

Logistics and Performance of a Large-Diameter Crossover TBM for the Akron Ohio Canal Interceptor Tunnel

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ABSTRACT: The Ohio Canal Interceptor Tunnel (OCIT) below the city of Akron is utilizing the first large diameter Dual Mode, “Crossover” type TBM in the United States. The 30.4 ft diameter machine is excavating in variable conditions including soft ground and shale rock. Due to the unique conditions, the TBM has been designed with features including a flexible cutterhead design and abrasion-resistant plating on the cutterhead and screw conveyor. As part of a predictive maintenance plan, measurements for the screw conveyor’s exposed features will be taken along the drive to report on the wear rate of these components in shale. This paper will concentrate on the logistics and process of the TBM launch, and component wear and performance at the jobsite in variable ground conditions.

INTRODUCTION

The OCIT is the key component of the city’s long-term control plan aimed at reducing Combined Sewer Overflows (CSOs) into the Little Cuyahoga River and surrounding streams. The tunnel will be combined with drop shafts, diversion structures, consolidation sewers, and related appurtenances that will decrease the flow of untreated CSO and direct wastewater and storm water through Akron’s water reclamation facility. Consent decree timing stipulates that the OCIT must be complete and operational by December 31, 2018 and the rest of the system and its structures must be online by 2028.

The city looked at rainfall records and identified 1994 as a typical year. The 6,200 ft long OCIT will thus be able to handle 450 gallons of CSO annually in a 27 ft finished inside diameter tunnel. If rainfall is above typical, a further 17 million gallons of overflow can be diverted through an Enhanced High Rate Treatment (EHRT) process that will allow the water to be directly released into the Little Cuyahoga. The EHRT is a separate project that will be completed in the future. The tunnel will pull from nine main regulators referred to as racks (overflow spots) along a narrow corridor to achieve the water storage, while the city’s other overflow spots are being controlled through storage basins, sewer separations, maximizing conveyance and green infrastructure (see Figure 1).

GEOLOGY

The Storage Tunnel will pass through three zones or reaches with distinctly different ground conditions. Starting at the construction portal, the generalized ground conditions in these reaches will consist of soft ground (Reach No. 1), mixed face conditions with soft ground overlying bedrock (Reach No. 2), and bedrock with two sections of low rock cover (Reach No. 3).

Reach No. 1—Soft Ground

Reach No. 1 extends from the construction portal to Sta. 13+50. Ground surface after the placement of fill between the construction portal and about Sta. 12+50 will range from approximately El. 845 to El. 885, which corresponds to a thickness of cover over the crown of the tunnel ranging from about 25 to 65 feet.

Reach No. 2—Mixed Face

Reach No. 2 extends from Sta. 13+50 to Sta. 19+50. Existing ground surface ranges from approximately El. 868 to El. 893, which corresponds to a thickness of cover over the crown of the tunnel ranging from about 45 to 70 feet. Ground conditions in Reach No. 2 are expected to range from a full face of soft ground to a full face of bedrock in the vicinity of Sta. 19+50, with the contact between soil and bedrock rising from north to south. Although geotechnical studies predict a relatively uniformly sloping bedrock surface in this reach, it is possible that the

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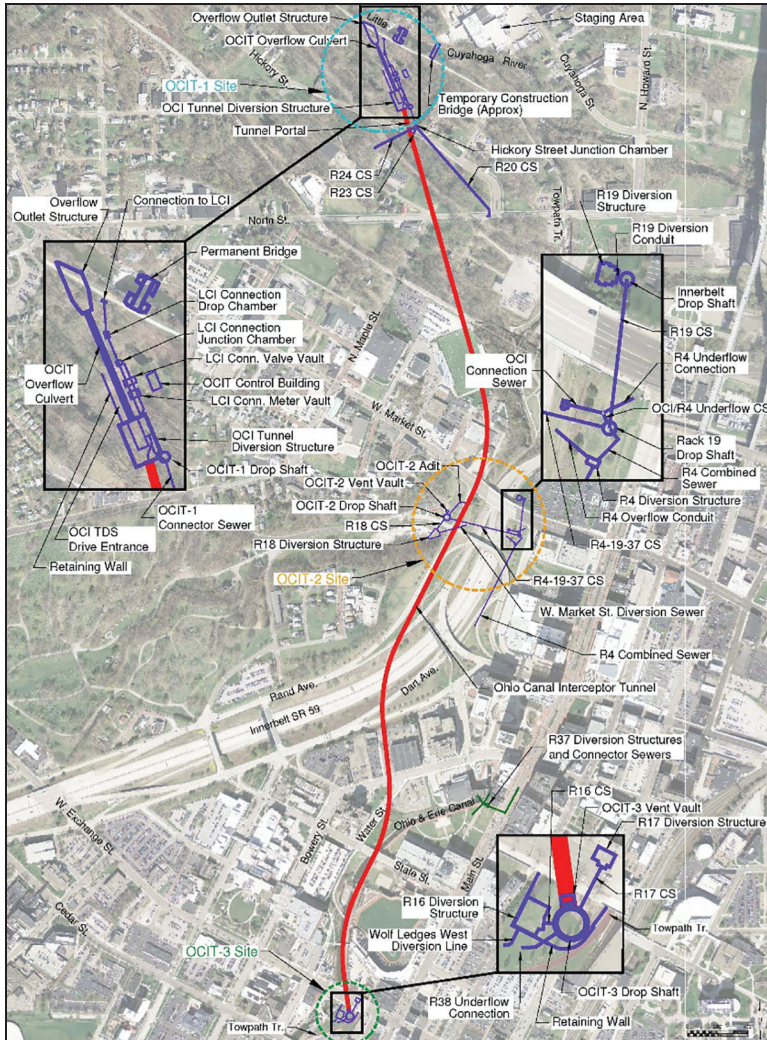


Figure 1. OCIT layout

bedrock surface has a stepped or staircase configuration as a result of the horizontal and vertical jointing in the rock mass.

Within Reach 2, four obstructions will be encountered within the soft ground section consisting of naturally deposited boulders with UCS no greater than 45 ksi. The bedrock in Reach No. 2 will consist primarily of shale with a slightly higher degree of weathering and more closely spaced joints than the overall rock mass due to the proximity of the top of bedrock. A zone of completely to highly weathered bedrock will be encountered at the top of the bedrock surface. For baseline purposes, the thickness of completely to highly weathered rock at the top of bedrock will be no greater than 10 feet in


Reach 2. Very widely spaced horizontal clay seams were observed in the rock core, parallel to bedding, and ranged from about 1 to 3 inches thick along the tunnel alignment in Reach 2.

Overall bedrock quality in Reach No.2, in terms of RQD is predominantly fair ($50 < RQD < 75$) to very good ($RQD > 90$), with some zones of poor ($25 < RQD < 50$), to very poor quality rock ($RQD < 25$). These zones of poor to very poor quality rock are associated with closely spaced, decomposed bedding joints.

Reach No. 3—Bedrock

Reach No. 3 extends from Sta. 19+50 to the OCIT-3 Drop Shaft. Existing ground surface in Reach No.

Table 1. TBM operating modes in varying ground conditions

Akron OCIT TUNNEL REACHES AND OPERATING MODE						
						
START STATION	STOP STATION	FOOTAGE	GROUND CONDITIONS	OPERATION CONDITION	FOOTAGE	TOTAL FOOTAGE
11 +40	14 +50	310	Full face soft ground, shale below invert	EPB, Alpha 20		310
14 + 50	19 + 50	500	Mixed ground, Partial face shale	EPB, Alpha 25		
19 + 50	27 + 50	800	Full face shale, low cover	EPB, Alpha 25		
27 + 50	51 + 00	2350	Full Face shale, good cover	Open Mode, 40 MPa shale		
51 +00	56 + 50	550	Full face shale, low cover	EPB, Alpha 25		1850
56 + 50	73 + 50	1700	Full Face shale, good cover	Open Mode, 40 MPa shale	1300	3650
				Open Mode, 70 MPa shale	400	400
TOTAL		6210	feet			6210 feet

3 ranges from approximately El. 893 to El. 992, which corresponds to a total thickness of cover over the crown of the tunnel ranging from about 70 to 165 feet. The thickness of bedrock cover over the crown will range from a few feet adjacent to Reach No. 2 to about 90 feet, with two zones of generally lower bedrock cover of between about 10 to 30 feet. The limits of the zones of low bedrock cover are from Sta. 19+50 to Sta. 27+50 and from Sta. 51+00 to Sta. 56+50 as shown on Figure 2. In addition, the Storage Tunnel will pass below the existing St. Vincent-St. Mary’s landfill between approximate Sta. 26+00 to Sta. 33+00.

The Storage Tunnel in Reach 3 will be entirely in shale and siltstone, with minor amounts of sandstone. A zone of completely to highly weathered bedrock will be encountered at the top of the bedrock surface. For baseline purposes, the thickness of completely to highly weathered rock at the top of bedrock will be no greater than 15 feet in Reach 3. Very widely spaced horizontal clay seams were observed in the rock core, parallel to bedding, and ranged from about 1 to 3 inches thick along the tunnel alignment in Reach 3.

Overall bedrock quality in Reach No.3, in terms of RQD will be predominantly good (75< RQD <90) to very good (RQD >90), with some zones of poor (25< RQD <50) to very poor quality rock (RQD < 25) above the tunnel crown and near the top of bedrock. These zones of poor to very poor quality

rock are associated with closely spaced, decomposed bedding joints.

TBM Operating Modes in Various Sections of the Tunnel

The geotechnical plans and profile from the contract documents, as well as the GBR, were studied to define the approximate sections of tunnel and operating modes, as displayed in Table 1.

TBM CUSTOM SETUP

The OCIT Project was awarded to the Kenny/Obayashi JV with a Notice to Proceed date of November 4, 2015. The contractor chose the 30.4 ft Robbins Crossover (XRE) TBM due to varying geology that begins in full-face soft ground, giving way to partial face shale and mixed conditions, and finally full-face shale rock. The machine is capable of operating in both hard rock and soft ground (EPB) configurations. The TBM has been customized in a number of ways, from cutting tools to abrasion-resistant wear plating (see Figure 2).

Crossover Design for Abrasive Ground

One of the main problems in mixed ground for TBM tunneling is related to abnormal flat and multi-flat cutter wear, causing the cutter to wear flat on part of its surface. This is because the soft ground material in the mixed face cannot provide sufficient rolling

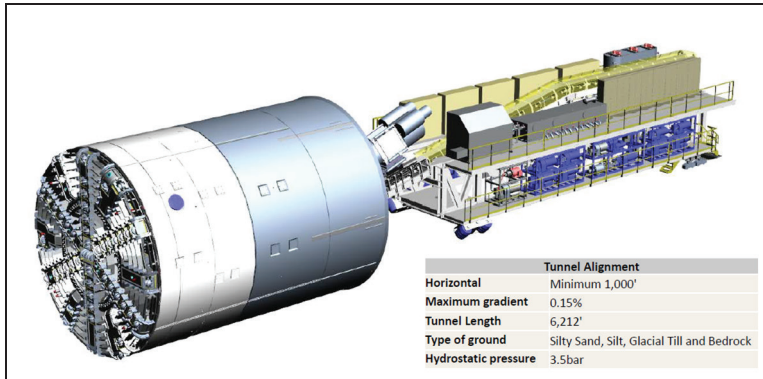


Figure 2. 3D Model of Akron OCIT TBM



Figure 3. View of the OCIT TBM cutterhead

force for cutters to overcome the pre-torque of cutter bearings. The XRE TBM cutterhead is equipped with 56 housings that can be dressed with either knife bits/rippers or 17-inch disc cutters. Due to geologic variability Kenny/Obayashi and Robbins decided that disc cutters would be beneficial from the outset, launching the machine with a full dressing of discs.

Since the disc cutters are operating in soft ground, the pre-torque of the cutter bearings has been reduced by 25% to require less rolling force for the cutter to rotate evenly. This could result in a shorter cutter life once in rock; however, the shale is not expected to be harder than 70 MPa so cutter ring wear is estimated to be very limited. Furthermore in order to avoid hyperbaric intervention in the first 1,610 ft (490 m), sacrificial rippers have been welded to intervene in case of ring wear greater than 0.6 in (15 mm). In the event a cutter gets blocked these rippers should be able to cut the face until the machine

reaches a section where it can operate in open mode. In consideration of the 65% drive in rock, the cutterhead has also been dressed with Hardox 450 faceplates and peripheral grill bars to reduce the risk of abrasive wear (see Figure 3).

The screw conveyor is another customized component: it is a shaft-type design, 64.5 ft long, 47 inches in diameter, with a tapered front nose to 30 inches. In consideration for the OCIT geology and the necessity to muck out shale bedrock, the single shaft-type screw conveyor required a much higher speed than would normally be provided. The hydraulic power unit has an output of 5×110 kW, which brings the max theoretical speed of the conveyor to 16 rpm at a limited torque of 232 kNm (see Figure 4).

In rock mode and mixed ground conditions, and to a lesser degree in EPB mode as well, the auger and the casings are in contact with abrasive material, creating wear. The screw conveyor features

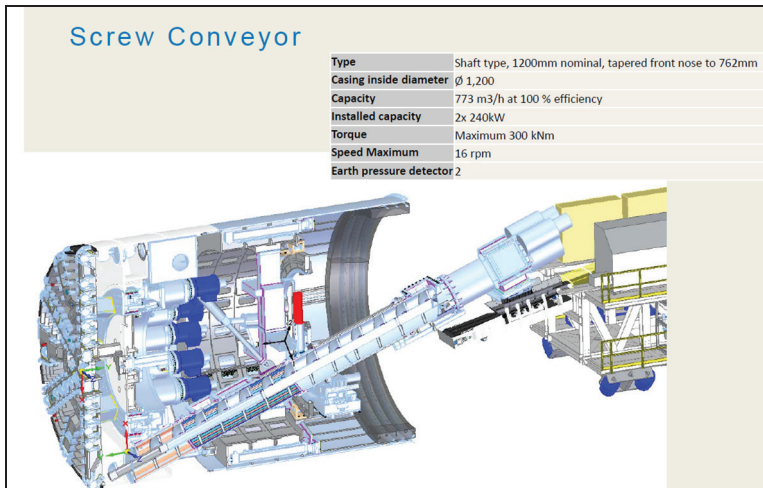


Figure 4. OCIT TBM screw conveyor

the following characteristics to limit wear due to abrasion:

- The leading face of the front auger flight and the outside diameter is covered with welded-in wear plates “inserts” made of Chromeweld 600™ and hardfacing in a crosshatch pattern
- The auger shaft is covered in hardfacing in a crosshatch pattern
- The inside diameter of the casing is lined with welded 0.4 in thick Chromeweld 600™ for the first 1/3 of the casing
- The inside diameter of the remaining 2/3 of the casing is covered with hardfacing
- Four ports have been incorporated into the design for lubricant injection of foam, bentonite, etc.

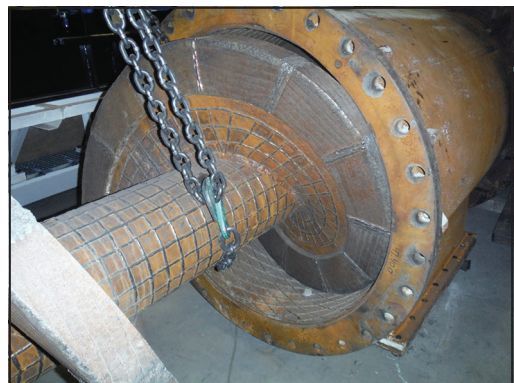


Figure 5. Screw conveyor designed with welded-in wear plates and hardfacing

Chromeweld 600™ is a premium grade of chromium carbide wear plate, produced with a mild steel base plate and hardfaced/overlayed chromium carbide wire (see Figure 5).

TBM LOGISTICS, ASSEMBLY, EXCAVATION, AND UPCOMING CHALLENGES

On May 30th, 2017 the commissioning of the TBM was performed in Solon, Ohio with representatives of the city of Akron, the contractor and the TBM manufacturer. During the commissioning in the factory all the main systems were tested. Once the TBM test was finished the manufacturer disassembled the machine into pieces most convenient for shipping to the jobsite.

A shipping plan was developed between the contractor and the TBM manufacturer to use the shop assembly location as an intermediate place to

store the TBM components. Components would then be shipped in the right assembly sequence to reduce double handling at the jobsite. Due to the fact the cutterhead was designed to avoid any field welds, it was shipped to be assembled and mounted directly to the cutterhead support (main drive); this setup proved to be a great benefit for the shipment and assembly sequence (see Figure 6).

One of the most critical items shipped to Akron was the cutterhead support assembly: a piece weighing approximately 142,000 kg. The main challenge for the transportation of the cutterhead support assembly was to find the right solution to cross a temporary bridge built inside the jobsite that was designed for a 23,500 lbs/ft² load per axle, or about 136,078 kg total (see Figure 7).

Another limiting factor was the local regulation limiting the maximum weight per axle to under

23,000 lbs/ft². It was therefore decided to use a special truck that spread the load across two different lanes, further spreading the load per axle. The truck selected for the transport of the cutterhead support was a 15-axle dual lane truck plus additional tractor in the back (see Figure 8–9).

The 15-axle truck was used for the transportation between the Robbins facility in Solon, Ohio to the jobsite in Akron. Once the cutterhead support arrived at the jobsite it was transferred again before crossing the bridge to a 19-axle truck that spread the load longitudinally and respected the maximum load that the bridge was designed for (see Figure 10).

TBM Launch

The TBM launched from its portal site October 20, 2017 with a depth to invert of approximately 40 ft through a jet grout plug installed to provide a controlled launch environment. The TBM is boring at a uniform slope of 0.15 percent through ground conditions that consist of soft ground, mixed face soft ground over bedrock, and bedrock.

The OCIT is being lined with a steel fiber reinforced precast concrete segmental liner installed concurrent with the mining advance. The low cover environment of the launch itself was the project's first challenge: There is only 20 ft of cover from the top of the TBM, in soft soils, so the challenge has been to ensure there is no impact to the ground above the TBM (see Figure 11).



Figure 6. TBM assembly site and setup

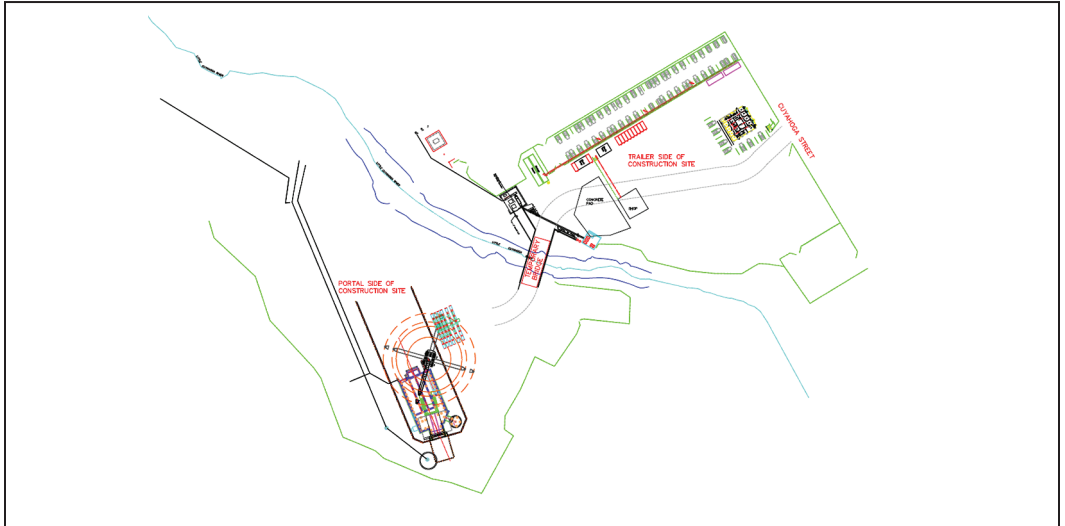


Figure 7. Temporary bridge crossing a waterway at the jobsite



Figure 8. Cutterhead support on the 15-axle dual lane truck

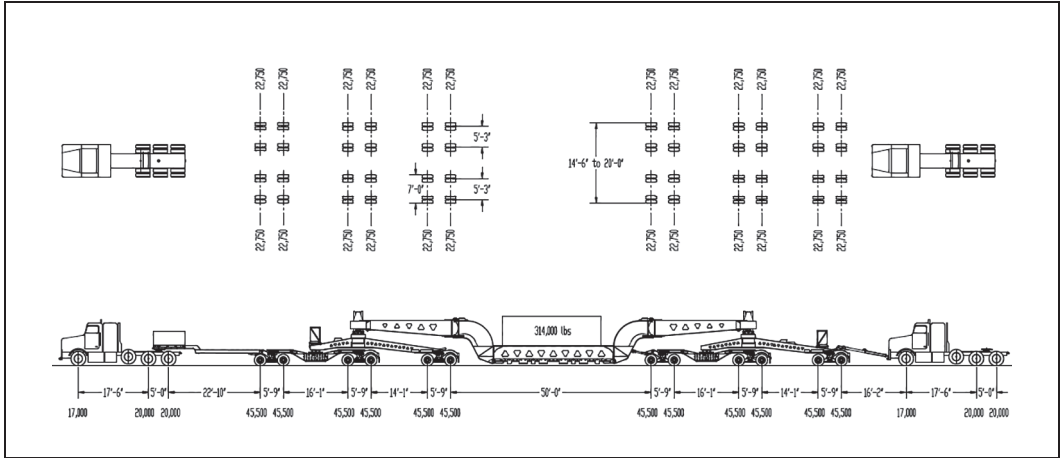


Figure 9. Schematic of transport using the 15-axle dual lane truck



Figure 10. Transfer of the cutterhead support to a 19-axle truck

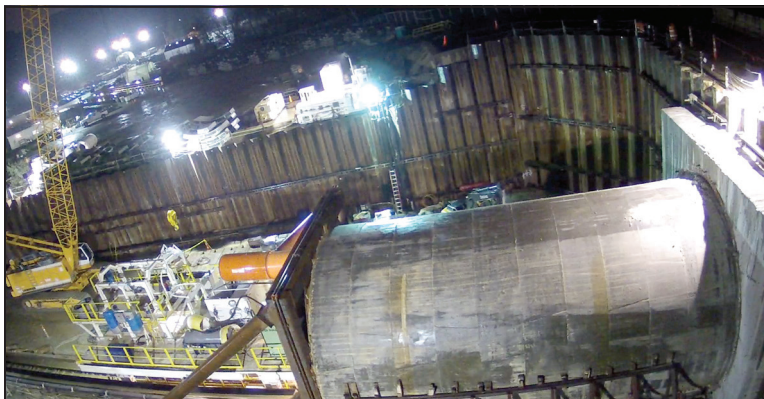


Figure 11. Launch of the TBM under low cover in October

Project Controls

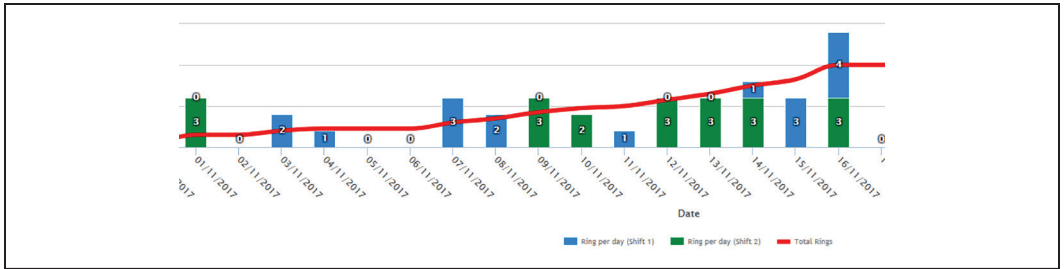


Figure 12. OCIT advance rates since October 2017

By mid-November 2017 the TBM had bored over 180 ft of tunnel, with the best performance on November 1st, 2017 when five rings were placed in two shifts. The performance of the TBM has been controlled and without any major issue since the start of tunnel boring (see Figure 12).

As previously mentioned the second challenge will come later, in the second half of the mixed face zone, when crews will encounter rock in more than 50% of the face. This challenge will be overcome with several strategies that have been evaluated to allow for multiple mix combinations of additives, bentonite and/or foam solutions to stabilize any face condition encountered. Additionally, the design of the cutterhead can be changed to maximize efficiency in all anticipated geology using soft ground tooling and lower bearing torque cutters. It is expected that the TBM will reach this point by the end of November or beginning of December 2017.

The TBM excavation will end at a retrieval shaft with approximately 180 feet from the surface to the invert of the tunnel. Tunneling is expected to take between seven and ten months. Once complete the tunnel will be connected to the network of associated structures that make up the OCIT and to the existing

sewers. There are a total of four shafts, six diversion structures, four hand-mined tunnels, and a microtunnel involved in this work. Associated construction is being performed simultaneously in order to meet the project goals for the City of Akron.

CONCLUSIONS

While tunneling has just begun at the Akron OCIT, much can be learned thus far about design, transport, assembly and launch of a large diameter, mixed ground machine in an urban setting. From the design point of view Robbins has identified three different types of geologies that affect machine design, and make the use of a Crossover TBM advantageous in the mixed ground conditions. In addition, having the jobsite relatively close to the manufacturer's assembly yard has been beneficial from a logistical standpoint, since all the big components did not require double handling; this reduced the cost at the jobsite and had minimal effect on the traffic of the City of Akron. Lastly, thoroughly planning the staging and delivery logistics of the Tunnel Boring Machine allowed crews to speed up the assembly and consequently shorten the period of time required for launching the TBM.