TTCI TECHNOLOGY DIGEST

AUGUST 2019 TD19-015

The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Influence of Rain Events on Fine-Contaminated Ballast

Stephen Wilk, Colin Basye, and Yin Gao

Key Findings:

- For ballast with a fouling index (FI) of 40 from natural ballast degradation, the wetted track settlement rate was greater than three times the dry settlement rate.
- Tests under wet, softened conditions revealed that track modulus was below 2,000 lbs./in./in. — the lower-bound recommended value of track modulus. After drying, track modulus increased to 3,000 lbs./in./in.
- For Rainy Section material, softening appears to begin at 10% moisture at the surface. Saturation and mud pumping appears at around 15% moisture. The moisture levels in the track will be dependent on initial moisture; rainfall intensity and duration; and drainage conditions.
- The time for surface ballast to drop below 15% moisture after rain was 0.8 day for the fine-contaminated ballast with no mud pumping, and 5.1 days when mud pumping was present. This large variation is attributed to surface fines inhibiting drainage in the mud pumping condition.

Transportation Technology Center, Inc. (TTCI) continues to perform tests at the Rainy Section of the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST) to quantify drainage, settlement, and dynamic behavior of fine-contaminated ballast. Testing allows TTCI to control the wetting and drainage of the section and simulate various rain events, in addition to dynamic loading of the test section under heavy axle load (HAL) traffic.

The second round of testing investigated how various rainfall events and moisture levels correlated with settlement and stiffness of the track. During a heavy rain event, rail and tie deflection began to increase about an hour into testing. This is believed to the be when the ballast reached the moisture softening threshold as mud pumping was observed at this time.

The critical region for this testing appeared to be directly underneath the tie. This means that maintenance should focus on improving the drainage at the surface. Potential methods to be tested include breaking up the surface, surface trench drains, shoulder cleaning, and track lifting.

This *Technology Digest* (TD) is one in a series that describes an ongoing study investigating the behavior of fine-contaminated ballast when exposed to moisture. The project was conducted by TTCI under the Association of American Railroads (AAR) Strategic Research Initiatives Program, with joint funding from the Federal Railroad Administration.

BACKGROUND

Fine-contaminated ballast is a condition in which the ballast layer becomes contaminated with fines from ballast degradation, surface infiltration, or pumping up from the sub-ballast or subgrade.[1] This condition, especially when wetted, can reduce the ballast performance by limiting drainage, decreasing track stiffness, and increasing track settlement. These affected track zones often become a reoccurring maintenance challenge. One issue with predicting the behavior of fine-contaminated ballast is that it is often dependent on the percentage of fines, fine material size and plasticity, and moisture.

TTCI created a Rainy Section in Section 36 of HTL in 2017 to investigate the behavior of fine-contaminated ballast under wet conditions. The overall objective is to better understand the underlying mechanisms producing higher rates of settlement and determine the effectiveness of maintenance practices. Previous TDs focused on the initial drainage and settlement observations during mud pumping.[2,3] This TD builds off previous work and goes in more detail quantifying rainfall events, moisture levels, and drainage times.

RAINY SECTION AND PREVIOUS WORK

The "Rainy Section" is a 13-tie (20-ft. long) portion of Section 36 in HTL that uses a watering system to control the moisture and drainage of the track section. The ballast consists of degraded (from track wear) granite ballast with 37.2 percent of fines passing the No. 4 sieve (4.76 mm) and 4.5 percent passing the No. 200 sieve (0.074 mm). This results in a fouling index (FI)[1] of 41.7 (37.2+4.5). The fine particles generally are non-plastic sand- and silt-sized and the result of granitic ballast wear, with minor eolian (windblown) silica.

Key findings from previous testing include:[2,3]

- The soaked section resulted in settlement rates about 3 to 10 times higher than the dry condition.
- Soaking resulted in mud pumping and blocked drainage, inhibiting the drainage of surface water.
- After drying, the settlement rate returned to its pre-wetting rate.

SIMULATING RAIN EVENTS

The first focus of the spring 2018 testing involved simulating various rain events to determine how the magnitude of rainfall affected softening and settlement. The rain events are listed in Table 1 and the rainfall intensities were based on publicly available rainfall charts.

Table 1: Simulated rainfall intensities

Event	Rainfall Intensities [mm/hr.]	Rainfall Intensities [in./hr.]	Duration [hr.]
Light	1	0.04	2
Heavy	10	0.4	2
Saturated	-	-	-

During spring 2018, the Pueblo area did not experience significant natural rainfall, so all moisture was added using the irrigation system. Additionally, enough time was allowed between test events for the track to dry, to be confident that the initial moisture levels within the ballast were relatively similar. The fully saturated case did not attempt to simulate rainfall but had the goal of soaking the track and building a water table. This has the benefit of being the worst-case situation.

The settlement rates measured from an unloaded rail at the center tie within the Rainy Section (Tie 295) are shown in Figure 5. Three main findings are observed from these results.

First, the heavy rain (10 mm/hr. for 2 hours) and the fully saturated case resulted in settlement rates about three to ten times the dry and light rain (1 mm/hr. for two hours) settlement rate. As a note, the dry condition experienced settlement rates ranging from 0.01 to 0.03 in./MGT but the 0.03 in./MGT value was selected in Figure 1 because it was considered more representative when comparing against the wetted conditions. This verifies that moisture does influence track settlement once a certain moisture level is exceeded and gives a quantifiable value to historically known field observation.

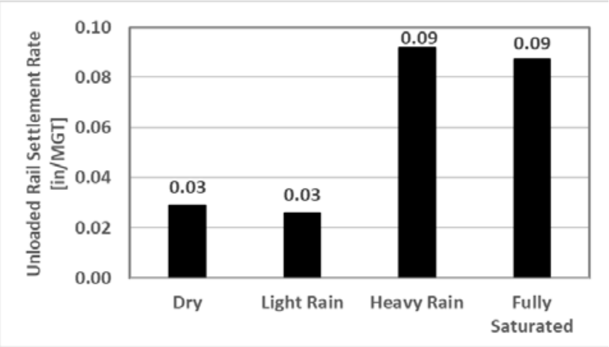

Figure 1. Settlement rates from various rainfall events

Second, the similar results from the dry and light rain suggests that the fine material can retain some moisture before softening. California bearing ratio testing on Rainy Section fine material showed similar results and even strengthening with low levels of moisture due to soil suction.[4] This was expected as it is well-known in geotechnical and construction fields that low levels of moisture help the compaction and stability of geotechnical materials. However, silty materials also are sensitive to moisture and have a narrow optimal moisture band during compaction.

Third, the similar results from the heavy rain, where only the top surface was saturated (this was visually verified from excavations), and fully saturated conditions, where the entire track section was saturated, suggest that the zone immediately below the tie is a critical region where most of the settlement and fines migration takes place. This means, in the Rainy Section, a water table or excess moisture in the lower ballast section is not required for increased settlement and mud pumping. The Rainy Section does not represent all mud pumping cases as there are other situations in which the water source does appear to come from the lower ballast section in the case of flooded track in cut regions. This emphasizes the importance of knowing the water source (top-down from rain events or bottom-up from a water table) and understanding how that affects the mud pumping mechanism and additionally appropriate remediation.

The dynamic rail and tie deflections at Tie 295 during the heavy rain wetting event is shown in Figure 2. The results show both the rail and tie deflections start to increase about an hour (or 0.2 MGT) into the wetting. Near the end of wetting, the deflections appeared to reach a stable value either continued at this deflection level for the remainder of the night or experienced a slight decrease.

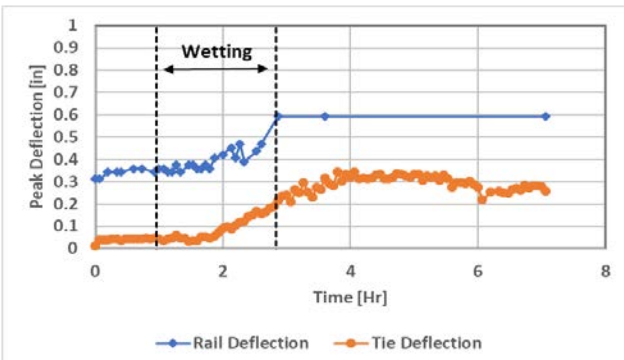

Figure 2. Rail and tie deflections during rain events

Results show the track required wetting for about an hour before enough moisture was present at the track surface for softening to take place. Additionally, mud pumping was noted about an hour into the testing, corresponding with the start of track softening. The TOR elevations could not be measured during train operations because of the train passing every four minutes; however, the settlement rate is anticipated to increase (see Figure 1) during the softening period.

This suggests that when the moisture level near the track surface reaches a particular level, it can affect three performance-related metrics. First, the track settlement rate increases. Second, the track deflection increases and is likely due to both hanging ties and decreased ballast stiffness. Third, excess water and dynamic action results in the accumulation of water and fines, commonly referred to as mud, at the track surface.

In fall 2018, moisture sensors were installed about an inch below the ballast surface in the crib to monitor moisture levels throughout the testing process. The moisture sensors were not installed at the critical location directly below the tie because the sensors cannot withstand the dynamic loads but the surface location will still give insight into surface moisture levels and drainage times.

The Pueblo area experienced more rainfall in the fall of 2018 so the Rainy Section received moisture from both natural and simulated rainfall. This means it was more difficult to control for varying initial moisture conditions so it was decided to take the moisture levels directly instead of rainfall values. A relation between moisture levels and settlement rates is presented in Figure 3. The results show the track begins to soften at about 10 percent moisture and then reaches saturation level at about 15 percent. The 15 percent moisture appears to be the general threshold when the fines lose their compaction ability, resulting in reduced track performance, mud pumping, and fines accumulate near the surface. The 10 and 15 percent values will be site- and fine material- dependent and more variation is expected with additional testing. However, this 15 percent threshold can be used to quantify drainage times.

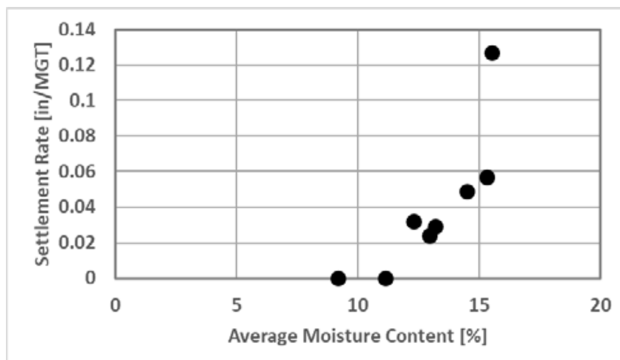

Figure 3. Relation between moisture content and settlement rate

Additionally, it should be emphasized that a wider range of settlement rates were measured in fall of 2019 (Figure 3) than in the spring of 2019 (Figure 1). This likely is dependent on the varying initial moisture conditions.

TRACK MODULUS

Track modulus is an indicator of track stiffness[1] and the results of track modulus in a variety of track conditions is presented in Figure 4. Based on previous studies, it is generally recommended that the track modulus exceed 2,000 lb./in./in. because rapid track geometry deterioration has been observed below this recommended value.[1] The results agree with the previous studies with the track modulus of the wet and mud pumped condition, which experienced higher rates of settlement, having a track modulus of 1,500 lb./in./in. However, prior to the mud pumping and after the mud pumped section dried, which did not experience high rates of settlement, the track modulus was in the recommended range of 3,000 to 3,500 lb./in./in.[3] This also means the pre-mud pumped and dry mud pumped surface conditions may look different but perform relatively similarly in both settlement rates and track modulus. This once again emphasizes the importance of surface moisture in track conditions similar to the Rainy Section.

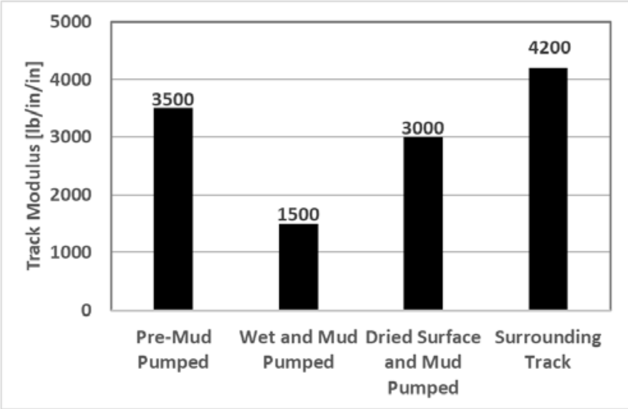

Figure 4. Track modulus of various ballast conditions

DRAINAGE TIMES

Besides increased settlement and reduced stiffness, mud pumping can rearrange and accumulate fines near the surface, inhibiting surface drainage. This presents an issue because the trapped water at the surface will maintain this reduced performance state for a longer period of time making the track more susceptible to track geometry deterioration.

Using the 15 percent moisture level as a threshold from Figure 3, the drainage times were monitored for 'no mud pumping' and 'mud pumping' conditions. This is shown in Figure 5. The time for the surface fine-contaminated ballast to drop below 15 percent moisture is compared. The results indicate 0.8 day when no mud pumping is present but the mud pumping conditions extends this drainage time to about 5.1 days. Additionally, observations of standing water on the surface were noted the next day after mud pumping.

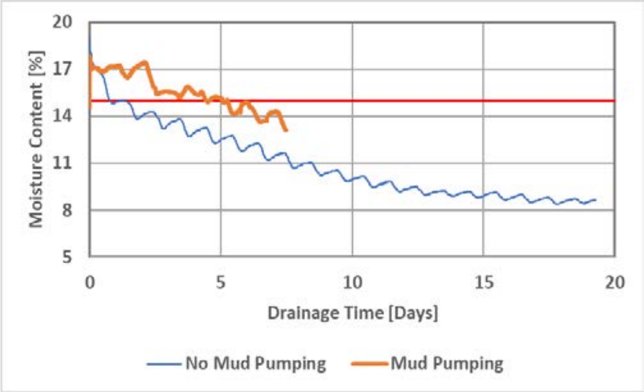

Figure 5. Drainage times with and without mud pumping

SUMMARY AND FUTURE WORK

The results show how excessive moisture near the surface increases settlement rates, increased rail and tie deflections, and reduces track modulus. The loss of compaction ability of the fines will allow fine particles to rearrange and inhibit surface drainage, extending the time the track experiences this reduced track performance condition.

While the specific values of the test are only applicable to this specific situation, the overall concepts are expected to apply to most fine-contaminated ballast situations. The next testing focus will be determining how maintenance techniques reduce the drainage time of the track when mud pumped.

References

1. Li, D., J. Hyslip, T. Sussmann, and S. Chrismer. 2016. *Railway Geotechnics*. CRC Press. Boca Raton, FL.
2. Basye, C., Y. Gao, and S. Wilk. 2018. "Drainage Properties Fine Contaminated Ballast Section." *Technology Digest*. TD-18-010. AAR/TTCI. Pueblo, CO.
3. Wilk, S., C. Basye, and Y. Gao. 2018. Settlement of Fine-Contaminated Ballast. *Technology Digest*. TD-18-011. AAR/TTCI. Pueblo, CO.
4. Qamhia, L., M. Orihuela, S. Schmidt, E. Tutumluer, and M. Moavenvi. 2018. Railway Ballast Strength and Permeability Affecting Track Performance under Dry and Wet Conditions. *Proceedings of the 2018 Joint Rail Conference.* April 18-20. Pittsburgh, PA, USA.

For comments or questions about this publication, contact Stephen_Wilk@aar.com