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SUPPORT OF TUNNELING WITH CHEMICAL GROUTING IN NEW JERSEY

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ABSTRACT: The Somerset Raritan Valley Sewerage Authority recently undertook construction of a treated wastewater outfall replacement project. The project consisted relocating a 72 inch concrete pipe utilizing conventional means and trenchless technologies. This paper focuses on ground improvements in the form of chemical grouting beneath three railroad tracks belonging to CSX Railroad to improve the successful completion of a 204-foot long tunnel section without exceeding the railroad authority's allowable track settlement of 0.75 inches. Northeast Remsco Construction served as the prime contractor for the work. Constellation Group LLC was retained as the grouting consultant. The settlement threshold limit included all settlements associated with the launch and receiving pits, required dewatering, and tunnel construction.

Project specifications required the use of sodium silicate grout for ground stabilization prior to tunneling. Sodium silicate has been used for many years in ground stabilization and support of excavations, but less frequently in conjunction with horizontally installed sleeve port pipes (SPPs) and tunneling applications. Soil conditions beneath the railroad tracks consisting of sand with gravel and cobbles, were deemed to be less than the ideal soil conditions for sodium silicate grouting (typically granular to fine grained soils). Complicating matters further, the soil borings taken from outside of the tracks and were not truly indicative of actual conditions.

A guided boring machine was used to install the 11 SPPs and allowed their installation from within the launch and receiving pits minimizing the work area required during construction. Use of a guided boring machine allowed installation of the pipes to extremely close lateral tolerances of within 1 inch of theoretical locations up to a distance of 204 feet away. After installation of the SPPs a comprehensive multi-staged chemical grouting program commenced. In total, nearly 85,000 gallons of sodium silicate grout were placed around the outside of the planned tunnel horizon. Grouting significantly reduced water flow from 60-100 gpm to 5 gpm into the operation pits. Tunnel construction was completed without reaching the allowable threshold settlement level.

1. INTRODUCTION

In summer 2010 the Somerset Raritan Valley Sewerage Authority (SRVSA) selected Northeast Remsco Construction of Farmingdale, NJ (NER) as their contractor to replace/supplement the existing outfall from their wastewater treatment plant in Northern New Jersey. As part of the project, a 204-foot long section of the proposed outfall pipeline needed to cross underneath three existing, heavily travelled freight railroad tracks. A trenchless solution was selected for this portion of the work. This consisted of installing a 108-inch diameter steel casing pipe on a zero percent grade using TBM construction methods to house a 72-inch precast concrete pipe (PCCP). Conventional open cut methods were used to complete construction of the outfall pipeline on either side of the railroad tracks.

CSX dictated a maximum allowable settlement threshold of 0.75 inches. Two pairs of the tracks have freight trains running several times per day. A significant contractual issue included maintaining the usability of these tracks and preventing disruption of the train schedule before, during and after tunnel installation. Ground improvements in the form of chemical grouting were implemented to meet the settlement threshold limit.

Sodium silicate chemical grouting prior to tunneling was selected by the Engineering Team (Mueser Rutlidge; Mellick-Tully, CDM) as the required ground improvement method. This stabilization was to control water flow, provide support of excavation through the tunnel zone and minimize settlement. The sodium silicate grout needed to be installed through horizontally directionally drilled sleeve port pipes (discussed later); again required because there would be no interruption of railroad activity for work on the tracks.

Northeast Remsco (NER) retained Constellation Group LLC (CGLLC) to help design the grouting program and execute the sodium silicate grouting operation. By performing this work in-house, NER was better able to control costs, and equally important, control schedule. Overall grouting operation duration, including HDD and SPP installation and pumping nearly 85,000 gallons of grout was about 8 weeks.

2. ENGINEERING- ANTICIPATED GROUND CONDITIONS

A total of 4 boreholes were completed in the vicinity of the railroad tracks by Mellick-Tully and Associates. The borehole logs and findings were provided in a geotechnical report. As with most railroad crossings, the geotechnical program was completed only where it was possible to setup the drilling equipment while maintaining freight traffic along the tracks with the assumption that the geotechnical conditions found between the railroad tracks were indicative of actual conditions beneath the tracks. Actual conditions under the railroad tracks varied significantly from those conditions on either side as discussed later. Some of these differences were caused during track construction, and subsequent reballasting (or adding stone to level tracks). See Figure 1.

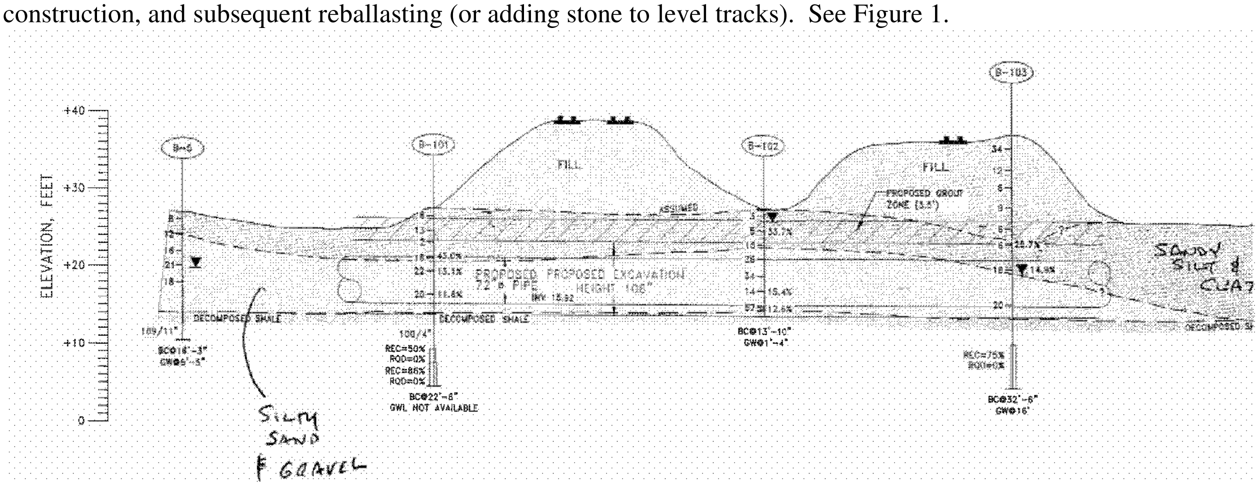

Figure 1. Geotechnical Cross Section of the Tunneling Zone

A review of the soil borings indicate conditions ranging from silty-sand near the surface, to fine to coarse sand and some coarse gravel at the soil/bedrock interface. The bedrock interface was approximately -16 feet below the ground surface, depending on boring location. The tunnel horizon would extend approximately 12 to18 inches into the decomposed shale layer. The ground water table was approximately 4-5 feet below the surface.

Based on the soil borings, ground treatment with sodium silicate was selected by the engineering team. Sodium silicate, as mixed and installed in the expected ground conditions, would perform very well, forming a collar around the anticipated tunnel path. See Figure 3 for the grouting plan.

3. SLEEVE PORT PIPE INSTALLATION

The design required delivery of the sodium silicate grout through sleeve port pipes (SSPs) installed using horizontal directional drilling or similar techniques. NER elected to use a guide boring machine (GBM) to install SPPs in lieu of more conventional HDD. The SPPs are also referred to as Tube-a-Manchettes (TAMs). These pipes are typically made of PVC or steel and have holes drilled at some intervals along its length. In the case of SRVSA, both PVC and steel pipes were utilized. Holes were drilled on 15 inch centers, with four holes located 90 degrees apart and covered with a heavy rubber banding-see Figure 2. A major advantage for this type of piping and grouting system is the ability to grout through each pipe multiple times, and to target specific locations. The ability to target specific locations multiple times along the SPP is facilitated by an inflatable packer.

The use of GBM installed grout pipes was necessitated because there could be no interruption of railroad activity. The SPP's were placed approximately 18 inches outside the planned tunnel bore and spaced about 2.5 feet apart. In addition to the SPPs shown in Figure 3, an additional SPP was installed at the 6:00 o'clock position to control water flowing along the soil/bedrock interface. The annular space between the bored hole and the SPP was filled with a cement-bentonite mix grout. Without filling this annular space, the sodium silicate grout would follow the path of least resistance, rather than permeate into the soil. When in a liquid state, this CB mix has the appearance of thick latex paint. After it hardens, this grout breaks (or fractures) like weak chalk or even crumbles.

Grouting sequence was determined by all parties to be performed in an alternating pipe pattern, starting from top to bottom. It was specified that three grouting passes through each SPP would be performed. This resulted in nearly 4,500 individual grouting episodes.

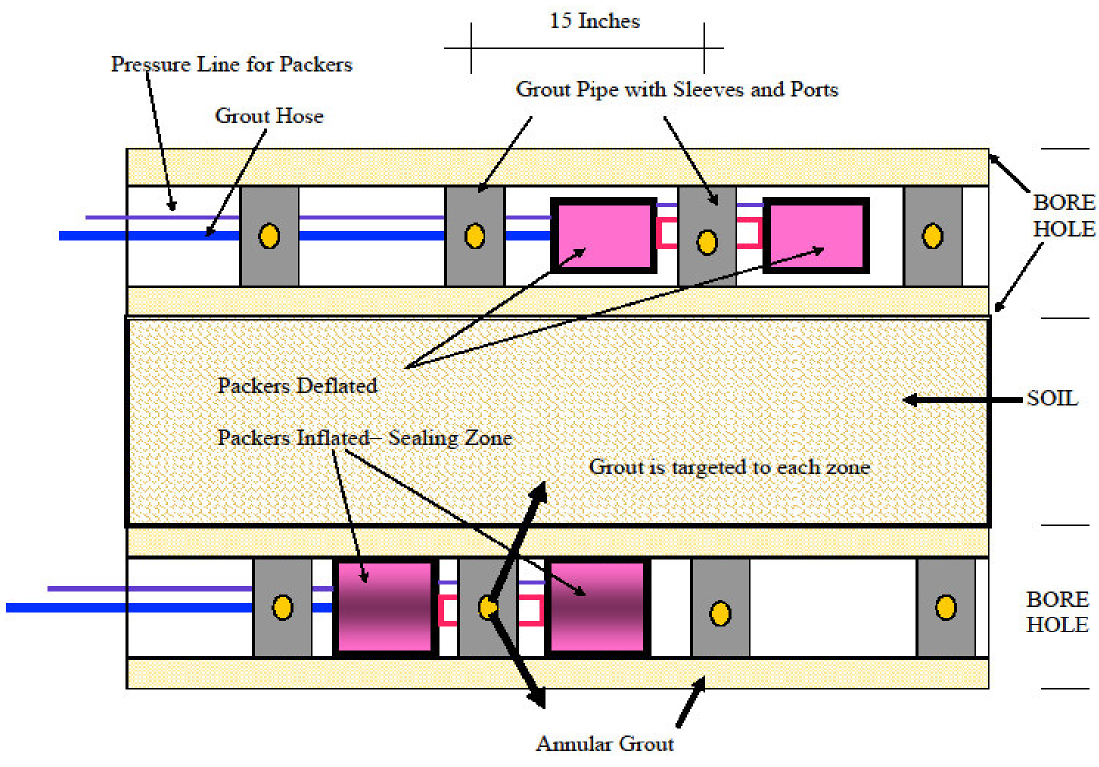

Figure 2. Typical Sleeve Port Pipe and Double Packer Operation

The double packer (two inflation bulbs) are located across a port and inflated. Grout is pumped to either a fixed volume or pressure, depending on specifications and geotechnical requirements. After this is completed, the packer is deflated and moved to the next port, reinflated; isolating that next port and the sequence is repeated.

4. PERMEATION GROUTING

In generic terms, this method of grouting is called Permeation Grouting. *The intent of permeation is to introduce grout into soil pores without any essential change in the original soil volume and structure (Ground Control and Improvement, Xanthakos, Abramson, Bruce 1994).* In the case of SRVSA, grouting served two purposes- provide a stable shell or crown for the Tunnel Boring Machine (TBM) to pass underneath, and to minimize water flow through the tunnel alignment. The presence of water at the face of the TBM increases the likelihood of wash-out or face collapse, not acceptable for tunneling operations. A wash-out or face collapse could cause settlement of the tracks above.

Permeation grouting is conducted under low pressure and flow rate parameters. If the grout is pumped too hard or too fast, the grout has a tendency to hydrofracture the soil rather than permeate. This fracturing will allow grout to travel to areas not requiring treatment, heave the ground or leave areas in the treatment zone untouched and otherwise not do the job at hand.

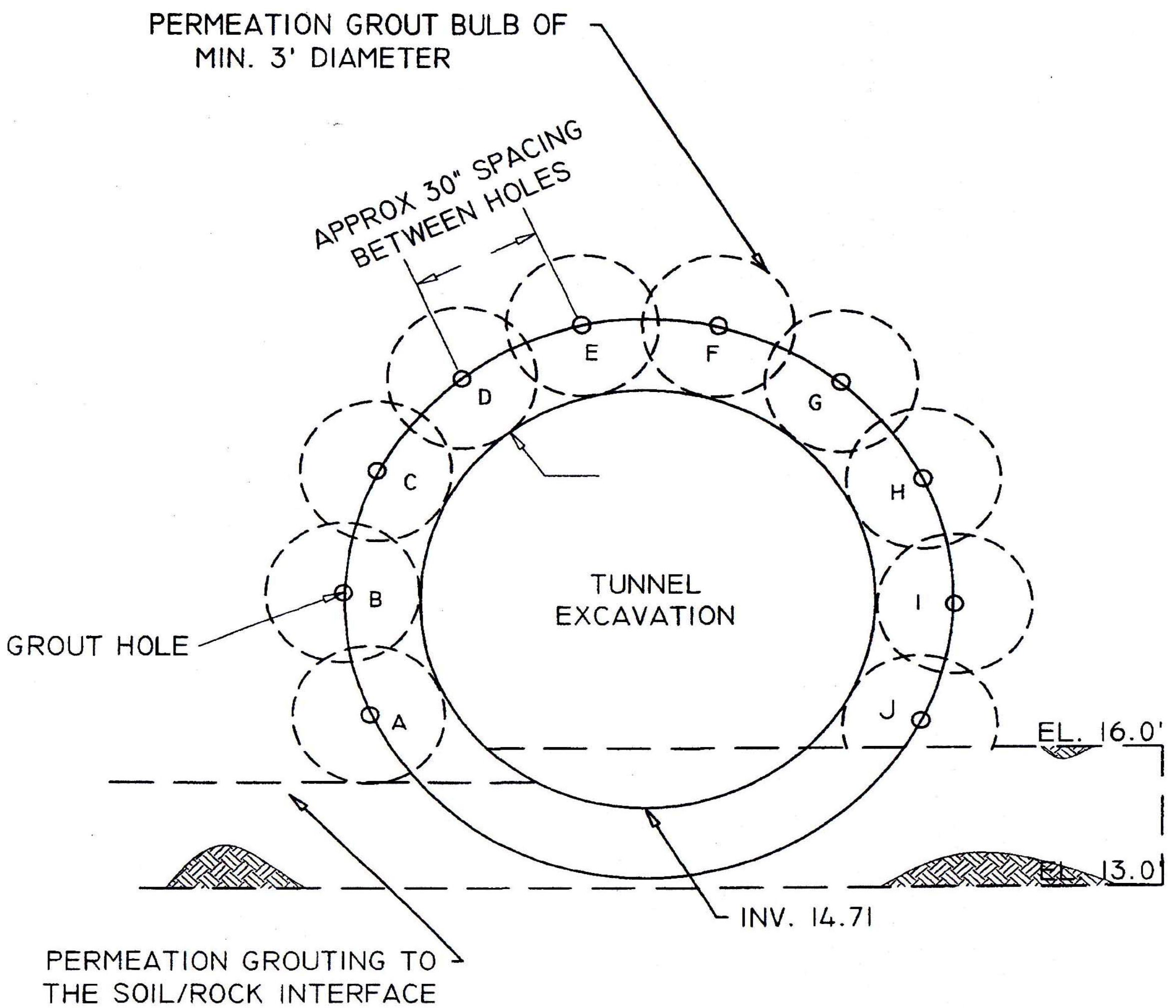

Figure 3. Preliminary Grout Hole Lay-out as provided by Northeast Remsco

5. SODIUM SILICATE GROUT and TRIALS

Sodium silicate grout is also referred to as water glass. If left out in the open raw sodium silicate will harden (eventually) into a nearly clear hard material. When mixed with water and appropriate reactant sodium silicate will become a semi-hard gelatinous material, with controllable set times, yet when fluid, has nearly the viscosity of water. It is frequently used for grouting in silty-sandy soils due to its ability to permeate into the soil using low pumping pressures. This is important when grouting under structures sensitive to high hydraulic pressures. Heaving the ground under railroad tracks would be just as detrimental as settling the tracks.

Prior to installing any grout into the ground, several tests were performed to examine the strengths, reactivity and behavior of the sodium silicate. Suppliers had to be identified and samples acquired. PQ Corporation was selected as the sodium silicate supplier, perhaps the largest in the US. PQ has a Grade N sodium silicate that has been used for ground stabilization for many years and is manufactured locally. BASF was selected to provide the reactant, a proprietary chemical used by CGLLC for many years with great success. This reactant produces a very stabile, uniform grout. The third component is water. The percentage of water used controls the overall strength of the grout. In this application, 40% sodium silicate was used, providing a good combination of strength and low viscosity. The final component is calcium chloride. Used in very small dosages, calcium chloride is an accelerator to the reaction and allows for adjusting set times. Typical dosage rate varied from 0.25% to 1.00% of total solution.

Sodium silicate grout set times are sensitive to temperature. During the course of operations, ambient temperatures varied as much as 60 degrees F. Calcium chloride dosages varied with the temperature (increasing dosage rate with decreasing temperature). Targeted set times were in the 20-50 minute range. See Table 1.

Table 1 Shop Test Set Times for Various Samples

Date		0% Accelerator	0.5% Accelerator	1% Accelerator*	2% Accelerator*
7-Jan-10	Start Gel	150 minutes	N/A	75 minutes	24 minutes
Temp 51.2 F	Gel	157 minutes	N/A	80 minutes	35 minutes
9-Jan-10	Start Gel	61 minutes	45 minutes	27 minutes	N/A
Temp 65.4 F	Gel	68 minutes	50 minutes	34 minutes	N/A

6. GROUTING EQUIPMENT

Sodium silicate grouts are usually pumped through a pair of pumps- Side A being sodium silicate and water; Side B being reactant, water and calcium chloride. These two components are combined prior to the packer. In rare instances and small quantities, all components can be batched and pumped through one pump, but is generally not permitted by specification. In the case of NER/SRVSA the grout plant consisted of four pairs of primary grout pumps, feeding four grout hoses. Each grout hose was terminated with an inflatable dual packer. These packers isolate each port (group of four holes) on the SPP and permit grouting in a specified location. Flow meters and pressure gauges on each line gave volume and pumping pressure for each pair of pumps.

Sodium silicate was delivered to site via tanker truck and stored in large 3,200 gallon polyethylene tanks. The reactant and calcium chloride was delivered in 275 gallon chemical totes. Both the reactant totes and the large sodium silicate poly tanks were plumbed into their respective mixing tanks. A water truck was used for the final component. Calcium chloride was added manually. After the respective materials were mixed, they were transferred into pumping tanks, and thereafter pumped by their respective A and B pumps. Pumps and hoses were colored coded for identification. Figure 4 shows the grout plant.

As each A&B component was pumped, they were mixed in a static mixer and then down the grout hose to the SPP. Pressure and volume was measured and recorded on each grout port.

Figure 4. The Grout Plant

7. QUALITY CONTROL AND RECORDKEEPING

Every batch of grout was recorded for quality control purposes. In addition, periodic samplings of mixed grout were taken to monitor set times. Each grout episode (pipe and port location) was recorded as to volume and pressure. Written records taken daily were then computerized. Grout episode volumes recorded each day were balanced against the daily batch tickets. Periodically, samples of grout were mixed with sand and checked for compressive strength. Typical requirements are 100 psi for grout/sand samples, yet higher compressive strengths were realized.

It was during GBM operations that varying ground conditions were encountered, particularly under the track locations. At the upper tunnel bore locations, the ground tended towards silty-sandy, but at the lower elevations, gravelly to cobbly conditions with voids were found. It was in these lower locations that steel SPPs were installed. Additional C-B mix was pumped to fill these voids. Without filling these voids, the sodium silicate would have flowed in the path of least resistance and not stabilized the needed grout zone.

Figure 5. Sleeve Port Pipes Going In

8. SURVEYING and MONITORING:

Surveying of the tracks was performed from before launch and receive pit installation until after final tunnel installation. The maximum allowable Threshold Limit Level for settlement was 0.75 inches. After launch and receive pit dewatering and prior to SPP installation and grouting, an average 0.375 inch settlement was recorded, leaving just 0.375 inch allowable settlement for grouting and tunneling operations. During the eight weeks of SPP boring and grouting, virtually no appreciable movement was detected. During and after tunneling, little movement was detected and the project stayed well within Threshold Limits. The grout program proved very effective.

9. GROUTING OPERATIONS:

Northeast Remsco, with input from Constellation Group LLC, built the grout plant on site. This included the grout pumps, transfer system from bulk to mixing stations and from mixing stations to pump tanks. After the grout plant was set up and the boring and SPP installation was completed, grouting commenced. Contract specifications required three passes on each grout pipe. With approximately 164 ports on eleven pipes, this resulted in nearly 4500 grout episodes. On the third pass, an inflatable packer utilizing a large cage allowed for grouting two ports simultaneously. Grouting operations took place at the receiving pit for logistical reasons- more room for equipment and trucks. Each pair of grout pumps required a 250 foot grout hose, connected to an inflatable packer. Paired with each grout hose was an air-pressurization hose for the packer. The hoses were colored coded, along with the pumps and control valves for identification. The hose/packer assemblies were pulled through the SPPs to the launch pit, and from this point grouting commenced, working back towards the receive pit. Each port was identified, #1 starting at the launch pit, #164 at the receive pit. SPPs were labeled from A to K.

The hoses were not only colored coded, but marked with port numbers as well- see Figure 6. At any given point in time, an individual hose could be indentified and the port being pumped could be determined. This proved important as certain zones required additional grout at later times.

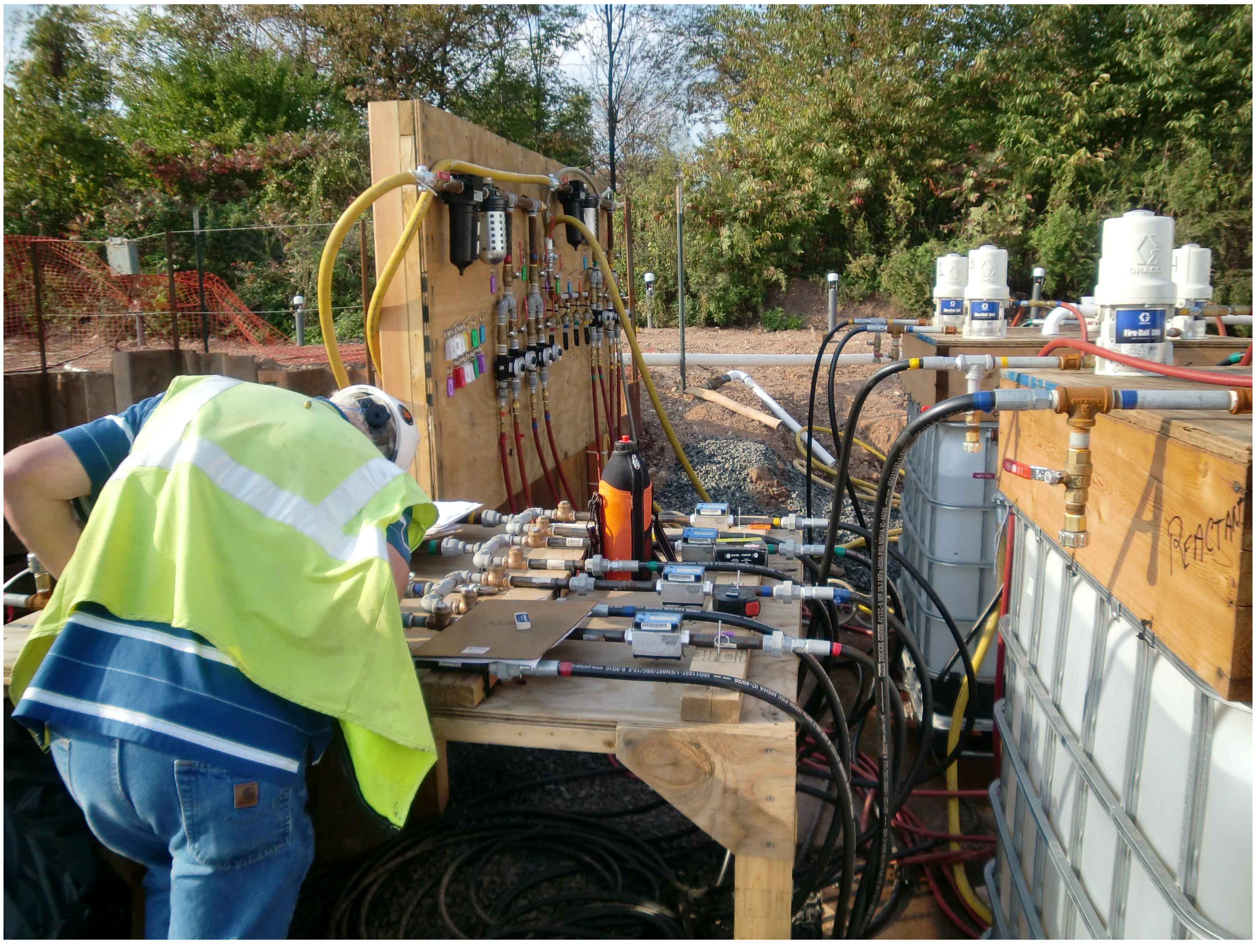

Figure 6. Grout Operations
Note Color Coding for Identification

The grouting sequence started with two upper SPPs, but staggered by one laterally. The second upper two SPPs were grouted the next day. This sequence was continued down along the tunnel grout zone until all ports were grouted once. The second and third passes were performed in a similar fashion. The total volume for each port averaged about 45 gallons of grout. This is a substantial amount of material, given the effective zone requiring grouting. The overall controlling factor was to minimize railroad track settlement, as exceeding the Threshold Limit for Settlement would have shut the project.

In this project, volume per port was the controlling factor, while monitoring pressure. It was noted during the second and tertiary passes that grout pumping pressures increased, indicating improving soil conditions. There were no requirements for testing ground permeation.

Another noticeable improvement during grouting was the reduction of water in the launch and receiving pits. The daily groundwater discharge volume was monitored. By the time grouting was completed, ground water discharge was down 75-85%. During tunneling operations, ground water encountered in the tunnel bore, a potential serious project threat, was reduced to a trickle. This minimized the possibility of tunnel face collapse. Tunneling was successfully performed by Northeast Remsco utilizing an in-house modified Tenbusch TBM.

Figure 7. The Receive Pit is Dried Out

10. CONCLUSIONS

Sodium silicate grouting has been around for a long time. Using horizontal directional drilling or bored grout pipes, support of excavation grouting can be performed from one location over substantial distances. Teamwork and planning are involved in a successful grouting operation, allowing the tunneling contractor to perform his primary goal of safely getting his bore complete. By stabilizing the ground prior to tunneling, NER was able complete its operations under the railroad tracks without comprising the settlement threshold of 0.75". Working with the Engineering Team, adjustments were made to the grouting program, 'on-the-fly'; resulting in a project completed safely and on schedule.

11. REFERENCES

Xanthakos, Abramson, Bruce 1994 Ground Control and Improvement, - for additional information on permeation and other grouting techniques