USING CHEMICAL GROUT TO CONTROL GROUNDWATER INFILTRATION

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Chemical grouting has been successfully used for over forty years to control the movement of groundwater in a wide variety of applications including tunnels, subway systems, sanitary sewers, mines and construction projects. This paper illustrates the versatility of chemical grouts by reviewing three projects featuring acrylamide grout for difficult water control challenges and a fourth project using urethane grouts for stabilizing soils, filling voids and lifting concrete slabs a with structural, high-density foam. Controlling groundwater aids in solving structural problems before, during, and after construction.

The featured product is acrylamide which can be used alone or in conjunction with other types of grout such as cementitious products. Acrylamide grout is injected as a two component product that will react and form an impermeable gel when the components combine. There are notable differences between the acrylamide based products and cementitious products. The most notable and significant difference is that acrylamide is a true solution grout that contains no particulates and has a viscosity of one-two cps. This feature enables the acrylamide grout to penetrate very small geological features that other grouts could not penetrate and to seal small cracks and fissures where groundwater seepage is occurring. The product also has an adjustable gel set time from a few seconds to several hours which enables the operator to determine the product travel before it forms a gel. When properly applied the product has a half-life in the soil of 362 years (per testing by the US Department of Energy).

Keywords: Groundwater, Infiltration, Stabilization, Pre-Excavation, Acrylamide, Viscosity, Restoration, Hydrophobic, Tunnel, Underground, Permeability, Encapsulate, Grout

Project I.

The City of Dearborn, MI was cited by the EPA for combined sewer overflow violations. The City elected to address these violations by constructing two 120' diameter by 150' deep shafts to collect and treat the sewer overflows that occurred during storm events. These shafts are positioned adjacent to outfalls along the Rouge River. The initial site investigations revealed that several types of very porous geology were located in the 150' shaft depth and that artesian conditions were also present. In addition, methane and hydrogen sulfide were detected in the groundwater.

Engineers and consultants elected to perform a pre-excavation grouting program around the perimeter of the two shafts prior to construction to prevent problems with water and gas entering the shafts during excavation and construction. The grout selected was required to meet the following performance criteria: i) Very low viscosity in the range of one-two cps capable of penetrating all of

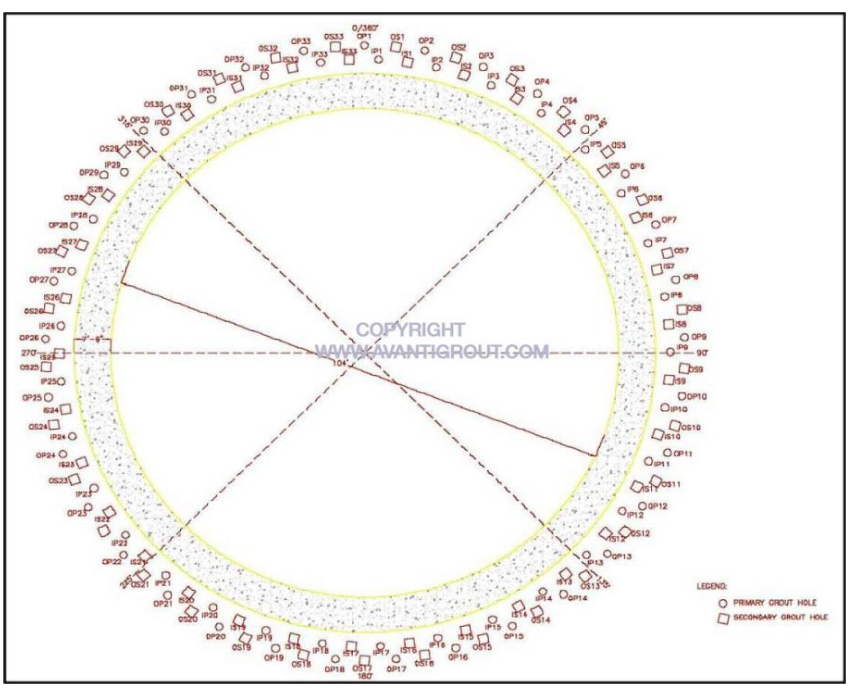

Figure 1. Grout holes on the perimeter of the shaft

the site geology which included silt, clay, glacial hardpan, gravel and rock, ii) Adjustable set times from a few seconds to several hours, iii) Chemically resistant to gases present which included methane and hydrogen sulfide, iv) Strong enough to withstand the artesian pressures of up to 100 psi, v) Compatible with the construction techniques being utilized and vi) Cost effective when compared with other options. Acrylamide grout was the only product that met the above stated.

An infiltration rating of two lugeons in the soil around the two shafts was established by engineers as the maximum water infiltration that could be accepted. Two grout curtains were established around the shaft perimeters, the outer curtain was formed using cementitious grout and the inner and less permeable curtain was formed using acrylamide grout. Testing revealed that the grouting program achieved a final permeability of 0.2 lugeons, ten times better than the specified objective.

Pre-excavation grouting for the City of Dearborn created one of the largest acrylamide grouting projects ever performed in North America and the final results far exceeded the original project requirements. The project was completed during some very challenging weather conditions including snow and freezing rain and was completed without any safety or environmental issues.

Project II.

Acrylamide grout was also utilized to complete a hazardous waste containment project at the Oak Ridge National Laboratory (ORNL) facility. In 1985 federal and state regulatory agencies began close monitoring of the waste management operations at the US Oak Ridge National Laboratory and other US Department of Energy (DOE) sites. At Oak Ridge, they discovered that remote monitoring wells were indicating radioactive waste leaks from several burial trenches containing mixed (radioactive and hazardous) waste. They concluded that the DOE did not have adequate solutions for long-term containment of the waste materials and a comprehensive study was undertaken to identify an acceptable containment method. Acrylamide grout was selected as part of the program because there is a long history of test work at ORNL which demonstrates that of the available grouting materials, acrylamide is the only material with a history of withstanding radiation exposure satisfactorily over time. US DOE testing also demonstrated that if acrylamide is properly injected into the soil it has a half-life of 362 years.

The project entailed encapsulating a large volume of mixed liquid and solid waste from the Manhattan project that was stored in several trenches at the facility. The largest of the trenches, trench five, is 300' long, 10' wide at the surface, 15 feet deep and 4' wide at the bottom of the trench. Polyethylene sheeting was originally used to contain the waste in the trenches. Fractures subsequently developed in the geology surrounding the trenches providing pathways for the contaminated liquid to seep into the soil and also into the groundwater which was located about 25 feet below the bottom of the trenches. To contain the waste material in the trenches, cementitious grout was injected into the trenches and acrylamide grout was injected into the surrounding soil to encapsulate the waste material. Injection of the grout was accomplished using sleeve pipes with rubber sleeves that function as valves to allow the grout to exit but prevent any contaminated material from exiting the trench. After completion of the project no further contamination has been noted in any of the monitoring wells around the project site.

Figure 2. Acrylamide chemical grout injected via probes to encapsulate hazardous waste, cementitious grout in the trench and acrylamide grout in the soil adjacent to the trench

Project III.

The Toronto Transit Commission (TTC) subway system is one of the largest in the world with over 27 miles of underground tunnels and numerous below grade structures in varying geological zones and hydrological conditions.

The geology includes glacial till, rock, gravel and silt. The tunnels were constructed in 1954 using three different types of construction, concrete box, precast concrete circular lined and cast iron circular lined, and for many years did not receive any sort of major restoration. As a result, water infiltration had been a problem with the TTC since the time of construction and numerous water leaks had developed throughout the system. Only emergency repairs were done on an as-needed basis to control the water infiltration problems. These problems included electrical and mechanical system problems and structural problems. It was determined that tunnel leak remediation was necessary as a result of these and other problems with water intrusion.

A regular program of maintenance was established in 1997 with the formulation of a tunnel leak remediation crew. The crew is comprised of 13 TTC employees who perform all of their work during times that the subway is not in operation. TTC consulted with a number of experienced grouting professionals during the development of their program and elected to utilize an "in-house" design-build approach to address the large and complex scope of work.

The mechanism for water infiltration into the tunnels is predominantly via the expansion and construction joint systems. The groundwater table is typically above the tunnel roof and is the source for all of the water infiltration problems. The grouting repair technique that has been successfully used to stop the water infiltration into the tunnels is curtain grouting. Curtain grouting creates a curtain of grout in the soil outside of the structure thereby preventing the water from contacting the structure surface. Acrylic grout is injected into the soil surrounding the tunnel structure where the grout permeates the voids in the soil and sets to form an impermeable soil/gel water barrier or curtain around the tunnel exterior. Extensive testing revealed that acrylamide grout was the best product for use under the challenging geological and hydrological conditions. The tests included the viscosity of the product (one-two cps), permeability of the grouted soil, ability to control gel set times to accommodate the varying geological and hydrological conditions (a few seconds to several hours), the longevity of the applied grout (US DOE tested to have a half-life of 362 years in the soil) and the ease of application. The success of this program has been exceptional and is still on-going.

Figure 3. Chemical grout permeating the soil to create an impermeable grout curtain

Project IV

Constructed in late 2010, a new elementary school in Jalisco, Mexico welcomed students in August of 2012, but only after satisfying engineers that the building was structurally sound. Carved into the foothills of the Sierra Madres mountain region, the building site had a 20% grade which included a 16 ft. retaining wall to the west of the building and natural grade to the east. Within one year, various signs of structural movement indicated settlement of the primary building and vertical cracks in the retaining wall.

Unfortunately, the retaining wall had no drainage system to relieve the hydraulic pressure and groundwater runoff from rain events. Therefore, the water trapped behind the retaining wall saturated the soils causing the building to settle and the retaining wall to crack. Soil testing indicated moisture content of soils behind the wall and below the slab at 7.2%, about four times greater than the norm.

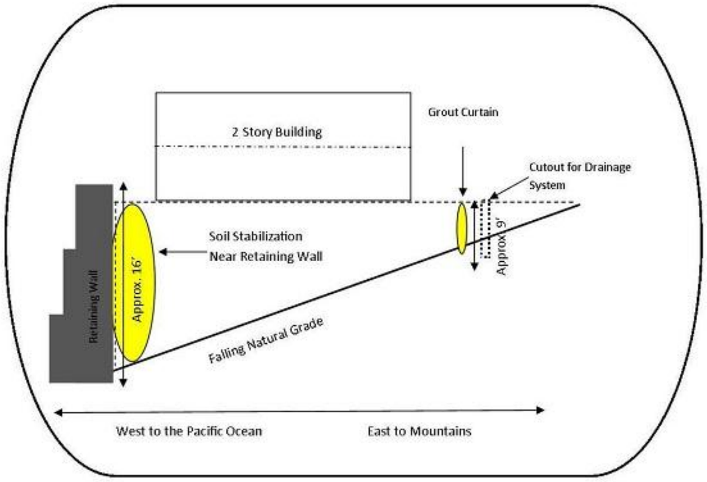

Figure 4. Diagram of site plan showing building, retaining wall, and slope, as well as curtain grouting and soil stabilization locations

Located just 10-12 feet from the retaining wall, the two-story building was constructed with 22 concrete columns supporting a concrete roof, concrete walls, concrete floors and concrete walkways. The estimated point load of each column was between 30,000-40,000 pounds. Initially, the scope of project called for lifting the two columns nearest the retaining wall which had dropped 2.8 inches. Between the columns, the concrete floors had sagged up to seven inches.

Before any building component could be structurally lifted, four preliminary steps were required:

Step 1: To protect against additional erosion and groundwater drainage problems, curtain grouting with hydrophobic foam was required to the east of the building or positive side of the runoff. The chemical grout used for creating the impermeable curtain was injected as a single-component, moisture-activated, hydrophobic polyurethane resin. Set times were controlled by a catalyst and in this case equaled 5%, which allowed the resin to achieve greater permeability before expanding.

Step 2: The retaining wall was injected with an epoxy to mitigate further damage or deterioration, and reinforce the wall where existing vertical cracks penetrated the entire thickness of the wall.

Step 3: Due to gravity, weight of the soil, and hydraulic pressure behind the retaining wall, two rows of hydrophobic foam were injected six feet apart. The intent of this soil stabilization technique was to displace water and prevent excess moisture in the future. The contractor used a low-viscosity, single-component resin which created a dense, closed-cell, semi-rigid foam that was impermeable to water.

Step 4: Inside the building, it was necessary to re-stabilize the supporting soil and address the voids beneath the concrete slabs ranging from three to fourteen inches. The structural foam used beneath the slab was a dual-component, hydrophobic resin (capable of withstanding wet/dry cycles) injected at a one-to-one ratio.

With the four corrective and preventative measures completed, stabilizing and lifting the columns became a one-time, permanent repair. Ultimately, 10 of the 22 columns were lifted. Of the desired 2.8 inches, 2.2 inches was achieved safely before the retaining wall began to show signs of stress. With the ground stabilized, voids filled, and soil moisture reduced from 7.2% to 2.1%, leveling the interior slabs to desired grade was accomplished successfully and with ease.

Chemical grout was preferred over cementitious grout due to the following characteristics:

- No shrinkage
- Up to 20-x expansion
- Fully cured in minutes versus days
- Light weight (4-lbs. cu/ft. versus 140-lbs. cu/ft.)
- Compressive strength— 90 PSI

To complete this project, the contractor performed Curtain Grouting, Soil Stabilization, Void Filling and Slab Lifting. As a result, the contractor eliminated the source of the problem, saved the structural integrity of the school building, and completed the project in the allotted 10 days—within one month of the school opening on time.

Figure 5. Photograph of the west end of the school building near the retaining wall

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