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PIONEERING UNDERGROUND TOGETHER

HERRENKNECHT
Tunnelling Systems

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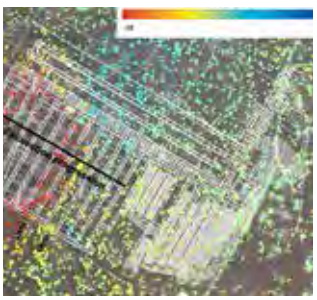

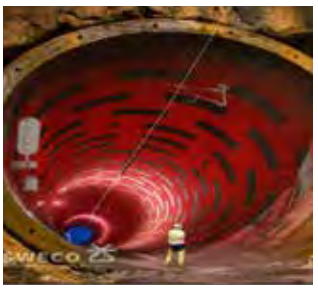

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UCA of SME needs your help

I spoke briefly in my last column about the importance of volunteers to the UCA of SME. After a few more of these articles, you might get a sense that this will be a trend of columns. I am always looking to bring others into the UCA while also getting current members more directly connected and involved in the work of the UCA.

There are many opportunities for you to get involved. One of these opportunities is now pressing and needs many of you to step up and volunteer and that opportunity is to improve our connection to the International Tunneling Association (ITA).

UCA is the United States representative association of the ITA. For this reason, the only way to get involved with the ITA from the Unites States is to join and be active in the UCA. We in the UCA are attempting to forge closer ties to the ITA and their working groups. We are looking for volunteers to integrate with these working groups and drive their work forward.

ITA has 16 active working groups and we have gathered leaders to represent the United States on every one of these working groups. The list of our current representatives is provided below for your reference.

Our plan is now to do the following:

Gather a U.S. subcommittee for each working group under the leadership of the current person in the role.

Have this group develop a strategy to interact with each ITA Working Group, and report to the

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Working Group number	Subject matter for research	U.S. lead point of contact for WG
WG 2	Research	William Hansmire
WG 3	Contractual practices in underground construtions	William Edgerton
WG 5	Health and safety in works	Steve Brandon
WG 6	Maintenance and repair of underground structures	Henry Russell
WG 9	Seismic effects	Conrad Felice
WG 11	Immersed and floating tunnels	Christian Ingerslev
WG 12	Sprayed concrete use	Michael Murray
WG 14	Mechanization of excavation	Brian Fulcher
WG 15	Underground and environment	Open
WG 17	Long tunnels at great depth	Lok Home
WG 19	Conventional tunneling	Nasri Munfah
WG 20	Urban problems – underground solutions	Harvey Parker
WG 21	Life cycle asset management	Jim Brady
WG 22	Information Modelling in Tunneling	Mark Johnson
WG 23	Design and construction of shafts	Verya Nasri, Mike Wongkaew
Young Member	ITA Young Member Group	Vojtech Gall, Jr.

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ARGENTINA'S AGUA SUR

In recent years, TERRATEC's order book has demonstrated significant growth around the world. In Argentina, two 4.66m diameter TERRATEC Earth Pressure Balance Machines (EPBM) are currently being deployed by Italian contractor CMC di Ravenna on a 13.5km-long tunnel that will carry drinking water from the newly expanded General Belgrano Water Treatment Plant to the city of Lomas de Zamora.

The tunnel is a key component of the multi-billion-dollar Agua Sur system that is being built by Argentina's national water company AySA. It is the country's largest water infrastructure project in 40 years and will provide fresh water to 2.5 million inhabitants in the southern region of Buenos Aires.

TUNNELLING SOLUTIONS | WATER

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SR-99 jury trial begins in Olympia, WA

The high-stakes jury trial over the delays of the SR 99 tunnel project in Seattle, WA began in October pitting the state of Washington against the tunnel contractors.

The Seattle Times reported that the state is asking Seattle Tunnel Partners (STP) to pay $57 million for delays caused when the tunnel-boring machine (TBM), named Bertha stalled in 2013.

STP says the state, and potentially taxpayers, should be on the hook for more than $300 million in damage and delays.

Washington State Department of Transportation attorney David Goodnight, in his opening statement, alleged that the delay was caused by mistakes made by STP.

STP contends that it was buried steel pipe that brought the TBM Bertha to a halt, leading to the hundreds of millions of dollars in cost overruns sought by the contractors for the breakdown.

Goodnight said the evidence will show Bertha's operators failed to maintain a soil consistency like toothpaste that's required for the machine to operate properly — so that muck either sprayed out the back of a conveyor screw, or clogs formed between spokes of the massive cutterhead.

STP's lawyer, John Dingess, in his opening statement displayed a message by a state-affiliated tunnel expert that said tunneling "looks beautiful," and a Washington State Department of Transportation (WSDOT) representative's view that Bertha showed "several days of stellar performance" shortly before the stall on Dec. 6, 2013.

The trial is expected to last 10 weeks. To select 12 jurors and two alternates for that burden, the court worked through most of a 170-member jury pool, according to Karl Oles, another WSDOT-hired construction litigator.

In pretrial documents, STP has claimed the state owes as much as $625 million, blaming the stall on a steel pipe struck by Bertha that was left over by the state from a ground water test well sunk in 2002 and used through 2012.

However, Dingess showed the jury a figure of only $300 million in losses by partners Dragados USA and Tutor-Perini. Asked later about lowering the claim, he would say only that costs "in excess of $300 million" will be explained as the trial moves along.

Other litigation will sort out whether insurance companies must cover either side's losses.

When the project began, Gov. Christine Gregoire lauded STP's schedule to complete the tunnel under downtown Seattle by the start of 2016, while the contract required it to be driveable by May 2016. The tunnel opened Feb. 4, 2019 and carries 80,000 vehicles per day. ■

The Boring Company to start its first commercial project

The Boring Company was scheduled to break ground in November on the Las Vegas Convention Center Loop, a twin tunnel loop system under the Las Vegas Convention Center. It will be the the city's first underground people mover, according to *KVVU* in Las Vegas. It is also the Boring Company's first commercial project.

The Boring Company has already begun digging to position one of its machines for the $52.5 million project, which is expected to be completed in January 2021. It will move passengers within its three stations in about a minute.

"A hole has been dug behind the (convention center's) South Hall and we're waiting for permits from the county to begin tunneling," authority spokeswoman Lori Nelson-Kraft told the *Las Vegas Sun*. "The boring machine has arrived on site and will be assembled and lowered into the pit. We hope to begin tunneling efforts in the next month."

Las Vegas Convention Center tunnel loop map.

The system will comprise two

(Continued on page 11)

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Norway to build world's largest ship tunnel

Norway's government has approved the construction of a marine tunnel under the mountains of Stad that will be deep enough to allow for passage of freight in cruise ships in waters that have been considered too dangerous for passage.

I'mnovation Hub reported that the tunnel will be built on a small peninsula in the Norwegian Sea characterized by high wind speed and its harsh weather conditions. There are some other underground excavations that enable ship navigation, such as the Canal du Midi in France, but this will be the first to allow passage to large vessels of up to 14.5 kt (16,000 st).

The tunnel is expected to cost about €300 million and measure 1.7 km (1 mile) long, 50 m (164 ft) tall and 36 m (120 ft) wide.

Typically, open-top canals are built, but in this case, the 335 m (1,100 ft)-high mountains caused the technical teams to choose a tunnel design. When construction procedures begin, operators will start to drill at opposite sides of the mountain, utilizing protection thresholds to prevent water from entering the tunnel until they meet in the middle.

Both ends of the tunnel will be flanked by concrete blocks and rubber rudders in order to withstand vessel impacts, and strict safety standards regarding boat clearance distance observation will be set so that collision risks between ships are avoided.

The tunnel excavated through the heart of this rocky peninsula in the northwestern part of the country will allow cruise, freight and small ships to take a safe subterranean shortcut, thus avoiding the harsh winds and waters of the Stadhavet Sea, one of the most treacherous areas along the coast of Norway.

Construction is expected to last until 2023. The Norwegian Coastal Administration says that from that moment on, approximately 100 cargo and passenger ships will be able to navigate through this new marine pathway every day.

Norse sailors and fishermen have reportedly longed for such a shortcut since as far back as the late 19th century to address the problem of safety due to harsh sea conditions that even the first settlers were already aware of. Thanks to technology and innovation, this request will finally be coming true. ■

UCA of SME members win ITA Awards in Miami

Amanda Kerr, UCA of SME member, was named the Young Tunneller of the Year at the International Tunnelling Association 2019 Awards Conference & Banquet. Kerr, a 2016 graduate of Arizona State University (ASU), is the first woman to win the prestigious award.

"This award is a great honor and helpful for increasing visibility for women in the industry. I look forward to many more female winners in the future," Kerr told *T&UC*.

Recently, she worked as project engineer for the joint venture of Michels-Jaydee on the Blacklick Creek Sanitary Interceptor Sewer tunnel project in Ohio. She is currently lead project engineer for the large diameter tunneling division of the Michels Corp.

She earned a bachelor of science in engineering in civil engineering and a master of science in engineering in construction engineering from ASU. Prior to the Blacklick project she worked as a heading engineer on the Northgate Link Extension project with Michels-Jaydee-Coluccio.

"I am really honored to get this award," said Kerr. "I honestly didn't expect to win because the other candidates were very strong."

Harvey Parker, member of UCA of SME, was also honored at the ceremony at the Hilton Downtown Miami Hotel in Miami, FL with the Lifetime Achievement Award. Parker's career spans 45 years in the U.S. and international tunneling industry.

Parker holds a M.S. in civil engineering from Harvard University and B.S. in civil engineering from Auburn Polytech. He has held adjunct or visiting teaching positions at University of Illinois and Columbia University and is the author or co-author of more than 60 publications.

Parker has made significant contributions to signature tunneling projects through leadership and expertise. He has been involved with many iconic projects including the Alaskan Way Viaduct replacement project in Seattle, WA, the Metro system in Los Angeles, CA, and the inception of the metro system in Washington, DC.

Also picking up an award was the Regional Connector Transit Project in Los Angeles, CA. It was named the Project of the Year between €50 million and €500 million.

The Regional Connector Transit Project is an underground light rail system with three new stations.

LA Metro estimates that the Regional Connector will increase ridership across the entire transportation system by 17,000 people per day and save commuters an average of 20 to 30 minutes by reducing the need to transfer to different lines.

Major challenges were encountered during the work and consequently, a few innovations were implemented. ■

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Compact TBM bores longest rock tunnel

In August 2019, a small-diameter, double-shield tunnel-boring machine (TBM) made a big impact. The 2.46 m (8.07 ft)-diameter Robbins machine completed 3,475 m (11,400 ft) of boring with no intermediate access, making it the longest rock tunnel ever bored by a double-shield TBM under 2.5 m (8.2 ft) in diameter.

The machine completed the Parmer Lane Wastewater Interceptor in Austin, TX for contractor S.J. Louis Construction. Despite obstacles, including two tight curves of 150 m (500 ft) radius and unexpected ground conditions that required modification of the cutterhead in the tunnel, advance rates were good. The machine reached up to 380 m/min (1,250 fpm) while mining in single, 12-hour shifts per day.

"It was a hard-rock TBM, and it performed better than expected through hard rock," said Zach West, project manager for S.J. Louis.

The challenges for the TBM and its crew were varied, explained West. "The pairing of this tunnel length, which is on the longer side, and the diameter, which is on the smaller side, is challenging. The survey in a small tunnel with tight radius curves and limited surface access for more than 3.2 km (2 miles) is very difficult." He added that the shallow tunnel depth, and the alignment to within a few feet of sanitary lines, high-pressure gas mains and fuel tanks for gas stations, made TBM guidance critical. "I would say that I am most proud of our ability to guide the machine successfully through these obstacles and into our retrieval shaft within our expected tolerances."

Through one stretch, the tunnel advanced directly between a 30-cm (12-in.) diameter, high-pressure gas main and fuel tanks for a gas station with limited as-built information. "Navigating this section took a great deal of coordination with the local utility companies. Because the tunnel diameter was too small for an automated guidance system, we manually surveyed the front of the machine at every push to ensure the machine was on track," said West.

"I'm proud that they mined the longest tunnel to date for a small shielded gripper machine of this size without any safety issues. Kudos to their management philosophy and jobsite team," said Tom Fuerst, Robbins Utility Tunneling sales manager. Robbins assisted the crew while in the tight 150-m (500-ft) curves and helped with modifications required to the cutterhead and disc-cutter arrangement.

The tunnel is located in an environmentally sensitive aquifer, with ground conditions ranging from soft dolomite with clay to limestone from 13 to 68 MPa (2,000 to 10,000 psi) UCS. "While we tunneled through the softer material, our best advance rate was close to 0.9 m (3 ft) per hour. When we tunneled through the expected limestone, advance rates were over 5.2 m (17 ft) per hour. Our best day was 25 m (81 ft) in a single shift," said West.

The majority of the tunnel used a simple two-rock-bolt pattern for support. In the last 10 percent of the tunnel, ribs and lagging were used as support. Final carrier pipe, which is now being installed, consists of 110 cm (42 in.)-diameter fiberglass pipe.

The successful project is part of a larger trend toward small-diameter, TBM-driven rock tunnels in the United States, said Fuerst. "It is primarily due to demographics and business growth. The parts of the United States that are growing need to build out their sewer and water infrastructure. TBMs can mine long distances with tight curves and reduce the need for multiple shafts, which lowers the overall project cost. And, given that most small-diameter pipelines follow a road or municipal right-of-way, traffic problems are reduced significantly compared with open-cut operations."

The Parmer Lane Wastewater Interceptor connects to two existing lift stations at Lake Creek and Rattan Creek. The tunnel allows for these lift stations to be decommissioned and will provide additional flow capacity by gravity, reducing operating costs for the city of Austin. ■

Chairman's Column: Volunteers are needed for UCA

(Continued from page 2)

UCA Executive Committee twice a year: in January to decide what is being delivered to the WG at the WTC held in the spring, and in June to debrief UCA on next steps and work to complete before the next WTC.

The UCA of SME needs a substantial number of new volunteers to join one of these U.S. subcommittees. It's an opportunity to network, learn something new and get outside of your normal project experience.

Please email or contact whomever you might know on this list, or contact me if you don't know any of these folks. Whatever subject inspires you, get involved. The tunneling world awaits you. ■

Robert Goodfellow
UCA of SME Chairman

UC of SME

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Grand Paris Express project work underway

Construction work on the Grand Paris Express is in full swing with multiple contractors building 200 km (124 miles) of new railway lines, 90 percent of which are beneath the French capital's congested streets. This mega project, possibly Europe's largest, will build four new metro lines and 68 new stations between now and 2030.

The project rivals the Crossrail Rail project in London in scope and complexity if not overall size. When complete, it is expected to serve two million passengers per day with a train running every two to three minutes. It will be a 100 percent automatic metro system with 90 percent of its lines underground.

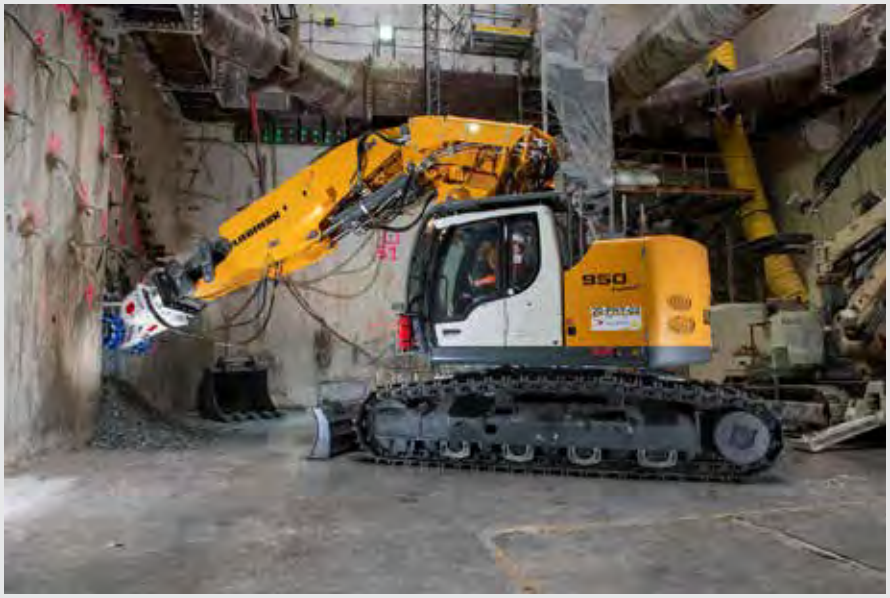
The Grand Paris Express will mark a break with the way the Paris transport network operates, creating new patterns of mobility by facilitating travel between the suburbs. In enabling regional areas to engage in dialogue with each other and with Paris, the Grand Paris Express will provide businesses with a wealth of opportunities fostering economic development.

New Civil Engineer reported that the project features an innovative aerial mucking pipe circuit designed to reduce truck movements, construction blight and the carbon footprint of excavation works. This dual conduit is delivering a bentonite slurry from a delivery and treatment station on the banks of the river Seine to the slurry tunnel-boring machine (TBM) face and then carrying excavation muck from the tunnel face back to the treatment station where it is shipped away.

Slurry is supplied and spoil will be removed via the Gambetta TBM launch shaft, which is a very constrained site.

Underground, the project will feature a fully automated, robotic method for installing concrete tunnel lining segments. It may be the next step to fully automating TBMs and is being closely watched by many in the tunneling industry.

A Liebherr R 950 tunnel crawler excavator at work at the Grand Paris Express project.



"Atlas is a new innovation. We started working on it three or four years ago. It is an automated system for installing lining ring segments," said Bouygues TP UK director Jérôme Furgé. "Time is optimized. Safety is improved. We are getting rid of the guy with the joystick," he said, referring to the operator who, in using conventional installation methods, guides the segment into position remotely using a joystick.

"It will be more accurate, safer, quicker. This is its first real test. We are looking for full implementation across Bouygues in one year," he said.

The system is designed to install one segment every three minutes, 30 seconds on average."

The project will use 20 TBMs as well as other equipment including a Liebherr R 950 tunnel crawler excavator that is at work on shaft 807 of Line 15. It has racked up more than 500 operating hours and is responsible for milling, creating arches and some handling operations.

The R 950 tunnel crawler excavator is suited to underground use. The lift height limitation automatically restricts the movements in order to reduce the risk of collisions with rocks to a minimum. The small swivelling radius and the cameras on the rear and sides also reduce the risk of collisions with walls, surrounding material or site personnel. Generally, collisions and therefore damage to the machine tools, hoses and lines, as well as collisions with the side surfaces and equipment in the gallery, are minimized.

The R 950 tunnel crawler excavator has an operating weight of approximately 45 t (50 st). The Liebherr diesel engine achieves an output of 190 kW (258 hp). This machine is suitable for a tunnel height of five to eight meters. At 14 L/h on this construction site, the R 950 has a low average fuel consumption for this model. ■

Tunneling begins at Brenner Base Tunnel in Italy

Two pairs of 10.7 m (35 ft) diameter double-shield tunnel-boring machines (TBM) from Herrenkencht began boring on the Brenner Base Tunnel (BBT) project in August. The tunnel, when completed in 2028, will pass under the Alps between Austria and Italy and form the longest underground tunnel route in the world.

The first pair of TBMs, nicknamed Flavia and Virginia, launched on the Italian side and will tunnel about 12 km (7.5 miles) to the Austrian border. This TBM work comprises most of the €993 million Mules 2 and 3 lot, or contract, which was awarded in 2016 to a consortium of Astaldi, Ghella, Oberosler Cav Pietro, Cogeis and PAC, which joined to form BBT SE.

Engineering News Record reported that the tunnel will serve high-speed-rail (HSR) passenger trains traveling up to 200 km/h (124 mph), and cargo trains up to 120 km/h (75 mph), slashing the travel time over the existing overground Brenner Pass to 25 min from 80 min. An integral part of the Scandinavia-Mediterranean Rail Corridor, the tunnel flattens the transit incline from 26 percent on the existing pass to just 6.7 percent and reduces the travel distance by 20 km (12 miles). The facilities are designed to be in service for 200 years.

The BBT consists of two tubes, each 8.1 m (26.5 ft) wide, running 40 to 70 m (130 to 230 ft) apart from one another. These tubes are each equipped with a single track and are linked every 333 m (1,092 ft) by connecting side tunnels, according to the BBT SE website.

A unique feature of the BBT is the exploratory tunnel running from one end to the other. This tunnel lies between the two main tunnels and about 12 m (40 ft) below them. With a diameter of 5 m (16 ft), it is noticeably smaller than the main tubes. The excavations currently underway on the exploratory tunnel should provide information on the rock mass and thereby reduce construction costs and times to a minimum. The exploratory tunnel will be essential for drainage when the BBT becomes operational. It will also serve a central logistical role as a rail supply line for prefabricated tunnel lining segments to feed the advancing main TBMs. Upon completion, the exploratory tunnel will morph into a maintenance and drainage tunnel.

All tunnels built as part of the €8.4 billion project — including HSR, emergency, ventilation, access and exploratory — add up to around 230 km (142 miles). In April, the project team crossed the milestone of 100 km (62 mile) of completed tunnels.

On the southernmost end of the Brenner Base Tunnel, the tunnel will pass just a few meters below the rapids of an alpine river. The €303 million Isarco River Underpass lot was awarded in 2014 to a consortium of Salini Impregilo, Strabag, Consorzio Integra and Collini Lavori. Upon completion in 2022, the contract will link the tunnel with the existing Brenner line and the railway station in Fortezza.

Around 3 km of 6 km (1.8 to 3.7 miles) of tunneling has been completed at the site. "We have done the easiest part, which was through rock, and we were able to excavate up to 10 m/d (3 fpd)," says Maurizio Ferrero, geotechnical engineer with BBT SE told *Engineering News Record*. For the river underpassing, productivity will slow to just a half meter per day in the alluvial soil, he said.

Four 25-m (80-ft) deep shafts, elliptical in plan to accommodate the varying angles of the four tunnels, have been completed, two on either side of the river. They provide access for crews who will spend months preparing for large-scale ground freezing to safely construct the underpasses. The four tunnels will be between 56 and 63 m (183 and 206 ft) long. Each will take four months to construct; two will be built in 2020 and the remaining two tunnels built in 2021.

Originally, the design specified a cut-and-cover method of construction. But this would have required shifting the river twice and lowering the water table by 20 m (65 ft). The contractor consortium proposed the ground-freezing alternative, which eliminated the environmental impact to the riverbed and associated underground aquifer, Ferrero said. ■

Las Vegas: Tunnel will pass under convention center

(Continued from page 4)

vehicular tunnels, both about a mile long, and could eventually be expanded to link the convention center with key tourist hubs including the Las Vegas Strip and McCarran International Airport.

According to the Boring Company's website, the loop system is a high-speed underground public transportation system in which passengers are transported via compatible autonomous electric vehicles (AEVs) at up to 155 miles per hour.

Any future expansion would be designed with similar compatible construction infrastructure and AEVs and would provide an express connection from the expansion site to LVCC Loop stations.

The Boring Company has drawn interest from several U.S. cities, though plans in Chicago and Los Angeles have hit roadblocks in the form of funding and environmental concerns.

Elon Musk, founder and president of Tesla, founded The Boring Company in December 2016. He launched a Chinese unit of the company in August of this year. ■

MWRA Metropolitan Boston Tunnel Redundancy program project update

In 1984, legislation was enacted to create the Massachusetts Water Resources Authority (MWRA). The MWRA is a public authority that provides wholesale water and sewer services to 3.1 million people and more than 5,500 large industrial users in 61 communities in eastern and central Massachusetts. The primary mission of the MWRA was to clean up Boston Harbor and modernize the area's water and sewer systems. Other key elements have included a major capital program to repair and upgrade the systems, increase staff to improve operations and maintenance, promote water conservation and plan for the future to meet growing demand.

Boston's water system has been governed by various water authorities over the years starting with the Cochituate Water Board (1845-1875), followed by the Boston Water Board (1875-1895), Metropolitan Water Supply Commission (1926-1946), Metropolitan District Commission (1946-1985) and finally the MWRA (1985-present).

The MWRA's water system currently has more than 200 separate facilities, including the John J. Carroll Water Treatment Plant, with a capacity of 1.5 GL/day (405 million gpd), 11 pump stations and 14 below- or above-ground storage tanks. The water transmission system includes 167 km (105 miles) of active tunnels and aqueducts, mostly 3 to 4.2 m (10 to 14 ft) in diameter, and 63 km (39 miles) of standby aqueducts.

History of Boston's water system

Although the MWRA's current water system of interconnected reservoirs, tunnels, aqueducts and pipelines provides an abundant supply of clean drinking water to millions of customers, the system was not always sufficient to meet the growing needs of the city of Boston and the surrounding communities.

Kathleen M. Murtagh and Fredrick O. Brandon

Kathleen M. Murtagh and Fredrick O. Brandon, members UCA of SME, are director of tunnel redundancy and director of design and construction, respectively. Massachusetts Water Resources Authority, email fred.brandon@mwra.com.

When the Boston area cities and towns first faced the problems of providing clean water sources in the 1600s, their methods were primitive, relying on local wells, rain barrels and spring rains on Boston Common. By 1795, wooden pipes delivered water from a centralized water supply at Jamaica Pond to Boston proper. By the late 1840s, however, Jamaica Pond was too small and too polluted to provide water to Boston's 50,000 residents. So, the pattern of continually moving westward in search of larger fresh water sources began.

Cochituate System: 1848-1951. In 1845, the Cochituate Water Board began construction of a new water supply and transmission system. A tributary of the Sudbury River was impounded, which created Lake Cochituate. Lake Cochituate, with its 44 km^2 (17 sq miles) of watershed, 7.5 GL (2 billion gal) of storage and yield of 38 ML/day (10 million gpd), became the cornerstone of the Boston water system.

The Cochituate Aqueduct, extending 23 km (14.5 miles), was completed to transport water to the Brookline Reservoir and then to smaller distribution reservoirs in all parts of the city. This aqueduct was in service for approximately 100 years, until 1951, when water quality had declined and alternate methods of transporting water to the hub of the distribution system had been constructed.

The Sudbury Aqueduct and Chestnut Hill Reservoir: 1878. Boston grew rapidly after the Irish Potato Famine of 1843-45 and by 1870, its population exceeded 200,000 and consumed 64 ML/day (17 million gpd) of water. Planners had not anticipated this rapid growth; they thought that the Cochituate system would be adequate for many years. In order to provide the growing city with the water it needed, the process of diverting water from a western pure upland source was repeated.

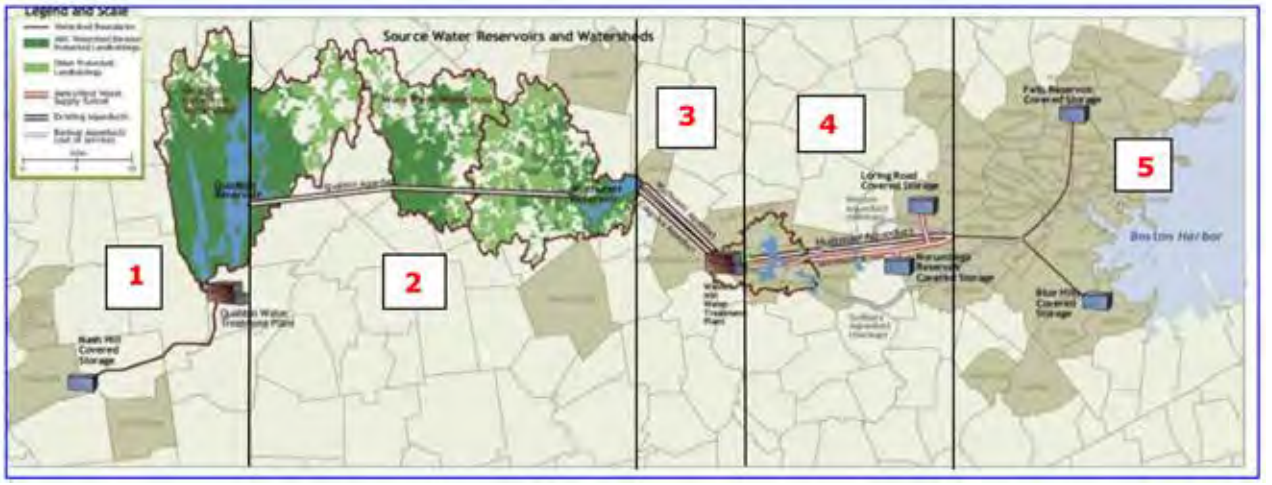
In 1878, the mainstream of the Sudbury River was diverted via the Sudbury Aqueduct to the Chestnut Hill Reservoir. Between 1875 and 1898, seven major reservoirs were constructed in the Upper Sudbury River Watershed. The Sudbury and Cochituate Aqueducts were designed to operate by gravity to fill the Chestnut Hill and Brookline Reservoirs.

Wachusett Reservoir: 1897. The Boston metropolitan area continued to grow rapidly through the 1890s. Indoor plumbing became commonplace. Planners had not foreseen this development and the current water supply had become inadequate. Under the leadership of Frederick Stearns, chief engineer of the Boston Water Board, it was decided that a new water source that could be gravity-operated and would not require filtration was required.

In 1897, the Nashua River above the Town of Clinton in Central Massachusetts was impounded by the Wachusett Dam. An area of 16.8 km^2 (6.5 sq miles) was flooded, and

FIG.1

MWRA water transmission system.



water was conveyed by the Wachusett/Weston Aqueduct to the Weston Reservoir and then by pipeline to the Chestnut Hill and Spot Pond Reservoirs. Work was completed in 1905 and the reservoir first filled in May 1908. The Wachusett system was built to service the 29 municipalities within a 16-km (10-mile) radius of the Massachusetts State House. At the time, the Wachusett Reservoir was the largest public water supply reservoir in the world with a capacity of 246 GL (65 billion gal).

Quabbin Reservoir, Ware River intake and Hultman Aqueduct: 1926-1946. Eventually the Wachusett System became inadequate for the increasingly industrialized city and a westward focus for a new water source resumed. The Quabbin Reservoir was Boston's fourth westward reach for a pure upland source of water that could be delivered by gravity and not require filtration. Construction of the Quabbin Reservoir required impoundment of the Swift River and the taking of the towns of Dana, Enfield, Greenwich and Prescott.

In 1926, construction began on the Wachusett-Coldbrook Tunnel, which is now the eastern section of the Quabbin Tunnel. During the 1930s, the Wachusett-Coldbrook Tunnel was extended to the Swift River. It is a two-way tunnel. Water flows west from the Ware River to the Quabbin Reservoir during the high-water months and then east from the Quabbin Reservoir to Wachusett at other times of the year.

Construction on the Quabbin Reservoir began in 1936. Filling commenced in 1939 and was completed in 1946 when water first flowed over the spillway. At the time, the 1,560 GL (412 billion-gal) reservoir was the largest man-made reservoir in the world that was devoted solely to water supply. The existing reservoirs, located at sufficiently high elevations, could now supply an abundance of water to the metropolitan Boston area by gravity through pressurized aqueducts or tunnels.

In the 1940s, planners believed that the Quabbin Reservoir would be sufficient to supply the metropolitan area into the foreseeable future, and at the time, was the last major investment in the water system with no plans in place for upgrades to carry the system into the next century. Many of the previous expansions used gravity for supplying water instead of costly pumping. Fortunately, these crucial foundations laid by the early water engineers provide the backbone of the system run today.

Origins of the pressure aqueduct system (Hultman Aqueduct): 1937-1941. In 1937, a plan was developed for a high-service pressure aqueduct system to deliver water to the metropolitan area. A portion of the plan included two parallel aqueducts to carry water from the Wachusett Aqueduct to the new Norumbega Reservoir and the terminus of the Weston Aqueduct in the town of Weston. Work began on schedule in 1939 and by the outbreak of World War II in 1941, one of the two proposed parallel pressure aqueducts had been built. This portion of the pressure aqueduct is the Hultman Aqueduct.

Pressure aqueducts and tunnels: 1950-1978. After World War II, additional segments of the pressurized transmission system came online with the construction of the Chicopee Valley Aqueduct, metropolitan tunnel system and Cosgrove Tunnel. As these sections of the pressure transmission system have come online, the need for pumping from open reservoirs was reduced because more of the service area could be supplied by this pressurized transmission system. Older facilities that originally provided a level of redundancy to the new pressure tunnels were eventually retired from use. More reliance was placed on the newer pressurized system to the point where it is now relied upon to deliver 85 percent of the metropolitan area demand.

FIG.2

Valve chamber filled with ground water.

FIG.3

Hydraulic valve actuators.

Redundancy in the transmission system

Transmission system overview. The current water transmission system can be divided into five major segments as shown in Fig. 1. Redundancy projects for segments 1 through 4 have been completed. The fifth segment, the metropolitan tunnels, represents the next challenge for the MWRA in improving the reliability of this great water system.

Metropolitan tunnel system (segment 5). The metropolitan tunnel system includes the City Tunnel (1950), the City Tunnel extension (1963), and the Dorchester Tunnel (1976). These three tunnels interconnect at shaft 7 at Chestnut Hill. Together, these tunnels carry approximately 60 percent of the total system daily demand with no redundancy.

Condition of metropolitan tunnel system. Each tunnel comprising the metropolitan tunnel system consists of concrete-lined deep rock tunnel sections linked to the surface through steel and concrete vertical shafts. At the top of each shaft, cast iron or steel pipes and valves connect to the MWRA surface pipe network. These pipes and valves are accessed through subterranean vaults and chambers. The tunnels and shafts require little or no maintenance and represent a low risk of failure. However, many of the valves and piping are in poor condition.

Valve reliability for the metropolitan tunnels is a concern. As an example, the City Tunnel (1950) appurtenances are 68 years old and cannot be adequately maintained or replaced until a back-up exists. Failure of some valves can cut off a majority of the system's capacity to supply water and, due to the physical condition, age and environment in which they were installed, have not been exercised for fear of failing in a closed position. These valves should be, but cannot be, replaced because shut down of the City Tunnel would be required.

Access to some of the valve structures and chambers is hampered by high ground water or damp conditions (Fig. 2). Original protective pipe coatings are gone, and pipes and valves are coated in thick layers of rust. Loss of metal thickness and structural strength is a concern. Bolts and fasteners have corroded and are planned to be replaced where feasible. Some chambers must be pumped down to allow access, which impedes any emergency response and aggravates further corrosion concerns.

At many of the top-of-shaft structures are piping and valves of varying diameters (ranging from less than an inch to several inches in diameter). These provide air and vacuum relief, along with drains, flushing connections, valve by-passes, and control piping for hydraulic valve actuators (Fig. 3). Some of these pipes and valves are in a similar deteriorated condition as the main pipes and valves. Failure of one of these smaller-diameter connections could require a tunnel shutdown to allow for a safe repair in some of these confined spaces. The amount of water that can flow out of a modest opening under high pressure can be significantly more than one might think: potentially more 378 GL/day (100 milion gpd).

Some of these concerns can be mitigated somewhat through replacement of corroded bolts, wrapping or coating of corroded pipeline segments, replacement of air valves, and installation of cathodic protection systems. A program is being developed to implement some of these measures to reduce the risk of certain failures that would require complete tunnel shutdown. However, all the

potential failure points cannot be addressed without tunnel isolation and complete replacement or maintenance of failed or failing components at some point in the future.

Water main break of May 1, 2010. MWRA experienced a major break on a 3 m (10 ft) diameter pipe connection at shaft 5 of the City Tunnel on May 1, 2010. The break occurred at a coupling on the surface pipe interconnection between the recently constructed MetroWest Water Supply Tunnel and the City Tunnel. The MWRA had a redundant pipe (Hultman Aqueduct) at this location, but at the time of the break, the Hultman Aqueduct was being rehabilitated and was out of service.

The incident resulted in a release of approximately 98 GL/day (25 million gpd) over a period of eight hours until the break was isolated (Fig. 4). During this time, an emergency water source was activated to maintain water supply prior to shutting down the affected pipe. While the pipe was being repaired over the following two days, the Boston metropolitan area was supplied through alternate, lower-capacity mains with augmentation from an emergency raw-water reservoir with chlorination. The water service area was issued a boil-water order during that time that affected approximately two million people in 30 serviced communities.

After the water main break, the MWRA performed an economic impact analysis of a failure and forced shutdown of the metropolitan tunnel system. The analysis estimated that the economic loss to businesses and residents within the Metropolitan area would be approximately $208 million and $102 million per day, respectively, for a total estimated economic impact of approximately $310 million per day.

History of redundancy planning for the metropolitan area

1937 plan. A redundant tunnel system was proposed as early as 1937. The plan included a proposed pressure aqueduct and tunnel system with a tunnel loop beginning in Weston near the Charles River and running east into Boston, turning north to Everett, looping west to Belmont and connecting back to Weston (Fig. 5).

While much of the 1937 plan for pressure aqueducts and tunnels was implemented from 1937 to present day, the proposed tunnel loop was never completed.

Redundancy planning 1990 through 2016. In 1990, a plan was proposed to construct a tunnel from Marlborough to Weston (the MetroWest Water Supply Tunnel) to provide redundancy for the Hultman Aqueduct and a future northern tunnel loop from Weston to Stoneham and Malden (Fig. 6). The MetroWest Water Supply Tunnel was approved for construction and was completed in 2003. However, the proposed northern tunnel loop was not constructed.

In 2011, the MWRA completed a new evaluation of alternatives for redundancy within the metropolitan Boston area. This evaluation included surface pipe alternatives in addition to tunnel alternatives with an objective of incorporating redundancy planning into the existing pipeline asset management program (that is, allocating funds already budgeted for rehabilitation of existing pipelines toward replacing the existing pipelines with larger pipelines). The result of that evaluation was a plan of constructing primarily large-diameter surface pipes to provide redundancy (Fig. 7). However, as the planning for this program progressed, it became apparent that the construction of large-diameter pipelines through dense urban areas would cause unacceptable community disruption and had serious implementation challenges.

Finally, in 2016 MWRA revisited the all-tunnel

FIG.4

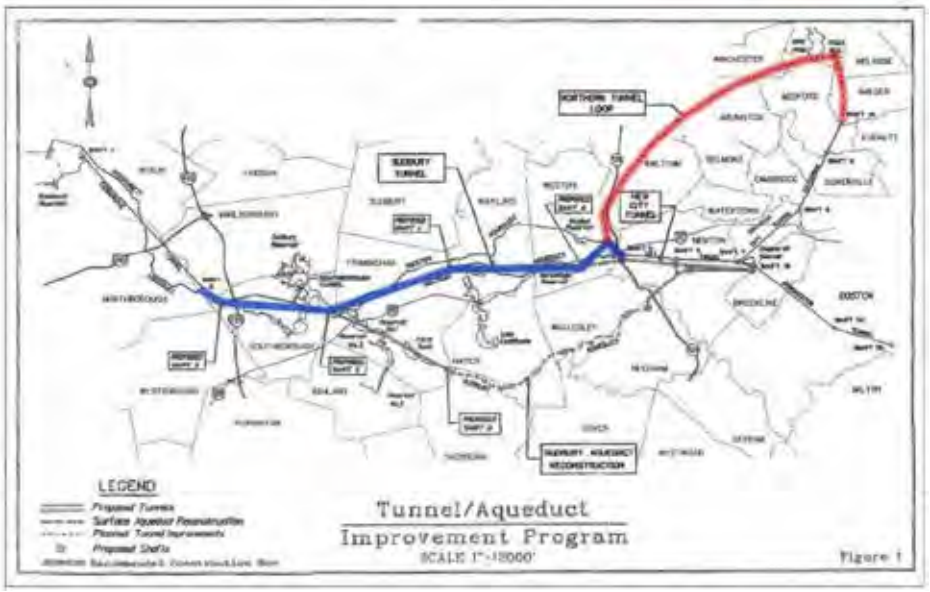
Water flowing at 250 million gpd.

FIG.5

1937 tunnel loop plan.

FIG.6

1990 northern tunnel loop plan.

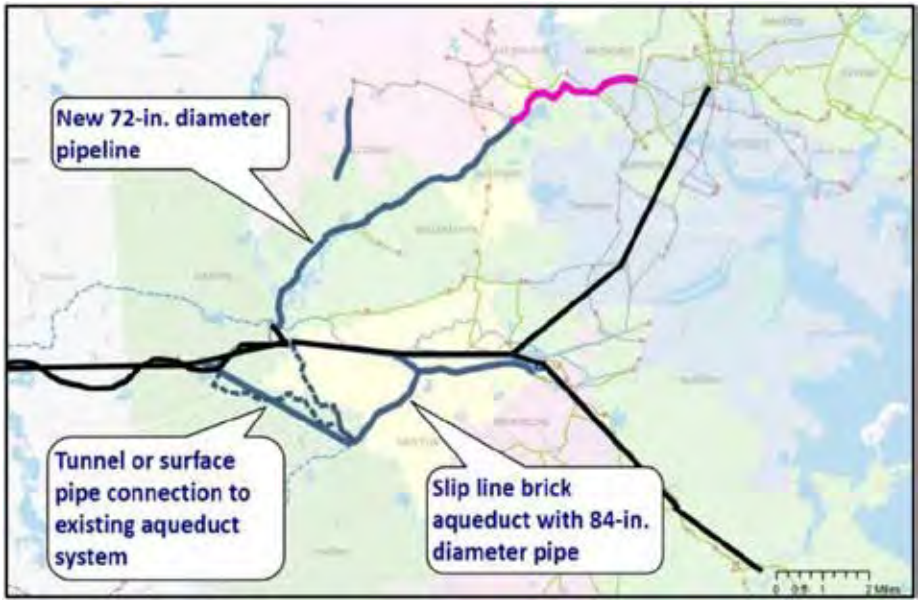


approach to providing redundancy to the metropolitan area. More than 30 alternatives were screened based on the level of redundancy, constructability, cost and operation and maintenance. Based on this evaluation, an all-tunnel alternative was recommended for redundancy.

Proposed plan

FIG.7

2011 surface pipe plan.



Given the difficulties associated with the construction and significant community impacts associated with large-diameter surface pipe together with operational reliability concerns, MWRA staff are pursuing a preferred all-tunnel redundancy alternative. The preliminary alignment, which will be subject to more detailed review and alternatives analysis during the public review period, is shown in Fig. 8.

This alternative consists of two deep-rock tunnels beginning at the same location in Weston near the Massachusetts Turnpike/Route 128 interchange. The Northern Tunnel generally follows the route of MWRA's existing Weston Aqueduct Supply Main (WASM) 3 transmission main to a point about midway along the pipeline near the Waltham/Belmont border, which will allow flow in WASM 3 in both directions. The length of the Northern Tunnel would be approximately 7.2 km (4.5 miles) and the tunnel would have a finished inside diameter of approximately 3 m (10 ft). It would include one connection shaft to provide a redundant supply to MWRA's Lexington Street Pump Station and to allow isolation of the WASM 3 line in segments for repair and maintenance. The Northern Tunnel has an estimated midpoint of construction cost of $472 million.

The Southern Tunnel would run east to southeast to tie into the surface connections at shaft 7C of the Dorchester Tunnel and about midway down the southern surface mains allowing flow in both directions. The length of the Southern Tunnel would be approximately 15.2 km (9.5 miles) and it would have a finished inside diameter of 3 m (10 ft). The estimated midpoint of construction cost of the Southern Tunnel is approximately $1.003 billion.

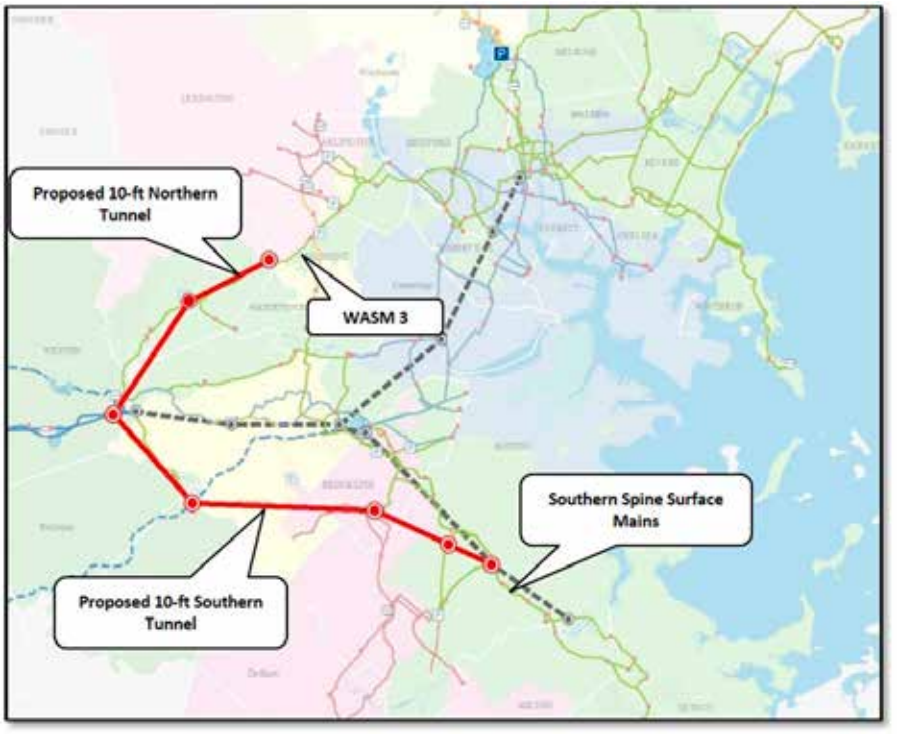
The proposed plan limits community disruptions and construction impacts to the locations of the tunnel construction and connection shaft sites. The all-tunnel alternative meets the strategic objective of being able to make a seamless transition to a

backup supply, allowing maintenance to be scheduled for the metropolitan tunnels without use of a boil-water order, without impacting the ability to provide for local fire protection, and without noticeable changes in customers' water quality, flow or pressure. It has the ability to meet high-demand conditions that extend the potential timeframe for future maintenance and rehabilitation activities.

To the north, the all-tunnel alternative will provide redundancy for the critical WASM 3 pipeline. To the south, it will eliminate the need for the Chestnut Hill Emergency Pump Station during metropolitan tunnel shutdowns, thereby reducing operational risks associated with extended use of the emergency pump Station at higher system pressures. The estimated total midpoint of construction cost for both the recommended north and south tunnels is $1.475 billion with an estimated time to completion of 17 years. This estimate includes 30 percent contingency and 4 percent annual construction cost escalation.

FIG. 8

Proposed tunnel redundancy plan.



Geologic conditions

The new redundancy tunnels will be hard-rock pressure tunnels, similar to the seven existing tunnels that currently make up the main MWRA water distribution system. These existing tunnels ranging in size from 3 to 4.2 m (10 to 14 ft) in finished diameter are primarily concrete lined with reliance on the overlying rock for confinement. Existing tunnel depths range from approximately 15 m (50 ft) to approximately 200 m (660 ft) below ground surface. Tunnels within the existing metropolitan tunnel system (City Tunnel, City Tunnel Extension and Dorchester Tunnel) are approximately 45 to 106 m (150 to 350 ft) below grade. The seven existing tunnels, constructed from the 1930s to the early 2000s, were mined using methods that progressed from drill and blast, drill jumbos, to modern tunnel-boring machines (TBMs). It is anticipated that the new redundancy tunnels will be mined using TBMs with only short segments (tail and/or starter tunnels) constructed using alternate methods.

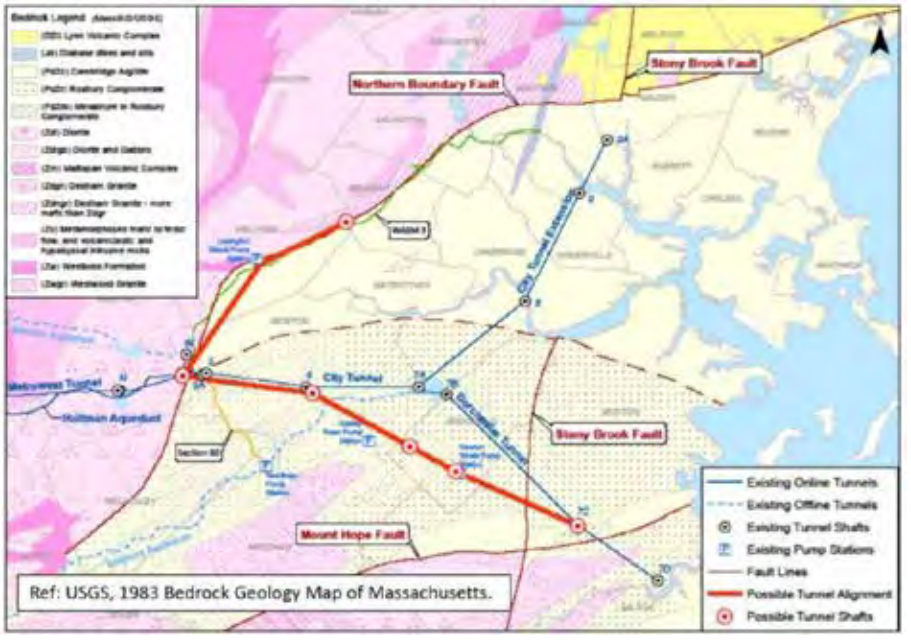
The alignments, both horizontal and vertical, of the new redundancy tunnels are not finalized at this time; however, it is possible that both tunnels could cross the Northern Boundary Fault and extend into the Boston-Avalon Terrace and the Boston Basin. Within the Boston-Avalon Terrace, the primary rock type is anticipated to be the Dedham Granite and within the Boston Basin, the primary rock types are anticipated to be the Cambridge Argillite and the Roxbury Conglomerate. The existing MetroWest Tunnel, City Tunnel, City Tunnel extension, and Dorchester Tunnel were mined in these same bedrock formations (Fig. 9).

The current proposed alignment of the North Tunnel generally follows the Northern Boundary Fault that could pose challenges for tunneling. The existing MetroWest Tunnel intersects this fault near its eastern limit. Extensive geotechnical investigations were conducted to determine the location of this fault as well as provide information on the anticipated behavior of the bedrock during mining. This level of investigation is largely credited for the preparedness that occurred during construction when the fault was actually encountered. It is worth noting that the only location along the MetroWest Tunnel where a steel liner was installed is along approximately 610 m (2,000 ft) of tunnel where it intersects this fault.

The current alignment of the South Tunnel places this tunnel primarily within the Roxbury Conglomerate formation; crossing the Stoney Brook Fault but not extending sufficiently south to cross the Mount Hope Fault. Both the existing City Tunnel and Dorchester Tunnel are located primarily within the Roxbury Conglomerate formation with only the southern limit of the Dorchester Tunnel extending past the Mount Hope Fault and/or into the Cambridge Argillite. The geology of these tunnels is well documented (Tierney et. al., 1968; Richardson, 1977).

FIG.9

Geologic conditions.



The quality of rock encountered along the City Tunnel is noted by Tierney as being excellent for tunneling. Just 5 m (16 ft) of the 7.7-km (4.78-mile) tunnel required structural steel support with the remaining approximately 7.7 km (4.7 miles) of tunnel mined with no need for temporary supports. The bedrock through which the City Tunnel extends was considered unusually good as compared to that encountered along other tunnels previously mined through similar geology in the greater Boston area.

The 10.2-km (6.4-mile) long Dorchester Tunnel was mined through bedrock consisting of Roxbury Conglomerate and Cambridge Argillite. This tunnel was excavated using drill and blast for approximately 90 percent of the tunnel length. A "mole" (rotary boring machine) was used to mine the remaining 10 percent of the tunnel length. Tunnel excavation using the mole was considered experimental at the time because the contractor had not used similar equipment in the past and it had not previously been used in the Boston area prior to this project. Steel supports were required over a fraction of the total tunnel length — primarily where the tunnel crosses the Stoney Brook Fault.

Previous large projects

The MWRA has planned, designed and constructed a number of large projects, including mega projects, in the past. The largest and most notable project in recent years is the Boston Harbor Project (BHP), which spanned from the mid-1980s to the early 2000s. This nearly 20-year program focused on the clean-up of a much polluted Boston Harbor and involved numerous significant program elements including construction of a new Deer Island wastewater treatment plant, a 15.3 km (9.5 mile) by 7.3 m (24 ft)-diameter outfall tunnel, and a 8 km (5 mile)-long and 3.5 m (11.5 ft)-diameter inter-island tunnel. The overall BHP cost was $3.8 billion.

Overlapping the BHP was the integrated water supply improvement program, which occurred between 1995 and 2005 and cost approximately $1.7 billion. This 10-year program included construction of the 28.3 km (17.6 mile)-long and 3.6- to 4.2-m (12- to 14-ft)-diameter MetroWest Water Supply Tunnel, seven covered storage tanks, and the new state-of-the-art John J. Carrol Water Treatment Plant.

Following the completion of the BHP and integrated water program, the MWRA moved on to other significant wastewater projects including the planning, design and construction of the Braintree-Weymouth relief facilities project. This $200 million project, executed between 2002 and 2010, included an intermediate pump station, 4.3 km (2.7 mile) long and 3.6 m (12 ft)-diameter deep-rock tunnel and shafts.

Alongside the Braintree-Weymouth project is the South Boston CSO storage tunnel and related facilities. This $260 million project, executed between 2006 and 2011, included a 3.4 km (2.1 mile) long and 5.2 m (17 ft)-diameter soft-ground CSO storage tunnel, shafts, pump station, sewer and storm drains, and ventilation building.

The MWRA currently executes approximately $100 million in capital programs each year to add redundancy to improve and maintain its current water and waste water assets.

Approval of a tunnel redundancy plan by MWRA Board of Directors

After the May 2010 water main break and during the mid-2010s, it became apparent that executing another large water tunnel program would be needed in the near future. On Oct. 6, 2016, the MWRA Board of Directors held a special meeting where MWRA staff provided a briefing on the status of the existing MWRA water transmission system and the lack of redundancy for the Metropolitan Tunnel System. The preferred alternative of constructing two tunnels, one to the north and one to the south, was recommended.

At the conclusion of the special meeting, staff members were directed to brief member communities and state and local officials on the Metropolitan Tunnel

Redundancy initiative in order to build consensus and support for the preferred project approach. On Dec. 8, 2016, a Long-Term Water Redundancy Forum hosted by the MWRA Advisory Board for the customer communities was held at Boston College. MWRA staff presented the history of the MWRA waterworks system, the need for metropolitan tunnel redundancy and the challenges, both implementation and financial, of building redundancy.

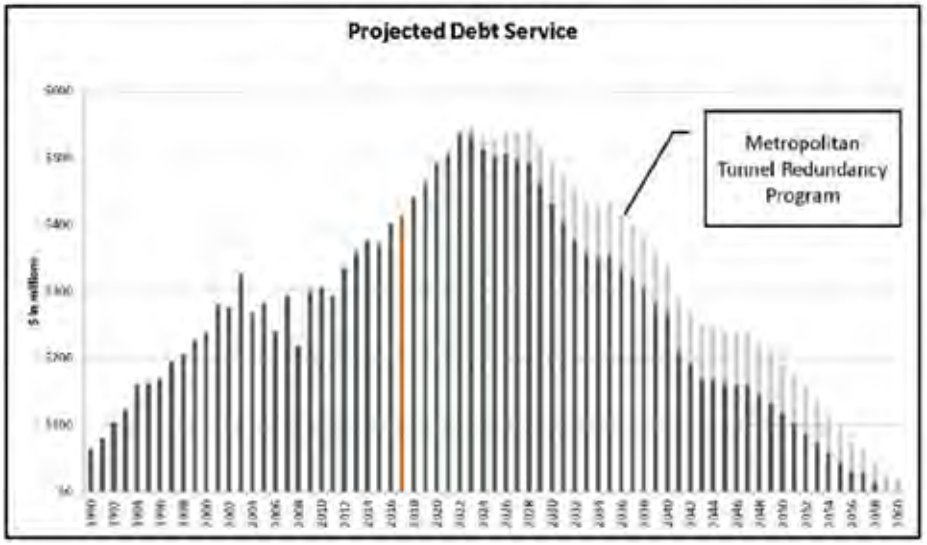
On Jan. 19, 2017, the MWRA Advisory Board met and voted to support moving forward with a deep-rock, two-tunnel project. They voted also to recommend: a program management division approach to manage the program similar to the model used for the BHP; concurrent construction of both tunnels rather than a phased approach; and allocation of any revenue from nontypical or one-time water users (for example, emergency drought connections) toward the cost of the program.

On Feb. 15, 2017, the MWRA Board of Directors approved the preferred alternative of construction of northern and southern deep-rock tunnels from the Hultman Aqueduct and MetroWest Water Supply Tunnel to the Weston Aqueduct Supply Main 3 (WASM3) and to the Southern Spine water mains for the purpose of providing redundancy for the metropolitan tunnel system (City Tunnel, City Tunnel Extension and Dorchester Tunnel), and directed staff to proceed with preliminary design, geotechnical investigations and Massachusetts Environmental Policy Act (MEPA) review of the project.

In June 2018, the MWRA Board of Directors approved the fiscal year 2019 capital improvement program (CIP), which includes $1.4 billion (2019 dollars) for the tunnel redundancy program.

FIG. 10

Projected debt service as of 2017.



Project goals

The Metropolitan Tunnel Redundancy Program was conceived to address several outstanding challenges, most notably the fact that the existing Metropolitan Tunnel System cannot be maintained or repaired nor can an emergency be readily addressed because shut down of the system is not currently possible without imposing a boil-water order.

The first and foremost goal of the program is an operational goal: to protect public health, provide sanitation and provide fire protection. The MWRA exists to provide these services. In support of this overall goal, the tunnel redundancy program is intended to:

- Provide full redundancy for the metropolitan tunnel system.
- Provide normal water service and fire protection when the existing tunnel system is out of service
- Provide the ability to perform maintenance on existing tunnels year-round.
- Provide uninterrupted service in the event of an emergency shutdown.
- Meet high day demand flow with no seasonal restrictions.
- Avoid activation of emergency reservoirs.
- Meet customer expectations for excellent water quality.
- Preserve sustainable and predictable rates at the water utility level.
- Minimize cost of borrowing.
- Be constructible.
- Result in no future boil-water orders.

The selected tunnel alternative is expected to meet all of these goals.

Project costs and financing

The cost of the Metropolitan Tunnel Redundancy Program is being allocated in the MWRA's CIP with the goals of: preserving sustainable and predictable rates, ensuring adequate capital is available when necessary and minimizing the cost of borrowing. Since 1985, MWRA has spent approximately $8.4 billion to upgrade the waste water and water systems. The majority of these improvements were funded through the issuance of tax-exempt bonds. The MWRA is projected to reach the peak of its debt service payments in fiscal 2022 (Fig. 10), which provides an opportunity to mitigate water rate impacts of

financing the proposed tunnel program.

MWRA uses a multi-year rate management strategy to provide sustainable and predictable assessments to its communities. The impact on the CIP and the debt service on the current expense budget (CEB) were evaluated for a variety of options for the Metropolitan Tunnel Redundancy Program. The options evaluated ranged from "do nothing" to the most expensive tunnel option.

MWRA communities are either combined water and sewer users, only sewer users or only water users. The projected average annual increase on the combined water and sewer assessment of the preferred alternative is 1.3 percent. The projected average annual increase on the water-only assessment of the preferred alternative is 4 percent.

The rate impacts of the preferred option on both the combined and water-only assessments are within the MWRA's long-term rates management strategy. The preferred option is both consistent with the authority's core mission of providing reliable, cost-effective and high-quality water, and its goal of providing sustainable and predictable assessments.

Project outlook

The Metropolitan Tunnel Redundancy Program is currently at the early stages of planning and design. The organizational framework to manage the program within the MWRA is in place in the form of the Tunnel Redundancy Department. Procurement of initial consultant contracts for program support services and preliminary engineering are underway.

It is expected that the next several years will include a number of program-wide activities including risk management planning, quality management planning, health and safety planning, design criteria and standardization, document management and project controls, work breakdown planning, procurement planning, construction package planning, field investigation procedures, rock core storage, critical path scheduling, and budget planning and management.

The preliminary design phase of the program will involve significant efforts on geotechnical investigations, preliminary route and shaft site alternative evaluations, preliminary design, an assessment of environmental permits needed and preparation of the Massachusetts Environmental Policy Act review for the project. This phase of the project will initiate actual design. Preliminary design is anticipated to be complete by 2023. It is envisioned that final design(s) will follow on the heels of preliminary design with the first tunnel construction package issued in or around 2027. ■

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InSar monitoring of subsidence induced by underground mining operations

Ground subsidence often accompanies underground excavation activities, and monitoring surface subsidence is essential to increase safety, avoid activity stoppages and provide timely detection of incipient damage to buildings and infrastructure. It has become an essential tool for mitigating the socio-economic risks related to activities that produce ground surface deformation.

The instrumentation used for monitoring surface deformation in and around excavation operations is generally based on conventional survey techniques (total stations, levelling, GPS receivers, ground-based radars) but none of these usually offer the high-density, bird's-eye view of the movement areas provided by satellite synthetic aperture radar interferometry (InSAR).

SAR interferometery

SAR satellites acquire images of the Earth's surface by emitting electromagnetic waves and analyzing the reflected signal. InSAR consists of the phase comparison of SAR images, acquired at different times with similar-looking angles from space or airborne platforms (Gabriel et al., 1989; Massonnet and Feigl,1998; Rosen et al., 2000; Bamler and Hartl, 1998). As SAR satellites are continuously circumnavigating the globe, a number of SAR images are collected for the same area over time.

The phase difference calculated between two SAR images acquired over the same area at different times is proportional to the surface deformation that occurs during that time interval (Fig. 1) but also contains topographic and atmospheric contributions. Differential InSAR (DInSAR) refers to the interferometric analysis of a pair of SAR images to identify and quantify movement by removing the topographic contribution using a digital elevation model.

Figure 1 presents an illustration showing the relationship between ground displacement measured along the satellite line of sight (LOS) and signal-phase shift. This is the basic principle of InSAR for measuring ground movement.

In the mid-1990s, after extensive application of the DInSAR technology, it became evident that the atmospheric contribution to the signal phase was significant, particularly in tropical and temperate areas. This led to the advent of advanced DInSAR (A-DInSAR) techniques in the late 1990s, which are based on the statistical processing of multiple images to remove atmospheric noise and reach a higher accuracy of deformation measurements. Permanent scatterer interferometry, the first A-DInSAR technique, identifies and monitors point-wise permanent scatterers, pixels that display stable amplitude and coherent phase throughout every image of the dataset (Ferretti et al., 2000, 2001). Permanent scatterers are objects such as rocky outcrops, boulders, manmade structures (buildings, street lights, transmission towers) and any structure that consistently reflects a signal back to the satellite. In 2011, Ferretti et al. presented a new technique known as SqueeSAR that also extracts information from distributed scatterers, areas with homogeneous ground surface characteristics that can be grouped to extract ground surface information from non-urban areas with limited infrastructure and light vegetation.

The existence of data archives going back to the 1990s initially led to the extensive use of InSAR data to perform historical ground deformation analyses. Recent advances in processing algorithms have significantly reduced computational time and the advent of newer satellites with increased spatial resolution and acquisition frequency has increased information density. Near-real-time InSAR monitoring is now widely applied in different applications: mining, civil engineering, natural hazard and oil and gas.

Mining applications

The complementary use of space-based InSAR with traditional systems has proven to be strategic for operational monitoring and risk assessment in mining operations. Successful applications to underground and openpit mines are presented by Carnec and Delacourt (2000), Raucoules et al. (2003), Colesanti et al. (2005), Jung et al. (2007), Herrera et al. (2007), Herrera et al. (2010), Espinosa et al. (2014) Iannacone et al. (2014), Paradella et al. (2015), Sanchez et al. (2016), Carla et al. (2018).

Two case studies of InSAR applied to longwall mining are presented, illustrating the use of SqueeSAR historical data to characterize the extent of long-term subsidence (Metropolitan Mine, Australia) and the use of DInSAR to detect short-term fast deformation (Bytom City, Poland).

Metropolitan Mine (Australia). The Metropolitan Mine is an underground coal mine located in the Southern Coalfields of New South Wales, about 40 km (25 miles) south of Sydney and in operation since 1888. A 3-m (10-ft)

Sara Del Conte and Giacomo Falorni

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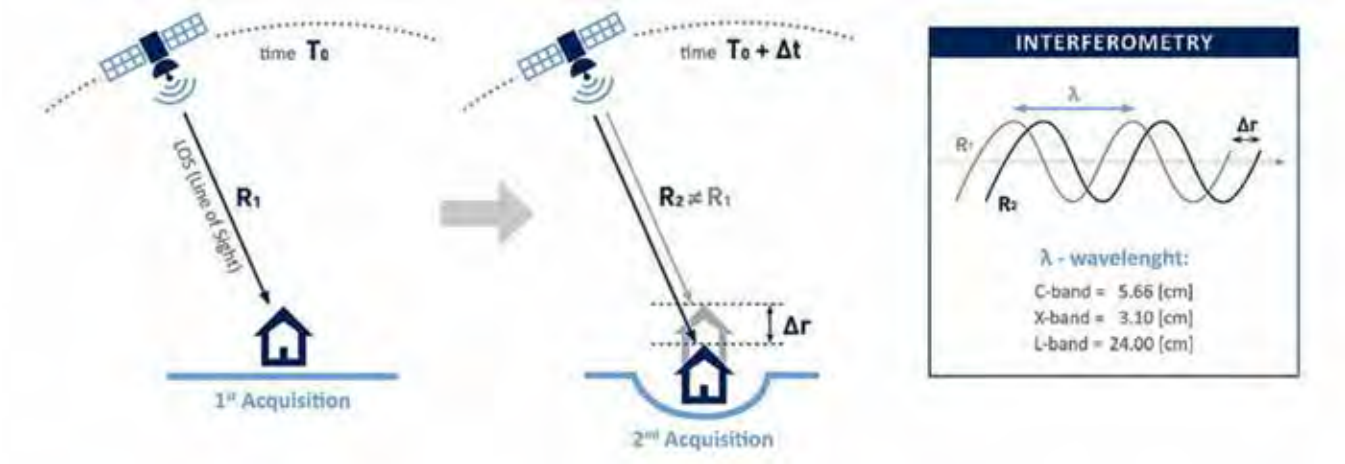
FIG.1

An illustration showing the relationship between ground displacement measured along the satellite line of sight (LOS) and signal phase shift. This is the basic principle of InSAR for measuring ground movement.



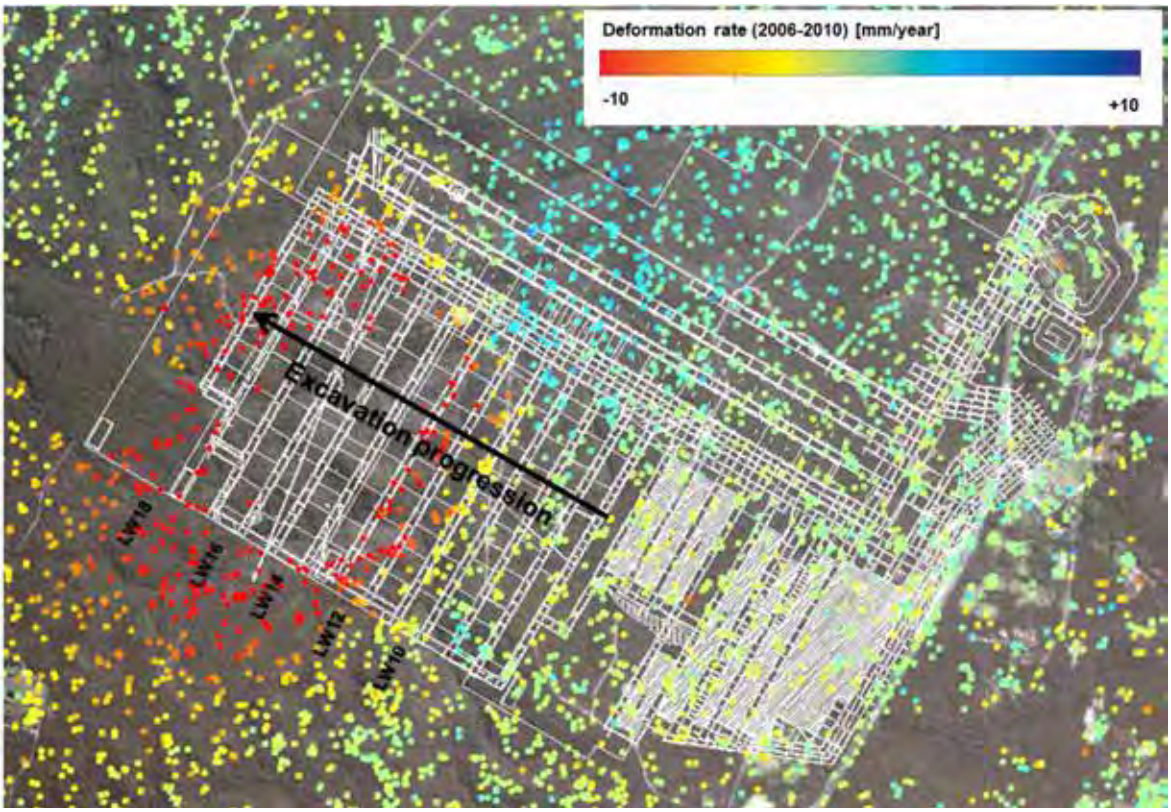
coal seam has been mined from the Bulli Seam (DeBono and Tarrant, 2011) using longwall mining. The Bulli Seam is the top seam in the Illawarra Coal Measures (Hutton, 2009) and is overlain by the Arrabeen Group (300 m or 985 ft of sandstones, claystones and shales), a Middle Triassic quartz sandstone and the Hawkesbury Sandstone. The depth of the cover varies from 400 to 520 m (1,312 to 1,706 ft) depending on the local surface topography (DeBono and Tarrant, 2011).

Mining started in the area of study with Longwall 1 in 1995 and finished in April 2010 with the extraction of Longwall 18 (Fig. 2). Mining progressed from the southeast toward the northwest, while the extraction direction of the individual longwalls proceeded from southwest to northeast (DeBono and Tarrant, 2011; Morgan et al., 2013).

The processed radar imagery consists of two archives

FIG.2

Longwall panel configuration with SqueeSAR measurement points at the Metropolitan Mine. The points are color-coded according to their annual displacement rate between 2006 and 2010.



of Envisat radar imagery that were processed using SqueeSAR (Iannacone et al., 2014). The data sets comprise 44 images acquired from an ascending orbit and 43 images acquired from a descending orbit and cover the period of June 2006 to September 2010, corresponding to the period in which panels from Longwall 13 to Longwall 18 were mined.

Longwall mining can induce large, rapid displacements in the weeks after panels are mined out, which can lead to a loss of measurement points above the longwalls. However, the focus here was to determine the extent of the subsidence area and to correlate the timing of deformation with mining operations. The analysis of the timing of ground movement within the subsidence bowl showed measurement points located close to the mining front accelerating followed by deceleration once the panel has been mined (Fig. 3). InSAR highlighted a kilometer-scale subsidence bowl with displacements that extended well beyond the surface area above the longwalls, and reached a cumulative value of more than 150 mm (6 in.) between 2006 and 2010. The extent of the subsidence bowl is usually defined by means of an angle of draw that extends upward and outward from the working face and varies from 8° to 45° off the vertical. The SqueeSAR results indicate a much higher angle of draw of around 64° with a wider than expected subsidence bowl. Furthermore, a significant number of measurement points located over older mining areas denoted a multiyear linear deformation trend, indicating that residual subsidence can last for many years after the mining has terminated.

Bytom City (Poland). Bytom City is located in the northwestern part of the Upper Silesian Coal Basin in southern Poland. Mining activities in this area are carried out by longwall mining. The excavated coal layer is 2.5 m (8 ft) thick, 250 to 400 m (820 to 1,300 ft) long, and about 680 m (2,230 ft) deep. Historical subsidence of up to 27 m (89 ft) over 33 years has been has been measured, affecting an area of nearly 300 km^2 (115 sq miles).

To monitor the rapid subsidence over the mine, SAR images acquired by the Terrasar-X satellite every 11 days were processed using a DInSAR approach (Colombo et al., 2018). Figure 4 shows some examples of 11-day interferograms (maps of difference in phase between two images), where colored bands, referred to as fringes, highlight areas with phase variations where deformation can be measured. Figure 4f shows estimates of the cumulative deformation on the surface during the observations.

While interferograms outline areas with centimeter-scale subsidence bubbles, SqueeSAR was applied to detect more subtle millimeter-scale displacements, thereby providing a more complete map of the area affected by mining-induced subsidence (Fig. 5).

Urban tunneling applications

InSAR monitoring of ground deformation has been applied to all phases (design, construction and operation)

FIG.3

Subsidence bowl evolution, as reconstructed from deformation time series.

FIG.4

Interferograms over longwall coal-mining area in Bytom municipality. Acquisition dates are reported in Table I.

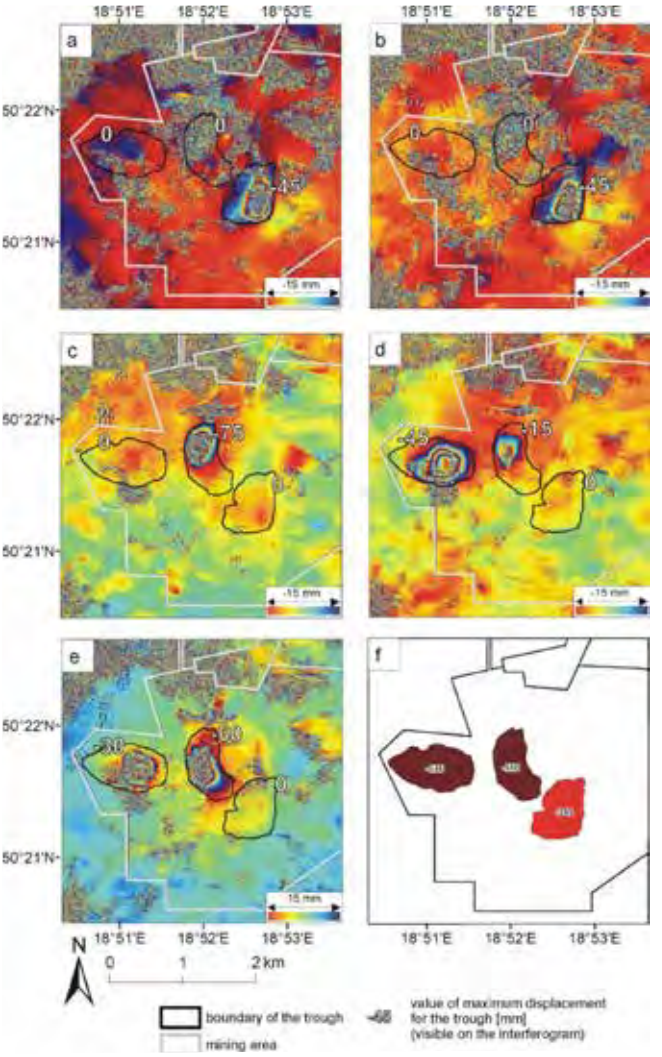


TABLE 1

Acquisition dates for interferograms in Figure 4.

Interferogram	1st image	2nd image
a	5 Jul 2011	16 Jul 11
b	16 Jul 2011	27 Jul 2011
c	23 Oct 2011	3 Nov 2011
d	17 Dec 2011	28 Dec 2011
e	14 Mar 2012	25 Mar 2012

of tunneling projects in both urban and nonurban areas (Bock et al., 2012; Iannacone et al., 2014; Hoppe et al., 2015). In urban contexts, where there is a higher need to monitor ground deformation associated with tunneling activities, InSAR significantly improves the quality of any monitoring program by refining and extending in situ observations. This is recognized by the inclusion of InSAR in the ITAtech Guidelines for Remote Measurements Monitoring Systems (2015), which provides recommendations and examples for monitoring projects in support of tunnel designers, contractors and owners to understand the benefits and limitations of remote measurement systems.

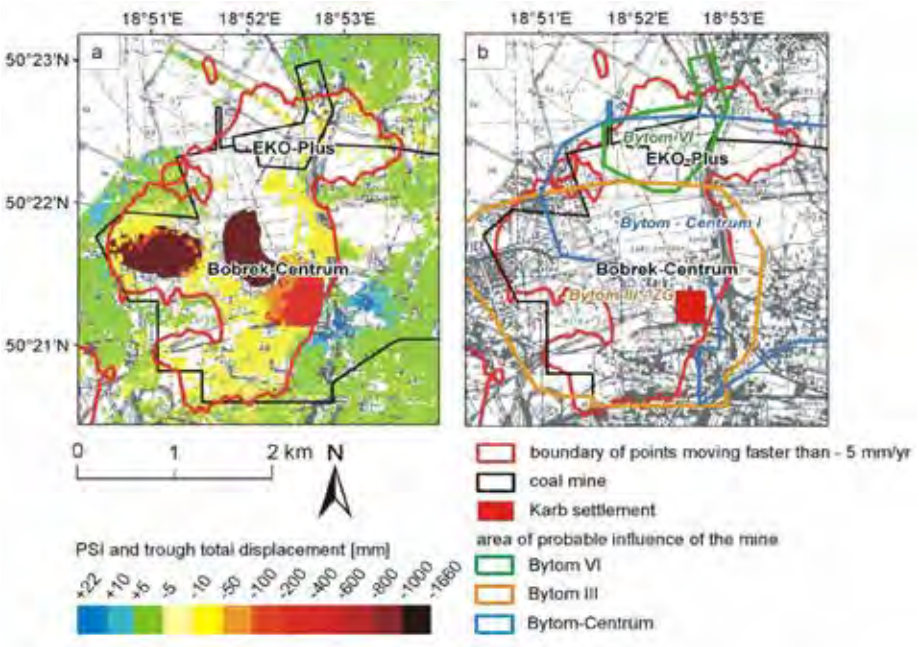
Rail tunnel (South Italy). The case study presented here regards a single-track, 60 m^2 (645 sq ft) cross-section rail tunnel being excavated in a city in southern Italy. The excavation caused surface displacements above the alignment, affecting a number of buildings. InSAR was used to investigate the correlation between excavation progress and induced surface settlements (Barla et al., 2016). This information was of particular interest along a stretch of tunnel where jet grouting from the ground surface was performed in order to deal with challenging geologic and hydrogeologic conditions. These involved a highly heterogeneous calcarenite formation, ranging from well-cemented to poorly cemented rock, that reaches from the surface down to the tunnel crown, and is underlain by a very fine sandy soil with silt, which in turn overlies the substratum (silty claystone with sandstone intervals). The water table is above the tunnel crown. Based on geological and hydrogeological studies, a low structural substratum locally acts as a drainage axis for the water flow.

Following completion of the jet grouting consolidation work, at the beginning of June 2014 tunneling advanced into this stretch. After 1 m (3 ft) of penetration into this area, 300 m^3 (3,230 sq ft) of water and silty sand collapsed into the tunnel, leading to the development of a subsidence trough at the surface and causing significant damage to the surrounding buildings.

The conventional topographic measurements (including a robotic total station) used along the tunnel axis were augmented by two InSAR data sets covering a time span of about five years before June 2014. The data were processed with the SqueeSAR algorithm to produce vertical and E-W horizontal displacement movements. An analysis of the vertical deformation progression along the tunnel alignment (Fig. 6) and of the subsidence bowl development allowed for the estimation of the total volume of displaced material and to correlate this to the volume of material that collapsed into the tunnel. The findings indicated the presence of previously unknown voids in the upper calcarenite formation that triggered further in situ investigations to identify the possible mitigation strategies for tunnel completion.

FIG.5

SqueeSAR cumulative displacement overlain on the DInSAR results.



Conclusion

The two cases presented here highlight the use of InSAR surface deformation monitoring to mitigate the socio-economic impact of ground subsidence induced by underground excavations.

In the metropolitan longwall mining example the InSAR analysis of historical satellite archives revealed a significantly higher angle of draw and larger extent of the subsidence bowl than previously thought. It also highlighted that residual subsidence over mined-out areas continues for many years. In the Bytom City mining example,

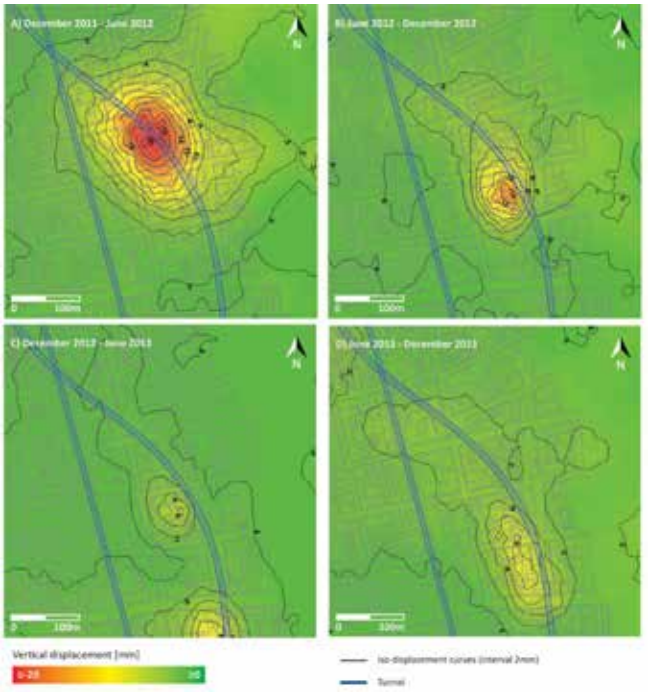
the combined use of traditional and advanced InSAR techniques allowed both rapid and slow deformation to be precisely monitored for a complete characterization of ground deformation associated with the longwall mining activities.

These longwall mining examples highlight the capability of InSAR surface monitoring to provide precise, spatially dense data and highly accurate information without the need for ground instrumentation and the ability to monitor both slow and rapid movement (from millimeters to meters) by applying different InSAR techniques.

The use of InSAR in the railway tunnel excavation example in southern Italy highlighted the advantage of using highly dense, precise spatial coverage in measuring far-field deformation in an urban environment, and the support provided in accurately defining possible mitigation strategies. ■

FIG.6

Time-lapse analysis of the vertical deformation along the tunnel alignment from January 2012 to December 2013. Each map represents cumulative vertical displacement in subsequent six-month periods.



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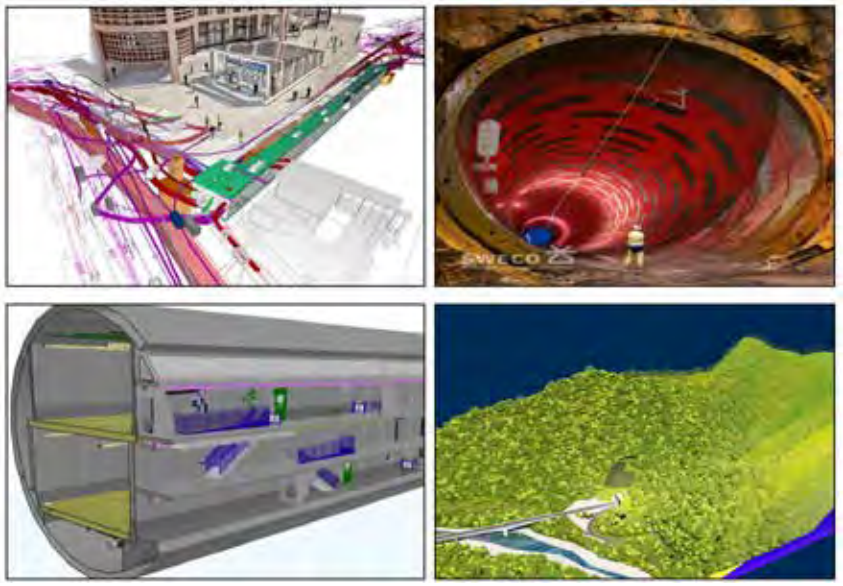
Smart office; a data-driven management tool for mechanized tunnel construction

Like other industries, construction firms today are capturing more data than ever before through information-sensing devices (such as job site sensors, smartphones and heavy-equipment tracking devices). Though there is an enormous potential of leveraging the power of captured data to increased productivity, much of the data is siloed without being utilized. In mechanized tunneling construction with tunnel-boring machines (TBMs), utilization of data to improve the construction process is limited to a small portion consumed by the machine operator. Indeed, much of that data is stored and filed away once a project is completed. With today's ease of data acquisition, in addition to TBM data, tunneling construction firms can capture more data than ever before through other information-sensing devices on the job site. Transforming these heterogeneous, seemingly unrelated data into coherent, visually immersive and interactive insights will enhance every aspect of the project execution.

FIG. 1

Example of BIM model. The Crossrail tunnel in London (top left), State Route 99 tunnel in Seattle (bottom left), Hallandsas tunnel in Sweden (top right), and Mikusa tunnel in Japan (bottom right).



Data-driven modeling systems (such as BIM, CIM) have become more popular in tunnel engineering construction. The Crossrail Tunnel in London (Heikkila and Makkonen, 2014), State Route 99 Tunnel in Seattle, WA (Lensing, 2016; Trimble, 2011), Hallandsas Tunnel in Sweden (Smith, 2014), Hangzhou Zizhi tunnel in China (Wang et al., 2015) and Mikusa Tunnel in Japan (Sugiura, S., 2015) are all examples of projects that have been executed by utilizing data-driven methods (Fig. 1). Despite the several advantages of BIM models in the design field, due to the disruptive nature of this system, there are several challenges in implementation for the construction firm (Davidson, 2009). For instance, BIM doesn't help to facilitate communication in the construction field, and it should be implemented with its full capacity to be effective.

Sporadic attempts have been made to utilize the power of data on job sites, and a few companies (such as Babenderede Engineering and Tunnelware) have developed data management and visualization software compatible with the tunneling construction market. This commercial software can be used as a tool to make better decisions, increase productivity, control the quality of materials and improve safety at job sites. For instance, modular software was developed by Babenderede Engineering to support the tunneling construction process. Babenderede Engineering simply equips the contractor's TBM with an external data acquisition system to pull relevant data from the machine PLC, and then, by processing raw data, helpful information is generated. The company has also developed software exclusively for tracking segmental lining through the lifecycle of the project (Cicinelli et al., 2017).

Tunnelware that is still in the development stage tries to consolidate data from several sources (such as TBM, site personnel reports, and job site sensors). According to the Tunnelware experts, the software will provide a robust tool for the constructors to visualize and analyze the tunnel excavation processes in a 5D format. Tunnelware is also

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Kamran Jahan Bakhsh and Jim Kabat, members UCA of SME, are office/tunnel engineer and project director, respectively, Dugway Storage Tunnel, email KJBakhsh@laneconstruct.com.

adding other features such as cutter-tool management and virtual meeting rooms to their software package.

Although available commercial services have several benefits, there are drawbacks that make contractors hesitant to utilize these services in their projects. For example, the software visualization is old-fashioned and dissociated. Indeed, it is crucial to prepare an easy-to-use interactive visualization platform that can facilitate construction processes for project personnel; otherwise, it will be abandoned throughout the construction period. In addition, because every tunnel project is unique, existing software on the market is not flexible enough to meet the uniqueness of the project.

In this article, the concept of a unified analytics center compatible for tunnel construction is presented. First, the Dugway Storage Tunnel project that is considered as a case study for testing our model is introduced. Later, the structure of the conceptual model, data collecting and required hardware and software are explained. Afterward, application of the proposed model throughout the construction period of the tunnel is partially examined. The advantages of implementing such a data-management system as a tool for project managers, engineers, safety superintendents and others are also addressed.

Dugway Storage Tunnel

Project description. The Dugway Storage Tunnel (DST) is the second of seven tunnel projects that will reduce 15.1 GL (4 billion gal) of pollution discharged into Lake Erie due to the seasonal overflows. The tunnel alignment is approximately 4.5 km (2.8 mile) in length with seven curves of variable radius, excavated using a single-shield, hard-rock TBM with 8 m (27 ft) excavation diameter. The finished internal tunnel lining diameter is 7.3 m (24 ft) using concrete segments of 0.3 m (1 ft) thickness. Depths of the tunnel invert ranges from 55 to 70 m (180 to 230 ft) below ground surface. The project includes a total of six deep shafts along the path of the tunnel with an internal lined diameter between 5 and 50 m (16 to 50 ft), and four adit connections between these shafts and tunnel of variable lengths between 15 and 304 m (50 and 1,000 ft) (Fig. 2). The 14 m (46 ft)-diameter shaft, known as DST-1, is the TBM launch shaft in which all the main conveyor systems will be installed. Part of the shafts were constructed through soft ground and part encountered Chagrin Shale bedrock. The project includes the construction of additional structures including diversion structures, gate structures, control vaults, ventilation vaults, drop manholes and modifications to existing regulatory structures. The project area is mainly older residential (pre-1950s interspersed with commercial properties and urban parks).

The TBM used to excavate the 8.2 m (27 ft)-diameter tunnel through the Chagrin Shale was a hard-rock, single-shield Herrenknecht machine type S-684 (Fig. 3). The machine was reconditioned on site by the contractor after excavating the first phase of the tunnel (Euclid Creek Tunnel). The TBM was partially assembled for the launch

FIG.2

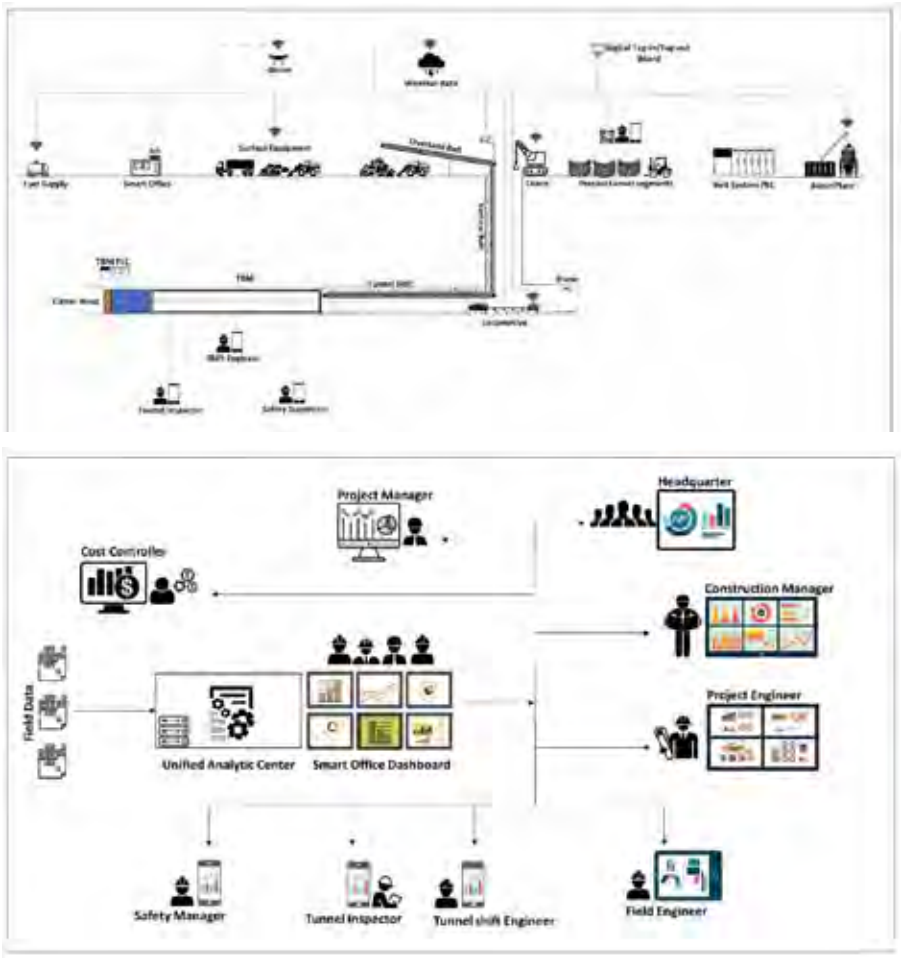
Project overview.

FIG.3

Dugway Storage Tunnel single shield Herrenknecht TBM.

FIG.4

Data flow model of the conceptual model. Data flow from various sensors and human interaction to the unified analytics center (top), and flow of processed data from the unified analytics center to end-user personnel (bottom).



with only three of the six gantries in the starter tunnel that was previously excavated by employing drill-and-blast method. At this stage, materials were hauled out using locomotives and muck boxes. After the first 91 m (300 ft) of tunnel had been excavated, the TBM was assembled in its final setup with six gantries. The tunnel conveyor system was comprised of five sections transporting materials from the tunnel to the vertical conveyor to overland belt and finally to the stacker. There was a total of 2,911 rings installed at a total length of 4,523 m (14,840 ft). The production average was 17 rings per day. The average of the excavation parameters were as follows:

1. Penetration 10.3 mm/rotation.
2. Cutter-head rotation 6 rpm.
3. Advance of the TBM 66.75 mm/min.
4. Thrust force = 10,000 KN.
5. Torque = 2,500 KNm.

There was no presence of water in the material, but the quantity of methane trapped between the layers was sometimes relevant.

Unified analytics center

Conceptual model. Managing this data and using it as a tool to make better decisions during the construction process is of utmost importance. The purpose of the conceptual model of the unified analytics center is to provide a robust tool to enhance decision-making for all levels of on-site and office personnel. The conceptual model comprises:

1. A physical smart office equipped with digital display screens.
2. Sensors, equipment and digital tools to gather data from the project site.
3. A platform to integrate, analyze and contextualize this information into a visual, meaningful representation.

Figure 4 shows the data flow model (DFM) of the proposed conceptual model. Data captured from the TBM, the conveyor system, equipment operating, inventory, material used, site personnel reports, labor hours, project documents and online weather reports are structured and pushed into a cloud-based collaboration and sharing system. Microsoft Power BI, which is a suite of analytics tools, is utilized to create interactive visualization and dashboards to share insight with individuals across the project and company. The model can provide customized dashboards suited to the end user that can be updated in real time, near real time or over a longer period. For instance, real-time monitoring of critical parameters of the TBM (such as thrust force, torque) can be visualized in the form of interactive dashboards to assist with optimizing the excavation process. As another example, historical data that have been collected over the years on the project can be presented to the headquarters to give overall insight into project progress and assist decision-makers to gain a competitive advantage when estimating and bidding on a new project with similar characteristics.

Application of the model in construction of the Dugway Storage Tunnel. Throughout the excavation phase of the tunnel, data from TBM PLC was pulled out and pushed

into the Power BI platform. This system provided a means to connect the project personnel (project manager, construction manager, project engineer, tunnel shift engineers and TBM operator) to a broad range of data via easy-to-use dashboards, interactive reports and meaningful interactive visualizations. Prepared customized dashboards helped to ease the decision-making process for those directly and indirectly involved in the project. Figures 5 to 7 show examples of crafted dashboards. For instance, as shown in Fig. 5, by integrating a real-time interactive map of the TBM location and data recorded from geotechnical instrumentations, a better understanding of the behavior of the ground subjected to excavation can be seen. This interactive dashboard can assist the TBM operator in adjusting steering parameters. Figure 6 outlines the volume of the injected accelerator admixture from each port for each ring separately. By analyzing this data an engineer or TBM operator can solve a problem related to accelerator injection and not just rely on the last ring data. Collected data can be formatted in a customized and easy-to-use dashboard to monitor production per shift (Fig. 7). Having access to historical data of shift production can help increase efficiency by switching between working shift patterns (rotating three eight-hour shift schedules and two 10-hour shift schedules).

Figures 5 to 7 are a few of many helpful dashboards that can be generated to get the right information to the right person at the right time. In order to have a better picture of the advantages of employing such a data-driven system, it is useful to address the model's application as follows.

As a tool for engineers. With a Wi-Fi system in the tunnel, job site engineers have permanent access to the real-time dashboard of all critical parameters of excavation, grout utilization, and navigation. As shown

FIG.5

Real-time location of the TBM on a satellite map.

FIG.6

Real-time dashboard of accelerator admixture parameters.

FIG.7

Near-real-time dashboard of the tunnel production progress based on a three-shift

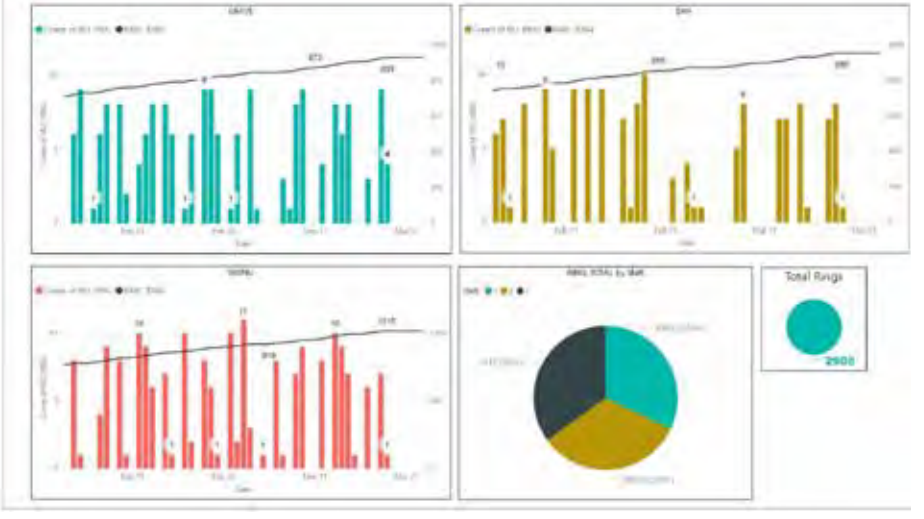


FIG.8

Real-time dashboard of the grout utilization parameter

FIG.9

TBM utilization dashboard.

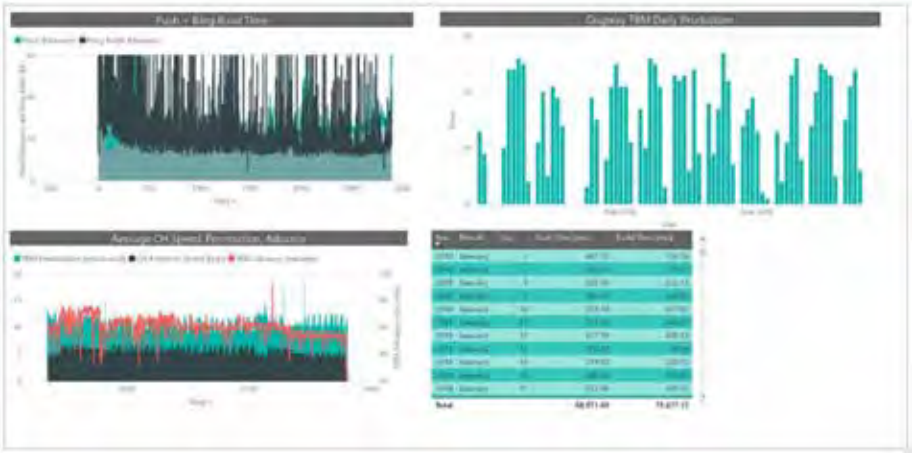


FIG.10

Production progress dashboard.

in Fig. 8, grout utilization parameters (such as grout and accelerator admixture pressure and volume) are integrated into a customized easy-to-use dashboard that can be used as a robust tool by engineers to monitor grout utilization per installed ring. As another example, we integrated daily production data with push and ring build time to get a better real-time picture of the TBM utilization throughout the excavation phase (Fig. 9). We also formulated several other dashboards to facilitate monitoring TBM cylinder pressure and extensions, gas infiltration location and values, ring installation effect on navigation, and the variability of tendencies during the advance and many other parameters and behaviors.

As a tool for project managers. The physical smart office is where people can meet to discuss the ongoing tunnel construction process. All critical data are available in the shape of interactive dashboards that provide a unique tool for project managers to hover over all aspects of the project from different viewpoints. For example, a dashboard can be generated to illustrate the production progress on shift, daily, weekly and monthly bases. Monitoring the project progress through this dashboard is far more convenient than exploring archived hard copies of a personnel report (Fig. 10).

As a tool for reporting. Digital custom reports for the construction process based on different time scales (shift, daily, weekly, monthly, full project) can be generated in the unified analytics center automatically. This platform also allows for the sharing of automatic reports on predefined timeframes with co-workers and any other recipients outside the company by including the list of email addresses in the system. For instance, a dashboard comprising production progress, grout utilization, TBM utilization, and the average of TBM excavation parameters can be an informative means for program

managers in a headquarter office as well as estimators when estimating and bidding on a new project with similar characteristics (Fig. 11).

FIG. 11

Overall TBM performance dashboard.

Conclusions

This article presented the fundamental principles of a unified analytics center as a robust tool for the tunneling industry. The application of a data modeling system in the construction of the Dugway Storage Tunnel was examined. Although data management in mechanized tunneling construction is not a new concept, there are several features that make this proposed model different. Interpreting data into meaningful easy-to-use, real-time visual dashboards that give all individuals insight into the project is the foremost advantage of the model. In addition, Microsoft Power BI as the backbone of the model is an analytics service entrenched in the Microsoft stack. Indeed, unlike other inflexible predefined data management and visualization platforms, Power BI compatibility increases adoption of data modeling for contractors. Although the system was implemented just by using TBM data, due to the flexible characteristic of the model, we could take advantage of the system in our decision-making process. The proposed system also allows for automatic generation of consistent reports on shift, daily, weekly, monthly scales. The system will be examined as a whole by inducing data from other sources (such as job site sensors, smartphones, and heavy-equipment tracking devices). The all-inclusive system will allow for improved decision-making and accordingly increase efficiency and reduce construction costs. ■

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Personal **News**

2020 Beaver awardees announced

Dave Miles of Kiewit Corp., 2019 president of the Beavers, has announced the selections for the 2020 Golden Beaver Awards. The awards will be presented at the 65th Annual Awards Dinner on Jan. 17, 2020 at the J. W. Marriott at LA Live in Los Angeles, CA.

Engineering Award

The Engineering Award will be presented to **DANIEL N. ADAMS**, (UCA of SME) president and chief executive officer of McMillen Jacobs Associates of Seattle, WA. After earning his bachelor's degree and master's degree (with a geotechnical concentration) in civil engineering from the University of Massachusetts, Adams joined the Boston, MA-based engineering firm of Haley & Aldrich in 1988. He transferred to the San Francisco, CA office in 1993 and joined Jacobs Associates in 1995, where he was sent to Melbourne, Australia to serve as the senior tunnel design engineer for the Melbourne CityLink project. Prior to being named president of the firm, Adams worked more than a decade as project manager or principal engineer for the design of mega projects in the water, wastewater, transit and transportation sectors. He led the firm's merger in 2014 with McMillen.


ADAMS

Service & Supply Award

JACK BROCKWAY, (UCA of SME) president of Herrenknecht Tunneling Systems USA, Sumner, WA, will receive the Service & Supply Award. After earning a bachelor's degree in aeronautics and astronautics from the University of Washington and spending a few years at Boeing, Brockway joined The Robbins Company in 1973, where he worked his way up to become general manager in 1991.


BROCKWAY

During these years, Brockway was part of the industry's transition to mechanized tunneling, where each rock tunnel-boring machine was a unique creation. In 1997, he joined Herrenknecht and was able to leverage his experience into soft-ground tunneling to help move the industry from hand mining under air to the pressurized face tunneling used on soft-ground tunnel projects today.

Management Award

The Management Award will be presented to **TIMOTHY BARNARD**, chairman of Barnard Construction Co. of Bozeman, MT.


BARNARD

Starting 44 years ago with only a pickup truck and some tools, Barnard developed his company into a successful contracting company that now takes on some of the most challenging civil engineering projects in North America, including a $2.5 billion mega project in Canada.

Supervision Awawrd

CLAYTON GILLILAND, senior vice president and area manager of Stacy and Witbeck Inc. of Alameda, CA will receive the Golden Beaver Award for Supervision. A 1990 civil engineering graduate of Kansas State University, Gilliland began his 28-year construction career as a surveyor and laborer for Herzog Contracting Corp. He steadily progressed through the ranks on major heavy civil projects in Florida, Oregon, California and Utah. He joined Stacy and Witbeck in 1999 and was the project manager (now principal-in-charge) of the $1.2 billion Mid-Coast Corridor Project in San Diego, CA, a joint venture of Stacy and Witbeck, Herzog and Skanska. ■

DFI presents the 2019 Legends Awards

Every four years, DFI and the DFI Educational Trust present its Legends Award to an engineer, a contractor and a manufacturer/supplier who have made significant contributions to the research, design, construction, manufacturing and use of deep foundations. The 2019 recipients are:

Engineering Legend: BENGT H. FELLENIUS, formerly a professor of civil engineering at the University of Ottawa, was recognized for 50 years of innovative engineering work in soil mechanics and foundation engineering.

Contractor Legend: THOMAS J. WYSOCKEY, chair emeritus of Thatcher Foundations, was recognized for his contributions to the construction industry as an inspirational leader and mentor and an advocate for research, innovative techniques and safety.

Manufacturer/Supplier Legend: THOMAS BAUER, past chair of the supervisory board of the Bauer Group, was recognized for his relentless desire to innovate and set the highest standard in foundation drilling equipment. ■

Obituary

LESTER M. BRADSHAW SR.

Lester M. Bradshaw Sr. died peacefully in Zephyrhills, FL Oct. 2, 2019 at the age of 86. He was born in Russell County, KY in 1933 and grew up working the family farm plowing fields behind a mule during the difficult depression years. He enjoyed trading livestock and playing basketball. At 18 he went to work as a tunnel laborer for S.A. Healy on the Chicago subway system and later in Pennsylvania on the Little Pentagon tunnel, a 9.7 m (32 ft) diameter drill and blast tunnel for NORAD's first underground bunker just north of Camp David.


BRADSHAW

At 20, Bradshaw was drafted by the U.S. Army during the Korean War and was honorably discharged in 1955. He attended two semesters at Western Kentucky University before returning to the tunneling industry to support his growing family, having married his high school sweetheart, Regina, and fathering his first of four sons.

Bradshaw was a superb tunnel miner and then supervisor building water and sewer tunnels throughout the Midwest while he was in his 20s. He was an expert in mining tunnels using compressed air ground stabilization to control difficult ground conditions. This included tunneling under the Missouri River in the late 1950s using 2.7 kg/cm^2 (38 psi) of air pressure.

By 1962, Bradshaw had worked his way across the Midwest to the East Coast troubleshooting difficult hand-mined tunnels. He settled his family in Maryland and cofounded Eastern Tunneling (ETC). As company president, he built ETC over the next 19 years into a premier hand-mine tunneling company. He continued using compressed air ground stabilization, sometimes in combination with ground dewatering, to install the most difficult hand-mine tunnels east of the Rockies. He was equally successful using drill and blast to mine hard rock in numerous projects such as 609.6 m (2,000 ft) along the Potomac River in Washington, D.C. and 1,524 m (5,000 ft) along the Chattahoochee River in Atlanta, GA. In 1976, he constructed 2.6 km (1.6 miles) of a 2.4 m (8 ft) horseshoe tunnel using sprayed shotcrete tunnel support (now known as NATM) mined by roadheader in Littleton, CO.

In 1982, Bradshaw dissolved Eastern Tunneling and founded Bradshaw Construction Corp. (BCC) with his four sons. He continued hand mining and BCC became the largest installer of 4-flange, tunnel-liner plate in the United States.

Bradshaw retired to Florida in the late 1980s, turning over the business to his sons. They have continued his legacy while successfully completing hundreds of manned TBM tunnels up to 4.4 km (2.7 miles) in length. BCC is an industry leader in microtunneling with unmatched success, microtunneling hard granitic rock in the United States. Bradshaw moved to Oldsmar, FL where he could be found out on the golf course, fishing with his grandchildren or simply having a quiet night playing card games and telling endless stories to family and friends. With his easy-going southern charm, he had a true gift of making everyone around him smile. He is survived by his wife of 66 years, Regina, three sons, nine grandchildren and five great grandchildren. ■

Risk management course offers scholarships

The Risk Management in Underground Construction course will take place March 10-11, 2020 in Houston, TX at the Hyatt Regency Houston Intercontinental Airport Hotel. This course, designed to help tunnel project stakeholders navigate the latest approaches to risk management, is offering scholarships to tunnel project owners.

Led by real-world experts, the course explores all aspects of risk management for complex underground construction projects, including:

- Recommended best practices.
- Geotechnical risk.
- Contractual approaches.
- Insurance claims/disputes.
- Cost/schedule risk.
- Acts of God, and more.

Government scholarships for the 2020 Risk Management in Underground Construction course will be awarded based on the applicant's submission explaining how they would benefit from attending the course.

Scholarships will be awarded to provide training and education for government agencies who have limited or no educational funds. Applications may be submitted online through Dec. 31, 2019.

Scholarship applicants must be a current, full-time government employee involved in planning, design and management of large underground construction projects (tunnels, underground pipelines).

The scholarship covers the cost of a full conference registration valued at $1,300. Travel, hotel and meals (except meals that come with a full conference registration) are not covered by the scholarship and are the responsibility of the scholarship recipient. Visit the website www.undergroundriskmanagement.com. ■

Products

Introducing Con Forms' 18-RZ4 Spider Placer

The 18-RZ4 Spider Placer is Con Forms' newest and most advanced mobile equipment solution. It combines all of the industry-leading features of the 16-Z with a longer and more versatile boom configuration.

By using a ZR boom-articulation style and extending the angular ranges of motion, the end hose can be located adjacent to the machine while maintaining its minimum-ceiling height requirement. Placement dead zones are eliminated, allowing for the maximum placement footprint possible for every setup location.

With the mobility of the crawler tracks, this spider can routinely get into jobsite locations and positions a 20-m-class boom truck cannot. Once set up in the optimal spot, the 18-RZ4 also covers the greatest pour area of any low-ceiling placement machine due to its longer reach, versatile boom and compact footprint. The lower price tag, lower maintenance costs and added versatility make the 18-RZ4 a cost-efficient solution for many applications. In addition, the tracked, spider units can be equipped to tow a trailer pump. This setup allows for faster and more accurate placement of concrete while moving down a line pour — saving time and labor costs.

The 18-RZ4 offers a versatile boom configuration.

www.conforms.com

Brokk delivers a rock drill for cramped jobsites

Brokk delivers a sleek, low-profile design and impressive power-to-weight ratio with its new MMB326 hydraulic drifter rock drill attachment from TEI Rock Drills. This versatile attachment seamlessly pairs with the Brokk 300 and allows for drilling multiple sizes of holes, up to 7.6 cm (3 in.), in concrete, rock and compact soil. The attachment is manufactured with a lightweight, compact TE326 drill head featuring patented technology to improve longevity and productivity.

At just under 76.2 cm (30 in.) long, the MMB326 delivers 271.2 J (200 ft-lbf) of impact energy at 3,480 blows per minute. The drill also produces 339 J (250 ft-lbf) of torque and reaches rotation speeds of up to 250 rpm, which makes it a more accurate and faster alternative to jackleg drilling through brick, concrete and rock. The combination also eliminates fatigue caused by operating heavy manual tools and promotes safety by allowing operators to stand farther away from the drilling site.

The drill head itself, TE326, is a versatile hydraulic drifter that incorporates TEI's patented automatic stroke adjustment (ASA) technology. The high-frequency and smooth operation provided by ASA technology prolongs the drifter and tool life, increasing productivity and profits for the user by reducing downtime and parts costs. Variable rotation speeds up to 250 rpm help minimize the risk of jamming, while the reversible rotation motors deliver high torque to ensure powerful drilling. The MMB326 attachment is a ready-to-use option that doesn't need to be modified before configuring to a Brokk machine. The attachment can be integrated directly with the Brokk controls, allowing workers to operate the Brokk and MMB326 simultaneously. ■

The MMB326 hydraulic drifter rock drill attachment.

www.brokk.com

Underground construction and tunneling history is made by the investment of companies worldwide that dedicate their efforts and vision to the advancement of the industry.

SME and T&UC acknowledge these companies that demonstrate a continued focus on providing the world with the best in underground technology, products and services.

Tunneling & Underground Construction

makers of **Underground** history

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

The Safety and Hazard Awareness for Tunnels (SHAFT) program seeks to provide comprehensive safety training for both new and experienced tunnel professionals.

The curriculum (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. Classes focus on tunnel safety, rail, and utilities.

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

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

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.

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Jennmar has been the innovative leader in ground control for the mining industry for more than forty years. Over the past decade, our growth has led us to above ground for structural buildings, implementing the same vigor and detailed processes. Our Jennmar Civil arch systems, girders, liner plates and Impact Resistant Laggings® are backed by experienced engineers and technicians who are with you every step of the way, from initial consultation to qualified instruction and on-going technical support. And, of course, our customer service is second-to-none. That's something we've always demanded of ourselves.

GLOBAL HEADQUARTERS • (412)-963-9071 • PITTSBURGH, PA USA • WWW.JENNMAR.COM

Brokk Inc.

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 introduces four new next generation demolition robots.

The new Brokk 170, Brokk 200, Brokk 300 and the diesel Brokk 520D incorporate the revolutionary new SmartConcept™ system.

The new Brokk 170, Brokk 200, Brokk 300 and the diesel Brokk 520D incorporate the revolutionary new SmartConcept™ system, which ensures improved performance and uptime. SmartConcept consists of three features: SmartPower™, SmartDesign™ and SmartRemote™. SmartPower senses when the power supply is poor or faulty then compensates before damage to components occurs. This allows contractors to use the machine with generators or unreliable power sources.

The new Brokk 200 represents a new weight class of demolition robots.

SmartDesign extends machine life and provides unprecedented ease of maintenance due to 70 percent fewer cables, hardened components, LED headlights and easily accessible grease points and hydraulic hoses. An ergonomic remote control, the SmartRemote, incorporates adjustable straps, intuitive controls and professional-grade radio technology with a 984-foot working range. Along with the new line, Brokk has also introduced new attachments, including BHB hydraulic breakers and three Darda concrete crushers.

The four new demolition robots from Brokk reflect the company's constant focus on innovation, improved performance and increased uptime. The new machines combine state-of-the-art technology, significant improvements in power-to-weight ratios and rugged reliability.

For more information:
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Monroe, WA 98272
800-621-7856
info@brokkinc.com
www.brokk.com

- **Facebook and Twitter: @BrokkUSA**
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Sandvik in Tunneling

Sandvik tunneling expertise covers a variety of methods: Drill and blast, mechanical cutting and breaking. The equipment range includes tunneling jumbos, roadheaders and cutting units, bolters and bolts, drilling and cutting tools, hydraulic breakers, loading and hauling equipment, mobile crushers, and financing, parts and consumables, training, technical support, and repair and rebuild service.

The Sandvik DTi series of intelligent tunneling jumbos are fast, accurate and user-friendly. The series is available in four models for excavation of 12–211 m^3 cross sections, including face drilling, bolt hole drilling and mechanized long-hole drilling.

Sandvik rock tools offer straight holes, high penetration rate and low costs per meter. As the only supplier with in-house resources for cemented carbide production and R&D as well as drill steel production and R&D, Sandvik can control the whole supply chain from raw material to finished products.

Sandvik roadheaders are extremely powerful, robust rock cutting machines that let you focus on the essential: breaking on through to the other side. These roadheaders are designed to excavate roadways, tunnels and underground chambers without using explosives that can cause harmful vibrations. This is highly valued for both environmental and safety reasons, making roadheaders extremely suitable for underground construction in urban areas.

Research & Development

In order to ensure the best solutions, Sandvik has specialized R&D centers for different fields of rock excavation. Sandvik also works in close cooperation with universities, research institutes and specialist associations everywhere in the world. As results of these R&D projects, Sandvik now offers an energy saving cutting system for roadheaders, a new roadheader type equipped with state-of-the-art profile control and automatic sequence control systems, as well as the DTi jumbos with iSURE® process optimization tool software – just to name a few.

Sandvik Cutting Technology Center runs its own in-house cutting test laboratory, addressing particular customer requirements and offers the latest solutions in mechanical cutting for all kinds of soil and rock. In addition, Sandvik has specialized R&D centers for Drilling Control, Rock Drill and Drilling Tools technologies. Sandvik is also the only manufacturer in the industry owning a unique test mine for practical testing in real life conditions.

Cleaner and safer tunneling

Sandvik focuses on continuously developing novel tunneling methods, making equipment safer, more efficient and more productive, giving results of the highest quality. As a key core value, Sandvik engineers are committed to safety, constantly developing solutions to offer a protective working environment, with efficient ergonomics. All Sandvik production operations are ISO14001 and ISO9001 certified.

Intelligent Solutions

Sandvik iSure® tunneling excavation management tool is designed for the people on site. Revolutionary in its approach - iSure® uses the most critical spot, the blast plane, as basis for the whole planning process. As a result, hole locations and blasting, are optimized. This translates into excellent accuracy, fast process and large-scale savings.

Find out more about Sandvik Tunneling offering on www.understandingunderground.com

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With penetration rates up to 17 percent higher than its predecessors* and a new cabin that increases visibility by 25 percent while minimizing noise levels, the fully-automated Sandvik DT922i twin-boom jumbo is engineered to improve your tunneling operations. Developed for versatility, Sandvik DT922i excavates cross sections up to 1345 ft², including face drilling, bolt-hole drilling and long-hole drilling. An intelligent, state-of-the-art control system and Sandvik iSURE® excavation management tool help ensure top tunneling quality.

*Test results and calculations are to be considered as results reached under certain and controlled test conditions. These test results and calculations should not be treated as specifications and Sandvik does not guarantee, warrant or represent the outcome of test results or calculations in any or all circumstances.

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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!


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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 300
Omaha, NE 68106
(402) 346-8535

Kiewit has been constructing underground facilities for over 50 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 mining 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

JOBS DONE WELL.

For more than 50 years, Kiewit has built some of the most complex tunneling and underground projects in North America. We have the capabilities to self-perform soft ground and hard rock TBM tunneling, along with conventional tunneling techniques such as SEM and Drill and Blast. At the heart of these projects is a workforce dedicated to industry-leading safety performance and unmatched quality excellence. From the unique, complex projects we build, to the committed professionals who design, engineer and construct them, Kiewit ensures the ordinary is always extraordinary.

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Derrick Equipment Company

Founded by H. William Derrick Jr. in 1951, Derrick® Corporation was created to solve some of the most challenging mechanical separation needs of the Mining Industry. At the heart of our present-day offering resides the Integrated Vibratory Motor which was invented by our founder and gave life to an entire line of innovative separation technology. To this day, our pioneering spirit pulses through the organization and inspires development of our leading-edge solutions.

Over the years, we have experienced exponential growth, expanding from our Mining roots to Oil & Gas Drilling, Civil Construction, Industrial, and other challenging industries worldwide. We have an expansive network of thousands of cohesive individuals located across the globe. Our success is fully dependent on people. Priority one is to serve our global families; our tenured employees, multi-national partners, and surrounding communities. Our unique, close-knit culture and shared, long-term outlook is not only paramount to our success, but to the success of all integral stakeholders.

SERVING THE DRILLING AND TUNNELING INDUSTRIES

Derrick has offered premium slurry separation and desanding equipment to the worldwide Microtunneling, Horizontal Directional Drilling, Large Diameter Tunneling, Slurry Wall/Foundation Drilling, Water Well Drilling, and other Civil Construction industries for nearly 30 years.

Throughout this time, Derrick has remained dedicated to complete in-house manufacturing of every piece of solids/liquid separation equipment. Each unit is created and assembled at Derrick's Buffalo, New York headquarters facility.

EQUIPMENT MAKES THE DIFFERENCE

Drilling or tunneling performance is directly related to the overall cleaning ability of the separation equipment. Drilled solids remaining in the slurry have numerous adverse effects on the overall operation, significantly reducing its profitability. Consequently, selecting the proper separation equipment for your fleet is just as critical as choosing the correct drill or tunnel boring machine. Derrick answers this critical need with innovative, high performance solids control equipment proven time and time again to increase the rate of advance while reducing:

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- Cost of drilling fluid and chemicals
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- Wear on downstream pumps, plumbing, and other equipment
- Environmental impact

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Since 1988, Derrick has manufactured innovative technologies for the Civil Construction industry. Derrick's separation technology offers unmatched solids removal performance. Using this equipment and innovative screen technology, customers continuously recycle and re-use drilling fluid, while also controlling drilled solids and impact on the environment.

Our Civil Construction solutions are currently used worldwide by companies that require high-efficiency separation and slurry dewatering in environmentally sensitive and urban environments.

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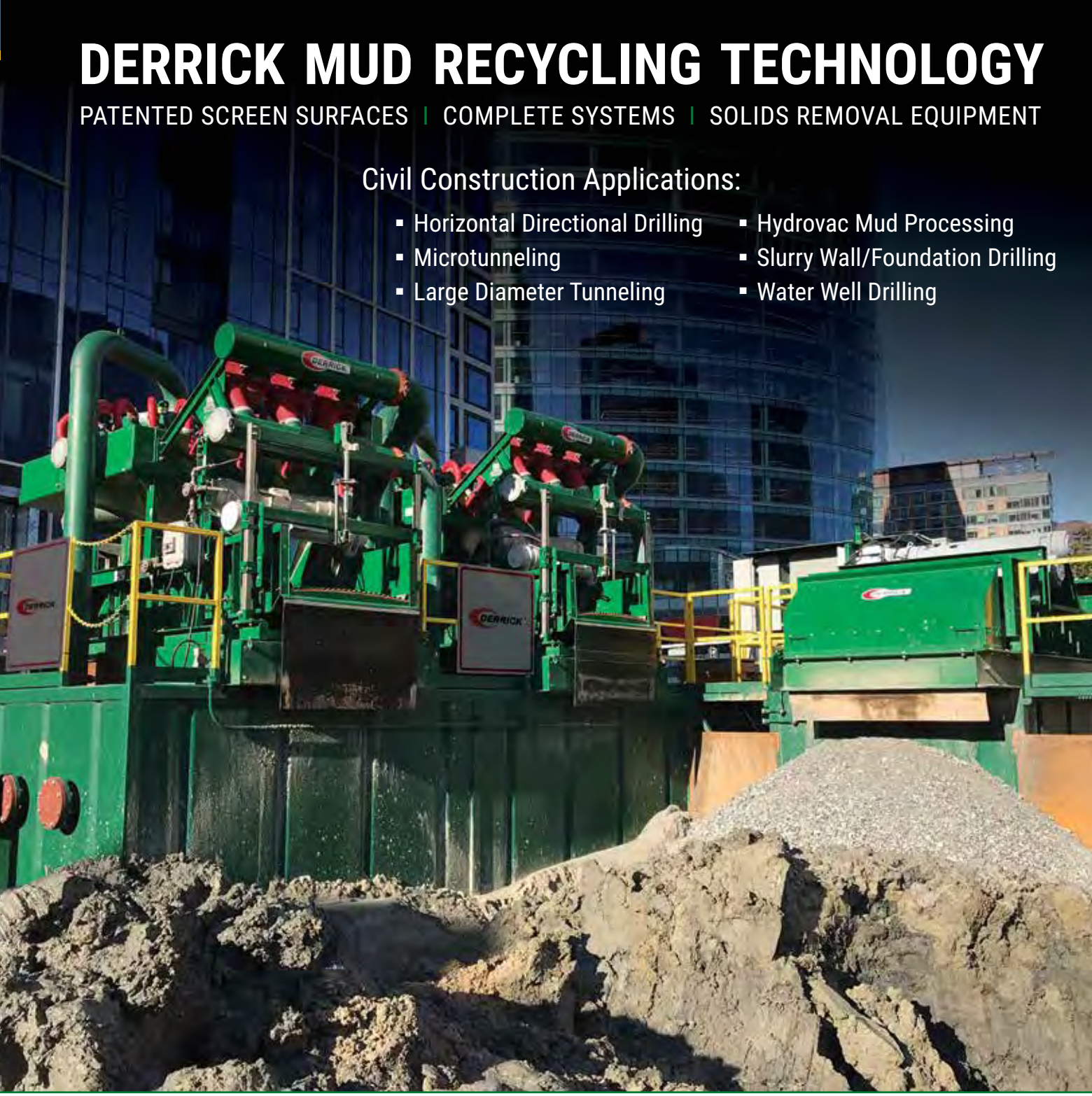

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Keller – The world leader in geotechnical construction

Effective January 1, 2020, North American Keller companies Bencor, Case Atlantic, Case Foundation, Hayward Baker, HJ Foundation, Keller Canada, McKinney Drilling and Moretrench will join together and rebrand to Keller.

Operating as one company in each local market, offering all products and services, we'll be easier to understand and engage with. Clients can be confident they're getting the best, most competitive solutions, especially when these involve multiple techniques.

Facing challenging subsurface conditions is a familiar scenario for tunneling contractors, and as the world's leader in geotechnical construction, 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 keep tunneling operations moving along for almost 100 years.

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

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

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:

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Herrenknecht: Pioneering Undergound Together

With the experience of more than 4,100 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 1,316 million euros in 2018. The independent family-run business employs over 5,000 people worldwide, including around 180 trainees. With around 80 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).

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HERRENKNECHT
Tunnelling Systems

The Robbins Company

Rock Solid Partners

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

Multi-Use Machines

If you're basing your choice of machine solely on initial cost, consider instead the entire life cycle of operation and maintenance. Robbins builds each of its TBMs with a 10,000-hour design life in mind, and with a robust steel structure, up to one-third heavier than other manufacturers' designs. Machines have been known to bore 50 km or more and Robbins TBMs are still in use worldwide that have been in operation for nearly six decades.

Over 50% of Robbins Main Beam TBMs ever produced have been used on three or more projects. It's a result that speaks to decades of engineering fine-tuned in the field. At the DigIndy project in Indianapolis, Indiana, one machine is putting the Robbins design to the test. The 6.2 m (20.3 ft) rebuilt Main Beam TBM was originally manufactured in 1980, and was chosen to bore a massive 45 km (28 mi) network of CSO storage tunnels below the city. The marathon machine achieved three world records on the first tunnel it completed at DigIndy and—with its most recent breakthrough on the White River Tunnel in April 2019—is over halfway through its epic journey with 27 km (17 mi) completed. Once the machine has bored the entire DigIndy network it will have over 60 km (37 mi) of tunnel under its belt and been in use for over four decades.

Making the Grade

Robbins recognizes the importance of having the right machine for each unique project. In Norway, innovative machines have been developed for several Small Hydropower Projects (HEPPs). At 3 m (10 ft) or smaller in diameter, these compact machines are capable of boring in hard rock at up to 45 degrees of incline using a secondary safety gripper. Both shielded and Main Beam TBMs have been developed and have proven themselves at steep inclines in hard rock. Currently a 2.8 m (9.2 ft) diameter specialized Main Beam at the Salvasskardelva HEPP is successfully boring at rates above 100 mm per minute in 150 MPa UCS mica gneiss and schist rock. It's just one example of our continuing role as a pioneer in hard rock tunneling.

The Robbins Company
Telephone: +1 (440) 248-3303
www.TheRobbinsCompany.com

DRIVEN TO THE CORE

SOLUTIONS FOR DIFFICULT GROUND

Akron Ohio Interceptor Tunnel Project
Akron, Ohio, USA
Robbins 9.26 m Crossover XRE TBM

POWERING THROUGH TOUGH GEOLOGY IN OHIO

From start to finish, crews at the Akron Ohio Canal Interceptor Tunnel guided North America's largest Crossover XRE TBM through soft ground, partial face shale and full-face rock, all while achieving advance rates up to 34 m per day.

therobbinscompany.com

Robbins
RELIABLE | RESPONSIVE

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 Bill Allen, UTT Business Development Manager — Tunneling. The UTT group is a successful division of MAPEI Group, which has provided proven construction system solutions for more than 80 years.

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.

Established in 1937, MAPEI Group is a global corporation, based in Milan, Italy, and with 87 subsidiaries that include 81 plants in 35 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 Wesley Morrison, UTT Regional Manager – 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.

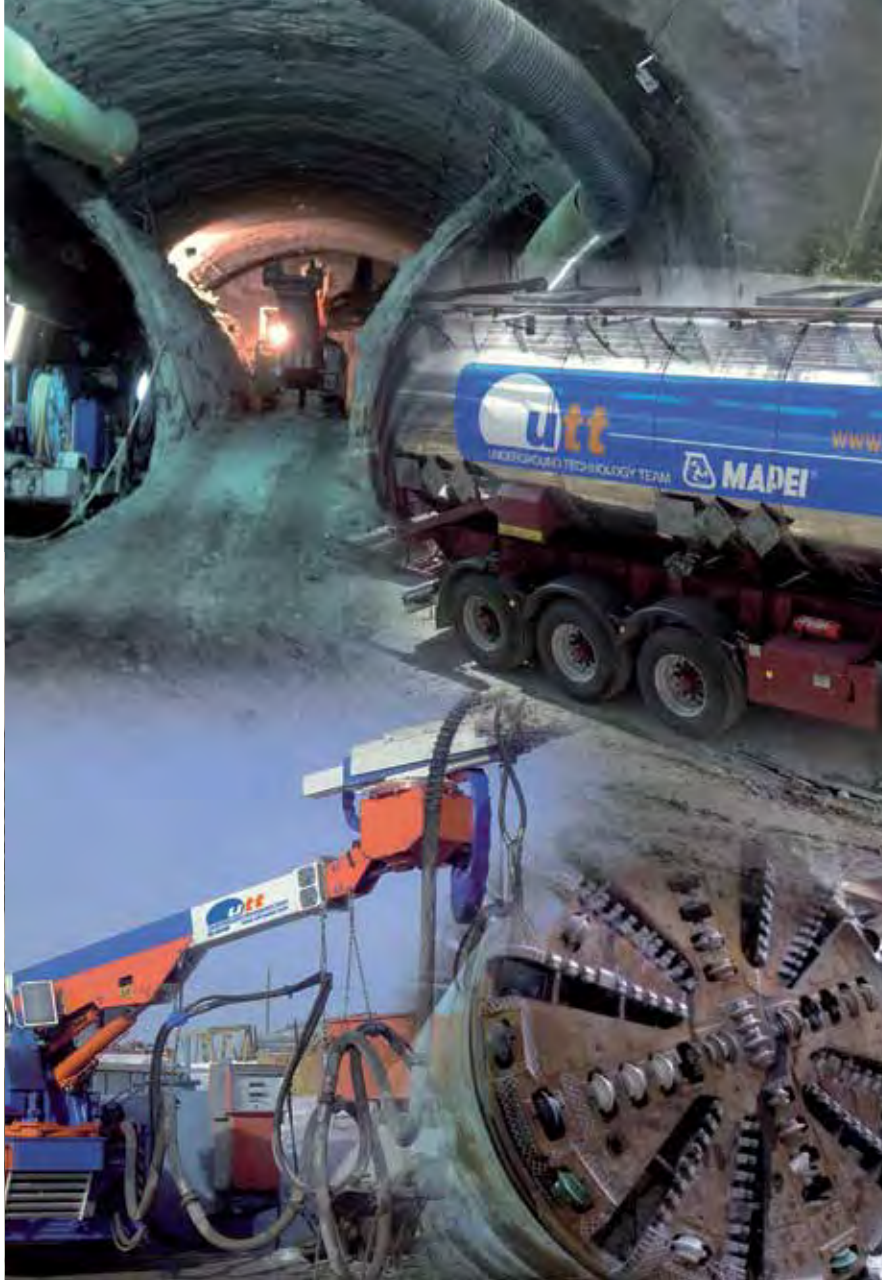
The UTT product line is divided into six categories: Concrete; Injection, consolidation and anchoring; Waterproofing; Renovation, maintenance and repair; Coatings for underground construction; and Mechanized tunneling.

No matter the division or the product line, MAPEI is known for quality products and for providing system solutions. As Allen 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."

Morrison concurred, agreeing that UTT's technical services and agility are unbeatable. "We service a project from the very beginning to the very end like no one else in the industry does," he said. "We also have the agility to adjust to the customers' needs when necessary."

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

Proven Technology for **Underground Construction**



Our commitment is the detail that makes the difference.

Reliable technology and expertise for underground construction

- Alkali-free set accelerators and admixtures for shotcrete
- Products for mechanized tunneling: foaming agents for soil conditioning, polymers, sealants and lubricants
- Products for grouting and consolidation
- Products for concrete repairing, protection and coating
- Products for waterproofing: synthetic waterproofing membranes and waterproofing accessories

Discover the world of MAPEI: Visit www.utt-mapei.com or email us at hq.utt@utt.mapei.com

MAPEI USA

utt
MAPEI

BASF

The Master Builders Solutions brand from BASF continues to break new ground in addressing the needs of tunneling professionals. Our BASF Underground Construction team brings a total solution 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 works with all relevant stakeholders to help maximize your production rates and to ensure the most successful product and system selection.

The MasterRoc product brand 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, bolting, injection and water management systems are also widely considered, selected and used for ground support and enhancement in tunneling. BASF 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 safely.

The Master Builders Solutions product line is designed to be a single source for all of 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 combinations, allowing for successful operations, coupled with the highest safety standards.

BASF, a world leader in reliable solutions specifically designed to address the requirements of tunneling projects worldwide is 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.basf.com

Dragados TBM Bertha
Photo credit-Catherine Bassetti Photography


Open Tunnel
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

BASF
We create chemistry

Photo credit: Catherine Bassetti Photography

HNTB: Trusted Innovative Underground Solutions

When the time came to replace Seattle's Alaskan Way Viaduct, an aging, double-deck highway structure dating back to the 1950s and severely damaged by a 6.8 magnitude earthquake in 2001, the answer was not to merely replicate this important mover of Seattle traffic. The solution: a single-bore large-diameter tunnel, with double-deck configuration to house both northbound and southbound lanes. The nearly 2-mile long State Route 99 tunnel beneath downtown Seattle is the largest soft-ground bored tunnel in North and South America, with a 57.5-ft. excavated tunnel diameter and a depth of 200 ft. at its deepest point. The tunnel was the critical component of the $3.3 billion Alaskan Way Viaduct Replacement Program, one of the largest infrastructure projects in the U.S. The tunnel was carefully mined under 157 buildings in downtown Seattle by a tunnel boring machine nicknamed "Bertha." HNTB provides tunneling and underground engineering expertise, including structure design and support services – from planning through final design and construction. Our full-service capabilities include:

SR 99 Tunnel's state-of-the-art features:

- Stacked 32-ft.-wide roadways that carry two southbound lanes on top of two northbound lanes
- World-class fire-detection, fire-suppression and ventilation systems
- Innovative security system with closed-circuit TVs
- Intelligent transportation system that includes variable message signs

HNTB congratulates WSDOT on the award-winning SR 99 Tunnel, honored as:

- ACEC Engineering Excellence Awards, 2019 Grand Conceptor Award
- ARTBA, Globe Awards, 2nd place winner in $100M+ projects category
- Washington ACI, Excellence in Concrete Construction Awards, Grand Award winner and Transportation category winner

The HNTB Companies
Infrastructure Solutions
hntb.com

The tunnel boring machine, "Bertha," breaks through into the receiving pit at the end of the SR 99 tunnel.

Cyclists race through the completed SR 99 tunnel during WSDOT's commemorative event to officially open the tunnel.

INNOVATIVE AWARD-WINNING UNDERGROUND SOLUTIONS

The Washington State Department of Transportation's Alaskan Way Viaduct Replacement Program and State Route 99 Tunnel set a new precedent in infrastructure design and construction.

HNTB Corporation served as engineer of record and lead tunnel designer.

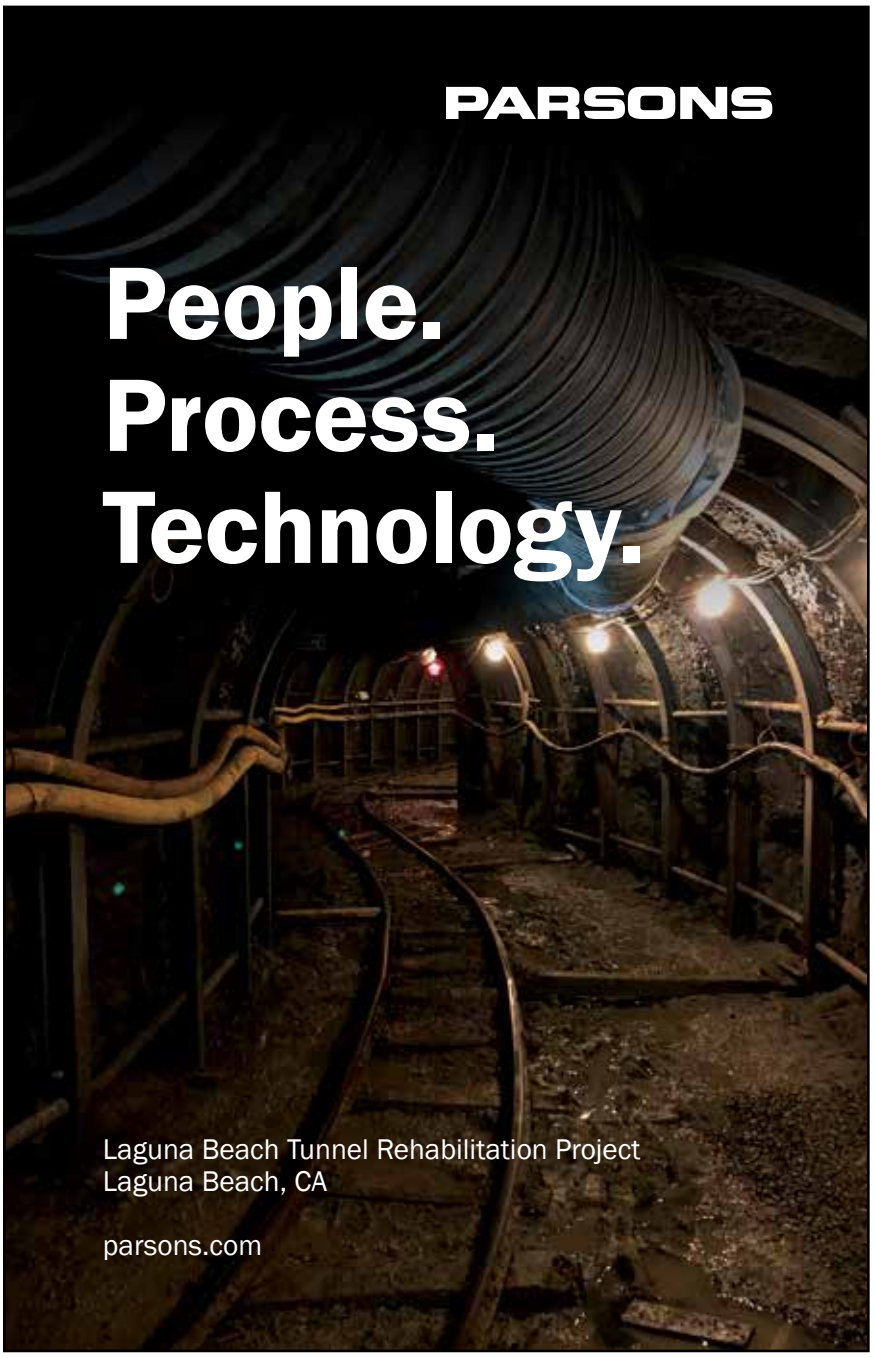
The HNTB Companies
Infrastructure Solutions

hntb.com

HNTB

Industry leaders. Delivering innovative solutions.

Parsons is a technology-driven engineering services firm with 75 years of experience in the engineering, construction, technical, and professional services industries. The corporation is a leader in many diversified markets with a focus on infrastructure, defense, and construction. Parsons delivers design/design-build, program/construction management, systems design/engineering, cyber/converged security, and other professional services packaged in innovative alternative delivery methods to federal, regional, and local government agencies, as well as to private industrial customers worldwide.



We have successfully delivered some of the largest and most complex tunneling and underground construction projects in the world. From planning and design through construction management and operations, Parsons provides a complete range of services for water, wastewater, and transportation tunnels. Whether your project involves soft ground, rock, or mixed-faced conditions, our dedicated staff of more than 100 tunnel professionals have the experience and skills to manage the risks and deliver safe, economical, and innovative solutions. Our recent 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.

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.

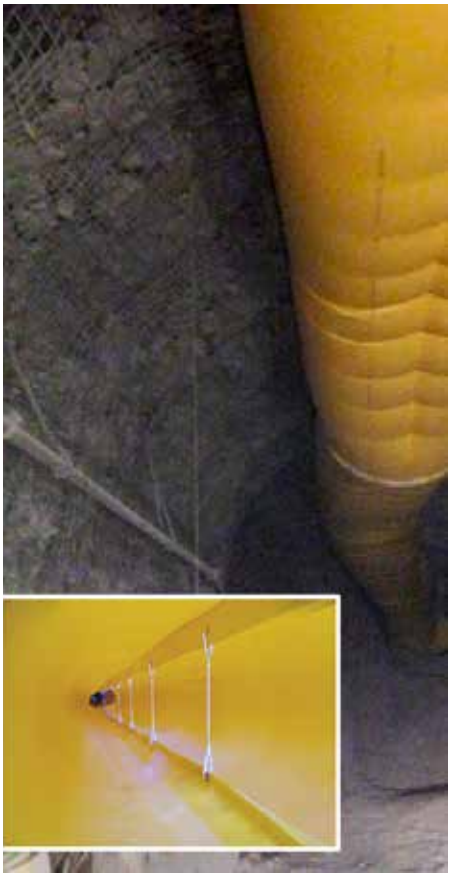
Mine Hoists International, a sister company of Mining Equipment, is based in North Bay, Ontario. They boast the world's largest inventory of used mine hoist and large capacity stage winches for mining and shaft sinking projects. Their new 20,000 square foot shop in North Bay, Ontario can handle the largest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

Mining Equipment 10 Ton Locomotives for Columbus, Ohio

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.**



Epiroc covers all the bases underground

Epiroc is a leading productivity partner for the mining, infrastructure and natural resources industries. Epiroc develops and produces innovative drill rigs, rock excavation and construction equipment, and provides world-class service and consumables. We focus on efficiency, safety and reliability, delivering the performance you need to maximize productivity today – and the technology to succeed in the future.

Our tunneling and underground infrastructure equipment includes:

Drilling equipment
We offer a wide variety of drill jumbos for face drilling, long hole drill rigs for production drilling, and one of the industry's largest range of top hammer and down-the-hole tools and accessories. All are designed for long life, maximum uptime and high efficiency.

Loaders and trucks
Our high-performance underground loaders, haulers and dumpers cover a wide range of hauling capacities and frame styles to fit specific needs. Products include electric loaders, continuous loaders, and diesel loaders and trucks.

Raiseboring
Epiroc offers tools and equipment for conventional raiseboring, boxhole boring and down reaming. These products are designed to reduce fatigue and maximize uptime, with features that enhance operator safety.

Ventilation systems
We supply a complete ventilation solution for tunneling and underground opertions, including system deisng and installation of fan stations and ducting.

Rock reinforcement equipment
We have your rock reinforcement needs covered with machines ranging from low seam to some of the largest mining and civil drive dimensions. Our rock bolting rigs, cable bolting rigs, concrete spraying equipment and ground support solutions are all designed to help customers achieve the highest productivity with the lowest maintenance costs.

Visit epiroc.us to learn more.

RUEN Drilling

Ruen Drilling provides drilling services including surface, underground, and horizontal directional core drilling for the geotechnical, exploration and geothermal industries throughout the United States. Drilling equipment includes truck, track, skid, and helicopter supported core drills. Rig capacities are to 10,000 feet vertical or angle and 3,000 feet horizontal. Crews all have extensive safety training, are trained in achieving a high degree of core recovery and are experienced in the installation of instrumentation and geophysical testing.

2320 River Rd., P.O. Box 267, Clark Fork, ID 83811
Ph: (208) 266-1151 Fx: (208) 266-1379
www.ruendrilling.com office@ruendrilling.com

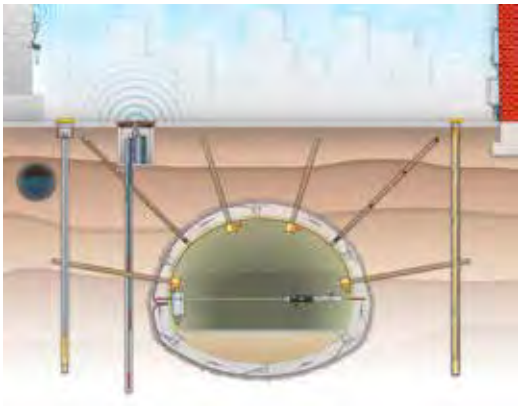
Geokon

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.

Geokon
Telephone: + 1-603-448-1562
Email: info@geokon.com
Web: www.geokon.com

Premier Pipe Systems Manufacturer for Over 90 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) 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
1270 East 92nd Street
Chicago, IL 60619 USA
Tel: 1-773-721-9400 Fax: 1-773-721-9494
Email: sales@naylorpipe.com
www.naylorpipe.com

Advanced Concrete Technologies, Inc.

– We Add Profitability to the Mix

Advanced Concrete Technologies, Inc. (ACT) is a single source supplier of turnkey concrete batching and mixing plant solutions that draws on over 55 years of experience and more than 5,000 concrete plant installations worldwide. ACT provides the industry's most flexible and proven solution for producing highest-quality, central mixed concrete and backfill grout for on-site construction, tunneling and mining projects. ACT's MobilMat batch plants, come in ten different sizes, ranging from 30 up to 240 cubic yards per hour concrete output. We offer high intensity HPGM counter-current mixers and DWM twin-shaft mixers, advanced WCS control automation, commissioning services as well as an industry leading training & support program.

ACT's plant solutions deliver superior quality concrete with the ideal combination of proven components, engineered by one of the world's most respected names in the industry – Wiggert & Co. GmbH.

Advanced Concrete Technologies, Inc.
300 Portsmouth Avenue
Greenland, NH 03840 USA
Telephone: +1-603-431-5661
www.concretebiz.com

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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Mahmood Khwaja, PE | KhwajaM@cdmsmith.com | 617-452-6391

CDM Smith
cdmsmith.com

Normet

Our value proposition:
Defining the Future Underground.

The underground future consists of three main pillars, which highlight our expertise and focus:

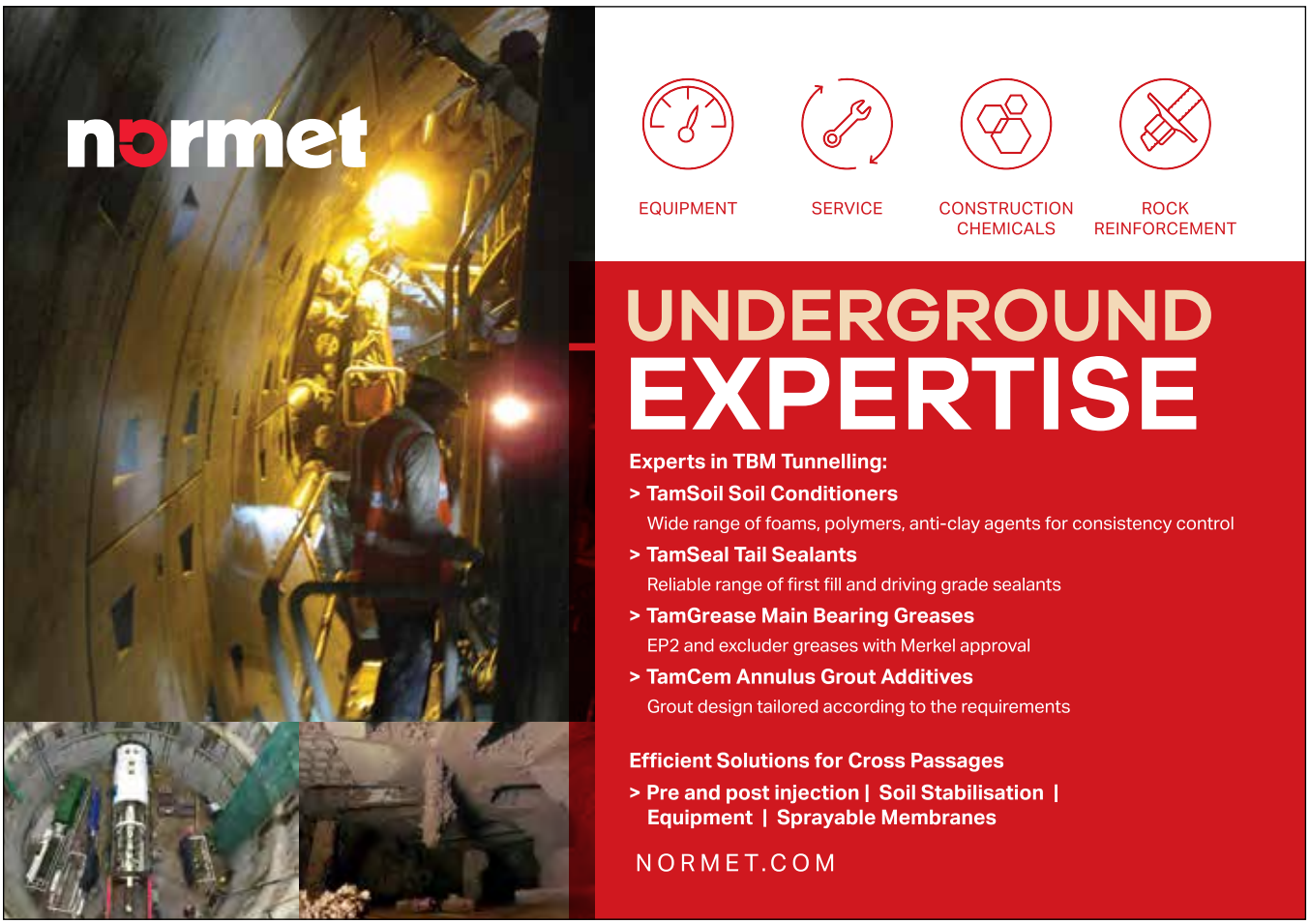
1. Securing a safe future – adopting safe & sustainable solutions for all underground operations to build the safest places underground
2. Innovating for Performance – providing the best process understanding & productivity
3. Partnering for the Future – co-developing with our customers solutions to fulfil the business needs

Normet encourages a strong collaboration with its customers. We have amassed process expertise over thousands of mines and tunnel projects all over (and under) the globe. The broad perspective means experience and expertise about what should and should not be done to achieve the optimum results. Normet improves underground mining and tunnelling processes with knowledge and technology translating process expertise into actions and financial results.

Normet has a broad underground offering:

- Equipment for concrete spraying and transport, explosives charging, scaling, lifting, installation works, and logistics.
- Construction chemicals for sprayed concrete, admixtures for all types concrete, injection systems for rock improvement, reinforcement systems for high deformation conditions, spray applied waterproofing systems and needed chemicals for Tunnel Boring Machine (TBM) technology covering hard rock, Earth Pressure Balance (EPB), open face and slurry type machines.
- High quality and innovative rock reinforcement products that reduce the risk and consequences of accidents and facilitate high productivity in challenging rock conditions.
- Services for underground mining and tunnelling, including for example spare parts, rental equipment, equipment refurbishment, performance and field services.

For further information, please visit us at: normet.com



HÄNY
Mixing and Injection Technology

Haeny, Inc.

Haeny, Inc., the North American subsidiary of Hany AG (Jona, Switzerland) has entered into the U.S. market, supplying grout mixing and injection equipment to the tunneling and foundation grouting industries. The new Irondale, Alabama facility serves as the U.S. headquarters with operations including equipment sales and rental, parts distribution, as well as service and technical advisement.

Family owned and operated for over 140 years, Hany AG is a leading provider of pumping, mixing and injection equipment. The extensive product line ranges from large automated mixing plants and high-volume pumping systems to compact mobile grouting units to serve any size job. The company currently operates in 27 countries and is excited to expand their network to serve customers in the United States, Canada, and Mexico.

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

Grindex

Grindex is a world leader in electric submersible pump technology used for demanding applications such as construction and mining – known worldwide for the high reliability and dependability. The built-in starter and motor protection unit make the pumps easy to install and the air valve allows longer periods of dry run time extending life of the pump. Available standard drainage pumps range in 2hp to 140 HP, with some models available in stainless steel and slurry pumps to meet any dewatering needs. Since 1989, Grindex North America (subsid.) has been servicing USA and Canada.

grindex

Surecrete Inc.

Surecrete Inc. specializes in furnishing bagged cementitious materials, mixing and placing equipment and related accessories to the heavy civil tunnel, geotechnical and mining markets throughout the US, Canada and Mexico.

Our product lines include ultrafine cements, rheology modifiers, fibers, admixtures, and a complete selection of packaged shotcrete, concrete and grout mixes. We also supply wet and dry shotcrete machines, predampeners, concrete pumps and grout plants.

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Fax: (206) 524-6972
Email: jeff@surecrete.com
For more information, visit our website at www.surecrete.com.

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.

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Brookville

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

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

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

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

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.

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.

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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 the firm in 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.

MRCE's 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 LIRR East Side Access, NYCT 2nd Avenue Subway, and the DEP's Catskills and Delaware Aqueduct Rondout-West Branch Tunnel and Brooklyn to Staten Island Harbor Siphon Tunnel.

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BabEng | Tunnelsoft

BabEng, as a worldwide engineering and consulting company, has supported more than 200 tunneling projects worldwide. Specialized in underground works involving TBMs we advise, plan and understand projects from pipe jacking for water supplies to large projects such as the Port of Miami Tunnel.

With our team we share the philosophy of mutual respect and the challenge of contributing to the continued success of our company during all phases – from feasibility study to design and from construction to contract closure.

Our division Tunnelsoft, as a member of BabEng, supports the tunneling industry with specialized software for excavation management and data visualization and can constantly count on the expertise of our TBM engineering experts in-house. Its major product is called TPC. Unique flexibility combined with powerful automatic reporting and notification tools makes TPC one of the leading solutions in the market. TPC has successful references all over the world.

Our network of offices in Germany and the US allows us to respond quickly and effective across the globe.

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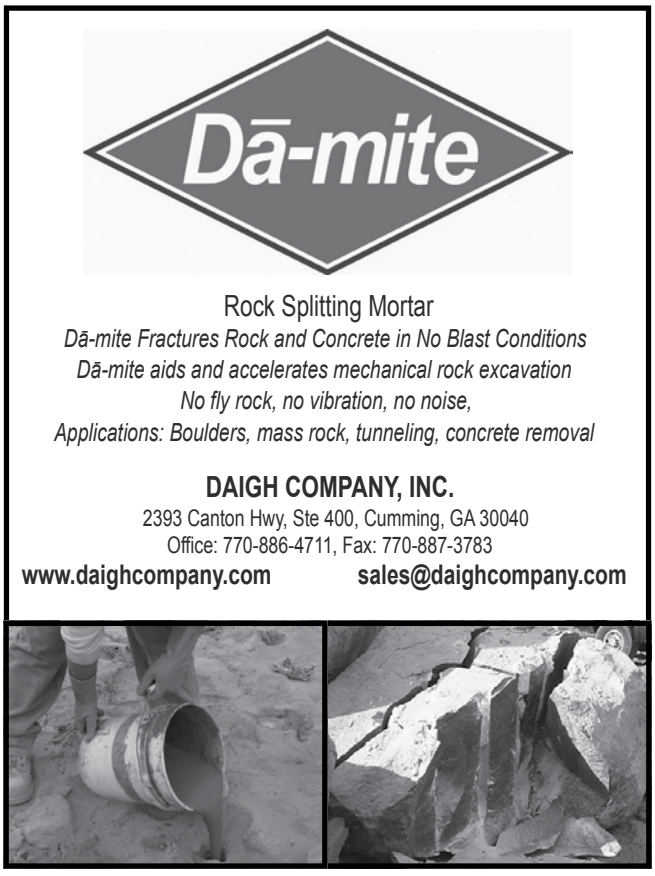

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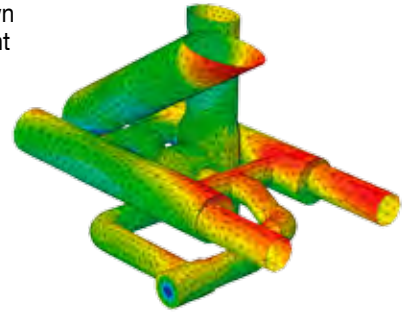
Dr. Sauer & Partners is a specialist, independent consultancy providing the full range of design and construction management services for tunnels, shafts and caverns. Delivering innovative, cost-effective and environmentally aware designs, the company has over 30 years' experience providing solutions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

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

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



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The N50 Power Splitter uses a feather and wedge system. Hanging from an excavator, the N50 uses the existing excavator hydraulics to push the wedge between the feathers exerting a force in excess of 2,700 tons! The Rock Splitter's wedge requires a pre-drilled 4" hole that is 4.3 feet to 5 feet deep. The wedge travels 700mm or 2.3 feet into the hole. The breaking of rock or concrete will happen immediately. RST also distributes the K25 hand held splitter.

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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	Design study
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, 4th quarter, 2019
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2022	Under study
Redundancy Tunnel Program - Northern	Boston MRWA	Boston	MA	CSO	23,760	10	2026	Under study
Redundancy Tunnel Program - Southern	Boston MRWA	Boston	MA	CSO	50,160	10	2028	Under study
Narragansett Bay CSO Phase III - Pawtucket Tunnel Conveyance Tunnel	Narragansett Bay Commission	Providence	RI	CSO	 13,000 8,800	 28 10	 2020 2024	 Under design Under design
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	40,000	32	2021	Awaiting funding
Hampton Roads Bridge-Tunnel Project	Virginia DOT	Hampton Roads	VA	Highway	7,500	42	2019	Dragados JV awarded
Alex Renew Long-Term Control Plan	City of Alexendria	Alexandria	VA	CSO	10,500	20	2019	Under design
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
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2019	Under design
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
Westerly Main Storage Tunnel	NEORSD	Cleveland	OH	CSO	12,300	24	2018	JayDee/ Obayashi awarded
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
ALCOSAN CSO Ohio River Allegheny River Mononghahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	 10,000 41,700 53,900	 30 30 30	 2021 2022 2023	 Under design Under design Under design
Enbridge Line 5 Tunnel	Enbridge	Traverse City	MI	Oil	23,760	12	2020	Under study

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

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
I-70 Floyd Hill Highway Tunnel	Colorado Dept. of Transportation	Denver	CO	Highway	15,840	60 x 25	2022	Under design
W-6: Highway 90 to SW Military Drive	San Antonio Water Systems	San Antanio	TX	Sewer	28,000	10	2020	Under design
D2 Subway - 2nd Light Rail Alignment	Dallas Area Rapid Transit	Dallas	TX	Highway	3,000	22	2020	Under design
Ship Canal Water Quality Project	Seattle Public Utilities	Seattle	WA	CSO	14,250	19	2018	Lane/Salini low bidder
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	Transit	10,500	18	2022	Under design
L.A. Metro Westside Phase 2 Phase 3	Los Angeles MTA	Los Angeles	CA	Subway	 26,500 26,500	 20 20	 2016 2018	Tutor Perini/O&G JV awarded Frontier-Kemper/ Tutor/Perini awarded
Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2020	Under study
Folsom Area Storm Water Improvement	SFPUC	San Francisco	CA	CSO	4,000	12	2022	Under design
SVRT BART	Santa Clara Valley Trans Authority	San Jose	CA	Subway	22,700	20	2019	Single tunnel option approved
California Waterfix 1 California Waterfix 2	Delta Conveyance Design and Const.	Sacramento	CA	Water	39,905 403,400	28 40	2020 2020	Delayed Delayed
Newell Creek Dam	City of Santa Cruz	Santa Cruz	CA	Water	1,500	14	2020	Under design
Coxwell Bypass Tunnel program	City of Toronto	Toronto	ON	CSO	35,000	12	2018	JayDee/Michels/C&M McNally awarded
Ashbridges Bay Outfall Tunnel	Metrolinx	City of Toronto	ON	CSO	11,500	23	2018	Southland/Astaldi JV Awarded
Yonge St. Extension	Toronto Transit	Toronto	ON	Subway	15,000	18	2016	Under study
Taylor Massey Tunnel	City of Toronto	Toronto	ON	CSO	20,000	18	2018	Under design
Inner Harbour West	City of Toronto	Toronto	ON	CSO	18,400	19	2021	Under design
Scarborough Rapid Transit Extension	Toronto Transit Commission	Toronto	ON	Subway	25,000	18	2018	Under design
REM Transit Tunnel	City of Montreal	Montreal	QC	Subway	27,000	22	2017	SNC/Dragados/ Aecon JV Awarded
Green Line LRT	City of Calgary	Calgary	AB	Transit	26,250	20	2018	Prequalifications underway
Second Narrows Tunnel	City of Vancouver	Vancouver	BC	CSO	3,600	14	2013	Traylor/Aecon JV awarded
Annacis Island Outfall	City of Vancouver	Vancouver	BC	Water	8,000	10	2017	Pomerleau/Bessac Awarded
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	Under design
Broadway Sky train	Trans Link	Vancouver	BC	Subway	25,000	18	18	Under design
Northern Gateway Hoult Tunnel	Enbridge Northern	Kitimat	BC	Oil	23,000	20	2014	Under design

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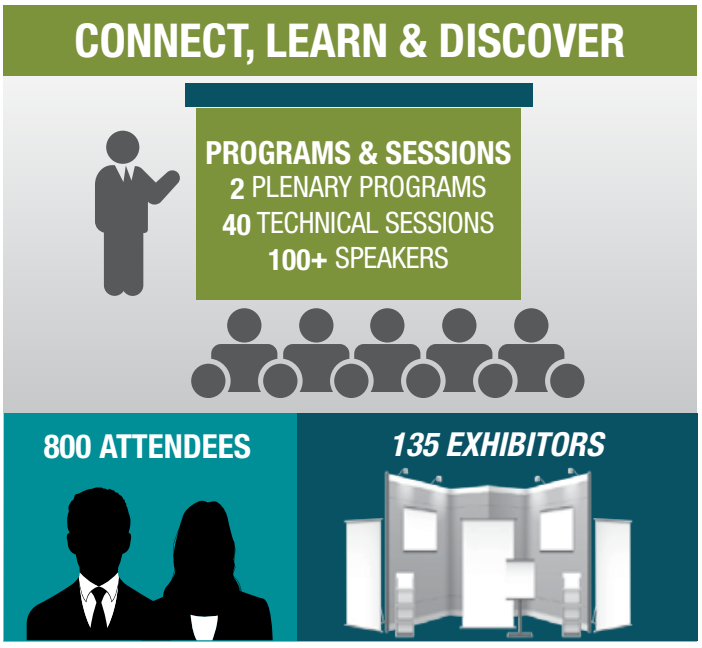

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