Railroad Embankment Stabilization Demonstration for High-Speed Rail Corridors

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Abstract

The development of high-speed railroad corridors in the United States is being considered by Congress as a fuel efficient and economical alternative to air or highway passenger travel. The existing infrastructure is, in many cases, suitable for freight traffic but not for the more exacting geometry standards of high-speed rail passenger trains. In many cases the proposed passenger service would use existing trackage heretofore carrying only slower moving freight trains (e.g., the newly opened service on the Northern New England Corridor (The Downeaster) between Boston, Massachusetts, and Portland, Maine). Instability in the roadbed can cause changes in track geometry at a rate unacceptable for safe or economical high-speed operation over existing lines. This project was conducted to demonstrate that existing ground stabilization techniques could be utilized to economically improve track performance for high-speed service.

Rail traffic and the resulting limited track time available for maintenance in high-speed corridors dictate that embankment stabilization methods must be employed with minimum traffic disruption. The Federal Railroad Administration (FRA) Office of Railroad Development initiated a demonstration project to identify an unstable railroad embankment and effect a remedy. The purpose of the project was to develop experience with and demonstrate the capabilities of ground improvement techniques for reducing track maintenance requirements.

The line segment selected for demonstration had a history of track settlement that continued after the line was rehabilitated for passenger service. After only a few years of renewed service, it became evident that the embankment was still subject to chronic settlement that required frequent resurfacing. A sub-surface investigation determined that a variable-thickness peat layer underlying the embankment caused the settlement.

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Based on the information from the site investigation, a remedial program was devised to minimize the track settlement by improving the stability of the peat layer. Grout pipes were installed from the side of the embankment with little disruption of rail service. A cement grout was pressure-injected into the embankment, targeting the peat layer. After grouting, the track elevation was monitored periodically to determine whether the program had stabilized the track geometry.

This paper describes the site, investigation procedures, rehabilitation, and post-stabilization monitoring of the embankment as an example of a method to economically address problematic track conditions with minimal disruption of rail operations. The program was successful and it is believed that similar strategies can be employed to fix a variety of embankment problems and reduce the cost of maintaining the high quality track geometry necessary for high-speed service.

Introduction and Background

There are many corridors in the United States connecting major population centers that are being considered for high-speed rail passenger service. The benefits of the service to ease highway congestion and to benefit conservation and the environment are quite clear (U.S. DOT, 1996). Most of the new high-speed tracks will take advantage of existing railroad track upgraded for higher speeds. The great majority of these lines were constructed over 50 years ago, many over unsuitable foundations.

Typical railroad embankment construction in the early twentieth century minimized haul by borrowing material from within the right-of-way. The existing ground was only minimally prepared for placement of the embankment. Often, the embankments were allowed to "winter" (i.e., sit untouched over the winter months, to "settle" in). After commencement of service, if the track continued to settle, ballast (the angular crushed rock surrounding the ties on top of the embankment) was added and the track resurfaced and raised (literally pulled up to proper elevation and cross-level). For most embankments, settlement would gradually slow and the track would become relatively stable. With a stable embankment to provide track support, track geometry degradation would be caused primarily by the service live loads.

Where soft or weak soil underlay the embankments, track geometry would continue to deteriorate because of bearing capacity or slope failures. The railroads would try various measures, even reconstruction, to solve this problem. Tracks that were built over swamps with embankments underlain by layers of fine-grained or organic material remained problems. Consolidation of the fine-grained layers could continue over many decades. Constant addition of ballast to compensate for the settlement would add to the total stress on the peat layer increasing the rate of consolidation and exacerbating the problem.

A railroad could usually abide long-term settlement with periodic resurfacing. For ordinary freight traffic, speed restrictions can be employed until geometry is brought back within tolerable limits. High-speed passenger service requires tighter tolerances on geometry and better on-time performance than freight service, making this strategy impractical. Frequent interruptions of service negate the advantages of the higher speeds, while lowering track geometry standards jeopardizes safety with potentially disastrous results. To make high-speed rail corridors practicable, it is necessary to develop a means of stabilizing the embankments to reduce settlement rates. To this end, the FRA Office of Railroad Development sponsored a demonstration stabilization project.

Site Description

The site chosen for the demonstration project was the newly reopened Plymouth/Kingston commuter line of the Massachusetts Bay Transportation Authority (MBTA) near South Weymouth, Massachusetts. The 3 m (10 ft) high embankment had been constructed over soft marshland in the early 1900s as part of the Old Colony Line. The line was abandoned for approximately 35 years and then reconstructed and reopened for service in 1996.

The embankment had settled over the 35 years of abandonment and was reconstructed by adding approximately 1 m (3 ft) of new fill and ballast to bring the rails to proper profile. After service resumed, the track had to be resurfaced once or twice a year to maintain Class 5 service. Amtrak, responsible for maintaining the track, sought a solution that would inhibit settlement and reduce maintenance requirements for the track.

Site Reconnaissance/Local Geology. The area traversed by the railroad at the problem site was a marshy lowland. Upon initial investigation, the presence of surface water to the west of the railroad embankment (see Figure 1) was noted. The Wisconsin era glacial retreat (8,000 to 15,000 years ago) eroded the Dedham Granite bedrock and the draining meltwater deposited the eroded material in stratified glacial deposits of sand and gravel over the bedrock in the lowlands (Kauffman and Trepanowski, 2000 and Peragallo, 1989). Repeated vegetation of the areas has since filled in many of the remaining smaller surface depressions (e.g., glacial lakes and ponds) making swamps, bogs, and marshes as observed during the initial site reconnaissance. The surface soil at the site was identified as Freetown Muck by Peragallo (1989) consisting mainly of very poorly drained soils formed of highly decomposed organic material and silty alluvium that developed near local rivers. The Freetown Muck is poorly suited for most uses because of the seasonal high water table, flooding, and low strength (Peragallo, 1989).

In the early 1900s, the original single line railroad embankment was constructed over the Freetown Muck. Typical construction of early railroad embankments consisted of building a roadbed of locally available granular soil at the approximate grade and alignment required for the line. Local railroad authorities report that this particular section of the railroad has a long history of settlement and repeated maintenance required to keep the line operational. The line remained in service until the 1960s, after which the line was abandoned until 1996. In 1996, the track was reconstructed for passenger service operations by the MBTA. Reportedly, the track at the site had settled up to 0.9 m (3 ft) during the 35 year abandonment.

During reconstruction, it is likely that the old track was removed, the surface of the existing embankment graded, and new fill placed to the approximate height of the present line. After service was reestablished, additional settlement of up to 0.3 m (1 ft) was observed between 1996 and 1999. Maintenance personnel estimated that the maximum settlement rate in the test zone was 8 to 15 cm (3 to 6 in.) per year.

Figure 1. Standing water at the base of the embankment.

The overall stratigraphy at the site consists of a track surface of ballast, followed by granular fill (placed during the 1996 reconstruction), over granular fill from the original embankment construction, a variable thickness of organic Freetown Muck, a glacial sand and gravel deposit, and Dedham Granite bedrock at a depth of approximately 13.7 m (45 ft) (Kauffman and Trepanowski, 2000). The mechanism causing the reported 0.9 m (3 ft) of settlement during the 35 year abandonment was, most likely, compression or consolidation of the Freetown Muck.

Site Investigation. The site investigation was conducted to confirm the source of the embankment settlement: either in the embankment fill or in the foundation soil. Three test borings, numbered B1-B3, were conducted using a hi-rail truck-mounted drill rig to provide on-track access to the site. The test borings consisted of advancing the drill hole with hollow stem augers and performing nearly continuous standard penetration tests (SPTs), conducted in general accordance with American Society for Testing and Materials (ASTM) D1586 (ASTM, 2000). The split spoon sampler was driven with a 63.5 kg (140 lb) hammer raised using a rope and cathead. A test boring made in 1993 during the design of the line reconstruction for the present passenger service was used to guide the investigation. The embankment was underlain by peat (Freetown Muck) over sand and gravel. The blow count (N) from the SPT ranged from 27 to over 75 for the original fill and from 37 to over 100 for the newly placed embankment layer indicating dense and well-compacted soil in each layer.

The four test borings, three from the testing conducted for the stabilization, and one from the design of the reconstruction, were made along the eastern track and

indicate a relatively uniform embankment. A longitudinal section along the eastern track is presented in Figure 2, which shows the relatively uniform embankment construction, but a variable thickness peat layer. The thickest portion of the peat layer approximately corresponded to the location of the maximum track settlement, which provided an indication that the peat layer in the foundation soil was the source of the settlement. A thin clay layer was identified in test boring B1 underlying the peat.

One undisturbed 0.076 m (3 in.) diameter, thin walled Shelby tube sample was obtained from the Freetown Muck/Peat subgrade material in Test Boring B1 at a depth of 4.3-4.9 m (14-16 ft). The sample was obtained for laboratory testing and appeared to be fine-grained, cohesive soil, but contained a large percentage of fibrous organic material.

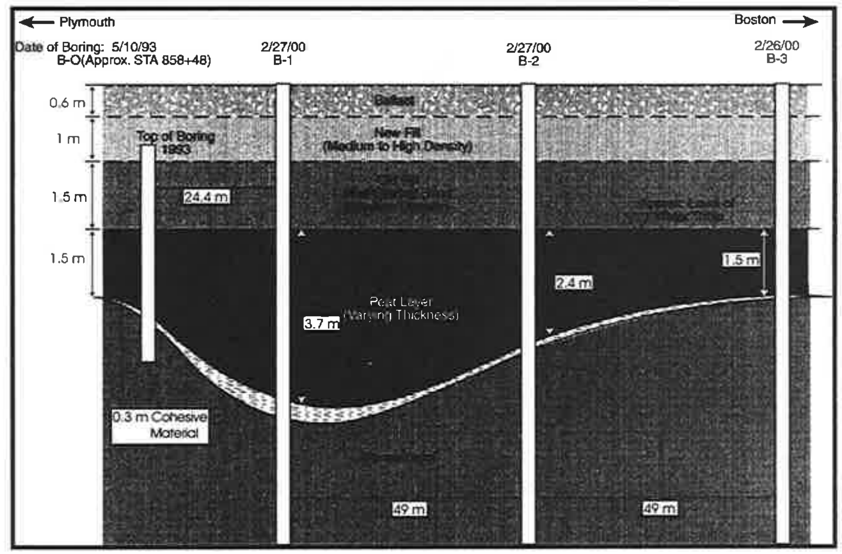

Figure 2. Variation in the subsurface conditions in the demonstration area.

Laboratory Testing. Laboratory testing consisted of grain-size distributions on the existing embankment fill and on the sand and gravel underlying the Freetown Muck/Peat, as well as an organic content test and a consolidation test on the Freetown Muck/Peat.

The Freetown Muck/Peat consisted mainly of loose black fibrous organics, with fine sand in some borings. The consistency of the peat varied with depth from mainly fibrous organics near the top of the deposit to what was classified as fine-grained peat at the bottom. In test boring B1, a layer of clay was found to underlie the peat. The organic deposit consists of a mixture of fine sand, silt, and clay with a large amount of fibrous organic material. The organics test on the peat sample indicated approximately 86 percent organic material.

A consolidation test was conducted on a portion of the undisturbed Shelby tube sample due to the appearance of some of the peat samples as a fine-grained soil and the presence of clay under the peat,. The results from the consolidation test are shown in Figure 3. The soil was found to be normally consolidated clay soil with a preconsolidation pressure of approximately 57.5 kPa (8.3 psi). The preconsolidation pressure was approximately equal to the current stress state of the soil at the surface of the peat deposit, indicating normally consolidated conditions (Craig, 1998).

Since the peat was found to behave similar to a normally consolidated fine-grained soil and since the location of the maximum settlement coincided with the location of the thickest layer of peat (Freetown Muck), it was concluded that consolidation of the peat layer was responsible for the track settlement.

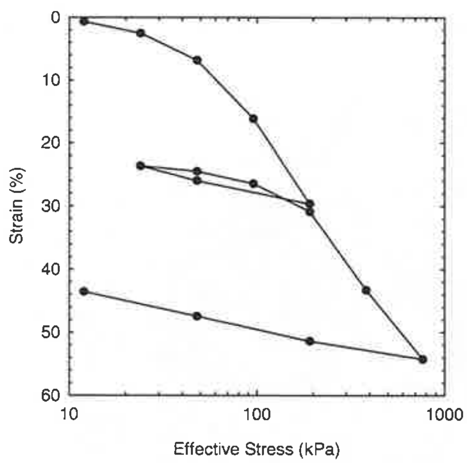

Figure 3. Consolidation test results.

Grout Application

A grout program was developed to mitigate the settlement of the embankment due to compression and consolidation of the organic peat layer. The grouting concept was to compress, compact, or consolidate the peat layer by adding grout under pressure (the actual mechanism depending on the local consistency of the peat which varied from the top to the bottom of the layer). The specific grout program could be termed compensation grouting, which is typically applied to compensate for loss of material volume. Since the embankment settlement was previously compensated for during track maintenance such as ballast dumping and track surfacing, the goal was to install the grout and maintain the grade of the track. The goals of this grout project fall within the goals of the general category of limited mobility displacement (LMD) grout, as described by Byle (1997 and 2000).

The procedure was to install sleeve port pipes through the embankment and the peat layer. Cement grout mixed in a 1:1 water-cement ratio by volume was pumped at a pressure between 1 MPa (150 psi) and 2 MPa (300 psi) through specific ports using nitrogen filled double packers (shown in Figure 4) to confine the grout to the desired port. During grouting, the track elevation was monitored to ensure the track surface did not move appreciably during grouting. The largest track movement recorded was 6.1 mm (0.02 ft).

Sleeve port pipes with grout injection ports spaced approximately every 0.9 m (3 ft), Figure 4, were installed from the side of the track at angles of 50°, 30°, and 20° from horizontal, as shown in Figure 5. To install the sleeve port pipes, a 0.13 m (5 in.) diameter casing was advanced past the bottom of the peat layer with a Davey Kent DK620 drill rig. The drilling was accomplished from the side of the track, as shown in Figure 6, to minimize operational delays. The casing was then washed out to remove any soil and the sleeve port pipe was inserted and the casing was removed. Thirty six sleeve port pipes were installed to treat the 76 m (250 ft) of the embankment where the peat thickness exceeded approximately 1.3 m (5 ft). The average spacing was approximately 2.1 m (7 ft), with sleeve port pipes spaced more closely where the peat layer was thickest.

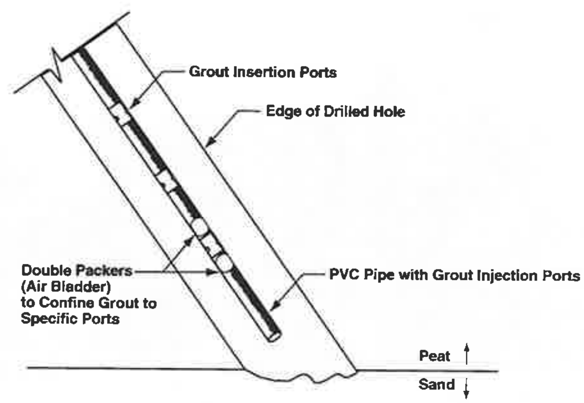

Figure 4. Grout injection concept.

The 50° sleeve port pipe was grouted first. After the grout cured in this location, it would provide confinement for the grouting in the 30° and 20° pipes. In all pipes, the ports near the ground surface were grouted first to seal the lower ports so that the grout would penetrate the peat layer instead of propagating to the surface. The initial grouting of the upper 50° pipe and the upper grout ports was done to seal the grout in the peat layer and prevent flow of the grout to the ground surface or into the adjacent layer. During grouting, volume was measured using a flow meter and the pressure was recorded on the grout pump. On average, 284 L (75 gallons) of grout was used for each port in the peat layer. The approximate total volume of grout pumped was 61,000 L (16,000 gallons). The sleeve port pipes were left in the embankment and the grout was washed from the pipes to accommodate future grouting, if any further settlement was observed.

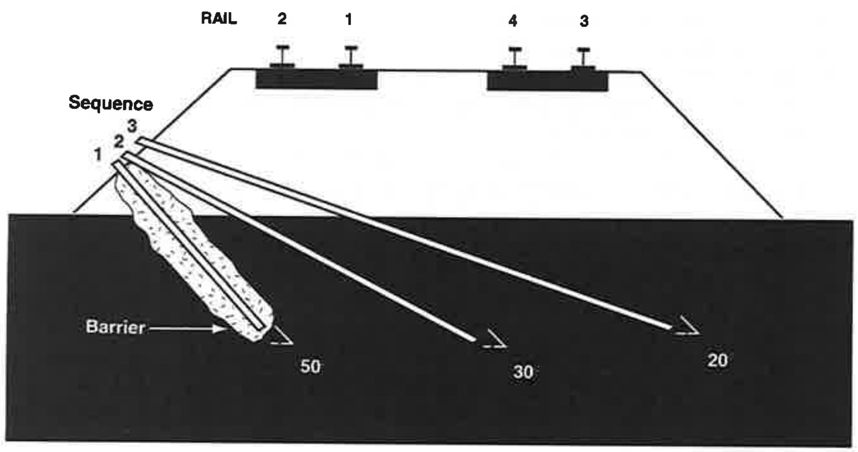

Figure 5. Sleeve port pipe installation plan.

A) Rig placement

B) Drilling grout holes

Figure 6. Drilling for grout injection pipe installation.

Post-Grout Monitoring and Maintenance

Track settlement was monitored by surveying the track elevation prior to and after grouting, directly before and after tamping, and over the 6 months following surfacing. The elevations were measured with a transit on the top of each rail every 13 m (50 ft) originating at the 1993 borehole (as shown in Figure 2). Figure 7 shows the measured changes in elevation. The track settled at an approximately uniform rate (5 mm/yr, 0.2 in./yr) for about 1 year after grouting, until the track was lifted and aligned. Track surfacing maintenance was conducted to lift and align the track in July 2001 and resulted in the 10-15 mm (0.4-0.6 in.) increase in elevation. Following surfacing (track lift and tamp), the behavior of the 2 tracks (rail 1 and 2 compared to rail 3 and 4) was different, likely due to rearrangement of the ballast, which was loosened by the surfacing operation, differently under each track.

After monitoring the track for 1 year after grouting, the maximum movement, 8.9 mm (0.35 in.), was seen on the west rail of the west track. The other three rails moved 6.4 mm (0.25 in.) or less. The total movement was probably not the result of consolidation settlement of the peat alone, but probably included movement in the ballast due to train action. During resurfacing, the rail was raised an average of 13 mm (0.5 in.). The observed movements over 6 months after surfacing was small and included heave on the west track, indicating that train loading may have had a larger impact on elevation changes than settlement. The railroad's conservative estimate of settlement prior to grouting was between 76 to 153 mm (3 to 6 in.) a year. After grouting, the settlement rate was reduced by more than an order of magnitude.

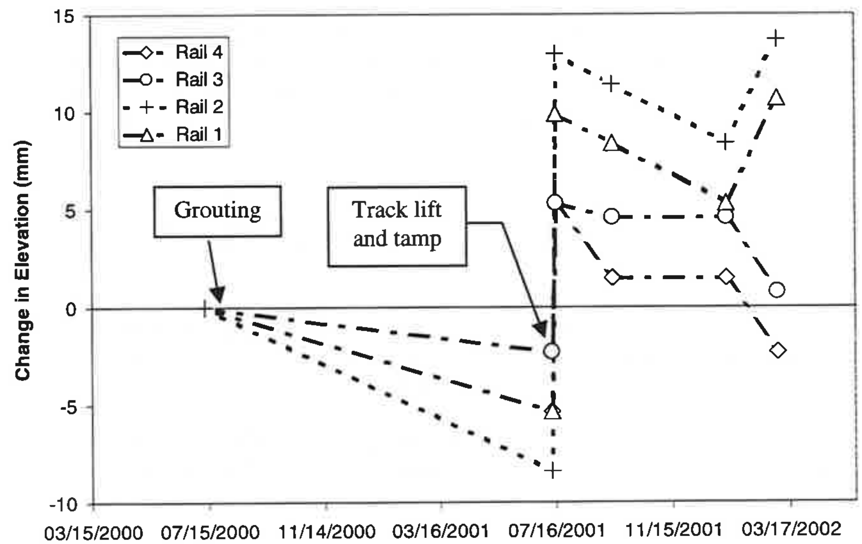

Figure 7. Settlement after grouting.

Conclusions

An investigation of a railroad embankment with a chronic settlement problem indicated that the source of the settlement was an organic peat layer underlying the embankment. The investigation consisted of several test borings using standard penetration tests to obtain samples and characterize the soil and one Shelby tube sample obtained from the fine-grained peat layer for laboratory consolidation testing. The embankment consisted mainly of dense sand, underlain by an organic peat deposit. A grout program was developed to compress, compact, or consolidate the peat layer.

Results from continued monitoring indicate that the settlement in the stabilized segment was reduced greatly after grouting and could have been eliminated altogether. For this scenario where the embankment was underlain by a relatively shallow layer of consolidating peat, early findings indicate that the compensation grouting has been effective. The MBTA has chosen to employ the method at other sites.

Future development of high-speed rail corridors will be needed to relieve congestion on highways and air routes between major urban centers. These developments require cost-effective and innovative techniques to improve existing infrastructure. In the example presented in this paper, a technique to identify the cause of an embankment settlement problem and to improve the condition of the embankment was demonstrated.

Acknowledgements

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ACTIVE SETTLEMENT CONTROL WITH COMPENSATION GROUTING - RESULTS FROM A CASE STUDY

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ABSTRACT: Near surface tunnelling in built-up urban areas has lead to the development of special geotechnical measures to protect buildings from damage resulting from undue (total and differential) settlements. In contrast to passive ground improvement techniques, compensation grouting is an active method applied to counteract subsidence induced by tunnel excavation. Compensation grouting is done in two stages: In the first stage grouting between the ground surface and the tunnel is performed for "conditioning" the soil. After the immediate response of the system is ensured, settlements monitored with accurate measurement devices are compensated in the actual grouting phase. In this paper compensation grouting operations for a tunnel excavation underneath a station building are described in a case study. The efficiency of compensation grouting is discussed for this practical example. To show the basic effects of compensation grouting, finite element calculations are provided for different stages of the grouting process and compared with in-situ measurements.

INTRODUCTION

The construction of shallow tunnels in urban areas requires special protective measure to prevent the structures within the zone influenced by the excavation from damage. To overcome problems associated with (total and differential) building movements, a variety of protective systems can be applied. After Harris (2001) protective measures can by divided into ground treatment measures, in-tunnel measures and structural measures.

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