Permeation Grouting for Tunneling Beneath Railroad Embankment and River Levee

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ABSTRACT

As part of a waste water sewer improvement project, twin force main pipes were to be installed beneath the Union Pacific twin mainline railway and the Riverfront Trail in South St. Paul, Minnesota. An 8-foot diameter casing for the force mains was to be tunneled for a length of approximately 260 feet, 25 to 30 feet below the active tracks through poorly graded sand to silty-sand below groundwater level. Along this alignment, the tunnel was to bore through and breach the City of St. Paul levee system adjacent to the Mississippi River.

The soil conditions beneath the mainline tracks and levee system were not ideal for tunneling. Due to the high water table and non-cohesive soils, soil stabilization by permeation grouting was performed ahead of compressed-air tunneling to provide additional ground support. Without stabilization by grouting, there were concerns that the Union Pacific mainline tracks could be adversely affected and interrupted as a result of the tunneling operations. The grouting program was designed to prevent settlement of the rail line. A sodium-silicate based grout was pumped from the surface using sleeve-port grout pipes. The grout pipes were installed between railroad ties and elsewhere in the railroad right-of-way with minimal impact to the day-to-day railroad operations.

This paper presents a summary of the ground conditions, site logistics including maintenance of rail traffic, and performance information collected during the grouting operation. Close coordination and proper planning allowed for successful completion of the project without measurable movement of the tracks.

INTRODUCTION

Twin 32-inch-diameter force main pipes were to be installed beneath the Union Pacific Railroad (UPRR) twin mainline railway and the Riverfront Trail in South St. Paul, Minnesota, as part of a waste water sewer improvement project. An 8-foot-diameter casing for the force mains was to be tunneled for a length of approximately 260 feet, 25 to 30 feet below the active railroad tracks and one of the City’s primary pedestrian transit pathways. Along this alignment a tunnel was to bore through and breach the City of St. Paul levee system adjacent to the Mississippi River.

GROUND CONDITIONS

The ground beneath the mainline tracks and levee system where the proposed tunnel was to be constructed consisted of poorly graded sand to silty-sand. The groundwater varied with the river elevation, typically 8-ft to 11.5-ft below grade. If left untreated, these soils had the potential to settle during tunneling operations, resulting in damage to the overlying railroad tracks.
The levee system running adjacent to the railroad tracks has been strengthened over the years. The top of the levee is nearly 25 feet above the surrounding terrain. The levee itself was constructed over time of varying layers of sand and silt, and protected with rip-rap on the river-facing side.

Due to the soil conditions, soil stabilization was required prior to the compressed-air tunneling. Specifications required permeation grouting to allow the railway and pedestrian corridor to remain active and not be impacted or settled as a result of the construction activities.

**GROUTING METHOD**

Chemical grouting is a permeation grouting technique used for a variety of applications including tunnel pre-support, underpinning, groundwater cutoff, and settlement control.

Chemical grouting was chosen for this project due to the highly permeable nature of the granular subgrade material. This permeation technique involves injection of a liquid sodium silicate-based material into a permeable soil requiring an increase in strength and/or a reduction in permeability. After a short duration (approximately 45 to 60 minutes), the grout solution hardens inside the soil matrix, increasing the strength of the soil.

Following treatment, the grouted mass will exhibit cohesive properties with a minimum unconfined compressive strength of 75 psi.

**GROUTING PROGRAM**

The primary intent of the grouting program was to prevent settlement of the ground surface and damage to Union Pacific structures during tunneling operations. By stabilizing the soils with chemical grout, the potential for areas of unconsolidated material and uncontrollable groundwater seepage was minimized.
Grout Pipe Installation

The grout pipes were installed vertically in predrilled holes (Figure 1) along the tunnel alignment (Figure 2), often requiring installation between the railroad ties, and elsewhere in the railroad.
right-of-way. The grouting contractor installed a total of 144 sleeve-port grout pipes (SPGP) on a typical square-grid pattern. Variations to the grid spacing occurred at locations with surface or subsurface conflicts, including several storm sewers and sanitary sewer lines ranging in size from 12 inches to 58 inches, a fiber optic line, and a gas line (Figure 3).

The site’s highly variable topography resulted in inconsistent drilling depths, requiring pipes to be installed to depths ranging from 20 feet to 44 feet. Despite the varying surface elevation, the treatment elevation was kept fairly consistent with a 0.5% down-slope towards the Mississippi River.

![Profile of grout treatment area.](image)

**Figure 3: Profile of grout treatment area.**

**Grout Pumping**

Following SPGP installation, a sodium silicate based grout was pumped from the surface. The SPGP system allows for grouting to be performed at discreet elevations established during the design phase of the project. Another benefit of the SPGP system is that grouting episodes may be repeated at any location if additional grouting is necessary. The grout effectively permeated the planned treatment area (Figure 4).

Approximately 65,000 gallons of grout were pumped. The grout was batched in an on-site pump house using computer controlled pumps to manage the mix proportions. From the pump house the grout travelled to a manifold system which then directed the grout to the appropriate grouting location.
Grouting Manifold and Data Acquisition

The grouting manifold’s electronic flow meters, pressure meters, and wireless capabilities were used to manage and record the grouting operation through an automated data acquisition system. This system provided real-time pumping data to the project team, and was a principal feature of the quality control program on site. Although multiple grout stages could be pumped at once, each grout stage was controlled and monitored independently by a qualified grout technician stationed in an office trailer on site. This grout technician observed and directed the grouting operation, including as many as 12 independent grouting procedures at once.

The project grouting specification limited the maximum grouting pressure to 0.6 psi per foot of overburden at each grouting location. The data acquisition system monitored the effective grouting pressure at each location, and alerted the grout technician when adjustments to the flow rate were necessary.

Grouting Sequencing to Address Lateral Groundwater Flow Concerns

The proximity of the grouting operation to the Mississippi River raised the concern of lateral groundwater flow in the treatment area caused by the natural flow of the river. The grouting sequence was developed to limit the possible “drift” effect of the grout prior to gelling. Consequently, the downstream row of injection locations was grouted first to create an effective barrier for the treatment area. In addition, a primary/secondary grouting sequence was utilized to evenly distribute the grout in the treatment zone and to minimize grout travel outside the treatment zone. After the primary grout stages and holes were completed, the grout technician and project team analyzed the performance of the treated area and adjusted the design parameters of the secondary holes as appropriate.
SITE LOGISTICS

Maintenance of Rail Traffic

The grout treatment zone spans two main lines. The tunnel alignment and treatment area intersected the tracks at a 25 degree skew.

Both mainline tracks were to remain in service during the permeation grouting activities. Train traffic consisted of approximately 5 to 10 trains per day, although most train traffic occurred in the early morning or late afternoon. Due to the proximity to the tracks, all work was overseen by a certified UPRR flagger.

At the beginning of each working shift, the grouting crews met with UPRR staff to discuss the day’s activities and the scheduled Form B. This meeting insured a safe working environment for the crews and that train traffic would not be interrupted. Work in high risk areas, such as between UPRR tracks or within the right-of-way, was authorized by the UPRR flagger, in communication with the UPRR dispatcher (Figure 5). Significant care taken during the grouting activities prevented fouling of the rail ballast with drill spoils or grout. Interruptions in work due to passing trains regularly occurred due to the proximity of the work to the mainline. This constant traffic required the grouting contractor to maintain mobile operations and to safely clear the track area within a reasonable amount of time at the request of the railroad. Constant communication and coordination between the UPRR and the grouting contractor allowed operations to proceed successfully and safely in this manner, and the UPRR was able to conduct its daily operations without impact.

Figure 5: Transporting the drill across the RR tracks.
QUALITY CONTROL
Performance Information Collected During Grouting Operations

The grouting contractor used its proprietary data acquisition equipment and software for real time monitoring of all grouting parameters during the chemical grouting process including flow rate, pressure, and total volume pumped. The data acquisition hardware on the grouting equipment wirelessly relayed this data back to the grout technician for analysis. A database server recorded data collected during grouting and produced a grouting log for each injection location (Figure 6). Use of this advanced monitoring and control system increased accuracy and efficiency, and reduced risk to the UPRR.

Figure 6: Sample grout log from the project
Testing of Grout Material

Grout samples were created periodically and evaluated for gel time and grout strength. The automated batching system used on site resulted in very consistent results. At the conclusion of all grouting operations, CPT (cone penetration test) testing was performed in several locations to verify the strength of the treated material (Figure 7). This investigation confirmed the presence of the successfully treated material, noting a significant increase in strength in the treated areas.

Figure 7: CPT testing after completion of the grouting program.

CONCLUSIONS

Close coordination and proper planning allowed for successful completion of the project, safely and without measurable movement of the Union Pacific mainline tracks. The work was sequenced to provide minimal impact to the day-to-day railroad operations.
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Matthew Didier, P.E.
Project Team

Owner:
- Metropolitan Council
  St. Paul, MN

Engineer:
- CNA Engineers
  Minneapolis, MN

Tunneling Contractor:
- Lametti and Sons, Inc.
  Hugo, MN

Grouting Subcontractor:
- Hayward Baker, Inc.
  Bloomington, MN

Railroad:
- Union Pacific Railroad

Project Overview - Bird’s Eye View

Proposed Tunnel Alignment - Plan View

South St. Paul Forcemain

Site Logistics - A lot going on...

Subsurface Conditions

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Soil Stabilization is Specified to Allow for Tunneling

- Permeation Grouting
  - Grouting technique that transforms granular soils into “sandstone-like” masses, by permeation with a low viscosity grout.

- Sodium Silicate ("Water Glass")
  - Inorganic chemical made by combining sand and soda ash (sodium carbonate) at high temperature

- Sodium Silicate Grout
  - Sodium Silicate
  - Catalyst
  - Water

Compressed Air Tunneling

- Liner plate tunneling operation
- Hand-dug tunnel

- Treatment specified at least 2-foot beyond limits of tunnel

Project Safety

- Safety was primary concern during planning and execution of work
  - Trains, Heavy Equipment, Workers, Pedestrians and Bicyclists

- Pre-Job Safety Plan
- Job Hazard Analyses
- Daily Toolbox Talks
- Safety Audits by crew and management

Railroad Communication

- Expecting ~10 trains per working shift
- 1/2 of work located on east side of tracks

- What is important to RR and Contractor?
  - Goal - Safety and No interruption to rail traffic
  - Daily coordination meetings
  - Hour by hour uncertainty
  - Flexible work schedule (15-30 mins to clear tracks)

Grout Pipe Installation

- Survey performed to determine grade elevation for every point
  - Maintain consistent treatment depth

- Injection pipe was drilled and grouted into place
  - Grid spacing

Chemical Grouting Operation

- Sleeve-port grout pipes allow for grouting at discreet elevations.
Grouting Production

- Grout was continuously mixed at the grout plant and pumped to grout manifold before being distributed to specific grout locations
  - Up to 12 locations at once
  - 65,000 gallons
- Grout lines placed in ballast cribs between ties
  - Hoses sleeved through 4-inch casing

Data Acquisition and Quality Assurance

- All pumping was monitored and controlled using a data acquisition system
  - Electronic sensors in manifold
  - Real-time analysis of multiple injection points
    - Flow Rate, Pressure, Volume, Temperature
  - Remote viewing capabilities

Maintenance of RR Traffic

- Significant care taken to protect tracks
  - Both tracks remained in uninterrupted service during grouting operation
  - Limited impact to grouting work also

Performance Testing

- Grout samples were obtained each shift to evaluate grout gel time and strength

- Following production, “Direct Push Sampling” was performed to verify stiffness of treated soils
  - Test results confirmed a significant increase in strength
Conclusion

- Close coordination and proper planning allowed for a successful completion of the project.
- The project was completed in a safe manner with no recordable injuries or near-misses.
- No measurable settlement of the UPRR tracks or levee occurred during construction.
- The work was completed with minimal impact to the day-to-day railroad operations.

Thank You!... Questions?

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