RAILWAY EMBANKMENT AND BALLAST POCKET STABILIZATION IN A SOFT SOIL ENVIRONMENT

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ABSTRACT

Upper embankment deformation and ongoing loss of track geometry in a section of railway track in Ohio occurred as a result of excess moisture in a clay subgrade and subsequent development of “ballast pockets.” Dynamic train loading was a major cause of this problem in the low strength embankment clay fill, as the ballast migrated downward in response to cyclic loading. Transportation Technology Center, Inc. and industry participants performed an investigation and installed remedial solutions designed to mitigate development of these ballast pockets and improve track geometry retention. Performance of the solutions was monitored for three years using ground penetrating radar, track geometry data, and visual observations, both for the initial investigation and for the final assessment of the embankment condition. It was found that a combination of triaxial geogrid, coupled with installation of ballast drains, reduced the needed maintenance from weekly before the installation to yearly after the installation. This paper details the investigation and results over the three-year period.

1. INTRODUCTION

Freight railroads in North America spend over a billion dollars annually for track maintenance. One of the largest areas of track maintenance expenditure is that of ballast and subgrade. Railroad ballast provides vertical and lateral stability needed for retention of track geometry. In soft, moist soil embankments composed of clay, ballast, without a properly graded subballast layer, can migrate downward into the clay, losing the ballast grain-to-grain contact that is essential for track substructure stability. As ballast pockets develop, they produce a “bathtub” effect consisting of a water saturated ballast-clay mixture with low shear strength, surrounded by a more impermeable clay mass that also undergoes gradual hydration.

In October 2012, Transportation Technology Center, Inc. (TTCI) and an eastern railway installed a multiaxial geogrid and ballast drains at ballast pocket locations in order to provide drainage and upper embankment stabilization, and to arrest further ballast pocket development.

The track was surveyed and the substructure was examined several times after installation of these remedies, with positive results noted each time. After 36 months (and 17 MGT/year) of heavy axle load traffic, the geogrid was found to be in good condition with no damage observed in the loaded zone, and it continued to support the ballast near the track surface. Only one tamping operation was needed per year during this time, as a result of a continuing localized deformation near a spring. In most of the 700-foot-long study area, it was found that the utilization of geogrid and ballast drains could reduce the track settlement and extend track maintenance cycles significantly. These remediation methods have also reduced ballast loss, thereby improving longevity and stability of the railroad track. This paper describes the problem, solution, and results of this study.

2. SITE CONDITIONS

This research was performed at an eastern US heavy haul rail location which has had ongoing track geometry problems for many years on a 20- to 25-foot-high embankment, which was constructed sometime near the beginning of the last century.
Fine grained soils present in the fill material, along with moist to wet conditions caused primarily by seasonal precipitation and development of ballast pockets in the subgrade zone, had resulted in the need to maintain the track weekly prior to remediation.

The track generally follows a nearby river, and the northwest side of the track is bounded by a steep mountainside, with a groundwater discharge zone lying adjacent to the track basal area on the uphill side. The water from the spring follows a shallow ditch that parallels the northwest base of the track embankment and is eventually routed to the river.

Figure 1 shows the layout of the study area and embankment. The red line represents the 700-foot-long area where the geogrid was placed, and the blue short lines represent ballast drain locations. The large blue groundwater discharge zone is a perennial spring that may contribute to lower embankment deformation in the adjacent track area.

The Figure 2 cross section shows several prominent features of the embankment. Ballast pocket development is apparent in the subgrade of the upper embankment area, and embankment moisture is captured and retained in these “bathtub features” until the water is drained out. Moisture in this area is thought to result from precipitation directly onto the upper track, where it penetrates through the upper ballast to the “ballast pocket” zone. Track geometry has historically shown more degradation on the mountain side of the track in some areas, as noted by the “more settlement” note on the pictorial.

It is suspected that there may be accelerated settlement in the lower embankment, caused by the presence of the higher relative elevation of the groundwater discharge zone and a “wicking effect” upward into the clay of the embankment. Soil types and texture were also noted to be different on each side of the embankment, with saturated, organic, higher plasticity clay noted on the mountain side of the embankment, and lower moisture content and lower plasticity clay on the river side. The significance of this will be discussed later in this paper.

Figure 3 illustrates the track geometry issues that were noted before remediation, including lateral track displacement, upper embankment subgrade cracking and lateral shearing, and loss of vertical geometry with settlement.

3. REMEDIAL APPROACH

Site Characterization

Initial testing was begun in 2010-11 using TTCI’s Track Loading Vehicle (TLV) (Figure 4), and ground penetrating radar (GPR), which identified zones with weak and water saturated subgrade, in addition to the presence of ballast pockets. The TLV was used to measure track deflection using a 10K and a 40K rolling
load, which produced a loaded deflection measurement. This was used to calculate track stiffness or track modulus. The TLV also measured track geometry metrics such as surface, cross level, and gauge; finally it was used to advance an instrumented cone penetrometer (Figure 5, CPT) into the track and subgrade to measure tip and sleeve (sidewall) resistance to a depth of 12 feet. This assessment method produced additional soil information to help characterize the ballast, subballast, and subgrade.

TTCI and a GPR service provider worked together to investigate track substructure (Figure 6), in order to provide additional assessment parameters and plan remedial strategies. The GPR assessment provided information on ballast moisture content and fouling levels, in addition to layer information such as ballast pocket depth.

Figure 4. Track Loading Vehicle and Load Bogie Inset

Figure 5. Cone Penetrometer (CPT)

Figure 6. GPR Investigation at Test Site

Remedial Plan and Implementation

Two solutions were chosen to address remedial issues. First, ballast drains were installed in two areas containing deep ballast pockets. Drainage of these areas would produce increased shear strength of the clay matrix in the embankment mass and would also reduce driving forces for embankment shearing. Ballast drains are a common practice used to address ballast pockets, and although they cannot drain all of the individual ballast pockets (since they form an uneven or undulating subsurface interface), they provide general improvements in the bearing capacity and shear resistance of the soil matrix.

Second, geogrid was chosen as an experimental remedy for this site, to test its effectiveness in mitigating upper embankment deformation and to prevent ballast migration downward. The geogrid forms a soil mat foundation as it goes into a tensional state, and it engages with the ballast. This helps to bridge over anomalous weak areas in the subgrade. Although the average tip resistance shown in the plot below indicates that the embankment soils average out to “moderately stiff” (which includes “dense” ballast and “very dense” subballast), the “very soft” blue zones will dominate with respect to shear and deformation of the embankment.
Figure 7. Average Embankment CPT Tip Resistance

Data analysis of the site characterization investigation resulted in targeting two areas for ballast drains. The GPR and CPT data was merged in order to be able to have data from multiple sources to aid in targeting and confirming the most advantageous sites for remediation. Figure 8 shows the merged data from GPR and CPT. The thin horizontal blue, green, and red lines represent a continuous GPR profile for the right, center, and left GPR antennas, respectively. The vertical multi-colored thicker lines represent tip resistance for the CPT. Red zones represent stiff soils, while blue zones represent soft soils; green and yellow areas are intermediate stiffness. From this data, the soil around CPT #12 was targeted for a ballast drain based on the presence of a ballast pocket with a weak zone near the base, indicating the presence of moisture, also identified by GPR in Figure 9. In addition, the base of CPT #5 also indicated another zone where basal soils were weak, although not as pronounced as CPT #12. The ballast pocket at CPT #3 was the deepest ballast pocket, but it appeared to be stable based on the very stiff soils at the base of the pocket.

Remedial System Installations

Ballast drains were installed in the CPT #12 and #5 areas of the study zone based on the combined CPT and GPR results and interpretation. The track at the site was removed in October 2012 as preparations were made to install the ballast drains. As the CPT #12 ballast drain area was excavated, it became apparent that the actual profile of the ballast pocket correlated very well with the GPR results. The left side of the section, labelled “A” in Figure 10, correlated with the shallower CPT #12 shown in blue in Figure 8 (the GPR vehicle was moving the opposite direction during the data gathering process, hence it was labelled “Right GPR” in Figure 8). Likewise, the deeper portion of the ballast pocket labelled “A’” in Figure 10, correlated with the deeper GPR ballast profile shown in red at CPT #12 in Figure 8.
After the installation of the ballast drains, water immediately began flowing from the ballast pockets (Figure 11). Water continued to flow for a number of weeks, after which it slowed to a steady state flow. As the ballast pockets drained out, the clay soil began to show improvement in shear strength. Additional improvements were observed as the geogrid began to stabilize the fouled ballast zone immediately above the subgrade elevation. This technology is discussed below.

Geogrid Installation

Geogrid is a flexible polypropylene or similar product that is designed to interact with and strengthen soil layers in at least two directions, to resist tensional load forces (Figure 12). The large aperture triaxial geogrid was chosen for this application because it is designed to function in multiple stress path situations. The aperture design targets 50 percent of the average ballast size in order to confine the ballast and engage the geogrid in a tensional state in order to provide optimal stiffened support.

Before the track was replaced, the geogrid was placed along the track parallel to the rail direction (Figure 13). Since the geogrid is 15 feet wide, it provided support not only for the area immediately beneath the rail,
but also in the track center and shoulder areas. Temporary concrete blocks were placed along the rail path on top of and in contact with the geogrid in order to provide support for the ballast cars as they dump the new ballast on top of the geogrid. The design called for 12 inches of ballast between the geogrid and the bottom of the ties, in order to facilitate tamping and future potential undercutting needs. However, the weight of the cars caused deformation and some perforation of the geogrid before the ballast could be placed (Figure 14).

Figure 13. Track Being Placed on the Geogrid

Figure 14. Geogrid is shown resting on the subballast. Geogrid is cut in some areas by the weight of the ballast cars.

Remedial System Monitoring

In order to monitor the effectiveness of the remedial solutions, tell-tales were used (described in detail in other TTCI publications (1)) in conjunction with top-of-rail elevation and GPR surveys, and biannual site visits to document and photograph the conditions. It was found that the need for tamping and track geometry corrections (including ballast dumping) was reduced from a weekly event to yearly after the remedial system was in place. There was only one small (80-foot-long) section, in the vicinity of CPT #12 that still needed yearly maintenance. Figure 15 shows that subsequent bi-yearly top-of-rail surveys indicate a stable track surface for most of the remedial track length.
Final Testing

In October 2014, a final run was conducted using GPR, and the following summer, the TLV was onsite to perform track geometry, CPT, and track stiffness measurements. The 2010 and 2014 GPR data was compared, revealing that the geogrid was deforming in an 80 foot-long zone near CPT #12, at the ballast drain (Figure 16). Although the GPR did not detect the actual geogrid itself, it is suspected that the geogrid forms a denser layer of ballast at the interface, which the GPR could detect. Figure 16 shows approximately 6 inches total deformation over the 3 year time period.

Subgrade Moisture Comparison

Ballast drains have been a common remedy for addressing high moisture conditions in railway embankments for some time. The GPR comparison of moisture content in the subgrade confirms that even a relatively small effort (2 drains in 700 feet) can produce favorable results in hydraulically continuous subgrade. Figure 17 indicates that the subgrade moisture content (shaded blue) in 2010 was greater than that in 2014, even though more precipitation had fallen in the area in the weeks and days preceding the GPR survey in 2014 than in 2010. The shading observed is indicative only of relative moisture content across the study area; GPR does not give an absolute moisture percentage for subgrade soils. Onsite soil sampling and laboratory determinations are necessary for that level of accuracy.
Figure 17. Comparison of Subgrade Moisture, Before and after Ballast Drain Installation

TLV Data Collection in 2015

In early September 2015, the TLV was deployed to the study site to perform final data gathering tasks for comparison with initial measurements. The data was collected before any corrective tamping or ballast placement was conducted for 2015. Data collection included track geometry measurements, track stiffness measurements using the 10K and 40K loading systems, and two CPT pushes in the area of the original CPT #12 down to a depth of 25 feet. This was done to characterize the lower embankment soil characteristics for future remedial planning.

It was found that the track geometry was still within specifications after one year of traffic since the last tamping operations, and the deflection measurements indicated that the track had good support, even in the area that exhibited a small amount of embankment deformation around CPT #12.

The new CPT penetrations showed the low shear strength remnants of the soft soil zone at a depth of 8 to 9 feet below top of rail, but this did not cause any apparent issues in the test zone because of the load spreading effect of the geogrid.

Figure 18 shows the tip pressure and sleeve pressure values in the CPT #12 zone (down to 25 feet) for 2015, and it may be noted that although softer zones were noted immediately below the subballast zone (starting approximately 6 feet below top of ballast); again, no surface manifestation was noted.

Figure 18. 2015 Tip and Sleeve Pressures for the CPT #12 area

Additional Work Planned

TTCI is currently involved in researching the ongoing deformation in the embankment near CPT #12, to determine the root cause of the continuing deformation issue. Although it appears that the adjacent
groundwater spring may have a role in hydrating the clay in the lower embankment and causing some of the issue, there could be ballast pocket issues or mid embankment problems that are dominant. We may find that certain soil injection technologies or specialized drain technologies may stabilize the remainder of the deformation in the embankment.

**Conclusions**

This test site has provided an opportunity to study the combined remedial effects of ballast drains and geogrid in a heavy axle load environment. As a result, track maintenance was extended from weekly to yearly following remedial installation.

**ACKNOWLEDGEMENT**

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**REFERENCES**

RAILWAY EMBANKMENT AND BALLAST POCKET STABILIZATION IN A SOFT SOIL ENVIRONMENT

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Outline
Slide Text

1. Site History
2. Remedial Investigation
3. Design Approach
4. Installation
5. Monitoring
6. Results
7. Additional Research
8. Summary and Conclusions

Site History

Site Issues
- Clay embankment over 100 years old
- Spring located next to track
- Differing native soils at the base on each side of the embankment

Track Geometry Issues
- Weekly maintenance needed for many years
- 13 to 17 yearly MGT on line
- Upper embankment tensional cracking

2012 Remedial Investigation Approach

Research Approach
- Characterize upper embankment issues using
- Ground penetrating radar
- Track Loading Vehicle
  - Cone penetrometer
  - Track Geometry Measurements
  - Track Deflection Measurements
- Top of Rail Surveys (TOR)
- Visual Assessments
- Track Maintenance Records
- Remedial Strategy Based on Results

Remedial Investigation - GPR

Ground Penetrating Radar
- Characterize Soil Layers
- Relative Soil Moisture
  - Fines incorporated in ballast mass
  - Fines retain water

Remedial Investigation - Track Loading Vehicle (TLV)

TLV Measures
- Track Stiffness
- Track Geometry
- Ballast and Subgrade Properties

Site History

Upper Embankment Issues
- Ballast pockets
- Increased moisture retention
- Tensional cracking
- Lowered shear strength
- Embankment deformation

Lower Embankment Potential Issues
- Shallow water table
- Upward wicking of groundwater
- Embankment deformation
Remedial Investigation – Combined Data

Results Help to Target
- Weak, moist or wet areas
- Cost effective techniques and zones for remediation

Ballast Drain Installation

Left and Right Side Ballast Pocket Profile
- Ballast pocket deeper at A’ than A
- Correlates with GPR and CPT results

Geogrid Design for Upper Embankment
- Triaxial geogrid selected
- Multi-axial support
- Tensile (mat foundation) support for upper subballast/subgrade interface
- Prevents downward migration of ballast into ballast pockets

Geogrid Remedial Installation
- 15 foot width
- Track removed in this case, but may not be necessary with undertrack rollout

Ballast Drain Installation

Two trench drains installed at active ballast pocket locations
Targeted using GPR and CPT
- Began draining water immediately
- Relatively high flow for weeks
- Currently at lower steady state condition
- Probably does not drain the entire ballast pocket zone
- Ballast pockets are not planar
- Drains are widely spaced
- Water retention may still cause some issues

Wet Zones Correlate with Soft Subgrade
- Blue or green active pockets – growing
- Red or yellow inactive pockets, static conditions

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Top of Rail Survey Monitoring

- Track maintenance extended from weekly to yearly
- Deviations caused by time difference between survey date and track maintenance date

2014 GPR Survey Results

- Most of the 700 foot-long zone is stable
- Small 80 foot-long area - about 3” settlement/year
- Geogrid not detectable by GPR, but
  - Reflection of denser, moist layer is detected
  - Deformation may be deeper in embankment

2014 GPR Moisture Survey Results

- GPR subgrade moisture comparison 2010-2014
- Less subgrade moisture noted in 2014 (but higher precipitation that year)
- Moisture content confirms:
  - A small effort (2 drains/700 feet) can produce favorable results
  - Subgrade must have fairly continuous hydraulic conductivity
  - The drains are still functioning after 3 years

Ongoing Research 2015-2017

- Continuing deformation in a small 80-foot long zone
- Provides opportunity to determine root cause
- Test mid-lower embankment remedial measures
  - 2015 CPT shows
  - Weaker zone lower in embankment
  - May be caused by spring water wicking upward

2015-2016 Survey Pin Monitoring

- Survey pins driven in on an approximate 10-foot grid to identify:
  - Where deformation is occurring
  - Magnitude and direction

Future Considerations for Embankment Treatment

- Test injection or other technologies depending on monitoring results
- Wick Drains
- Soil Nails
- Grout or polyurethane injections
- Chemical injections
Summary and Conclusions

- Ballast Drain and Geogrid installations have improved the maintenance cycle from weekly to yearly at this site.
- Some areas of higher moisture are still present at the base of the ballast pockets.
- The deleterious effects of these high moisture pockets are mitigated by the bridging effect of the Geogrid.
- Small scale lower embankment deformation may still be occurring on the eastern side of an 80 foot long section.
- Current monitoring activities may provide an opportunity to test additional stabilization measures.

Thank you!