FEATURE ARTICLE

Small footprint, big challenges: Design and construction of the Allen Park storage tunnel

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 its 2005 consent order and 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.

FIG. 1

Project alignment and overview.

The tunnel is sized to transport and store 507 million L (1.34 million gal) of wet-weather flow. The tunnel will convey flow to a new 0.24 L^3/s (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 355-mm- (14-in.-) diameter force main that will outlet to an existing trunk sewer outlet north of Outer Drive. This arrangement replaces the existing 457-mm (18-in.) gravity sewer that was unable to deliver the maximum outlet capacity to the Outer Drive Lift station without significant surcharge upstream.

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.

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Project description

Located within the Ecorse Creek Watershed in an urban area congested with existing utilities and structures, the 1,250-m (4,100-ft) long 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 1.4-m (54-in.) 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, a local landmark that consists of the repurposed Ferris wheel attraction from the 1964-1965 World's Fair in New York.

A dynamic mix of five different trenchless construction and rehabilitation methods were used to complete 2.4 km (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 928 m (3,045 Lft) of 2.4-m (8-ft) diameter tunnel sewer in primary and secondary lining. A 609-mm (24-in.) diameter, 213 m (700 Lft) section under the interstate highway was constructed using microtunneling methods (MTBM). Pipe bursting was used to install a 122-m (400-ft) section with only one service connection to increase the sewer diameter from 381-457 mm (15-18 in.). A combination of directional drilling, slip-lining and opencut techniques was used to install 396 m (1,300 Lft) of 355-mm (14-in.) force main. The alignment also included opencut construction of 241 m (790 Lft) of 2.4-m and 1.5-m (8-ft and 5-ft) diameter sewer and 442-m (1,450-ft) of 457-mm (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 Figs. 1 and 2. Individual tunnel runs are described below.

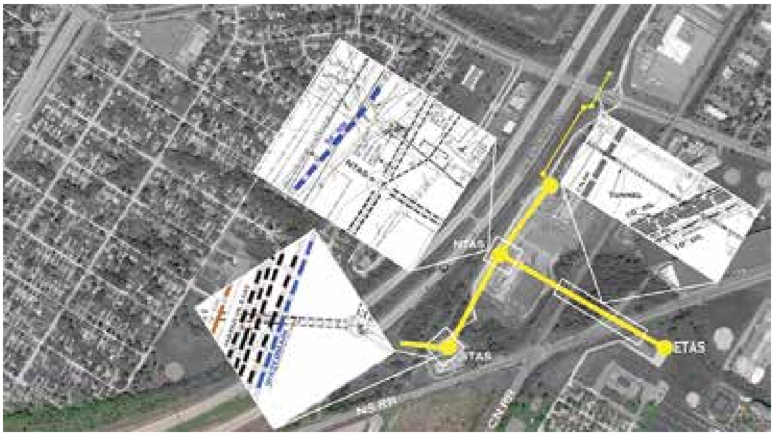
Run 0 (North tunnel access structure [NTAS] to Westerly Tail Tunnel): To accommodate the tunnel locomotive and muck cars, a tail tunnel was constructed by hand mining and placing liner plate 3 m (10 ft) in diameter through the secant pile shaft wall, extending 11.5 m (38 ft) from the west face of NTAS. This run was constructed below and perpendicular to a 1.3-m (54-in.) DWSD water transmission line.

Run 1 (NTAS to ETAS): This run progressed east out of NTAS to the East Tunnel Access Shaft approximately 419 m (1,375 ft) in length with an invert approximately 9 m (30 ft) below ground surface. This run consists of 3.6-m (12-ft) diameter rib and lagging primary liner, with a 2.4-m (8-ft) diameter secondary liner, that traverses below a primary Wayne County Drain (Ecorse Creek), five tracks of railroad and a 254 mm (10 in.) diameter oil pipeline.

Run 2 (Pump station access shaft [PSAS] to NTAS): This run is 94 m (309 ft) long, parallel to the 1.3-m (54-in.) DWSD transmission main, approximately 10.6 m (35 ft) to the east. Consistent with Runs 3 and 4, the tunnel has a 3.6-m (144-in.) rib and lagging primary liner with a 2.4-m (96-in.) reinforced concrete pipe as the secondary insertion.

FIG. 2

Critical utility crossings.



Run 3 (NTAS to south tunnel access shaft [STAS]): This run crosses beneath Ecorse Creek and the retention pond of Baker College's storm system. The 259-m (850-ft) tunnel run is also approximately 10.6 m (35 ft) deep, and is comprised of a 3.6-m (144-in.) rib and lagging primary liner with 2.4-m (96-in.) reinforced concrete pipe as the secondary liner.

Run 4 (STAS to the east junction chamber [EJC]): This tunnel is constructed below the 1.3-m (54-in.) DWSD water main, oil pipelines, high-pressure gas mains and a 304-mm (12-in.) sanitary sewer in which there was 1.5 m (5 ft) of clearance between each of the utilities. Cover over the tunnel crown ranged from 1.3 to 5.8 m (4.5 ft to 19 ft).

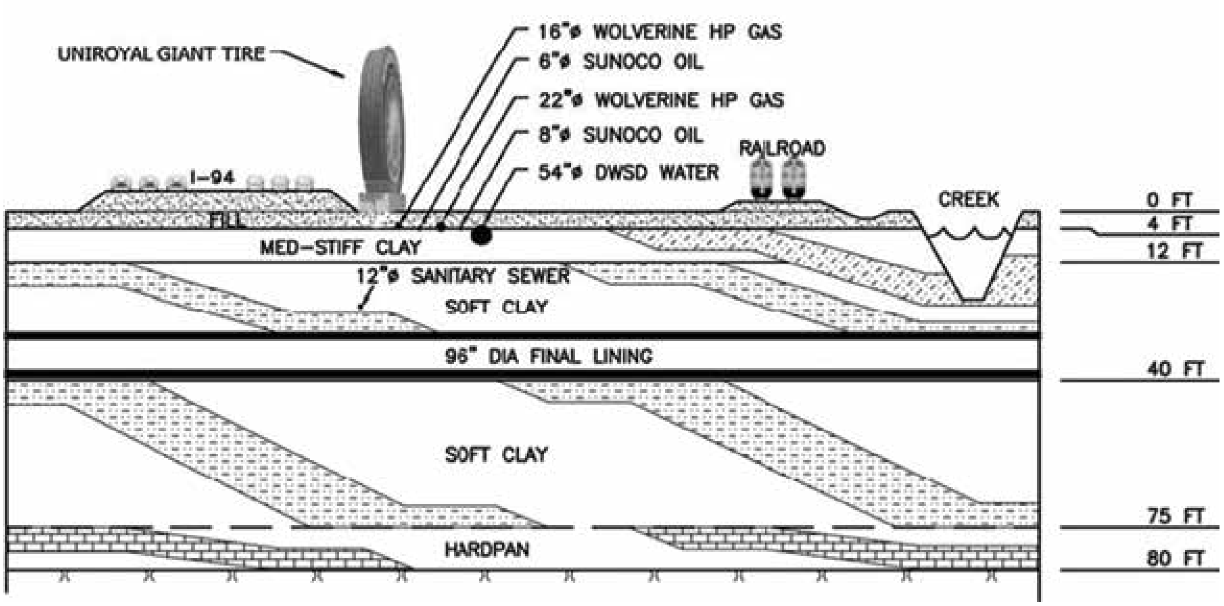
Run 5 (EJC to the west junction chamber [WJC]): This 244-m (800-ft) run crosses beneath seven lanes of I-94 with a depth of 12-13 m (40-45 ft) and was constructed by microtunneling with a 1.3-m (54-in.) steel primary liner and a 0.6-m (2-ft) diameter secondary liner. This was a late design change dictated by the governing highway agency. The mining shaft for this run was located approximately 9 m (30 ft) from the Uniroyal Giant Tire, one of the world's largest roadside attractions.

Runs 6 and 7 (WJC to west tunnel access structure [WTAS] to west diversion chamber [WDC]): These runs comprise 237 m (780 ft) of 1.5-m (5-ft) diameter concrete pipe approximately 9 m (30 ft) deep constructed by cut-and-cover methods between Ecorse Creek and Rogers Elementary School.

Run 8 (WDC to Sanitary MH 14-3): Pipe bursting of 381-m (15-in.) vitrified clay with an existing CIPP liner upsizing to a 457-mm (18-in.) PVC C900 fusible pipe. The length was 137 m (450 ft), approximately 5.8 m (19 ft) deep.

FIG. 3

Generalized soil profile.



Runs 9 and 10 (MH 14-3 to diversion chamber 14-1 at intersection of Russell and Larme streets): Upsize existing rear yard 304-m (12-in.) sanitary to 457-m (18-in.) pipe of 293 m (962 ft) in length on south side of Shenandoah and Russell streets with complete street replacement. Required to be completed between July 5 and Aug. 31 while Rogers Elementary was closed.

Run 11 (PSAS going north toward existing sanitary MH 228): Directional drilling of a portion of the new pump station's force main (193 m or 632 ft) with subsequent placement of 355-mm (14-in.) HDPE pipe.

Run 12 (Sanitary MH 228 to the existing pump station): Slip lining of 533-mm (21-in.) sanitary sewer with 55 m (183 ft) of 355-mm (14-in.) HDPE beneath the major thoroughfare of Outer Drive.

Subsurface conditions

The subsurface stratigraphy along the proposed tunnel alignment is relatively uniform (Fig. 3), consisting of a thin layer of variable surficial fill extending from the ground surface down 1-1.6 m (3-5.5 ft). Below the fill layers are natural soil deposits consisting of a thin desiccated layer of medium to stiff silty clay that extends 3.8 m (12.5 ft) below ground surface, underlain by a thick layer of soft to medium silty clay that extends below ground surface ranging from 20-23 m (67-77 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 lb/sq ft near the top of the deposit, to less than 600 lb/sq ft 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 25-27 m (83-90 ft) below ground surface. The long-term, static ground water is typically 4.5-6 m (15-20 ft) below ground surface. Low levels of hydrogen sulfide gas are typically within the substrata throughout the alignment.

Design considerations

Shafts. To accommodate the variety of subsurface improvements, the project required construction of seven shafts, ranging from 3.6-m- (12-ft-) diameter for the smaller sanitary sewer improvements, to 12-m- (40-ft-) diameter for the pump station mining shaft. The shafts ranged in depth from 5.4-18 m (18-60 ft), with the deepest shaft required for the permanent structure of the dewatering pump station. Rigid mining shafts were specified for three critical locations to minimize potential for ground movement during tunneling operations. The contract included provisions for the use of secant piles, diaphragm slurry wall or sinking caisson methods of shaft construction at these locations. Detailed performance criteria including minimum structural requirements and ground deformation limitations were also included. However, the contractor was required to ultimately select and take design responsibility for the temporary support of excavation.

FIG. 4

Each shaft location presents unique challenges.

Primary and secondary tunnel lining. A two-pass tunnel liner was specified that required steel ribs and timber lagging for the primary liner and 2.4-m (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. Secondary lining consisted of 2.4-m (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. ASTM C443 gasketed joints with grouted inside annulus were specified to ensure a water-tight sanitary storage vessel and a smooth finished surface to allow efficient transport and effective tunnel flushing. Maximum allowable ground water infiltration was specified to not exceed 20 gal/in. of diameter, per 152 m (500 ft) 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. 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 25 mm (1 in.) and maximum allowable heave of 12.7 mm (0.5 in.). Where the tunnel crosses the MDOT right-of-way for Interstate 94, the maximum allowable surface settlement was further restricted to 12.7 mm (0.5 in.). The contract was required to restore the site to pre-existing

TABLE 1

Summary of TBM performance.

Run	From-To	Linear ft. mined	Actual yd^3 mined	Total days of operation	Total days mined	Linear ft./day	yd^3 mined/ day	Avg. settlement per run
#1	NTAS-ETAS	1,357	6,092	41	36.5	37.1	166.9	0.84″
#2	PSAS-NTAS	309	1,322.5	23	17	18	77.7	1.48″
#3	NTAS-STAS	770.3	3,148	21	19	40.5	165.8	0.06″
#4	STAS-EJC	396.5	1,677	15	15	26.4	11.8	0.21″

FIG. 5

Secant pile shaft and TBM prior to insertion.

grades and profile and repair any damage should these threshold values be exceeded.

Boulders. Historical data indicated that boulders were likely to be contained within the silty clay throughout the tunnel alignment. The contract documents advised the contractor that cobbles and boulders may be encountered at the tunnel face. The tunneling specifications indicated that boulders less than 609 mm (24 in.) in the average of three dimensions as measured protruding into the bore would be incidental and required that the mining machine include provisions for removal of boulders at the tunnel face. In addition, a contingency bid item was included to cover unforeseen physical conditions that might be encountered during construction. These measures ultimately minimized changed condition claims from the contractor during tunneling operations.

TBM features. Face stability analyses indicated that a tunnel mined in the soft to medium clay strata using open face mining would result in overload factors from 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 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 the selected TBM be compatible with anticipated ground and ground water conditions, capable of providing full-face support and equipped with face closure doors. The face was to be accessible through the cutter head for removal of obstructions.

Construction and performance

The construction contract was awarded on Oct. 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 Aug. 6, 2010.

Third party coordination and community relations. During the preliminary phases of construction, extensive coordination with the various utilities, railroads, transportation agencies and other impacted property owners was undertaken to ensure that the work progressed according to the project schedule.

Community relations. To minimize public inconvenience due to construction activities and 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 residents of pending work that would include street closures, equipment deliveries and heavy truck traffic at muck haul routes.

School influences. The construction schedule was controlled indirectly by the needs of three schools within the project area. Rogers Elementary School at the west end of the project was impacted by the installation of 457 mm (18 in.) 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. To avoid conflict with school traffic, the contract specified that the

FIG. 6

Mining operation with effective boulder removal.

work be completed between July 1 and Aug. 31, 2010.

A mining and access structure (ETAS) on the project's east end served as the retrieval shaft for Run 1. This structure was situated on Inner City Baptist School's property, on the east end of the school's junior varsity soccer field. Decommissioning of the mining shaft, construction of the permanent 10 m (30 ft) diameter, below-grade flushing chamber and restoration of the playing field was required to be complete for the fall 2011 season.

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 along the campus' entrance drive. The work site temporarily occupied approximately 6.5 percent of the campus parking area, which typically accommodates 1,000 students daily. Daily coordination and routine meetings with Baker College representatives took place to ensure that the safety and activities of the students and administrators were not adversely affected.

Transportation agencies. During the FHWA and MDOT review of the final design documents, a decision was rendered that required approximately 243 m (800 ft) of the 2.4-m (8-ft) diameter storage tunnel to be downsized to 0.7-m (2-ft) finished diameter, so that storage would not occur within the right-of-way. The excavation was further limited to 1.3 m (4.5 ft), and a jack and bore operation was proposed and accepted by 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 1.3-m (4.5-ft) microtunnel (MTBM) approach and successfully worked with MDOT to revise the permit for the crossing (Fig. 4).

Railroad crossing. Based on the permit for crossing the Norfolk Southern Railroad right-of-way, fixed steel liner plates that bolt together when tunneling under track were required to be used as the primary liner. Because 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, the contractor proposed to use steel channel lagging and steel ribs instead. It was demonstrated to the railroad decision-makers that steel rib and lagging materials would provide a greater degree of protection against above-ground settlement during construction and ultimately, the rib and steel lagging alternative was accepted.

Shaft selection and construction. For the rigid shaft locations at the pump station (PSAS), NTAS and STAS, the contractor used 10-m- (33-ft-) diameter shafts comprised of secant piles with reinforced-concrete ring wales. The contract required 1 m (3 ft) minimum diameter for secant piles; however, the contractor successfully proposed the use of 0.7-m (2-ft) diameter piles, with the secondary piles reinforced with HP12 x 53, and concrete ring wales.

The secant pile shafts were installed using the continuous flight auger method. Initially, grout was maintained at a constant pressure of approximately 25 psi and injected at the base of the auger stem during withdrawal. Because the excavated clay soils exhibited better strength properties than anticipated, the contractor attempted 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 and 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, many of the 24-m- (80-ft-) long piles were not within vertical tolerance within the lowest one-third 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 used to document the as-built shaft conditions and determine what modifications to the permanent structure would be necessary (Fig. 5).

Flexible shafts consisting of steel sheet piling and reinforced concrete ring beams were used 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 used a 4-m- (12-ft-) diameter, Lovat model ME 142/150 PJ/RL TBM, which is a bidirectional 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 its face. Muck removal was accomplished by a 300° muck ring, mounted in the center of the forward shell, which transferred 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 two shifts of nine hours per day. When mining within the zone of influence for the railroad and critical utility crossing, the work proceeded 24 hours per day, using two 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).

As would be expected, the production rates varied considerably between the four major runs of the 3.6-m (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 9.2 m/d (30.5 ftpd). The best production day was 22 m (72 ft), while the worst day was 1 m (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 (Fig. 6). Cobbles were routinely encountered and easily removed by cutterhead and conveyor. Throughout the project, 13 boulders ranging in size from 304-812 mm (12-32 in.) in average dimension were encountered during mining. Since the contract required that boulders less than 609 mm (24 in.) were to be considered incidental to the project, only one boulder encountered 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 1.5-158 mm (0.06-6.24 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 24.6 mm (0.97 in.), which equates to approximately 2 percent 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 used to minimize settlement in critical locations, particularly the railroad crossings. The maximum settlement of the seven sets of tracks that were crossed for this project was found to be only 2.3 mm (0.09 in.).

Other trenchless methods. 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, seven-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 (243 m (800 ft) long, 1.37 m (54 in.) diameter, MTBM): The contractor proposed an alternate to the proposed 1.2-m (48-in.) boring and jacking method that is shown in the contract 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 1.37-m (54-in.) 0.563 w/steel casing placed using a purpose built Akkerman 1.37-m (54-in.) microtunnel 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 accepted by MDOT, the owner assumed an appropriate credit to the contract and the run was completed within the specified allowable settlement tolerances of less than 12.7 mm (0.5 in.).

Run 8 (137 m (450 ft) long, 457 mm (18 in.) 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 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 58.2 t or 64.2 st). This necessitated some unexpected additional excavation and restoration in the work area. Nonetheless, the work was completed, upsized and the sewer flow was re-established through the pipe until the new pump station was ready.

Run 11 (192 m (632 ft) long, 355 mm (14 in.) diameter, directional drill): This portion of the new force main was designated to be constructed by slip lining 355 mm (14 in.) PVC C-905 through the existing 533-mm (21-in.) sanitary sewer. The contractor proposed to change the force main to a direction drill using 355-mm (14-in.) HDPE with tracer wire to be placed approximately 2.4 m (8 ft) 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 a 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 guardrail of the Outer Drive bridge along I-94. This work was accomplished successfully within several days.

Run 12 (56 m (183 ft) long, 533 mm (21 in.) diameter, slip lining): The slip lining and ultimate tie-in of the new system was successfully completed during a three-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.

Conclusion

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 railroads, three schools and several bustling residential neighborhoods to achieve success. The proactive and coordinated approach to informing and interfacing with the community and the other third-party stakeholders, was well-received and resulted in well-informed project participants who 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 preconstruction 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, at the surface and below, required detailed engineering solutions and precise construction 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. ■

Acknowledgments

The authors thank the city of Allen Park for its permission to publish this paper, as well as Jason Yoscovits, who served as the full time inspector for the duration of the project, for his input regarding performance and execution of the work.

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