Deep Dive Shaft Grouting

Location: **Mount Pleasant, New York**

Sector: **Utilities**

Case Description

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.

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

Two side-by-side shafts over 150 m deep connect the Cat-Del water supply tunnel system to the UV plant - raw water supply shaft and treated water return shaft. 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.

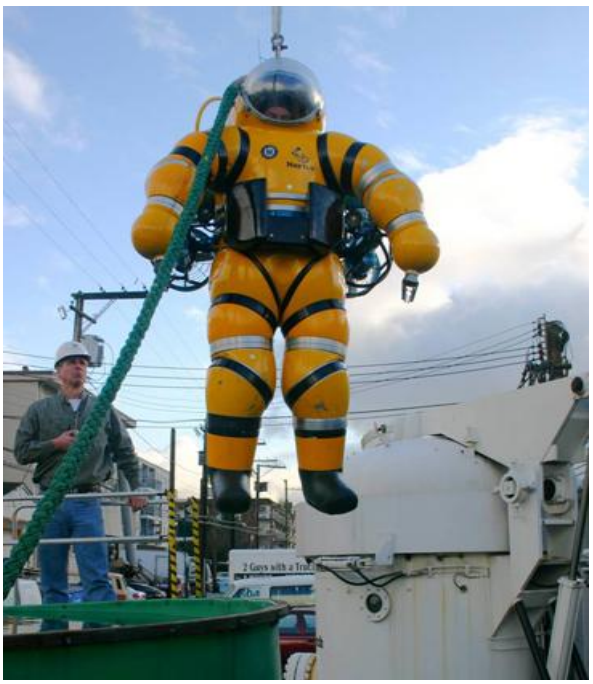
Solution

Since the Cat-Del water supply system could only be shut down for brief overnight periods when city water demand was low, diving activities were 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 aspects of the pipe sealing work were the underwater diving operations to prepare both ends of the bronze bypass pipe with water-tight seal plates prior to the bypass 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.

Several full-scale mock-ups were constructed for testing purposes

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



Specialized atmospheric diving suits used during the underwater diving operation

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

Peter recently had recently completed a technical grouting project in Port Colborne, ON in cooperation with a local diving contractor to decommission an old industrial water supply channel.

The Port Colborne grouting 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 cement grouting project proved to be a warm-up for the significant technical 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.

A water-to-cement (W:C) ratio of 0.64 by weight of cement and GGBFS was selected for this project based upon experience with past cement grouting projects. 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.

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

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 bypass 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 water-filled 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 to prepare the grout mixture at a water-to-cement 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

An agitator tank of 400 liters capacity was used to receive batches of cement 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 3.7 kW electric motor and variable frequency drive was used to supply cement grout at various flow rates ranging from 20 to 60 liters per minute as required during various stages of the grouting trials and during the actual grouting operation.

Electromagnetic flow meters were used to measure the rate of grout flow and cumulative volumes, 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 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 diameter of grouting hose for 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 into the submerged bronze bypass pipe 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 gravity pressure differential of up to 1,100 kPa.

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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 bypass pipe location.

Grouting trials conducted at a deep quarry test site 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.

After months of detailed preparations, hundreds of diving hours using the Atmospheric Diving Suits, and several days undertaking mockup cement grouting trials, the actual cement grouting operation was successfully completed in less than 3 hours from start to finish.

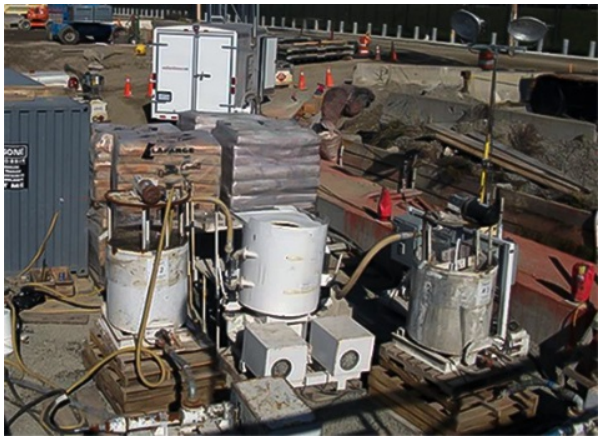
The day following the underwater grouting operation, diving crews recovered grouting manifolds from the shaft bottom that were plugged solid with cured cement grout - a positive indication of the state of the sealed bronze bypass pipe.

References :

- NYC DEP Website:
http://www.nyc.gov/html/dep/html/dep_projects/cp_catskill_delaware_uv_plant.shtml

- Video of Atmospheric Diving Suit:
http://www.youtube.com/watch?v=2Mv4vmB81Qo

Peter White, P. Eng., is a senior engineer and grouting specialist with over 25 years of experience working on many different types of pressure grouting operations at hundreds of project locations around the world.



Grout plant setup
adjacent to shaft grouting location

Diving suit hoist over raw water intake shaft where grout overflow from bypass pipe was monitored