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Tunnel boring machine innovation
TBM conversion at Mill Creek
George Fox and Cutting Edge recap

All New
Business Profiles
Inside!

Special Editorial Supplement from the publisher of Mining engineering

METRO LOS ANGELES, USA

SUCCESS STORY IN CALIFORNIA WITH 10 TBMS

120 million passengers are travelling through Los Angeles every year. In the past 15 years a total of 10 EPB Shields have been built for more than 35 km of new metro lines. Herrenknecht guarantees the local support with their office in Sumner, WA.

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Client:
- Los Angeles Metropolitan Transportation Authority

Customer:
- Purple Line Section 3 – Frontier-Kemper Constructors, Inc. / Tutor Perini JV
- Purple Line Section 2 – Frontier-Kemper Constructors, Inc.
- Purple Line Section 1 – Skanska / Traylor / J.F. Shea JV
- Regional Connector Transit Corridor - Regional Connector Constructors (Skanska / Traylor JV)
- Crenshaw/LAX Transit Corridor – Walsh / Shea Corridor Constructors
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PIONEERING UNDERGROUND TOGETHER

HERRENKNECHT
Tunnelling Systems

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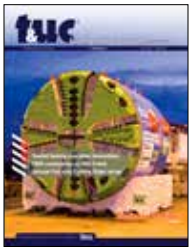

In This Issue

Tunnel boring machine (TBM) manufacturers like Robbins and Herrenknecht have been remanufacturing TBMs for decades. By putting the machines, or the main components, back to work contractors and owners can save money, time and reduce the carbon footprint of tunneling projects. On page 9, representatives from both companies talk about the benefits and challenges of remanufacturing TBMs. Cover photo courtesy of Herrenknecht.

Feature Articles

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Special editorial section from the publisher of Mining Engineering

Mining engineering

The Cutting Edge: Innovation, new technology and moving the industry forward

There is an adage that goes: "If you do what you always did, you'll get what you always got." And while that may be a zone of comfort for some, history shows that it typically leads to stagnation, at best, and demise, at worst. Others might rally to the cry of "change and grow or die," or "evolution is the natural progression." Wherever you may stand in the spectrum, it's hard to argue that innovation, in its many possible incarnations, has made the industry what it is today. Further, innovation has increased the competitiveness of tunneling with other alternatives such as those built on the surface or at elevation.

So, where do we go from here … and how quickly?

It seems clear that the element of risk, particularly in terms of cost, is the primary headwind against innovation. I don't think anyone necessarily innovates for the sake of it but rather because, with different approaches or implementation of new technologies, they visualize a better future state. One should always measure the potential benefit against what could go wrong … but not be paralyzed by it. Fortune also reportedly favors the brave and, for some like the British Special Air Service, it becomes their motto (They who dare, win!). So, by all means, evaluate and mitigate risk but do not reject innovation. You will pay a price in the long term.

A decade ago, the UCA took the innovative step of partnering with *Tunneling Journal* and creating the annual Cutting Edge Conference, a forum conceived with the intent of showcasing novelty, innovation, current issues and future visions in the tunneling industry. I have had the privilege as Chair to be a part of the organizing committees of the last two conferences (2021 in Dallas, TX and 2022 in Long Beach, CA). The feedback received for this two-day, single-track forum has been overwhelmingly and effusively positive. If you have not yet attended, I encourage you to do so in 2023 and beyond. It feels like real momentum is building behind this event.

Michael Rispin
2022-2023 UCA Chair

In 2021, it was my honor to moderate a panel, comprised of one owner, engineer, contractor supplier and academic, to discuss the state of innovation in our industry. We discussed how good or bad we thought we were, what obstacles needed to be removed to foster innovation, and how did we measure innovation and its effects. The discussion was brisk, with great input and perspective from the audience. While celebrating that the industry has moved forward, there was also acknowledgment that our industry tends to be a technology adoption laggard, that cut-and-paste specifications are completely counter to innovation and adoption of new technologies, and that owner bodies tend to be against things that have not been proven somewhere else.

Hey, somebody's got to be first; and then there is the rush to lead the way to be second. In the 2022 conference, there was an engaging

(continued on page 6)

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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.

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President Biden visits New York to announce $292 million in funding for Gateway Tunnel

President Joe Biden announced a $292 million grant to Amtrak to finish the Hudson Yards "tunnel box" concrete casing, a project that was started in summer 2013 to preserve the route of the Gateway Tunnel from Penn Station to the Hudson River as foundations were built for the Hudson Yards project.

The funding for the third and last phase of the tunnel box is from the National Infrastructure Project Assistance program, known as MEGA, which covers 50 percent of the costs of major construction projects of national or regional significance that otherwise would be too large or too complex to receive funding under traditional transportation programs. The program was announced last March.

The *Associated Press* reported that the $292 million mega grant is part of $1.2 billion in mega grants being awarded under the 2021 Infrastructure Investment and Jobs Act.

"We are looking at this as an early action construction project that will move ahead this year," Eric Daleo, chief program officer and Megan Strickland, deputy chief program officer of the Gateway Development Commission said. "It is a critical project that preserves a right of way and allows for development above ground and leads the other packages."

The Hudson Yards Concrete Casing — Section 3 is one of nine nationally significant projects selected for this first year of the program out of 100 applications, U.S. Transportation Secretary Pete Buttigieg said in a statement. This grant will be funded over the course of four years from fiscal year 2022 to fiscal year 2025.

Another early construction project is at the Tonnelle Ave. Bridge. It was the first project that was undertaken 10 years earlier when the project was still called the Arch Project before it was canceled. Daleo said the Gateway Development Commission planned to issue a request for proposal for construction management and invitation for bid for services within a month for the Tonnelle Ave. Bridge.

The Gateway project will renovate the 1910 tunnel that is already carrying about 200,000 weekday passengers beneath the Hudson River between New Jersey and Manhattan, a long-delayed upgrade after decades in which the government underfunded infrastructure. The mega program is expected to invest a total of $5 billion through 2026 to help rebuild the nation's infrastructure.

The $16 billion Gateway Project to build two new rail tunnels and rehabilitate the existing 112-year-old tunnels has been pending since 2011. It took on greater urgency when a 2014 engineering report commissioned by Amtrak warned of deterioration from river water driven by Hurricane Sandy. Train capacity would be cut by 75 percent if one tunnel is shut down for a year to rehabilitate, Amtrak officials said.

"Building the Gateway Tunnel remains the tri-state's most critical large-scale infrastructure priority," Thomas Wright, Regional Plan Association chief executive officer said in a statement. "We applaud President Biden and his administration for recognizing the national economic significance of the project and supporting its advancement through one of the first major Infrastructure Investment and Jobs Act investments in the region."

The project is being overseen by the Gateway Development Corp. New Jersey and New York will fund 50 percent of the cost under a 2022 agreement. ■

Tunnel contract for subsea tunnel in Norway awarded

A joint venture between Switzerland's Implenia and Norway's Strangeland Maskin has been awarded for the world's longest and deepest subsea tunnel.

Implenia will take on the excavation and construction of an 8.6-km (5.3-mile) stretch of the Boknafjord tunnel, while Strangeland Maskin undertakes the construction of a 125-m (410-ft) section of connecting road, as well as the transportation of all excavated material, *Construction Europe* reported.

Implenia said its activities amount to 80 percent of the contract, equating to a value of approximately €304 million.

Erwin Scherer, global head of tunneling with Implenia said, "We are excited to win such a major and prestigious project together with our JV partner Stangeland Maskin.

"The project E03 Boknafjord tunnel is a large and complex infrastructure project in line with our strategy, where we can contribute our many years of experience and proven expertise in tunnel construction and related civil-engineering disciplines."

The wider Boknafjord tunnel project comprises a 27 km (16.7 mile) long roadway, running below the huge Boknafjorden fjord in Rogaland in central Norway.

The responsibility of the Norwegian Public Roads Administration, the tunnel has seen a number of delays and cost increases and has a current completion date of 2033 and a budget of approximately €2.55 billion. ■

Tunnel boring machine for Brenner Base Tunnel ready to begin boring after completing test

Webuild and CSC announced that the Herrenknecht tunnel boring machine (TBM) named Lilia successfully completed the factory acceptance test and is ready to begin excavating one of the longest sections of the main tunnels of the Brenner Base Tunnel on Austrian territory.

The factory acceptance test was conducted at the Herrenknecht workshops at Schwanau in Germany. Lilia is one of the two TBMs that will be used to build Lot H41 Gola del Sill-Pfons. With its twin sister named Ida, with a cutting head more than 10 m (32 ft) in diameter, it will face approximately 8.2 km (5 miles) separating the assembly cavern, at the southern end of the lot.

The H41 Gola del Sill-Pfons, with an overall value of €651 million, was awarded to the Webuild Group last year in a joint venture with Implenia. Building the project will directly employ 400 workers. Webuild is participating in the project with its Swiss subsidiary CSC Costruzioni, with an overall stake of 50 percent in the joint venture. The client is BBT SE, a European-listed company aimed at building the Brenner Base Tunnel, the railway line that will allow overcoming the natural barrier of the Alps between Italy and Austria.

The Brenner Base Tunnel measures an overall 64 km (40 miles) becoming the world's longest railway tunnel. It is one of the most significant priority infrastructure projects currently being built in Europe, a junction of the European SCAN-MED (Scandinavian-Mediterranean) corridor.

Lot H41 foresees a section of the Brenner Base Tunnel in Austria and consists of the construction of the railway from Gola del Sill near the city of Innsbruck in the north to the town of Pfons, located further south. It will excavate 22.5 km (14 miles) of main tunnels and 38 transversal underground passages with an overall length of approximately 2.3 km. The tunnels that have already been excavated in previous lots will also be lined, as well as the underground emergency stop at Innsbruck, the access window, the explorative tunnel and other portions of secondary tunnels.

The construction project of Lot H41 started in January 2022. Currently, the excavation activities of the assembly caverns present in the emergency stop of Innsbruck and building the partition wall of the interconnection tunnels are being carried out.

Webuild is already working on the Isarco Underpass and Mules 2-3 lots of the Brenner Base Tunnel. In Austria, it has already built the Tulfes-Pfons Lot. Webuild is also committed to building the southern access sections to the Brenner Base Tunnels, between Fortezza and Ponte Gardena. ■

TBM named Diggy Scardust launched in Toronto

It has been more than nine years since the Toronto City Council approved the Scarborough subway extension project and now construction has begun.

The tunnel boring machine (TBM) named "Diggy Scardust" was launched in January. Metrolinx officials have said that the machine will create a single subway tunnel with a diameter of 10.7 m (35 ft), which will be large enough to accommodate trains traveling in both directions.

The TBM will advance about 10 m (33 ft) each day, officials said, with crews using a belt conveyor to transport soil and rocks back to the launch shaft site, CP24 reported.

"Today, we have hit another major milestone in delivering this much-needed project. Diggy Scardust, the largest tunnel boring machine ever used for a transit project in Canada, has started tunneling," a spokesperson for Minister of Transportation Caroline Mulroney told CP24.

The 7.8-km (4.8-mile) subway extension is likely still years away from completion with the latest timeline suggesting that it won't be operational until 2030.

The project is expected to host 105,000 daily boardings, including 52,000 by new users. The project will include improved access to transit and jobs while reducing yearly gas emissions by 10 kt (11,000 st).

The City of Toronto has said that it will shut down the Scarborough RT next fall due to the significant costs associated with maintaining the aging rapid transit line.

A portion of the Scarborough RT's right-of-way will be turned into a dedicated busway to help provide supplementary service until the completion of the subway extension.

But that project could take until late 2025 to complete, according to the Toronto Transit Commission (TTC).

The Scarborough RT opened in 1985. It was initially supposed to be replaced by a light rail transit network that would have been completed in 2020 but that project was canceled under the leadership of former Mayor Rob Ford in 2010.

The Ministry of Transportation said that the new Scarborough subway extension will accommodate more than 100,000 daily trips once complete. ■

Chair's column: Innovation drives us forward

(continued from page 2)

panel of owners, with four representatives willing to sit and comment on tunneling from their perspectives, and to entertain questions from the audience. It was asked whether owners would be supportive of first-time innovation on one of their projects. One respondent stated confidently that if it was in respect to means, materials and methods, they would, provided a requisite risk analysis had been completed. A second panel member had a different take with the response being along the lines of "we can only do so much," elaborating that there would be reticence to try things that were not already applied elsewhere.

Contractors tell me that they want to innovate more, particularly where efficiency, cost and/or safety benefits can be realized on their projects at-hand, but that their hands get tied if it is something "new." Engineers may be open to evaluating new technology, but somewhere between avid interest and convincing their client that it is the way to go, enthusiasm gets lost. Suppliers, while happy to provide the tried-and-true, also keenly understand the need to innovate or their business will suffer when the next best mousetrap comes along from a competitor. But there also must be a receptive audience. Does this illustration strike a chord for anyone?

All industry participants have a part to play. Coming full circle, where do we go from here? It seems that in terms of stakeholder awareness (infrastructure owners, society-at-large), our industry is in the public eye more now than ever. We have the opportunity to show how the tuneling and underground construction industry has innovated and got us to where we are now. We also have a burden to continue innovating, enabling the building of safer, bigger and better underground infrastructure, in lieu of alternatives at the surface.

Tunnel on! ■

Webuild wins rail bypass contract in Trento, Italy

Construction consortium Webuild and its partners announced that they have won a €934 million contract from Rete Ferroviaria Italiana (RFI) of state rail operator Gruppo FS Italiane for a rail bypass at Lot 3A of a project in Trento, Italy.

Webuild, which has a 55 percent stake in the consortium, will lead the design and construction of approximately 13 km (8 miles) of rail line, nearly all of it underground, as part of a quadrupling of the Fortezza-Verona section of the high-speed railway south of the Brenner Base Tunnel.

The contract is designed to create approximately 1,000 jobs, directly and indirectly, with significant involvement from the supply chain.

Webuild's consortium partners include Ghella with 35 percent and Collini with 10 percent. Webuild has a 51 percent stake with subsidiary SELI at 4 percent.

Lot 3A, which has been identified as a strategic project for the development of sustainable mobility in Italy under the National Plan for Recovery and Resilience, will contribute to improving the international transport of cargo and the improvement of the country's competitiveness. The rail line belongs to the strategic Munich-Verona corridor, as well as a broader program to upgrade transportation services in Trento such as the bypass, which is expected to reduce more than 65 kt (76,000 st) of carbon dioxide every year.

The contract includes the construction of a natural tunnel — the Trento Tunnel of approximately 10.6 km (6.6 miles) in length — and two short sections above ground alongside the existing line. Four tunnel boring machines (TBMs) will be deployed to excavate the tunnel with two working at either end of the projected tunnel. The rate of excavation is to reach between 15 and 20 m/d (50 to 65 ft/day), helping accelerate the work.

The bypass — known in Italian as the "Circonvallazione di Trento" — will be part of the southern access to the Brenner Base Tunnel.

Webuild is working on three of the five sections, or lots, of this tunnel: Mules 2-3 and Isarco River Underpass in Italy, and Gola del Sill-Pfons in Austria. The group has completed Lot Tulfes-Pfons in Austria, while working on the Fortezza-Ponte Gardena access line in Italy that is also part of the Munich-Verona corridor. ■

Final tunneling contract for Sydney Metro West infrastructure project awarded

The third and final major tunneling award of the Sydney Metro West infrastructure project in Sydney, Australia was awarded to the John Holland, CPB Contractors (CPB) and Ghella joint venture (JCG JV).

The tender process for the Sydney Metro West tunnel began in April 2020 after the project to create 24 km (15 miles) of metro rail tunnels from Westmead to the Sydney central business district (CBD) was announced in 2017.

When the project opens in 2030, the project will double rail capacity between greater Parramatta and the Sydney CBD, while also connecting new communities to rail services.

Valued at A$1.63 billion (US$1.09 billion), the contract includes a tunnel boring machine (TBM) launch site at The Bays, 3.5 km (2.2 miles) of tunnels from The Bays to the Sydney CBD, a turnback cavern to the east of the new Hunter Street Station, and excavation and civil works for two new cavern stations at Pyrmont and Hunter Street.

Sydney Metro reported that two TBMs will be used to tunnel from The Bays toward Hunter Street, with preparations scheduled to begin in 2023.

Early 2023, construction of the twin tunnels between The Bays and Sydney Olympic Park and between Sydney Olympic Park and Westmead will also begin.

In preparation for this work, the project's first two TBMs arrived at The Bays Station site in October.

These machines include refurbished parts from those used on the Sydney Metro City and Southwest project, scheduled to open in 2024. ■

Sandvik to supply tunneling machines to Australia

The New South Wales government, Tansurban and M7 Westlink shareholders have awarded Sandvik a contract to supply tunnel machinery for the construction of the NorthConnex project that will link M1 Pacific Motorway at Wahroonga to the Hills M2 Motorway at West Pennant Hills.

WorldHighways reported that Sandvik will supply 13 of the 19 road headers.

The machine supply deal was made by the Lend Lease-Bouygues joint venture to Sandvik Mining and Construction Australia. The order includes six of the large MT720 units, one MT620 model and six of the MT520 units. This represents the largest single order for Sandvik tunneling road headers since it received an order for the Sochi Olympic Park excavation more than five years ago.

The project is of strategic importance for New South Wales and is designed to help cut travel times and traffic congestion in and around Sydney. This new route will link Sydney's north to the Orbital network and form part of a national highway route when complete.

The project includes driving twin motorway tunnels, each measuring 9 km (5.6 miles) long. The tunnels will have two lanes and a breakdown lane in each direction, as well as a height clearance of 5.3 m (17 ft) with a speed limit of 80 km/h (50 mph). The project is estimated to cost approximately US$3 billion in total and will be Australia's longest road tunnel when the link opens to traffic.

The Lend Lease-Bouygues joint venture (LLB JV) was originally formed to construct the East-West Link project in Melbourne and NorthConnex. The joint venture was the successful bidder on both projects, but following the cancellation of the East-West Link project the focus switched to NorthConnex. Lend-Lease is globally operating the Australian construction company, and Bouygues is one of the largest construction companies in the world with headquarters in France. The joint venture is a 50-50 partnership.

Mechanical cutting with roadheaders was selected as the most suitable excavation method for NorthConnex. This was due to the large number of different tunnel profiles (intersections, ramps, shafts) in the project scope, and the accurate excavation profile required. ■

Biden administration visits Potomac Tunnels

President Joe Biden met with rail officials managing the Baltimore and Potomac Tunnels in a push for the long-awaited overhaul of the aging infrastructure of this busy corridor connecting Baltimore and Washington, DC. Biden was there to champion the $1 trillion bipartisan infrastructure legislation and the anticipated massive investment in fixing roads and tunnels throughout the United States.

The project is expected to take roughly a decade and will have two tubes with up to four tracks total, allowing trains to travel at more than 100 mph. The total project including related bridges and equipment modernization is anticipated to cost $6 billion.

Baltimore was the first of three stops related to infrastructure that President Biden visited in February. ■

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Benefits of remanufactured tunnel boring machines include cost and carbon savings

This Robbins TBM was originally built in 1995 and has been used on six tunnels around the world including in Laos, Mexico and most recently at Ashbridges Outfall in Canada.

The practice of remanufacturing or refurbishing tunnel boring machines (TBM) is not new to the tunneling industry. Tunnel project owners and contractors have often turned to TBM manufacturers for "used" machines for many years, and for a variety of reasons.

However, the term "used" can be a bit misleading when it comes to TBMs. Rarely is an entire machine pulled from one project and put to use at another project. The diameter of each tunnel often changes as do the requirements for the TBM. And the ground conditions of each project is always different from other projects.

"It comes down to the ground conditions and unless it is parallel tubes, no two projects experience the exact same ground conditions. That is the nature of our business. Even if the diameter of the tunnel stays the same, which is rare, everything that is related to the ground interface such as the cutter head or mucking system has to be optimized to the ground conditions of the specific project," Werner Burger, chief engineer at Herrenknecht said.

Because of this, larger and more complex TBMs are rarely used in their entirety; however, the main components of a TBM, such as drive systems, man locks, large hydraulic cylinders, erector, powerpacks, gantry components, or main structural components can be remanufactured and given an entirely new life cycle. And these tried-and-true components often provide as much or better success than a new machine.

Brad Grothen, vice president-engineering of Robbins told *T&UC* that his company has been in the practice of rebuilding TBMs for decades.

A case in point is a main-beam TBM that was

William Gleason, Editor

originally built in 1995 and has been used on six tunnels around the world. "At its three most recent tunnels, it has been refurbished as an 8.7 m (28 ft) diameter, single-shield TBM at Theun Hinboun Expansion Project in Laos, start date 2009; as an 8.7 m (28 ft) diameter, crossover XRE TBM at Tunel Emisor Poniente II in Mexico, start date 2015; and as a 7.96 m (26 ft) diameter, single-shield TBM for the Ashbridges Bay Outfall Tunnel in Canada, start date 2019," said a Robbins spokesperson.

Likewise, Herrenknecht is committed to getting the most out of its machines. The company offers a buy-back program for its machines and has a worldwide unique plant that extends more than 100,000 m^2 in Kehl, Germany dedicated to the remanufacturing and refurbishment of components. Olaf Kortz manages the facility and explained to *T&UC* that Herrenknecht's process closely follows the International Tunnelling Association's (ITA-AITES) ITAtech group guidelines "ITAtech Guidelines for Rebuilds of Machinery for Mechanized Tunnel Excavation" that were first drafted in 2014-15 and revised in 2019 to include computer and guidance systems. Accordingly, Herrenknecht is quite clear about the distinction between refurbishment and remanufacture: refurbishment allows the part to be used for the rest of its design life, or to extend the original design life to some extent, whereas remanufacturing re-engineers the part to the beginning of a new life cycle. According to the ITAtech guidelines, remanufacturing does not take place on the jobsite due to the required special equipment.

Herrenknecht remanufactures components at its plant to be certified to be as good as new, including updates to the latest technical standards. Over the past decade the company has had numerous machines and components return to action.

One of the three Herrenknecht TBMs used at the Washington Clean Rivers Project. Herrenknecht remanufactures TBMs at its plant in Kehl, Germany.

Why choose a refurbished machine

In a paper titled "Rebuilding TBMs; Are used TBMs as good as new?" presented at the Rapid Excavation and Tunneling Conference (RETC) in 2019, Doug Harding of Robbins wrote that for years, the advantage of using a refurbished TBM versus a new machine built specifically for a job was based on economics and time. The costs can vary from as much as 75 percent for a simpler machine on a project with tried-and-tested ground conditions to around 20 percent for a project with more complex requirements (Harding, 2019). A refurbished machine can also represent significant savings in terms of time. A refurbished machine can sometimes be ready in a matter of months while it might take more than a year for a new TBM to be manufactured.

"As long as the TBM is well maintained, there will be jobs it can bore economically," Harding wrote in the 2019 RETC paper. "Optimal TBM refurbishment on a used machine requires a broad knowledge of the project conditions, and there are some limitations: Machine diameter can be decreased within the limits set by free movement of the grippers and side/roof supports; machine diameter can be increased subject to the structural integrity of the machine and the power/thrust capabilities, and propel force can be increased only to the level supported by the grippers' thrust reaction force."

Carbon savings

For manufacturers such as Robbins and Herrenknecht as well as tunnel project owners and contractors,

Herrenknecht estimates that on average, as a result of the remanufacturing process per ton of components, 71.42 percent of the emissions are saved compared to the production of new components.

remanufactured TBMs or TBM components often make good business sense. Recently, the additional factors of sustainability and carbon savings have gained more attention as well.

Tunnels and underground infrastructure, by their very nature, provide solutions to many urban growth challenges, including climate goals, such as reducing carbon emissions from tunnel projects. While mass transit tunnels are one of the most efficient ways to reduce road traffic and the carbon emissions from automobiles and freight trucks, the construction of a tunnel is a carbon-intensive process and many owners are facing increasing pressure to reduce the carbon footprint of each tunnel project.

In many public tenders for tunneling projects, environmental criteria are now standard, and it is expected that in many countries this trend will continue and environmental regulations will continue to tighten.

Grothen said that Robbins has seen demand for completely new machines and components wane as project owners realize the sustainability benefits of remanufactured components and machines.

Herrenknecht has calculated that "on average, as a result of the remanufacturing process per ton of components 71.42 percent of the emissions are saved compared to the production of new components." And in Herrenknecht's calculation this includes carbon dioxide (CO_2) emitted during the transport of components from the jobsite to Kehl.

According to Kortz, with a completely remanufactured tunnel boring machine the energy savings are about 80 percent. In addition, when compared to a new machine, about 99 percent less materials have to be used. This is a huge saving that conserves resources, reduces CO_2 emissions and improves the environmental balance of the machine — and thus the entire construction project.

In addition to the sustainable benefits from reused parts, there can be a significant savings in transportation of components.

"Remanufacturing components and TBMs is a big part of our business," Grothen said of the Robbins process of refurbishing TBMs. "I think the challenge comes as you look at what gets refurbished. It is always tricky — its price and carbon footprint — and when you consider refurbishment, the shipping of big, heavy pieces of equipment is also a huge cost and carbon producer.

"When you do the refurbishment you have to consider where you are going to do the work — onsite or back at the factory," said Grothen. "The location is important and for shield machines like an open main-beam machine, you don't have many pieces touching the tunnel wall so slight changes in diameter are not so detrimental, but when you look at a shield machine it is more difficult to change diameters. They are designed more around the segment of that project so unless there is standardization of the segment it is more difficult to reuse the outer shield of the TBM and all the weight that goes with the shield. So machine type really matters and where you refurbish it."

For Robbins, remanufacturing components of tunnel boring machines has been a common practice for decades. It can save money, time and reduce the carbon footprint of a tunnel project.

Available equipment

Because TBMs are more like a mobile factory than an individual machine, inventory is a challenge.

Some TBMs are moved around the world, while others can stay in the same region. Grothen said that some regions of the world have tried to create a standardized segment lining for certain types of tunnels. This makes it easier to repurpose TBMs for tunnels with the same diameter and helps with the issue of inventory; however, changing ground conditions remain a challenge.

"I have never found two jobs with identical ground conditions," Burger said. "A project in its early design is maybe 10 years out, so knowing which machine might be available is difficult. When a project is in the design phase there are informal contacts but hardly ever a situation that a project is designed for an existing TBM. What could help in the future would be if there are specs in the bid process that indicate a range of flexibility for the machine or the tunnel. For example, for a water tunnel, if it has a diameter that is 4 inches larger than the specs it doesn't really change the tunnel, but it could open the door more to bring in existing equipment."

Next steps

Much of the programming at the 2022 Cutting Edge Conference presented by UCA and *Tunnelling Journal* was dedicated to sustainability in the tunneling industry (see page 23). Project owners, contractors and engineers are facing increasing pressure to not only convince outside stakeholders that their tunneling project will be a net positive for the community in which it is built, but to reduce the carbon footprint of building the project.

Innovation and technology will be needed to carry the industry forward.

"We now have more digitization in the machines including artificial intelligence (AI), and this contributes to optimized energy and efficient use of the machines," said Burger. "These technologies give the operators advice by telling them which motor could be switched off or even having automated systems determine the amount of energy needed. Downsizing of machines could be an option as well, but we would still need to know the ground conditions. There is a compromise of having sufficient power installed to overcome the unexpected but not overstressing."

Burger said that in the next decade he expects to see more technology incorporated to help TBMs become more efficient in their use of power and fuels.

"For the future I think we need to consider not just one element of the tunneling process but to look at the complete tunnel operation from the project design all the way through equipment and materials," Burger said. "There is a potential to bring the industry forward in the direction of more sustainable solutions. This will need the cooperation of all involved parties starting with the owners to the equipment supplier." ■

Unprecedented in-tunnel diameter conversion of the largest hard rock TBM in the United States

The Mill Creek/Peaks Branch/State-Thomas (MCPBST) Drainage Relief Tunnel is a 5-mile (8-km) underground tunnel that will provide flood protection for the east Dallas, TX area. The project required a drainage tunnel starting at a diameter of 11.6 m (38 ft) and ending with a diameter of 9.9 m (32.48 ft). The upstream 5.2 km (3.23 miles) are designed with a circular cross section for a peak flow of 425 m^3/s. The downstream 2.8 km (1.74 miles), running between the outfall shaft to the East Peaks Branch intake (Fig. 1), was originally designed with a horseshoe cross section to allow a higher peak flow of 566 m^3/s. The horseshoe section was to have been excavated by the tunnel boring machine (TBM) initially and expanded by roadheader to create a flat invert. Two different sets of formwork would also have been required to cast the final lining for both the round and horseshoe profiles, making the process potentially time consuming and costly (Rowland, 2019). Because of the cost and time to excavate by roadheader, one TBM was selected instead.

A Robbins rebuilt TBM along with a continuous conveyor (including a vertical conveyor) was chosen as the boring system. During early project discussions with the machine supplier, a decision was made to reduce the boring machine diameter in the tunnel, lowering project costs and reducing the construction period (see Fig. 2).

FIG. 1

The 8-km (5-mile) route of the Mill Creek Drainage Relief Tunnel.

FIG. 2

The 11.6 m (38 ft) diameter Robbins main-beam tunnel boring machine (TBM) at launch. It is the largest hard rock TBM ever used in the United States.

Without a prepared chamber, in situ diameter changes raised the number of challenges encountered. The changeover was designed and conducted in three distinct parts, with each presenting its own difficulties and corresponding opportunities to be collaboratively solved:

- The TBM proper.
- The trailing gear.
- The tunnel conveyor system.

TBM reduction

The TBM story begins with the design phase. Working with a rebuilt machine, the designers started with the concept to build a smaller machine and then install a wrap to make the larger diameter. It was hoped this way would reduce the difficulty inherent in the diameter reduction. Several items taken into consideration included:

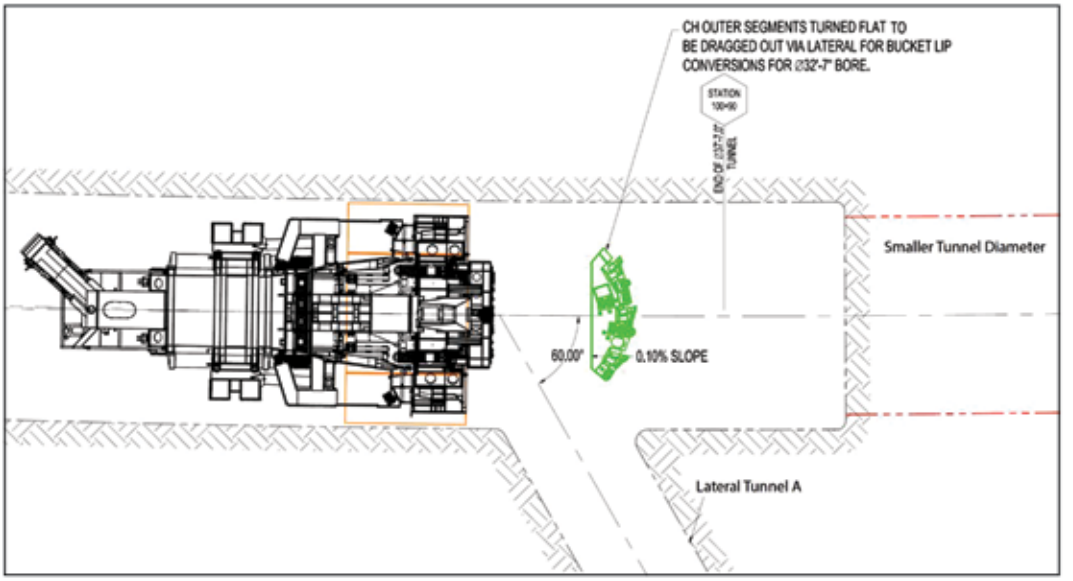
- Cutterhead segments and how to handle them.
- Thinking ahead with skin-weld placement with

Steve Chorley and Evan Brinkeroff

Steve Chorley, member UCA, is vice president operations, and Evan Brinkeroff is site manager, Robbins. Email chorleys@robbinstbm.com.

FIG. 3

The tunnel boring machine plan view in relation to lateral tunnel A at diameter change site.



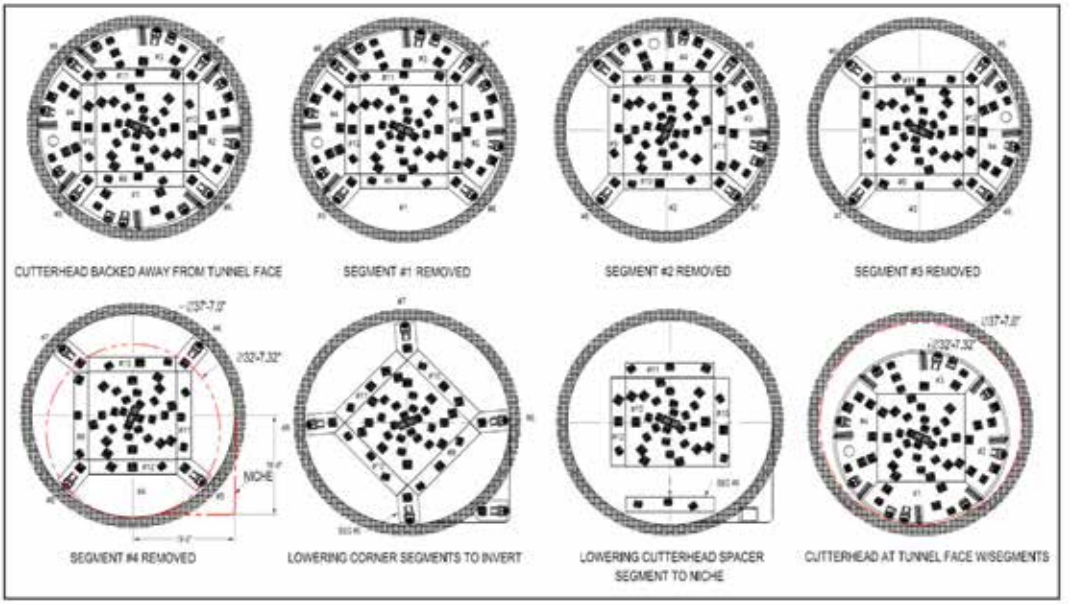
respect to interior accessibility.
- Thinking ahead about gripper-shoe wraps.
- Adjustability of the drills.
- Ground support platforms and associated extensions.

The original strategy was to excavate to the transition station, back the TBM system approximately 22 m (72 ft), change the diameter, then commence boring at the smaller diameter while adding conveyor parts to adapt to the new diameter. During the initial design phase, the concentricity of the two diameters was discussed, and it was decided that the two tunnels should be concentric. A communication misunderstanding led to the conveyor system beginning component construction understanding the two tunnels to be eccentric — a fortuitous misunderstanding, as we shall see.

As per the contract requirements, the ground support consisted of rock bolts spaced 1.5 m (5 ft) apart longitudinally, along with woven wire fabric, and crown straps as needed. Additional bolts, straps and mesh were to be installed as needed. Part of the transition plan was

FIG. 4

Cutterhead diameter change sequence.



to back the TBM approximately 22 m (72 ft) leaving cutterhead sections behind; upon arrival at the transition the ground turned bad — the crown became loose rock and required additional rock support that could not be removed, thus obviating the required back up as the entirety of the work had to be done from supported ground. The straps and bolts protruded into the TBM envelope even with the roof support fully retracted, so another solution was needed. The contractor, Southland Holdings, and Robbins Co. personnel put their heads together and found a solution that required only backing the head a mere 76 cm (2.5 ft). The process would be achieved by removing cutterhead sections and other pieces through lateral tunnel A, a 6 m (19.6 ft) diameter, 90 m (295 ft) long, horseshoe tunnel built using excavators and hydraulic hammers. The lateral tunnel connects with drop shaft A, at 52 m (170 ft) deep and 6 m (19.6 ft) in diameter. The arrangement allowed personnel and equipment to access and begin the conversion process through the lateral tunnel, and remove pieces on rails through the shaft and up to the surface (Fig. 3).

The reduction took place from the front of the machine starting with the cutterhead and ending with the conveyor. The cutterhead was designed to have four spacer segments installed between the cutterhead center section and the outer sections, with four small, intermediate sections filling in the gaps at the so-called corners (Figs. 4 and 5).

The team dismantled and removed the four cutterhead sections, the four intermediate sections, and the four spacers from a lateral tunnel, lateral A, which intersected the main tunnel precisely at the diameter change. The heaviest section weighed just over 15,000 kg (33,069 lb) and given the small access window, required planning to maneuver the pieces out of the lateral access to the surface for refitting for the small diameter, and returning to the installation position.

Working from the lateral tunnel, the welds securing the intermediate spacers were removed through the buckets. The team made the decision to remove the spacers in sections, cutting them from the lateral, leaving the mounting flanges in place. The spacers were then pulled from the cutterhead in sections.

The crews were then able to remove the cutterhead sections entirely from within the safety of the confines of the cutterhead and the lateral access. Working on the bottom section and from within the cutterhead, the crews then removed the fasteners and allowed the cutterhead section to rest on the invert. As the TBM was not retracted, the cutterhead sections settled in the invert nicely as they waited to be removed. To facilitate the cutterhead section removal, the cutterhead drive motors, controlled via variable-frequency drives, were used to rotate the cutterhead and push the first cutterhead section out through the lateral where it could be collected and sent to the surface.

FIG. 5

Cutterhead segments being removed in the lateral access.

The cutterhead was then rotated 180° and the process was repeated, removing the next cutterhead section. After the first two sections were removed, the process was repeated until all the sections were removed. The next step was to remove the cutterhead spacers.

The spacer fasteners were removed from within the cutterhead. To control the lowering of the spacers, hydraulic jacks and spacers were used to lower each

FIG. 6

Transition area showing the roof shield skins and transition area from the top.

FIG. 7

TBM roof shield skin removal.

section in a controlled manner once the fasteners were removed.

The rest of the TBM, trailing gear and conveyor work was accomplished while the cutterhead sections were being refurbished. When the cutterhead sections were returned, they were installed using the jacks and spacers that were used to remove the spacers. A dedicated transport sled was fabricated to facilitate the positioning and lifting of the spacers to the cutterhead center section.

Working from within the shield skin the crews removed the outermost skins from the roof supports and side supports. The crews then fashioned chain action rollers supported by hydraulic jacks to maintain roof support pressure against the crown, especially as the TBM advanced until the front of the roof support skin could be secured in the crown with rock bolts and straps. The roof support skin and roof support extensions were secured in place using rock bolts and crown straps (Figs. 6 and 7).

As part of the planning phase, it was thought that the smaller-diameter roof shield extensions would be too unwieldy to maneuver within the confines of the tunnel. With minimal overhead clearance, just 76 cm (2.5 ft), it was thought that hoisting a heavy-shield extension from the invert up and around the main beam would be too great an obstacle. The solution was to cut the smaller-diameter roof support extensions into three smaller pieces and weld them in place on the roof shield extensions. It was then just a matter of sliding the precut pieces into position and completing the welds. During the excavation of the larger diameter there were a few inconveniences but they were insignificant to the larger picture.

The vertical front support did not need to be removed from within; the crews needed only to remove the fore and aft welds to free the small-diameter TBM and allow the TBM to push off the vertical front support when the time came. The crews carefully fashioned the side support skins and reinforcing ribs into supporting members for the gripper shoe skins. The gripper shoe skins were positioned carefully onto the side support skins and welded in place. A few rock bolts were installed into the side supports to ensure they did not shift as the TBM passed through, and crews worked closely in, on and around them. Once the cutterhead was reassembled the TBM started mining forward (Fig. 8).

FIG. 8

Installation of the smaller-diameter cutterhead structure.

This phase of the transition required many stops to remove the accumulated material from in front of the vertical front support. Mining with a concentric tunnel meant there was a 76-cm (2.5-ft) step between the two bores and the rock would accumulate and prevent the TBM from advancing until it was clear. Once the vertical front support was abutted to the transition step, the aft welds were removed and mining began again, with the TBM sliding from the vertical front support and into the new-diameter, freshly bored tunnel. The gap between the vertical front support and the newly bored tunnel was about 7 to 10 cm (2.75 to 3.9 in.), and this gap was mostly filled with accumulated material from the mining operations and presented no difficulty.

Concurrent with the TBM advancement, permanent roof support anchors were installed to secure the shield skins to the tunnel wall. The temporary chain rollers and supports were then removed.

Once the TBM was excavating at the smaller

FIG. 9

The gantry lift process.

FIG. 10

The completed diameter transition area.

diameter, the crews cut the shield wrap inner reinforcements into manageable size parts and removed them on a flat car, leaving the skin plate in place. The contractor was granted a variance to leave the roof support skins and skin extensions secured to the crown. These will be cast in place during the lining of the tunnel.

With the TBM beginning to advance at the small diameter, the next part of the transition was the gripper shoe extensions. This again highlights where the planning phase is of utmost importance. During the side support extension removal phase, consideration was given to the gripper shoes as they passed the transition area and carefully laid out cuts were made to the side support wraps and re-enforcing ribs such that the gripper shoe extensions would lay neatly in place supported by the cutouts. The gripper shoe extensions were then welded in place to the side support extensions with a couple of rock bolts securing the tops of the extensions.

After the gripper shoe extensions were laid into the side support cutouts, the remaining welds holding the extensions to the shoes were removed. The TBM then began a regrip cycle with a noteworthy additional step. Just prior to the gripper shoes rear half being placed on the forward part of the gripper shoe extensions, the voids in the extensions were filled with sandbags to allow the gripper to apply full force to the tunnel walls. The sandbags prevented the supporting members of the wrap from racking under the propel and gripping forces.

The final item for the TBM reduction was the rear support shoe extensions. These were abutted against the rear of the vertical front support and then the extensions were removed; the next boring cycle brought the shoes to rest fully upon the vertical front support.

The trailing gear reduction was neatly taken care of during the design phase. Instead of reducing the diameter of the trailing gear, a smaller-diameter trailing gear was used with extensions on the wheel bogies to bring the trailing gear to the correct elevation when the TBM was 11.6 m (38 ft) in diameter. All that remained at the diameter change was to remove the wheel bogie extensions and position the trailing gear in the small diameter. There were a few platforms that had extensions upon them that needed to be removed, but they were minor and handled as needed.

The original design was to lead the trailing gear up a two percent slope requiring a substantial amount of civil works to build the ramp between the TBM and the first gantry of the trailing gear. There was not much space within which to work, so this design was not desirable. The bad ground encountered at the diameter change station eliminated the ability to back the TBM more than absolutely necessary. There were several discussions held in an effort to find a workable solution, and ultimately the contractor and Robbins decided a novel approach would work. The decision was to use rented hydraulic cylinders in conjunction with fabricated

spacers and raise the entire trailing gear at the same time. This decision naturally created obstacles, but these were overcome (Fig. 9).

While the gripper shoe extensions were being removed, the crews installed fabricated supports to the tunnel walls upon which were placed hydraulic jacks. Four jacks were used per gantry with each gantry having a dedicated pump and each jack having a dedicated isolation valve. During the lift, crews took careful measurements to ensure the trailing gear raised at the same rate and at no point were any two jacks allowed to become more than 3 mm different in extension, thereby ensuring the entire trailing gear lifted equally. (Each jack had a maximum capacity of 45 t (50 st), so with the maximum weight of the heaviest gantry at 61,700 kg, the job was done with a generous safety factor.)

As the gantries were lifted, spacers were inserted as an extra measure of safety until all four gantries were lifted to the correct elevation. The wheel bogies were removed and spacers were installed to the gantries and the bogies installed to the spacers. The gantries were then lowered until the weight was borne by the bogies and mining resumed.

When the leading bogie for the first gantry reached the abandoned vertical front support, mining was paused and the front of the first gantry was raised enough to install the same continuous chain rollers used for the roof support. They were installed onto spacers welded to the vertical front support and then the gantry was lowered onto the chain rollers such that the weight of the front of the gantry was borne by the chain roller. The leading bogie and extension were removed from the front of the first gantry and mining resumed. When the TBM had pulled the trailing gear sufficiently far, mining was once again paused. The front of the first gantry was again lifted, the chain rollers removed and the bogie (without extension) was reinstalled. The gantry was lowered and mining resumed.

This process was repeated until all the trailing gear was inside the newly mined tunnel (Fig. 10).

The tunnel belt also had to be transitioned to the smaller tunnel diameter.

- The transition occurred in a curve just after the first carry booster was scheduled to be installed.
- Due to a collaborative misunderstanding, the TBM division knew the tunnel was concentric while the conveyor division thought it was an eccentric tunnel.
- Originally a carry booster was designed to be installed a few hundred feet into the smaller-diameter tunnel, this required a substantial elevation correction to the tunnel belt to allow space between the carry belt and return belt to fit the booster rollers.
- The elevation difference was 76 cm (2.5 ft) on the radius, the installation of the first carrying booster was 91 cm (2.9 ft) — a fortuitous coincidence. The decision was made to postpone the installation of the carrying booster while excavating the wall for installation until the belt elevation only required 15 cm (0.49 ft) of transition.
- After the TBM and trailing gear passed through the transition diameter phase the team used a remnant of the large-diameter shield as a

TABLE 1

Ground support requirements based on rock mass classification.

Rock mass class	Description of ground conditions	Rock mass rating	TBM production (m/h)	Ground support	Rock bolt type	Installation time (approximate)
Type I	Very good	81-100	1.5-3.2	Generally no support required, only spot bolts.	Mechanical anchor/split set friction bolt	≤3 mins per bolt
Type II	Good	61-80	2-3.5	Local bolting with occas-sional mesh.	Mechanical anchor/split set friction bolt	≤3 mins per bolt
Type III	Fair	41-60	1.1-1.5	Systematic bolting with wire mesh in crown.	CT bolt resin anchored bolt	3 to 5 minutes per bolt
Type IV	Poor	21-40	0.8-1.1	Systematic bolting with wire mesh crown on side walls. Light steel ribs and local shotcreting.	CT bolt resin anchored bolt	Depends on length of hole to be drilled and exposed ground condition.
Type V	Very poor	<20	<1	Systematic bolting with wire mesh over crown and side walls. Heavy steel ribs and shotcreting.	CT bolt resin anchored bolt	Depends on length of hole to be drilled and exposed ground condition.

mounting base upon which to install the first of five tunnel belt boosters, in this case a 375-kW dual motor carrying booster.

The conveyor booster installation was relatively easy and was carried out in a timely manner.

Overall, the diameter change process took about four months to complete — the revised setup backing the machine up by only 76 cm (2.5 ft) saved about one month compared to the originally devised plans to excavate a transition station and back the machine up 22 m (72 ft). The ground conditions, particularly poor rock quality in the crown, dictated the change in plans, and was ultimately highly successful.

Ground conditions and TBM performance

The TBM at Mill Creek is well equipped for rock bolting with dedicated rock drills mounted on a ring gear allowing for installation of rock bolts in the needed areas of the tunnel. Table 1 gives a general overview of rock bolt types that may be considered in relation to rock mass classification. (It should be noted that ultimately the decision on which type of rock bolt is to be used should be made on a case-by-case basis.)

The Mill Creek machine is operating in Austin chalk and Eagle Ford shale with a compressive strength between 17 and 30 MPa. The requirement for systematic rock bolting is in part due to the rock being classified as mainly Type III and some areas of Type IV conditions. In Type IV conditions, the contract called for eight additional rock bolts, resulting in 76 cm (2.5 ft) linear spacing with wire mesh covering the crown and steel straps as needed. Once through the learning curve, the crew began installing eight bolts in the Type III conditions within 20 to 25 minutes (Fig. 10).

Probing is also required to 60 m (196 ft) in front of the machine in every 46 m (150 ft) of mining, thereby providing a safe zone of 15 m (49 ft) ahead of the machine. To date, there have been no significant water inflows into the tunnel.

Due to the required systematic approach to production, the machine is currently averaging approximately 16 m (52 ft) advance per day. Limiting factors to production are the probing requirements and the capacity of the vertical conveyor. At the time of this writing, the machine has achieved some impressive performance results:

- Best day: 41 m (134 ft) (at the 11.6 m (38 ft) diameter)
- Best week: 118 m (387 ft)
- Best month: 498 m (1,633 ft)

At the current rates of advance, boring is scheduled to be completed in June 2022.

Due to the relatively favorable ground conditions in much of the tunnel, including low rock strength and low abrasivity, only eight cutters were changed during the length of tunnel bored at the larger diameter. At the time of diameter change, the full dress of cutters was changed. As in the larger diameter tunnel, cutter inspection times and the downtime associated with them are limiting and are generally only carried out when trouble is suspected.

Conclusions

Construction sites can be contentious working environments, and sometimes it is far too easy to put the blame on another party for whatever fails to transpire. If, however, we consider the four C's approach to this situation:

- Communication: Exchanging ideas and information.
- Cooperation: Understanding the goals of all stakeholders to achieve the desired results while minimizing downtime.
- Collaboration: Working together collectively on a plan that could not have been designed by one party.
- Coordination: The ability of management to lead the team in completing the works (Macfadden, 2018).

then we can achieve the desired results. The success of the in situ diameter change in the tunnel is a result of this "four C's" approach between all parties involved with the project. It is obvious that the ability of the TBM manufacturer's engineering and management team and the contractors project team to communicate and understand the requirements of what had to be done resulted in the successful diameter change.

Moreover, it was the ability of the personnel carrying out the work to communicate on a daily basis to adapt to the problems they faced and come up with solutions as situations arose that led to the smooth transition from one diameter to another.

This was a unique time- and cost-effective solution to a not-so-common situation. A diameter change in mid-tunnel is a rare event. The success of this in-tunnel diameter change shows that with careful planning and cooperation there is an opportunity to use this method, albeit adapted to the particularities of any project, that would require a similar mid-bore diameter change in the future. ■

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UCA hosts Cutting Edge and George A. Fox Conferences

In November 2022, nearly 300 people gathered in Long Beach, CA for the 2022 Cutting Edge Conference hosted by UCA and *Tunnelling Journal*.

The United Nations estimated the world's population would hit 8 billion people on Nov. 15, 2022 and that it would climb to 10.4 billion by the end of the century. According to the World Bank, 56 percent of the world's population now lives in cities or urban areas and that trend is expected to continue with urban populations more than doubling its current size by 2050 to a point at which nearly 70 percent of the world's population will live in urban areas.

This growth of urban areas will undoubtedly lead to challenges of accelerated demand for affordable housing, employment, basic services and a viable infrastructure that includes transportation systems, water, sewage and other utilities.

According to the World Bank the expansion of urban land consumption outpaces population growth by as much as 50 percent and 1.2 million km^2 of new urban built-up area will be added by 2030. This will add immense pressure on land and natural resources around the world. Cities already represent two-thirds of global energy consumption and produce more than 70 percent of greenhouse gas emissions.

Where cities can no longer expand out or up they will increasingly look to grow below ground. Tunnels and underground infrastructure have always provided a solution to many urban growth challenges, and as the world confronts climate change and a need to decarbonize, tunnels will continue to play an essential role in the global efforts to meet the climate goals set by the Paris Accord. Mass-transit tunnels like the proposed West Seattle Project in Seattle, WA or the Sepulveda Pass tunnel in Sacramento, CA could help remove thousands of vehicles from daily commutes and the emissions that come from them. Combined sewage overflow tunnels, such as the Thames Tideway Tunnel in London, England will help clean the Thames River and the city itself. And increased underground infrastructure can help make way for useable space above such as a community park over Interstate 70 in Denver, CO.

However, just because the end result of tunnels provides many solutions to the challenges presented by urban growth, the tunneling industry has found that is does not get a pass for the means in which the tunnels are constructed.

William Gleason, Editor

On the same day the global population hit the 8 billion mark, nearly 300 of those people gathered in Long Beach, CA for the 10th Annual Cutting Edge Conference presented by UCA and *Tunneling Journal*. The issues of advances in tunneling technology and specifically, the industry's role regarding sustainability and carbon neutrality were top-of-mind for the two-day conference that has earned a reputation for its high-quality programming.

Andy Alder, Tideway project director, Jacobs opened the conference with a keynote address that focused on the social value delivered by the Thames Tideway Tunnel Project, a 25 km (16 mile) tunnel in London, England that will intercept, store and ultimately transfer sewage waste away from the River Thames. The project itself is one of the most impressive tunneling projects in the world as it incorporated six tunnel boring machines (TBM) to complete the 7.2 m (24 ft) diameter tunnel, and while Adler could speak at length about the engineering feats associated with the tunnel, he instead focused on the other impacts of the project.

London's combined sewer system has been overwhelmed by the population growth of the city. The original system was built when there were about 2 million people in the city compared to the current population of nearly 10 million. Rains can often overwhelm the system's capacity, leading to about 40 million tons of sewage overflows into the river. From an environmental stance, this overflow destroys wildlife and is a massive public health hazard, Alder said.

The environmental and public health issues were

drivers for many of the decisions made on the project.

"Our mission is to prevent sewage from getting to the River Thames, and by extension we are making the river something that adds value to the city," Alder said. "We wanted to embrace that vision and we set out to create a legacy and a commitment to the environment, and the health, safety and wellness of the people in London."

Alder noted that the project committed to reducing carbon emissions through the use of electric-powered cranes over diesel power and to use the river itself for the transportation of construction materials. Using barges on the river had the added health and safety benefit of reducing the need for transportation on roads by about 50,000 loads.

Nine scholarship winners (not in order) Maksymilian Jasiak, Hassan Al Kaaby Al Zoaby, Karen E. Mena Arango, Pa Ousman Njie, Valli Eugenio, Jack Lawrence, Milad Ghahramanieisalou, Wendi Zhao, Charbel Beaino and Mustafa Suner were given scholarships by the Cutting Edge Conference committee.

Alder also spoke about the project's commitment to the community to employ a large local workforce including people who have had previous legal or financial troubles. The project also set high diversity and inclusion standards. Some of the commitments included personal protective equipment (PPE) for males and females as well as PPE that is inclusive for religious traditions.

The Cutting Edge Conference was established in 2012 and has grown in the past decade thanks in part to a reputation for presentations about cutting-edge technology and practices in the industry. This year the program included many high-level technical talks as well as an important discussion about mental health.

Robert Labbe from American Global gave a very personal presentation about the need to look out for each other. The construction industry is a male-dominated industry with high stress, long hours, many military veterans and unfortunately, an unacceptably a high suicide rate. While the issue of mental health has moved from the shadows in many parts of society, it can be difficult to talk about in some sectors such as the construction industry. Labbe stressed the importance of checking in and keeping an eye on friends and coworkers in the industry.

Carbon emissions

One of the central themes during Cutting Edge 2022 was how can the industry improve its environmental, social and governance (ESG) status. Yes, tunnels are often part of the solution for a greener environment, but the construction of tunnels and of tunnel boring machines (TBMs) and other equipment often requires a large carbon output.

During the conference there were presentations about innovations in tunneling and the challenges that exist in getting to lower carbon through alternative means and methods. There was also significant time spent focused on incorporating sustainability into the planning of projects including a panel discussion focused on sustainability and carbon neutrality.

"In the UK we are seeing the public demand change that our projects are more sustainable," said Adler. "We need to get the public's support and convince the public that we are driving toward net zero. If we cannot get public support we won't get political support either."

During a panel discussion, Fernando Vera, Wolgang Aldrian, Alder and Chris Nelsen spoke about the challenges in making the tunneling industry more sustainable. Some of the issues facing the industry include getting support from clients and finding alignment with local and national governments.

The panel agreed that ultimately there has to be a framework that is flexible. Sustainability should be seen with the same level of importance as health and safety programs, and the players in the industry should recognize that it is a collaborative effort that includes the right funding and the right policies to make everything work. This will require innovation, and the risk should be shared between owners and contractors.

From an engineering perspective, Katherine Westerlund gave an impassioned presentation on the need for the industry to confront the challenges presented by climate change head on.

The decarbonization of equipment and construction materials is another issue that was discussed during the panel discussion and beyond. Werner Burger of Herrenknecht spoke about the rising trend of refurbishing equipment such as TBMs to greatly reduce the amount of carbon emissions needed to construct the machines.

The refurbishment of TBMs is a complex process that must be considered early in the planning phase of any project. There is a finite number of TBMs in the world and the diameter of the proposed tunnel must work with the diameter of the machine. There is also the challenge of incorporating state-of-the-art technology into a machine that was constructed for a project five to 20 years earlier.

Decarbonized construction material was also discussed during the conference. The fundamentals of tunneling remain largely unchanged, but new and more efficient materials offer potential improvements for the industry.

More than 480 attend 2023 George A. Fox Conference in New York City

On the same day that President Joe Biden was in New York City to announce $292 million in funding for part of the Gateway Rail Project, many professionals in the tunneling industry were gathered just a few miles away for the George A. Fox Conference at the New York Hilton Midtown.

The president's visit on Jan. 31 did create a scheduling conflict for Kris Kolluri, chief executive officer of Gateway Development Commission who had been scheduled to present at the Fox Conference on the project but was pulled away to speak with President Biden about the funding that will be used to finish the Hudson Yards tunnel box.

On Jan. 31, President Joe Biden announced $292 million in funding for the Hudson River tunnel project. (Photo credit: Gateway Development Commission.)

Eric Daleo, chief program officer and Megan Strickland, deputy chief program officer both of the Gateway Development Commission presented in place of Kolluri and gave updates on what the commission is planning.

In light of the expected announcement of funding, the commission, which is composed of representatives from New York, New Jersey and Amtrak, is building the legal and financial capacity to manage the project. Strickland said there is good momentum for the project and the commission will work to keep that going.

The *Associated Press* reported that the $292 million mega grant announced on Jan. 31 is part of $1.2 billion in mega grants being awarded under the 2021 Bipartisan Infrastructure Law.

The grant will be used to finish the Hudson Yards tunnel box concrete casing, a project that was started in the summer of 2013 to preserve the route of the Gateway Tunnel from Penn Station to the Hudson River as foundations were built for the Hudson Yards project.

"We are looking at this as an early action construction project that will move ahead this year," Daleo said. "It is a critical project that preserves a right of way and allows for development above ground and leads the other packages."

The Hudson Yards Concrete Casing – Section 3 is one of nine nationally significant projects selected for this first year of the program out of 100 applications, U.S. Transportation Secretary Pete Buttigieg said in a statement. This grant will be funded over the course of four years from fiscal years 2022 to 2025.

Another early construction project is at the Tonnelle Avenue Bridge. It was the first project that was undertaken 10 years earlier when the project was still called the Arch Project before it was canceled. Daleo said the Gateway Development Commission planned to issue a request for proposal for construction management and invitation for bid for services within a month for the Tonnelle Avenue Bridge work.

The Gateway project will be a renovation of the 1910 tunnel already carrying about 200,000 weekday passengers beneath the Hudson River between New Jersey and Manhattan, a long-delayed upgrade after decades in which the government underfunded infrastructure.

Arnold Dix, president of the International Tunnelling and Underground Space Association and barrister, scientist and professor of engineering of counsel, White & Case gave the keynote presentation at the Fox Conference in which he emphasized the need for the industry to make a case to President Biden and other world leaders that tunneling and underground construction provides sustainable solutions for society.

"It's no accident that President Biden is here meeting about the projects that you are working on," said Dix. "The sustainability agenda is listed as part of the United States' national security agenda. That tells you that the money and resources that you need to deliver your projects are nearby. That challenge is to make sure that your projects

address the national security agenda in the delivery of health and wealth and well-being for your communities."

The grant announced by Biden would also be used to help complete the concrete casing for an additional rail tunnel beneath the river, preserving a right of way for the eventual tunnel. In total, the project is expected to cost $16 billion and help ease a bottleneck for New Jersey commuters and Amtrak passengers going through New York City.

Other projects to receive mega grants include the Brent Spence Bridge, which connects Kentucky and Ohio; the Calcasieu River Bridge replacement in Louisiana; a commuter rail in Illinois; the Alligator River Bridge in North Carolina; a transit and highway plan in California; and roadways in Oklahoma, Pennsylvania and Mississippi.

Along with the announcement from the Biden administration, the Fox Conference included a number of talks about the current state of the industry and the projects that are in the works or are expected to begin soon. Good news for the industry and attendees, but also challenging news. Like many industries, the tunneling and underground construction industry is challenged with significant workforce issues. The hours can be long, and the industry can be demanding with professionals asked to relocate around the nation and even the world. And for the most part, the work of a tunneling professional goes largely unseen. The industry is also one on which many of its top-tier professionals are nearing retirement, thus a knowledge gap is looming.

One of the afternoon sessions was a continuation of a panel discussion that began at the previous Fox Conference and focused on these workforce challenges.

More than 480 people attended the George A. Fox Conference at the New York Hilton Midtown on Jan. 31.

Arnold Dix, president of the International Tunnelling and Underground Space Association and barrister, scientist and professor of engineering of counsel, White & Case gave the keynote presentation at the Fox Conference.

Mike Rispin, vice president of tunneling, Strata Worldwide and UCA Chair moderated a panel discussion that included Elisa Comis, managing director, Pini Group USA Inc. and member of UCA Women in Tunneling;

Vojtech Gall, senior tunnel engineer, Gall Zeidler Consultants and member of UCA Young Members; Everett Litton, assistant vice president, WSP - UCA Student Outreach / Down for That and Mike Mooney, Grewcock Chair, professor of underground construction and tunneling, Colorado School of Mines and coordinator of UCA's Teach the Professors program.

The panel addressed three overall questions:

1. What do we need to do differently to make a career in the underground construction industry more attractive to young professionals?
2. What do we need to do to improve retention of the young people currently in the industry?
3. What should we be doing to market the industry?

While the answers from the panel covered a breadth of issues it was generally agreed upon that the industry needs to engage with students at the high school or even grade school level to create awareness of the good things it has to offer. And the inherent sustainability of tunnels for the improvement of society is an important aspect to be promoted to young people who want to have a career that has a positive impact on society.

At the conclusion of the panel discussion the audience was asked to carry the positive messages of the tunneling and underground construction industry forward to their local schools. ■

From the American Underground Construction Association to the current-day UCA

The Undeground Construction Association (UCA), formerly known as the American Underground Association (AUA) was established in 1975 when representatives from a number of construction organizations realized the need for an association focused on tunneling and underground construction.

In the ensuing decades the AUA established itself as the leading association for professionals in tunneling and underground construction.

In the 1990s, the AUA took over U.S. representation to the International Tunnelling Association and initiated the North American Tunneling (NAT) Conference. In 2000, the AUA established the George A. Fox Conference.

In 2006, the AUA merged into the Society for Mining, Metallurgy & Exploration (SME) to become the Underground Construction Association (UCA), a Division of SME. By doing so the UCA gained the benefits of SME's professional association management team and its members gained full access to SME benefits.

The UCA continues to manage the NAT conference (even years), the Rapid Excavation & Tunneling Conference (RETC) (odd years) and the George A. Fox Conference. In 2012, the annual Cutting Edge Conference in conjunction with *Tunneling Journal*, AUA's quarterly publication, *AUA News*, was discontinued and in September 2006, *Tunneling and Underground Construction* (**T&UC**) was launched as a quarterly publication to cover the tunneling and underground construction industry. The Tunnel Demand Forecast moved from the AUA publication and continues to this day in *T&UC*.

In 2023, the UCA is a growing community of tunneling and underground construction experts with more than 1,700 members. The UCA supports a variety of conferences, committees and workforce development efforts to bring its mission alive. While focused on the future, it is also important to reflect on how the UCA began.

History

The AUA was founded to promote the development and use of underground facilities. Charles Fairhurst, who was head of the Civil and Mineral Engineering Department at the University of Minnesota, was its first president. Members included U.S. and international professionals who were interested in the planning, design and construction of underground facilities.

Underground associations links

Beginning in 1986, the AUA initiated links with other underground associations and committees including the ITA, the Underground Construction Research Council, the U.S. National Committee on Tunnelling Technology (USNC/TT), the Institute of Shaft Drilling Technology (ISDT), the North American Society for Trenchless Technology (NASTT), the Association of Engineering Geologists (AEG) and the American Institute of Architects (AIA).

AUA – Representation

Since its founding, the AUA has had a significant international membership — at one point the association had members from 25 countries outside of the United States. Since 1987, representatives of AUA have attended ITA conferences and some have been elected to the ITA Executive Council including Jack Lemley, Dan Eisenstein, Dick Robbins, Harvey Parker, Amanda Elioff, Randy Essex, Jamal Rostami and Sanja Zlatanic. Lemley, Eisenstein and Parker were elected as ITA presidents, and Robbins, Elioff, Essex and Rostami were elected as ITA vice presidents.

Many AUA members have led ITA working groups. Because of this involvement, the AUA was confirmed as the U.S. representative to ITA when the USNC/TT was disbanded in 1993-94. In 1996 and again in 2016, AUA/UCA hosted two ITA conferences in the United States. The AUA was also a sustaining member of the Associated Research Centers for Urban Underground Space (ACUUS), representing planning of underground space and facilities around the world. ■

McMillen Jacobs rebranded as Delve Underground

McMillen Jacobs Associates, specializing in delivering underground infrastructure throughout North America and Australasia, is pleased to announce it has rebranded as Delve Underground.

"Delve Underground's mission is to solve our clients' infrastructure challenges with our collective expertise and legacy of underground excellence," said Victor Romero, president of Delve Underground. "Our new name reflects our company culture of working collaboratively and delving deep to inspire bold and responsive solutions."

Founded in 1954 as Jacobs Associates, Delve Underground is an employee-owned heavy civil engineering firm serving the water, wastewater and transportation markets.

" With 21 offices and 350 team members, we offer comprehensive design, design-build, construction management, and dispute resolution capabilities," the company said in a press release.

"The rebrand was a thoughtful and well-planned effort that involved our clients and team members from across our offices," said Gregg Davidson, chief operating officer of Delve Underground. "Our new brand is modern and creative, yet retains the spirit of our underground roots." ■

International Tunneling Awards announced; Two U.S. projects win prestigious awards

The International Tunneling and Underground Space Association (ITA) announced the winners of its 2022 awards, and American projects and engineers were represented in the international competition that is in its eighth year.

Organized by the ITA, the awards showcase the most ambitious underground projects all over the world as well as the latest innovations, techniques and methods in tunneling.

Major Project of the Year

The Purple Line Expansion project in Los Angeles, CA was named the Major Project of the Year winner. This award is for projects with budgets of more than €500 million ($530 million). The Skanska-Traylor-Shea joint venture (STS) is constructing the $1.9 billion design-build of the Purple Line Extension, Section 1, in Los Angeles, CA. This is the first of three projects to extend the Purple Line from Wilshire/Western Station to Santa Monica, a tunnel project that has been in the works for more than 60 years.

This portion of the project will add 6.3 km (3.92 miles) to the Purple Line, beginning at the Wilshire/Western Station. The twin tunnel alignment travels beneath Wilshire Boulevard, and underground stations are under construction at Wilshire/La Brea, Wilshire/Fairfax, and Wilshire/La Cienega.

The tunnels, mined by two Herrenknecht tunnel boring machines (TBMs), are 10,287 m (35,750 linear ft) long with an inner diameter of 5.7 m (18.8 ft).

Technical Innovation of the Year

The Technical Innovation of the Year was awarded for the "unprecedented in-tunnel diameter conversion of the largest hard rock TBM in the United States."

The largest hard rock TBM ever to bore in the United States, an 11.6 m (38 ft) diameter main-beam TBM, recently underwent a planned in-tunnel diameter change to a more compact 9.9 m (32 ft). The first-of-its-kind conversion process for the main-beam TBM was undertaken 2.8 km (1.7 miles) into the bore and was not done inside a shaft or pre-excavated portal (see feature on page 13).

Young Tunneller of the Year

Erica Frederickson was named the Young Tunneller of the Year.

"Just two weeks after graduating from university in 2011, I started my career in the tunneling industry. I got my first taste of tunnels as a field engineer with Traylor Bros. Inc. on the NYC MTACC LIRR East Side Access Queens Bored Tunnels and Structures project," Fredrickson wrote. "Looking back, I had no real idea of what to expect, other than I thought underground construction seemed "cool." I did not expect to continue working for the same company and industry for 11 years, but there is something special about the tunneling industry that hooked me.

"Since that first job, I have worked on three more tunnel projects in three different cities across North America: the DC Water Blue Plains Tunnel in Washington, DC; the LACMTA Westside Purple Line Extension Section 1 in Los Angeles, CA; and the Second Narrows Water Supply Tunnel in Vancouver, BC. Each project has had its share of challenges, triumphs, stressed-out moments and opportunities for growth. But most of all, I remember each project for the friendships formed with my incredible colleagues who call tunneling their career, and for the reward of providing essential infrastructure that will improve the lives of millions for many years to come."

2023 ITA Awards

- **Tunneling project of the year** (€50 million-500 million) – World's first spiral excavation using H&V shield tunneling method (Japan).
- **Project of the year** (Up to €50 million including renovation) – Guanyinyan tunnel, an urban tunnel project of the unequal span four-arch-tunnel with two-ways and 10 lanes (China).
- **Beyond engineering** – Multipipe jacking method for the construction of city core metro station in soft soil. ■

MIke Rispin (L), chair UCA, and Arnond Dix (R) president, International Tunneling Association, congratulate Henry Russell, PE, PG, on receiving the ITA Distinguished Service Award for being the animateur (Chair) of the ITA Working Group 6 Repair and Maintenance of Tunnels for 20 years. During Russell's leadership, the working group developed two significant documents: Study for the Repair of Tunnel Liners, 2001 and Guidelines for Structural Fire Protection for Road Tunnels, 2013, which has become the basis for current fire protection for road tunnels in the United States.

TUNNEL NAME	OWNER	LOCATION	STATE	BID YEAR	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	STATUS
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	2023	CSO	24,000	18	Proposal bid 4/23/2023
Minneapolis Central City Parallel Tunnel	City of Minneapolis	Minneapolis	MN	2023	CSO	4,200	10-19	Final planning
I-70 Floyd Hill Highway Tunnel	Colorado Dept. of Transportation	Denver	CO	2023	Highway	15,840	60 x 25	Under design
Folsom Area Storm Water Improvement	SFPUC	San Francisco	CA	2023	CSO	4,000	12	Under design
Downtown Extension (DTX)	TJPA	San Francisco	CA	TBD	Transit	TBD	TBD	Under design
CA High Speed Rail (Northern Section)	CA High Speed Rail Authority	Fresno	CA	2023	Transit	TBD	TBD	Design 3Q 2023
CA High Speed Rail (Southern Section)	CA High Speed Rail Authority	Bakersfield	CA	2023	Transit	TBD	TBD	Design 3Q 2023
West Santa Ana Line	LACMTA	Los Angeles	CA	2023	Transit	TBD	20	RFQ pending
Ontario Airport Tunnel	San Bernardino Co. Trans. Authority	San Bernardino	CA	2023	Transit	22,000	24	Under design
Gateway Tunnel Project	Amtrak	Newark/New York	NJ/NY	2023/2024	Transit	14,600	28	PDP Procurement ongoing
2nd Ave. Phase 2	NYS-MTA	New York	NY	2023	Subway	16,000	20	Fed approval process ongoing
2nd Ave Phase 3-4	NYS-MTA	New York	NY	2024-2029	Transit	89,600	20	Under study
Amtrak B&P Tunnel	Amtrak	Baltimore	MD	2023	Rail	40,000	32	PDP Procurement ongoing
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	 2023 2024	Sewer	 30,000 21,000	 18 14	 Under design Under design
Ontario Line North Extenstion	Metro Linx	Toronto	ON	2023	Subway	29,500	20	RFP in 2023
West Vaughn Sewage Servicing Project	York Region	Toronto	ON	2023	Sewer	36,000	10	RFQ shortlist completed
Yonge North Subway Extension	Metro Linx	Toronto	ON	2023	Transit	40,000	20	RFQ Pending
Blue Line Extension	Societe de transport de Montreal	Montreal	QC	2023	Transit	19,000	33	Under design
REM-S Project	Societe de transport de Montreal	Montreal	QC	2023	Transit	23,000	33	Under design
Southerly Storage Tunnel	NEORSD	Cleveland	OH	2023	CSO	18,000	23	Under design
DELORCA Wastewater Tunnel	DELCORA	Chester	PA	2023	CSO	45,500	13	Under design
Enbridge Line 5 Tunnel	Enbridge	Traverse City	MI	2023	Oil	23,760	12	Bid Submitted
Mill Creek Trunk Improvements	City of Nashville	Nashville	TN	2023	CSO	13,800	10	Under design
Green Line LRT	City of Calgary	Calgary	AB	2023	Transit	9,000	40	RFP submitted
Nose Hill Project	City of Calgary	Calgary	AB	2023	CSO	10,800	10	Under design
Kensico-Eastview Connection Tunnel	NYC-DEP	New York	NY	2024	Water	11,000	27	Under design

TUNNEL NAME	OWNER	LOCATION	STATE	BID YEAR	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	STATUS
Silver Line Extenstion	Boston Transit Authority	Boston	MA	2023	Transit	8,400	22	Under design
Yonge North Subway Extension	Metro Linx	Toronto	ON	2023	Transit	40,000	20	RFQ Pending
Stanley Park Water Supply Tunnel	City of Vancouver	Vancouver	BC	2023	Water	5,000	15	RFQ Q4 2023
ALCOSAN CSO Ohio River Allegheny River Monongahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	 2025 2028 2030	 CSO CSO CSO	 20,000 28,000 28,000	 18 18 18	 Under design Under design Under design
Germantown Winghocking Relief	City of Philadelphia Water	Philadelphia	PA	2025	CSO	28,000	20	Under design
Project Connect Subway Program	City of Austin	Austin	TX	2025	Transit	8,500	20	Design delayed
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	2025	Transit	10,500	20	Under design
Northside Interceptor Tunnel	City of Akron	Akron	OH	2025	CSO	6,850	24	Under design
Taylor Massey Tunnel	City of Toronto	Toronto	ON	2025	CSO	20,000	15	Under study
Quebec City - Levis Tunnel	Quebec Trans. Ministry	Quebec	QC	2025	Transit	27,230	60	Under study
Del Mar Bluffs Tunnel	SANDAG	San Diego	CA	2025	Rail	TBD	TBD	Under study
Fraser River Tunnel	BC Ministry of Transportation	Vancouver	BC	2025	Highway	3,000	TBD	RFP expected
Queensway Tunnel	Region of Peel	Toronto	ON	2025	Sewer	18,000	9	RFP Ongoing
Stormwater Control Program	Harris Co. Flood Control District	Houston	TX	2026	CSO	52,800	25-40	Under study
LA Metro Sepulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	2026	Transit	55,000	TBD	Under design
D2 Subway - 2nd Light Rail Alignment	Dallas Area Rapid Transit	Dallas	TX	2026	Transit	7,230	22	Delayed
Flushing Bay CSO Tunnel	NYC-DEP	New York	NY	2026	CSO	16,500	22	Under study
Cross Harbor Freight Tunnel	PANYNJ	New York	NY	TBD	Rail	25,000	30	Under study
Superconducting Maglev Project - Northeast Corridor	TNEM/BWRR	Washington	DC	TBD	Rail	146,500	43	Under design
Big Creek Storage Tunnel	NEORSD	Cleveland	OH	2026	CSO	22,450	20	Under design
Metropolitan Tunnel Program - Northern Tunnel Southern Tunnel	MWRA	Boston	MA	 2027 2028	 Water Water	 23,760 55,000	 10 10	 Under design Under design
Horizon Lateral Tunnel	Southern Nevada Water Authority	Las Vegas	NV	2027	Water	42,000	9	Delayed
Inner Harbour West Tunnel	City of Toronto	Toronto	ON	2027	CSO	18,400	20	Under design

To have your major tunnel project added to the Tunnel Demand Forecast, or to update information on a listed project, please contact Sanja Zlatanic at szlatanic@hntb.com.

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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.

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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 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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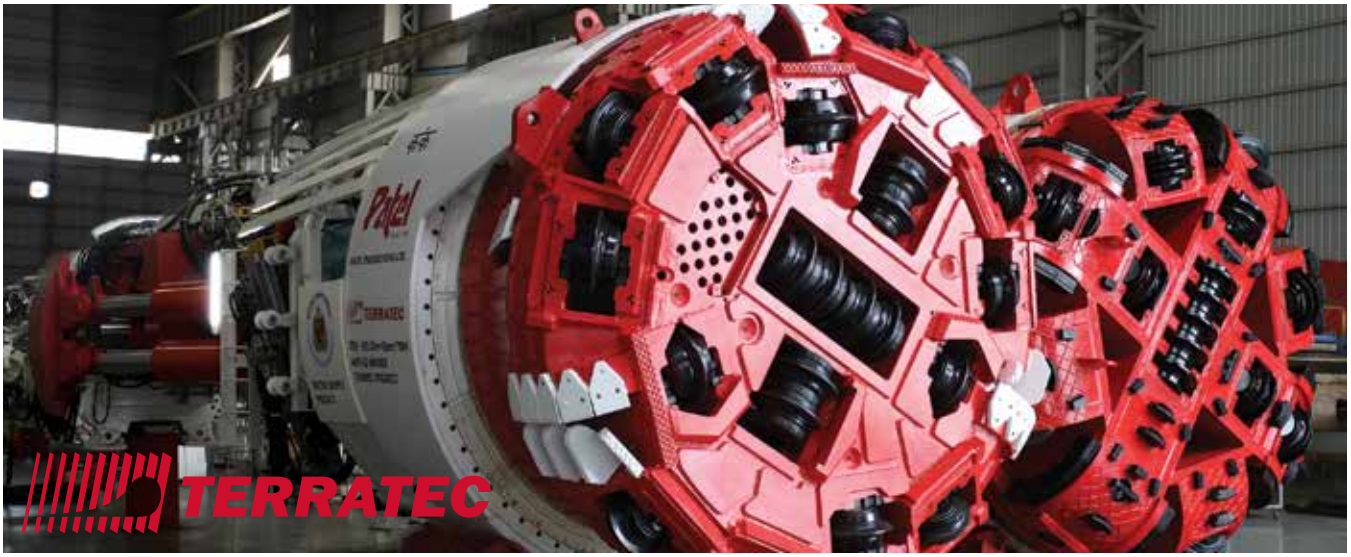

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- Mining

Award-Winning Projects

UCA Project of the Year Award (2022), projects between $50 to $500M, Bergen Point Southwest Outfall Replacement

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

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

Contacts:
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617-452-6391

Demanding Conditions, Demand JENNMAR

We are a diversified manufacturer and services provider for above and below ground infrastructure that sets standards in terms of quality and safety for our stakeholders. Our mission is total customer support and satisfaction.

Our portfolio of brands are rebuilding America's infrastructure. Because we understand the ever changing and demanding conditions above and below ground we have built the richest portfolio of diverse and complementary brands. From engineering to resin manufacturing, rolled-steel and drill-steel manufacturing, custom steel fabrication, precision wear parts, tools and bits, chemical roof support and sealing products, staffing solutions, transportation and more – we ensure the customer has the support at every stage of their projects. Visit our diverse portfolio of brands at www.jennmar.com.

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:

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

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.

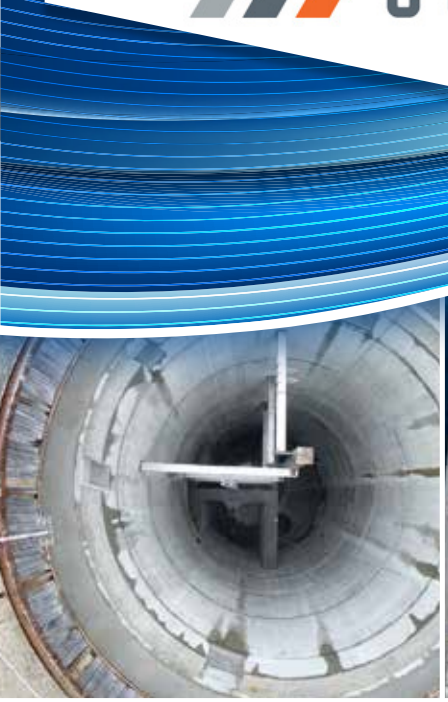
The project includes extending the current automated people mover system and renovating the baggage claim facility increasing its passenger capacity from 10,000 an hour to 12,000 an hour. JENNMAR Civil and Turnstone Industrial Solutions LLC. are proud to be on-site for this The City of Atlanta project.

VISIT US AT **BOOTH #S61249**

MARCH 14-18 | 2023 | LAS VEGAS, NV

CONEXPO CON/AGG

JENNMAR CIVIL






DEMANDING CONDITIONS
DEMAND JENNMAR.

JENNMAR Civil offers a wide range of products used in supporting, building and rebuilding our infrastructure from above and below ground. Our strength lies in our ability to offer our customers solutions in every phase of their projects. We manufacture arch systems, girders, liner plates and Impact Resistant Laggings® and much more for your projects. Whether mining, rehabbing or re-supporting transportation, water, wastewater or infrastructure tunnels, Jennmar Civil is backed by experienced engineers and technicians who are with you every step of the way, from initial consultation to qualified instruction and on-going technical support to make your project a success!

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

For more information on our portfolio of diverse and complementary brands visit us at www.jennmar.com.

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.

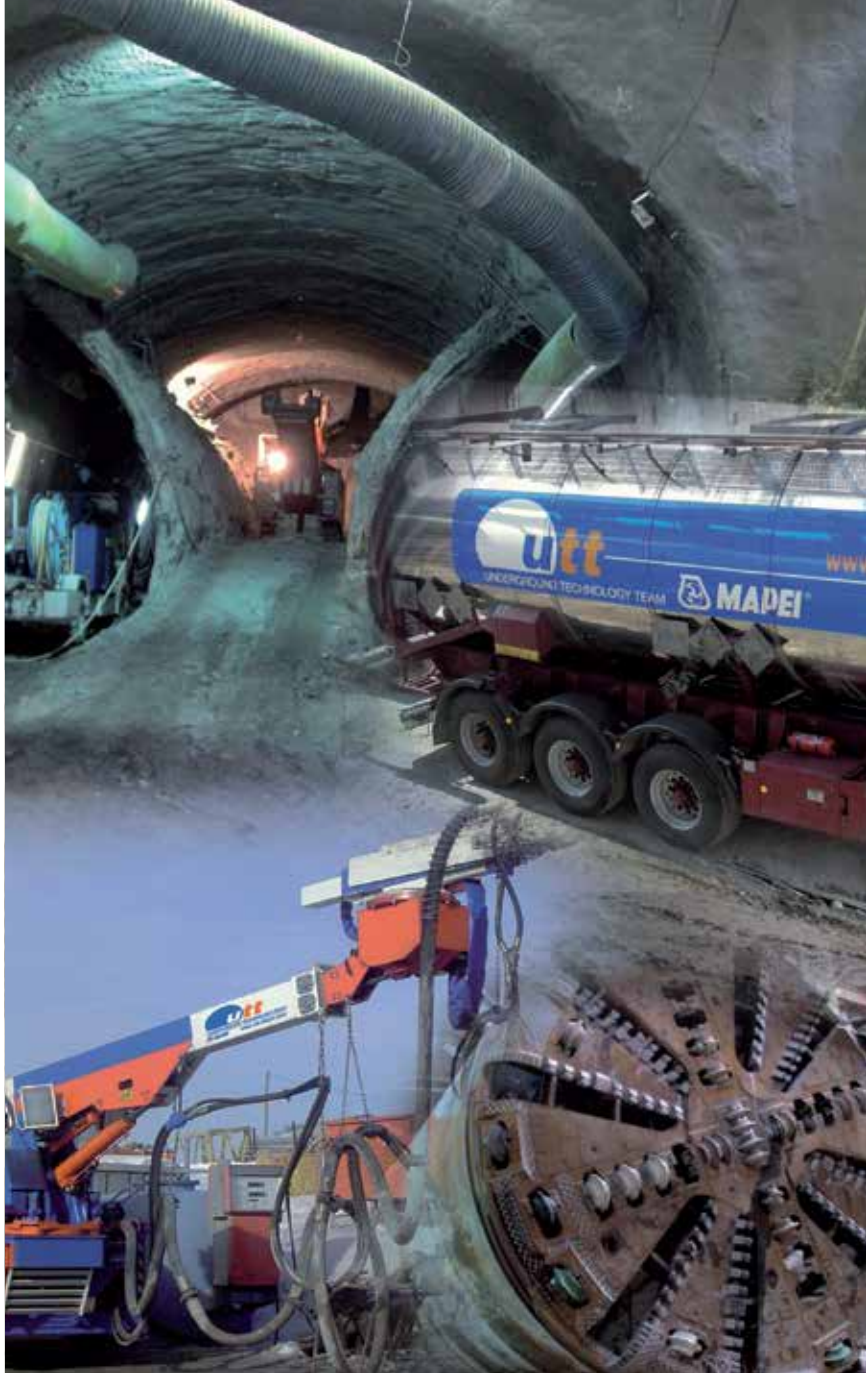
"The UTT group started in earnest in the U.S. in 2015," stated James Pinkley, Country Manager UTT – North America. "But the business has grown substantially since then." In the underground industry, speed is essential – not only of the products themselves, but also of the evolution of technology. MAPEI 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.

Proven Technology for

Underground Construction



Our commitment is the detail that makes the difference.

Reliable technology and expertise for underground construction

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

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

MAPEI USA

MAPEI®
ADHESIVES · SEALANTS · CHEMICAL PRODUCTS FOR BUILDING

Reliable Automatic Sprinkler Co., Inc.

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 it all possible.

We have been a leader in the underground support business in North America since 1920. 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 alongside you, we help you progress towards your objectives - quickly, reliably, cost-effectively.

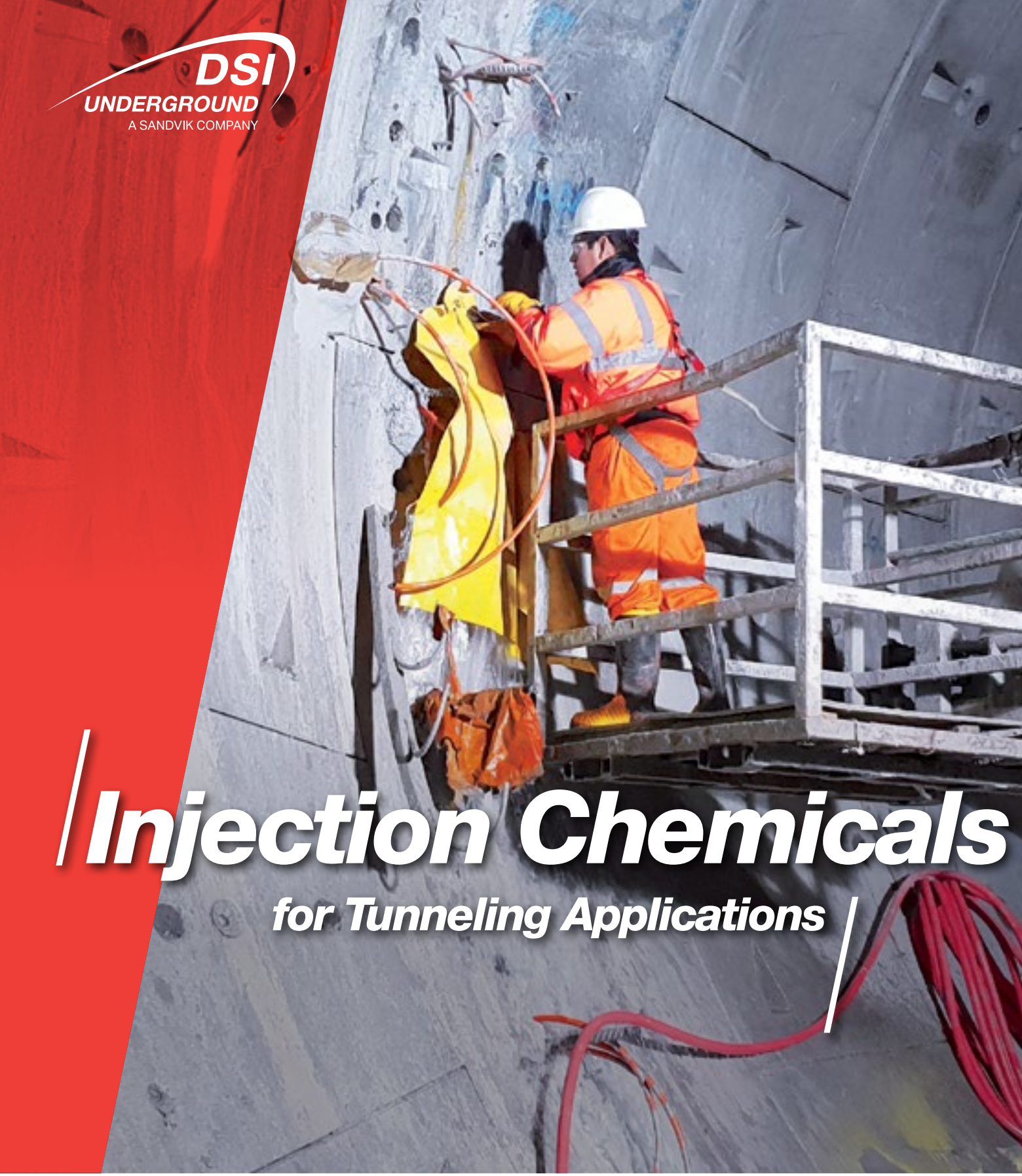
When you're tackling a seemingly insurmountable objective, facing tons of rock and earth, and need the skills and knowledge to achieve it, we're with you. We understand the complexities and considerations, the depths, and dangers far below the ground - and we work with you to navigate them, taking you 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

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

SENTINEL SOLUTIONS - LET US BUILD YOUR MASTER PLAN

Sentinel was founded in 2016 with the specific goal of bringing the Geotechnical and Underground Construction markets superior equipment and engineered fluid solutions. Our expertise in solids control along with our mud engineering allows Sentinel to provide a true turnkey fluid solution on any project. We bring a high level of field experience coupled with a history of equipment manufacturing which allows us to deliver the right equipment to each project we service.

OUR EQUIPMENT


Shaker Systems


Centrifuges

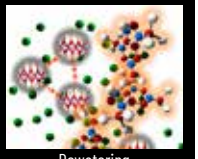

Auto Dewatering System

Sentinel's focus and dedication to the geotechnical and underground construction industry have impacted our equipment designs and created the most mobile and agile fleet in the US. This market specific design gives Sentinel customers the ability to utilize this separation equipment in tight locations and even on short term projects without the need of pole trucks and cranes to rig up and mobilize.

OUR PRODUCTS


Bentonite Products


Polymer


Dewatering

As a full-service mud company, Sentinel's various locations maintain a full suite of drilling fluids and additives. From bentonite and PHPA/PAC polymers, all the way through to dewatering chemistries and solidification reagents.

OUR SERVICES

- Drilling Fluids/Additives
- Dewatering Chemistries
- Solidification Reagents
- Solids Control Equipment
- Custom Equipment Manufacturing
- Fluid Engineering Services
- Screens and Consumables

Sentinel Solutions
www.sentinel-solutions.com
chuck.skillman@sentinel-solutions.com
555 Furrows Road, Holtsville , NY 11742
832-434-4559

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
+1 (800) 240-9112 www.nwlett.org

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

Kiewit

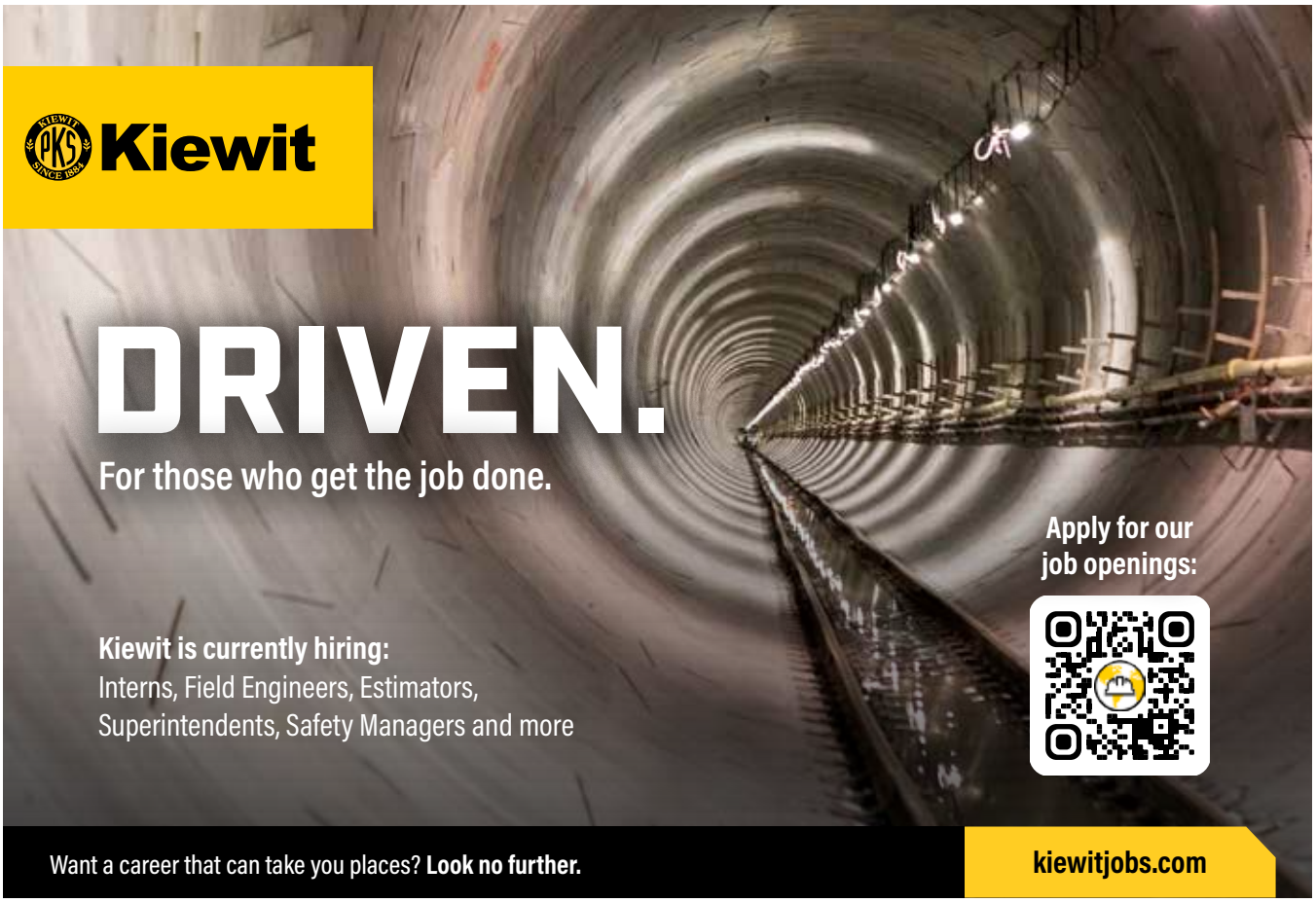
As a construction, mining, and engineering leader, Kiewit is a FORTUNE 500 company consistently ranking in the ENR's Top 10 Contractors. Kiewit is owned by active employees, creating a level of motivation that keeps the company on top. Kiewit, through its operating companies, brings a wealth of diverse 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 75 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



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.

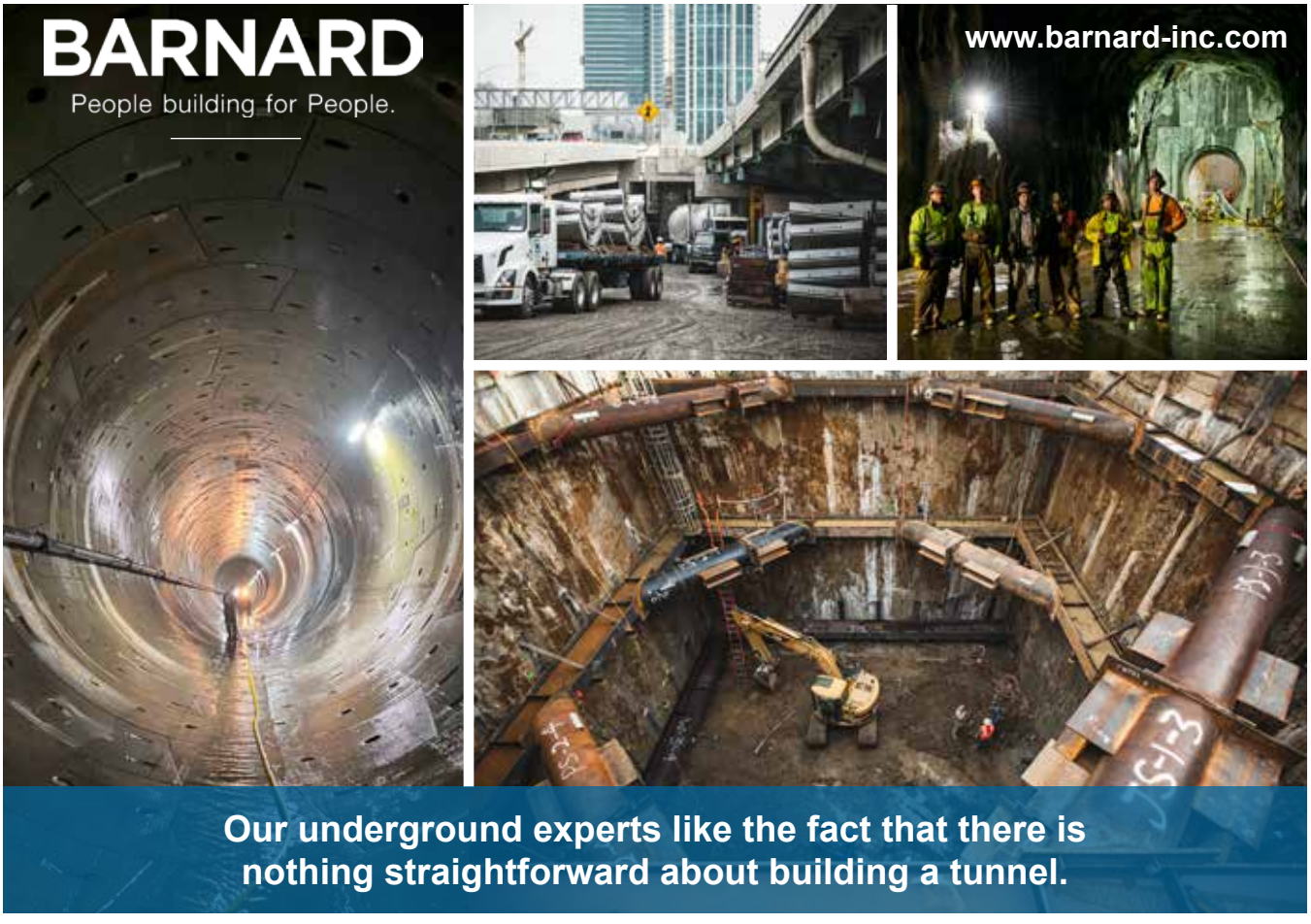
Normet is a Finnish company operating globally with over 50 locations in 33 countries worldwide. This breadth allows rapid response and reliability to all customers whenever and wherever in the world they may be. Company revenue in 2020 was over 300 M€.

BARNARD

Whether we're tunneling through the mountains of northern British Columbia or below the streets of downtown San Francisco, our people arrive at projects determined to do the best for their communities and be the best in the industry. We self-perform heavy civil and underground construction including TBM tunneling, drill and blast, and sequential excavation methods. Our work also encompasses power transmission, dams and reservoirs, pipelines, and environmental construction. We have built our reputation on skill, innovation, reliability, safety, and our ability to complete projects on budget and ahead of schedule.

This work has been conducted under a wide range of contracts, including one of the first Progressive Design-Build tunnel projects in the US, the Silicon Valley Clean Water Gravity Pipeline Project in Redwood City, California. On the Lake Mead Low Lake Level Pumping Station Project, a CMAR contract for Southern Nevada Water Authority, our project team was onboard from the Early Contractor Involvement phase and through construction. Our teams stick with projects from start to finish, serving on a bid team and then heading into design or directly to the field to construct the project they've bid. We live where we work and know our projects personally. We build for People.

For more information, please visit our website, www.barnard-inc.com.



STRATA MACHINE VISION SYSTEMS – AI SENSORS FOR TAG-FREE COLLISION AVOIDANCE

Strata SafeSITE HazardAI sensors are machine-mounted intelligent vision systems that employ edge computing and advanced deep neural networks to identify objects in close proximity and work to prevent incidents and collisions.

All-in-one HazardAI artificial intelligence collision avoidance sensors detect and differentiate between people, vehicles and other objects in close proximity to operating machinery and use stereoscopic 3D vision (improves the accuracy of depth perception) to measure distance to the person or object. Collision avoidance algorithms analyze the potential for collision, and automated alarms warn all parties if danger is detected. A display screen installed inside the operator's cab provides camera visuals of the surrounding area and identifies the object and its distance from the machine.

SafeSITE HazardAI requires no pedestrian wearables, such as tags or PADs, nor any vehicle-mounted receivers. AI sensors can be installed on the front, rear and/or sides of machinery and multiple sensors can be used on a single vehicle.

Strata's HazardAI is ISO21815-compliant for full Level 9 implementation. This means that the AI system can be interfaced into the equipment controls to automatically slow or stop machinery without operator intervention. This capability ensures the highest level of safety while working around machinery.

mySafeSITE Platform

All interactions, alarms and incidents are recorded and logged on a comprehensive AI platform. Users can elect for notifications to be sent to supervisors and managers via text or email, ensuring they remain aware of all incidents when applicable. Comprehensive views of critical metrics and site status enables managers to track data and manage HSE reporting.

The Strata family of HazardAI sensors gives site managers confidence that workers and heavy machinery will be kept at safe distances while effecting true long-lasting safety-based workforce behavioral change via the SafeSite AI platform.

For more information please email us at: info@strataworldwide.com.

www.strataworldwide.com/tunneling

STRATA WORLDWIDE

AKKERMAN: COMMITED TO EXCELLENCE

Incorporated in 1973, Akkerman will be celebrating our 50th year as one of North America's leading and most-trusted manufacturers of online and grade trenchless equipment.

Founded in 1963 by D.H. Akkerman to support his own contracting efforts, Maynard Akkerman continued to drive corporate growth and innovation. Today, Akkerman is a third generation company that produces multiple products lines to support the trenchless industry.

Akkerman offers small town values coupled with a global perspective. Our business operates with the highest level of integrity and all Akkerman employees have a personal investment in our customers' success. Akkerman takes pride on our ability to manufacture high-quality trenchless products using American made materials with dedicated employees. For the past 50-years, Akkerman continues to support American jobs that ensure safety, quality, and reliability. We design, manufacture, and assemble all of our equipment in Brownsdale, Minnesota, USA.

Since nearly 98% of trenchless projects are funded through tax payer dollars, supporting American companies and their workers will stimulate additional infrastructure funding through tax revenue. This investment will strengthen the U.S. economy and further support future infrastructure projects. Akkerman will continue to support American trades by sourcing the highest quality raw materials, components, and supplies.

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

What Makes a CAB® Product Special?

Each and every CAB® Product ordered supports the mission of the Cambria County Association for the Blind and Handicapped which is to develop and support an environment for persons with disabilities which promotes vocational and employment training, independence, and community involvement through rehabilitative, recreation and low-vision services, and education for the prevention of blindness.

Your orders also enable us to provide vision services to our local community.

CAB® Products range from durable hooks and hangers to custom sewn safety products to high visibility reflectors and streamers. We offer a variety of products for the tunneling, mining, pipeline, marine, and solar industries.

We are thankful for each of our supportive and amazing customers!

Cambria County Association for the Blind and Handicapped

Ebensburg Division
175 Industrial Park Road
Ebensburg, PA 15931
(814) 472-5077

Johnstown Division
211 Central Avenue
Johnstown, PA 15902
(814) 536-3531

Independence for Persons with Disabilities...

CAB

...Quality Products for our Customers Woldwide

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.

Michels Construction, Inc.

Michels is one of the largest, most diversified energy and infrastructure contractors in North America. By combining the collective strengths of the Michels Family of Companies, Michels delivers a team of hard-working people, sophisticated equipment fleet and unparalleled experience. Michels supports tunneling and underground construction projects with creative, safe solutions from pre-construction to completion.

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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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Kelley Engineered Equipment

Kelley Engineered Equipment (KEE) enters their 16th year of supplying custom equipment solutions 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.

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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.

Kelley Engineered Equipment

Gall Zeidler Consultants

Gall Zeidler Consultants is a global engineering consultancy firm specialized in innovative solutions for tunnel and underground projects. 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.

With over 21 years of project involvement in the LIRR's Grand Central Madison Program (The East Side Access) in New York, we have been part of the largest passenger rail terminal built in the US in nearly 70 years. GZ has provided tunnel engineering and construction management services for the station and running tunnels. Among our other major projects are Amtrak's Gateway Program, California High Speed Rail, Ballard and West Seattle Extensions, Rihyad Metro, Cross Rail in London, and the UK High Speed Rail 2.

With the most recent completion of the LIRR Grand Central Madison, we congratulate the MTA on this significant milestone and are proud to be part of the program accomplishments from its early design stages through construction, ready for operation and beyond.

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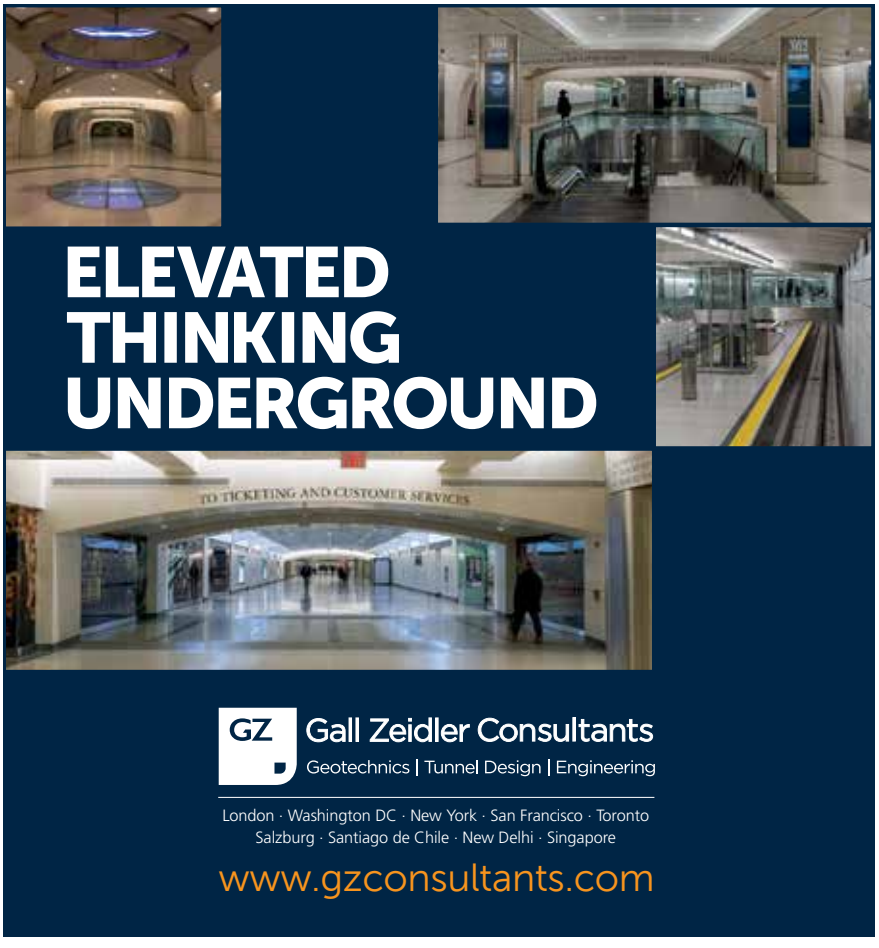

Bradshaw Offers Innovative Tunnel Engineering and Construction Technology

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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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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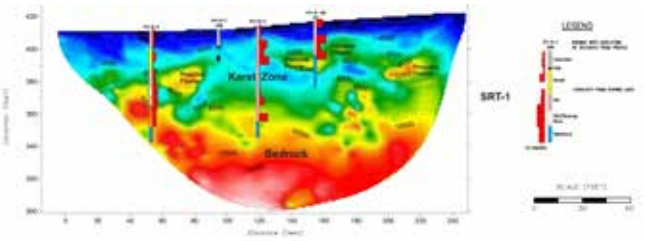

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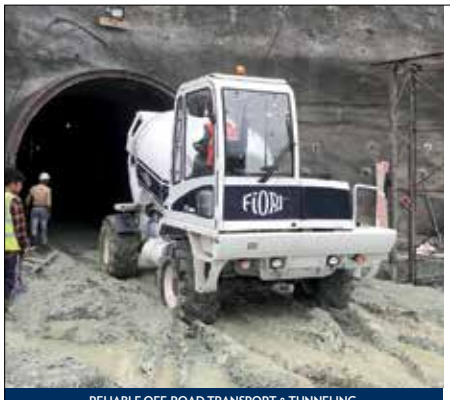

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Kilduff Underground Engineering

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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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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