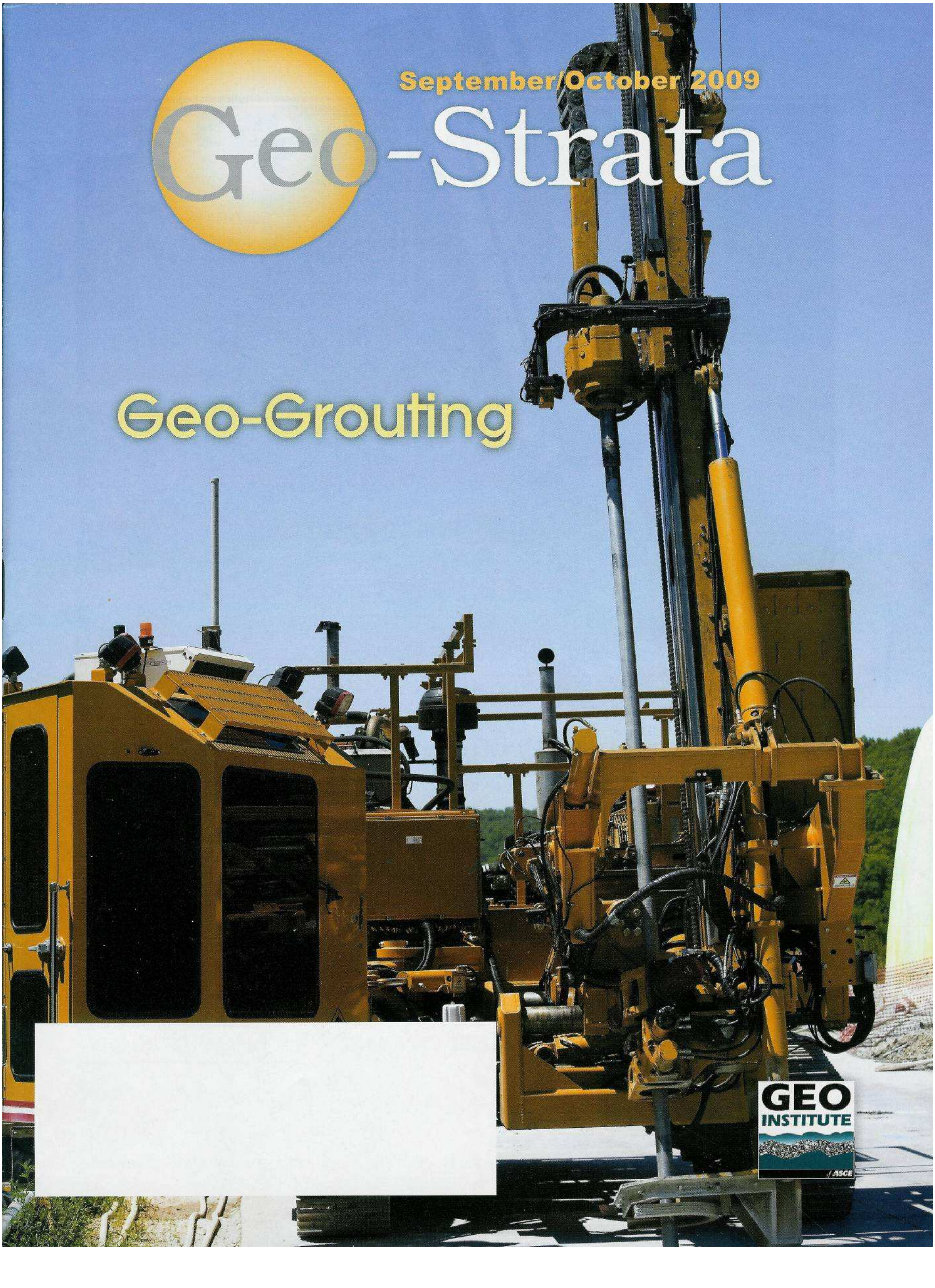
September/October 2009

Geo-Strata

Geo-Grouting



Pre-Excavation Grouting of Contact Zone and Rock Formation

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Figure 1. City of Dearborn, plan of CSO sites (courtesy of Layne GeoConstruction).

The Environmental Protection Agency has cited combined sewer overflow (CSO) discharges as a significant source of pollution to the nation's surface waters and, in the Clean Water Act of 1972, called for the correction of water quality problems caused by discharges from combined sanitary and storm sewers. The City of Dearborn, MI has chosen to accomplish this task by constructing large-diameter shafts to collect and treat the large combined overflows during storm events. These shafts are strategically positioned adjacent to outfalls along the Rouge River and were constructed utilizing traditional concrete shaft sinking techniques to bedrock.

Geology

Geotechnical investigations for two of the 120-ft-diameter by 150-ft-deep shafts revealed a highly permeable layer of soil and fractured rock, designated as the Contact Zone, directly above the underlying competent, but fissured, bedrock. The Contact Zone thickness varies from 0 to 20 ft and consists of sand, silt, gravel, and fractured limestone. This highly permeable zone is under considerable artesian pressure and, combined with the presence of naturally-occurring methane and hydrogen sulfide gas within the groundwater, presented a significant challenge for shaft construction.

Below the Contact Zone, layers of pervious limestone capable of producing an inflow of thousands of gallons per minute presented the next challenge. The geotechnical investigation concluded that dewatering was not feasible. A grouting program was implemented to construct a circular grout curtain within both the Contact Zone and the bedrock to minimize water and gas infiltration during the shaft construction process. The goal of the Contact Zone and rock grouting program was to create a grout curtain with an average residual permeability of 2 Lugeon (approximately 20 ft/yr).

Construction

To achieve the project objectives, the selected grout had to withstand the harsh environment produced by hydrogen sulfide and remain intact for the duration of the construction project. Furthermore, a non-evolutive, low-viscosity solution grout with adjustable set times was required to permeate the various soil strata encountered in the Contact Zone and the fine features in the bedrock formation. The ultimate strength of the grout was also considered in the selection process, as the grout had to be weak enough to facilitate multiple injection passes in the Contact Zone and, more importantly, had to be compatible with the caisson-sinking technique. Finally, the cost of the grout played a role in the selection process. Based on these criteria, the engineer concluded that an acrylamide-based solution grout was the most suitable grout to permeate the soils in the Contact Zone and fine

Figure 2. Production oriented drill rigs during drilling of grout holes (courtesy of Layne GeoConstruction).

features in the bedrock. Cement-based grout was selected to permeate the larger features encountered in the bedrock.

Acrylamide is a monomer that is used as an aqueous solution in geotechnical grouting applications. Three components are mixed together to obtain a grout polymer solution. Polymers are subunits (monomers) joined together like beads in a necklace. The acrylamide grout represents a true solution grout, as it is a liquid without suspended solids and has the viscosity of water. The acrylamide solution grout penetrates the pore volume of the soil matrix and quickly changes from a liquid to a gel-type solid.

The Contact Zone grouting program involved the installation of a double row grout curtain around the perimeter of the future shafts. Each grout hole was cased and drilled 3 ft into competent rock. The overburden was drilled using a rotary duplex with air and water flush through 75-85 ft of glacial silts and clays, 10-20 ft of sand, silt, and gravel (hardpan), and 10-20 ft of clay, silt, sand, and gravel to the rock interface. An overburden casing outfitted as a sleeve pipe (OCSP) was installed into the bottom of the cased hole and extended by riser pipe to the ground surface, through which grouting could later take place. Barrier bags inflated with cement-based grout were installed within the hardpan zone to eliminate artesian flow conditions during grouting operations. All drilling and installation of OCSP was conducted prior to the acrylamide grouting program.

Acrylamide-based grout was then injected into the Contact Zone through the OCSPs in a stage- or bottom-up fashion. Different grout formulations were selected to grout the Contact Zone, utilizing either 23 percent concentrated acrylamide or 11.5 percent concentrated acrylamide, depending on the number of injection passes in the area and the encountered soil conditions. Upon gelation, the acrylamide was flushed from each hole to facilitate multiple passes of grouting from within each sleeve pipe. An engineering evaluation of the real-time monitoring data was conducted after each hole was grouted to evaluate the need for additional grouting. All holes were grouted utilizing the split spacing method. The inner row grouting was performed first, followed by the outer row grouting.

The second part of the pre-excavation grouting program was the rock grouting program. The outside row of grout holes was used to fill the larger features amenable to cement-based suspension grout, and was grouted first. This was followed by the drilling and grouting of the inside row, predominantly using acrylamide grout. After conducting an acid stimulation program, each hole was injected in one stage and one pass. The grout curtain extended to 50 ft below the future shaft bottom.

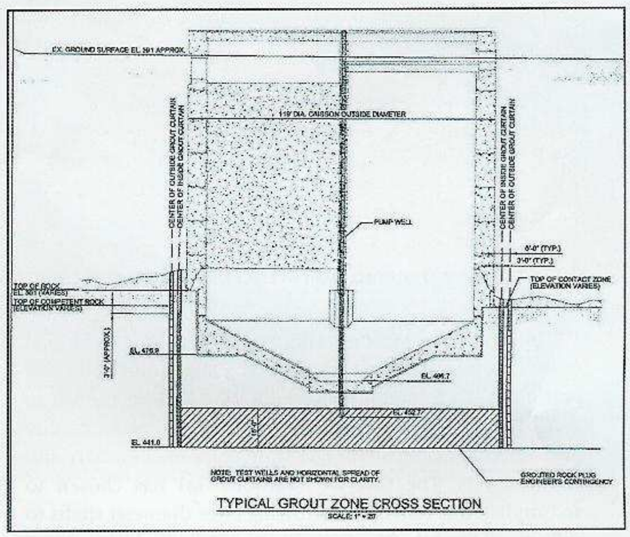

Figure 3. Cross-section of shaft (courtesy of NTH Consultants Ltd.).

The rock drilling was done by using down-the-hole water hammers. The water hammers lessened the amount of hydrogen sulfide released into the atmosphere, increased production, and provided a cleaner hole for grouting. Grouting operations were monitored, evaluated, and recorded using a real-time grout monitoring system. Two monitoring stations were located adjacent to the grouting circumference in a temperature-controlled trailer, each capable of monitoring up to four separate grouting operations simultaneously. Two engineers from the design team constantly monitored and evaluated the grouting data

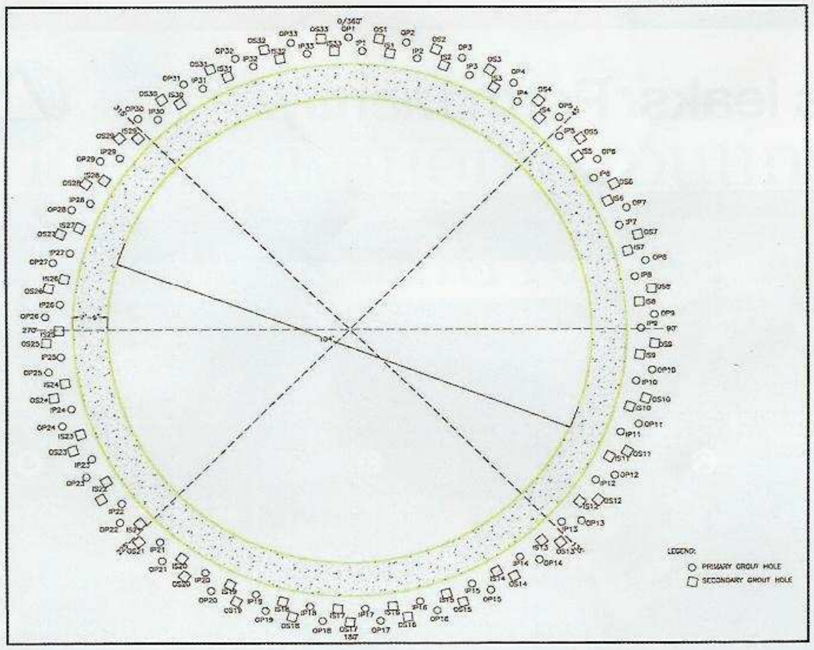

Figure 4. Plan of two-row grout curtain around the perimeter of the future shaft (courtesy of Layne GeoConstruction).

and field operations to maximize the performance and efficiency of the grouting program.

This acrylamide grouting project is one of the largest in North America. The grouting contractor designed a sophisticated acrylamide mixing and placement system to handle the large volume capacity of the project. The acrylamide grouting plant, tank storage farm, and grout mixing and pumping set-up were all designed to accommodate grouting in excessive weather conditions such as sub-freezing temperatures, rain, and extreme heat. A state-of-the-art automated batching system, along with a closed ventilation system and stringent personnel safety procedures, enabled the acrylamide grouting to exceed all industry standards for safety.

Safety training of all the personnel was also provided by the acrylamide grout supplier. Environmental concerns were addressed by a combination of double containment tanks, self-erecting portable containments, and closed system designs. The central header container was designed to both mix and control flow and pressure to eight separate enclosed and temperature-maintained grout carts, each containing powered grout reels to lower inflatable packer assemblies to depths of up to 230 ft.

Program Results

Throughout the grouting program, monitoring software was utilized to evaluate the apparent permeability values in real time. Following each injection pass, the residual permeability values of the formation were evaluated. After grouting was complete, several samples of the grouted Contact Zone were retrieved, providing further indication that the Contact Zone had been successfully grouted. A pump test revealed that the residual permeability of the rock formation and Contact Zone had been reduced to 0.2 Lugeon. Inflow into the unlined shaft protected by the grout curtain is anticipated to be less than 10 gpm.

Special Challenges

CSO projects can entail construction across large geographic areas and often pose special construction challenges often due to the presence of poorer ground conditions along rivers and other water courses. As a result, geo-designers, specialty geo-constructors and product suppliers need to work collaboratively pool their collective resources and experiences to identify solutions to meet the varied and difficult subsurface conditions encountered. The Dearborn CSO project exemplifies the types of problems that must be tackled and the effectiveness of teamwork in overcoming them.

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David Magill is chief executive officer of Avanti International in Webster, TX. Avanti supplies chemical grouts used to stop water infiltration in concrete structures, stabilize soils, encapsulate hazardous waste, prevent structural movement due to groundwater, and seal entire sewer and underground transit systems via grouting. Mr. Magill can be reached at 800.877.2570.