Small Footprint, Big Challenges-Design and Construction of the Allen Park Sanitary District 1 Storage Tunnel

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ABSTRACT: Integrating new infrastructure into urban areas requires precision in design and construction. The new infrastructure has to virtually thread the needle of existing infrastructure and buried utilities while meeting the requirements of regulatory agencies, property owners, and other entities. These factors make it particularly challenging for large-diameter pipelines like the Allen Park Sanitary Sewer Overflow (SSO) Tunnel that had to cross an interstate highway, several railroads, gas and oil pipelines, a transmission water main, two creeks with limited cover, as well as a residential area and college campus. Rigid mining shafts, detailed specifications for tunneling materials, a fully breasted TBM, and various trenchless technologies were successfully utilized in conjunction with robust geotechnical instrumentation and monitoring, to mitigate settlement risks and overcome historical challenges with tunneling in the area.

INTRODUCTION

The Allen Park Sanitary Sewer Overflow (SSO) Tunnel and Relief Sewer project, located in the City of Allen Park, MI, is a long-term corrective action designed to bring Sanitary District One's sanitary system into compliance with their 2005 Consent Order and their service contract with the Detroit Water and Sewerage Department (DWSD). The $20 million project is intended to reduce Allen Park's wet weather discharges to DWSD, reduce bypass pumping to the Ecorse Creek, and limit the future risk of basement flooding, by providing storage during wet weather events, and eliminating hydraulic bottlenecks in the sanitary sewer system.

A year of final system flow monitoring was performed in 2006 and 2007 to collect data after short-term improvements were implemented. The data was used to calibrate a computer model that was then used to analyze the performance of the system through a statistical analysis of a continuous simulation which included 36 years of rainfall and snowmelt data. This helped verify the size, type and location of improvements needed to bring the sanitary system into compliance. The project was a decade in the making when it received a jump-start from the American Recovery and Reinvestment Act of 2009 stimulus funding. This resulted in 40% principal forgiveness on Allen Park's SRF loan and set the "shovel-ready" Project's 2-year construction period in motion.

The tunnel is sized to transport and store 1.34 MG of wet weather flow. Designed to be empty during dry weather and smaller wet weather events, it is estimated that the tunnel will convey wet weather sanitary flow an average of 10 times per year. Approximately three times per year, the excess sanitary flow entering the tunnel will exceed the downstream pump station capacity and the flow will be temporarily stored in the tunnel until it can be dewatered. The tunnel will need to be flushed with flow stored in upstream portions of the system one to four times a year to prevent the buildup of solids and gasses that can generate excessive odor and degrade the tunnel lining.

The tunnel will convey flow to a new 8.4-cfs submersible dry weather/wet weather lift station at the north tunnel connection on Outer Drive near Baker College's campus. Flow will be carried to a new 14-inch-diameter force main that will outlet to an existing trunk sewer outlet north of Outer Drive. This arrangement will replace the existing 18-inch gravity sewer that was unable to deliver the maximum outlet capacity to the Outer Drive Lift station without significant surcharge upstream. The new 8.4-cfs submersible pump station and 14-inch force main will lower the surcharge at the existing upstream junction manhole and eliminate this hydraulic "bottleneck" in the system.

Located within the Ecorse Creek Watershed, the 4,100 ft long tunnel alignment minimizes disturbance to existing wetlands and adjacent property owners. A portion of the alignment was designed to minimize the impact to the proposed greenway alternative from the future widening of the North Branch of Ecorse Creek. Implementing a storage tunnel and other trenchless methods for improving the wastewater infrastructure were utilized to provide an environmentally sound and sustainable solution to meet the City of Allen Park's needs, now and into the future.

PROJECT DESCRIPTION

Located in an urban area congested with existing utilities and structures, the Allen Park SSO Tunnel was designed and constructed to minimize impacts on surrounding areas while meeting the requirements of regulatory agencies, property owners, and other entities. To facilitate the proposed storage and conveyance improvements, while delivering a sustainable and environmentally sound project, tunneling and other trenchless methods were selected by the project team. The overall alignment crosses an interstate highway I-94, Canadian National and Norfolk Southern railroads, gas and oil pipelines owned by various utilities, a 54-inch DWSD transmission water main, a natural drain at two locations, as well as a residential area and Baker College's campus. The alignment even included a mining shaft located in the shadows of the famous "Uniroyal Giant Tire," which is a local landmark that consists of the repurposed Ferris wheel attraction from the 1964/65 World's Fair in New York.

A dynamic mix of five different trenchless construction and rehabilitation methods were used to complete 1.5 miles of sewer, minimizing impacts on existing structures and residential, commercial and environmental properties. A tunnel boring machine (TBM) was used to install 3,045 Linear ft (Lft.) of 8 ft diameter tunnel sewer in primary and secondary lining. A 24-in diameter, 700 Lft. section under the interstate highway was constructed utilizing microtunneling methods (MTBM). Pipe bursting was used to install a 400 ft section with only one service connection to increase the sewer diameter from 15 to 18 inches. A combination of directional drilling, slip-lining and open-cut techniques was used to install 1,300 Lft. of 14-in force main. The alignment also included open cut construction of 790 Lft. of 8 ft and 5 ft diameter sewer and 1,450 feet of 18-in diameter upstream relief sewer improvements.

The overall alignment of the soft ground tunneling portion along with an aerial view of the surrounding setting is shown in Figures 1 and 2. The following describes the various project elements.

Run 0 (North Tunnel Access Structure [NTAS] to westerly tail tunnel)

Prior to commencing the production tunneling, a tail tunnel was constructed to accommodate the tunnel locomotive and associated muck cars. The tail tunnel was constructed by hand mining and placing liner plate (10 foot in diameter) through the secant pile shaft wall, and extended 38 ft from the west face of NTAS. This run was constructed below and perpendicular to a 54-in DWSD water transmission line.

Run 1 (NTAS to ETAS)

This run progressed east out of NTAS to the East Tunnel Access Shaft (ETAS) approximately 1,375 ft in length with an invert approximately 30 ft below ground surface. This run consists of 12 ft diameter rib and lagging primary liner, with 8 ft diameter secondary liner, that traverses below a primary Wayne County Drain (Ecorse Creek), two tracks of the Canadian National Rail Road, three tracks of the Norfolk Southern Rail Road, and 10-in diameter British Petroleum Oil pipeline.

Run 2 (Pump Station Access Shaft [PSAS] to NTAS)

This run is 309 ft long, parallel to the 54" DWSD transmission main, approximately 35 ft easterly thereof. Consistent with Run 3 and 4, the tunnel consists of 144-in rib and lagging primary liner with 96-in reinforced concrete pipe as the secondary insertion.

Run 3 (NTAS to South Tunnel Access Shaft [STAS])

This run once again crosses beneath the Ecorse Creek and also beneath the retention pond of Baker College's storm system. The 850 ft tunnel run is also approximately 35 feet in depth, and is comprised of 144-in rib and lagging primary liner with 96-in reinforced concrete pipe as the secondary liner.

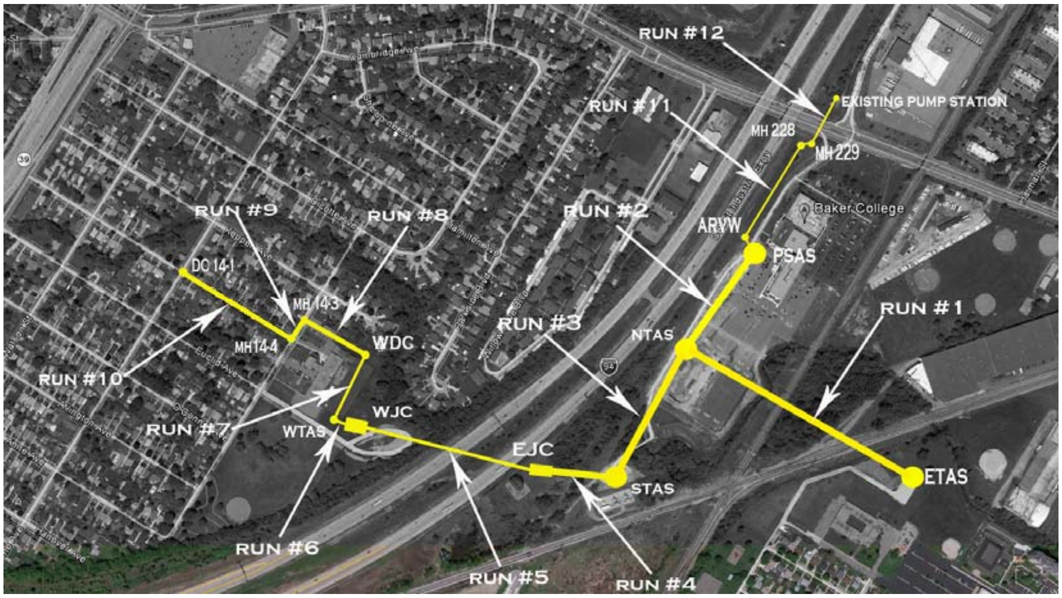

Figure 1. Project Alignment and Overview

Run 4 (STAS to the East Junction Chamber [EJC])

This tunnel is constructed below the 54-in DWSD water main, 8-in diameter Sunoco Oil pipeline, 22-in diameter Wolverine high pressure gas main, 6-in diameter Sunoco Oil pipeline, a 16-in diameter Wolverine high pressure gas main, and an existing 12-in sanitary sewer in which there was 5 ft of clearance between each of the utilities. Cover over the tunnel crown ranged from 4.5 ft to 19 ft.

Run 5 (EJC to the West Junction Chamber [WJC])

This 800 ft run which crosses beneath 7 lanes of Interstate highway I-94 with a depth of 40-45 feet is constructed by micro-tunneling with a 54-in steel primary liner and 2 ft diameter secondary liner. This was a late design change dictated by the governing highway agency. The mining shaft for this run was located approximately 30 ft from the “Uniroyal Giant Tire,” one of the world’s largest roadside attractions.

Run 6, 7 (WJC to West Tunnel Access Structure [WTAS] to West Diversion Chamber [WDC])

These runs comprise 780 ft of 5 ft diameter concrete pipe approximately 30 ft deep and are constructed by cut and cover methods between the Ecorse Creek and Rogers Elementary School.

Run 8 (WDC to Sanitary MH 14-3)

Pipe bursting of 15-in vitrified clay with an existing CIPP liner upsizing to a 18-in PVC C900 fusible pipe. The length of sewer was 450 ft approximately 19 ft below ground surface.

Run 9, 10 (MH 14-3 to Diversion Chamber 14-1 @ intersection of Russell and Larme Street)

Upsize of existing rear yard 12-in sanitary to 18-in pipe of 962 ft in length on south side of Shenandoah and Russell Streets with complete street replacement. This portion of the project required to be completed between July 5th and August 31st during which Rogers Elementary students are on summer vacation.

Run 11 (PSAS going north toward existing sanitary MH 228)

Run consists of directional drilling of a portion of the new Pump Station’s force main (632 ft) with subsequent placement of 14-in HDPE pipe.

Run 12 (Sanitary MH 228 to the existing pump station)

Slip lining of existing 21-in sanitary sewer with 183 ft of 14-in HDPE beneath the major thoroughfare of Outer Drive.

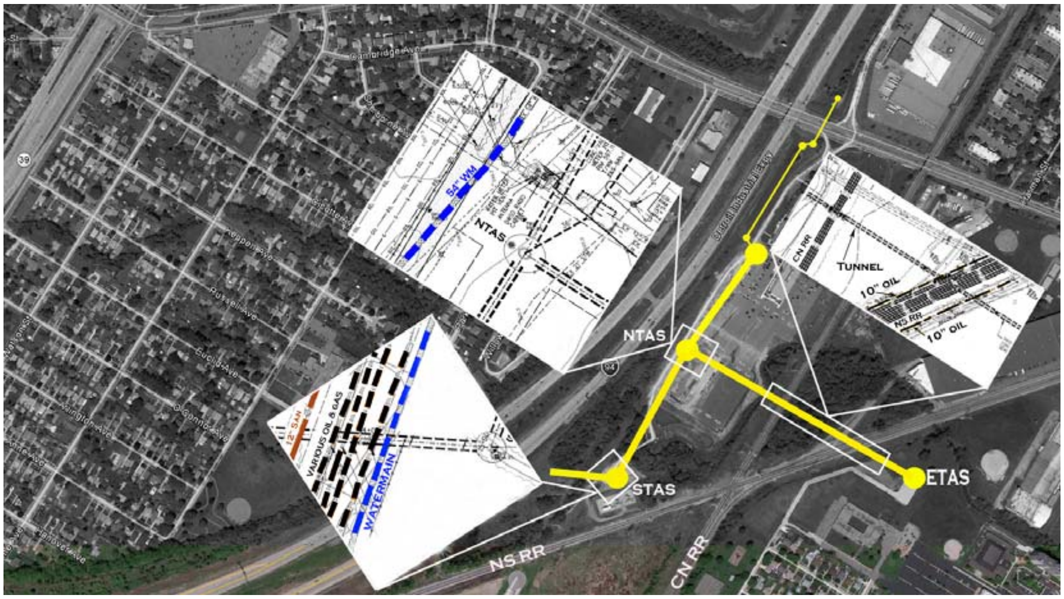

Figure 2. Critical utility crossings

GROUND CONDITIONS

The ground conditions in southeastern Michigan consist of glacial drift, characterized as clayey tills, outwash sands and gravels, and glaciolacustrine silts and clays that are underlain by glacial till. The clay soils frequently contain intermittent sand and gravel layers with cobbles and boulders produced from glacial river deposits as glacial lake levels fluctuated. Overlying the bedrock is often a layer of highly over consolidated glacial till locally referred to as "hardpan". The underlying bedrock consists of layers of sedimentary rocks comprised of shales, limestones, and dolomites that slope or dip inward from the rim of the Michigan Basin toward the center of the basin

Geotechnical Investigation

To support the design of the tunnel, shafts, and other underground structure design, a detailed geotechnical investigation was conducted along the project alignment. The investigation included 19 borings along the alignment with depths ranging from 7.5 to 90 ft. The borings included 14 shallow borings within the overburden, and 5 borings extending into the underlying bedrock. The borings were advanced in the overburden with hollow-stem augers and rotary wash equipment, with sampling by split-spoon or thin walled tube. Field testing included SPT testing by split spoon, and in-situ vane shear testing. Laboratory testing program included determination of dry density and moisture content, unconfined compressive strength, and Atterberg limits. Investigation of the bedrock included continuous sampling with NQ conventional core barrel tooling, recording percent recovery, RQD, and fractures per foot. The data and investigation results were summarized in geotechnical data (GDR) and interpretive (GIR) reports that were appended to the contract documents.

Generalized Soil Profile

The subsurface stratigraphy along the proposed tunnel alignment is relatively uniform (Figure 3), consisting of a thin layer of variable surficial fill extending from the ground surface down 3 to 5.5 ft. Below the fill layer are natural soil deposits consisting of a thin desiccated layer of medium to stiff silty clay that extends to a depth of about 12.5 ft below ground surface, underlain by a thick layer of soft to medium silty clay that extends to a depth below ground surface ranging from 67 to 77 ft. The deep portion of the soft to medium clay strata contained occasional thin granular stratum consisting of silt and silty sand. The unconfined compressive strength of the soft to medium clay, which comprises most of the tunnel alignment, varies from approximately 1,200 psf near the top of the deposit, to less than 600 psf for the lower portion of the strata. The soft to medium clay layer is generally underlain by a thin layer of hard to very hard silty clay ("hardpan") that extends to the limestone bedrock encountered at a depth of 83 to 90 ft below ground surface.

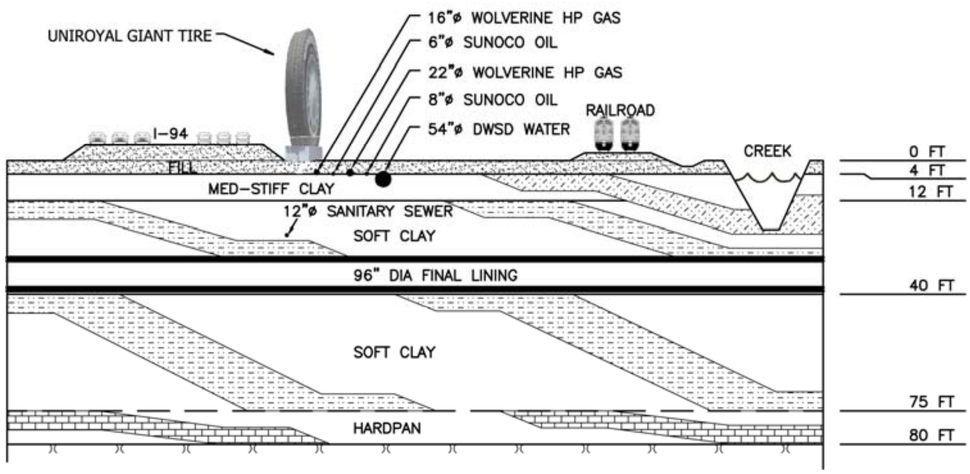

Figure 3. Generalized soil profile

Groundwater and Gas Conditions

The long term static groundwater is typically located 15 to 20 ft below ground surface, and is dependent upon seasonal variations of perched groundwater from the adjacent floodplain and granular surface deposits that are hydraulically influenced by adjacent water bodies. Additionally, groundwater is also present in silt and sand seams found within the deeper glaciolacustrine clay deposits. Deep granular layers at or near the soil-rock interface may be hydraulically connected to the underlying bedrock aquifers and have greater recharge capacity. The confinement of these layers from the overlying clay often results in artesian groundwater conditions in the area.

Low levels of hydrogen sulfide gas are typically present within the substrata throughout the project alignment. Hydrogen sulfide was detected during exploration at concentrations ranging from 2 to 3.5%.

DESIGN CONSIDERATIONS

During the design phase of the project, several performance criteria were established as critical for achieving project success. These included minimizing risk of 3rd party damages resulting from excessive ground deformation, minimizing cost overruns, and meeting the project schedule for construction. In order to achieve these goals, provisions were incorporated into the Contract Documents that were intended to minimize the Owner's risk of damage to existing utilities and adjacent infrastructure, facilitate a competitive bidding process, and to minimize financial risk to the Owner while still enabling the Contractor enough flexibility to address his perceived risk accordingly when tendering a bid.

Shafts

In order to accommodate the variety of subsurface improvements, the project required construction of 7 shafts, ranging in size from 12 ft diameter for the smaller sanitary sewer improvements, to 40 ft diameter for the pump station mining shaft. The shafts ranged in depth from 18 ft to 60 ft, with the deepest shaft required for the permanent structure of the dewatering pump station.

Rigid mining shafts were specified for three critical shaft locations to minimize potential for ground movement during tunneling operations. These included PSAS, NTAS, and STAS, each of which was to be located approximately 30 ft from the utility corridor which included the 54-in DWSD transmission main as well as the series of high pressure gas and oil pipelines. Many of these aging utilities had been in service for 60 years. The contract included provisions for the use of secant piles, diaphragm slurry wall, or sinking caisson methods of shaft construction at these locations. The contract included detailed performance criteria including minimum structural requirements and ground deformation limitations; however, it required that the successful contractor ultimately select and take design responsibility for the temporary support of excavation.

Primary and Secondary Tunnel Lining

A two-pass tunnel liner design was specified which required steel ribs and timber lagging for the primary liner and 96-in reinforced concrete pipe for the secondary liner. The contract requirements for the primary tunnel lining included minimum rib spacing, as well as structural and dimensional properties of lagging to mitigate potential difficulties encountered in previous tunneling projects in the area's soft ground.

Minimum allowable bending strength for design of timber lagging was specified as to not exceed 1,200 psi where kiln dried product would be used, and not to exceed 750 psi where non-kiln dried product would be used in the execution of the work. Actual board thicknesses were required to be used in the design of the lagging.

Secondary lining consisted of 8 ft long sections of ASTM C76, Class IV, Wall B, Reinforced Concrete Pipe, fitted with cast in place fittings in the pipe wall as necessary for the proper application of grout between primary liner and secondary liner. Although groundwater penetration was not a significant concern given the geotechnical characteristics, ASTM C443 gasketed joints with grouted inside annulus were specified to ensure a water tight sanitary storage vessel as well as to ensure a smooth finished surface to allow efficient transport and effective tunnel flushing. Maximum allowable groundwater infiltration was specified to not exceed 20 gallons per inch of diameter, per 500 feet of pipe, per 24 hours for the individual runs.

Settlement Tolerance

Strict requirements for geotechnical instrumentation and monitoring were specified to further manage owner risk by monitoring soil movement and utility settlement/heave from shaft, tunnel and cut-and-cover construction activities. Inclinometers, tell tales, monitoring point arrays, and deformation monitoring points were utilized. A specific action plan was developed to respond to ground movements encountered in the field, to mitigate risk of settlement and/or damage to the critical utilities and infrastructure within the tunnel zone of influence.

The specifications identified a maximum allowable surface settlement of 1-in and maximum allowable heave of 0.5-in. Where the tunnel crosses the MDOT right-of-way for Interstate 94, the maximum allowable surface settlement was further restricted to 0.5-in. The contract required that the contractor restore the site to pre-existing grades and profile, and repair any damage should these threshold values be exceeded.

Boulders

During the design phase, it was documented that historical data indicated that boulders were likely to be contained with the silty clay throughout the tunnel alignment. Accordingly, the contract documents incorporated measures to advise the contractor that cobbles and boulders may be encountered at the tunnel face. The tunneling specifications indicated that boulders less than 24 inches in the average of 3 dimensions as measured protruding into the bore would be incidental to the project. The specifications also required that the mining machine include provisions for removal of boulders at the tunnel face. In addition, a contingency bid item was included in the construction contract to cover unforeseen physical conditions which might be encountered during construction. These measures ultimately minimized changed condition claims from the contractor during tunneling operations.

TBM Features

Face stability analyses during design indicated that for a tunnel mined in the soft to medium clay strata utilizing open face mining would result in overload factors in the range of 6 to 9. This indicated a marginally stable tunnel face that may be subject to excessive squeezing. Based on other underground projects in the area, however, it was believed that the clay soils in the area would be capable of short term self-support even with overload factors up to 10. As such, it was determined that a conventional mining shield with positive face control would be suitable for installation of the primary lining.

The specifications required that the selected tunnel boring machine (TBM) was to be compatible with anticipated ground and groundwater conditions, be capable of providing full-face support, and be equipped with face closure doors. The face was to be accessible through the cutter head for the removal of obstructions.

CONSTRUCTION AND PERFORMANCE

The construction contract was awarded in October 14, 2009, and mobilization commenced in early-November 2009. The first mining shaft (NTAS) construction commenced May 5, 2010 and was completed by the end of June 2010. The TBM was assembled and mining of Run 1 began on August 6, 2010.

3rd Party Coordination and Community Relations

During the preliminary phases of construction, extensive coordination with the various utilities, railroads, transportation agencies, and other impacted property owner's was undertaken to ensure that the work progressed according to the project schedule.

Community Relations

In an effort to minimize public inconvenience due to construction activities, and to ensure appropriate precautions were taken to protect public lives and property, several public outreach meetings were conducted to present the schedule and scope of activities near residential areas. As work activities were ready to commence in a given area, a door-to-door campaign was instituted to remind residences of pending work which would include street closures, equipment deliveries, and heavy truck traffic at muck haul routes.

School Influences

The construction schedule for the project was controlled indirectly by the needs of 3 schools that were interlaced within the project environs. Rogers Elementary School was situated at the west end of the project and was to be impacted by the installation of new 18" sanitary sewer and associated excavation and paving work. Additionally, the haul route for Runs 7 through 10 traversed the area adjacent to the school and through the surrounding residential area. In order to avoid the conflict with school traffic consisting of 9 buses and 250 cars per day between the hours of 8AM to 9AM and 3PM to 3:30PM, the contract specified that the work was to be performed between July 1st and August 31st. The contractor successfully completed this work in the summer of 2010.

A mining and access structure (ETAS) was located on the project's east end and served as the retrieval shaft for tunnel Run 1. This structure was situated on Inner City Baptist Schools property, particularly on the east end of the school's junior varsity soccer field. Decommissioning of the mining shaft, construction of the permanent 30ft diameter, below-grade flushing chamber, and restoration of the playing field was required to be complete for the fall 2011 season. The contractor successfully completed all activities to meet the schedule milestone.

The most crucial coordination necessary for project progress was with Baker College. The site included the main mining shaft (NTAS), the pump station shaft (PSAS), and the south tunnel shaft (STAS). Access to the site, as well as the muck hauling route, was via the campus' entrance drive. The work site temporarily occupied approximately 6.5% of the campus parking area, which typically accommodates 1,000 students daily attending both day and evening classes on campus. Daily coordination and routine meetings with Baker College representatives took place to ensure that the safety and daily activities of the students and administrators were not adversely affected.

Transportation Agencies

During the FHWA and MDOT review of the final design documents, which ultimately extended into the bidding period, a decision was rendered that required approximately 800 ft of the 8 ft diameter storage tunnel to be downsized to 2 ft finished diameter, such that "storage" would not occur within the right-of-way. The excavation was further limited to 4.5 ft, and a jack and bore operation was proposed and accepted by the MDOT. The design was revised by addendum, adding two additional shafts and permanent structures to accommodate the transition in pipeline size. Ultimately, the contractor proposed a 4.5 ft microtunnel (MTBM) approach and successfully worked with the MDOT to revise the permit for the crossing.

Figure 4. Each shaft location presents unique challenges

Railroad Crossing
Based on the permit for crossing the NSRR right-of-way, liner plate was required to be used as the primary liner. The contractor proposed to utilize steel channel lagging and steel ribs, in lieu of liner plate. It was also believed that the expanded ribs and lagging would minimize ground settlement while tunneling under the tracks. Typically, many railroads require the use of fixed steel liner plates that bolt together when tunneling under track. This method often results in greater settlement as the plates cannot be expanded to meet the ground beneath the TBM and the operation proceeds more slowly. In the preliminary phase of construction, it was demonstrated to the railroad decision-makers how steel rib and lagging materials would provide a greater degree of protection against above ground settlement during construction. Ultimately, the proposed rib and steel lagging alternative was accepted for use and was successfully installed, resulting in maximum track settlement of less than 0.1in.

Shaft Selection and Construction

For the rigid shaft locations at the pump station (PSAS), NTAS, and STAS, the contractor selected to utilize 33-ft diameter shafts comprised of secant piles with reinforced-concrete ring wales. The contract required 3 ft minimum diameter for secant piles; however, the contractor successfully proposed the use of 2 ft diameter piles, with the secondary piles reinforced with HP12x53, and concrete ring wales.

The secant pile shafts were installed using the continuous flight auger (CFA) method. Initially, grout was maintained at constant pressure of approximately 25 psi and injected at the base of the auger stem during withdrawal. It was observed, however, that the excavated clay soils exhibited better strength properties than anticipated, and as such, the contractor elected to attempt excavation of the piles without grouting the hole during the drilling process. It was determined through observation and measurement that the excavated piles indeed held up without appreciable deformation. Ultimately the remaining secant piles were constructed in this manner, with the open holes ultimately being filled with grout or structural concrete by pump and tremie tube.

As the excavation of the rigid shaft for the pump station progressed, it was observed that many of the 80 ft long piles were not within vertical tolerance within the lowest 1/3 of the excavation. The use of smaller diameter piles compounded the effect of this problem. This required modification to the ring beam design and resulted in encroachment into the clear working diameter of the shaft. Upon completion of the excavation, three-dimensional laser scanning was employed to document the as-built shaft conditions and to determine what modifications to the permanent structure would be necessary.

Figure 5. Secant pile shaft and TBM prior to insertion

Flexible shafts consisting of steel sheet piling and reinforced concrete ring beams were utilized for the ETAS mining shaft and the MTBM mining shafts. The contract specifications had less stringent requirements for these locations due to their proximity to adjacent utilities or infrastructure.

TBM Selection and Performance

The contractor employed a 12 ft diameter, Lovat model ME 142/150 PJ/RL tunnel boring machine, which is a bi-directional, rotary head, soft ground machine. The machine incorporated a fully enclosed forward shield and a soft ground cutterhead equipped with spade/ripper type teeth and flood control doors at the face of the machine. Muck removal was accomplished by a 300 degree much ring, mounted in the center of the forward shell, which transfered muck through pressure relief gates to a conveyor in open mode or to a screw conveyor in closed mode, and ultimately transported to the rear of the machine by conveyor for final removal by muck carts and locomotive. Sawdust, obtained from a local producer, was used to condition the soft clay at the tunnel face.

Production rates

The typical mining operation included 2 shifts of 9 hours per day. When mining within the zone of influence for the railroad and critical utility crossing, the work proceeded 24 hours per day, utilizing 2 working shifts of 12 hours. Maintenance was generally performed on Saturdays when no mining was taking place. The average downtime over the duration of the project for maintenance or repairs was approximately 45 minutes per day.

Table 1. Summary of TBM performance

RUN	FROM - TO	LINEAR FEET MINED	ACTUAL CYDS MINED	TOTAL DAYS OF OPERATION	TOTAL DAYS MINED	LINEAR FEET PER DAY	CYDS MINED/DAY	AVERAGE SETTLEMENT PER RUN
#1	NTAS - ETAS	1357	6092	41	36.5	37.1	166.9	0.84"
#2	PSAS - NTAS	309	1322.5	23	17	18	77.7	1.48"
#3	NTAS - STAS	770.3	3148	21	19	40.5	165.6	0.06"
#4	STAS - EJC	396.5	1677	15	15	26.4	11.8	0.21"

As would be expected, the production rates varied considerably between the 4 major runs of the 12 ft bore, with the higher production rates occurring during the longer runs of tunnel. The average production rate for the TBM-mined tunnel was 30.5 ft per day. The best production day was 72 ft, while the worst day was 3 ft, with only a single set installed due to mechanical failure and subsequent repair of the rib expander.

Boulders

During the mining operation, the excavated material was primarily soft clay that was conditioned with sawdust, to allow efficient removal from the face. Cobbles were routinely encountered and easily removed by cutterhead and conveyor. Throughout the project, 13 boulders ranging in size from 12 to 32 inches in average dimension were encountered during mining. Since the contract required that boulders less than 24 inches in the average of 3 dimensions were to be considered incidental to the project, only 1 boulder, encountered in Run 3, resulted in additional cost to the project.

Settlement Analysis

Due to the location of the tunnel with respect to critical utilities and infrastructure, a detailed instrumentation and monitoring plan was developed during the design phase and identified in the contract documents. Instruments included inclinometers, tell tales, monitoring point arrays, and deformation monitoring points installed at critical utility locations, shaft locations, and rail/highway crossing. The monitoring program was designed, installed, and maintained by the owner, with daily communications transmitted to the contractor to allow appropriate action to be taken should threshold levels of deformation be encountered.

The frequency of monitoring varied, but typically consisted of weekly measurements of ground deformation in the vicinity of shafts, and daily measurement of monitoring points and arrays within the vicinity of the tunnel face. The tunneling induced settlement measurements ranged from 0.06 in to 6.24 in, the largest occurring due to significant ground loss that occurred at the tunnel eye when the TBM was launched from the shaft for Run 3. The average measured surface settlement for the project was 0.97 in, which equates to approximately 2% of the excavated volume.

Measurements indicated that the largest surface settlement occurred during the maintenance shifts, when the TBM was not advancing. Twenty-four-hour tunneling operations were thus used to minimize settlement in critical locations, particularly the crossing of CN and NS Railroads. The maximum settlement of the 7 sets of tracks that were crossed for this project was found to be only 0.09 in.


Figure 6. Mining operation with effective boulder removal

Other Trenchless Methods

As indicated above, the project consisted of a variety of trenchless methods to not only incorporate existing utilities into the improved sanitary system but also to accomplish the existing system tie-in without interrupting the 24 hour per day, 7 day a week capability of the pump stations. The following is a commentary on these trenchless methods including location, success thereof, and issues encountered, as well as significance to the project:

Run 5 (800 ft long, 54" diameter, MTBM)

The contractor proposed an alternate to the proposed 48 in boring and jacking method that is shown in the contracts documents for the crossing of I-94. This alternate eliminated a bore pit and a manhole in the median and consisted of increasing the casing diameter to a 54", .563 w/steel casing placed using a purpose built Akkerman 54" micro-tunnel machine. The MTBM used a rotating wheel to loosen and remove the spoil. This change was advantageous in that it was performed with a manned machine and operator at the face, monitoring the soil conditions constantly, as well as being articulated and steerable and guided by a laser guidance system. This change was ultimately accepted by MDOT and the owner assumed an appropriate credit to the contract. This run was successfully completed within the specified allowable settlement tolerances of less than 0.5 in.

Run 8 (450 ft long, 18" diameter, pipe bursting)

This portion of the project proved to be extremely difficult and quite problematic to the contractor. With the depth and upsizing required the burst could be classified as "Challenging" according to Tables 1 and 2 Project Classification as depicted on pages 20 and 21 covered in NASTT publication "Pipe Bursting Good Practices." The contractor incurred excessive overburden pressures on the C-905 PVC pipe due to delays in shaft preparation. This resulted in exceeding the maximum pulling pressures of the pipe (greater than 64.2 tons). This necessitated some unexpected additional excavation and restoration in the work area. Nonetheless, the work was completed, upsized and the sewer flow was reestablished through the pipe until the new pump station was ready.

Run 11 (632 ft long, 14" diameter, directional drill)

This portion of the new force main located in the green belt just west of Enterprise Drive was designated to be constructed by slip lining 14" PVC C-905 through the existing 21" sanitary sewer. Contractor proposed to change the force main to a direction drill using 14" HDPE with tracer wire to be placed approximately 8 feet above the existing line. By using this approach the temporary bypass line and pumping of the existing sanitary line could be eliminated as the extent of the tie-in on the new main was significantly reduced (Run 12). This change resulted in an appropriate credit to the owner and eliminated the MDOT mandated 30-day maximum period for the temporary bypass line that was to be installed along the east guard rail of the Outer Drive bridge along I-94. This work was accomplished successfully within several days of time.

Run 12 (183 ft long, 21" diameter, slip lining)

The slip lining and ultimate tie-in of the new system was successfully completed during a 3 day weekend. The existing flow in the sanitary sewer was stored in the wet well of the new pump station and its contents pumped into the new discharge manhole upon completion of the tie-in of the new force main.

CONCLUSIONS

In addition to the typical engineering and construction challenges associated with underground construction, the Allen Park Storage Tunnel Project, nearly a decade in the making, required thorough coordination with multiple federal, state, and local agencies, two rail roads, three schools, and several bustling residential neighborhoods in order to achieve success. The proactive and coordinated approach to informing and interfacing with the community and the other 3rd party stakeholders, was well-received and resulted in well-informed project participants that have worked together to see this project through completion without significant changes, delays, or disruptions.

Detailed, performance based specifications provided for successful risk management through the design and contracting phase, yet allowed the contractor adequate flexibility in determining the most appropriate and cost-effective approach to perform the various types of shaft, tunnel, and other trenchless installations. A collaborative effort between the Contractor and Owner/Engineer during the pre-construction activities ensured that the project performance expectations with respect to shaft and tunnel construction, and settlement limitations were understood and achieved. Ground deformation was successfully minimized in the vicinity of the critical utility, railroad, and highway crossings, resulting in no adverse impact to any of the project stakeholders.

The project alignment, dictated by the constraints of the existing infrastructure, both at the surface and below, required detailed engineering solutions and precise construction in order to successfully utilize the underground space for the much needed sanitary storage and conveyance improvements. In addition to successfully achieving the technical goals of the project, substantial completion was achieved in January 2013, ultimately meeting the project's schedule and budget.

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