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TUNNELING & UNDERGROUND CONSTRUCTION

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RETC in New Orleans

Cooks Lane Tunnel

Black River Tunnel

Special Editorial Section from the publisher of *Mining Engineering*

FK LAKE SHORE

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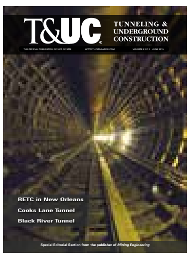
COVER STORY



In this issue — The RETC is set for June 7-10 in New Orleans, LA. This biennial conference will bring together about 1,400 underground construction and tunneling professionals. A preview of the conference begins on page 22. Also, phase one of the Black River Tunnel project is profiled on page 11. Cover photo of the project is courtesy of NTH Consultants Ltd.

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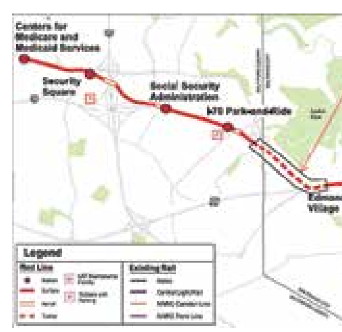


DEPARTMENTS

CHAIRMAN'S COLUMN

Mega-projects present more than just technical challenges

Over the past several years, the increase in the number of mega-projects has drawn attention to an unsettling trend within our industry. As our underground projects get larger — in scope, amount of time to build and cost — they undeniably stretch the capabilities of current contractor, engineer and owner staff — not in a technical sense, but with respect to certain elements of management capability, particularly the effective management of personnel.

The nature of underground projects is that they take a long time to develop, plan, design and construct. Five years is not uncommon, and some last for 10 to 20 years. If we assume that graduates from engineering schools will be active at the project level from their mid-20s through their mid-60s, a period of 40 years, and the first 10 years will be spent in technical rather than management responsibilities, then project managers responsible for successful completion of our mega-projects may be expected to have, at most, three to four projects worth of upper-level management experience to prepare them for their last and, presumably, most challenging project. This is simply not enough time to experience first-hand the technical and personnel management responsibilities associated with the large complex mega-projects that we expect will comprise the future of the underground industry.

What we need is a better system of training and education for the management staff of such large construction projects. The most important management skills are not typically taught in undergraduate- or graduate-level engineering programs, but are instead learned through on-the-job training. I am not suggesting that our existing engineering programs should take on this responsibility, for to do so would mean foregoing other necessary skill training. If we are going to make the mega-projects of the future successful, completely different methods of management training must be developed, and this training must include contractor, engineer and owner staff. One such method might be a one- to two-week project management "institute," where case studies of management practices, both successes and failures, are reviewed in frank and open discussion. Another might be the development of an organizational workshop to be held at the beginning of the project cycle, with the intent to identify successful management practices for use on project-specific sites.

If such different methods are not developed, the projects of the future, both aboveground and underground, will suffer management failures, which will be at least as costly, in time and money, as engineering failures. I encourage an industry dialogue about how we can address this shortcoming. ■

William W. Edgerton,
UCA of SME Chairman

California Governor defends plans for $15 billion twin tunnel water diversion

California Gov. Jerry Brown is defending his $15 billion plan to build twin tunnels for a water diversion to southern California and told critics to "shut up" until they spend more time studying issue.

California has imposed strict water conservation rules as it continues to grapple with a fourth year of drought.

The Sacramento Bee reported that Brown's remarks to shut up prompted laughter at a meeting of water agency officials in Sacramento, and his office said he made them in jest However, the remarks came at a time of tension over his twin tunnels plan and the statewide water conservation efforts.

Brown previously announced major changes to his plan to build two tunnels to divert water around the Sacramento-San Joaquin Delta to the south. The administration, while moving forward with a $15 billion conveyance, dramatically reduced the amount of habitat restoration originally proposed.

"Until you've put a million hours into it," said Brown, estimating the amount of staff time devoted to the project, "shut up."

Barbara Barrigan-Parrilla, executive director of Restore the Delta, said in a prepared statement that Brown "has his fingers in his ears and will not listen" to criticism.

The viability of the project remains uncertain, but the high stakes for Brown are clear. He has made a Delta conveyance a priority of his administration since he was governor before, from 1975 to 1983.

The Democratic governor's earlier Sacramento River diversion plan, the peripheral canal, was defeated in a referendum in 1982.

Californians for Water Security, a group that includes the California Chamber of Commerce, farm and labor organizations, said that it released TV and radio ads supporting the tunnels project. A spokeswoman declined to specify how significant the ad buys were, except to say the group was spending "well into the six figures" on TV, mostly in the Bay Area.

Brown spokesman Evan Westrup told *The Sacramento Bee* that the administration listens "to critics and supporters alike. That's a big part of the million hours we've put into this project and we'll keep the same open spirit in the coming months."

Brown ordered a 25-percent mandatory reduction in urban water use statewide earlier this year, and the State Water Resources Control Board approved rules for achieving that goal.

Many local water officials have balked at the order, arguing the restrictions are overly burdensome.

> **"Until you've put a million hours into it (California's water issues) shut up."**
>
> **California Gov. Jerry Brown**

Each of the state's 411 urban water agencies has been assigned a reduction target, based on existing water use. The cities with the heaviest per-capita consumption will have to save the most - 36 percent.

The new rules will hit the Sacramento area and other inland regions the hardest. Those cities had argued that they were being penalized for being located in the state's hottest and driest regions. But state officials said those cities' residents are using too much water on their lawns and have to cut back. ■

Brierley Associates merges with Mike McTeer Consulting

Brierley Associates and Mike McTeer Consulting have merged to expand Brierley's Building Information Modeling (BIM) capabilities. BIM is an intelligent, model-based design process that adds value across the entire lifecycle of infrastructure and building projects. Virtual design and construction BIM has proven to reduce costs by avoiding conflicts and re-work. Ultimately, savings are realized by shorter project duration, decreased claims and litigation.

McTeer has been involved with the design and construction of heavy civil engineering projects for more than 30 years. McTeer's experience serving as construction estimator, superintendent and project manager is integrated into each model to deliver BIM in a practical manner.

"Brierley Associates and McTeer have collaborated on a number of successful BIM-coordinated deep excavation projects during the last four years, and we are excited to expand the role of BIM in project delivery to our clients." Brierly Associates' director of engineering Eric Lindquist said, "Having Mike join us elevates this already successful business relationship and expands Brierley's capabilities to use BIM in creating space underground." ■

Tunnel option one of four for I-81 replacement

New York highway officials will study four concepts, including a tunnel option, as a replacement to Interstate 81 through Syracuse. The other options are a community grid (similar to the boulevard option), a new viaduct or a no-build option (which is required by the federal government).

The state rejected any tunnel ideas offered so far, including the Syracuse Access Plan backed by Destiny USA but it pledged to keep the concept in consideration, *Syracuse.com* reported.

The decision reverses a previous recommendation from the same state and federal highway officials, who last year deemed a tunnel to be too expensive and complicated.

However, the most recent report also points out that any tunnel now under consideration will not be the same as ideas already studied by the department of transportation. That could likely mean the so-called hybrid option — a shorter tunnel on I-81's current pathway — made it to the next round.

It does not mean any tunnel is the final, or winning, pick. Nor does it rank any of the three other basic options as best or worst. This report marks the beginning of that process.

The four options now under consideration are:

No-build alternative — This would maintain the highway in its existing configuration while providing routine maintenance and minor repairs. A no-build option is required under federal environmental laws in order to serve as a baseline comparison for the other alternatives.

Viaduct — This would involve replacing the elevated section of highway.

Community grid — This would reroute traffic from the interstate around the city and weave it into the existing street grid to enhance traffic flow.

Tunnel — This would route traffic through a tunnel. However, none of the four tunnel alternatives presented in the draft scoping report met the project's screening criteria. The New York State Department of Transportation will conduct more engineering and analysis to find if there's a workable tunnel idea. ■

King County sues insurers over Brightwater project

The legal saga from the Brightwater Wastewater Treatment System in King County, WA continues as King County announced that it is suing an engineering company and two insurance providers over a 2011 testing accident at a pump station for the Brightwater Wastewater Treatment System for failing to pay millions in unanticipated costs and "playing hardball" with ratepayers, the television network *KING5* reported.

The lawsuit, filed in March in Superior Court and moved to U.S. Federal Court in April, alleges Lexington Insurance and Allied World Assurance, both of which provided coverage for the $1.8 billion project, are forcing ratepayers to "absorb millions of dollars in damages due to design errors."

Defendants, including CH2M Hill engineering, declined to comment.

The lawsuit stems from an incident in May 2011 during a test of Brighwater's Influent Pump Station in Bothell. Testing involved shutting down large engines that drove the pumps to see what would happen if power was lost, and critically, if it would cause overflows in the system.

As it turned out, according to the county, there were flaws in the motor design, and subsequently a "potentially catastrophic chain of events" took place. At the end, a valve connection burst, sending high-pressure water spewing into the pump station.

CH2M Hill admitted design flaws and said it would re-engineer the engines. However, while the insurance companies agreed to release millions of dollars to pay for that, it has refused for years to agree to King County's claim that it is owed $4 million for unanticipated costs.

"We're happy with what was done with the redesign," said Brightwater project manager Gunars Sreibers. "At the same time, we're unhappy from the standpoint that we still haven't been paid."

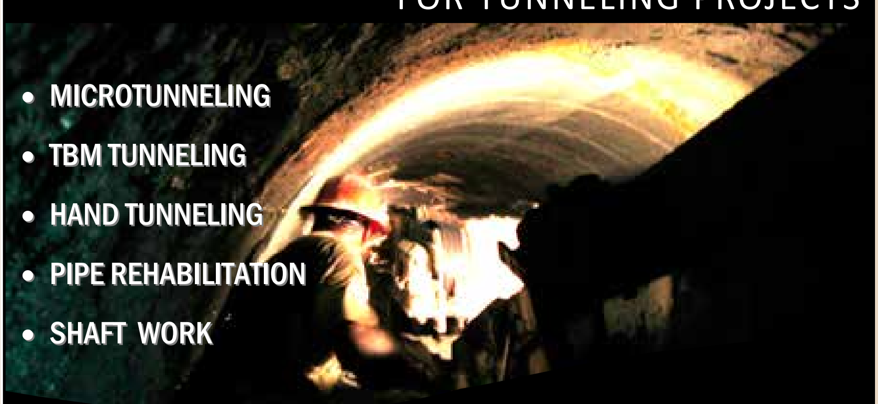
In one instance, the county alleges insurers refused to release money to engineers for new engines unless it lowered the amount it was claiming for damages.

"Insurers started to bargain with the money that they owed," the suit claims.

"King County incurred costs operating in this interim mode between the time we found the problem and we had the problem fixed," said Sreibers.

This is far from the first time King County has had a legal fight over Brightwater. A multi-million judgment over the tunneling project connecting the pump to the wastewater treatment facility is still being appealed.

Sreibers said he was confident ratepayers will not end up on the hook for someone else's mistakes. "In this particular case, (insurers) are a little more difficult than I hoped they would be." ■



China considers tunnel under Mount Everest

Chinese state media reported that a railway between China and Nepal that could include a tunnel under Mount Everest is under consideration.

The Telegraph reported that China is considering the railway as it looks to build ties with Nepal.

The Tibet railway already links the rest of China with the Tibetan capital Lhasa and beyond, and an extension running as far as the international border is already being planned "at Nepal's request," the *China Daily* newspaper reported, quoting an expert at the Chinese Academy of Engineering.

This is expected to be completed by 2020, the *China Daily* cited a Tibetan official as saying.

Such a plan could see a tunnel being built under Mount Everest, the *China Daily* said.

Chinese foreign minister Wang Yi visited Kathmandu in December and, according to Nepalese reports, said the line could eventually be extended to the Nepalese capital and further, potentially providing a link between China and the huge markets of India.

"The line will probably have to go through Qomolangma so that workers may have to dig some very long tunnels," expert Wang Mengshu told the newspaper, referring to Everest by its Tibetan name.

He said that, due to the challenging Himalayan terrain with its remarkable changes in elevation, trains on any line to Kathmandu would probably have a maximum speed of 75 km/h (46 mph).

The proposal underscores China's influence in the impoverished Himalayan nation, where Beijing has for years been building roads and investing billions of pounds in hydropower and telecommunications.

Chinese tourism to Nepal, which is home to eight of the world's 14 peaks higher than 8,000 m (26,000 ft), is also climbing.

Beijing's increasing role has raised alarms in New Delhi that China, already closely allied to Pakistan, is forging closer economic ties with Sri Lanka, the Maldives and Nepal in a deliberate strategy to encircle India.

In an apparent countermove, Indian Prime Minister Narendra Modi pledged that South Asia's largest economy would fund a series of regional investments and free up its markets to its neighbors' exporters.

Chinese plans to expand the rail network in Tibet have also come under criticism from rights groups including the International Campaign for Tibet. ■

Robbins TBM begins work on North Link project

On March 5, 2015, a Robbins 6.2-m (20.2-ft) diameter main beam tunnel boring machine (TBM) finished boring a 2.8-km (9,175-ft) long extension tunnel, known as the Eagle Creek Tunnel, for the Indianapolis Deep Tunnel System in Indiana.

The contractor, Shea/Kiewit joint venture (S-KJV), had much to celebrate. "I'm proud of our world records, and, most of all, our men and the hard work they have done as a team, working together to accomplish a project of this size," explained Stuart Lipofsky, project manager, for S-K JV. "We finished the first 12.5 km (41,000 ft) [of the main tunnel] almost a year ahead of schedule. The extension added time, but what is remarkable is that we were still able to finish within the original contractual dates," continued Lipofsky.

The completion of the first leg of a much larger tunnel system targets three critical combined sewer overflows (CSO) that flow into the nearby White River and will go online in 2017. The completed tunnels bring the city one step closer to achieving its consent decree with the U.S. Environmental Protection Agency (EPA), set to be achieved by 2025, to eliminate overflows into the city's rivers.

The rebuilt Robbins hard rock TBM was first used on the 12.5-km (7.8-mile) long main tunnel, called the Deep Rock Tunnel Connector (DRTC). The new cutterhead arrived onsite in November 2012, and the machine was launched from a 76-m (250-ft) deep shaft to bore through limestone and dolomite. The TBM achieved world records in its size class of 6 to 7 m (20 to 23 ft), including "most feet mined in one day" (124.9 m/409.8 ft); "most feet mined in one week" (515.1 m/1,690 ft); and "most feet mined in one month" (1,754 m/5,755 ft). According to Tim Shutters, construction supervisor for the project owner, Citizens Energy Group, there were two main factors for the TBM's high performance. "The first one is the very nice cutterhead provided by Robbins. It has performed very well. Second, rock conditions are favorable for mining operations and optimal for fast production."

The Eagle Creek Extenstion Tunnel was the first tunnel completed in the larger CSO project in Indianapolis.

Another important element that helped the speedy machine achieve a fast advance was, as Lipofsky put it, "one of the most complex continuous conveyor systems in North American tunneling construction." The custom-built Robbins system, consisting of 25 km (82,000 ft) of belt, included horizontal and vertical conveyors for efficient muck removal. The system was the first built by Robbins to go through such sharp curves. "The belt is going through two 90° curves in opposite directions and S-curves in other places. It's very unusual and amazing to see a belt system perform as well as this one did," said Lipofsky.

Once complete, the deep tunnel project will reduce the amount of raw sewage overflows and clean up tributaries along the White River. Shutters described the environmental benefits the project will provide the Indianapolis community: "I've lived in Indy all of my life, and the White River has never been a focal point for the city as there is a lot of pollution. I really think that once it has been cleaned up, people will want to visit, they will swim and fish, and property values along that body of water will go up. Being able to finally utilize the river is key for us."

After the early completion of the Eagle Creek Tunnel, the project will be moving into its next two tunneling phases. The White River Deep Tunnel will continue 8.5 km (5.3 miles) north of the completed DRTC and pump station. The Lower Pogues Run Deep Tunnel will split off 2.7 km (1.7 miles) from the White River Deep Tunnel heading east. Two additional tunnels, including Fall Creek and Pleasant Run, are anticipated to be built in 2020, and the project (27 km/17miles of tunnels in total) is expected to be fully completed by the end of 2025. ■

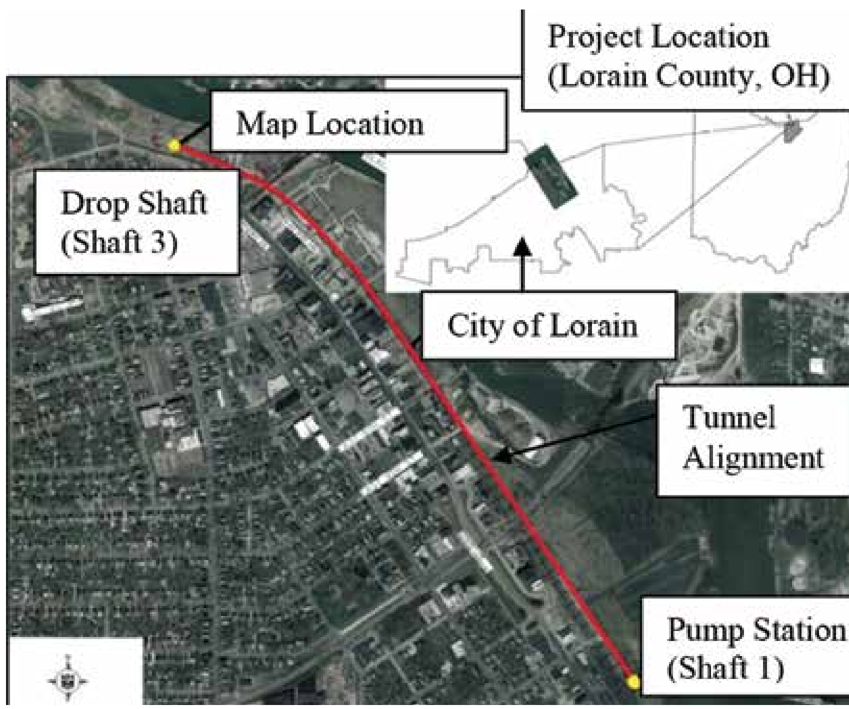
FEATURE ARTICLE

Black River Tunnel project phase 1: Innovative quality control approach for installation and testing of rock bolts in shafts

This article details the use of an alternative testing method to the 2004 "Post-Tensioning Institute (PTI) Recommendations for Prestressed Rock and Soil Anchors" manual's recommendations for temporary and permanent rock anchors for applications in shafts and tunnels. This method was developed and used for the Black River Tunnel (BRT) project in Lorain, OH as a means to reduce testing time of rock bolts during shaft construction while maintaining a similar level of quality control and assurance. The following sections will detail the project background, subsurface characteristics, shaft construction, the 2004 PTI testing method and associated difficulties, the alternative testing method and conclusions reached.

FIG. 1

Project plan view.



Project background

The city of Lorain is located in north central Ohio on the south shore of Lake Erie, approximately 40 km (25 miles) west of Cleveland and 119 km (74 miles) east of Toledo. The city chose to build a large-diameter storage tunnel and pump station to meet its requirements to reduce sanitary sewer overflows to the nearby Black River. NTH Consultants Ltd. (NTH) was retained by the city's prime consultant, Malcolm Pirnie Inc. (now the water division of Arcadis), to perform a geotechnical investigation, develop design and construction bid documents for the tunnel and shaft liner systems and ultimately provide oversight assistance during the construction phase of the project.

The BRT is an approximately 1,700-m (5,560-ft) long, 7-m (23-ft) diameter rock tunnel to be lined with a 5.8-m (19-ft) inside diameter secondary concrete lining (Fig. 1). The tunnel is designed to accept flow at a new drop shaft (Shaft 3) located on the west side of the Black River, across from the city of Lorain Black River waste water treatment plant (BRWWTP). The tunnel will be dewatered at the south end by a large diameter pump station (Shaft 1) located in the existing Lorain Port Authority Public Boat Launch. Flow from the new pump station will be discharged into an existing shallow interceptor sewer and directed back to the BRWWTP.

Subsurface characteristics

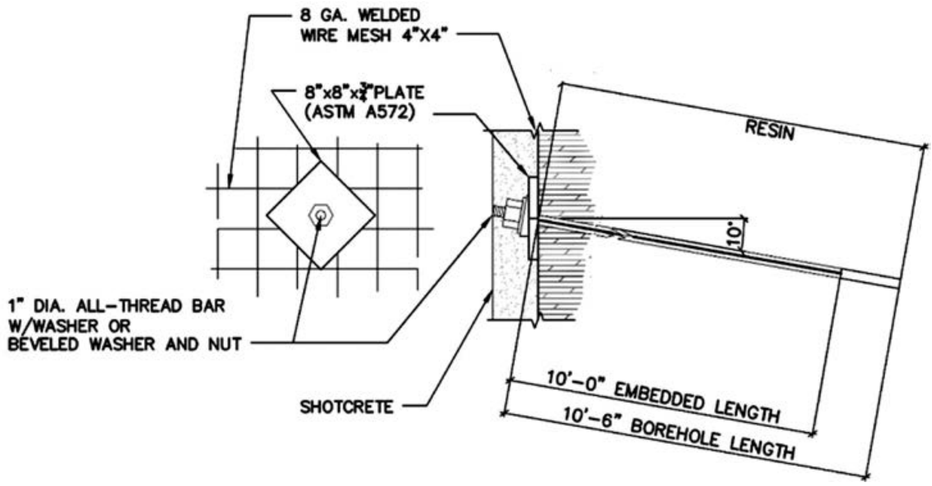
The subsurface characteristics at the shaft sites generally consisted of overburden soils underlain by horizontally bedded shale bedrock that varies from highly weathered to fresh (unweathered). The shale is characterized as the upper Devonian-aged Ohio Shale Formation of northeastern and southeastern Ohio, according to the Ohio

J. Edberg

J. Edberg is vice president with Arcadis, US, email jedberg@nthconsultants.com.

FIG. 2

Rock bolt detail.



Department of Natural Resources Division of Geologic Survey's "Generalized Column of Bedrock Units in Ohio" (State 2004). In general, the top of weathered rock slopes downward from south to north with depths 6 and 12.5 m (20 and 41 ft) below existing ground surface for Shaft 3 and Shaft 1, respectively. The highly weathered rock zone may vary from several inches to approximately 7.6 m (25 ft) in thickness. Vertical joint sets are present in the rock formation. Average RQD values from top of bedrock to approximately 24 to 33.5 m (80 to 110 ft) are 55 percent, with fractures per foot of 2 (ranged from 0.5 to 5.9 fractures per ft). Below this level, RQD values average 86 percent. For design of the shaft liners, the unconfined compressive strength was chosen as 1,500 psi. Other pertinent parameters for shale in the tunnel influence zone include the following: average indirect tensile test strength of 340 psi, average Cerchar abrasivity index of 0.3 and average slake durability of 76 percent. These numbers indicate the shale formation can be characterized as a soft rock with medium durability (Gamble, 1971) that becomes less weathered and is of higher quality as depth increases. Ground water infiltration was expected to be in the range of 13 gpm for Shaft 1 and 44 gpm for Shaft 3.

Shaft construction

The temporary earth retention systems for the shafts were constructed as a two-tiered system consisting of a steel rib and liner plate upper portion through the soil overburden and highly weathered shale, followed by a grouted steel thread bar rock bolt with wire mesh and shotcrete temporary support system for the lower portion, through the less weathered to intact shale. Shaft 1 had a 14-m (46-ft) diameter upper portion with a 13-m (42-ft) diameter lower portion and an overall depth of 56 m (184 ft). Shaft 3 had a 16-m (53-ft) diameter offset upper portion (to accommodate an influent chamber) and a 11-m (35-ft) diameter lower portion with an overall depth of 35 m (117 ft). For both shafts, the overburden was excavated using an excavator, bucket and muck bins. The lower portion of Shaft 1 was excavated using blasting techniques, whereas the lower portion of Shaft 3 was mechanically excavated using a rock ripper and hydraulic hammer. The excavation methods at each of the shafts left the rock face uneven, particularly so with the use of blasting at Shaft 1. Additionally, both shafts had infiltration from the surrounding rock mass that was light but consistent. Both the uneven rock face and presence of water proved to be challenging to rock bolt testing as discussed later in this article.

The rock bolts used for the lower portions of both shafts were 2.5 cm (1 in.) diameter, 3.2-m (10.5-ft) long A615 all threaded steel bolts that were to be fully resin-grouted into the rock on a 3.14 (pi) ft. x 3 to 3.5 ft grid spacing. They not only functioned as the primary liner system of the shaft, they also were designed to provide uplift resistance for the final concrete liner system.

The installation sequence involved drilling a 3.5-cm (1.375-in.) diameter bore hole 3.2-m (10-ft, 6-in.) deep on a 10° downward angle (Fig. 2), blowing out the hole with pressurized air, inserting the two-part resin cartridges into the hole, and then driving and spinning the rock bolt through the resin cartridges to thoroughly mix the resin. The resin was set within 30 minutes. The contractor used a four-wheel hydraulic, self-propelled drilling unit to both drill the borehole and insert the rock anchor. After installation, 10-cm x 10-cm (4-in x 4-in.), eight-gage wire mesh was placed over the rock face and then a 20-cm x 20-cm (8-in. x 8-in.) thick steel plate and nut were installed over the mesh and locked off at a load of 25 kips according to design. The contract documents specified that each rock bolt be proof tested according to the "2004 PTI Recommendations for Prestressed Rock and Soil Anchors" manual to verify it was capable of holding the design load. The rock bolt was then pre-tensioned to a required load of 25 kips. Finally, unreinforced shotcrete was applied to a thickness of 12.7 cm (5 in.) to protect the shale from water and temperature exposure.

PTI testing procedure

The 2004 PTI manual proof test recommends that each rock bolt first be subjected to an incremental loading sequence, starting at a small "alignment load" typically between 5 percent and 10 percent of the lock-off load, followed by loadings of 25 percent, 50 percent, 75 percent, 100 percent, 120 percent and 133 percent of the design load (25 kips). A 10-minute hold at the 133 percent load is then performed at the end of the incremental loading and is referred to as a "creep test."

The test loads were applied through the use of a calibrated center-hole jack that was set up over a cribbing system. The cribbing system allowed for a rod extension to be put on the end of the rock bolt to accommodate the jack. The system also provided access to the nut in order to lock off the nut against the plate at the required design load upon completion of the test. See Fig. 3 for an illustration of the test setup.

For the incremental load test, a deflection gauge was fixed to the jacking plate prior to beginning the loading sequence. The rock bolt was then subjected to each loading increment established by a jack pressure that was correlated to an axial load through a calibration procedure. Upon each loading increment, deflection readings were taken from the gauge. During the creep test, readings were taken at the 1, 2, 3, 4, 5, 6 and 10 minute time intervals with the load maintained at the 133 percent level.

The deflection readings taken during the incremental loading phase were then plotted against predicted theoretical deflection under the same axial load using a bar length consisting of the unbonded zone (free bar beyond the rock face) with 20 percent of the resin zone and a length consisting of the unbonded zone with 50 percent of the resin zone. An example of such a plot from the initial testing of Shaft 1 is shown in Fig. 4.

In typical practice, Fig. 4 provides an indication of how much resin is being mobilized to resist the applied load. For the bolt to be acceptable by PTI standards, the actual deflection should fall within the theoretical ranges in the plot. In reviewing Fig. 4, it is apparent that the deflection falls outside the deflection parameters allowed by the PTI manual for most of the rock bolts, with the exception of rock bolt A1. Therefore, only rock bolt A1 would be considered a passing bolt. The remaining rock bolts, in fact, yielded values that exceeded the theoretical deflection using the entire bolt length. This would indicate that the bolt should have pulled out of the wall. In reviewing these tests, and acquiring other results and observations from the initial testing, it became apparent that on many of the tests, the baseplate was locally crushing and ultimately embedding into the shale. This was due to the unevenness of the rock face and the softening of the rock caused by exposure to water. The movement of the baseplate ultimately resulted in a certain amount of angular distortion of the cribbing, which, in turn, would then artificially inflate the deflection readings. The angular distortion of the cribbing impacted testing in several ways:

- Proved difficult to determine how much of the resin was being mobilized to develop the load. Therefore, the criteria outlined in the PTI manual for the incremental load phase could not definitively be used to pass or fail a bolt.

FIG. 3

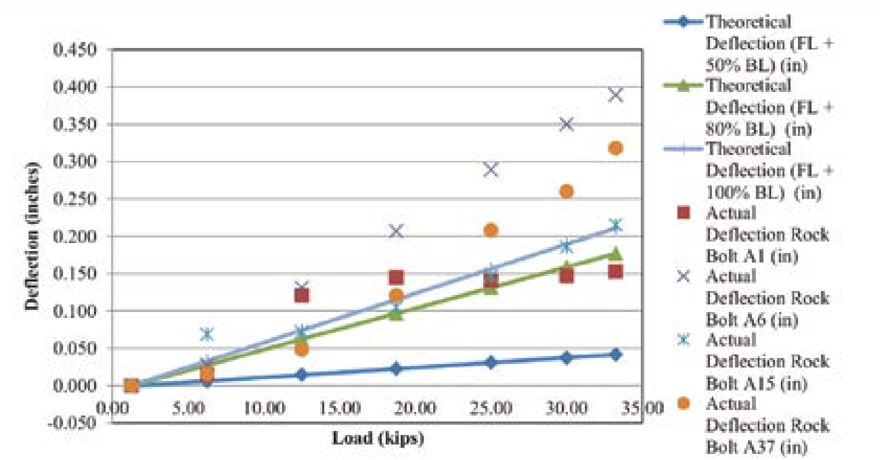
Rock bolt testing setup.

- Necessitated more frequent reliance of the creep test to verify that the rock bolt was satisfactorily holding the load. The PTI criterion of 0.04 in. was assigned as the threshold for a passing rock bolt. If the rock bolt deflected less than this value during the 10-minute hold, the rock bolt was deemed acceptable. For this project, since the rock bolts were used for uplift resistance in which the rock bolt would be sheared rather than pulled, the long-term pullout performance of the bar was of less importance. This essentially allowed focus to be placed more so on the rock bolts ability to hold the load, rather than how it is exactly holding it.
- Resulted in increased test time as a result of constantly resetting the deflection gauge due to the cribbing movement.

The contractor attempted to mitigate the cribbing movement by using a pneumatic drill to "pre-torque" the bolts so they were seated better for testing. However, a single test still could take between 20 and 30 minutes to perform. For a given row in Shaft 1 (42 bolts), this required as much as 41 man-hours using a two-man crew to complete. It became apparent that the contractor had

FIG. 4

Deflection vs. load for select initial shaft 1 rock bolts.



not fully accounted for the schedule impacts the testing regime would have on the project. In order to maintain schedule, the contractor asked if the NTH/Arcadis team could develop an alternative procedure that would save schedule while maintaining the required level of testing quality.

Alternative testing method

The engineering team developed a procedure to maintain full testing of the rock bolts while significantly reducing the amount of time required for testing. The method involved transitioning from a predominately quality control approach solely through PTI testing to a more proactive quality assurance approach supplemented with quality control PTI and torque wrench testing. It should be noted that there are other rock bolt tests, such as pull-out testing (ASTM, 2007) and electronic non-destructive testing (Hartman, et al., 2010). However, torque wrench testing was selected for its ease and familiarity of use, as well as its ability to test the strength of the rock bolt while simultaneously allowing the rock bolt to be locked off and used as a production rock bolt. To specify the correct torque, the manufacturer provided a correlation chart between axial load and torque (Fig. 5). The prescribed torque for the 25 kip load was approximately 830 ft-lbs.

The alternative test method generally followed these steps:

1. Performed PTI testing of all rock bolts within the first two rows while maintaining full-time observation of installation by the engineer. Installation observation verified that the rock bolts were installed according to the contract drawings/specification as well as the manufacturer's recommendations. It also provided a measure of installation consistency between rock bolts. In particular, it was important to take note the following:
   - Length of borehole
   - Borehole cleaning
   - Resin cartridges used
   - Rotation and spin time of the rock bolt
2. The initial PTI testing allowed an understanding of the performance characteristics of the rock bolt and verified that the contractor's rock bolt installation practices resulted in a rock bolt that produced a passing bolt. As stated previously, due to rock face conditions, emphasis was placed more on the rock bolt's ability to pass the creep test than a review of the incremental loading data. For this project, initial testing of the first row yielded a 29 percent failure rate (12/42). Failures ranged from immediately pulling out of the wall to failing during the 10-minute creep test at the 133 percent load. It is worth noting that the initial installation procedures varied between rock bolts, where some rock bolts were overspun (spinning transcended into gel time), had insufficient spinning to mix the resin, or in one particular instance, did not install the resin cartridges. Knowing that the installation practices were producing failing bolts, the contractor then established uniform, proper procedures within the second row to produce rock bolt that passed PTI testing.
3. Once acquiring an installation procedure that resulted in passing rock bolts, continued full time installation observation of subsequent rows to verify installation procedures were consistent with the initial passing rows.
4. Incrementally reduced the amount of PTI to 10 percent of the rock bolts. The approach on this project was to perform 10 PTI tests on the third row, with subsequent rows then reduced to 10 percent PTI testing. The 10 percent PTI testing was continued in order to verify that the performance and behavior of the rock bolts were consistent with previous rows and were satisfactorily passing according to PTI standards.
5. Tested all remaining rock bolts within the row with a torque wrench to ensure the rock bolts could carry the design load. The torque wrench was utilized in lieu of the PTI testing based on the following considerations:
   - The design load of 25 kips was chosen on the basis that it was not only the required lock-off load, but during the initial testing of the rock bolts, the majority of failures occurred below this load. The rationale was that if the torque wrench successfully locked off to the design load, it was probable that the rock

bolt would pass a PTI test. In future applications, it may be more prudent to lock off at the 133 percent level (highest PTI level), then back the load off to 100 percent for lock-off.

- Installation observation verified consistency between rock bolts within a given row that were PTI tested and rock bolts that were torque tested. Similar to the above rationale, provided the PTI tested rock bolts passed and the torque tested rock bolts were installed in the same manner, they also should pass a PTI test.

6. In the event of a failure, whether it be through the PTI test or the inability to lock off the rock bolt with the torque wrench, the PTI testing is increased to restore confidence in the installation procedure and verify performance metrics that ensure the rock bolts satisfy the design and PTI criteria.

This change in testing procedure resulted in a reduction in test time per row from 41 man-hours to approximately eight man-hours per row (using a two-man crew) while still maintaining a similar testing quality. However, there are some specific limitations that must be considered prior to implementing this procedure.

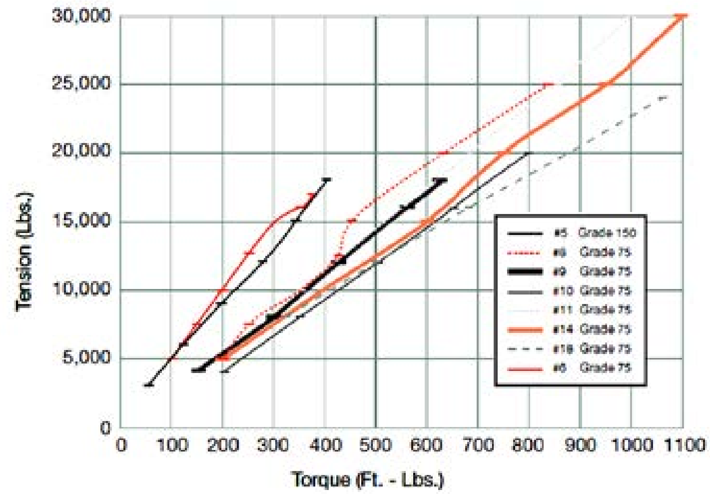
Alternative test limitations

Maintaining lock-off and creep considerations. The rock bolts utilized did not have an unbonded zone. Without an unbonded zone that is post-grouted after testing, the tensioning is essentially not locked-in. This deviates somewhat from the PTI recommendations and can result in additional creep and loss of tensioning. For this project, since there was a small free length, the rock bolt would only need to mobilize (creep) 1/25th of an inch to regain the design load. This was considered negligible. For other applications in which creep could generate excessive movement (>1-in.) that may be detrimental to a wall system, a bond zone should be introduced. The PTI test or torque lock-off should be implemented and the rock bolt locked off before the unbonded zone resin gels. Additionally, it may be prudent to develop more long-term time-load-creep relationships through the use of extended creep tests. Depending on the results of the testing, pre-tensioning loads may be increased to accommodate for the creep potential.

Bonded zone penetration considerations. As previously stated, moving of the cribbing made it difficult to ascertain from the incremental loading phase of the PTI test how much of the bonded zone was penetrated to develop the load resistance. Again, for this case, since the rock bolts were used for uplift resistance in which the rock bolt would be sheared rather than pulled, the long-term pullout performance of the bar was of less importance. In instances where long term conditions and the bond zone performance are critical, shotcrete could first be applied prior to placing the plate and nut and testing the rock bolt. This would provide a more stable surface that would allow bar deflection to be measured more accurately. If this is not possible, it may be more prudent to test the rock bolts to failure according to ASTM D4435 and determine an appropriate factor of safety.

FIG. 5

Correlation chart between applied torque and axial load.



Conclusions

Full testing of the rock bolts using the 2004 PTI technique proved to be difficult due to the jaggedness and softening of the rock face after excavation. This resulted in an increase in testing time that the contractor had not accounted for. The proposed alternative testing method involved a sequence of full PTI testing of the rock bolts to establish performance characteristics and verify the installation technique produced a passing bolt, followed by a transition to only 10 percent PTI testing. The remaining rock bolts were tested through a hand torque wrench. The testing method essentially allowed for a transition from a predominately quality control approach through full PTI testing, to a combination of heightened quality assurance through full time oversight with appropriate levels of quality control using PTI and torque wrench testing. This effectively maintained a similar quality of testing while reducing the overall test time. However, use of the technique must consider the effects of creep and the necessity for maintaining an appropriate lock-off load. The introduction of a bond zone and the development of a firm surface, such as shotcreting, prior to application of the pre-tensioning force, would allow for a more accurate understanding of creep and allow the pre-tensioning force to be more effectively maintained at the lock-off load. ■

Engineering of Cooks Lane Tunnel: An overview of challenges

FIG. 1

Red Line LRT project plan view.

The Baltimore Red Line Project is a proposed 22.7-km (14.1-mile) long east-west light rail transit (LRT) line envisioned to connect the areas of Woodlawn, Edmondson Village, West Baltimore, downtown Baltimore, Inner Harbor East, Fells Point, Canton and the Johns Hopkins Bayview Medical Center Campus. The Red Line LRT System has two tunnel segments — the Cooks Lane Tunnel (CLT) and the Downtown Tunnel (DTT). The CLT segment is roughly 1,920-m (6,300-ft) long. It commences at the west portal located at the highway ramp for I 70 (to be removed) and terminates at the east portal that is at the intersection of Edmondson Avenue (U.S. Route 40) and Glen Allen Drive. This segment of the project consists of the following construction components: approximately 1,458 m (4,786 ft) of tunnels, 143 m (469 ft) of cut-and-cover tunnel, and 318 m (1,045 ft) of retained cut (U) section. The approximate horizontal alignment for the Red Line LRT Project is shown in Fig. 1.

Ground and ground water conditions

The CLT will be excavated beneath the ground water level, and in a range of ground conditions that are described as high strength and highly abrasive rock, in addition to mixed face of rock overlain by transition group material (TGM), and three fault zones, each with distinct properties. The ground geological condition is classified based on the International Society of Rock Mechanics (ISRM, 1982) system of grading, as shown in Table 1. Ground Classes I, II, and III represent rock and Ground Classes IV and V represent TGM.

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A major portion of the tunnel profile will traverse through class IV and V material that is completely weathered and relatively permeable. This portion consists of the first 244 m (800 ft) of the tunnel drive, which starts at the west portal and the last 122 m (400 ft) just before the east portal where the tunnel boring machine (TBM) will be extracted. The remaining tunnel path between these two zones is through competent rock as well as various combinations of ground types that create challenging mixed-face excavation conditions. Top of competent rock was defined as the level below which recovery with an NQ3 triple-tube core barrel is greater than 50 percent. In terms of the geotechnical ground class descriptions presented in Table 1, this definition is equivalent to a Ground Class III, or better rock. Depth of this level ranges from about 4.8 m (16 ft) along the central part of the alignment, where ground surface is highest, to greater than about 21 to 24 m (70 to 80 ft) at inferred fault zones. Mixed-face conditions are concentrated near the two ends of the tunnel, adjacent to the cut-and-cover sections (Fig. 2). Excavations for both the west cut-and-cover and retained cut section and the east cut-and-cover and retained cut section will be in all three types of earth materials: competent rock, the transition group material, and overburden.

Ground water levels along the proposed CLT alignment are generally near the top of the transition group, within about 9 m (30 ft) of the ground surface.

Overburden permeability is likely to be low (10^{-7} to 10^{-5} cm/sec) in the clay-rich residual soils but higher in the localized sandy zones. Permeability in the transition group is expected to be generally low to moderate (10^{-5} to 10^{-3} cm/sec) but much higher locally (10^{-2} to 10^{-3} cm/sec) at open relict fractures, which could produce significant inflows.

Water-bearing properties of rock along the alignment are generally defined by fracture flow, with low permeability of intact rock. Rock mass permeability is expected to be highest in the fractured rock associated with fault zones. Results of packer permeability tests confirm that permeability in the rock mass is generally low (10^{-7} to 10^{-5} cm/sec), with higher permeability (10^{-4} to 10^{-3} cm/sec) in localized zones of closely spaced interconnected fractures or faulting. Preliminary information suggests that artesian conditions may have developed in deeper fractured rock at either end of the alignment.

Due to the high percentage of mafic minerals in much of the rock along the proposed Cooks Lane Tunnel alignment, ground water is expected to be highly alkaline.

TABLE 1

Ground class descriptions.

Ground class	Description (ISRM weathering grades)
V	Completely weathered rock where all material is decomposed and disintegrated to soil but with original rock mass structure remaining intact; disintegrates when agitated in water.
IV	Highly weathered rock where more than half is weathered to soil, does not disintegrate when agitated in water.
III	Fair to poor quality, closely to very closely fractured, slightly to moderately weathered rock.
II	Good quality, moderately fractured, fresh to moderately weathered rock.
I	Excellent quality, widely fractured, fresh to slightly weathered rock.

Tunnel construction method

The challenging geologic conditions along the proposed CLT alignment required a detailed study to determine the most appropriate and cost effective construction technique for the tunnel. The factors that will contribute to the preferred excavation method include: overall construction cost, construction duration, suitability of a particular method to the ground conditions, project site constraints, tunneling lengths, tunneling risks, and availability of appropriate expertise. Each of the construction methods offers advantages and disadvantages in their application for construction of CLT.

As stated earlier, the excavation adjacent to the tunnel portals has to take place in transition group material, which is soil-like material as well as mixed-face zones of transition group material overlying competent rock. It is also important to note that approximately 975 m (3,200 ft), or 67 percent of the tunnel drive is expected to be in competent rock with a rock cover thickness of at least one to two times tunnel diameter over the crown of the tunnel. The CLT excavation in rock is expected to encounter mostly mafic rocks, including amphibolite and diorite, amphibole (actinolite) schist, and amphibole gneiss. Mica schist is also present in the western portion of the alignment. The median unconfined compressive strength (UCS) for the amphibolite and amphibole gneiss rocks at CLT is about 32,000 psi. Excluding the

FIG. 2

Cooks Lane Tunnel geological profile.

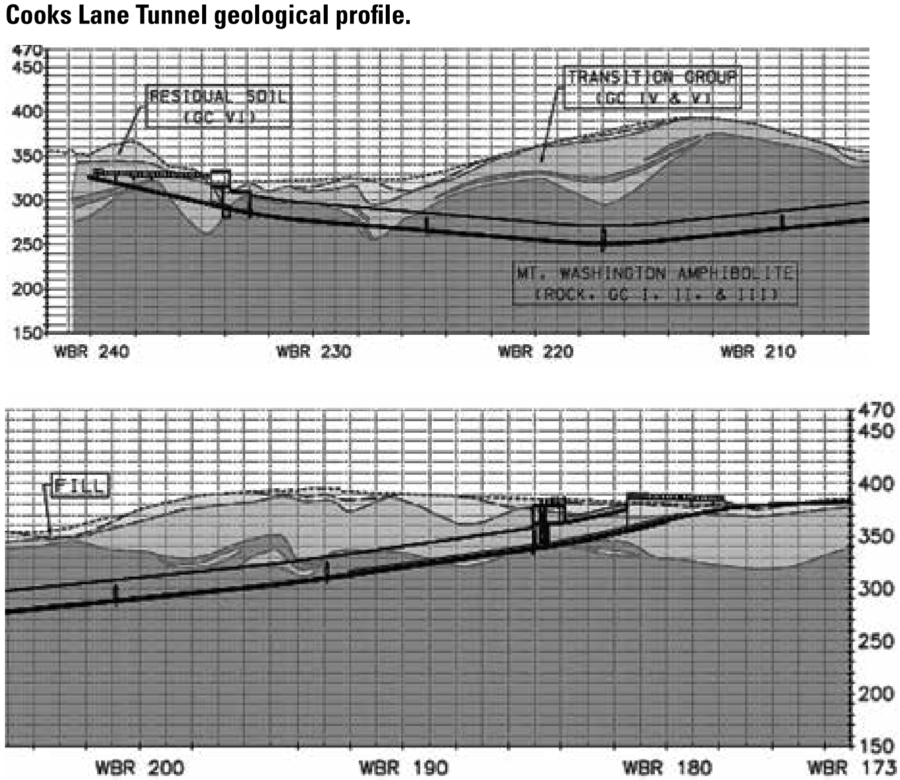


TABLE 2

Results of SINTEF tests.

Drillability index	Rating
Drilling rate index (DRI)	Extremely low
Bit wear index (BWI)	Medium to very high
Cutter life index (CLI)	Medium

relatively few tests for which failure occurred along an existing discontinuity, UCS typically ranged from about 15,000 to 54,000 psi for intact rock failures.

The results of SINTEF tests on samples of amphibolite and amphibole gneiss are summarized in Table 2.

The construction methods considered included cut and cover, New Austrian Tunneling Method (NATM), and excavation by TBM. A discussion of the applicability of each method is presented in the following sections.

Cut-and-cover. The use of cut-and-cover construction method for the construction of the entire tunnel was not considered a viable option due to high cost and its disruptive impact on the surface roads and neighboring properties.

New Austrian Tunneling Method. Rock excavation by NATM, also known as sequential excavation method (SEM), can be done using drilling-and-blasting method, road header or a combination of the two. The advantage of this method is the adaptability, relatively quick commissioning and lower capital investment as compared to excavation using a TBM.

Prior excavation experience through transition group material near proposed CLT construction site has shown that this material is highly unstable once disturbed, requiring extensive stabilization efforts. The other issue is the abrasiveness and high strength of the competent rock formation along a large portion of the CLT alignment that limits the excavation method to drilling-and-blasting. Lower excavation rate, increased construction risks, blasting-induced noise and vibration, and the length of the tunnel are among the factors that make this option less desirable than tunnel excavation by TBM.

Tunnel excavation by TBM. TBMs offer significant advantages with respect to excavation advance rates, reducing ground-borne vibrations, face stabilization and ground settlement control. The use of a TBM will allow for significantly higher production rates as compared with other methods of tunneling. It is anticipated that a TBM will be able to bore through the existing ground at the proposed CLT horizon at an average rate of 12 m/d (40 ft/day). However, the advance rate will be re-evaluated as laboratory and additional site data becomes available.

Use of a TBM also offers comparative benefits with respect to impacts on the adjacent properties. For the most part, all of the construction activities will be focused around the launch pit, which is located away from most of the stakeholders. TBM extraction at the end of the drive on Edmondson Ave is a short duration activity.

TBM selection

A critical element of this project is control of ground water inflow. Based on previous experience, with the anticipated poor ground behavior especially within the transition group material and mixed-face zones combined with the relatively large excavation (approximately 7 m or 23 ft), use of a compressed-air TBM would be a risky endeavor.

In the past 20 years, tunnel excavation in a challenging environment such as the CLT has made spectacular improvements with excavation control by the application of pressurized-face shielded TBMs, such as earth pressure balanced (EPB) or slurry face (SF) TBMs. Regardless of the TBM type used, there are challenges when tunneling in mixed grounds such as uneven/unbalanced cutter force distribution at the excavation face between the rock and soil. In such situations, the cutters on rock attract more applied thrust than those on soil, causing frequent impact loading and intense hammering effect on cutters and bearings resulting in high cutter wear and damage. The TBM operator will need to lower thrust pressure and reduce advancing rate resulting in lower cutting efficiency. Other potential issues include excessive overcutting of soil, leading to large ground settlement, high ground water seepage at interfaces, jam of roller and cutter bearings, and difficulties in removal of mixed muck from the excavation chamber.

An alternative for circumventing the potential complications for excavating tunnels in mixed ground using TBM is to either modify the design of TBM to suit the ground conditions or to condition the ground to suit the available TBMs.

Any TBM to be utilized will need to excavate tunnel sections at various locations along the alignment consisting of full-face competent rock (high strength and highly abrasive) and mixed-face conditions consisting of rock overlain by transition group (highly weathered or completely weathered). The TBM while excavating within the full-face competent rock sections will not need pressurized-face support to maintain face instability. It is also unlikely that while within competent rock, it would be required to operate with pressurized-face support due to ground permeability characteristics. However, in locations exhibiting a mixed-face condition of rock overlain by transition group as well as zones passing entirely through transition group material, will be require the TBM to operate in pressurized mode to maintain tunnel face stability. When properly configured, hybrid machines, are capable of efficiently excavating a full-face of competent rock as well as mixed-face condition.

Tunnel geometry

The two TBM-bored tunnel options include single-bore, dual-track (large diameter) tunnel and twin-bore, single-track (small diameter) tunnel.

Single-bore, dual-track. The single-bore option consists of dual tracks separated by a fire-rated wall to satisfy NFPA 130 requirements. Due to the need for dual tracks and a fire-rated wall, the preliminary inside tunnel diameter was established at approximately 10 m (34 ft). The advantages of single-bore, dual-track option include:

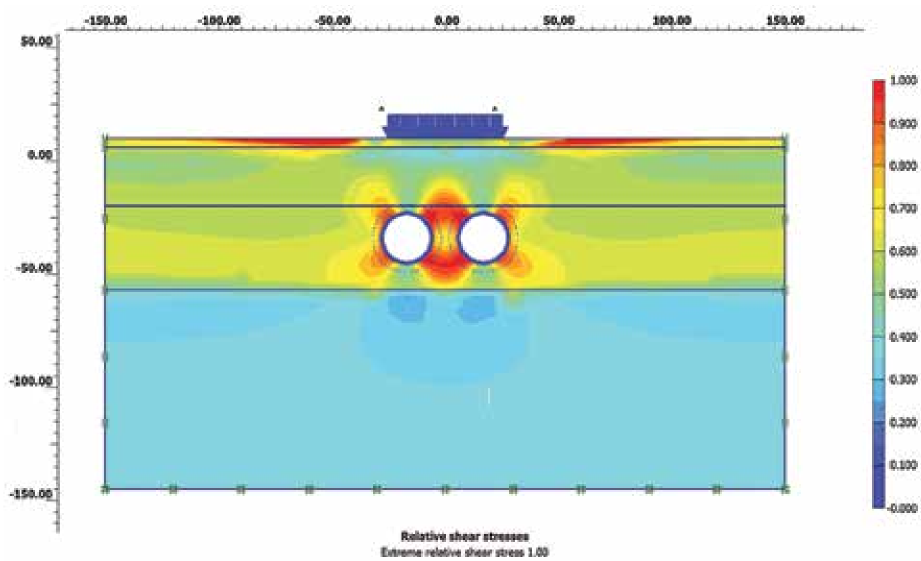
- Provides potential cost savings compared with twin-bore and SEM construction.
- Requires single TBM extraction effort at the east portal.
- Provides opportunity to reduce construction duration compared with twin-bore option.
- Eliminates the need for dedicated ventilation structures at portals.
- Minimizes footprint impact for construction staging.
- Eliminates ROW impacts along Cooks Lane.
- Eliminates the need for cross-passages and associated risks with penetrating lining for cross passage construction.
- Provides ample systems space within the tunnel envelope.

Twin-bore, single-track. The twin-bore option consists of driving parallel tunnels between portals, each carrying one track. This results in an inside tunnel diameter equal to 6 m (20 ft), approximately 4.2 m (14 ft) smaller than that of the single-bore. The advantages of the twin-bore, single-track option include:

- It is easier to maintain tunnel face in competent rock and minimize mixed-face tunneling due to the smaller bore diameter.
- The smaller cross-section results in less muck being generated.
- Conforms to a more common size.
- Provides additional cover (compared to single-bore option) under properties at the intersection of Cooks Lane and Edmondson Avenue.
- Provides additional cover (compared to single-bore option) under utilities at west portal; alternatively, the profile gradient for the west approach can be reduced.

FIG. 3

Ground relative shear stress (TGM, 0.5 % ground loss).



The current design has adopted the twin-bore, single-track option.

Ground water control

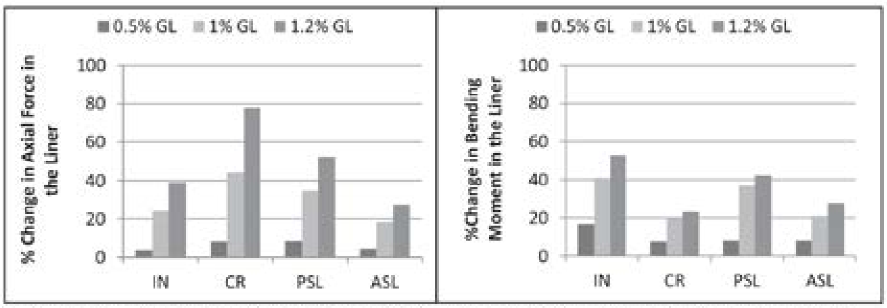
Based on the anticipated ground and ground water conditions along the proposed CLT alignment, a convertible hard rock TBM capable of operating in open and pressurized-face modes has been recommended. The machine will be operated in pressurized-face mode during tunneling through all soft ground, mixed-face conditions, transition group material, and short stretches of fractured rock with high groundwater inflow and should be converted to open mode (i.e., unpressurized) during tunneling through competent rock.

The TBM-bored tunnels require a gasketed pre-cast concrete segmental lining to prevent the inflow of groundwater into the tunnel over the lined portion of the tunnel. The ground water control measures should therefore provide positive control of the inflow from the advancing tunnel face. Ground water control during pressurized-face tunneling using a convertible earth pressure balance TBM is achieved by the formation of a soil plug inside the face plenum (i.e., excavation chamber) to balance earth and hydrostatic pressures. The face pressure is primarily maintained by the screw conveyor operations and the presence of a soil plug.

Should the inflow of ground water or loose materials during open mode tunneling in rock start to increase, it can be controlled by changing the operation mode from open face into a pressurized face mode to control the ground water and material. For the pressurized face mode in

FIG. 4

Increase in the liner forces of the first bored tunnel (TGM).



IN: Tunnel Invert, PSL: Tunnel Springline (Pillar-side), CR: Tunnel Crown, OSL: Tunnel Springline (Opposite to PSL)

rock, ground conditioning material will need to be added to facilitate the formation of the plug inside the screw conveyor since rock spoil typically has characteristics that are not conducive to plug formation.

When the TBM is operating in competent rock (open mode) the following ground water control measures are anticipated depending on the expected amount of groundwater inflow:

- Dewatering at the tunnel face.
- Drainage from probe holes.
- Rock mass grouting.

Muck handling and removal

More than 65 percent of the CLT excavation will be done in rock, where the TBM can operate in open face mode. Muck resulting from hard rock chipping is predominantly granular and includes a high percentage of gravel and possibly small, cobble-size particles. As a result of chipping mechanism, the gravel and cobble-size particles within the muck are elongated in one direction. The process of chipping also generates sand and silt-size particles. Combined with infill in joints, fractures, and weathered seams, the resulting muck from hard rock TBM excavation is generally a coarse grained material consisting predominantly of gravel-size rock chips, but also includes significant percentages of sand and fines. This material generally classifies as a silty or clayey gravel depending on the nature and volume of fine-grained weathered rock or joint infill within the overall rock mass.

The open cut excavations will be performed using conventional earthwork equipment and will result in muck consistent with conventional bulk excavations. However, it is worth noting that the majority of the excavated materials will be below the ground water table and may therefore, be in a saturated condition when excavated. The portal excavations will proceed from the ground surface to the tunnel depths, and will, thus, encounter all soil and rock strata above the base of the structure. As a result, muck from these excavations through the fill material may include miscellaneous debris and obstructions.

Hazardous materials. Preliminary investigations indicated that naturally occurring asbestos minerals may be present in rock to be excavated for the CLT. These minerals pose a potential inhalation hazard if they are disturbed during excavation and allowed to become airborne, requiring worker protection and dust control. Specialized handling and disposal at an approved facility are also required for excavated asbestos-containing rock. Additional testing is required before naturally occurring asbestos can be ruled out along the CLT alignment.

Radon gas is another potential naturally occurring hazardous material. The Red Line project is in the U.S. Environmental Protection Agency Radon Zones 1 and 2 (high to moderate radon potential). The radon source is most likely the quartz-rich crystalline rock, but pockets of high radon can also occur in sediments. Radon gas would not pose a hazard for workers during excavation because the tunnels will be ventilated, and the workers will not have long-term exposure. Gabbroic rock types such as those at Cooks Lane often contain sulfide minerals, including pyrite, as observed in recovered CLT rock core samples. Sulfide minerals can potentially produce hydrogen sulfide gas as well as potentially corrosive ground water, both of which will require consideration for construction and muck handling.

The CLT segment passes through an area that has experienced urban development, redevelopment as well as industrial activity since Baltimore was founded in 1729. As with many industrial activities during the last few hundred years, industrial practices have changed and developed over time. Manufactured hazardous materials are likely to have been discharged, either intentionally or unintentionally, into the subsurface due to the various commercial and industrial operations throughout this area. Both solid and liquid hazardous materials of varying concentrations are likely to be present in isolated locations within the general area of the CLT. This is typical of many cities of comparable age and development history throughout the country and is a potential issue on any large underground project.

Contaminated soil and ground water, if encountered, will require special handling and treatment for disposal. Tunnel construction may also affect the direction and transport rate of any existing contaminant plumes. A detailed assessment of the depths and strata that may include hazardous contaminants has not been performed yet. Further study is underway to assess whether the bored tunnels will encounter any hazardous contaminants.

Traffic impacts of muck disposal. The largest source of construction traffic will be the transport of excavated materials from the tunnel to various permanent disposal areas. Tunnel excavation will generate large volumes of muck. It is anticipated that tunnel construction will proceed as one heading at a time from the west portal. Muck will be hauled away using three-axle dump trucks, assuming a maximum allowable fully loaded truck weight of no more than 55 kips — based on the state of Maryland regulations. The daily truck traffic volume is proportional to the volume of the excavated material per day. For the bored tunnels, this will be directly proportional to the TBM advance rate. For the retained cut and the cut-and-cover segments, it will be proportional to the staged excavation progress. The total estimated muck volume for the CLT is presented in Table 3.

An average TBM advance rate of 12 m/d (40 ft/day) is currently assumed based on the anticipated ground conditions along the CLT alignment. The estimated number of construction truck trips per day for one tunnel heading and excavation advancing rate of 12 m/d (40 ft/day) is 62 truck loads per day.

Tunnel numerical analysis

The literature suggests that for parallel tunnels of diameter D, which are separated by a pillar of width W, the interaction effects are small at W/D = 1 and vanish at W/D ≥ 2 (Ghaboussi and Ranken, 1977). The Cooks Lane twin tunnels are approximately 3 m (10 ft) apart, which is less than one tunnel diameter 6.7 m (22 ft). Excavating the tunnels in such close proximity will cause interaction between the two during the construction. The TBM excavating the first tunnel modifies the state of in situ stresses and causes disturbance within the soil or rock surrounding that tunnel. The size of this affected zone depends on the TBM operation, ground type, in situ stresses, tunnel depth, tunnel diameter and characteristics of tunnel support system. Excavating the second tunnel will also create the same effect. If the distance between the two tunnels is small, these two zones will overlap. Such overlap, or interaction, manifests itself as changes in the stress field around the first tunnel resulting additional stresses in the concrete liner of this tunnel. These additional stresses must be taken into account in designing the pre-cast concrete liner of the tunnels and may also require pillar strengthening where deemed necessary.

Several analyses were performed to evaluate the zone of ground disturbance around each tunnel, degree of overlap between the disturbed zones, ground settlement, and the increase in liner forces and moments of the first tunnel due to the excavation of the second tunnel. These analyses were performed for different ground conditions surrounding the tunnels and by employing three levels of ground loss (0.5 percent, 1 percent and 1.2 percent). Figure 3 shows the ground relative shear stress distribution after completion of the second tunnel for the case where tunnels are excavated in transition group material (TGM) and the ground loss is 0.5 percent. The darker shaded zones around the tunnels in this figure are indicative of zones where shear strength of the soil has been exceeded. Therefore, when the tunnels are bored within the transition group material, regardless of percentage ground loss assumed in the analysis, the pillar experiences plastification. The zones of ground shear failure expand as the percentage of the ground loss increases from 0.5 percent to 1.2 percent.

The change in liner axial force and bending moment of the first tunnel due to excavation of second tunnel is shown in Fig. 4 at four-quarter points of the liner. The results shown in this figure are obtained for the case where the tunnels are excavated in transition group material.

TABLE 3

Total bulk volume of muck for each ground class.

Ground class	Bulk volume (cy)
Fill	87,949
Transition group material	136,778
Rock (I, II, III)	289,188
Total	513,915

Tunnel Excavation impact on existing structures

The existing buildings alongside Cooks Lane are adjacent to the CLT. Just before Cooks Lane intersects with Edmondson Avenue, the tunnels turn toward the east passing directly beneath two, two-story homes. Approximately 853 m (2,800 ft) of the tunnels will be bored in competent rock with at least one tunnel diameter of rock cover above tunnel crown. The ground surface movement due to tunneling in this area will be negligible. The ground movements resulting from tunnel excavation in transition group materials and mixed-face were estimated during preliminary engineering using two-dimensional numerical analysis. The impact of tunneling on the existing buildings was then evaluated in accordance with the methodology proposed by Boscardin and Cording (1989). The results of this study have indicated that, in general, the building damage caused by tunneling would be negligible provided that the ground loss due to tunneling is properly controlled.

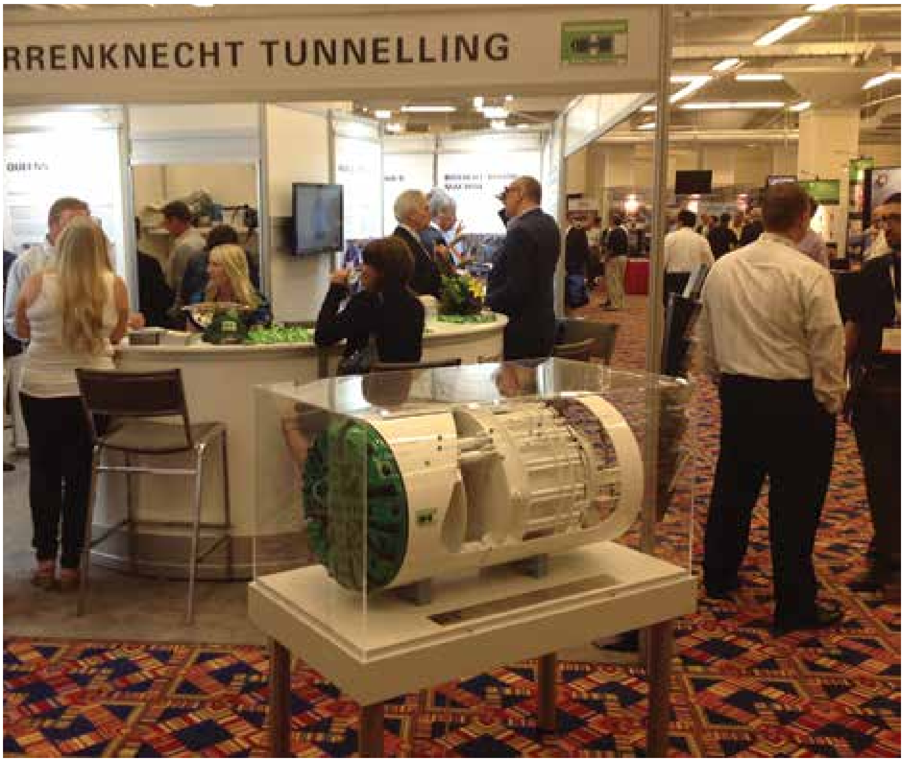
Conclusions

This paper presented the major design and construction considerations for the preliminary engineering of the Cooks Lane Tunnel including construction methodology, viable tunnel configurations, ground water control during construction, tunnel muck removal, and tunnel excavation impact on existing structures. The paper also presented the results of tunnel numerical analyses performed to date. The engineering and geotechnical investigation for the Red Line LRT project are still ongoing and the design evolves as new information becomes available. ■

RETC headed to New Orleans for 2015 conference

The Rapid Excavation & Tunneling Conference (RETC) is a world-renowned event that attracts some of the best minds in the global underground construction and tunneling industry. The experts gather at this conference to impart new technologies, discuss challenges to their projects and learn about new technologies that have become available to them.

About 1,400 underground construction professionals are expected to attend the 2015 Rapid Excavation & Tunneling Conference in New Orleans, LA.



The 2015 RETC will be held June 7-10 at the Sheraton New Orleans, in New Orleans, LA.

This biennial conference, of which SME is a sponsor, is expected to attract about 1,400 attendees from around the world. These professionals represent all parts of the global tunneling and underground construction industries — contractors, engineers, owners, consultants and equipment suppliers.

More than 110 technical papers in 21 sessions will be presented over two-and-a-half days. Paid attendees will receive a proceedings volume of the conference. The proceedings will also be available from SME. In addition to the technical programming, the accompanying exhibit will include 155 exhibitors occupying 175 booths, providing RETC attendees the opportunity to get a look at the latest in equipment and service technology. Three short courses will be held on the Sunday preceding the start of the show. And there will be plenty of opportunities for attendees to meet and chat during several social activities that are scheduled throughout the conference.

Conference speakers

Monday's Welcoming Luncheon speaker will be Angela DeSoto Duncan. She spent 24 years with the U.S. Army Corps of Engineers and three years with Tetra Tech. There, she led nationwide, multi-disciplinary teams of engineers, scientists and support staff for federal, state and local government clients. With the Corps, Duncan was chief of a multi-disciplinary branch responsible for the budget oversight, scheduling, cost estimating, design, real estate acquisition, and environmental compliance documentation of the Hurricane Protection Office's five-year, fully funded $7-billion Hurricane and Storm Damage Risk Reduction System (HSDRRS) program for the metropolitan New Orleans area. The HSDRRS program includes about 50 construction contracts consisting of levees, floodwalls, sector gates, lift gates, flood control structures, pump-station rehabilitation, control houses and urban drainage projects.

Lt. General Russel Honor, USA (Ret.) will be the banquet speaker on Tuesday evening. He arrived in a Hurricane Katrina-battered New Orleans in 2005 and took charge of military relief efforts.

He will address how the public and private sector can solve an array of issues — from jobs and energy to healthcare and technology — by emphasizing in-

Steve Kral, Editor

novation, risk assessment and social entrepreneurship. Honor's experience directing military operations gives him rare insight into the "new normal," an era where businesses, policymakers and the citizenry must lead the way in creating a "culture of preparedness" that is equipped to safeguard our economy and natural resources. He will also share how all sectors of industry can get the most out of their people in ways that optimize efficiency and effectiveness of operations, and why we need to save our best leadership for home because our children represent the next generation of problem solvers.

The accompanying exhibit at RETC will feature 155 exhibitors in 175 booths.

Short courses

Shaft construction and design. This short course will provide a review of the various shaft construction methods and some of the basic design guidelines. It covers classification and application of the shafts, excavation methods, ground support methods and special topics dealing with ground water and hoisting. The objective is to review the state-of-the-art and common practice of shaft construction for civil and mining applications for the engineers involved in underground construction. The course will cover drilling and blasting, mechanical excavation, muck haulage, ground water issues, ground freezing, slurry walls, steel support, shotcrete application and shaft site layout. Several case histories will be reviewed. The instructor is Jamal Rostami of The Pennsylvania State University. Other industry experts will be on hand.

Grouting in underground construction. This short course will present an overview of the materials, equipment and various grouting methods used in underground construction and tunneling in soils and rock. A few of the subjects covered include cements and admixtures, grouting equipment and practices, chemical and cementitious permeation grouting, jet grouting, compaction grouting, pre-excavation grouting, backfill and contact grouting, and cellular grouts. Nine industry experts will give the lectures on these grouting subjects and techniques. Attendees will receive a course notebook containing all presentation material by the speakers. This course is recommended for contractors, engineers, owners and consultants involved in any aspect of underground design and construction. The instructors are Raymond Henn, of Brierley Associates, and Paul Schmall, of Moretrench.

Underground blasting technology and risk management. This course reviews information that engineers, managers and professionals overseeing underground shaft and tunnel construction should know regarding the safe and efficient use of conventional drilling and blasting methods. Topics include a review of modern explosive and initiation systems, blasting physics and rock breakage, principles of tunnel and shaft round blast design, control of blast-induced ground vibration and air-overpressure, estimating drill-blast costs and important risk management practices. Practical elements of controlled blast design and risk management will be reviewed in an interactive blast design workshop and demonstrated in case histories involving many North American tunnel projects. Gordon R. Revey, of Revey Associates Inc., is the instructor.

Technical sessions

As always, the centerpiece of the RETC is its technical programming. The 113 presentations will provide attendees a good deal of new technological information about what works in underground construction and some of the challenges involved. Here is a sampling of some of the presentations.

**Sunday, June 7 — **Tunnel safety and other challenges for the industry. Papers presented in this session include

Tunnel rescue in America — a realistic view; Cleaning risky behavior from the workplace; Tale of two cities — subaqueous tunneling in London and New York 1879-1910; Engaging future generations for the benefit of the underground industry.

Tunneling issues regarding risk and uncertainty. This session addresses how to better understand uncertainties and human behavior in the planning and building of projects using models, case studies and class exercises.

Monday, June 8 — The morning session will consist of four sessions. They include: Design and planning I, chaired by J. Sankar, of HNTB, and G. Fairclough, of Schiavone Construction; Difficult ground, chaired by G. Hauser, of Dragados USA, and A. Smith, of CH2M Hill; New and innovative technologies, chaired by P. Finn, of JF Shea, and N. Chen, of Jacobs Engineering; and Pressure face TBM case histories I, chaired by B. Hagan, of Jay Dee Constractors, and K. Banek, of Frontier Kemper Constructors.

The afternoon sessions include Caverns and large spans, chaired by S. Hoffman, of Skanska USA Civil, and D. Mount, also of Skanska; Contracting practices, chaired by A. Delle, of Schiavone Construction, and F. Klinger, of FK Engineering Associates; Design-build projects, chaired by M. Younis, of Aldea Services, and J. Dillio, of Traylor Bros.; and TBM technology, chaired by M. Burdick, of Traylor Bros., and J. Gabelein, of Sound Transit.

Tuesday, June 8 — Morning sessions will include Future projects, chaired by D. Field, of Hatch Mott MacDonald, and N. Garavelli, of Frontier Kemper ULC; Ground support and final lining, chaired by A. Mukherjee, of Parsons Brinckerhoff, and A. Finney, of CH2M Hill; Hard rock tunneling, chaired by L. Piek, of Arup, and P. Townsend, of JF Shea; and Major projects, chaired by M Leong, of Jacobs Associates, and M. Vitale, of Hatch Mott MacDonald.

Afternoon sessions include Geotechnical considerations I, chaired by R. Goodfellow, of Aldea Services, and K. Rotunno, of the Northeastern Ohio Regional Sewer District; Grouting and ground modification, chaired by J. Sopko, of Moretrench American, and J. Frietas, of McMillen Jacobs Associates; SEM/NATM, chaired by C. Lyons, of Kiewit Infrastructure, and J. Funchi, of San Francisco Metro Transit Authority; and Shafts, chaired by F. Esmail, of Frontier Kemper, and G. Millener, of Kiewit Construction.

Wednesday, June 9 — Sessions on the final day of the RETC include Design and Planning II, chaired by D. Deere, of Deere & Ault Consulting, and M. Lang, of Frontier Kemper; Geotechnical considerations II, chaired by M. Shinouda, of Jay Dee Contractors, and C. Lavassar, of Jacobs Associates; Risk management, chaired by E. Frederickson, of Traylor Bros., and M. Preddy, of Washington State Department of Transporations; and Trenchless tunneling and rehabilitation, chaired by A. Thompson, of Hatch Mott MacDonald, and M Giorelli, of Aecon Constructors.

Field trip

Thursday's field trip will be to the Permanent Canal Closures and Pumps (PCCP) project in New Orleans. For the past year, Traylor has been working on this post-Hurricane Katrina project for the U.S. Army Corps of Engineers. PCCP Constructors is a joint venture between Kiewit Louisiana Co., Traylor Bros. Inc. and the M.R. Pittman Group LLC.

The project includes building three permanent structures to block future hurricane storm surges to New Orleans from Lake Pontchartrain. These new stations must be designed to block surges from a 100-year storm. They must also take into account expected increases in the height of Lake Ponchartrain's water level during the next 50 years to account for the rising sea level caused by global warming and local subsidence. When the surge closures are operated during storms, the pumps will move 354 m^3/sec (12,500 cu ft/second) of water from the 17th Street Canal into Lake Pontchartrain, 76 m^3/sec (2,700 cu ft/second) from the Orleans Avenue Canal and 255 m^3/sec (9,000 cu ft/second) from the London Avenue Canal.

The project is about 35 percent complete, with the preliminary site work and access roads completed. The team has also begun building the concrete structures. Project completion is scheduled for Sept. 27, 2016.

World Tunnel Congress 2016

The Underground Construction Association of SME (UCA) will be hosting the World Tunnel Congress 2016 in San Francisco, CA, and it is not too early to begin making plans to attend. The Congress, scheduled for April 22-28, will include more than 600 technical presentations, short courses, an exhibit with more than 200 companies and many social events.

WTC 2016 is unique in that it will be held in lieu of the UCA's North American Tunneling (NAT) conference. The advantage of this is that the resources, talents and participants of the NAT will be on hand at WTC in San Francisco. Information about WTC, including registration and exhibiting materials, can be found at www.wtc2016.us. ■

Compiled by Jonathan Klug, David R. Klug & Associates

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Gateway Tunnel	Amtrak	Newark	NJ	Subway	14,600	24.5	2016	Under study
2nd Ave. Phase 2-4	NYC-MTA	New York	NY	Subway	105,600	20	2015-20	Under study
Water Tunnel #3 bypass tunnel	NYC-DEP	New York	NY	Water	20,000	22	2015	Kiewit - Shea JV awarded
Water Tunnel #3 Stage 3 Kensico	NYC-DEP	New York	NY	Water	84,000	20	2017	Under design
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Highway	25,000	30	2016	Under study
South Conveyance Tunnel	City of Hartford	Hartford	CT	CSO	16,000	26	2015	Bid date 3rd Q 2015
Red Line Tunnel - Cooks Lane Tunnel	MD Transit Administration	Baltimore	MD	Subway	14,000	22	2015	Under design
Red Line Tunnel - Downtown Tunnel	MD Transit Administration	Baltimore	MD	Subway	36,000	22	2015	Under design
Purple Line - Plymouth Tunnel	MD Transit Administration	Baltimore	MD	Subway	1,000	30x40	2015	Bid date 08/19/15
Northeast Branch Tunnel Northeast Boundary Tunnel	DC Water and Sewer Authority	Washington	DC	CSO CSO	11,300 17,500	15 23	2018 2021	Under design Under design
ICCS/Dekalb Tunnel	Dekalb County	Decatur	GA	CSO	26,400	25	2016	Under design
Bellwood Tunnel Phase 1 Phase 2	City of Atlanta	Atlanta	GA	Water	6,000 21,000	12 12	2016 2016	Under design Under design
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2016	Under design
Blacklick Creek San. Interceptor Tunnel	City of Columbus	Columbus	OH	Sewer	24,000	10	2015	Under design
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	30,000 21,000	18 14	2016 2017	Under design Under design
Doan Valley Storage Tunnel	NEORSD	Cleveland	OH	CSO	9,700	17	2017	Under design
Westerly Main Storage Tunnel	NEORSD	Cleveland	OH	CSO	12,300	24	2020	Under design
Shoreline Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,100	21	2021	Under design
Southerly Storage Tunnel	NEORSD	Cleveland	OH	CSO	17,600	23	2024	Under design
Ohio Canal Interceptor Tunnel	City of Akron	Akron	OH	CSO	6,170	27	2015	Bid date 4th Q 2015
Continental Rail Gateway	CRG Consortium	Detroit	MI	Rail	10,000	28	2015	Under design
ALCOSAN CSO Program	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	35,000	20	2016	Under design
Lower Pogues Run	Indianapolis DPW	Indianapolis	IN	CSO	9,000	18	2016	Under design
Fall Creek	Indianapolis DPW	Indianapolis	IN	CSO	19,600	18	2016	Under design
White River Tunnel	Indianapolis DPW	Indianapolis	IN	CSO	28,000	18	2016	Under design

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Three Rivers Protection/Overflow	City of Fort Wayne	Fort Wayne	IN	CSO	26,400	12	2017	Under design
Pleasant Run Deep Tunnel	Citizens Energy	Indianapolis	IN	CSO	38,000	18	2020	Under design
St. Louis CSO Expansion	St. Louis MSD	St. Louis	MO	CSO	47,500	30	2014	Under design
KCMO Overflow Control Program	City of Kansas City, MO	Kansas City	MO	CSO	62,000	14	2014	Under design
Mill Creek Peaks Branch Tunnel	City of Dallas	Dallas	TX	CSO	5,500	26	2014	Advertize 4th Q 2015
East Link Light Rail Extension	Sound Transit	Seattle	WA	Transit	30,000	22	2016	Bid date 8/06/2015
L.A. Metro Regional Connector	Los Angeles MTA	Los Angeles	CA	Subway	20,000	20	2014	Skanska-Traylor JV Awarded
L.A. Metro Westside Extension Phase 1 Phase 2 Phase 3	Los Angeles MTA	Los Angeles	CA	Subway	42,000 26,500 26,500	20 20 20	2014 2015 2017	Skanska/Traylor, Shea awarded Under design Under design
Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2017	Under study
Northeast Interceptor Sewer 2A	LA Dept. of Water and Power	Los Angeles	CA	Sewer	18,500	18	2014	RFQ under way
River Supply Conduit - Unit 7	LA Dept. of Water and Power	Los Angeles	CA	Water	13,500	12	2015	Under design
JWPCP Effluent Outfall Tunnel project	Sanitation Districts of LA	Los Angeles	CA	Sewer	37,000	18	2015	Under design
Freeway 710 Tunnel	CALTRANS	Long Beach	CA	Highway	26,400	38	2016	Under design
BDCP Tunnel #1 BDCP Tunnel # 2	Bay Delta Conservation Plan	Sacramento	CA	Water	26,000 369,600	29 35	2017 2018	Under design Under design
Iowa Hill Pumped Storage Project	Sacramento Muni. Utilities District	Sacramento	CA	Water	3,500	20	2018	Under design
SVRT BART	Santa Clara Valley Trans Authority	San Jose	CA	Subway	22,700	20	2016	Under design/ Delayed
Coxwell Bypass Tunnel program	City of Toronto	Toronto	ON	CSO	35,000	12	2015	Under design
Yonge St. Extension	Toronto Transit Commission	Toronto	ON	Subway	15,000	18	2016	Under study
Scarborough Rapid Transit Extension	Toronto Transit Commission	Toronto	ON	Subway	25,000	18	2017	Under design
CSS - East-West	City of Ottawa	Ottawa	ON	CSO	14,400	10	2015	Under design
CSS - North-South	City of Ottawa	Ottawa	ON	CSO	5,300	10	2015	Under design
Energy East Pipeline	TransCanada	Quebec City	QC	Oil	13,780	16	2015	Under design
Second Narrows Tunnel	City of Vancouver	Vancouver	BC	CSO	3,600	14	2013	Under design
UBC Line project	Trans Link	Vancouver	BC	Subway	12,000	18	2015	Under design
Northern Gateway Clore Tunnel Hoult Tunnel	Enbridge Northern	Kitimat	BC	Oil Oil	23,000 23,000	20 20	2014 2014	Under design Under design

The UCA of SME wishes to thank its Corporate and Sustaining Member companies.

Their support for the underground construction industry and its professionals is sincerely appreciated.

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Rapid Excavation and Tunneling Conference 2015 Proceedings

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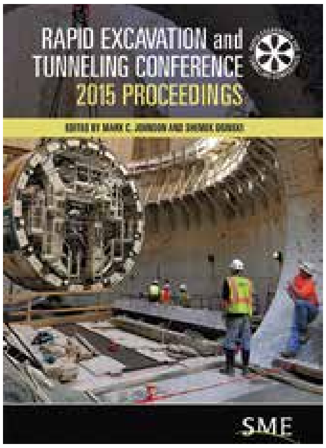

Tunnels are getting larger, deeper and are being excavated in more challenging conditions. The expectation for the industry is to successfully complete these projects while meeting the other heavy construction challenges of sustaining quality, schedule,performance and safety. This comprehensive proceedings will keep the reader informed about the ever-changing and growing tunneling industry. It includes the full text of 113 papers presented at the 2015 RETC conference, with case studies from projects in Istanbul, Lima, Lake Mead, London and more. Stay on top of new trends and technologies as well as innovative concepts, new equipment, materials, management, financing and design challenges. A fully searchable CD containing the entire proceedings is included. ■

TUNNELING COURSE

CSM offers tunneling short course

The Colorado School of Mines will offer the short course Breakthroughs in Tunneling on Sept. 14-17, 2015 in Golden, CO. This three-and-a-half day intensive short course brings together world-renowned experts to present lectures on every aspect of mechanized and conventional tunnel design and construction in hard rock, soft ground and soils.

Attendees will gain in-depth knowledge of the latest developments in tunnel design and construction. They will also have the opportunity to network with tunneling industry professionals and discuss projects, whether in the planning, design or construction stage, with recognized experts.

The course provides in-depth, specialized instruction not offered anywhere else and will benefit anyone involved in the multibillion dollar global tunneling sector — owners, engineers, contractors and consultants.

CSM will award 2.3 continuing education units upon successful completion of the course. Levent Ozdemir and Tim Coss are the course directors. For more information or registration, visit www.csmspace.com/events/tunneling. ■

PERSONAL NEWS

Avanti International has appointed **BRITT N. BABCOCK**, PE, (SME) as vice president of sales. In his new position, he will further develop a growing portfolio of customers and partners nationwide. Babcock comes with a wealth of experience within the industry, having spent the last four years as Avanti's geotechnical market director focusing on mining, tunneling, subways and soil stabilization. His new role is focused on continuing the company's growth nationally and globally.

BABCOCK

Coming Events

2015 Cutting Edge Urban Tunneling
September 21-23. 2015
Grand Hyatt, Denver, CO, USA

2016 World Tunnel Congress
April 22-28, 2016
Moscone Center
San Francisco, CA, USA

FOR ADDITIONAL INFORMATION CONTACT: Meetings Dept., SME 800-763-3132, 303-948-4200 fax 303-979-4361, email sme@smenet.org

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