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TUNNELING & UNDERGROUND CONSTRUCTION

THE OFFICIAL PUBLICATION OF UCA OF SME WWW.TUCMAGAZINE.COM VOLUME 12 N0. 1 March 2018

Mexico's longest road tunnel

Ground freezing at DC Water's First Street Tunnel

Fox Conference attracts 350

Special Editorial Supplement from the publisher of **Mining** engineering

Conquering

Connecting Norway by rail: 5 Herrenknecht Hard Rock TBMs are on the move for **45 km of new first-class rail tubes** at the New Ulrikentunnel and Follo Line projects.

Toughest

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COVER STORY

In this issue — Acalpulco, Mexico's Alternate Roadway Project is an 8-km (5-mile) roadway that includes 3,160-m (110,350-ft) long drill-and-blast tunnel. Details of the project begin on page 10. DC Water's First Street Tunnel is designed to reduce sewer overflows into local water ways. The story begins on page 16. Cover photo is of Acapulco's Alternate Roadway Project.

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EDITORIAL STAFF

Editor
Steve Kral
kral@smenet.org

Senior Editor
William M. Gleason
gleason@smenet.org

Senior Editor
Georgene Renner
renner@smenet.org

Production Graphic Artist
Ted Robertson
robertson@smenet.org

BUSINESS STAFF

Media Manager
Advertising
Ken Goering
goering@smenet.org

Phone +1-800-763-3132 or +1-303-973-4200
Fax +1-303-973-3845

Internet www.smenet.org

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CHAIRMAN'S COLUMN

UCA Executive Committee updates and coming attractions

In concert with the Fox Conference, the UCA of SME Executive Committee held its annual Winter Meeting in January. There was a tremendous amount of business covered.

Funding was approved for an inaugural "Teach the Professor" course to be conducted in conjunction with NAT 2018. This course is designed to educate professors on the underground construction industry, and give them a suite of instructional tools for direct integration into their courses. This will result in additional exposure to tunneling careers at both the undergraduate and graduate student levels. Our first class will feature 10 professors from various colleges and universities around the United States.

Replenishment funding was approved for the joint UCA/ASCE "Tunnel Tour" program. This program is a key element of our education and student outreach initiative. In the short history of this effort, 25 underground construction projects and 15 university visits have been conducted. This funding also covers additional industry outreach and marketing studies to further promote careers in underground construction and engineering. There are plentiful opportunities for our members to get involved in this program. Please contact Paul Schmall for details as to how you can contribute.

Scholarships have always been a large part of the UCA program. As in past years, we are awarding our annual UCA of SME scholarships, NAT Conference scholarships and Young Members Student scholarships. Each of these awards includes attendance at NAT this summer. Please reach out to the dozens of students that we are bringing to our biennial event.

Four Executive Committee Director terms of service are due to expire at the end of June. As directors are limited to no more than two full (four year) terms, Colin Lawrence and Mike Rispin were not eligible for reappointment and will be rotating off of the executive committee. I want to personally thank Colin and Mike for their tireless support of the UCA and our industry as a whole. Reappointed for their second terms were Lonnie Jacobs and Mike Mooney; both indispensable contributors to the UCA. Our two new directors are Mark Johnson and Alan Campoli. Mark and Alan will begin their four-year terms beginning July 1.

The recommendations of the UCA Awards Committee were approved for the following categories.

- Outstanding Individual
- Outstanding Educator
- Lifetime Achievement
- Project of the Year

These awards will be presented at NAT 2018.

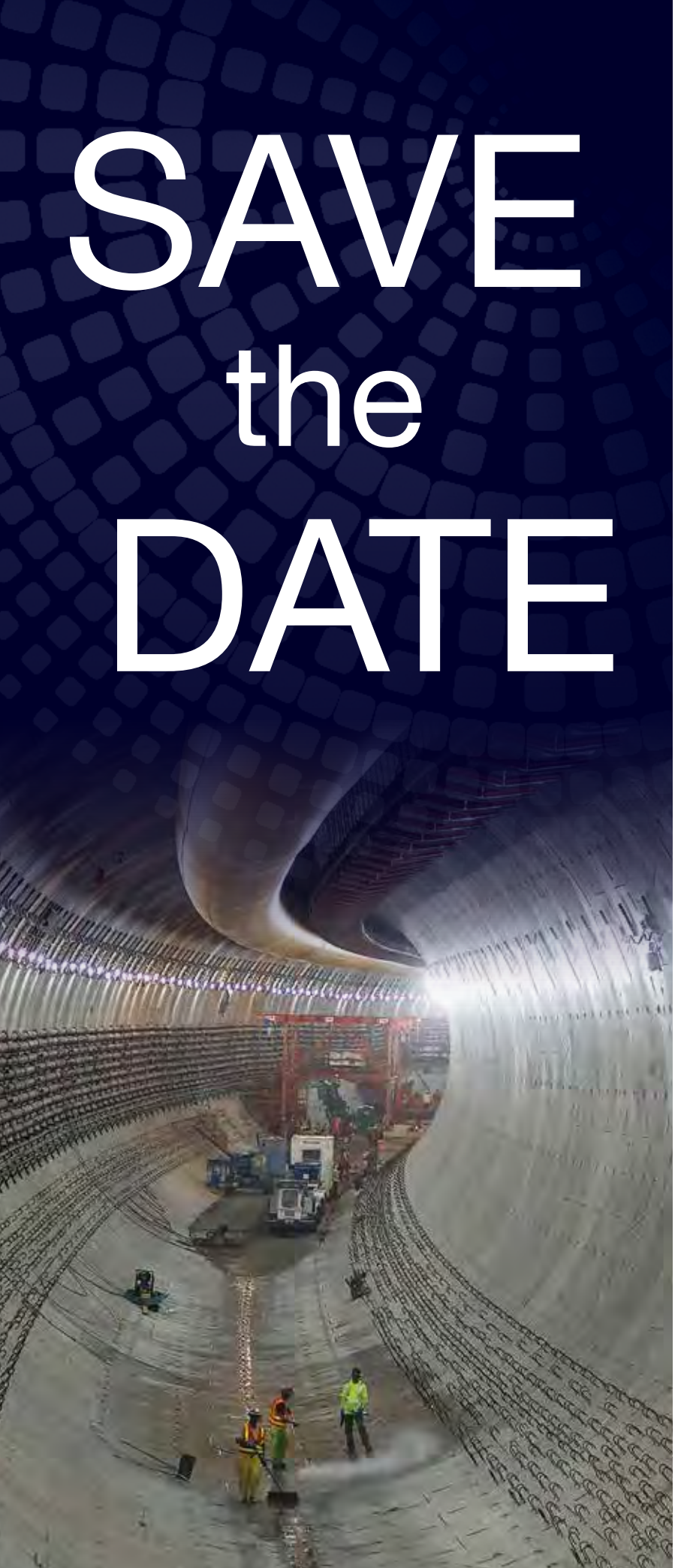
Francis Arland and his team produced another outstanding George A. Fox Conference in January. This year's theme was "Managing Construction of Complex Underground Projects: Strategies for Tunneling in Populated Areas.". Speakers presented their experiences and insights for a variety of mega-projects from around the world.

Planning is well under way for Cutting Edge 2018. This year's event will be held in Atlanta from Oct. 29-31 and will include a technical tour of the City's Water Supply Project, transforming the Bellwood Quarry into a 2.4-billion-gallon raw water storage reservoir.

The 2018 North American Tunneling (NAT) Conference

Mike Roach,
UCA of SME Chairman

SAVE the DATE



NAT 2018

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KEY DATES

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March, 2018	Housing Opens
May 25, 2018	Housing Deadline

REGISTRATION

March, 2018	Registration Opens
May 25, 2018	Early Bird Registration Ends
June 1, 2018	Registration Deadline

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California scales back WaterFix project

The ambitious California Water Fix plan has been scaled back again. California state officials said they will press ahead with a smaller version of a long-planned water delivery project, but the new plan will include initially building one massive tunnel in the heart of California's vast waterworks instead of two.

The *Los Angeles Times* reported the decision to downsize California WaterFix boils down to money. The urban and agricultural water districts that are supposed to pay for the multibillion dollar project have only committed to enough funding for one water tunnel that would extend 56 km (35 miles) under the Sacramento-San Joaquin Delta.

The plan to send more water to the San Joaquin Valley agribusiness and Southern California cities from the north has been in play for more than 10 years. Originally, it called for two tunnels at a cost of $17 billion. Questions about WaterFix's impact on the delta environment, opposition by delta interests and funding shortfalls have steadily whittled down the project's ambitions and scope. A major habitat restoration program was dropped. The construction footprint was reduced. And now the state is planning to move ahead with one tunnel that would cost $10.7 billion.

The changes are likely to add more delays to WaterFix. The Metropolitan Water District of Southern California and other agencies that approved funding for the two-tunnel plan have to decide if a scaled-back version will deliver enough water to maintain the project's appeal.

"Metropolitan recognizes that a staged approach to California WaterFix reflects the project's economic realities at this time," Metropolitan general manager Jeffrey Kightlinger said in a statement. "Metropolitan continues to explore pathways that align cost and benefits and will work with our partners on a financing agreement. But the final decision regarding participation in the staged project will ultimately be made by our board of directors."

The Department of Water Resources said it would take until October to complete a supplemental environmental review of the modified plans.

And shrinking the project won't quiet criticism that big tunnel diversions on the Sacramento River will hurt migrating salmon and worsen water quality in the delta.

The project also has yet to finish the permitting process, which could throw still more hurdles in its path.

The tunnel proposal is the latest attempt to halt the delta's steep environmental decline while continuing major water exports that have helped drive that decline. The project's many stumbles illustrate how difficult — if not impossible — it is to attain that goal.

In a memo to water contractors, state officials said the ultimate scope of WaterFix depended on the participation of local agencies — construction could begin on a second tunnel if additional funding materialized. "Being prepared and having the option of a staged implementation of WaterFix is prudent, fiscally responsible and meets the needs of the public water agencies funding the project," wrote DWR Director Karla Nemeth.

Even a smaller WaterFix would involve a mammoth construction job. Two new intakes, with a total capacity of 6,000 cfs, would be built on the Sacramento River in the north delta near Courtland. The tunnel — taller than a three-story building and buried as much as 45 m (150 ft) underground — would feed existing government pumping plants in the south delta.

Those pumping operations are so powerful that they have altered delta hydrology, caused delta channels to flow backward and pushed imperiled native fish closer to extinction — triggering endangered species protections that at times restrict southbound water exports.

WaterFix is intended to diminish the environmental impacts of the pumping — heading off further export restrictions. But opponents argue that the new river diversions will create another set of environmental problems, while years of construction will disrupt one of California's most tranquil farming regions.

The original funding plan called for the largely urban water agencies supplied by the State Water Project to pay for 55 percent of the tunnels, while the largely agricultural customers of the federal Central Valley Project paid for the remaining 45 percent. ■

Michigan tunnel plans move forward

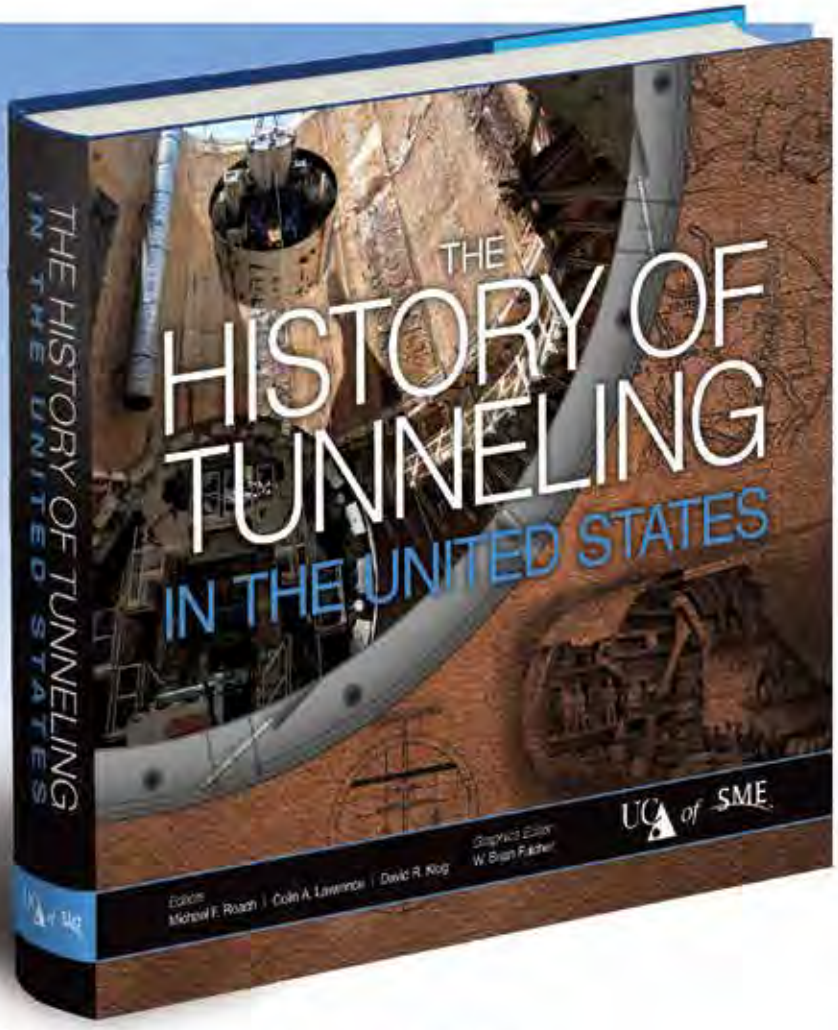
Plans are moving forward on a tunnel in Ann Arbor, MI to improve access to riverfront recreation areas and curb flooding, the *Detroit News* reported.

The Ann Arbor City Council voted on Feb. 12 to take a step forward on the project that will go under railroad tracks between Depot Street and the Huron River.

The tunnel will accommodate pedestrians as well as a stormwater sewer. Construction is expected to start this year.

City officials estimate that the flood-control portion of the project totals $5.1 million, with $3.7 million covered by Federal Emergency Management Agency grant funding. The pedestrian trail elements total $2.3 million, including grant money. ■

New Book Chronicles 200 Years of Tunneling in the United States



What has surprised most of us within the underground world is actually the success story that has unfolded as we unearthed surprises and unexpected achievements that were long forgotten by the tunneling industry.

Klug, Lawrence, Roach, Fulcher

The History of Tunneling in the United States

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Feasibility study for world's longest undersea rail tunnel completed

A feasibility study completed by Finland and Estonia found that the world's longest undersea rail tunnel linking the two nations could cost up to $24.7 billion and be opened for traffic by 2040.

Reuters reported that following years of investigations, Helsinki and Tallinn are looking to build a permanent undersea link between the two northern capitals, situated on the opposite sides of the Gulf of Finland.

Tens of thousands of Estonians work in the Helsinki region, many of whom commute over the sea weekly, and many Finnish tourists visit Tallinn.

The proposed 103-km (64-mile) long tunnel would shorten the travel time between Helsinki and Tallinn to about 30 minutes, from at least 90 minutes currently by fast ferry.

The tunnel would connect the cities' airports and it would also link up with Rail Baltica, a railway connection between Tallinn and Warsaw, projected to be completed in 2026.

"Estonia will be connected to central Europe ... and we must not stop here," Estonian Prime Minister Juri Ratas said at a conference in Tallin.

"I have heard that many people in Finland ... say that they feel like living on an island. But it does not have to be like that."

Without the tunnel, passenger traffic between the cities is expected to grow from 9 million in 2017 to 14 million by 2050. With the tunnel, the traffic would grow to 23 million, of which 10 million would still be transported by ferries.

The feasibility study estimated the tunnel would cost $16-$24 billion, hoping that 40 percent of the costs would come from the European Union.

A 2015 Helsinki report had a smaller price tag for the project, of $11-$16 billion.

The governments said they would evaluate the results in more detail during the spring. ■

UCA seeks volunteers to update "Recommended Contract Practices" book

The UCA of SME is working on a revision to the *2008 Recommended Contract Practices for Underground Construction*, edited by W. Edgerton, which updated the *1974 Better Contracting for Underground Construction Manual*. The updated manual will review emerging trends in contracting practices and recommend best practices for owners and other project participants. The primary focus remains underground construction: tunnels and shafts for highway, rail, water, wastewater and other uses.

Editor Sarah Wilson seeks individuals interested in volunteering their time and expertise by reading drafts of specific chapters, providing comments and participating in a consensus-building workshop at the North American Tunneling Conference in June 2018.

The committee hopes individuals who represent a broad spectrum of experience, background and geography will participate. The manual includes chapters on the following topics: Relationships; Project Planning; Subsurface Conditions; Risk Management; Design and Construction Management; Cost Estimates; Schedules; Pricing and Payment Provisions; Contracts; Changes; Dispute Resolution; and a new chapter on Insurance. The review process will begin in May 2018. Reviewers will have two to four weeks to read a chapter and provide written comments to the editor.

The first round of comments is expected to be due on Sunday, June 24, 2018 at the NAT Conference in Washington, D.C.

Interested individuals may find workshop information on the NAT website: www.natconference.com. Please send an email to wilson@mcmjac.com to receive materials for review. ■

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Officials narrow route options for high-speed Maglev rail line

The U.S. Federal Railroad Administration (FRA) has narrowed to two the number of possible routes for a superconducting maglev train line that would take passengers from Washington to Baltimore in 15 minutes.

The proposed 64-km (40-mile) train line that some have dismissed as unrealistic, is planned as the first leg of a system that would move people from Washington to New York in an hour. Building the D.C.-Baltimore stretch could cost between $10 billion and $12 billion, of which Northeast Maglev says it has secured $5 billion from Japan.

The *Washington Post* reported that the FRA. which is leading a federal review process, can move to select a preferred route and construction process. The federal government's next step would be giving clearance for tunneling to begin as early as 2020 and operations in 2027.

That's what project proponents are betting on, anyway. But upon completion of the environmental impact statement in mid-2019, the FRA could also rule against building the line.

Northeast Maglev, the team of private investors behind the project, touts the line as a way to ease travel along congested Interstate 95. Chiefly, the group says, it would add rail capacity to the Northeast Corridor — the nation's busiest rail network — while the technology would revolutionize train travel, bringing it closer to flying and free it of the delays that plague today's railroads.

"Our infrastructure is crying out for some kind of change," Wayne Rogers, chief executive of Northeast Maglev, told a panel of Maryland lawmakers. Northeast Maglev's sister company, Baltimore Washington Rapid Rail, would develop and operate the train.

The two remaining routes parallel the Baltimore-Washington Parkway. On the east side of the highway, the route would encroach on federal land, including the parkway, the National Security Agency at Fort Meade and NASA in Greenbelt. Northeast Maglev officials say this is their preferred option.

On the west side, the rail line would track along the edge of the Baltimore-Washington Parkway right of way and affect some residential properties.

About 75 percent of the route would run underground — 24 m to 30 m (80 ft to 100 ft) below, project officials say. Northeast Maglev estimates the project will create 74,000 construction jobs during the seven-year building period and 1,500 permanent positions once the system is operational.

Maryland transportation officials recently announced progress on the federal environmental review, stressing that the state isn't funding the project but that it views it as vital to its economy. ■

Four groups submit bids for O'Hare Express job

Chicago, IL Mayor Rahm Emanuel announced the Chicago Infrastructure Trust (CIT) has received four responses to the Request for Qualifications (RFQ) to design, build, finance, operate and maintain the O'Hare Express operating system. The project aims to deliver express service that would take 20 minutes or less to travel from downtown Chicago to O'Hare International Airport (ORD), cutting more than 50 percent off current travel times.

"Four visionary groups have stepped forward because they see what we see — a connected Chicago is a stronger Chicago," Mayor Emanuel said. "Strengthening connections between the economic engines of downtown Chicago and O'Hare airport will build on Chicago's legacy of innovation and pay dividends for generations to come."

The CIT, on behalf of the City of Chicago, received responses from the following respondents:

- The Boring Company.
- Oaktree Capital Management.
- O'Hare Express Train Partners (OHL Infrastructure, Kiewit, Amtrak).
- O'Hare Xpress LLC (Meridiam, Antarctica Capital, JLC Infrastructure, Mott MacDonald and First Transit).

The responses demonstrate strong private sector interest in the project to create a fast and convenient option for travel directly from ORD to downtown Chicago. The CIT and the City will now begin to evaluate the statements of qualifications. Upon conclusion of that review, qualified respondents will be permitted to continue in the process. The next planned step is issuance of an RFP to qualified bidders.

The RFQ specifies that the O'Hare Express Service should include a downtown station, an ORD station and one maintenance facility. Corridors may be above or below surface level. Goals of the project include travel times of 20 minutes or less with a reliable service frequency of at least every 15 minutes for the majority of the day with reasonable premium service fares less than the cost of current taxi and ride-share services. ■

Power supply for West Africa secured with help of microtunneling project

In late July 2017, Coleman Microtunnelling, a subsidiary of Bothar Group Australia, successfully completed tunneling for two power plant cooling water lines in Ghana with a Herrenknecht utility tunnel boring machine (TBM). The new oil-gas power plant puts the supply of electricity for people and businesses on the West African Atlantic coast on a more solid foundation.

The 2,700 GWh per year capacity of the new Kpone Independent Power Plant (KIPP) is enough to reliably supply approximately 1 million households with electricity. The oil-gas power plant, located about 25 km (15.5 miles) east of the Ghanaian capital Accra directly on the coast, will be cooled with sea water from the Atlantic Ocean via two cooling water lines.

For the construction of these underground sea water intake and outfall tunnels (2 m or 6 ft inner diameter), Coleman Microtunnelling, ordered a Herrenknecht AVND2000AB utility tunneling machine. Herrenknecht specially designed the tunnel boring machine with a salvage module for this special application. In the sea-outfall method, pipelines are constructed from the coastline into the open sea. There, the machine has to be recovered under water. The salvage module prevents the machine and the tunnel from flooding. In addition, for cutter tool changes under high ground water pressure, Herrenknecht equipped the machine (outside diameter 2.5 m or 8 ft outer diameter) with a hyperbaric chamber.

Two shafts on the coast served as starting points for the jobsite crew and the Herrenknecht AVND for a total of four pipe jacking drives between May and July 2017. In total, they covered a distance of 2,530 m (8,300 ft). First, the tunneling specialists of Bothar Group Australia's subsidiary Coleman Microtunnelling produced two tunnels from the two shafts toward the power plant. These 545- and 520-m (1,790- and 1,710-) long tunnels run under the mainland and connect the sea-outfalls and the power plant. Afterward, construction of the challenging tunneling sections under the sea floor started. Initially, the machine excavated a 1,085-m (3,560-ft) long tunnel from the coast to the target spot on the seabed for the extraction of the cooling water (sea-intake). There, the TBM was recovered by the jobsite crew at a depth of 17 m (56 ft). Finally, the machine created a parallel 380-m (1,246-ft) long tunnel toward the sea that will later take the cooling water back into the Atlantic (sea-outfall).

Herrenknecht AVND2000AB equipped with a special salvage module as well as a hyperbaric chamber for cutting tool changes under high ground water pressure.

Brent Jones, project manager for Coleman Microtunnelling, was impressed with the Herrenknecht support in Schwanau and the Herrenknecht service team responsible for the region: "We could not have done it without this extraordinary support. All through Christmas the supply of spare and wear parts went smoothly." Swen Weiner, area sales executive middle east for the Herrenknecht business unit Utility Tunnelling, is certain: "The good project performance for the long sea-outfall drive in Kpone will be a benchmark for the future in the region." The supply of another Herrenknecht machine to the Bothar Group for a next sea-outfall drive in Ghana followed almost seamlessly. ■

Chairman's column: Start planning for NAT

(Continued from page 2)

June 24-27 in Washington, D.C. is our next chance to get the entire UCA membership together. This four-day conferene focuses on underground design, construction and new technology. It is an essential experience for contractors, engineers, owners, vendors, academia and students. Given this year's conference location, we are also hoping to attract a fair number of our legislative decision makers. Short courses, technical sessions, panel discussions and technical field trips make NAT the can't miss underground industry event.

UCA is continuing its sponsorship of the Young Members Reception at NAT. New this year will be UCA sponsorship of the Women in Tunneling and Owners' Receptions. Additional information for each of these events will be available during conference registration.

The Executive Committee would again like to thank all of our members, sponsors and staff that work so hard to make all of our efforts successful endeavors.

Mike Roach,
UCA of SME Chairman

Construction of the longest road tunnel in Mexico

Construction of the longest road tunnel in Mexico is part of Acapulco's alternate roadway to the scenic roadway project. This article provides a brief summary regarding details of the construction since the project began. Work was done by skilled engineers and Mexican workers that includes outstanding execution of the work in an urban and tourist area. This project will have a strong impact on the steady development of the port of Acapulco.

Project location

Acapulco's Alternate Roadway Project is currently under construction in the city of Acapulco, located in the Guerrero state of Mexico. It is an 8-km (5-mile) long roadway that starts at the Icacos neighborhood, heading toward Acapulco's airport, crossing a drill-and-blast tunnel that is 3,160 m (10,350 ft) long under Veladero Park, a mountainous area. The tunnel overburden reaches a depth of 380 m (1,250 ft) approximately at the central point of the horizontal alignment, and continues with a 4-km (2.5-mile) long elevated road to connect to the existing Viaducto Diamante toll road (Fig. 1).

Tunnel construction has already been finished using two portals for drilling and blasting operations; Brisamar Portal on the west side and Cayaco Portal on the east side (Fig. 2).

Geometric data

Only two main excavation cross-sections were considered in the executive design. The first one corresponds to the running tunnel for a three-lane vehicle section, with cross-section areas between 120 and 130 m^2 (1,290 and 1,400 sq ft) taking into consideration different geological and geotechnical conditions to be encountered (Fig. 3).

Hector Conseco Aragon and Miguel Angel Banuet Rodriquez

Hector Conceso Aragon, member UCA of SME, is with MHFCC Contrucciones, and **Miguel Angel Banuet Rodriquez**, is with Ingenieros Civiles Asociados email mhfcc2@hotmail.com.

FIG. 1

Plant location of Acapulco's Alternate Roadway Project in Acapulco City, Mexico.

The second one corresponds to eight emergency bays, each one 50 m (164 ft) long, laid down within the tunnel outline, located at 400 m (1,312 ft) from each one with excavation cross-sections between 156 to 169 m^2 (1,680 to 1,820 sq ft), in accordance to geological and geotechnical conditions to be encountered (Fig. 4).

The tunnel's horizontal alignment is completely straight, having a small curve within the vertical alignment on Cayaco portal, because there were some differences in levels when tunnel excavation started.

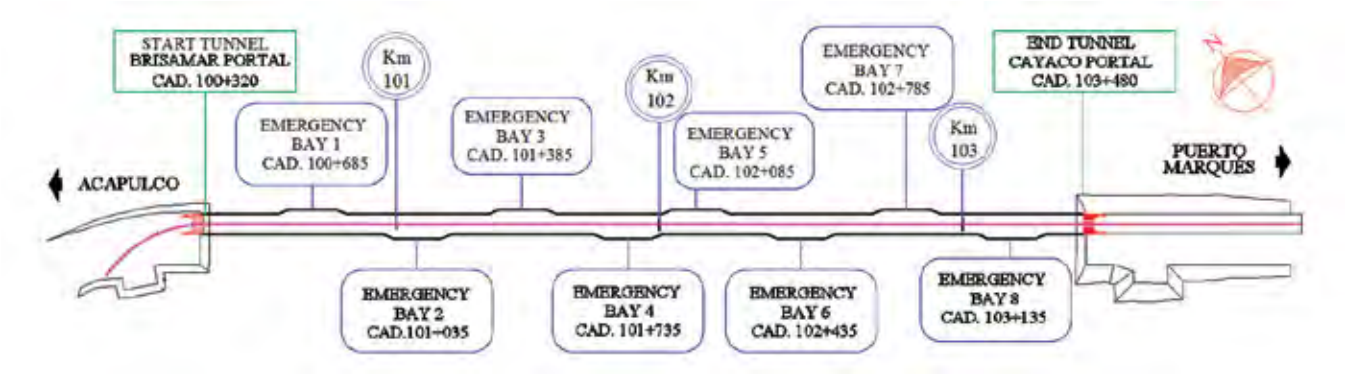
Tunnel slopes were designed in such a way that rainwater does not run down into the tunnel at any time.

Construction process of the running tunnel and bays, primary lining of the tunnel and equipment used

Drill-and-blast construction was planned to be used for the entire tunnel excavation, adjusting the excavation sequence as a function of the geological-geotechnical conditions, resulting from the exploration carried out during the design stage. Only seven direct borings for sample recovery and six transient electromagnetic borings at distances between 370 and 530 m (1,213 and 1,740 ft) were executed. Taking into consideration that most of the direct exploratory borings were near

FIG.2

Schematic plan location showing Brisamar and Cayaco portals, and emergency bays along tunnel alignment.



the portals, 70 percent of the tunnel distance was not explored properly, and rock formation parameters were inferred in large measure. Because of these reasons, the executive design presented several constructive sequences to cover different mechanical conditions of the rock formations, that were only indicative of measures to be applied by the contractor.

Because of the uncertainty due to the lack of information about geological and geotechnical conditions of the site's rock formations, tunnel excavation was planned to be done in three stages; the top-heading section first, keeping a 4-m (13-ft) bench for the lower section, that would be alternatively excavated after having advanced 500 m (1,640 ft) in the upper middle section. Drilling patterns and explosives were consequently adjusted accordingly to found rock-formation conditions.

Tunnel excavation at bays was done in two stages for the top-heading section, due to the larger dimensions. Bench excavation was also done in two stages, allowing access to the face at all times.

Primary support was in direct relationship to rock quality. A combination of steel fiber shotcrete in thickness from 5 to 20 cm (2 to 7.8 in.), IPR profile steel arches for poor to very poor rock conditions, in accordance to criteria established by Bieniawski for rock mass rating (RMP) determination was used. For regular rock conditions, it was recommended a 5-cm (2-in.) thick layer of steel-fiber reinforced shotcrete, plus 6-m (20-ft) long friction rock bolts at the top covering a 160-degree area was used.

Micropiles umbrellas and rock bolts. For very bad to bad rock conditions where underground water was leaking or flowing throughout joints and cracks, a systematic array of micropile umbrellas were installed first to prevent cave-in formations after each blasting, making it easier to advance safely under the micropile umbrella protection. 37 micropiles were originally considered for installation along the running tunnel arch, distributed at a 40-cm (15-in.) distance from each other. Micropiles were made of special steel pipe (10 cm or 4 in. inner diameter) and were installed simultaneously as boring drilling was being done (Fig. 5).

Drilling length for each micropile umbrellas was 12

FIG.3

Cross section of the running tunnel.

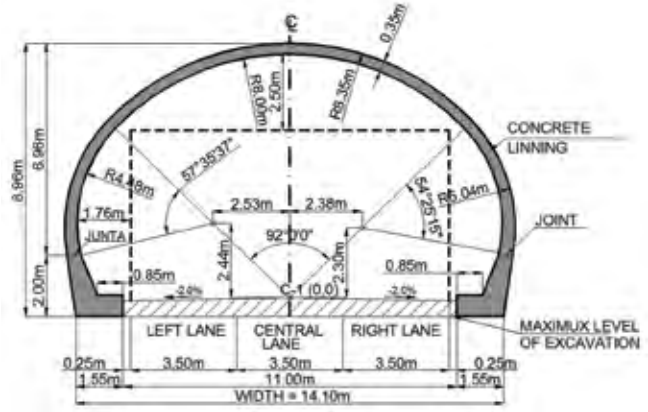


FIG.4

Cross section at the bay tunnels.

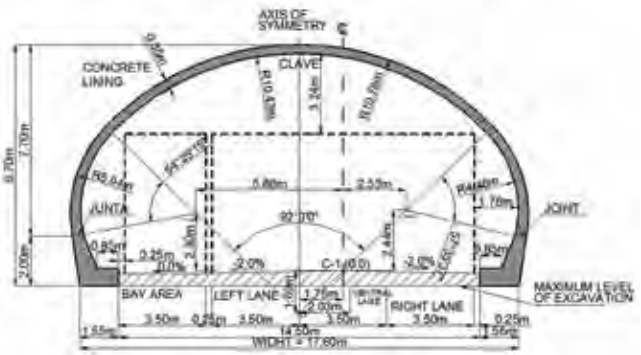
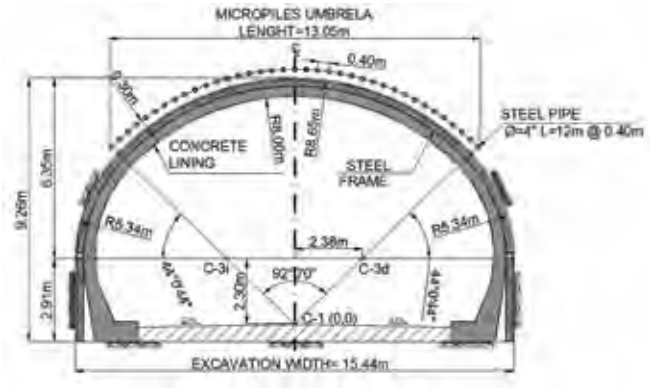


FIG.5

Micropile umbrella array for running tunnel section.



m (40 ft), allowing 3 m (10 ft) length overlap between each umbrella, giving 9 m (30 ft) of reinforcing length to each one. The number of micropiles installed was directly related to cross-section stability for rock conditions and water inflow, and thus this number was decreased or increased to cover tunnel arches and walls of the top heading as required. Steel arches and lagging installations were mandatory under these circumstances, as the micropile umbrellas needed a complementary support as tunnel excavation progressed.

Machinery used for excavation and primary support. Excavation of the running tunnel was done efficiently with great-performance machines, which reduced work cycle times and allowed for excavation production rates for the top heading section of more than 9 m (30 ft) long per 24-hour work day, when geological conditions were fair. This equipment is as follows:

- Three-boom, electro–hydraulic jumbo for drilling.
- Electro-hydraulic, self-propelled mobile concrete sprayer.
- Telehandlers 5 t (5.5 st) capacity and reach till 8 m (26 ft) height.
- Wheel loaders, 16.73 t (18.4 st), 170 hp, 3.10 m^3 (33.3 sq ft) bucket.
- Hydraulic excavator, 30.5 t (33.6 st) with hydraulic hammer.
- Backhoe loaders of 6.79 t (7.5 st), 74 hp, 0.73 m^3 (7.8 sq ft) bucket.
- Extraction of excavated rock was carried out with many dump trucks, 14 to 16 m^3 (150 to 172 sq ft) capacity, owned by members of the local union.

Geological and geotechnical conditions encountered during construction. The previous geological and geotechnical works consisting of direct and indirect exploration carried out for the executive project, were not enough for a proper evaluation of geological-geotechnical conditions on rock formations where the tunnel alignment was located.

Good practice in engineering recommends having sample recovery borings along the tunnel alignment at distances between 150 m and 300 m (492 and 984 ft) for a tunnel in rock with fair conditions, which means

FIG.6A

Geotechnical conditions in accordance to the executive project Acapulco's Alternate Roadway Project.

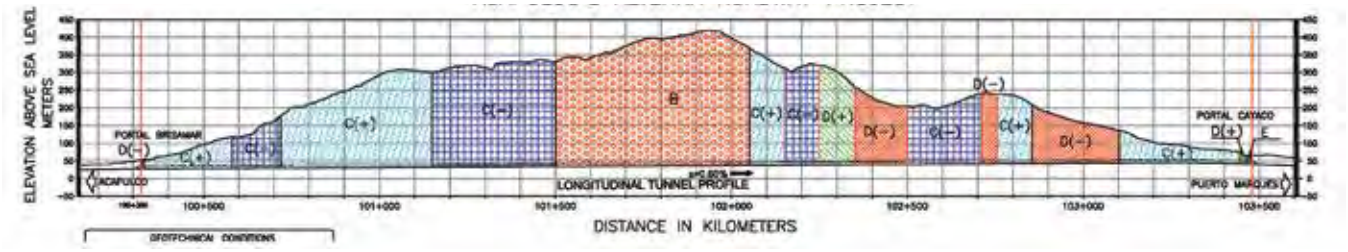
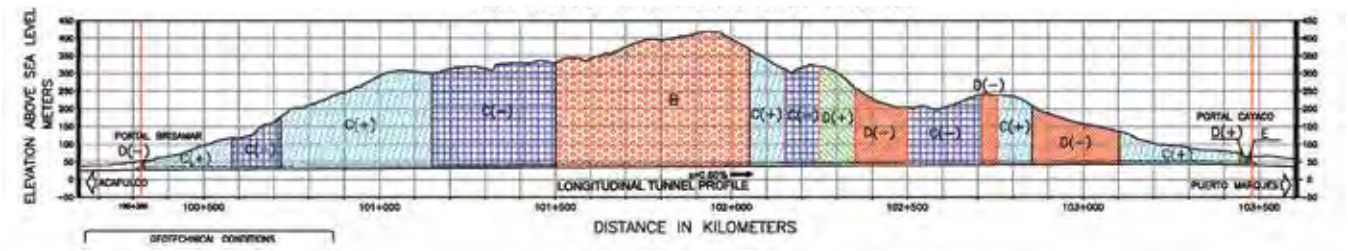


FIG.6B

Actual geotechnical conditions encountered.



that in this case it was at least necessary to have 16 borings for direct exploration, complemented by geophysical borings for exploration to 300 m (984 ft) depth. Instead only seven direct sample recovery borings were made.

This article presents the longitudinal tunnel profiles that show the differences between the real rock conditions encountered in comparison with the rock conditions predicted by the executive project (Figs. 6a and 6b). Figure 6b is the result of a very close follow up to geological-geotechnical reports that were taken every day as tunnel excavation progressed by both portals. The most remarkable difference is a very bad to bad rock condition encountered in the first 465 m (1,525 ft) of the tunnel starting from Brisamar Portal, when the executive project indicated a regular-quality rock formation.

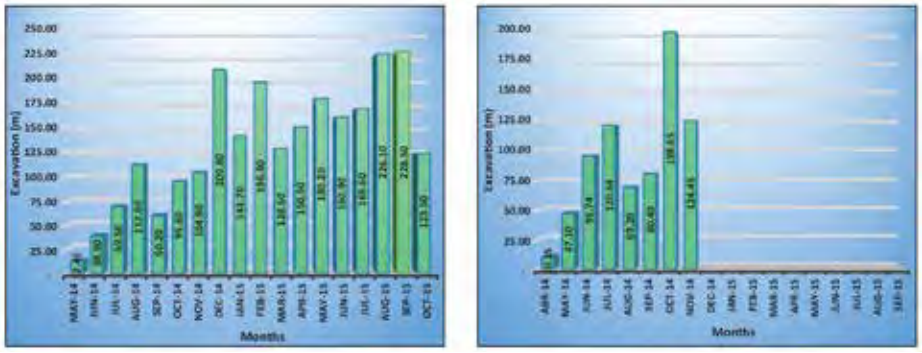
In this stretch, some cave-ins happened when there was an omission to install micropile umbrellas at places where rock fractures presented an unfavorable angle, allowing rock wedges to destabilize the tunnel section.

For the remaining length of the stretch, the real conditions of the rock formations in comparison to the ones indicated by the executive project, were also quite different, as can be seen in the comparison chart.

It is suitable to mention that, since the beginning of the work, several approaches were made to complement the geological-geotechnical exploration that was missing. However, this attempt was not successful.

FIG.7

Monthly tunnel excavation progress at the top heading of section by Brisamar portal (L) and monthly tunnel excavation progress at the top heading section by Cayaco portal.



Progress accomplished during tunnel construction

Figure 7 shows the monthly progress for the tunnel excavation at the top heading section by both portals, underlying a good production achievement for several months, to get 230 m (754 ft) maximum for a single heading, once most of the problems that arose during the start of the work were solved.

Descriptions of details found during tunnel excavation for each portal are given in the following section.

Tunnel excavation by Cayaco portal. Tunnel excavation by Cayaco Portal started on April 17, 2014, through a medium hardness metamorphic rock. Two micropile umbrellas, 12-m (40-ft) long were installed as indicated by the executive project, with steel arches separated 1 m (3 ft) from each other. On June 23, 2014, after 114.45 m (375 ft) of tunnel excavation, the first cave-in event occurred suddenly after a blasting execution, due to the presence of unfavorably wedging formations in the arch of the top heading section. The blasted section length was 3.4 m (11.2 ft). Seepage water ran throughout fractures of the wedging rock. The time taken to surpass this event was seven days, after placing steel fiber shotcrete to stabilize sliding wedges, the installation of 13 steel arches and scaffolding formwork covering the entire area, and the pumping of hydraulic concrete to fill most of the volume left by the cave in event, which was close to 450 m^3 (588 cu yd) After 120 m (390 ft) of tunnel excavation, there was another cave-in of minor proportions, due to similar rock wedging problems and water leakage. Steel fiber shotcrete and seven steel arches were installed, and formwork scaffolding and concrete were pumped for support of the area affected. As tunnel excavation progressed and regular to bad rock conditions were encountered, it was necessary to keep installing steel arches and steel fiber shotcrete, facing one more event of minor problems by fractured rock and water leakage. However, it is very important to say that production daily rates increased significantly as tunnel-worker skills and coordination improved.

Unfortunately, on Nov. 19, 2014 tunnel works were suspended at Cayaco Portal, because of social problems between the state government and former land owners, after a tunnel length of 746.3 m (2,450 ft) had been reached. Under these circumstances there was only one way to make the tunnel connection, which was through the Brisamar Portal.

Tunnel excavation by Brisamar Portal. Tunnel excavation by Brisamar Portal began on May 17, 2014 through very weathered granite formations and water leakage. These rock formations were classified as very bad to bad quality, in accordance to the geological-geotechnical conditions found. The construction method for the first 465 m (1,525 ft) of tunnel required systematic installation of micropile umbrellas, steel arches separated

FIG.8

Tunnel breakthrough on Oct. 27, 2015 by Brisamar Portal. It concludes tunnel excavation at the top heading section.

between 1 and 1.5 m (3 and 5 ft) and a shotcrete layer 20 cm (7.8 in.) thick for primary support. Drill-and-blast operations were only partially used for excavation of the cross-section as mechanical excavation employing excavator and hydraulic hammer was necessary for tunnel stability reasons at the top heading.

Production rates achieved for tunnel excavation after the first 465 m (1,525 ft) improved as the rock conditions upgraded to fair condition, although several areas with bad rock were found, where some small cave-ins occurred in association with the presence of water leakage. The environmental conditions inside the tunnel began to be a problem, as ventilation calculations for the additional length of tunnel by Brisamar Portal had not been adjusted. The problem was solved by replacing the whole ventilation system with more powerful and better-suited fans, and ducting to the actual conditions of the work.

It is important to mention that some important water inflows were found at this heading and the overall flow was close to 30 L/s. Fortunately, rock conditions had improved and there was not a potential stability problem, as drilling and hoses were used to conduct all water inflow.

Tunnel excavation by Brisamar Portal was successfully finished on Oct. 27, 2015, making the breakthrough with the tunnel stretch that had been excavated by Cayaco Portal (Fig. 8).

Special considerations for work at the Brisamar Portal

Taking into consideration that the Brisamar Portal is located at one side of Joyas de Brisamar, a private high-class residential development within an urban area, it was of high priority and importance to minimize the construction impact on buildings and especially the life quality of residents. It was mandatory to take special measures to reduce all noise of drilling and blasting, as well as to buffer the effects of vibrations caused by blasting. The task was not easy, because residents reacted quickly to oppose the execution of the work, to the extent that legal action was taken and work was suspended on a judge's order. The relationship with representatives of the residents of Joyas de Brisamar was often strained and with many complaints. After several meetings, the following measures were taken:

1. Blasting was not allowed during night shifts.
2. Electronic detonators were used to reduce noise blasting and detonating cord was not used.
3. The use of low explosives for tunnel excavation for the first 500 m (1,640 ft) was restricted below the zone of influence of the houses and buildings. Only high explosives were used.
4. Neighbors were kept informed about blasting times through written notes delivered to the Joyas de Brisamar administration and use of a siren system to alert prior to the execution of any blasting.

Thanks to these measures, the buildings located within the radius of influence of blasting suffered only minor cracks and/or damage. Vibration and noise were satisfactorily controlled within allowable limits.

Construction procedure for tunnel lining

Geometric sections of the final lining for the running tunnel section and bay section are shown in Figs. 1 and 2, appreciating the thicknesses of hydraulic concrete and reinforcing steel, as indicated by the executive project. These thicknesses correspond to theoretical sections of excavation, because actual thicknesses are based on geological rock conditions and measures taken to avoid over excavation and cave-ins during the stage of excavation.

Pouring the final lining of hydraulic concrete was originally planned using two monolithic and collapsible

steel forms, 15 m (50 ft) long. Each piece was supplemented with two steel form sections for the bays (Fig. 9), designed exclusively for the ceiling and walls; one for each portal, as well as several modular sections of metal formwork for curve, walkway and a starting short wall section where the tunnel formwork overlaps.

With activities having been suspended by Cayaco Portal, the program related to the tunnel lining was fitted to the actual conditions of the work schedule, so both monolithic steel forms were armed and introduced by Brisamar Portal.

FIG.9

Final lining construction activities at a bay area. The steel form has been assembled.

Activities for pouring concrete in curves and walkways began on March 9, 2015 by Brisamar Portal, and activities for pouring concrete at the tunnel upper section and walls continued until June 19, 2015. Due to logistical issues related to the activities for reinforcing steel-bars installation, a geotextile liner combined with a water proofing geomembrane was fixed to the shotcrete primary lining.

It is important to emphasize the simplicity in the design of the steel formwork for concrete pouring in the bay areas, manufactured by a Mexican company recognized for its technology and ingenious design, making an easy fitting of both steel forms (running tunnel and bay).

Conclusions

Tunnel construction within an urban area has faced several special situations, due to the systematic use of explosives. However, the excavation was successfully completed and there is no doubt that it will bring great benefits to the people of Acapulco. National and international visitors will enjoy the benefits too.

The use of the electronic initiators for blasting operations was a successful measure for a substantial reduction of noise and vibrations.

The geological monitoring carried out in each blast was very useful for determining corrective actions required to be applied at subsequent blasts.

The work highlights the importance of adequate planning of prior geological-geotechnical studies, as well as of its magnitude and scope, in such a way that the executive project gets all the elements for the proper design of the primary tunnel support, and the best tools possible to avoid uncertainties during tunneling construction.

Micropile umbrellas were shown to be a good tool of support for safer and faster tunnel excavation when facing bad to very bad rock conditions.

All facts mentioned have led to an excellent step further in training young Mexican engineers and skilled workers, to continue building the great tunneling projects that Mexico needs, with Mexican contractors specialized in tunneling and underground works.

The average advance rates in linear meters of excavated tunnel, made in combination with good coordination, fair to good rock conditions, high-production equipment and specialized machinery are very significant, close to 230 m (754 ft) per month for a single tunnel heading,

Excellent ventilation and preservation of good environmental conditions inside the tunnel must be the starting point for the selection of the equipment that will be used in these tasks, thus ensuring the safety, health and efficiency of the engineers, technical workers and technical staff that work in underground projects. ■

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FEATURE ARTICLE

Sequential Excavation Method with ground freezing for DC Water's First Street Tunnel

DC Water's First Street Tunnel (FST) is part of the $2.6 billion Clean Rivers Project designed to reduce the occurrence of combined sewer overflows into local waterways. Due to flood events in the Bloomingdale and LeDroit Park neighborhoods, the FST Project was accelerated by DC Water to mitigate future flooding by boosting storage capacity and thus relieving the undersized combined sewers.

The FST Project was finalized in 2016 as a collaborative effort between DC Water, its consulting team consisting of Greeley & Hansen and McMillen Jacobs Associates, and the design-build team of Skanska, Jay Dee Contractors (SKJD) with WSP Parsons Brinckerhoff as the designer.

Scope of project. The FST Project (Fig. 1) included four primary shaft sites, a large 6 m (20 ft) internal diameter, 823-m (2,700-ft) long bored tunnel and three adit connections from the off-line shafts to the large-diameter tunnel. The adits which vary in size and length, are the subject of this article. The Channing Street site (Fig. 2) was established as the main site for an Earth pressure balance tunnel boring machine (TBM) and included a 49-m (160-ft) deep shaft with slurry wall support of excavation and 20-m (65-ft) internal diameter final cast-in-place permanent concrete liner. The construction sites at Adams Street, V Street and Thomas Street each consisted of off-line shaft structures tied to near-surface sewer diversion chambers and ventilation facilities. These three off-line shafts were connected to the large bored TBM tunnel via adit tunnels. Each of the three adits had a portion or the entire length excavated by sequential excavation method (SEM) in frozen ground.

The Adams Street adit (Fig. 3) was constructed in two phases. The first phase is the 23-m (75-ft) long and 5-m (16-ft) diameter section immediately outside the drop shaft which also serves as the de-aeration chamber and was excavated by SEM. The second phase which is 91 m (300 ft) long and 3 m (10 ft) in diameter was excavated by Micro TBM

Ivan Hee, William Bracken, Harald Cordes and Stephen Njoloma

Ivan Hee and **William Bracken**, members UCA of SME, are engineer and project manager, Skanska USA Civil; **Harald Cordes**, member SME, is engineering manager, WSP and **Stephen Njoloma**, is member SME, is lead associate, McMillen Jacobs, email ivan.hee@skanska.com.

FIG. 1

Project overview.

FIG.2

Channing Street site overview.

FIG.3

Adams Street site (note freeze pipes).

(MTBM) launched from within the permanently lined deaeration chamber. MTBM excavation commenced toward a reception chamber that was excavated by SEM from the previously bored FST TBM tunnel. This SEM excavation had a 5 m (17 ft) diameter and a length of 4.5 m (15 ft).

The V Street adit was the largest SEM excavation of the FST Project and included a 6 m (20 ft) diameter, 21 m (70 ft) long SEM tunnel. This SEM tunnel was excavated with a 24 m (80 ft) radius curve from the 33 ft (110 ft) deep drop shaft toward the previously bored TBM tunnel. The reference design by DC Water initially included a straight alignment that was revised by the design-build team to a constant curve to avoid passing beneath a residential property and to allow the utilization of vertical ground freezing for both the SEM excavation and the deep Near Surface Structure excavation above.

The Pumping Station adit at Thomas Street had an excavation diameter of 4 m (13 ft). The 15-m (50-ft) long SEM tunnel was excavated from a 27 m (90 ft) deep shaft that will function as the temporary Pumping Station until the adjacent Northeast Boundary Tunnel connects the FST to the Clean Rivers Project.

Ground conditions. Ground conditions along the FST alignment consisted of an upper layer of recent fill, followed by Quaternary Alluvium, Cretaceous Potomac Group above Bedrock.

The Potomac Group was previously overlain by several hundred feet of soil deposits that were later eroded away and fine-grained cohesive soils are hard and over-consolidated. The coarse-grained cohesion-less soils are dense to very dense. The upper portion of the Potomac Group consists of Patapsco/Arundel Formation with transitional layers of fine-grained soils with high plasticity (G1) and lower plasticity (G2). SEM excavation was fully located in the lower portion of the Potomac Group, and consisted of the Patuxent Formation which included predominantly non plastic silty or clayed sand (G3A) or non plastic silty or clayed gravel (G3B). These G3 subgroups are distinguished from each other solely on the basis of whether the sand or the gravel fraction has the higher percentage in the particle size analysis. The G3 soil group within the Patuxent Formation is transitional interlayered with G1 and G2 clay, fine to coarse sand with traces of gravel and fines (G4) and fine to coarse gravel with traces of sand and fines (G5).

A shallow ground water aquifer exists, predominantly in the fill and Quaternary Alluvium. This unconfined alluvial aquifer is generally perched on the confining clay units of the upper Potomac Group of the Patapsco/Arundel Formation. Ground water within the confined water bearing layers and lenses of the lower Potomac Group of the Patuxent Formation exhibit artesian conditions.

All three adits have been excavated predominantly through G3A soils with various amounts and thicknesses of G1 and G2 layers in the face. When unsupported in the excavation, these G3A soils will exhibit fast-raveling to flowing behavior. The G1/G2 clay is prone to slide or fall as discrete blocks or wedges along fissured and slickensided fractures and therefore ground freezing was utilized to stabilize these soils for all three SEM excavations.

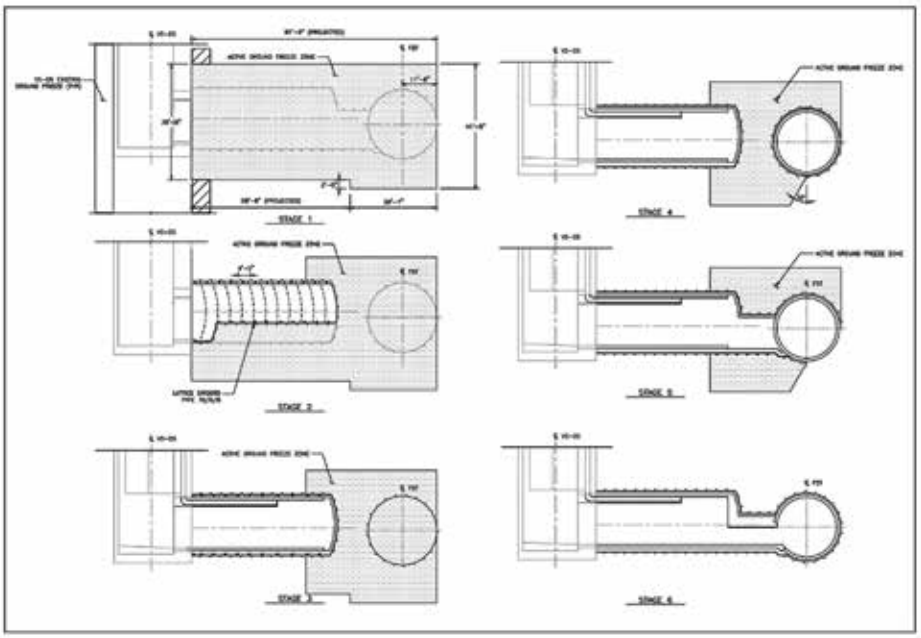
Design and constructions

SEM designs. Due to desired low impact on the urban and historic residential neighborhood and to mitigate risks of SEM excavation in unstable ground under high ground water pressure, ground freezing to temporarily improve the ground was utilized for all three adit excavations.

In a first step, the properties of the freeze body around the excavation were established based on empirical correlation of similar soils with a target temperature of –10 °C (14 °F). With these pre-established frozen ground

FIG.4

V Street adit construction sequence.



properties, the required limits of frozen ground around the SEM excavation were developed with the help of numerical modeling. Initial support for the adits included shotcrete with lattice girder and welded wire mesh. The final liner for the V-Street and Adams Street adits included cast-in-place reinforced concrete and the Pumping Station adit was furnished with a hobas pipe.

In a second step, in order to verify the frozen ground properties derived by empirical correlation, frozen soil testing was performed. Representative split spoon samples from the ground investigation program were selected and recompacted to simulate undisturbed field conditions. Samples were saturated and tested in the laboratory under design target temperatures. A total of three unconfined compression tests and three pulse velocity tests on frozen soil test specimens were performed in accordance with ASTM standards. The test results confirmed previous empirical assumptions with a Young's Modulus of 2,280 ksf to 4,100 ksf, thus finalizing the SEM design.

A freeze pipe layout with vertical and slightly inclined freeze pipes drilled from the surface was generated to provide a required freeze boundary with a target temperature of –10 °C (14 °F). However, since the SEM excavation was cutting through vertical freeze pipes, the numerical model assumed a reduction of frozen ground properties (thawing) while the shotcrete liner was gaining strength at the same time. Information on shotcrete strength gain curves, sprayed on frozen ground, was utilized from previous projects and a trial test was performed prior to and during construction to support and verify the required shotcrete strength.

Brine, as the freeze medium, was circulated via a utility trench to all three sites from the central freeze plant located within the Channing Street site. The brine had an initial temperature of –29 °C (-27 °F) going out and typically returning around –27 °C (-16.6 °F), with a warming of about 2 °C (35 °F). Freeze formation of the three adits, in order to generate the required freeze boundary with pre-defined properties, took between 40 and 60 days and was confirmed via temperature-monitoring pipes with thermocouples at various depth intervals that were read automatically.

Convergence monitoring in the SEM excavation was installed to verify proposed excavation length and initial support measures to allow possible adjustments during excavation.

V Street adit construction. The V Street adit (VS-A), which was the largest of the headings to be excavated, was the first adit to be constructed. The drop shaft size limited the equipment selection due to size constraints. The physical constraints required that the adit be excavated with a heading and bench excavation (Fig. 4). The top heading cross section was excavated at a 4.2 m (14 ft) height for the full length of the adit. Once the shotcrete initial liner was installed, the bench was excavated to the full 6 m (20 ft) cross section.

Vertical freeze pipes were installed to accelerate the overall schedule of adit construction, as well as facilitating ground support for the North Capital Street Diversion Chamber, directly above the adit that was being excavated concurrently with adit construction. The vertical freeze pipes were activated as the final liner of the drop shaft was being constructed. This saved more than six weeks of schedule as the freeze was able to be developed during the lining process. Excavation of the adit began as soon as the cast-in-place liner of the 7 m (23 ft) diameter V Street Drop Shaft was complete. The SEM was developed for the first 2.2 m (7.5 ft) using a Brokk 400 electric demolition robot with an Atlas Copco SB552 hydraulic hammer. The first two lattice girder arch sections were installed and shotcreted to full lining thickness. The excavation duration in the top heading dictated that the freeze pipes be re-established both on the crown and in the bench excavation to maintain the freeze temperatures (Fig. 5). A separate glycol freeze unit was set up onsite and a header was installed down the shaft into the adit. Each invert freeze pipe was hooked into this header once it was cut out of the top heading cross section (Fig. 6).

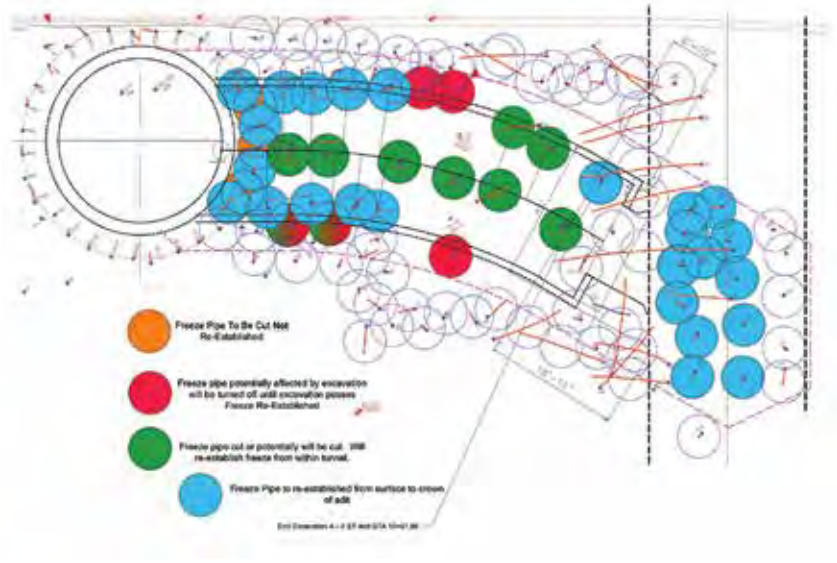
Once the initial heading was developed with the Brokk 400, an Antraquip AQM 150 roadheader was selected for

excavation of the remainder of the adit. A skidsteer was used to tram the muck from the conveyor to the shaft. Excavation progressed by excavating 1.2 m (4 ft) of total cross section, installing the lattice girder, wire mesh and shotcrete. Both dry and wet shotcrete were tested and approved for use in the adits, but due to low sprayed shotcrete quantities and advantages in timely supply, dry shotcrete was selected for the initial support. The small size of the site and concurrent excavations on the site dictated that the shotcrete setup had to be set up and torn down each shotcrete cycle. Quickcrete 5,000 psi shotcrete was the supplied mix with 3 percent dry accelerator premixed into the super sacks. A silo and Putzmeister GM 060 were used for the shotcrete plant.

Construction of the adit's top heading excavation used a Meyco Oruga shotcrete robot that was modified with a dry shotcrete nozzle. Due to the surface area and height of the heading, spraying with the robot was more safe and efficient as the nozzleman did not have to stand under the shotcrete as it was being sprayed. A temporary concrete invert was placed with the skidsteer to protect the bench frozen ground. This was completed before the shotcrete was applied. The adit was excavated to within 5 ft of the First Street Tunnel (FST). The tunnel was not constructed by the time the excavation of the adit was complete. A shotcrete bulkhead with wire mesh was installed until the FST tie in was made. The bench was excavated in 2.4 m (8 ft) advances with a Brokk 400 diesel demolition robot. As the re-established invert freeze pipes were encountered, each pipe was removed and backfilled. At each 2.4 m (8 ft) advance, the lattice girders from the top heading were completed through the invert. Wire mesh and shotcrete were applied to complete the initial support (Fig. 7).

FIG.5

V Street adit freeze pipe layout.



Adams Street adit construction. The Adams Street adit (AS-A) was excavated concurrently with the bench excavation for the V Street adit and the Pumping Station adit SEM excavation. The Brokk 400 electric demolition robot was used to develop the first 2.2 m (7.5 ft) of heading similar to the V Street adit. The cross section of the Adams

FIG.6

Re-establishment of invert freeze at V Street Adit.

FIG.7

Completed excavation of V Street Adit.

FIG.8

Permanent liner construction at Adams Street Adit.

FIG.9

Shotcrete application by hand.

Street adit allowed for full-face SEM excavation. The Antraquip AQM 150 Roadheader was used to excavate the deaeration section of the adit. Mucking was done by a 2 cy muckbox on light gage rail. Excavation was advanced in 1.2 m (4 ft) sets. Each set would allow for installation of lattice girder, wire mesh and shotcrete. Due to limited space, a shotcrete robot could not be utilized and shotcrete was applied by hand in this excavation. Once the adit was excavated to the end station of the deaeration chamber a shotcrete bulkhead with wire mesh was installed to allow for construction of the cast-in-place lining (Fig. 8).

Pumping Station adit construction. The Pumping Station adit (PS-A) was excavated in full face with a Brokk 400 electric demolition robot with hydraulic breaker. Muck was removed by skidsteer from the heading to the shaft. The 3.6 m (12 ft) excavation was excavated in 1.2 m (4 ft) advances. Each advance allowed for lattice girder, mesh and shotcrete installation. Shotcrete was applied by hand for this heading (Fig. 9). Similar to the other headings the adit excavation was completed before the FST tunnel was mined. A shotcrete bulkhead with wire mesh was installed 1.5 m (5 ft) from the FST. The adit was then lined with a 2.4-m (96-in.) Hobas pipe and grouted.

Adit connections to First Street Tunnel. As the TBM excavated the FST, each location of the adit tie-in was blanketed with a surface freeze loop on the concrete segments and a series of invert freeze pipes were drilled and installed through the precast segmental liner from within the FST to allow for continuance of freeze and water cutoff at the invert of the adit tie in. This was work done on nonproduction shifts during mining of FST. Additionally, the aluminum freeze pipes that were cut while the TBM advanced were sleeved to the surface and reestablished to maintain the freeze block at the tie-in location at the crown and springline of the FST. Once the TBM was decommissioned and buried in place at the tunnel termination, a steel propping ring assembly was installed at each adit tie in location. The segments were then saw cut and removed in the cross section of the excavation. The SEM excavation at the Pumping Station adit (Fig. 10) and V Street adit were tied into the adits that were constructed from the drop shafts. Each were 1.2 m (4 ft) advances with lattice girders, wire mesh and shotcrete. The Adams Street adit connection was excavated by the same method but was terminated 4.5 m (15 ft) from the FST springline to provide enough space to receive the MTBM within the reception chamber (Fig. 11). A shotcrete bulkhead was constructed for the MTBM reception chamber. Once the cast-in-place tie-ins were constructed, the invert and surface freeze pipes were removed from service.

Lessons learned

Overall, the freezing process and SEM excavation worked out very well, with stable ground for both shaft and adit excavations (Fig. 12). Maintenance of freeze was achieved with resleeving cut freeze pipes (either by TBM or SEM excavation) from the top with a smaller diameter pipe and reestablishment of brine flow. A couple of freeze pipes were punctured by excavation equipment, but shut off valves enabled system isolation which enabled freezing to be maintained in other sites while repairs were made. Overall, aluminum pipes were easily mined through by the TBM. Due to concerns of warming in the invert zone once the TBM passed through, additional freeze pipes were successfully installed by drilling through the precast segmental lining to maintain the invert freeze which was not able to be reached by the resleeving from the top.

There was a learning curve in shotcrete operations. The pumping station shaft SOE was selected as a field trial location to spray the shotcrete on exposed frozen ground. The shotcrete was then cored at the required time after application in order to determine and verify actual shotcrete

FIG.10

Breaking out from First Street Tunnel with Brokk.

FIG.11

MTBM reception chamber excavation.

strength grain on frozen ground under field conditions. Nozzleman testing and certification was done in the frozen shaft, enabling the nozzleman to practice shooting on frozen ground. Utilization of premixed dry shotcrete that already included 3 percent accelerator was very beneficial to eliminate an additional step during shotcrete application and to avoid any over dosage. During placement, the heat of hydration of shotcrete coupled with frozen ground caused thick fog to develop and limited visibility of the shotcrete nozzleman, thus causing high rebound. Increased ventilation and blow-in exhaust proved to be sufficient in clearing the fog. The design for the initial support of shotcrete allowed for 50 mm (2 in.) of sacrificial shotcrete that was not required for the full design loads. This sacrificial layer insulated the remainder of the shotcrete layer from contact with the frozen ground and maintained the heat of hydration for the initial 152 mm (6 in.) pass of shotcrete.

The sizes of the drop shafts were the main factor in the selection of equipment for SEM operations. Due to the multiple heading sizes, choosing a single piece of equipment that could satisfy the size constraints of the shaft as well as heading size took collaboration with the equipment suppliers. Antraquip Corp. was selected to provide the roadheader (Fig. 13) for excavation of the headings. A modified Antraquip AQM 150 was utilized which used a AQM 150 turret, boom and transmission assembly mounted to an AQM 100 body which allowed for installation in the smaller diameter shafts and allowed full reach of the machine for the SEM headings. Other modifications were made to accommodate the unusual

FIG.12

Stable face of frozen ground.

FIG.13

Road header excavation.

conditions caused by the freeze in the roadheader's cooling system, electrical and hydraulic system.

Due to scheduling constraints, all three headings were excavated concurrently at a certain phase of the schedule. The Brokk 400 demolition robot was used due to its nimbleness and small footprint from within the shafts. The unit was able to reach the full height of the headings and muck during the initial development of the portal in each heading. The Brokk 400 was used to completely excavate the Pumping Station adit which had the least effect on the schedule. Due to removal for mucking this was the most inefficient of the mucking cycles. The V Street adit bench excavation utilized a Brokk 400 diesel demolition robot which sat on the bench and chipped material into the bucket of a skidsteer at the toe of the bench. In general, the headings cycled roughly 2 to 2.5 cycles/week which included mobilization and demobilization of the shotcrete plant for each cycle.

The adit tie-ins were excavated with the Brokk 400 Diesel demolition robot due to the necessity to move within each adit location in the tunnel. The machine was able to tram itself to the subsequent adit tie-in once excavation was complete. Both the roadheader and Brokk 400 proved to be good and suitable equipment in the abrasive sand and gravel frozen ground. Roadheader teeth were checked after every round, and worn teeth were replaced. Selected equipment was suitable for the sizes of SEM excavation and confined space.

Convergence monitoring in the adit excavations showed very little to no deformation in the excavation and stayed well below the normal predicted convergences of 10.6 mm (0.4 in.) in the design. This verified that the design parameters for the frozen ground were prudently selected. Excavation at the face and within the unsupported section prior to shotcrete application was stable at all times and allowed application of shotcrete initial support the following day.

All adits were constructed at locations with existing structures and utilities in close proximity. These structures had to be monitored for potential movements due to both ground deformations due to the adit excavation and the freeze-related heave and/or settlement. Because of the difficulty in accurately estimating freeze-related heave and/or settlements it is important to have a robust and proactive instrumentation and monitoring program. There is need for close coordination between the freeze designers and the instrumentation team to allow for early mobilization of mitigation actions when excessive freeze-related movements are observed. There were several successful mitigations to counter impacts of heave on adjacent utilities that included installation of heat trace rows to counter the growth of the ground freeze body. The success of these types of measures is dependent on proactive monitoring. Furthermore, the selection and locations of ground monitoring equipment should consider the frozen mass. For example, an inclinometer will not be responsive to excavation related ground deformation if it is installed within a mass that eventually freezes. Our recommendation for adit instrumentation is to have beyond SEM monitoring a plan that addresses the effects of ground freezing and installation of heat pipes at critical utilities such that freeze mitigation measures can be implemented immediately as necessary.

Summary

Ground freezing proved to be a good solution for ground improvement of SEM excavation for the FST project. This low-impact and less intrusive method of ground improvement enabled SKJD to adhere to the strict contract working hours of 7 am to 7 pm. The stable ground created by ground freezing enabled efficient use of the limited working hours. A significant benefit that ground freezing provides during the SEM mining cycle is the flexibility in stand-up time. For example, during the week work days, partially excavated ground could be left by covering with blankets at the end of the day, without the need for temporary support, such as a flash coat of shotcrete. This is unlike other ground improvement techniques, where temporary support needed to be installed before leaving for the day or in some instances, the requirement of round-the-clock construction. Re-establishment of freeze pipes was considered a more critical SEM construction factor than partially completing the initial support and ground freezing allowed for this flexibility in the sequence of construction.■

Coming Events

2018 North American Tunneling Conference (NAT)
June 24-26, 2018
Washington Marriott Wardman Park
2660 Woodley Road NW, Washington, DC

2018 Cutting Edge
October 28-31 2018
Loews Atlanta Hotel
1065 Peachtree St. NW
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FEATURE ARTICLE

More than 350 attend George A. Fox Conference in New York

Replacing the century old rail tunnels that run beneath the Hudson River and carry about 200,000 passengers per day between New York to New Jersey has been a high priority for many years. But after Superstorm Sandy hit the east coast of the United States in 2012, the urgency to replace the tunnels increased dramatically.

The Hudson Tunnels project is one of nine projects that make up the larger $30 billion Gateway Project. The Gateway Project has been called the most urgent infrastructure program in the country and the Hudson Tunnels is the most critical part of the project, as it will build a new rail tunnel under the Hudson River and rebuild the existing and deteriorating North River Tunnel that connects New York and New Jersey.

"Superstorm Sandy proved the level of resiliency of the tunnels, which was not very good," Amtrak deputy chief engineer structures James Richter told attendees of the George A. Fox Conference in New York City on Jan. 23. Age and corrosive salts deposited by flood waters from the storm in 2012 have affected interior concrete and copper wiring in the tunnels. "Since then, things have been deteriorating and getting less reliable."

Richter, along with Mohammed Nasim, senior director engineering design, both with Amtrak, spoke at the 2018 George A. Fox Conference where more than 350 tunneling and underground construction professionals attended the conference at the Graduate Center of the City University if New York to share insights about the complexities many of them face on daily basis.

Under the theme of "Managing construction of complex underground projects: Strategies for tunneling in populated areas," the one-day conference featured presentations from some of the top minds in the tunneling and underground construction industry. The presentations touched on everything from the highly technical challenges of constructing tunnels through changing geology while working beneath cities and rivers, to navigating the complex financial issues and contracts that come with the projects that have many stakeholders.

All of those challenges, and more are part of the Hudson Tunnels project. It is one of the best examples of the full complexities of a complex tunnel project, with the added pressure of securing funding from state and federal government entities under an increasingly tight deadline.

More than 350 people attended the 2018 Fox Confefrence in New York.

The addition of new tunnels beneath the Hudson River was part of plan in 2010 to replace the 100-year old tunnels currently being used. That project was cancelled in 2010 by then New Jersey Gov. Chris Christie in a funding dispute.

If just one of the tunnels is taken out of service for repairs it has devestating consequences on the region that supports about 10 percent of the nation's gross domestic product.

While there is a consensus that the project is desperately needed, funding for the project has recently become more complex.

In President Donald Trump's proposed budget for 2018 released on Feb. 12, the White House envisions $1.5 trillion in infrastructure spending over the next 10 years. However, only $200 billion would be direct federal spending aimed at leveraging state and local dollars.

The Associated Press reported that state and local governments would be able to use the federal money for up to 20 percent of their project's cost, which is vastly different from the model state and local officials supporting the Hudson tunnel project have relied upon.

Their estimates have been based on a 50/50

agreement, reached with President Barack Obama, that would have the states and federal government splitting the cost for the larger Gateway project.

Even before the draft budget was released, things did not look good. A letter from the Federal Government on Dec. 31, 2017 cast doubt over the funding of the project. According to the *New York Times,* a letter from K. Jane Williams, the acting administrator of the Federal Transit Administration, scuttled a funding agreement for the first phase of the project, which was estimated to cost about $11 billion. Amtrak and the states of New York and New Jersey had hoped that the federal government would cover half of that cost, but a Trump administration official disputed that notion, calling any such agreement "nonexistent."

Another issue, far away from the challenges beneath the river or tunneling through rip rap rock that has been in place for 100 years, is a 2012 law that threatens to hold up funding. The *USA Today* reported that "both states (New York and New Jersey) must obtain certification by April 15, 2019 for their State Safety Oversight programs, which Congress required in a 2012 transportation bill to prevent and mitigate accidents on rail transit systems. Both states now remain short of achieving that goal.

If they fail to meet the deadline, they would be ineligible to not only receive money for the tunnel, but they also would forfeit hundreds of millions of dollars in federal transportation money annually to support their transit systems."

If the current tunnel fails, hundreds of thousands of commuters would be stranded from their jobs, causing a multi-billion dollar debacle for workers and the companies that employ them, said Kathryn Wylde, president of the Partnership for New York City, a civic association comprised of chief executives of some of the city's largest companies.

The Trans Hudson Tunnels project, Richter said, will improve reliability to double the capacity in the region, by adding redundancy and resiliency to the tunnels while maintaining uninterrupted commuter rail service between New Jersey and New York and intercity Northeast Corridor rail service. According to New Jersey Transit, "The project addresses a specific need related to deterioration of the North River Tunnel. When completed, the project will address a critical infrastructure need, will also strengthen the resilience of the Northeast Corridor to provide reliable service by providing redundant capability at the critical Hudson River crossing, and will help to facilitate a future expansion of rail capacity between New York and New Jersey. However, while the Hudson Tunnel Project addresses maintenance and resilience of the Northeast Corridor Hudson River crossing, it will not directly increase rail capacity. Ultimately, an increase in peak period service between Newark Penn Station and Penn Station New York cannot be realized until other substantial infrastructure capacity improvements are built in addition to a new Hudson River rail tunnel."

Estimated completion date for the project is 2026 and the rehabilitated tunnel will open in 2030. During the new tunnel's creation, the current one will remain open.

The Hudson project was just one of many that were talked about at the conference.

"The conference focused on the challenges faced by owners, designers and contractors with projects of various complexities," said conference chairman Frank Arland. "The Keynote presentation kicked-off the conference and provided attendees insight from Giuseppe Quarta, chief executive officer for the consortium that managed the design and construction of the Panama Canal Expansion, constructed to accommodate the larger size Panamax ships. Of interest is that approximately 3 percent of the world's maritime commerce moves through the canal. Construction required about 74 Mm^3 (2.6 billion cu ft) of excavation and placement of over 5 Mm^3 (176 million cu ft) of concrete which is illustrates the scale of this massive project."

That projected was completed in June of 2016 and not only was it an extremely challenging engineering feat, it was a job that included as many as 11,000 workers. Quarta spoke of the construction accomplishments and the challenges of keeping people out of harm's way on such a large project.

Thilo Tecklenburg, chief operating officer, North America for Meridam spoke about financing complex infrastructure projects. The rise of PPP projects has lessened the risk for owners, contractors and other stakeholders, but it has added complexity. Techkenburg spoke about the how risks are shared between public sector partners and private sector partners and said "each risk should be allocated to the party that is best able to handle it.

Another massive project that was talked about is the Brenner Base Tunnel, in fact, it is the largest rail tunnel in the world at 40 miles long, connecting Italy and Austria beneath the Brenner Pass, a trading route that dates back centuries. At the Fox Conference, Gerhard Urshitz provided an update on the project.

Industry update

2017 was an eventful year in the tunneling industry. Bertha finished its work on the SR-99 project in Seattle, Phase 1 of the Second Ave. Subway in New York was completed, Jacobs acquired CH2M to create a $15 billion professional services firm and Elon Musk grabbed headlines with his foray into the industry with the Boring Company. Jim Rush, editor of *Tunnel Business Magazine* provided the always popular Tunnel Industry Update. He covered the highlights of 2017, talked about ongoing projects like the East Side Access project and finished with a look at upcoming projects such as Phase 2 of the Second Ave. Subway and California's Water Fix project and high speed rail project. ■

T&UC

Business Profiles

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March 2018

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JENNMAR Civil is dedicated to providing products and services to the Civil Construction and Tunneling industries. Products include various types of rock support bolts, anchoring systems and resins to support tunneling, geotechnical, foundation and earth retention projects.

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Delivering liquid nitrogen to the Port Mann off-shore working platform.

Port Mann Water Main: Ground Freezing
Mining of the new, 3,280-ft long Port Mann Water Main was well underway deep below the Fraser River in Vancouver, British Columbia, when an unanticipated mechanical failure occurred in the cutter head, halting mining operations. When initial more conventional approaches to allow access for repair were ruled out, the tunneling contractor contacted Moretrench. Moretrench developed a liquid nitrogen ground freezing solution that would not only allow safe access for inspection and repair but could also be implemented quickly. The remote TBM location, 160 ft below river mud line and 650 feet from the exit shaft, meant that all equipment and materials, including liquid nitrogen storage tanks, had to be ferried to the pile-supported work platform. Pinpoint drilling for freeze pipe installation was critical to ensure freeze build up exactly as designed. After just 12 days of freezing, the freeze was sufficiently formed to allow safe entry into the cutter head for repairs to begin.

High mobility grouting of karstic rock enabled dry excavation of the OARS CSO shafts.

OARS Relief Sewer Phase 2 Shafts: High Mobility Grouting
Drill and blast installation of three deep shafts through highly variable karstic conditions was the challenge facing the design and construction teams for Phase 2 of the CSO project in Columbus, OH. The shafts extended through shale underlain by three distinct strata of karstic limestone. With the water table 20 ft below the surface, and the high hydraulic conductivity of the rock evident from pumping tests, it was estimated that inflows of thousands of gallons per minute could be anticipated during shaft excavation under hydrostatic head of up to 150 ft. Pre-grouting was therefore required. A Moretrench-designed alternate to the original in-shaft staged grouting plan allowed all grouting to be accomplished around the shaft perimeter from the surface. A suite of four, balanced-stable grouts developed by Moretrench catered to the highly variable subsurface conditions. With grouting complete, excavation proceeded with only minimal shaft inflow.

Jet grout cut-off for installation of the Mulry Square vent plant.

Mulry Square Vent Plant: Jet Grouting:
The Mulry Square emergency vent plant is designed to serve a portion of both the 8th and 7th Avenue subway lines in Manhattan, New York. With offsite groundwater drawdown during construction prohibited, a perimeter cut-off was required. This was designed as secant pile walls, with jet grouting specified for closure where the vent plant penetrated the wall of the subway tunnel. Groundwater modeling by Moretrench demonstrated that the jet grouting would need to extend only to a minimum depth of 53 ft to achieve cut-off, rather than the 100 ft originally anticipated, reducing the quantity of secant piling and jet grouting required. Subsequent groundwater monitoring during excavation to full depth within the secant pile/jet grout cut-off structure confirmed the accuracy of the groundwater modelling and offsite drawdown did not exceed the specified limits.

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LACMTA Regional Connector Subway
Los Angeles, CA

The LACMTA Regional Connector consisted of two 21-foot-diameter subway tunnels. Compensation grouting was required to minimize settlements induced by soft ground tunneling. Due to the remote drilling location, directional drilling was used to install the injection sleeve port grout pipes. Compensation grouting was then successful in controlling structure movements. GEO-Instruments, a Keller Company, provided instrumentation and real-time data visualization for a critical segment of the project. Structures along the tunnel route were instrumented with precise wireless tiltmeters and hydrostatic level. In addition, two long shape arrays were installed in 450-foot-long boreholes that followed the curve of the tunnel alignment. The grouting program, together with instrumentation, was a great success and provided data that allowed a record pace for the second tunnel boring machine (TBM) drive.

LACMTA Regional Connector Subway

Blue Plains Nitrification Tunnel
Washington, D.C.

To construct a tunnel at the Blue Plains Advanced Wastewater Treatment Plant, a shaft needed to be installed to allow a microtunnel boring machine access to perform its work. Since there were two distinct soil layers at the site, HBI constructed a very unique shaft using two types of excavation support. In the top approximately 35 feet of soil, a jet grouted soilcrete wall with walers was constructed and in the next 30 feet, soil nails and shotcrete completed the support system.

Faraday Launching Tunnel Shaft
Carlsbad, CA

The Carlsbad Desalination Plant was excavating a 55-foot-deep, 18-foot-diameter secant pile supported shaft installed by another contractor when soil and water leakage occurred due to insufficient pile overlap. The leakage resulted in a sinkhole opening near the perimeter of the shaft. HBI performed compaction grouting to stabilize the sinkhole. Once the area was stabilized, HBI used jet grouting to restore the continuity of the shaft and seal the perimeter of the excavation, stopping the soil and water seepage. Compact equipment was used to safely navigate the congested project site.

Faraday Launching Tunnel Shaft

Thornton Tunnel Grouting
Thornton, IL

The Thornton Composite Reservoir project included a 30-foot-diameter connecting tunnel and a 20-foot-diameter connecting tunnel. Grouting was required to create cut-off rings to reduce groundwater movement along the exterior of the tunnels and to tie into the double row grout curtain around the reservoir. HBI was contracted to reduce the permeability of the bedrock to an approximate value of 1 Lugeon by drilling and grouting from inside the tunnels (tunnel grouting) in a 360-degree ring-pattern, drilling holes with strict alignment requirements and injecting a suite of balanced and stable grouts in multiple stages overhead. HBI used upstage and downstage techniques to complete the ring drilling and grouting operation.

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T&UC

Herrenknecht tunnel borers continue success story in L.A.

Los Angeles is a vibrant center of international film art and innovation – not just on the surface. The area below ground is the scene of state-of-the-art engineering achievements. German high-tech machines from Herrenknecht are creating underground arteries for the American city. Tunnel boring machine (TBM) »Harriet« successfully completed her drive for the Crenshaw/LAX Transit Project in April 2017. »Angeli« just finished digging the first of two tunnels for the Regional Connector Transit Corridor on July 18th. From spring 2018 onward the tunnel boring stars will have additional company: for each of the "Purple Line Extension Sections 1 + 2", two more Herrenknecht TBMs will be working their way through the difficult ground. All three projects are part of the strategic subway extension in L.A. to relieve the traffic above ground.

Los Angeles, the city of angels, suffocates in traffic during rush hour. For this reason the Los Angeles Metropolitan Transportation Authority (Metro) is pushing ahead at full speed with the expansion of local transport links. In the coming years, the existing metro rail network will be expanded in a number of different places. The latest example is the Crenshaw/LAX Transit Corridor. The nearly 14 kilometer long new light rail route will improve the connection between the urban centers of Crenshaw and Inglewood as well as the region around Los Angeles International Airport (LAX). LAX passenger numbers alone show the high demand for public transport capacity: in 2016, more than 80 million passengers were processed – and the trend is rising.

Between May 2016 and April 2017 the Earth Pressure Balance Shield (EPB) »Harriet« worked its way forward underground for a section of the Crenshaw/LAX Transit Corridor. The Herrenknecht TBM (Ø 6.51m) first excavated a 1.6 kilometer long tunnel between the future stations of Expo/Crenshaw and Leimert Park. It was then disassembled and transported back to the launch shaft for the second, parallel section. In April 2017 »Harriet« completed her mission below Los Angeles with the second breakthrough in the target shaft at the Leimert Park station. With a 24 hour best performance of 43 meters a new record in mechanized tunnelling with a subway sized EPB Shield was set for the city of Los Angeles – four more times 40 or more meters were created within one day. Thanks to weekly best performances of 170 meters the Crenshaw/LAX Transit Corridor is expected to go on line on schedule in 2019.

Meanwhile, in February 2017 the Earth Pressure Balance Shield »Angeli« got under way. The TBM is boring a section of the Regional Connector Transit Corridor. It will link the existing Gold, Blue and Expo Metro Lines to new and faster direct connections. From 2020 this will allow locals and visitors to travel north-south from Azusa to Long Beach and east-west from East Los Angeles to Santa Monica without having to change. »Angeli« has just finished the first of two 1.7 kilometer long tunnelling routes. On July 18th she reappeared in the target shaft at 4th Street.

High-tech machine »Harriet« built two tunnels and covered 1,600 meters for each of them.

The machine S-952 »Angeli« for the construction of the Regional Connector Transit Corridor.

Next she will dig a parallel tunnel with the final breakthrough scheduled for the end of the year.

One of the greatest challenges in mechanized tunnelling under L.A. are the possible gas deposits. In order to master these safely, the contracting joint ventures have opted for special technology from Herrenknecht. The electrical components in »Harriet« and »Angeli« are explosion-protected so that safe tunnelling can be realized at all times. This measure has previously proved its worth worldwide in various reference projects. Despite the complex geological conditions and the inner city drive beneath densely populated areas, thanks to the active communication of Metro the two Earth Pressure Balance Shields have already gained a certain cult status with the population of L.A. The much-read Twitter account of »Harriet« was closed after its breakthrough, »Angeli« continues to communicate with the interested population (account: Angeli@regionaltbm).

To name the machines, Metro ran a competition for school children. From the many suggestions, the majority of the more than 50,000 online voters chose »Harriet«, thereby honoring anti-slavery activist Harriet Tubman. »Angeli« also comes from the pen of a school child. The term comes from Latin and means "angel".

In the meantime, designers and engineers at the Herrenknecht headquarters in Schwanau are already working on the next order for Los Angeles. The existing Purple Line is also planned to grow by 14.5 kilometers and seven stations. To this end, in both the spring of 2018 and the spring of 2019 two additional Herrenknecht Earth Pressure Balance Shields each are to be launched in the USA. In just a few years the four machines will produce over 11 kilometers of high quality tunnel tubes. A decade ago, under similar conditions two EPB Shields from Herrenknecht had already built a total of 4 kilometers of tunnel for the expansion of the Gold Line. Herrenknecht technology in Los Angeles is thus already a real success story. To be continued.

www.herrenknecht.com

A total of six Herrenknecht tunnel boring machines are realizing state-of-the-art metro tunnels for the Los Angeles metro rail extension

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With more than 65 years of innovation and experience, The Robbins Company is the world's foremost developer and manufacturer of advanced, underground construction machinery. Each piece of equipment, from our TBMs to our conveyors and everything in between, is engineered for maximum durability and premium performance, ensuring the successful completion of even the most difficult underground construction projects. Robbins is a total supply company, offering customized equipment, knowledgeable personnel, and technical support.

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Have a challenging project? Robbins offers the ideal machine for mixed ground conditions that might otherwise require multiple tunneling machines. Robbins supplies three types of Crossover machines: the XRE (Crossover between Rock/EPB), the XSE (Crossover between Slurry/EPB), and the XRS (Crossover between Rock/Slurry). Today's tunnel boring machines must adapt to shifting conditions, and Robbins Crossover TBMs do just that by combining the most powerful features from different types of machines.

The first Crossover to ever be used in the U.S. is currently boring the Ohio Canal Interceptor Tunnel (OCIT) in Akron, Ohio. The TBM was launched from a 12 m (40 ft) deep portal site and is excavating in soft soils that transition into mixed face and then full face shale. Unique aspects of the XRE machine include a versatile cutterhead that is configured for both the short soft ground section and the longer section (about 65 percent of the tunnel) in hard rock. The project will be complete by the end of 2018.

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Robust, long-lasting tunnel boring machines have been a core part of Robbins' business for decades. A rebuilt machine with updated systems can offer exceptional value without increasing risk, while also allowing your project to get started faster. The flexibility of used equipment may be one of its biggest advantages: Boring diameters can be increased or decreased and machine configurations can be changed—even by adding shields to an open-type machine, for example.

On the Albany Park project in Chicago, Illinois, a Robbins Hard Rock Main Beam TBM was rebuilt by contractor Kenny Construction with size modifications designed by Robbins. This particular TBM has been owned and used on projects by Kenny since the early 1990s. Prior to its ownership by Kenny the machine has successfully bored tunnels in the Dominican Republic, Saudi Arabia, New York, and Chicago—totaling at least 12 miles (19.5 km).

Robbins took the existing cutterhead, rebuilt it, and then added segments, taking the machine from 17.2 feet (5.2 m) to 20.4 feet (6.2 m) in diameter. Other modifications were also made underground, resulting in a highly successful project with a breakthrough in August 2016. The Albany Park TBM is the rule, not the exception: over 50 percent of all Robbins Main Beams ever manufactured have been used on three or more projects. Incredibly, many Robbins TBMs that have been used on multiple projects are approaching over 31 miles (50 km) of use.

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MAPEI Corporation

MAPEI, a global leader in supplying adhesives, grouts and chemical products to the construction industry, provides a combination of products and a skilled, experienced Underground Technology Team to assist contractors on projects involving tunnels, mining, and other underground construction. Recently, UTT representatives assisted on the Anacostia River Tunnel (ART) Project. The ART is the second in a series of four tunnels that comprise the DC Water's Clean Rivers Project, which is intended to reduce the ongoing pollution of the Potomac and Anacostia rivers.

MAPEI products from the Underground Technology Team (UTT) were used to help the tunnel boring machine "Nannie" dig a tunnel 2.37 miles (3,81 km) in length that extends from Robert F. Kennedy Stadium in northeast D.C. to Poplar Point in southeast D.C. These solutions included soil conditioners as well as products utilized for the two component grout.

As the TBM Nannie bored through the earth, it utilized a two-component grout to fill the annulus space between the concrete segmental liner and the ground. The grout needed to be pumped for long distances and exhibit good stability. Therefore, the project utilized Mapebent CBS 5, a sodium bentonite, to keep the grout from segregating as well as Mapequick CBS System 1, which allowed the grout to be pumped for long distances while retarding the setting time. Once the grout reached the point of placement, it required a quick set. To accomplish this, the sodium silicate Mapequick CBS System 2 was used to produce the rapid set required, typically in 5 to 10 seconds, to support the segmental lining.

The ground that is being mined is often treated as it is being excavated in order to facilitate the extraction and removal of the spoils (soil, dirt and rubble). For the ART project, MAPEI provided Polyfoamer FP/CC, which is foamed before being injected into the ground. It works to reduce the stickiness of the clay that the tunnel boring machine passed through and to provide body to the coarse sands and silts.

More importantly, MAPEI UTT utilized their laboratories to develop and optimize the two component mix design and the soil conditioning parameters prior to the commencement of the project. In addition, members of MAPEI UTT were on hand during production to consult with the project engineers and workers and to ensure that the dosage of the MAPEI products was optimal for the ART project. Nannie passed under many pieces of critical infrastructure and MAPEI products were part of the project all the way.

In addition to the ART project described here, global MAPEI UTT personnel work on large tunneling projects worldwide. These projects include the Thomson-East Coast (Contract T208) in Singapore, the Ejpovice Tunnel in the Czech Republic, the Cucchero Tunnel in Italy, the Gotthard Base Tunnel in Switzerland, and a number of tunneling projects elsewhere around the globe. Details on these projects can be found on the MAPEI web site at **www.mapei.com.**

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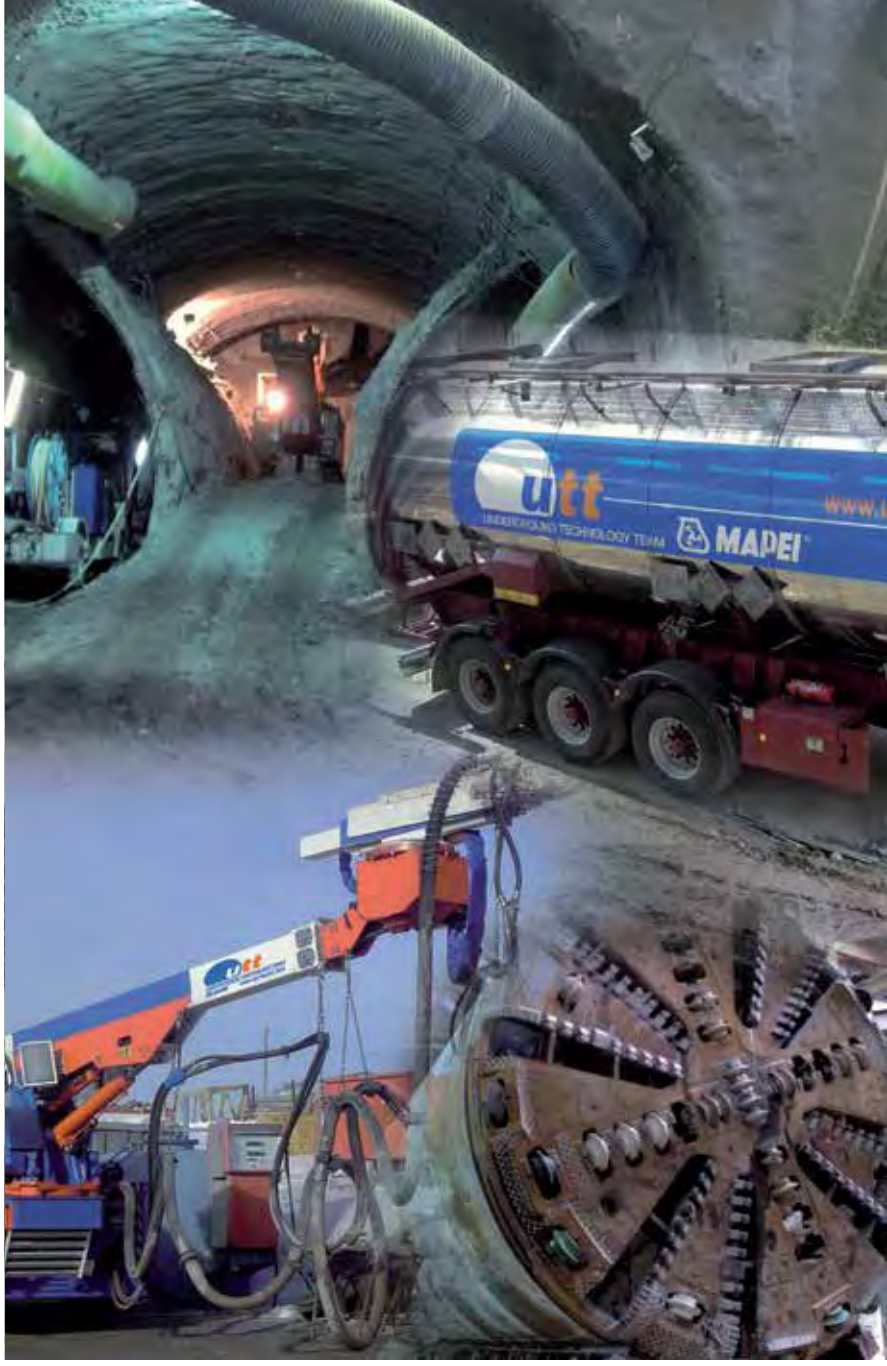

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Brokk Inc.

Brokk, the world's leading manufacturer of remote-controlled demolition robots, introduces the new electric Brokk 500, which features 40 percent more demolition power than the Brokk 400. It also has the Brokk SmartPower™ electrical system, a more powerful breaker, extended reach and industry-leading serviceability. Brokk's remote-controlled demolition machines open a wide range of possibilities when it comes to tunneling applications, from excavating cross passages and safety niches, to tunnel boring machine launch chambers. The machines excel in underground applications, as well as in confined spaces due to its electric motor and maneuverability.

The new Brokk 500 adds 40 percent more breaking power than its predecessor, the Brokk 400. The machine delivers 1,086 foot-pounds (1,472 joules) with each blow of the 1,510-pound (685-kilogram) Atlas Copco SB 702 hydraulic breaker. On top of that, it adds more length to Brokk's signature three-part arm system, now reaching 24.3 feet (7.4 meters) vertically and 23 feet (7 meters) horizontally, making it ideal for work where extra reach is important.

The new Brokk 500 incorporates the industry-leading reliability and serviceability that Brokk has become known for over the years. New on this machine is that operators can complete all daily and weekly maintenance without having to lift the covers of the machine. Plus, replacing any damaged hydraulic hoses is now simpler than ever.

Still, the Brokk 500 retains most of the compact proportions of the Brokk 400. Weighing 11,464 pounds (5,200 kilograms), it is only slightly heavier, and the width of the machine is the same. It also is "backward compatible," so all the tools and attachments used for the Brokk 400 can also be used on the new Brokk 500.

The Brokk 500 comes with Brokk's new intelligent electrical system, Brokk SmartPower, which is a key part in creating the machine's performance improvement. It maximizes the power output of the machine at any given time based on both environmental and operating factors.

The Brokk SmartPower system is uniquely designed for the extremely tough operating environments of a demolition robot. Its components are either designed by or modified by Brokk to withstand the demolition forces over time. In addition, the SmartPower system helps the operator start the machine on a poor power supply while at the same time it protects the Brokk machine from harmful faulty power.

The Brokk 500 incorporates the industry-leading reliability and serviceability that Brokk has become known for over the years. New on this machine is that operators can complete all daily and weekly maintenance without having to lift the machine covers. Replacing damaged hydraulic hoses is now simpler than ever.

Combined with other items, such as the strengthened new Brokk machine design, the reinforced casted details, and the new headlight protections, and the result is a machine truly hardened for the tough Brokk environment.

About Brokk

Brokk has been the world's leading manufacturer of remote-controlled demolition machines and attachments for more than 40 years. Through continuous innovation in engineering and design, Brokk is able to offer unique solutions to multiple industries worldwide, including construction, demolition, mining and tunneling, cement and processing, nuclear and other specialty applications.

For more information:
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Brokk introduces the new Brokk 500, which features 40 percent more demolition power than the Brokk 400 as well as the Brokk SmartPower™ electrical system, a more powerful breaker, extended reach and industry-leading serviceability.

The new Brokk 500 delivers 1,086 foot-pounds (1,472 joules) with each blow of the 1,510-pound (685-kilogram) Atlas Copco SB 702 hydraulic breaker. On top of that, it adds length to Brokk's signature three-part arm system, which now extends 24.3 feet (7.4 meters) vertically and 23 feet (7 meters) horizontally.

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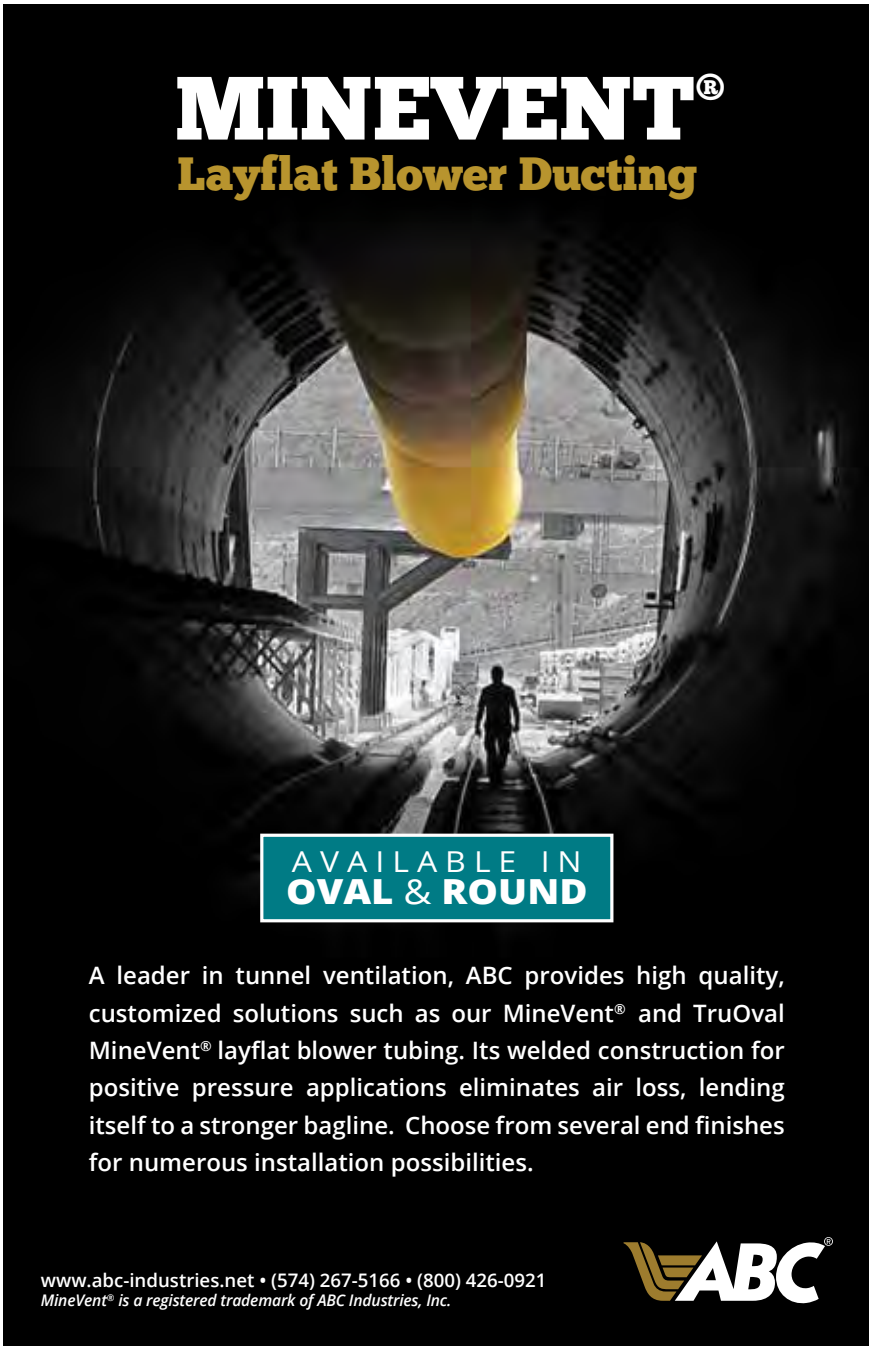

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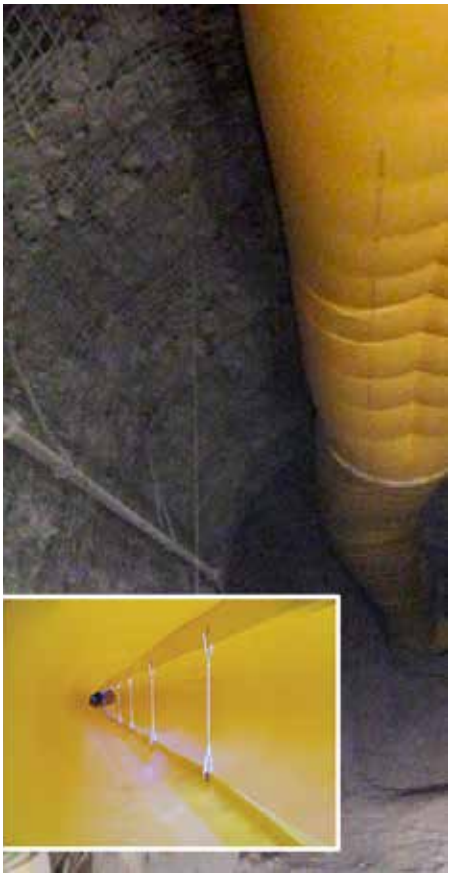

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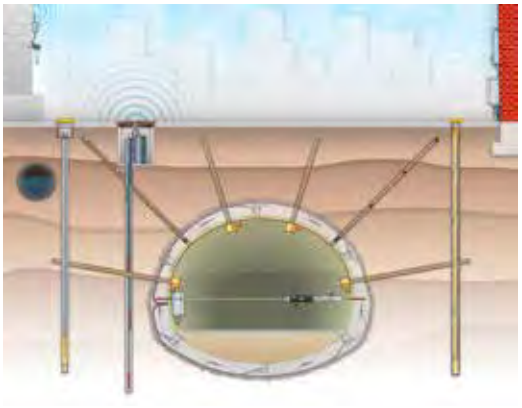

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Gall Zeidler Consultants (GZ) is a worldwide leader in geotechnics, tunnel design and engineering, and tunnel construction management, with special expertise in transportation and infrastructure projects. GZ offers exceptional expertise in urban tunneling with shallow overburden and the related protection of neighboring structures and surface operations by innovatively combining conventional (SEM / NATM) and mechanical tunneling methods (TBM) with ground improvement and state-of-the-art waterproofing techniques.

The company specializes in mastering difficult ground conditions by using cutting-edge ground improvement methods such as dewatering, grouting, and ground freezing. GZ employs over 50 staff worldwide, and has a history of over 170 miles (275 kilometers) of successfully completed international tunneling projects. The company's expertise has consistently been sought after by major contractors and project owners in the industry developing tailored tunnel solutions and to assist with the mitigation of risks associated with tunneling.

GZ's ongoing projects include East Side Access, New York, Northgate Link Extension, Seattle, Crossrail, London and Riyadh Metro. GZ was involved in the recently completed Caldecott Tunnel Fourth Bore and Devil's Slide Tunnels in California, Dulles Metrorail Extension, Washington, D.C., Cable Tunnels in London and Singapore and multiple underground station upgrades in London.

Northwest Laborers-Employers Training Trust – Safety and Hazard Awareness for Tunnels (SHAFT) program

The Safety and Hazard Awareness for Tunnels (SHAFT) program, developed by the Northwest Laborers-Employers Training Trust with input from a team of industry experts and stakeholders, is comprised of a blend of classroom discussion and interactive use of materials and mockups.

The curriculum offers comprehensive safety training for both new and experienced tunnel professionals; classes focus on tunnel safety, rail, and utilities.

The training facility, located in Elma, Washington, features a TBM mockup, rail, and access to 1,400' of 12' diameter tunnel – providing students with a unique educational experience.

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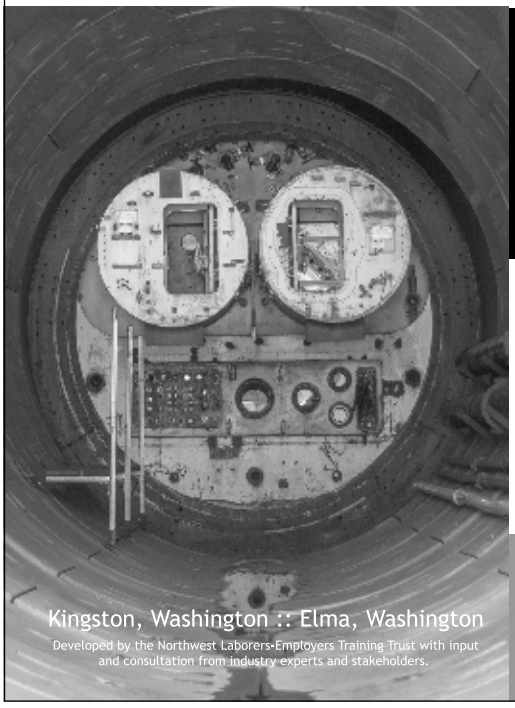

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Brookville

BROOKVILLE 27-Ton MSHA Permissible Locomotives Boosting Safe Work Environment at Major Los Angeles Tunneling Project

Brookville Equipment Corporation (BROOKVILLE) recently shipped three 27-ton MSHA-permissible tunneling locomotives to the Walsh-Shea Corridor Constructors for use on the Crenshaw/LAX Transit Corridor Tunnel Project in Los Angeles. By design, the locomotives reduce the risk of explosion due to geological conditions that may host the presence of methane and other combustible gases. Cal-OSHA has classified the tunnel drives on this project "gassy", mandating the use of MSHA permissible locomotives.

The 27-ton locomotives' special safety features include air start, an enclosed engine block, an exhaust filtration system, wiring and piping guards, and an intake flame arrestor, among other upgrades, to fully comply with MSHA's permissibility requirements. Featuring an 8.3L Cummins six-cylinder diesel engine and four-speed transmission, the 185-horsepower locomotives operate on 36-inch rail gauge underground for Walsh-Shea Corridor Constructors .

"BROOKVILLE was selected based on past performance, simplicity of operation and diagnostics, their ability to communicate locally with MSHA, and knowing we would be dealing with the good people of Brookville, PA, U.S.A," said Walsh-Shea Corridor Constructors Tunnel Construction Manager David Girard, P.E.

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The Heintzmann Group, which has been in business approximately 165 years, manufactures support systems in the tunneling and mining industries. In the last decade, we have greatly expanded our line of products, as well as our regions of service. We currently have offices located in Virginia, West Virginia, Alabama, Colorado, and Illinois. Our range of products and services include but are not limited to standing supports, pumpable roof support, arches, square sets, pre-stressing devices, heat treated beams, polyurethane grout injection, shaft rings, lattice girders, two flange liner plates and four flange liner plates.

The goal of the Heintzmann Group is to provide resources to make the tunneling and mining environments safer and to achieve the highest level of customer satisfaction by providing our customers with a variety of support options.

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McMillen Jacobs Associates provides technical engineering design and construction expertise in the conveyance (water, wastewater, stormwater), dispute resolution, energy and power, transportation, underground, and water resources industries. We offer a full range of design, design-build, self-performing construction and construction management services.

We work closely with our clients at every stage of a project, assisting them with planning, design expertise, project management, construction, and start-up. Our 21 offices in North America and Australasia and more than 400 staff serve clients locally and worldwide.

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Announcing Doctor Mole Incorporated

Dr. Gary S. Brierley started operating as an independent consultant under the corporate name of Doctor Mole Incorporated (DMI) on January 1, 2013. Doctor Mole Incorporated is a one-stop-shopping-center for the design of all types of underground openings in all types of ground conditions. DMI can help clients meet their underground design and construction needs. No job is too small and it is our intention to help owners, designers, contractors, geotechnical engineers, and developers create successful underground projects from start to finish. Based in Denver, Colorado, DMI is strategically located and available to help with projects across the United States. Give us a call at 303.797.1728 or visit us on the web at www.drmoleinc.com.

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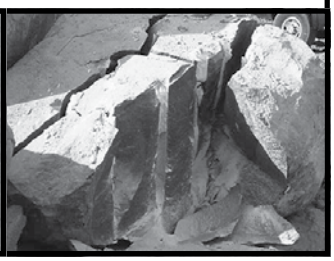

Dā-mite Rock Splitting Mortar from the Daigh Company, Inc.

Daigh Co. is the supplier of Dā-mite Rock Splitting Mortar. Dā-mite is used to fracture rock and concrete in "no-blast" conditions. Dā-mite is an ideal and effective tool for fracturing mass rock, boulders, trench rock, dimensional stone, concrete and reinforced concrete. "Dā-mite is mixed with water and placed in the appropriately placed predrilled holes, where it sets and expands, fracturing the rock/concrete". No license required. There are four grades of Dā-mite, providing enough versatility to be utilized in drilled hole diameters from 1 in. to 2 ¾ in.

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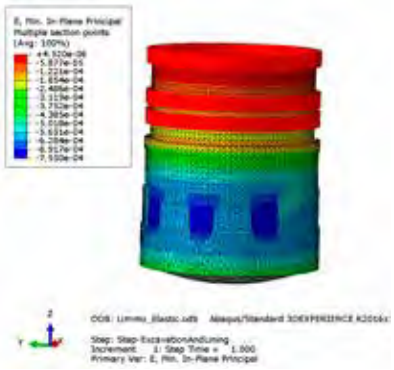
Dr. Sauer & Partners is an independent consultancy specialised in providing the full range of design and construction management services for tunnels, shafts and caverns. Delivering innovative, cost-effective and environmentally-aware designs, the company has over 30 years' experience providing solutions for some of the world's most challenging tunnelling projects (Metro, Highway, Water, Rail and Mining). Dr. Sauer & Partners provides designs for urban and rural tunnels, in any type of geology.

Services delivered include initial consultation and feasibility studies, final design, supervision and construction management, tunnel inspection and condition surveys, rehabilitation, waterproofing and water control, geotechnical engineering, and mining support services.



Current and recent projects include: Chinatown Station (San Francisco, USA), Ottawa Light Railway (CAN), Bank Station Capacity Upgrade Project (London, UK), Crossrail (London, UK), Red Line (Tel Aviv, Isreal), Eglington Crosstown LRT (CAN).

AWARD

George K. Burke receives the DFI Distinguished Service Award

George K. Burke, PE, D.GE, has been named the 2017 recipient of the Deep Foundation Institute's (DFI) Distinguished Service Award. DFI is an international association of contractors, engineers, manufacturers, suppliers, academics and owners in the deep foundations industry. The Distinguished Service Award recognizes individuals who have made exceptionally valuable contributions to the advancement of the deep foundations industry. The award was presented at DFI's 42nd Annual Conference on Deep Foundations in New Orleans, LA on Oct. 26, 2017.

Commenting on the award, DFI Executive Director Theresa Engler stated, "George's significant efforts in the development and adoption of soil mixing and jet grouting have contributed greatly to the advancement of the deep foundations industry. He has also generously shared his knowledge through active participation in technical committees and educational seminars."

Burke retired from Hayward Baker in 2015 as senior vice president engineering. He continues to contribute to the company as senior risk manager. Burke has been a member of the Hayward Baker family for 30 years. ■

George Burke (center) receives the 2017 DFI Distinguished Service Award presented by DFI Executive Director Theresa Engler (left) and Hayward Baker Director and DFI President John Wolosick (right).

SHORT COURSE

CSM offers grouting and ground improvement short course

Colorado School of Mines' (CSM) Center for Underground Construction and Tunneling (CUCT) offers a short course on Grouting and Ground Improvement in Golden, CO, May 14-16, 2018. The three-day course will be held on the CSM campus and covers engineering, equipment, materials and methods for grouting and ground modification used in civil and geotechnical engineering, underground construction, tunneling and mining. It combines classroom instruction by internationally recognized experts with hands-on labs and demonstrations, providing an opportunity to see grouting and ground improvement field equipment in action.

Some of the course topics include: ground improvement in glacial soils: Seattle tunneling experience; overview of underground construction grouting; cellular concrete use and application; fundamentals of soil and rock mechanics; geotechnical site investigation; risk evaluation, Rondout Bypass Tunnel Project update and laboratory demonstrations. The final day of the course will include field demonstrations of compaction, chemical, permeation and cellular grouting.

Participants will be able to earn 2.1 CEUs upon successful completion of the course. Course directors are Ray Henn, CSM and RW Henn LLC, rhenn@rwhenn.com and Reza Hedayat, CSM, hedayat@mines.edu. For more information, visit csmspace.com/events/ggi. For more information about the CUCT 2018 short course series, visit https://csmspace.com/static/cpes-catalog.html. ■

PERSONAL NEWS

McMillen Jacobs Associates announces six promotions to principal in the firm's underground division. **JOHN MURRAY** PE (SME) is the firm's New York, NY and Roseland, NJ office manager. He has 20 years of experience as a design engineer and project manager on several major tunnel design projects. He has served as a design lead and project manager on a number of design-build and design-bid-build tunnel projects and his experience includes planning, preliminary design,

MURRAY

(Continued on page 68)

OBITUARIES

DON U. DEERE

An appreciation by Christoph Goss, Principal, Deere & Ault Consultants

Don U. Deere, a world-renowned engineering geologist, died on Jan. 14, 2018, in Gainesville, FL. He was 95. An expert on tunneling, dam building and design, and the construction of large underground spaces, in 1989 he was appointed by President Ronald Reagan as chairman of the U.S. Nuclear Waste Technical Review Board. He received numerous distinctions throughout his career, including being elected to both the National Academy of Engineering and the National Academy of Sciences, the Golden Beaver Award, and the nonmember Award of Moles.


DEERE

Born in 1922, Deere received his B.S. in mining engineering from Iowa State University in 1943, an M.S. in geology from the University of Colorado in 1949 and a Ph.D. in civil engineering from the University of Illinois in 1955.

After working as a mining engineer in Arizona and New Mexico, Deere taught at the University of Puerto Rico, Mayaguez, and started the Foundation Engineering Co. of Puerto Rico. In 1955, he accepted a joint appointment as an associate professor in the departments of Civil Engineering and Geology at the University of Illinois and helped lead its geotechnical engineering program to international prominence. He resigned his appointment as professor in 1972 to pursue full-time consulting and moved to Gainesville, where he co-founded Deere and Merritt, an international consulting firm in geology and rock mechanics. He also joined the University of Florida as an adjunct professor.

In 1964, Deere developed the Rock Quality Designation (RQD), which became a standard index for core logging and scan line surveys. RQD also remains a key input parameter in rock mass classification systems. In the 1970s, he brought attention to the importance of foliation shear zones. In 1993, together with Giovanni Lombardi, he developed the Grouting Intensity Number method for rock mass grouting.

Major projects to which he contributed include the construction of the World Trade Center, the Channel Tunnel, Cheyenne Mountain NORAD, Yucca Mountain, New York City water tunnels, the Washington D.C. Metro subway, the Hong Kong Island tunnel, the Suez Canal Crossing and numerous hydroelectric facilities throughout the Americas, most notably Itaipú, the world's largest hydroelectric project at the time. Perhaps his greatest legacy was that of a teacher where, at the universities of Illinois and Florida, he mentored a whole generation of leaders in the tunneling industry. ■

PERSONAL NEWS

(Continued from page 67)

final design, procurement support and design support during construction. His experience includes large-diameter water, wastewater, mass transit and highway tunnels. Murray is currently the design manager for the Catskill Aqueduct Repair and Rehabilitation Project in Upstate New York and is leading the firm's efforts as part of the program management team on the Ottawa Rail Transit project for the City of Ottawa.

TROY PAGE PE, (SME) is an underground cost estimator with 34 years of experience. Page spent 24 years with heavy construction contractors, primarily working on tunnels, shafts and underground caverns. He has experience in most tunneling methods, as well as grouting, estimating and claims. His extensive knowledge base affords him the ability to develop detailed engineer's estimates, perform design feasibility and constructability reviews, and review contractor submittals. He has provided cost estimating services on some of the firm's most significant tunneling projects, including Akron Ohio Canal Interceptor Tunnel, Ottawa Light Rail Transit, Central Subway PM/CM, and Ship Canal Water Quality Project.


PAGE

SARAH WILSON, PE, CCM (SME) has applied her combined experience in design and construction management to solving problems on underground projects, primarily in water supply and rail transit, for more than 18 years. Wilson recently served as resident engineer for the $234 million SFMTA Central Subway's Tunnels and $294 million Union Square Market Street Station contracts. She currently oversees the firm's construction management practice as well as serving on the board of directors. She is a past president of the American Rock Mechanics Association and is currently working on an


WILSON

(Continued on page 69)

PRODUCT NEWS

C20 rock splitter from Brokk offers more power

Brokk has introduced the C20 rock splitter attachment, manufactured by Brokk's German sister company, Darda. The C20 offers contractors a safe and quiet alternative to explosives and hydraulic breakers. It increases productivity in the tunneling, mining and quarrying industries. Brokk featured the C20 rock splitter during Conexpo-Con/Agg 2017 in Las Vegas, NV.

Paired with a Brokk 280 demolition robot and counterweight, the C20 rock splitter allows operators to split rock with all the speed and effectiveness of breakers and chippers, but without the noise, vibration and danger common with that type of equipment.

The C20 rock splitter comes in four models: two vertical options ranging from 163 to 183 cm (64 to 72 in.) long and two horizontal options from 179 to 211 cm (70 to 83 in.) long. The C20 rock splitter quickly breaks large boulders and solid rock in mining and shaft-sinking applications, as well as cross-passage work in tunneling. Contractors drill a 7.6-cm (3-in.) diameter hole into the rock with a separate attachment before inserting the splitter. The attachment expands with as much as 1,633 t (1,800 st) of force, splitting the rock.

The method is quieter, safer and produces fewer vibrations and dust than breakers and explosives. It gives contractors a productive alternative in areas where potentially disruptive demolition techniques are not allowed, such as near hospitals, plus it works faster than expanding demolition chemicals, which can take hours. It's also a safer alternative to handheld tools, such as pneumatic breakers, that produce heavy vibrations and can cause worker fatigue and injuries. ■

The C20 rock splitter can be quickly interchanged on a Brokk machine for greater versatility on a jobsite.

PERSONAL NEWS

(Continued from page 68)

update to the UCA of SME's publication *Recommended Contract Practices for Underground Construction*. She is a regularly invited lecturer at the University of California Berkeley.

KRISTIAN NELSON, CPE, PEng, IntPE, is the firm's Auckland, New Zealand office manager. He has worked for 19 years as a civil engineer in Canada and New Zealand, specializing in complex marine, temporary works and ground improvement methods. He has extensive experience planning and delivering projects that maintain client access to facilities and working around operational activities. He has managed projects from design to delivery and has a deep understanding of the impacts and interrelationships of design, construction, options and constraints. Nelson is currently the design manager on the Army Bay WWTP Upgrade and Outfall Replacement in Auckland.

NELSON

MARK TRIM, CPEng, PE, has 19 years of experience working as a design engineer and manager specializing in permanent and temporary underground structures, with an emphasis on tunnel design, deep excavation support systems, soil structure interaction and ground improvement technology. Notable projects he has worked on in North America and Australia are the WestConnex M4 East Project (Sydney), Ottawa Light Rail Transit Project, Airport Link Project (Brisbane), and Northern Sewerage Project (Melbourne). Trim works in the Sydney, Australia office, which he opened in 2014.

TRIM

Avanti International has appointed **FRANK AGUILAR** as president of the company. **ANGELA MAGILL,** widow of Avanti founder David Magill, has been elected director. Aguilar will work closely with Magill to achieve strategic operational goals. Aguilar joined Avanti in 1999 and has served as regional sales manager, technical product manager, vice president of customer service and, most recently, vice president of operations. ■

AGUILAR

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	2018	Design study
2nd Ave. Phase 2	NYC-MTA	New York	NY	Subway	16,000	20	2020	Under design
2nd Ave. Phase 3-4	NYC-MTA	New York	NY	Subway	105,600	20	2017-22	Under study
Water Tunnel #3 Stage 3 Kensico	NYC-DEP	New York	NY	Water	84,000	20	2020	Under study
Bergen Point Wastewater Outfall	Suffolk Co., DPW	Babalon	NY	Sewer	14,200	12	2017	OHL/Seli JV awarded
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2022	Under study
Narragansett Bay CSO Phase III - Pawtucket Tunnel	Narragansett Bay Commission	Providence	RI	CSO	13,000	28	2020	Under design
Narragansett Bay CSO Phase III - ConveyanceTunnel	Narragansett Bay Commission	Providence	RI	CSO	8,800	10	2024	Under design
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	10,000	30	2018	Under design
Thimble Shoal Parallel Tunnel	Chesapeake Bay Bridge & Tunnel Dist.	Chesapeake	VA	Highway	5,700	45	2016	Dragados/ Schiavone awarded
Hampton Roads Bridge-Tunnel Project	Virginia DOT	Hampton Roads	VA	Highway	7,500	42	2018	Under design
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	4,500	33	2022	Under design
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2017	Under design
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	30,000 21,000	18 14	2018 2019	Under design Under design
Westerly Main Storage Tunnel	NEORSD	Cleveland	OH	CSO	12,300	24	2020	Bid date 2/6/18
Shoreline Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,100	21	2021	Under design
Shoreline Consolidation Tunnel	NEORSD	Cleveland	OH	CSO	11,700	9.5	2022	Under design
ALCOSAN CSO Ohio River Allegheny River Monongahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	10,000 41,700 53,900	30 30 30	2019 2020 2021	Under design Under design Under design
Three Rivers Protection/Overflow	City of Fort Wayne	Fort Wayne	IN	CSO	26,400	12	2016	Salini/Impreglio/ Healey awarded
I-75 Modernization	Michagan DOT	Detroit	MI	CSO	20,000	14	2018	Pequals underway
Louisville MSD Tunnel	Lousville MSD	Lousville	KY	CSO	13,200	22	2018	Shea/Traylor low bidder
Blacksnake Creek Tunnel Project	City of St. Joseph	St. Joseph	MO	CSO	6,650	10	2017	Super Excavators awarded
KCMO Overflow Control Program	City of Kansas City	Kansas City	MO	CSO	62,000	14	2018	Under design

To have your major tunnel project added to the Tunnel Demand Forecast, or to update information on a listed project, please contact Jonathan Klug at jklug@drklug.com.

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Mill Creek Peaks Branch Tunnel	City of Dallas	Dallas	TX	CSO	5,500	26	2014	Southland/Mole JV low bidder
Ship Canal Water Tunel	Seattle Public Utilities	Seattle	WA	CSO	14,250	14	2018	Under design
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	Transit	10,500	18	2022	Under design
L.A. Metro Westside Phase 2 Phase 3	Los Angeles MTA	Los Angeles	CA	Subway	 26,500 26,500	 20 20	 2016 2017	Tutor Perini/O&G JV awarded Bids 03/23/2018
Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2018	Under study
Northeast Interceptor Sewer 2A	LA Dept. of Water and Power	Los Angeles	CA	Sewer	18,500	18	2014	Delayed indefinitely
River Supply Conduit - Unit 7	LA Dept. of Water and Power	Los Angeles	CA	Water	13,500	12	2015	Advertise 01/18
JWPCP Effluent Outfall Tunnel project	Sanitation Districts of LA	Los Angeles	CA	Sewer	37,000	18	2015	Bid date 4Q 2018
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	2018 2019	Under design Under design
SVRT BART	Santa Clara Valley Trans Authority	San Jose	CA	Subway	22,700	20	2016	Redesign activated
Silicon Valley Clean Water Tunnel	Silicon Valley Clean Water	Silicon Valley	CA	CSO	17,500	13	2017	Barnard/Bassac JV awarded
Coxwell Bypass Tunnel program	City of Toronto	Toronto	ON	CSO	35,000	12	2015	JayDee/Michels/C&M McNalley low bidder
Highway 401 Rail Tunnel	Metrolinx	Toronto	ON	Subway	580	35x28	2017	EllisDon/Strabag JV awarded
Keswick Effluent Outfall	City of Toronto	Toronto	ON	CSO	11,600	23	2018	Under design
Yonge St. Extension	Toronto Transit Commission	Toronto	ON	Subway	15,000	18	2016	Under study
Taylor Massey Tunnel	City of Toronto	Toronto	ON	CSO	20,000	18	2018	Under design
Inner Harbour West	City of Toronto	Toronto	ON	CSO	18,400	19	2021	Under design
Scarborough Rapid Transit Extension	Toronto Transit Commission	Toronto	ON	Subway	25,000	18	2018	Under design
REM Transit Tunnel	City of Montreal	Montreal	QC	Subway	27,000	22	2017	Award 1Q 2018
Newfoundland-Labrador Fixed Link	Gov. of Newfoundland/Lab	Newfoundland	NL	Transit	56,000	40	2020	Under study
Green Line LRT	City of Calgary	Calgary	AB	Transit	26,250	20	2018	Under design
Second Narrows Tunnel	City of Vancouver	Vancouver	BC	CSO	3,600	14	2013	Under design
Annacis Island Outfall	City of Vancouver	Vancouver	BC	Water	8,000	10	2017	Under design
Burnaby Mountain	Kinder Morgan	Vancouver	BC	Oil	8,000	12	2017	Under design
Broadway Sky train extension	Trans Link	Vancouver	BC	Subway	25,000	18	18	Under design
Northern Gateway Hoult Tunnel	Enbridge Northern	Kitimat	BC	Oil	23,000	20	2014	Under design

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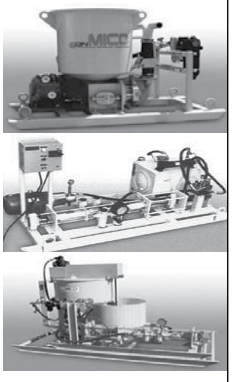

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smesherri@gmail.com

DARREN DUNAY
CANADA
+1-201-781-6133
Cell: +1-201-873-0891
sme@dunayassociates.com

EBERHARD G. HEUSER
EUROPE
+49 202 2838128
Fax: +49 202 2838126
egh@heusermedia.com

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UNITED KINGDOM
+44 1702-477341
Fax: +44 1702-177559
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