Boring Hard, Abrasive Gneiss with a Main Beam TBM at the Atlanta Water Supply Program

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ABSTRACT: Atlanta, Georgia's water supply program is a priority project involving a 5.0-mile long tunnel connecting up with the Chattahoochee River, which will establish an emergency water supply for the city. A 12.5 ft diameter Main Beam TBM is boring the area's deepest tunnel through hard, abrasive Gneiss rock at rates of up to 100 ft per day. This paper will examine the project specifics and design, as well as the performance of the TBM. It will then draw conclusions as to the optimal TBM design for excavation in the area's exceedingly hard geology based on this project and past projects in the area.

INTRODUCTION

The average North American public utility has only a three-day back-up supply of clean drinking water. The City of Atlanta, Georgia, USA, was, until recently, no exception to that rule. In fact, just three cast-iron water mains built in 1893, 1908, and 1924 conveyed raw water to treatment facilities for ultimate use by 1.2 million customers in the city and surrounding areas. The overtaxed system, paired with the increasing risk of drought, prompted the city's Department of Watershed Management into action. In 2006, the department took steps to purchase the Bellwood Quarry from Vulcan Materials Co.-a 300 ft deep, vertical-sided quarry where granitic gneiss was mined for a century to become structural blocks for Atlanta's buildings as well as crushed stone aggregate for roads.

The USD \$300 million project would turn the inactive quarry into a 2.4 billion gallon raw water storage facility connected up with the Chattahoochee River and various water treatment facilities, bolstering the city's emergency water supply to 30 days at full use and to 90 days with emergency conservation measures. The price is a small one to pay by many estimates: if the city were to lose its water supply, the estimated economic impact could be at least USD \$100 million for just one day.

To make the program a reality would require excavation of Georgia's deepest tunnel (400+ ft), starting at the quarry and running under two treatment facilities for 5.0 miles to an intake at the Chattahoochee River. It would also require construction of two pump stations at the Quarry and Hemphill Reservoir, five blind-bored pump station

shafts at the Hemphill site up to 420 ft deep, as well as two more pump station shafts, one riser shaft, and one drop shaft. The quarry would ultimately store raw water before it is withdrawn for treatment at the Hemphill and/or Chattahoochee water treatment plants, connecting the quarry to the Hemphill Water Treatment Plant (HWTP), the Chattahoochee Water Treatment Plant (CWTP) and the Chattahoochee River. After construction, the area around the quarry would then be turned into Atlanta's largest park totaling 300 acres complete with hiking and biking trails, baseball fields, and an amphitheater (see Figure 1).

The project schedule, primarily driven by the condition of the City's existing water infrastructure, compelled the city to consider Alternative Project Delivery (APD) instead of traditional design-bidbuild. The project schedule required a start date for construction of January 2016 and a substantial completion date of September 2018. The method selected was Construction Manager at Risk (CM@R), where the contractor acts as a consultant to the owner during the development and design phase and as a general contractor during the construction phase. The setup resulted in a unique process to start TBM manufacturing, in particular, before the tunneling subcontractor was mobilized at the site. The decision to use a new TBM by the City of Atlanta was primarilv risk-based.

The PC Construction/HJ Russell (PCR) JV was selected as the CMAR for the project, who then purchased a 12.5-ft diameter Robbins Main Beam TBM for the tunnel. The designer for the construction works including tunnel and shafts, JP2—consisting of Stantec, PRAD Group, Inc., and River 2 Tap—specified the hard rock TBM. The project arrangement is unique: in fact the CMAR purchasing the machine and the Engineer-of-Record specifying the machine may represent the longest such tunnel to be delivered under this setup in North America.

Detailed Project Description

Phase 1 involves design and construction of one TBM tunnel, two pump station shafts, one drop shaft, one riser shaft, five blind bored (top-down) pump stations shafts, and a quarry highwall rockfall protection system to provide long-term protection of the tunnel inlet. Specific details include the following (Del Nero et al., 2016):

- The TBM tunnel is approximately 5,500 ft long and partially concrete lined with a finished diameter of 10 ft;
- The primary pump station shaft at the quarry is approximately 250 ft deep with a finished diameter of 35 ft. The low level pump station shaft has a finished diameter of 20 ft and is approximately 340 ft deep. The primary and low level pump station shafts are connected to the tunnel and quarry via adits;
- The drop shaft at the quarry is about 320 ft deep with a finished diameter of 25 ft above

El. 805 ft and 4.5 ft below El. 805 ft. The drop shaft is connected to the Quarry low-level pump station shaft and riser shaft through adits. The drop shaft provides a flow capacity of 90 million gallons per day;

- The riser shaft at the quarry is about 320 ft deep with a finished diameter of 25 ft above El. 805 ft and 12 ft below El. 805 ft.
- The quarry riser shaft is connected to the quarry drop shaft through an adit;
- The five pump station shafts at the HWTP are about 420 ft deep and 9.5 ft in bored diameter;
- Each pump station shaft will have a 76-in. diameter grouted steel casing to house the pump; and
- The five pump station shafts are connected to the main tunnel by five, 7.9 ft adits with lengths ranging from 20 ft to 30 ft.

Major elements of the Phase 1 Extension project include one TBM tunnel, an extension of the Phase I tunnel, and one combined drop (baffle type) and construction shaft. The construction shaft is 250 ft deep with a finished diameter of 30 ft. The TBM tunnel is approximately 18,470 ft long and partially concrete lined with a finished diameter of 10 ft (see Figure 2).



Figure 1. Atlanta WSP tunnel alignment

GEOLOGY

The project is located in the Piedmont Physiographic Province. The geology of the Piedmont in the greater Atlanta area generally consists of medium-grade metamorphic rocks with granitic intrusions. These crystalline rocks are some of the oldest rocks in the Southeastern United States.

Detailed geotechnical and hydrogeological field investigations were made, comprising 25 deep borings along the tunnel alignment and 30 shallow borings in the areas for shaft construction. The borings revealed granitic gneiss rock averaging 25,000 psi UCS along with five transition zones between soil and bedrock where groundwater was expected. These zones had the potential for high-yield fracture flows, as local wells in the area had been reported to yield up to 500 gallons per minute.

Lithologies Along the Tunnel Alignment

The majority of the proposed tunnel alignment is located in the in the Clairmont Melange (Bedell et al., 2017). The following text is from the Geologic Report as provided by PetroLogic Solutions as part of the preliminary geotechnical investigation. The order of the geologic unit descriptions proceed from the quarry to HWTP and then through to the Chattahoochee Water Treatment Plant (CWTP).

The majority of the Contorted Unit consists of a sphene-epidote-muscovite-biotite-quartz-feldspar gneiss, medium-grained, schistose in part; interlayered with sphene-epidote-muscovite-quartzfeldspar-biotite schist, medium- to coarse-grained; garnets may be present, but are small and scarce. Hornblende gneiss/amphibolite lenses and layers (commonly boudinaged) are common. Contains, in many places, lenses and discontinuous layers of unfoliated granite on a scale of feet and tens of feet. Concordant and discordant quartz veins are common. Pegmatitic layers and coarse pegmatites up to 60 in. thick are abundant and characteristic; shear foliation in the gneiss/schist wraps around the coarse pegmatites and small bodies of granite, which are generally not sheared.

This rock mass is extremely contorted; foliations are quite variable over short distances, and are generally low-angle and undulatory. Random fractures are abundant; through-going joint sets are scarce and not well-developed.

The zoned feldspar gneiss consists of an epidotemuscovite-biotite-quartz-feldspar gneiss, fine- to medium-grained, with disseminated very coarse zoned feldspar crystals; very feldspathic overall; deep weathering is characteristic.

The Brevard Zone black mylonite is generally composed of biotite, quartz, and feldspar. This unit is typically extremely fine-grained and weakly foliated. Where the foliation is better developed, the rock is shown to be very contorted. In most outcrops, the black mylonite is dark gray to black and locally contains thin light colored layers of white mylonite (see rock unit 2B description). Weathering of this unit generally yields a reddish brown to red, uniform fine clayey residuum.

The Brevard Zone white mylonite is interpreted to be sheared granite. This mylonitized granite is



Figure 2. Shaft, adit and tunnel configuration

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composed of muscovite, quartz, and feldspar; much of the feldspar is pink and coarse-grained. Shearing was pervasive and produced a well-developed shear foliation. Reduction in grain size was not as extreme as in Rock Unit 2A. Weathering of this unit generally yields a white to tan, uniform fine clayey residuum.

Rocks encountered through shaft sinking and TBM tunneling at the quarry all reflect the information as provided in the preliminary geologic report. Foliation is quite contorted over the scale of the excavation, and degrees of schistosity vary across the excavation.

TBM PROCUREMENT AND ASSEMBLY

The open-face, main beam TBM procurement played an essential part in meeting an aggressive project schedule. Considering the CMAR would be contracted before the tunnel subcontractor, an evaluation was conducted to determine if the city, CMAR or tunnel subcontractor should supply the TBM. Additionally, the evaluation included considering whether a used or new TBM should be supplied. Ultimately, the evaluation determined the best riskreward scenario was for the purchase of a new TBM by the CMAR under an on-site first time assembly (OFTA) model.

The basis for this approach included, but was not limited to, the following:

- The CMAR entity would be more familiar than the city with the purchase of major equipment;
- A new TBM could be manufactured before the tunnel contractor was contracted or even mobilized, saving as little as two months and as much as six months in project schedule;
- A used TBM, supplied by the tunnel subcontractor, would need to be refurbished, delaying the start of TBM mining at the portal located at the base of the quarry (i.e., there was no shaft to be excavated, which would otherwise delay the start of tunnel mining);
- An OFTA scenario saves 4 to 5 months as compared to factory assembly and testing;
- An open-face, main beam TBM is a proven machine in the ground conditions in the Atlanta area; and
- An open-face main beam TBM is less sophisticated than an Earth Pressure Balance or Slurry TBM, so an engineer derived design specification did not involve excessive risk.

The new TBM for the project was manufactured by The Robbins Company. TBM components were shipped in truckloads to the jobsite in summer 2016 to be assembled using Onsite First Time Assembly (OFTA)—a method developed by the



Figure 3. Overview of the quarry with tunnel portal in view

TBM manufacturer to build machines on location rather than in a manufacturing facility. The method has the potential to shave months off of the delivery schedule and millions in USD.

The PCR JV sub-contracted the Atkinson/ Technique JV (ATJV) to work on the assembly and launch of the machine, and to operate the TBM during tunnel construction. This was done in concert with a small contingent of TBM manufacturer assembly staff as required in the TBM specifications. Components were moved via 70 truckloads down steep roads to the bottom of the massive quarry—an approximately 11-hour journey from the facility in Solon, Ohio (see Figure 3).

Crews including TBM manufacturer personnel worked in the blazing heat of summer at the bottom of the quarry, which was below sea level, on days where highs hit 110 degrees Fahrenheit at 100 percent humidity. The challenges of working under these difficult site conditions, paired with the new contract relationship, caused some delays over the originally planned schedule. However, the TBM's start of boring still commenced months ahead of what would have been possible with full shop assembly followed by reassembly at the quarry portal.

The machine was launched in the second week of October 2016 following a large ceremony in which Atlanta's Mayor Kasim Reed and local and national media were in attendance (see Figure 4).

MACHINE DESIGN

Specifications for the robust hard rock machine were made following detailed geotechnical and hydrogeological field investigations comprising 25 deep borings along the tunnel alignment and 30 shallow borings in the areas for shaft construction. The borings revealed granitic gneiss rock averaging 25,000 psi UCS along with five transition zones between soil and bedrock where groundwater was expected. These zones had the potential for high-yield, fracture



Figure 4. The completed Main Beam TBM during the launch ceremony in October 2016

flows, as local wells in the area had been reported to yield up to 500 gallons per minute.

It was decided that the TBM cutterhead would be designed for 19-in. cutters to excavate the hard rock geology with greater penetration while offering longer cutter life and greater wear volume—40% more over 17-in. disc cutters based on the TBM manufacturer's research and empirical observations. The key TBM parameters are shown below:

- Bore diameter—3.8 m
- Disc cutter diameter—19 in.
- TBM weight-220 tons
- Total number of cutters—26
- Number of face cutters—16
- Number of center cutters—4
- Number of gage cutters—6
- Maximum individual cutter load— 70,000 lbs.
- Average instantaneous penetration rate of 5.8 ft/hr to 6.7 ft/hr
- Operational cutterhead thrust— 1.82 million lbs
- Operational cutterhead RPM—11.5
- Operational torque—727,516 ft-lbs
- Average ring life—32 ft
- Primary voltage—13,200 volts
- Installed power—1,770 hp
- Variable frequency drives—4
- TBM boring stroke—6.6 ft
- TBM dust control water flow rate—18.5 gpm
- Turn radius—1,200 ft

Tunnel support along the alignment was classified into three types: A, B, and C. The TBM would erect ground support consisting of two rows of double corrosion protection dowels as both excavation support and permanent support in Type A ground. Type B ground support would consist of four friction dowels with welded wire mesh, and Type C support would consist of steel ribs with welded wire mesh as lagging. Both Type B and Type C ground would be concrete lined after excavation. Tunnel lining would have a 100-year design life, making the finished internal diameter 10 ft. Ultimately the tunnel is expected to be lined along approximately 40% to 50% of its length.

SITE PREPARATION AND TUNNEL EXCAVATION

A substantial scaling program of the quarry walls was undertaken to provide safe egress and ingress to the quarry bottom and TBM location throughout assembly and machine launch. Scaling around the quarry rim took place from April through August 2016. To secure the approximately 300 ft tall rock face above the tunnel portal at the base of the quarry, a stabilization system was designed. The system covers the full depth of the quarry and a width of approximately 400 ft centered over the portal. 3 mm mesh and rock dowels have been installed in the locations identified to have potential rock wedge failures. Canopies were installed as additional protection to workers at the portal. At the tunnel "eye," where the tunnel breaks into the ground from the portal, 20 ft long spiles were installed along the tunnel crown to stabilize the transition area. While scaling of the quarry could last indefinitely in such a large drill and blast excavation, following initial inspection, ATJV implemented a scaling protocol that requires visits quarterly to inspect the rock mass and quarry rim.

Since the October launch, the machine has advanced at rates up to 15 ft per hour and 50 ft per day in two eight-hour mining shifts with a daily maintenance period. As of late December 2017 the TBM had advanced 12,000 ft.

The machine is generally in favorable geology, but like other Atlanta area tunnels, is in very hard and very abrasive rock. Cutter wear has been good; well within estimates. The crew typically performs three to four cutter changes per day. Muck removal is being accomplished with five-car muck trains. One train covers 6 linear ft of tunnel. While much of the excavation has been uneventful the crew did come across an old abandoned well directly in the tunnel alignment, which was promptly sealed off (see Figure 5).

CONCURRENT CONSTRUCTION AND UPCOMING CHALLENGES

Construction of the shafts and pump station at the Hemphill site, where an existing reservoir is located, is being done concurrent with tunneling. The construction of the five blind-bore shafts was found to pose a significant risk to the unlined reservoir. As such, a shaft pre-excavation grouting program was designed for the soil to rock transition zone and rock



Figure 5. Abandoned well directly along the tunnel alignment

zone to greatly reduce the chance of communication between the reservoir and the five pump shafts. Grouting from the surface was planned with special care taken to additionally avoid any risk to the tunnel structure. By October 2017 the Peachtree shaft at the Hemphill site had been completed (see Figure 6).

The shafts are being constructed using blind bore techniques since surface blasting is prohibited at HWTP due to adjacent reservoirs. Upon the completion of the five, 11-ft diameter steel casings in overburden, the 9.5-ft diameter 400-ft deep blind bore shafts are then being drilled from the bedrock surface to tunnel depth through the steel casings in overburden. Upon completion of the blind bore drilling, a 76" ID steel pipe casing with 1-in. wall thickness will be lowered into the shaft and grouted in place. Ultimately the shafts will be directly connected to the tunnel via five, 8-ft diameter adits with lengths ranging from 20-ft to 30-ft. As of December 2017, all of the deep pump station shafts have been completed, and four of the five blind-bored shafts, to a depth of 425 ft, have been completed.

As for tunnel construction, several zones requiring systematic probe drilling still lie ahead at various locations along the alignment including under the Hemphill Reservoir. However ground conditions are



Figure 6. Completed Peachtree shaft

expected to remain favorable overall. Project completion is scheduled for September 2019.

CONCLUSIONS

The Atlanta WSP is an important example of excavation in abrasive hard rock conditions. It also is an example of a unique and successful project structure with the CMAR purchasing a TBM and subcontracting tunneling work. Many of the challenges for the tunneling operation are upcoming and will be reported on in detail at the NAT conference.

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