TTCI TRANSPORTATION TECHNOLOGY CENTER, INC.

TECHNOLOGY DIGEST

MAY 2021

TD-21-008

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

Stabilization of a Failed Subgrade Section at FAST

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Key Findings:

- Two subgrade stabilization methods, cement grout ash mix and polyurethane, were successful at stabilizing a failed subgrade section at FAST.
- Currently, the section stabilized with these two methods has accumulated over 610 million gross tons (MGT) and has not shown signs of track or material deterioration.
- No track heave was experienced during the installation of either stabilization material.
- Before use of the current stabilization materials, two other remediation methods attempted (soil nails and wick drains) did not address the root cause of the failed section, emphasizing the importance of understanding root causes and selecting remediation techniques that specifically address that root cause.

Since 1991, Transportation Technology Center, Inc. (TTCI) has studied the effect of heavy axle loads (HAL) on soft subgrade at the Facility for Accelerated Service Testing (FAST), Low Track Modulus (LTM) Section 29. This study has included the influence of granular layer depths, poor drainage in subballast, subgrade failures, and the benefits of various remedial techniques.[1] FAST is located at the Federal Railroad Administration's Transportation Technology Center, near Pueblo, CO.

Soft subgrades are an issue for all railways in North America because subgrade was not often a consideration for track placement 100 years ago, or the soft subgrade locations could not be realistically avoided. This has led to locations experiencing recurring issues or becoming more severely damaged after a line increases in tonnage or axle loads.

Soft subgrade locations are difficult to maintain because they cannot be easily replaced compared to other track components and typical ballast maintenance does not address the underlying subgrade problem. This issue forces railroads either to accept the high level of necessary maintenance or to try to address the problem by increasing the granular layer, i.e., reinforcing or stabilizing the subgrade.

Subgrade issues can occur for multiple reasons and if the root cause is undetermined, some solutions may end up being ineffective. One of TTCI's subgrade research focus areas is the improvement of subgrade remediation effectiveness by better connecting the various underlying root causes with the appropriate remedial solutions. This is being accomplished using the past research at Section 29[1] and current revenue service studies.[2] The long-term goal is to develop a database that matches the various solutions with situations in which those solutions will be helpful.

This issue of *Technology Digest* summarizes the results of several subgrade remediation techniques used to address a subgrade failure in Section 29 of FAST. The results verified that appropriate remedial measures can be successful, if implemented correctly.

FAST SECTION 29

The LTM section of FAST Section 29 was installed in 1991 to assess the influence of HAL environments and remedial techniques on soft subgrade environments.[1,3] In 1999, a 700-foot hot-mix asphalt (HMA) layer was poured to determine the benefits of a 4- and 8-inch HMA thickness on the soft subgrade.[4] The HMA section performed well until 2005 when part of the 4-inch HMA section failed and had to be remediated with French drains.[5]

In October 2013, part of the 4-inch HMA section failed again, revealing similar issues to the 2005 failure in which the subgrade and HMA deformed and heaved under the inside rail (closer to the adjacent track). The inside rail had a maximum 62-foot profile deviation of 2.05 inches and a cross level deviation of 2.05 inches. These both exceeded TTCI internal track geometry limits for Class 4 test track.

An investigation determined that water was accumulating on the upper clay layer under the HMA. This standing water increased the moisture content of the upper few inches of the clay region, lowering its shear strength. The loading during train passage would cause surface shear failures (top layer of the clay) that progressively settled and eventually resulted in the failure that was observed in 2013. Figure 1 shows this failure: the HMA heaving on the inside rail. Figure 2 shows rail elevation of the inside rail at the initial failure (red line) along with the locations of the 4- and 8-inch HMA layers.

Figure 1. Failed clay/HMA of Section 29 at FAST

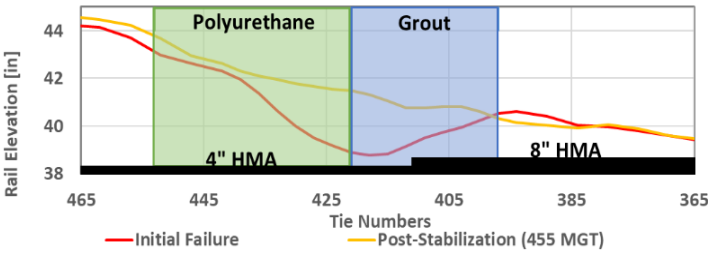

Figure 2. Inside rail surface profiles of initial failure, post-soil nails, and post-stabilization

INITIAL REMEDIATION

Two initial remedial techniques were undertaken. First, in spring 2014, soil nails were installed at a low angle underneath the HMA in an attempt to stabilize the clay. This technique was unsuccessful because while soil nails can be successful at stopping global embankment movement, they did not stabilize the local subgrade surface issue experienced in Section 29. In fall 2014, wick drains were installed to drain the excess water. While this method was partly successful since water was observed draining from the wick drains, the track geometry degradation continued at its near pre-remedial rate, as shown in Figure 3.

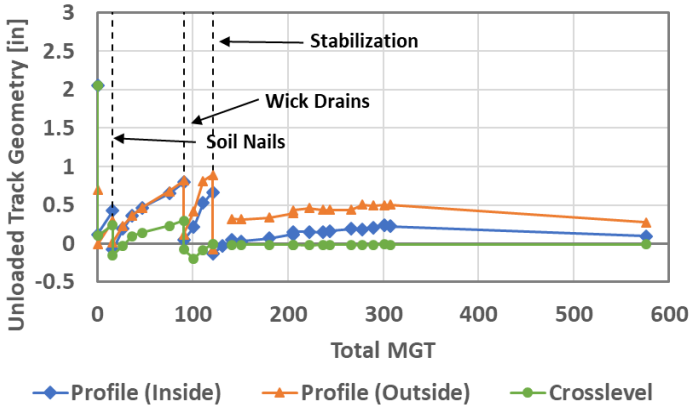

Figure 3. Track geometry with MGT

The lack of success of the wick drains was likely due to the retention of moisture despite water drainage. Excess water would drain, but the moisture content was near saturation thus surface shearing still occurred. While these two remedial techniques (soil nails and wick drains) may be successful in other scenarios, neither was successful in this particular case because they did not address the root cause of clay surface shearing.

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STABILIZATION

To directly address the surface shearing, another attempt was made in early spring 2015 using two types of subgrade stabilization materials: cement grout fly ash mix and polyurethane. It was decided that both subgrade stabilization methods would be used with the grout stabilizing roughly half of the failed section and polyurethane stabilizing the other half. Each material was injected initially at three locations per crib every other crib. However, the polyurethane vendor ended up stabilizing every crib to ensure the subgrade was stabilized, and the number of injections was switched from three to two injections per crib.

Both stabilization techniques were fairly new in 2015 and, based on the method of installation, could be improved in terms of speed and logistics. The grout injections used a hi-rail truck and took about a one day to stabilize about 50 feet of track. The cure time took about 12 hours. In revenue service, this remediation technique would require a block of track time. The polyurethane injections were performed using hand drills to place the rods and then injected with hoses. The entire process took about two days to stabilize about 65 feet of track; the cure time, however, only took about one hour. In revenue service, this remediation technique could use multiple blocks of track time and workers have the ability to get off track in about 15 minutes.

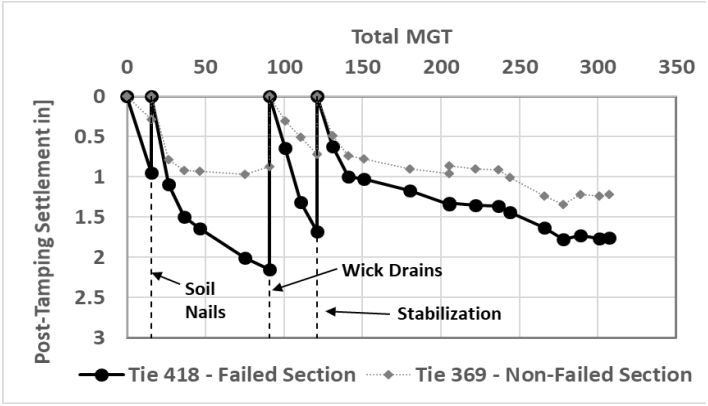
Both the grout and polyurethane emphasize quality control to prevent track heave during installation. The track did not experience any heave during installation for either stabilization technique.

RESULTS

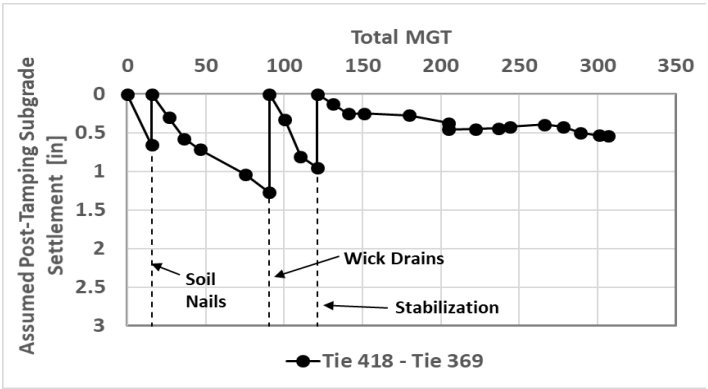
Settlement and unloaded track geometry, both measured from top-of-rail survey elevations, were used to analyze the success of the stabilization. The measurements were taken for two years through the end of 2016 (307 MGT) with a final measurement at the end of 2019 (576 MGT) to verify no further degradation had occurred.

One issue with comparing the settlement pre- and post-remediation is that track settlement after surfacing includes both the ballast and subgrade components. The ballast will typically settle over an inch after surfacing, but this can vary from surfacing cycle to surfacing cycle. To isolate the subgrade component, the rail settlement in the middle initial failed section (above Tie 418) was compared against a tie in a non-failed section (above Tie 369). Since the ballast settlement at Tie 418 and Tie 369 should be similar, this isolates the subgrade component.

Figure 4(a) compares the settlement of Tie 418 (black) and Tie 369 (gray) while Figure 4(b) subtracts the settlement of Tie 369 from Tie 418, which should isolate the subgrade settlement. Figure 4(b) shows a significant reduction in subgrade settlement after stabilization. The latest measurement is not included because the baseline elevation (reference elevation) was different; therefore, will not give an accurate result. However, this last measurement can be used for the track geometry portion, (Figure 3), which gives a good visualization of track geometry performance among various remedies tested.



a.



b.

Figure 4. Settlement of Ties 418 and 369 (a), and Tie 369 subtracted from Tie 418 (b)

The success of the stabilization is further emphasized in Figure 2, which shows a stable post-stabilization surface profile.

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POST-TEST INVESTIGATION

While the track geometry of the stabilized region has continued to hold up after 455 MGT (610 MGT at the publish date), TTCI was still interested in how the stabilization material distributed itself in the clay and whether it infiltrated the ballast and surrounding shoulder. A few trenches were excavated in the test zone in December 2019.

It was discovered that because the grout injections were more fluid and the grout material was pumped until it was visually observed at the surface of the injection holes, the grout distributed above the stabilization region (i.e., the ballast layer) making it difficult to tamp in some regions if surfacing was needed. In an adjacent, non-HMA section, the grout remained about 8 inches below the tie because more care was taken at that section. This shows the importance of quality control and making sure the grout remains in the region where it is needed.

The polyurethane remained localized and formed "bulbs" underneath the track. In this case, quality control is important to ensure the bulbs are large enough to stabilize the subgrade without causing track heave. No obvious evidence of polyurethane causing track heave or infiltrating the ballast was observed.

During the trenching, both the grout and polyurethane appeared to be of good quality, and no deterioration was observed. Neither material directly fully mixed with the clay but both materials infiltrated any lateral cracks and appeared to have a layering effect. This was clearly enough to stabilize the upper clay layer and minimize track geometry degradation.

ACKNOWLEDGEMENTS

The authors would like to acknowledge former TTCI employee Colin Basye for leading most of this work, as well as, stabilization suppliers Keller (formerly Hayward Baker) and URETEK, USA. In addition, former Hayward Baker employee Jeff Hill is acknowledged for his input into this test.

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