MULTIURETHANES

DEEP DIVE SHAFT GROUTING FOR THE CATSKILL-DELAWARE WATER SYSTEM

by Peter White, P.Eng.

New York City drinking water is world-renowned for quality. Each day, more than 3 million cubic meters of fresh, clean water is delivered from large upstate reservoirs – some more than 200 km from the City – to the taps of nine million customers throughout New York state. New York City remains one of only five large cities in the United States that is not required to filter its drinking water.

Several full-scale mockups were constructed to observe various aspects of the grouting operation

An Ultraviolet Disinfection Facility is presently under construction for the Catskill-Delaware water system and will be commissioned in 2012 at a cost of US$1.6 billion. The UV plant will provide secondary disinfection for Cat-Del water, which is currently treated with chlorine before entering the in-city distribution system.

Two side-by-side shafts, a raw water supply shaft and a treated water return shaft, both of which are over 150 m deep, connect the Cat-Del water supply tunnel system to the UV plant. When these shafts were constructed over 70 years ago, a 600 mm diameter by 12 m long bronze bypass pipe was constructed between the two adjacent shafts at a depth of 140 m below surface and 120 m below water elevation.

To prevent untreated water from short-circuiting through the bronze bypass pipe, it was decided to fill the bronze pipe with a high-strength grout prepared using materials meeting NSF/ANSI Standard 61 for drinking water system components.

Since the Cat-Del water supply system could only be shut down for brief overnight periods when city water demand was low, diving activities had to be undertaken using two Atmospheric Diving Suits; with one "suit" working in each of the adjacent shafts in combination with remote submersibles (ROV) that provided lighting and underwater cameras to monitor work activities.

The most significant aspect of the pipe sealing work was the underwater diving operation to prepare each end of the bronze bypass pipe with water-tight seal plates, prior to the pipe being filled with grout. Dive crews conducted detailed inspections of the existing site conditions and developed custom tools and equipment capable of performing complex underwater technical tasks with a high degree of precision and reliability.

Prior to filling the bypass pipe with grout, several full-scale mockups of the bypass pipe were constructed so that trial grouting operations, such as flow rates, pressures and dispersion of grout within the water-filled mockups, could be observed to verify various aspects of the grouting operation.

Cement grouting equipment set-up during the trial phase of the project

The diving contractor selected Multiurethanes of Mississauga, ON to design the high-strength grout mixture, supply rental grouting equipment and provide hands-on engineering supervision for this unique grouting operation. Multiurethanes personnel brought over 25 years of technical grouting experience, including prior experience working with underwater divers and many deep shaft grouting assignments undertaken for the mining industry to this deep dive project.

Multiurethanes personnel had recently completed a technical grouting project in Port Colborne, ON in cooperation with a local diving contractor to abandon an old water supply tunnel. This project involved a time-critical plant shutdown and required precise control of grout volumes and grouting pressures to accomplish a one-shot grouting operation where failure was not an option. This project proved to be a warm-up for the challenges involved with the deep dive project in New York.

The first step in planning the deep dive grouting operation was to choose suitable grouting materials. For this project, Type I/II Portland cement and ground granulated blast furnace slag (GGBFS) were selected, both of which conformed to NSF/ANSI Standard 61. No other additives or admixtures were required for this grout mixture.

Based upon experience with past grouting projects, a water-to-cement (W:C) ratio of 0.64 by weight of cement and GGBFS was selected for this project. While a lower W:C ratio would have been desirable based on inherent properties when cured, a higher W:C ratio would be less likely to encounter mixing or pumping problems during placement.

The grout volume to be placed was approximately 4 cubic meters and it was preferred to place this quantity within a couple of hours to minimize the potential for gradual stiffening of the grout mixture within the bronze pipe part way through the grouting operation. Mockup trials demonstrated that a slow rate of pumping would minimize dilution and dispersion of grout within the bypass pipe.

The second step was to configure appropriate cement grouting equipment to prepare a high-quality grout mixture, provide for redundancy of critical equipment components and incorporate variable frequency drives to facilitate rapid and controlled adjustment of grout flow rates and grouting pressures.

A colloidal grout mixer was chosen for preparing the grout mixture at a W:C ratio of 0.64 by weight of cement and GGBFS. A critical property of colloidally mixed grout is that subsequent dilution in water is minimal, making such mixing equipment well suited for underwater grouting applications.

Each batch of mixed grout consisted of the following ingredients:

- 200 liters water
- 170 kg Type I/II cement
- 144 kg GGBFS
- 1.68 kg/liter density
- 300 liters batch volume

Pipes were set-up at the bottom of a quarry to test the effective delivery of the grout even when the equipment was located over 70 m higher than the point of injection

An agitator tank of 400 liters capacity was used to receive batches of grout from the colloidal mixer and to provide for adequate grout retention between the mixer and the grout delivery pump.

A 2L6 progressive cavity pump with a 3.7 kW electric motor and variable frequency drive was used to supply grout at various flow rates ranging from 20 to 60 liters per minute as required during various stages of both the grouting trials and during the actual grouting operation.

Electromagnetic flowmeters were used to measure the rate of grout flow and cumulative flow; from which information the pump speed was adjusted as determined by site conditions. Pressure gauges were used to monitor grouting pressures at the connection between of the surface grouting equipment and the grout hose that descended to the point of connection at the shaft bottom.

The third step in planning the deep dive grouting operation was to select an appropriate grouting hose for the transfer of mixed grout from the surface grouting plant to the point of injection at a depth of 140 m below surface.

One of the project design requirements was to limit the potential grouting pressure differential at the point of injection to not more than 100 kPa above hydrostatic pressure. With a grout density of 1.68 kg/liter, the 140 m deep grout column was capable of creating pressure differential of up to 1,100 kPa.

The remedy for this situation was to use a 20 mm diameter high-pressure hose for pumping grout down the shaft. At the target grout delivery rates between 20 to 60 liters per minute, this small diameter grouting hose created very high fluid velocities with corresponding high resistance due to internal friction that offset the potential pressure effects of gravity at the shaft bottom.

Grouting trials conducted at a deep quarry demonstrated the effectiveness of this approach, when cement grout could be delivered in a controlled manner at low pressure differential even when the grouting equipment was located over 70 m higher than the point of injection.

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After months of detailed preparations, hundreds of diving hours using the Atmospheric Diving Suits, and several days undertaking mockup trials, the grouting operation was successfully completed in less than 3 hours from start to finish. The day following the underwater grouting operation, diving crews recovered grouting manifolds from the shaft bottom that were plugged solid with cured cement grout - a positive indication of the state of the sealed bronze bypass pipe.

Specialized atmospheric diving suits used to conduct the underwater diving operation

The successful decommissioning of the bronze bypass pipe allowed the Catskill-Delaware water system project to continue on schedule without complication.

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