Use of a Reinforced Jet Grout Excavation Support System for a Major Sewer Line Repair

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A portion of the roof for a 129 x 144-inch, nearly 100-year-old sewer outfall in the City of Baltimore had deteriorated to the point that it resulted in the development of a large sinkhole in a residential neighborhood. A subsequent video inspection of the sewer outfall indicated that there was a hole in the sewer outfall, and it would need to be repaired. After initial backfilling of the sinkhole and repairs to the water service lines, a conventional wood shoring system was used to support the excavation and expose the Main Outfall Sewer to inspect and repair it. This excavation was unsuccessful because of loose sandy soils and high groundwater conditions. An innovative use of a steel reinforced jet grout excavation support system was ultimately used to underpin an adjacent 20-inch water main and other nearby utilities, and provide access to the top of the Main Outfall Sewer some 22 feet below the street surface to facilitate inspection and repair of the sewer. This excavation support system was also successfully utilized in the final repair of the sewer roof by serving as a buttress for the new roof system.

1.0 Introduction

The project site is located in a residential neighborhood with brick masonry row houses situated on the south side of Chase Street and a brick masonry church on the north side of the street. Figure 1 illustrates the location of the site. The City right of way is 65 feet wide, and the street is 40 feet curb to curb. The centerline of the Main Outfall Sewer runs parallel to and a few feet south from the centerline of the street. Other utilities running parallel to the street include a cast iron 20-inch water line built about 1910, a 24-inch terra cotta storm drain, a 6-inch terra cotta sanitary sewer, a 4-inch cast iron gas line and a 40-inch electrical duct. Cross utilities included a 4-inch gas line and several smaller water and gas service lines to the church and row houses. One gas line that was not shown in the City's GIS database was exposed during the excavation.

The Main Outfall Sewer under Chase Street is the main conduit to the Back River Wastewater Treatment Plant, one of two wastewater treatment plants in Baltimore. This sewer outfall was built in approximately 1907, has an arch cross section, and is constructed from unreinforced cast-in-place (CIP) concrete with brick lining in the lower half. The wall thickness ranges from 12-inches at the crown and the invert to 26-inches at the sidewalls. The cross section of the existing pipes, derived from the original construction plans is shown in Figure 2. It is thought that this portion of the outfall was built using cut and cover techniques. The crown of the Main Outfall Sewer is located about 22 feet below the existing ground surface. The typical flow through the outfall is 140 million gallons per day (MGD) with a peak flow of 223 MGD. There were no possibilities of diverting flow to other bypass systems as no such bypass systems exist.

Early in 2002, several water leaks from the 20-inch water line caused some sinkhole damage to Chase Street. After the water line and street were repaired, a CCTV inspection of the Main Outfall Sewer was performed. This inspection revealed a hole in the Main Outfall Sewer about 60 feet from the nearest manhole in the area of the street damage. This hole appeared to be a significant infiltration source and could lead to future unraveling and sinkhole development.

The City attempted to repair the Main Outfall Sewer by using a conventional wood excavation support system to conduct an inspection and repair, but was unsuccessful because of loose sandy soils and high groundwater conditions. The City decided that given the high groundwater and unstable sandy soils a more substantial excavation support system would need to be installed.

2.0 Geology and Subsurface Conditions

Geotechnical and structural engineers visited the site on August 20, 2002 to observe the wooden excavation support system and the surrounding area. The existing utilities were located using record drawings and vacuum trucks for test pits. A soil boring was also drilled to explore the subsurface conditions.

According to the Geologic Map of the Baltimore East Quadrangle, Maryland (1976), the project site is mapped within the Coastal Plain Physiographic Province. Natural soils in this region are mostly sedimentary materials consisting of Sand Facies of the Patuxent Formation, a member of the Potomac Group. The Patuxent Formation typically consists of highly variable, interbedded sand and gravel with pockets of silt and clay. This formation is believed to have been deposited during the late Cretaceous Period. Isolated areas of hematite-limonite cemented sands are also common.

The subsurface conditions encountered in the boring consisted of man-placed fill to a depth of about 3 feet below the existing ground surface; medium stiff Silty CLAY (CL) to a depth of about 7 feet; loose Clayey SAND (SC) to a depth of 9 feet; loose, poorly graded SAND (SP-SM) to a depth of about 24 feet; medium dense, poorly graded SAND (SP-SM) to a depth of about 33 feet; and dense Silty SAND (SM) to the termination depth of the boring at 41 feet below the existing ground surface. SPT N-values typically ranged from 5 to 9 blows per foot within the CL and loose SP soils, 5 to 17 blows per foot in the medium dense SP soils, and 36 to 42 blows per foot in the dense SM soils. In areas where running sand was encountered the SPT N-values were typically about 2 to 4 blows per foot except in the dense SM layer where the SPT N-values seemed unaffected.

Groundwater was encountered at a depth of 17 feet below the existing ground surface.

The SP material had between 5 and 8 percent fine-grained material; the SM soils were non-plastic, and contained about 14 percent fine-grained material.

3.0 Engineering Evaluation

3.1 Geotechnical Engineering Considerations

During the month of September 2002, construction documents were submitted to the City for an excavation support system and repairs to the Main Outfall Sewer. It was thought that given the high groundwater and sandy soils conventional soldier pile and lagging would not be suitable even with extensive dewatering. The soils would likely unravel and flow into the excavation. This could undermine the existing utilities and perhaps the buildings. Driving piles would also be a source of noise and vibration and would disturb the neighborhood. Steel sheet piling could seal off the ground water, but vibrations and driving could cause damage to the Main Outfall Sewer and other utilities. It was decided to use jet grouting because it would not cause excessive vibration, as would conventional sheet piling or pile driving. Use of a secant auger cast pile wall could damage the Main Outfall Sewer and would create more noise than the jet grouting operations. Chemical grouting could be used to supplement the jet grouting to form a tight seal over the Main Outfall Sewer, but to use chemical grout as the excavation support system would offer less control of the influenced mass, would not provide adequate support, and would likely cost more than jet grouting. Jet grout could also be used to underpin the existing utilities as needed.

A reinforced jet grout secant wall was determined to provide the most secure excavation support system for the depth needed while minimizing the settlement of the surrounding utilities, and providing a good water seal with relatively quiet construction.

The invert of the Main Outfall Sewer is located about 17 feet below the ground water level. There was concern that if the site was dewatered the resulting water flow could result in piping and underground erosion. In addition, the increase in effective stress could cause settlements in the buildings and nearby utilities. Many of the utilities were old and fragile and could not tolerate much differential settlement. MODFLOW software was used to aid in modeling the effects of dewatering in the excavation. The MODFLOW results were checked using more conventional techniques. To reduce the effect of dewatering outside of the excavation the jet grout walls were extended to a depth of 16 feet below the invert of the Main Outfall Sewer. Since this was deeper than the boring extended, it was assumed that the sandy soils extended to an infinite depth. The jet grout walls would be reinforced to act as a buttress to support the Main Outfall Sewer as the stress regime changed due to the excavation and the dewatering. For this reason, the reinforcing steel was required to extend the full depth of the cut off walls.

There was also concern that if too much water was removed, then differential hydrostatic pressure could cause unbalanced uplift loads on the bottom of the Main Outfall Sewer. Since the condition of the Main Outfall Sewer was unknown, but was obviously deteriorated, the dewatering system was designed to keep the pore water pressure on the bottom of the Main Outfall Sewer about the same as the wastewater flow in the Main Outfall Sewer. This was monitored by observing the water level in the well casing.

During the installation of the jet grout walls a hard clay layer was encountered below the invert of the Main Outfall Sewer; this was deeper than the termination depth of the initial boring. To verify the nature of the hard clay material the contractor hired a local drilling company to drill a second boring. This boring extended to a depth of 50 feet below the existing ground surface. The clay layer extended to the termination depth of the boring. Upon examination of the samples by the Geotechnical Engineer this clay layer appeared to be the Arundel Clay, a hard overconsolidated Cretaceous Age deposit widespread throughout the local area. This stratum was known to be as thick as several hundred feet.

Since the jet grout rig operator could determine when the hard clay layer was encountered it was decided to terminate the jet grout wall 2 feet into the clay layer. This saved time and cost. By sealing the jet grout walls on either side of the Main Outfall Sewer into the clay layer the ground water flow into the area under the Main Outfall Sewer along with what was pumped out of the excavation.

3.2 Structural Engineering Considerations

The new excavation was sized to allow equipment access and expose the full width of Main Outfall Sewer. A thorough records review allowed for confident placement of the excavation and the jet grout support system provided some verification during construction occurred due to the sensitivity of the equipment operator to ground conditions. A water main with lead joints which are sensitive to pipe settlement and a gas line were located immediately on either side of the proposed excavation.

The soil beneath the water main was to be stabilized with jet grout under-pinning as an additional safety precaution. Steel pipe or rebar was to be used for the reinforcement in the center of each grout column. Steel wide flange members used as walers and struts were provided at three levels to within one-foot of the top of the existing Main Outfall Sewer. The cross section and plan of the excavation support system are shown in Figures 3 and 4, respectively. The wales and struts are not shown in these figures for clarity.

The stability of the Main Outfall Sewer structure resulting from pressure changes during excavation was a paramount concern. It was thought that it would be prudent to provide lateral support to the Main Outfall Sewer as the vertical stress was relieved due to the excavation. The two walls parallel to the sewer were located flush up against the sides of the Main Outfall Sewer to provide support lateral. To provide room for pressure relief wells, the south wall needed to be offset away from the Main Outfall Sewer walls. To seal the floor of the excavation and still maintain positive support for the Main Outfall Sewer, a grout plug was installed between the south wall and the Main Outfall Sewer. Using jet-grout, it was possible to specify the top and bottom limits of the grout plug and place grout directly against the Main Outfall Sewer with minimal if any damage to the existing structure.

The grout walls perpendicular to the axis of the Main Outfall Sewer extended to the top of the sewer. The jet grout operator slowed the drilling rate and reduced pressure when he suspected the grout monitor was close to the sewer. Chemical grouting was used to provide a tight seal between the top of the sewer and the jet grout wall.

The nature of the needed repairs was not known at the time contract drawings were prepared. Provisions were made in the contract drawings for two of the most likely repairs that have been performed in the past in other areas of the Main Outfall Sewer. Cracks were to be sealed using rapid setting grout. Holes were to be repaired by fitting a fiberglass form through the hole, placing the form against the inside of the Main Outfall Sewer, and completely filling the hole with rapid setting concrete. Eyebolts installed in the fiberglass form would extend above the opening and would be used to suspend the fiberglass form from hangers. Once the Main Outfall Sewer was repaired, the excavation was to be filled with flowable fill to a height of 2 feet above the crown of the Main Outfall Sewer and then the remainder of the excavation filled with select fill.

The excavation proceeded well and successfully exposed the top of the Main Outfall Sewer. While no hole through the conduit was found, a condition inspection at the top of the Main Outfall Sewer found the concrete to be soft with no sound concrete located after digging into it several inches. It was possible to remove concrete from the Main Outfall Sewer with a garden hose and with minimal effort using hands and hand tools.

A full width Main Outfall Sewer repair option was developed based on consultation between the structural and geotechnical engineers and the contractor. The repair included using reinforced cast-in-place structural concrete designed to span the tunnel and support all dead and live loads.

It was decided that the entire roof of the Main Outfall Sewer should be replaced. It was not possible to remove the existing roof without causing significant environmental effects to the residents and the workers. Therefore, a reinforced concrete cap was cast over the sewer. The existing roof would be used as the lower portion of the form to cast the new concrete roof. While it was thought that friction between the concrete roof and the jet grout walls would be able to support the cap, for redundancy, steel shear connectors were welded to the steel wide flange members. The cross section of the structural cap is shown in Figure 5. On May 14, 2003, the structural cap was designed and forwarded to the contractor.

4.0 Construction

The City gave Notice to Proceed to the jet-grouting contractor effective March 17, 2003, with 90 days allowed to complete construction and repave the road. The jet-grouting contractor acted as the general contractor since the jet-grout excavation support system was an unusually large part of the project. The first task was to establish a temporary water supply to the local residents. This was done so that water could be turned off in the area of the work. This way if a leak did develop it would limit the damage to the roadway and not inconvenience the public. To ease detours to the public and speed construction the entire block was closed to vehicles, but the sidewalks remained open to pedestrians. This allowed the contactor to use the entire block to set up the batch plant, storage trailer, spoil pond, and stage and operate the equipment. The spoil pond was constructed using the material removed from the excavation.

The contractor chose to install W12x65 steel wide flange members within the jet grout wall instead of the steel pipes and to replace the struts with diagonal braces. The walers and braces were also constructed of W12x65 steel members. The jet-grout columns were designed to be 3 feet in diameter and spaced 2 feet on center. The reinforcement design was based on the assumption that the soil-crete would have an unconfined compressive strength of at least 125-psi. As it turned out, the minimum 28-day unconfined compressive strength test result was about 750-psi.

Once the existing pavement was removed and wasted, the jet grout operations started. The walls were constructed by inserting steel wide flange members into the jet-grouted soil-crete columns. The steel members were lowered into the freshly installed columns where they were held in place with a template until the soil-crete cured. Once cured, the combination of steel wide flange members and soil-crete columns created retention system stiff enough to allow excavation to take place in adjacent areas without the use of additional shoring or support systems. Chemical grouting was used to seal the gap between the Main Outfall Sewer and the jet grout columns.

Extreme care was exercised during drilling of the jet grout columns over the Main Outfall Sewer. Drilling pressure and speed were reduced when it was thought that the grout monitor was getting close to the Main Outfall Sewer. Depth of refusal at each location was plotted so that depth of refusal could be predicted. Figure 6 shows the templates suspending the steel members over the conduit and the placement of another steel member.

Some groundwater did seep through the contact between the soil-crete and the Main Outfall Sewer, but little water seemed to seep through the soil-crete walls. The water level in the excavation could be kept at acceptable levels with little pumping effort.

The photograph in Figure 7 shows the soil-crete and the lowest level of walers and braces as well as the excavation equipment.

Excavation safety was maintained throughout with heavy equipment working on steel platforms framed into the excavation support. All personnel were harnessed to a crane above the excavation prepared to haul them to safety if needed. Figure 7 also shows the dewatering pump and the means of excavation as well as some of the safety precautions taken at the site such as the tie-offs and the vent tube to supply fresh air. During the excavation, the wood shoring used during the original construction was exposed in the side of the excavation confirming that the tunnel was built using cut and cover methods.

The jet grout operations and excavation proceeded smoothly and the Main Outfall Sewer was exposed. There appeared to be a hole at the contact with the Main Outfall Sewer and the jet grout wall, but it was not certain if that was the hole that caused the initial sinkhole. The hole was filled in with chemical grout. Shown in Figure 7, at the extreme right end of the conduit was a crack. This crack was about 7 feet long and 8-inches deep. Post completion video inspection did not reveal any evidence of a hole in the Main Outfall Sewer.

The excavation was filled with controlled low strength material (CLSM) once repairs to the sewer line were complete. The project was completed with the restoration of asphaltic and concrete paving.

The contractor demobilized on June 27, 2003. The project was completed successfully, on time and within budget with allowances for the redesigned structural cap repair.

5.0 Summary

The final construction cost was about $694,000 including the structural cap and repaving.

Although the excavation was not deep, given the high groundwater level, unstable soils, adjacent old utilities, and difficult access this was deemed a reasonable cost. when considering all the associated risks. This project is an excellent example of the use of innovative technology and cooperation of the various design disciplines of geotechnical, structural and environmental engineering with the contractor and the City. Given the need for infrastructure repair across the country this project can serve as an example of a project that can repair deteriorated structures in difficult situations at a reasonable cost and with a minimum of disruption to the community.

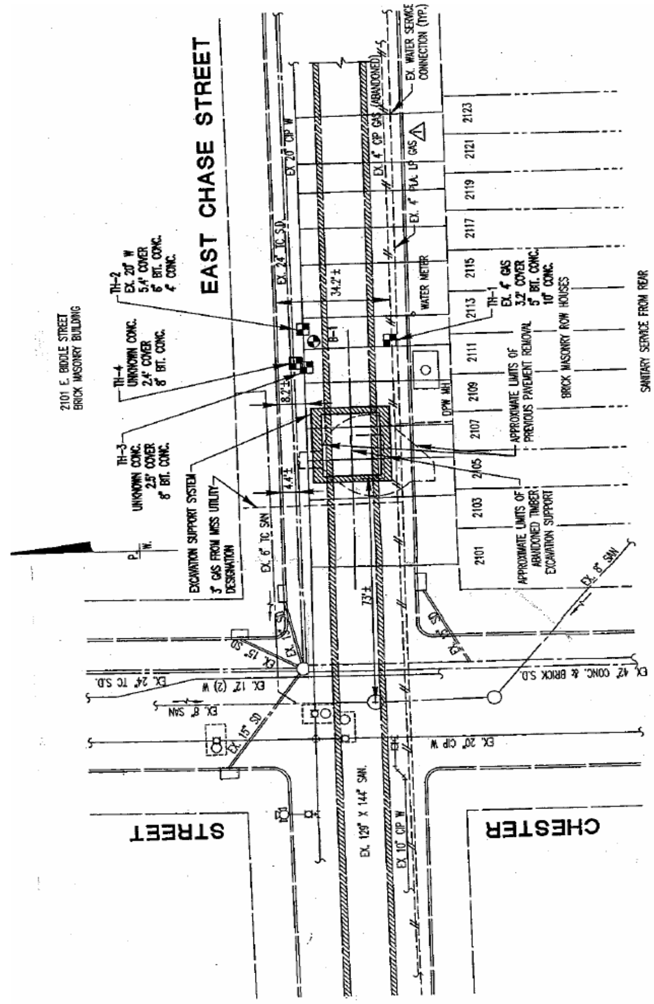

Figure 1 Site Plan

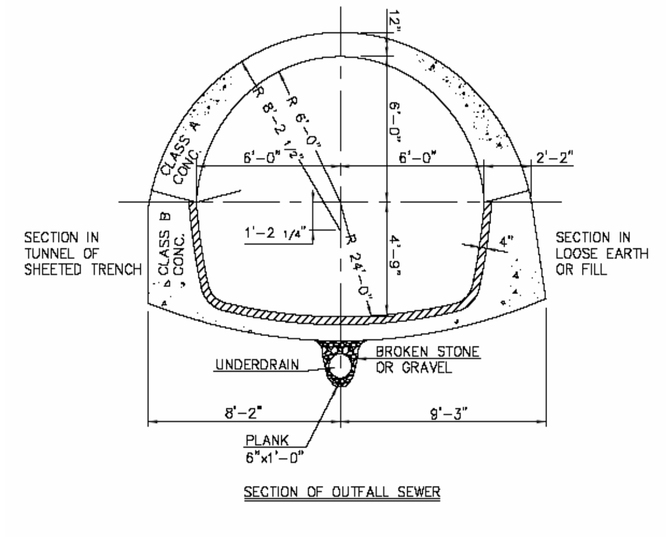

Figure 2 Cross Section of Existing Main Outfall Sewer

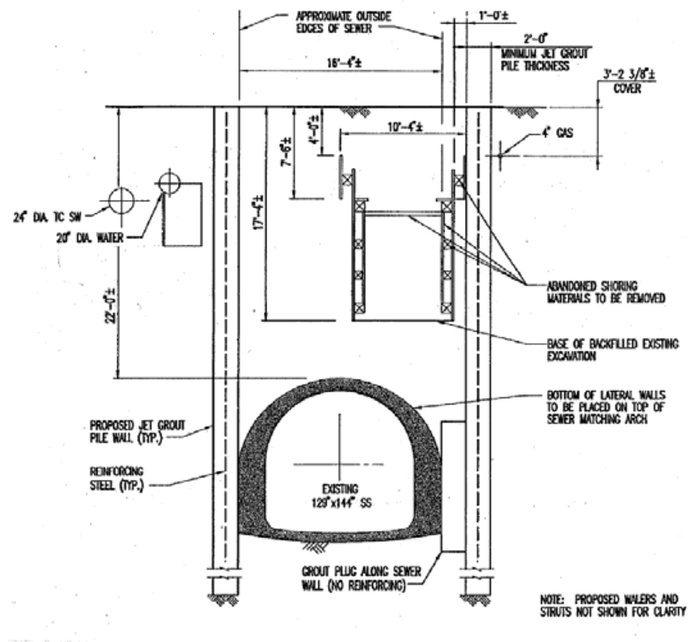

Figure 3 Cross Section of Excavation

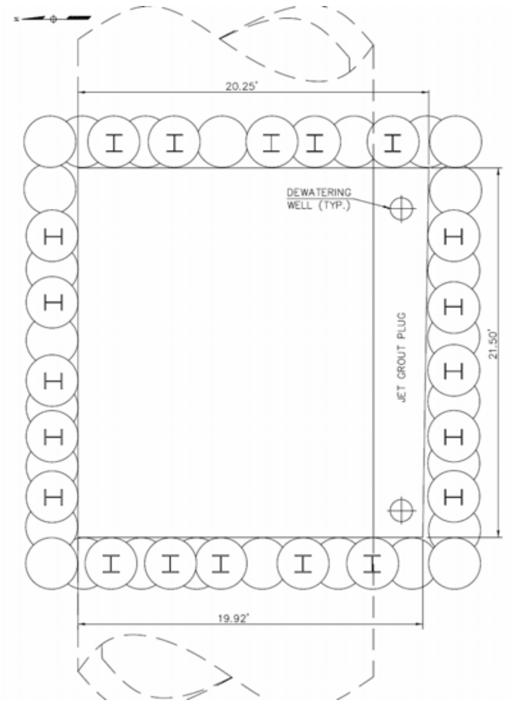

Figure 4 Plan View of Excavation

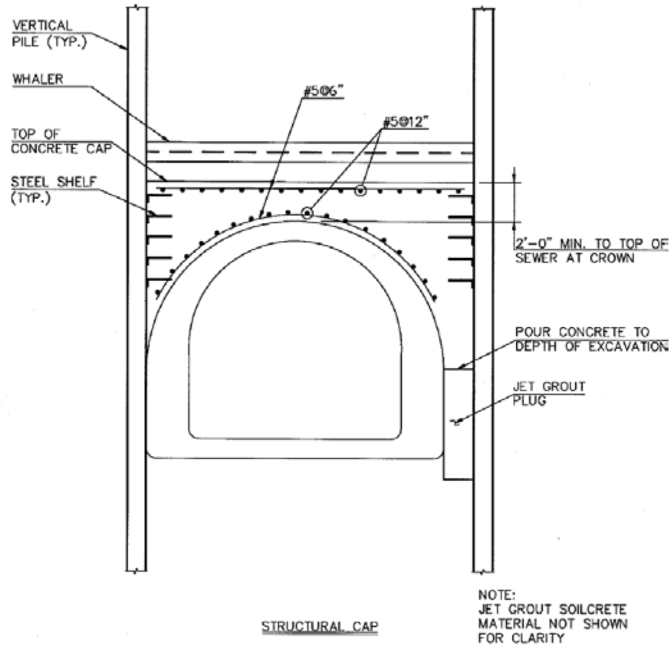

Figure 5 Cross Section of Structural Cap

Figure 6 Placing steel in the west wall of the excavation

Figure 7 Photograph of Excavation showing exposed outfall, walers and jet grout walls