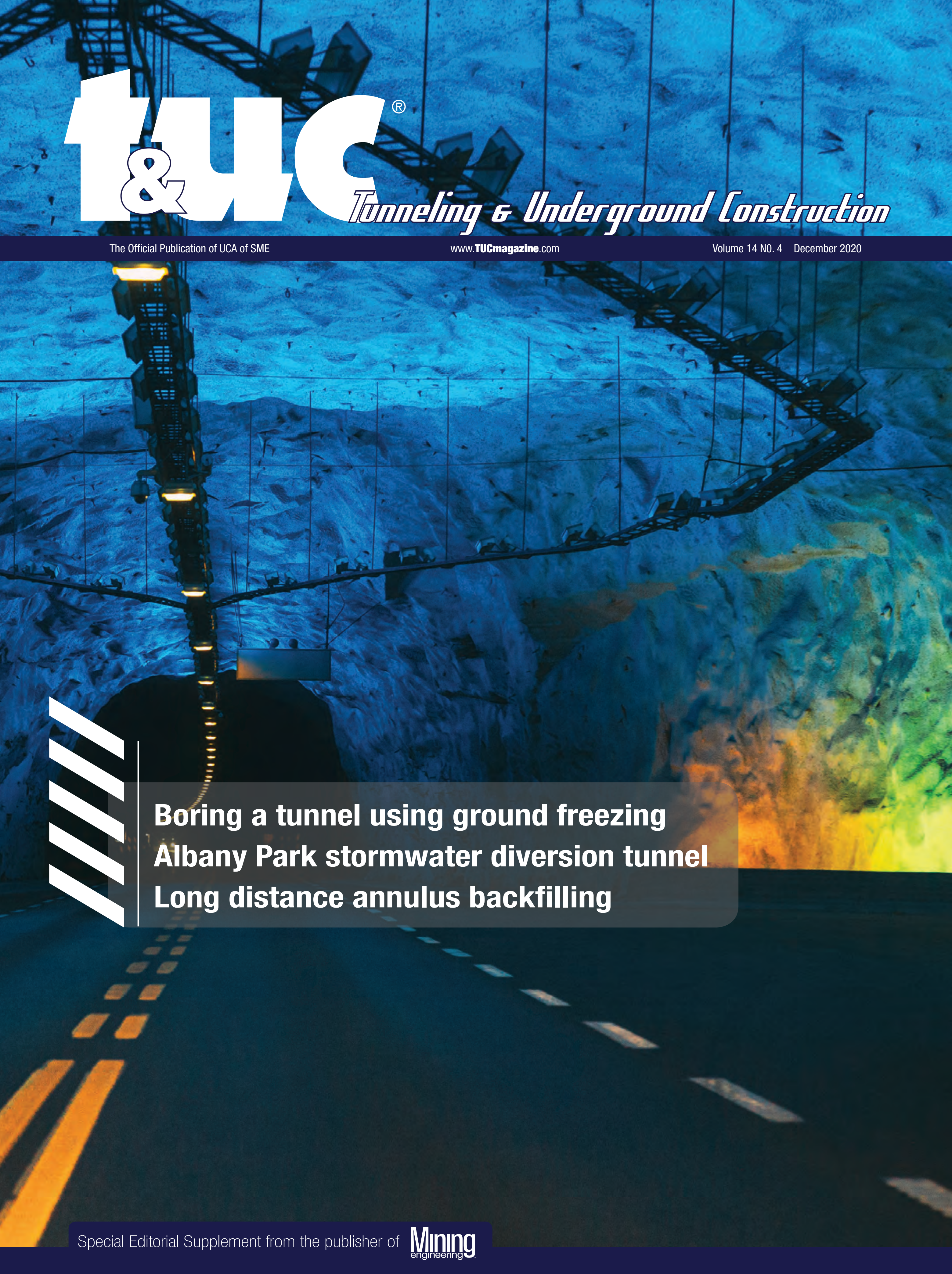

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Tunneling & Underground Construction

The Official Publication of UCA of SME www.TUCmagazine.com Volume 14 NO. 4 December 2020

Boring a tunnel using ground freezing

Albany Park stormwater diversion tunnel

Long distance annulus backfilling

Special Editorial Supplement from the publisher of Mining engineering

December Contents

Departments

Cover Story

In This Issue

The Line 14 extension project to the north of the Parisian subway in France is one of the first of a long series of tunneling works managed by a company called Société du Grand Paris. Package 3 of the Line 14-North project includes the creation of a subway station, three pedestrian accesses, a ventilation shaft and a 26 m- (85-ft) long rectangular tunnel linking the station and the shaft. Starting on page 12, an article from Marc Bouffier and his co authors focuses on the construction of the rectangular tunnel that joins the station and the shaft which utilized artificial ground freezing due to a complex hydro-geotechnical context.

Feature Articles

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Special editorial section from the publisher of Mining Engineering

As 2020 comes to a close, it's business as "normal" for the UCA

In-person events are the most visible and, in many people's eyes, the lifeblood and purpose of the UCA, a division of SME. While this is a substantial chunk of our efforts through the year, meetings are only a part of our mission. We seek to promote the industry in a variety of areas.

Nevertheless, as we continue to meet virtually — we most recently completed the Cutting Edge conference— we are planning a few hours of virtual sessions in place of the George A. Fox Conference in January after that in-person event was also cancelled because of COVID-19 restrictions. I realize that nobody really wants to get good at virtual events, but inevitably the UCA will get better at organizing such events as we learn from others and put on more of these events ourselves.

Away from events, the work of the UCA goes on unabated. Indeed, this work proceeds at an accelerated pace. SME has recently completed a strategic planning process. Thanks to the involvement of Dave Rogstad, Frontier Kemper Construction, and Bill Edgerton, McMillan Jacobs Associates, tunneling and underground construction is represented well in the overall strategic plan of the association. UCA is currently undertaking its own strategic plan discussions. A select group of industry leaders have been interviewed for their opinions on what we could and should be doing to better serve the industry as your professional organization. We hope to get some great feedback, so that we can improve our service to you and to the industry that we represent.

It appears that our ongoing efforts to nurture and expand the volunteer base of the UCA is beginning to bear some fruit. Our list of industry guideline publication subcommittees is blossoming. The following topics are currently in production listed here with the subcommittee leader: Alternative Delivery Guidelines (Chris Mueller, Black & Veatch); Guidelines for Improved Risk Management — a How-To Guide (Erika Moonin, Moonin Associates); Cellular Grout Backfill Guidelines (Ray Henn, RW Henn) and an exciting joint venture between UCA of SME and Deep Foundations Institute to publish a coffee-table book on precast segmental tunnel lining systems (Verya Nasri — AECOM, Brian Fulcher — McMillan Jacobs Associates, David Klug — David R. Klug and Associates, James Morrison — COWI North America and a group of chapter authors).

The UCA welcomes our new executive committee members: Erika Moonin for her second term, Shane Yanagisawa, Lane Construction, Sarah Wilson, McMillan Jacobs Associates and Grover Vargas, Sika. A call has just been advertised for new members of the executive committee — hopefully to begin their term in June 2021 at our in-person meeting in Las Vegas, NV at the RETC, June 13-15.

We are excited to have doubled our number of UCA Student Chapters to two. Kudos to Mike Vitale and the faculty of University of Illinois at Urbana-Champaign for making this happen. We would love to see more connectivity to students around the United States, so please step forward if you have the connection and want to be an industry mentor for a UCA Student Chapter.

We've never been more vibrant as an organization and that starts and ends with you, our members. I, for one, will be happy to see the back of 2020. I wish you a Happy New Year and hope that 2021 brings you good health, good fortune and, more than anything else, I hope to see you all in person again very soon. ■

Robert JF Goodfellow,
UCA of SME Chair

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Robotic arms to be installed on TBMs boring London's HS2 high-speed rail project

The two Herrenknect tunnel boring machines (TBM) that will bore the 16-km (10-mile) Chiltern tunnel will be assisted by robotic arms that are designed to improve safety and efficiency.

The Chiltern tunnel is part of the larger HS2 project in London, England, a high-speed rail project that will link London to the Midlands, the North and Scotland, serving more than 25 stations and connecting about 30 million people. The project will be completed in three phases. The Chiltern tunnel is one of the two phase one tunnels that will have 51 km (32 miles) of tunnels.

The two 170 m (557 ft) long, 2-kt (2,200-st) TBMs — nicknamed Cecilia and Florence — were revealed in August. Beginning at a site near the M25, they will dig as deep as 90 m (300 ft) below the Chilterns, boring through 16 m (52 ft) of chalk and flint every day and lining the tunnels with a concrete ring.

Florence will begin work in early 2021, with Cecilia following soon after on the other half of the tunnel. They are expected to operate almost non-stop for three years to excavate the 16-km (10-mile) Chiltern Tunnel.

An onboard robot called Krokodyl was developed by Align, the joint-venture team made up of Bouygues, Sir Robert McAlpine and VolkerFitzpatrick.

The robot works in a similar manner to robotic arms used on factory production lines: carrying out basic repetitive tasks: removing wooden spacers between tunnel segments and inserting connection dowels. Each of the 112,000 tunnel segments weighs up to 8 t (8.8 st). They are delivered to the TBM with wooden spacers between them, which are typically removed by hand. The robot then places the dowels into position, in preparation for slotting the segment into place.

Automating these processes will reduce the need for humans to work in this potentially hazardous environment.

"Safety is a key priority for HS2, and the introduction of these innovations that essentially remove personnel from harm's way is an excellent example of the sort of initiatives we are pleased to see implemented on the project," said Eddie Woods, head of tunnelling at HS2 Ltd. "It is one of the ways that 'safe at heart' can be achieved by minimizing exposure in high-risk locations."

Didier Jacques, underground construction director for Align, said: "A lot of work has been undertaken by all concerned that has enabled us to develop and introduce this robot, thereby reducing the risk to our personnel operating in our state-of-the-art TBMs. We are very proud of these innovations, which we would be happy to share with tunnelling teams working on other projects across the world, to help reduce the likelihood of accidents and injuries."

HS2 will connect London to Manchester and Leeds via Birmingham with a Y-shaped railway network. Trains will be able to travel at up to 360 km/h on the tracks. It is hoped that building the high-speed rail will boost capacity while causing minimal disruption to existing services, and eventually help rebalance the South-East-centric UK economy.

Following years of planning, disagreement and reviews, the government gave HS2 the green light in February. Construction has started on the London-Birmingham segment with initial focus on major engineering challenges, such as tunneling.

HS2 has been criticized for its potential environmental disruption and its budget, which has ballooned from an estimated £30.9-£36 billion in 2010 to as high as £106 billion according to a 2019 review, which also warned that it could be delivered up to five years behind schedule. Anti-HS2 groups have also argued that the shift to remote working — triggered by the coronavirus pandemic — has raised further questions about the necessity of the project. ■

Virginia launches Hampton Roads Bridge-Tunnel project, largest infrastructure project in state

Virginia Gov. Ralph Northam joined the Virginia Department of Transportation (VDOT) and state and local leaders to break ground on the Hampton Roads Bridge-Tunnel (HRBT) Expansion Project on Oct. 29. The $3.8 billion project will increase tunnel and interstate capacity along 16 km (9.9 miles) of Interstate 64 between Hampton and Norfolk, reducing congestion and easing access to the Port of Virginia and the world's largest Naval base.

"For too long, traffic in the Hampton Roads region has bottlenecked at the tunnel," said Northam. "Folks in this region deserve an easier, more reliable commute. This is the largest project in our history, and it will ensure that people can move around faster, that commerce flows more easily, and that we finally connect the Peninsula and the Southside. This project will make everyone's lives easier when it is completed."

"The world's best designers,

(continued on page 10)

Cutting Edge and George Fox conferences go virtual

by Margo Ellis, Associate Editor

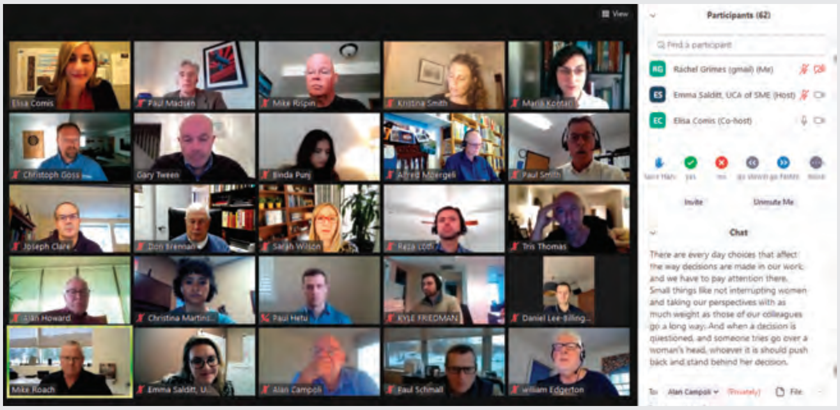
This year's Cutting Edge Conference virtual event, organized in partnership with the *North American Tunneling Journal* and UCA a Division of SME, delivered on its expected high-end technical sessions that focused on innovation and advances in tunneling technology and reviews of North America's major upcoming underground projects. Held exclusively online due to COVID-19 restrictions, the two-day conference, Nov. 10-11, provided a balanced mix of technical sessions, keynotes and live coffee break discussions with high turnout and participation from attendees across the globe.

The conference's opening session featured chair Mike Roach, Traylor Bros., who introduced keynote speaker and SME President-Elect William Edgerton of McMillen Jacobs Associates who presented on "DC Clean Rivers Project: Potomac River Tunnel Contractors' Preliminary Briefing." The afternoon sessions included topics such as the use of artificial intelligence to improve tunnel-boring machine operations and advances in SCL tunneling, followed by a live Zoom question-and-answer session.

Wednesday's sessions began with a live diversity discussion of women in tunneling, moderated by session chair Elisa Comis from McMillen Jacobs Associates and hosted by the UCA's Women in Tunneling group. Comis led an active conversation of about 80 participants on topics of mentorship, early exposure to the industry, inclusive work environments and appreciating women's perspectives.

Prompting key discussion points, an article in *Breakthrough* magazine, a publication of the International Tunnelling Association's (ITA) Young Members Group (ITAym), was highlighted. Kristina Smith, contributing editor, who wrote the article titled "Diversity Matters" and editor Amanda Foley were both present for the discussion, which included poll questions about how to promote and facilitate more diversity in the tunneling industry. A majority, 55 percent, responded that the best method is to promote a company equality culture. Smith brought up the important real-world example that when the sewer company Tideway, based in London, wanted to attract more women as employees, they changed the language used to describe the project. So instead of focusing on the huge engineering feat, the conversation shifted instead to the benefit for the environment and society, which generally holds more appeal for women.

More than 60 people joined a virtual discussion about diversity during the 2020 Cutting Edge Conference on Nov. 11.



Keeping with the schedule, the Zoom call wrapped up after 30 minutes, although participants seemed to have left feeling like there was still plenty to discuss and enjoyed the collaboration.

Rounding out Session 3: New Faces: UCA Young Members included presentations on restoring New York City's lower Catskill aqueduct and a review of Rondout Bypass, followed by a session titled "Building from the Bottom: UCA Young Members" with a live question-and-answer session.

Sessions 4 and 5 included topics on advances in alternative delivery and then a related panel discussion with experts weighing in regarding developments in approaches to project procurement, financing opportunities, risk management and how the industry can and should adapt.

George A. Fox Conference

2021 marks the 20th anniversary of UCA of SME's George A. Fox Conference. This event has historically taken place in New York City at the City University of New York Graduate Center. However, because of COVID-19 restrictions, the conference will be virtual on Jan. 26.

This year's conference will be an abbreviated program that will be pre-recorded so that everyone can view it at their convenience. The on-demand video recording will be approximately 2.5 hours long and will be available for a nominal fee on the UCA website starting on Jan. 26, 2021, the day that the conference was originally scheduled.

The video will include the "Tunnel Industry Update" by James Rush, Editor, *Tunnel Business Magazine*. Rush will review the status of the current ongoing major tunnel projects and will present information on the major upcoming tunnel projects. There will also be a panel session that discusses the measures that owners and contractors implemented to allow work to continue during the pandemic.

Finally, Ed Plotkin will give an overview of his planned 2022 presentation that will provide some unique insight into who George A. Fox was and how he influenced the tunneling industry. Plotkin will also discuss some of the major advancements in the tunneling industry that have occurred during the past 20 years. ■

Connection to Allegiant Stadium in Las Vegas approved

The Boring Co. has received approval to move ahead with the construction of an underground connection at Allegiant Stadium in Las Vegas, NV, *KVVU TV* in Las Vegas, NV reported.

The company owned by Elon Musk has already has spent about a year drilling the $52.5 million Convention Center people mover, which has three stations along parallel 1.6-km (1-mile) tunnels connecting exhibit halls and parking at the conference facility just east of the Strip.

It is expected to open by the end of the year to provide trips of less than two minutes for conventioneers in 16-passenger Tesla vehicles.

On Oct. 22, the Clark County Stadium Authority approved a land use application for 3333 Al Davis Way submitted by Musk's Boring Co..

The Boring Co. wants to widen its scope and build a people-mover tunnel system beneath the Las Vegas Strip in a project dubbed the Vegas Loop.

It would drill underground from downtown Las Vegas, beneath the Las Vegas Boulevard resort corridor, to the newly opened Allegiant Stadium, a distance of about 11.25 km (7 miles), according to a presentation to the Las Vegas Convention and Visitors Authority (LVCVA).

A connection to McCarran International Airport is also being considered, the *Las Vegas Review-Journal* reported.

The Associated Press reported that no cost projections were disclosed by LVCVA CEO Steve Hill and Boring Co. President Steve Davis. But they said taxpayer dollars would not be used, and passenger stations would be paid for by property owners.

They said the company is seeking a city permit and will submit plans to Clark County.

The concept includes a loop of about 24.15 km (15 miles), with perhaps 50 stations where passengers would board self-driving electric Tesla vehicles. Passenger fares have not yet been determined.

The Boring Co. will have to obtain building permits to proceed with expanding its underground transportation system.■

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Lower Thames Crossing Tunnel tender launched by Highways England

Highways England has invited firms to submit tenders to build the longest road tunnel in Britain which is part of the Lower Thames Crossing project, one of the most ambitious projects in the United Kingdom in decades.

The £2 billion contract is the largest contract in the history of Highways England.

The *Tunnelling Journal* reported that the Lower Thames Crossing will improve journeys by almost doubling road capacity across the Thames east of London, with 22.9 km (14.3 miles) of new road featuring two 4.3 km long (2.6 mile) tunnels.

Highways England said work on the project could begin in as soon as 18 months.

The Tunnels and Approaches contract includes design and construction of the twin road tunnels under the River Thames. The 16-m (52-ft) diameter tunnels will be bored mostly with tunnel boring machines and will be some of the largest bored tunnels in the world. They will also be the longest road tunnels in the UK. The scope also includes the portal buildings, approach roads and the tunnel systems.

Keith Bowers, the Lower Thames Crossing's Tunnels and Systems Director, added: "This contract is unparalleled in its ambition, and we need the right partner to match that ambition. From our bidders we're looking for outstanding construction, health, safety and wellbeing performance. We have committed to targets that mean by 2040 nobody will be killed or seriously injured on our roads and motorways, and we need our contractors' design and delivery to meet that target for our road users and workers.

"We are setting priorities in our contracts that will reward excellence during delivery by offering an enhanced share of cost savings for high performance in areas including health and safety, customer focus, delivery, environment, people and communities and economics."

The Tunnels and Approaches contract is the first of the three main works contracts to be procured for the scheme, with the Roads North and the A2 M2 contracts expected to be announced early in 2021.

The scheme's planning application was submitted on Oct. 23, and the Planning Inspectorate now has 28 days to review the application and decide whether to allow the application to proceed to examination. A decision is expected from the Secretary of State for Transport in 2022, with construction expected to start later that year.

The A303 Stonehenge (Amesbury to Berwick Down), another significant Highways England tunneling scheme, is due to receive a decision on its Development Consent Order application by the Secretary of State for Transport on Nov. 13. ■

Sen. pushes to get Gateway Project permits moving

The Gateway Tunnel project linking New York and New Jersey has been stalled in limbo for nearly three years while the Environmental Impact Statements needed to move the project forward have remained unsigned.

On Nov. 16, U.S. Sen. Charles Schumer (D, NY) said he is hopeful a new administration in the White House could advance the project. NJ.com reported that the Federal Railroad Administration (FRA) is closing in on three years since it missed a March 30, 2018, deadline the U.S. Department of Transportation imposed to issue a record of decision after reviewing the Environmental Impact Statement for the Gateway rail tunnel.

After citing "four years of gratuitous delay" from President Donald Trump's administration, Schumer said he is counting on some help from President-Elect Joe Biden to get the Federal Railroad Administration to finally make a decision on the Environmental Impact Statement, which has held up the project.

"Trump refused to allow Gateway to go forward, (U.S. Transportation Secretary Elaine Chao) refused to sign the EIS," Schumer said at a press conference. "Biden said repeatedly he wants to fund Gateway. As soon as he becomes president and his appointees take office, I'm urging them to sign the EIS and Gateway can move forward."

A number of officials in New York and New Jersey have voiced support for the tunnels. The tunnels connecting the states are 100-years-old and if one were to be put out of service it could have a devastating economic impact on the region.

While the COVID-19 pandemic has reduced commuter rail travel to 20 to 25 percent of pre-COVID-19 levels as many employees work from home, supporters say the tunnels are needed for when workers do return to Manhattan offices.

NJ.com reported that during the last four years, New Jersey and New York's congressional delegation sparred with Trump over funding Gateway.

Schumer also talked about the federal funding that he said could come to Gateway with the "stroke of a pen." Construction costs of new tunnels are estimated at $9.5 billion and rehabilitation of the exiting 110-year old tunnels at $1.8 billion. ■

Kelley Digger Shield begins work on water supply tunnel in Atlanta, GA

On July 1, 2020, The Atkinson/Technique Joint Venture entered into a contract with Kelley Engineered Equipment (KEE) for the supply of a 2.3-m (90.25-in.) digger shield. On Aug. 15, just six weeks later, the machine was on site and ready to work. Averaging about 1.6 m/d (5.3 ftpd), the distance needed to install four rings of liner plate, the shield finished its drive on Oct. 6, 2020.

The task at hand was tunneling 109 m (356 ft) of varying stiff clays, saprolite and mylonite for the city of Atlanta's Water Supply Project Phase II. This undertaking connects a new 12.9 million m³ (3.4 billion gal) emergency drinking water reservoir to a new treatment plant. However, the shield's most important job was to provide the required Cooper E-80 Loading support under 47 m (154 ft) of the CSX railroad passing intermittently overhead with cover as low as 4.6 m (15 ft).

In addition to thrust and steering systems, the unit was designed with special features to expedite assembly and disassembly in the heading. After the collapsed shield was lowered down a 9.1 m (30 ft) diameter shaft, it was transported through an existing prelined tunnel and assembled at the mining site. The shield was assembled within these liner panels and thrust off smaller ID panels that were erected within the safety of the shield.

Fabrication, workshop assembly and factory acceptance testing were performed at KEE's longtime partner, Wolf Hills Fabricators, LLC in Abingdon, VA. Wolf Hills supplied exceptional quality and was instrumental in achieving the very quick delivery.

Atkinson Construction's Konner Horton was quoted as thanking KEE for "a machine that worked great and getting it done for us so quickly." ■

Hampton Roads: $3.8 billion project is the largest in the history of the Commonwealth

(continued from page 4)

builders, engineers, and technology are converging here in Virginia to build your new tunnel," said Secretary of Transportation Shannon Valentine. "We are bringing every asset to the table to give people what they may value most — time."

Virginia crews will use a highly specialized tunnel boring machine to dig through soil and construct tunnel segments simultaneously. The advanced technology is used in the construction of highly complex projects, such as Manhattan's Second Avenue Subway. The new HRBT is only the fourth roadway project to use this equipment in the United States. The machinery is under construction in Germany and is expected to arrive in Hampton Roads in 2021 for assembly, which will take several months. It is expected to begin tunneling operations in early 2022, HRBT Expansion said in a release.

"VDOT is using this advanced boring technology for the first time ever," said VDOT Commissioner Stephen Brich. "We're doing it because this is one of the nation's most important maritime channels, and this technology means less disruption to military and commercial activity, and less impact on marine life."

The project has received support from the Commonwealth of Virginia, the Hampton Roads Transportation Accountability Commission (HRTAC), federal and local partners. Design-build contractor Hampton Roads Connector Partners (HRCP) received a Notice to Proceed for full construction activities in September. The project is expected to be completed in November 2025.

"The HRBT expansion project is a great example of how the legislature, VDOT and HRTAC are working together to achieve a greater vision for transportation in Hampton Roads and provide solutions to bring the region out of gridlock," said Kevin Page, HRTAC Executive Director.

A Project Administration and Funding Agreement with HRTAC first announced in April 2019, commits 92 percent of locally sourced funding for the expansion. Additional financing includes $200 million from the Commonwealth's SMART SCALE program and $108 million from VDOT.

The HRBT Expansion Project will add twin, two-lane bored tunnels and widen the four-lane segments of Interstate 64 in Hampton between Settlers Landing Road and the Phoebus shoreline, and in Norfolk between the Willoughby shoreline and the I-564 interchange. More than 100,000 vehicles currently use this facility during peak travel periods.

State and regional leaders, including Secretary of Transportation Valentine, VDOT Commissioner Stephen Brich, Hampton Mayor Donnie Tuck, Norfolk Mayor Kenneth Alexander, Suffolk Mayor and HRTAC Chair Linda Johnson, and representatives from VDOT, HRTAC and HRCP attended the social-distanced groundbreaking event with Gov. Northam. ■

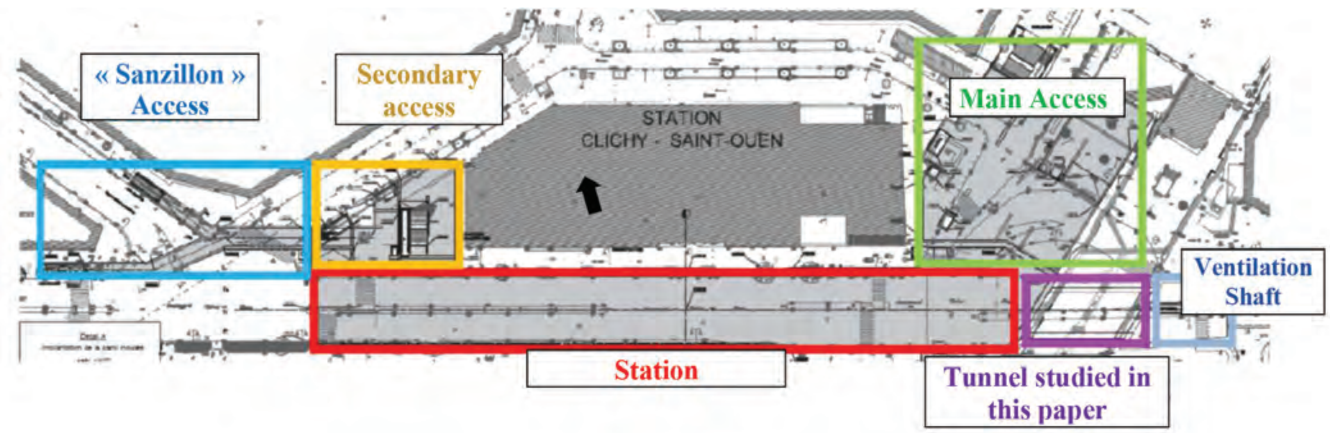

Make Plans
to Attend

Boring a tunnel under a train station using ground freezing:

Line 14-T03 - Extension of a subway line in Paris

FIG.1

Plan view of the L14-3 project.



This article presents the outlines of the ground freezing works of the Line 14 extension project to the north of the Parisian subway in France. This project is one of the first in a long series of tunneling works managed by a company called Société du Grand Paris, which is in charge of the construction of approximately 200 km (124 miles) of tunnels and 68 subway stations around Paris. The subway lines will be opened, one by one, from 2020 to 2030. Package 3 of the Line 14-North project includes the creation of a subway station, three pedestrian accesses, a ventilation shaft and a 26 m- (85-ft) long rectangular tunnel linking the station and the shaft (Fig. 1).

This article focuses on the construction of the rectangular tunnel that joins the station and the shaft. The project will utilize artificial ground freezing due to a complex hydro-geotechnical context.

Marc Bouffier, Louis Delmas, Benjamin Lecomte, Laurent Buissart and Christian Gilbert

Marc Bouffier and Benjamin Lecomte, members UCA are, lead design engineer and design office director, Vinci Construction Grands Project, Louis Delmas and Christian Gilbert are geotechnical engineer and deputy director infrastructure division Systra and Laurent Buissart is project director, Spie Batignolles, email marc.bouffier@vinci-construction.

Presentation of the project

The tunnel. The rectangular tunnel is located 3.2 m (10.5 ft) under an active commuter train station (RER Line C) that was built in 1984 on deep concrete piles (Fig. 2).

The as-built position of the piles was only partially known at the beginning of the project, which required the excavation of a small gallery just above the RER-Line C (RERC).

Because Line 14 trains will circulate between the station and the shaft, the central pile (B11) was taken down and a section of the northern pile (B12) had to be reduced, as it extended beyond the external lining of the vertical wall. The southern pile (B3) will stay in its initial configuration.

At the center of the structure, two massive concrete beams were cast to transfer the loads onto concrete walls, requiring a hat-shape excavation line (Fig. 3). The tunnel was then divided into two cross sections:

- Section A-A: 8 m (26 ft) high by 14.5 m (47.5 ft) wide at each end of the tunnel.
- Section B-B: 11.2 m (36.7 ft) high by 14.5 m (47.5 ft) wide in the middle.

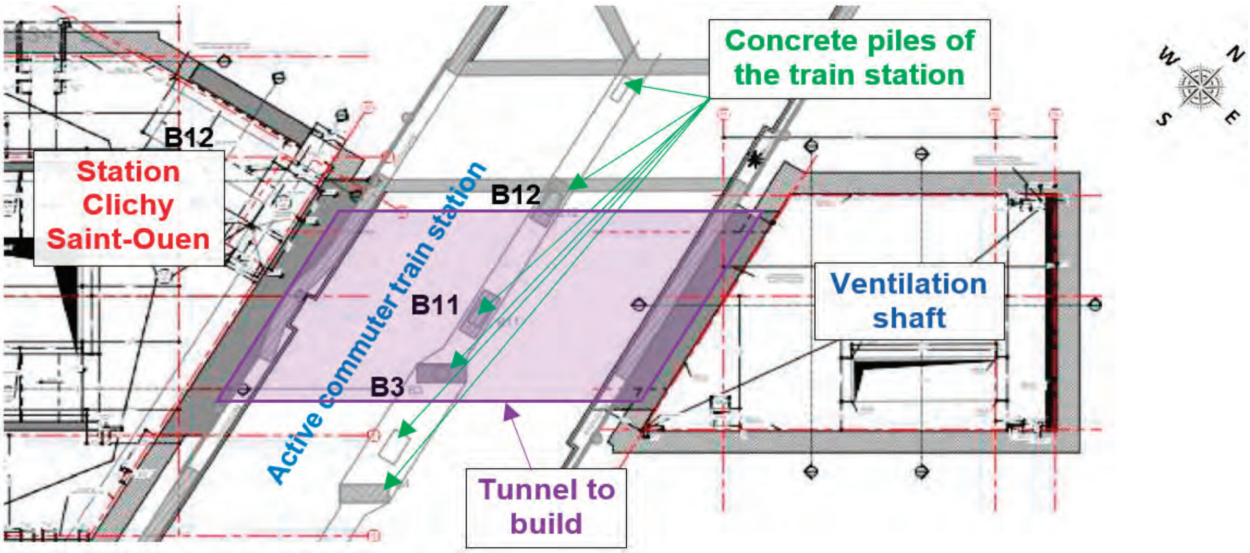
The transition from one section to the other is about 4 m (13 ft) (Fig. 3).

Geotechnical context. Most of the tunnel is excavated within the Beauchamp Sands formation, a geotechnical unit that includes three sublayers:

- Upper layer, consisting of fine sands or silts.

FIG.2

Plan view of the tunnel to build.



- Intermediate layer, which is much more clayey and can contain up to 30 percent fine particles (<2 µm).
- Lower layer, similar to the upper layer, but it is not in the tunnel's path.

Beauchamp Sands were found up to the roof of section A-A and a marly-limestone formation (Saint-Ouen Limestone) in section B-B. This layer is basically a marl, with blocks of limestone reinforcing the ground.

A thin layer of very fractured limestone (Ducy limestone) divides the upper Beauchamp Sands and the Saint-Ouen limestone layer. Its thickness ranges from 40 cm to 1 m (15 in. to 3 ft).

The station is located under a former industrial site that has polluted the soil for several decades, leaving behind small quantities of hydrocarbons, which were found during initial investigations. The salt content was not significant enough to prevent the use of artificial ground freezing.

Hydrological context. The water level is located approximately 6 m (12 ft) above the tunnel's crown, thus the ground is fully saturated.

Construction of the Clichy Station and the ventilation shaft completely modified the initial water flow trajectories, creating a north-south artificial channel under the RERC. The diaphragm walls created a dam effect with nearly 0.5 m (1.6 ft) of head difference between the north and the south piezometers. A secondary consequence of the dam effect was an increased flow speed underneath the RERC in the bottleneck created by the two shafts.

Chemical tracings were implemented during construction work to quantify the water flow speed and to confirm the

FIG.3

Longitudinal section and excavation works in the transition area.

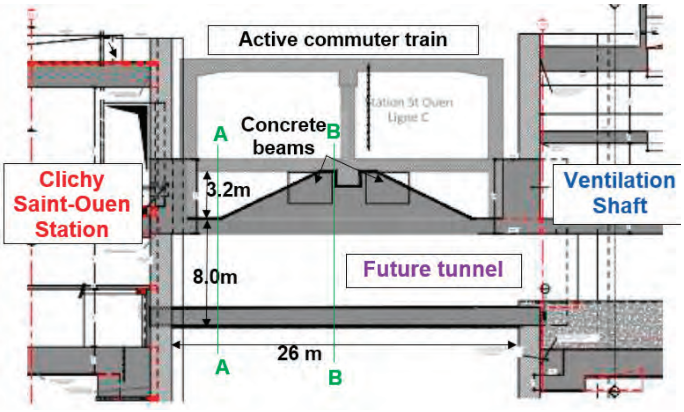
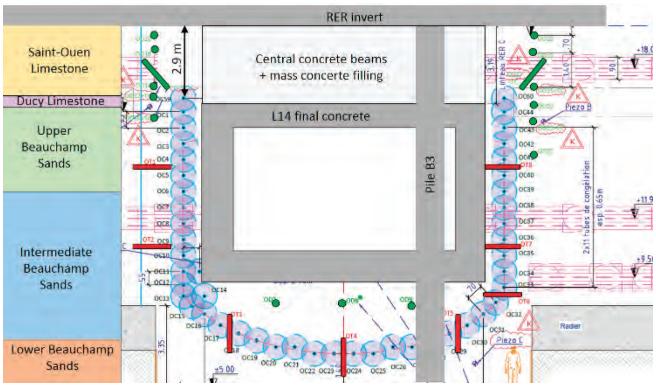


FIG.4

Frozen-body pattern.



feasibility of ground freezing. The hydrological study showed that flow speeds could be very high locally (20 m/day), which was due to the presence of the fractured Ducy limestone. However, the majority of the fluorescein was not detected even a few weeks after the injection, leading to the conclusion that the average water flow speed (< 0.5 m/day, < 1.6 ftpd) was low enough to practice artificial ground freezing.

Two hypotheses were made to explain the location of the largest flow speeds. One possibility was that there would be some heterogeneity in the soil-diaphragm wall interface. The other was that the Ducy limestone permeability had increased due to the washing out of its fracture filling. Indeed, during the drilling of the drains, the water was found to be charged with dark clay particles.

Frozen body pattern. The frozen-body shape was designed to account for two primary constraints:

- The train station just above the tunnel: the frozen body had to remain open on top.
- The necessity to completely freeze the sandy layers: the uppermost freeze pipe had to be located in the Ducy limestone formation, 2.9 m (9.5 ft) from the RER base slab.

A U-shape frozen body was therefore designed, with a pipe spacing of 65 cm (26 in.) along the vertical sidewalls and 80 cm (31 in.) on the inverted vault. For geometrical reasons (location of the piles, lack of space in the ventilation shaft), local adaptations were made in the freeze pipe position plan (Fig. 4).

A total of 2,500 linear m (8,202 ft) of drilling was performed from both the station and the shaft:

- 1,709 m (5,606 ft) for 122 freeze pipes (61 per side), averaging 14 m in length.
- 450 m (1,476 ft) for 30 thermocouples. Sensors were placed every 2 m (6.5 ft) along the tunnel.
- 495 m (1,624 ft) for 34 drains: 19 to relieve water pressure inside the "U" during initial freezing and 15 to lower the water table at the top of the "U".

In order to reduce water inflows inside the excavation area, tube-a-manchette injections were performed between the frozen body and the RER base slab. Several drains had to be installed to lower the water table because permeability criteria were not reached in the grouted area. These drains were active from the beginning of the excavations to the end of concreting works.

Mixed artificial ground freezing. The ground-freezing work took place in two stages:

- Initial freezing with liquid nitrogen N_2 until the mechanical criteria were reached.
- Maintenance freezing with cooled brine (-35 °C). All pipes were therefore retrofitted with bigger tubes prior to excavation in order to ensure normal flow.

The transition from liquid nitrogen to brine was progressive and sequenced, which required that both circulate at the same time. A valve and a thermometer were installed at the head of each freeze pipe.

In order to maintain mechanical stability in zones where water flows were significant, there was a second switch from brine to liquid nitrogen during excavation works.

Ground freezing design

Frozen body characteristics — *Ground freezing temperature.* For this project, a frozen body was defined with a temperature at least equal to -10 °C. Frozen volumes for which temperatures were higher than -10 °C were neglected in the analysis, and frozen volumes for which temperatures were lower than -10 °C were considered to be as strong as if they were -10 °C.

This criterion was generally easy to reach except in the area at the top of the frozen sidewalls, where water inflows affected the freezing.

Ground characteristics. The frozen body's mechanical and thermal characteristics were determined using particle size distributions following the methodology described by ISGF Working Group 1 in 1991. No laboratory tests were undertaken on frozen samples for this

TABLE 1

Mechanical and thermal ground characteristics.

	Upper and lower layers			Intermediate layer		
	Unfrozen		Frozen (-10°C)	Unfrozen		Frozen (-10°C)
Conductivity [W.m-1.K-1)]	2.25		3.4	1.8		2.76
Thermal Capacity [kJ.m-3.K-1)]	2,710		2,000	2.550		1,830
Cohesion [kPa]	0		600	55		800
Internal Friction Angle [°]		38			17	
UCS [kPa]	0		2,500	150		2,200
E-Modulus [MPa]		270			100	
Poisson Ratio	0.3					

project, but the values were chosen in accordance with tests performed for a similar project nearby.

The ground characteristics used for the project are summarized in Table 1.

Minimum dimensions of the frozen body. The minimum frozen body shape was determined by the distance between the isothermal temperature -10°C and the nearest freeze pipe. The design was performed with a minimal thickness of:

- 80 cm (31 in.) on the vertical sidewalls.
- 60 cm (21 in.) on the inverted vault, which is much less stressed.

This defined the mechanical criterion, which was verified numerically using the RS2 2D software. The safety factor was defined as the ratio of the radius of the Mohr-Coulomb circle to the Mohr-Coulomb failure criteria. The FEM analysis concluded that the safety factor at each point of the frozen body ranged from 2 to 4 in the upper Beauchamp Sands, from 4 to 11 in the intermediate Beauchamp Sands and from 5 to 10 in the lower Beauchamp Sands. The global safety factor was much higher when considering the real thickness of the frozen body with its actual temperature distribution from -30 °C to 0 °C and the temperature-dependent mechanical properties.

Thermal analysis. A 2D finite elements analysis (FEA) was performed with CESAR v5 software (Fig. 5) to anticipate initial freezing time to reach the predefined mechanical criteria using nitrogen, which was around three days.

FIG.5

Thermal analysis.

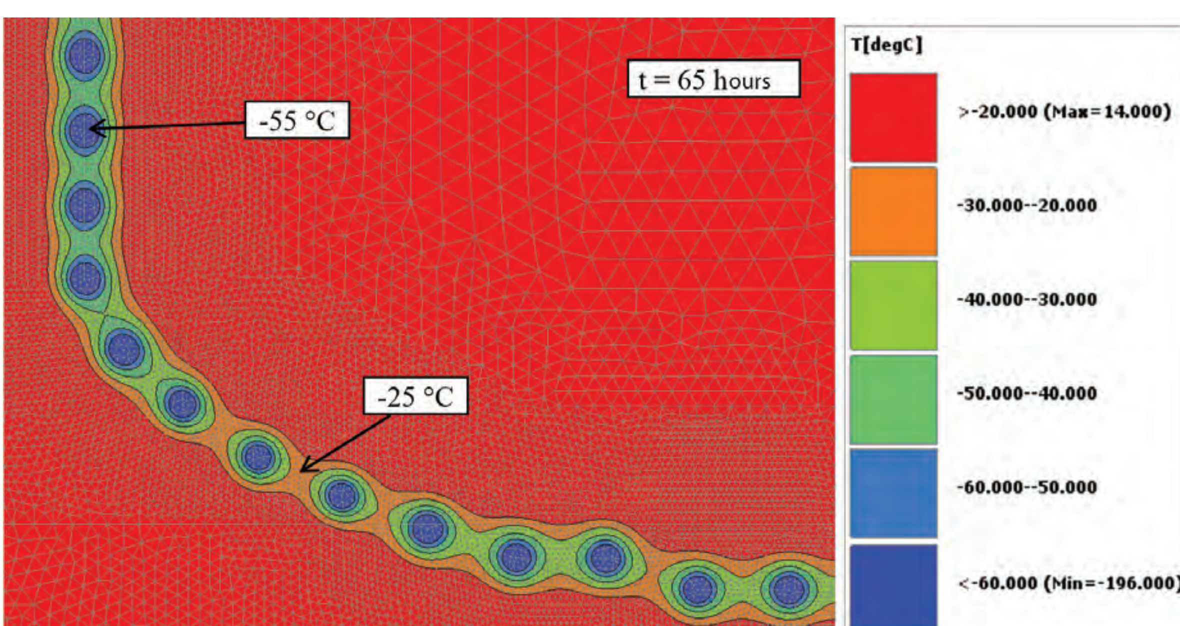
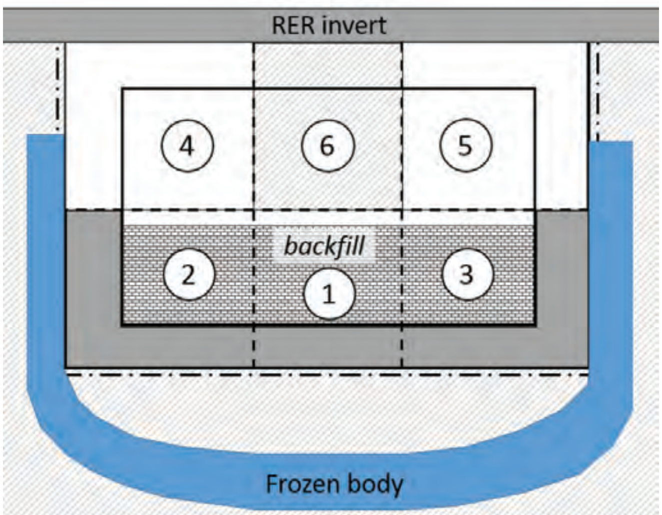


FIG.6

Excavation phasing.



Additional durations were anticipated:

- Deviations of 2 percent added around one day (numerically calculated).
- Ground heterogeneity, particularly undetected clay lenses, could add another day.

All things considered, a duration for initial freezing of approximately five days was anticipated.

In addition to the anticipation of initial freezing duration, the FEA simulations enabled:

- An estimate of nitrogen consumption and of the thermal power necessary to maintain brine at - 35 °C. A total value of 2,000 m^3 and a minimum thermal power of 150 kW were anticipated. The thermal power was split in two units but for practical reasons, a total power of 210 kW was installed on site.
- An increase in probe spacing over the inverted vault, which ensured that the mechanical criterion on the frozen inverted vault and on the vertical frozen sidewalls was reached more or less at the same time.

Phasing. The phasing of the work was dictated by the buoyancy of the U-shaped frozen body, which would generate vertical constraints on the RER invert (base slab). The tunnel's excavation was divided into six sections. Three sections in the lower part were excavated first and were backfilled after the formwork was cast, which created a working platform for the excavation of the three upper sections (Fig. 6).

Temporary support design. Because of the creep behavior of ice, the strength of the frozen body decreases with time. Heavy steel ribs (HEM 220 and HEM 200) were installed every meter as temporary support together with a 27-cm thick

FIG.7

Temporary supports of gallery No. 1.

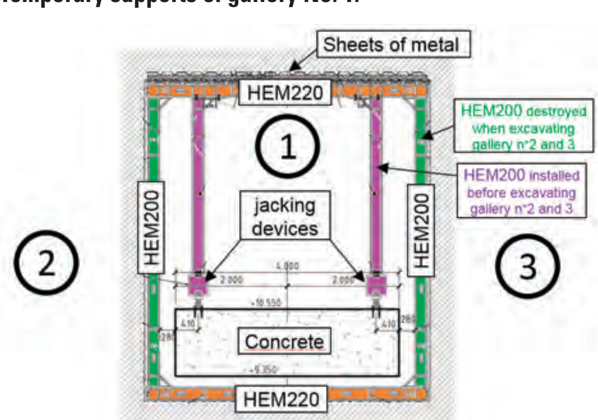
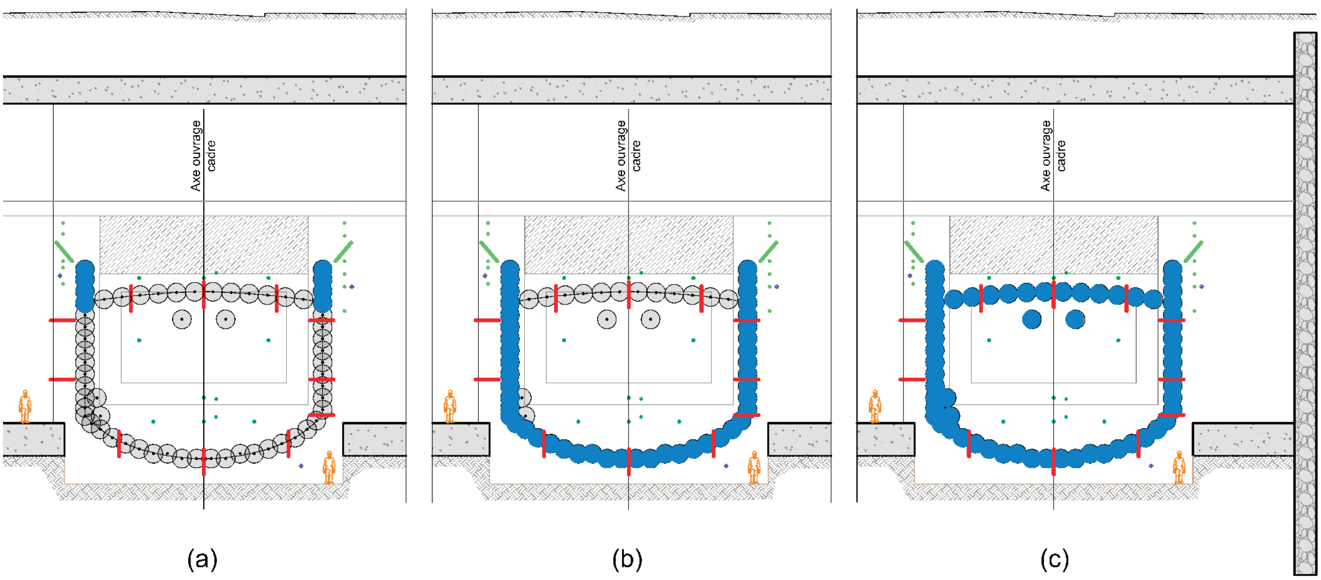


FIG.8

Sequence of initial freezing: (a) Ducy limestone freezing; (b) Beauchamp sands freezing; (c) end of freezing.



layer of fiber-reinforced shotcrete. Rib size was dictated by the rectangular shape of the galleries. Moreover, due to the geometrical constraints to drill the freeze pipes, the space between the frozen body and the excavation line was quite limited.

Given the poor characteristics of the upper Beauchamp sands (c = 0 kPa) and of Saint-Ouen limestone, sheet piles were installed at the crown of the lower galleries and at the transition from the short section to the high section (sections AA and BB in Fig. 3), which was very difficult due to the presence of hardened limestone. In addition, jacks were used to redistribute loads from the sidewalls of gallery No. 1 when excavating gallery No. 2 (Fig. 7).

Ground-freezing piloting

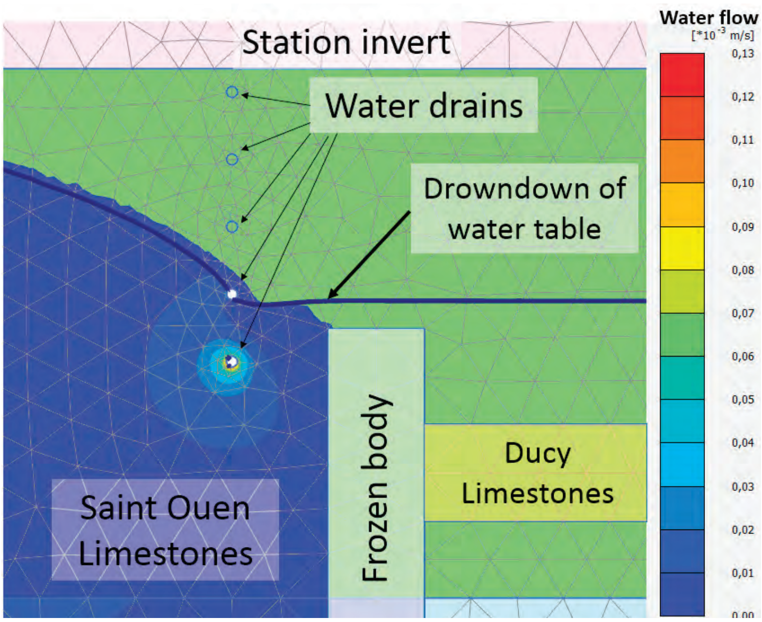
Initial freezing sequence. To cope with the significant water circulations previously described, a solution could have been to grout the Ducy limestone, since the clay filling was removed from the fractures. However, this was not feasible within the schedule. Instead, the initial freezing with liquid nitrogen was sequenced, taking into account the critical water flow speed required to close the space between freeze pipes using liquid nitrogen, which is around 20 m/day (65 ftpd) (Andersland, 2003).

To avoid the bottleneck effect in the Ducy limestone that would appear if the sands and marls were frozen first, the ground freezing was sequenced in three steps (Fig. 8). The Ducy limestone was frozen first (Fig. 8-a), thus redirecting water circulation above and below the frozen ground wall. The closure of the flow in the Ducy limestone was verified through regular temperature monitoring and by using drains located at the center of the frozen shell. The rest of the U-shaped shell was then frozen with liquid nitrogen (Fig. 8-b).

Finally, the central inverted vault was frozen with liquid nitrogen initially, and with brine for maintenance (Fig. 8-c). The goal was to strengthen the upper Beauchamp sands — a geotechnical unit without any cohesion — and to close off the shell, creating a watertight "box" for the excavation of galleries 1 to 3. However, the freezing of this horizontal line generated significant heave of the RERC station, and was abandoned prior to excavation works.

FIG.9

Water flow calculations generated by drains around the frozen body.



Thermal erosion test. Two drain lines were placed on either side of the gap between the upper freeze pipes and the bottom slab of RERC, to capture water seepage before it entered the tunnel. These drains were also used to reduce the volume of water that would flow over the U-shaped shell.

One concern was the risk of thermal erosion due to water flow from the top of the U shape, which could have caused a reopening of the Ducy limestone fractures. This, in turn, would have increased flow speed in the Ducy limestone because of the dam effect created by the frozen U shape, further hindering closing the fractures. Given the risks involved, an erosion test was conducted after the switch to temperature maintenance using brine.

The erosion test consisted of discharging the drains located inside the "U," thus artificially causing water flow over the arms of the "U." Temperatures in the frozen body were monitored for three weeks. No increase was observed, even at higher brine temperatures (up to T brine = -28 °C tested). This demonstrated the robustness of the frozen body against external water flow (and thermal erosion).

A full tank of liquid nitrogen was nonetheless kept on site to switch back to liquid nitrogen cooling if necessary.

Temperature monitoring and frozen wall thickness evaluation. Chains of thermocouples were installed in dedicated boreholes (Fig. 4). The longitudinal spacing between each individual thermocouple was set at 2 m (6.5 ft).

To ensure that the mechanical criteria were verified for the duration of the tunneling work, the position of the -10 °C isotherm had to be extrapolated from the temperature measured at each sensor point.

The hypothesis on temperature distribution was logarithmic, following Sanger and Sayles's equation (Sanger 1979). The temperature distribution was calculated with:

$$T(r) = T_0 - (T_0 - T_{f.tube}) \frac{\ln\left(\frac{R}{r}\right)}{ln\left(\frac{R}{r_0}\right)}$$

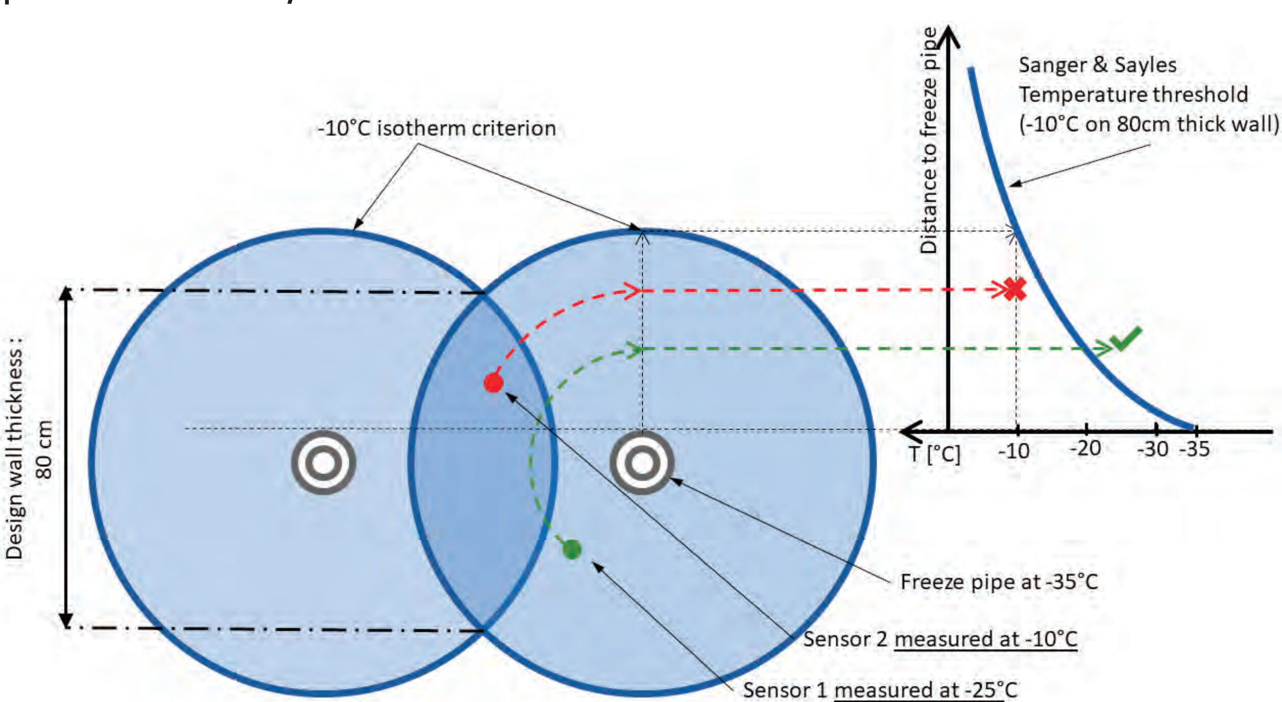
with *r* the running coordinate, *R* the distance between the sensor and the freeze pipe surface, r_0 the freeze pipe radius (external), T_0 the temperature of the sensor (e.g. -10 °C), $T_{f.tube}$ the freeze pipe temperature (e.g., brine temperature).

Once all the freeze pipes and temperature sensor pipes were drilled, their 3D position was measured and entered in a 3D CAD model. The analysis of this 3D CAD model had the following objectives:

- To measure the real distance *R* between each sensor and the closest freeze pipe, deviations are included. This is a sensitive input to the Sanger and Sayles formula (*R*).
- To verify the spacing between each pipe maximum deviations of 40 cm (15.7 in.) were recorded. This implied a longer initial freezing time for the sections of the shell with wider spacing. Additional freeze pipes were installed to correct wider spacing and selected boreholes from the ventilation shaft were

FIG.10

Temperature threshold to verify thermomechanical criterion.



prolonged to compensate for significant deviations of drillings originating from the station.

An automated alert system was installed in order to ensure safety in the thickness of the frozen wall during the duration of artificial ground freezing. The temperature was recorded every 15 minutes and uploaded onto a web application for data gathering and plotting. Threshold temperatures were defined and notifications were automatically sent when the threshold temperatures were reached.

The temperature/thickness criteria were defined considering the overlap of two circular isotherms as the thickness of the frozen wall (Fig. 10). Because this approach does not take into account the relative influence of the freeze pipes, which tend to smoothen the overlap, the specified criteria were conservative:

- Design criteria: thickness 0.8 m (2.6 ft) in diameter at -10 °C.
- Alert threshold: Isotherm -2 ° C at 0.75 m (2.4 ft) from the cold source = overlap of 0.4 m (1.3 ft).
- Alarm threshold: Isotherm -2 °C at 0.65 m (2.1 ft) from the cold source = overlap of 0.2 m (0.65 ft).

The goal of the alert and alarm thresholds was to safeguard the continuity of the ice wall over the full duration of the project in order to ensure water tightness. The geometric thresholds were transformed into temperature thresholds, using the Sanger and Sayles formula for each sensor, depending on the distance between each sensor and the closest freeze pipe.

These thresholds were used to drive the active freezing phase. Temporary thresholds, defined using a lower T*f.tube* temperature of -80 °C (i.e., the exhaust temperature of nitrogen) were used during the liquid nitrogen sequences. The switch to brine took place after all temperature measurements passed under the liquid nitrogen threshold, thus reducing frost heave and nitrogen consumption at the same time.

Uplift due to frost heave. Freezing-related frost heave in soil is the result of two different processes, which are associated with the ground's hydraulic conductivity and texture. In very permeable grounds, frost heave is unlikely to occur since water dilation during the phase change from water to ice pushes away liquid water toward the unfrozen parts, thus absorbing the dilation.

The freezing front advance speed depends on the freezing temperature. There is a critical ground hydraulic conductivity threshold at which the water does not have time to escape the freezing front before being frozen. For ground with hydraulic conductivity lower than this critical value, frost heave is possible and is a function of the initial water content being frozen (thus dilated) minus the part of the water that can migrate toward the unfrozen parts. This occurs in fine sands, such as clayey Beauchamp sands.

In silts, another process takes greater importance: cryogenic suction. At the freezing fringe, free water freezes at 0 °C (in the absence of solutes), but adsorbed water freezes at lower temperatures due to the intermolecular forces between the grains and the water (Khakimov, 1957). This effect also exists in coarser soils such as sands, but the consequences are negligible due to the lower specific surface area. In silts, the specific surface area is large, and the adsorbed water content is not negligible compared with the free water. The presence of liquid water at temperatures below fusion temperature implies a contraction of water, which leads to a pressure decrease known as suction. To cancel this suction effect, liquid water is drawn toward the freezing fringe until the pressure is high enough for the phase change to occur. This process leads to a constant increase in water content.

During the initial freezing of the "U" with liquid nitrogen, a degree of displacement of the pile standing on barrette B11 was measured. This was the result either of frost heave under the tip of B11, or of an upward friction force due to frost heave along the barrette. In any case, the frost heave occurred because the water could not escape from the less permeable Beauchamp sands as a consequence of the fast advance of the freezing front during initial freezing with liquid nitrogen (-196 °C to -80 °C). When the coolant was switched to brine at a higher temperature (-35 °C to -28 °C), the frost heave stopped.

The upward force created by frost heave and transmitted by the barrette caused an uplift of the central part of the RERC and also had the secondary effect of unloading the ground located under the RERC base slab.

The uplift continued during initial freezing of the

FIG.11

Pile B11 movement during the ground freezing process.

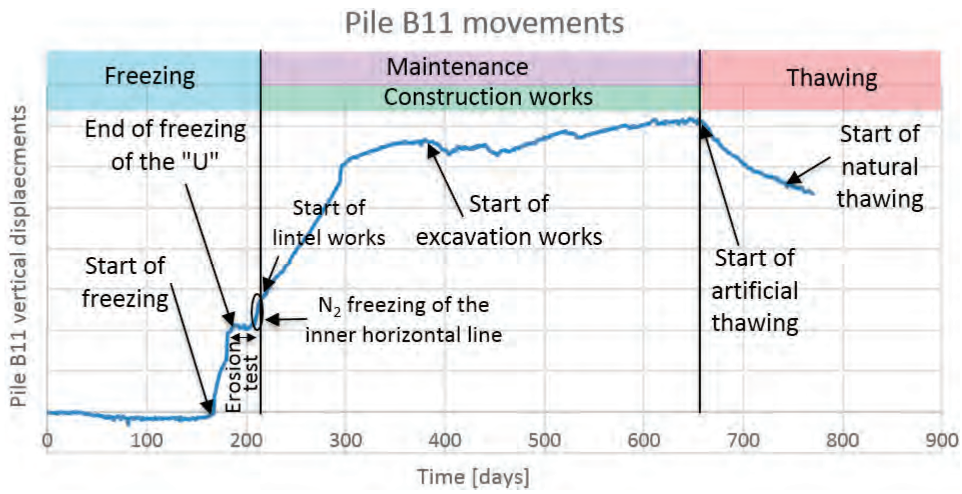
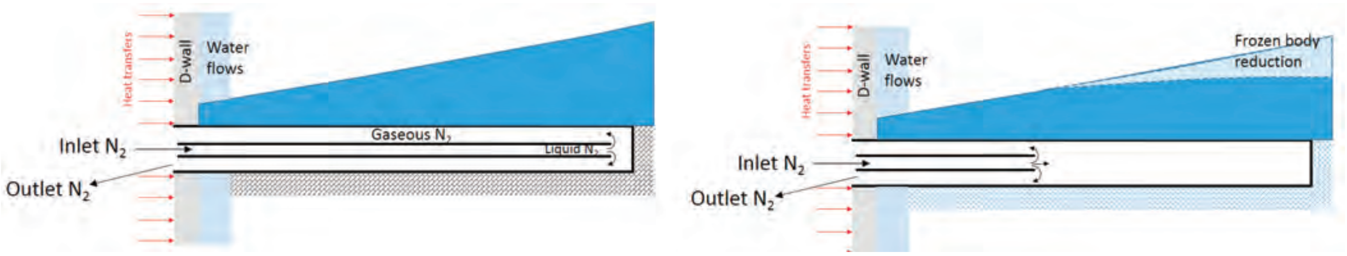


FIG.12

Frozen body reduction.



horizontal line, which acted as a forepoling umbrella, but the heave did not stop when switching the refrigerant to brine. In this case the frost heave process was continuous, probably influenced by the silt content in the Saint-Ouen limestone and the continuous water inflow under RERC.

Several adjustments were tested without any noteworthy effects on the uplift: a full opening of the lateral drains to reduce water inflows, an increase of the brine temperature, and stopping brine flow in the umbrella freeze pipes. The only solution was to abandon the frozen umbrella and actively melt it. When forepoling was necessary, it was implemented using flat sheet piles.

The major steps of the freezing project are presented in Fig. 11.

Maintenance with liquid nitrogen. In September 2018, the caution threshold was reached on a sensor located near the diaphragm wall of the ventilation shaft. This occurred as the lower lateral section was being concreted. The increase in temperature was associated with several factors:

- The proximity to the shaft and ventilation air-fluxes.
- The recent concreting of the tunnel abutment. During the 48 hours following shotcrete placement, heat emission from concrete hydration increased the temperatures up to 7 °C in the thermocouple probes located 50 cm from the excavation line.
- A warmer initial ground temperature in this particular area, probably due to water circulation under the RERC station. This last factor had been identified at the start of the project.

The corrective measures triggered by reaching the threshold were to decrease brine temperature and fully open the drains. But they were not sufficient to stop the warmup and to refreeze the frozen wall. The decision was made to switch to liquid nitrogen maintenance.

Liquid nitrogen maintenance was reintroduced using intermittent injections (for four to eight hours per night, depending on energy needs). A specific threshold was put in place to ensure the mechanical criteria were always verified and triggered an injection of liquid nitrogen N2. After a period of adjustment and calibration with the dynamic temperature response of the ground, the injections were performed during the night to limit interactions with the civil works.

After a few weeks of intermittent liquid nitrogen injections, another upward shift in the RERC was measured. Pile P8, located on top of barrette B3, started to lift because of a difference in heat flux at the proximity of the shafts and along the axis of the RERC. As stated above, the external heat flux (air convection) increased as it approached the diaphragm walls. Given that the freeze pipes were coaxial with an input flux from the center pipe and a return (and heat exchange with the ground) in the annulus space, the coldest part of the freeze pipe was its tip. In order to verify the mechanical temperature criteria at every point of the frozen shell, the intermittent injections of liquid nitrogen were triggered based on the temperature sensors closest to the diaphragm wall (warmer part). The cold removal along the freeze pipe created a much larger wall thickness along the axis of the RERC, whereas the wall thickness barely met the mechanical criteria close to the diaphragm walls.

By December 2018, the frozen wall had expanded just under the RERC base slab causing the uplift. The problem was solved by cutting the central pipe of the freeze pipe to half its initial length. This reduced heat removal at the tip of the freeze pipes and increased it closer to the diaphragm wall. This effectively stopped the frost heave (Fig. 12).

Active thawing and settlement control. Given the underpinning of barrette B11 to the L14 tunnel, some adjustments were needed to limit differential ground settlements between B11 (fixed point, attached to L14N), B3 (lateral friction deactivated at the height of the tunnel) and B12 (lateral friction deactivated on one side of the barrette at the height of the tunnel).

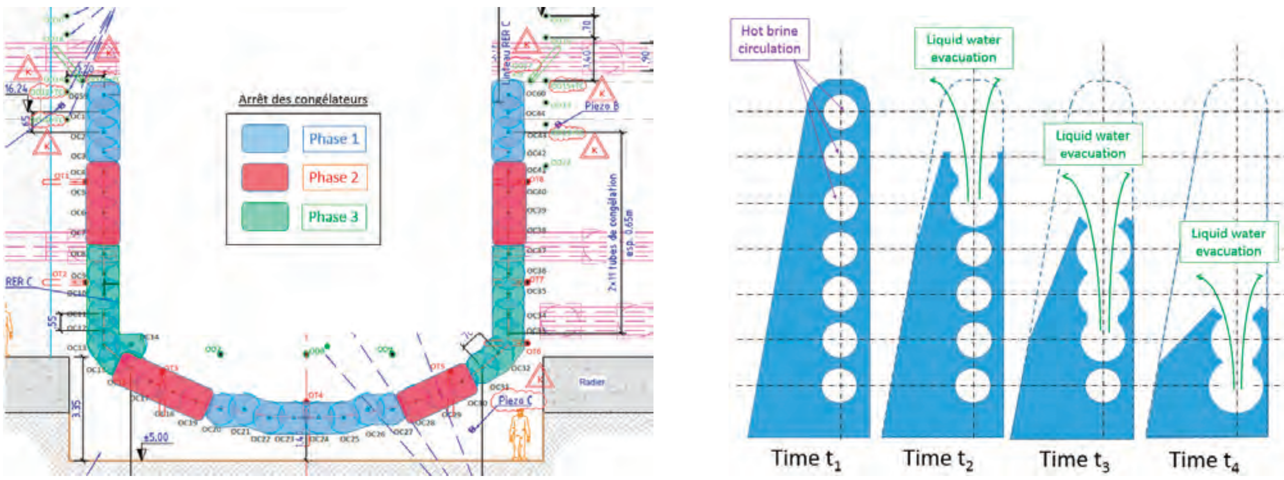
With artificial freezing, some extra-lateral support was provided to B3 and B11 due to increased frozen soil properties. Three sources of settlement are considered in thawed soil:

- Decreased soil properties during thawing.
- Redistribution of bearing capacity between lateral friction and tip resistance due to the structural modifications of B3 and B12.
- Heave/thaw settlements.

In order to avoid differential settlements, the top slab of the L14 tunnel was mounted on jacks, with the possibility to move the slab up or down to follow the movements of B3 and B12. This implied that the adjustment gap could not be

FIG.13

Artificial thawing sequence.



concreted over until settlement was stabilized and the jacks were no longer needed.

When the ground was frozen, at the level of the adjustment gap, the ground water was retained by the frozen ground, the temporary support and the waterproofing membrane. During thawing and when support was necessary, a drainage system was put in place to prevent water from damaging the waterproofing membrane, involving the management of exhaust water at a very late stage of the works, such as electrified rail installation.

In order to accelerate soil settlement after the civil works were completed, the ground was actively thawed using warm brine (+30 °C to +55 °C) circulating through the brine distribution network, which created holes in the frozen shell. The thawing process was associated with a loss in ground resistance, especially after heaving had occurred. Some localized increases in water content pockets may have remained after heaving and needed to dissipate for the ground to regain resistance properties close to its initial state.

The presence of the barrettes was beneficial, as they helped transmit the vibrations of the trains into the ground, which participated in the reorganization of the grains. However, grain reorganization can occur only if the melted water is connected with the free ground water (e.g., melted water is not locked into a frozen ground pocket). This configuration would have delayed grain reorganization, and thus ground settlement, until after the whole ground was melted. This was avoided by sequencing active thawing from the top of the "U" to its base; creating a water evacuation "chimney" along the axis of the pipes (Fig. 13).

A new temperature distribution model was developed for monitoring purposes. Numerical modeling showed that the freezing front at the end of active freezing was hardly affected by active thawing. Indeed, in order to thaw, the frozen ground needs to collect energy, mainly the latent heat of fusion. As this energy is provided by the center of the frozen body, a melting front develops inside the frozen body, using all the energy provided by the active warming for latent heat. In contrast, the outer melting front can gain energy only from the surrounding ground (natural thawing).

Numerical modeling also showed that the temperature distribution in the thawed ground could be considered linear from the imposed freeze pipe temperature to the 0 °C isotherm. This enabled monitoring of the thawing process using the temperature sensors.

Some drains were equipped with manometers that followed the piezometric head under the tunnel until it reached a value compatible with the external water level. Total melting was achieved in three months with brine temperatures of up to +50 °C. The temperature in the ground at the end of melting was stabilized around +35 °C to ensure no ice pockets remained.

Conclusion

Artificial ground freezing was necessary to realize the Line 14 tunnel under the train station base slab. The open shape of the frozen ground led to two concurrent constraints. On the one hand, the train station uplift was mitigated by warmer brine temperature. On the other hand, colder brine temperatures were necessary to respect the mechanical criterion and ensure safety in a complex geotechnical and hydraulic context. Because of significant water flows above the frozen body, liquid nitrogen was locally used to maintain the frozen body thickness during the second part of excavation works. The 16-month period of construction work finally ended with artificial thaw during two months. ■

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Feature **Article 2**

Construction of the Albany Park stormwater diversion tunnel

Flooding has been a decades-long concern for the residents of the Albany Park neighborhood of Chicago, IL. Following a catastrophic flooding event in April 2013, the city pledged to address the problem affecting the residents' lives, properties and local businesses. The solution was to construct an approximately 1.6-km (1-mile) long tunnel that diverts more than half the river flow during a flood event from the North Branch of the Chicago River (NBCR) to the North Shore Channel (NSC). When the tunnel is filled with the NBCR overflow, the system will operate as an inverted siphon, bypassing approximately 2,000 cu ft/sec of river water during the 1 percent annual chance design event (100-year storm) and less flow for smaller storm events that exceed the NBCR inlet weir elevation. The diverted flow leaves the tunnel system through the outlet shaft by way of the 20-m (64-ft) long outlet structure located along the east bank of the NSC south of the Foster Avenue bridge at River Park. After the NBCR and NSC river levels have subsided, water remaining in the tunnel system will be pumped out by two dewatering pumps installed within the outfall shaft sump.

It is the first time in Chicago that a tunnel of this magnitude has been used to connect two existing rivers. The completed Albany Park Stormwater Diversion Tunnel Project is considered a major flood-risk reduction measure planned and constructed with the long-term benefit of the community in mind. Because of the project, more than 300 residential structures will be relieved from the 100-year floodplain of the NBCR. Paired with the restoration improvements at the inlet and outlet sites, both within Chicago Park District parks, this project improves neighborhood aesthetics, property values and the overall quality of life for Albany Park residents all within a highly visible public platform spanning three of Chicago's most affluent aldermanic wards.

The project was funded using a combination of funds from the City of Chicago, Metropolitan Water Reclamation District of Greater Chicago, Illinois Department of Natural Resources and U.S. Department of Housing and Urban Development with Chicago Department of Transportation (CDOT) as the lead city of Chicago agency. Design of the tunnel was performed by MWH Americas Inc. and, overall, eight contractors submitted cost proposals to CDOT. Kenny Construction Co. was awarded the contract and a notice to proceed was issued in April 2016. WSP USA Inc. served as CDOT's construction manager for the project. Tunneling commenced in late fall 2016 and continued through late 2017. Substantial completion of the project was accomplished in August 2018.

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Project description

The Albany Park Stormwater Diversion Tunnel consists of a 1,778-m (5,835-ft) long, 5.4-m (18-ft) internal diameter tunnel with a slope of 0.1 percent to the downstream end (Fig. 1). The tunnel depth is approximately 42 m (140 ft) below the ground surface and the tunnel was constructed entirely in rock by a main-beam tunnel boring machine (TBM) with ground support by a two-pass lining system. The inlet shaft is located at a bend in the NBCR in Eugene Field Park just east of Pulaski Road. The tunnel ends at the outlet shaft at River Park just south of Foster Avenue adjacent to the NSC. Details of the shafts are included in Table 1.

The outlet shaft served as the TBM launch shaft and was the contractor's main staging area. Up to 2 ha (5 acres) of space were available at the site to utilize as the contractor's primary work/staging area, positioning a crane, materials storage, laydown area, contractor office trailers, substation, workshop and parking. The outlet structure was constructed with a 20-m (64-ft) long weir set at -0.6 m (-0.2 ft) continous collision detection (CCD), approximately 0.6 m (2 ft) above normal channel flow to prevent inflow into the tunnel under normal flow conditions. The shaft was constructed to an internal diameter of 9 m (30 ft) and is approximately 52 m (170 ft) deep with the upper 21 m (70 ft) constructed through overburden materials and the lower 30 m (100 ft) of the shaft through bedrock. The shaft includes a 4.5-m (15-ft) deep sump located below the invert of the tunnel in which a pump was constructed to dewater the tunnel after flood events.

The inlet shaft, located in Eugene Field Park, was used to retrieve the TBM. The size of the site is approximately 0.4 ha (1 acre), which provides sufficient laydown space for construction activities. The shaft is 43 m (142 ft) deep with depth to bedrock of approximately 21 m (70 ft). The inlet structure was constructed with a 63-m (208-ft) long weir set at 3.1 m (10.1 ft) CCD. The weir spilled to an approximately 6.7-m (22-ft) wide channel which connected to the shaft at -1.7 m (-5.7 ft) CCD. The shaft

FIG. 1

Albany Park Stormwater Diversion Tunnel alignment.

was constructed to an internal diameter of 5.4 m (18 ft).

Geologic setting and subsurface condtions

Chicago is situated on the eastern flank of the southward-plunging Wisconsin Arch. Silurian rocks thicken eastward into the Michigan Basin and the underlying Cambrian and Ordovician strata thicken southward into the Illinois Basin. The bedrock in Chicago is covered by up to 91 m (300 ft) of unlithified surficial materials consisting of clay, silt, sand and gravel deposited primarily by glacial processes. Silurian dolomites are present at the bedrock surface over nearly the entire city. The Paleozoic-era Silurian system rocks range in thickness from zero in a few areas in the northwestern part of the city to more than 91 m (300 ft) on the far eastern side along the lake shore (Hannes et. al., 2004).

The subsurface investigation program for the project implemented a phased investigation approach (MWH, 2015). The first phase consisted of four borings conducted in May and June 2013. Subsequently, the second phase consisted of eight borings drilled intermittently from July to November 2014. The boring depths ranged from 11 to 52 m (35 to 170 ft) below ground surface. Two of the borings were inclined at 30 degrees from vertical to improve the likelihood of encountering near-vertical joint sets. The remainder of the borings were drilled vertically.

Packer testing was performed in seven borings to evaluate the hydraulic conductivity of joints and bedding planes in the bedrock. Tests were accomplished at intervals ranging from 3 to 12 m (10 to 40 ft) using double packers starting from the bottom of the boring and continuing up hole. Bailout tests were performed in three borings. Results varied from about 10-7 to 10-5 cm/sec in unweathered rock and from 10-6 to 10-3 cm/sec near the top of rock where fractures are prevalent and rock quality is poorer (MWH, 2015). These results from the tests were used to estimate the average groundwater inflow rate into the unlined tunnel which was estimated not to exceed 12.6 L/sec (200 gpm) averaged over the full length of the tunnel (MWH, 2015).

Laboratory testing was performed on samples of soil and rock obtained from the borings. Rock tests included uniaxial compressive strength, specific gravity, density, point load (axial), Brazilian tensile, direct shear, Mohs hardness, Cerchar abrasivity and punch penetration. Soil testing included moisture content, Atterberg Limits and unconfined compression testing.

Based on the results of the investigations, overburden materials were generally found to be about 18 to 21 m

TABLE 1

Construction shaft developments.

Shaft name	Construction purpose	Approx. project station	Excavated depth	Excavated inside diameter
		Feet	Feet	Feet
Outlet Shaft	TBM Launch Shaft and Primary Staging Area	58 + 33.58	70 (soil) 100 (rock)	40 (soil) 35 (rock)
Inlet Shaft	TBM Retrieval Shaft	0+00	70 (soil) 72 (rock)	20 (soil) 18 (rock)

FIG. 2

Initial support of outlet shaft.

(60 to 70 ft) thick and consist predominantly of glacial till material composed of mainly silty clay with trace sand. Below the silty clay materials and overlaying the bedrock is a layer of 1.5 to 3 m (5 to 10 ft) thick till layer primarily composed of very dense sand and gravel. Northern Illinois is underlain by limestones and dolomites of the Silurian system. During the decline of glaciation at the early phase of the Silurian, seas entered the region thereby depositing carbonate sediments. More specifically, bedrock conditions within the project area consist of the Racine Formation underlain by the Joliet Formation. Silurian rocks vary generally in thickness due to erosion effects with maximum thickness in the range of 152 to 182 m (500 to 600 ft) (Mikulic et al., 2010). The region underwent four geologic depositional sequences, the latter of which resulted in the formation of the Racine dolomites.

The tunnel was constructed entirely within the Racine Formation which extends to approximately 61 m (200 ft) below the ground surface in this area. The Racine Formation is an argillaceous dolomite that is often more than 91 m (300 ft) thick and is medium to light gray, dark gray, mottled, gray weathering, medium grained and vesicular to highly vuggy (Willman, 1973). Rock core data within the Racine Formation indicated bedding planes are mostly horizontal to subhorizontal with bedding spacing at the tunnel horizon ranging from 0.06 to 1.2 m (0.2 to 4 ft) (MWH, 2015). Three sets of near vertical joint sets were encountered with spacings described as moderately wide to very wide. Rock quality designation values ranged from 70 to 100 percent within tunnel horizon. Rock mass rating (RMR) classifications were performed based on observation of rock core samples obtained from the borings and subsequent laboratory tests. RMR values presented within the geotechnical baseline report (MWH, 2015) ranged from a worst case of 52 to a best case of 84 with best estimate of 70. The mean uniaxial compressive strength was recorded as 9,340 lbs/sq in.

Launch shaft and assembly chamber construction

Construction commenced with the preparation of the staging area at the outlet shaft location on the banks of the NSC and subsequent excavation of the shaft itself. The shaft served as the TBM launch shaft for tunnel construction. It is approximately 51 m (170 ft) deep with the upper 21 m (70 ft) constructed through overburden materials and the lower 31-m (100 ft) of the shaft through bedrock. Within the overburden, the shaft was excavated to a diameter of 12 m (40 ft) and excavation support was provided by means of a soldier pile and lagging system (Fig. 2). HP 14x73 (Grade 50) piles spaced 1.6 m (6 ft) on center were set in 0.6 m (2 ft) diameter drilled holes from the ground surface to the top bedrock and filled with 200-lbs/sq in. compressive strength grout. Internal bracing of W 12x87 (Grade 50) ring beams were installed at vertical spacings ranging from 1.6 to 2.4 m (6 to 8 ft). At the soil-rock interface, a 0.5 by 0.3 m (1.5 ft by 1 ft) cast-in-place concrete ring beam was constructed on the rock ledge around the excavation.

Prior to excavation into bedrock, a pre-excavation grouting program was implemented to limit ground water infiltration near the top of bedrock. Grout holes were installed using rotary drilling equipment at the top of bedrock spaced at 3 m (10-ft) intervals around the perimeter of the shaft. Holes were angled at 20 degrees from the vertical and were 1.5 in. in diameter. Grouting was only performed within the primary grout holes as secondary holes were not required based on the results and grout takes observed in the primary holes.

Excavation within bedrock was performed by controlled drill-and-blast methods. The shaft in the bedrock was excavated to a diameter of 10.6 m (35 ft) with rounds ranging from 1.8 to 3 m (6 to 10 ft) lifts. Rock bolts were installed near the top of the bedrock and just above the tunnel intersection. Rock bolts were No. 8 steel bar elements installed on a 1.5 m by 1.5 m (5 ft by 5 ft) pattern to a length of 3 m (10 ft) and inclined at 10 degrees from the horizontal. Rock dowels were installed to the same pattern and dimensions as the rock bolts throughout the remainder of the shaft excavation.

A 27-m (90-ft) long starter tunnel and 38-m (125-ft) long tail tunnel (Fig. 3) were excavated by controlled drill and blast to provide space for the TBM assembly, trailing gear fitment and operation startup. The starter tunnel was excavated to a 6.7-m (22-ft) span, horseshoe-shaped and was excavated in two stages. The top heading was excavated to a height of 4.2 m (14 ft) and followed with a bench/invert stage of 2.4 m (8 ft). The tail tunnel was excavated to two dimension/sections: a 6 m (20 ft) high, 9 m (30 ft) wide horseshoe-shaped section was excavated directly adjacent to the shaft and a 4.2-m (14-ft) high section for the remainder of the tunnel. The 6-m (20-ft) high section was excavated in two stages with a 4.2 m (14 ft) high top heading and a 1.8-m (6-ft) deep bench/invert. The 4.2 m (14 ft) section was excavated in one stage.

TBM tunnel construction

The tunnel was mined with a remanufactured main beam TBM from Robbins (model MB186-207-3) originally built in 1979 and now named Keri (Fig. 4). Among other updates and repairs, the then 38-year-old TBM was fitted with a larger cutterhead of 6.2 m (20.3 ft) excavation diameter compared to its original configuration of 5.6 m (18.5 ft). It was also fitted by the manufacturer with new mounts for V-mounted cutters, which were the cutter type available in stock by the contractor, as well as with newer technology removable scrappers. The TBM had six drive electric motors of 300 hp each for a total of 1,800 hp. The cutterhead transmission and drive system allowed for a base rotational speed of six revolutions per minute and a total of 714-t (1,576,170 lb)-foot of torque. The TBM's nominal thrust was 650 t (1,433,500 lbs) with a maximum rating of 1,858,250 pounds. The cutterhead was fitted with 40 cutters. The first four positions in the center are covered by two 43 cm (17 in.), twin V-mount cutter assemblies mounted on a quad saddle. The positions five through 35 are founded on 43-cm (17-in.) V-mount face saddle assemblies while 36 through 40 are fitted with 43 cm (17 in.) V-mount gage saddle assemblies.

Roof support and scaling facilities were installed at two locations on the TBM twin drill decks mounted behind the TBM gripper assembly, each equipped with hydraulic drill packages. This location was used to install any pattern bolting installed for temporary support. Roof support drills can cover from approximately 17 degrees from vertical to 22 degrees from horizontal centerlines. The TBM provided an additional location for installing rock support by means of twin, fixed position drill decks at the front of the TBM, rear of the cutterhead drive motors, and under the extended roof finger shield. The latter was a measure added to the TBM onsite as the original configuration had a solid shield canopy. Use of this location was limited to installation of bolts, dowels and other primary supports for unstable ground with handheld pneumatic equipment where immediate support of the tunnel roof is required before it is exposed from behind the TBM roof supports.

The TBM started mining from the outlet shaft in April 2017 and mined approximately 1,706 m (5,600 ft) of tunnel in a period of nearly five months to reach the target. The TBM excavation was a 24-hour operation, five days per week including time required for any cutter changes. Major repairs and maintenance were reserved for weekends. Daily advance rates ranged from approximately 3 to 40 m/d (10 to 131 ftpd) as indicated on Fig. 5. During the initial period of the learning curve, the TBM encountered a fractured rock zone that necessitated the pause of the TBM advancement for modifications proposed by the contractor and for installation of

FIG. 3

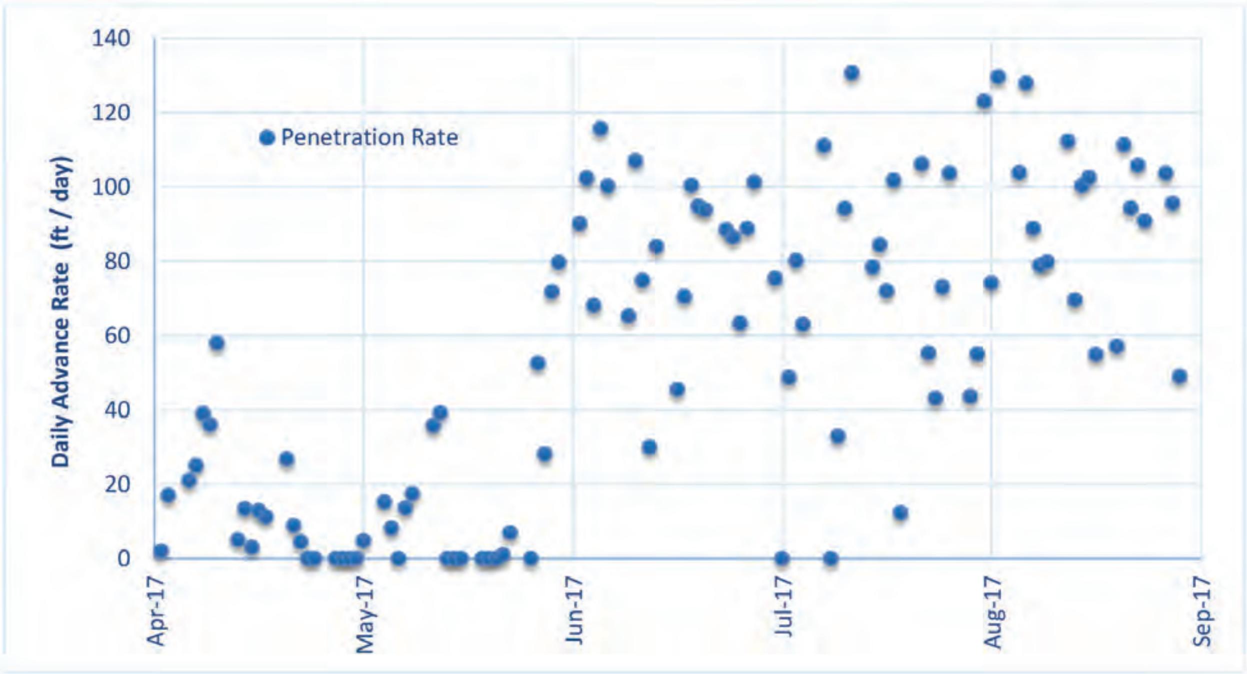
Excavated trail tunnel.

FIG. 4

The Robbins TBM, called Keri.

FIG. 5

TBM advance rate.



additional rock-support measures as described in the next section. Once the TBM passed beyond the fracture zone, its productivity rapidly increased and advancement generally remained at an average of approximately 24 m/d (80 ftpd) until reaching the inlet tunnel. Select points showing no progress correspond to cutter changes, holidays or other unforeseen mechanical issues. Minimal seepage and generally good rock mass conditions beyond the fractured rock zone resulted in a good progress and timely completion of the tunnel. The TBM broke through at the inlet shaft on Aug. 30, 2017.

The baseline initial ground support system in the TBM mined tunnel consisted of 2.1 m (7 ft) long, No. 8, Grade 75 steel resin grouted rock dowels installed on a 1.5-m (5-ft) square spacing. Spot dowels, steel-fiber-reinforced shotcrete, wire mesh and rolled steel channels were also installed at selected locations as needed.

Fractured rock zone

During the early stages of mining with the TBM at approximately station STA 55+85, a loose rock zone was encountered (Fig. 6). The weak zone originally was encountered between the 8 and 10 o'clock positions facing west (toward the direction of advancement). The TBM managed to advance through the area for approximately 6 m (20 ft) prior to halting due to additional rock loosening experienced around the springline, shoulder and crown areas. This loosening zone corresponded to the existence of a subvertical joint feature, as described in the geotechnical baseline report (MWH, 2015), which intersected the excavation subparallel to the tunnel axis. The report identified such features and the possibility that rock falls may be more frequent within proximity of the two shafts due to tunneling parallel to the predominant joint set striking at N50°W to N70°W.

The material within this zone varied from large rock fragments with widths of up to 0.5 m (1.6 ft) to smaller rock fragments mostly shale-like with occasional clay layers or seams. In areas where the fractured rock zone extended to the springline, the bearing of the gripper pads became inadequate for TBM propulsion. The intersection of these weakness features with the subhorizontal limestone bedding created loosening zones with subsequent overbreaks (Fig. 7). Based on discussions among the contractor, the construction manager and the designer, it was determined to perform onsite modifications to the TBM shield by adding a finger shield and installing a steel set erector to provide for the safe passage of the TBM and the continuation of the excavation.

The contractor also designed and provided 19 W6x20 steel sets that were installed at 1.2 m (4 ft) spacings along with wood lagging. Approximately 30 m (100 ft) of tunnel length were impacted by the presence of this fractured rock zone. The fractured rock zone was no longer observed within the tunnel at approximately STA 54+18 and mining beyond that point generally continued uninterrupted with an average advance rate of approximately 25 m/d (80 ftpd).

The original design of the final liner consisted of 0.3 m (1 ft) thick, unreinforced, cast-in-place concrete. However, installation of the W6x20 steel ribs for additional rock support within the fractured rock zone encroached upon the design line of the final lining. Therefore, a modification was made to the design of the final concrete liner within the fracture zone. Ultimately, a fiber-reinforced, full-diameter final concrete liner integrated within the steel ribs for the affected section of the tunnel was installed. In addition, a detailed contact grouting plan was implemented to ensure proper contact between the cast-in-place liner and rock.

Challenging urban environment

In preparation for controlled drill-and-blast and other tunnel mining operations in the dense, urban Chicago neighborhood of Albany Park, a rigorous communication plan was implemented with the various community groups and businesses throughout three aldermanic wards. Regular communications occurred with the local Aldermen, Office of Emergency Management and Communication, the Chicago Transit Authority, numerous utility companies and the North Park University Campus to establish public awareness for the potential impacts of construction. In facilitating the plan, concerns regarding potential conflicts between the outlet shaft blasting activities and the nearby Swedish Covenant Hospital's facility equipment operations were identified. There was a risk that blast vibrations could affect the operation of the proton accelerator cancer-treatment equipment in the hospital's facility. In response to the concerns, a communication plan for blast detonations was established that eliminated the risks by coordinating the blasting schedule with the treatment schedule. To provide the hospital with the utmost confidence that all risks were allayed, construction inspection personnel were assigned to be present in the hospital equipment room during detonations and required a hold point from the contractor to confirm no proton accelerator operations were ongoing for each blast detonation. Through this frequent communication, it was possible to coordinate the construction detonations to eliminate any risk to the hospital's patients while allowing construction to proceed without significant delays.

For controlled blasting operations, the maximum allowable peak particle velocity (ppv) as measured at any adjacent structure or facility per the contract documents was 0.2 in./sec at frequencies of 1 Hertz or less and 0.5 in./sec at frequencies between 2.6 Hertz and 40 Hertz. The maximum allowable air blast overpressure limit was 134 decibels at a 0.1 Hertz frequency, 133 decibels for a 2 Hertz frequency, and 129 decibels for a 5 to 6 Hertz frequency. Four seismographs were installed at both the inlet and outlet shafts to monitor every blast detonation. Locations were determined based on the closest building structure, the nearest bridge structure, closest utility and nearest sensitive community landmark. The seismographs continuously monitored ppv and air blast overpressure. All monitoring devices were programmed to trigger an alert if the thresholds for vibration and overpressure were exceeded. A web-based, mobile-accessible data-reporting platform was provided for real-time data and alerts in addition to the required reporting procedures. This provided the project team with instantaneous performance data throughout all controlled blasting operations. During construction, the monitored ppv were below the allowable thresholds for all blasts. The maximum allowable overpressure limit per the contract documents, however, was exceeded once. The contractor was directed to reevaluate his blasting sequence and design to reduce the overpressure levels and after his revisions to its work plan, the remainder of blasts conformed to the contractual requirements.

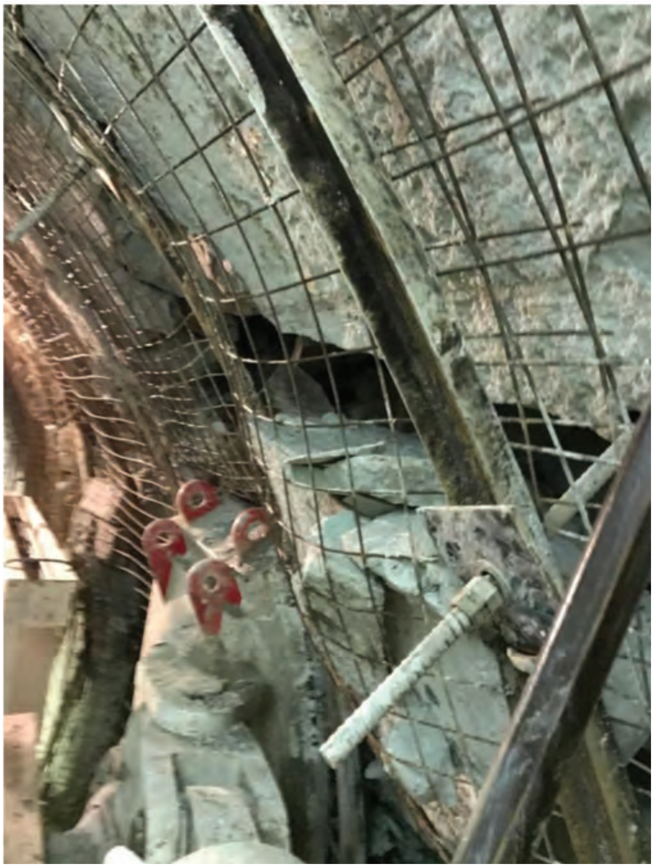
In addition to blasting, for all excavations the contractor was required to perform a settlement monitoring program. Full topographic data at both the inlet and outlet shafts were obtained prior to construction. In addition, 26 settlement baseline points were established and monitored regularly during all excavation and tunnel mining to confirm a maximum threshold of 0.25-in. settlement was not exceeded. As an added precaution, the contractor was required to offer and perform pre-construction property inspections for building owners within a 152 m (500 ft) radius from the center of both shafts, and 61 m (200 ft) from the centerline of the

FIG. 6

Fractured rock zone with channel supports.

FIG. 7

Weakness zone preventing application of the gripper loads.



proposed tunnel alignment, resulting in hundreds of preliminary property inspections.

Lastly, one of the major concerns identified prior to the start of construction was a potential need to operate the tunnel prior to project completion should a flood event occur. Through advanced planning with the project team, an emergency operation plan was developed to allow the rising river waters into the tunnel to help alleviate any flooding. Constant weather forecasts, river-level monitoring, the application of historical empirical data and 24-hour communication afforded CDOT and the project team 12-hour notice to remove the contractor's 100-year storm flood protection before the river levels compromised access. The first use of the tunnel during construction occurred on May 3, 2018. The temporary steel-plate dam between the weir structure and inlet shaft was removed as the river levels increased, literally opening the flood gates for operation. The tunnel was operated to reduce the risk of local flooding three more times during the next two months prior to the completion of the project. The tunnel operated as planned and the neighborhood did not flood.

Summary

The completed Albany Park Diversion Tunnel Project is a great example of a major flood-risk reduction project designed and constructed with the long-term benefit of the community in mind. It provides a high level of flood mitigation to Albany Park Chicago area residents and businesses while enhancing the aesthetics and usefulness of precious open space and recreational areas within a dense urban environment adjacent to the Chicago River corridor.

CDOT made a commitment to provide benefit to the Albany Park neighborhood. In addition to the construction of the tunnel, and as part of the project the outlet shaft site location was restored with a new regulation-size baseball field, a soccer field and several landscaping improvements within River Park. Improvements at Eugene Field Park at the inlet shaft site included landscaping, new trees, a bike path, benches and a water fountain.

The effective techniques and methodology practiced to overcome the construction challenges of controlled blasting in a dense urban environment, encountering a fractured rock mass zone during TBM mining, and multiple tunnel flood operations during construction are prime examples of the numerous accomplishments encountered on the project. But most importantly, the Albany Park Stormwater Diversion Tunnel Project helped improve the overall quality of life for Albany Park residents. The project's overall success has been recognized for this accomplishment with the 2019 Engineering Excellence Award by The American Council of Engineering Companies, Illinois Chapter and a 2019 National Achievement Award from the Construction Management Association of America. ■

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Long-distance annulus backfilling of a rehabilitated sewer tunnel

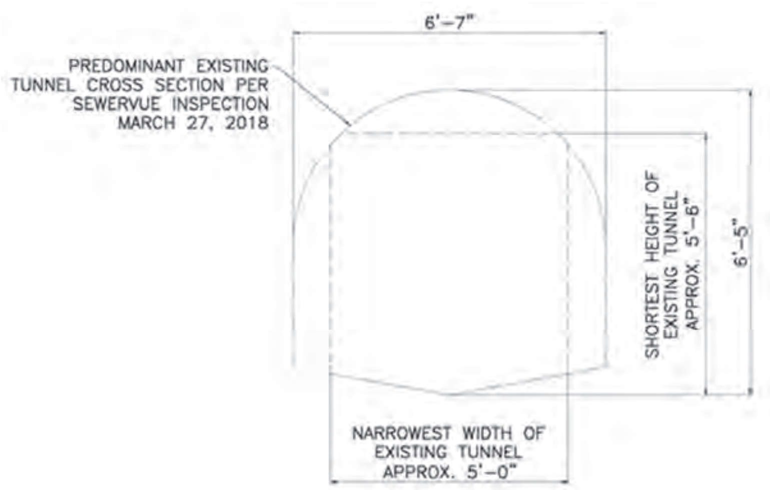
The Colsman Tunnel, located in Greenwood Village and Centennial, CO, is part of the Big Dry Creek Interceptor sanitary sewer system and is owned and operated by the Southgate Sanitation District (the district). Flow from the district's entire waste water collection system (approximately 80,000 residents) is conveyed through the tunnel. Average flows of approximately 10 million of gallons per day are constant and cannot be turned off or diverted.

The tunnel was constructed around 1977 using hand tunneling and road-header equipment. The 2,320-m (7,614-ft) long, mushroom-shaped tunnel is approximately 175 cm (69 in.) wide, 190 cm (75 in.) tall and varies in cross section and shape along its length (Fig. 1). The tunnel was constructed with a slight downward slope of 0.36 percent to the west. At its deepest point, the top of the tunnel is about 27 m (90 ft) below the existing ground surface. Access to the tunnel is provided by a portal structure on the east side of the tunnel (east portal) and a buried outlet structure on the west side of the tunnel (west portal). Four ventilation shafts (designated Vent Shaft #1 through Vent Shaft #4) used during construction are spaced approximately 487 m (1,600 ft) apart along Orchard Road (Fig. 2). Access into the tunnel is complicated by the tunnel's depth and its location beneath Orchard Road, a heavily traveled arterial roadway adjacent to a busy shopping center and residential areas.

Tunnel ground support reportedly consisted of a variety of different lining systems according to different sources reviewed (Meurer, Serafini and Meurer, 1975; Lachel & Associates, 1991; HDR Engineering 2016). Based on as-built tunnel drawings, a manned entry condition assessment and a remote closed-circuit television (CCTV) condition assessment, several potential tunnel lining systems were utilized, including steel liner plate/welded-wire fabric/shotcrete, welded wire fabric/shotcrete with rock bolts, and 10 cm (4 in.) wide steel sets placed at 1- to 2-m (3- to 6-ft) centers. The lining is coated in coal-tar epoxy and has experienced multiple phases of spot repairs, making visual evidence of lining type difficult to discern in CCTV inspections performed over the years. For this reason, it is unknown where the different types of reported lining types are located in the tunnel, or whether all of the lining types cited are actually present.

FIG.1

Typical cross-section of the Colsman Tunnel. Source: Dewberry Engineers, 2019.



Tunnel condition and need for rehabilitation or replacement. Two manned entry inspections of the tunnel were carried out in 1981 and 1991 (Lachel & Associates 1991). In 2015, a multisensor robotic inspection was also performed (HDR Engineering 2016). This most recent condition assessment revealed that the tunnel needed rehabilitation and/or replacement due to deterioration of the shotcrete lining, ground water infiltration and other structural defects.

Based on the age of the tunnel, the highly corrosive waste water environment, the inability to safely perform internal spot repairs, and lack of system redundancy, the district became increasingly concerned with the ability of the tunnel to provide an additional 75 years of service life.

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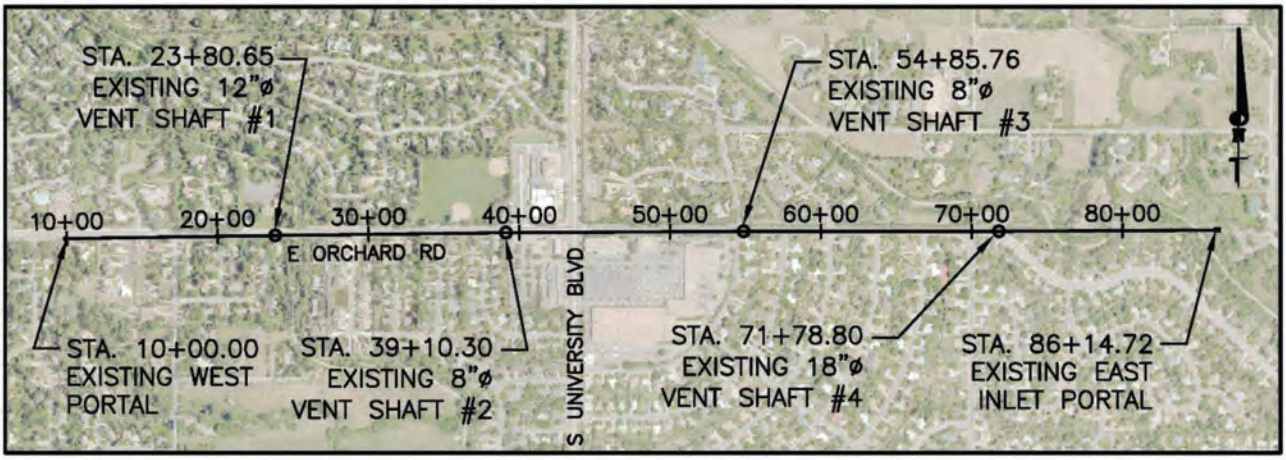
FIG.2

Colsman Tunnel alignment with existing vent shafts. Source: Dewberry Engineers, 2019.



The district engaged Burns & McDonnell Engineering Co. Inc. (Burns & McDonnell) as their owners engineer/technical advisor to assist with the tunnel rehabilitation. Based on the complicated nature of the work, the district selected a progressive design-build approach. The team of Garney Construction (Garney), Dewberry Engineers (Dewberry) and Shannon & Wilson Inc. (Shannon & Wilson) was retained after a qualifications- and interview-based selection process.

Tunnel rehabilitation approach and execution. After considerable analysis and evaluation, a solution consisting of tunnel rehabilitation via sliplining with high-density polyethylene pipe (HDPE) was selected. The sliplining process allowed the installation of a fully structural, completely inert, continuous pipe within the tunnel, and was completed under live-flow conditions that eliminated expensive and high-risk bypass pumping. The slipline was completed using horizontal directional drill (HDD) equipment with the capacity to pull the nearly 2,346 m (7,700 linear ft) of heavy-wall HDPE pipe and associated drill stem through the tunnel. The pipe consisted of 122-cm (48-in.) diameter SDR 13.5 IPS HDPE (PE 4710) with a wall thickness of approximately 9 cm (3.6 in.) and a weight of 218 lbs/ft.

FIG.3

American Auger DD-440T HDD rig at east portal. Source: Global Underground 2018.

Garney retained Global Underground Corp. (Global) as the specialty subcontractor to perform the sliplining operation. Global utilized an American Auger DD-440T HDD machine with a 440,000 pound thrust/pullback capacity set up at the east portal (Fig. 3). A cartridge-style pipe string approach was utilized at the west portal, with fusing operations performed on 15-m (50-ft) long pipe segments (Fig. 4). The work was successfully completed in 42 days in January 2019, averaging four fusions per day for 61 m (200 ft) of pipe installation. More than 1.6 million lbs of pipe was installed.

After completion of installation, flows were re-directed into the HDPE pipe, which rested on the bottom of the tunnel. There was an annular space left between the HDPE pipe and the tunnel ranging from approximately 5 to 28 cm (2 to 11 in.) horizontally and 46 to 74 cm (18 to 29 in.) vertically over the pipe centerline. Based on a pre-construction LIDAR and sonar survey of the tunnel, the volume of the annulus space was estimated by Dewberry to range from approximately 6,900 to 7,100 cu yd.

Annular space backfilling

During the design phase, the team agreed that it was desirable to backfill the annular space between the HDPE pipe and the original tunnel to reduce future risks to the pipeline. Annular space backfilling (also known as grouting) would mitigate the consequences of future tunnel lining degradation/collapse and would also provide lateral support to the HDPE pipe. The design intent was to fill the annular space as fully as is practicable, understanding that successfully backfilling 100 percent of the annulus would be challenging for several reasons.

Annulus backfilling is a common practice in the tunneling industry. A variety of materials are utilized for backfilling, including cementitious grout, conventional concrete, low-density cellular concrete or flow fill (Henn, 2003). Which backfill material is selected depends on a multitude of factors, including specific project needs, tunnel geometry and carrier pipe type, to name a few.

Placing annular space backfill is generally accomplished in one of two ways. If the carrier pipe is large enough for manned entry, backfill can be pumped into the annulus through pre-installed grout ports in the pipe. For smaller-diameter pipes, backfilling is performed from outside the pipe with the use of bulkheads. The distance over which backfill can be placed varies and is dependent on material properties and project geometry but is generally no more than 152-182 m (500-600 ft). For this reason, backfilling is typically performed in sections, and access is required at the injection points. Slicklines can be used to extend the length of backfill placement where intermediate access is not available.

For the Colsman Tunnel, the annular space backfill design was complicated by several factors. First, an external slickline was unable to be attached to the HDPE pipe prior to placement due to the damage that would occur from the rotation of the HDPE pipe during HDD pullback. A slickline was also unable to be installed after the HDPE pipe was in place, as there was insufficient room for manned entry. Second, the HDPE pipe was placed into service upon completion of installation, carrying live sewer flows that could not be disrupted. While the pipe could have been designed with pre-installed grout ports to facilitate backfilling from inside the pipe, this option was not considered viable as it would have required costly and risky bypass pumping. Instead, the HDPE pipe was installed during live sewer flows, which were then immediately channeled into the pipe once it was installed. Not only did the operating conditions preclude entry into the pipe, it increased the risks of the backfilling operation which could not damage or otherwise impact the HDPE pipe.

Most importantly, access into the tunnel for backfilling operations was very limited, consisting of two portals and four intermediate vent shafts. The spacing between these six grout injection points ranged from approximately 396 m to 518 m (1,300 ft to 1,700 ft). During the design phase, consideration was given to adding intermediate grout injection points in between the existing vent shafts by drilling into the tunnel. However, the team was concerned about rock or lining debris that could potentially fall into the tunnel during drilling, or the potential for deflecting the tunnel lining inward, either of which could complicate the pull-in of the 122-cm (48-in.) HDPE pipe. In addition, the team was unsure if drilling into the tunnel would be possible due to its depth below the existing ground surface and the uncertainty involved with the type of tunnel lining system that could be expected.

The team selected low-density cellular concrete as the most appropriate backfill material for several reasons. Cementitious grout and the more traditional backfill materials have a relatively high density when compared to the HDPE pipe and would result in pipe floatation and/or collapse during placement. Furthermore, cementitious materials have a higher heat of hydration, which would cause a significant degradation the structural properties of the HDPE pipe. However, low density cellular concrete made with hydraulic cement, water and preformed foam has a lightweight density and significantly lower heat of hydration. Due to the risks associated with drilling into the tunnel, the design-build team decided to attempt to fully grout the annular space using only the existing vent shafts and portals as grout injection points. While this approach was considered achievable, it was understood to be at the upper limits of the technology due to the large distances between injection points and the relatively flat slope of the tunnel.

FIG.4

HDPE insertion at west portal. Source: Global Underground 2018.

Garney retained Cematrix Cellular Concrete Solutions (Cematrix) as the specialty subcontractor to perform the annulus backfilling, after receiving and evaluating bids from multiple specialty subcontractors. For simplicity, "placement of annular space backfill" and "low-density cellular concrete" are generally referred to as "grouting" and "grout," respectively, for the remainder of this paper.

Initial grouting plan and performance

Grouting plan and equipment setup. The original grouting plan was to inject grout from the upstream end of the tunnel at the east portal and progress westerly down the tunnel to each of the four vent shafts for subsequent placement, terminating at the west portal. Two lifts of grouting would be performed from each location. The first lift would consist of approximately 382 to 535 m³ (500 to 700 cu yd), and would be terminated before the placement location was grouted off to permit the second lift to follow on the next day. The second lift was planned to top off the

TABLE 1

Summary of initial grouting reaches.

Reach		Vent shaft depth		Distance	Estimated grout volume	
From	**To**	**Shaft**	**Feet**	**Feet**	**Low (cu yd)**	**High (cu yd)**
East Portal	Vent Shaft #4	‡NA	‡NA	1,436	1,149	1,166
Vent Shaft #4	Vent Shaft #3	Vent Shaft #4	44	1,693	1,561	1,575
Vent Shaft #3	Vent Shaft #2	Vent Shaft #3	71	1,576	1,597	1,621
Vent Shaft #2	Vent Shaft #1	Vent Shaft #2	88	1,530	1,520	1,531
Vent Shaft #1	West Portal	Vent Shaft #1	55	1,381	1,150	1,215
			Total	7,616	6,977	7,108

Source: Dewberry, 2019; ‡NA = not applicable.

remaining volume to be placed in that reach and would close out that access point. The planned grouting reaches, including distances between injection points, depths of the vent shafts and estimated theoretical volumes of grout, are presented in Table 1. During grouting, Garney planned to lower a camera into the adjacent vent shaft to look for visual confirmation of grout. Not all of the vent shafts were installed at the crown of the tunnel; therefore, visual monitoring would be complicated by limited line of sight at some locations. The volume of grout placed would also be compared against the theoretical volume to determine if the reach was effectively grouted.

Cematrix developed the following grout mix design to produce a minimum 28-day compressive strength of 100 pounds per square inch (psi) and unit weight of 30 pcf, per project specifications: 500 pounds Envirocore IL (10) MS cement; 250 lbs potable water (0.50 to 0.65 water to cement ratio); and 58 lbs preformed foam produced with Provoton foam agent with 3.5 percent water.

The grouting operation included a dry cement silo and mixing trailer (Fig. 5). Cement was delivered via truck and placed into the silo; approximately 10-12 trucks were required per day to produce approximately 765 to 917 m^3 (1,000 to 1,200 cu yd) of grout. The grout was produced in an on-site automated batch plant where cement and water were combined to form slurry. Water and foam concentrate were mixed, then compressed air was added to create the preformed foam. The rates of slurry production and preformed foam production were linked via a central control panel to create the desired density of the finished cellular grout material. The grout was pumped via a 10-cm (4-in.) hose, from the mixing trailer to the injection point. The entire grouting equipment setup was portable and was moved to each vent shaft and portal location for grout placement. Due to the limited space available along Orchard Road, utilizing fly ash in the mix design was not considered to avoid the need for two silos and truck deliveries of two components.

FIG.5

Low-density cellular concrete equipment setup. Source: Shannon & Wilson, 2019.

During grouting, Cematrix performed quality control (QC) testing of the grout. Shannon & Wilson provided a full-time engineering technician onsite to perform quality assurance (QA) construction materials testing of the cement slurry, along with part-time engineering oversight (Fig. 6). Testing included Marsh funnel viscosity and unit weight measurements of the cement slurry on at least an hourly basis. In addition, both Cematrix and Shannon & Wilson collected a set (four each) of 15-cm by 8-cm (6-in. x 3-in.) cylinders of grout for compressive strength testing at the same frequency. The hourly testing frequency corresponds to one sample for approximately every 130 cu yd of grout placed, based on the anticipated rate of grout placement.

Initial grout placement. Grouting operations began at the east portal on March 15, 2019. The intent was to backfill between the east portal and Vent Shaft #4 (a distance of 437 m (1,436 ft) in two lifts. The calculated volume of grout in this reach was estimated to range from 878 to 891 m^3 (1,149 cu yd to 1,166 cu yd). Cematrix stopped grouting the first lift after placement of 217 cu yd, because the grout had begun to back up into the portal and they did not want to risk grouting off access for the planned second lift. At the request of Cematrix, Garney poured a concrete bulkhead at the east portal outfitted with a grout injection nozzle and air vent to accommodate the remainder of grouting. Grouting resumed on March 18, 2019. As the bulkhead allowed for grout injection to be performed under low pressure (less than 5 psi), Cematrix was able to place 937 m^3 (1,225 cu yd) of grout in the second lift. A total of 1,102 m^3 (1,442 cu yd) of grout was placed from the east portal, which exceeded the theoretical annular space volume, but no grout was visually observed with the camera setup in the adjacent Vent Shaft #4. It is normal for cellular grouts to experience in-place yield loss due to the dissipation/consolidation (bubble popping) of the air bubbles as the grout travels. The longer the grout travel distance in an annular space, the greater the yield loss. This observation led Cematrix and the design-build team to suspect that the grout may not be performing as intended.

The grouting operation was moved to Vent Shaft #4 on March 21, 2019. Vent Shaft #4 was approximately 46 cm (18 in.) in diameter, and penetrated the tunnel crown near the northern edge of the tunnel, offset from the centerline. The vent shaft was approximately 13 m (44 ft) deep. The 10-cm (4-in.) grouting hose was setup over the vent shaft with a steel frame, which allowed the grout to be injected vertically into the shaft without any applied pressure or use of a tremie pipe (Fig. 7). During the first 115 m^3 (150 cu yd) placed, the grout was observed to be flowing both upstream and downstream from the vent shaft. After that, the grout began flowing downstream only, leading Cematrix to believe that it had filled to the leading edge of the grout placed from the east portal. After only another approximately 76 m^3 (100 cu yd) of placement, the grout began to back up from downstream and was in danger of closing out the vent shaft. The low slope of the tunnel was effectively flat, and the very lightweight grout may have been mounding up rather than flowing. Cematrix terminated grouting after placing only 204 m^3 (267 cu yd) that day.

Cematrix concluded that the flowability of the grout was not as they had expected; the grout was not flowing as far as planned and was gelling faster than expected. Although the slope of the tunnel was relatively flat, Cematrix had reasonably expected that gravity would provide more assistance in moving the grout downhill. For the grout that was placed during this initial operation, Cematrix estimated a volume loss or yield of approximately 11 percent, which was higher than the expected yield of 5 percent. While some loss is inevitable due to the nature of the low-density cellular concrete, as the grout is pumped longer and longer distances it is subject to more mechanical stresses that can affect the structure of the air voids and lead to unacceptable performance. The design-build team elected to halt grouting operations to revisit the current approach.

FIG.6

Low density cellular concrete quality assurance testing. Source: Shannon & Wilson 2019.

Re-evaluation of the grouting plan and exploration of alternatives

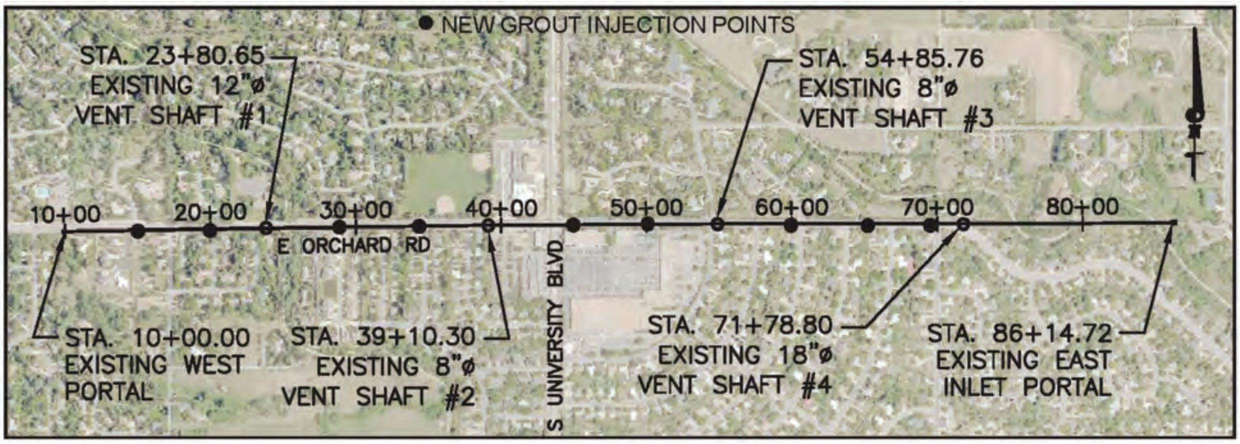
Although it was considered to be at the upper limits of the technology, the design-build team had anticipated that it would be possible to fill the annular space using only the tunnel portals and the four existing vent shafts as grout injection points. However, based upon the demonstrated flowability of the grout during the first three grout placement days, the team concluded that a different approach was needed. Multiple methods were considered and weighed, and two alternatives were ultimately considered by the project team: 1) allowing for only partial grouting of the annulus and 2) adding additional grout injection points by drilling into the tunnel. Increasing the flowability of the grout by using a heavier mix design was considered but was ultimately

FIG.7

Grout injection into existing vent shaft along Orchard Road. Source: Shannon & Wilson 2019.

FIG.8

Colsman tunnel alignment showing original vent shafts and new group injection points. Source: Dewberry Engineers, 2019.



rejected due to the increased risk of pipe flotation and damage due to high heat of hydration.

Partial grouting of the annulus. The team carefully considered allowing the grouting operation to continue as is, recognizing that the entire annulus would not be backfilled. If Cematrix were to continue placing grout from the remaining injection points, an unknown volume of grout would be placed at each vent shaft, forming a grout plug. These localized grout plugs would serve to anchor the pipe in the tunnel, thus preventing movement during any surge events. In addition, the grout plugs would isolate the tunnel annular space from corrosive atmospheric conditions, as the space would eventually fill up with ground water seeping into the tunnel. However, the ground water seepage would also serve to float the pipe due to buoyancy, that would result in low spots and sags along the pipe which would reduce its capacity. In addition, future degradation of the tunnel lining and/or tunnel collapse could damage the pipe in areas where backfilling wasn't completely performed. For these reasons, the team concluded that leaving the annulus only partially filled was not acceptable to the long-term performance of the tunnel, and that modifications to the grouting plan were needed to ensure the service life of the sewer.

Drilling additional grout injection ports. The design-build team determined that an additional nine grout injection points located between the west portal and Vent Shaft #4 would be required to reduce the length of the grouting reaches to a maximum distance of 180 m (590 ft) (Fig. 8). Increasing the number of injection points would result in a grouting program more consistent with the conventional 152 to 182 m (500 to 600 ft) flow range and a 306 to 459 m^3 (400 cu yd to 600 cu yd) placement range with pressure grouting.

However, there were considerable risks that needed to be addressed before proceeding with drilling into the tunnel, primarily related to two key questions: 1) could injection points be drilled into the tunnel effectively; and 2) could injection points be drilled into the tunnel without damaging the HDPE pipe which was carrying live sewer flows? As previously discussed, the team was unsure if drilling into the tunnel was feasible. There were a variety of tunnel lining systems that were reportedly utilized during construction, but as-built drawings do not indicate where the different materials were utilized. In addition, the team did not know the thickness or condition of the steel liner plate, or if the welded wire fabric and steel sets themselves would be difficult or impossible to drill through or would only partially deflect (which could damage the HDPE pipe).

There were additional risks related to the drilling process itself, including the vertical tolerances of the drilling operation and how much control the drilling subcontractor would have when advancing through the different types of material. The depth to the top of the tunnel was known at the existing vent shafts, but was interpolated between these locations based on the pre-construction LIDAR and sonar survey of the tunnel. For this reason, the targeted depth was only approximate, leading to some uncertainty. Would the driller be able to tell by drilling action when the top of the tunnel was reached? Or would the drill bit readily puncture the lining and keep on drilling into the tunnel, potentially damaging the HDPE pipe?

After considerable discussion between the design-build team and multiple drilling companies, an air-hammer drilling approach was selected to advance the grout injection points. Based on a combination of suitability of equipment, approach to the work, and availability, Xtreme Drilling (Xtreme) was retained as the drilling subcontractor. Xtreme utilizes small, compact drill rigs with a small working footprint. The compact drill rigs have relatively precise downhole and rotational speed control, and are light enough for the driller to have a good degree of feel that allows him to know when drilling behavior changes. Xtreme recommended using a scratcher bit to drill through overburden soils and bedrock. Once the top of the tunnel was near, Xtreme would change their drilling operation to utilize an air-hammer bit to penetrate through the remaining bedrock and through the lining. The air hammer needs to be in contact with the bottom of the borehole to operate and will immediately stop operation if it were to hit a void as it would lose air circulation. This fail-safe would prevent the drill from advancing into the HDPE pipe.

Drilling field demonstrations. To evaluate the condition of the lining, Garney made an exploratory excavation near the west portal to observe the composition of the tunnel liner. The tunnel liner was found to consist of weak degraded shotcrete without the presence of welded wire fabric or steel sets. While this field demonstration alleviated the concern that the drilling operation would not be able to penetrate the lining, it increased the concern that conventional drilling equipment would not be able to distinguish between the soil/rock and the tunnel.

Garney mobilized Xtreme to the east portal to test the effectiveness of the air-hammer approach. A section of HDPE pipe was placed inside a section of concrete portal roof that had been removed from the tunnel. The annulus between the pipe and the concreate was approximately 30.4 cm (12 in.). The purpose of this test was to verify the reaction of the hammer drill to penetrating the tunnel roof and encountering the void space before impacting the pipe. The hammering action halted by itself as soon as the void space was encountered and the pipe remained untouched, exactly as anticipated. The drill stem was then purposely lowered onto the HDPE pipe and allowed to hammer for approximately one minute, resulting in little more than surface scratching on the pipe.

Grout injection point drilling. Based on these demonstration tests, Xtreme mobilized to the site to perform the injection point drilling. Xtreme was able to drill the additional nine grout injection points in less than a week without incident. Drilling proceeded relatively quickly through the overburden and bedrock until the drill bit was to within about 1.5 m (5 ft) of the targeted top of the tunnel liner, where Xtreme switched to the air-hammer bit. The top of the tunnel was typically encountered within one or two feet of the estimated depth. Drilling through the liner proceeded with relative ease, as no steel sets, liner plates or welded wire fabric were encountered.

Execution of the revised grouting plan

Based upon the behavior of the grout during the first three grout placements, the revised grout plan included pumping the grout under pressure rather than to place grout by gravity and depend upon unpressurized flow. Pressurized flow was achieved by the use of a 7-cm (3-in.) steel casing pipe along the entire length of the newly drilled grout injection points. Pressurized flow was achieved at the existing vent shafts by installing a sewer plug with a bypass hole. The grouting pressure was monitored at the ground surface utilizing a pressure gauge on the injection stack, and the allowable pressure was calculated for each injection point based upon the vertical depth (head) to the HDPE pipe.

Cematrix field-verified grout placement by closely monitoring installation pressures and by using specially developed closed-circuit cameras. The cameras were lowered into adjacent grout injection locations to visually verify when grout had reached the next installation port (Fig. 10). Once the grout was visually confirmed to have reached the next injection location, grouting operations stopped to avoid overfilling and inadvertently sealing off the subsequent grout injection point.

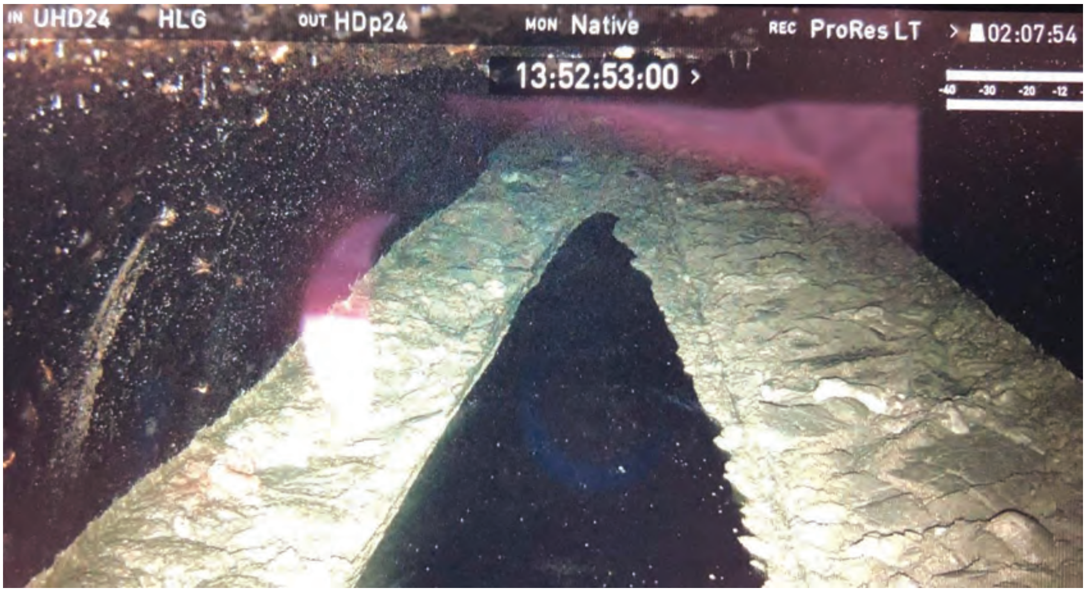
During grout installation, a barometric loop was installed on the downstream end of the tunnel. The barometric loop served to raise the hydraulic grade line within the HDPE sewer pipe so that the entire line was fully submerged (flooded). The submerged line served two primary purposes. First, the filled pipe helped to ballast and weigh down the buoyant HDPE so that it wouldn't float during grouting operations. Second, the high water in the pipe helped to transfer away the heat of hydration developed during grout curing. Removal of the

FIG.9

Xtreme Drilling advancing one of the new grout injection points. Source: Shannon & Wilson, 2019.

FIG.10

Camera showing placement of low-density cellular concrete around the HDPE pipe. Source: Shannon & Wilson, 2019.



heat during curing was important to protect the physical characteristics of the new plastic pipe.

Using the additional grout injection points, Cematrix moved numerically from the upstream end of the tunnel toward the west portal. Cematrix set up its operation at four locations along Orchard Road. From these four locations, all 13 grouting locations were able to be reached. Approximately 7,400 cu yd of LDCC was placed and pumped. Records and audits were performed with regard to expected voids to fill and actual quantity of grout installed. Physical properties of the grout were tested and grout cylinders were collected for every 99 m^3 (130 cu yd) of grout placed. All of the grout placed met the intent of the specifications with regard to unit weight and compressive strength. At the completion of grouting, the quantity of grout placed was within 5 percent of the predicted volume of void space to be filled. Based on a combination of the visual verification of grout placement using the downhole cameras and the 5 percent variance on estimated grout volume placed, the team was able to conclude that backfilling of the annulus had been substantially completed to the degree practical. Grout loss was estimated to be less than 5 percent. ■

Conclusion

The Colsman Tunnel project was successfully completed through the initiative, creativity and exceptional problem-solving skills of everyone involved. The teamwork and cooperation among multiple organizations allowed the project to be completed under budget and at a fraction of the cost of other feasible alternatives. The design-build process was without a doubt the most effective procurement method for a project with so many complexities and risks, and Burns & McDonnell and the district were well-served by the process.

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Main beam tunnel boring machine carves out win in Louisville, KY

A 6.5 km (4 mile)-long tunnel for waste water storage below Louisville, KY has more to it than meets the eye. "At first glance, this seems like a straightforward project, but it turned out to be much more challenging," said Shemek Oginski, project manager for the contractor, a joint venture of Shea/Traylor. The 6.7 m (22 ft) diameter Robbins Main Beam tunnel boring machine (TBM) and conveyor system had to cope with overstress in the crown that resulted in significant rock fallout in seven different areas, as well as methane gas in the tunnel. By the machine's breakthrough on Sept. 22, 2020, the crew had much to celebrate.

The machine was refurbished and consisted of older components as well as a brand new cutterhead supplied by Robbins and completely rebuilt electrical and hydraulic systems. "This was definitely an older machine — I actually operated it on the DART [Dallas Area Rapid Transit] tunnels in Dallas, TX in the 1990s, but with many of the components being new we were confident in it," said Oginski.

The original tunnel was expected to be 4 km (2.5 mile) long, but a change order added to the length by 2.1 km (1.3 mile). The extension was ordered by the owner, Louisville Metropolitan Sewer District (MSD), and its Engineer-of-Record Black & Veatch in order to eliminate four surface combined sewer overflow (CSO) storage basins. That included one basin originally located at the site of the TBM breakthrough, explained Oginski: "The original CSO site was located in close proximity to Beargrass Creek and had flooded multiple times. It was decided to extend the tunnel to that site in order to use the tunnel as storage instead, and connect it to the sewer system." MSD installed a sheeting wall to protect the site from floodwaters while Shea-Traylor installed liner plate in the retrieval shaft, resulting in a site that is in much better shape.

On Sept. 22, 2020, a Robbins Main Beam TBM broke through at the Ohio River Tunnel in Louisville, KY.

It was in the 2.1-km (1.3-mile) extension, essentially a bifurcation of the main tunnel, where the crew encountered much of the crown overstress. "The longest section of overstress was 700 m (2,300 ft) and took two and a half months to get through," said Oginski. The crew switched up the prescribed rock bolt pattern of four to six bolts at 1.5-m (5-ft) centers, and instead installed six bolts at 1-m (3-ft) centers. "It worked out to two rows per push. When that wasn't enough, we installed wire mesh in the crown, mine straps and channels. It definitely took extra time to install steel support, remove loose rock and deal with the rock coming down so we could install rock support safely." Overbreak varied from a few inches above the machine to 30 cm (1 ft) or more.

"We also had encountered natural methane gas in the tunnel just shortly before holing through," said Oginski. The methane was discovered while the crew were probing out 45.7 m (150 ft) ahead of the machine — something that the crew did continuously throughout the bore, using one, two or four probe holes depending on the geology. "We were down for about two weeks and were able to contain the methane within the cutterhead, where concentration spiked at 100 percent LEL. We were able to resume work after systematically ventilating, probing and grouting multiple times."

Despite the challenges, the TBM was able to achieve up to 658 m (2,159 ft) in one month and 192 m (630 ft) in one week. The Robbins conveyor, including a 68.6 m (225 ft) long vertical belt, made this progress achievable, said Oginski: "The conveyor is definitely the way to go, especially for longer drives. There was quite a difference in performance between the extension tunnel, which we mined with lift-boxes, and mining with the conveyor. Our best month in the extension tunnel with the boxes was 221 m (725 ft), so that is a big difference."

With tunneling now complete, Oginski is "definitely proud that we got to the end, as this is a challenging project." The contractor is removing the components of the TBM to be stored in their yard in Mt. Pleasant, PA, and sees future applications for the equipment. "If the right project comes up then yes, it's likely we would use this machine again." ■

Beavers announce winners of the 2020 awards

Michael Crawford of Sukut Construction and the 2020 president of the Beavers, has announced the recipients of the 2021 Golden Beaver Awards. The awards dinner has been postponed from January to April 23, 2021 at the J.W. Marriott at L.A. Live due to COVID-19 restrictions. The awards were restructured earlier this year to create the Leadership, Management, Supervision and Engineering/Service & Supply award categories.

Leadership Award

WILFORD CLYDE, president, chairman and CEO of Clyde Companies Inc., Orem, UT, will receive the Leadership Award. He is a past president of the Beavers and is currently the vice chair of the Beavers Charitable Trust. He joined the family-owned business after graduating from Brigham Young University. As the president of Geneva Rock Products, he led a combination of the various family-owned businesses under the Clyde Companies in 1999 and became president of the parent company in 2001. Under his tenure, the organization grew from $200 million to $1.1 billion in annual revenue.

CLYDE

Management Award

The Management Award will be presented to **SCOTT CASSELS**, executive vice president of Kiewit Corp. and president of the Kiewit Infrastructure Group. Cassels joined Kiewit in 1976 as an intern while earning degrees in construction management and business administration from Washington State University.

After graduation, Cassels joined Kiewit and began a 40-year career leading to his current position. He was instrumental in the formation of the Kiewit Development Group, to pursue public-private ventures, and of Kiewit Infrastructure Engineers, to focus the company's unique capabilities on design build projects. A champion of jobsite safety, he increased the number of firms participating in the Construction Industry Safety Initiative (CISI) and recently served as co-chair of the CISI annual Construction Safety Week.

CASSELS

Supervision Award

SAM AIELLO, general superintendent for Sukut Construction, LLC, will receive the Supervision Award. He started with the company 35 years ago as an equipment operator/grade checker and was then promoted to grading foreman and to general superintendent. He oversaw the Eastern Transportation Corridor toll road in Orange County, CA, which included 51 million m^3 (67 million cu yd.) of earthmoving, including 11 million m^3 (15 million cu yd.) of rock. In the last decade, he oversaw the Calaveras Dam Replacement Project in Sunol, CA, where Sukut handled the earthwork as part of a $569 million joint venture. Currently, he is involved with the $250 million Lake Isabella Dam Safety Modification.

AIELLO

Engineering/Service & Supply Award

TIM MIKOLAJEWSKI, president of Liberty Mutual Surety and executive vice president of Global Risk Solutions, will receive the Engineering/Service & Supply Award. He joined Safeco Surety (now Liberty Mutual) in 1984 after earning a business administration degree from the University of Cincinnati. In 1986, he transferred to Southern California and, by 1988, he was the regional contract manager for the Pacific Southwest. In 1994, he moved to the home office in Seattle, WA as assistant director of contract surety and assumed the director position three years later. He was promoted to vice president, senior vice president and, after successfully leading the integration of Safeco Surety into Liberty, president of Liberty Mutual Surety in 2008. He has a reputation for supporting his clients through good and challenging times, assisting contractors to work through problems rather than pursuing remedies that would benefit the surety alone.■

MIKOLAJEWSKI

SCOTT RAND (SME) has been appointed North American vice president of Shotcrete Tunneling and Mining (STM). STM is a new business unit established by Sika following its acquision of King Packaged Material Co. It will focus on complete shotcrete solutions, including materials and equipment, and will service the growing Canadian and U.S. mining, tunneling, refractory, concrete construction and concrete rehabilitation markets. Rand has more than 20 years of experience representing the King brand and will lead an expanded sales team consisting of King Construction Products team members and Sika North America team members. ■

James E. Monsees
In memoriam

James Eugene Monsees died Aug. 5, 2020 after a long battle with Parkinson's disease. He was recognised internationally as an expert in the design and construction of underground structures and in the sciences of soil and rock mechanics.

Monsees was born March 27, 1937 in Smithton, MO, the son of Olen and Ruth Weiffenbach Monsees. He married Leda Hoehns Oct. 8, 1961 in Smithton. He earned bachelor's and master's degrees in civil engineering from the University of Missouri and a Ph.D. in geotechnical engineering from the University of Illinois. During that time of study, he also served in the Air Force for three years.

Monsees worked for Parsons Brinckerhoff at its headquarters in New York, NY, rising to senior vice president and technical director for underground structures. During a career of more than 50 years, he played key roles on Parsons Brinckerhoff projects for transit, water, hydro, highways and nuclear-waste disposal projects. He also worked on geotechnical studies, protective structures, and on the location and laboratory testing of soil and rock. He served as chief tunnel engineer for the first segment of the Los Angeles Metro Red Line during the 1990s, responsible for the design of all underground facilities for the heavy rail transit system. He then served as a senior advisor for technical review of the Eastside Extension of the Los Angeles Metro Gold Line, which was completed in November 2009. In 2010, he was selected by the Los Angeles County Metropolitan Transportation Authority to lead the development of seismic design criteria for all tunneling projects to be undertaken by the agency as part of its capital investment program.


MONSEES

Other projects to which Monsees contributed his expertise included the Central Link light rail system in Seattle, the extension of the No. 7 Line subway in New York City, the West Side and East Side CSO projects in Portland, OR, and the East Side Access railway project in New York, NY.

Monsees was a principal author of the *Technical Manual for the Design and Construction of Road Tunnels* published in 2009 by the U.S. Federal Highway Administration.

Monsees was elected to the National Academy of Engineering in 1991, which is the highest honorary recognition in the field. He was a Legion of Honor member of SME (UCA) and an active member of the American Society of Civil Engineers, the Underground Technical Research Council, the American Rock Mechanics Association, the Beavers and the Moles. In 2011, he received the Golden Beaver award recognizing his outstanding contributions to the engineering industry.

Monsees loved fishing, Civil War and World War II history and German Shepherds. He is survived by his wife Leda; his daughter, Brenda; his son, Mark; his brother, Ned; his sister Betty Jean and four grandchildren. ■

DFI members receive President's Awards

Matthew Janes, president of the Deep Foundations Institute (DFI), presented four President's Awards during the DFI 45th Annual Conference on Deep Foundations held online Oct. 29, 2020. Established in 2016, the awards are given at the discretion of the DFI president to recognize the efforts and service of members to advance the work of DFI.

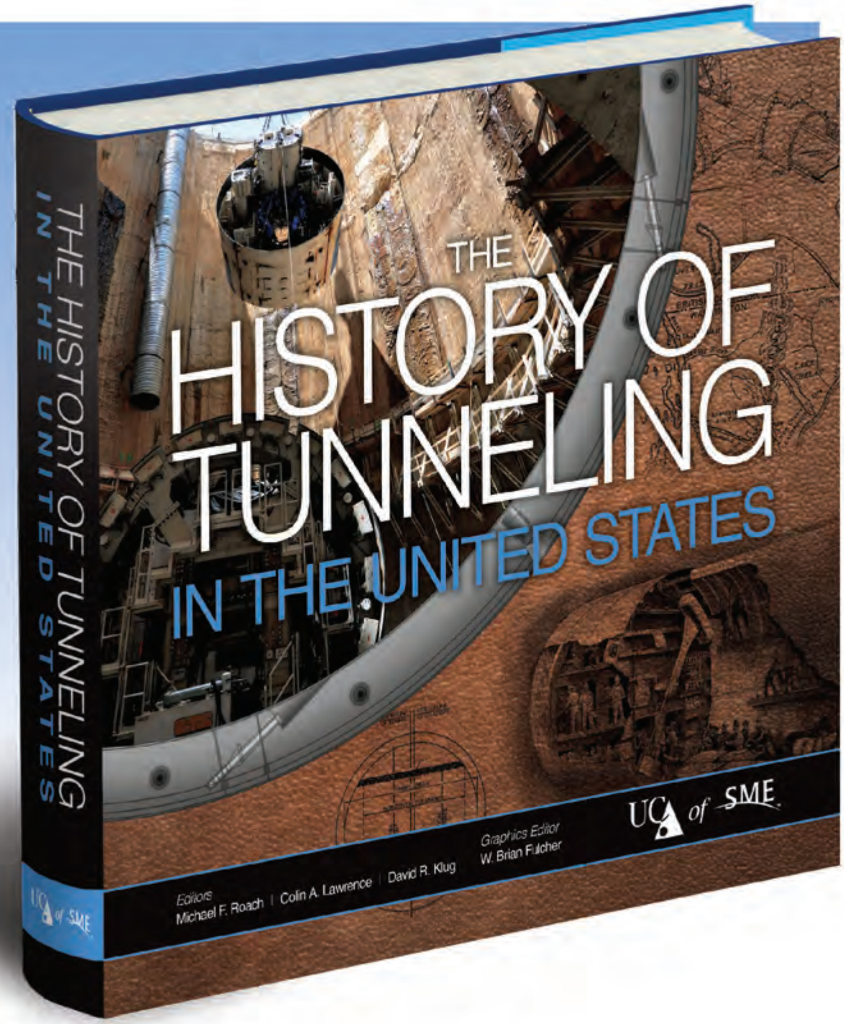
PEGGY HAGERTY DUFFY, P.E., president of Hagerty Engineering and technical director for the International Association of Foundation Drilling, was recognized as the driving force behind DFI's informative recruitment video, "What is the Geotechnical Field?" The video has more than 7,700 views. She also serves as a driving force for safe construction by fostering the joint efforts of the Working Platforms Industry-Wide Working Group.

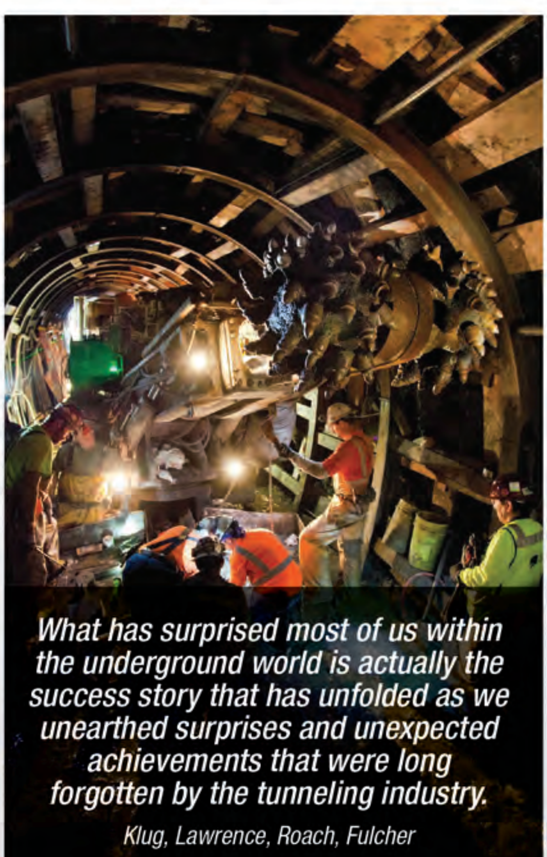
LUCKY NAGARAJAN, general manager-engineering and business development at Giken America, was recognized for her work as the co-chair of the DFI of India Regional Chapter Support Committee, chair of the Women in Deep Foundations Committee and founder of the Women in Deep Foundations subgroups in India and the New York Metro area. She led a team of DFI members to present the webinar series "Converting Crisis into Opportunity — Different Perspectives."

BEN TURNER, P.E. and project engineer at Dan Brown and Associates, was recognized for his participation with DFI. He chairs DFI's young professor and student paper competitions, leading a team of reviewers to select award-winning papers to be published in the DFI journal. He also led this year's S3 virtual software discussion on the use of deep foundations for stabilizing slopes.

ANDREW VERITY, P.E. and national account manager for Terracon's transportation and infrastructure sector, was recognized for his many contributions to DFI. He currently supports DFI as an Educational Trust board member and leader of the annual 5K fundraiser. He also facilitated a donation by Terracon to establish a scholarship for university students. ■

New Book Chronicles 200 Years of Tunneling in the United States





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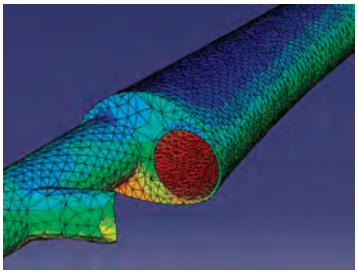

Current and recent projects include MTA Long Island Railroad Project (USA), Chinatown Station (USA), Ottawa Light Railway (Canada), Bank Station Capacity Upgrade (UK), Crossrail (UK), Red Line (Israel) and Eglinton Crosstown LRT (Canada).

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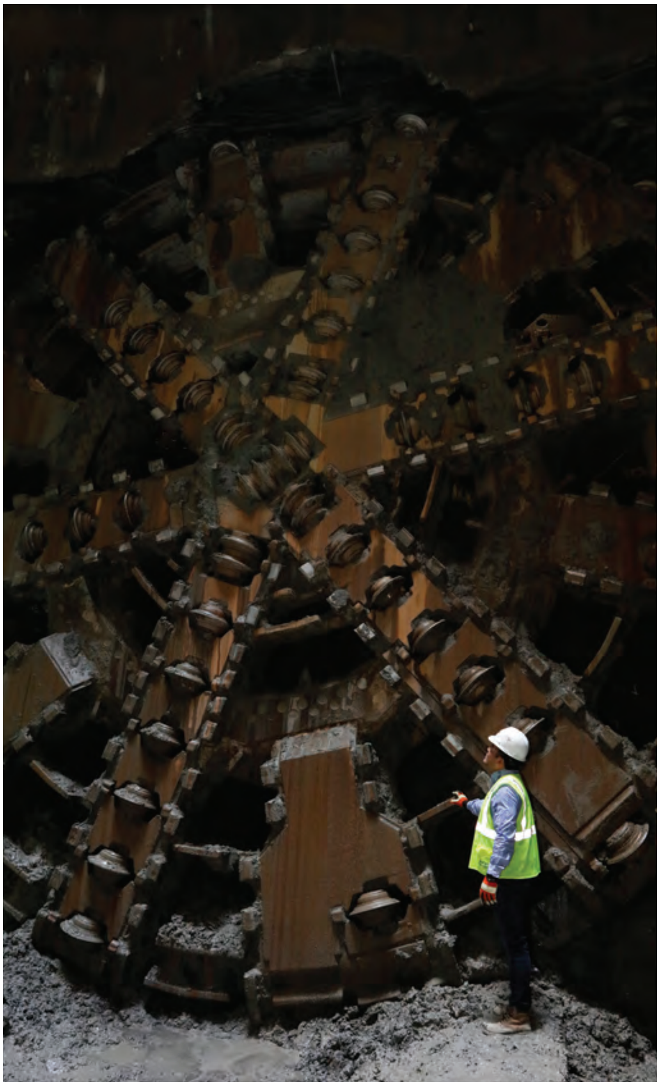
Master Builders Solutions continues to break new ground in addressing the needs of tunneling professionals. Our Underground Construction team brings a total solutions approach to your projects, providing an added resource to help meet your challenges underground. Our solution-based systems enhance the efficiency and performance of the TBM operations and offer performance-based ground support solutions, from novel soil conditioning technologies to innovative anchoring systems; no matter the tunneling method. Throughout the life of your project, our team of specialists work with all relevant stakeholders to help maximize your production rates and to ensure the most successful product and system selection.

The MasterRoc® product line offers a wide range of solutions for TBM excavation in soft ground and hard rock, with high-performance products including soil conditioners, polymers and anti-clay agents. Our full line of greases and sealants help to maximize efficiency for every excavation method and soil type.



Sprayed concrete, Rock Bolt Anchoring systems, Injection and water management systems are also widely considered, selected and used for ground support and enhancement in tunneling and Mining applications. Master Builders Solutions offers customers innovative product solutions and experienced technical resources to tailor cost-effective solutions to specific project needs. These solutions dramatically improve working environments, production and safety.

The Master Builders Solutions product line is designed to be a single source for all your underground construction needs. In addition to the wide range of products and systems, our globally connected team assists our customers in selecting the right systems and combinations, allowing for successful operations, coupled with the highest safety standards.

Master Builder Solutions, a world leader in reliable products specifically designed to address the requirements of tunneling projects worldwide… where production meets performance and safety. Utilizing our global expertise, we are steadfastly focused on the needs of tunneling professionals.

For more information, please visit https://www.master-builders-solutions.com/en-us

Dragados TBM Bertha
Photo credit-Catherine Bassetti Photography

Photo credit-Catherine Bassetti Photography


MASTER® BUILDERS SOLUTIONS
SOLVING YOUR UNDERGROUND CHALLENGES
Our customers shape the future. By listening to their needs and challenges, we have developed a complete and comprehensive offering for the tunneling industry.
We continue to focus our R&D efforts on safe, sustainable, innovative solutions for tomorrow's challenges.
www.master-builders-solutions.com/en-us/products/mining-and-tunneling
12
Photo credit: Catherine Bassetti Photography
® registered trademark of a MBCC Group member in many countries of the world
A brand of MBCC GROUP

Jennmar

JENNMAR is a global, family-owned company that is leading the way in ground control technology for the mining, tunneling and civil construction industries. From humble beginnings, we have grown to include a family of partners, reaching new heights that help us help you. Since 1972, our mission has been focused on developing and manufacturing quality ground control products.

In addition to more than twenty strategically located manufacturing facilities, our brands include engineering services, resin manufacturing, rolled – steel and drill – steel manufacturing, custom steel fabrication, road, miner, and specialty bits, chemical roof support and sealing products, soil stabilization, reclaiming, grading, trenching and foundation drilling, staffing solutions, and our own trucking company.

Our brands ensures quality, efficiency and availability providing complementary products and engineering solutions. This ability to provide a complete range of complementary products and services ensure quality, efficiency and availability resulting in reduced costs, reduced lead times and increased customer satisfaction!

SAFETY, SERVICE, and INNOVATION

J-LOK Resins
J-LOK manufactures state-of-the-art resin anchorage systems that are designed to complement JENNMAR products, provide an optimum bolt, and resin system.

JENNCHEM
JENNCHEM designs and delivers chemical roof support, rock stabilization and ventilation sealing products to the mining and underground construction industries.

JM Conveyors
Manufactures conveyor belt structures, idlers and related components, providing belt through an alliance partnership with Fenner Dunlop.

JENNMAR Specialty Products
JENNMAR Specialty Products provides custom steel fabrication services to the mining, tunneling industries.

JENNMAR McSweeney
JENNMAR McSweeney is a leading manufacturer of forged drill steel for use in the underground mining industry, as well as snowplow and road grader blades and railroad products.

JENNMAR Civil
JENNMAR Civil provides products and services to the tunneling industry, including rock support bolts, anchoring systems, liner plate and resins.

JM Steel
JM Steel provides a variety of flat rolled steel products including master coils, slit coils, blanks, beams, sheets, flat bars and panels

JENNMAR Sanshell
JENNMAR SanShell manufactures roof bits and continuous miner bits for the mining industry as well as specific bits for construction and metal cutting.

JENNMAR Services
Supplying safe and productive employees to the energy, oil & gas, industrial and manufacturing industries.

TungsteMet
TungsteMet manufactures standard and custom-molded carbide products for many different industries.

JM Construction Tools
JM Construction Tools takes pride in manufacturing and selling a full line of road planing, soil stabilization, reclaiming, grading, trenching and foundation drilling bits and carbide tooling products that are American-made. Our in-house operations gives us the flexibility to quickly test and adapt to changing environments and customer needs.

MARJENN TRUCKING
MARJENN Trucking provides trucking services to transport raw materials, supplies and finished products between JENNMAR plants, suppliers and customers.

JENNMAR
258 Kappa Drive
Pittsburgh, PA 15238 USA
Phone: +1-412-963-9071
Web: www.jennmar.com

ANTRAQUIP CORPORATION – your reliable, innovative partner

Antraquip Corporation continues to solidify its position as a leading designer, manufacturer and supplier of roadheaders, hydraulic rock cutting attachments, shaft sinkers, specialty tracked machines with a variety of boom options and ground support solutions for NATM tunnels.

Within Antraquip's rock cutting attachment product line, Antraquip has introduced diamond and carbide saw attachments for excavators ranging from 1 to 60 tons. Additionally, Antraquip has designed and manufactures the world's most powerful rock cutting attachment with 400 kW+ cutting power for excavators in the 80+ ton weight class. By continuing to invest heavily into research and development Antraquip strives to be able to cut hard rock which has previously not been possible with mechanized excavation methods.

As to roadheaders, Antraquip offers not only standard roadheaders in the 12 – 85 ton class but is proud to offer project oriented engineering solutions whenever requested and necessary. Some of the recent projects have included AQM roadheaders equipped with customized drilling attachments, fully automated remote control systems and automated guidance systems.

Within its ground control program, Antraquip specializes in any support product needed for NATM tunnels like lattice girders, steel ribs, specialized rock bolts, spiles, wire mesh and arch canopy systems (barrel vault system or arch pipe system).

In addition to offering project consultations, innovative cutting and support solutions, Antraquip recognizes the importance of after sales service. Their commitment to offering the best service and technical support is carried out by highly proficient and experienced service engineers and technicians, all reinforced with large spare part inventories at hand. Innovation, reliability and experience offered by Antraquip makes them a reliable partner for any tunneling project.

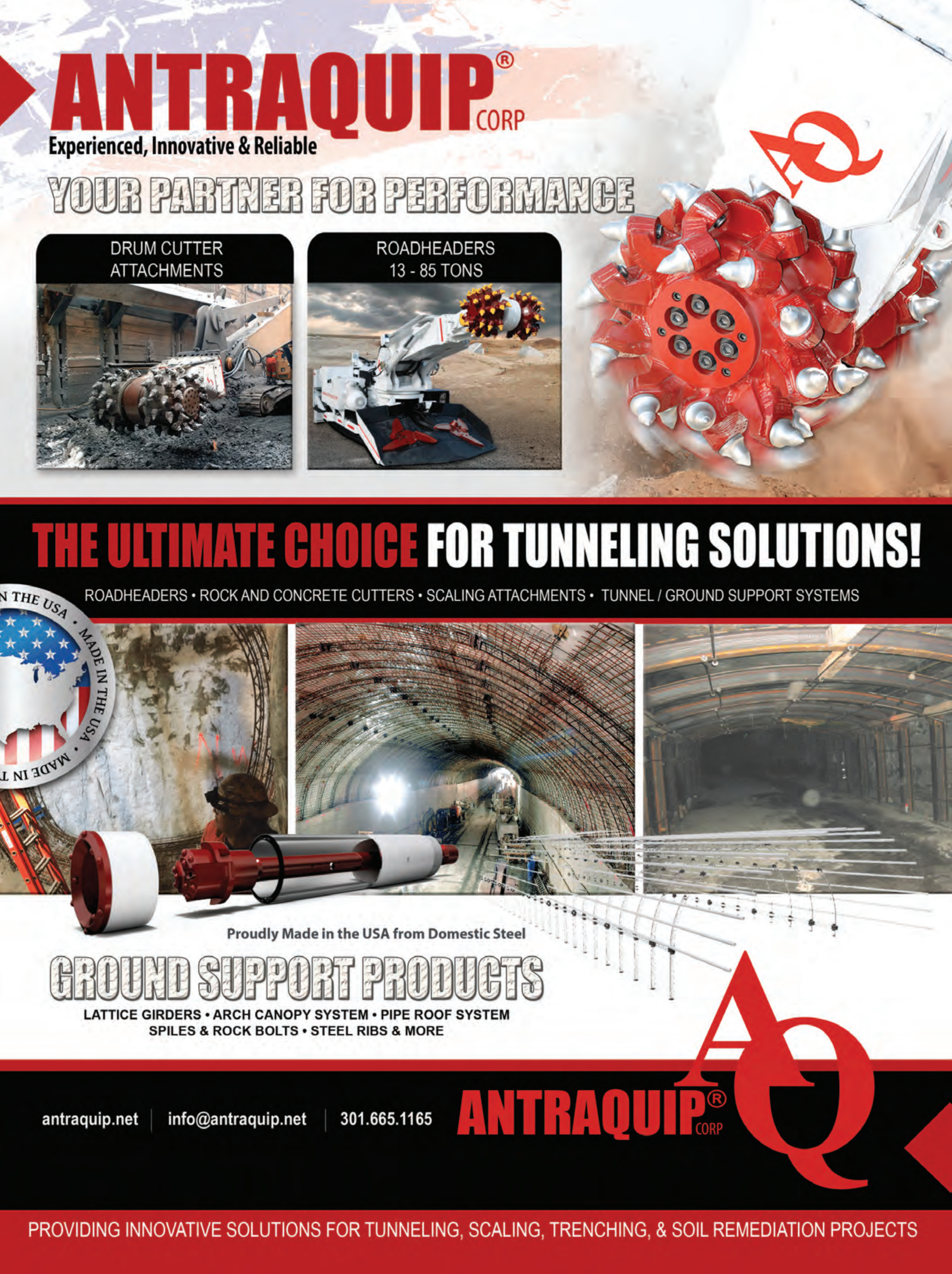
Antraquip's main goal is: SAFETY, SAFETY and again SAFETY! Antraquip continues to strive to offer innovative products to make any job safer, faster and increase the bottom line for any contractor and owner.

Antraquip is well represented all over the world, but takes pride in paying detailed attention to any local tunneling challenge small or large.

IN THE FUTURE, THE WORLD WILL NEED MORE AND MORE TUNNELS – AND ANTRAQUIP INTENDS TO BE AN IMPORTANT, RELIABLE PARTNER FOR ANY UNDERGROUND PROJECT!

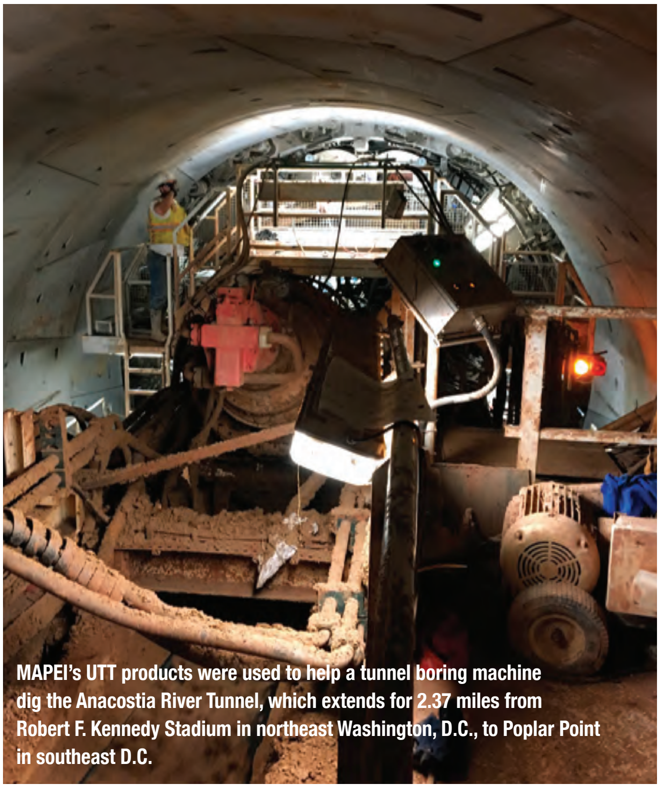
AQ6 Hydraulic Cutting Attachment

AQC180 on CAT336

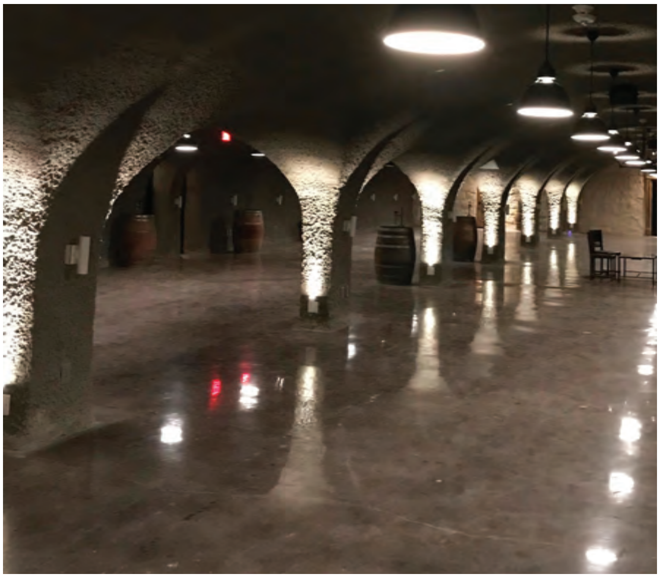

ANTRAQUIP® CORP
Experienced, Innovative & Reliable
YOUR PARTNER FOR PERFORMANCE
DRUM CUTTER ATTACHMENTS
ROADHEADERS 13 - 85 TONS
THE ULTIMATE CHOICE FOR TUNNELING SOLUTIONS!
ROADHEADERS • ROCK AND CONCRETE CUTTERS • SCALING ATTACHMENTS • TUNNEL / GROUND SUPPORT SYSTEMS
MADE IN THE USA
Proudly Made in the USA from Domestic Steel
GROUND SUPPORT PRODUCTS
LATTICE GIRDERS • ARCH CANOPY SYSTEM • PIPE ROOF SYSTEM
SPILES & ROCK BOLTS • STEEL RIBS & MORE
antraquip.net
info@antraquip.net
301.665.1165
ANTRAQUIP® CORP
PROVIDING INNOVATIVE SOLUTIONS FOR TUNNELING, SCALING, TRENCHING, & SOIL REMEDIATION PROJECTS

MAPEI Corporation

MAPEI's Underground Technology Team (UTT) provides the construction market with a range of products dedicated to underground construction work. MAPEI's UTT group and the products it represents were created to meet the expectations of these challenging environments. From the project specification to the admixtures for shotcrete and concrete to the final protective coatings, MAPEI's UTT group and technology are there "for the whole job," said Cristina Onate, PhD, UTT Business Development Manager — Tunneling.



MAPEI's UTT products were used to help a tunnel boring machine dig the Anacostia River Tunnel, which extends for 2.37 miles from Robert F. Kennedy Stadium in northeast Washington, D.C., to Poplar Point in southeast D.C.



The UTT group is a successful division of MAPEI Group, which has provided proven construction system solutions for more than 80 years. Established in 1937, MAPEI Group is a global corporation, based in Milan, Italy, and with 90 subsidiaries that include 83 plants in 36 countries. MAPEI is the world-leading manufacturer of mortars, grouts and adhesives, as well as complementary products for installing floor and wall coverings. MAPEI manufactures chemical products for building, including waterproofing products, admixtures for concrete and repair products, and decorative and protective exterior coatings — as well as the UTT product line.

"The UTT group started in earnest in the U.S. in 2015," stated James Pinkley, Country Manager UTT – North America. "But the business has grown substantially since then." In the underground industry, speed is essential – not only of the products themselves, but also of the evolution of technology. MAPEI reinvests a considerable percentage of its annual profits back into research and development to maintain a leading technological advantage. MAPEI's commitment to R&D ensures that the UTT line comprises the most innovative and technologically advanced products available. In addition to the latest in cutting-edge products, the UTT team is trained in their use.

The UTT product line is divided into six categories: Mechanized Tunneling; Injections for Heavy Civil and Mining Applications; Waterproofing & Water Membranes; Shotcrete Products; Renovation, maintenance and repair; and Coatings for underground construction. No matter the division or the product line, MAPEI is known for quality products and for providing system solutions. As Pinkley stated, "The distinguishing point for UTT is our field support, and our applied technology in the field. Simply put, we don't just sell a product, but rather we go into the field and help our customers use our products – on their jobsite, with their conditions, personnel and equipment. MAPEI UTT services a project from the very beginning to the very end like no one else in the industry does," he said. "UTT also has the agility to adjust to the customers' needs when necessary per the demands of changing geological settings"

For more information, contact MAPEI's UTT group at www.utt.mapei.com.

DSI Underground

Reinforcing Progress - DSI Tunneling LLC.

Our future begins underground. From providing the commodities on which everyday life depends, to creating the spaces, transport conduits and communications networks that connect our world, mining and tunneling are vital to human progress. As ground support specialists, and a proactive partner to underground operations everywhere, we're the people that make it all possible.

We have been a leader in the underground support business in North America since 1920: celebrating 100 years of excellence. Our core product line ranges from steel ribs and liner plates to lattice girders, injection chemicals, anchors, bolts and pre-support systems. We design and develop technically sophisticated Tunneling Systems; offer technical planning with integrated customer support and produce in house to ensure the availability of our systems and our special equipment – anytime and anywhere.

Each support system is customized and professionally engineered to your specific application. Our ground support systems are designed to make tunneling safer. Thanks to our local presence around the globe, we can satisfy your needs for ground control quickly and efficiently - no matter where you are. Our customized products and systems are just in time delivered to service our customers.

Wherever you are in the world, whenever you need us, we'll be on the ground – and beneath it – to reinforce your operation and drive you deeper, further, faster.

You want to advance your operations efficiently. To improve safety. To minimise downtime and maximise productivity and performance. We have the people and the products for every challenge, and a supply chain you can rely on to deliver. Working alongside you, we help you progress towards your objectives – quickly, reliably, cost-effectively.

When you're tackling a seemingly insurmountable objective, facing tonnes of rock and earth, and need the skills and knowledge to achieve it, we're with you. We understand the complexities and considerations, the depths and dangers far below the ground – and we work with you to navigate them, taking you downward and forward, efficiently and intelligently, safely and sustainably. By helping you progress, we're helping our society progress. Which is why it all begins underground. Together, we can help you advance into the earth – and into the future. **DSI Tunneling LLC. Reinforcing progress.**

DSI UNDERGROUND

www.dsiunderground.com
502.473.1010

Kiewit

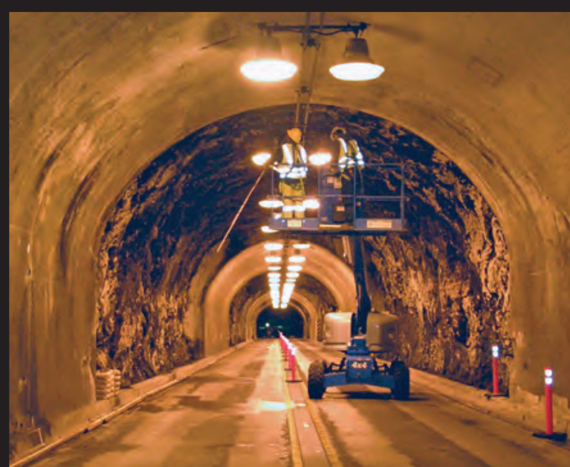
As a construction, mining, and engineering leader, Kiewit is a FORTUNE 500 company consistently ranking in the ENR's Top 10 Contractors. Kiewit, through its operating companies, brings a wealth of diverse resources and track record for delivering the highest quality results – on budget and on schedule. Kiewit's size and experience provides the stability, predictability and knowhow our clients and partners expect – and the flexibility and overall best value they deserve.

Kiewit Infrastructure Co.
1926 S 67th Street, Suite 200
Omaha, NE 68106
(402) 346-8535

Kiewit has been constructing underground facilities for over 60 years, offering some of the most highly skilled and experienced teams in the industry. We have completed hundreds of underground projects, totaling several billion dollars of contract revenue in the markets of transportation, water/ wastewater facilities, power, mining and telecommunications. In addition, Kiewit has the resources to construct cut-off walls, structural slurry walls, drilled shafts and various ground improvements. We perform these operations with our fleet of specialty equipment and the management resources of one of the top builders in North America. Through the use of cutting-edge technology, industry-leading safety performance and the wide range of capabilities, we offer our clients an innovative, one-stop shop for all their tunneling needs.

Our projects range from fast-track rehab jobs to billion dollar rail tunnels. No project is too large or small when it comes to meeting our clients' needs. Our clients in these markets have come to expect the industry's safest work environments, the highest- quality delivery and superior compliance with requirements of all types. Behind it all are the core values that have shaped how we manage our business – for our clients and other key constituents.


Kiewit



Matrix: How Can a High-Speed Wi-Fi-Enabled Tunneling Network Operate Without Specialized Staff?

In the past, it would have been impossible to install a high-speed network with Wi-Fi and Ethernet communications in a tunneling project without specialized installation and maintenance personnel. N-Connex now makes it possible – and simple. This award-winning, modular plug-and-play network is easy to install, expand and maintain. The cables and extenders come pre-terminated, eliminating the need for on-site splice repairs. And the modular components allow you to customize your network based on environmental conditions and communications requirements.

N-Connex is the most comprehensive and flexible gigabit Wi-Fi network – with the lowest cost per mile – on the market today.

Used by forward-thinking mining and tunneling companies around the globe, N-Connex offers a basic network to which multiple solutions can be added. N-Connex's unique design allows third-party electronics and hardware integration, providing a one-stop shop for add-on solutions and eliminating the need for sourcing components.

Tomorrow's communications have arrived

Why have Wi-Fi in your tunnel? The first reason is communications. Voice and data comms enable private calls, PTT broadcast, IP intercoms, phones, tablets, laptops, wireless adapters, input/output devices, tracing tags, radios and more. Reception over Wi-Fi is crystal clear and calm with multiple channels over which you can talk individually or as a group. Additionally, being able to transfer data and get updates provides you with the ability to make changes mid-shift to enhance efficiency and productivity.

Second, the N-Connex tracking solution offers a reliable, detailed and flexible approach to locating personnel, vehicles and assets throughout a project. Tracking also interfaces with a suite of emergency features such as N-Connex's alarm module and advanced evacuation technology. These features alert and help provide the exact location of all personnel in the event of an emergency. Increasing personnel health and safety are primary goals of the N-Connex system.

In addition to tracking, N-Connex offers telemetry data in real-time on vehicles, providing you the ability to remotely monitor the health of your machines, including TBMs, and make adjustments or pre-empt failures. Less down-time means more production.

Most anything you can imagine

N-Connex's suite of solutions is incredibly diverse, typically providing the operator with additional levels of functionality well beyond their initial use cases. In addition to communications, tracking and safety features, it offers a multi-level map interface and zone management, as well as video, real-time condition and environmental monitoring. All of this functionality is packaged in a ruggedized enclosure, specifically designed to withstand harsh environments.

Lowest cost to invest – lowest cost to advance

N-Connex has lowered Wi-Fi access costs, creating a highly affordable networking solution with the lowest cost-to-advance rate on the market. And since you can install a basic system, then add on the adaptable modular features as you go, the network gives you financial flexibility. The simple beauty of the N-Connex system is its ability to meet your exact needs today *and* address your expansion or available resources tomorrow.

Matrix is the authorized sales and service distributor of N-Connex in the United States and Africa.

www.matrixteam.com
812-490-1525
sales@matrixteam.com


LIGHTS, CAMERAS, DETECTION & CONNECTION.
Make your Tunneling Operation Safer and More Productive.
Lighting
Industrial-grade LED lighting for mobile equipment and fixed installations. Brighter, cleaner light for a safer work environment.
Camera Systems
Several options for machine-mounted cameras or video monitoring.
For MSHA & Non-MSHA Tunneling Environments
OmniPro® Visual Proximity Detection
OmniPro® is a camera-based recognition system that uses Visual Artifical Intelligence (VAI) technology to detect people in the path of mobile equipment. Auto alerts the operator. Workers do not wear a signalling device.
N-Connex High-Speed Modular Network
N-Connex is a rugged, "plug and play" fiber optic, Ethernet and Wi-Fi network for tunneling operations. It delivers clear, reliable communications via IP phones, smart phones, IP radios, laptops and tags.
Lowest cost per installed mile!
Matrix is the authorized sales and service distributor of NLT N-Connex in the United States and Africa.
MATRIX
Email: sales@matrixteam.com
Phone: 812.490.1525
www.matrixteam.com

Herrenknecht: Pioneering Underground Together

With the experience of more than 4,800 projects, Herrenknecht is a technology and market leader in the area of mechanized tunnelling technology. Herrenknecht is the only company worldwide to deliver cutting-edge tunnel boring machines for all ground conditions and in all diameters – ranging from 0.10 to 19 meters. The product range includes tailor-made machines for traffic, supply and disposal tunnels, technologies for pipeline installation as well as drilling equipment for vertical and inclined shafts and deep drilling rigs.

The Herrenknecht Group achieved a total output of 1.145 million euros in 2019. The independent family-run business employs over 5,000 people worldwide, including around 180 trainees. With around 70 subsidiaries and associated companies working in related fields in Germany and abroad, Herrenknecht is able to provide a comprehensive range of services close to the project site and the customer, quickly and in a targeted way. Under the umbrella of the Herrenknecht Group, a team of innovative specialists offers integrated tunnelling solutions with project-specific equipment and service packages upon request: separation plants, belt conveyor systems, navigation systems, rolling stock systems as well as segment moulds and even turnkey segment production plants.

As a reliable project partner, Herrenknecht supports its customers with an extensive range of services from the beginning of the project to breakthrough. From the initial project idea through manufacturing, transport, assembly, tunnelling support and spare parts service to disassembly, Herrenknecht accompanies the process at the customer's side. Even personnel solutions for the temporary supplementing of jobsite crews are provided if required. With competent service specialists and and more than 40 years of experience in the tunnelling industry, the company regularly supports around 300 jobsites worldwide and offers customized service packages tailored to individual project requirements.

Road, metro, and railway tunnels for efficient traffic network.

By the middle of this century, the world´s population is expected to reach nine billion, and two thirds of these people will live in large conurbations. To keep people and goods on the move, the way ahead for new efficient infrastructures is leading underground. With state-of-the-art technologies, efficient infrastructures are created exactly where they are needed, even in cramped and complex jobsite conditions. Herrenknecht technology pushes the boundaries of feasibility and creates new tunnelling standards worldwide. Herrenknecht technology extends existing transport networks and creates new connections in urban and rural areas – under mountains or deep beneath water.

Innovative solutions for underground supply and disposal systems.

As the world's population grows the need for underground supply tunnels is also increasing; in emerging and developing countries as well as in modern metropolises. That is why more than 850 Herrenknecht Utility Tunnelling Machines are in operation around the world constructing or laying water and wastewater systems, gas and oil pipelines, as well as conduits for electricity and telecommunications. Here, trenchless tunnelling technology offers a range of advantages compared to conventional construction procedures: transport, business and the environment remain mostly undisturbed when Micromachines, HDD rigs or shaft sinking equipment are being used. Innovations such as Direct Pipe® set new standards in the semi-trenchless installation. The new technology E-Power Pipe® allows the secure and quick installation of underground cable protection pipes with smaller diameters and long advance lengths. Innovative HDD tools simplify pipeline construction operations at key sections. The Herrenknecht product portfolio is completed by a broad range of equipment for the areas of mining (construction of underground infrastructures around raw material deposits) and exploration (oil, gas and geothermal energy).

Herrenknecht Tunnelling Systems USA Inc.
1613 132nd Avenue East, Suite 200
98390 Sumner, WA
USA
Phone +1 253 4472300
Fax +1 253 8639376
pr@herrenknecht.com
www.herrenknecht.com

HERRENKNECHT
Tunnelling Systems


SECOND NARROWS WATER SUPPLY, VANCOUVER, BC
NAVIGATION THROUGH CHANGING GEOLOGY
The new Second Narrows water supply tunnel will be excavated deep under the Burrard Inlet, just east of the Ironworker's Memorial Bridge. Due to complex geological conditions, the first ever Mixshield in Canada will be utilized in this project. With project-specific technology and support from the local Herrenknecht subsidiary, the 1,100 meters of new tunnel will replace the existing aging mains that convey drinking water.
› herrenknecht.com/secondnarrows
metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION
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AECON
MOTT MACDONALD
McMILLEN JACOBS ASSOCIATES
Client:
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Contractor:
› Traylor-Aecon General Partnership
PIONEERING UNDERGROUND TOGETHER
HERRENKNECHT
Tunnelling Systems

Miller Contracting

MILLER has the ability to sink shafts conventionaly from 16’ diameter and larger to depths of 1,600’ or greater. We utilize nontraditional mucking methods that give us an edge on both safety and productivity. We own two raise bore machines with the capacity to do shafts as small as 48” diameter with our Atlas Copco 73R and as large as 26’ diameter with our Herrenknecht RBR400 and up to 2,400’ deep. We offer steel lining or cast in place concrete lining. We also offer pilot hole guidance to ensure tight tolerances are attained on hole deviations for elevators, man and material hoist, or emergency escape hoist applications. A MILLER shaft is not just another hole in the ground, it is a finely crafted structure that the owner can use and be proud of! Please give us the opportunity to do one/another one for you!

At MILLER, we strive to bring the best value to our customer’s projects With fair prices, superb service, and outstanding quality, all delivered by an honest hard-working team of professionals. We are committed to seeing that our values are a part of every project we do. We strive to practice the hightest levels of intergrity with all persons involved and praise God in every interaction.

Please contact us with all your shaft needs! email- Jake Welch jwelch@millercontracting.us or Matthew Miller matthew@millercontracting.us or call them at the office- 618.994.4616 -Jake ext. 115 or Matthew ext. 103

MILLER
shaft division

MILLER has the ability to sink shafts conventionaly from 16′ diameter and larger to depths of 1,600′ or greater. We utilize nontraditional mucking methods that give us an edge on both safety and productivity. We own two raise bore machines with the capacity to do shafts as small as 48″ diameter with our Atlas Copco 73R and as large as 26′ diameter with our Herrenknecht RBR400 and up to 2,400′ deep. We offer steel lining or cast in place concrete lining. We also offer pilot hole guidance to ensure tight tolerances are attained on hole deviations for elevators, man and material hoist, or emergency escape hoist applications. A MILLER shaft is not just another hole in the ground, it is a finely crafted structure that the owner can use and be proud of! Please give us the opportunity to do one/another one for you!

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email- Jake Welch jwelch@millercontracting.us or Matthew Miller matthew@millercontracting.us or call them at the office- 618.994.4616 -Jake ext. 115 or Matthew ext. 103

The Robbins Company

For Robbins, Adaptability on Projects is Key

The Robbins Company is the world's foremost developer and manufacturer of advanced, underground construction machinery. Every single piece of equipment you receive from Robbins is built to last. We ensure that our equipment is crafted and engineered for maximum durability and premium performance, guaranteeing the successful completion of even the most challenging construction projects. Our team of dedicated experts is committed to getting your equipment delivered on time and to providing continuous support from TBM launch to breakthrough.

A Glimpse into the New Era: Remote Machine Acceptance

Adaptability has been key for ongoing projects across the U.S. and Canada for 2020. In April, Robbins assembled a 7.95 m diameter Single Shield TBM at a facility in Mexico and conducted the company's first ever fully remote machine acceptance testing. The Robbins machine was disassembled and transported to the Ashbridges Bay Treatment Outfall in Ontario, Canada, where it is in the process of being launched alongside a continuous conveyor system. This tunnel will be bored through shale interbedded with limestone, siltstone and sandstone to replace a 70-year-old existing outfall.

Essential Tunnels Made Possible With Adaptable Machine Design

The largest hard rock TBM ever to operate in the U.S. is currently in Dallas, Texas, and is making strides on the Mill Creek Drainage Relief Tunnel. Designated essential by the City of Dallas, the tunnel's purpose is to provide 100-year flood protection for east and southeast Dallas; both areas that were affected by severe storms in recent years. Launched in April 2020, the 11.6 m diameter Robbins Main Beam machine and continuous conveyor system have excavated more than 1,000 m of the 8 km long tunnel for the Southland/Mole JV. The adaptable machine will change size partway through the bore, to a more compact 9.9 m. Another highlight worth mentioning is that this machine recently had a best day of 34 m in 24 hours.

The Longest Overland Robbins Conveyor

TBM tunnels are not the only underground projects underway in the U.S. A Robbins conveyor system is being readied for the Long Baseline Neutrino Facility (LNBF), a project for Fermilab in Lead, South Dakota. Contractor Kiewit will use the conveyor to renovate a disused gold mine into a world-class neutrino research facility. There are two caverns that are up for excavation by drill & blast and roadheader about 1.5 km below the surface. Rock will be transported by cable hoist up the 1.5 km deep Ross Shaft to a rock crusher at the surface using much of the original but refurbished mining equipment, and from there will be transported via conveyors. The Robbins conveyor systems are designed for the unique application, and include the longest overland conveyor Robbins has ever provided (550 m), which travels over a main road, city park, and also is near a residential area. The system includes sound dampening, dust filters, sound-proofed transport points, and monitoring systems, among other features.

For more about Robbins products and projects worldwide, visit our website: www.TheRobbinsCompany.com

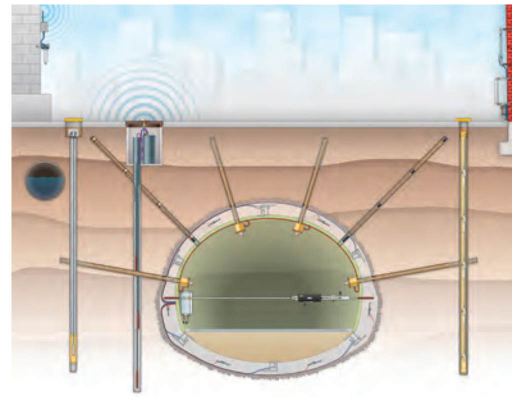
GEOKON

GEOKON is a recognized world leader in geotechnical instrumentation. Founded in 1979, the company offers a full complement of products for a wide range of applications including tunnels, dams, mines, piles, pipelines, embankments, foundations, landfills, bridges and wind turbines. GEOKON's worldwide network of over 45 agencies distribute globally to North and South America, Europe, the Middle East, China, Russia, Asia Pacific and Australia/New Zealand.

With over 100 associates, GEOKON incorporates state-of-the-art manufacturing processes and equipment to produce the highest quality and performing products on the market. Geotechnical, mechanical, electrical and software engineering teams collaborate to develop the highly innovative, accurate and reliable instrumentation. As a result, GEOKON has been awarded ISO 9001:2015 registration from both ANSI•ANAB, USA and UKAS of Great Britain. GEOKON's calibration program complies with the ANSI/NCSL Z540-1 Calibration Laboratory and Measuring and Test Equipment General Requirements and all products have achieved Russian GOST certification for safety.

Specific for the tunnel and tunneling industries, GEOKON offers a full range of instrumentation including:

- NATM-style pressure cells
- Convergence meters
- Tape extensometers
- Multiple-point borehole extensometers
- Instrumented rock bolts
- Piezometers
- Strain gages



- Load cells
- Inclinometers and tiltmeters
- Crackmeters
- Settlement systems
- Dataloggers and Web-based software

All products are backed with a full 13-month warranty and supported by an experienced team of factory-trained associates ready to assist in instrument design, selection and installation. For more information, please visit www.GEOKON.com, email us at info@GEOKON.com or call +1-603-448-1562.

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Web: www.GEOKON.com

Keller – The leading geotechnical specialty contractor

North American Keller companies Bencor, Case Atlantic, Case Foundation, Hayward Baker, HJ Foundation, Keller Canada, McKinney Drilling and Moretrench joined together and rebranded to Keller.

Operating as one company, offering all products and services in each local market, we are easier to understand and engage with. Clients can be confident they're getting the best, most competitive solutions, especially when these involve multiple techniques. This integration further differentiates Keller as the leading geotechnical specialty contractor in North America.

Tunneling contractors often face challenging subsurface conditions. Providing solutions to these challenges is what Keller does. Keller is an industry leader in safety, quality, and innovation. We have the resources, expertise, and in-depth project experience to resolve even the most complex geotechnical issues.

Our combination of detailed local knowledge and connected global resources ensures no question goes unanswered, no problem goes unsolved, and no job goes unfinished. We remove the guess work, mitigate the risk, and give you peace of mind knowing your geotechnical projects are in the best possible hands.

Collectively we've been improving the ground to assist tunneling operations for almost 100 years. Keller's full range of geotechnical construction techniques has been applied to hundreds of tunneling projects to ensure the highest quality product and service.

Solutions for tunnels:
- Soil stabilization
- Settlement control
- Groundwater control
- Earth retention
- Dewatering
- Ground freezing
- Access and ventilation shafts
- Soft ground and hard rock solutions
- Mixed face conditions
- Real-time monitoring

Contact us today about your next tunneling project.

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Northgate Link Extension, Seattle, WA, ground freezing for groundwater control and support of excavation

DC Clean Rivers Project, Washington, DC: Division A - Blue Plains Tunnel, reinforced concrete slurry diaphragm wall shafts (pictured); and Division I Diversion Structure, jet grouting for underpinning, support of excavation, and groundwater control

Sika Corporation

For over a century, Sika has been involved in highly challenging tunneling and mining projects around the globe. Sika supplies solutions for the largest and technically most complex projects - from below the Atacama Desert in Chile inside the large Chuquicamata block caving mine to the Gotthard base tunnel which is 2,500 meters below the Swiss Alps.

All projects below ground have unique challenges and requirements. Together with our partners, we take on these challenges and implement tailored solutions for their specific technical requirements, environmental conditions and logistical hurdles.

Sika is at the forefront when it comes to efficiency improvements in tunneling and mining, reducing excavation times with faster shotcrete solutions and optimizing the cost performance of concrete in all underground operations. With a fully integrated and smart, high quality product portfolio, we are your ideal business partner to continue forging ahead in underground construction.

Sika at Work – The Gotthard Base Tunnel, Switzerland – Where it all Began

More than a 100 years ago, the success story of the Sika Group – now a multinational operation – began on the Gotthard in tunneling. With the waterproofing for the rail tunnel electrification in 1918, Sika created the conditions for the success of the railway on the north-south axis and also the basis for the company's global success. The Gotthard Base Tunnel posed similar challenges to those of 1918 along with some new ones.

Sika's Total Construction Expertise

At the heart of the new trans-alpine rail route in Switzerland is the Gotthard Base Tunnel and with a length of 57 km, it is the world's longest and the deepest rail tunnel. It opened to traffic and became operational at the end of 2016, after more than 15 years of design and construction works.

Sika was involved in this project from the beginning, providing assistance to the project team from their global expertise and experience, including many previous tunneling projects in the Alpine regions of Europe. Sika's support was particularly valuable in developing all of the concrete and sprayed concrete (shotcrete) systems, as well as for the complete waterproofing concept.

Some of Sika's Solutions included; Sika® ViscoCrete® Superplasticizers, Sigunit® Shotcrete accelerators, SikaTard® Set retarders, Sika®-PM Shotcrete spraying systems, Aliva® TBM Spray robots, and the Sikaplan® Tunnel waterproofing system. In total, Sika supplied more than 40,000 metric tons of products, including over 3 million m^2 of waterproofing systems.

Building Trust

Sika is an ideal partner on such projects because of the wide range of products and applications we offer for almost any site construction requirements. Sika specialists and our Technical Support team can advise and help meet these challenges with the "right" solution. This cooperation on the Gotthard Base Tunnel project was strengthened by the year-round, on-site presence.

Scott Rand (SME), was recently appointed North American Vice President of Shotcrete, Tunneling and Mining (STM). STM is a new business unit established by Sika following its acquisition of King Packaged Material Company. It will focus on complete shotcrete solutions, including materials and equipment, and will service the growing Canadian and US mining, tunneling, refractory, concrete construction and concrete rehabilitation markets. Rand, with more than 20 years of experience, will lead an expanded sales team in North America. Please visit our website at usa.sika.com and contact us for your next project!

Sika Corporation – STM – North America
Phone – 1-800-933-7452
usa.sika.com

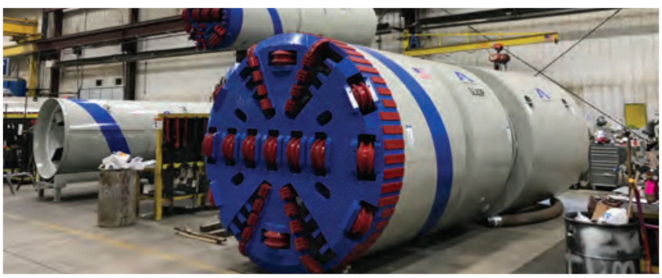
AKKERMAN: OUR EQUIPMENT SYSTEMS

Akkerman develops, manufactures and supports powerful and versatile guided boring, microtunneling, pipe jacking, sliplining, tunneling and earth pressure balance underground construction solutions that accurately install a variety of pipe in an extensive range of ground conditions and project challenges.

Since 1973, our industry-leading equipment has enabled contractors worldwide to productively and cost-effectively install water, wastewater, and other infrastructure.

DRIVEN FOR CUSTOMER SUCCESS

Symmetry with contractors has been the backbone of our business and a point of distinction above our competition. Before Akkerman the equipment manufacturer there was D. H. Akkerman Construction Company. To satisfy their need to accurately install pipe under crossings, the manufacturing branch of Akkerman was founded over forty-seven years ago.



Akkerman employees have a personal investment in our customers' success. Our sales team has the pulse on industry demands and will guide you through the process to select equipment solutions to address your project's challenges. Our in-house engineering department delivers innovative designs with advanced technology, and robust specifications which are expertly manufactured on-site.

SERVICE & SUPPORT

We back our equipment systems with a powerhouse of skilled sales, engineering and technical professionals dedicated to superior reliability and responsive service.

Akkerman factory certified field technicians represent an extensive portfolio of hands-on equipment experience to train your crew on the project site.

Aftermarket parts sales are efficiently dispatched to minimize project delays and ensure that your equipment is prepared for optimal performance.

Contact us at (800) 533.0386 to discuss your next project and visit akkerman.com.

Industry leaders. Delivering innovative solutions.

Parsons (NYSE: PSN) is a leading technology firm driving the future of critical infrastructure, defense, and intelligence. Our expertise in engineering, construction, technical, and management services allows us to provide innovative, alternative delivery methods to customers worldwide. We provide groundbreaking solutions to some of the largest, most complex tunnel and underground construction projects in the world. Our experts are dedicated to overcoming the toughest challenges to help our customers move safely under or through any obstacle.

From planning and design through construction management and operations, Parsons provides a complete range of services for underground utilities, water storage, wastewater, and transportation tunnels, as well as underground buildings. Whether your project involves soft ground, rock, or mixed-faced conditions, our dedicated staff of more than 130 tunnel professionals have the experience and skills to manage the risks and deliver safe, economical, and innovative solutions. We offer a host of cutting-edge tunneling techniques to minimize the risks associated with underground structures of all sizes and levels of complexity. Our award-winning projects, such as Lake Mead Intake No. 3, Anacostia River Tunnel and Ohio River Bridges-East End Crossing Tunnel, demonstrate Parsons' position as an industry leader and our dedication to delivering on challenging projects.

Learn more at parsons.com/tunnel/

ABC Industries, Inc.

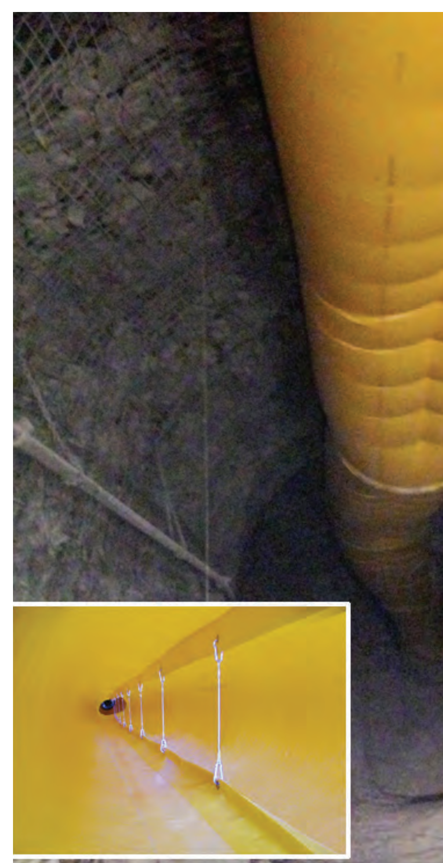
For over 90 years, ABC Industries continues to be a leading supplier of high quality, customized ducting solutions in many of the largest mine, tunnel and underground construction operations worldwide. ABC's complete line of layflat blower tubing, ducting, brattice, fly pads, blast curtains, fans and accessories offer a complete ventilation solution for underground professionals. As tunneling and underground construction continue to evolve, ABC proactively collaborates with industry professionals to engineer unique, premium ventilation products exceeding the needs of the industry.

Our featured MineVent® and TruOval MineVent® ducting products, with their welded construction, eliminate air loss and weakening associated with conventional sewn ducting. Our available RipStop substrate technology option prevents small tears from expanding into sizable holes. ABC's ducting also features several easy-to-handle accessories that are more cost-effective, require less space and smoothly transfer air through bends and turns. To view more of our innovative products, please visit our website at:
www.abc-industries.net.

RIGIDUCT®

Filament-Wound Fiberglass Tubing

A leader in tunnel ventilation, ABC provides high quality, customized solutions such as our RigiDuct® filament-wound fiberglass tubing. Its excellent strength under high degrees of negative pressure, high resistance to attack from acid or alkaline conditions, and its UV-stabilized rubberized elastic gaskets resist degrading while remaining pliable in cold weather conditions. Learn about our other tunnel offerings, such as MineVent® and TruOval MineVent® layflat blower tubing by visiting us at abc-industries.net.



Premier Pipe Systems Manufacturer for 95 Years

Since 1925, Naylor Pipe Company has been the premier manufacturer of Spiralweld pipe systems.

Naylor Spiralweld is available in diameters from 4” through 96” and wall thickness from 14 Ga. through 1/2” wall. The Spiralweld pipe is complemented with all types of fittings, fabrications to specification, and joint connections, including the exclusive Naylor Wedgelock Coupling, to complete your pipe system.

Naylor Spiral Buttweld pipe features two welds along the spiral seam. This creates a pipe structure in which the weld is as strong or stronger than the parent metal.

The Naylor manufacturing process creates a pipe that maintains an accurate diameter throughout its length. The uniformity of the pipe ends speed connection, whether mechanically coupled or welded.

Uniform wall thickness is assured because tolerances of steel strip are governed by the standards established by the American Iron and Steel Institute. In addition, the pipe is furnished in any required length with a cutting tolerance of plus or minus 1/8”.
In addition to carbon steel, spiralweld pipe can be formed from many steel grades, including abrasion resistant, weathering (A-588/A-606) and stainless.

Every length of Naylor Pipe is inspected and where required hydrostatically tested to applicable ASTM specifications. The pipe is available in lighter weights than other pipe making it possible to save money, not only on initial cost, but also in transportation, handling and installation. By sizing the diameter of the pipe to the exact requirements, with exact lengths and factory-sized ends, the greatest economies can be realized.

Quotations are immediately available on inquiry.

Naylor Pipe Company
1230 East 92nd Street
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Email: sales@naylorpipe.com
www.naylorpipe.com

Mining Equipment Ltd.

Mining Equipment Rolling Stock for Columbus, Ohio

"Rolling for more than 35 years"

Mining Equipment continues to supply the tunneling and mining industries with top-quality rolling stock, Jetair fans and steel ventilation ducting, as well as a large inventory of rebuilt equipment such as scooptrams, trucks, drill jumbos and other underground gear.

Mining Equipment is based in Durango, Colorado, with a main shop facility in Farmington, New Mexico. They also have steel fabrication capabilities near Shanghai.

Mine Hoists International, a sister company of Mining Equipment, is based in North Bay, Ontario. They boast the world's largest inventory of used mine hoist and large capacity stage winches for mining and shaft sinking projects. Their new 20,000 square foot shop in North Bay, Ontario can handle the largest of hoist and winch rebuilds.

Mining Equipment 10 Ton Locomotives for Columbus, Ohio

Drill Tech Drilling & Shoring, Inc.

Drill Tech Drilling & Shoring, Inc. is a recognized leader in the foundation and excavation industry in the United States. The same guiding principles that helped Drill Tech become a top 10 Foundation Contractor, according to ENR's Top Specialty Contractors, can be seen in Drill Tech's Mining & Tunneling Division (DTM&T).

On the Barrick Range Front Declines, DTM&T has almost completed over 18,000 feet of twin declines almost six months ahead of schedule. Rock conditions varied in strength along the decline and while the contract was initiated using Roadheader excavation methods, DTM&T has utilized both drill & blast and roadheader techniques to overcome these varied rock strengths. Throughout the execution of the work, DTM&T focused on building a safe project ahead of schedule that met the quality expectations of Barrick. Drill Tech's efforts were recognized by Barrick and additional work was issued to Drill Tech's contract.

In addition to the twin declines, DTM&T performed contract work for other contractors on the project site that included Mass Excavation of 129,314 CY of rock and the application of 15,995 CY of shotcrete. During the course of these projects, DTM&T has performed safely for 814 days.

For more information, please visit www.drilltechdrilling.com, email us at dtds@drilltechdrilling.com or call at 925.978.2060
Drill Tech Drilling & Shoring, Inc.
2200 Wymore Way
Antioch, CA 94509

CDM Smith – A Leader in Tunnel Engineering

Urbanization and rapid population growth have increased demand for tunnel and underground engineering to address infrastructure needs and maintenance challenges facing metropolitan areas worldwide. CDM Smith is a leader in underground space and tunnel engineering. Working collaboratively with our clients, we employ our extensive global tunnel design and construction experience to develop holistic and optimal solutions for a wide range of projects.

Tunneling Expertise
With our experience encompassing soft ground, mixed face, and rock tunnels and excavations, CDM Smith offers a unique perspective and skillset that addresses the specific needs of each project. Our capabilities are comprehensive and include:

- Tunnel engineering: Tunnel and trenchless engineering
- Lining design: segmental, sprayed and cast-in-place
- Soil-structure interaction: 2-D & 3-D numerical modelling
- Ground improvement and ground freezing
- Deep excavations and ground support
- Groundwater modelling and control
- Shafts and caverns
- Documenting and baselining geotechnical conditions

To support our clients, we offer consulting, engineering and construction support services including:

- Environmental, permitting and planning process
- Preliminary design through bid/construction support
- Value engineering and peer review
- Program/construction management
- Inspection and rehabilitation of underground structures
- Risk management
- Cost estimation and life cycle cost analysis

Market Sector Experience
Tunneling and ground engineering is unique – it crosses market sector boundaries. CDM Smith's global tunneling assignments are executed within all market sectors, including:

- Transportation (rail, highway, aviation)
- Environment
- Water/Wastewater (utilities and conveyance)
- Mining (access adits and mines)

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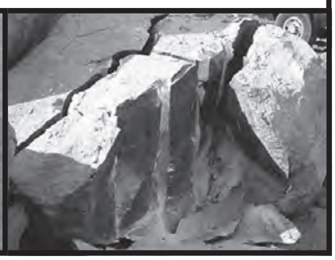
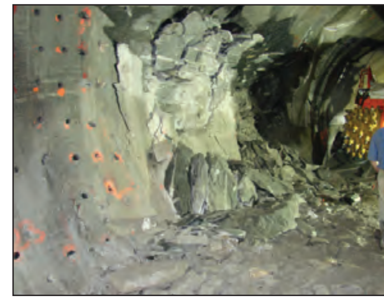
CDM Smith
cdmsmith.com



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.

Daigh Company, Inc.
2393 Canton Hwy., Ste. 400
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Fax: +1-770-887-3783
Email: sales@daighcompany.com
www.daighcompany.com

Dā-mite® Rock Splitting Mortar

MTA-NYCT Canarsie Tunnel Rehabilitation
New York, NY

PROVIDING DESIGN SOLUTIONS FOR TUNNELS AND SHAFTS

Mueser Rutledge Consulting Engineers (MRCE), founded in 1910, is a leading engineering firm focused on the below-ground disciplines of geotechnical engineering and structural foundation design for all structures.

MRCE specializes in providing design solutions for tunnels and shafts. This specialty involves a wide array of tunnel projects in both soft ground and rock for railroads, highways, subways, pedestrians, utilidors, CSOs, interceptors, as well as water and wastewater treatment.

Recent tunneling projects include the MD 355 Crossing in Bethesda which involves a new entrance and underpass for WMATA's NIH Medical Center station; the CSX Virginia Avenue Tunnel, VDOT Midtown Tunnel, DC Water's Blue Plains and First Street Tunnels; PSE&G Crossing #2 - Southern Reinforcement Project in Newark NJ; Toronto Subway Yonge-Eglinton Station, and New York City's NYCT Canarsie Tunnel, LIRR East Side Access, NYCT 2nd Avenue Subway, and the DEP Catskills and Delaware Aqueduct Rondout-West Branch Tunnel and Brooklyn to Staten Island Harbor Siphon Tunnel.

Mueser Rutledge Consulting Engineers PLLC
14 Penn Plaza, 225 W. 34th Street, New York, NY 10122 USA
Telephone: 917-339-9300, Fax: 917-339-9400
Email: farland@mrce.com
www.mrce.com

Brokk 200 packs power of 3-ton machine into a 2-ton package

Brokk Inc. 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 metal processing, nuclear and other specialty applications.

Brokk offers the Brokk 200, a new weight class of machine, ideal for heavy duty, difficult-to-access projects and applications and represents the new standard in compact remote-controlled power. The model packs the power of a 3-ton Brokk machine into a 2-ton package. It is equipped with Brokk's signature SmartConcept™ technology for increased efficiency. SmartConcept includes the extra power of SmartPower™, the added reliability of SmartDesign™ and enhanced ergonomics and productivity of SmartRemote™. The 27.5-kilowatt machine operates tools with requirements typical of one weight class above. When paired with the new Brokk BHB 305 breaker, the unit's hitting power is increased by 40%. The new class of machine delivers 450 foot-pounds (610 joules) with each blow of the 650-pound (295-kilogram) hydraulic breaker. Additionally, the Brokk 200 offers 15% longer vertical and horizontal reach in a compact footprint similar to the Brokk 170. The extra chassis length and machine weight ensures proper balance, even when wielding heavy attachments.

For more information: For more information:

Brokk Inc., 1144 Village Way, Monroe, WA 98272; 800-621-7856; info@brokkinc.com; www.brokk.com; Facebook:@BrokkUSA; YouTube: @BrokkIncUSA; LinkedIn: Brokk Inc.; Twitter @BrokkUSA; and Instagram: @BrokkUSA.

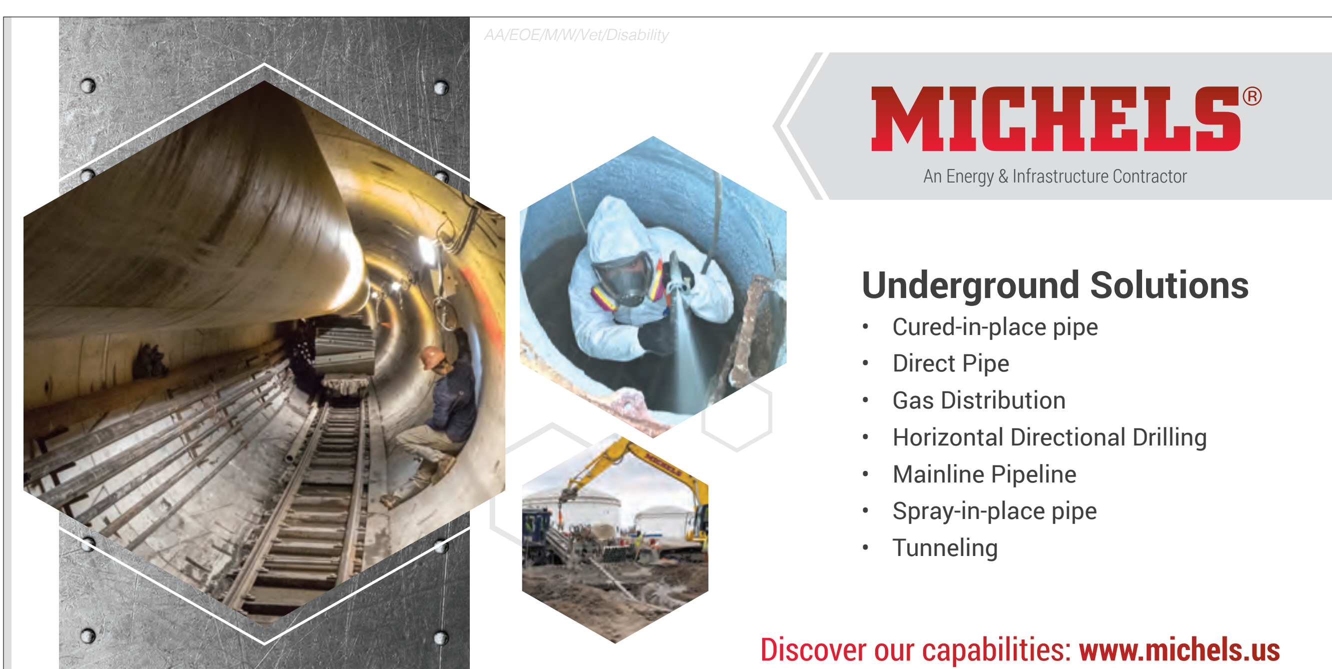
Brokk offers the Brokk 200, a new weight class of machine. The model packs the power of a 3-ton Brokk machine into a 2-ton package.

MICHELS

Michels Corporation has been pioneering innovative new technologies for more than six decades, growing from a small pipeline construction company into one of the largest, most diversified energy and infrastructure contractors in North America. Michels delivers construction, engineering and procurement services that exceed customers' expectations in the energy, transportation, and infrastructure construction industries.

Michels supports its customers' projects with more than 8,000 employees and 14,000 pieces of equipment. In 2019, Michels was ranked No. 24 among Engineering News-Record's (ENR) Top 400 Contractors in the United States.

Michels is among the most experienced contractors performing trenchless construction technologies, including Horizontal Directional Drilling, Direct Pipe, Tunneling, Microtunneling, CIPP, SIPP and Pipe Rehabilitation. Michels built the first tunnel under the San Francisco Bay and is a leader in the successful execution of water retrievals of microtunneling machines and in the completion of microtunnel drives with complex curves.



Strata Worldwide

Strata Worldwide is a global leader in advanced safety systems and communication technologies for underground working environments. To enhance worker safety in tunneling, Strata offers a collection of support products including emergency refuge chambers, communication and remote monitoring networks, and proximity detection systems. These solutions can be used independently, or uniquely interfaced to expand functionality and deliver a higher level of overall operation awareness.

Strata refuge chambers, for the immediate shelter of workers in emergency situations, can be integrated with Strata's networking systems to provide communication connectivity, environmental monitoring and live video feeds while shelters are in use.

HazardAvert proximity detection and collision avoidance systems help to prevent machinery-to-machinery and machinery-to-person accidents and collisions. They can be interfaced with Strata's wireless networking technology to pull data off machine systems and stream to the surface.

Strata Worldwide is headquartered in Atlanta, Georgia USA and offers global distribution.

For more information please visit our website at www.strataworldwide.com or contact us at 770.321.2500

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.

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.

NORTHWEST LABORERS - EMPLOYERS TRAINING
EST. 1983

Northwest Laborers-Employers Training Trust
+1 (800) 240-9112 www.nwlett.org

David R. Klug & Associates, Inc.

David R. Klug & Associates, Inc. provides international and national manufacturers representative services to the underground heavy civil and mine construction industries. The company specializes in the sale and coordination of specialty products, equipment and services for soft ground, conventional and NATM/SEM tunneling practices. Expertise is offered in the supply of various componentry used in the manufacture of one pass precast segmental tunnel linings inclusive of EPDM gaskets, plastic and steel connectors, grout lifting assemblies and precision steel segment casting moulds plus final lining forming systems for C-I-P final lining applications. Through their distribution company, Klug Construction Systems, LLC offers GFRP rock bolts and soft-eyes, steel and synthetic fiber reinforcement, prefabricated welded wire fabric and rebar reinforcing panels plus specialty grout systems for various tunnel backfill grout requirements for highway, rail, subway, water and CSO tunnel construction applications.

David R. Klug & Associates, Inc.
6000 Waterdam Plaza Dr, Ste 120
McMurray, PA 15317 USA
Phone: (724) 942-4670
Fax: (724) 942-4671
Email: information@drklug.com
Website: www.drklug.com

Bradshaw Offers Innovative Tunnel Engineering and Construction Technology

Bradshaw Construction Corporation strives to apply the most appropriate tunneling technology to each project based on its purpose, subsurface conditions and surface restrictions. The company's management team is proud of its ability to construct any type of tunnel in any soil condition both above and below the water table. From small hand mined, wood-box and liner plate tunnels to large NATM shotcrete-lined tunnels; from small pilot tube guided auger bores to large rib-and-board shield and tunnel boring machine (TBM) tunnels; from conventional pipe jacking to slurry microtunneling (MTBM) to earth pressure balance (EPB) TBM tunnels; and from hand mined drill and blast to rock tunnel boring machines (TBMs), Bradshaw Construction has a solution.

For your next project, let our knowledgeable staff of tunnel engineers and construction professionals create the most cost effective, safest, and highest quality solution for your unique tunneling needs.

Bradshaw Construction Corporation
175 West Liberty Road
Eldersburg, MD 21784 USA
Telephone: +1-410-970-8300
Fax: +1-410-970-8340
www.bradshawcc.com

McMillen Jacobs Associates

McMillen Jacobs Associates is a multi-disciplined firm, with self-performing design-build capability. We are experts in tunneling and water resources and deploy this expertise to serve water, dams, energy, wastewater, transportation, aquaculture, federal, private, and regulatory clients using a wide range of delivery methods. For 75 years we have worked closely with our clients at every stage of a project, assisting them with planning, permitting, design, project management, construction, and start-up. Our 21 offices in North America and Australasia and more than 400 staff serve clients locally and worldwide.

McMillen Jacobs Associates
Telephone: 800.842.3794
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McMILLEN JACOBS ASSOCIATES

Design with Vision, Build with Integrity
www.mcmjac.com

Gall Zeidler Consultants

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 has a history of over 300 miles of successfully completed national and 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 selected recent and ongoing projects include East Side Access, New York, East Link Extension in Seattle, WA, California High Speed Rail, CA, BART Extension to San Jose, CA, High Speed Rail 2, United Kingdom, and the Riyadh Metro, Saudi Arabia. GZ was involved in the recently completed Bellevue Tunnel, Northgate and University Link Extensions in Seattle, WA, Caldecott Tunnel 4th Bore Project in Walnut Creek, CA, Dulles Metrorail Extension, Washington, D.C., Cable Tunnels in London and Singapore and multiple underground station upgrades in London.

Haeny, Inc.

Since 2018, Haeny, Inc. has provided grout mixing and injection equipment to North American customers in the tunneling and foundation grouting industries. The Irondale, Alabama headquarters serves as the center for Haeny's sales, rental, and service operations. Known for their state-of-the-art, reliable equipment, Haeny, Inc. provides unparalleled customer service with their readily available parts stock and technical expertise.

Parent company, Hany AG, is the world's leading provider of pumping, mixing and injection equipment, and has been family owned and operated for over 140 years. With an extensive product line ranging from large automated mixing plants and high-volume pumping systems, to compact mobile grouting units, Hany AG can serve jobs of any size. Headquartered in Switzerland, the company currently operates in 27 countries, and has expanded their network to serve customers in the United States, Canada, and Mexico.

For more product information please contact Haeny, Inc. +1 (205) 201-5505, or visit www.haeny-inc.com.

Tunnel Demand Forecast

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	2022	Awaiting funding
2nd Ave. Phase 2	NYC-MTA	New York	NY	Subway	16,000	20	2021	Under design
2nd Ave. Phase 3-4	NYC-MTA	New York	NY	Subway	89,600	20	2022-27	Under study
Kensico-Eastview Connection Tunnel	NYC-DEP	New York	NY	Water	10,500	27	2024	Under study
Flushing Bay CSO	NYC_DEP	New York	NY	CSO	13,200	20	2026	Under study
Bay Park Conveyance Project	NY DEC	New York	NY	CSO	18,500	8	2020	RFQ submitted
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2022	Under study
Metro Tunnel Program - Northern	Boston MRWA	Boston	MA	Water	23,760	10	2027	Under study
Metro Tunnel Program - Southern	Boston MRWA	Boston	MA	CSO	50,160	10	2028	Under study
Silver Line Extension	Boston Transit Authority	Boston	MA	Subway	8,400	22	2024	Under design
Narragansett Bay CSO Phase III - Pawtucket Tunnel Conveyance Tunnel	Narragansett Bay Commission	Providence	RI	CSO	13,000 8,800	28 10	2020 2024	CBNA-Barletta JV Awarded Under design
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	40,000	32	2021	Awaiting funding
Alex Renew Long-Term Control Plan	City of Alexandria	Alexandria	VA	CSO	10,500	20	2019	Bid submitted - under review
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	24,000	18	2022	Under design
Superconducting Maglev Project - Northeast Corridor	TNEM/BWRR	Washington	DC	Rail	146,520	43	2021	Under design
Lower Olentangy Tunnel	City of Columbus	Columbus	OH	Sewer	17,000	12	2020	Granite Const. low bidder
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	30,000 21,000	18 14	2019 2020	Under design Under design
Shoreline Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,100	21	2021	Under design
Shoreline Consolidation Tunnel	NEORSD	Cleveland	OH	CSO	11,700	9.5	2021	Under design
Southerly Storage Tunnel	NEORSD	Cleveland	OH	CSO	18,350	23	2024	Under design
Big Creek Storage Tunnel	NEORSD	Cleveland	OH	CSO	22.450	18	2029	Under design
Enbridge Line 5 Tunnel	Enbridge	Traverse City	MI	Oil	23,760	12	2020	Contractor selected

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 Demand Forecast

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
ALCOSAN CSO Ohio River Allegheny River Mononghahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	 10,000 41,700 53,900	 14 14 14	 2022 2023 2024	 Under design Under design Under design
I-70 Floyd Hill Highway Tunnel	Colorado Dept. of Transportation	Denver	CO	Highway	15,840	60 x 25	2022	Under design
Minneapolis Central City Parallel Tunnel	City of Minneapolis	Minneapolis	MN	CSO	4,200	10-19	2021	Under design
Stormwater Control Program	Harris Co. Flood Control District	Houston	TX	CSO	52,800	25-40	2021	Under design
Mill Creek Trunk Improvements	City of Nashville	Nashville	TN	CSO	13,800	10	2023	Under design
D2 Subway - 2nd Light Rail Alignment	Dallas Area Rapid Transit	Dallas	TX	Highway	3,000	22	2020	Under design
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	Transit	10,500	18	2022	Under design
LA Metro Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2020	LOI received
Folsom Area Storm Water Improvement	SFPUC	San Francisco	CA	CSO	4,000	12	2022	Under design
BART Silicon Valley Phase 2 Tunnel	Santa Clara Valley Transit Authority	San Jose	CA	Subway	26,400	56	2021	Under design
California Waterfix 1 California Waterfix 2	Delta Conveyance Design and Const.	Sacramento	CA	Water	39,905 403,400	28 40	2020 2020	Delayed Delayed
Yonge St. Extension	Toronto Transit	Toronto	ON	Subway	15,000	18	2016	Under design
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	RFQ due 1Q, 2021
Elington Crosstown West Extension	Toronto Transit Commission	Toronto	ON	Subway	40,000	18	2020	RFQ due Jan. 12, 2021
Blue Line Extension	Societe de transport de Montreal	Montreal	QC	Subway	19,000	20	2021	Under design
Green Line LRT	City of Calgary	Calgary	AB	Transit	26,250	20	2018	RFQ submitted
Nose Hill Project	City of Calgary	Calgary	AB	CSO	10,800	10	2020	Under design
Second Narrows Tunnel	City of Vancouver	Vancouver	BC	CSO	3,600	14	2013	Traylor/Aecon JV awarded
Annacis Water Supply	City of Vancouver	Vancouver	BC	Water	7,500	15	2021	RFQ requested
Millennium Line Broadway Extenstion	Metro Vancouver	Vancouver	BC	Subway	18,700	18	2020	Short list announced
Eagle Mt. Pipeline	Fortic BC Woodfibre	Vancouver	BC	Oil	29,500	13	2020	Short list announced
Stanley Park Water Supply Tunnel	City of Vancouver	Vancouver	BC	Water	5,000	15	2021	Under design

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