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Drainage Properties of Fine-Contaminated Ballast

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Summary

In 2017, Transportation Technology Center, Inc. (TTCI) performed initial tests on a "Rainy Section" in the High Tonnage Loop at the Facility for Accelerated Service Testing (FAST) to measure drainage, settlement, and dynamic behavior of a fine-contaminated ballast section. This test section allows TTCI to control the wetting and drainage of the section and simulate various rain events.

The first iteration of the testing involved the use of sand-sized and non-plastic silt-sized fines from granite ballast degradation to represent fine-contaminated ballast that would occur progressively during dynamic ballast degradation and not from surface or subgrade infiltration. This test section at FAST has 37.2 percent fine content (grain size below No. 4 sieve, 4.76 mm), with the fines filling a significant percentage of the available ballast voids.

Multiple tests were conducted to measure the drainage rate in the Rainy Section after wetting, and the following observations were made:

- For the degraded ballast and unimpeded drainage, the section took approximately 20 hours to drain to pre-wetting conditions. This drainage time depends on the amount of fine-material, type of fine-material, and the drainage routes of the ballast section. Smaller grain sizes, e.g., clays, will generally result in longer drainage time, whereas larger grain sizes, e.g., sands, will generally result in shorter drainage time.
- Mud pumping occurred after 0.5 million gross tons (MGT) when the drainage was blocked and a 6-inch water table developed, resulting in the accumulation of fines in a mud slurry near the surface.

Future drainage tests will involve sampling the ballast at various depths after mud pumping to determine if fine segregation is occurring and determining the benefits of remediation techniques. Also, different fine materials, such as sand, clay, or coal fines will be used in future testing iterations.

This *Technology Digest* is the first in a series of an ongoing study investigating the dynamic behavior of various fine-contaminated ballast when exposed to moisture. The study includes drainage, settlement, and dynamic behavior of different types of fine-contaminated ballast and the benefits of various remediation. The project was conducted by TTCI under the AAR Strategic Research Initiatives Program, with joint funding from the Federal Railroad Administration.

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INTRODUCTION

Fine-contaminated ballast is a condition in which the ballast layer becomes contaminated with fines from various sources.[1] This condition, especially when wetted, can reduce the ballast performance by limiting drainage, decreasing track stiffness, and increasing track settlement. These track conditions often become a reoccurring maintenance challenge. One issue with predicting the behavior of fine-contaminated ballast is it is often dependent on multiple nonlinear metrics, such as the degree of fines contamination, fine material size and plasticity, and moisture.

To investigate this issue, TTCI created a "Rainy Section" in Section 36 of FAST to better understand how track behavior is related to fine material and moisture along with better understanding the underlying mechanisms producing accelerated rates of settlement in fine-contaminated ballast. The overall goals of this project are (1) to create a database to help forecast ballast performance using results from the Rainy Section and laboratory tests and (2) improve or develop techniques to mitigate the track settlement in regions of fine-contaminated ballast.

This *Technology Digest* focuses on drainage of the Rainy Section when contaminated with silt-sized fine particles from ballast degradation and the change in drainage behavior after mud pumping.

RAINY SECTION

The Rainy Section is a 40-foot-long portion in Section 36 of FAST that has two test sites: a 13-tie (20 foot-long) test site (Site 1) and a 13-tie control site (Site 2). Both sites are lined with waterproof and electrically nonconductive material to a depth of 18 inches below the bottom of the tie and is filled with degraded, fine-contaminated ballast. Site 1 can be wetted with a watering system while Site 2 remains under in-situ moisture conditions. This allows for a direct comparison of track behavior of a wetted and non-wetted region. Site 2 still retains residual (field capacity) moisture that is dependent on precipitation, temperature, and other conditions.

The Rainy Section consists of degraded granite ballast that has previously experienced 600 MGT and has added fines passing the No. 4 sieve (4.76 mm) to 37.2 percent and No. 200 sieve (0.074 mm) to 4.5 percent. This results in a Selig Fouling Index (FI)[1] of 41.7 (37.2 + 4.5). The fine particles are generally sand-sized and non-plastic silt-sized and the result of granitic ballast degradation with minor eolian (windblown) sand, so they represent a naturally degraded granite ballast section. A grain-size distribution is presented in Figure 1, which shows much finer materials than what is recommended by AREMA.[2]

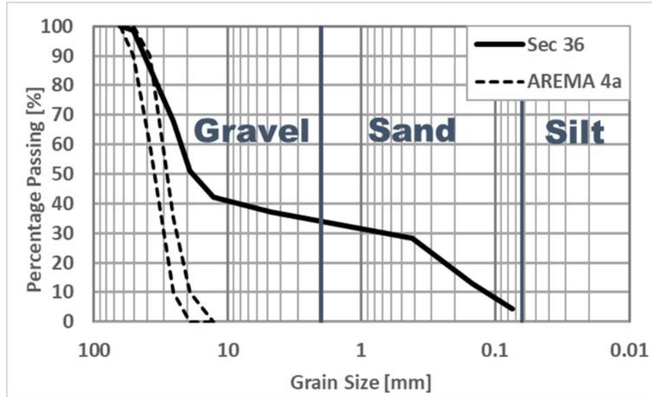

Figure 1. Grain Size Distribution for Rainy Section Ballast

Watering System

The moisture in the Rainy Section is controlled by an irrigation and drainage system. The irrigation system has four 10-foot PVC pipes with 20 sprinkler heads to spray water onto the track. The location, type, and magnitude of spray can be controlled, and the water volume (gallons per minute, gpm) is measured with a mag flow meter.

The drainage system collects water along the sides of the Rainy Section and circulates the water back through a filtration and storage system. Figure 2 is a photograph of the watering system.

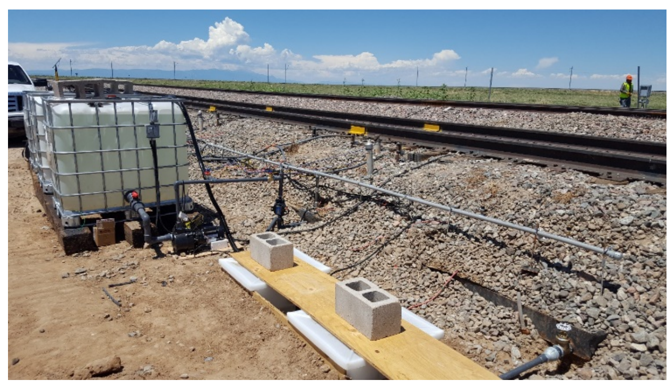

Figure 2. Watering System at FAST Section 36

Moisture Content Monitoring

Resistivity methods are used to monitor the moisture content in the Rainy Section. Resistivity is a material property, measured in ohm-m, from four equally spaced probes that were inserted in the section. The outer two rods carry current and produce a flux field while the inner two rods measure the voltage drop. This voltage drop has been calibrated to soil moisture content, since soil type is held as a constant value in the test. Since resistivity is also dependent on temperature, values of field capacity (the amount of moisture the section can hold before it starts to drain) and a fully saturated condition (building up a 6-inch water table) are taken during single-day tests to reduce the influence of temperature.

In both the Test (Site 1) and Control (Site 2) sections, the most accurate resistivity measurement has been found to be at an elevation corresponding to 10 inches below the bottom of tie, because the electrode set placed near the base is subject to edge effects.

FREE DRAINAGE

Initial tests of the Rainy Section involved wetting the test section and observing the time for the section to drain back to initial conditions. This drainage time assumes sand-sized and silt-sized fine-contamination and no drainage impedance. If these assumptions are changed, i.e., different fine material or impeded drainage, the results will also change, so it should be emphasized that drainage times will be site-specific.

Two drainage tests were conducted: one on August 15, 2017, and the second on September 17, 2017. The test section was wetted by spraying water on the section at 20 gpm and allowing the water to drain. For both tests, the upper resistivity in the test section was monitored.

Since the irrigation system sprayed water at a greater rate than the drainage system could remove it, a 6-inch water table developed. This is defined as a fully saturated condition in that zone. The time to wet the section to a fully saturated state depended on the initial moisture in the section. If it was near field capacity, saturating only took a few minutes. If the section was drier, saturation took longer, typically approximately 30 minutes.

Figure 3 presents the moisture content during wetting on August 15, 2017, and it shows a rapid increase in moisture during wetting, starting from ~16.8 percent and reaching full saturation at ~18.1 percent. The remainder of the curve shows the section drained halfway in ~2.5 hours and required ~20 hours to fully drain.

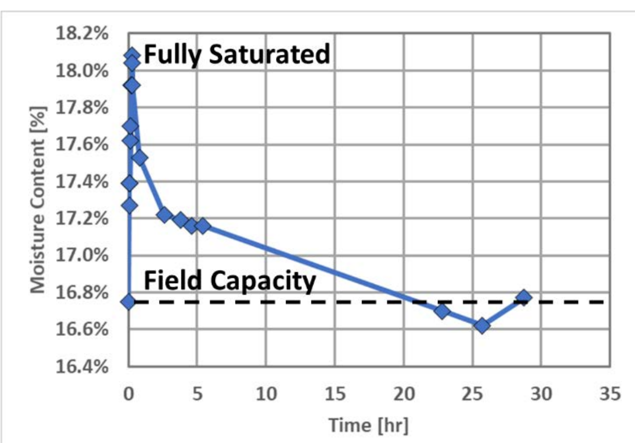

Figure 3. Moisture Change during Wetting and Drainage on August 15, 2017

The drainage curves from both tests are displayed in Figure 4, which shows that drainage occurs on a logarithmic time-scale. The earlier test on August 15, 2017, shows full drainage after ~20 hours, whereas the second test shows full drainage after ~50 hours. Drainage times continually increased over the course of testing, leading the authors to believe the drainage was slowly being sealed off. Therefore, an approximate drainage time of 20 hours is considered representative of a freely draining ballast section contaminated with silt-sized fine particles.

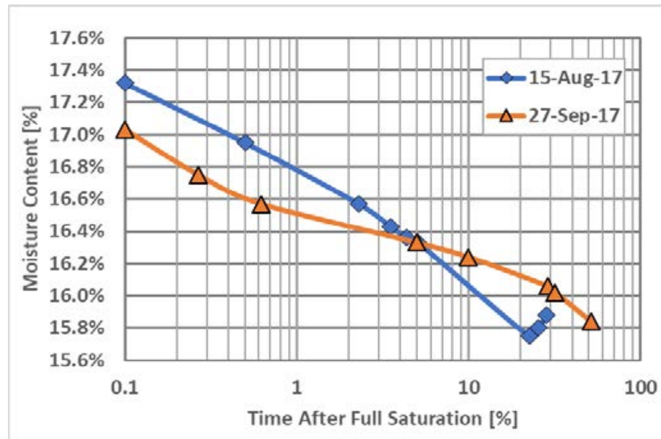

Figure 4. Drainage Curves after Full Saturation

IMPEDED DRAINAGE

As mentioned, ballast sections that have impeded drainage from abutments and confining wing walls without adequately working drainage systems, ballast shoulders containing less permeable material such as clay, or filled drainage ditches will not drain as the freely draining section (blue diamonds) shown in Figure 4. In these cases, the section will reach full saturation and maintain that moisture level until the water can be drained. This indicates conditions that could lead to mud pumping and reduced track support from high porewater pressures during train loading.

MUD PUMPING

During a later test involving running trains with 39-kip wheel loads over the test section at 40 mph on October 11, 2017, the drainage valves were turned off to maintain a standing water table. Within 36 train passes, ~0.5 MGT, mud pumping was observed with fines accumulating on the ballast surface, ties, and rails. The section was allowed to drain, and the next night (October 12, 2017) another 37 train passes, ~0.5 MGT, was performed while the Rainy Section was fully saturated. This led to even more mud pumping, with standing water remaining on the surface.

The mud pumping process is believed to occur from the dynamic loading of the trains increasing the porewater pressure of the standing water in the lower ballast, causing the water and fines to move outwards and upwards towards the ballast surface with each dynamic wheel pulse.

After the pulse is finished, a lower pressure fluid response transports finer material back into the perimeter zone of the tie. This repetitive process leads to the development of a low-permeability zone near the ballast/fines interface. Figure 5 is a photograph of the track surface on October 12, 2017, and Figure 6 shows a diagram of the possible conceptual low-permeability interface. The development of a fine's "mud cake" near the surface can also slow the drainage of the coarser sand beneath it, because of the higher matric potential of this mud cake preventing vadose zone development beneath it.[3]

Figure 5. Photograph of Mud Pumping in the Rainy Section

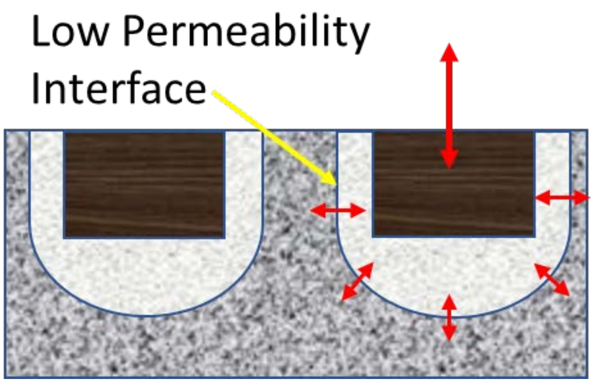

Figure 6. Diagram Showing Low Permeability Interface

When the standing water in the lower ballast drained after the October 12, 2017, test, the water on the ballast surface remained. Although the resistivity rods were too deep to measure this observation, it appeared that the accumulation of silt-sized fines in the upper ballast layer prevented drainage of the upper ballast layer, creating a condition similar to a perched water table (higher moisture at shallower depth). This is notable, because successfully draining the lower ballast layer may not result in the immediate draining of the upper ballast layer, because the surface water is blocked by the accumulated fines near the surface.

Future tests will investigate this phenomenon by sampling the ballast with depth after mud pumping. Insight into the degree of segregation of fine particles during pumping is anticipated. For example, if the percentage of fines prior to pumping is 40 percent in both the upper and lower sections, how much, if any do these values change after pumping? Fine percentages of 45 percent in the upper layer and 35 percent in the lower layer would have different drainage implications than 60 percent in the upper layer and 20 percent in the lower layer, because the ability to drain the surface water will reduce as the fine levels increase.

CONCLUSIONS

Initial tests involving wetting and draining of the Rainy Section at FAST have led to the following observations:

- It takes ~20 hours to drain a ballast section with ~40 percent silt-sized fine particles with no blockage of drainage routes.
- Mud pumping causes the development of a low-permeability zone, preventing drainage of surface water. The amount of fine segregation is currently unknown.

FUTURE WORK

Future Rainy Section testing at FAST will involve the testing of different loading, remediation, and fine-material conditions. Immediate future tests will attempt to better understand how the mud pumping process affects the fine materials and the degree to which they segregate. Later tests will involve testing the benefits of shoulder cleaning and other remediation techniques, as well as filling the Rainy Section with different materials to compare how fine material affects drainage, pumping, and track behavior.

References

1. Li, D. J. Hyslip, T. Sussmann, and S. Chrismer. *Railway Geotechnics*. CRC Press. Boca Raton, FL. 2016.
2. American Railway Engineering and Maintenance-of-Way Association. *Manual for Railway Engineering.* Chapter 1 – Roadway and Ballast. Lanham, MD. 2017.
3. Freeze, R. and J. Cherry *Groundwater*. Prentice-Hall. Englewood Cliffs, N.J. 1979.