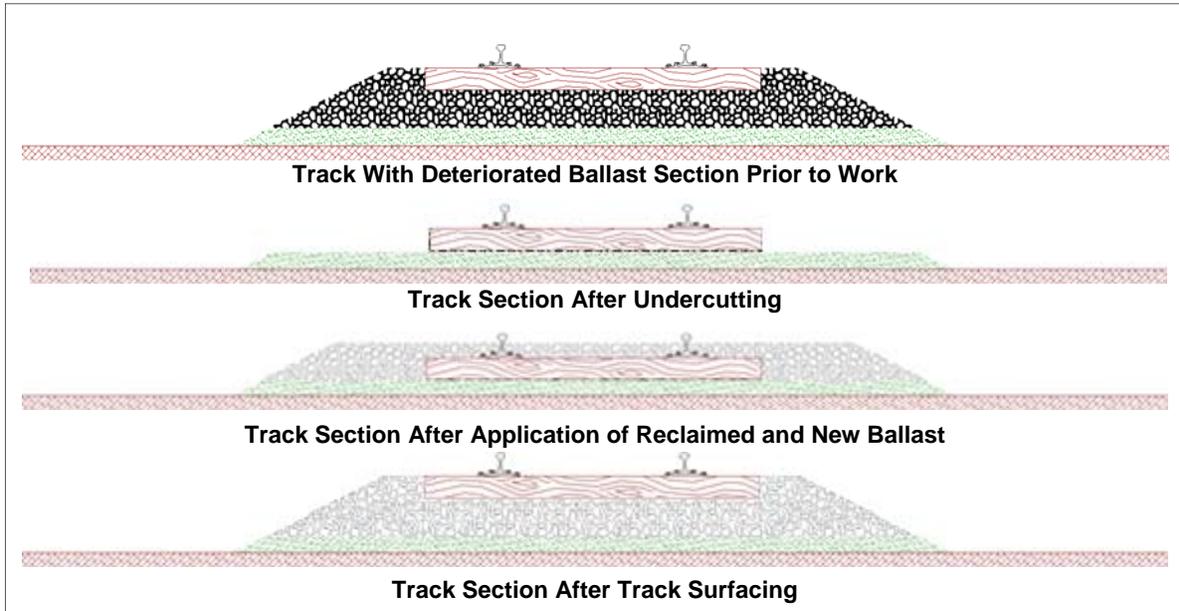


Figure 8. Track Undercutting

3.1.3 Track Lifting

Track lifting is a modern variant of track sledding. With track sledding, track is lifted and a device is inserted under the ties. Using a locomotive, the sled is pulled along under the track. The ties pass over the top of the sled, and the ballast section below is plowed smooth (see Figure 9). The two benefits of this process are high productivity and the preservation of well-compacted tie beds, which improve the track stability when the work is complete. Figure 10 shows Loram's modern adaptation of this process is a machine

³ Image provided by Loram

called a “track lifter.” This is a self-propelled machine and does not require a locomotive for operation. This process provides a higher level of productivity than track undercutting, but does require the addition of new ballast for the rehabilitated ballast section. Figure 11 provides an example of before and after the process using track lifting. For a typical ballast section, with 12 inches of ballast below the ties and 12-inch shoulders with 2:1 slopes, this could require as much as 3,784 cubic yards of ballast per mile, where little or no makeup ballast is required for shoulder cleaning. With ballast weighing 1.35 tons per cubic yard, this equates to approximately 5,100 tons of ballast or fifty-two 100-ton ballast cars per mile.

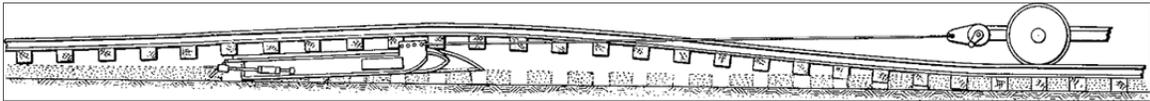


Figure 9. Track Sledding⁴



Figure 10. Loram Track Lifting Machine⁵

⁴ Image from L.B. Franco/Mannix Ltd. Patent 2,769,172 - 10/1959

⁵ Image provided by Loram

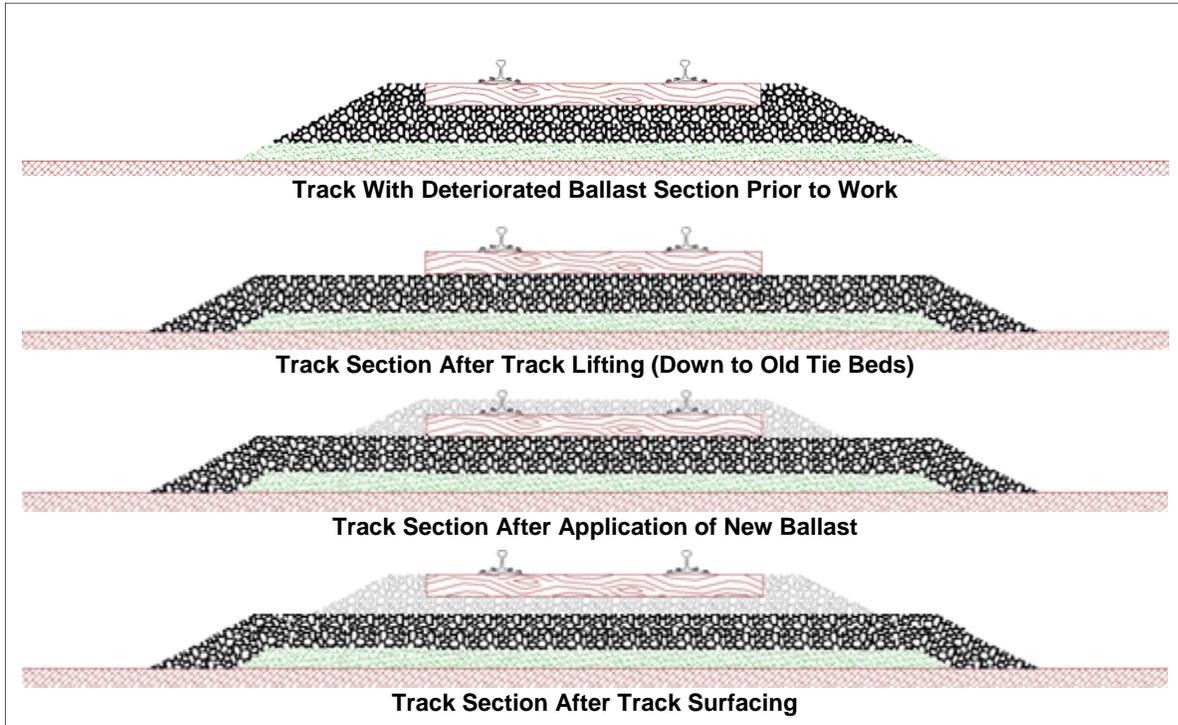


Figure 11. Track Lifting

3.1.4 Vacuuming

Ballast vacuum machines are equipped with large articulated nozzles that fit between the ties and removes ballast using suction. The suction nozzle is equipped with rotating digging fingers that aid in the displacement of cemented ballast under the ties (see Figure 12). These machines use the same principal as a home vacuum cleaner, only scaled up significantly in size and capacity. The removal production of these machines is typically about 30 cubic yards of ballast per hour, which is equivalent to about 30-track feet of full ballast section per hour. While the production rates of this type of machine are much lower than other treatments, they have the benefit of being able to work in areas with limited clearances, create additional drainage paths, and can easily avoid damaging other accessories in and around the track, such as communications, train control, and traction power equipment. Additionally, set-up and clear-up times are very short, which can improve overall productivity where only short work windows are available and where spot work is required.

These machines are typically designed only to remove the ballast for wasting, so the full-ballast section must be replaced, as Figure 13 shows. However, the location of the removed ballast can be carefully controlled with this process. It is possible to leave the tie supporting ballast under the ties, such that immediate track surfacing is not required. If the entire ballast section is removed, then approximately 3,784 cubic yards of ballast per mile or 5,100 tons (at 1.35 tons per cubic yard) or fifty-two 100-ton ballast cars per mile is required, less if the tie supporting ballast is not removed.



Figure 12. Loram RAILVAC™ Ballast Vacuum Machine⁶

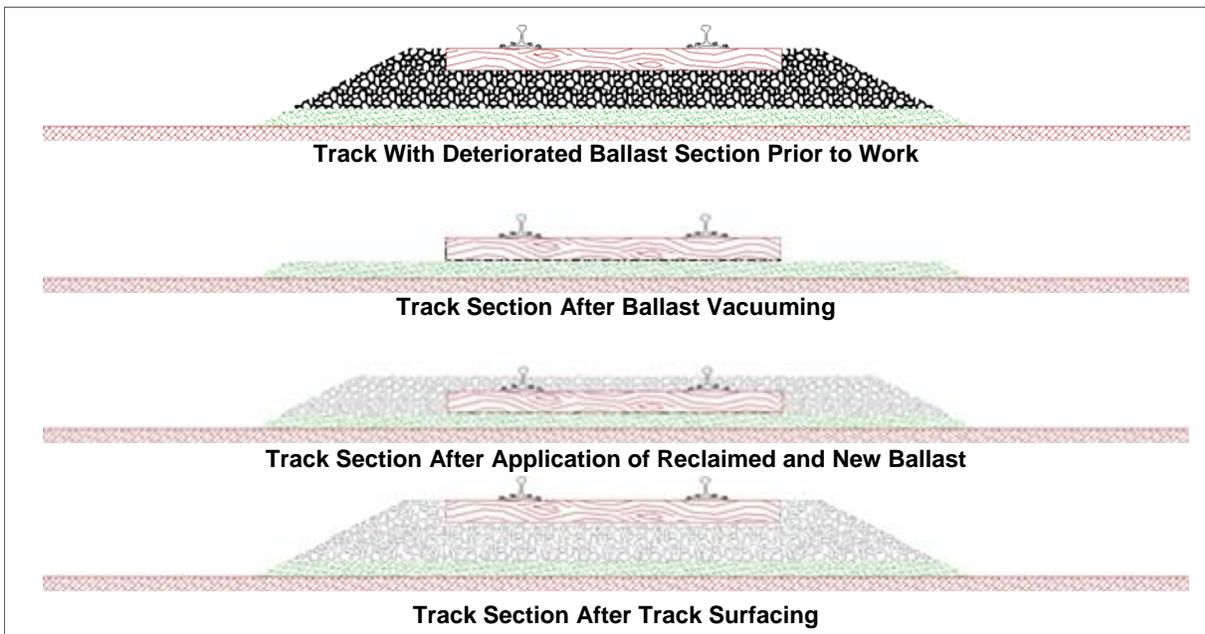


Figure 13. Ballast Vacuuming

⁶ Image provided by Loram

3.1.5 Shoulder Cleaning

Ballast shoulder cleaning machines have large cutting wheels that run along both ends of the ties. Without disturbing the track geometry, the ballast shoulders are completely removed. Most shoulder cleaning machines process the removed ballast, screening out the fines and returning the recovered 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, as the cleaned ballast is returned to the track, the ballast shoulder is regulated and the tops of the ties are broomed, completely restoring the ballast shoulders. Only a short segment of track has the tie ends exposed, under the ballast cleaning machine, during production, with the track restored as a part of the process. Unlike many other ballast cleaning or replacement processes, ballast shoulder 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 for clearing 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 further improve track drainage (see Figure 14). Assuming an average 3-inch track raise and a full-ballast section, the additional tamping requires approximately 850 cubic yards (1,150 or eleven 100-ton cars) of ballast per mile. Table 2 compares the ballast requirements for the various processes described.

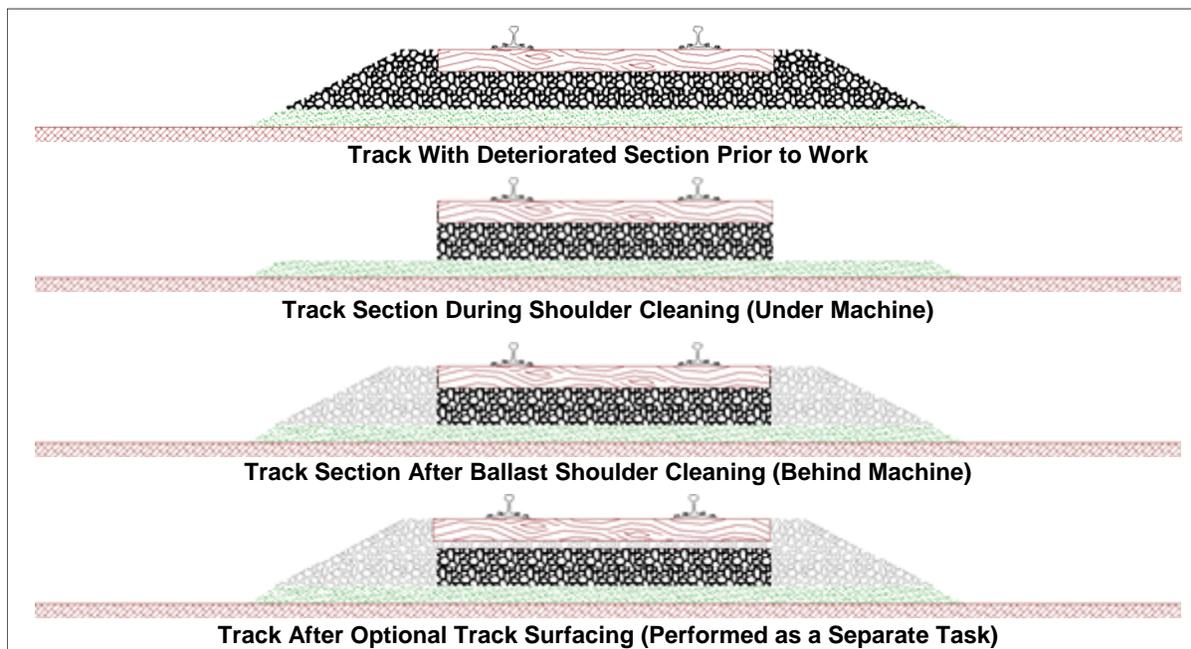


Figure 14. Ballast Shoulder Cleaning

Table 1. Comparison of New Ballast Requirements for Ballast Cleaning Operations

Ballast Cleaning Process	Estimates Ballast Quantities Per Track Mile		
	Cubic Yards	Tons ⁷	100-Ton Ballast Cars
Shoulder Cleaning	0	0	0
Shoulder Cleaning with Optional Track Surfacing (3-inch lift)	850	1,150	11
Track Surfacing (3-inch lift)	850	1,150	11
Track Surfacing (3-inch lift) with Shoulder Cutting	2,450	3,300	33
Track Undercutting	1,892	2,600	26
Track Lifting	3,784	5,100	52
Ballast Vacuuming	3,784	5,100	52

4.0 TEST SITE

4.1 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

⁷ 1.35 tons per cubic yard of ballast used for calculation

4.2 Test Site Description

The location selected was on the Union Pacific (UP) Railroad, Council Bluff's Division, Clinton Subdivision, running between Clinton and Council Bluffs, Iowa. The sample sites were near milepost 37 between Wheatland and Lowden Iowa located on Track 2 (see Figure 15). This line is subjected to approximately 170 million gross tons of mixed heavy axle load freight traffic annually, including unit mineral ore trains. The track has 136RE continuously welded rail with wood ties using AREMA⁸ 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 degrees (8,530-foot radius) with 2¼ inches of superelevation. The maximum freight train speed through the test site is 60 miles per hour.

According to the UP's track chart, Track 1 was originally constructed by the Chicago, Iowa and Nebraska Railroad in 1858. Track 2 was later constructed by the Chicago Northwestern Railway (CNW) in 1894. The CNW merged with the UP in 1995.

One of the selection criteria for the test site was high annual precipitation. The annual rainfall at the test site is approximately 35 inches (see Figure 16). The test site met all of the predetermined site selection criteria, with the exception of having both wood and concrete ties.

⁸ American Railway Engineering and Maintenance-of-Way Association (AREMA)

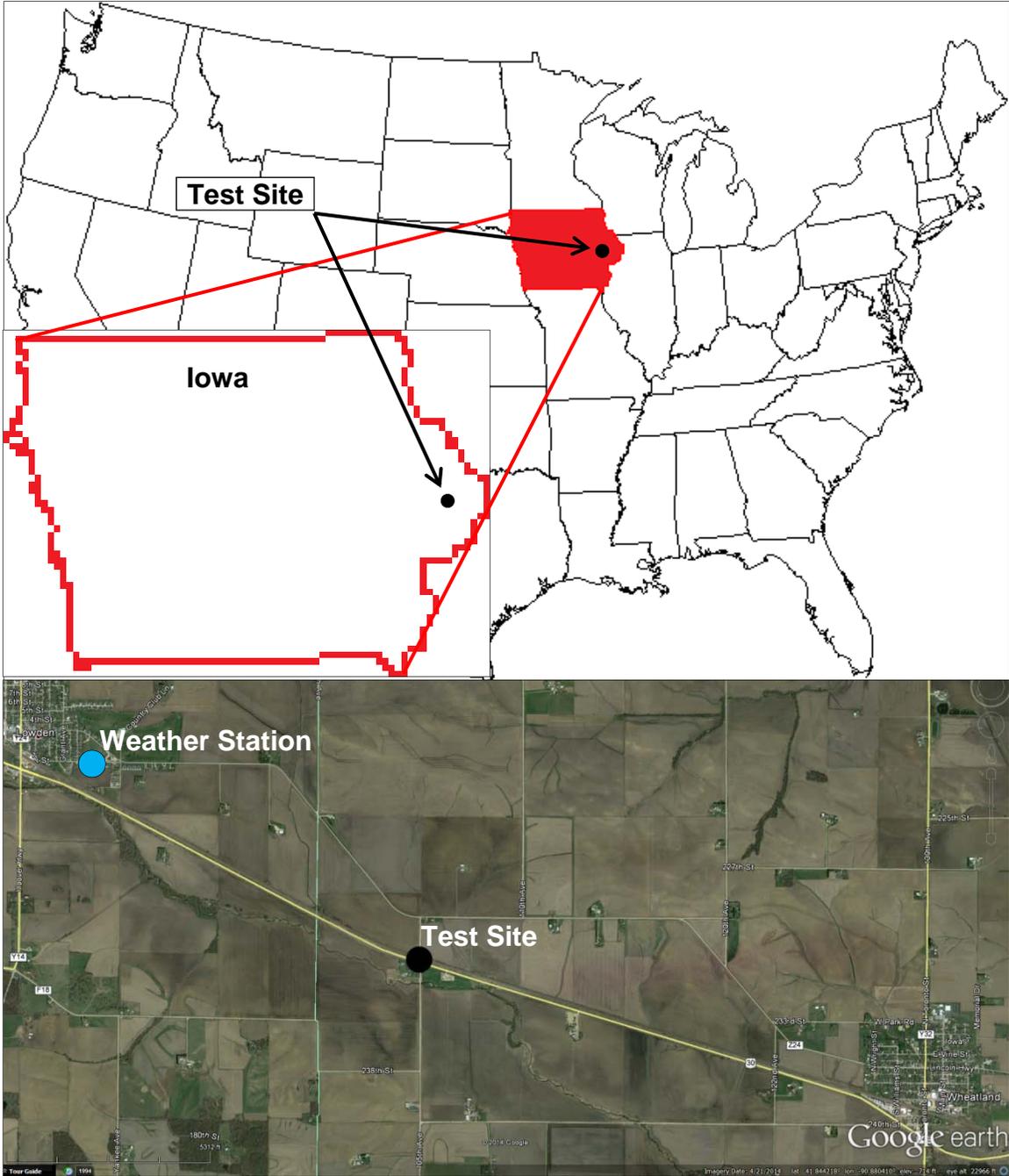


Figure 15. Test Site

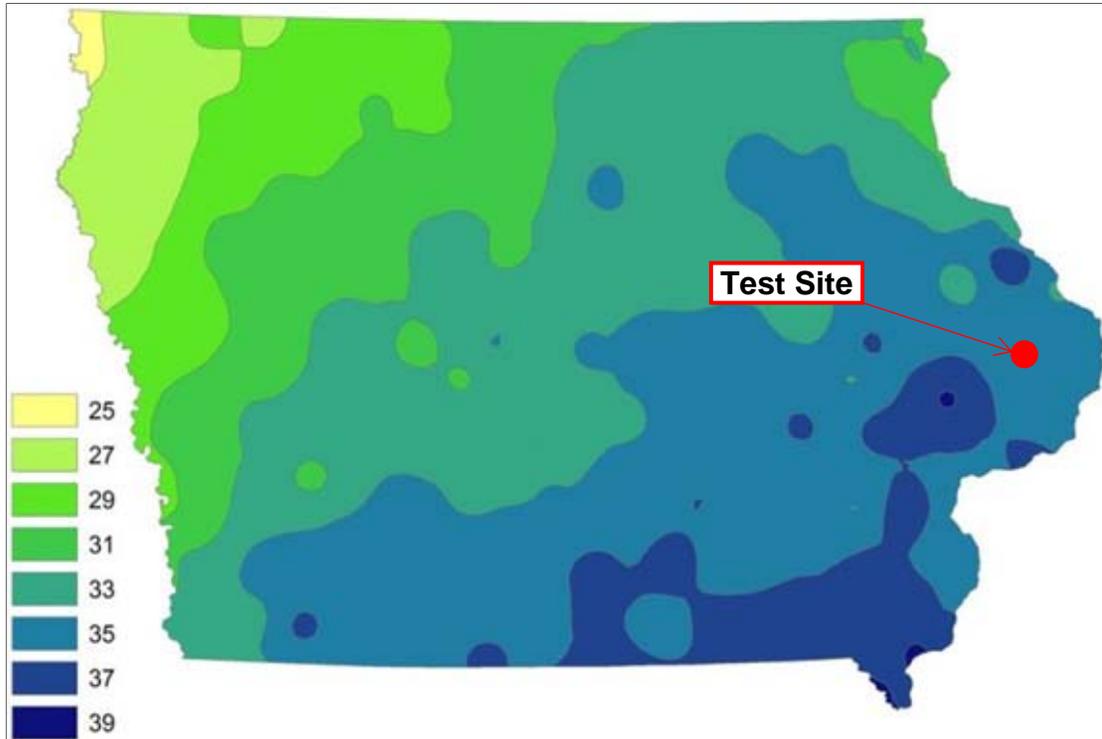


Figure 16. Iowa Annual Rainfall (inches)⁹

4.3 Test Site Layout

There were four ballast sample collection zones at the test site. 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 to filter out any external fines (see Figures 17, 18, and 19). Each zone was approximately 100 feet long.

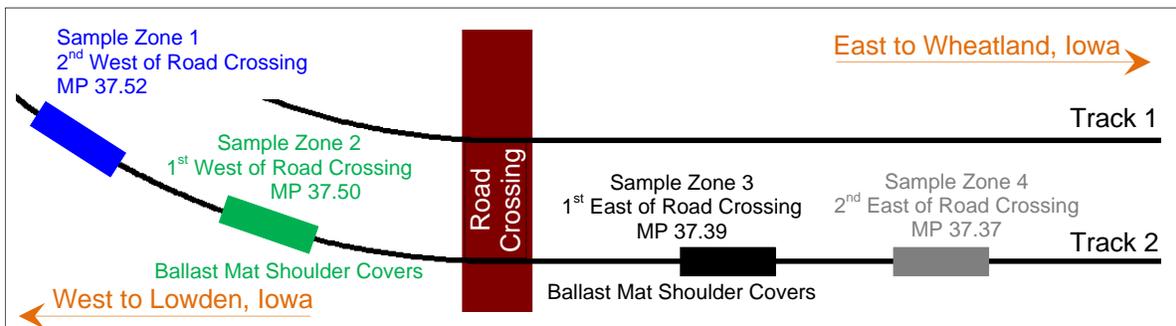
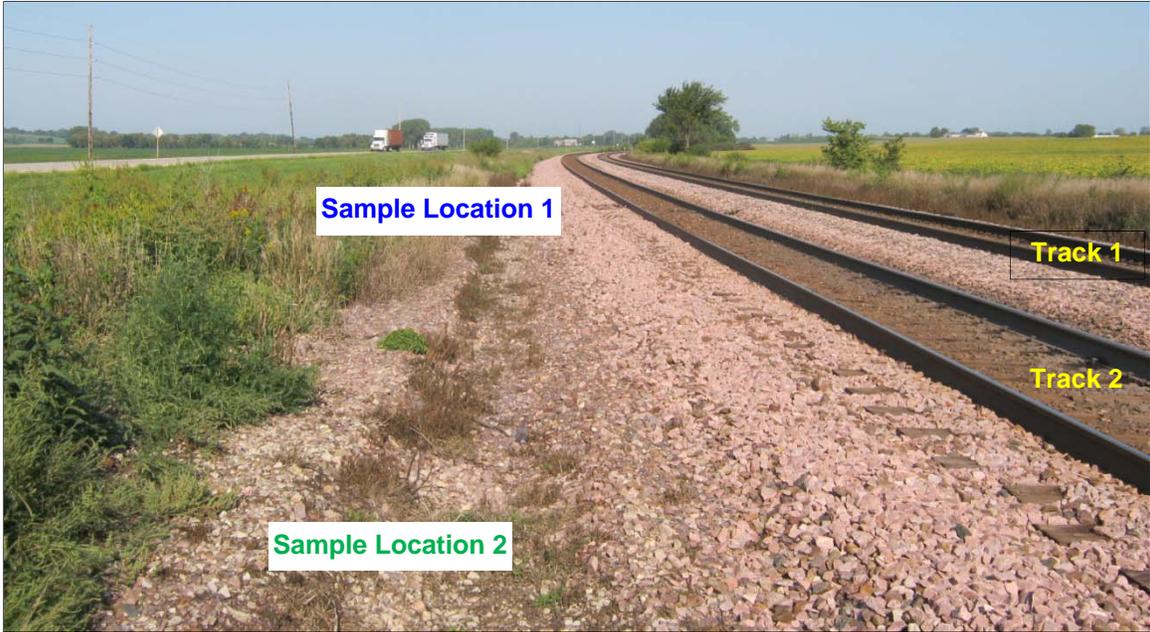
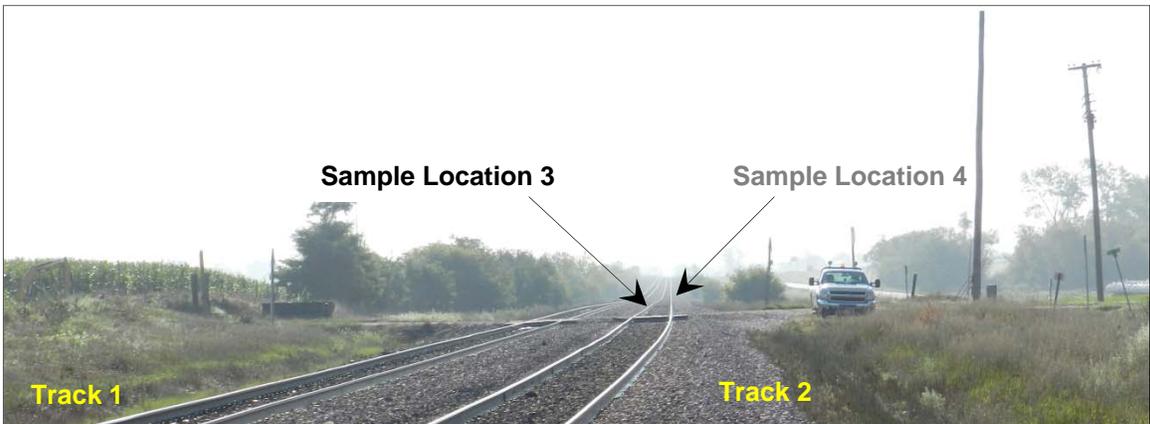


Figure 17. Test Site Layout

⁹ Data source: Bill Whittaker, wikipedia.org, using Iowa Department of Natural Resources data



**Figure 18. Test Site Before Shoulder Cleaning Operations
(Curved Zones, Facing West towards Lowden, Iowa)**



**Figure 19. Test Site Before Shoulder Cleaning Operations
(Tangent Zones, Facing East towards Wheatland, Iowa)**

One each of the curved track (Sample Location 2) and tangent track (Sample Location 3) sample locations had ballast mats 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 (see Figure 20). 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.



Figure 20. Ballast Mat Shoulder Covers

Five samples were planned to be collected at each of the four sample locations (20 total) but varied at each collection cycle. Samples were collected, from the bottom of the tie to the depth of the ballast shoulder cleaning, approximately 12 inches below the bottom of the tie as Figure 21 shows.

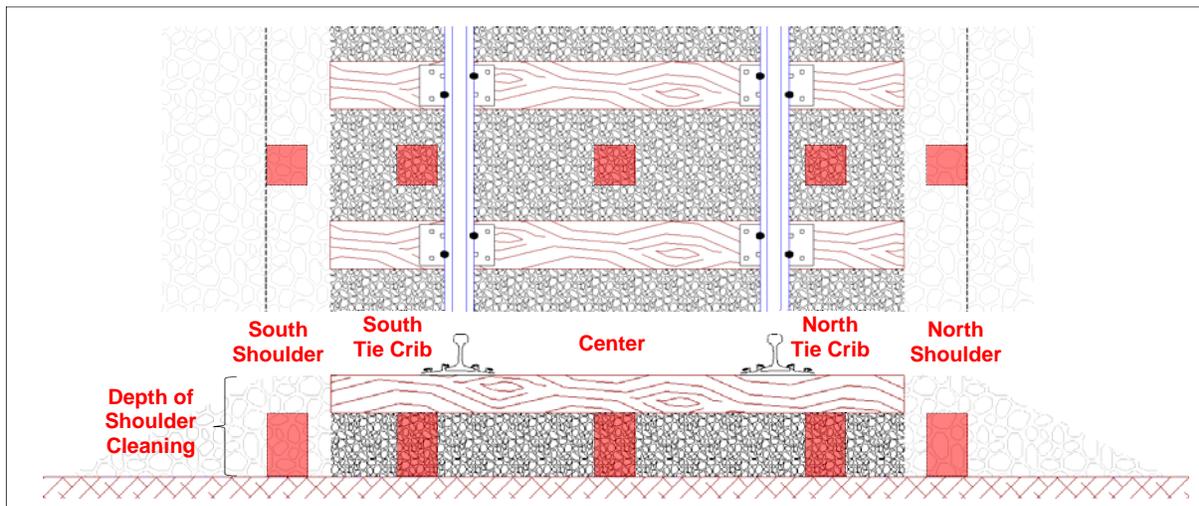


Figure 21. Ballast Sample Locations

5.0 WEATHER DURING TEST

The nearest National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center weather monitoring station, is located in Lowden, Iowa, less than 2 miles away from the test site.¹⁰ Figure 22 shows the weather throughout the duration of the test. The dates that samples were collected are identified by vertical grey lines in these graphs. From August 2012 through October 2014, the test area accumulated over 89 inches of precipitation.

¹⁰ NOAA Station Data: GHCND:USC00134963, LOWDEN IA US, 41.855,-90.920

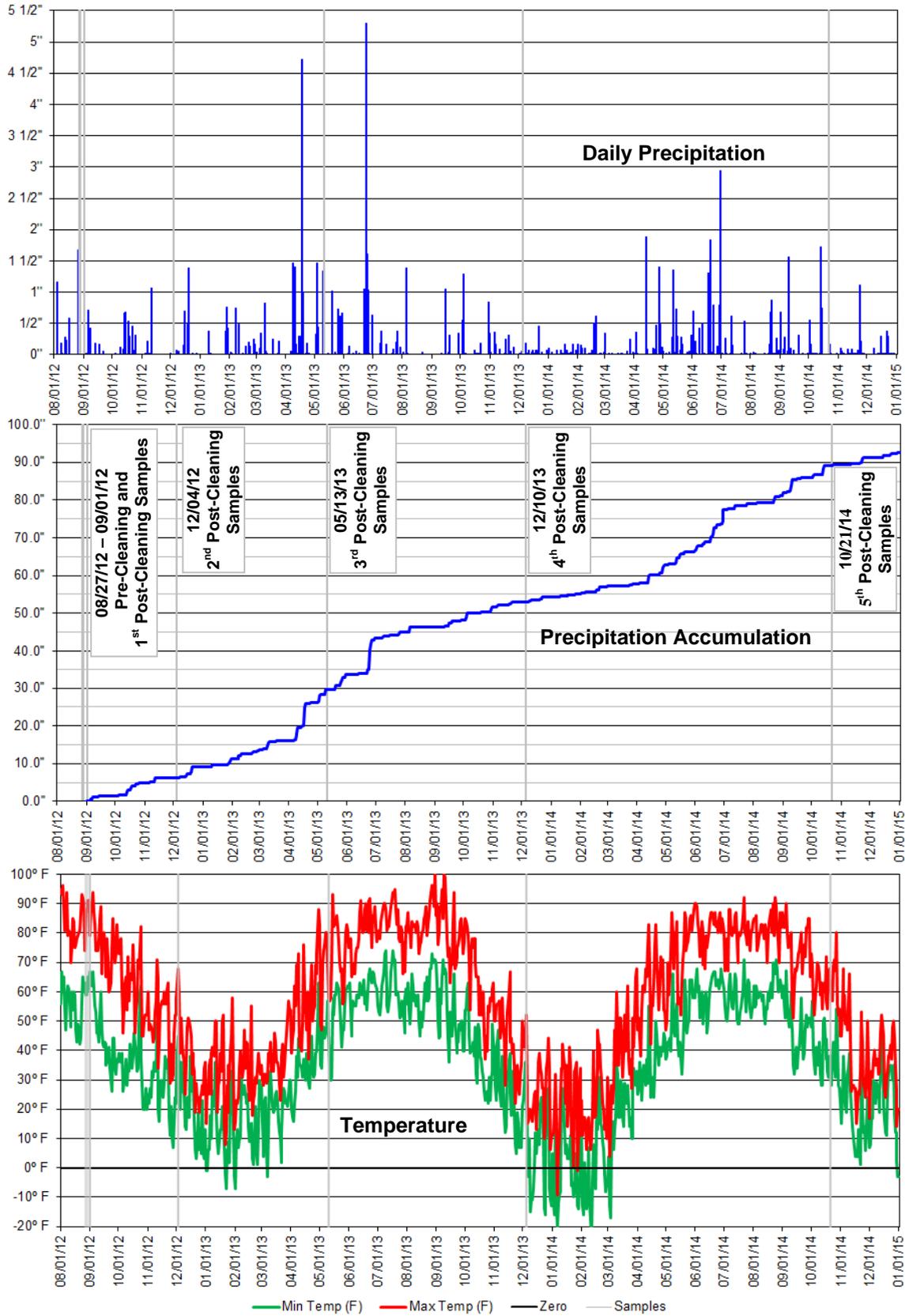


Figure 22. Test Site Weather Station Data

6.0 TEST NARRATIVE

6.1 Shoulder Cleaning Operations

Ballast samples were collected immediately before and after Loram's ballast shoulder cleaning operations. A total of four additional sets of samples were collected over a period of approximately 2 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 (see Figures 23 through 28).



Figure 23. Loram Ballast Shoulder Cleaning Consist



Figure 24. Details of Loram Ballast Shoulder Cleaning Operation

Note: Machine is symmetrical and cleans shoulders on both sides of the track simultaneously

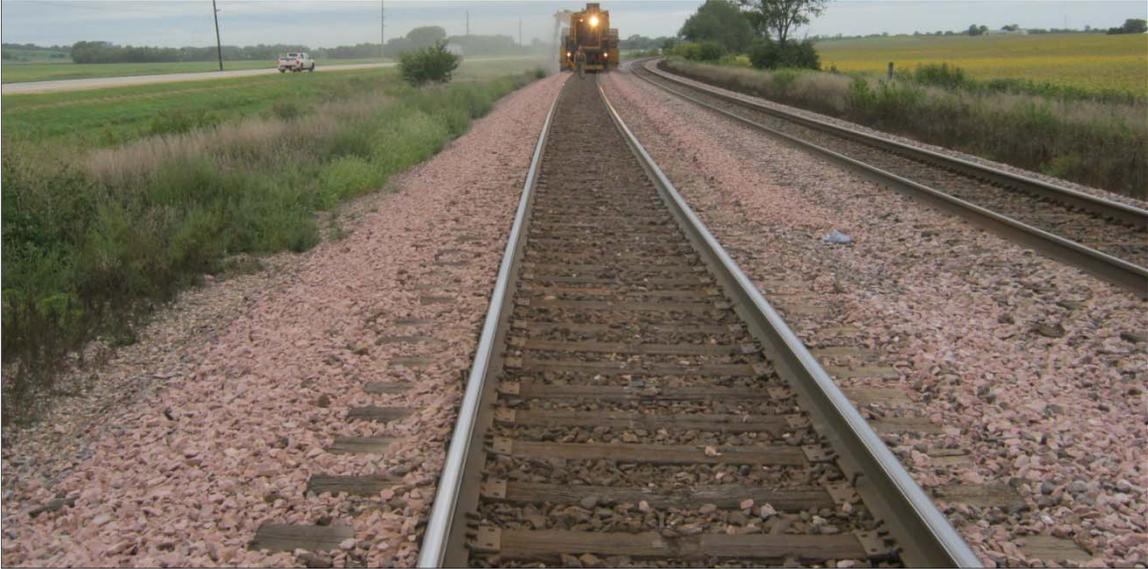


Figure 25. Test Site before Ballast Shoulder Cleaning
Note. New ballast (pink colored) along both ballast shoulders



Figure 26. Exposed Ballast Section at Test Site



Figure 27. Test Site after Ballast Shoulder Cleaning



Figure 28. Disposed Waste Fines Removed by Ballast Shoulder Cleaning

6.2 Site and Sampling History

This first set of samples was collected prior to the ballast shoulder cleaning operations, on Monday, August 27, 2012. The test site received 1.7 inches of rain on the day before; the samples collected were heavily deteriorated and very wet as Figure 29 shows.



Figure 29. Example of Ballast Conditions before Ballast Shoulder Cleaning

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, as Figures 18, 19, and 25 show.

Shoulder cleaning was attempted through the test site on Tuesday, August 28, 2012. 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.

Shoulder cleaning was performed on Saturday, September 1, 2012. 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 provided in the samples collected, just a few days before in the pre-shoulder cleaning sample sets. Samples of the waste materials were also collected.

The second set of post-shoulder cleaning samples was collected on Tuesday, December 4, 2012. The ballast mat shoulder covers were installed at this time.

The third set of post-shoulder cleaning samples was collected on Monday, May 13, 2013. Some of the ballast mat shoulder covers had been disturbed apparently related to the replacement of the adjacent road crossing. The ballast mats were restored after the samples were collected.

The fourth set of post-shoulder cleaning samples was collected on Tuesday, December 10, 2013. The track through the test site was disturbed, apparently by an out-of-face track surfacing operation, after the surfacing work the ballast mats had been restored. 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.

7.0 PRE- AND POST-SHOULDER CLEANING ANALYSIS

7.1 Pre-Shoulder Cleaning Ballast Condition

Figure 30 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. Note the large percentage of ballast particle sizes less than 1½ inch in the pre-cleaning samples, indicating deteriorated ballast.

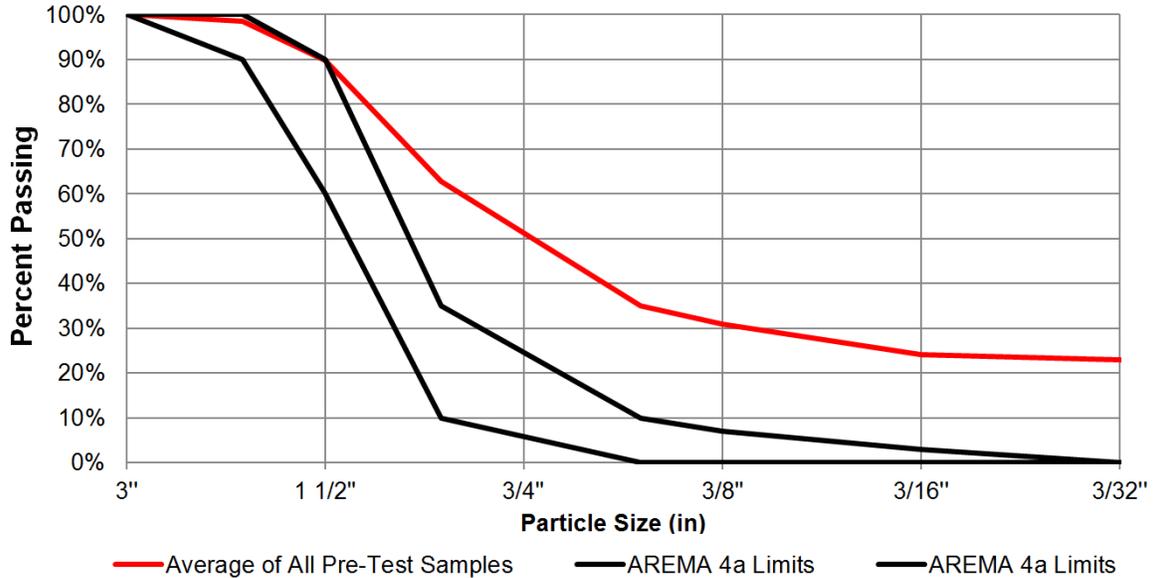


Figure 30. Pre-Shoulder Cleaning Samples Sieve Analysis Results

The Selig Ballast Fouling Index¹¹ is commonly used in North America to describe the level of ballast deterioration. Table 2 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 2. 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

The average fouling index of the 20 pre-shoulder cleaning samples collected was 33¹² (fouled) and ranged between a minimum of 21 (fouled) to a maximum of 40 (highly fouled). In comparison, new AREMA No. 4a ballast would be less than 1 (clean).

¹¹ Track Technology and Substructure Management, Selig & Waters, Chapter 7 and Table 7.2.

¹² $R_{3/16"} + R_{pan}$ used.

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 percent (ranging from 25 percent minimum to 43 percent maximum). 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 percent.

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. Figure 31 illustrates the condition of the ballast prior to shoulder cleaning.

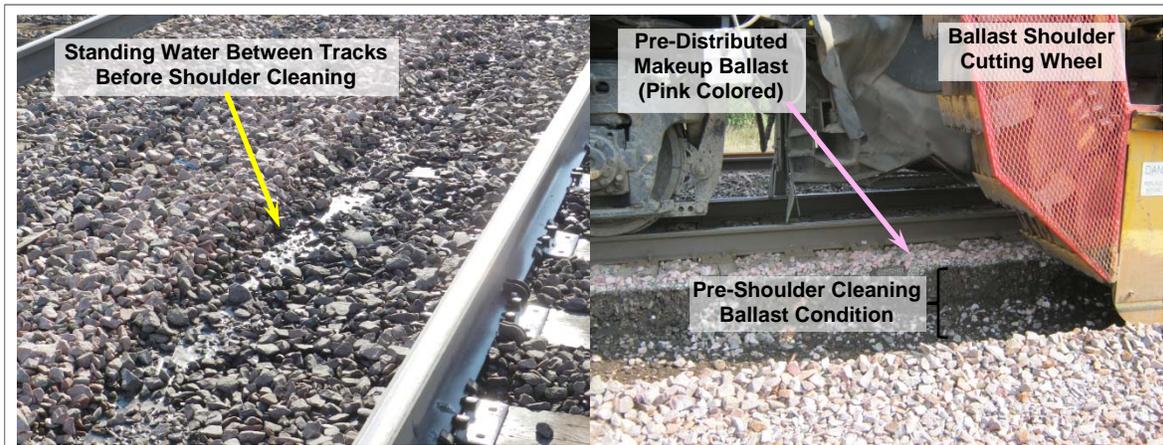


Figure 31. Pre-Ballast Shoulder Cleaning Ballast Conditions

7.2 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. Figures 32 and 33 show the average results of the sieve analysis of all of the waste samples collected. Figure 33 shows that 99 percent of the waste material removed during the ballast shoulder cleaning process was ½ inch or less.

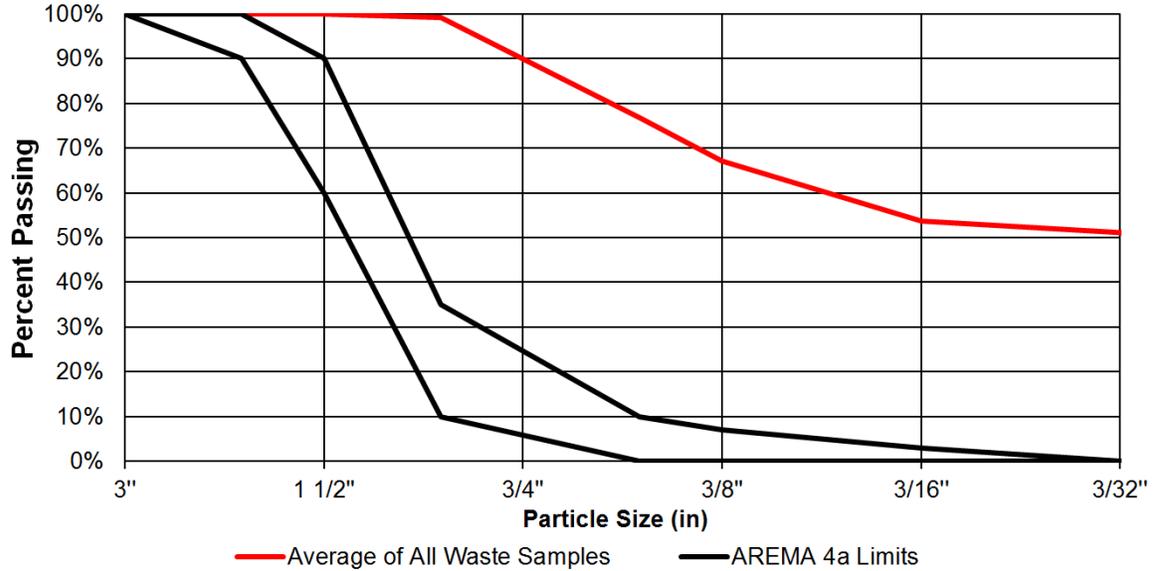


Figure 32. Ballast Shoulder Cleaning Waste Sieve Analysis Results

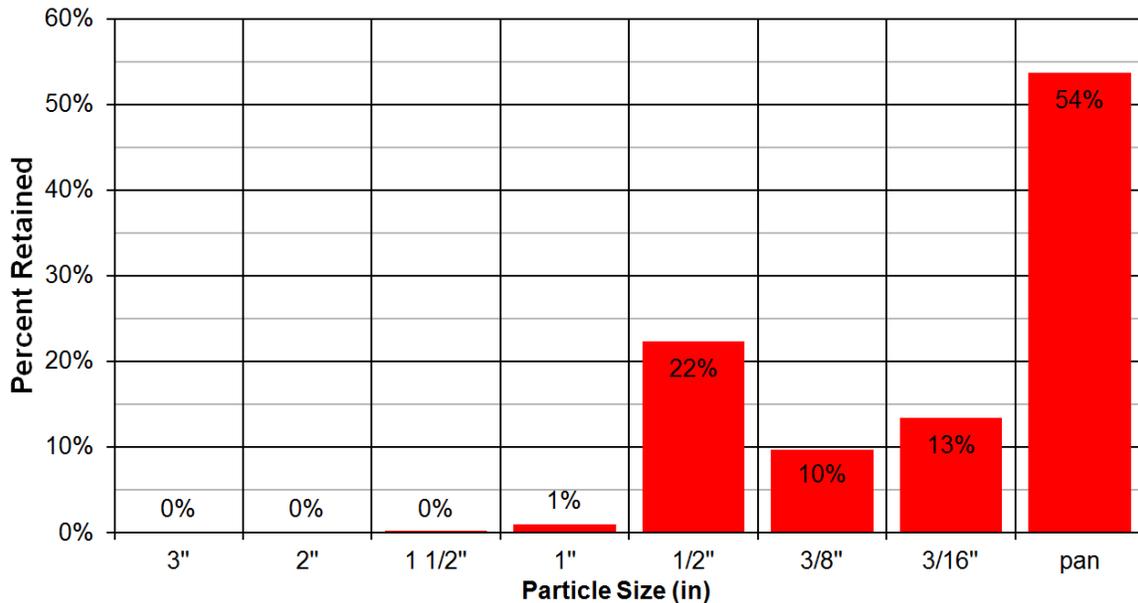


Figure 33. Ballast Shoulder Cleaning Waste Sieve Analysis Results

7.3 Effectiveness of Ballast Shoulder Cleaning

Figures 34 and 35 show the results of the sieve analysis for samples once immediately before and after ballast cleaning. The data from sieve analysis of the waste materials (Figures 32 and 33) is also included for comparison. Figures 34 and 35 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.

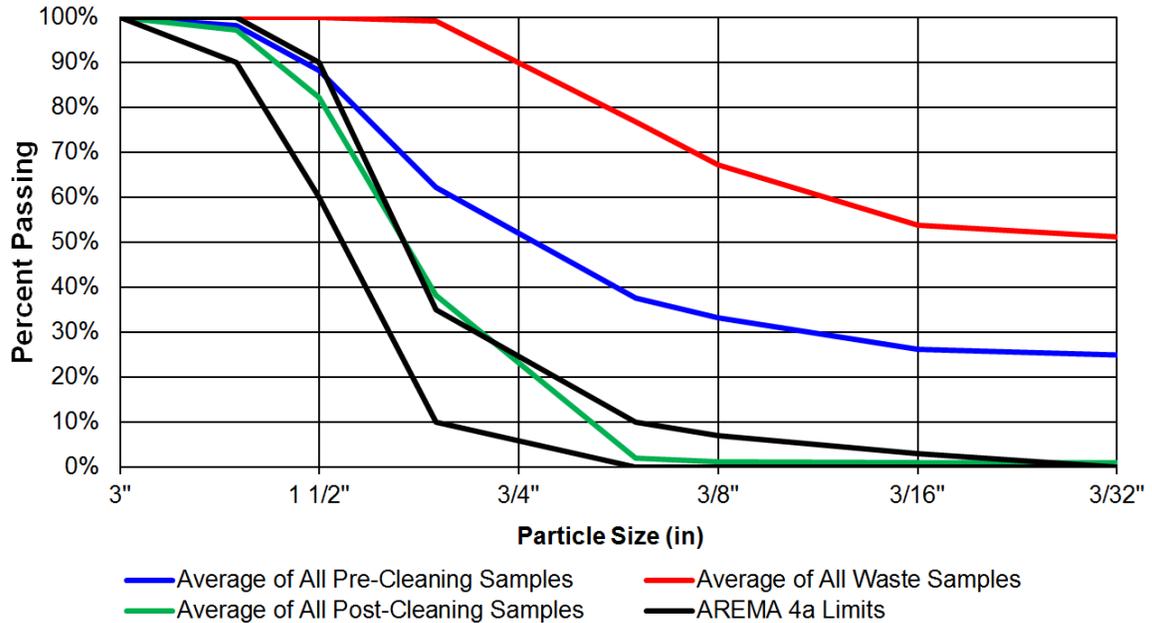


Figure 34. Results of Sieve Analysis Before and After Ballast Shoulder Cleaning

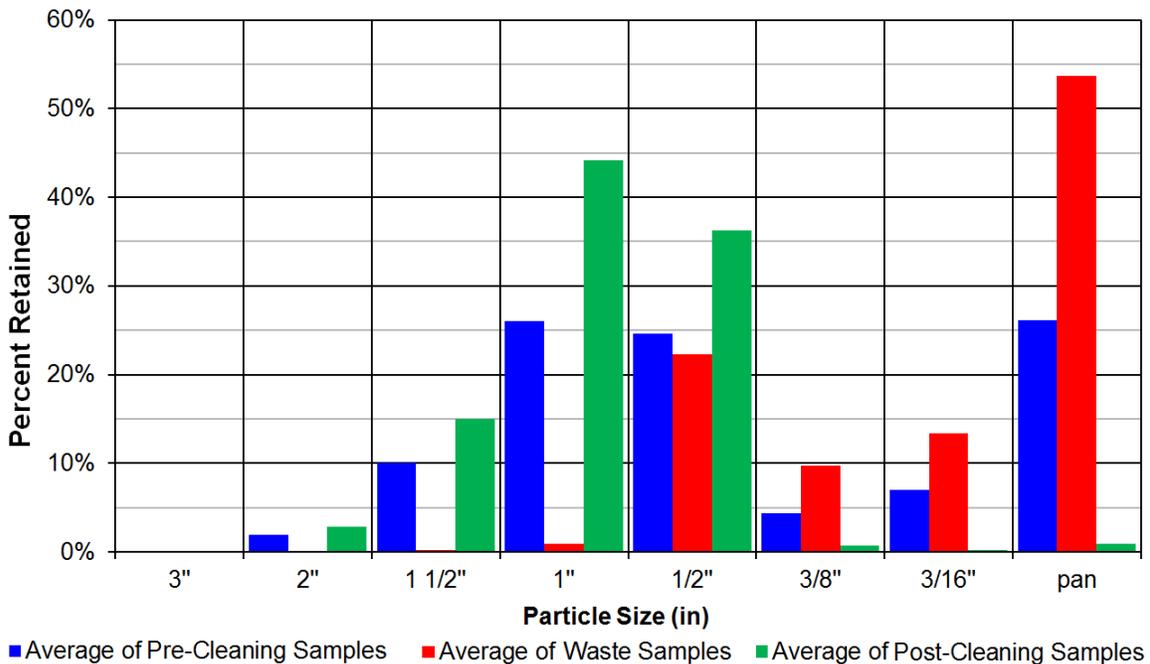


Figure 35. Results of Sieve Analysis Before and After Ballast Shoulder Cleaning

As Figure 36 shows, the fouling index was reduced from 33 (fouled) to 1 (clean). The average of the fine material, less than 3/16 inch in the first post-cleaning sample was 1 percent, and the average percent passing a 1/2-inch sieve size was reduced to 2 percent. All of this data indicates that the ballast shoulder cleaning process was highly effective in removing fines and restoring the shoulder ballast to the sieve sizes recommended for AREMA No. 4a ballast.

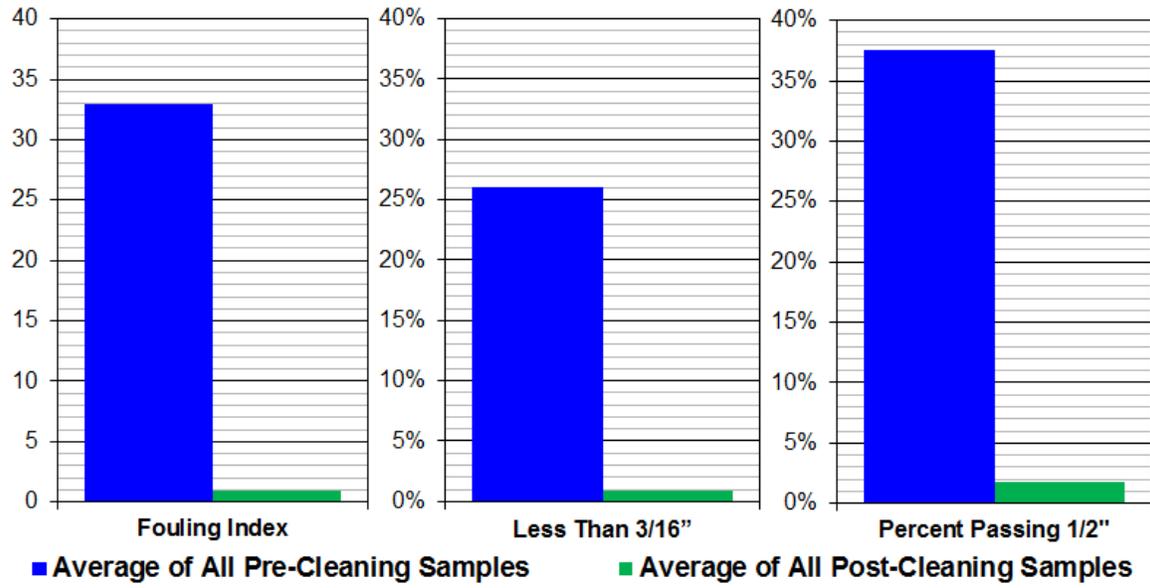


Figure 36. Comparison of Before and After Indices

8.0 BALLAST SAMPLE COMPARATIVE ANALYSIS

8.1 Analysis of Pre-Shoulder Cleaning Ballast Samples

The pre-shoulder cleaning samples were collected on Monday, August 27, 2012, prior to ballast shoulder cleaning operations. Figures 37 and 38 show the average results of the analysis.

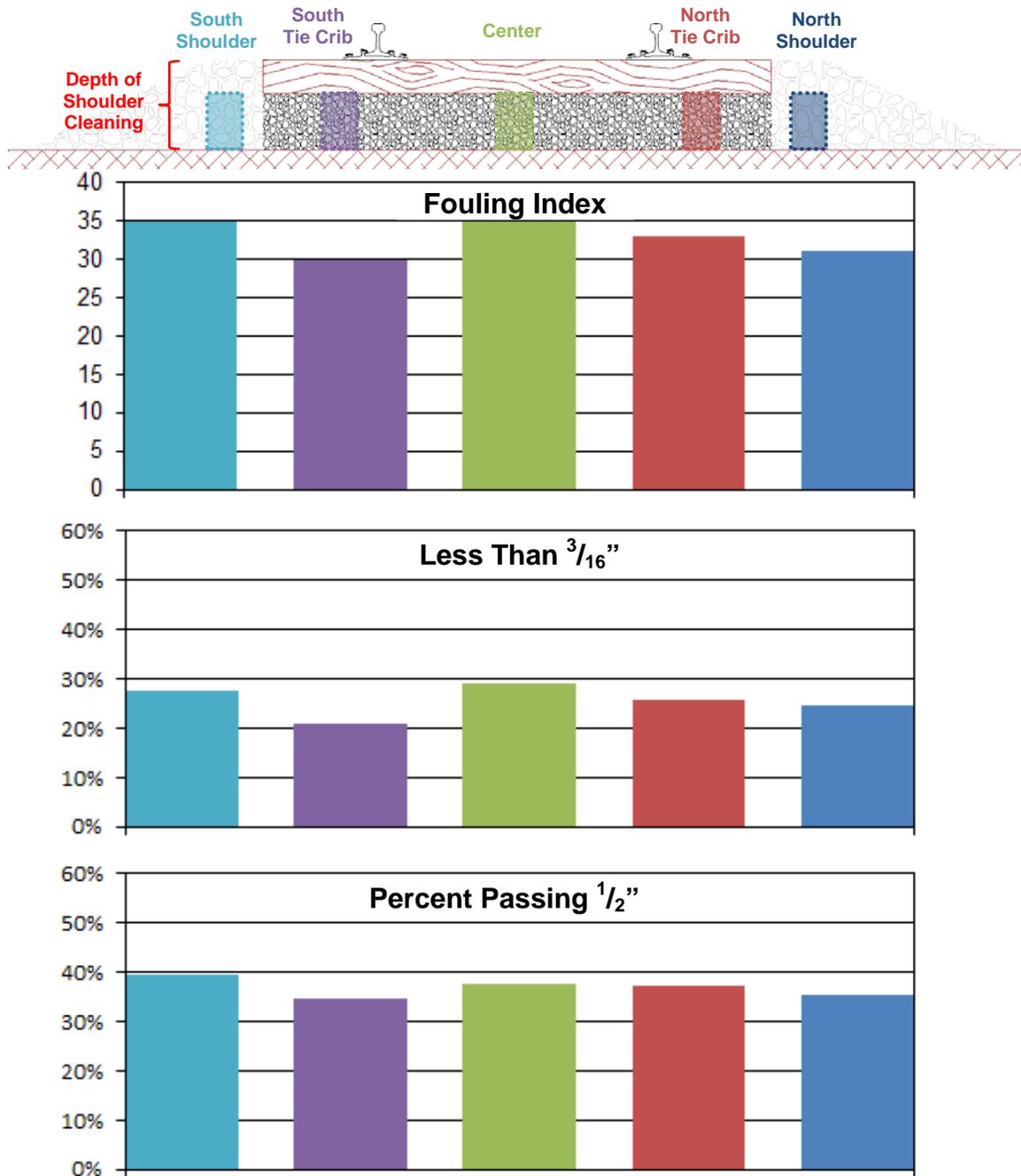


Figure 37. Sieve Analysis Indices for Pre-Shoulder Cleaning Ballast Samples

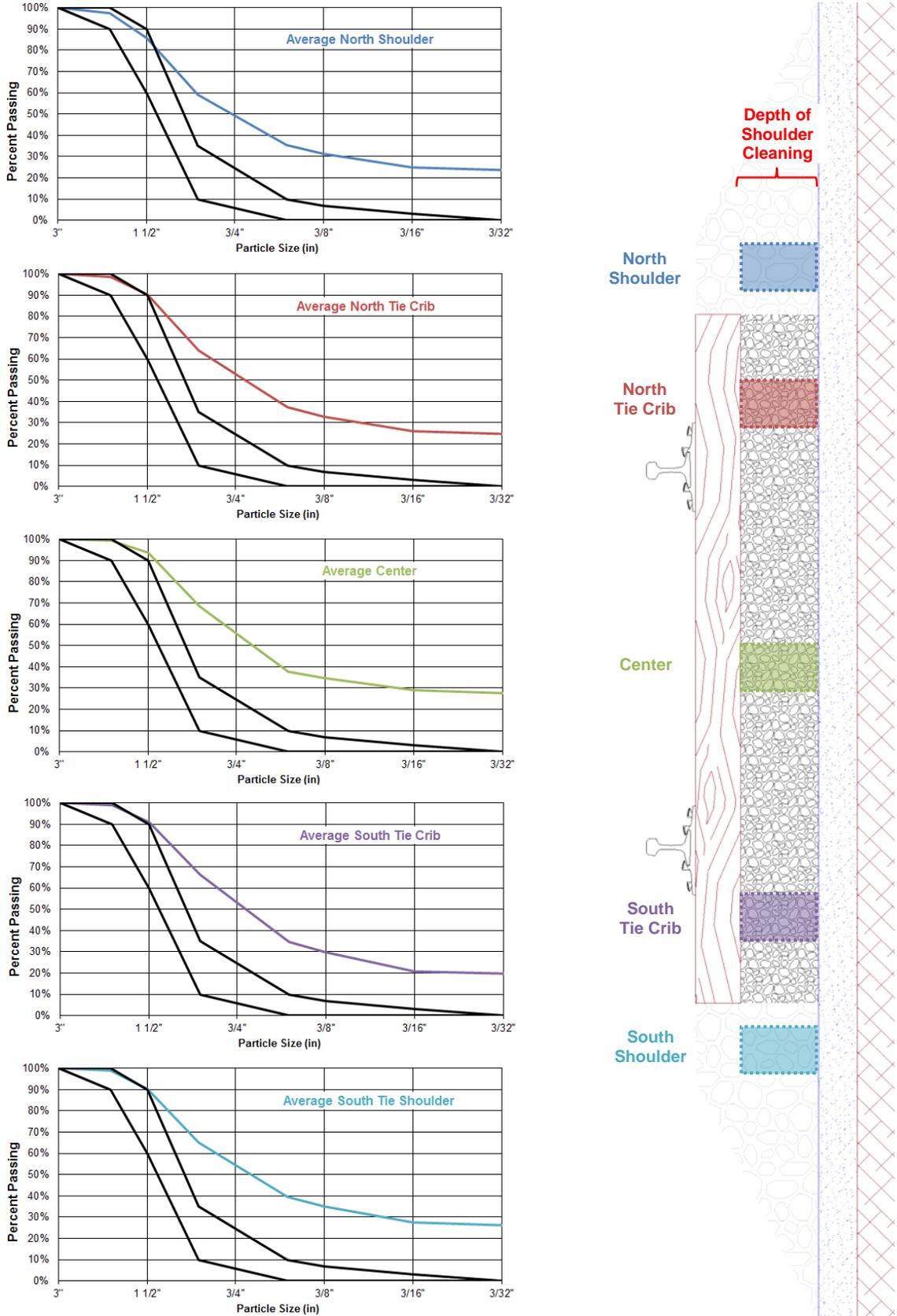


Figure 38. Sieve Analysis Results of Pre-Shoulder Cleaning Ballast Samples

8.2 Analysis of First Post-Shoulder Cleaning Ballast Samples

The first set of samples after the shoulder cleaning samples were collected on Saturday, 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. Figures 39 and 40 show the average results of the analysis.

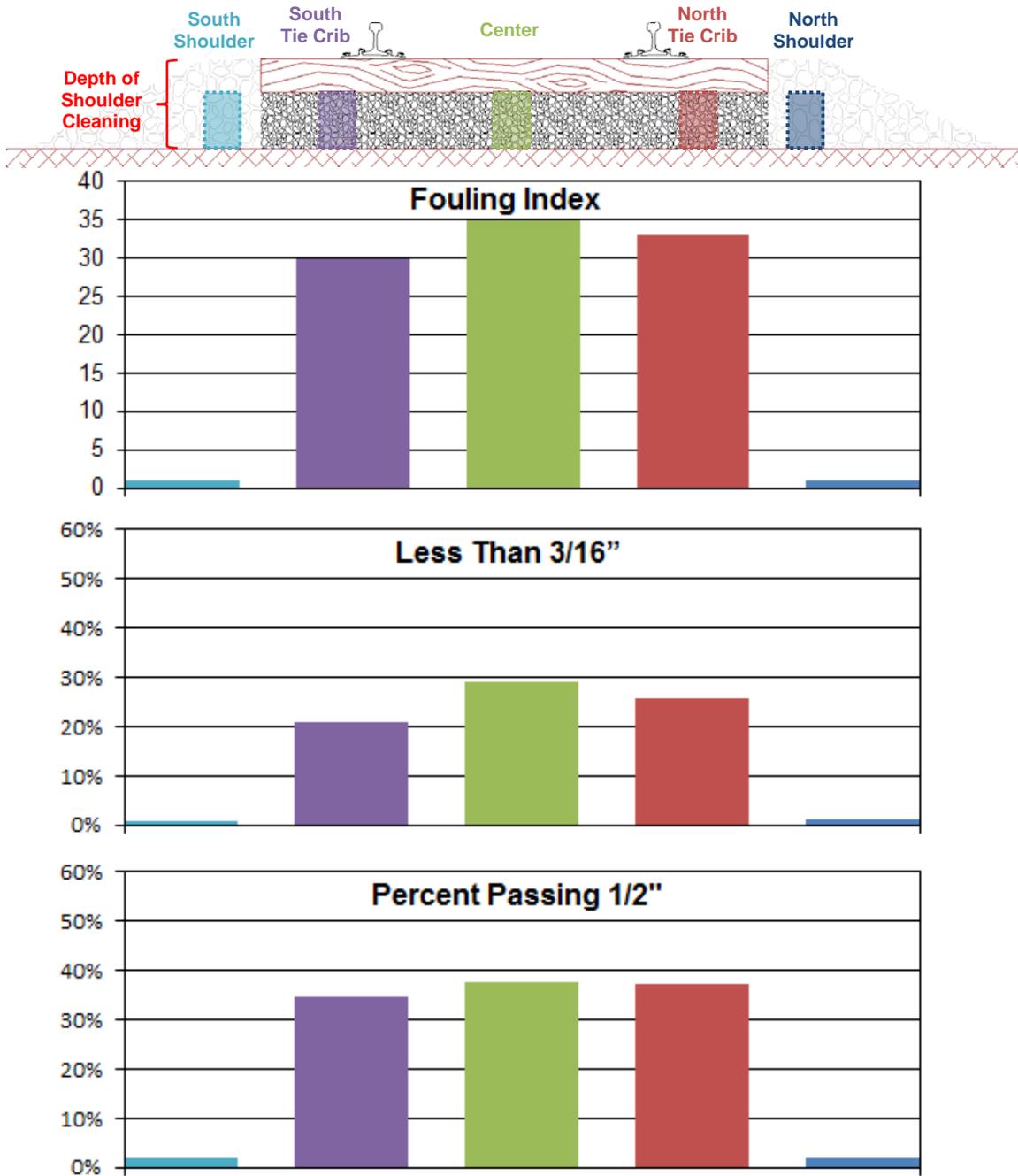


Figure 39. Sieve Analysis Indices for First Post-Shoulder Cleaning Ballast Samples

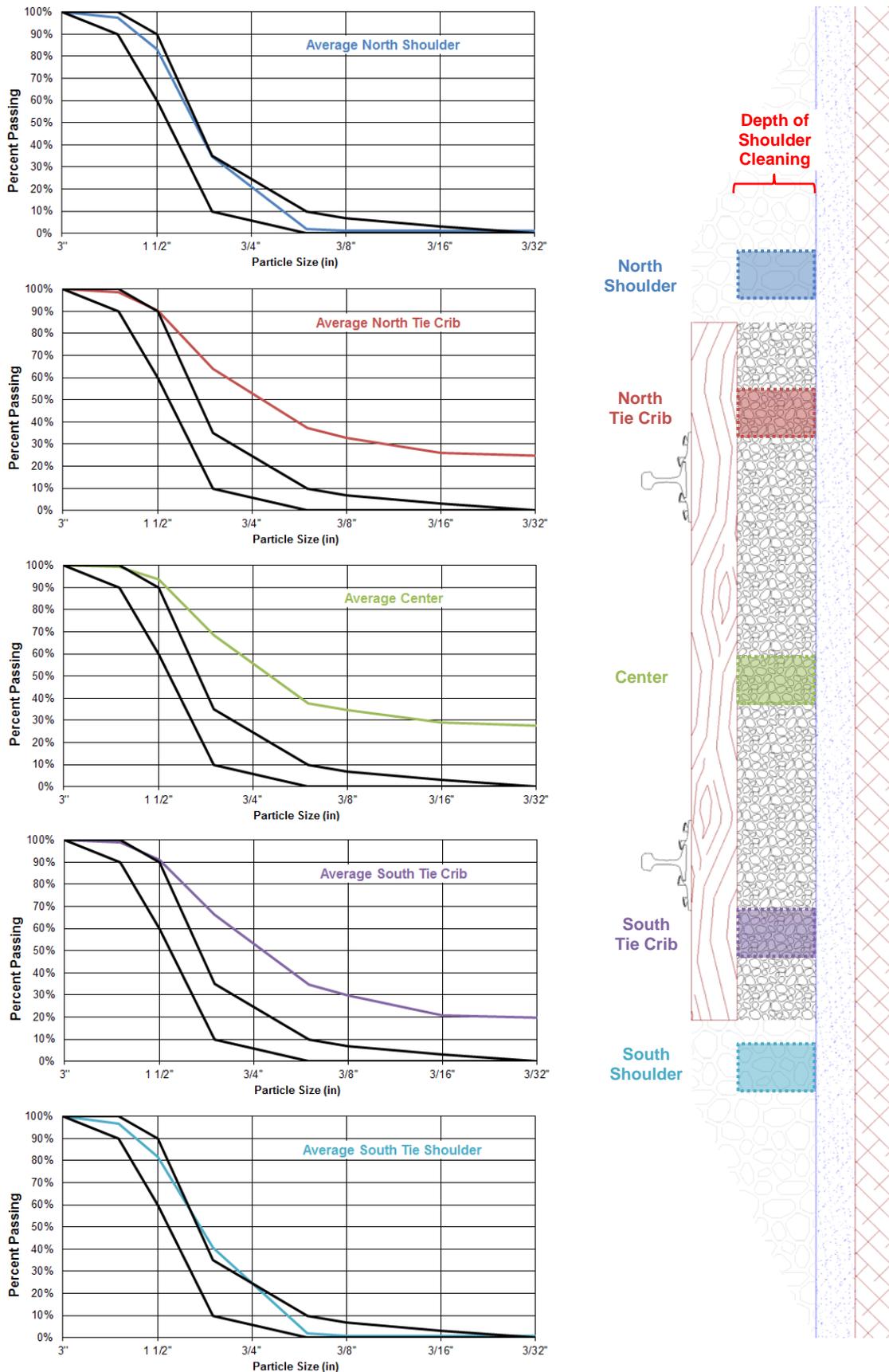


Figure 40. Sieve Analysis Results for the First Post-Shoulder Cleaning Ballast Samples

8.3 Analysis of the Second Post-Shoulder Cleaning Ballast Samples

The second set of samples after the shoulder cleaning was collected on Tuesday, December 4, 2012. The average results of the analysis are shown in Figures 41 and 42.

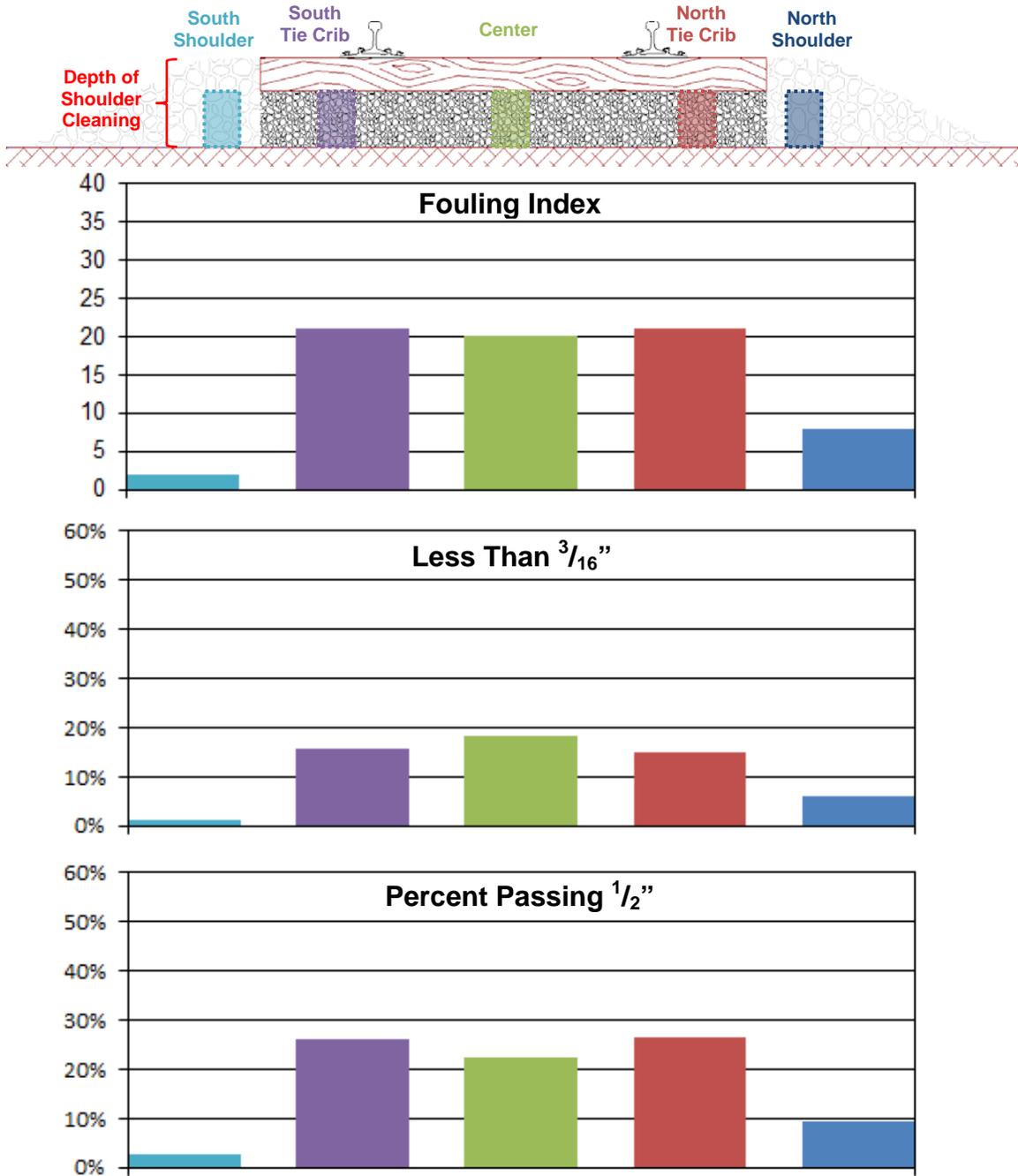


Figure 41. Sieve Analysis Indices for Second Post-Shoulder Cleaning Ballast Samples

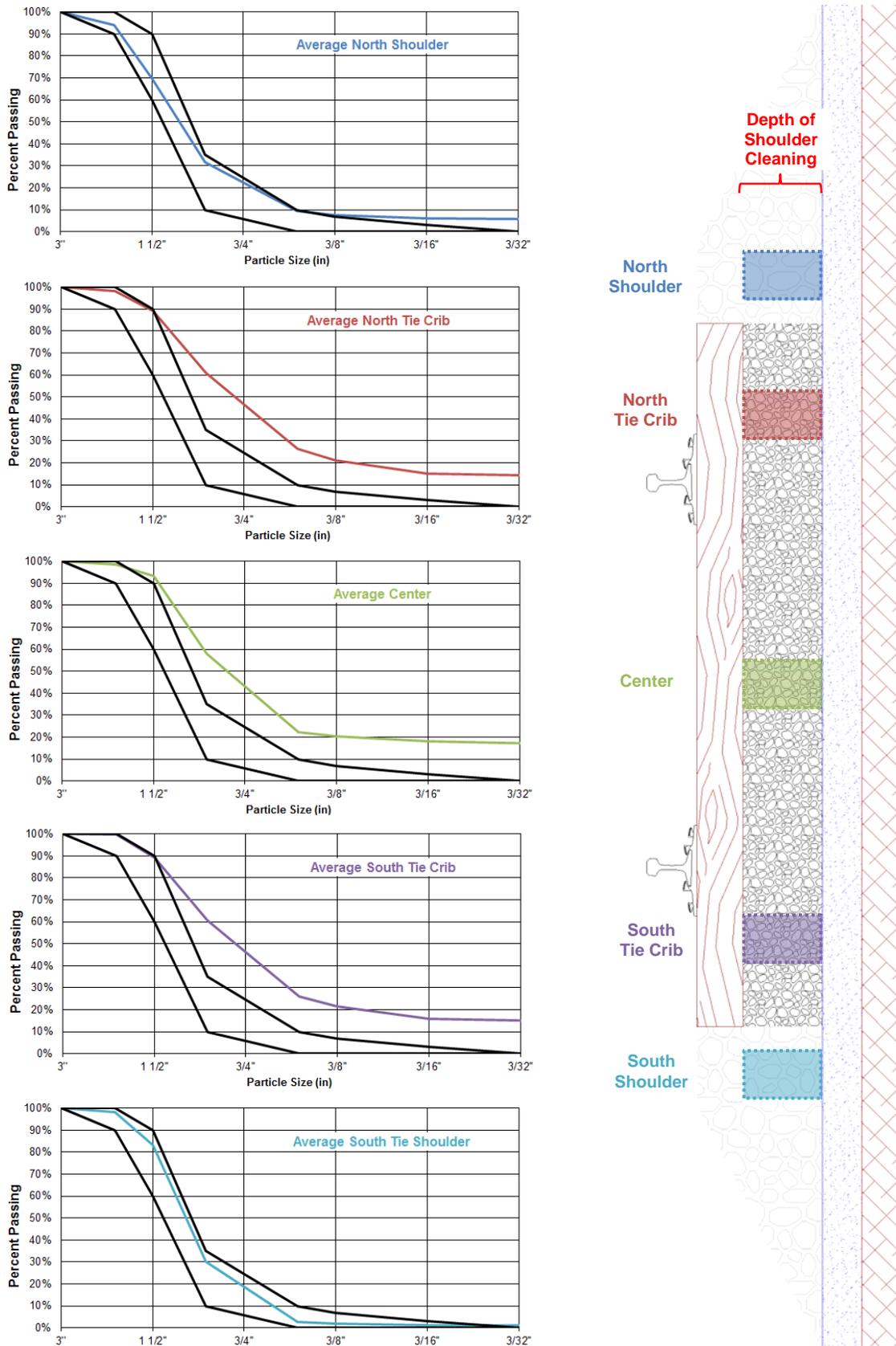


Figure 42. Sieve Analysis Results of Second Post-Shoulder Cleaning Ballast Samples

8.4 Analysis of the Third Post-Shoulder Cleaning Ballast Samples

The third set of samples after the shoulder cleaning was collected on Monday, May 13, 2013. Figures 43 and 44 show the average results of the analysis.

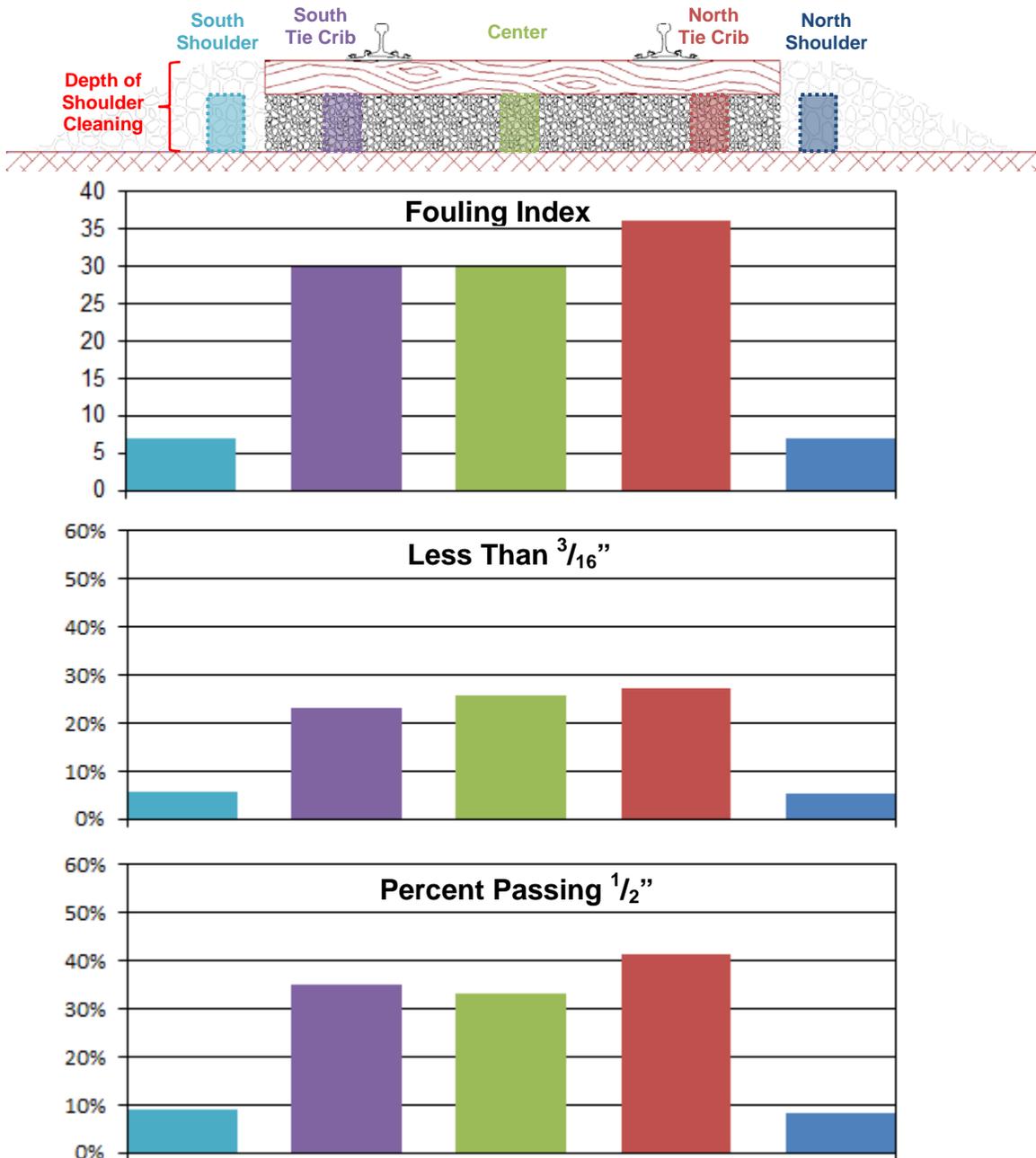


Figure 43. Sieve Analysis Indices for Third Post-Shoulder Cleaning Ballast Samples

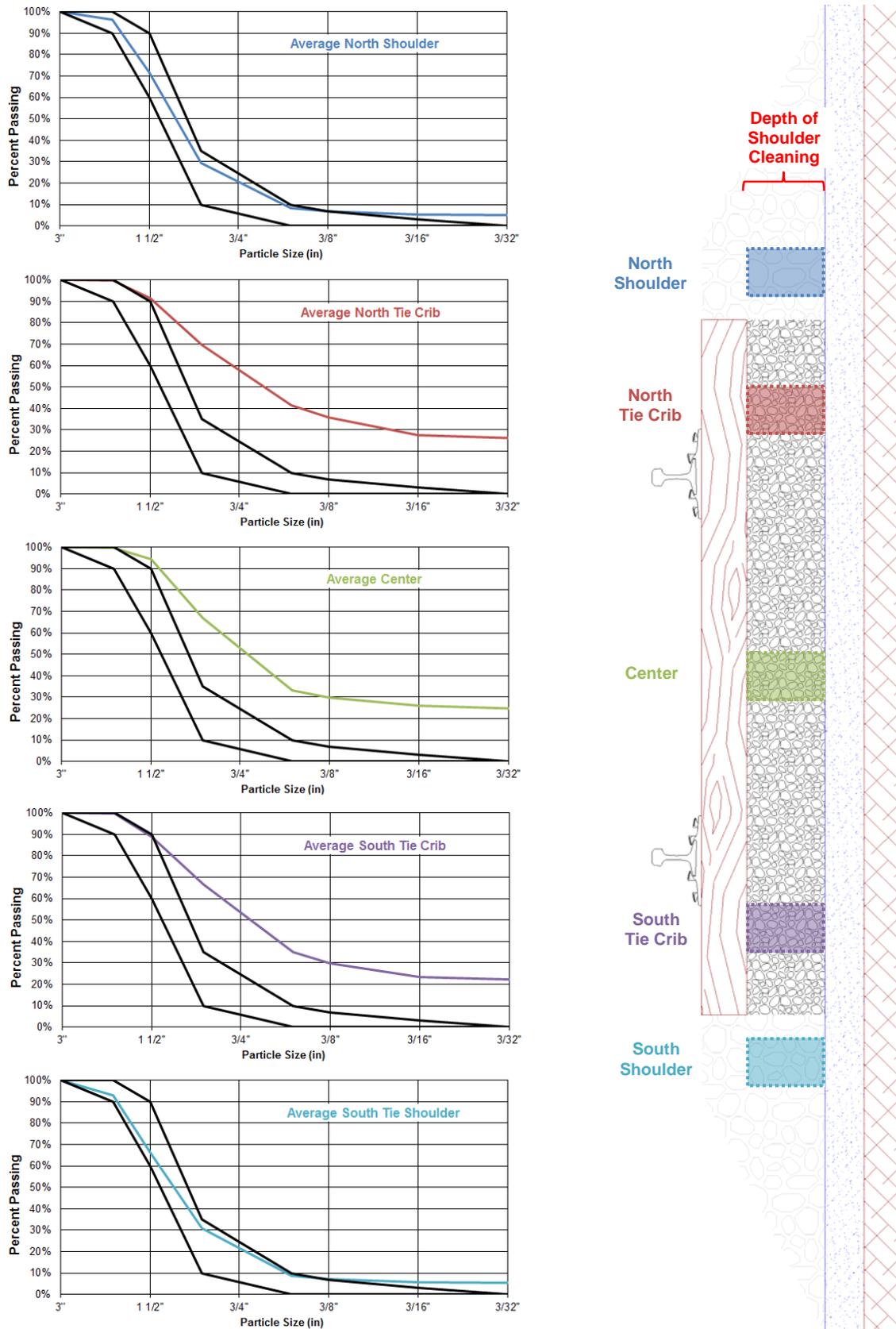


Figure 44. Sieve Analysis Results of Third Post-Shoulder Cleaning Ballast Samples

8.5 Analysis of the Fourth Post-Shoulder Cleaning Ballast Samples

The fourth set of samples after the shoulder cleaning was collected on Tuesday, December 10, 2013. Figures 45 and 46 show 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.

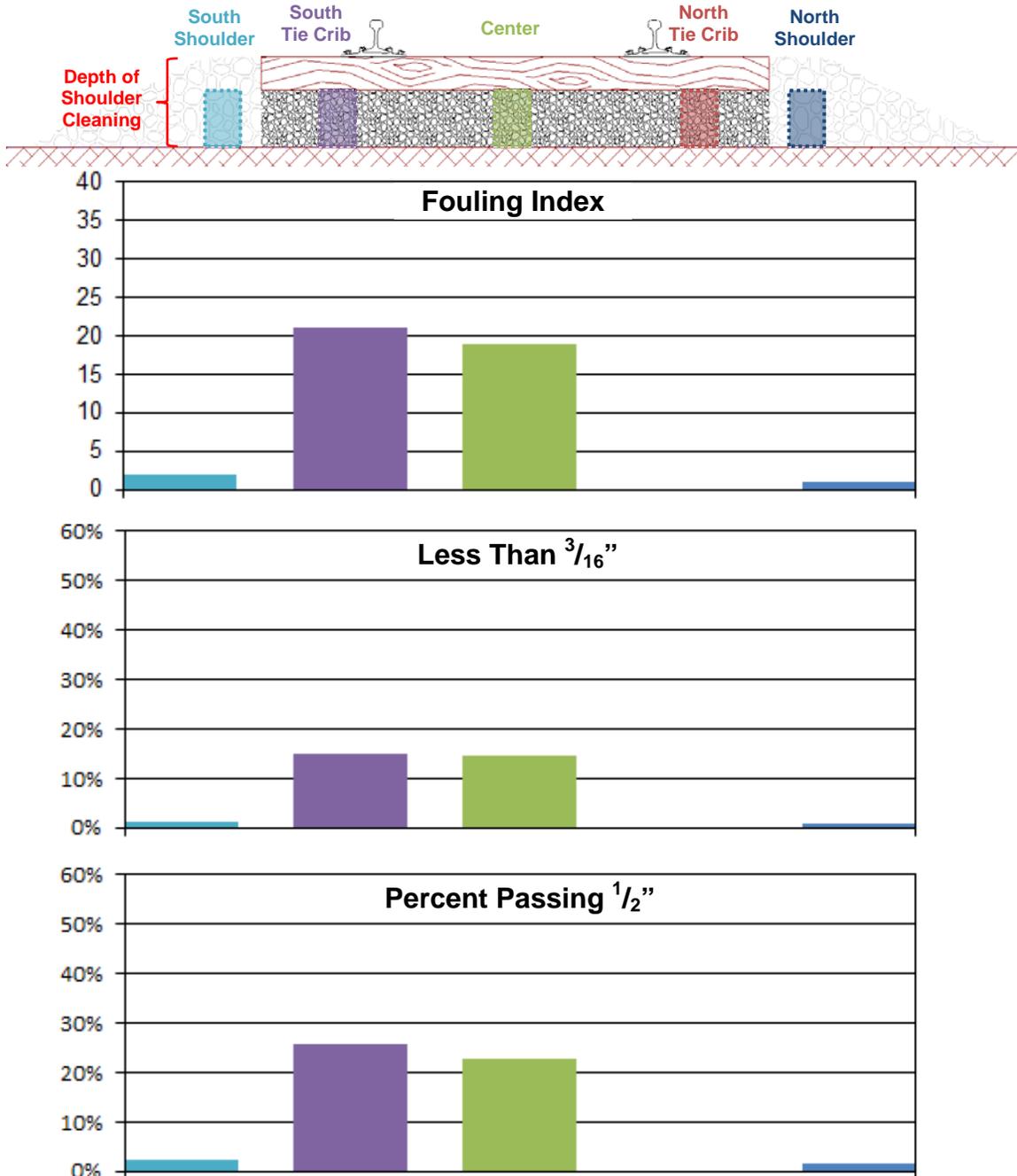


Figure 45. Sieve Analysis Indices for Fourth Post-Shoulder Cleaning Ballast Samples

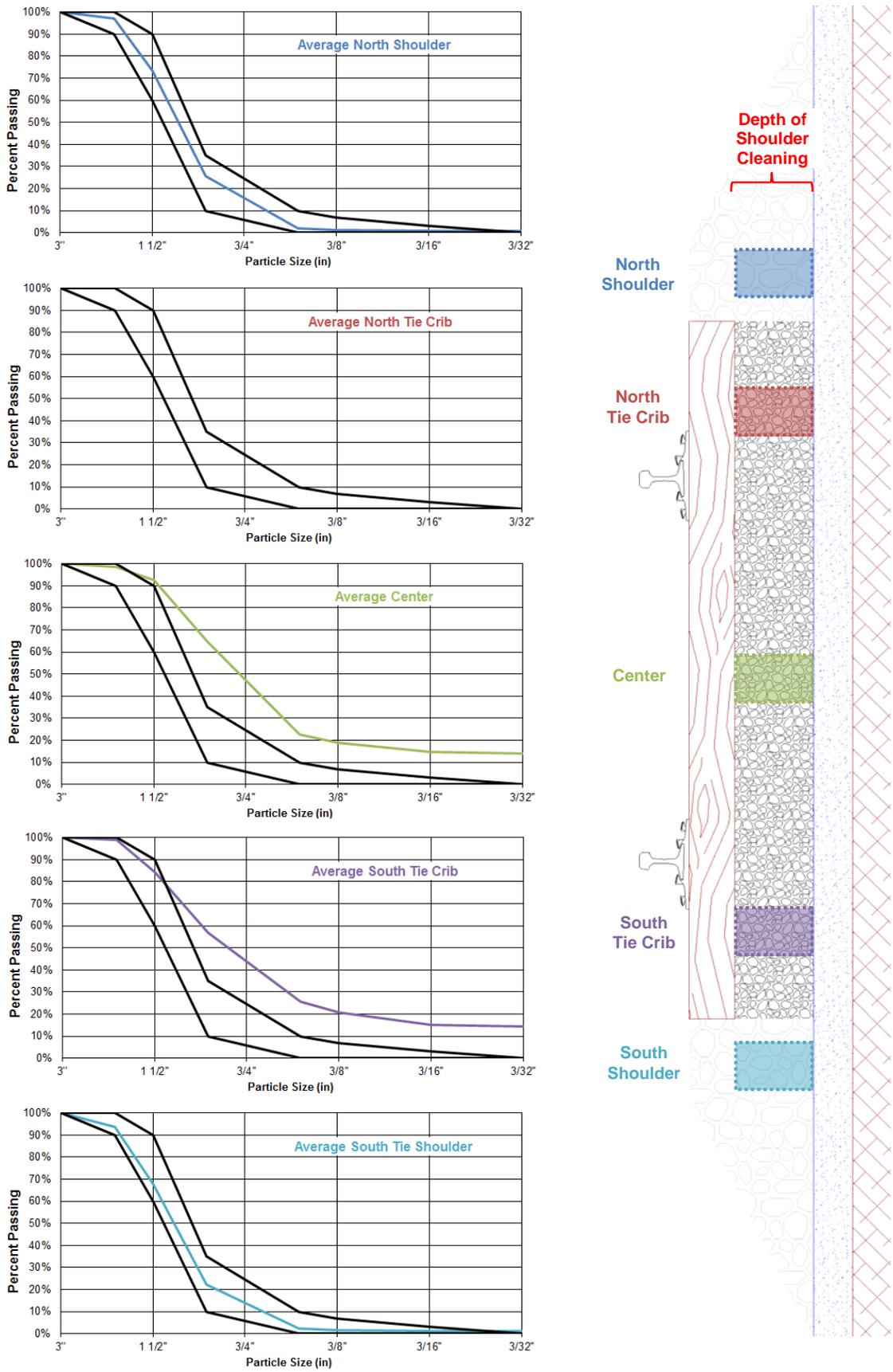


Figure 46. Sieve Analysis Results of Fourth Post-Shoulder Cleaning Ballast Samples

8.5 Analysis of the Fifth Post-Shoulder Cleaning Ballast Samples

The fifth set of samples after the shoulder cleaning was collected on Tuesday, October 21, 2014. Figures 47 and 48 show the average results of the analysis.

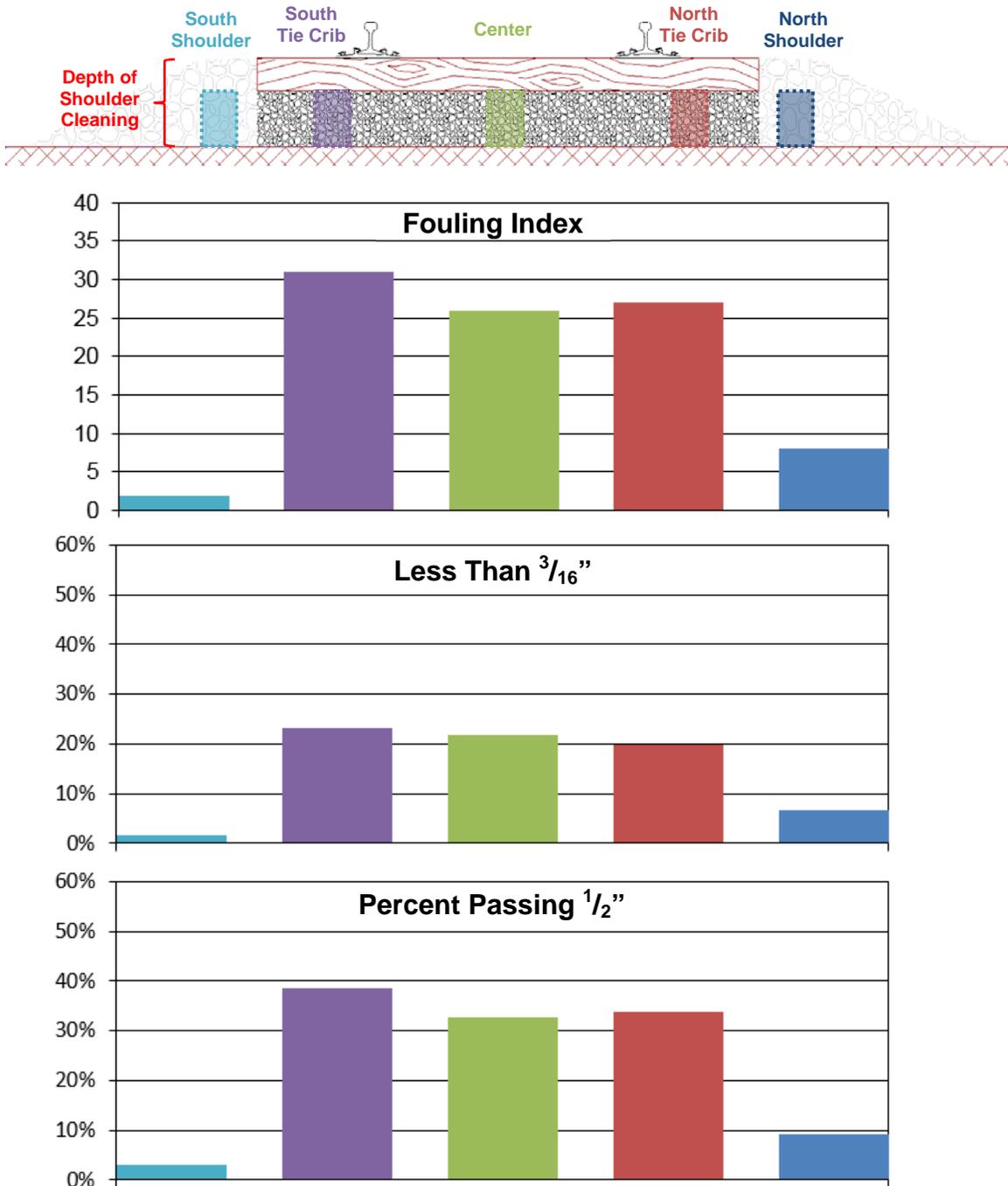


Figure 47. Sieve Analysis Indices for Fifth Post-Shoulder Cleaning Ballast Samples

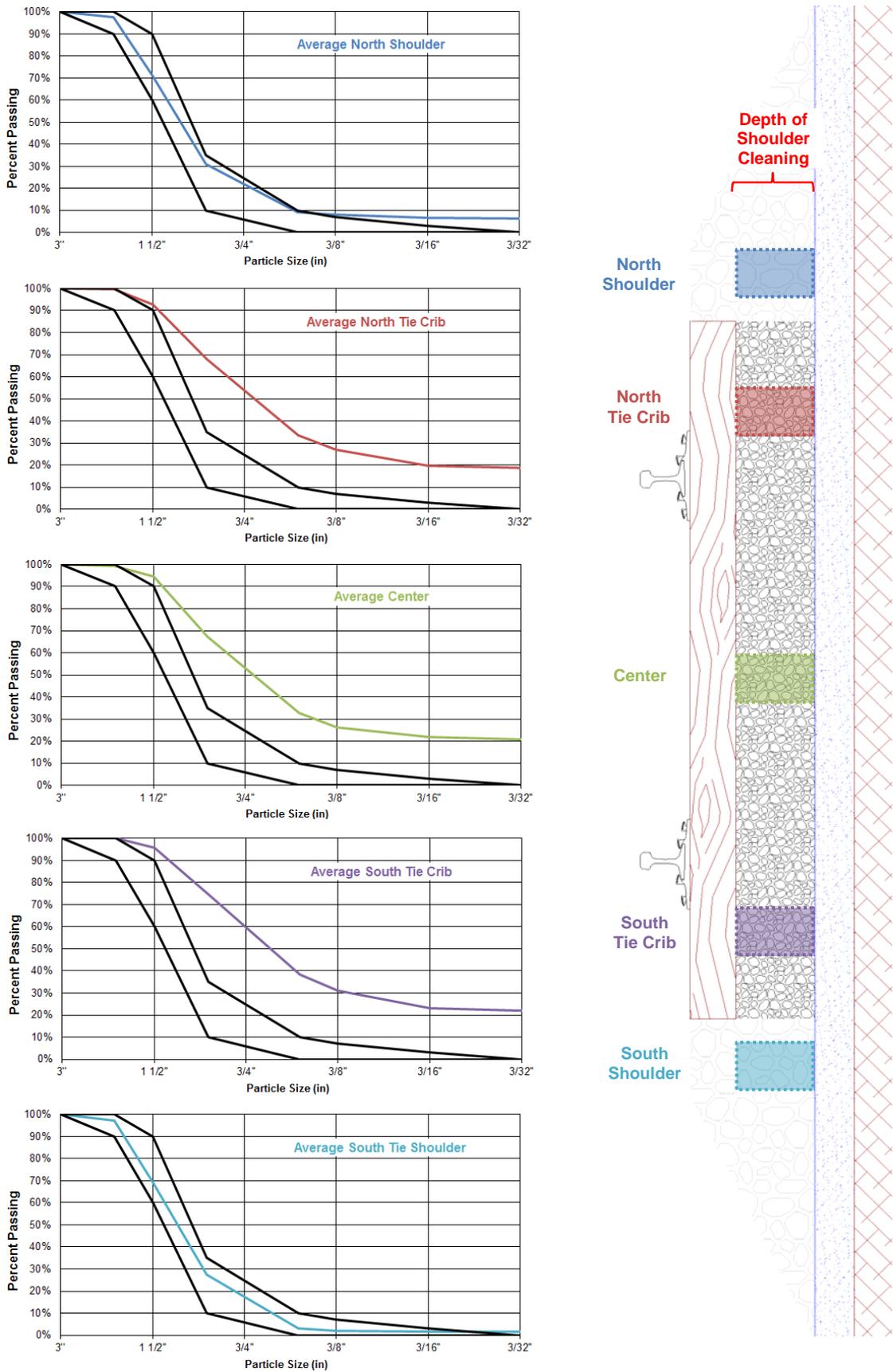


Figure 48. Sieve Analysis Results of Fifth Post-Shoulder Cleaning Ballast Samples

9.0 COMPARISON OF CENTER AND FIELD SIDE 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 49 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.

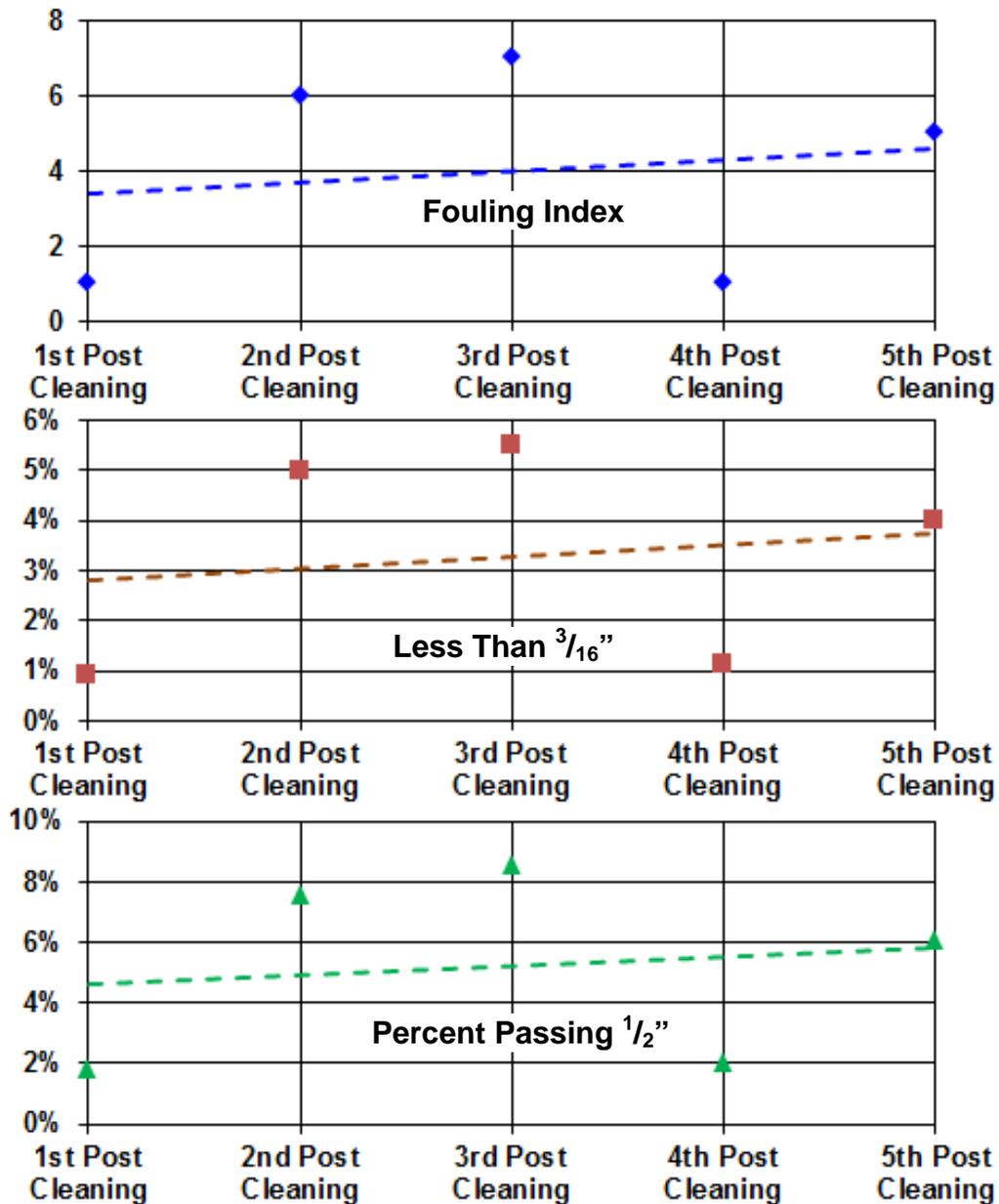


Figure 49. Combined Sieve Analysis Results for All Shoulder Samples

Figures 50 and 51 detail the combined sieve analysis results for all of the ballast shoulder samples through the life of the test. The north shoulders, located between the tracks (Figure 50) show a much higher rate of increase of fines, nearly double, than the south shoulders, located along the outside of the trackway (Figure 51). This suggests that the shoulders cleaned between the two tracks are draining both tracks, not just the track where ballast cleaning was performed.

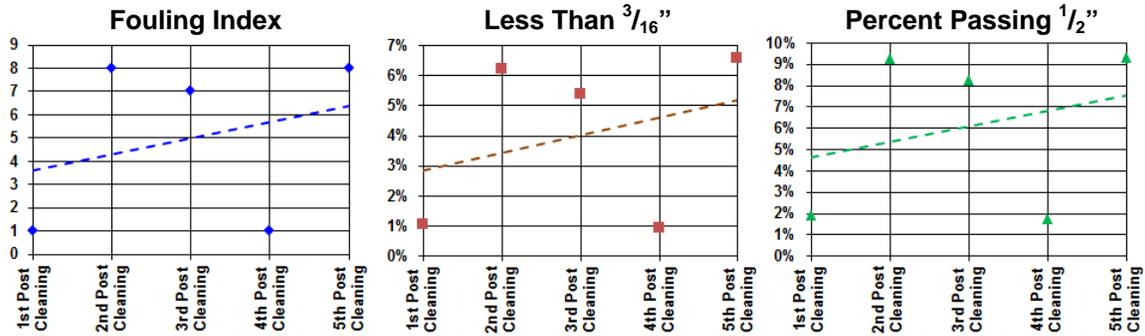


Figure 50. Combined Sieve Analysis Results North Shoulders (Between Tracks)

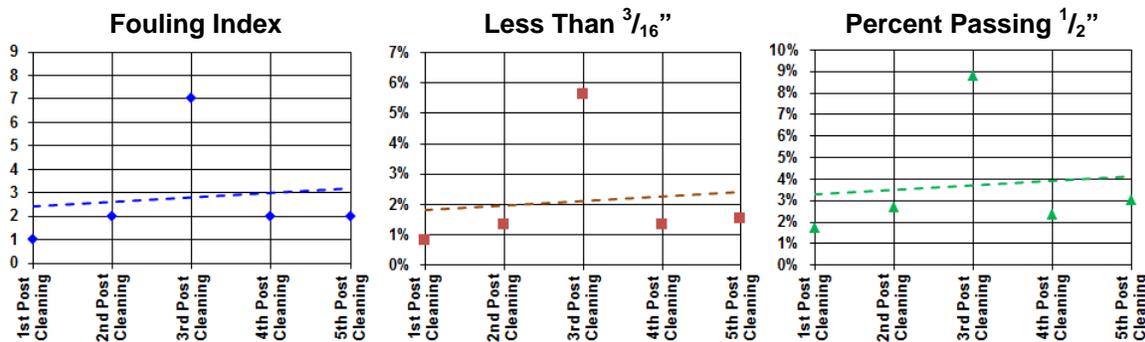


Figure 51. Combined Sieve Analysis Results South Shoulders (Outside Shoulder)

Figure 52 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 53 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 54 shows the results of the combined analysis for the tangent track sample locations, located between the two tracks. Figure 55 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.

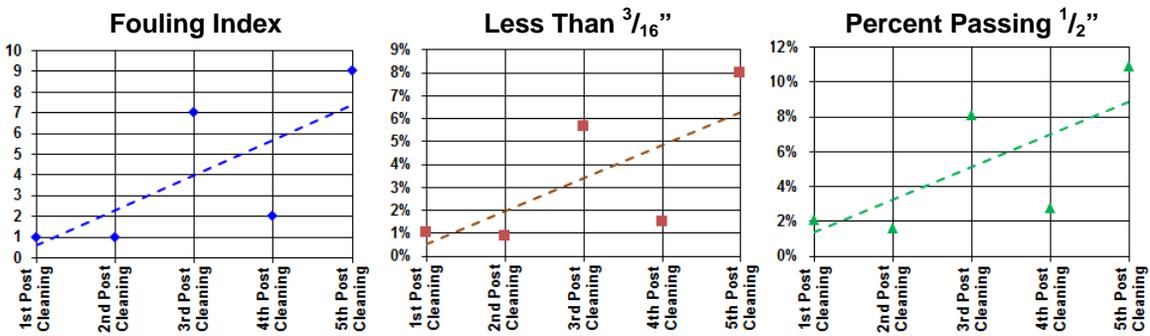


Figure 52. Combined Sieve Analysis Results Curved Track North Shoulder (Low Side Shoulder Between Tracks)

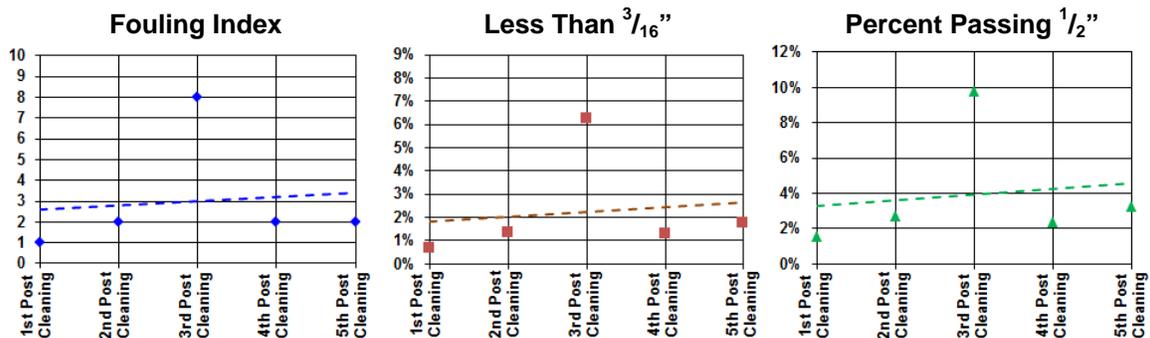


Figure 53. Combined Sieve Analysis Results Tangent Track North Shoulder (Outside High Side Shoulder)

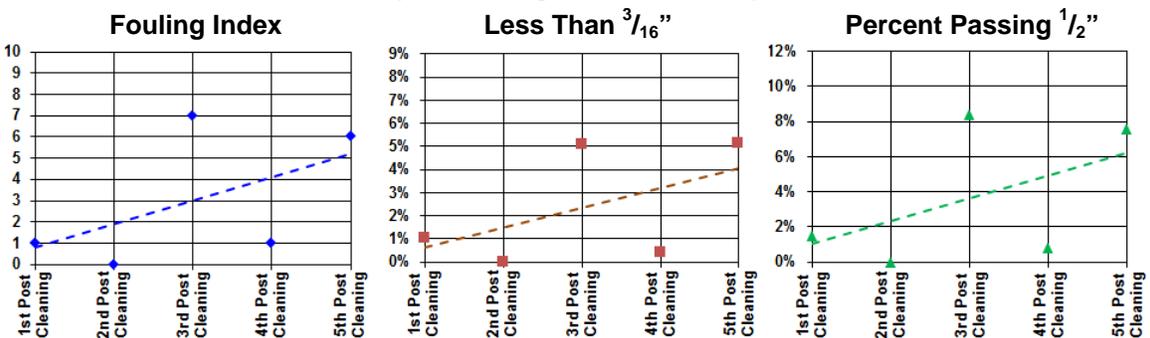


Figure 54. Combined Sieve Analysis Results Tangent Track North Shoulder (Between Tracks)

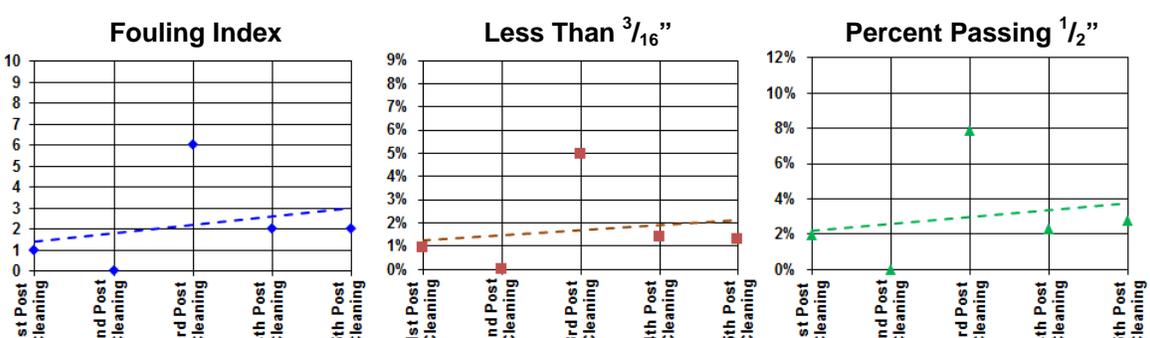


Figure 55. Combined Sieve Analysis Results Tangent Track South Shoulder (Outside Shoulder)

10.0 CONCLUSIONS

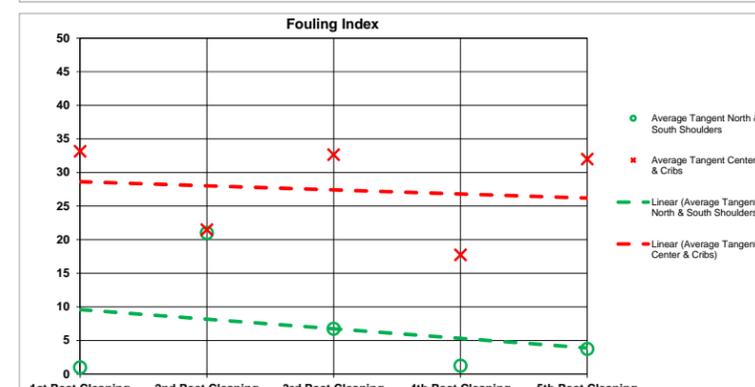
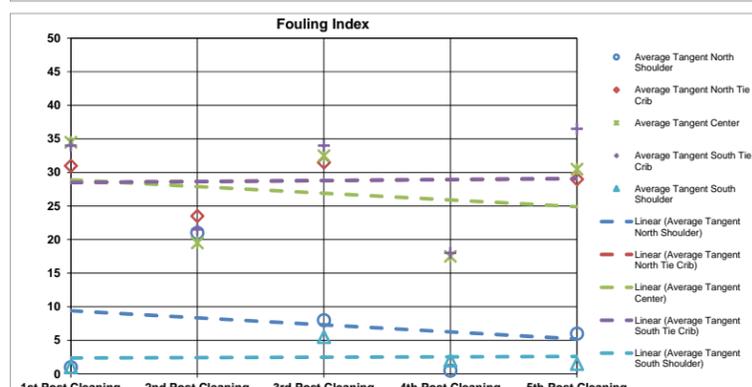
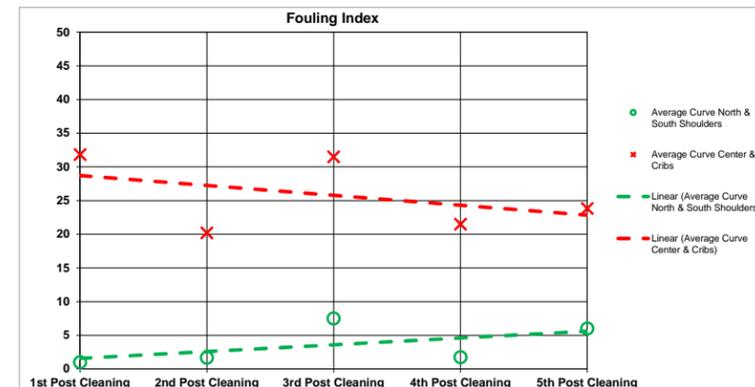
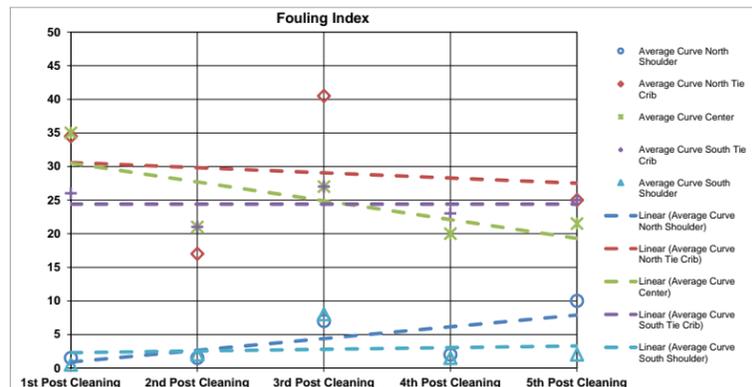
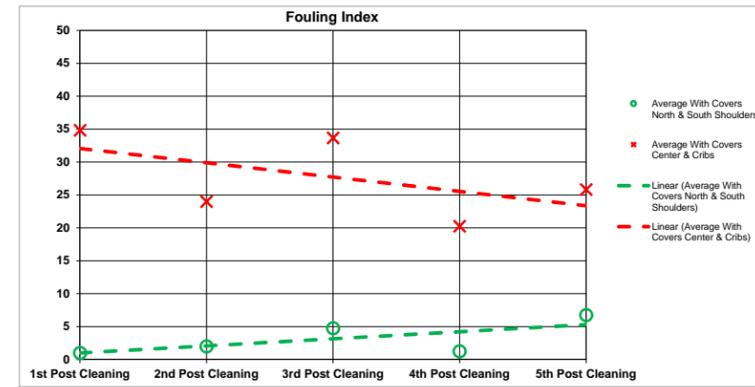
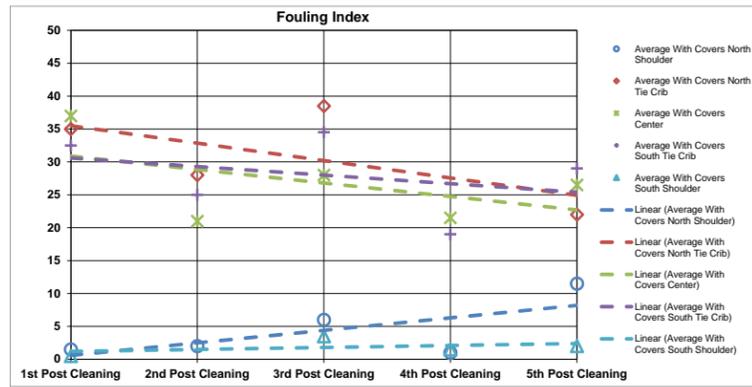
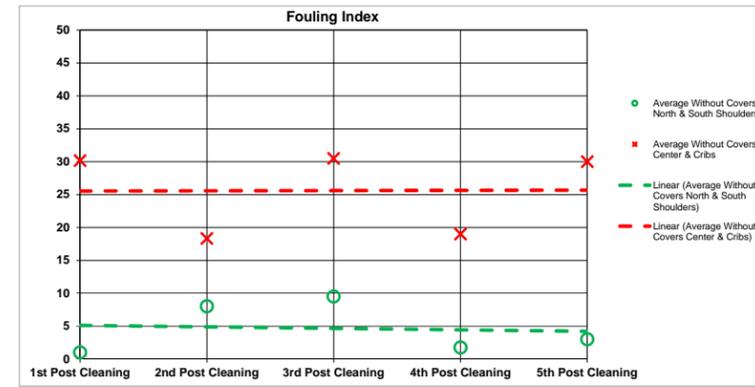
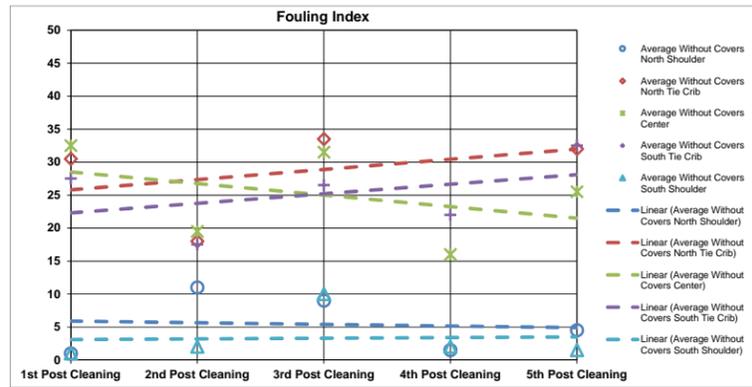
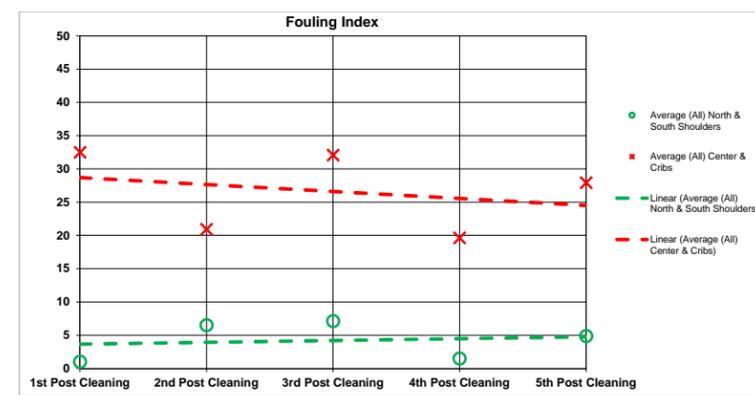
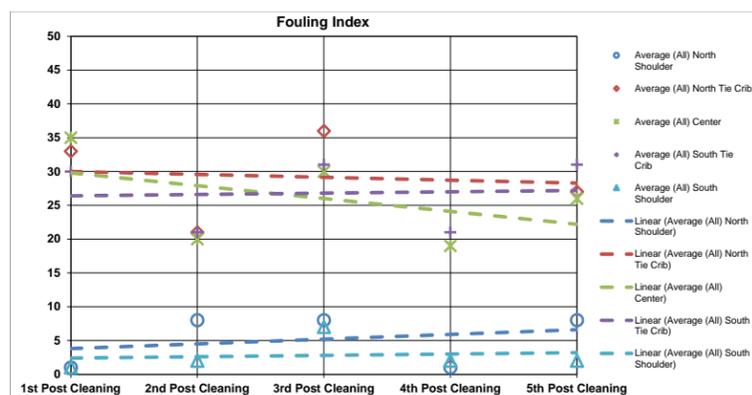
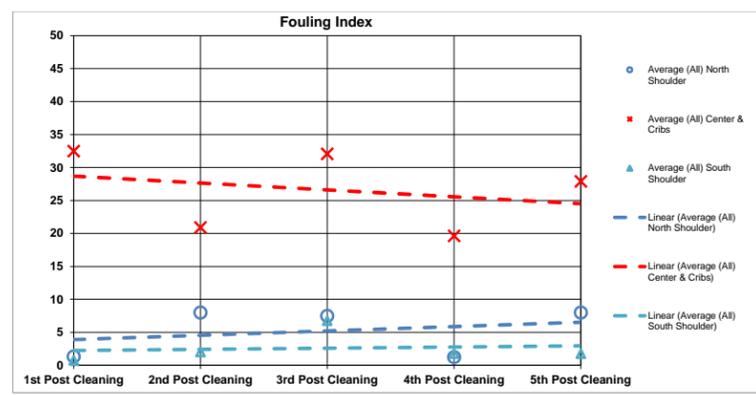
The results of the sieve analysis immediately before and after ballast shoulder cleaning shows that the ballast shoulder cleaning process was effective in removing fines and restoring the shoulder ballast.

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.

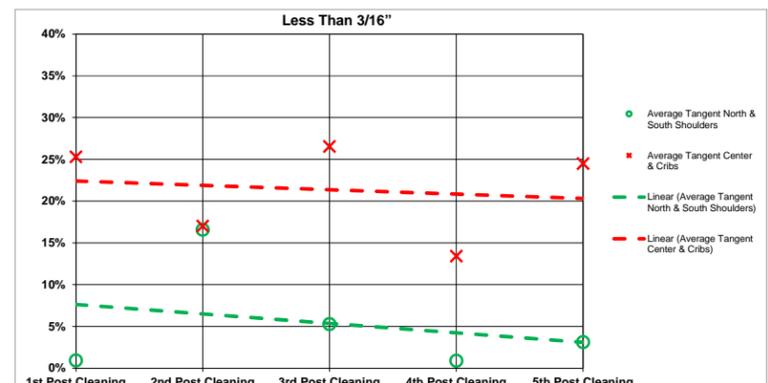
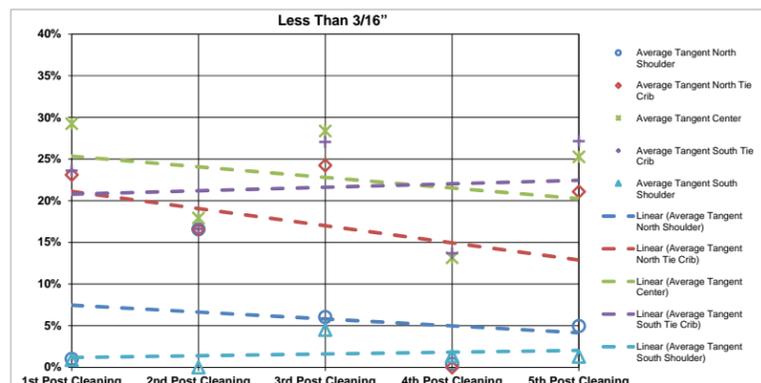
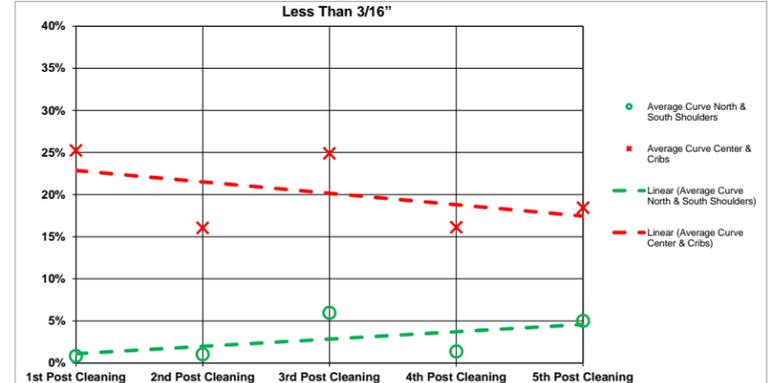
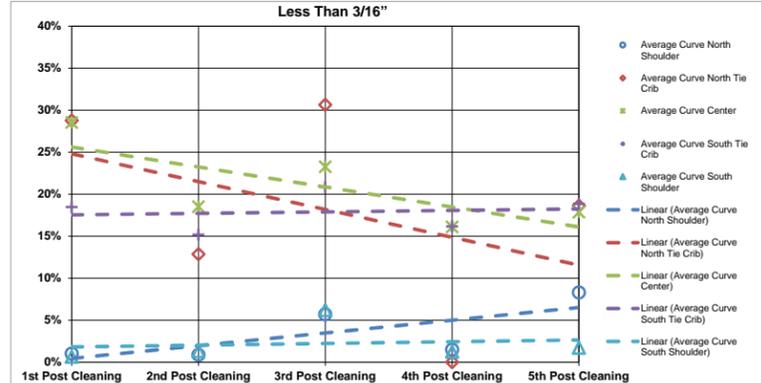
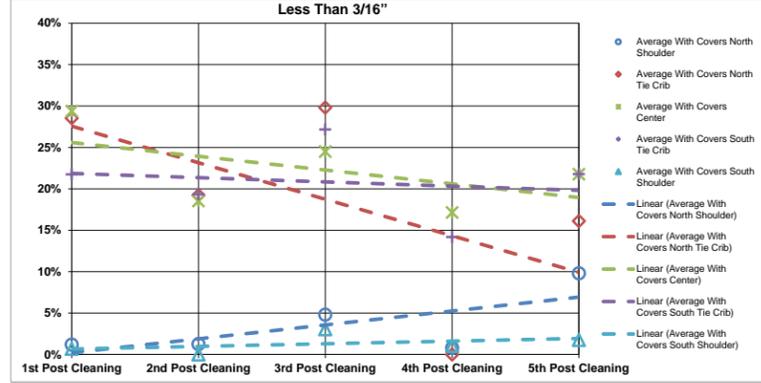
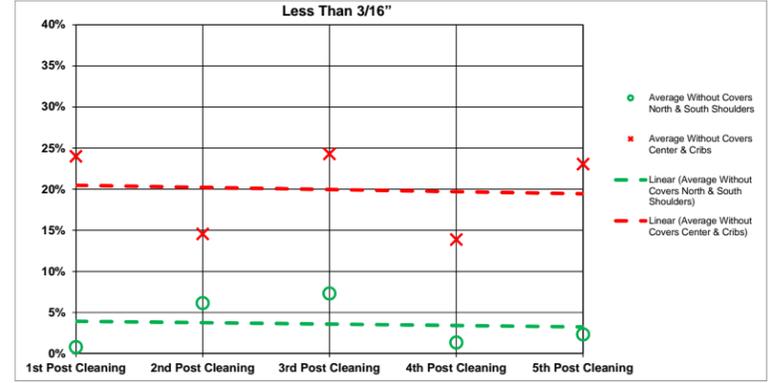
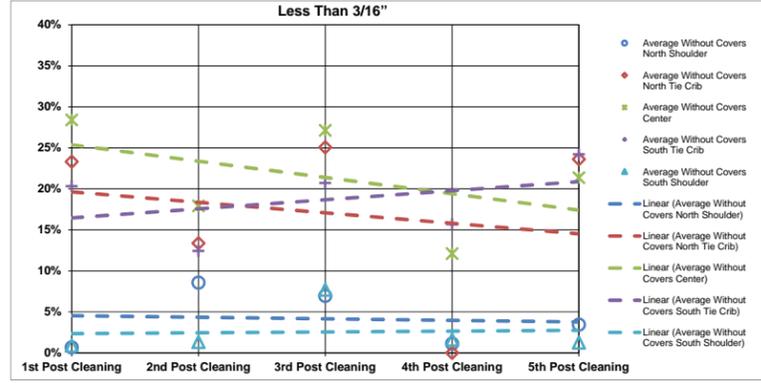
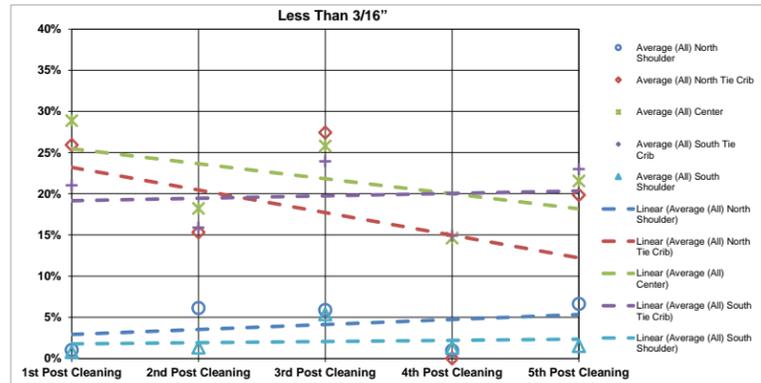
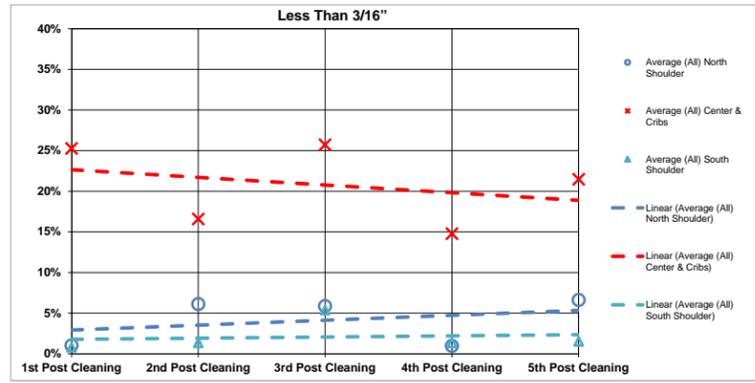
The results of the sieve analysis suggest that fines have a higher propensity to migrate towards the low side of tracks with superelevated curves, even though the shoulders on both sides of the track were cleaned.

APPENDIX A
Fouling Index Trends



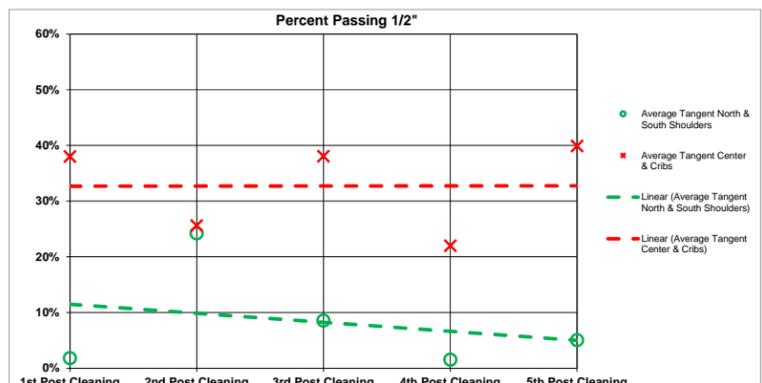
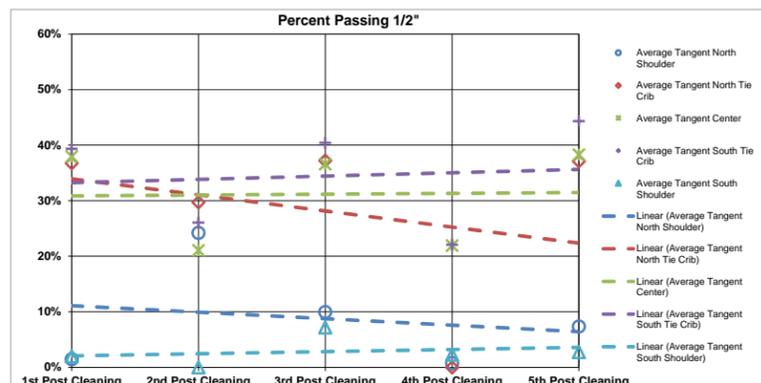
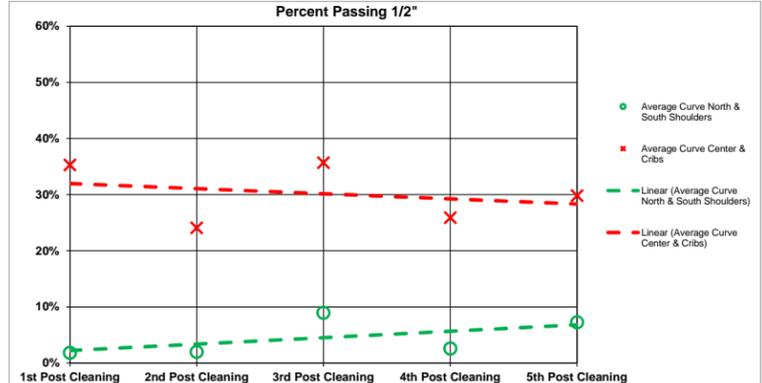
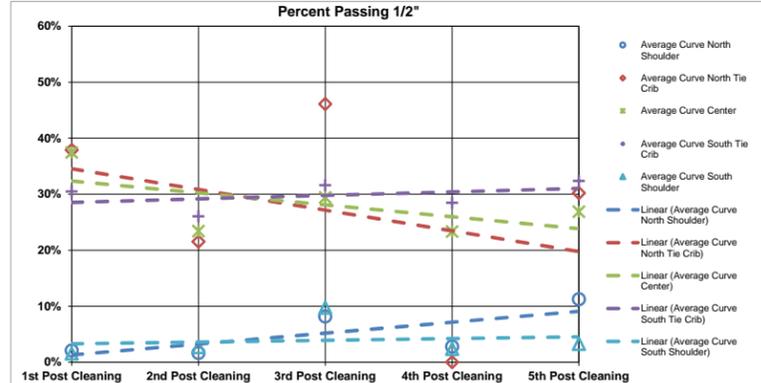
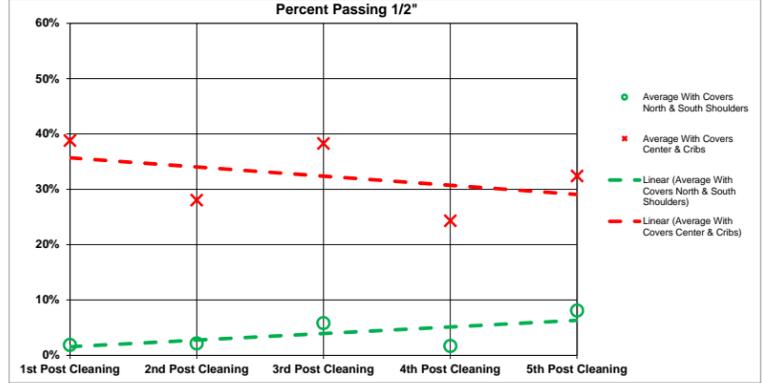
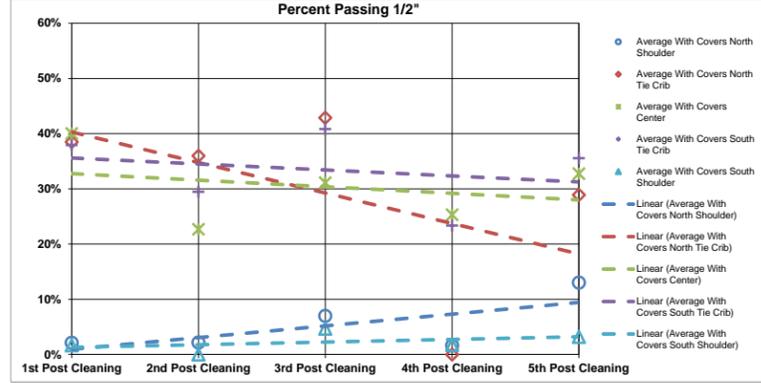
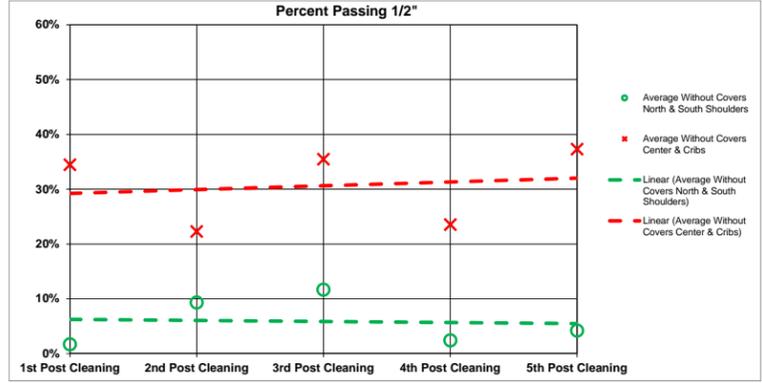
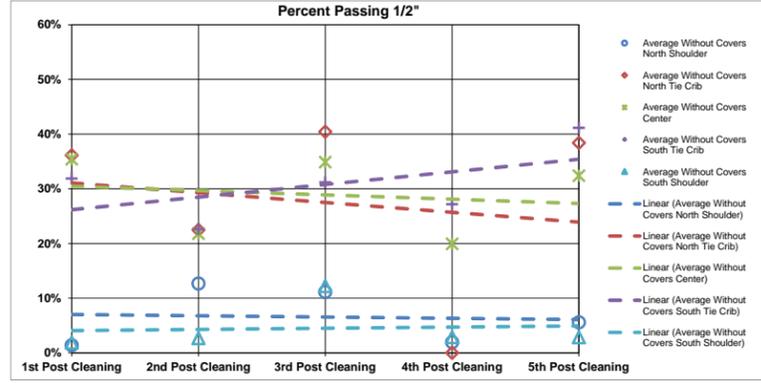
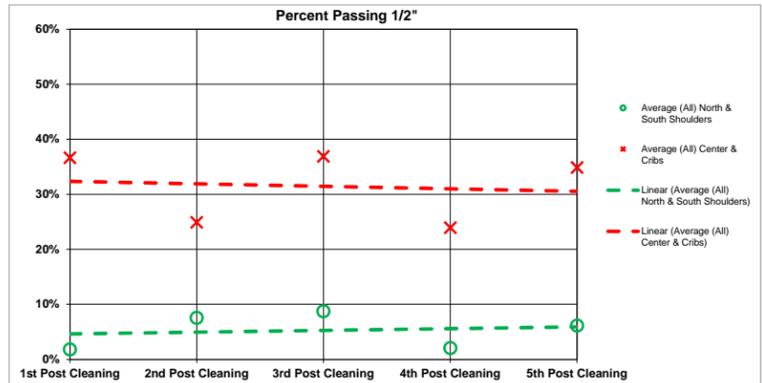
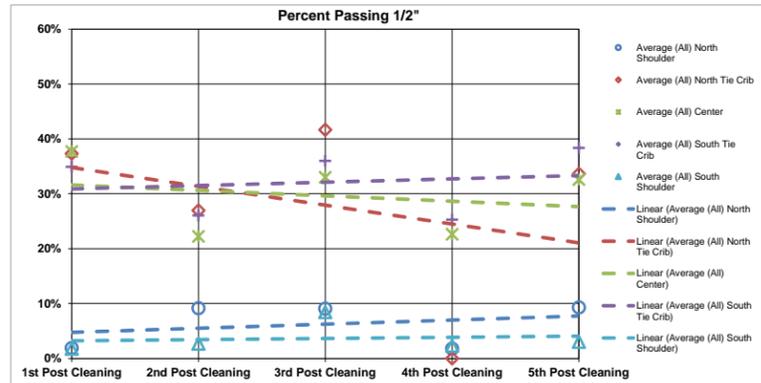
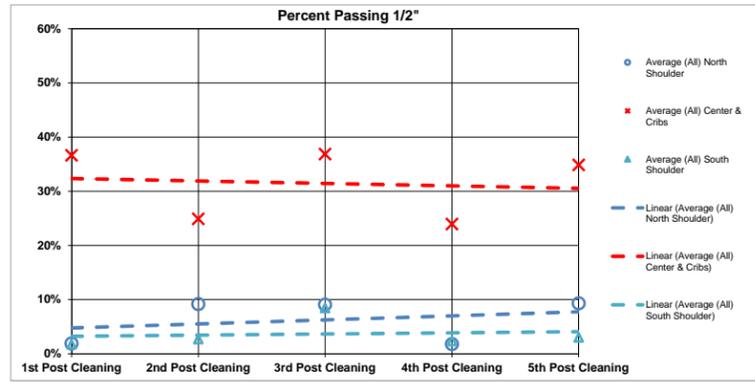
APPENDIX B

Trends of Fines Less Than 3/16 inch



APPENDIX C

Trends of Fines Passing ½-inch Sieve



TRANSPORTATION TECHNOLOGY CENTER, INC.
A SUBSIDIARY OF THE ASSOCIATION OF AMERICAN RAILROADS

P.O. Box 11130
55500 DOT Road
Pueblo, CO 81001
