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Ballast Rainy Section at FAST: Phase I Report

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[Transportation Technology Center, Inc.'s \(TTCI\)](#) ongoing research into mud pumping and fine-contaminated ballast has investigated how moisture affects the performance of fine-contaminated ballast with the goal of improving the detection of problematic locations and maintenance recommendations. TTCI has completed Phase I testing that quantified how moisture can increase settlement and reduce track modulus and drainage capabilities of the ballast section. In cases that the water source is from rainfall, the testing has identified several inches around the tie as the problematic region, which will be the focus of maintenance activities in the subsequent Phase II testing.

Fine-contaminated ballast is a general term for ballast that has been contaminated by fine particles and is a common ballast problem faced by all railroads. Especially when wet, fine-contaminated ballast can increase track geometry degradation, requiring increased maintenance. Improved identification of problematic or future fine-contaminated ballast locations can improve maintenance planning efficiency and reduce the need for reactive maintenance.

Multiple factors affect the performance of fine-contaminated ballast, including fine level, fine type, and fine distribution, moisture level, moisture source, and moisture distribution in the track section, along with many other variables.^{1,2} Fine levels above 20 percent are generally considered a problem and the majority of ballast voids are filled with fine particles at about 40 percent fines by mass. The type of fines present in the ballast will be dependent on location but is primarily from ballast degradation, but may also result from surface infiltration or pump up from the subgrade when sub-surface water is present. Smaller and more plastic fine particles are considered a greater problem than ballast degradation fine particles, but is not the focus of this *Technology Digest* (TD).

To investigate the influence of these variables, TTCI developed a test section at the Facility for Accelerated Service Testing (FAST) in 2017 and this TD summarizes the previous two years of work (Phase I), explains the mechanism of mud pumping, and discusses how the findings from Phase I testing will guide the future testing at the Rainy Section.

BALLAST RAINY SECTION

The Rainy Section is a 20-foot long section of track in Section 36 of FAST that contains upwards of 40 percent fines from natural ballast degradation and has an irrigation and drainage system that allows the replication of rainfall and control of drainage in the track. This mimics a severe fine-contaminated ballast condition in which the

Key Findings:

- High moisture levels can negatively affect performance of fine-contaminated ballast by: increasing settlement rate, decreasing track modulus, and increasing drainage time. This reduced-performance is typically, but not always, associated with mud pumping.
- Specific ballast performance will be dependent on many factors such as fine level, fine type, moisture level, moisture source, and fine distribution.
- Mud pumping requires three main factors: 1) fine-contaminated ballast, 2) water source, and 3) tie pumping under train operation.
- When rainfall is the water source, the primary problematic region is several inches around the tie and the location of the low-permeable mud slurry that forms during mud pumping.
- Based on Phase I results, maintenance of mud pumping locations should focus on draining excess water under the tie and removing the slurry that inhibits shoulder and top ballast layer drainage. Future studies will quantify the benefits or lack of benefits of various ballast maintenance activities.

majority of ballast voids are filled by ballast degradation material and the fines are evenly distributed amongst the ballast section. The irrigation system replicates rainfall as the water source on the ballast. As a note, different fine level, fine type, moisture source, and fine distribution may significantly affect results. Additional details of the Rainy Section setup can be found in previous publications.²⁻⁴

PHASE I TESTING

The first phase of testing at the Rainy Section primarily involves characterizing how moisture affects track performance and the mechanism leading to surface mud pumping. Previous TDs go over the results in detail,²⁻⁴ but a high-level overview is presented in this TD.

To determine performance, multiple measurements were taken. Unloaded top-of-rail (TOR) elevations were collected after each night of FAST operations (~2 MGT) to determine the elevation profile and unloaded settlement rates. Additional measurements were performed to determine track modulus at various stages of testing. Moisture sensors also were installed at various locations in the Rainy Section to monitor moisture levels. This quantified track settlement, stiffness, and drainage.

Multiple tests were conducted on the Rainy Section during Phase I but they can be simplified into three main conditions: dry and no mud pumping, wet and mud pumped, and dry and mud pumped. After surfacing, the fines were typically evenly distributed in the ballast section. During wetting (10 mm/hr. of rain for one hour, for example) and train passage, the fines underneath the ties became saturated and had a slurry-like consistency. As train passage continues, the tie pressure would pump the mud slurry up around the ties and onto the surface. This condition is commonly referred to as mud pumping. After being allowed to dry, the mud

slurry remained at the surface but had dried out representing the dry and mud pumped condition.

Figure 1 shows how each of these conditions, along with the clean ballast condition as a baseline, affects track performance at the Rainy Section. The results are presented conceptually (higher bars represent higher severity of negative performance) because of the variation between tests and dependence on specific measurements. However, this should give a general idea on the effect of moisture and fine distribution on performance. The results also may vary for different situations. The Rainy Section results show:

- **Clean ballast:** This baseline condition typically shows small track settlement, track modulus value of about 4,200 lbs./in./in., and excess water can drain within minutes.
- **Dry fine-contaminated ballast:** This condition showed no visual signs of fines on the surface, had similar settlement rates to clean ballast when dry, a slightly lower track modulus (3,500 lbs./in./in.), and inhibited drainage that took about one day to drain out excess water.
- **Dry mud pumped ballast:** This condition had visual signs of mud at the surface, similar settlement rates as the dry fine-contaminated ballast condition, a lower track modulus (3,000 lbs./in./in.), and greater inhibited drainage that took about five days to drain out excess water.
- **Wet mud pumped ballast:** This condition had standing water and visual signs of mud at the surface, settlement rate much greater than the other conditions (~3x greater), a low track modulus (1,500 lbs./in./in.), and inhibited drainage that took about five days to drain out excess water.

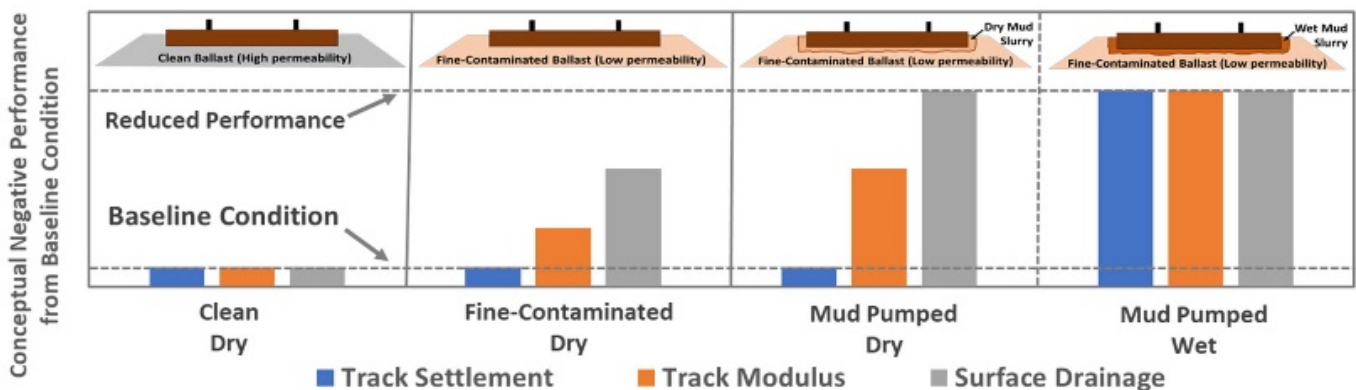


Figure 1. Conceptual performance of four ballast conditions (higher bars indicating poorer performance)

MUD PUMPING MECHANISM

The overall objective of the fine-contaminated ballast research is to improve identification of potential problem regions and quantify the benefits of various maintenance and remediation action. In order to get to that stage, a thorough understanding of mud pumping and its causes is needed.

Rainy Section-specific

The observed process for mud pumping at the Rainy Section (see Figure 2) is as follows and shown in Figure 3. From the (a) dry initial condition, (b) rainfall (blue color) begins to wet the surface and upper ballast layer and ponds underneath the ties. After the rainfall has increased the moisture levels underneath the ties to a high enough level and train passage causes the ties to pump up and down, (c) the fines and water form a mud slurry that is very soft and mobile (rust color). Excess water is anticipated to pond underneath the tie as well. Continual train passage causes the tie to pump which pushes the mud slurry outward away from the tie, while sucking surrounding fines to the voids generated. This likely causes the slurry to move downward and outward, but the easiest escape path is upward around the tie. Eventually, the slurry coats the tie and surface (d). The final cross-section is shown in Figure 4.

Multiple tests were run to determine the depth of the wet region (slurry). This involved moisture sensors, trenches, and geoscopes (devices that can view downward into the ballast). All three methods agreed that the wet region in the Rainy Section is the top several inches below the bottom of the tie. This suggests that the problem is primarily surficial and does not extend deep into the ballast section.



Figure 2. Photograph of mud pumping with standing water

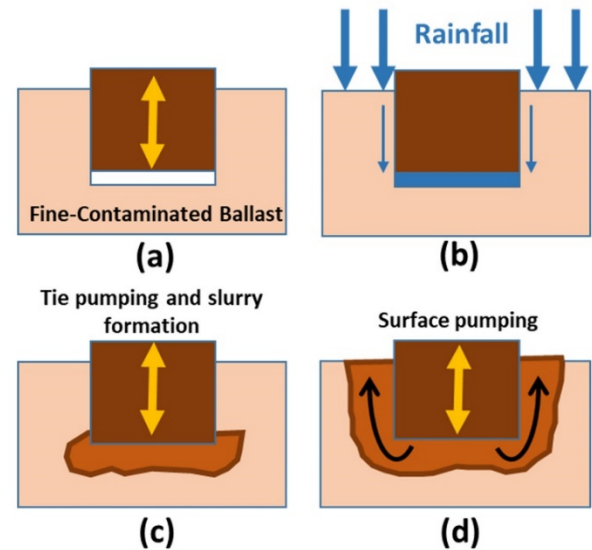


Figure 3. Step-by-Step of mud pumping in Rainy Section (blue=rain, light brown=fine contaminated ballast, rust=slurry, brown=tie, yellow= tie pumping due to train operation)

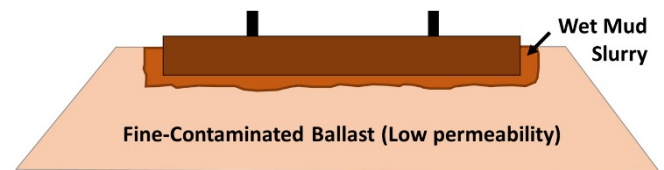


Figure 4. Cross-section of Rainy Section with surficial mud pumping

GENERAL

The Rainy Section only represents a single scenario but the main ballast degradation condition and mud pumping can occur in other ballast and subgrade situations as well.

The three requirements for mud pumping are observed as the following: 1) fine-contaminated ballast, 2) water source, and 3) tie pumping. These are expanded below:

- **Fine-contaminated ballast:** Fines are an obvious precursor for mud pumping but the influence of fine level and fine type is significant. There should be a fine level threshold that is needed for the slurry to form and different fine types will likely affect how the slurry acts.
- **Water Source:** The source of water plays a significant role in mud pumping. At the Rainy Section, the water source comes from rainfall that accumulates at the surface because the low permeability of the ballast inhibits drainage. However, there have been other documented cases in which the water source is from a high water table (subsurface water), often from blocked drainage ditches. This likely causes fines from the lower ballast section to pump upward toward the surface. This

suggests a deeper ballast layer problem and would require different remedial solutions.

- **Tie Pumping:** The tie moving up and down from train passage will not only help produce the slurry, but also push it upwards around the ties to the surface. This indicates that the severity of mud pumping could be dependent on the amount of tie pumping.

DISCUSSION AND FUTURE WORK

The main new finding from Phase I testing is that when ballast degradation is the fine type and rainfall is the water source, the moisture and slurry formation is a surficial problem. TTCI has reviewed other similar mud pumping locations that developed at FAST and previous revenue service investigations⁵ and the observations agreed with the Rainy Section behavior. However, more investigations would be needed before any broad generalizations can be made.

This has implications on maintenance and remediation because the results suggest maintenance should focus on ensuring the upper ballast layer is drained (see Figure 5).

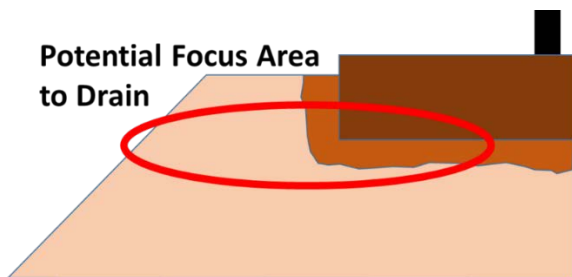


Figure 5. Focus of Future Maintenance Studies

Phase II of the Rainy Section is planning on testing the effectiveness of potential methods by comparing settlement rates, drainage times, and visual observations. Initial options for testing are listed below:

- **Crib trenching:** This maintenance method would be simplest and just requires localized work to remove the fines in the shoulder of the cribs of the muddy section. This will allow the drainage of any existing excess water and would hopefully allow additional drainage until it likely gets clogged by new slurry formation.
- **Shoulder cleaning:** This will involve removing all the shoulder fine material and replacing with clean ballast.

- **Track lift:** This maintenance method would lift the track one or two inches and could provide separating between the fines and bottom of tie.
- **Undercutting:** This will involve removing all the fine material 6 to 8 inches below the bottom of the tie and replacing with clean material.

Revenue service investigations also will be important to verify that Rainy Section results are applicable to most revenue service conditions. These investigations also should allow the categorization of different mud pumping situations so these various situations can be identified and appropriate maintenance methods that address the root cause of the problem can be applied. Additionally, this work will help to enhance detection methods, ground penetrating radar to better focus on important variables that correlate to track geometry degradation.

References

1. Li, D., Hyslip, J., Sussmann, T., and Chrismer, S. "Railway Geotechnics." CRC Press. Boca Raton, FL. 2016.
2. Wilk, S., Basye, C., and Gao, Y. "Influence of Rain Events on Fine-Contaminated Ballast." TD-19-015. AAR/TTCI Pueblo, Colorado. August 2019.
3. Wilk, S., Basye, C., and Gao, Y. "Settlement of Fine-Contaminated Ballast." TD-18-011. AAR/TTCI Pueblo, Colorado. May 2018.
4. Basye, C., Gao, Y., and Wilk S., "Drainage Properties of Fine-Contaminated Ballast." AAR/TTCI Pueblo, Colorado. May 2018.
5. Read, D., Hyslip, J., McDaniel, R., and Li, D. "Revenue Service Track Substructure Investigation." AAR/TTCI Pueblo, CO. March 2010.

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