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Emerging safety technologies
Ellicott City North Tunnel
Building Information Modeling in tunneling

All New
Business Profiles
Inside!

Special Editorial Supplement from the publisher of Mining engineering

CLEAN RIVERS PROJECT, WASHINGTON, DC

METICULOUSLY UPGRADING THE UNDERGROUND

The new 28 kilometers of tunnel are aiming to reduce 96% of combined sewer overflows (CSO's) into Washington DC's waterways – the Anacostia and Potomac Rivers and Rock Creek. Four Herrenknecht EPB Shields are building a tunnel system to store and convey overflows to one of the largest wastewater treatment plants in the world. Through careful monitoring, the Herrenknecht TBMs are able to navigate the underground of the city.

› herrenknecht.com/cleanrivers

Client:
› DC Water
Contractor:
› North East Boundary Tunnel – Salini Impregilo / Healy JV
› First Street Tunnel – Skanska / Jay Dee JV
› Anacostia River Tunnel – Salini Impregilo / Healy / Parsons JV
› Blue Plains Tunnel – Traylor / Skanska / Jay Dee JV

PIONEERING UNDERGROUND TOGETHER

HERRENKNECHT
Tunnelling Systems

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The top priority of tunnels is to safeguard health and life both during the construction of the tunnels and through the life of the structure. In this issue new technologies to keep workers safe are discussed on page 12. On page 17, the design of a tunnel that will protect Ellicott City, MD is covered. Cover photo courtesy of Steven Gallyer
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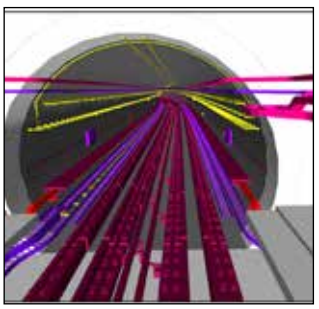
Feature Articles



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What's new with the International Tunneling Association ...

Well, a lot …

As some but maybe not all of you know, the International Tunneling Association (ITA) was founded as a nongovernmental organization in 1974 by the initiative of 19 nations. Since then, the ITA has developed considerably. Presently, it encompasses 78 member nations and 266 corporate or individual affiliate members, has 14 working groups and four committees, and has as its goals:

- To encourage new uses of underground space for the benefit of the public, environment and sustainable development.
- To encourage studies of underground alternatives to surface construction, not only considering construction costs but also indirect life-cycle costs and savings as well as social and environmental advantages.
- To stimulate the development of guidelines for a positive public strategy to take advantage of subsurface potential.
- To encourage the development of better and cheaper methods for planning, geoinvestigation, design, construction, operation, maintenance and safety of underground structures by using improved methods such as new technical developments and risk-management principles.
- To improve training of everyone, especially young professionals, by conducting workshops, by improving and coordinating academic programs worldwide and by improved on-the-job training.
- To bring together engineers, owners and others involved in the development of underground space, such as architects, planners, authorities, economists, lawyers, insurers, financers and politicians.
- To arrange international exchange on developments in underground technology and experience from its use.

Michael Rispin
2022-2023 UCA Chair

The UCA represents the United States in the ITA as the member nation. As the current Chair of UCA, I vote on all matters that come before the ITA General Assembly involving the activities of ITA when called upon.

I, members of UCA staff, and a strong delegation from the United States tunneling industry participated in September in the World Tunnel Congress (WTC) in Copenhagen, Denmark. This is an event that is held annually but has not been in-person since 2019 because of the pandemic. Since the goals of the UCA align so well with the goals of ITA, we always benefit from participating in the WTC, benchmarking the industry with our global colleagues (until we start tunneling on other planets or galaxies, it's the most comprehensive cohort we can reach), broadening our knowledge of technologies and practices, and furthering the industry

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BANGKOK FLOOD PROTECTION: AHEAD OF THE CURVE

The Bueng Nong Bon to Chao Phraya River Diversion Project is a major flood prevention tunnel being built in the capital as part of the Bangkok Metropolitan Administration's (BMA) long-term plan to manage flash floods.

Due to the dense urban environment, the tunnel's route has been dictated by the need to stay within public road easements, which has imposed a number of very tight radius curves on the alignment. To achieve these, TERRATEC has delivered two new 5.70m diameter tight radius EPBMs, which have been designed with an extreme X-type articulation system that can accommodate a minimum radius curve of 35m. Machine operation will be assisted by TERRATEC's highly-experienced Field Service staff to ensure optimum performance and successful project completion.

TUNNELLING SOLUTIONS | UTILITIES

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Herrenknecht picks up prestigious innovation award at bauma trade show

The world's largest trade show for construction, building materials and mining equipment, bauma, kicked off on Oct. 23 in Munich, Germany. During the opening event the bauma Innovation Awards were given in five categories.

Herrenknecht was named the winner of the Machine Technology award for its development of continuous tunneling in mechanized construction of high-performance underground infrastructures.

"Continuous tunneling is the next significant innovation step in mechanized tunneling. New underground traffic routes have to be built ever faster. Continuous tunneling gives clients and contractors a decisive time advantage that ultimately benefits the entire project and all partners involved," said Martin Herrenknecht, founder and chief executive officer of Herrenknecht AG in a statement. "Railroad, metro and road tunnels can be built and put into operation significantly faster. I am particularly proud of the Innovation Award because the new tunneling method was developed and put to use in Schwanau by our experienced engineers together with young colleagues."

This is the third time that Herrenknecht AG has won the bauma Innovation Award: in 2019, the prize was awarded for the E-Power Pipe method for the environmentally friendly laying of underground cables, and in 2013 for Pipe Express, a semi-open method for laying pipelines.

Until now, mechanized tunneling with shield machines in soft ground has always been a stop-and-go sequential process. Each excavation stroke is followed by the ring building sequence, so that the excavation has to pause and the subsequent driving cycle be only started when the next segmental ring has been completely installed. The interruptions to tunnel advance in soft ground formations caused by these sequential operations cost time when viewed over longer distances. In contrast, a continuous tunneling process in which the machine can continue excavation while the lining rings are being installed can contribute to considerable savings in construction time. For this purpose, Herrenknecht engineers designed a process based on the latest technologies and engineering.

With regard to tunneling, the innovation facilitates the following process sequence: In continuous tunneling, those thrust cylinders that push the machine forward during advance take over the force share of those cylinders that are retracted for ring building. To ensure that the machine reliably maintains on course under these conditions the center of thrust resulting from the combined driving forces of the applied thrust cylinders must remain unchanged in its position. At the heart of continuous tunneling is therefore a powerful computer system and process-specific software programs that can precisely calculate the necessary pressures in the thrust cylinders. It ensures that the machine

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Petra acquires trenchless tunneling company Zilper

Petra, a company that says it is the first company capable of undergrounding critical utility infrastructure from difficult hard rock to soft ground geologies, announced the acquisition of Zilper Trenchless, a pioneer in the trenchless technology space. Zilper Trenchless machines uniquely install critical utility infrastructure through challenging geologies such as flowing sands, cobbles and high water table environments.

"We've both been building methods to excavate problematic geologies in the underground industry. Combined, Zilper and Petra provide a complete undergrounding solution to construction and utility companies who need to de-risk undergrounding projects and bore through all geologies," the company said.

The vast majority of the world's electric, water and sewer utilities were not designed to withstand the storms, extreme heat and drought brought on by climate change and rapid population growth. Above-ground power lines have caused thousands of wildfires in drought-prone areas, and blackouts during hurricanes. In coastal areas, increased flooding and sea-level rise cause sewage to leach into waterways. There is a growing demand by municipalities to expand underground utilities, but in many populated areas with hard and soft ground nightmare geologies, conventional technology has difficulty boring through flowing sand, high water table content and cobbles. According to the Black & Veatch 2022 Water Report, the United States would need to increase its investment in water infrastructure by $2.2 trillion over the next 20 years, or roughly $109 billion per year to close the water industry's current

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HS2 Tunnel project launches fifth TBM; Herrenknecht machine to bore 8 km in London

The fifth tunnel boring machine (TBM) to be put to work on London's HS2 tunnel project has been launched from a site in West Ruislip in west London.

The 140 m (460 ft)-long, 2-kt (2,200-st) Herrenknecht TBM — named Caroline — will bore 8 km (5 miles) toward Greenpark Way.

New Civil Engineer (NCE) reported that Caroline will be operated by Skanska Costain Strabag JV (SCS JV), HS2's main works civils contractor constructing the HS2 tunnels in London.

HS2 civils delivery director Michael Lyons told *NCE* that the ground conditions at this site are quite different from the other HS2 tunneling locations but that the team was able to draw from experience from other major tunneling projects in London, notably the Crossrail project.

Planning to alter certain methods when driving the TBMs through the West Ruislip site started back in March 2018 when a prehistoric clay coastline was discovered by HS2's ground investigations team.

They named the subtropical coastline, dating back 56 million years, the Ruislip Bed, which consists of a large layer of black clay roughly 33 m (108 ft) below the surface. Geological experts believe the bed was formed from densely wooded marshes close to a subtropical sea.

As well as the mixture of materials that make up the geological composition, there is a lot of water content in the area. How the TBM is used will be affected by changes in the composition of the ground along the tunnel drive: for example, if the amount of moisture, chalk or clay reduces or increases.

The SCS team is also aiming to reuse the spoil excavated by the drive to aid the project and rebuild the West Ruislip golf course, which was located on the TBM launch site before HS2 set up. Spoil from the tunnels at West Ruislip will also be used for sustainable placement to the north, creating embankments for the new railway, as well as new environmental habitats.

All of the TBMs operated by SCS JV are earth-pressure-balance machines. Caroline and Sushila are slightly different from other TBMs as they both have automated systems to place the concrete rings behind the cutter head. Machinery to aid placement has been used for many years but previous TBMs have called for manual input to position the rings. The automation idea came from Align JV, which is boring the Chiltern tunnels.

TBM Sushila is now 67 m (220 ft) into its dig, but both machines have a long way to go. They will drive 24/7 for 22 months, only excluding Christmas Day. Named after 18th century astronomer Caroline Herschel, TBM Caroline will be operated by a crew of 15 people, working in shifts. An additional 25 people will directly support each tunnel drive on the surface.

Separately, two other TBMs will set off toward Greenpark Way in Greenford from HS2's Victoria Road site in Acton in 2023 to build a further 5.4-km (3.4-mile) twin-bore tunnel. Combined, the quartet of TBMs will build 13.5 km (8.4 miles) of twin bored tunnels between West Ruislip and the new high-speed-rail super hub station at Old Oak Common. ■

Award: Herrenknecht for Machine Technology

(continued from page 4)

operator can reliably control the tunnel boring machine along the specified alignment as before.

In continuous advance, the machine operator no longer controls the pressures in the thrust cylinders manually using rotary controls (potentiometers) on the control panel. For this purpose, Herrenknecht has newly developed the center of thrust (CoT) system, which helps the shield operator to precisely control the machine. It consists of a display panel that shows the operator the current position of the center of pressure and on which he selects the desired position of the center of thrust. The corresponding control of the thrust cylinders is handled by the algorithms in the computer system. Compared to manual control by potentiometers, the CoT offers the prospect of maintaining the specified alignment more efficiently and effectively. The CoT system can thus make a sustainable contribution to the economic efficiency of the construction project in addition to the quality of the underground structure.

With continuous tunneling, an increase in total tunneling performance of up to a factor of 1.6 can be achieved compared to the previous discontinuous method. This can lead to a significant reduction in construction time for long tunnels. The unique feature of Herrenknecht's solution is that continuous tunneling can be used on all machine types in soft ground.

The continuous tunneling method is being used in the major High Speed 2 project — a new rail link between London and Birmingham. ■

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Boring marks a milestone for Broadway Subway Project in Vancouver, Canada

Tunnel excavation at the Broadway Subway Project in Vancouver, British Columbia, Canada is set to begin. The project will connect six new underground stations on the 5.7-km (3.5-mile) extension of the Millennium Line.

The expanded line will transform the way people travel and live along the Broadway corridor and throughout Metro Vancouver and will provide faster, more convenient and more affordable travel options for workers and families.

"Today's TBM launch is a significant milestone for the Broadway Subway Project and a proud moment for all of us at ACCIONA. It's also a testament to our strong collaboration with our client, TI Corp., and the Province of British Columbia, and to the tireless effort of our subcontractors," said Carlos Planelles, managing director for North America, ACCIONA, in a statement.

The two cylindrical tunnel boring machines (TBM), each of them 6 m (20 ft) in diameter and weighing about 1 million kg, will be launched separately from the Great Northern Way-Emily Carr Station and tunnel 5 km (3.1 miles) to reach their final destination at Cypress Street, near the future Arbutus Station.

"We are delighted to have been chosen to deliver Broadway Subway Project to our client, the Province of British Columbia. We have been preparing for this moment for two years now, with the support of the City of Vancouver, Metro Vancouver, BCIB and our valuable subcontractors. We are finally ready, and today all GHELLA's crew and staff cannot wait to launch the first TBM and bore the subway tunnel all the way to Arbutus Station," said Marco Ciarlantini, area manager for West Canada, GHELLA Canada Ltd.

Each TBM is expected to take about a year to carve out the subway's inbound and outbound tunnels. The TBMs have been given the names Elsie and Phyllis, after two influential British Columbian women, Elizabeth (Elsie) MacGill and Phyllis Munday. Elsie is about to start tunneling. Phyllis is currently being assembled and is expected to begin operating this winter.

In preparation for the TBMs, tunnel liner rings, manufactured in Nanaimo, were transported to the construction site as crews built the concrete base slab and assembled the conveyor system to transport the excavated material out of the tunnel. At the same time, work is progressing on the elevated guideway and station locations along the line, including relocating utilities, building traffic decks and excavation.

Once tunnel boring finishes, crews will complete construction of the underground stations and install the train tracks and supporting systems. The final steps include testing and commissioning of the new line.

The Broadway Subway will extend the Millennium Line from VCC-Clark Station to Broadway and Arbutus, providing people with fast, convenient SkyTrain service all along the Broadway corridor, which is home to British Columbia's second largest jobs center, world-class health care services, an emerging innovation and research hub, and growing residential communities.

The project will result in faster travel, better access and fewer cars on the road in this heavily used corridor. Once opened, the trip from VCC-Clark to Arbutus Station will take 11 minutes, saving the average transit commuter almost 30 minutes a day and relieving congestion along Broadway. ■

Largest TBM of its kind built in China

The largest tunnel boring machine (TBM) of its kind, a machine with a diameter of more than 7 m (23 ft) rolled off the production line in Changsha, Hunan province in China.

China Daily reported that the TBM was produced by China Railway Construction Heavy Industry Corp., and China Railway 18th Bureau Group Corp. The machine is about 100 m (330 ft) long. It can achieve a horizontal turning radius of 200 m (660 ft) and a vertical curve radius of 380 m (1,246 ft) of tunneling.

As the first large-slope tunnel-boring machine in the world, the so-called Beishan No. 1 will be used in the construction of an underground laboratory to research disposal technologies for high-level radioactive waste in Beishan, Gansu province.

The machine will excavate a spiral curve slope in Beishan, about 7.2 km (4.5 miles) long. With each 10 m (32 ft) of excavation, the working height of the machine will drop 1 m (3 ft).

The landscape in Beishan consists mainly of granite, a type of hard rock, making work more challenging, said Xu Chunxian, head of the Beishan construction team from China Railway 18th Bureau Group.

The design of the cutting head of Beishan No. 1 has a rock-breaking efficiency three times that of a machine with a traditional plane cutter head, said Wu Min, vice president of the TBM Design Institute of China Railway.

The design team improved the space structure of the machine and added advanced guidance, direction control and an automatic cruising system to assist driving and increase the flexibility of the machine in cutting large-slope spirals. ■

Sub Space Energy Hub aims to fast-track underground mining electrification

A diverse group of companies have come together to develop the Sub Space Energy Hub at the Hagerback Test Gallery in Switzerland to advance the electrification of underground mining and tunneling projects. The group includes Irish company Xerotech, Switzerland-based VersuchsStollen Hagerbach (VSH) as well as Amberg Group, Normet, Motics, Alumina and Fortescue.

The Sub Space Energy Hub will focus on the development of battery-electric vehicles for underground operations as well as the development of new energy storage technologies to help communities transition to renewable energy.

"This facility provides a platform to continue pushing the boundaries of our next-generation battery technology as we continue to break the limitations of what is possible in terms of nonroad mobile machinery electrification," Barry Flannery, chief executive officer of Xerotech said in a statement. "This will rapidly benefit our customers who are under increasing pressure to find viable ways to electrify vehicles that at one point were thought to be too big or difficult to convert to electric."

"Together with partners like Xerotech, VSH will be transformed into a visionary sustainable and CO_2-neutral underground infrastructure where construction and operation of underground space usage will be developed, prototyped and launched," said Michael Kompatscher, general manager at Hagerbach Test Gallery Ltd. "This will be a model ecosystem of sustainable energy storage and delivery, above and below ground, and how it supports green energy use in future cities."

Sub Space Energy Hub is finding a way to store renewable energy, such as solar, wind power, geothermal and biogas, so that the peaks and troughs of energy generation can be smoothed out. "There will be more and more renewable energy being generated, and we need to be able to store it for off-peak times. The questions is: how do we do that," said Ross Dimmock, head of tunneling at Normet. Technologies under trial could include compressed air, creating hydrogen from water or pumped storage.

Initially the plan will be to power the Hagerbach facilities underground, from renewable energy sources that could be located above and below ground. Once that has been achieved, the next step could be to power a nearby community too. "With energy storage, the longer-term ambition would be to power the local village so that communities can come to Hagerbach and see a working system," said Dimmock. ■

Sydney Metro West gets greenlight for tunneling

The New South Wales Department of Planning and Environment announced that Sydney Metro has received the green light for tunneling between The Bays and Sydney CBD, completing plans for the 24-km (15-mile) twin tunnels from Westmead to Hunter Street in the heart of the city.

Minister for Planning and Homes Anthony Roberts said planning approval has been granted for Sydney Metro to deliver 3.5-km (2.2-mile) twin tunnels from The Bays into the CBD, under Johnstons Bay and Darling Harbor, as well as excavating Pyrmont and Hunter Street stations.

"Two major tunneling contracts have been awarded for tunneling between Westmead and The Bays." Roberts said. "Starting at The Bays, tunnel boring machines will cross under the harbor, alongside Anzac Bridge, before heading to the new Pyrmont Station, then under Darling Harbor before reaching Hunter Street Station in the Sydney CBD."

Minister for Transport, Veterans and Western Sydney David Elliott said the project is another step closer to delivering world-class transport infrastructure for the people of New South Wales.

"This is the final tunnel section for the new 24-km (15-mile) metro line on this game-changing project that will double rail capacity between Greater Parramatta and the Sydney CBD," Elliott said.

"Sydney Metro West will significantly cut crowding on three major train lines, take tens of thousands of cars off the road every day and support the creation of 10,000 direct and 70,000 indirect jobs in western Sydney."

Sydney Metro has shortlisted three consortia to deliver the third and final tunneling section between The Bays and Sydney CBD. This tunneling package is expected to be awarded in late 2022.

Future planning approvals for Sydney Metro West will consider rail infrastructure, station buildings and precincts and over and adjacent station development at various locations. These will be subject to further community and stakeholder engagement.

Construction started on Sydney Metro West in 2020, with the project on track to be completed by 2030. In 2030, Sydney will have a network of four metro lines, 46 stations and 113 km (70 miles) of new metro rail. ■

TBM launched at Jefferson Barracks project

A specialized Robbins 4.1 m (13.5 ft) diameter main-beam tunnel boring machine (TBM) launched in St. Louis, MO in the spring of 2022 to complete a critical infrastructure tunnel for contractor SAK Construction. The machine, named Mrs. Vera, is boring phase 2 of the Jefferson Barracks tunnel, a 3,050 m (10,000 ft) long tunnel in karstic limestone. Designed to detect karst and other underground features, the unique machine comes equipped with enhanced 360-degree probe drilling capabilities, as well as versatile ground-support options including McNally crown support, wire mesh, ring beam erector and roof drills.

"The overall design of the machine is a good fit for our project, not only for the mining aspect but also for the capability to run two probe drills in multiple locations around the TBM," said Brotherman Bragg, project superintendent for SAK Construction.

"The challenges I anticipate during tunneling are mostly related to ground conditions. The area that we are tunneling in has a potential for karst features. The probe drills are our lifeline and with the two probe drills on the machine, I believe that we will find out what's in front of us before we get there, giving us the ability to take care of potential problems," Bragg said.

During phase 1 of Jefferson Barracks, a rebuilt 3.35 m (11.0 ft)-diameter Robbins main-beam TBM hit challenging conditions about 2,400 m (7,900 ft) into tunneling. The machine encountered a large vertical feature along with flowing and unstable ground that required the TBM to remain in place. While various options, including ground freezing, were considered, they were ultimately deemed infeasible.

A 62 m (205 ft) deep recovery shaft and 60 m (200 ft) long adit were built to stabilize the area and remove the machine in what would be an intensive and ultimately successful undertaking. After recovery of the machine, SAK Construction turned to Robbins for a solution to bore the remaining tunnel in what would become phase 2 of the project.

SAK and Robbins agreed to do extensive in-shop testing of the new, larger TBM to ensure there would be no unnecessary delays on site. The TBM was ultimately delivered a couple months late due to Covid-19-related matters and the additional in-shop testing. SAK operational personnel and Robbins personnel were heavily involved in final assembly and testing procedures.

The customized Robbins TBM is designed to detect karst and other underground features, with enhanced 360-degree probe drilling capabilities, as well as versatile ground-support options.

After arriving in St. Louis, the TBM was swiftly assembled and launched from the recovery shaft.

"The Robbins Field Service techs have been excellent in their support, helping us assemble the machine, and troubleshoot the machine. Our challenges during the assembly and launch from the shaft were minimal — this is the fastest and most efficient assembly we've ever had on a machine. We assembled the TBM in four weeks, which was a huge hurdle," said Bragg.

"The overall design of the TBM is very functional and thus far in the early stages it seems to be mining very well," continued Bragg. "So far, I'm very pleased with the machine and with the technicians." Early indications were good, with the machine advancing 21 m (70 ft) in its first two shifts after launch.

The Jefferson Barracks project is a key component of MSD Project Clear, a massive $6 billion program undertaken by the Metropolitan St. Louis Water District to target water quality and wastewater concerns in the city and surrounding areas. The 5,400 m (17,800 ft) long, 2 m (7 ft) internal diameter Jefferson Barracks tunnel runs parallel to the Mississippi River and extends to the Lemay Wastewater Treatment Plant located at the confluence of the River des Peres and the Mississippi River. The tunnel is slated for completion in the fall of 2023. ■

Chair's column: UCA aligns with ITA

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for global stakeholders. I'm pleased to share that our working group (WG) leaders and others made strong contributions to the WG meetings, in various capacities, and brought back action items intended to continue to move the industry forward.

At each WTC, a General Assembly of the ITA Executive Council and all member nations takes place. In Copenhagen, we had some important matters to discuss and decisions to make.

Most notably, we elected new members to the executive council, received a report from the governance council (which provides oversight to the activities and management of ITA), and received a report entitled "Organizational Review and Compliance Assessment" (ORCA).

I'm very pleased that the U.S. candidate for the executive council, Sanja Zlatanic of HNTB, was one of the members elected on the first ballot. Our global colleagues recognized her credentials and desire to work on behalf of the global tunneling industry and endorsed it with her election. I look forward to coordinating and communicating our member nation business with her and her colleagues going forward and thank Randy Essex for his service as he steps down from his tenure as vice president of ITA.

The new executive council, just starting its three-year term, comes in at a watershed time for the ITA. The committee will lead the organization through a period of relatively intense change, as the ORCA has signaled that the ITA administration, with the growth experienced since inception, needs meaningful transformation. The United States/UCA endorses the recommendations of the ORCA and will support the change management process that has already begun.

The new president of ITA, Australia's Arnold Dix, is championing sustainability as a hallmark of the international industry and has already begun taking up speaking engagements globally, trying to reach as many of society's stakeholders as possible. Dix is hard at work around the globe, spreading the tunneling gospel at various industry gatherings and forums that impact our society's future with respect to construction, infrastructural investment, transportation (highways, trains and subways), and the environment.

One of his upcoming station stops will be New York City on Jan. 31, as Zlatanic has arranged for the next in-person executive council meeting to be held just before our George Fox Conference and the Moles Awards Dinner. For those of you at Fox, you will have the opportunity to meet and interact with these international industry leaders.

The UCA will continue its ongoing participation with the ITA. In addition to meeting with Executive Council members in New York, we also plan on attending the next WTC in Athens, Greece, in May 2023, and we hope that the strength of the U.S. contingent continues to maintain and grow.

Tunnel on! ■

Petra: Combined company will de-risk projects

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investment gap.

"Changing ground conditions are the biggest risk in undergrounding," said Petra chief executive officer Kim Abrams. "The world needs a more versatile tool that can de-risk undergrounding projects by boring through more geologies, especially nightmare geologies. Zilper has built trenchless products that can uniquely bore through some of the riskiest soft ground conditions on earth like flowing sands, dense clay, cobbles and water-logged ground. The Zilper machine is innovative because it dramatically reduces the risk of excavating these nightmare geologies. The proprietary Zilper technology suite has successfully completed numerous trenchless tunnels where competing technologies have failed to deliver. Together, we're building the future of trenchless tunneling."

The combined company, in an industry first, will be delivering a solution that de-risks the social, environmental and economic costs of utility undergrounding in hard and soft soils.

Zilper's trenchless technology has been used for sewage, transmission and water projects. The versatility of the Zilper method enables it to work in extremely complicated conditions. For example, on a recently completed job to clean up waterways, Zilper installed a 16-inch metal casing beneath a river while encountering flowing sands with less than five feet of cover, a feat unique to Petra capabilities.

"The combination of Petra and Zilper brings together complementary teams and technologies," said former chief executive officer of Zilper and new chief operating officer of Petra Daniel Zillante. "We've both been building methods to excavate problematic geologies in the underground industry. Combined, Zilper and Petra provide a complete undergrounding solution to construction and utility companies who need to de-risk undergrounding projects and bore through all geologies."

Petra will begin manufacturing Zilper's technologies in the United States in September 2022 for introduction to the U.S. and European markets in early 2023. ■

Emerging safety and productivity technologies for North American tunneling

The safeguarding of health and life is the number one priority for underground infrastructure projects. While culture and approach are critically important, the industry has also seen the development of innovative tools and technologies that assist in making the underground environment and working places more safe and secure, both on an everyday basis, and in the event of an unexpected occurrence.

This article explores four technologies that are finding a place in the North American tunneling industry:

- Refuge chambers.
- Proximity detection and collision avoidance.
- Gas detection and environmental monitoring.
- Automated conveyor health monitoring.

These technologies are either new or new to the North American tunneling industry. The benefits and applicability of each will be reviewed as well as identifying evolving features that improve on past capabilities or practices. Some of these technologies also deliver productivity benefits in addition to their primary safety purpose.

Introduction

Technology innovation or introduction into an industry typically takes one of three forms:

- Adaptation of benchmark technologies from other industries.
- Adaptation of technology from other geographical sectors in the same industry.
- Grassroots innovation.

In the case of the technologies explored in this article, the channels are primarily adaptational, although there is an element of building-block innovation with conveyor monitoring.

While the motivators for this technology introduction are overwhelmingly safety driven, there are also synergistic productivity benefits to the development of the technology itself. These factor into the decision-making process of the tunnel constructing entity as to when and how to deploy them. In some cases, the technology is an ingrained part of the tunneling culture in other jurisdictions while relatively new or lesser known in North America. In other cases, the technology is cutting edge, and just beginning to have its potential explored.

This article reviews the benefits and applicability of each of the four technologies presented as well as identifying evolving features that improve on past capabilities or practices.

Mike Rispin, Mike Walling, Rob Albinger and David Maust

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Refuge chambers

Refuge chambers are used worldwide in the underground mining industry. They are designed to provide a suitable safety haven as a temporary environment for a specific number of occupants and a specific timeframe when an incident has caused a hostile environment in the underground workings. Their purpose is to safeguard human life for a reasonable duration until the occupants can be safely evacuated.

Similarly, refuge chambers are deployed in tunneling projects. Drill-and-blast or sequential excavation method (SEM) projects of greater length with limited egress options will almost always include refuge chambers in their safety strategy. The presence and judicious use of refuge chambers may also benefit tunnel design and construction by reducing egress requirements.

Most mechanically driven projects over a certain diameter will have a refuge chamber incorporated into the tunnel boring machine (TBM) structure. This may also be supplemented with a refuge chamber in the tunnel behind the TBM for those projects where significant work will be taking place once the supported excavation has been created.

Rigid rescue chambers. The most commonly used type of chamber, a rigid, steel-supported structure is shown in Fig. 1.

In many sectors overseas, the refuge chambers are ingrained in the culture and specified in bid documents. In North America, the historical trend has left the use of refuge chambers up to project discretion.

The International Tunnelling Association's (ITA) Working Group 5 (WG5), whose mission is "Health and Safety in Works" published in 2018 the revised "Guidelines for the Provision of Refuge Chambers in Tunnels Under Construction." This is a comprehensive guideline that the authors have used as an indispensable

FIG. 1

Rigid, steel refuge chamber.

reference in designing refuge chambers. In a nutshell, the key factors to consider as represented in Fig. 2 are:

- 24-hour duration requirements.
- Space, volume and seating requirements.
- A manual or automated positive-pressure system.
- Lighting, noise level, signal and electrical requirements.

FIG. 2

Refuge chamber features per ITA guidelines.

- Extended-life CO_2 components, remote monitoring systems (temperature, humidity, power, external air supply, voice communication and maintenance reminders).

Inflatable refuge chambers. Inflatable, air-powered refuge chambers designed specifically for the U.S. underground coal mining industry occupy a high share of the market. They are designed to be mobile, for placement relocation, with a low profile, are easily handled compared to rigid refuge chambers and are easily deployed in a matter of minutes when circumstances dictate. Figure 3 shows them in predeployment and deployed modes.

While relatively unknown to North American tunnelers, the features and benefits of this technology, custom-designed to ITA requirements and to specific project capacity needs, can make them an economical and attractive option for project builders to safeguard the workforce. Inflatable chambers with capacities up to 48 residents have been designed (4.7 m (15.5 ft) long × 2.1 m (6.8 ft) wide × 1.15 m (3.8 ft) high prior to deployment and 18.6 m (61 ft) long × 3.6 m (12 ft) wide × 121 cm (48 in.) high deployed). A typical inflatable chamber for 18 people has a representative dimension of 4.1 m (13.5 ft) long × 1.5 m (4.9 ft) wide × 0.9 m (2.9 ft) high, prior to deployment and 9.6 m (31.7 ft) long × 3.6 m (12 ft) wide × 122 cm (48 in.) high deployed).

Proximity detection and collision avoidance

Equipment-to-personnel and equipment-to-equipment collisions are real risks in underground work environments. Confined quarters, reduced visibility, less-than-ideal sightlines, noise, driver distraction and complacency may all be factors that contribute to collisions and pose injury or loss-of-life scenarios.

Proximity detection and collision avoidance (PD/CA) systems take portions of control away from humans in a manner similar to today's systems in state-of-the-art automobiles and provide measures that contribute to incident avoidance or mitigation. As a result, these systems are accepted and ingrained in many tunneling markets just as they are in mining. Per the authors' experience, they are newer to the North American tunneling industry and have been left to project discretion, as opposed to making up part of the bid documents as they do elsewhere.

PD/CA systems either come as part of the package from original equipment manufacturers (OEM) or are system add-ons. Representative types include:

- Camera.
- Radar.
- Lidar.
- Electromagnetic.

Each have their strengths and drawbacks, and the authors have chosen to focus on electromagnetic systems, believing that they offer the greatest benefits from a safety perspective.

Electromagnetic PD/CA. Electromagnetic systems are typically OEM agnostic and can be easily deployed across a contractor's entire fleet of equipment, including surface gear (such as cranes) and conveyor belts and other fixed equipment. They offer secure 360° stable field coverage (including the capability of custom-programming "hazard" and "critical" zones) and are typically unaffected by visibility and penetrate almost any material, allowing them to "see" around corners

and obstacles. This is particularly beneficial in complex workings such as caverns or SEM excavations.

Some electromagnetic systems also offer an attractive feature: the ability to automatically slow or stop a piece of equipment to avoid an incident without relying on human response times. Electromagnetic PD/CA has the unique capability of differentiating between pedestrians and other machinery and allows the operator to have awareness of which hazard is nearby in real time.

Safe working conditions promote productivity. Stable PD/CA systems help to mitigate the workforce learning curve and dramatically reduce nuisance alarms, which have proven to be a downfall of earlier PD/CA types whereby personnel began to ignore the warnings in a "boy who cried wolf" manner.

A representative electromagnetic system is shown in Fig. 4.

Gas detection and environmental monitoring

The need to monitor one's environment underground and detect gases is certainly not new to North American tunneling. This has existed for a long time as a requirement with demand varying from project-to-project.

Today, however, with the progression of digitalization and the development of new technologies, new approaches can be taken to calibrating equipment,

FIG. 3

Inflatable refuge chamber.

FIG. 4

Electromagnetic PD/CA components and functionality.

FIG. 5
Wired and wireless gas monitoring systems.

collect data, manage data and pursue downstream automation in the form of such benefits as ventilation-on-demand.

Both fixed/wired and battery-powered wireless sensor technology is now available (see Fig. 5) that gives users the capability to monitor multiple atmospheric variables as well as up to 64 types of gases. E-module sensor technology now permits easy changing and reprogramming of detection units, as well as an attractive feature of being able to quickly exchange sensors for calibration at the surface. This negates the need to bring calibration gas samples underground, a tedious process for those responsible for the monitoring system.

Today's sensors are facilitated by two-way communication allowing remote control and command, permitting on/off toggling, threshold manipulation and alarm activation/deactivation. Data from the sensors is transmitted to a site server. From that server, corresponding manipulation of underground ventilation may be automatically controlled as a function of varying numbers of personnel or equipment underground or other programmable factors.

The wireless sensor technology enables versatile functionality, such as emplacement on project multiservice vehicles (MSV), so that monitoring is managed along the length of the tunnel rather than simply at fixed points.

Progress with gas detection and environmental monitoring technology gives tunnel builders new tools and approaches to meet the specification demand, to safeguard the workforce, to respond to events and to benefit from the data generated to potentially operate more efficiently.

Conveyor health monitoring

In North American tunneling, conveyor health monitoring has largely fallen under the purview of the "walking boss," an individual with potentially many more pressing duties who is charged with visually and auditorily checking the conveyor belt over the course of a shift, looking for potential problem areas. Conveyor downtime means excavation downtime — an expensive proposition. The task is even more challenging if extraneous noise, diminished lighting or an elevated belt installation is involved.

A new technology is emerging from the mining industry that permits high-tech monitoring of a conveyor system's rollers on a continuous, real-time basis using a single fiber-optic cable retrofitted along the length of the system. This technology was introduced at the Underground Construction Association (UCA) Cutting Edge Conference in November 2021 and has been adapted for application to tunneling based on interest demonstrated by industry leaders.

In this system, the fiber-optic cable detects acoustic changes along the conveyor and categorizes them into known parameters. Data is transmitted to and processed in the cloud with certain thresholds programmed to preemptively alert operators. Operational conveyor system aberrations, such as broken balls or cracked cages in a ball race, worn idler bearings or imminent bearing seizures are identified and thus the operator can prioritize roller replacements during planned maintenance shutdowns rather than due to an emergency breakdown event. This is accomplished with technology in a way that no human can match. In addition to avoiding downtime, the risk of heat generation from bearing or roller failure that may lead to a fire can be avoided. In this case, problems are avoided rather than cured. This technology is in its infancy in tunneling.

Conclusion

Culture and attitude are critically important to safety success. At the same time, technology, training and reinforcement are also important.

Technology evolves … just think where the tunneling industry was safety-wise a century, a half-century or even a decade ago. Now tunnelers can be kept safe for a prescribed period in a hostile atmosphere underground. Avoidance of collisions is no longer solely reliant on human ability, and conveyors can be monitored far more effectively. Gas sensors can also be calibrated on surface.

The technology discussed in this article shows that the continuum moves onward, and that safety and productivity can be intertwined. ■

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Design and construction challenges for the Ellicott City North Tunnel

The major flash floods of 2016 and 2018 inundated the downtown area of Ellicott City, a historic district in Howard County, MD, situated in the hills above the Patapsco River. These catastrophic floods resulted in significant property damage and, tragically, loss of life. Approximately 231 m^3/s (8,170 cu ft/s (2016) and 335 m^3/s (11,860 cu ft/s) (2018) surged through Main Street in Ellicott City, causing millions of dollars in property damage and the tragic loss of life (Doheny and Nealen, 2021). As of October 2021, the county has developed and is implementing a collective flood mitigation plan, known as the Safe and Sound Plan, with nine unique projects, two of which are under construction and four more are in various stages of design. The selected plan option, which includes the North Tunnel, will reduce the anticipated flood level from a 100-year event along lower Main Street from approximately several feet to less than 0.3 m (1 ft).

One major component of this Safe and Sound Plan is the Ellicott City North Tunnel, a stormwater conveyance tunnel that will capture stormwater flows from the upland watershed to be diverted directly to the Patapsco River east and downstream of Ellicott City. The proposed tunnel will be ~1,770 m (5,800 ft) long, with a minimum internal diameter of 4.5 m (15 ft). It is currently envisioned that the tunnel will slope between 0.1 percent and 0.5 percent from the inflow drop shaft adjacent to Frederick Road to the eastern outfall structure at Lot B. An intermediate diversion structure with a drop shaft is anticipated at Lot F, approximately 1,220 m (4,000 ft) along the alignment. The final design is anticipated to be complete by Q4 2022. Construction is anticipated to begin in 2023. This article describes the proposed tunnel and stormwater capture system. In addition, the major challenges are identified, and proposed solutions are explored.

The left side of Fig. 1 illustrates the proposed tunnel alignment starting at the mining site on the 8800 block of Frederick Road, running roughly parallel to Frederick Road to the Lot F site at Ellicott Mills Drive, and finally to the outfall site at the Patapsco River. The right side of Fig. 1 depicts the flood mitigation anticipated for the Ellicott City North Tunnel as determined by a hydrologic modeling study conducted as part of the Safe and Sound Plan evaluation.

Project background

Ellicott Mills was founded in 1772 by the Ellicott Brothers, Quakers who ultimately settled in a fertile river valley along the Patapsco River, not far from ports in Baltimore and farms to the west. The Ellicott Brothers eventually came to operate a number of mills along the river, generally between what is now known as Ellicott City and Elkridge, to the south. Ellicott City is a vibrant and rich historic district, with structures dating back to the 1700s. However, the same qualities that appealed to the Ellicott Brothers some 250 years ago — the location at the bottom of a river valley surrounded by steep terrain — present challenges today.

Throughout its history, Main Street and the Ellicott City Historic District have seen at least 15 significant flood events dating back to the 1700s. One noted flood in the 1800s destroyed much of what was originally Ellicott Mills, and spawned construction of most of the district as it is known today. Over the last 10 years, three flood events have affected Ellicott City. Most recently, the community has seen two major flash floods within the last five years. The most recent flash-flood events have been referred to as "top-down" flood events, in which stormwater ran from adjacent topography through the Main Street area. Top-down flooding has occurred in Ellicott City throughout history. These flood events cause significant damage, as the flood waters travel at a high velocity, collecting anything in their path. Storms in 2011, 2016 and 2018 resulted in significant damage to infrastructure and buildings. Although structures have since been repaired or replaced, what cannot be replaced are the lives lost in both the 2016 and 2018 storms.

Upon taking office in late 2018, county executive Calvin Ball announced the Ellicott City Safe and Sound Plan, a major improvement project benefitting the county, which consists of multiple facets, including flood mitigation. Prior efforts were re-evaluated, with a renewed focus on preservation and public safety. In May 2019, the county executive announced that he had selected to proceed with Option 3G7.0, a series of nine projects that collectively seek to mitigate the potential for future top-

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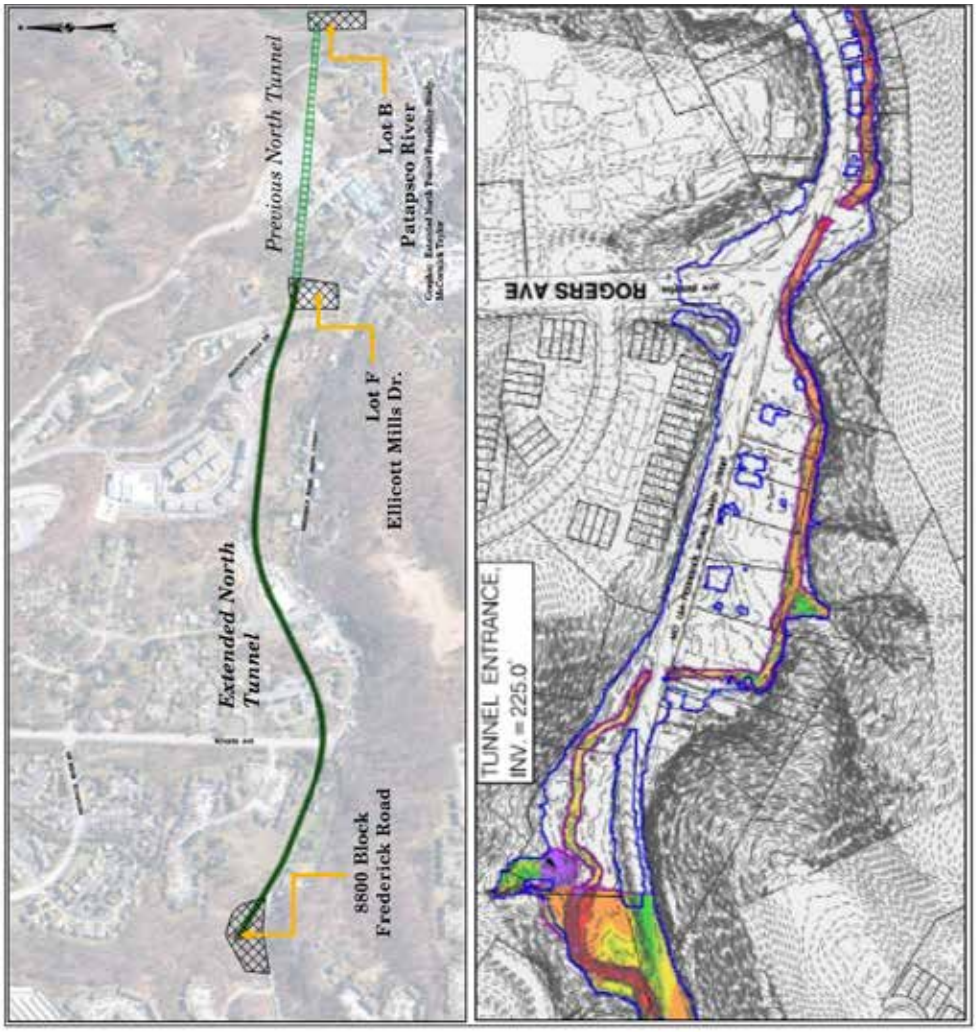
FIG. 1

Preliminary Ellicott City North Tunnel alignment (left) and Flood Mitigation Model (right) (Mahan Rykiel et al., 2020).



down flash-flooding events.

Most notably, the plan includes the preservation of six buildings originally slated to be demolished, as well as inclusion of the North Tunnel, intended to divert flood waters from the western end of Main Street directly to the Patapsco River. To ensure the plan would meet its intended goals, the county solicited a peer review of the proposed flood mitigation strategies by the U.S. Army Corps of Engineers (USACE). Upon conclusion of their peer review, USACE noted "Overall, the team determined that the county followed a comprehensive process, that the flood risk management (FRM) measures being considered by the county are similar to those utilized during USACE FRM projects, and that the current County-selected alternative can significantly reduce flood risk to downtown Ellicott City" (USACE, 2019).

Since the inception of Option 3G7.0, the county has revised and extended the original proposed North Tunnel project to eliminate two smaller projects and improve the efficacy of the plan. Most notably, the extension of the tunnel precludes the need for demolition or partial demolition of nine residential structures throughout Ellicott City's West End, which constitute important contributions to the character of the historic district. When completed, the plan should reduce water levels and velocities seen during the 2016 and 2018 storms along Lower Main Street to levels where nonstructural floodproofing of buildings would be effective.

Generally, the flood mitigation projects work as a system to collectively mitigate flash flooding, incorporating both stormwater retention facilities and conveyance system improvements. In order to be most effectively implemented, significant constrictions in the conveyance system need to be alleviated. The Maryland Avenue Culvert project, one of the nine aforementioned components of the Safe and Sound Plan, will provide significant additional stormwater conveyance from the Tiber/Hudson Branch to the Patapsco River while

mitigating a significant constriction to water flow. The North Tunnel functions similarly; however, it captures its flow much further upstream. The plan is being primarily developed from the Ellicott City Hydrology/Hydraulic Study and Concept Mitigation Analysis (McCormick Taylor, 2017).

Finally, in conjunction with the flood mitigation projects, the county developed a master plan for Ellicott City and the surrounding watershed: the Ellicott City Watershed Master Plan (Mahan Rykiel et al., 2020). Aside from prescribing policies and implementing actions associated with the flood mitigation plans, the master plan addresses a number of other needs in the watershed, including transportation. This plan was adopted by the County Council in January 2021.

As of November 2022, one project is substantially complete and one is nearing completion (Q1, 2023). Two others are in the late stages of design while design of a third is fully funded. The county received a Water Infrastructure Financing and Innovation Act (WIFIA) loan from the U.S. Environmental Protection Agency (EPA) to support remaining construction, including the North Tunnel Project.

Geological setting

Ellicott City is within the Piedmont Physiographic Province on the eastern edge of Howard County along the border of Baltimore County. The eastern Piedmont is generally characterized by relatively low, rolling topography, with major streams incised into narrow, steep-sided valleys (Reger and Cleaves, 2008). Thin soil deposits are underlain by igneous and metamorphic rock. The Howard/Baltimore County line is delineated by the Patapsco River, which locally runs south. The city and the project extents are underlain by the Ellicott City Granite of the Silurian Period. Ellicott City Granite is typically characterized as a uniform, medium- to coarse-grained, weakly foliated to massive granite (Edwards, 1993). Inclusions of fine-grained gneiss are common and elongated in the plane of foliation (Crowley and Reinhardt, 1980). The granite body in Ellicott City generally strikes northwest–southeast, discordant to the general strike in the Piedmont region. The granite is an intrusive igneous formation that contacts the Wissahickon schist and Baltimore Gabbro Complex. A characteristic outcrop of the Ellicott City Granite is depicted in Fig. 2, near the proposed tunnel outfall location.

A phased geotechnical investigation was conducted from 2020 to 2022 and consisted of 29 soil borings and rock cores ranging from 28 to 87 m (92 to 284 ft) below ground surface (bgs). The investigation identified top-of-rock depths ranging from 1.5 to 46 m (5.0 to 150 ft) bgs. The granite bedrock is typically hard to very hard, slightly weathered to fresh, with very close to wide fracture spacing. A transition zone of highly to completely weathered rock was identified at the contact between soil and bedrock. Dip angles range from 5 to 85° with a minimum of six joint sets.

FIG. 2

Photograph of rock outcrop near eastern outfall.

These include a subhorizontal set and five steeper sets dipping between 30 and 85deg. Rock mass classes (RMC) along the tunnel alignment vary from Class I to Class IV with corresponding descriptions of Intact to Moderately Joint, Moderately Jointed, and Blocky & Seamy (both III & IV) with various degrees of weathering and discontinuity condition. 2022a).

The soil overlying the granite bedrock typically consists of silty sands and sandy silts with some clays and gravels. Typical standard penetration test (SPT) N values range from 7 to 45 blows per ft with some values exceeding 50 blows over 15 cm (6 in.) close to top of rock. Additional test pits and UAV-based photogrammetry has been completed to further characterize the ground conditions.

Design challenges

Ground support. As the tunnel approaches the Lot F site, it will be advanced through decomposed to intensely weathered granite. Localized overbreak is expected where intensely to slightly weathered, blocky and seamy to moderately jointed rock is present in the crown and sidewalls. Ground support will be required to address the poor ground conditions at the turn under. Supplementary initial support consisting of spiles will be required for some tunnel reaches.

Tunneling method selection. The preliminary design discussions eliminated drill and blast excavation methods, mainly because of concerns with vibrations of historic structures along the project alignment and excessive noise causing disturbance to the community. A hard-rock tunnel boring machine (TBM) has been selected as the preferred excavation method. TBM specifications will be developed as part of the final design process, but a main-beam TBM with an open gripper is likely the preferred option.

The small outfall site will likely require the TBM to be retrieved through the tunnel back to the mining shaft — a more difficult undertaking than breaking through the end station. Additional complications will arise if steel ribs are required for support along the alignment.

Railroad crossing/outfall. The outfall of the tunnel will cross under a single-track CSX railroad line that runs parallel to the Patapsco River. The tracks are bedded in 15-cm (6-in.) compacted subbase overlying the Ellicott City granite. A staged construction approach will allow for the construction of a load transfer slab between the tracks and the tunnel prior to excavation. This will allow installation of vertical rock dowels and a reinforced concrete slab. After the load transfer slab is in place, the TBM will mine under the tracks with just 8 inches of natural cover remaining below the slab. This will allow for TBM excavation of the entire tunnel alignment without the need for alternative excavation methods at the outfall or TBM extraction from a blind heading while mitigating the risk of adverse impacts to the CSX tracks.

Historic considerations. As part of the regulatory approval processes for the Section 404 permit, the proposed project constituted an "undertaking" subject to review by the U.S. Army Corps of Engineers under Section 106 of the National Historic Preservation Act (NHPA). The undertaking included substantial review and consideration of the impacts not only of the proposed project, but of the Safe and Sound Plan as a whole. Ultimately, while it was determined that the project is necessary and the plan is sound, the plan will have an adverse impact on the historic resource. To limit the adverse impact of the project, the county and its consultant teams extended the length of the tunnel, in the process eliminating several proposed structure removals, as well as changed the originally anticipated drill-and-blast method of construction to a proposed tunnel-boring-machine method of construction. Immediately adjacent to or atop the proposed alignments are numerous historic and architecturally significant structures. While the tunnel itself is envisioned as a deep bedrock tunnel, thus limiting the potential damage to these structures, evaluation and consideration of the risks of damage are critical. During preliminary design, a preliminary construction impact assessment report (McMillen Jacobs, 2022b) was prepared, and an initial review of structures in the area of the proposed alignment was undertaken. Ultimately, through the Section 106 process, the project was found to mitigate adverse effects. The final Section 106 Programmatic Agreement includes stipulations for monitoring and other actions that must be implemented through design and, ultimately, construction.

Construction challenges

Site access. Site access restrictions will be a significant construction challenge at all three of the near-surface structures. One option for the inlet structure and drop shaft site is approximately 2 acres on undeveloped county property adjacent to homeowners-association (HOA) and historic properties. The site will span a small creek; special considerations for erosion and sediment control will be required to protect the creek from construction runoff. The site will need to accommodate truck loading areas, staging areas, a 17 ft ID drop shaft, a 40 ft ID mining shaft, ventilation/cooling/electrical equipment, deaeration equipment, a crawler crane, a TBM maintenance shop, rail assembly area and muck piles.

The Lot F site is approximately 2.4 acres on developed county property adjacent to commercial and historic properties. The site will need to accommodate dump truck loading areas, an office trailer, a muck pile, deaeration equipment, generator/compressor/ventilation equipment, and a 25 ft × 25 ft (inner) square drop shaft and 30 ft × 20 ft (inner) diversion structure.

The available work area for the outlet structure is tightly constrained by the Patapsco River to the east and the CSX rail line to the west. The contractor's means and methods should consider the difficult access, limited staging area and steep haul roads. The construction area will also need to be isolated from the river because of elevated water surface elevations in the Patapsco River due to seasonal precipitation events and its position within the 100 year floodplain of the Patapsco River. This will require a coffer dam or other separation structure.

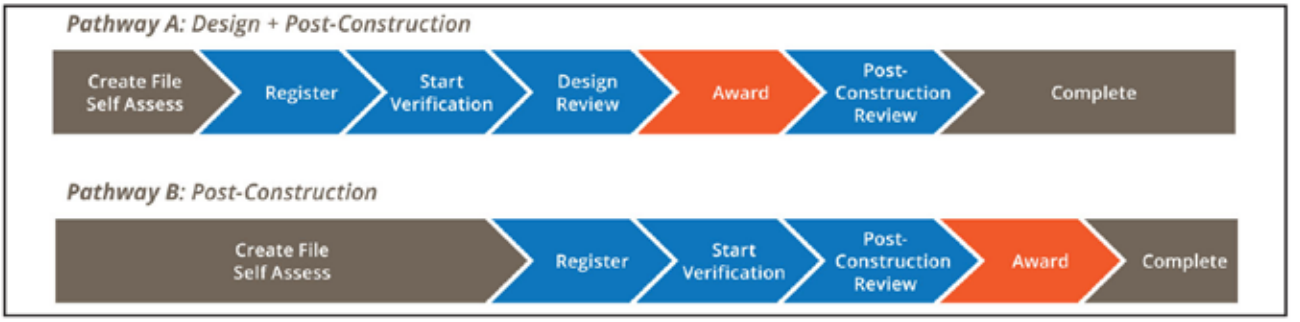
Impacts to Historic Ellicott City. The potential for construction traffic and other related impacts to the Historic Ellicott City represents a significant construction challenge. Generally, the launch and outlet sites are accessed by a single two-lane roadway (Frederick Road/ Main Street), which is designated as an arterial collector and has approximately 15,000 daily vehicular trips. While not a significant distance away, Baltimore National Pike/U.S. Highway 40 has the capacity to carry additional vehicular traffic, and maintaining vehicular flow through the historic district is important to its viability. With the potential of 75 or more trips of muck removal a day, planning the haul routes to limit impact to businesses that have not only been impacted by two floods but also a pandemic represents a key consideration.

Other considerations. The proximity of the Intake Structure to the Hudson Branch presents a risk of inundation during construction. Weather monitoring and evacuation protocols will need to be developed to address this project risk.

Drill and blast operations will likely be required to excavate the drop shafts at the mining site and Lot F. Vibration, noise and air overpressure will need to be considered during the blast design process to prevent community disturbances. The round thickness, drill pattern and explosive load will be adjusted to keep vibrations and noise below acceptable levels.

FIG. 3

Envision verification pathways (ISI, 2020).



Tunnel hydraulics have been thoroughly evaluated during the design process. This evaluation included watershed hydrologic and hydraulic modeling, alternative development and evaluation, hydraulic transient modeling, and the construction and use of two physical models.

Sustainability

Envision framework. The Institute for Sustainable Infrastructure's (ISI) Envision framework will be used to guide and quantify sustainable aspects of the project's design, proposed construction and operation. Developed by ISI, an organization founded by the American Public Works Association (APWA), American Society of Civil Engineers (ASCE) and American Council of Engineering Companies (ACEC) in collaboration with the Harvard University Graduate School of Design, Envision is a comprehensive tool to help deliver infrastructure projects that address climate change, public health and safety, environmental justice and economic recovery. It is similar to LEED certification for building projects.

The Envision framework is divided into five categories, 14 subcategories and 64 credits. The five categories (Leadership, Quality of Life, Resource Allocation, Climate & Resilience, and Natural World) are structured to guide project teams to have a positive impact on community sustainability. Infrastructure projects are evaluated for applicability and level of achievement in each of the 64 credits. Additional points are available for innovation in each of the five categories. A project's score is the percentage based on the total points awarded and the total applicable points. Award levels (Verified, Silver, Gold and Platinum) are defined at 20 percent, 30 percent, 40 percent and 50 percent achievement.

Verification pathway. The project will use Envision's Verification Pathway A, which includes an iterative review process after 95 percent design completion. A graphic illustrating the two Envision verification pathways is provided in Fig. 3. Any award level granted to the project will require a post-construction audit to maintain the award.

Predesign checklist and anticipated award. Prior to schematic design, a predesign checklist was completed to identify key credits and required supporting documentation. The checklist was also used to predict the anticipated Envision award level for the project using many assumptions regarding applicability and level of achievement for individual credits based on preliminary design documents. The anticipated score for the Ellicott City North Tunnel is 32 percent with 245 total awarded points out of 764 total applicable points (1,000 maximum applicable points). If this score is achieved during the design review and maintained after the post-construction review, the project will be awarded the Envision Silver Award.

This award level is a realistic and beneficial goal that has recently been achieved by another project in Howard County, MD. The Biosolid Processing Facility Improvements Project at the Little Patuxent Water Reclamation Plant earned an Envision Silver award in September 2021 after a nine-year design and construction process (ISI, 2021).

Key credits. Several key credits were identified during the predesign checklist exercise. Design and construction decisions will be made with consideration of the sustainability impact of those decisions and consequently the level of achievement for related Envision credits. Selected key credits are summarized below (ISI, 2018).

QL 3.2 Preserve historic and cultural resources. This credit is intended to preserve or restore significant historic and cultural sites and related resources. A maximum of 18 points will be awarded if (1) the project team works with the community and required regulatory and resource agencies to identify historic and cultural resources, (2) the project team develops strategies to document, protect or enhance historic and cultural resources to the project, (3) the identification of historic/cultural resources extends beyond registries to identify important parts of the community culture, (4) the project team works with stakeholders to develop a sensitive design and approach, (5) the project avoids all historic/cultural resources or fully preserves/protects their character-defining features, and (6) the project enhances or restores threatened or degraded historic/cultural resources in the community,

or adds a resource to a protected registry. The predesign checklist assumes that the project will score 7 out of 18 possible points for this credit.

LD 1.4 Pursue byproduct synergies. This credit is intended to critically reconsider whether traditional waste streams can be beneficially reused. A maximum of 18 points will be awarded if (1) the project team assesses the availability of either internal or external excess resources or capacity, (2) the project team identifies opportunities for byproduct synergies or reuse, (3) the project team actively pursues a byproduct synergy or reuse, (4) the project includes a long-term regularly recurring byproduct synergy/reuse throughout project operations, and (5) the project is part of a circular economy whereby the majority of operational byproducts are beneficially repurposed or the majority of operational resources consumed are beneficially repurposed. The predesign checklist assumes that the project will score 12 out of 18 possible points.

RA 1.4 Reduce construction waste. This credit is intended to divert construction and demolition waste streams from disposal to recycling and reuse. A maximum of 16 points will be awarded if (1) the project team develops a comprehensive waste management plan to decrease project waste and divert waste from landfills during construction, and (2) during construction at least 95 percent of waste materials are recycled, reused and/or salvaged. The predesign checklist assumes that the project will divert 75 percent of construction waste and score 10 out of 16 possible points for this credit.

NW 2.4 Protect surface and groundwater quality. This credit is intended to preserve water resources by preventing pollutants from contaminating surface water and groundwater as well as monitoring impacts during construction and operations. A maximum of 20 points will be awarded if (1) the project team determines the potential for surface water and/or groundwater contamination during construction and operations, (2) the project includes spill and leak prevention and response plans and avoids creating new pathways for contamination during construction and operations, (3) the project reduces the risk of quality degradation to surface water and/or groundwater, (4) the project incorporates adequate and responsive surface water and/or groundwater quality monitoring and reporting systems, (5) the project actively eliminates at least one source of hazardous and/or potentially polluting substances, and (6) the project improves surface water and/or groundwater quality. The predesign checklist assumes that the project will score 9 out of 20 possible points for this credit.

CR 1.1 Reduce net embodied carbon. This credit is intended to reduce the impacts of material extraction, refinement/manufacture, and transport over the project life. A maximum of 20 points will be awarded if (1) the project team determines materials that are the primary contributors to embodied carbon for the project during construction and operation, (2) the project team calculates the primary contributors to overall embodied carbon, and (3) the project team demonstrates at least a 50 percent reduction in total embodied carbon of materials over the life of the project compared to the baseline. The predesign checklist assumes that the project will demonstrate a 5 percent embodied carbon reduction and score 5 out of 20 possible points for this credit.

Conclusions

The Ellicott City North Tunnel will significantly mitigate the frequency and severity of flooding in the Historic Ellicott City. The project is not without challenges in design and construction, but the project team is well equipped to overcome them. The Envision framework for sustainable infrastructure will provide a consistent and forward-thinking basis of design for the technical and socioeconomic aspects of the project. ■

Acknowledgments

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Development of the ITA BIM in Tunneling — Guideline for bored tunnels

Building Information Modelling (BIM) is becoming an increasingly important aspect of tunnel projects worldwide. Due to the rapid development of new technology, software, data management tools, and data management concepts, BIM has the capacity to fundamentally change how tunnels, or more generally, underground infrastructure, is designed, built and maintained. While the rapid development of BIM within the past decade has certainly led to improvement in tunneling projects, it has also led to a certain degree of ambiguity concerning the core concepts behind BIM and its implementation. This ambiguity can be further exacerbated by the differences in goals of BIM implementation between project partners, i.e., between owners, engineers and contractors within a tunnelling project.

To address these issues, the International Tunnelling Association (ITA) Working Group (WG) 22 has developed a guideline for the implementation of BIM within a bored tunnel project, which was officially published at the World Tunnel Congress (WTC) in Copenhagen this year, and is now available on the WG 22 website for download at https://about.ita-aites.org/publications/wg-publications/content/208-working-group-22-information-modelling-in-tunnelling.

This guideline intends to support the tunnelling industry by presenting international 'best practice' solutions for owners, engineers, and contractors. Rather than competing with existing owner's BIM guidelines, the ITA guideline is intended to provide a reference framework for the implementation of BIM for tunnel projects for which there are no pre-existing standards. The guideline provides recommendations for selected important elements to be included in a project BIM execution plan (BEP) or similar contractual documents in which an owner's BIM requirements are set forth.

Because BIM is such a broad topic, the ITA guideline is specifically focused on the implementation of BIM for the heavy civil works of segmentally lined bored tunnels. Additional structures, such as stations, and additional disciplines, such as systems, are not directly covered by the guideline, as these are assumed to be addressed via general civil/MEP standards. Nonetheless, it is the intent of WG 22 to develop further specific guidelines for different tunnel methodologies (e.g., mined tunnelling) and to include non-tunnel components (e.g., cross passages) into future editions of the guideline.

Building information modelling

The ITA WG 22 has adopted the following definition for BIM: **Building Information Modelling (BIM)** is a process that involves the generation and management of project and asset information using digital representations of physical and functional characteristics of structures and facilities over their entire life cycle. This process is supported by various digital tools and software as well as by contractual information management agreements. In current practical usage, BIM is often used as an umbrella term to describe the use of any number of digital tools, such as, but not limited to, 3D modelling, computational design, visualization, clash detection, 4D/5D modelling and information management used to improve project delivery, asset management, and collaboration.

While the ITA WG 22 does not purport to have the authority to provide a definitive definition of BIM, the above definition has been developed to address two common issues. First, in describing BIM as a process, rather than as a single software, program, model, or data structure, the definition provides a technically accurate description of BIM. In contrast, the final portion of the definition addresses the reality of the usage of the term 'BIM' in the tunneling industry. While experienced BIM professionals may consider BIM to be primarily an information management process supported by tools such as 3D modelling, less experienced BIM users tend to refer to the 3D models or 3D modelling tools themselves as BIM. The definition above aims to reconcile this divergence in perception.

To differentiate between BIM as a process and the various models used when implementing BIM for a project, the following definition will be employed in this article: Building information models (BIMs) are digital files or models that store information regarding a built asset.

When fully implemented, BIM involves the creation of a central storage location for all digital information of the project/asset during its lifecycle, from design to operation and maintenance. This information is stored within a

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multitude of BIMs that accurately capture the desired project/asset information at each project phase. The BIMs together with the information management/storage system with which they are connected make up the "digital assets" of a project.

Guidelines for bored tunnels

The guideline addresses the following core concepts that are necessary for BIM to be successfully implemented in a project:

- Assets
- BIM use cases
- The information management process and responsibilities
- Model interoperability and data environment
- Level of definition
- Classification systems
- Exchange data formats
- Ground modelling
- Sustainability

Finally, the ITA guideline provides a list of endorsed BIM documents, such as the DAUB BIM guidelines [DAUB, 2019; DAUB, 2020] or the ISO 19650 series [ISO, 2018(1); ISO 2018(2)], as well as providing a list of reference projects, and a list of otherwise relevant standards to provide a set of reference documents for further education.

The following sections provide a more detailed description of the contents of the sections discussed above:

Assets. The ITA guideline is focused primarily on the project delivery phase of a tunnel project. Owners, however, often desire that the digital assets developed during a project be used for asset management purposes after handover. The ITA guideline therefore provides a short introduction to BIM for asset management. This introduction covers the differing terminology involved when discussing asset management, i.e., project information models (PIMs) and asset information models (AIMs) and describes important aspects to consider when transferring information between a PIM and an AIM. In addition, the guideline provides a reference to ISO 55000, which specifically covers the primary aspects of asset management.

BIM use Cases. Before BIM can be used on a project, the goal of its application (e.g., BIM for spaceproofing, for cost calculation, for construction scheduling, etc.) should be clearly defined and outlined. These goals are referred to as BIM Use Cases in the ITA Guideline. It should be noted, however, that other terminology, e.g., Use Cases, as employed by buildingSMART [buildingSMART, 2020], is often used to refer to the same concept.

BIM Use Cases are the tasks or processes for which BIMs are used. In order to give each project participant the information they need, it is vital to know in which way various BIMs are engaged and how they are interrelated. A BIM Use will determine the necessary software or information storage environment required to develop a BIM and at which project stage the BIM information must be provided. Within the ITA BIM guideline, the determination of BIM Use Cases before design is strongly encouraged.

To aid the determination of BIM Use Cases, the WG22 has developed a summary of common examples. The BIM Use Cases provided by the WG22 are largely based on the existing literature, with several cases being adapted from the DAUB [DAUB, 2019] and buildingSMART [buildingSMART, 2020]. To provide more transparency for the project participants, the examples provided by the WG 22 have been sorted by applicability to different project stages. An excerpt of the BIM Use Cases is provided in Fig. 1.

It should be noted that the ITA BIM Use table is necessarily non-exhaustive. BIM Use Cases vary with the project needs. In addition, the continuous development of BIM software leads to the continuous expansion of potential BIM Use Cases within a project.

Information management process and responsibilities. A clear information management framework is required to successfully adopt, integrate, and apply BIM processes within a project. Such a framework must regulate and define the workflow which governs the process of creation, modification and verification of digital project information within a project. In doing so, it should be determined which project participant (i.e. client, engineer, contractor, etc.) is responsible for which task (e.g., creation, modification or verification of information) at each stage of a project or asset's life cycle. Once such a framework is developed, it is further recommended to adopt a contractual agreement between participants that codifies the information management process. This agreement can, for example, be made in the form of a BEP.

The ISO 19650 series [ISO, 2018(1); ISO, 2018(2)] provides a standard framework for information management of built assets using information modelling processes applicable throughout the asset life cycle. As the ISO 19650 series is already frequently adopted by the tunneling industry, the ITA WG 22 has chosen to endorse the adoption of the ISO 19650 series, rather than developing an independent guideline. To support this process, the ITA WG 22 has developed a companion document to the ITA BIM guideline regarding the adoption of the ISO 19650 series. This companion document is titled "ITA-AITES Recommendations for the Application of ISO 19650 Series during the Delivery of Underground Projects and Assets – Information Management Process and Responsibility Matrix." These ITA recommendations are intended to provide a guideline for the adoption of the ISO principles in the underground construction industry. The ITA recommendations for the application of ISO 19650 Series will be officially published

FIG. 1

Excerpt of BIM use list as provided in the ITA WG 22 document "BIM in Tunneling — Guideline for Bored Tunnels."

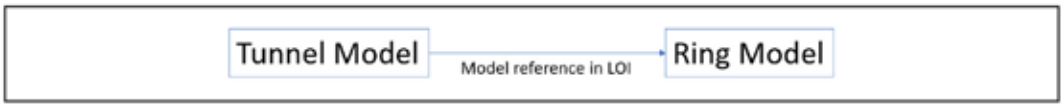
USE CASE	DESCRIPTION	Source	STRATEGIC DEFINITION	PREPARATION & BRIEFING	CONCEPT/PRELIM DESIGN	BASELINE/REF DESIGN	DETAILED/ CONTRACTOR DESIGN				CONSTRUCTION	COMMISSIONING & HANDOVER	USE/OPERATION
							30%	60%	90%	100%			
Design variants investigation	Variant investigation based on 3D models of the existing condition including conflict analysis	DAUB	X	X	X	X	X						
Visualisation (public relations work)	Visualisation of the design including existing buildings and infrastructure	DAUB		X	X	X	X	X	X	X	X	X	X
Cost estimation and cost calculation	Model-based and structured quantity determination; Linking of the 3D model with cost data	DAUB		X	X	X	X	X	X	X	X		
BIM/structural/FE model co-ordination	Co-ordination of domain-specific sub-models by combining models in coordination software for detecting interferences	IFC		X	X	X	X	X	X	X	X		
Sustainability	Incorporation of sustainability parameters in the BIM model with the target to support quantifications 'for EG, carbon content' and provide data for variant investigation	WG22		X	X	X	X	X	X	X	X		
3D ground modelling	Provision of all geotechnically relevant data over the entire course of the project; Use of the data as input quantities for further use cases; Constant updating of the model as knowledge is gained	DAUB			X	X	X	X	X	X	X		
GIS	Integration of GIS data into the BIM environment to improve design co-ordination and clash analysis	WG22			X	X	X	X	X	X	X		
Change management	Handling of deviations identified in construction progress controls ... as well as changes during the design process	DAUB			X	X	X	X	X	X	X		
Geological documentation	Assessment of geotechnical risk along tunnel route	IFC			X	X	X	X	X	X	X		
Spaceproofing	Interface document / agreement between disciplines to determine the space requirements for each individual design component - classified as design basis	WG22				X	X	To be replaced with design development					
Bill of quantities, tendering, award	Use of the 3D models produced in the preliminary design phase and updated for the process of tendering the works in underground construction; Standardisation of the tendering process	DAUB				X							
Digital Twin (in the design stage)*	Creation of a coordinated workflow to set a single source of truth between digital models in the design development, e.g., between the Structural model and BIM model, Hydraulic model and BIM model	WG22				X	X	X	X	X	X		
Construction Scheduling	Model-based scheduling of construction; Linking of individual construction elements from the structure model with the associated activities in the schedule; Representation of the project structure in the schedule structure and the BOQ structure	DAUB					X	X	X	X	X		
Quantity determination	Basis for cost estimation, tendering, billing, logistics, planning as well as during construction for billing and payment purpose	IFC					X	X	X	X	X		
Invoicing of construction works	Use of the model, which is promptly updated with the on-site excavation classes and any additional and/or reduced quantities of supportmeasures, as the basis for the payment of excavation works, taking into account the associated time-related costs; Use of the „construction time model" in BIM	DAUB									X		
Monitoring	Monitoring of ground deformations during tunnelling	IFC									X		
Digital Twins (Asset Management)	Advanced asset management is expected to leverage a Digital Twin of a tunnel, in the form of a continuously updated digital mirror of the current conditions.	IFC										X	X
Use for operation and maintenance	Provision of a facility model with all relevant data for operation; Data administration and updating at a central location (database)	DAUB											X

at the WTC in Copenhagen in 2022.

Model interoperability and data environment. It is often falsely believed by non-BIM experts that all digital project information can be stored within a single BIM. This is largely impossible, as computing power and software capabilities are not yet sufficient to do so. Rather, several BIMs (e.g., separate geotechnical, structural, and systems models) according to the selected BIM Use Cases are typically developed for a tunneling project. Although not all BIMs interact with one another, all BIMs should be stored in a centralized location, referred to as the common data environment (CDE), which is subject to the information exchange requirements set forth in the

FIG. 2

Schematic of the relationship between tunnel and ring model in a BIM for a bored tunnel.



BEP or by ISO 19650. A CDE can be, for example, a ProjectWise environment (or similar in another platform, e.g., Autodesk BIM360) in which the file structure as well as the uploading, editing and approval process is strictly controlled.

CDEs are well defined in ISO 19650 and may be directly adopted in the field of tunneling. The WG 22 therefore recommends that the ISO 19650 standard be followed for the creation of a CDE in tunneling projects.

Level of definition. Within the context of the ITA BIM Guideline, the level of definition describes the level of complexity to which a BIM model is developed. This is further divided into the level of detail (LOD), which defines the level of geometrical detail to which a BIM object is developed, and the level of information (LOI), which is used to refer to non-geometrical information (i.e., material type, volume price, equivalent CO_2 output per kg, etc.). For example, a tunnel segment can be modelled to a LOD incorporating only its inner radius, outer radius, and faces, or a tunnel segment can be modelled such that it accounts for all the geometrical details such as the gasket groove, contact area for the longitudinal joint, etc. The LOD and LOI of each object within a BIM develop throughout the life of a tunneling project. This terminology is borrowed from the PAS 1192-2:2013 [BSI, 2013], within which it was introduced. It should, however, be noted that this terminology is no longer used by the BSI as they have moved to use the term "level of information need." Nevertheless, the terms LOD/LOI have proved to be helpful in the context of the tunnel and therefore have been continued to be used.

To simplify this concept for easier inclusion into a tunnelling BIM environment, the ITA guideline provides a simplified table that accounts for most of the objects found in a tunnel and provides recommendations at which stage which object or detail should be included. An excerpt is provided in Fig. 4.

To account for the complexities in the delivery process, the WG 22 guideline proposes to split the bored tunnel BIM into two models: a ring model and a tunnel/alignment model. The ring model is included as a reference within the tunnel model through the tunnel model's level of information (LOI). The LOI describes semantic, i.e. non-geometrical, information associated with objects in a BIM. A schematic of the interaction between the tunnel and ring model is provided in Fig. 2.

The tunnel model is a tube model that defines the location of the tunnel in the three-dimensional space. The tunnel model also includes all information generalizable to the tunnel as a whole (clearance envelopes, linear internal structures, etc.). It does not contain the location of the ring segments, as the achieved construction tolerances, and corresponding segment location, are unknown during the design process. The segmentation information is contained in the ring model. During design, only a single ring of each ring type generally needs to be modelled. In addition to the segmentation, the ring model should contain all relevant information needed to define the segmental lining, i.e, exact geometry, number and location of embedded items, reinforcement content, etc. The ring model is intended to form the basis of the segmental lining drawings and can be used at a later date by the contractor to generate the as-built tunnel models with the exact

FIG. 3

(a) Tunnel model including interior systems, (b) ring model including segments.

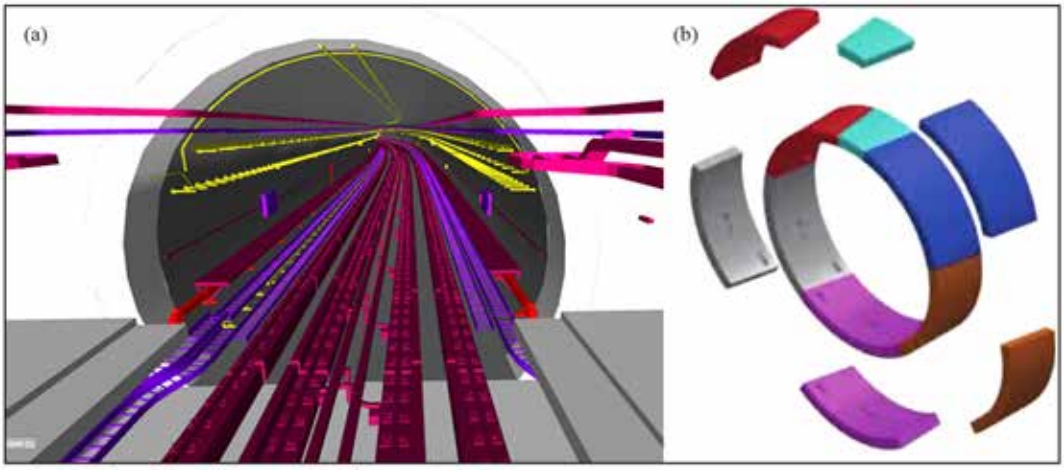


FIG. 4

Excerpt of the LOD/LOI table developed by the ITA WG 22. NR signifies "Not Required."

ISO 19650	STRATEGIC PLANNING	PROJECT DELIVERY								OPERATION PHASE	
ITA WG22	STRATEGIC DEFINITION	PREPARATION & BRIEFING	CONCEPT & PRELIM DESIGN	BASELINE REFERENCE DESIGN	DETAILED/ CONTRACTOR DESIGN				CONSTRUCTION	COMMISSIONING & HANDOVE	USE/OPERATION
					30%	60%	90%	100%			
Level of Detail											
Object											
Alignment	NR	NR	X	X	X	X	X	X	X	X	By Asset Owner
Clearance Envelope	NR	NR	NR	NR	X	X	X	X	X	X	
Tunnel Intrados	NR	NR	X	X	X	X	X	X	X	X	
Concrete Outline	NR	NR	NR	X	X	X	X	X	X	X	
Annular Grout	NR	NR	NR	NR	X	X	X	X	X	X	
Segmentation	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
HDPE Lining	NR	NR	NR	NR	NR	X	X	X	X	X	
Reinforcement content	NR	NR	NR	NR	NR	X	X	X	X	X	
Openings	NR	NR	NR	NR	NR	X	X	X	X	X	
Opening Tolerances	NR	NR	NR	NR	NR	X	X	X	X	X	
As-built Object											
Lipping	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	By Asset Owner
Stepping	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Alignment deviations	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Ovalisation	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Ring Roll	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Structural Defects	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
Non Structural Defects	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
3D Survey Model	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Level of Information											
Ring Model	NR	NR	NR	X	X	X	X	X	X	X	By Asset Owner
Basis of Design	NR	NR	NR	X	X	X	X	X	X	X	
Design Report	NR	NR	NR	NR	X	X	X	X	X	X	
Geotechnical Report	NR	NR	NR	X	X	X	X	X	X	X	
Durability Report	NR	NR	NR	NR	NR	X	X	X	X	X	
Coating Specification	NR	NR	NR	NR	NR	X	X	X	X	X	
Related Specifications	NR	NR	NR	NR	X	X	X	X	X	X	
Defect Report	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Repair Report	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Future Loading	NR	NR	NR	NR	NR	X	X	X	X	X	
As built Survey	NR	NR	NR	NR	NR	NR	NR	NR	NR	X	
Carbon Coefficient	NR	NR	X	X	X	X	X	X	X	X	
Ring Type	NR	NR	NR	NR	X	X	X	X	X	X	
Concrete Grade	NR	NR	NR	NR	X	X	X	X	X	X	
Rebar Grade	NR	NR	NR	NR	X	X	X	X	X	X	
Fiber Content	NR	NR	NR	NR	X	X	X	X	X	X	
Exposure Classification	NR	NR	NR	NR	NR	X	X	X	X	X	
Fire Rating	NR	NR	NR	X	X	X	X	X	X	X	
Water Retaining (Y/N)	NR	NR	NR	NR	NR	X	X	X	X	X	
Water tightness Critera	NR	NR	NR	X	X	X	X	X	X	X	

known ring orientation and locations. The as built models, in contrast to the design models, should contain the as-built location of the individual ring segments. An image of an exemplary tunnel model is shown in Fig. 3 (a), whereas a schematic of a ring model is shown in Fig. 3 (b).

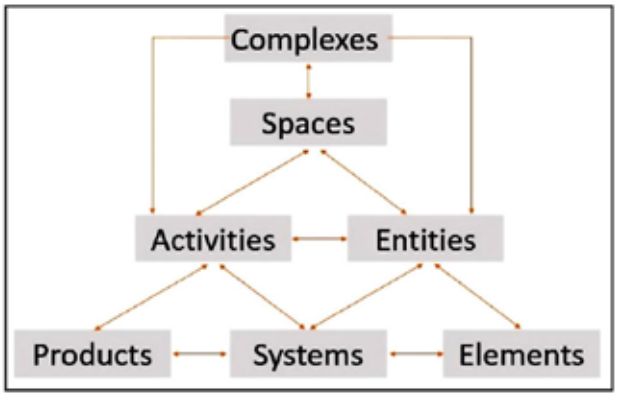
Classification systems. Objects within BIMs (i.e. the tunnel lining or tunnel segments) should be properly named or labelled so that a model may be properly queried. Classification systems are used within a BIM context to achieve this purpose. These systems provide a naming hierarchy which allows all objects within a BIM to be named in a consistent but unique manner.

Classification systems may be project specific or may be dictated by pre-existing owner's requirements. In the absence of owner's requirements, the ITA recommends the adoption of existing classification systems. Examples are the Uniclass [NBS, 2021] or DAUB [DAUB, 2020] classification systems. The DAUB standard is tunnelling focused and provides an extensive naming convention for BIM objects within both TBM and conventional tunnelling frameworks. The DAUB standard is, however, complex and results in long object names that adopt local national conventions. The NBS Uniclass 2015 system has been more broadly developed for the entire construction industry. In being broader, the Uniclass system provides less direct guidance on naming conventions for specific tunnel-based objects, but is therefore also easier to manipulate. A schematic of the Uniclass structure is provided in Fig. 5. An example of named objects using the Uniclass convention is provided in Table 1.

Exchange data formats. BIMs within a project often need to exchange and share information. Importing,

FIG. 5

Uniclass object hierarchy.



exporting, creating, or editing data, may, however, require software-specific exchange formats. These formats may have limited interoperability with other software used in the BIM environment. Consequently, data requirements and file formats for data interactions between BIMs must be pre-selected and codified in a contract document (e.g. BEP or similar) before use. If data between BIMs cannot be directly transferred through native file formats, interfaces modifying the export or import information must be manually created using specialized coding tools.

File formats for BIM programs are typically proprietary and often unique to a specific program or software family. To increase transparency and compatibility between BIM programs, the ITA WG 22 guideline supports the adoption of the Industry Foundation Class (IFC) format. The IFC format presents a vendor-independent format for the exchange of information between BIMs. Tunneling-specific object classes (titled IFCTunnel), have been in development by Building Smart International [buildingSMART, 2020] since 2019. Although significant progress has been made towards the adoption of IFC in commercial BIM software, the IFC format may not be available in all commercial programs.

In lieu of the IFC format, it is generally advantageous to combine software packages from one developer to improve interoperability between disciplines and tasks. In doing so, the ITA guideline provides the following additional recommendations:

- Tunnels are linear structures, and not all software are capable of handling chainages. Care should be taken in determining the right software to provide the ideal working environment for tunnels.
- In contrast to the above, local structures (e.g. shafts or stations) may require different modelling software than the primary tunnel alignment.
- Generally, the adoption of fewer software platforms leads to better integration between BIMs as the number of interfaces is minimized.
- All tunnel and other project models should share the same co-ordinate system from commencement of modelling.
- A federation strategy to transmit information containers or models should consider the maximum file size that is practical for upload and download with the specified IT infrastructure (e.g. 250MB, 1 GB, 10 GB, etc.). The information model should be subdivided such that no single information container exceeds these limits. These limits are typically set forth in a project Master Information Delivery Plan (MIDP) and Task Information Delivery Plans (TIDP).

Ground modelling. The inclusion of ground information (e.g., borehole data, geophysical data, geological models) in a BIM environment is often hindered due to a variety of reasons, with some being:

- The development of a full geological database of all available ground information is often difficult due to the large volume of geological information available.
- In contrast to a civil design, ground information cannot be largely determined a priori.
- Ground information changes during tunneling, and previous assumptions concerning geological layering are updated or replaced as the project progresses (e.g., borehole vs face map records, latest readings from I&M, etc.).
- Much available geological information is not factual, and is a result of specialist interpretation.

Despite the complexities surrounding the subject, ground information is a vital component of underground

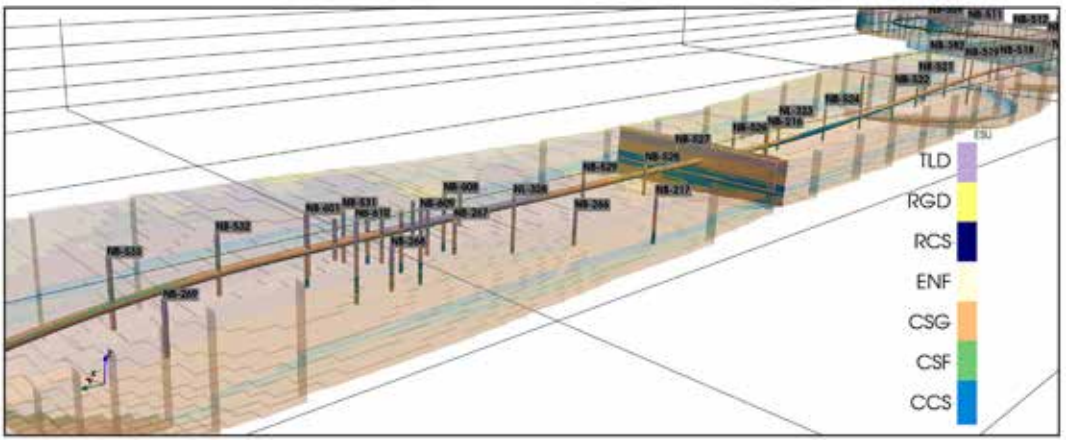
TABLE 1

Tunnel-specific examples of Uniclass object naming structure.

Uniclass element	Object	Uniclass code
Complex	N/A	
Spaces	Tunnel and shaft spaces	SL_80_96
Entities	Lined tunnels	En_80_96_49
Systems	Tunnel structure systems	Ss_37_50_92
	Cementitious grout systems (i.e., annular grout)	Ss_20_05_80_12

FIG. 6

Geotechnical BIM showing positions of boreholes along a tunnel alignment.



construction, as many of the risks and successes of a project hinge on the correct interpretation of its geology. The ITA guideline strongly encourages the inclusion of ground information within a BIM environment.

Integration of geological and geotechnical data within a BIM context. Ground information in a geotechnical 'BIM' environment often follows a different data structure than structural or architectural data included within BIM models. For this reason, the ITA guideline recommends that the geotechnical / geological model be kept separate from the main tunnel model. This also supports the practicality of reducing model sizes in line with software / hardware limitations. Furthermore, the inclusion of different types of information will be dependent on the stage of a project. Some examples of information to include in geotechnical BIMs at different project stages are:

- Conceptual and preliminary design model – Historical borehole data.
- Baseline reference design model – borehole data (with links to relevant reports), initial geotechnical/geological models and sections.
- Detailed/contractor design model – borehole data, geotechnical / geological models and sections, baseline I&M readings.
- Construction model – Borehole data, I&M (real-time or not), updated models and sections.
- Handover/operational model – The asset management model is assumed to be the construction model as often no further information is created after completion of construction. The asset stage is, however, outside of the scope of this work as it needs to be defined by the asset owner suitable to their systems.

An example of a BIM showing borehole data is provided in Fig. 6.

Factual vs. non-factual (or contractual vs. non-contractual). Ground information can be factual or non-factual (i.e., interpreted data). It is recommended to include factual data (examples outlined above) in project-wide BIM models.

Non-factual data include interpolations for geological models and sections, recommended baseline parameters or interpretations from geophysics. The inclusion of non-factual data should be carefully considered since this information may impact risk-sharing arrangements within a project. The inclusion of non-factual data within a project-wide geological BIM model does, however, carry significant benefits. Interpretive data, such as the in situ stratigraphy, and other actual ground conditions can be very useful to make informed engineering decisions, and provide direct comparisons to the baseline or reference model, especially in projects with complex geology. In addition, such data included within a BIM model can significantly streamline future engineering decisions, as future engineers may use past interpretations as a basis for their own assumptions or interpretations. This is especially true with regard to BIM models intended to be used as asset management aids during the use/operation phase.

If non-factual data is to be included in the BIM, it should be explicitly evident that this information is an interpretation from factual data. Uncertainties in this interpretation should be quantified and reported. Methods for clear classification of factual vs. non-factual data vary based on projects and are owner dependent. One example of how to distinguish geotechnical data is that provided by Building Smart International [buildingSMART, 2020] in which geotechnical data is stored as "factual data," "interpreted data," and "conception (design) data." In addition to correctly identifying non-factual geotechnical data, the source of interpretive information should be traceable. Traceability within a BIM model can be achieved by, e.g. consistently tracking author information within a BIM object.

Sustainability. BIM can facilitate the early tracking of sustainability parameters and quantify the emissions associated with geometrical objects. The ITA WG 22

guideline recommends tracking equivalent carbon emissions as a primary sustainability marker of a project. This approach supports informed decision making by clients and consultants. Other life-cycle analysis design tools specific to tunnelling projects that include geology, structural design options and alignment can additionally provide early embodied carbon calculations for best-practice results.

Conclusion

The field of BIM is continuously changing due to the ever-increasing number of tools available to architects and engineers. Nevertheless, some core concepts, such as organized data management and workflows or centralized data structures, have established themselves as necessary for the successful integration of BIM into a tunneling project. The ITA "guideline for the implementation of Building Information Modeling concepts for Bored Tunneling Projects" aims to clearly depict these core concepts to both owners and engineers and therewith support the continued adoption of BIM within the tunneling industry. ■

Acknowledgements

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UCA creates Tunnel Watch List to highlight the benefits of tunnels and underground construction

Last year, the Underground Construction Association (UCA), a Division of SME, formed a committee to identify the top 20 tunneling and underground construction projects that will provide sustainable economic and environmental benefit to the communities in which they are built.

"The point of the Tunnel Watch list is to have that list so people can see what projects are out there and are in need of funding," said committee chair Greg Hallet "This list will help generate visibility and hopefully we can assist in helping those projects get funding or get public approval that is needed."

Projects are ranked based on five criteria and each project is then scored against those criteria to identify tunnels that will provide the most benefit to society.

"These rankings tell us the importance of the project to the environment and to the people in the areas where they will be built," said Hallet.

Among the many benefits tunnels provide are transportation tunnels that can help reduce carbon emissions and water tunnels that provide freshwater or provide for the storage of wastewater for treatment.

The updated 2022 Tunnel Watch list includes tunnels from the entire United States: from the East Coast, such as the Gateway Tunnel Project connecting New York and New Jersey, to the Lowell Creek Diversion Tunnel in Seward, AK. The 20 proj-

(continued on page 32)

2022 Tunnel Watch List

Project	City	State	Owner	Tunnel use
Gateway Tunnel Project	NE Corridor	NY/NJ	Amtrak, Port Authority NYNJ, Gateway Development Corp	Transit
US 64 Corridor K Tunnel	Polk County	TN	Tennessee DOT	Highway
Delta Conveyance	Sacramento	CA	California Department of Water Resources	Water
Sepulveda Pass	Los Angeles	CA	LA Metro	Transit
West Seattle Project	Seattle	WA	Sound Transit	Transit
Silver Line Extension	Boston	MA	Massachusetts Bay Transit Authority	Transit
Continental Rail Gateway (Detroit-Windsor Tunnel)	Detroit	MI	Windsor Port Authority, Borealis Infrastructure Trust and Canadian Pacific	Railroad
LA Westside Purple Line Extension - Phase 4	Los Angeles	CA	LA Metro	Transit
Red Line Blue Line Connector	Boston	MA	Massachusetts Bay Transit Authority	Transit
Ontario International Airport and Cucamonga Station Tunnel	San Bernardino	CA	San Bernardino County Transportation Authority	Transit
Horizon Lateral Project	Las Vegas	NV	Southern Nevada Water Authority	Water
Connector Conveyance Tunnel, Ph IIIC	Providence	RI	Narragansett Bay Commission	Wastewater
CSO Control Parallel Interceptor	Newark	NJ	Passaic Valley Sewerage Commission	Wastewater
Gordon Butte Pumped Storage Hydro Project	Martinsdale	MT	Gordon Butte Energy Park	Energy
Lowell Creek Flood Diversion	Seward	AK	Corp of Engineers	Water
Banks Lake Pumped Storage Project	Grand Coulee	WA	Columbia Basin Hydropower	Energy
Harlem River Drive Ramp	New York	NY	New York DOT	Highway
Steel Bridge Replacement Tunnel	Portland	OR	Tri-County Metropolitan Transportation District of Oregon (TriMet)	Transit
Vermont Transit Corridor	Los Angeles	CA	LA Metro	Transit
Houston Flood Control Tunnels	Houston	TX	Harris County Flood Control District	Wastewater

UCA's Sanja Zlatanic named to ITA Council

On Sept. 8, Sanja Zlatanic, P.E., HNTB, was elected to represent the United States on the ITA-AITES Executive Council during the ITA World Tunnel Congress annual meeting in Copenhagen, Denmark.

Zlatanic has more than 30 years of national and international experience in the engineering and design management of multibillion dollar tunnel and underground projects and has been responsible for managing all phases of major multibillion-dollar projects, including extensive multidisciplinary joint-venture staff, from feasibility and conceptual engineering through final design and construction.

As a member of the ITA Executive Council she will bring a global perspective, having worked on an array of tunneling projects including the SR-99 Alaskan Way Project in Seattle, WA; the LA Metro Sepulveda Transit Corridor in Los Angeles, CA and the Istanbul Strait Road Crossing Tunnel project in Istanbul, Turkey.

Through collaboration with other industry professionals, Zlatanic will help the ITA advance its image throughout the tunnel and underground industry, globally and in the United States, as a positive force bringing innovations and improvements for the betterment of people's quality of life and safety, especially in the realm of global climate change and related impacts.

She intends to establish qualitative and quantitative criteria toward motivating and measuring the engagement and efficiency of ITA working groups and committees while assuring their broader outreach throughout the international tunneling and underground industry and help formulate, promote and advance ITA initiatives toward broader engagement of young professionals, globally and in the United States.

"Tunneling and underground projects are among the riskiest engineering practice areas; solid engineering judgement and practical solutions that always have safety as a primary concern are paramount," Zlatanic said. "Throughout the years, I have learned that the only way to successfully conquer great challenges is to rely on a team contribution, and having the courage to pursue one's own vision and convictions."

Zlatanic is an active member of various tunneling and underground societies and is well recognized in the profession. She has published numerous articles, chaired conference sessions and made many presentations on the design of construction of tunnels and underground facilities at national and international tunneling conferences.

She received a Technical Excellence Award and has been recognized as a Fellow for extraordinary career-long accomplishments, from practicing technical excellence and championing innovative approaches to solving underground engineering issues, especially in relation to minimizing the impacts of tunneling beneath densely populated urban environments, communities and businesses.

Sanja Zlatanic

Zlatanic is an elected board member and secretary general of the Associated Research Centers for Urban Underground Space (ACUUS), an international, nongovernmental organization dedicated to partnerships among experts who research, plan, design, construct and decide upon the best use of urban underground space. ■

Tunnel Watch List; 2022 includes new projects

(continued from page 31)

ects include well-known multibillion-dollar transportation projects that will eventually carry millions of people underground as well as combined overflow sewage projects that few people will ever see the inside of.

The Tunnel Watch List committee is chaired by Hallett and includes Greg Hauser, Mark Johnson, Ericka Moonin, Mike Roach, Jim Rush, Robert Goodfellow, Marc Herren, Mike Rispin, Grover Vargas and Mike Vitale.

The committee considered a number of factors when picking projects for the list including cumulative benefits of the project both regionally and nationally with an emphasis on societal and environmental benefits and not just economic benefits.

Geography was a factor as well as the need to help promote projects that may need funding or are particularly important to their local community, or any other reason to justify why the public needs to be aware of the need for this infrastructure.

"We want to have the list out there so that people can see what projects need funding," said Hallet. "By giving these projects some visibility it gives people the chance to do some research and find out the benefits of each project."

A pass/fail criteria was used to prioritize projects that have passed the initial concept design hurdle and are at least into preliminary engineering, the committee said.

The overall goal of the project is to raise awareness of the importance of tunnels to the United States. ■

A call for UCA volunteers

by Genny Homyack, SME Staff

The world needs tunnels, now more than ever, and the UCA, a Division of SME, is working hard to communicate that message to lawmakers and other stakeholders. Recently, the UCA Executive Committee established a Government and Public Affairs Committee (GPAC) to better spread the word about the benefits of tunnels and underground construction.

Tunnels can contribute to the success of many of the sustainable development goals set forth by the United Nations in ways that many politicians or members of the general public might not be aware of, such as providing clean energy and water.

UCA's new GPAC will gather the results of existing efforts in areas such as the Tunnel Demand Forecast, Tunnel Watch List, History of Tunneling Book and associated photos, UCA/ITA Working Groups, ASCE Legislative Fly-in and individual contacts to educate and inform legislators and elected officials about the benefits of taking infrastructure underground, according to Bob Goodfellow, who is leading the effort for the UCA.

"Elected officials will be contacted at all levels of government, from city, region, state and federal," Goodfellow said. "Representatives will be targets for our activities. We have identified groups of UCA members who have an interest in being part of this effort, focusing on both geographic and market sector diversity.

"In general, our goals are to educate the elected officials that consistent funding and the approval of underground infrastructure leads to societal and environmental benefits for their constituents."

The UCA plans to continue to gather a group of volunteers to support the industry in these efforts to promote tunneling projects to elected officials. This group will then decide on the specific goals and activities of this group.

"Stakeholder awareness is one of our association's three key strategic goals," said UCA Chair Mike Rispin. "We have decided, with the formation of the GPAC, to be more structured and systematic toward this goal, with the intent of getting more tools and information into the hands of those decision makers contemplating infrastructural investment, and ensuring that they understand the true long-term benefits of underground construction in meeting their needs.

"Under Bob Goodfellow's experienced leadership, we will unite and expand the effort going forward," Rispin added. "Our nation's decision makers at the federal, state and local levels will benefit from the resources that we intend to bring to bear."

If anyone has an interest in participating in this industry effort, they should contact Goodfellow at rgoodfellow@aldeaservices.com, Rispin at mike.rispin@strataworldwide.com or Erika Moonin at erika@mooninassociates.com.

Executive Committee nominations

UCA will be seeking Executive Committee members to fill the positions of vice chair and up to four at-large members. The term is for four years, starting July 1, 2023 with an option to renew one time. Executive Committee members are required to attend all in-person and virtual meetings. The deadline to submit nominations is Dec. 20, 2022. Send a brief biography, resume, statement of interest and commitment to attend all meetings, and a history of UCA activities along with a head shot to Genny Homyack at homyack@smenet.org. ■

Paul Schmall named President of the Moles

Paul Schmall, Ph.D., P.E. was named the president of The Moles for the 2022-2023 term. Schmall is vice president in Keller's Specialty Services business unit, which focuses largely on tunneling and dam work. Schmall is also a member of the UCA Executive Committee.

With 35 years in the geotechnical industry, Schmall has extensive experience with complex ground water control, grouting and ground freezing solutions for underground construction, and forensic investigation and remediation of geotechnical "failures" related to groundwater. He is active within the tunneling community.

Schmall has been a member of The Moles since 2002, serving as a member and chair of the Education Committee from 2009 to 2015. Recently, he served as the first chair of the Moles Charitable Fund, that part of the Moles which oversees awarding scholarships to engineering students. This summer, Schmall accepted the Moles presidency at the spring Members Dinner.

Fellow Moles member and president of Keller North America Eric Drooff said, "Congratulations to Paul on his presidency. It is fantastic to have Keller represented within the leadership of The Moles and for the acknowledgment of Paul's outstanding efforts."

The Moles are a national fraternal organization of individuals now or formerly engaged in the construction of tunnel, subway, sewer, foundation, marine, subaqueous or other heavy construction projects. Founded in 1936 by a group who worked together between 1914 and 1919 on projects under Newark Bay and on the waterfront of Port Newark, the organization is considered the most prestigious heavy construction organization. ■

Paul Schmall

COMPILED BY JONATHAN KLUG, DAVID R. KLUG & ASSOCIATES

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Gateway Tunnel	Amtrak	Newark/NYC	NJ/NY	Subway	14,600	24.5	2023	Under design
2nd Ave. Phase 2	NYC-MTA	New York	NY	Subway	16,000	20	2023	Under design
2nd Ave. Phase 3-4	NYC-MTA	New York	NY	Subway	89,600	20	2024-29	Under study
Kensico-Eastview Connection Tunnel	NYC-DEP	New York	NY	Water	11,000	27	2024	Under study
Flushing Bay CSO	NYC_DEP	New York	NY	CSO	16,500	22	2026	Under study
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Rail	25,000	30	2026	Under study
Metro Tunnel Program - Northern	Boston MRWA	Boston	MA	Water	23,760	10	2027	Under study
Metro Tunnel Program - Southern	Boston MRWA	Boston	MA	CSO	50,160	10	2028	Under study
Silver Line Extension	Boston Transit Authority	Boston	MA	Subway	8,400	22	2024	Under design
Narragansett Bay CSO Phase III - Conveyance Tunnel	Narragansett Bay Commission	Providence	RI	CSO	8,800	10	2024	Under design
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	Rail	40,000	32	2023	Under design
Ellicott City North Tunnel	Howard County	Ellicott City	MD	CSO	5,800	15	2022	Kiewit/Traylor JV awarded
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	24,000	18	2022	Proposal due April 23, 2023
Superconducting Maglev Project - Northeast Corridor	TNEM/BWRR	Washington	DC	Rail	146,520	43	2026	Under design
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	30,000 21,000	18 14	2023 2024	Under design Under design
Southerly Storage Tunnel	NEORSD	Cleveland	OH	CSO	18,000	23	2023	Under design
Big Creek Storage	NEORSD	Cleveland	OH	CSO	22.450	20	2026	Under design
Northside Interceptor Tunnel	City of Akron	Akron	OH	CSO	6,850	24	2025	Under design
ALCOSAN CSO Ohio River Allegheny River Monongahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	 20,000 28,000 28,000	 18 18 18	 2024 2028 2030	 Under design Under design Under design
DELORCA Wastewater Tunnel	DELORCA	Chester	PA	CSO	45,500	13	2023	Under Design
Enbridge Line 5 Tunnel	Enbridge	Traverse City	MI	Oil	23,760	12	2023	Shortlist announced
Minneapolis Central City Parallel Tunnel	City of Minneapolis	Minneapolis	MN	CSO	4,200	10-19	2022	Final planning

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
Stormwater Control Program	Harris Co. Flood Control District	Houston	TX	CSO	52,800	25-40	2024	Under design
Project Connect Subway Program	City of Austin	Austin	TX	Subway	8,500	20	2023	Under design
D2 Subway - 2nd Light Rail Alignment	Dallas Area Rapid Transit	Dallas	TX	Highway	7,230	22	2023	Delayed
Mill Creek Trunk Improvements	City of Nashville	Nashville	TN	CSO	13,800	10	2023	Under design
I-70 Floyd Hill Highway Tunnel	Colorado Dept. of Transportation	Denver	CO	Highway	15,840	60x25	2022	Under design
Horizon Lateral Tunnel	Southern Nevada Water Authority	Las Vegas	NV	Water	42,000	12	2024	Under design
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	Transit	10,500	18	2025	Under design
LA Metro Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2026	LOI received
Ontario Airport Tunnel	San Bernardino Co. Trans. Authority	San Bernardino	CA	Subway	22,000	24	2023	Under design
Folsom Area Storm Water Improvement	SFPUC	San Francisco	CA	CSO	4,000	12	2022	Under design
BART Silicon Valley Phase 2 Tunnel	Santa Clara Valley Transit Authority	San Jose	CA	Subway	26,400	43	2022	Kiewit/Traylor/ Shea awarded
Delta Conveyance #1 Delta Conveyance #2	California Dept. of Water Resources	Sacramento	CA	Water	39,905 200,000	28 40	2025+ 2025+	Delayed Delayed
Ontario Line North Extenstion	Toronto Transit Commission	Toronto	ON	Subway	29,500	20	2022	RFQ Q3 2022
Ontario Line South Extension	Toronto Transit Commissiton	Toronto	ON	Subway	29,500	20	2022	Shortlist announced
Taylor Massey Tunnel	City of Toronto	Toronto	ON	CSO	20,000	15	2025	Under design
Inner Harbour West	City of Toronto	Toronto	ON	CSO	18,400	20	2027	Under design
Yonge North Subway Extension	Toronto Transit Commission	Toronto	ON	Subway	40,000	20	2024	Under design
West Vaughn Sewage Servicing Project	York Region	Toronto	ON	Sewer	36,000	10	2022	RFP Q3 2022
East West Tunnel - Contract 2	Region of Peel	Toronto	ON	Sewer	5,200	12	2022	Technicore awarded
Blue Line Extension	Societe de transport de Montreal	Montreal	QC	Subway	19,000	33	2022	Under design
REM-S Project	Societe de transport de Montreal	Montreal	QC	Subway	23,000	33	2023	Under design
Quebec City - Levis Tunnel	Quebec Trans. Ministry	Quebec City	QC	Highway/ Transit	27,230	60	2025	Under design
Green Line LRT	City of Calgary	Calgary	AB	Transit	9,000	40	2023	RFQ submitted
Nose Hill Project	City of Calgary	Calgary	AB	CSO	10,800	10	2023	Under design
Stanley Park Water Supply Tunnel	City of Vancouver	Vancouver	BC	Water	5,000	15	2024	Under design

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Safety Challenges in Long Rail Tunnels

Long rail tunnels pose particular challenges in emergency situations due to prolonged time required for engaging rescue forces at a site of an incident. For this reason, advance planning and later operation of rail tunnels and their facilities require implementation of special standards to prevent incidents, first and foremost, and to ensure health and safety of passengers and staff if such incidents occur.

The most important aspect of minimizing response time in emergency situations is the planning of the tunnel and related facilities, and associated equipment and procedures – all these elements, individually and in combination, must actively support the inherent simplicity of procedures to be implemented in the event of an incident. Proper emergency planning reduces decision-making errors during emergency response while providing effective hazard mitigation for passengers, operating crew and first responders.

This paper discusses best industry practices in managing the incident response for long rail (and transit) tunnels and includes lessons learned from the construction and operation of the longest rail tunnels in the world, such as Gotthard Base Tunnel (Switzerland), Brenner Basel Tunnel (Austria/Italy), and Channel Tunnel (France/Great Britain). The paper addresses tunnels currently under construction, such as Brenner Base Tunnel (Austria), Lyon-Turin Tunnel (France/Italy), Semmering Base Tunnel and Koralm Base Tunnel (Austria).

SPECIAL SAFETY CONCEPT

Long tunnels pose challenges in emergency situations. Rescue teams often navigate long access routes to incident sites, and passengers might encounter difficulties during a self-rescue operation since it is unlikely that rescue forces could be engaged quickly.

Planning of tunnel facilities, associated equipment and procedures must inherently support simplicity of incident management operations. For this reason, a fundamental safety question must be addressed during an early planning stage, primarily: What measures can be taken to reduce the probability of a disabled train on fire in the tunnel?

Best emergency planning and management reduce decision-making errors during emergency response scenarios while providing effective hazard mitigation for passengers, operating crew and first responders. Creating four-stage safety concepts has been proven effective and shall be considered before any detailed planning and design are undertaken.

The first and most important measure of tunnel safety is prevention of fire events, primarily defining operational emergency procedures and technical and performance specifications of rolling stock.

SAFETY AND OPERATIONAL CHALLENGES

The specific safety risks are summarized as follows.

- **Fire in Tunnel** – Passenger train fires represent the highest risks with regard to the impact and the likelihood; they accomplish both - endanger the lives of passengers and train crew and might lead to longer term loss of the infrastructure.

  Fire departments and rescue teams cannot reach site of an incident quickly especially in mountainous regions. Also, number of access points are usually limited (this might be less problematic in urban areas). Often evacuation must be conducted without help by rescue teams. Safe areas must be accessible by all passengers and the train crew within a reasonable timeframe.

- **Increased Air Temperature in Tunnel** – Railway equipment decreases its robust operational features at air temperatures above 86 °F (40 °C). Additionally, maintenance of long rail systems becomes difficult and time consuming (limited accessibility).

- **Poor Air Quality in Tunnel (Equipment and Health Risks)** – Limited or low ambient air exchange rate can lead to accumulation of metallic rail dust in running tunnels and adjacent technical rooms. As concentration levels of rail dust increase tunnel air conditions develop a severe risk for the operation of the electromechanical equipment. Increased concentration and fine grain size of the rail dust create additional maintenance requirements for wayside rail controls and safety equipment. In addition, these conditions introduce health hazards for maintenance staff requiring special personal protection means (self-contained breathing apparatus, SCBA), OSHA-certified passive filtration breather masks, or consistent vacuum operations protocol. Together with the limited access routes and access times, maintenance is a particular challenge for safe and secure rail operation.

APPROACH TO SAFETY

The approach to safety of rail systems shall be understood as 'absence of unacceptable risks' since achieving an absolute (100%) level of safety goal is not practical. If probabilities of safety risks are

minimized and resulting impacts reduced, approach to safety should be considered acceptable.

In this regard, safety concept should follow a four-staged approach. [This is similar to the approach as per European railway tunnel guidelines (European Commission 2014), considered standard practice within legal framework in Europe.] The concept varies for different rail assets depending on safety goals, operational objectives (passenger, freight or mixed operation) and related risks.

The four-staged safety approach results in a high-level safety concept and is complementary to the NFPA 130 guidelines for rail tunnels. Application of this concept would minimize the risks to passengers, staff, and rescue teams; the risks to the infrastructure (tunnel, overlying structures, rail facilities, etc.), and the risk to operations (absence of incidents and rapid recovery operation after incidents). The four-staged safety concept correspond to four layers of defense:

First Layer of Defense: Prevention
Prevention has the highest impact on the level of safety and is the most effective measure. Examples for prevention measures comprise adequate maintenance plans and procedures with regular inspections and repair work, choice of rolling stock materials, way-side monitoring (hot box axle detectors, heat detection, train profile detection, gas detectors, etc.), prohibition of encounters between freight trains and passenger trains, separation of tunnel bores for either direction, etc.

Second Layer of Defense: Mitigation
Mitigation measures help to limit the impact of an incident on the rail infrastructure. Examples for mitigation measures include emergency break override, fire extinguishers onboard and fire rating of rolling stock (fire compartments, redundancy of train control elements and the electrical circuits, etc.).

Third Layer of Defense: Evacuation
Evacuation measures help passengers and staff. Examples for evacuation measures include earthing/grounding, length and width of egress ways (sidewalk, doors, emergency stairs), handrails, signage, emergency light, subterranean safe areas, etc.

Fourth Layer of Defense: Rescue
Rescue measures support rescue teams to carry out their work in an emergency. Examples for rescue measures include rescue trains, communication measures, protective equipment, training/drills, etc.

FACILITY SAFETY

Need for facility measures is determined based on the operational concept implemented (passenger trains, freight trains or mixed traffic). These measures are costly and require careful planning. For instance, features of emergency and maintenance egress ways should be a result of detailed safety assessment that would include considerations of smoke propagation in a tunnel, passenger density and evacuation times.

Rail systems solely designed for freight train operations require less egress ways. A key safety element for freight rail incidents (hot or cold) is the drainage system, capacities of which should comply with firefighting volume rates and volumes of the transported cargo tanks (usually volumes of three standards tanks are used). Drainage pits are typically situated at the lowest point of a tunnel. Special attention should be given to transporting hazardous liquid cargo. For this application, the drainage sinks should be fitted with explosion protection measures.

Important facility safety elements are as follows:

Passenger trains

- Escape routes to safe areas (unassisted evacuation)
- Safe areas (adjacent to the tunnel bores)
- Cross-passages
- Safety tunnels
- Emergency stations
- Simple drainage system to support firefighting water volume flow rates

Freight trains

- Drainage system (comply with firefighting volume flow and multiple volumes of transported tanks) and explosion proofed drainage sinks for hazardous liquid goods.
- Minimum distances between freight trains and passenger trains as an operational measure.
- No passenger train between two freight trains (as an operational measure).

Lessons Learned
Experiences gained after several years of operation of Gotthard base tunnel (57 km, double bore, single-track) show a) the maintainability of the rail and safety equipment in long rail tunnels needs more attention during the planning phase of the project and b) that this aspect should be considered for the rail systems selection.

Ehrbar, et al. have compiled design bases for rail tunnel systems decision-making. For long tunnels, considering current experiences with systems maintenance, the overall costs of a system with two rail tunnels and one service tunnel are lower than the costs of only two rail bores when overall life-cycle costs are considered, including costs for maintenance. An exploratory tunnel might be a cost-effective solution for subsurface exploration in areas with difficult access or complex geology.

These tunnels could be instrumental for later use as emergency or maintenance egress purposes or for utility or systems routing.

ROLLING STOCK (PASSENGER TRAINS)

Rolling stock plays a key role in tunnel safety considerations, and preventive measures implemented directly on the rolling stock have the greatest impact on passenger safety.

Internationally, European Standards for the Fire Protection of Rolling Stock usually govern (EN 44545) and include provisions for fire compartmentalization/fire barriers; evacuation and rescue egress provisions; choice and testing of materials; electrical equipment; fire control and management systems, etc.

Lessons Learned

Long European tunnel design (Gotthard Basel Tunnel, Loetschberg Base Tunnel, Katzenbergtunnel, etc.) is based on TSI LOC&PAS standard and legal requirements (per European Commission Regulation). The trains are specified according to the following specifications:

- Chapter 4.2.10.4.4. (2) The unit shall be designed so that, in the event of fire on-board, the running capability of the train will enable it to run to a suitable firefighting point.
- Chapter 4.2.10.4.4. (3) (...) braking and traction for rolling stock of fire safety category B: these functions shall be assessed for a duration of 15 minutes at a minimum speed of 80 km/h (50 mph).

Therefore, these trains are not only equipped with fire detection systems that stop them from entering a tunnel if fire on board is detected (prevention)—they are specified to keep traction and braking capabilities fully functional (with a fire on board) for 15 min and for a speed of 50 miles per hour. They can readily reach an exit portal or a location in a tunnel where evacuation is facilitated.

TUNNEL EQUIPMENT

Proper tunnel equipment helps passengers and train crews during evacuation and supports rescue teams egressing site of an incident especially in case of a fire in the tunnel.

Communication Systems

Specific rail/tunnel communication systems support the train crew communications with the operator during the incident. Additional communication systems are used by rescue services that work close to the fire event.

Signage, Emergency Lighting and Handrails

Signage, emergency lighting and handrails play an important role during any evacuation phase.

Camera Systems

Video surveillance is typically not part of tunnel equipment due to the limited advantages provided by optical systems. The major drawback of any kind of surveillance camera is the need for cleaning when exposed to the metallic rail dust. However, in some cases it is reasonable to install them at portal areas to identify unwanted tunnel access attempts.

Ventilation

Unlike metro tunnel applications (where systems have underground stations at relatively short intervals), ventilation systems are rarely used for long rail tunnels for three reasons:

1. During the self-rescue phase, ventilation can only be used to provide tenable conditions upstream of the incident. Passengers downstream of an incident would be exposed to the smoke and heat transported by ventilation flows used to establish a tenable evacuation path in the upstream area of the tunnel (e.g., several fatalities metro fire Baku 1995).
2. Fire heat and smoke release can increase due to the oxygen supply provided by ventilation.
3. Rolling stock are specified to maintain traction power and braking capacities for 20 km (12.5 miles) with fire on board according the TSI specification (EN 45545, Lok and Pass 2013). For example, very long tunnels through mountains of the European Alps provide emergency stations with smoke extraction facilities and evacuation chamber approximately every 20 km (12.5 miles).

Per NFPA 130 guidelines, ventilation provides a safe evacuation path by pressurizing non-incident tunnel bore in the case of a fire event. Also, longitudinal ventilation can be used to avoid back layering and support rescue and fire-fighting services. In addition, tunnel ventilation is required during congested mode, for climate control and for maintenance work in a tunnel.

Using ventilation ducts in the tunnel, with dampers in ceilings or along the tunnel walls, are not considered practical for the following reasons:

- In long tunnels a system with trackside dampers is impractical to maintain. Pressure differences and rail dust harm the damper blades and mechanisms as well as actuators.
- Ventilation system capacity and reliability will degrade over time due to the compounding influence of cyclical pressure loads and rail dust deposition on damper assembly and damper leakage. This degrades damper efficiency and volume flow rates over time.
- Pressurizing the non-incident tunnel bore when incident tunnel is ventilated, requires additional ventilation equipment.

Automatic Tunnel Reflexes

Automatic tunnel reflexes can be used to limit reliance on human decisions during initial time period of unexpected train incidents where emergency operations may be necessary. The main idea is to use information of the train control system to trigger tunnel safety equipment as required.

In the event of an incident, predefined automatic response can be triggered for the tunnel systems, such as lighting, ventilation, doors, etc., depending on the type of incident. The coordination and activation of the systems are carried out without time-consuming manual intervention.

OPERATIONAL PROCEDURES

Signaling Systems

Modern train control systems signaling arrangements enable the transmission of the signals necessary for train control to the driver's cab (the in-cab signaling without external signals). The risk of ignoring a 'stop' signal accidentally is almost eliminated. Additionally, the in-cab signaling permits dynamic information of the train driver in the case of an incident in the trail system.

Lessons Learned:

Automatic Hazard Management System

An automatic hazard management system was specifically developed for and used in the Gotthard Base Tunnel (57 km). This is a special safety system with severity-reducing provisions that can be applied to any rail tunnel and does not depend on Swiss or high-speed signaling technologies. This system continuously monitors the positions of trains passing through the tunnel and automatically takes initial decisions should a train reduce its speed without apparent reason as:

- Following trains are kept 5 km from the train affected.
- The traffic controller is informed, and their decision is expected within a stipulated time (max. 2-3 min.).

If the traffic supervisor confirms the alarm because, for example, they are unable to contact the train driver, the system automatically initiates further actions in order to restore a safe condition in the tunnel in the shortest possible time as follows:

- The system moves the affected train to the next emergency station.
- The system stops the next train from entering the tunnel.
- All following trains are stopped.
- All trains in the non-incident tunnel are stopped at the emergency station.
- Emergency station is set to "ready" condition (the ventilation system is activated, and an escape route is made ready, and lights are turned on)
- The firefighting-and-rescue train is alerted.

All provisions are intended to protect the traffic manager from premature or false decisions. Defined actions are implemented automatically to ensure the best possible conditions for a successful rescue of passengers in case of a possible emergency.

Way-side Monitoring
Recent fires on freight trains in long tunnels (Channel Tunnel, Simplon Tunnel) have been initialized by train cargo loads. The Channel Tunnel fire started on a truck on the train, and the Simplon Tunnel fire was caused by an unfixed truck tarpaulin onboard the train. Both cases led to the development and application of way-side monitoring systems, preventing hazardous trains from entering tunnels.

Different way-side monitoring parameters are as follows:

- **Fire and chemical detection:** Measurement of small concentrations of typical combustion products and dangerous substances.
- **Hot box and brake locking detection:** Monitoring rail vehicles temperatures of axle box bearings and brakes.
- **Profile clearance and areal detection:** Comparing rail vehicles compliance with clearance profile.
- **Natural hazard detection:** Detecting rockfalls, landslides, and mudslides near the track.

CONCLUSIONS

The operation of long railroad tunnels is associated with particular risks and challenges, such as:

- The prolonged time required for engaging rescue forces at a site of an incident. Evacuation in the tunnels must initially be carried out without the support of the rescue forces.
- If a train stops in the tunnel, the non-affected incident tunnel is also affected since it is considered as a safe place. Trains in either tunnel and approaching trains must be stopped or slowed down.
- The air temperatures that develop in the tunnels and the metallic rail dust can have adverse effects on the rail and safety systems.
- Access for maintenance operations can only take place during breaks in operation, reducing the availability of the tunnel.

Modern safety concepts, based on a layers-of-defense approach have been proven effective. The four layers are in the order of priority and cost effectiveness: (1) prevention, (2) mitigation, (3) evacuation and (4) rescue.

Safety Concepts to not only address the equipment of the rail tunnels (egress ways, emergency light, signage, ventilation, handrail, standpipes, drainage, etc.) but consider the operational aspects and the rolling stock as well.

Train Control Systems are also used for incident management by triggering tunnel reflexes, monitor speed violations, preventing overfilling of a tunnel and by the optimization of running times.

Rolling Stock plays an important role for incident management. Passenger trains are equipped with fire detection systems, allowing to stop a train before entering a tunnel (prevention). Additionally, trains can be specified to keep traction and braking capabilities even with a fire on board for 15 min and for a speed of 50 mph. Such trains can reach an exit portal or a location in a tunnel where evacuation is facilitated.

Also, way-side monitoring is becoming increasingly important, allowing to stop trains entering a tunnel. These systems are not limited to fire detection; they are used for landslide/mudslide detection, chemical detection, earthquake or wind detection – these latter ones allow trains to slow down before reaching the exit portal.

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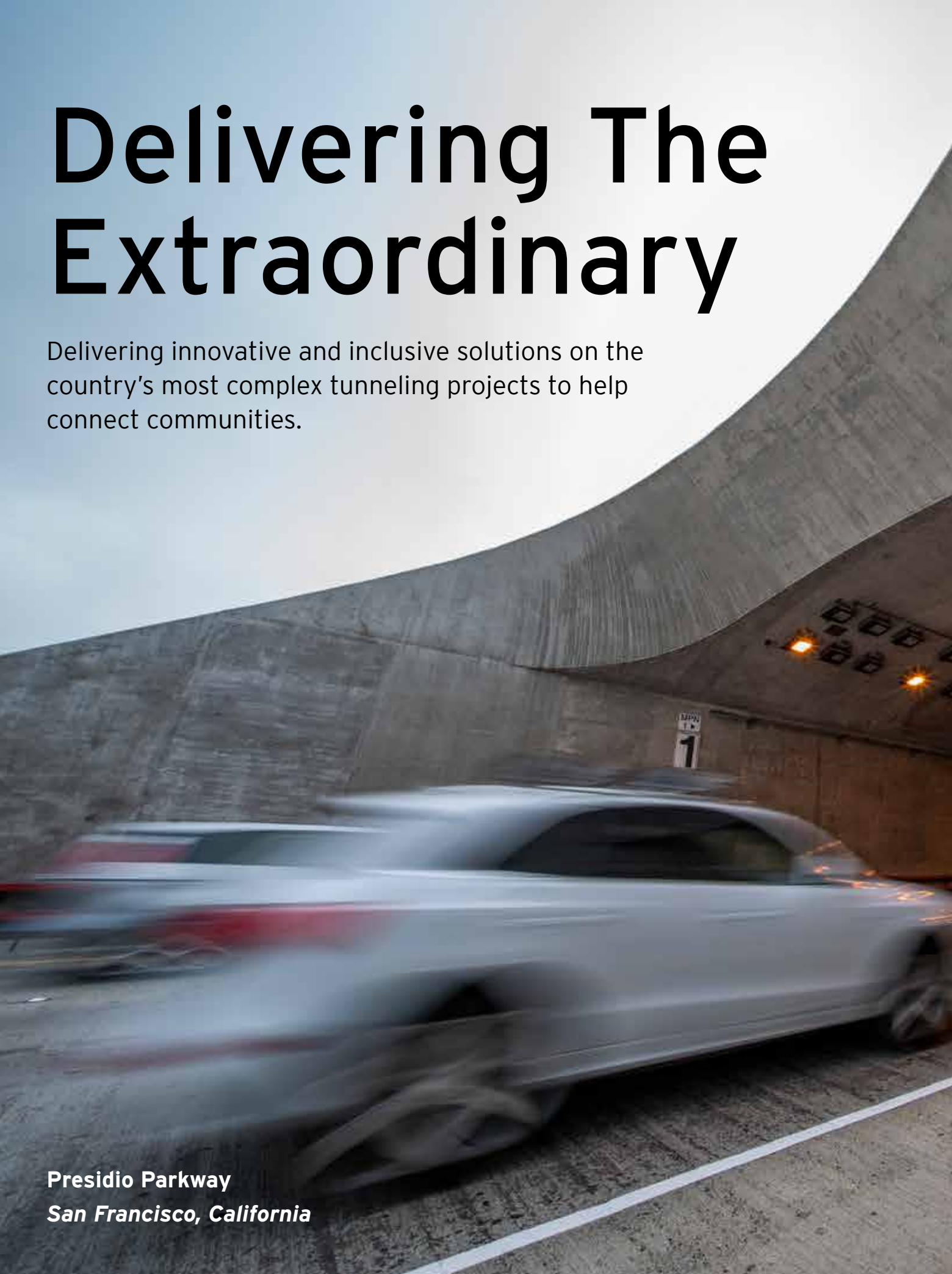

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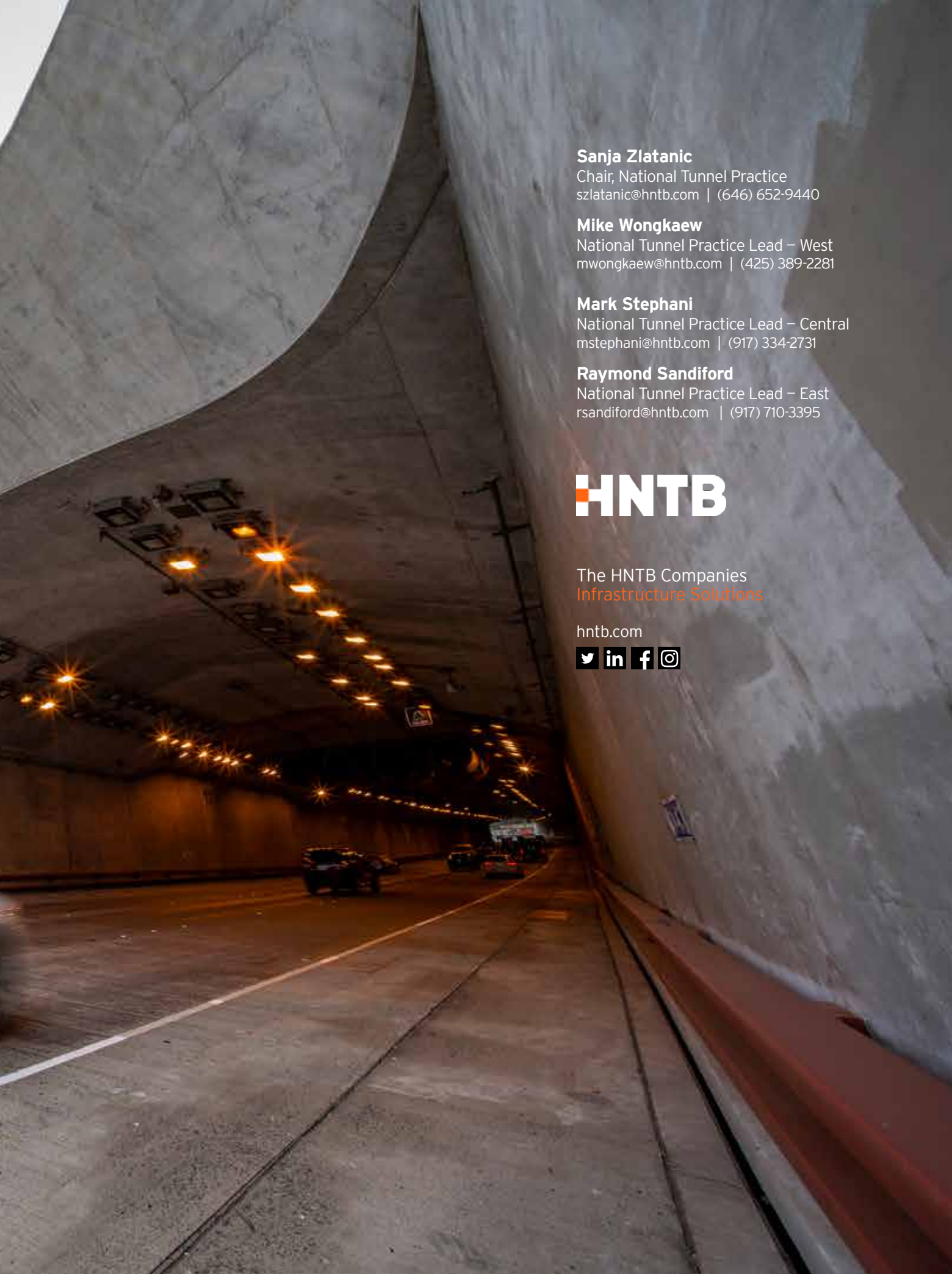

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Northgate Link Extension, Seattle, WA, ground freezing for groundwater control and support of excavation

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



PIONEERING UNDERGROUND TOGETHER

With the experience of more than 5,700 projects, Herrenknecht is a technology and market leader in the area of mechanized tunnelling technology. Herrenknecht is the only company world-wide 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 1,185 million euros in 2021. The independent family-run business employs around 5,000 people worldwide, including around 200 trainees. With around 70 subsidiaries and associated companies working in related fields in Germany and abroad, Herrenknecht is able to provide a comprehensive range of services close to the project site and the customer, quickly and in a targeted way. Under the umbrella of the Herrenknecht Group, a team of innovative specialists offers integrated tunnelling solutions with project-specific equipment and service packages upon request: separation plants, belt conveyor systems, navigation systems, rolling stock systems as well as segment moulds and even turnkey segment production plants.

As a reliable project partner, Herrenknecht supports its customers with an extensive range of services from the beginning of the project to breakthrough. From the initial project idea through manufacturing, transport, assembly, tunnelling support and spare parts service to disassembly, Herrenknecht accompanies the process at the customer's side. Even personnel solutions for the temporary supplementing of jobsite crews are provided if required. With competent service specialists and more than 45 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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EarthGrid

EarthGrid has invented plasma tunnel boring robots (think Star Wars light sabers) that are electric-powered, use no water, drilling mud or chemicals, have zero emissions and can bore tunnels 100x faster at up to 70% lower cost versus conventional techniques.

EarthGrid's Plasma Trenching System and Tunnel Boring Robots can bore through hard rock (proven in very hard 360 MPa basalt) at speeds ranging from 300 meters (3 football fields) to 1,000 meters per day, with diameters of 1 meter to 2.5 meters. There are (2) products available:

- BOOM - Build, Own, Operate & Maintain, for customers who prefer to lease space from EarthGrid in a tunnel or trench (EarthGrid covers 100% of permit & construct costs); or
- BADASS - Boring And Drilling As a Simple Service, for customers who want to own the tunnel/trench but want EarthGrid to provide a cheaper, faster solution.

EarthGrid is approved as a utility in 20 states, representing >60% of the US population, allowing EarthGrid to obtain access to public rights of way for its tunnels and trenches.

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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 as well as 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 t on 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 as well as drill and blast 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. This 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.

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Terratec

Incorporated in 1990, TERRATEC is a world renowned designer & manufacturer of Tunnel Boring Machines, encompassing all ground conditions and diameters – ranging from 0.60 to over 16 metres – as well as TBM back-up equipment, Raise Boring Machines and other custom-engineered products for the tunnelling and mining industries. TERRATEC's success is based on the experience and excellence of its global engineering team. TERRATEC is also fully managed by engineers enabling quick and efficient solutions that meet customer expectations.

TERRATEC products are well-known in the industry as Robust, Durable and Safe, basic principles that must prevail in the design of any equipment made to work in the extreme conditions encountered underground. As a provider of Total Tunnelling Solutions, TERRATEC's scope of work extends to custom engineering, as well as the operation and maintenance of tunnel boring equipment and the supply of ancillary equipment.

TERRATEC's capacity to provide a wide range of services means that it is not only an equipment supplier but a qualified and experienced partner in the execution of tunnelling works.

As a result, it is becoming more and more common for TERRATEC to supply a Total Tunnelling Solution package consisting of the TBM/s, other main equipment in the tunnel (Trains, Conveyors, Segment Moulds and Ventilation), spares and consumables for the equipment and a team of TERRATEC field personnel who can assist in the operation and maintenance of the supplied equipment throughout the duration of the project.

TERRATEC offers full range of equipment from pipe jacking machine to open TBM, soft ground to very hard rock machine. TERRATEC's continuing success on global projects is a result of tailor-made robust TBM design, prompt onsite assistance, readily available stock of TBM spares and highly-skilled specialised TBM support throughout tunnelling operations.

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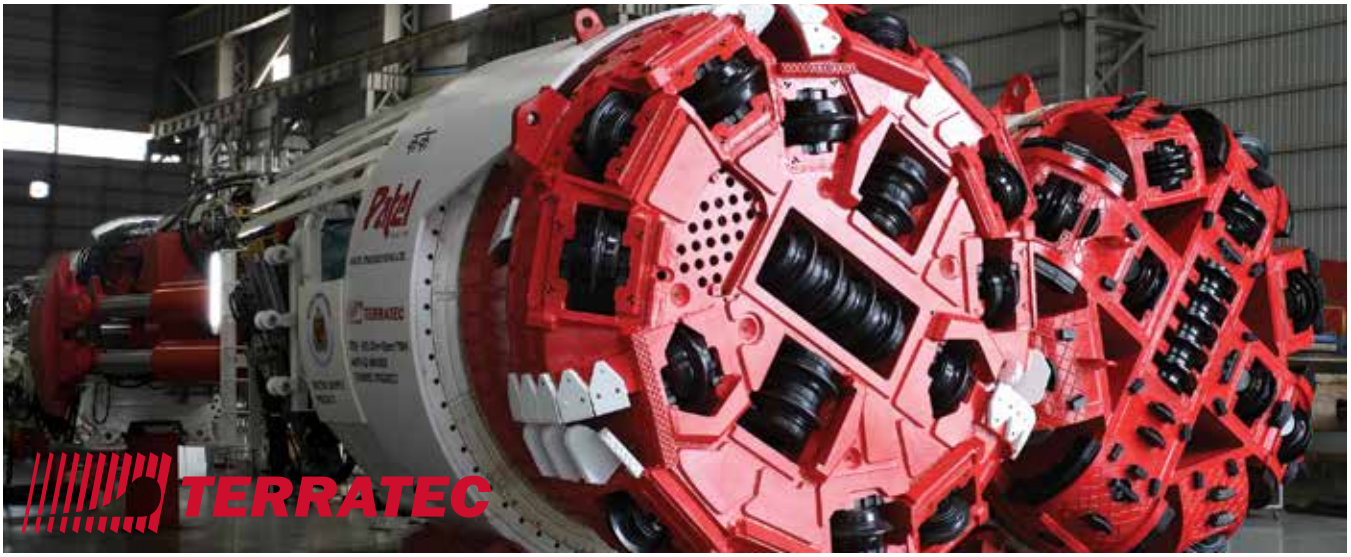

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JENNMAR continues to grow, but our focus will always be on the customer. We feel it is essential to develop a close working relationship with every customer so we can understand their unique challenges and ensure superior customer service. Our commitment to the customer is guided by three words: SAFETY, SERVICE, and INNOVATION. It's these words that form the foundation of our business. It's who we are.

JENNMAR Civil, a brand of JENNMAR has been working on some exciting projects over the past year. See photos and description below:

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JENNMAR Civil and Turnstone Industrial Solutions are excited to be a part of the design-build Atlanta Plane Train Tunnel West Extension Project at Hartsfield-Jackson Atlanta International Airport, where JENNMAR Civil supplied lattice girders, bolts, and shaft ground support products to reinforce the terminal and sky train above.Turnstone Industrial Solutions LLC. supplied ventilation and tunnel liner.

The project includes extending the current automated people mover system and renovating the baggage claim facility increasing its passenger capacity from 10,000 an hour to 12,000 an hour. JENNMAR Civil and Turnstone Industrial Solutions LLC. are proud to be on-site for this The City of Atlanta project.

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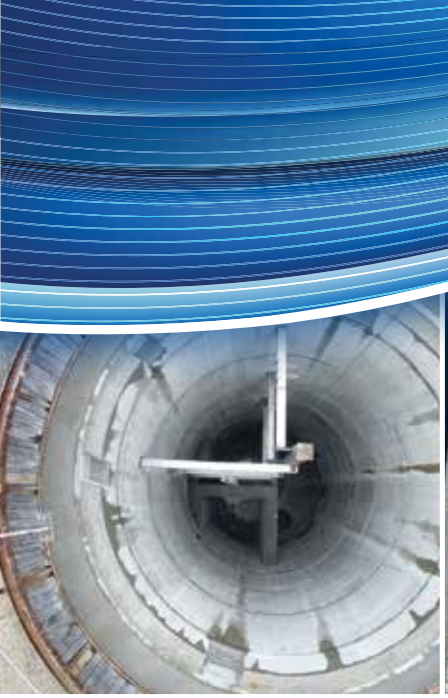




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MAPEI Corporation

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

The UTT group is a successful division of MAPEI Group, which has provided proven construction system solutions for more than 80 years. Established in 1937, MAPEI Group is a global corporation, based in Milan, Italy, and with 91 subsidiaries that include 84 plants in 35 nations. 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.

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

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

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

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

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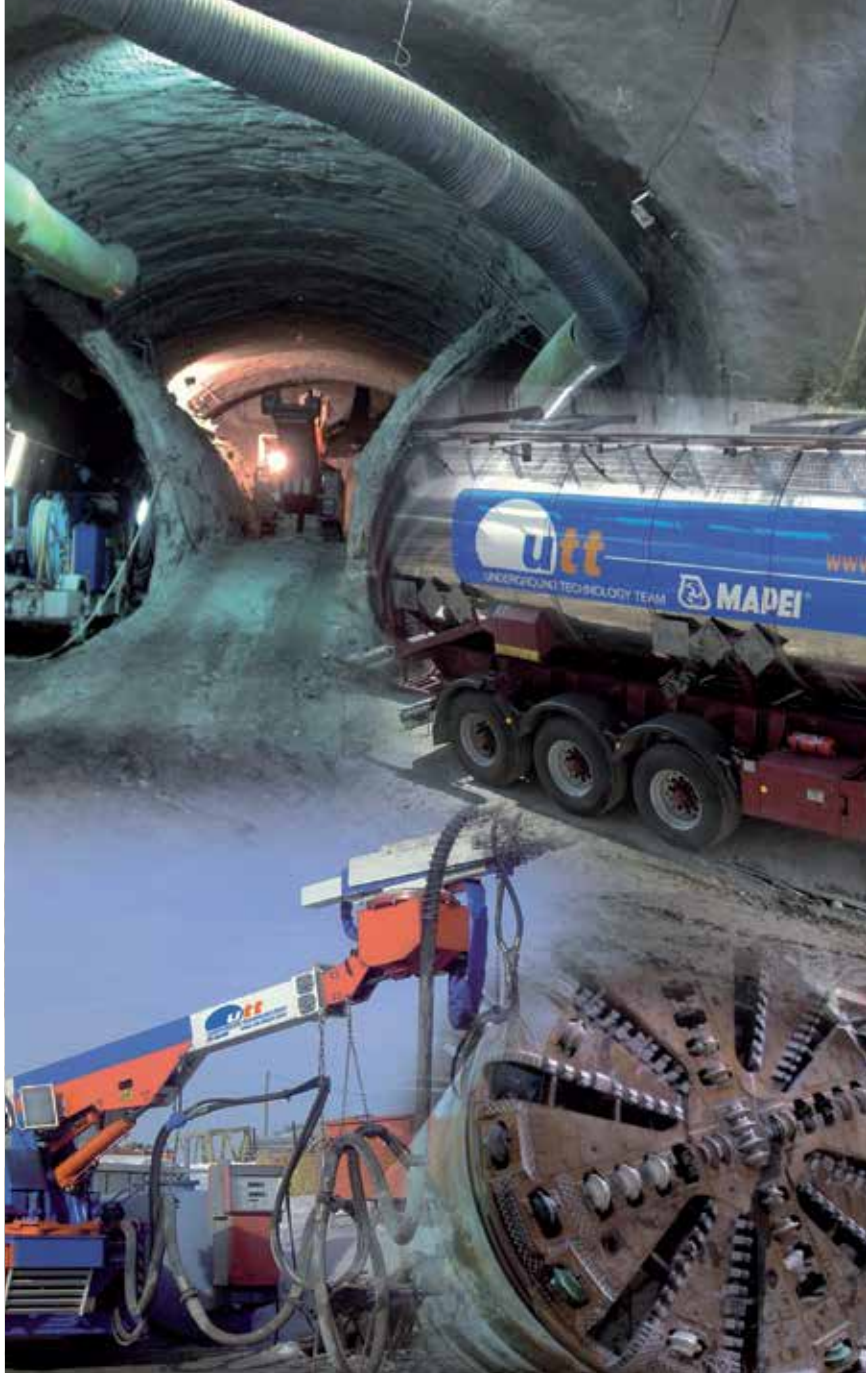
Underground Construction



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Protecting the 'New M4' East Tunnel

About the Tunnel

The 'New M4' East (M4E) tunnel project is located in the inner west of Sydney, Australia. The M4E tunnel is a twin tube design of 3 lanes in both directions. Each tube is 5.5 km (3.4 miles) in length. Therefore, the project has approximately 11 km (6.8 miles) of tunnels in total. The tunnels are divided into 517 fire deluge zones along the entire length, including the covered entry & exit ramps. Each fire deluge zone is approximately 30 meters (98 ft) long. The tunnel is equipped with fibre optic detection that signals a central monitoring station. Each deluge zone is monitored by operators and manually activated.

When the specifications for the project were being developed, the design brief called for "an extended coverage nozzle that could effectively deliver 10 mm/min (0.25 gpm) density". At the time, no such product was commercially available. In response to this requirement, the Reliable® model TNL280 nozzle was developed.

About Deluge Systems

Deluge systems consist of water supply, a valve, a system of piping and nozzles that are open to atmosphere, and a means of detection and actuation. When the deluge valve is activated, water flows through all nozzles controlled by the valve. Unlike automatic sprinkler systems, where water flows only through individual sprinklers that have activated close to the heat source, deluge systems are designed to "surround and drown" an entire zone to prevent the spread of fire in hazardous environments.

About the TNL280 Nozzle

The Reliable TNL280 pendent nozzle has been specifically designed to provide an extended coverage nozzle suitable for use in vehicle tunnels. Key to the design of the nozzle is a very large K-factor (orifice size). The large nozzle coverage area typically results in lower installed costs by reducing the amount of material (pipe and hangers) and facilitates faster installation. By comparison, traditional tunnel nozzles — usually spaced at around 9 m^2 (97 ft^2)— are much more material and labour intensive.

Project Quick Facts:

- Consulting Engineer: Norman Disney Young (NDY)
- Site Engineer: Jessica Keogh
- Number of Deluge Systems: 417
- Tunnel height: 5.3m (17.4 ft)

Learn More:

Reliable Automatic Sprinkler Co., Inc. is a manufacturer and distributor of fire protection equipment. Reliable manufactures the highest quality and most innovative fire sprinklers, valves, and special systems on the market. Reliable also distributes a full line of best-in-class system components. All Reliable products are backed with premier customer service. Reliable's corporate headquarters is located in Elmsford, NY with manufacturing headquarters in Liberty, SC. Regional sales and distribution centers are located throughout the US and around the world.

For more information on Reliable® products, systems, and innovation, visit our website at www.reliablesprinkler.com/tunnels

Disruption is not an option

Reliable® Tunnel Deluge Systems protect your most critical infrastructure assets

Reliable deluge systems are the perfect solution for the challenges of tunnel environments:

- The Model DDV Diaphragm Deluge Valve is simple to maintain and rated for pressures up to 400 psi (27.6 bar). Available with a remote resetting pressure regulating option, the Model DDV features a compact footprint and can be installed in any orientation.
- The industry-leading low-pressure/high density TNL280 nozzle features a corrosion-resistant Electroless Nickel PTFE (ENT) finish and anti-reflective black paint topcoat.

TNL280

Over 100 Years of Reliable Experience

Reliable Automatic Sprinkler Co., Inc. has been a trusted source for high-risk fire protection solutions since 1920. Our manufacturing headquarters are in Liberty, South Carolina, USA, while our Sales and Technical Services teams span the globe.

Reliable®

Manufacturer and Distributor of Fire Protection Equipment

Contact our Technical Services team to identify the ideal solution to your specific need—no matter what the challenge.

reliablesprinkler.com/tunnels

DSI Underground

Reinforcing Progress - DSI Tunneling LLC.

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

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

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

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

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

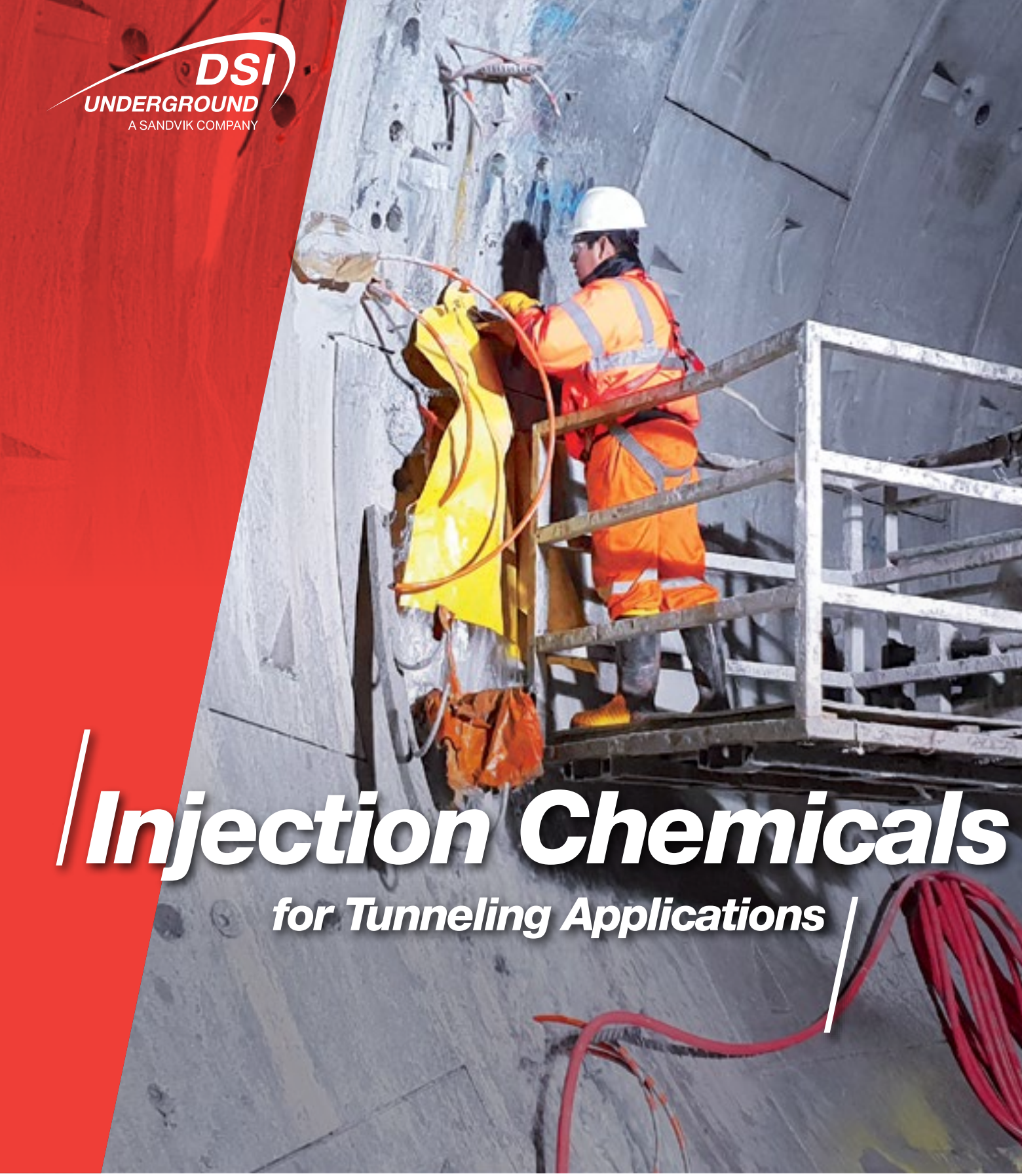
When you're tackling a seemingly insurmountable objective, facing tons of rock and earth, and need the skills and knowledge to achieve it, we're with you. We understand the complexities and considerations, the depths and dangers far below the ground - and we work with you to navigate them, taking you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

DSI Tunneling LLC. Reinforcing progress.

DSI UNDERGROUND

www.dsiunderground.com
502.473.1010

DSI
UNDERGROUND
A SANDVIK COMPANY



Injection Chemicals

for Tunneling Applications

We design and develop flexible and safe ground support products, that are produced in house with high quality standards and norms. To provide only the best quality to our customers we are continuously monitoring our products and systems. Our product portfolio includes Resin Cartridges, Silicates, Acrylic, Polyurethane Resins and Phenolic Resins.

DSI Tunneling LLC
502-473-1010

dsitunneling.com
dsiunderground.ca

Derrick Corporation

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. 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 markets worldwide. We have an extensive network of thousands of cohesive individuals located across the globe.

SERVING THE CIVIL INDUSTRIES

Derrick has offered premium slurry separation and desanding equipment to the worldwide Microtunneling, Diameter Tunneling, Slurry Wall/Foundation Drilling, Horizontal Directional Drilling, Hydrovac Mud Processing, Water Well Drilling, Dredging and other Civil Construction Industries for over 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 THAT 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 the 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:

- Non-production time
- Hauling and disposal of solids-laden drilling fluid
- Cost of drilling fluid and chemicals
- Water usage and hauling
- Wear on downstream pumps, plumbing, and other equipment
- Environmental impact

Visit us at **www.Derrick.com** to discover more.

Derrick Corporation
15630 Export Plaza Drive
Houston, Texas 77032 U.S.A.
Office: (281) 590-3003
Email: Info@derrick.com
www.Derrick.com

SCREENING TECHNOLOGY THAT MAKES A DIFFERENCE.

DERRICK®

CONVENTIONAL FLAT SCREEN
SOLIDS IMPEDE FLUID FLOW

CORRUGATED PYRAMID SCREEN
ENHANCED PERMEABILITY

Gravity and vibration force the solids into the corrugated screen's troughs, thus allowing more fluid to pass through the top of the screen.

Derrick has revolutionized screening technology with the patented **Pyramid Plus™ (PMD+)** screens. These three-dimensional screens offer the benefits of traditional flat multi-layered screens while adding a significant increase in usable screen area, fluid handling capacity and in some cases, an increase in rates of penetration.

Hyperpool® shakers with Pyramid Plus screens also provide an easy, cost effective difference in shaker performance. Designed with the latest technology, Derrick API RP 13C compliant Pyramid screens allow underground construction contractors to screen finer faster, thus significantly reducing operating costs and improving downhole production.

www.Derrick.com

HYPERPOOL® SHAKERS

Miller Contracting

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

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

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

MILLER

MILLER is a family owned and operated company that was founded in 2001. We started out doing residential, light commercial, and agricultural concrete. With our location in the Illinois Coal Basin, we soon had opportunities to do projects in coal mines. Since then we have shifted our focus entirely to the industrial and mining sectors. Today we have projects across the United States, reaching 21 states but are always looking to add states and countries and are in all types of mining! This includes salt, limestone, trona, frac sand, and coal mines, as well as heavy industrial construction for aluminum plants and other manufacturing facilities.

Our high quality contracting services include: shafts, fans, hoisting, complete portals, foundations, and declines. As well as custom projects to meet each customers particular needs. We are an innovative company that approaches each project with an out-of-the box attitude aimed at efficiency, higher quality, added value, and safer job sites.

Our most important resource is our people and and we believe there is no "I" in "Team".

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

for more information please visit our website: millercontracting.us

Innovative Onsite Concrete Production Equipment for Rent

OUR SERVICES, EQUIPMENT & PARTNERSHIP

GALLOVICH CONSULTING LLC, with over 20 years of professional experience in American Concrete Industry and the support of a concrete machinery manufacturer, Fiori Group SpA, a worldwide leader known for its history and industry leadership of over 70 years, brings to the market the most innovative onsite concrete production and transportation solutions with our Simple Rent or Rent-to-Purchase program.

Our fleet is exclusively made by FIORI GROUP SpA, always keeping equipment new or with few hours, providing maximum performance experience to customers.

Fiori Group SpA has its headquarters in Finale Emilia (MO) Italy, that designs, develops and manufactures off-road Concrete Batching Vehicles and Dumpers for the construction industry. The company's product portfolio is rounded off by the Group's capabilities in finding the most effective solution for any customer in making and transporting concrete on-site with great flexibility, minimizing energy costs and reducing environmental impact.

Let us help you to set up your concrete production and transportation equipment for your next tunneling project.

info@gallovichconsultingllc.com
P: +1 (786) 762-4068
M: +1 (240) 893-6580
8333 NW 53rd Street
Suite 450
Doral, FL 33166

Premier Pipe Systems Manufacturer for Over 95 Years

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

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

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

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

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

Every length of Naylor Pipe is inspected and where required hydrostatically tested to applicable ASTM specifications. The pipe is available in lighter weights than other pipe making it possible

to save money, not only on initial cost, but also in transportation, handling and installation. By sizing the diameter of the pipe to the exact requirements, with exact lengths and factory-sized ends, the greatest economies can be realized.

Quotations are immediately available on inquiry.

Naylor Pipe Company
1230 East 92nd Street
Chicago, IL 60619 USA
Tel: 1-773-721-9400 Fax: 1-773-721-9494
Email: sales@naylorpipe.com
www.naylorpipe.com

Drill Tech Drilling & Shoring, Inc.

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

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

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

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

Crux Subsurface - New Look, Same Innovative Solutions

In 2022, Crux's brand received a much-needed refresh. While our core competencies of providing quality drilling services to logistically challenging projects will never change, our service offerings have expanded to include so much more than this.

Our multidisciplinary team has grown to include the expertise of structural, civil and geotechnical engineers, along with experienced construction managers, geologists and GIS database specialists. Our service offerings have grown in tandem to include a suite of geotechnical exploration, subsurface construction, engineering, and EPC foundation services. Combined with a change in leadership, Crux has had a year full of development and growth, which has expanded our opportunities and continues to allow us to provide unmatched services to our clients. The transition away from our original borehole logo and toward a more updated look is intended to represent this growth and a continued commitment to forward thinking and innovation across every industry in which we work.

Project highlight: Recent tunneling projects include providing pre-excavation ground freezing services for the Northeast Boundary Tunnel project in Washington DC. The new tunnel connects with the existing DC sewer system and was commissioned to mitigate sewer flooding in the area. Working with two different construction partners over the course of two years, Crux successfully installed 72 permanent horizontal casings to support ground freezing. Challenges included drilling below the water table in soft soil conditions, as well as accessing the work location within a congested DC neighborhood.

Kiewit

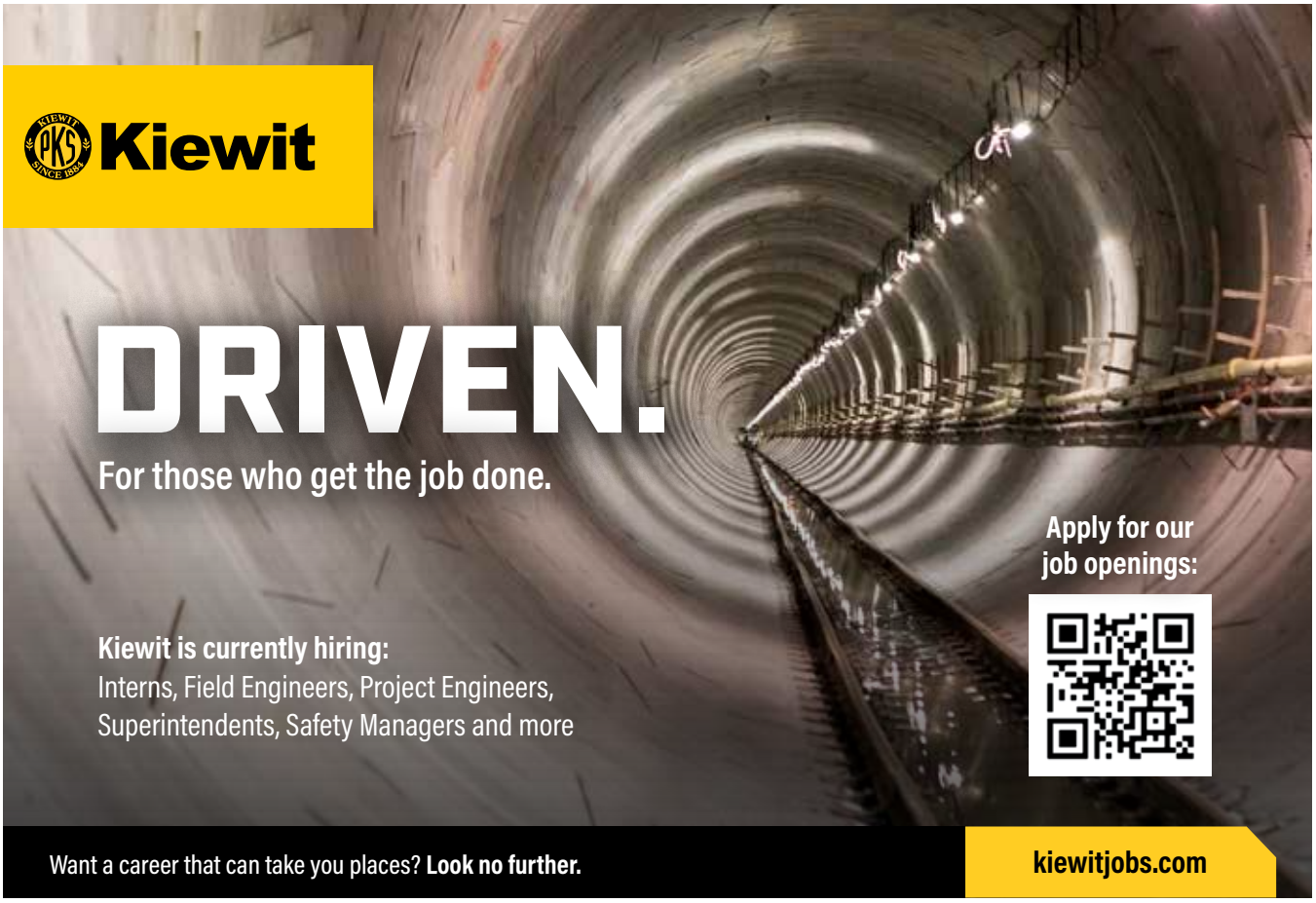
As a construction, mining, and engineering leader, Kiewit is a FORTUNE 500 company consistently ranking in the ENR's Top 10 Contractors. Kiewit is owned by active employees, creating a level of motivation that keeps the company on top. Kiewit, through its operating companies, brings a wealth of diverse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

Kiewit has built some of the most complex tunneling and underground projects for more than 60 years. We self-perform soft ground and hard rock TBM tunneling, along with conventional tunneling techniques such as SEM and Drill and Blast, and trenchless technologies such as MTBM and HDD. As one of North America's largest and most respected construction and engineering organizations, Kiewit's underground capabilities offer clients unique advantages to navigating complex, challenging projects from engineering and design, through construction.

We're hiring. Go to kiewitjobs.com to learn more.

Kiewit

Kiewit Infrastructure Co.
1550 Mike Fahey St.
Omaha, NE 68102
(402) 346-8535



CDM Smith – A Leader in Tunnel Engineering

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
- Geotechnical engineering
- Geotechnical data & baseline reports
- Lining & structural engineering
- Numerical analysis
- Ground improvement & ground freezing design
- Deep excavations & ground support design
- Groundwater modelling & control
- Soil and rock testing

To support our clients, we offer comprehensive consulting, engineering, and construction support services.

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
- Environment
- Water/wastewater
- Mining

Award-Winning Projects

MEED Project Award (2020), International Project of the Year, Ismaïlia Tunnels under Suez Canal

ENR Global Best Projects (2017), Best Water/Wastewater, Abu Hamour Surface and Groundwater Drainage Tunnel

ACEC Engineering Excellence Award (2018), New York Harbor Water Siphon

Contacts:

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

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

Normet - Defining the Future Underground.

The underground future built on three pillars, which highlight our expertise and focus:

1. Securing a safe and sustainable future – means building the safest places underground while minimising the impact to the environment and is committed to exceeding industry standards.

2. Innovating for Performance – means delivering productivity with leading-edge solutions and technology.

3. Partnering for the Future – means that our whole team is committed to our customers' goals, and we build capacity for agile cooperation.

We work in close collaboration with our customers. The process expertise amassed over thousands of mine and tunnel projects all over (and under) the globe translates into experience and expertise about what should and should not be done to achieve the optimum results. We utilise our process expertise into concrete actions and financial results for our customers.

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 and water control, 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, remanufacturing and upgrades, performance and field services.

Normet has delivered over 14,000 built-for-purpose underground machines which are serviced and supported with a broad service portfolio.

Normet currently employs over 1600 business professionals with a passion for doing "big" things for its customers and for the industries which the company serves.

Normet is a Finnish company operating globally with over 50 locations in 33 countries worldwide. This breadth allows rapid response and reliability to all customers whenever and wherever in the world they may be. Company revenue in 2020 was over 300 M€.

Brokk 200 Packs the Power of a 3-ton Machine Into a 2-ton Package

Brokk Inc. has been the world's leading manufacturer of remote-controlled demolition machines and attachments for 45 years. Through continuous innovation in engineering and design, Brokk is able to offer unique solutions to multiple industries worldwide, including construction, demolition, mining and tunneling, cement and metal processing, nuclear and other specialty applications.

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

For more information: Brokk Inc., 17321 TYE Street SE, Suite B, Monroe, WA 98272; 800-621-7856; info@brokkinc.com; www.brokk.com; Facebook:@BrokkUSA; YouTube: @BrokkIncUSA; LinkedIn: Brokk Inc.; Twitter @BrokkUSA; and Instagram: @BrokkUSA.

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

STRATA WORLDWIDE BRINGS BORAID® DIRECTLY TO TUNNEL BUILDERS

Traylor Bros., Inc is a heavy civil construction company with decades of extensive experience throughout North America. They specialize in TBM tunneling, the sequential excavation method (SEM), and drill and shoot excavation.

Traylor Bros. experts employ state-of-the-art technology to deliver projects in every type of ground. TBM tunneling methods include mixed shield/slurry, earth pressure balance and hard rock tunnel boring.

In earth pressure balance (EPB) applications, special soil additives are typically used to assist with and optimize the TBM mining. These ground conditioners create more stable, cohesive conditions, which in turn improve the speed and efficiency of production and help to protect the TBM and its components from excessive wear and tear.

The team of skilled engineers at Traylor Bros. crafted these conditioning agents and polymers to meet specific customer needs and solve specific problems. Over the years, they have successfully formulated a collection of Boraid® ground conditioning agents.

- Soilax®-S – A concentrate for sands and silts.
- Soilax®-AC – An "anti-clay" concentrate that converts clay into perfect EPB muck.
- Soilax®-P – A water-absorbent polymer that is used in sandy, high-water content ground to help to improve muck consistency.
- Bert's Drillin' Juice – Specially formulated concentrate for sands and silts that was developed in response to difficulties experienced in specific conditions.
- Soilax®-DF.L – A recently developed agent designed specifically for neutralizing unwanted foam bubbles.

"Foam ground conditioners typically used for TBM tunneling sometimes cause unintentional bubbles in sumps and dewatering systems," states Josh Jonasen, Mechanical Engineer for Traylor Bros.. "We developed Soilax DF.L to combat these unwanted bubbles."

The Soilax® DF.L can be sprayed over the affected area or can be added to sumps and tanks where affected water is stored.

"At Traylor Bros. we use a combination of technological knowledge and applied experience in developing the soil additives, and continually adapt and modify them to work in differing conditions." stated Chris Hebert, Vice President and Underground Division Manager for Traylor Bros. "They are not solutions formulated in labs, but rather tested, used and proven in the field on real projects."

In 2021, Traylor Bros. selected Strata Worldwide to exclusively represent the Boraid® line and the companies jointly announced their new partnership agreement in November. Previously not sold directly to the market, the Boraid® line has been available through Strata, being sold directly to tunnel builders. This includes all soil conditioners, polymers and the Brush Butter TBM shield sealant.

"It has been very effective working with Traylor Bros. to bring the Boraid® line directly to market," states Mike Rispin, VP of Tunneling for Strata Worldwide. "For Strata, it is not only about offering the products and technologies, but also about bringing expertise to help solve problems."

For more information please contact Mike Rispin at: 385-234-1474 or email us at: info@strataworldwide.com.

www.strataworldwide.com/tunneling

BORAID

STRATA WORLDWIDE

David R. Klug & Associates, Inc.

Since 1996, David R. Klug & Associates, Inc. has provided international and national manufacturer's 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 Nittetsu ultrafine cement, GFRP rock bolts and soft-eyes, steel and synthetic fiber reinforcement, prefabricated welded wire fabric and rebar reinforcing panels, and specialty grout systems for various tunnel backfill grout requirements for highway, rail, subway, water and CSO tunnel construction applications.

David R. Klug & Associates, Inc.
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Wheeling, WV 26003
Tel: 304-905-8932
Fax: 304-905-0154
Cell: 304-281-4239
E-mail: jklug@drklug.com
Website: www.drklug.com

Michels Construction, Inc.

Michels Construction, Inc.'s foundations capabilities serve the deep foundation, ground improvement and earth retention requirements of the energy, heavy highway and building trade industries.

As one of North America's largest infrastructure contractors, Michels Construction's design-build capabilities ensure cost effective, engineered solutions for even the most complex deep foundations projects. Look to us for a variety of foundations work including Secant Drop Shafts, Temporary ERS, Augercast Piles, Micropiles, and more. Our in-house professional engineers can design temporary and permanent solutions that are cost effective in any soil condition.

We are conditioned to operating on challenging sites, including urban, high-traffic, low-headroom and off of barges. Our specialized equipment can meet any subsurface and site access conditions.

Safe access is a critical aspect of many underground construction projects. Michels Construction builds and designs shafts to the specific size and depth you need to supply crews, material and equipment to your work area.

Contact us today at 920.583.3132 or visit www.Michels.us.

EOE/AA/M/F/D/V

Infrastructure. Delivered.

Whether building new or maintaining existing, we enhance North America's infrastructure. It takes strength, adaptability, and the alignment of your goals and ours.

Challenging projects require the dedication and skill of true pioneers.

That's what we deliver.

MICHELS®
CONSTRUCTION, INC.

An Energy & Infrastructure Contractor

www.Michels.us

Reliable hands free charging

Stäubli provides a universal solution for automatic charging of electric mining equipment with its innovative **QCC** (**Quick Charging Connection**). For high power charging systems designed to stand up to the harshest environments, the Automated Connection Device (ACD) makes it possible to **transfer high levels of power (1MW+)** which ensures fast recharging of energy storage devices such as Li-Ion batteries and super capacitors.

The **high efficiency** and **reliability** of the QCC means less maintenance with decreased down time. The ability to quickly charge with the QCC allows manufactures to offer smaller onboard battery packs so that machinery can better serve its intended purpose – to transport the weight of ore, not the weight of extra batteries.

To find out more about the QCC solution, scan the QR code or call us at
+1 707 838 0530
www.staubli.com/en-us/

STÄUBLI

Connection solutions designed for safety and reliability

Stäubli Electrical Connectors meet the highest standards in even the most demanding and competitive industries, where absolute performance, safety, durability, reliability and efficiency are crucial.
High performance, long-term reliability and highest mating cycles for the connection of all types of industrial applications. We calculate our solutions for maximum reliability in the harshest environments.
With its innovative connector for high power charging systems the QCC by Stäubli provides a universal solution for automatic charging of various kinds of electric vehicles (Mining equipment, AGVs, buses, trucks, etc.). The automated connection device (a so-called ACD) makes it possible to transfer high levels of power, which ensures fast recharging of energy storage devices such as Li-Ion batteries and super capacitors. The QCC offers high efficiency and low maintenance requirements. The amount of stored energy required is reduced due to quick recharging stops, which enables the vehicle to better serve its purpose – transport of the weight of goods, not the weight of batteries.

Working closely with our customers, both conceptually and geographically, we assist with the most uniquely demanding tasks of our longstanding partnerships. Our customers' requests or project requirements are processed quickly, creatively and competently. These collaborations motivate us to move forward and constantly improve our products and services. Innovation is the driving force, which supports us to start trends and set standards.

Contact Info:
PH: +1 707 838 0530
Email: ec.us@staubli.com
Web site: https://www.staubli.com/en-us/electrical-connectors/multi-pole-connectors/e-mobility-connection-solutions/qcc/
Video: https://youtu.be/WEQHFK8Zt2w

Brookville

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

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

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

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

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

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

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

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

Northwest Laborers-Employers Training Trust
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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.

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Gall Zeidler Consultants

Gall Zeidler Consultants is an international engineering consultancy firm specialized in innovative solutions for tunnel and underground projects. For over 20 years, we use our broad

expertise in transportation, infrastructure, water conveyance, energy and mining projects to help our clients overcome challenging conditions and providing innovative solutions from conceptual and planning phases through construction and operation.

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With our diverse team of experts and professionals, we are represented in all major global markets in North America, Latin America, Europe, Asia and Australia.

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Kelley Engineered Equipment

Kelley Engineered Equipment (KEE) celebrates their 15th anniversary of supplying custom equipment and professional engineering services to the tunneling and underground construction industry. KEE provides innovative, efficient designs optimized for safety and productivity. A growing team of 40+ professionals and a Seattle office staffed by TBM experts, the Kelley team has professionals with decades of underground experience, PE Licenses in 10 states and more on the way. KEE accepts your challenges and provides solutions with unmatched quality and customer support.

Contact KEE for: Tunneling Equipment, below-the-hook lifting systems, gantries, pipe carriers, mucking systems, trailing gear, custom tunneling shields, custom hydraulic attachments, conveyors, lift cars, equipment modifications, heavy load handling, custom cranes, personnel access systems and bespoke engineered solutions.

KEE is proud to represent Terratec TBMs in the USA and Canada along with Roxard Industries' TBM Cutters and Soft Ground Tools in North and South America.

HAGER-RICHTER GEOSCIENCE, INC.

HAGER-RICHTER GEOSCIENCE, INC. (HRGS) is an established small business that specializes in surface and borehole geophysical services for engineering and environmental applications (NAICS 541360). The firm has been in business since 1984, has grown to be one of the largest full service geophysical specialty firms in the eastern United States, and has earned a national reputation for quality geophysical services. HRGS specializes in surface and borehole geophysical services for the support of large-scale tunneling projects including Phases 1A and 1B of the MWRA Tunnel Redundancy Program as well as tunneling projects of similar scope and size throughout the eastern US and beyond. HRGS has fully staffed and equipped offices in Salem, New Hampshire and Fords, New Jersey, and the firm owns the equipment it normally uses so that it does not rely on the rental schedules of others, allowing rapid response to projects throughout the United States. HRGS works exceptionally well as a member of a team providing specialty geophysical services that complement the expertise of clients and other project team members.

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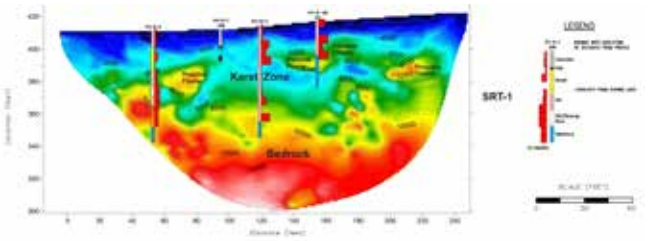

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Kilduff Underground Engineering

Kilduff Underground Engineering (KUE) was established in 2014 to support contractors, A/E firms and owners nationwide. The firm specializes in underground design with a specific focus in the design, inspection and rehabilitation of tunnels with sizes ranging from 12-inches up to 60-feet in diameter. KUE is capable of designing tunnels utilizing all available technologies to excavate and support the proposed opening. Additionally, the firm provides standard geotechnical design services, deep excavation support designs (SOE), claims support, construction management services, as well as designs, installs and monitors geotechnical instrumentation.

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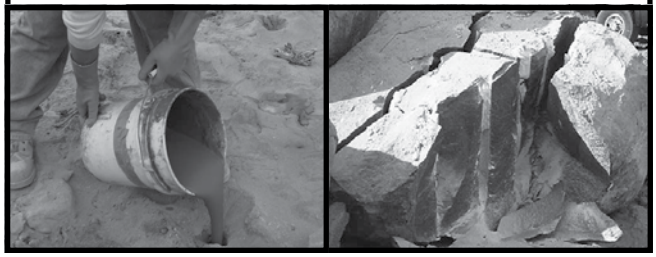

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Daigh Co. is the supplier of Dā-mite Rock Splitting Mortar. Dā-mite is used to fracture rock and concrete in "no-blast" conditions. Dā-mite is an ideal and effective tool for fracturing mass rock, boulders, trench rock, dimensional stone, concrete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

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Dr. Sauer & Partners

Dr. Sauer & Partners is an independent consultancy specialized in providing the full range of design and construction management services for underground tunnelling and infrastructure projects. The company has nearly 40 years' experience delivering innovative, cost-effective designs, providing solutions for some of the world's most challenging tunnelling projects for metro, highway, water, rail and mining, and in any type of geology.
Services delivered include initial consultation and feasibility studies, final design, temporary works, supervision and construction management, tunnel inspection and condition surveys, rehabilitation, waterproofing and water control, geotechnical engineering, and mining support services. Dr. Sauer & Partners' approach is to work collaboratively and integrate fully with all disciplines (design and construction) on a project to achieve a robust and innovative solution.

Current and recent projects include: Hampton Roads Bridge Tunnel Expansion (USA), Chesapeake Bay Bridge Tunnel (USA), Effluent Outfall Tunnel Los Angeles (USA), Westside Purple Line Extension Los Angeles (USA), Eglinton West Extension Toronto (Canada), Bank Station Capacity Upgrade (UK), Metro M2 Tel Aviv (Israel).

www.dr-sauer.com

Dr. Mole, Incorporated

Doctor Mole, Incorporated is a sole-proprietor consulting practice that was started in January, 2013 when Dr. Brierley stepped down as President of Brierley Associates Corporation. DMI specializes in providing advice to project owners, contractors, and designers about all aspects of the design and construction of underground openings. Dr. Brierley has also been involved with the implementation of scores of subsurface investigations and with the preparation of the Geotechnical Data and Baseline Reports associated with those investigations. As has been noted many times in the project literature, the single-most important aspect of project success for a tunneling project is the provision of accurate and reliable discussions of the ground conditions inside of which the underground openings will be constructed.

DMI is also retained on a regular basis to provide forensic evaluations relating primarily to claims for Differing Site Conditions. Doing "Battle with Mother Earth" is never easy, and when things go wrong during construction it becomes necessary to evaluate what is happening in order to minimize potentially detrimental impacts both to the construction process itself and to existing third party structures and utilities.

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